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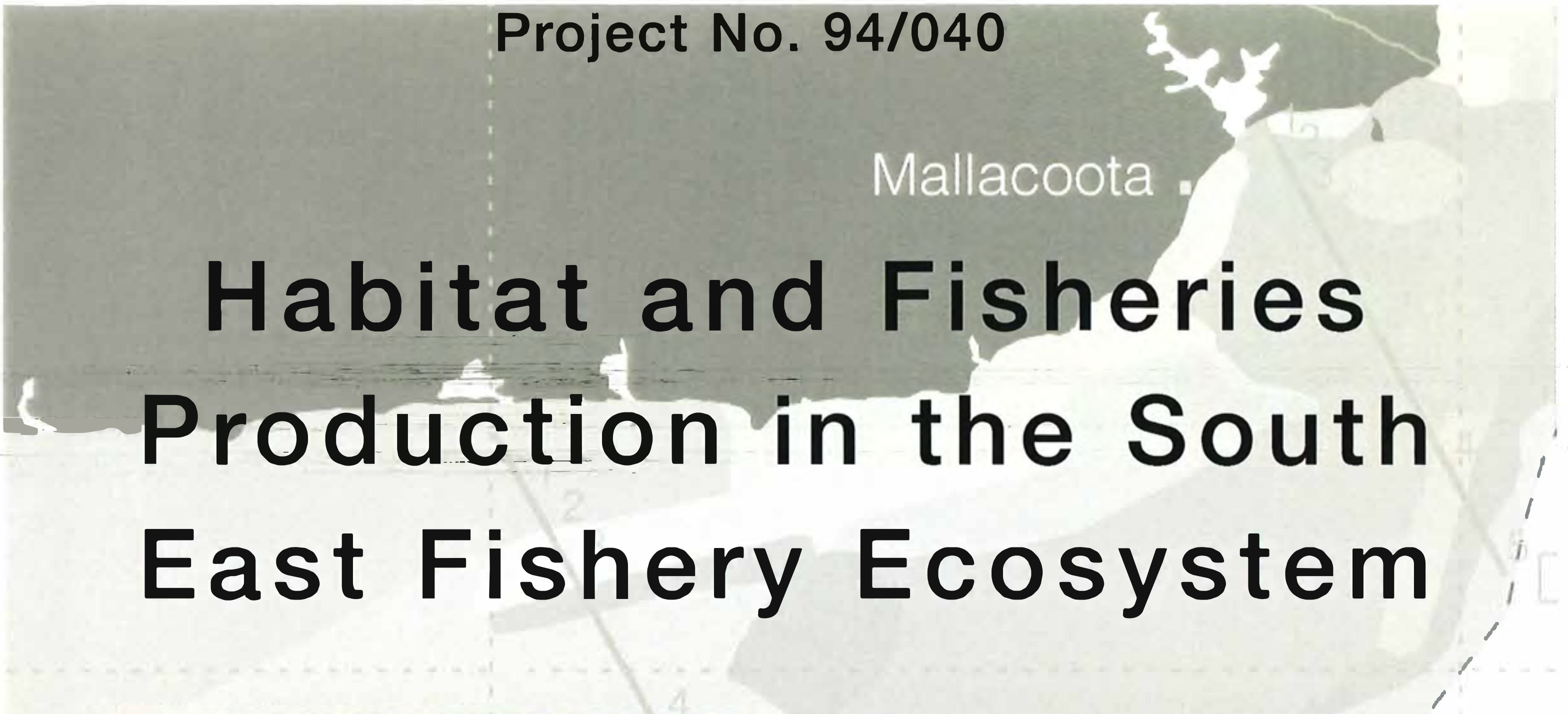

Habitat and Fisheries Production in the South East Fishery Ecosystem

Final Report to the Fisheries Research and Development Corporation

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MARINE RESEARCH

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CORPORATION

HABITAT AND FISHERIES PRODUCTIVITY IN THE SOUTH EAST FISHERY ECOSYSTEM

Nicholas J. Bax

Alan Williams [Eds.]

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NON-TECHNICAL SUMMARY

94/040 Habitat and Fisheries Production in the South East Fishery Ecosystem

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Objectives

1. Survey the structure and broad distributions of habitat types and associated fish assemblages in the SEF shelf ecosystem.

2. Assess the selectivity of different commercial gear types (demersal trawl, gillnet and trap) for quota species in different habitats.

3. Assess the relative abundance, age composition, distribution, and vulnerability to fishing gear of key commercial species, primarily redfish (*Centroberyx affinis*) and warehous (*Seriolella* spp.).

4. Evaluate the importance of hard-ground as refuge for commercial fish species.

5. Define the major trophic linkages (including predators) of SEF quota species by habitat type and identify the relative importance of benthic, pelagic, and inshore (e.g. seagrass, macroalgae) sources of production to quota fish species.

6. Develop hierarchical models based on the fishery (selectivity and effectiveness of different gears and relationship with bottom type) and on the fishery ecology (productivity of fish populations, their relative abundance in, and associations with, different benthic environments, and the role of benthic habitats as sources of production and refuge).

Summary

In 1994 CSIRO and FRDC started a 5-year ecosystem study of the southeastern Australian continental shelf. Fisheries management in this area is currently based on individual species. Our goal was to identify ecosystem features that could extend the data available to manage the fisheries in this area. We focussed on the area of the shelf between Wilson's Promontory and Bermagui, where there are important fishing grounds. We were particularly interested in how habitat influences productivity of the fishery.

Management of marine ecosystems, rather than of individual fish species, is a frequently expressed goal of involved scientists and managers, but what does it really mean? In stressed ecosystems, ecosystem functions e.g. nutrient processing, may remain unchanged while the proportion of species and diversity in the ecosystem and even the health of individuals, can change dramatically. Species are more sensitive indicators of stress than is the system itself. Therefore, we did not try to study the marine ecosystem as a whole, but rather, concentrated on examining interactions of people and the particular ecosystem components that influence the quantity and quality of desired products. These particular interactions are known as 'leverage

points'. Leverage is based on the notion that small, well-focussed actions can produce enduring improvements if they are directed at sensitive system components. We used the notion of leverage to direct our research.

We identified and examined four potential leverage points:

1. Primary production from coastal seagrasses or algae, and the influence of shoreline management.
2. Predation on commercial fishes, and the opportunity for selective removal of predators.
3. Effects of fishing on commercial fishes (harvest, bycatch, feeding on bycatch), and the opportunity to influence fishing selectivity through biological (rather than technical) factors.
4. Importance of benthic habitat to fishery productivity, and the opportunity to influence impacts of fishing on habitat through spatial management of fishing effort.

1. Estuarine and terrestrial sources of primary production, including seagrasses, contribute to productivity over the tropical Australian continental shelf, as well as to such deep-shelf quota species as the blue grenadier. However, our analyses with stable isotopes and photoreactive pigments [*Section* 6] detected negligible contributions from either terrestrial production, seagrasses or benthic algae, to the food webs of the southeastern continental shelf. The primary source of productivity in the water column and on the seabed of the shelf ecosystem is pelagic plankton and micronekton transported to the shelf from the open ocean by deep upwellings [*Section* 5]. This production source is not amenable to management intervention.

2. Fish predation is a potential leverage point if the abundances of desirable fish species can be increased by removing their predators. However, although many of the larger and more abundant (usually commercial) fish species ate high proportions of fish, they ate mainly non-commercial species. [*Sections* 6 and 10]. A variety of non-commercial bottom fish ate fish, but they also ate few commercial species. Marine mammals and birds ate a lot of fish, but mainly smaller surface and mid-water species. We found no indications that predation on commercial fish species controlled their numbers; it is more likely that fish numbers are controlled by the availability of suitable prey. This may be symptomatic of a fishery where predators have been reduced by a century of harvesting. We identified no opportunities for management to influence predation on commercial fishes.

3. Direct impacts of fishing on fish populations was the first of the potential leverage points that was clearly important–selectivity of a fishery is influenced by fish availability as well as selectivity of the fishing gear. A 'bigger-deeper' pattern in redfish, pink ling, ocean perch, morwong, tiger flathead, white trevalley, blue warehou, silver warehou and John dory results from their general oceanward movement with increasing age [*Section* 9]. Ecologically, this process partitions habitat (depth range) and food resources between size (age) groups within species, as well as giving adults access to the most productive foraging grounds which are at the outer-shelf and shelf-break [*Sections* 6 and 7].

Leverage is provided by the potential to reduce discarding by directing effort away from shallower areas where smaller (non-marketable) individuals are abundant. Depth-related discarding typically occurs either when sea conditions prevent vessels from fishing offshore, or when adults of commercial species move to shallow waters and are targeted. Modifying fishing practices has the potential to reduce discarding, but the implications for fishers' activities and financial return have not been determined.

4. The link between the fish community and seabed habitat was the second potential leverage point that we identified as impacting fishery productivity. Distinct fish communities of the SEF shelf are associated with particular seabed habitats that serve as feeding areas, shelters or aggregating structures [*Section* 8]. Therefore the role of habitat for fishery productivity is to provide environments in which commercial fishes 'grow-on', and to aggregate key species in commercial quantities at particular places or times. It is for the second reason that fishers target very specific habitats on the southeast Australian shelf [*Section* 11].

We identified significant habitats by determining their fish communities, and then mapped the seabed and assessed its vulnerability to fishing impacts, based on such attributes as hardness, relief and patch-size [*Section* 7]. Spatial management of fishing effort presents a means of intervening effectively to maintain, or increase, fishery productivity.

Gaining the fishers' acceptance of spatial management, even though it reduced selection of juvenile fish or maintained (perhaps even increased) productive habitat, would be difficult because it restricts the fishers' access to specified areas of the seabed in space and time. Management intervention must be clearly shown to provide benefits for fishery productivity without unnecessarily impeding fishing practice. The cooperation of fishers would be needed, because significant habitats are frequently small and close to prime fishing grounds, and involving fishers in habitat mapping would be the most reliable and cost-effective way to identify these areas.

Improved remote sensing and satellite-tracking technology has enabled scientists to cost-effectively research new features of marine ecosystems. The same technology has enabled fishers to target particular habitats more precisely, increasing their impact on particular productive habitats. Management of marine ecosystems requires more than management of landed catches. "Fisheries management is environmental management" (Martin Cabot, head Newfoundland Inshore Fishermen's Association 1993). If fisheries managers are to become environmental managers, then fisheries (environmental?) scientists must provide them with the appropriate concepts, tools and information. In a complex system it will be essential to understand where the leverage points are. We have identified two such points for the continental shelf off southeast Australia, but it remains for managers and fishers, supported by scientists to determine how these particular leverage points can be profitably used.

Keywords

South East Fishery/ continental shelf/ habitat/ seabed/ water column/ fishery productivity/ fishery management/ leverage/ physical oceanography/ production/ isotopes/ pigments/ underwater photography/ acoustics/ sediments/ geology/ fishing grounds/ habitat mapping/ fish communities/ benthic invertebrates/ size distribution/ age distribution/ otoliths/ trophodynamics/ fishing effort

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1 BACKGROUND

In 1992, CSIRO proposed a SEF 'effects of fishing' study for FRDC support. CSIRO recognised the need for, and interest in their involvement in this fishery, which is changing rapidly and proving a challenge to effective management because of its multi-species and multi-gear nature. FRDC support was not received for the 1992 proposal. CSIRO took the opportunity to review with industry, stock assessment scientists, and managers the most useful research direction to take to develop an understanding of the SEF. Additionally, CSIRO made an internally funded exploratory cruise of the shelf area from Wilson''s Promontory to Bermagui in winter 1993 to test sampling gear, and to familiarise ourselves with the taxonomic problems and sampling variability of this area.

Through our outside discussions and internal review, it is apparent that the 1992 CSIRO proposal was inappropriate at that time. While the proposal concerned the important question of the effects of trawling on the benthic community and the possible consequences for SEF quota species, it did not place trawling in the perspective of the SEF as a whole, it did not account for the diversity of bottom habitats found in the SEF area, and it did not address the functional significance of the different benthic habitats in the SEF ecosystem.

We have taken the shortcomings of the 1992 proposal into account in preparing this (1993) proposal. Here we propose research to gain an understanding of the key factors that drive the abundance of species in the SEF, the influence of different fishing gear types on these species, and the value of the varied benthic habitat as prey resource or structural refuge.

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2 NEED

The South East Fishery (SEF) regularly catches more than 80 fish species, 16 of which constitute most of the landed catch. The SEF has been a productive fishery for many decades, but recent and dramatic declines or fluctuations in abundance of some major commercial species (gemfish, orange roughy, redfish, scallops, etc.) and changed management objectives (introduction of ITQ's and Ecologically Sustainable Development) have increased the requirement for reliable and effective fisheries assessments. SEF fisheries research has typically been focused on only the most important commercial species, and has typically concentrated on parameters that were the easiest to measure (e.g. market sampling and logbook data). This may have been sufficient at a time when resources appeared relatively stable and when direct quotas had not been imposed. It is woefully inadequate now that several stocks have declined abruptly while other stocks may be recovering at varying rates, and when managers are expected to make directives that reflect the fishermen's reality that one fisher has to discard some quota species he's caught while others with quota remaining or using different gear types can retain those species. The lack of detailed knowledge of some species and of a general knowledge of how the different species are affected by biological (predation or resource competition) or technical mechanisms (different gear types) are a serious impediment to providing reasoned advice to managers. This is at a time when detailed advice is demanded to tackle pressing questions, for example:

- how many juvenile redfish in how many year classes are there at present in the SEF, and do the reports of large numbers of juveniles signify a long-term recovery?
- what is the impact of the different gear types (trawls, traps, set-nets and long-lines) on the SEF quota species and how can quotas be set in a multi-species, multi-gear fishery?
- what species assemblages are caught together, and what level of targeting is possible?
- how effectively do changes in reported catches reflect changes in the abundance of fish?
- what is the impact on quota species of fishing the hard-ground that previously provided them with a refuge from commercial exploitation?
- what is the level of risk (or benefit) associated with alternative management strategies? and
- what is ecologically sustainable development in a multi-species, multi-gear fishery subject to severe climate-driven (or climate-mediated) fluctuations?

Despite a long time-series of catch and effort data, market sampling, and the recently initiated domestic observer program, relatively little attention has been given to the ecosystem that supports the SEF. The wide geographic spread of fish resources, the diversity of both the retained and discarded catch, and the wide range of habitats occupied by SEF species have made it difficult to develop a good base of biological information on which to manage the fishery. This sparse information base on the SEF ecosystem is no longer adequate for management or in the best interests of the fishery.

Current research in the SEF is concentrated on data collections from trawlable areas (hard-ground areas are largely inaccessible to commercial and research trawls, and so there is little information on them). Recent evidence in the form of scientific data (CSIRO acoustic survey, 1993) and large commercial catches of species such as blue warehou indicate that the hard-ground and reefs support high concentrations of fish. Commercial fishers have suggested that these reefs provide a refuge for some commercial species, including redfish, which are only caught in quantity when they leave the reefs during periods of "dirty water" (1993 Redfish Workshop). The reefs also appear to sustain a greater biomass and diversity of epifauna than live off the reef (CSIRO exploratory camera survey 1993); this epifauna may assist the productivity of the SEF.

The exploitation of fish on reefs and hard-ground has increased in recent years through long-lining, gillnetting, trapping, and the use of heavier ground-gear on trawls. It is likely that these once-unfished areas provided a refuge for some species and a source of productivity for others. These areas may now be less protected and be providing less insurance against growing fishing pressure on readily accessible ground. This expansion of areas where SEF quota species can be caught increases the species' susceptibility to fishing pressure and increases the risk associated with particular quota levels. We believe that understanding the role of hard bottom is of particular importance to the ongoing management of the SEF; the hard-bottom areas may well have operated in the past as an insurance policy against poorly determined quotas and excess fleet capacity.

The CSIRO Division of Fisheries (now Marine Research) is proposing a three year-study to describe the distribution of major habitat types in the SEF, the association of fish assemblages with habitat types, the selectivity of different gear types on different habitat types, and the value of the different habitat types to the major commercial species. Our aim with this study is to provide the information necessary to model the habitat dependence and gear susceptibility of individual commercial species and to determine the ecological processes that sustain them. Our study will examine areas and habitat types previously unstudied by fisheries researchers, in addition to areas about which there is existing information. A series of hierarchical models will be developed to examine the relationship between different methods of commercial fishing on SEF fish populations and the range of habitat types occupied by those populations. We will also investigate the trophic interactions of fish species on and off the reefs, with the goal of determining the importance of different habitat types in the providing food and protection from possible predators.

In the short term, this study will provide information to researchers and managers on the vulnerability of commercially fished species to different gear types; the importance of particular habitat types in the ecology of individual commercial species; and the likely biological interactions of species. In the long term, the study will point out what is needed for ecologically sustainable development and the maximisation of harvesting opportunities in the SEF. Without such basic knowledge it will prove impossible to manage SEF stocks rationally and impossible to recognise, let alone develop, an ecologically sustainable ecosystem.

3 OBJECTIVES

For the shelf fishery component of the SEF,

1. Survey the structure and broad distributions of habitat types and associated fish assemblages in the SEF shelf ecosystem.

2. Assess the selectivity of different commercial gear types (demersal trawl, gillnet and trap) for quota species in different habitats.

3. Assess the relative abundance, age composition, distribution and vulnerability to fishing gear of key commercial species, primarily redfish and warehous.

4. Evaluate the value of hard-ground as refuge for commercial fish species.

5. Define the major trophic linkages (including predators) of SEF quota species by habitat type and identify the relative importance of benthic, pelagic and inshore (e.g. seagrass, macroalgae) sources of production to quota fish species.

6. Develop hierarchical models based on the fishery (selectivity and effectiveness of different gears and relationship with bottom type) and on the fishery ecology (productivity of fish populations; their relative abundance in, and associations with, different benthic environments; and the role of benthic habitats as sources of production and refuge).

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4 INTRODUCTION AND SCIENTIFIC APPROACH

Nicholas Bax and Alan Williams

Our sampling strategy was designed to describe features of the fishery ecosystem at a regional scale, with a focus on 'hard-ground' (reef and bedrock) habitat. This was accomplished with a two-phase field program, and through a liaison program with the fishing industry.

Firstly, a 'broad-scale' survey examined the distribution of biota, substrates and the physical oceanographic structure over a broad area of the SEF shelf region in each of four seasonal cruises: July 1993 (winter), August 1994 (spring), April 1996 (autumn) and November 1996 (summer)(*Section* 4.1.1).

Secondly, a 'focussed habitat' survey intensively sampled a variety of seafloor habitats characteristic of the SEF shelf region to determine their physical structures and associations with assemblages of fishes and invertebrates (*Section* 4.1.2). Focussed habitat surveys were made on the last three cruises. A habitat survey consisted of a research vessel survey with acoustics, video, physical and biological sampling to define the habitat, followed by a survey with chartered commercial fishing vessels to sample fish with gillnets and traps.

Samples and information collected during both phases were used to determine the relations between biological species, especially fishes, and the physical attributes of their habitats. These relations were interpreted in the context of fishery production by habitat habitats and incorporating fishers, knowledge.

4.1 METHODS

4.1.1 Broad-Scale Survey

The broad-scale survey covered the area from Wilson''s Promontory to Bermagui with five depth-stratified stations (25, 40, 80, 120, and ~200 m) on each of seven cross-shelf transects (Fig. 4.1.1.1). These transects were based on three surveyed by the Victorian Marine Science Laboratory (MSL) in the early 1980's (transects A-C) and additional transects off Gabo Island, Disaster Bay, Merimbula and Bermagui (transects D-G respectively). Two of the corresponding 35 stations could not be sampled with demersal gears: the 200 m depth at Wilson''s Promontory (A5) where no trawlable bottom was found, and the 25 m station off Merimbula (F1) where a steeply sloping bottom at the 25 m depth contour was dangerously close to shore.

Each survey aimed to:

- determine the seasonal distribution and abundance of demersal fish species by demersal trawling,
- determine the characteristics of the primary water masses in the sampling area from hydrological sampling,

- provide samples of fish, plankton and seafloor invertebrates for analysis of stable isotopes to identify their positions in the community food web,
- provide samples of stomach contents from commercial and other abundant fish species to determine their immediate feeding links and to compare with stable isotope analyses of trophic structure,
- collect water column and benthic sediment samples for analysis of phytoplankton, their disposition in the sediments and physical sediment properties.

In addition, the same stations were sampled by a benthic/ epibenthic sled to determine the abundances of seafloor invertebrate species. Samples from the final survey were used for analysis. Sediment samples were collected variously with an attachment on the sled, and dedicated sediment samplers (see below).

The food web of the SEF ecosystem was described using three approaches. First, measurements of primary production from phytoplankton and benthic algae using chemosynthetic pigments and their breakdown products and stable isotopes was used to determine the source and relative importance of different sources of productivity. Second, secondary production was measured directly from zooplankton catches in bongo nets. Third, extensive collections of biotic tissue were made to describe the trophic level of as many different species as possible using stable isotopes of carbon and nitrogen.

An Oracle database was developed for the research vessel to meet the needs of this project that included an interface for the length frequency measuring boards used on commercial vessels. This permitted the entry and verification of all records for station details, trawl and sled catch compositions, biological and length frequency data at sea.

The details of sampling gears used and the methodology employed for each component of the study are provided in subsequent *Sections* (4.1.3— 4.1.5).

4.1.2 Focussed Habitat Survey

The choice of general habitat study areas was based an overview of the topography and substrate types in this region of the SEF provided by the local fishing industry, and by preliminary survey work during the first cruise. Industry contribution to the process of selecting suitable and representative sites was critical due to the large spatial scale and complexity of the SEF shelf region. However, the information was gained only after a considerable effort was spent in developing sound working relationships with several key operators from the ports of Eden and Lakes Entrance. Once a level of trust had been established, the fishers generously provided us with advice and their personal charts (on paper and electronic media) detailing their observations on habitat and habitat-fish associations collected over many years fishing. A summary of the information provided is presented in results *Sections* (7.2.1; 11.2.1); the spatial information, recorded as series of diagrams, was digitised and incorporated into a single ‘coarse-scale habitat map’.

Sampling was undertaken using the RV *Southern Surveyor* and chartered industry vessels. We anticipated it would be considerably more efficient to use commercial fishing vessels to sample with gillnets and traps, and this proved to be the case. However, the considerable additional

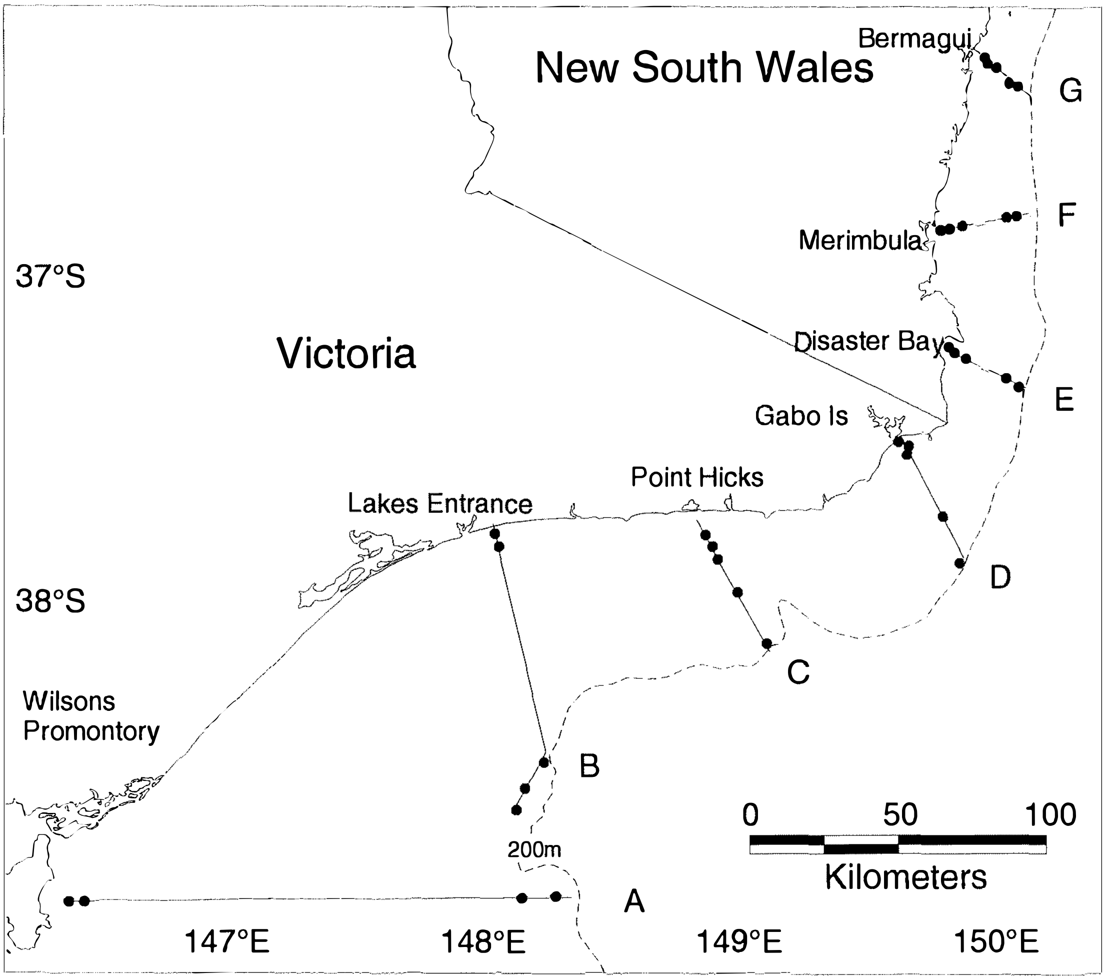

Figure 4.1.1.1 Map of study area showing transects and stations for the four seasonal broad-scale surveys.

benefits in this approach were the expertise and local knowledge passed on by the skippers and crew of the vessels, and the opportunities to build relationships that come from spending extended time at sea.

Data are presented for mesohabitats (an area measured in km and defined by physiography and depth, Greene *et al.* 1995) within the megahabitat (an area measured in 100's of km defined by oceanography and proximity to seafloor, Greene *et al.* 1995) of the southeast Australian shelf. Each mesohabitat can be subdivided into macrohabitats (an area measured in 100's of m defined by substratum features, Greene *et al.* 1995). How we define habitat determines the questions we ask and therefore the description of the environment that results. For the purposes of this study, and following Hudson *et al.* (1992), we define habitat as "simply the place where an organism lives".

Six key study areas ('mesohabitats') that represented the variety of shelf habitats described by fishers were sampled with a full range of gears (cameras, fishing gears and benthic sled) at 17 sites ('macrohabitats'). Three were on the inner-shelf— 'Black Head', 'Disaster Bay', and 'Point Hicks' and three on the mid/ outer-shelf— 'Big Gutter', 'Gabo Reef ' and 'The Horseshoe' (*Sections* 7.1.5; 8.1.1-8.2.3). Another seven mesohabitat areas were sampled, but not by all gears: 'Broken Reef', 'Gabo Island', 'New Zealand Star Banks', 'Little Horseshoe', '10 x 10 Reef', 'Southeast Reef' and 'Smithy's Corner'.

The final mesohabitat boundaries and the locations of macrohabitat sampling sites within them were based on bottom topography and 'bottom-typing' acoustic indices from sounding surveys during the 1996 surveys. In brief, sounder echograms were examined visually at sea to delineate macrohabitats that contrasted with respect to two measures of the echo return. The first measure, index E1, is an integration of the tail of the first bottom echo, where the energy in the tail is assumed to be derived from scattered reflections that increase in rough habitat. The second index, E2, is an integration of the entire second bottom echo and provides a measure of the total energy reflected from the seabed and therefore a measure of acoustic reflectivity. On this basis, contrasting macrohabitats in each mesohabitat were nominally classified as relatively 'soft', 'hard' or 'rough'. Subsequent analysis of stored digital E1 and E2 data permitted quantification and verification of our classification (*Section* 7).

The meso- and macrohabitats sampled are shown in Fig. 4.1.2.1 and described in *Section* 7.2.7. Summary acoustic signatures for the mesohabitats based on the positions of the fish samplers are given elsewhere (*Section* 8).

4.1.3 Surveys Completed

The broad-scale survey design involved the systematic collection of samples at five depth-stratified stations along each of seven cross-shelf transects. One station was too close to shore to sample safely and another too rough to sample with bottom gears leaving 33 stations sampled on four surveys (*Section* 4.1.1). A summary of the samples taken is given below while the details of the sampling protocols, the material collected and its use in analyses is given in the respective results sections (primarily *Section* 8). Transects A to C (14 stations) were locations sampled at three-monthly intervals by the Marine Science Laboratories (State of Victoria) between 1982 and 1984.

Precise details of each survey were documented in 'CSIRO Cruise Reports' that were circulated to the relevant national research agencies, AFMA, FRDC as well as the fishing cooperatives in

Lakes Entrance, Eden and Bermagui. These reports included all sampling positions, summaries of sample collections and a daily narrative. Survey numbers starting with 'SS' were conducted from the RV *Southern Surveyor*; other surveys were from chartered fishing vessels. In brief, the following sampling was undertaken:

Survey SS9305

Overall, 32 of the 33 standard trawls as well as 20 replicate trawls were completed with 27.2 tonnes of fish (~240,000 specimens) caught. A new demersal sampler, the combination benthic sled, was tested and used to complete 34 tows for samples of infaunal and epifaunal invertebrates and to take photographs of the seafloor. Sediment samples were taken with Smith-McIntyre and Shipek grabs and a pipe dredge, and 34 CTD casts were successfully completed. Zooplankton was collected in oblique bongo net tows (500 micron mesh) and drop net samples (100 micron mesh) at the 40 m and 200 m stations. Phytoplankton was collected from filtered water samples at the same stations. Acoustic data from the EK500 sounder and the RoxAnn seafloor classification software were logged continuously throughout the cruise.

Survey SS9405

Overall, 33 trawls, 34 sled tows and 34 CTD casts were successfully completed. A total of about 13.8 tonnes of fish was caught. A sediment sampler was added to the sled to take a complete set of sediment samples. Zooplankton was collected in oblique bongo net tows (500 micron mesh) and drop net samples (100 micron mesh) at the 40 m and 200 m stations. Phytoplankton was collected from filtered water samples at the same stations. Acoustic data from the EK500 sounder and the RoxAnn seafloor classification software were logged continuously throughout the cruise.

Survey SF9405/ EJ9405

This survey used two commercial vessels and provided initial data from Gabo/ Howe Reef complex for focussed habitat sampling. In total, 1.4 tonnes of fish were caught overall with nearly two thirds of the catch taken by the traps. The gill net fleet was deployed 15 times: one trial soak plus 14 sampling stations. Traps were set at 15 trap stations — 5 traps per station for the first 14 stations and 2 traps at station 15.

Survey SS9402

Five trawl samples on each of two transects (Disaster Bay and Gabo Island) were sampled opportunistically in conjunction with a separate survey. A total of 1.4 tonnes of fish (> 14,500 specimens) was caught. These data have not been used in analysis of fish community, but biological samples were collected and used. Phytoplankton for stable isotope analysis was collected from filtered water samples from a CTD cast in 250 m depth off Point Hicks.

Survey SS9602

Overall, 33 demersal trawls, 34 CTD casts and 34 sediment samples were completed on the transect stations. A total of 8.3 tonnes of fish (~91,700 specimens) was caught. Zooplankton was collected in oblique bongo net tows (500 micron mesh) and drop net samples (100 micron mesh) at the 40 m and 200 m stations. Phytoplankton was collected from filtered water samples

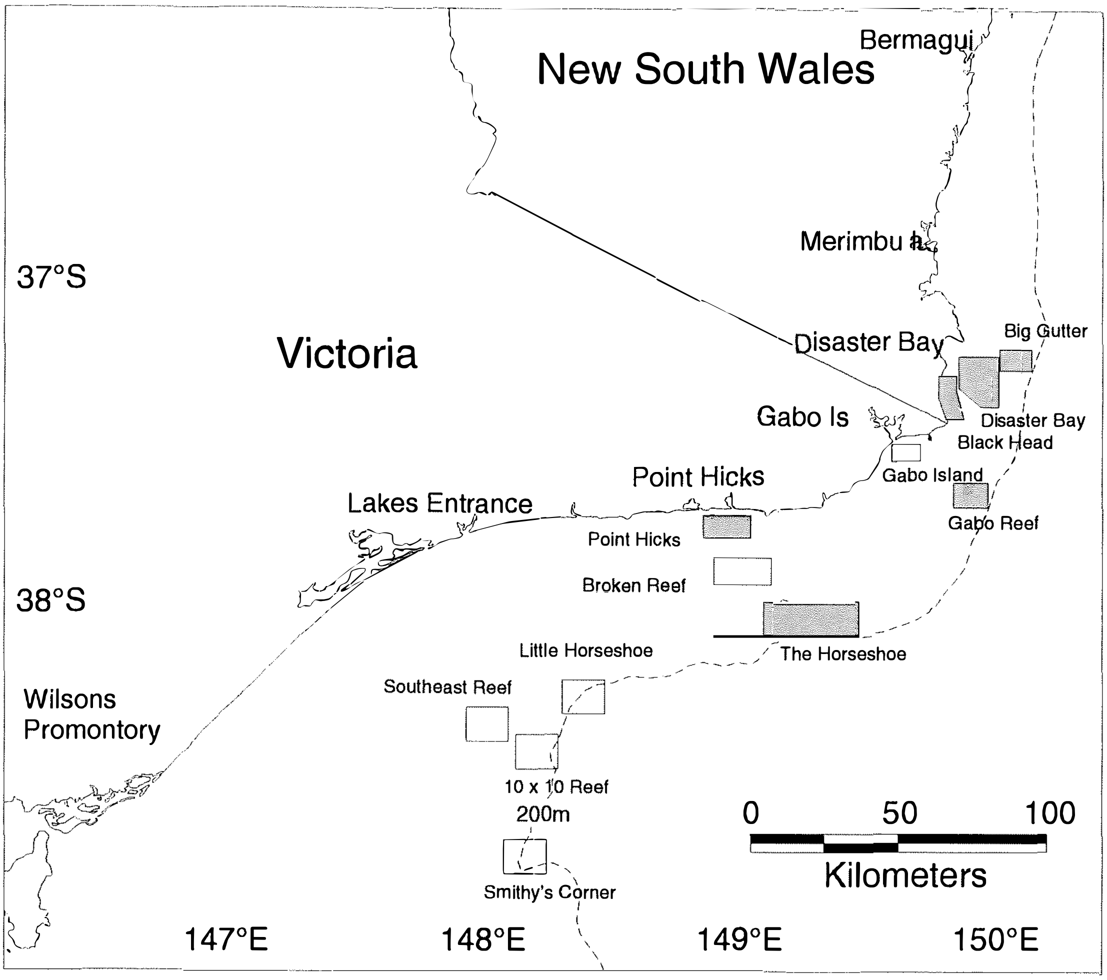

Figure 4.1.2.1 Map of habitat areas sampled during focussed habitat surveys showing six intensively sampled mesohabitats (shaded polygons) and mesohabitats sampled less intensively (unfilled polygons).

at the same stations. Biological samples for analysis of phytoplankton pigments were taken from the plankton nets and from the sediment sampler on the benthic sled. In

addition, four benthic sled tows targeting mollusc concentrations and a cross-shelf photographic transect off Bermagui, requiring 5 deployments of the sled, were completed. The newly developed towed camera array (TACOS) was successfully used to photograph all types of habitat down to 100 m depth.

Macrohabitats in three inner-shelf mesohabitats ('Black Head', 'Disaster Bay', and 'Point Hicks' were identified using acoustics to determine substrate types and subsequently characterised by photography and biological sampling. Acoustic data from the EK500 sounder and the RoxAnn seafloor classification software were logged continuously throughout the cruise. Successful acoustic surveys to characterise seafloor types were carried out at night around known fishing grounds and key habitat areas ('New Zealand Star Banks', 'Smithy's Corner', 'Ten x Ten Reef', 'Everard Reef', 'Little Horseshoe', the 'Gabo Reef/ Howe Reef' system and areas of the shelf-break north of Eden).

A new shipboard data acquisition system was used for the first time at sea. Shipboard use permitted fine-tuning of several components of the system resulting in data for station details, trawl catch compositions and biological data to be entered into the Oracle database and checked.

Survey SF9602/ EJ9602

Sampling during this cruise concentrated on eight macrohabitats in three mesohabitats identified during the *Southern Surveyor* survey SS9602. Six were in Disaster Bay off southern NSW (Black Head and Disaster Bay), and two in Victorian waters off Pt. Hicks. Each was sampled by gillnet and trap during the day and night. The gears were deployed and retrieved at dawn and dusk (approximately 0530–0630 hr and 1730–1830 hr) giving near-equal 12-hour daytime and night-time soaks .

The gillnet was deployed 17 times. Overall, 5,187 fish weighing 5,647 kg were caught. Traps were set at 18 stations. Each set included 5 standard wooden fish traps plus two modified commercial crab traps for catching invertebrates plus one or two comparative metal traps. The total catch was 1,935 fish (1,025 kg) plus 258.5 kg hermit crabs. Biological samples, mainly whole specimens, for stable isotope and dietary analysis were collected from a wide range of species.

Survey SS9606

Overall, 33 demersal trawls, 33 benthic sled tows, 33 CTD casts and 33 sediment samples were completed successfully at the transect stations. About 6.9 tonnes of fish (~63,000 specimens) were caught. The composition of functional taxonomic groups in sled catches were recorded by weight, and by numbers where possible. Zooplankton was collected by bongo and drop nets at all 40 m and 200 m stations.

Macrohabitats in three mid/ outer-shelf mesohabitats ('Big Gutter', 'Gabo Reef' and 'The Horseshoe') were identified using acoustics to determine substrate types and subsequently characterised by photography and biological sampling. In addition, six mesohabitats ('Broken Reef', 'Smithy's Corner', 'Ten x Ten Reef', 'Everard Reef', 'Little Horseshoe', and 'Southeast Reef') were sampled with acoustics and cameras only. Successful acoustic surveys to characterise seafloor types were carried out at night around known fishing grounds and key habitat areas.

Acoustic data from the EK500 echosounder were logged continuously throughout the cruise to characterise seafloor types. Transects were run over areas of particular interest which had not been surveyed during previous cruises. These were identified by mapping previous cruise tracks, fishing grounds and recognisable habitat areas in a GIS display.

Current meter moorings were successfully deployed close the outer edge of Gabo Reef–one just off the reef and one on the reef top— close to an important fishing location. These were retrieved during the focussed habitat sampling.

Forms in the shipboard Oracle database were developed to meet the needs of invertebrate sampling, and an interface was developed for the length frequency measuring boards. This permitted the entry and verification of all records for station details, trawl and sled catch compositions, biological and length frequency data at sea.

Survey SF9701

Three mesohabitats sampled on *Southern Surveyor* cruise SS9606 were re-sampled with traps and gillnets: the Gabo/ Howe Reef complex at 'Big Gutter' and high-relief outer edge of 'Gabo Reef' and 'The Horseshoe'. One set was also completed at 'Broken Reef'.

The gill net fleet was deployed 19 times: a day and night set in each habitat plus a night set at an additional site (Broken Reef). Overall, 6,457 fish and squid (3,965 kg) were caught. A daytime trap set was completed in each habitat. The total catch was 1,402 fish, squid and hermit crabs species for 673 kg; this included 76 kg of hermit crabs. Length measurements from 6,920 individuals were taken. All catch composition and length data were entered onto computer at sea. Biological samples, mainly whole specimens, for stable isotope and dietary analysis were collected from key species (primarily redfish, morwong, ocean perch and John dory).

4.1.4 Industry liaison: port visits and observer trips to sea

Communication with the fishing industry was an important component of this project, particularly in the planning stage when the survey design and choice of sampling gears was considered. To facilitate communication we liaised with a variety of people involved in the SEF fishery through port visits and trips to sea on commercial vessels, as well as having open days on RV *Southern Surveyor* when in port. This provided a great deal of useful background information on the area of interest, gave us insights into current fishing practices, and established long-standing relationships which proved valuable for many aspects of project development. The details of these visits and communication with industry are summarised in Table 4.1.4.1.

4.1.5 Data synthesis and hierarchical models

Our final objective in this study was to develop hierarchical models based on the fishery and fishery ecology. The purpose of these models is to assist management of the fishery ecosystem

Table 4.1.4.1 Summary of the components of industry liaison and communications throughout the duration of the project.

Activity	Location	Vessel	Dates	Aims
Port visits	Lakes Entrance, Eden		19 June - 2 July 94'	Obtain information on fishing practices and gear
Sea-going	Lakes Entrance, Eden		20-24 June 94'	Collect fish samples from the commercial vessels/ general liaison
Sea-going	Lakes Entrance, Eden	Erin Jay, Starfire	3-14 October 94'	Charter for focussed habitat sampling by gillnet and trap
Sea-going	Lakes Entrance, Eden		3-5 September 95'	Collect fish samples from the commercial vessels/ general liaison
Port visits	Lakes Entrance, Eden, Mallacouta		21-27 September 96'	Construction of 'Fishers map'
Sea-going	Lakes Entrance, Eden	Erin Jay, Starfire	20-30 May 96'	Charter for focussed habitat sampling by gillnet and trap
Sea-going	Lakes Entrance, Eden	Starfire	6-16 January 97'	Charter for focussed habitat sampling by gillnet and trap
Industry meetings	Lakes Entrance		7-10 September 95'	Presentation of study results to industry and AFMA at Southeast Fishery Workshop
Industry meetings	Canberra		18-20 September 96'	Presentation of study results to industry and AFMA at Southeast Fishery Workshop
Media	Eden, national		All surveys	Presentation of study results to research stakeholders and general public
Southern Surveyor open days	Batemans Bay, Eden	Southern Surveyor	1994 and 1996	Inspection of research vessel and gear

by supplementing single-species management with broader ecological principles. This management process is frequently called “ecosystem management”.

At the outset of the study, a conceptual model of the factors that could affect productivity of the fish community was developed (Fig. 4.1.5.1a) and refined after the preliminary survey (SS9305) (Fig. 4.1.5.1b). The sampling program then was focussed on key factors that a) seemed to impact fisheries productivity, and b) could benefit from management intervention. Using this approach, we planned to reduce the complexity of managing an ecosystem to managing one or two pertinent operational procedures that would benefit the ecosystem.

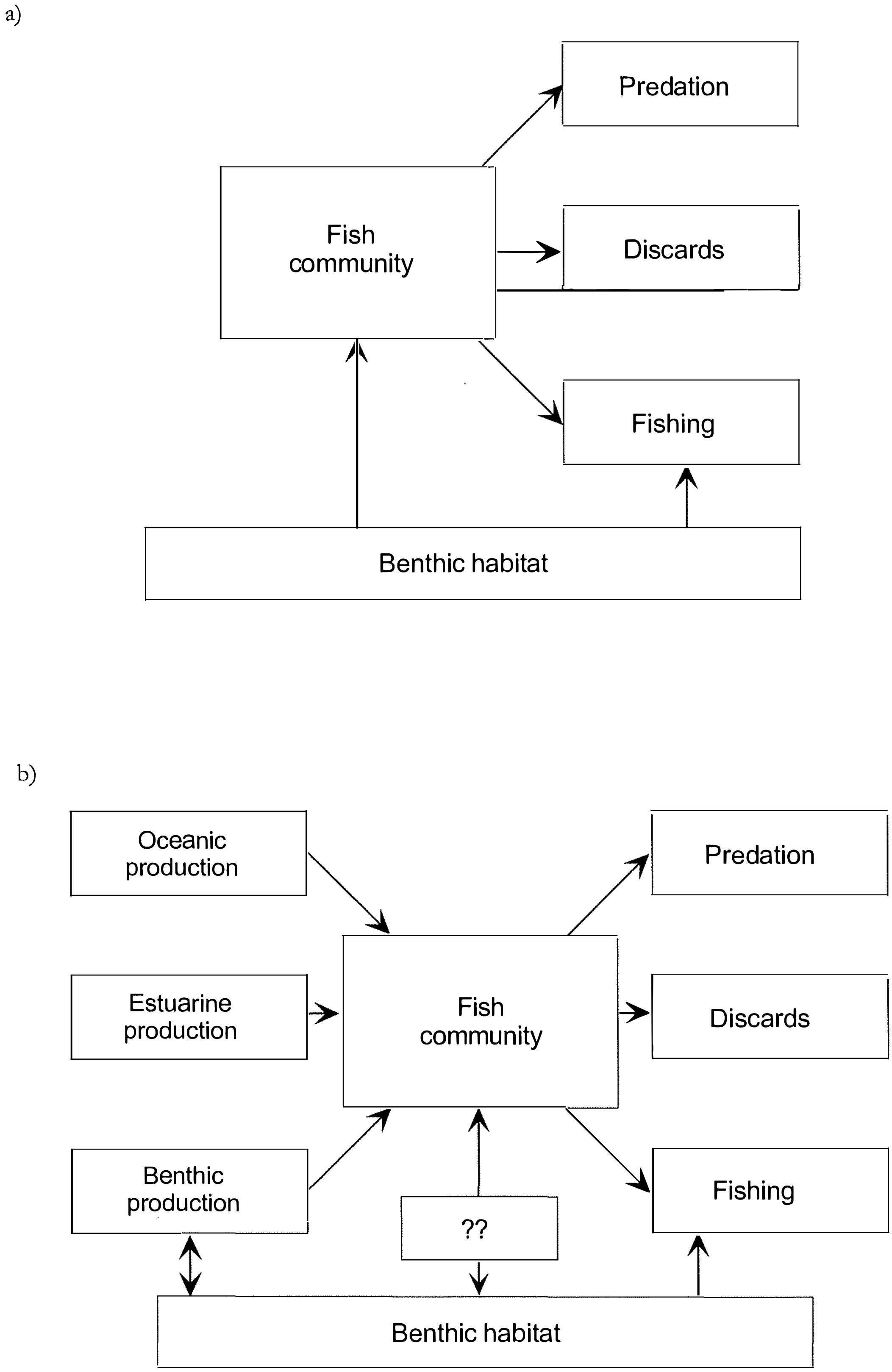

Figure 4.1.5.1 Conceptual models of factors influencing the southeast Australian continental shelf fish community (a) before sampling began, and (b) after the first survey.

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Hudson, P.L., R.W. Griffiths, and T.J. Wheaton (1992). Review of habitat classification schemes appropriate to streams, rivers, and connecting channels in the Great Lakes drainage basin. *In*: The development of an aquatic habitat classification system for lakes. W.D.N. Busch, and P.G. Sly eds. CRC Press, Ann Arbor, Michigan, 73-107.

5 PHYSICAL OCEANOGRAPHY

Nicholas Bax, Alan Williams and Stevie Davenport

The goal of this part of the study was to evaluate the importance of water column habitat to fish of the southeast Australian continental shelf. "Habitat is where fish live" (Hudson *et al.* 1992) and this includes the water column and the seafloor. Physical oceanographic properties were measured in this study to determine the different water masses in the study area and their potential to influence the productivity of different habitats. The distribution of these water masses will be compared in subsequent sections with the distribution of biological communities.

5.1 METHODS

Literature reviews provided background oceanographic information for the study area.

CSIRO Marine Research processes LAC (1 km resolution) NOAA-12 Advanced Very High Resolution Radiometer (AVHRR) data received in Alice Springs by Australian Centre for Remote Sensing (up to 2 passes/day), to generate composite images of seasurface temperature (SST) (Walker and Wilkin 1998). Four SST products have been prepared for this report.

First, 5-km, 10-d composite images were used to generate monthly SST images from 1993 to 1996 (from http://www.dmr.csiro.au/~griffin/OISST/).

Second, 1-km, 15-d composite images were generated for every 5th day of each survey (Rathbone, CSIRO Marine Research, personal communication). Each pixel in the image is coded to represent the 94th percentile of the SST estimates within the period, in order to reject clouds wherever possible.

Third, the time series of average sea-surface temperatures from the 5-km, 10-d composite images were computed at two boxes in the study area and graphed (from http://www.dmr.csiro.au/~griffin/OISST/). The two boxes in the study area were chosen to represent EAC water off southern NSW (Box 1, Fig. 5.1.1.1), and cooler Bass Strait water off eastern Victoria (Box 2, Fig. 5.1.1.1).

Fourth, 1-km resolution individual SST images were reviewed for the fine scale detail that gets averaged out of composite images.

Conductivity, Temperature and Salinity (CTD) casts were made at each of the five stations along the seven transects to define the general oceanography in the area at the time of the survey (Fig. 4.1.1.1). In addition to conductivity and temperature, fluorescence and dissolved oxygen were measured continuously for each cast, and water samples were taken at representative depths. Water samples were analysed for temperature, salinity, oxygen, phosphate, nitrate, silicate, nitrite, and ammonia, using standard methods described in CSIRO Marine Labs Report No. 166.

Hydrographic and CTD data at the surface and bottom at each station for each survey were analysed to highlight patterns and water mass structure. Missing data were replaced if there was another sample taken on the same CTD cast at a similar depth and there was no obvious vertical structure at these depths on adjacent transects. Groups of samples formed from between-sample similarities in a cluster analysis (hierarchical agglomerative clustering) were displayed in 2-d MDS (non-metric multidimensional scaling) space using the PRIMER software package (Carr 1996). Euclidean distance was used as the measure of dissimilarity on untransformed data, because data were approximately normally distributed, contained few zeros, and the relationship between variables was close to linear.

5.2 RESULTS AND DISCUSSION

5.2.1 General Hydrological Pattern

Three main water masses affect the study region: the East Australian Current (EAC) and its eddies flow southwards, carrying warm, high salinity, nutrient-poor water; high salinity, cool Bass Strait water flows eastwards driven by the prevailing westerly winds; low salinity, cool subsurface sub-Antarctic water flows slowly from the south after sinking at the Subtropical Convergence.

There is strong seasonality in the presence of the water masses in the study region. In winter, Bass Strait water is well-mixed as a result of intense winds and tide-induced mixing and surface cooling. Driven by prevailing westerly winds, cool, salty Bass Strait water moves eastwards, cascading over the shelf at the eastern edge of Bass Strait–the "Bass Strait Cascade" (Godfrey et al. 1980). The cool salty water sinks to a depth of about 500m beneath warmer, fresher water from the Tasman Sea. Some of this water is carried northwards along the slope of the east coast of Australia for great distances (over 1100km)(Church and Craig 1998). SST images show a sharp front in winter across eastern Bass Strait, just inshore of the 200 m isobath. The region of strongest outflow from Bass Strait is near 38°30′S, 148°30′where the shelf executes a 90°bend (Tomczak 1981, 1985).

Water originating in northeastern Bass Strait in the winter that moves northward along the coast reaching the New South Wales coast was called Eden coastal water by Newell (1961) and has a salinity of around 35.5ppt. Cooling and mixing on the continental shelf may increase its density, causing it to downwell to almost 300 m (Newell 1961). There is uplifting (aka deep upwelling) of fresher sub-Antarctic water (~35.1ppt) at the shelf-break more or less continually, except in May (Fig. 5.2.1.1; Newell 1961). This downwelling occurs along the 400km of continental shelf up to Jervis Bay (35°S) (Tomczak 1985).

In summer, mixed East Australian Current and sub-Antarctic water invade Bass Strait. Flow is generally westward, but slower and more spasmodic than the eastward winter flow. Eddy fields from the EAC bring intrusions of continental slope water onto the shelf, particularly in spring and summer (Church and Craig 1998). Intrusion of EAC water onto the shelf at Eden leads to strong temperature fronts (2°C in 0.5 mile), "tide rips", foam lines and water colour changes (Newell 1961). These conditions can change on a weekly basis (Cresswell 1989).

An underlying northward countercurrent at the shelf-break also transports cool, slope water onto the shelf (Cresswell 1994). Northerly winds sometimes enhance these intrusions by bringing nutrient-rich water to the surface (Cresswell 1994). Associated with north-easterly winds, intermittent upwellings off the Gippsland coast bring cool, nutrient-rich water to the surface (Edwards 1990). Further north, off Bermagui, uplifting of cooler water from 200m or deeper

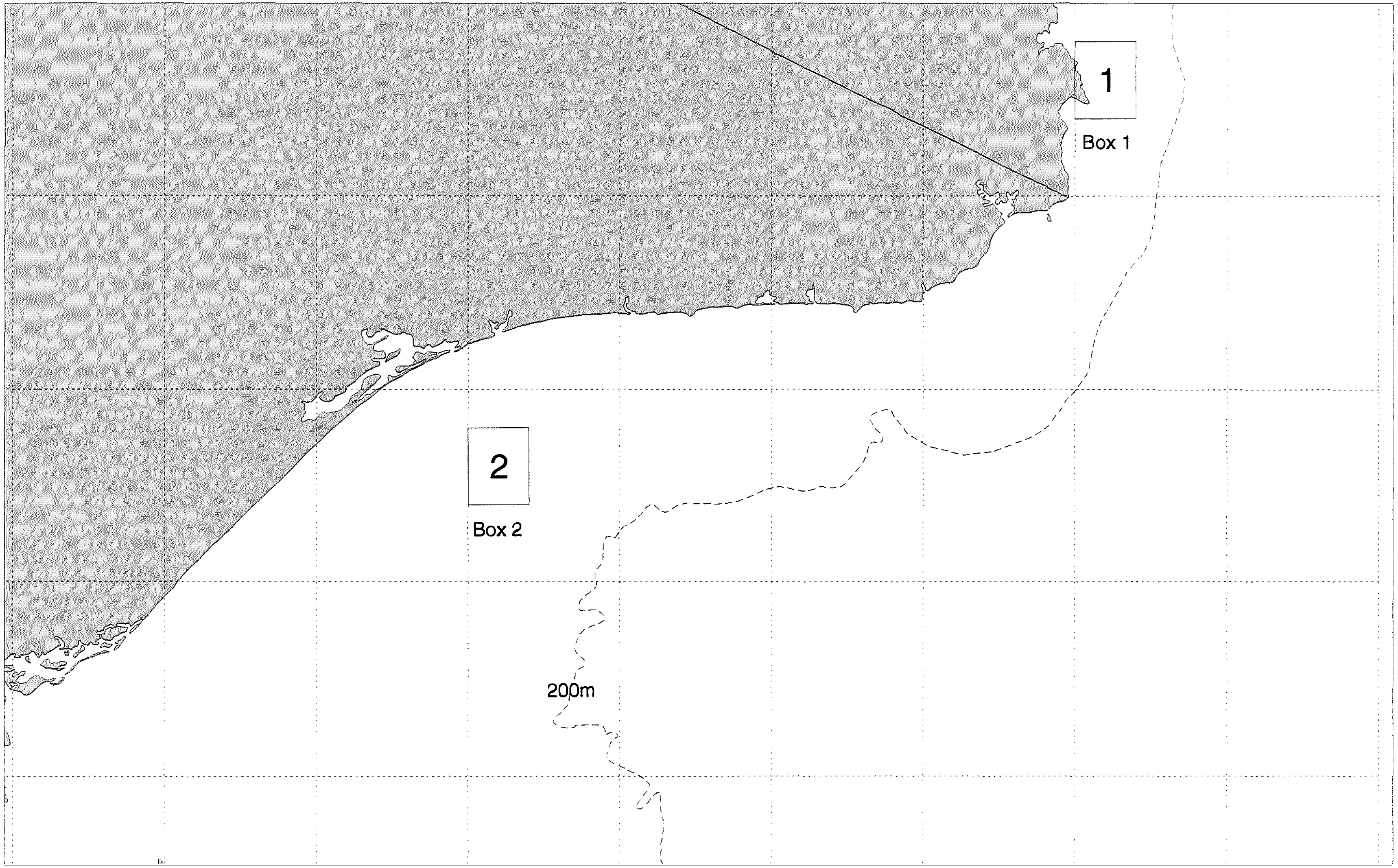


Figure 5.1.1.1 Map of survey area showing the two boxes where AVHRR SST data were averaged in Figure 5.2.2.1.

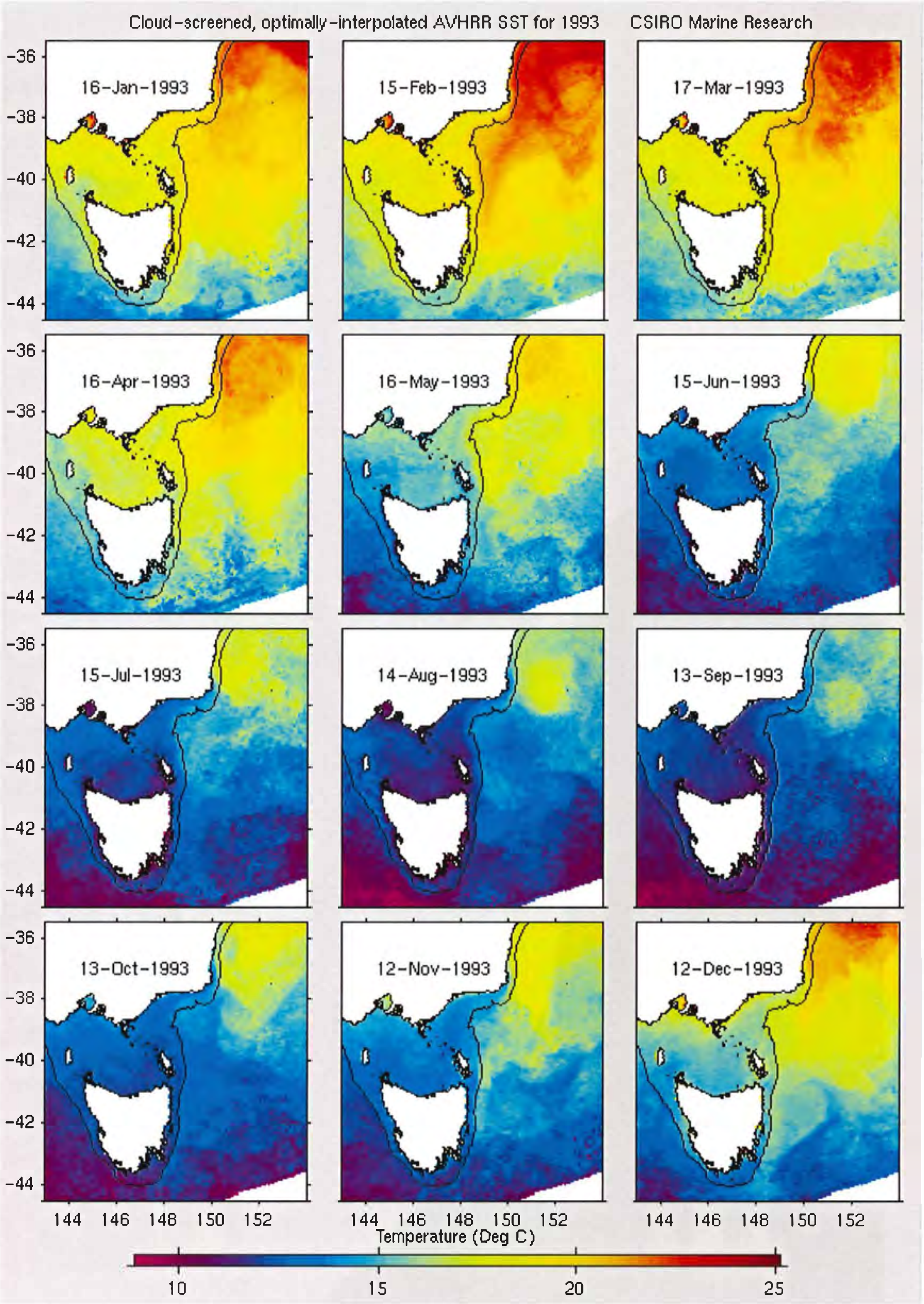


Figure 5.2.1.1 Monthly AVHRR SST images for 1993 to 1996 (5-km resolution, composite image).

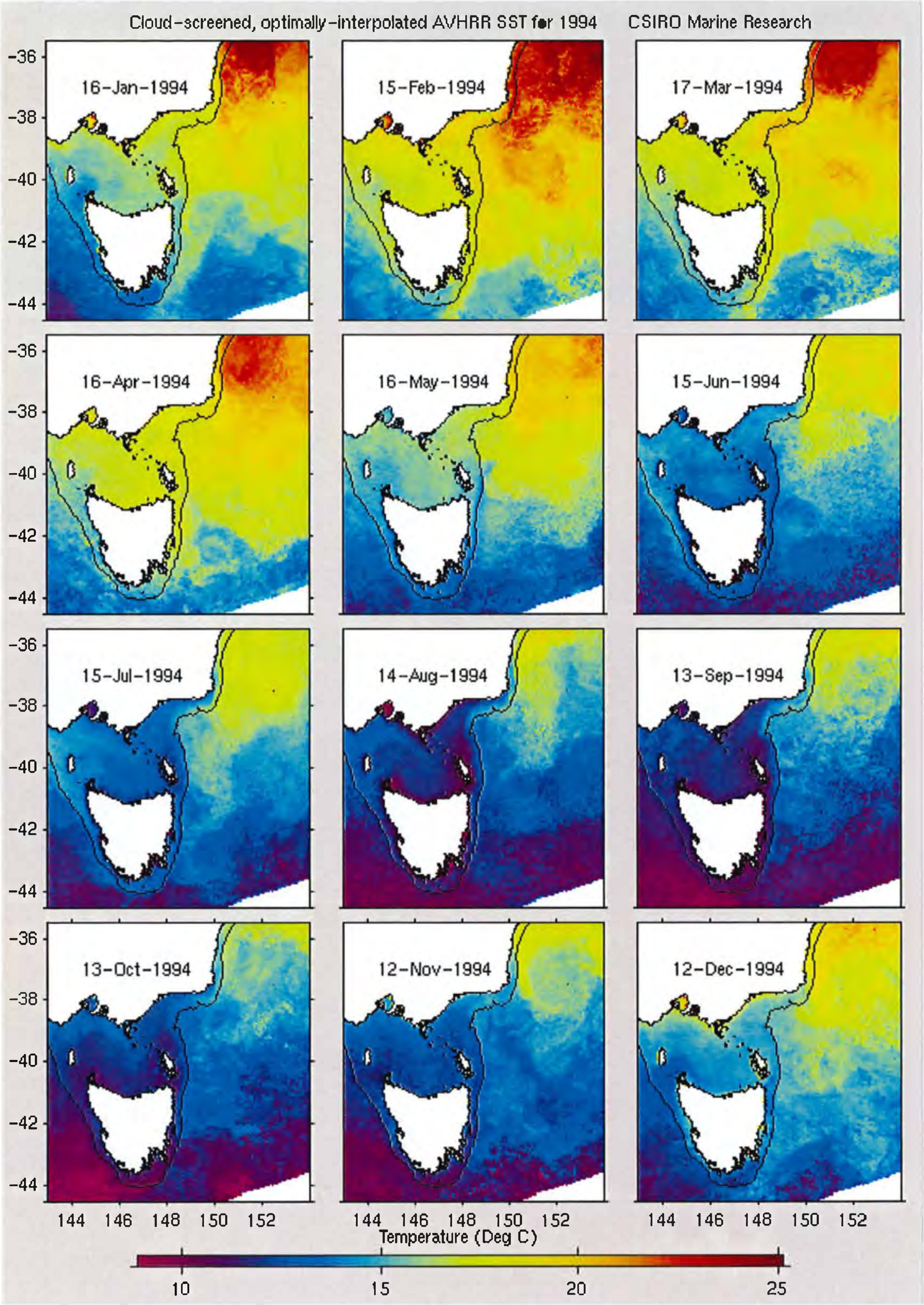


Figure 5.2.1.1 continued

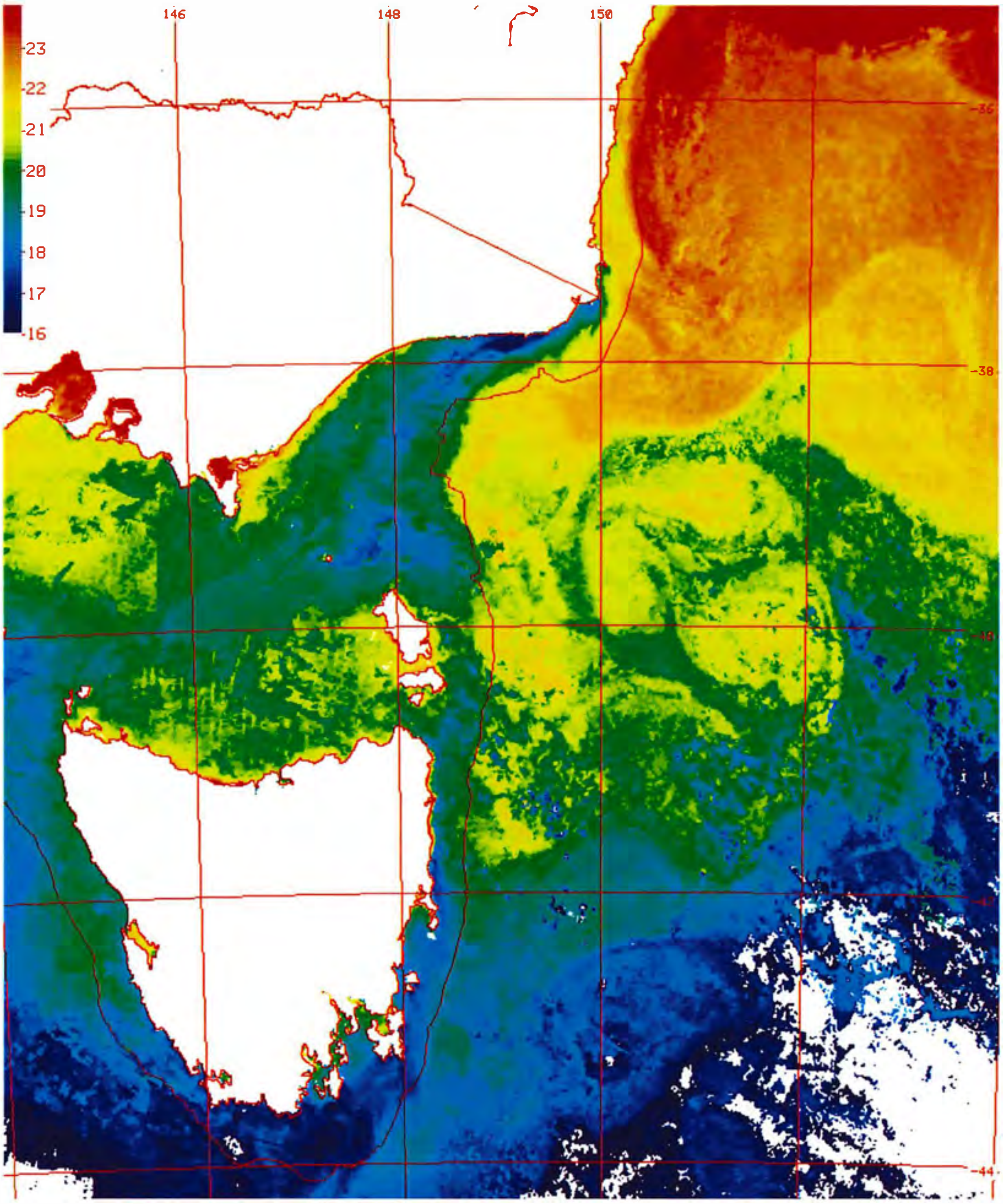


Figure 5.2.1.2 Daily AVHRR SST image for February 1997, showing an upwelling of cool water (16 °C) inshore of "The Horseshoe" (1 km resolution, composite image).

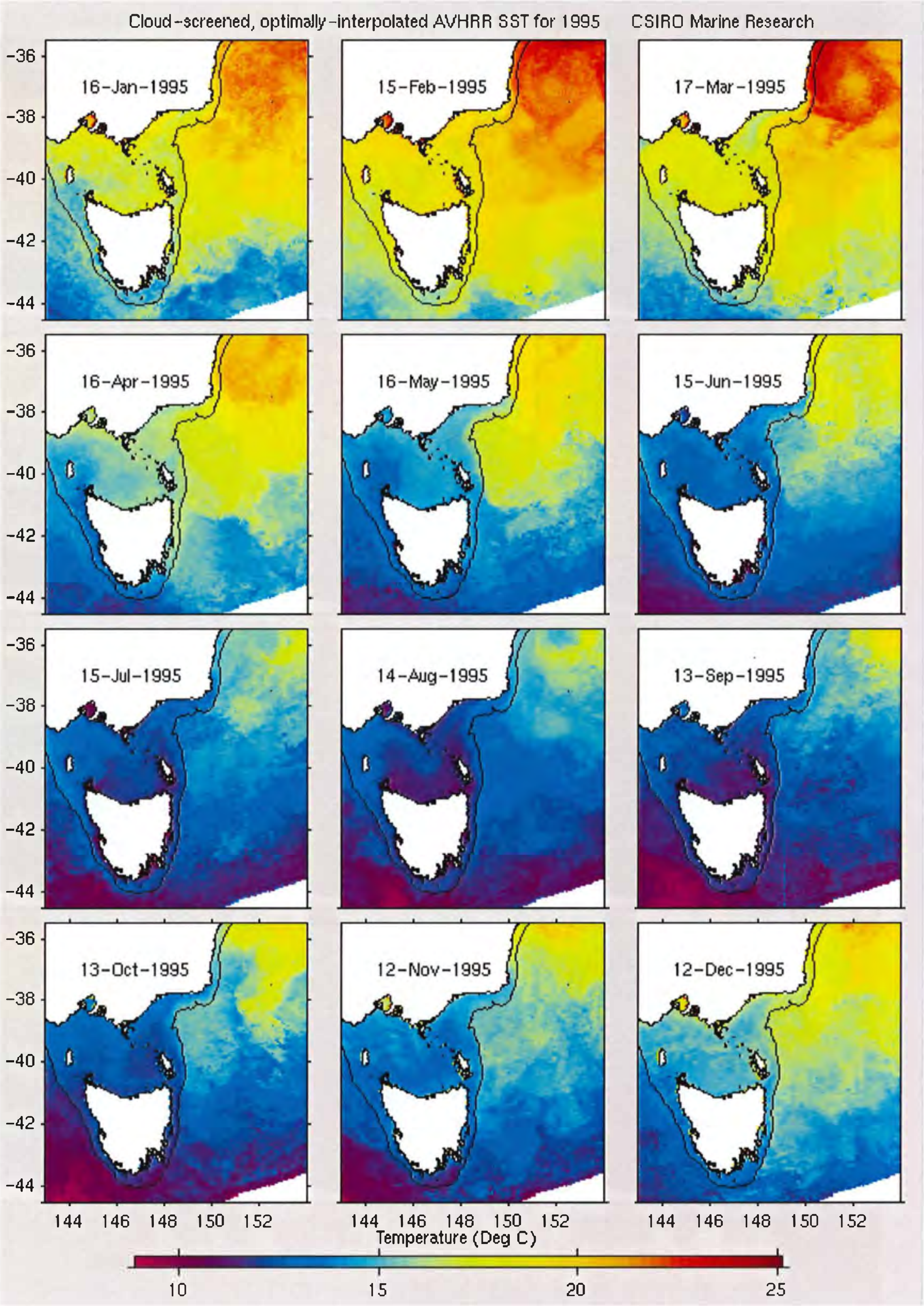


Figure 5.2.1.2 continued

can be seen across the shelf leading to bottom temperatures as much as 8°C cooler than surface temperatures. This uplifting may be driven by the EAC or its eddies (Cresswell 1989).

Sea-surface Temperature (SST) images clearly show the surface currents of the EAC and North Bass Strait water (Fig. 5.2.1.1) The obvious surface features are the seasonal advance and retreat of two main water masses. Cool (12-13°C) northern Bass Strait water moving eastward and hugging the inshore eastern Victorian coast, licking around the Gabo corner to southern NSW reaching as far as Eden in some winters. It reaches its furthest northern extent between the end of July and early September. Warm water from the EAC and its eddies moves south on a broad front, reaching part-way into Bass Strait and down the east coast of Tasmania in summer.

The occasional summer appearance of cool (14°C) upwelled water in shallow water near the 'Horseshoe' off the Gippsland coast of Victoria has been documented (e.g. Rochford 1977, Edwards 1990). It has been characterised as a transient event, occurring only in a narrow coastal zone, mainly between mid-February and late March. Upwelled water was nutrient poor, about 14°C, and thought to originate from a depth of about 100 m (Rochford 1977).

This feature was seen in December 1993, early March 1995 and January/February 1997 (Fig. 5.2.1.2). A similar feature: cooler water appearing at the surface near the 'Horseshoe' was also observed at other times of the year — 8°C water in September 1992 and October 1994 and 10°C water in June and October 1995.

Average waves in the area are 1-3 m in height, with 5-6 s period and penetrate to 60 m depth or more (Morrow and Jones 1988). The southeast Australian continental shelf is, therefore, a moderate to high-energy, wave-dominated environment.

5.2.2 Oceanography 1993-1996

The expected seasonal changes in the primary water masses overlying the study area were observed in each year of the study (Fig. 5.2.1.1). SSTs showed a winter pattern typically persisting between June and August when cool water (~12-14°C) gradually extended eastwards from central Bass Strait, along the shelf from Wilson''s Promontory to Gabo Island and close inshore along the southern NSW coast. Temperatures were sometimes higher (~15-17°C) towards the outer-shelf north of Gabo Island and were distinctly higher (~14-16°C) off the shelf in eastern Bass Strait where a sharp surface interface was seen level along the shelf-break (Fig. 5.2.1.1). Between December and March the shelf region throughout the study area typically lay beneath EAC water of 18-22°C, and was not distinct from offshore waters at the shelf-break.

The time series of temperatures indicates that the SS9305 survey, in early August, occurred at the start of the 1993 winter pattern (Fig. 5.2.2.1). The SS9405 survey occurred in late August towards the end of the 1994 winter pattern that was of similar magnitude to the 1993 winter pattern. The SS9602 survey occurred in April at the transition between a preceding weak summer pattern and typical winter pattern. The SS9606 survey (especially the broad scale survey that occurred in the first quarter of the survey period) occurred during the start of a moderate summer pattern.

5.2.3 Oceanography during each survey

Processed CTD and hydrology data were plotted to show the profile of temperature, salinity, density, nitrates, silicates, nitrites, phosphates and dissolved oxygen with depth at each station. We present results only for temperature, salinity, neutral density and nitrates in the following discussion, because phosphate and silicate generally showed the same trend as nitrate – exceptions will be noted. One nitrite sample was taken at each station. Offshore samples had higher values (~100 micromole/l) than inshore samples (~25 micromole/l), but because offshore nitrite samples were taken at a greater depth in the water column than inshore samples, interpretation is unclear. Dissolved oxygen tended to decrease with depth, especially at offshore and northern stations.

SS9305–Early winter

No water chemistry samples were taken on this first cruise and interpretation is based on the temperature, salinity measurements from the CTD and neutral density derived from these measurements. No data were collected at inner stations on transect D due to equipment malfunction.

Cooler water occurred inshore and to the south at the surface and at depth (Figs. 5.2.2.2a and 5.2.2.3a). Water was well mixed throughout the water column at southern transects (A and B) – (Figs. 5.2.2.3a, and 5.2.2.4a). Some vertical structure can be seen at about 80m depth on offshore stations on transects C and D, with cooler, less saline water at depth. There is increased water column stratification on offshore stations of the northern transects (D-G), with warmer, more saline surface water overlaying the cooler, lower salinity, and denser water. Temperatures at the inner (25 and 40m) stations on the southern transects (A-C) were lower than on the northern transects (E-G). Salinities were similar (Figs. 5.2.2.3a, 5.2.2.4a).

The patterns indicate a variable excursion of cool, low salinity slope water onto the outer-shelf stations of transects C and D. Warmer EAC water is present at the surface on outer-shelf stations on northern transects (D-G). There is a very slight signal of slope water to the 80m (outer-shelf) station in transects A and B, but it is difficult to validate without nutrient data. Lower temperatures at inner stations on southern transects (A-D) compared to northern transects, while salinities remain similar throughout, indicate Bass Strait water to the south changing to EAC water between transects D and E. The origins of the southern offshore water is unclear.

SS9405 – Late Winter

Surface Water

The cluster analysis and MDS plot indicated 4 main groups: one minor group and 2 single stations for surface water masses (Fig. 5.2.2.6a).

Inshore stations on southern transects (A, B and C) were characterised by well-mixed, cool water with very low nutrients and high salinity (Figs. 5.2.2.4b, and 5.2.2.5a)

Offshore stations in southern transects (A, B and C) showed vertical differentiation with warmer water overlying cooler water. Nutrients were higher at depth, but the surface waters also had higher nutrient levels than inshore stations.

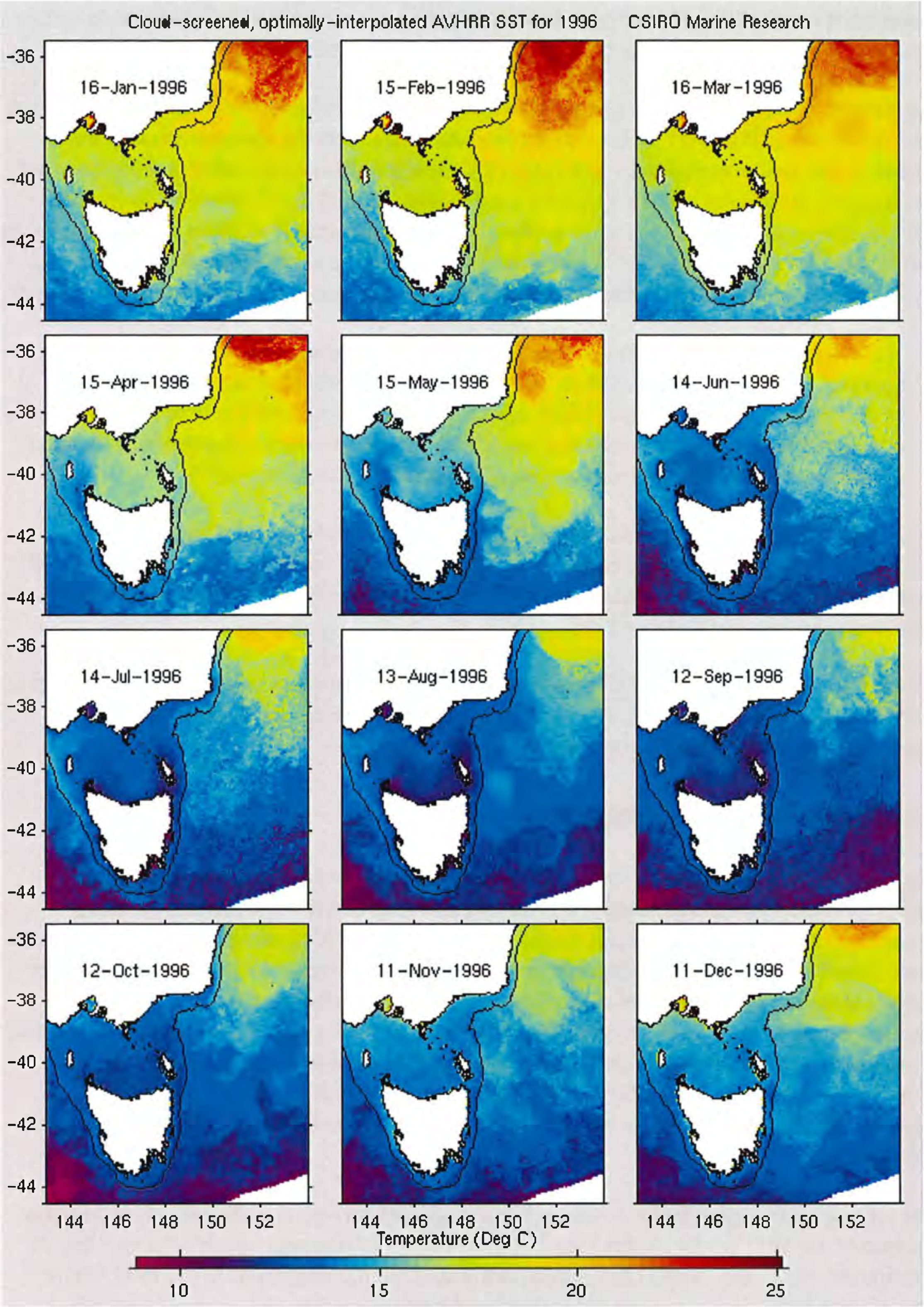


Figure 5.2.1.2 continued

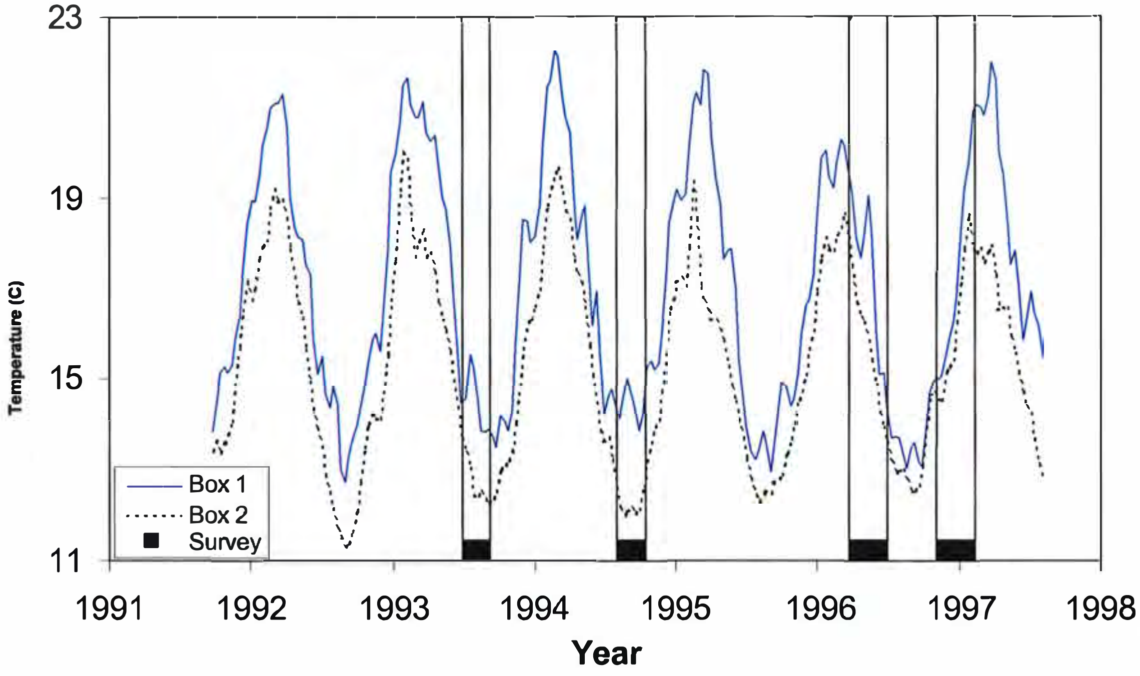


Figure 5.2.2.1 Average AVHRR SST at Box 1 (150 150.2 -37.3 -37.1) and Box 2 (148 148.2 -38.3 -38.1) with times of research surveys superimposed as vertical bars.

15 Day Composite SST Images – SS9305

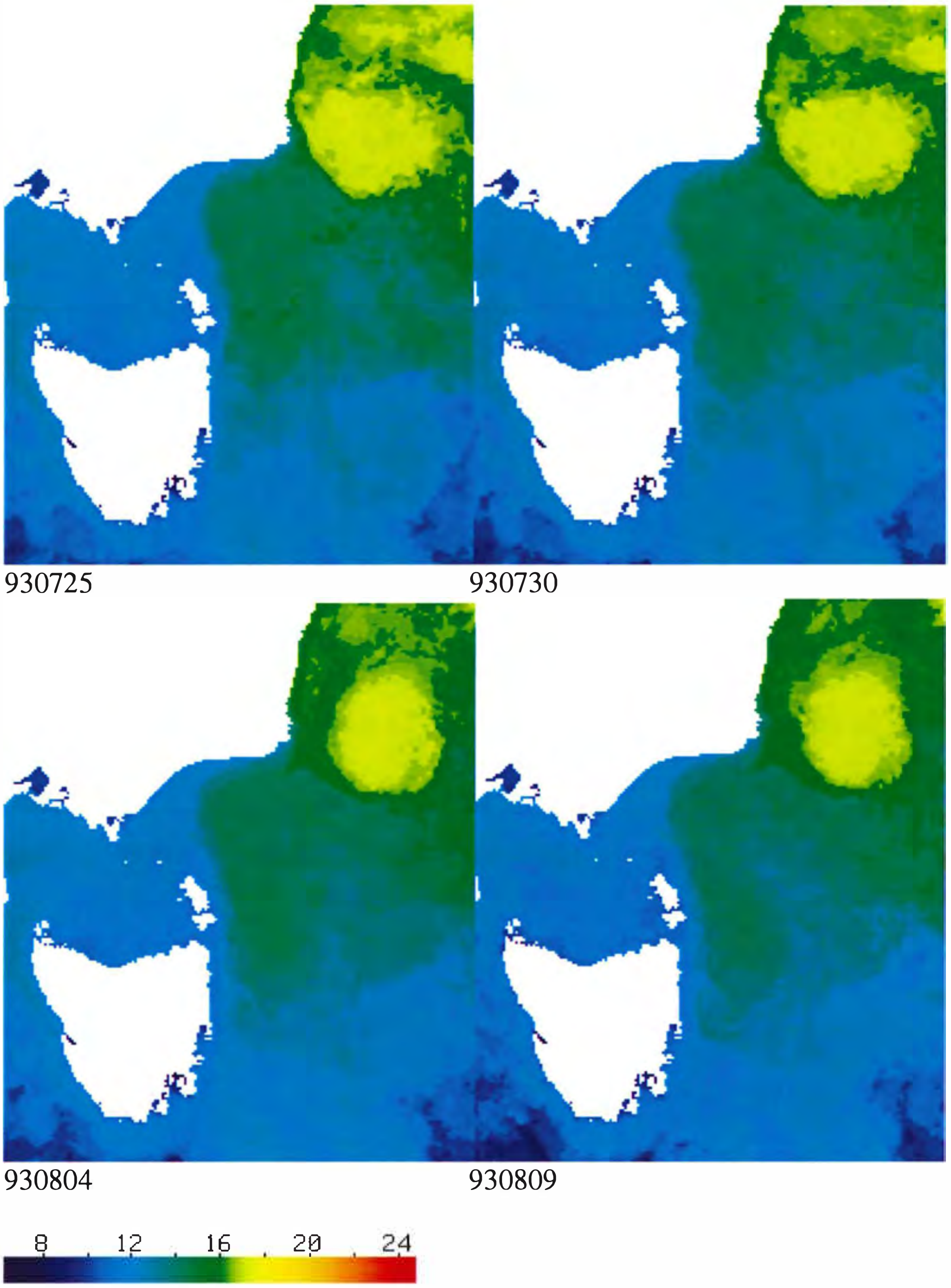
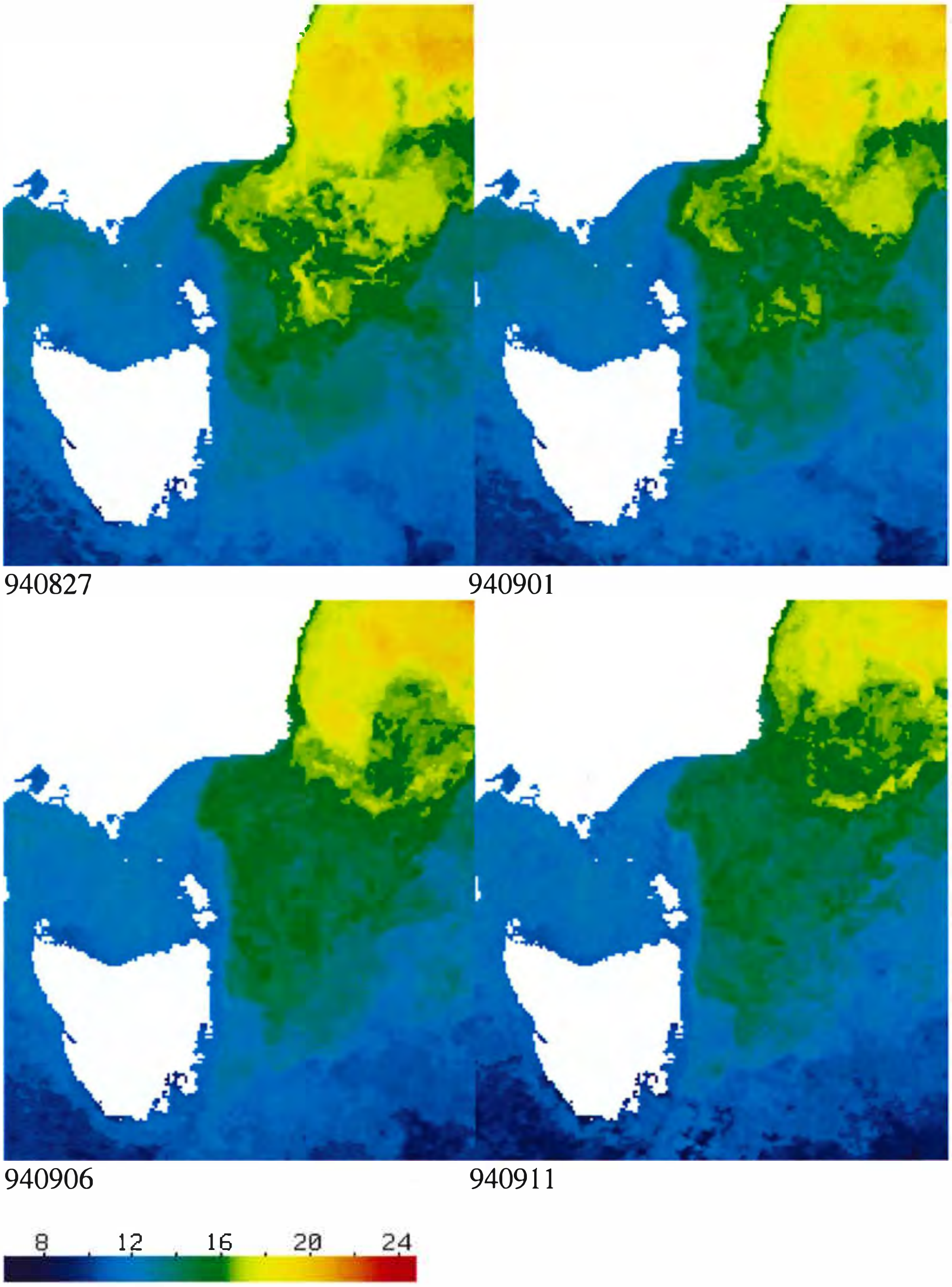


Figure 5.2.2.2 (a) AVHRR SST images for each of the four surveys: a) SS9305 (Early winter); b) SS9405 (Late winter); c) SS9602 (Autumn); and, d) SS9606 (Spring). (1-km resolution, 15-d composite image)

15 Day Composite SST Images – SS9405



940827

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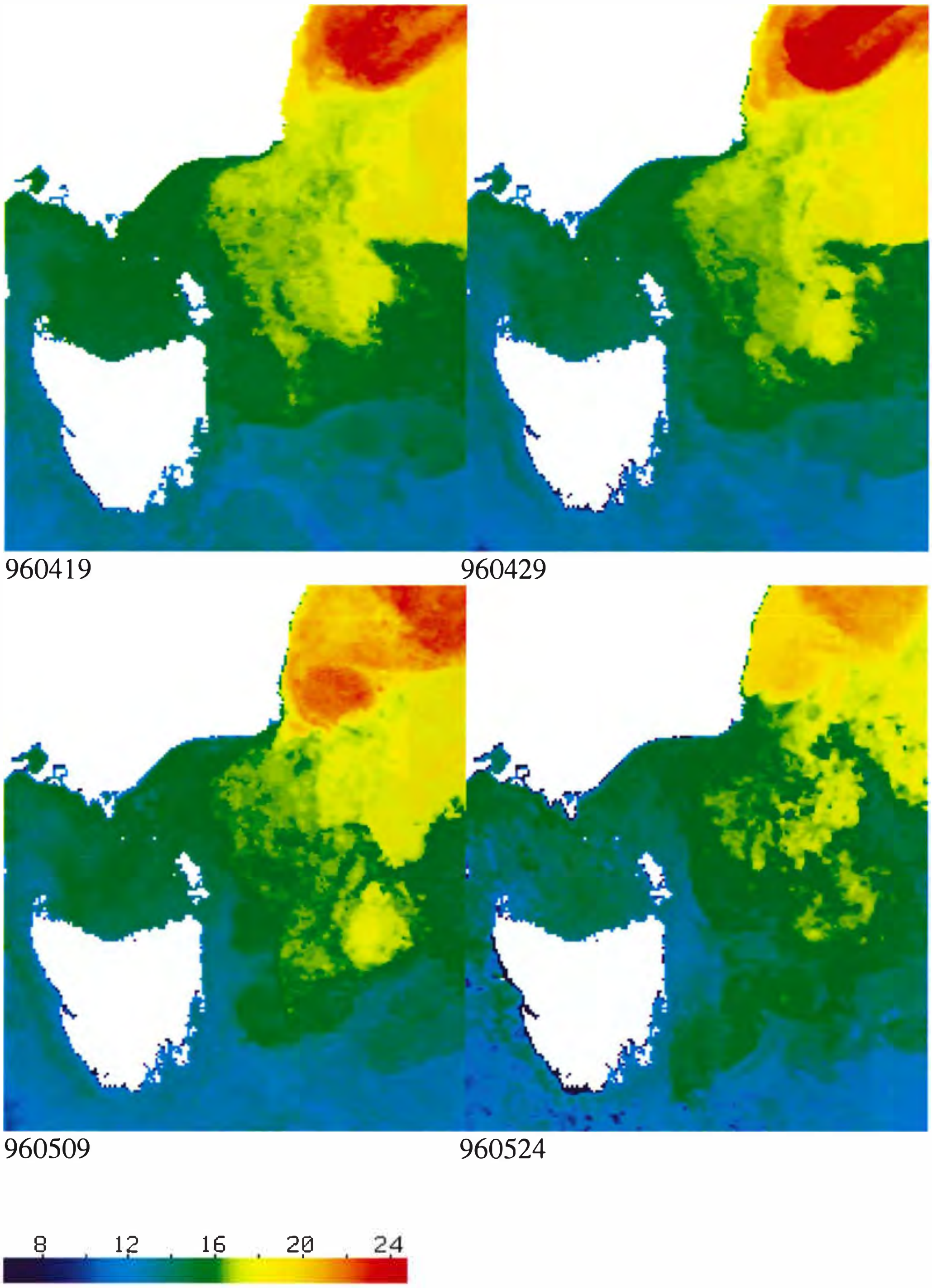
940911

Figure 5.2.2.2 (b)

15 Day Composite SST Images – SS9602



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960429

960509

960524

Figure 5.2.2.2 (c)

15 Day Composite SST Images – SS9606

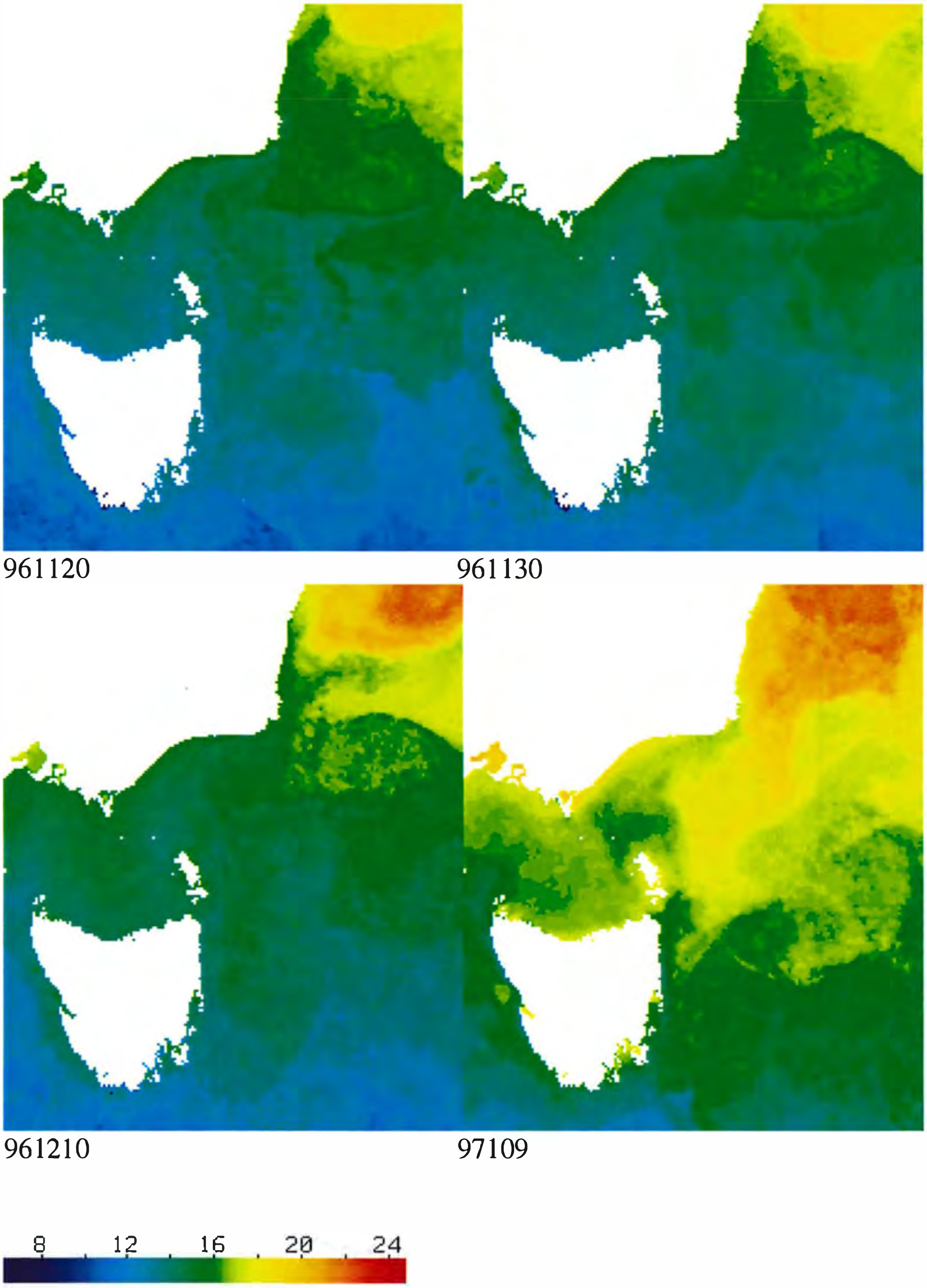
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Figure 5.2.2.2 (d)

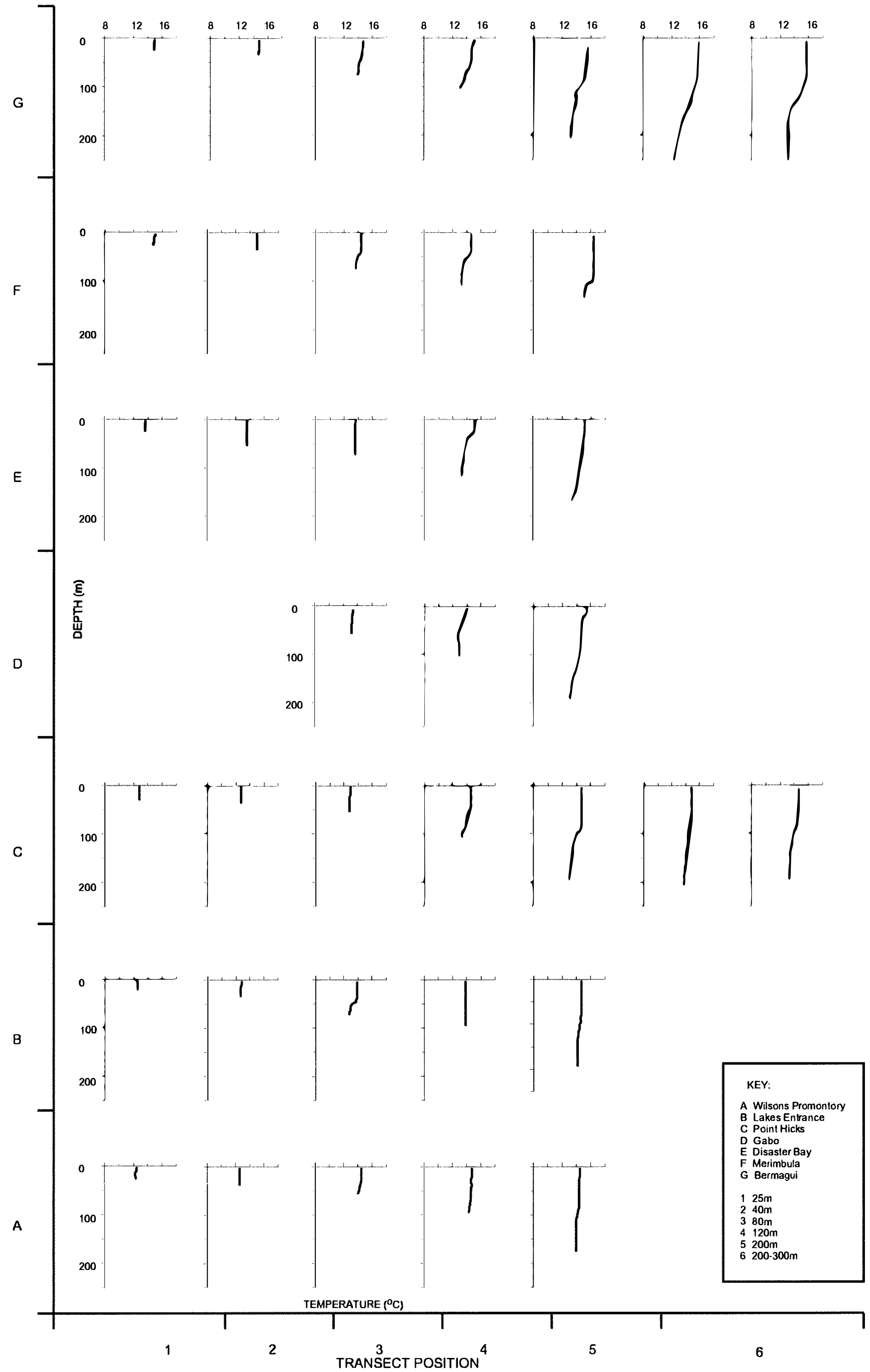


Figure 5.2.2.3 (a) Water temperatures at 2 m depth intervals for broad-scale stations sampled on: a) SS9305 (Early winter); b) SS9405 (Late winter); c) SS9602 (Autumn); and, d) SS9606 (Spring).

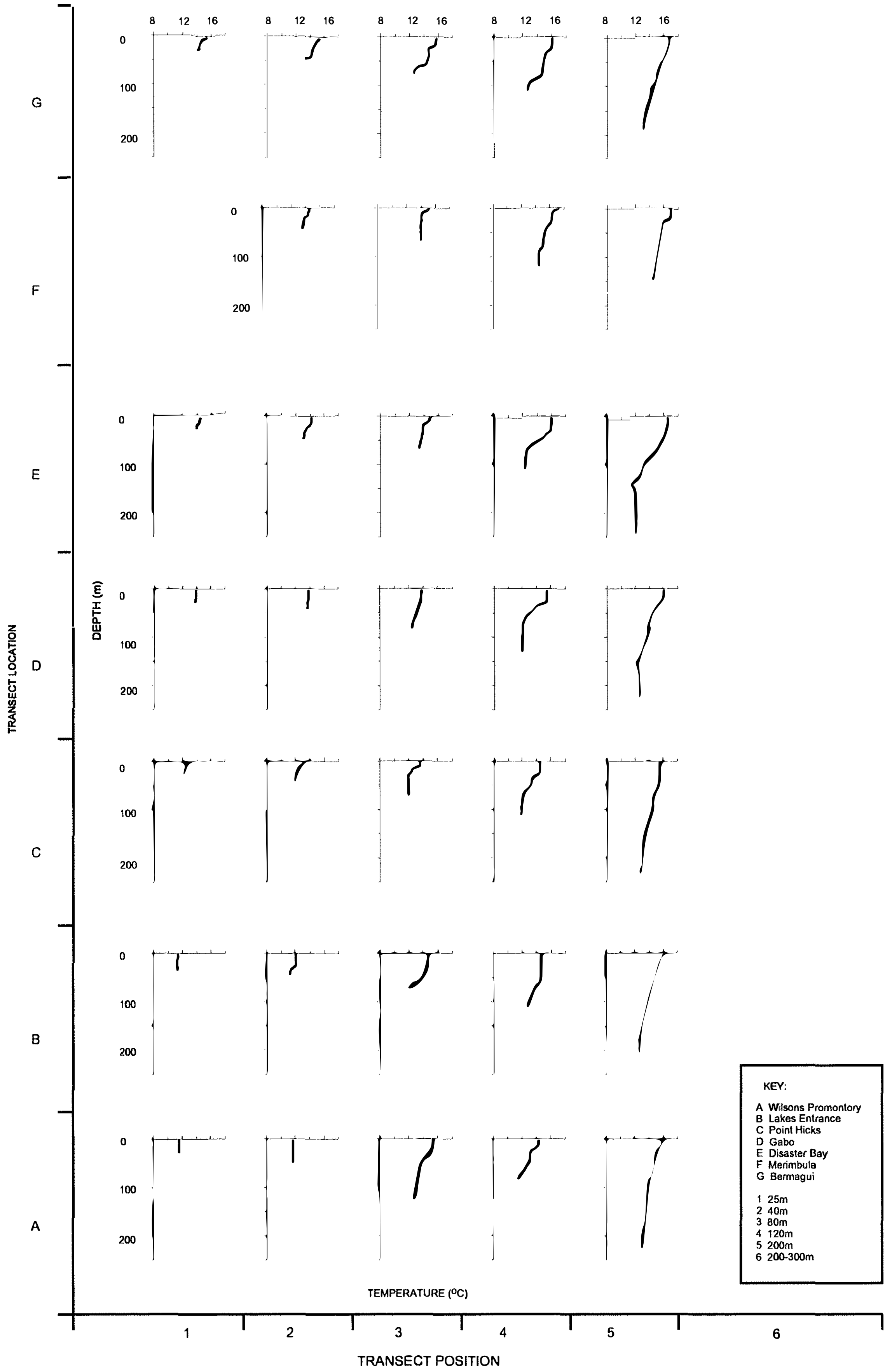


Figure 5.2.2.3 (b)

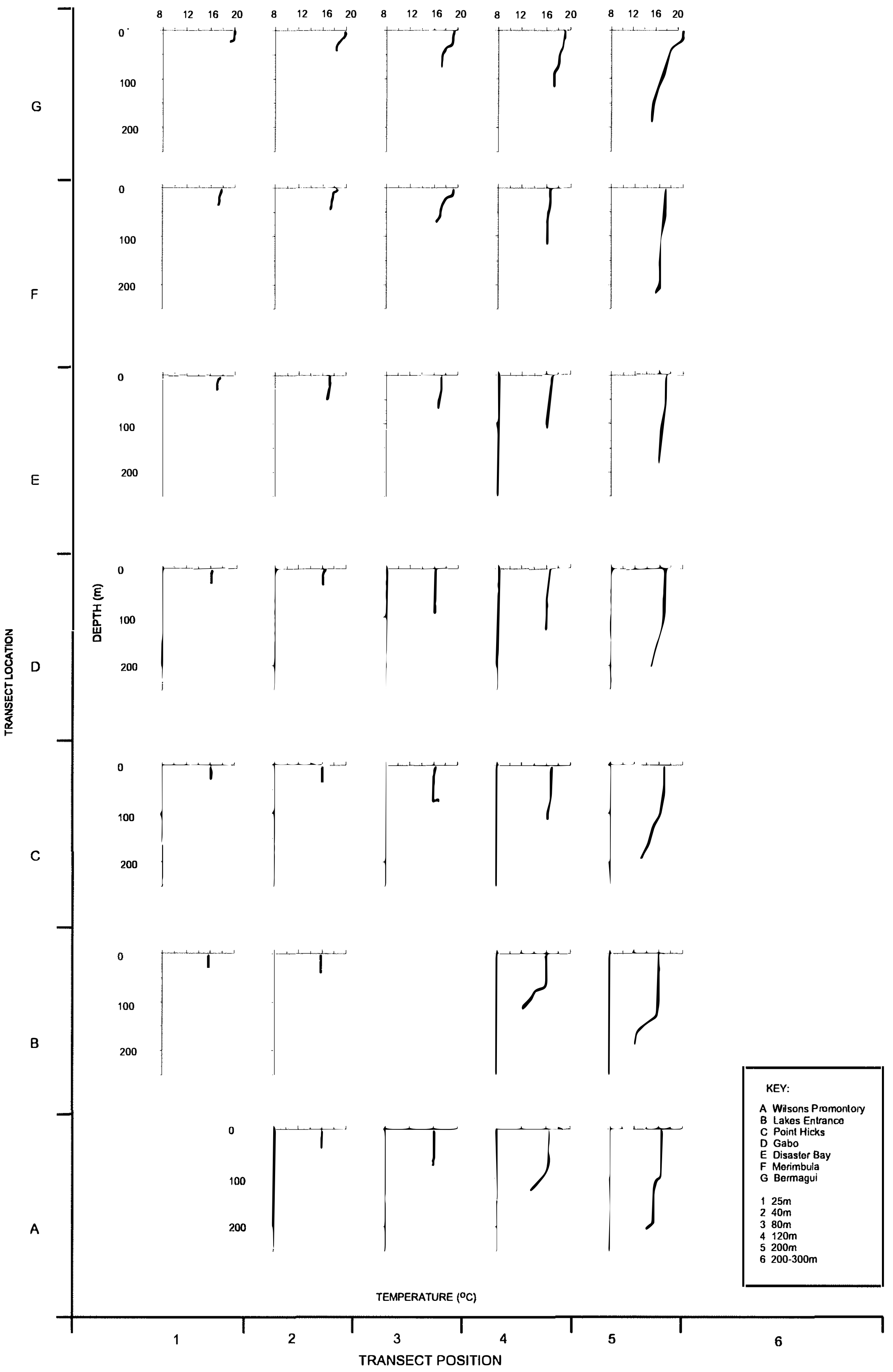


Figure 5.2.2.3 (c)

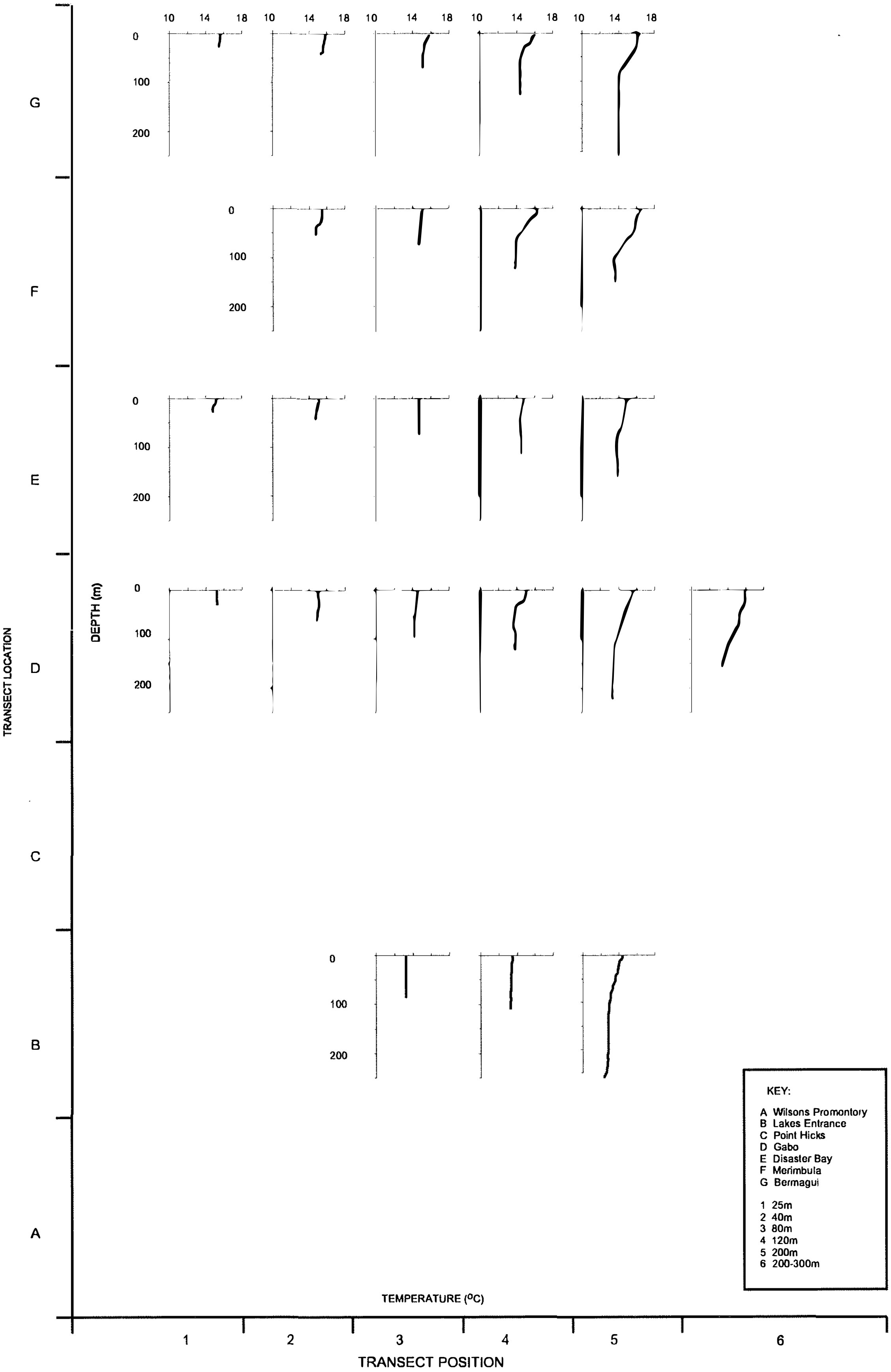


Figure 5.2.2.3 (d)

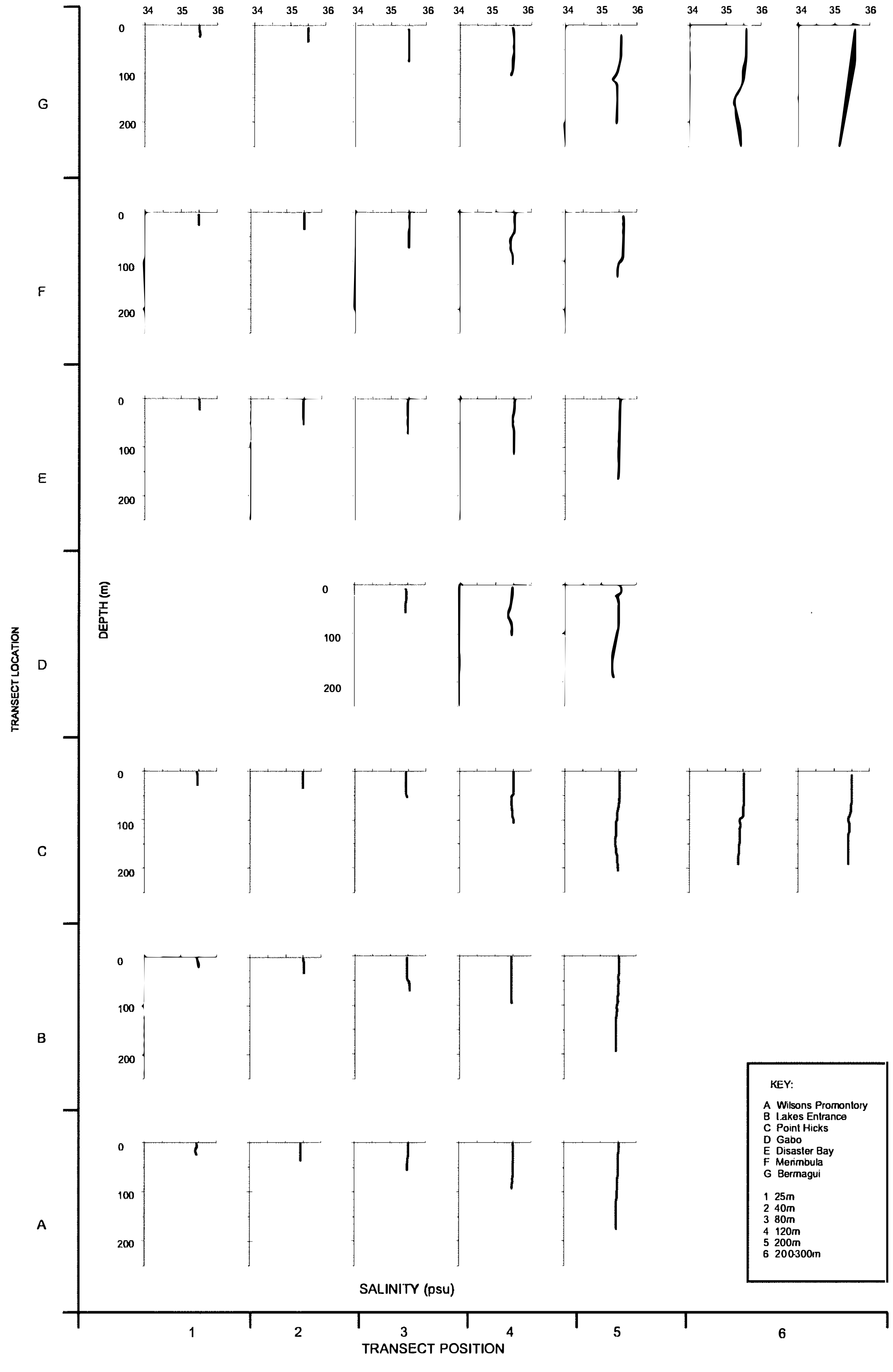


Figure 5.2.2.4 (a) Salinity at 2 m depth intervals for broad-scale stations sampled on: a) SS9305 (Early winter); b) SS9405 (Late winter); c) SS9602 (Autumn); and, d) SS9606 (Spring) (point samples only at indicated depths).

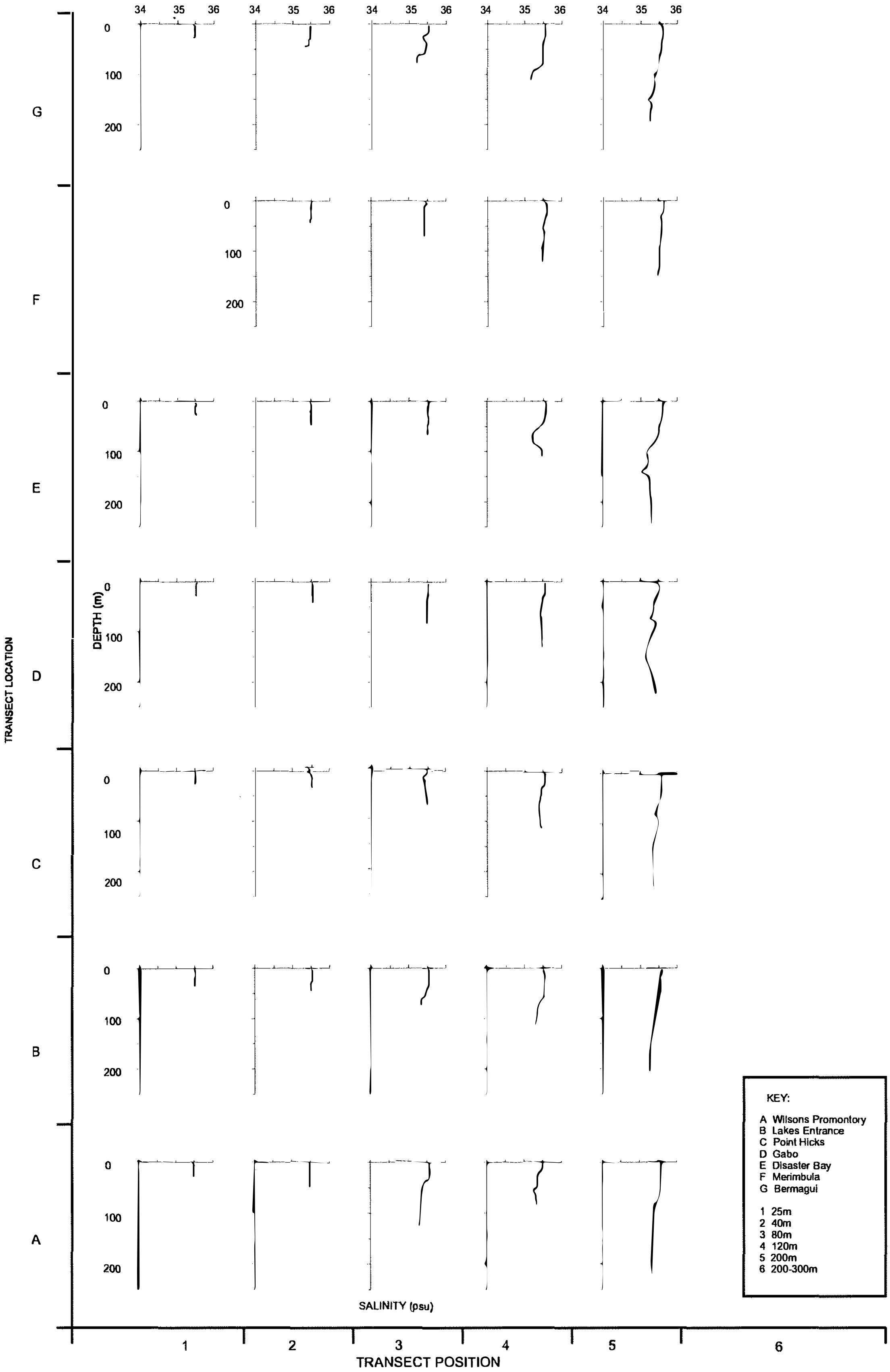


Figure 5.2.2.4 (b) SS9405 (Late winter).

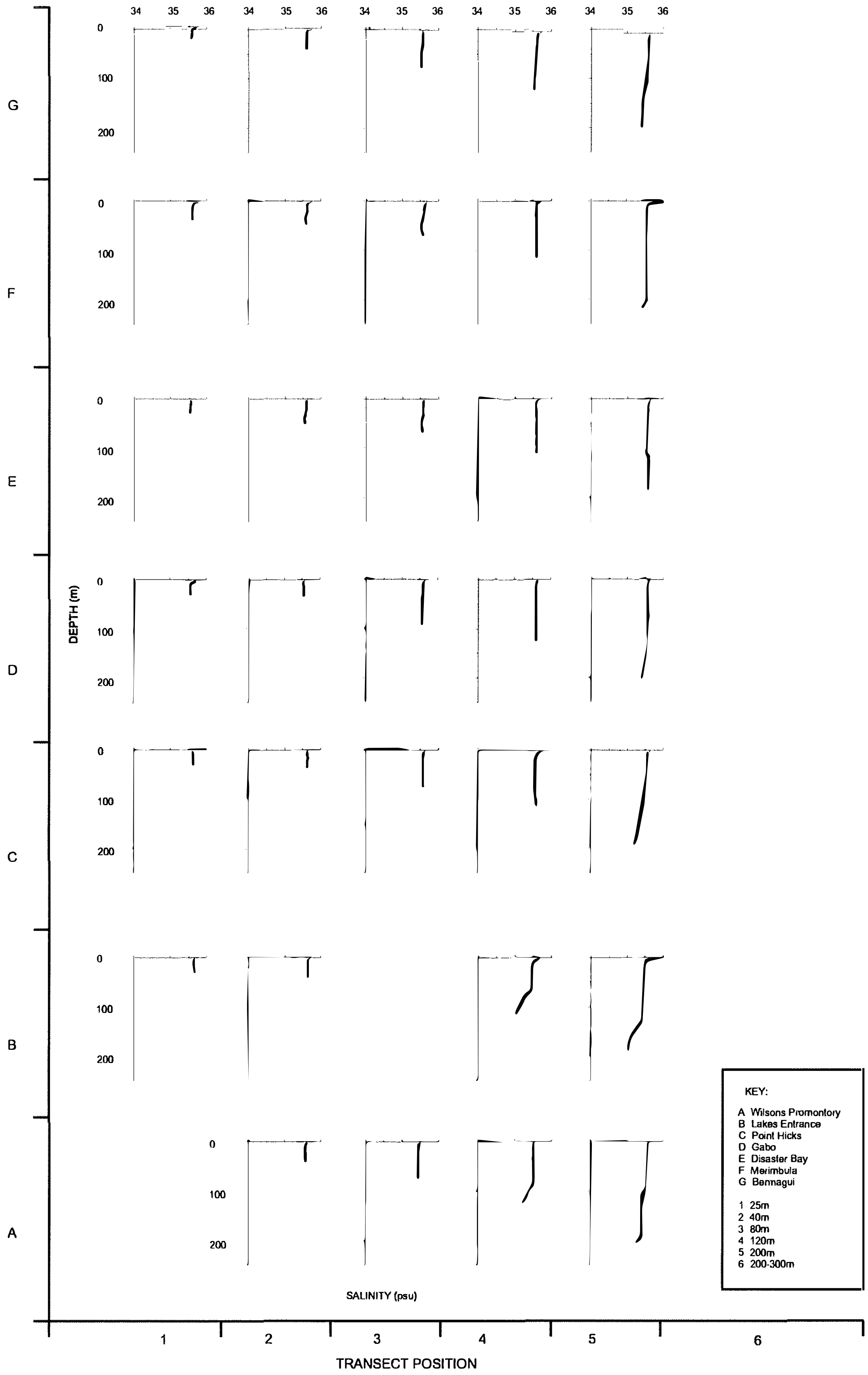


Figure 5.2.2.4 (c) SS9602 (Autumn).

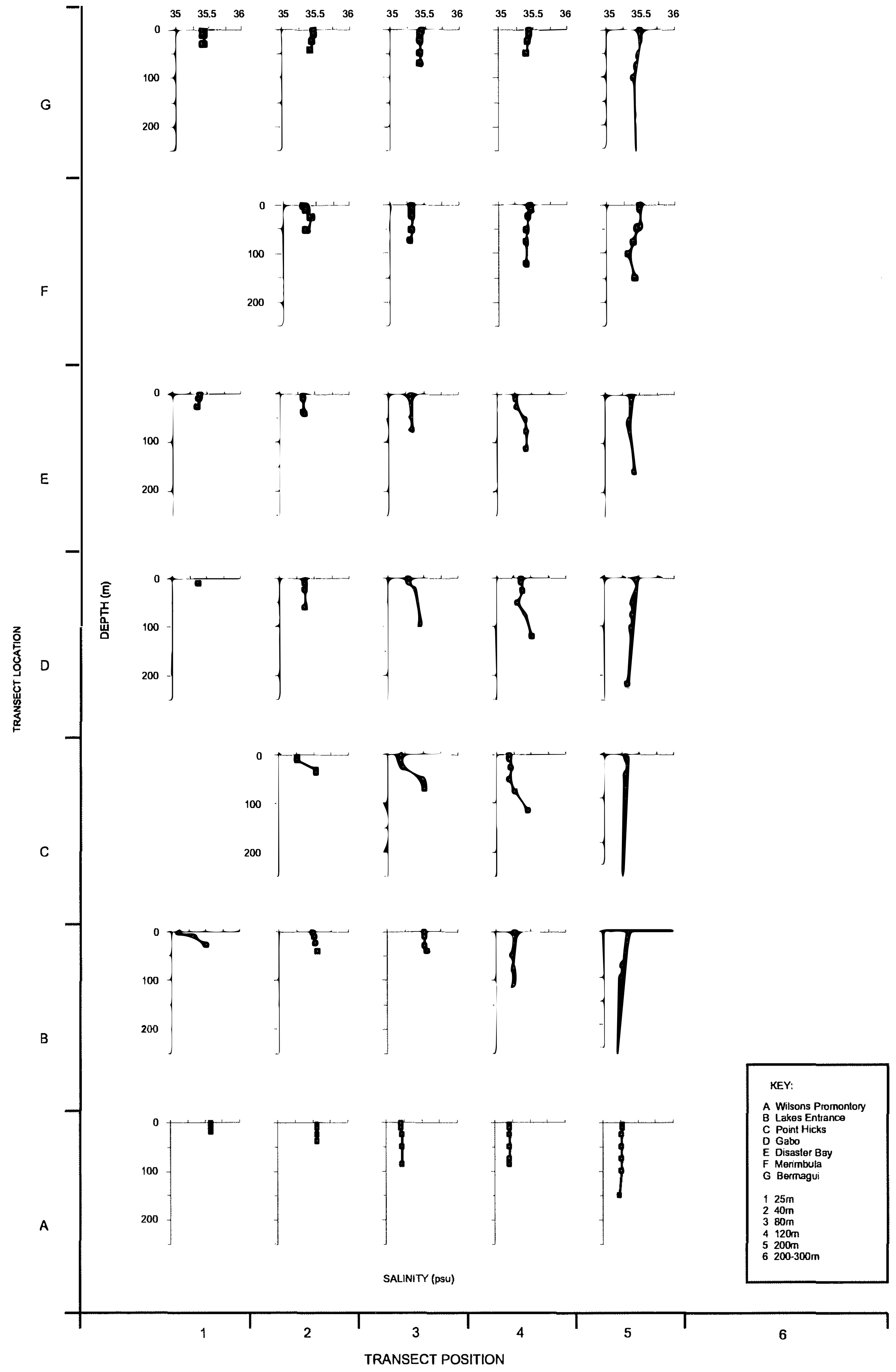


Figure 5.2.2.4 (d) SS9606 (Spring).

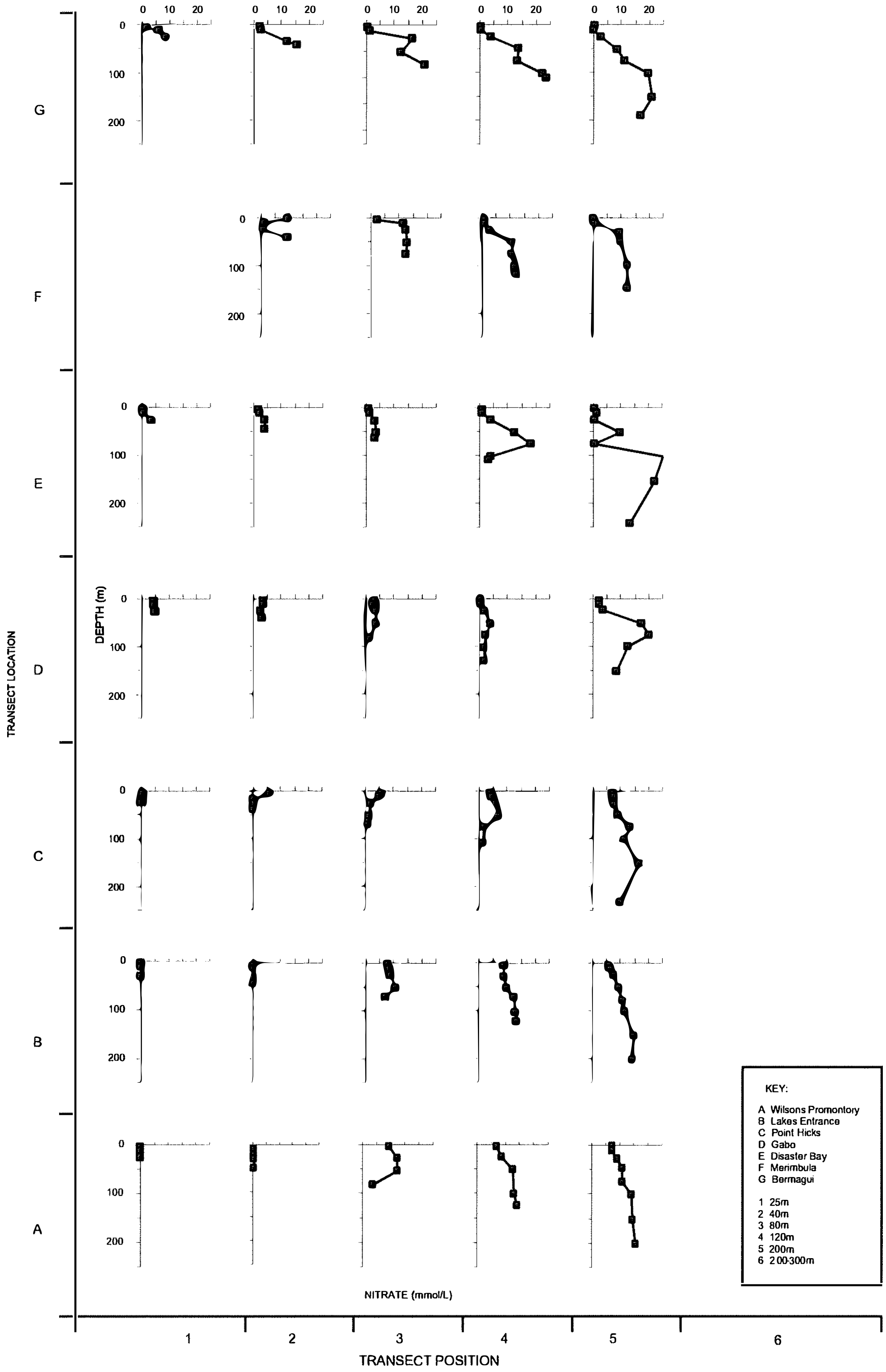


Figure 5.2.2.5 (a) Nitrates in hydrographic samples at indicated depths for broad-scale stations sampled on: a) SS9405 (Late winter); b) SS9602 (Autumn); and, c) SS9606 (Spring).

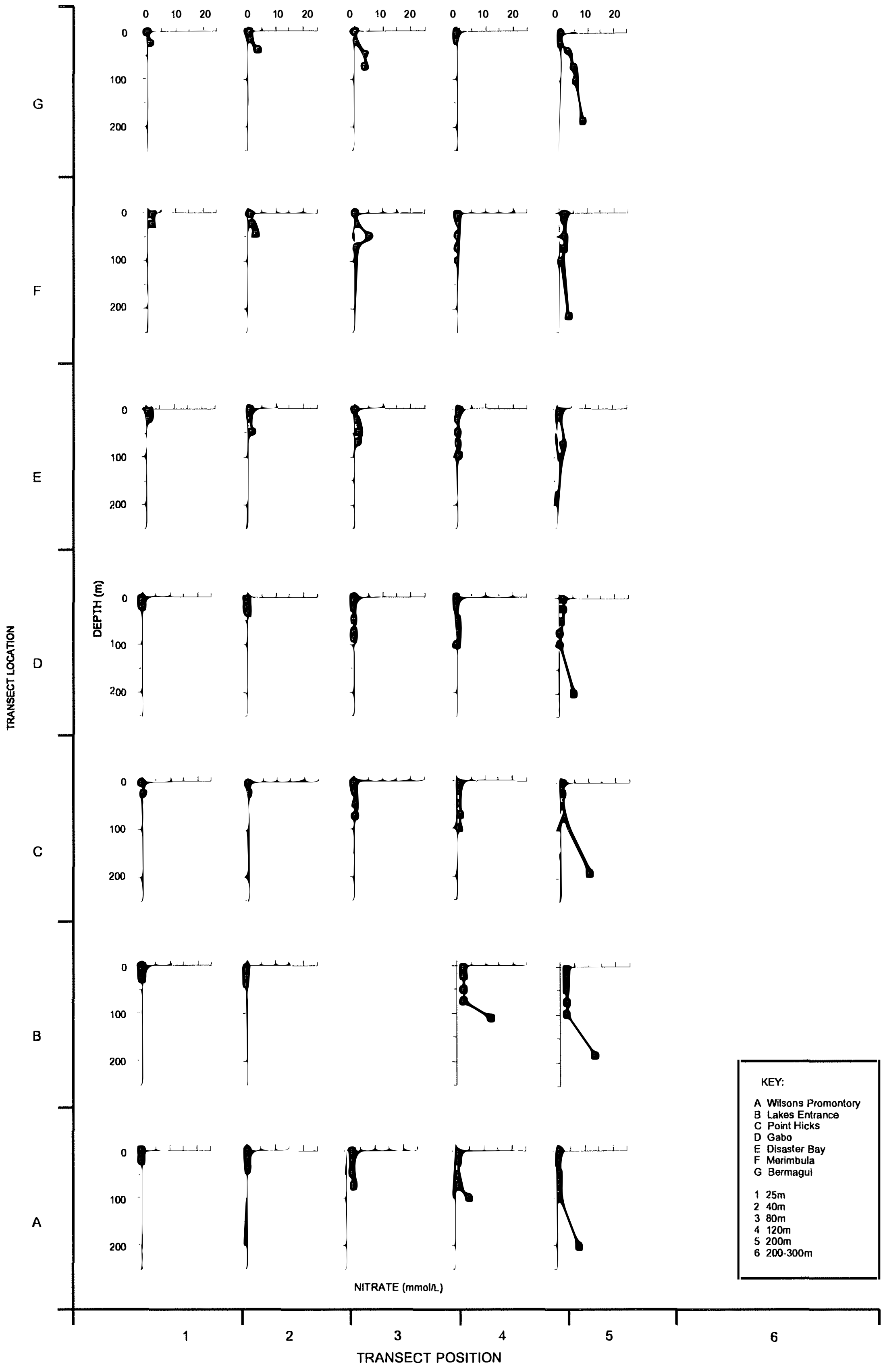


Figure 5.2.2.5 (b) SS9602 (Autumn).

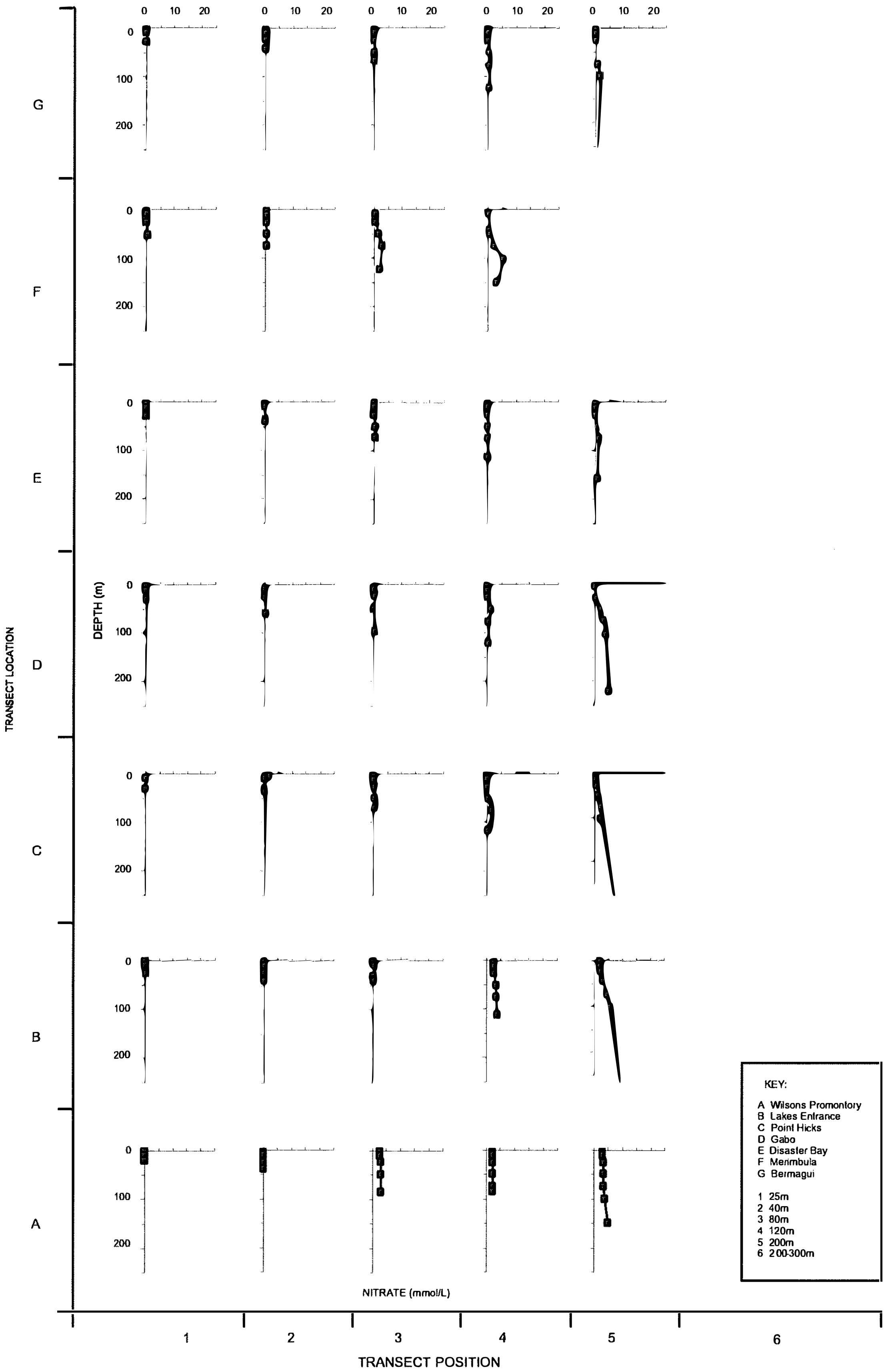
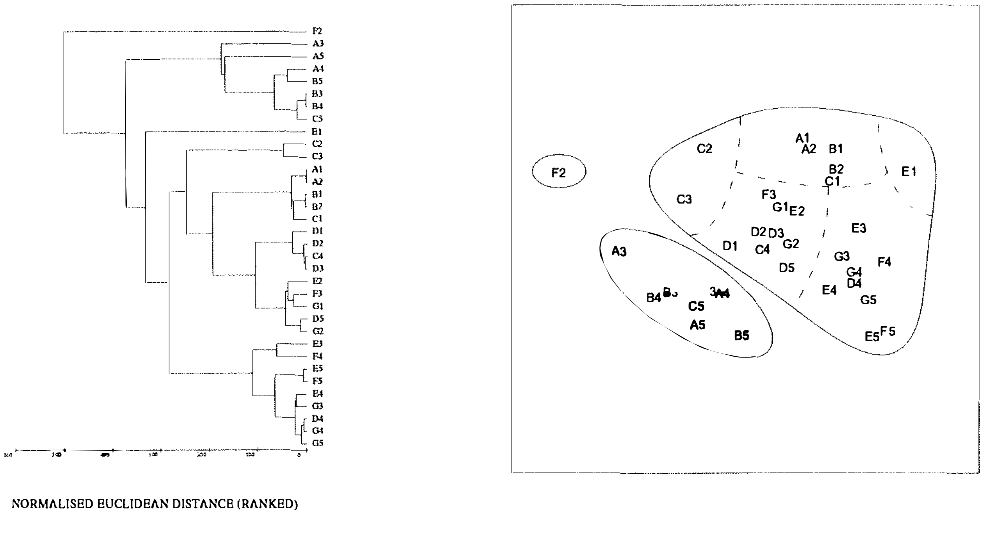
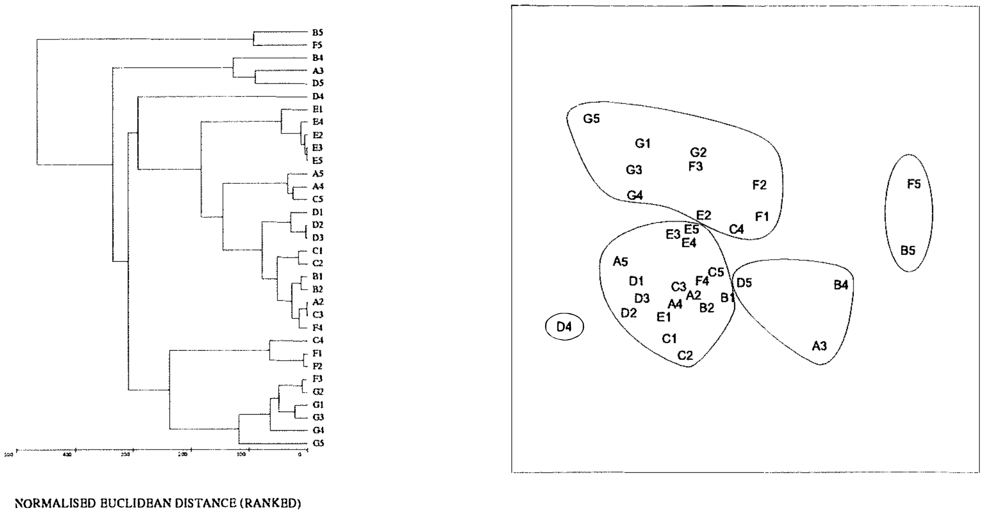


Figure 5.2.2.5 (c) SS9606 (spring).

SS9405 Surface, Stress=0.11



SS9602 Surface, Stress=0.13



SS9606 Surface, Stress=0.15

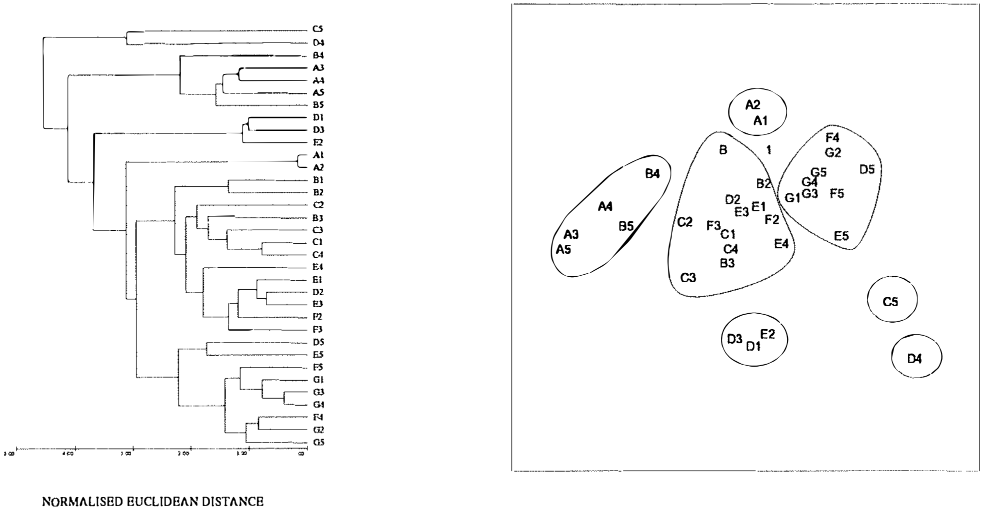


Figure 5.2.2.6 (a) Cluster analyses and MDS plots grouping stations on hydrological properties of surface water.

Inshore stations on northern transects (D, E, F, and G) grouped with mid- and outer-shelf stations on transect (D), and were characterised by well mixed water, with higher temperatures, similar salinities and nutrients to the southern inshore stations.

Offshore stations on northern transects (D, E, F, and G) were characterised by more distinct vertical structure than southern offshore stations, and by similar salinities, a tendency to higher temperatures, but much lower nutrients. Temperatures and salinities were higher than northern inshore stations.

Grouping of the remaining stations was not as clear. Stations C2 and C3 may be transitional between inner and outer-shelf stations, showing slightly elevated nutrients but little elevation in temperature. Stations E1 and F2 were characterised by high dissolved oxygen.

Bottom Water

Multivariate analyses indicated two main groups and one minor group of stations based on bottom water characteristics (Fig. 5.2.2.6b).

Inshore and mid-shelf stations from southern and middle transects (A-E) were vertically mixed and characterised by very low nutrients (nitrates almost absent, perhaps even lower than at surface), low temperatures and relatively low salinities.

Offshore stations from southern transects (A-E) grouped with cross-shelf stations from northern transects (F and G). There was some vertical structure at these stations, with bottom water having lower temperature, lower salinity (than inshore), and high nutrients. Stations on transects F and station G1, formed a subgroup identified with slightly elevated temperatures.

Stations G3 and G4 formed a minor group, characterised by particularly high nutrients and low salinities relative to other adjacent stations.

Summary

Two main patterns were evident on SS9405. First, relatively cool, low salinity, high nutrient slope water was present at depth on all transects. This water reached outer-shelf stations only on southern and middle transects (A-E), but covered the entire shelf on northern transects (F and G; Fig. 5.2.2.2b). Inshore and mid-shelf stations on the southern and middle transects were vertically mixed with the very low nutrients, relatively low temperatures and salinities suggesting Bass Strait water.

Second, this pattern was complicated by a wedge of warmer, low nutrient water at the surface of inshore stations on northern transects (E, F and G) that extended across the shelf on transect D. This warmer water split the outer-shelf stations into two groups – north (E, F and G) and south (A, B and C). The northern group characterised by warmer, very low nutrient water, was very similar to the inshore northern group. Together they represent EAC water entering the study area at the north, but becoming less distinct at shallower, inshore stations where the water column is more mixed. The southern offshore group contained the only stations with measurable nutrients, which may reflect greater vertical mixing of slope water in this area.

Some smaller groupings e.g. G3 and G4 for bottom water suggest the presence of small-scale features – in this instance a particularly contained filament of slope water. Two stations (El and

F2) had higher dissolved oxygen at the surface than adjacent stations. This seems to be a recognizable feature of some stations inshore of Gabo Reef.

SS9602 – Autumn

Surface Water

The multivariate analysis indicated two major groups, two minor groups and one distinct station (that was also distinct on SS9606) (Fig. 5.2.2.6a).

Stations on southern and middle transects (A–E) formed one major group characterised by little vertical structure, low nutrients and relatively high salinity (Figs. 5.2.2.4c and 5.2.2.5b).

Stations on northern transects (F and G) formed a second major group, characterised by very low nutrients, but slightly warmer than southern stations and with evidence of a thermocline at about 25 m.

Two outer-shelf stations (B5 and F5) formed a minor group, characterised by a sharp spike of high salinity water within 5 m of the surface. Nutrients at these stations were higher than at other outer-shelf stations; temperatures were similar.

Three stations (A3, B4 and D5) formed the second minor group that was characterised by higher nutrients than adjacent stations.

Station D4 grouped separately from other stations due to high dissolved oxygen (second highest level on the survey).

Bottom Water

Two groups can be distinguished (Fig. 5.2.2.6b)

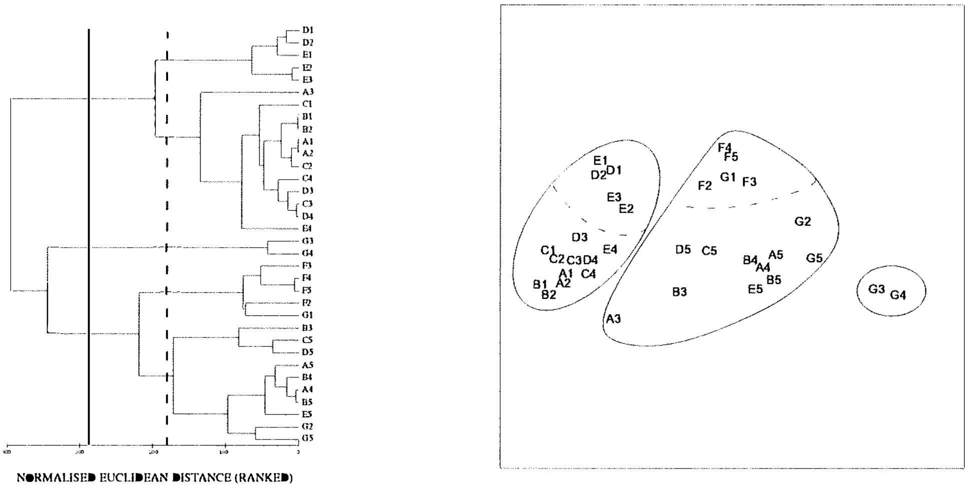
The first group comprises inshore and mid-shelf stations on all transects (A–G), and was characterised by little vertical structure and low nutrients (Figs. 5.2.2.4c and 5.2.2.5b). The northernmost stations (G1 and G2) had warmer water.

The second group included the outer-shelf stations on transects A, B, C, D and G, and was characterised by distinct stratification at 80-100 m depth with low temperature, low salinity, high nutrient water with low dissolved oxygen below this depth. Stratification was particularly strong on transect B, while at G5 stratification occurred at 25 m rather than deeper and this station could be considered a sub-group.

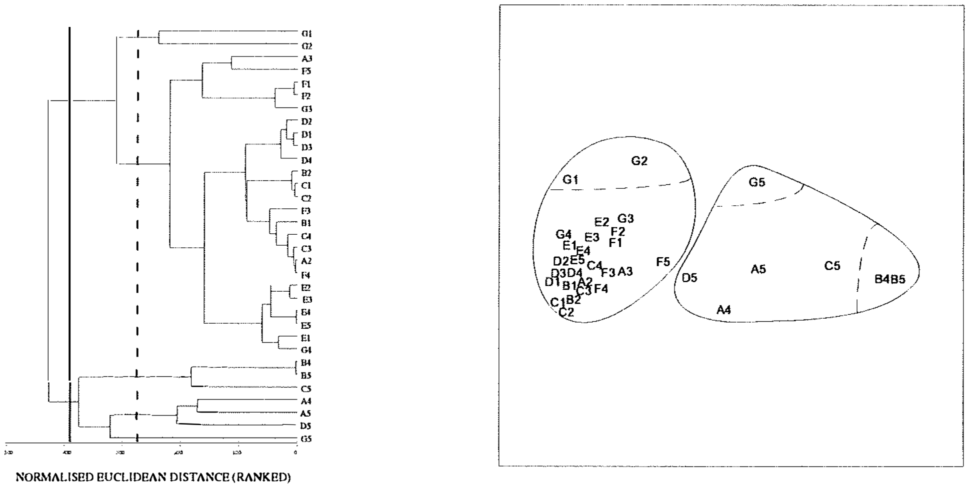
Summary

Low nutrient water covered most of the study area during SS9602. At the surface, low nutrient, well-mixed water extended almost to the shelf-break with patchily distributed areas of higher nutrient water at A3, B4, B5, D5 and F5. At depth, outer-shelf stations (A4, A5, B4, B5, C5 and D5 and G5) had the higher nutrients, lower salinity and low temperature characteristic of slope water. This pattern is consistent with low nutrient (Bass Strait and EAC) water flooding the shelf except very close to the shelf-break, where outer stations had uplifted slope water at depth, that only inconsistently reached the surface.

SS9405 Bottom, Stress=0.02



SS9602 Bottom, Stress=0.03



SS9606 Bottom, Stress=0.08

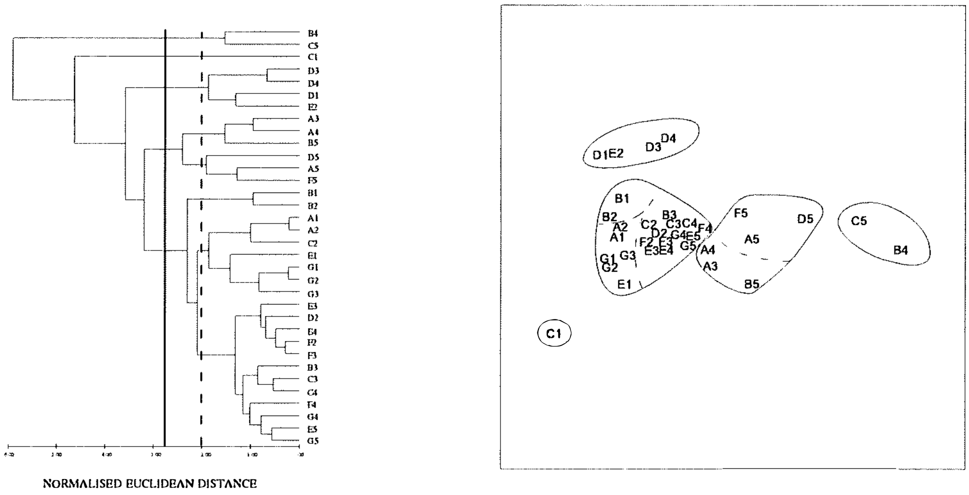


Figure 5.2.2.6 (b) Cluster analyses and MDS plots grouping stations on hydrological properties of bottom water.

There was a north-south division at the surface and depth. At the surface, warmer, low nutrient (EAC?) water covered all stations of the northernmost transect (G) and inshore stations of the next transect (F). At depth, warmer water was apparent only on inner-shelf stations on the northernmost transect (G1 and G2). This pattern is consistent with the dominant water mass being Bass Strait water except for the northernmost transects where EAC water occurred at the surface down to 40m.

SS9606 – Spring

Technical difficulties with the CTD compromised data collection on southern stations. Salinity and temperature measured from the hydrological samples were used when CTD measurements were not available. Temperature data from B2 were missing and, for the purposes of the multivariate analyses, were set equal to B1. Bottom temperature for C4 was missing and, because vertical structure was evident at C3 and C5, was set equal to the average of C3 and C5. Bottom temperatures at A1, A2, B1 and C1 were missing and set equal to surface temperatures; these stations have had well-mixed water in previous surveys and water at the few adjacent stations in this survey appeared well-mixed. Salinities at C1 were missing and set equal to those at C2.

One minor group (SD1, SD3, and SE2) separated from adjacent stations due to high salinities in the surface and bottom water analyses. However, because salinities were high for the CTD, but not the hydrological samples, this was likely an equipment malfunction and these stations were therefore pooled with the adjacent stations.

Surface Water

There were three main groups and two reliable minor groups in the multivariate analysis (Fig. 5.2.2.6a).

The first major group comprised all inshore and mid-shelf stations on all but the northernmost transect (G). These stations were vertically mixed, low in nutrients, relatively low salinity and temperature (Figs. 5.2.2.4d and 5.2.2.5c). A minor group (A1 and A2) could be subdivided from this major group due to lower temperatures, but there is no clear mechanism for this.

The second major group comprised the southern offshore stations (A3-5, B4-5), which showed vertical structure, had low temperatures and relatively low salinities. These were the only stations with nitrates at greater than the minimum detectable level.

The third major group comprised all stations on the northernmost transect (G) and offshore stations of other northern and middle transects (C-F). These stations were characterised by vertical structure (with salinity reaching a minimum and nitrates a maximum at 100 m depth rather than at the bottom as was the case for southern stations), low nutrients and higher temperatures and salinities than other stations. A minor group (C5 and D4) had higher dissolved oxygen than adjacent stations, but was otherwise similar to this major group.

Bottom Water

There were three major groups, two reliable minor groups and a singe station indicated by the multivariate analysis (Fig. 5.2.2.6a).

The first group comprised the inshore stations on transects from north to south (A1-2, C2, E1, G1-3), and was characterised by well mixed cool water, that was low in nutrients (Figs. 5.2.2.4d and 5.2.2.5c). This group was split by a minor group (B1-2), which was slightly higher in nutrients than adjacent stations. Surface salinity at station B1 showed a rapid freshening close to the surface, suggesting that freshwater outflow from Lakes Entrance may have impacted these stations. A single station (C1) was distinguished from adjacent stations only by low silicates.

The second major group contained the outer stations on all southern transects (A-D) and the outer station on transect F. The water at these stations showed vertical structure and was high in nutrients while temperatures and salinities were relatively low. Stations B4 and C5 formed a minor group with the highest nutrient levels.

The third major group comprised the outer stations of the northernmost transect (G), mid-shelf stations of transects F, E, C and B and station E5. The water was generally stratified with elevated temperatures. Salinities increased with depth.

Summary

Low nutrient, cool water covered most of the shelf during SS9606. This water has the characteristics of Bass Strait water, although at the northern end of the study area could also represent EAC water that had cooled over winter. Inner-shelf stations off Lakes Entrance appear to have been influenced by freshwater outflow.

Outer shelf stations, especially in the south, were the only stations with elevated nutrients. Vertical stratification was evident with cool, low salinity, high nutrient slope water, moving up onto the shelf on all transects except E and G. Slope water was mixed to the surface on the two southern transects only.

Northern and middle stations, especially around the middle-shelf were inundated with higher salinity, warmer, low nutrient EAC water that appeared to some extent flowed beneath the cooler, less-saline Bass Strait water. This EAC water may have prevented the movement of high nutrient slope water onto the shelf on transects E and G.

EAC water moved rapidly southward during SS9606 (Fig. 5.2.2.2d), and this was reflected by the more complex water mass structure on this survey, compared to earlier surveys.

Two stations D4 and C5 had high dissolved oxygen. Station D4 is situated just inshore of the southern arm of Gabo Reef. On SS9602 it had the second highest dissolved oxygen of all stations. On SS9606 had a dissolved oxygen level of 282 micromole/l and this was outside the range for all other stations (254-268 micromole/l).

5.3 SUMMARY AND IMPLICATIONS

Three different water masses impact the study area. Cooler, salty Bass Strait water is pushed into the study area by strong westerly winds in the winter. This water can be seen on the surface as far north and east as Eden, where it is known as Eden Coastal Water (Newell 1961). In summer, mixed East Australian Current(EAC) and sub-Antarctic water flow spasmodically into Bass Strait. Eddies of the current bring intrusions of sub-Antarctic water onto the shelf, particularly in spring and summer (Church and Craig 1998). An underlying northward countercurrent at the shelf-break also transports cool, sub-Antarctic water onto the shelf

(Cresswell 1994). Northerly winds sometimes enhance these intrusions by bringing nutrient-rich water to the surface (Cresswell 1994).

Nutrients are generally low in the study area, except where nutrient-rich sub-Antarctic water flows onto the outer-shelf from the slope. Sub-Antarctic water was evident on outer-shelf stations on all surveys (Figs. 5.2.2.7a-d). It was most consistent on the southern transects (A and B), where it was evident at the surface on all except the SS9305 survey. The presence of nutrient-rich sub-Antarctic water on northern transects (F and G) was less consistent, perhaps because the outer stations on these transects were often affected by warmer, saltier, but nutrient-poor, EAC water. However, Newell (1961) found sub-Antarctic waters were uplifted onto the shelf more or less continually except in May.

The extent of sub-Antarctic water on the shelf was greatest during late winter (SS9405), and spring (SS9606), when it was present at depth on outer-shelf stations throughout the study area. It was particularly extensive on the SS9405 survey, when it appeared even at the inner-shelf stations on the northernmost transects. On southern transects, sub-Antarctic water was detectable at the surface. Later in the year, in autumn (SS9602) it was present at only southern offshore stations at depth, with a very variable presence at the surface on these stations. In early winter (SS9503), sub-Antarctic water was detected only at the outer-shelf stations of two transects (D and E).

The inner and mid-shelf stations of all but the most northern transects are primarily inundated with nutrient-poor Bass Strait water. On northern transects, this is replaced by warmer, nutrient-poor EAC water. The cooler Bass Strait water extends further north at the bottom than it does at the surface, so SST images show the maximum (surface) extent of EAC waters; water at the depth will be more influenced by Bass Strait water.

In the spring survey (SS9606), fresher water extended offshore of Lakes Entrance to the 25 and perhaps 40 m station, elevating nutrients marginally.

The four surveys planned to cover the four seasons did not match directly with the seasonal cycle of water mass exchange in the study area. The surveys are best characterised as:

Survey	Dates of broad-scale survey	Intended season	Actual season
SS9305	July 27–August 15, 1993	Winter	Early winter
SS9405	August 24–September 8, 1994	Spring	Late winter
SS9602	April 17–April 30, 1996	Autumn	Autumn
SS9606	November 21–December 3, 1996	Summer	Spring

Implications

1. Nutrient enrichment of waters overlying the shelf is primarily by sub-Antarctic water uplifted from the slope. The mechanisms that drive this deep upwelling–an interaction of EAC eddies, wind and topography–result in an uneven and seasonally variable enrichment. The outer-shelf, perhaps especially in the southern region of the study area, experiences greater and more consistent uplifting.

2. This uneven distribution of nutrient-rich uplifted water results in small-scale variability in this habitat characteristic.

3. Local topography at the shelf-break influences the hydrology: deep upwelling is particularly evident at the Big Horseshoe; the “Bass Strait Cascade” is at its maximum at the Little Horseshoe.

4. Because the timing and magnitude of seasonal hydrological cycles vary inter-annually, ‘true’ seasonal coverage cannot be ensured in survey design.

5. Stratification of water masses means that hydrological conditions experienced by fishes on the seabed are not necessarily seen in remotely-sensed sea-surface temperature (SST) data.

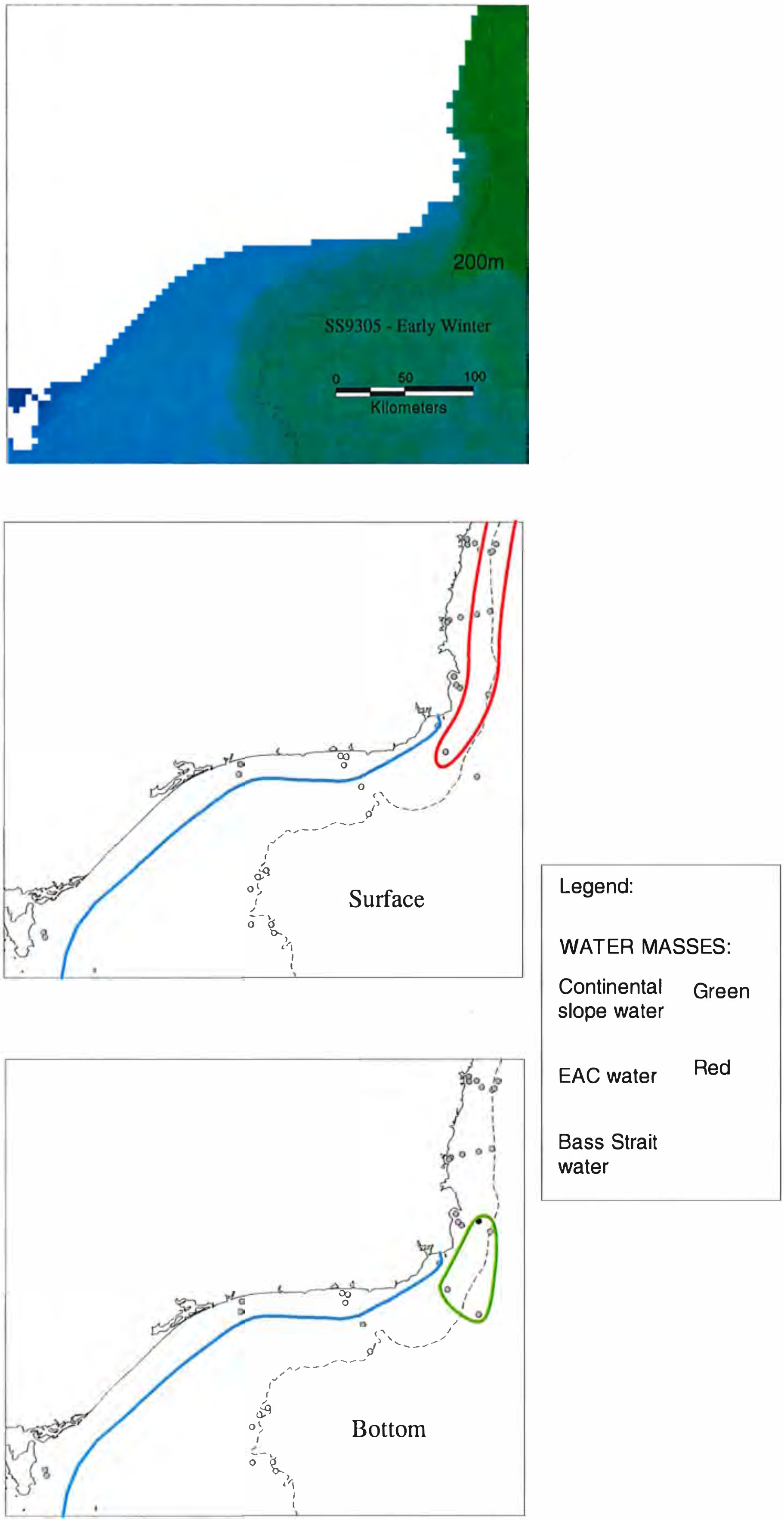


Figure 5.2.2.7 (a) Schematic of water mass structure and bottom during: a) SS9305 (Early winter); b) SS9405 (Late winter); c) SS9602 (Autumn) and d) SS9606 (Spring).

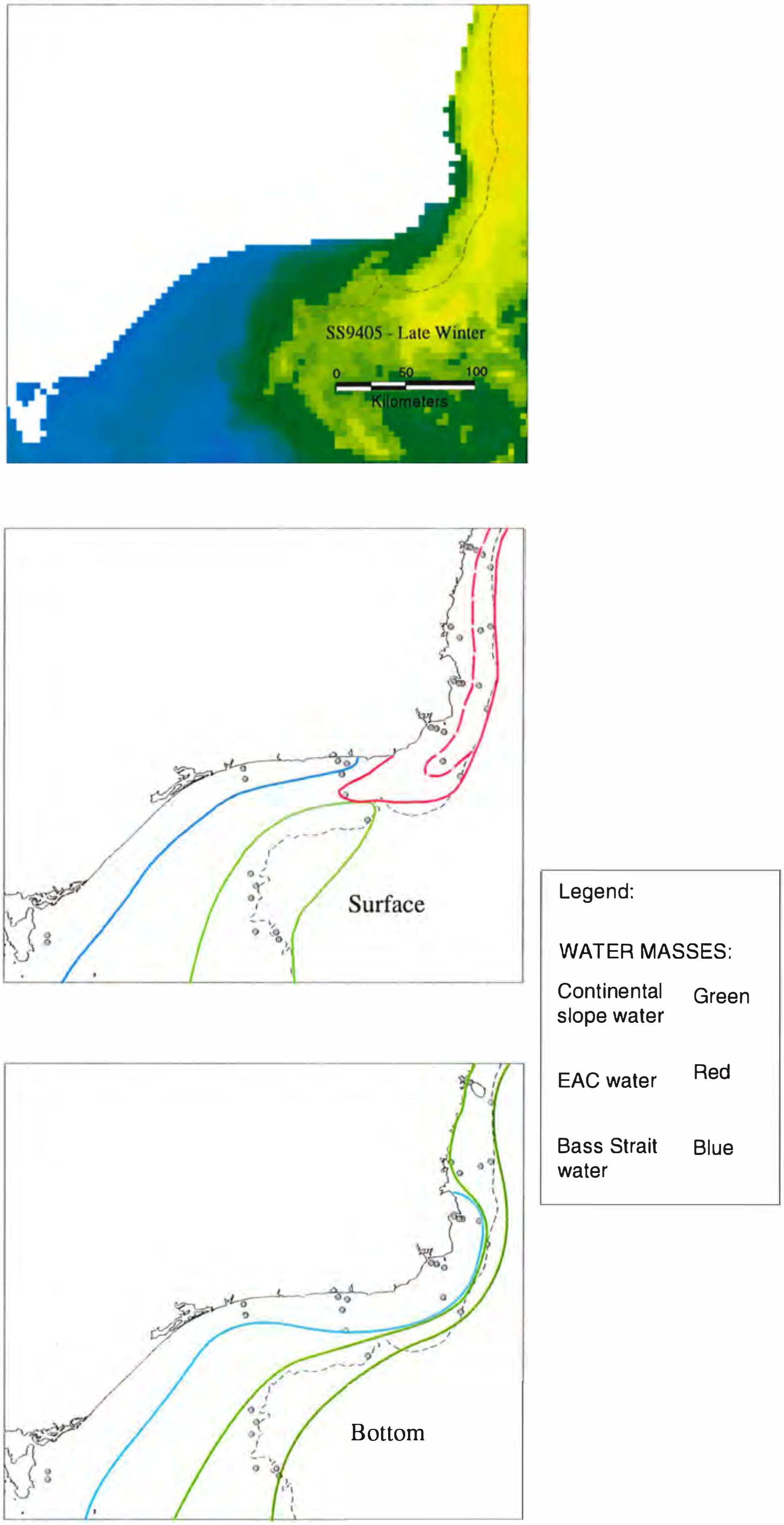
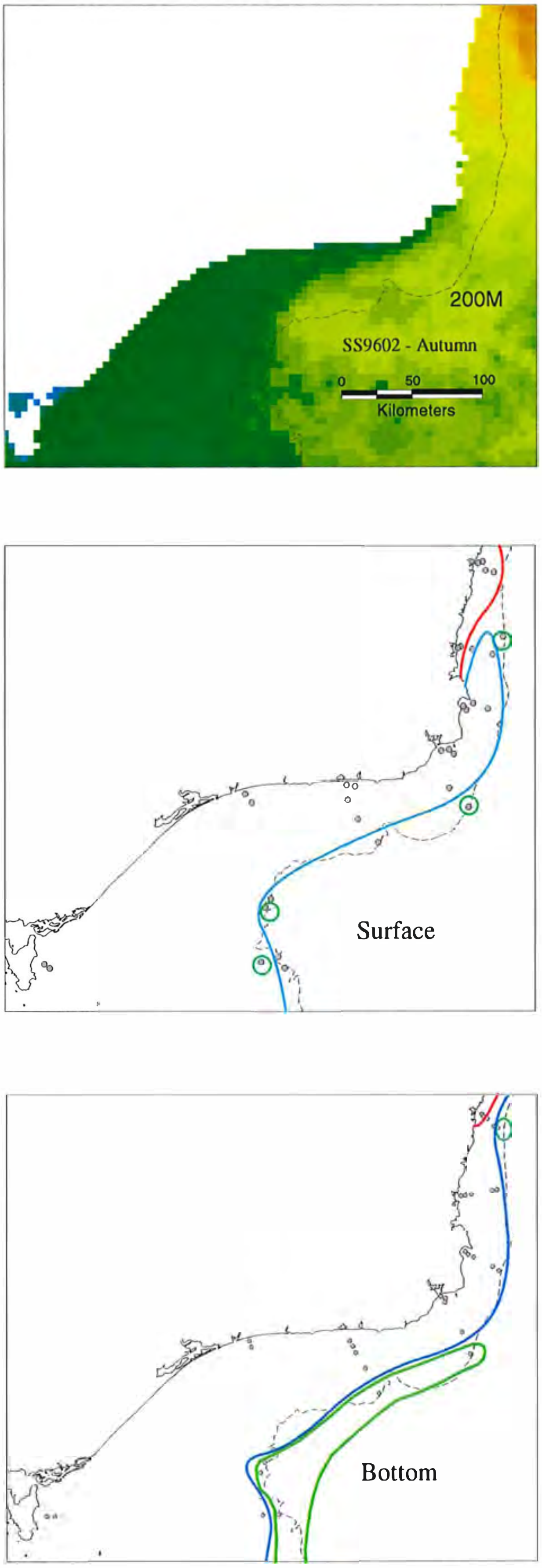


Figure 5.2.2.7 (b) SS9405 (Late winter)



Legend:

WATER MASSES:

Continental slope water	Green
EAC water	Red
Bass Strait water	Blue

Figure 5.2.2.7 (c) SS9602 (Autumn).

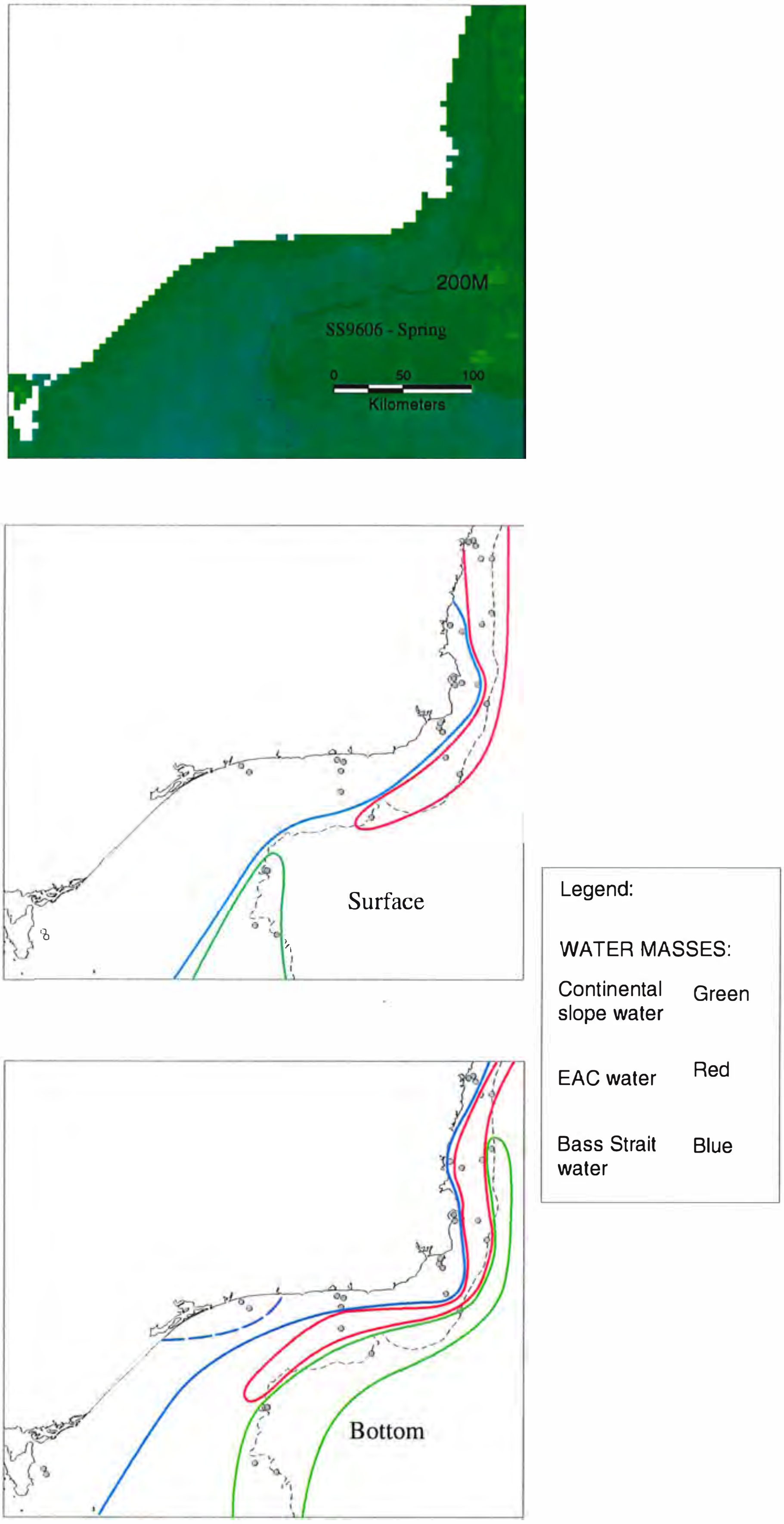


Figure 5.2.2.7 (d) SS9606 (Spring).

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6 BIOLOGICAL OCEANOGRAPHY

Stevie Davenport, Nicholas Bax and Alex Terauds

Biological oceanography examines production at the lowest trophic levels–the origin of production on the continental shelf. The aims of this component of the study were to determine the origins of production in the water column and its relation to water mass structure determined in *Section* 5, and provide information on its transfer to higher trophic levels. Spatial variability in production has the potential to influence habitat use by higher trophic levels.

6.1 METHODS

6.1.1 Primary Production

Particulate organic matter (POM) in water samples was analysed for pigments and stable isotopes to determine the amount and source of the productivity in the study region during SS9405, SS9602 and SS9606. No samples were taken on the first survey SS9305. An inshore (40 m) and offshore (200 m) station was sampled on each transect.

Water samples were collected in niskin bottles at the water surface, and at the depth of the chlorophyll maximum (if the maximum was sub-surface), during CTD casts (Fig. 6.1.1.1). Two water samples of 4.0 to 9.01 from each depth were filtered through Whatman GF/F glass fibre filters (c.f. Burford and Pollard 1994). One set of filters was immediately placed into liquid nitrogen for pigment analysis; the second set was frozen at –20°C for analysis of stable isotopes of carbon and nitrogen.

Pigment Analysis

Samples for pigment analysis were extracted in 90% acetone and analysed using a Waters high performance liquid chromatograph, comprising a 600 controller, 717 plus refrigerated autosampler and a 996 photo-diode array detector. Pigments were separated using a stainless steel 25 mm X 4.6 mm I.D. column packed with ODS2 of 5 µm particle size (SGE) with gradient elution as described in Wright *et al.* (1991). The separated pigments were detected at 436 nm and identified against standard spectra using Waters Millenium software. The concentration of each pigment in the samples was determined using response factors calculated from external calibration of pure pigment standards.

Determination of Algal Groups

It is not a straightforward process to determine algal groups from pigment data. While some algal divisions or classes have unique pigments (e.g. Prasinophyceae and Prasinoxanthin), other pigments are common to many algae (e.g. all groups except non-symbiotic marine Prochlorophyta have chlorophyll *a*). In addition only a few representatives of each division or class have been analysed (Jeffrey *et al.* 1997).

We have therefore taken two approaches for analysis. First, the presence or absence of algal groups was determined from presence or absence of pigment groups following Jeffrey *et al.* (1997) and Jeffrey (pers. comm) (Table 6.1.1.1) and the results mapped to show the distribution of the identified algal divisions or classes.

Second, pigment concentrations themselves were analysed to determine regions with similar pigments and pigment concentrations. Pigments defining these groups are then interpreted to indicate the algal divisions or classes contributing to the regional differences. Data from each survey were analysed separately using modules of the PRIMER program (Carr 1996): CLUSTER (hierarchical agglomerative clustering) was used to form groups of samples based on between-sample similarities, and MDS (non-metric multidimensional scaling) used to display between-sample similarities in 2-dimensional (2-d) space. In all analyses, the Bray-Curtis similarity index (Legendre and Legendre 1983) was used. All chl *a* pigments (chl 1, chl *a* allomer, chl *a* epimer and chl *a*-like) were combined before analysis as were cis fucoxanthin and fucoxanthin. Violaxanthin was recorded as presence/absence. Data were transformed with natural logarithms (+1 to account for zeros), because earlier analyses had shown this transformation to provided representative groupings and a logarithmic transformation is often appropriate for biological count data, which these concentrations were assumed to be indicators of.

Groups determined from the multivariate analysis were used as the samples in subsequent SIMPER (percentage similarity module in PRIMER) analyses to determine the pigments contributing to within group similarity and between group dissimilarity.

Stable Isotope Analysis

An outline of stable isotope analysis and its role in ecosystem studies in included in Appendix II.

Frozen glass fibre filters with POM for stable isotope analysis were thawed, dried in an oven at 60°C for 24 hours then ground finely with a mortar and pestle. The powdered samples were sent to Dr Stuart Bunn (Faculty of Environmental Sciences, Griffith University, Queensland) (Survey SS9405) or Dr Andy Revill (CSIRO Marine Laboratories) (Surveys SS9602 and SS9606) for analysis for stable isotopes of carbon and nitrogen.

Powdered samples were weighed into tin capsules. The samples analysed at Griffith University were oxidised by a Roboprep–CN Biological Sample Converter. The resultant CO_2 and N_2 were analysed with a continuous flow-isotope ratio mass spectrometer (CF–IRMS, Europa Tracermass, Crewe, U.K.). At CSIRO Marine Laboratories, samples were analysed for % Nitrogen, % Carbon, $\delta^{15}N$ and $\delta^{13}C$ using a Carlo Erba NA1500 CNS analyser interfaced via a Conflo II to a Finnigan Mat Delta S isotope ratio mass spectrometer operating in the continuous flow mode. Combustion and oxidation were achieved at 1090 °C and reduction at 650 °C. Where necessary the carbon signal was diluted using helium.

Ratios of $^{13}C/^{12}C$ and $^{15}N/^{14}N$ were expressed as the relative per mil (‰) difference between the sample and conventional standards (the primary standards are Pee Dee Belemnite–a marine limestone fossil, and N_2 in air). The formula used to express these values is –

$$\text{Delta X} = [\ (\text{R (sample)}) / (\text{R (standard)}) - 1]\ \text{X}\ 1000\ ‰$$

where $X = {}^{13}C$ or ${}^{15}N$ and $R = {}^{13}C/{}^{12}C$ or ${}^{15}N/{}^{14}N$.

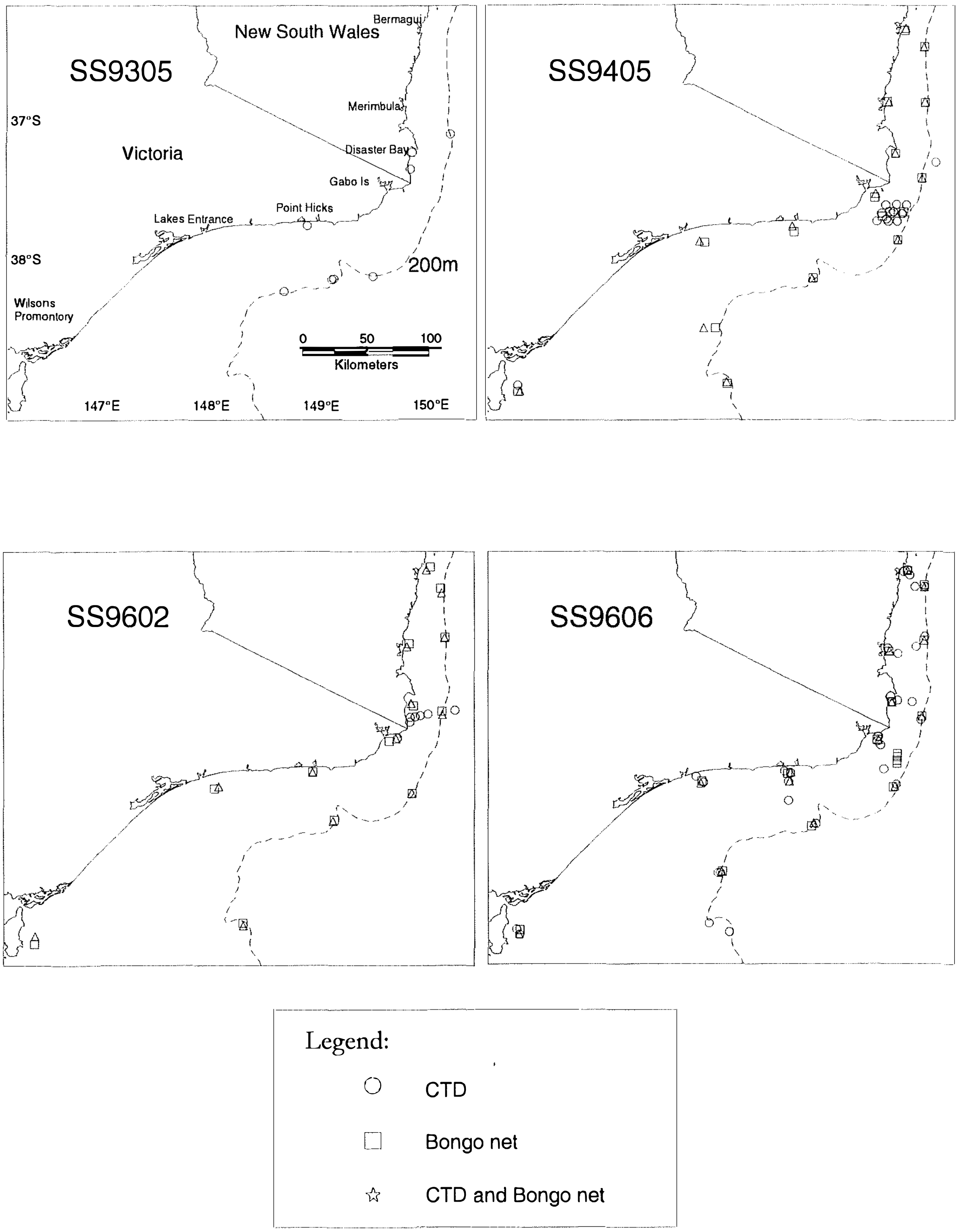


Figure 6.1.1.1 Location of CTD casts for collection of water column particulate organic matter; and bongo net tows for zooplankton collection during surveys SS9405, SS9602 and SS9606 (there was no zooplankton sampling during survey SS9305).

Table 6.1.1.1 Distribution of major and taxonomically significant pigments in algal divisions/classes. Data are from Jeffrey et al. 1997. Only pigments detected in water samples for this study are presented[1].

Pigment	Algal Divisions/Classes												
	Cyanophyta (cyanobacteria)	Prochlorophyta	Rhodophyta	Cryptophyta	Chlorophyceae	Prasinophyceae	Euglenophyta	Eustigmatophyta	Bacillariophyta	Dinophyta	Prymnesiophyceae	Chrysophyceae	Raphidophyceae
Chl c_3											◆	◆	
Chl $c_1 + c_2$				◆					◆	◆	◆	◆	◆
Peridinin										◆			
But-fucoxanthin											◆	◆	
Hex-fucoxanthin											◆		
Fucoxanthin									◆		◆	◆	◆
Prasinoxanthin						◆							
Diadinoxanthin							◆		◆	◆	◆	◆	◆
Alloxanthin				◆									
Diatoxanthin							⬩		⬩	⬩	⬩	⬩	⬩
Lutein					◆	♦							
Zeaxanthin	◆	◆	◆		♦			⬩					
Chl a	◆		◆	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆
Chl b					◆	◆	◆						
Phaeophytin a			algal breakdown product										
Phaeophytin b			indicator of terrestrial detritus										
Pyrophytin b			indicator of terrestrial detritus										
β,ε–carotene		♦	♦	♦	⬩	⬩					⬩		
β,β-carotene	♦	♦			♦	♦	♦	♦	⬩	⬩	⬩	⬩	♦
Violaxanthin					◆	◆		◆					

[1] Pigment distribution data is taken from recent modern analyses of algal cultures; Jeffrey et al. (1997) caution that only very few representatives of each class or division have been examined (e.g. <0.5% of diatoms)

◆ = major pigment (>10%); ♦ = minor pigment (1 - 10%); ⬩ = trace pigment (<1%).

6.1.2 Secondary Production

Zooplankton samples were collected with 70 cm diameter bongo nets (500 μm mesh) and a 56 cm drop net (100 μm mesh) at the same inshore (40m) and offshore (200m) stations as sampled for primary production (Fig. 6.1.1.1). It was not possible to sort the fine-mesh drop net tows reliably, because zooplankters were tangled in often dense filamentous phytoplankton. Only results from the coarser mesh bongo net tows are reported here.

Bongo net tows were made obliquely through the water column between the surface and within 10 m of the bottom during daylight hours. Tows were targeted at 20 min duration, except during the dense phytoplankton blooms of SS9405 when this was reduced to 10 min. Flowmeters (General Oceanics) were mounted in each bongo net to calculate the amount of water filtered for each tow to account for the vagaries of weather, currents, ships speed and operator. Upon retrieval, the sample from one cod-end was preserved in 10% formalin for later zooplankton identification and enumeration, while the other cod-end sample was frozen and retained for stable isotope analyses.

The 500 μm bongo net samples for zooplankton identification were split 3–6 times using a Folsom splitter to reduce them to a manageable level (i.e. 100–200 individuals in the final sample). After splitting, the displacement volume of the samples was calculated to estimate sample biomass (see Ahlstrom and Thrailkill, 1963). The sample was then examined under a dissecting microscope and the organisms sorted, identified, and counted.

Abundances were corrected for the number of splits (K) using the following equation (McEwan *et al.*, 1954):

$$N = n/(1/2K) \qquad (1)$$

Abundances were then standardised to numbers per $100\mathrm{m}^3$ using the flowmeter readings from the bongo net. Flowmeter readings were converted to volume of water filtered using the following equations (General Oceanics Digital Flowmeter Mechanical and Electronic Operators Manual):

$$\text{Distance(m)} = \text{counts} \,.\, \text{Rotor Constant}/999999 \qquad (2)$$

$$\text{Volume } (\mathrm{m}^3) = \{(\pi \,.\, (\text{Net Diameter})^2)/4\} \,.\, \text{Distance} \qquad (3)$$

Analysis

Data from all three surveys were included in one multivariate analysis. Data were first reduced by removing any taxa that occurred in 10 percent or less of the samples, and those few samples were not consistent in sampling area or season. Similarities of samples were analysed using modules of the PRIMER program (Carr 1996): CLUSTER (hierarchical agglomerative clustering) was used to form groups of samples based on between-sample similarities, and MDS (non-metric multidimensional scaling) used to display between-sample similarities in 2-dimensional (2-d) space. In all analyses the Bray-Curtis similarity index (Legendre and Legendre 1983) was used. Data were analysed untransformed, and transformed with square root, double square root, natural logarithms (+1 to account for zeros), and presence/absence to provide analyses that emphasised the most abundant species through to rarer species, respectively. The transformation that provided the clearest assemblage structure was selected for further analysis.

Groups determined from the multivariate analysis were used as the samples in subsequent analyses of species diversity, richness, species contributing to within group similarity and species contributing to between group dissimilarity. The SIMPER (percentage similarities) module in PRIMER was used for the latter two analyses.

6.2 RESULTS AND DISCUSSION

6.2.1 Primary Production

One survey stood out from the others–SS9405. Over much of the survey area, the sea had a "pea soup" appearance; plankton nets and the ship's engine intake filters clogged quickly with a thick green slime. This was the annual spring phytoplankton bloom.

Microscopic examination of phytoplankton samples from several sites (G2 and G5 on the Bermagui transect; E2 and E5 on the Disaster Bay transect; D2 on the Gabo transect; and A5 on the Wilson''s Promontory transect) showed the most abundant phytoplankton species to be the diatom *Thalassiosira partheneia*. This is a species that provides good food value for grazing zooplankton, but its packaging is difficult to deal with–it forms irregular gelatinous masses (G. Hallegraeff pers. comm.). It is likely that we encountered early bloom conditions as *Thalassiosira* typically appears at the start of the annual spring blooms (Jeffrey *et al.* 1982, Hallegraeff and Jeffrey 1993). The typical pattern of spring blooms along the NSW coast begins with small chain-forming species (like *Thalassiosira*). These give way to large centric diatom species which are followed by large dinoflagellates (Hallegraeff and Jeffrey 1993).

Pigments and Algal Groups

Over all surveys, the pigment composition indicated that prymnesiophytes were the most widespread, and often most abundant, algal group. Diatoms were abundant and widespread during the spring bloom encountered during survey SS9405. They may have been widespread during the 1996 surveys also, but only in small quantities. In general, most of the main pigments were present in greater concentrations during survey SS9405 than in the 1996 surveys (Table 6.2.1.1).

Figs. 6.2.1.1, 6.2.1.2 and 6.2.1.3 indicate an interpretation of algal groups present during the surveys on the south east Australian shelf from pigments detected in water column samples. These pigments in particulate organic matter (POM) for surveys SS9405, SS9602, and SS9606 are reported in Appendix Tables 6.2.1.1, 6.2.1.2, and 6.2.1.3. An explanation of the abbreviations of pigment names appears in Appendix Table 6.2.1.4.

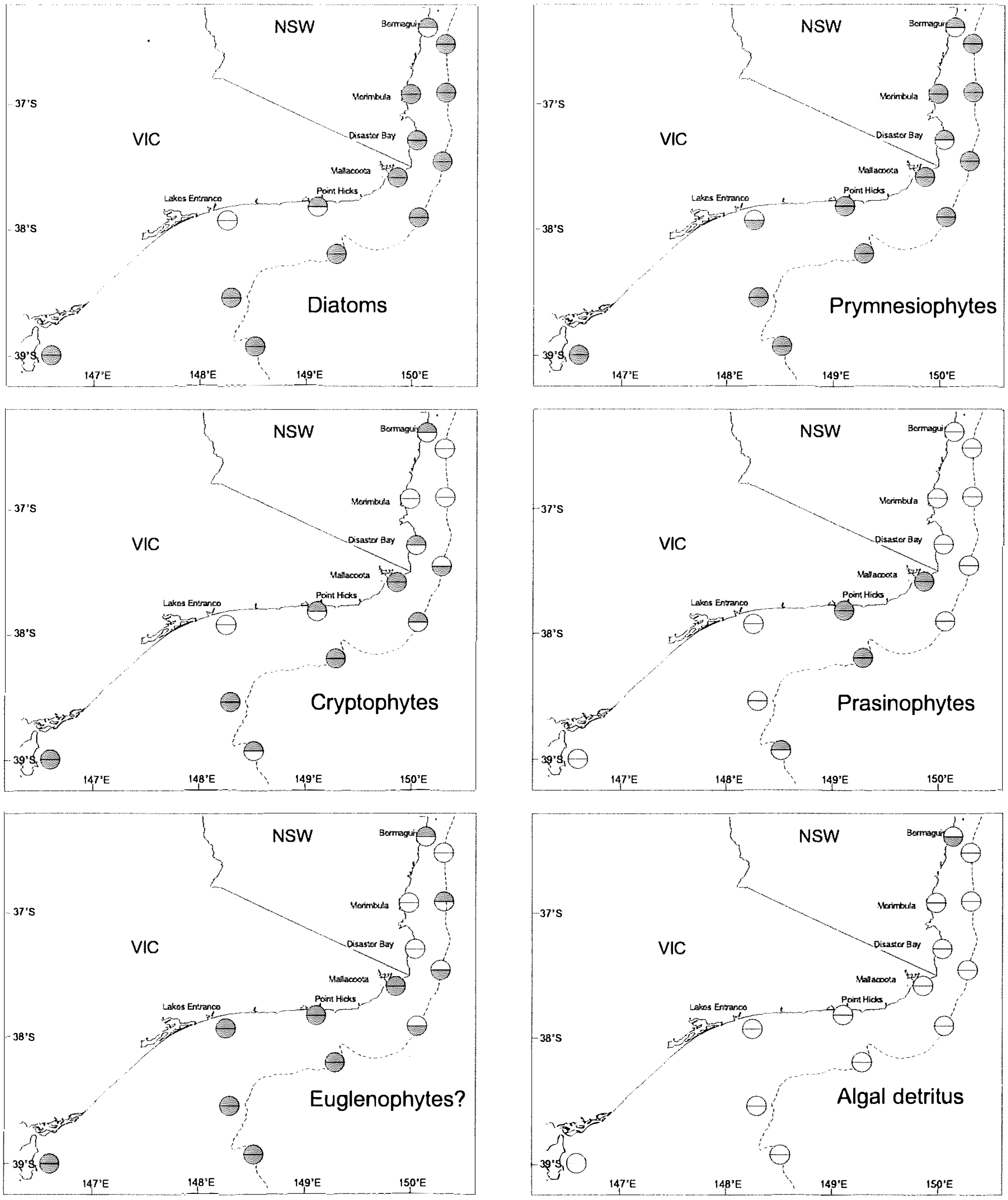
Distribution of Algal Divisions/Classes

Survey SS9405

Chlorophyll *a* concentrations accorded well with general observations of bloom conditions (i.e. water colour and amount of net clogging during bongo net tows). The depth of the chlorophyll maximum was usually about 25 m at offshore stations (except off Point Hicks where it was at the surface and Wilson''s Promontory where it was at 44 m) and 0–33 m at inshore stations–typical depths for coastal phytoplankton blooms (Jeffrey & Hallegraeff 1989).

Table 6.2.1.1 Chlorophyll *a* (mean ± SD, range in $\mu g\ l^{-1}$) in water column samples over three surveys on the south east Australian continental shelf.

		Survey		
		SS9405	SS9602	SS9606
chlorophyll *a*	mean	620 ± 229	509 ± 174	403 ± 234
	Range	115 – 1322	294 – 876	21 – 1111
	n	28	28	26



Legend:

⌓ surface sample

◡ subsurface sample (20 - 40 m)

Shading (⊖) represents presence of algal groups

Fig 6.2.1.1 Distribution of algal groups interpreted from water column pigments on the south east Australian shelf during survey SS9405 (August - September 1994).

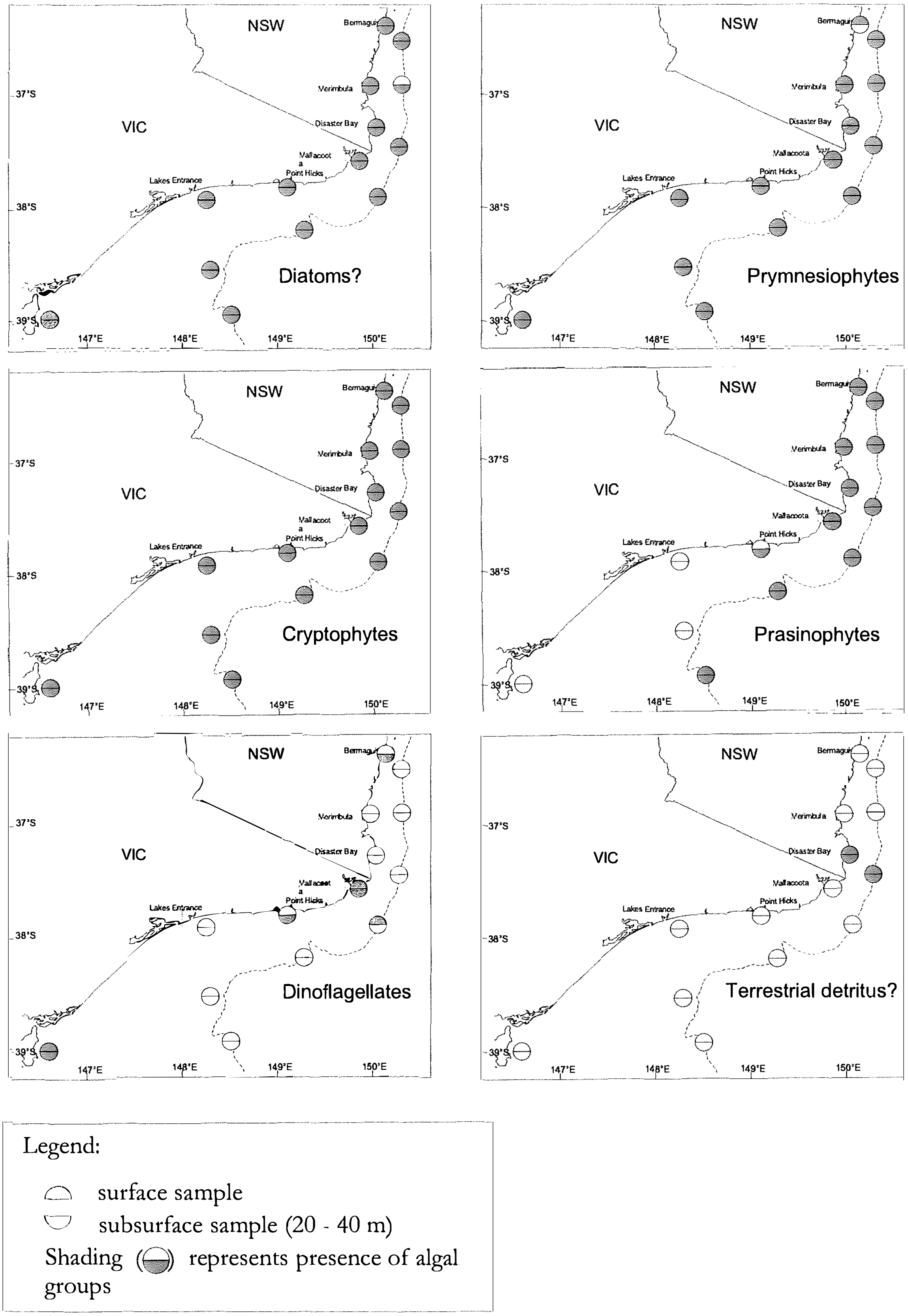
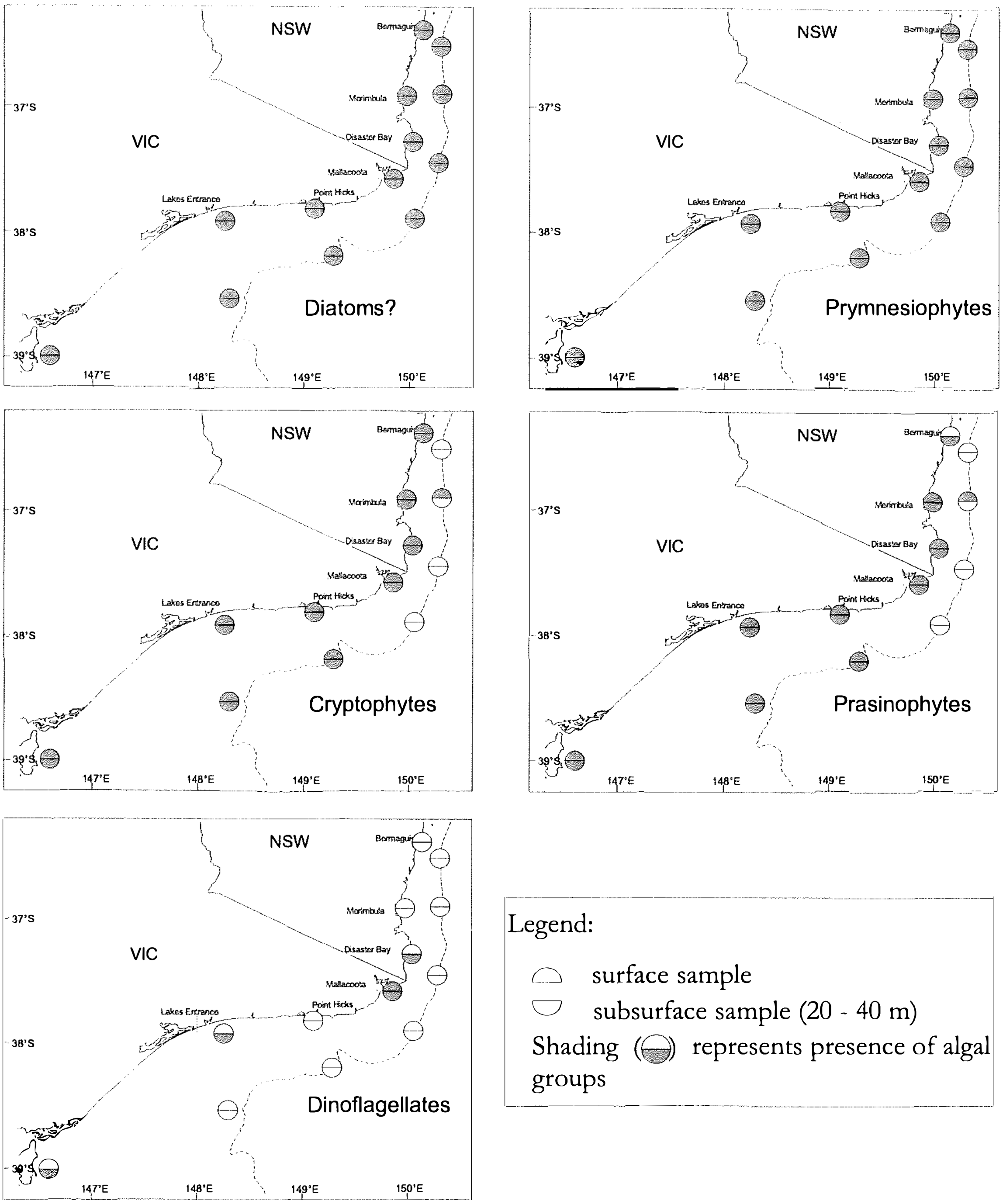


Figure 6.2.1.2 Distribution of algal groups interpreted from water column pigments on the south east Australian shelf during survey SS9602 (April - May 1996).



Legend:

⌓ surface sample

◡ subsurface sample (20 - 40 m)

Shading (⊖) represents presence of algal groups

Fig 6.2.1.3 Distribution of algal groups interpreted from water column pigments on the south east Australian shelf during survey SS9606 (November - December 1996).

Chlorophyll *a* values were highest in sub-surface samples at the offshore sites of the Bermagui, Disaster Bay and Gabo transects and the inshore sites on the Disaster Bay and Gabo transects — the most dense part of the bloom. The lowest concentration of chlorophyll *a* coincided with the appearance of phaeophytin *a* at the northern end of the survey area (the inshore site on the Bermagui transect). This was towards the end of the two-week sampling period. Phaeophytin *a* is a breakdown product of chlorophyll *a*, and indicates phytoplankton death. The bloom was coming to an end.

Diatoms were widespread, occurring at all sites except the inshore site on the Lakes Entrance transect.

Prymnesiophytes were abundant and widespread occurring at all sites, except perhaps at the inshore Lakes Entrance site where few pigments, at low concentrations, were present.

Cryptophytes appeared at the inshore sites on the Bermagui, Disaster Bay, Gabo, Point Hicks and Wilsons Promontory transects; and at the offshore sites on the Disaster Bay, Gabo, Point Hicks, Lakes Entrance and Wilson's Promontory transects.

Prasinophytes occurred at the inshore site on the Gabo transect, inshore and offshore on the Point Hicks transect and at the offshore site on the Wilson's Promontory transect.

Euglenophytes may have been present (indicated by the presence of chlorophyll *b*) at the inshore site on the Bermagui transect, the offshore site on the Disaster Bay transect, and inshore and offshore sites on the Gabo, Point Hicks, Lakes Entrance and Wilsons Promontory transects. An alternative interpretation is that chlorophyll *b* might indicate terrestrial run-off. If this had been the case, it is likely that chlorophyll *b* concentrations would be consistently higher at inshore than at offshore sites. This was not always the case.

SS9602

Chlorophyll *a* concentrations were much lower during survey SS9602 than SS9405. The maximum concentration at each site was found between the surface and 40 m depth.

Prymnesiophytes and cryptophytes were widespread, occurring at all sites.

Prasinophytes occurred at most sites; exceptions were the inshore and offshore sites on the Lakes Entrance transect, and at the inshore site on the Wilson's Promontory transect.

Diatoms may have been present and widespread (detected pigments are not unique to diatoms), but only in very low concentrations.

Dinoflagellates appeared in low concentrations only at inshore sites on the Bermagui, Gabo, Point Hicks and Wilson's Promontory transects; also at the offshore site on the Gabo transect.

Phaeophytin *b* and 'pyrophaeophytin *b*' appeared at the inshore and offshore sites on the Disaster Bay transect, and is probably an indicator of terrestrial detritus.

SS9606

The offshore site on the Wilson's Promontory transect was not sampled on this survey.

Chlorophyll *a* concentrations were more variable during this than the two previous surveys. The greatest concentrations were at the inshore site on the Merimbula transect (1.06 $\mu g\ l^{-1}$) and the offshore site on the Point Hicks transect (1.03 $\mu g\ l^{-1}$). The lowest levels (within 50 m of the surface) were found on the offshore Bermagui transect (0.15 $\mu g\ l^{-1}$).

Prymnesiophytes (and perhaps diatoms in very small quantities) appeared at all sites sampled.

Cryptophytes and prasinophytes had a similar distribution and appeared at all sites except the offshore sites on three of the eastern transects: Bermagui, Disaster Bay and Gabo.

Dinoflagellates appeared (in very small quantities) at inshore sites on the Disaster Bay, Gabo, Lakes Entrance and Wilson''s Promontory transects (at subsurface chlorophyll maximum depths at all sites, additionally at the surface on the inshore Gabo site).

Community Analyses

Distinct pigment communities were formed in all instances (Fig. 6.2.1.4). In general there appeared to be a distinct northern and offshore community, a southern inshore community and some stations which did not fit in this overall pattern in the centre.

SS9405

Four distinct groups were present on SS9405 and the largest group could be further subdivided into a northern and southern group (Figs 6.2.1.4 and 6.2.1.5).

Northern and Offshore Group

This was the largest group with 10 of the 14 stations. It generally had higher pigment concentrations than the remaining stations, especially chlorophyll *a*, chlorophyll c3, chlorophyll c1+c2, fucoxanthin, and diadinoxanthin (Table 6.2.1.2). This indicates higher abundances of prymnesiophytes, as all groups had moderate concentrations of 19'-Hexanoyloxyfucoxanthin, although Chlorophyll c3 can also indicate diatoms (12% of 73 strains of diatoms tested had c3 instead of c1, Jeffrey *et al.* 1997).

The northern sub-group was distinct from the southern offshore group by the absence of Prasinoxanthin, (lack of Prasinophyceae), and 19'-Butanoyloxyfucoxanthin and Zeaxanthin.

Southern Inshore Group

This group lacked chlorophyll c3, and 19'-Butanoyloxyfucoxanthin, but had 19'-Hexanoyloxyfucoxanthin suggesting that prymnesiophytes were present (Table 6.2.1.2). Presence of Prasinoxanthin indicated the presence of Prasinophyceae.

Lakes Entrance Inshore Station

This station was the most dissimilar from all other stations. Many pigments were absent, indicating a lack of at least prymnesiophytes, Prasinophyceae, and Cryptophyta, Other pigments were present only at low levels.

Table 6.2.1.2 Average concentration of pigments at groups of stations selected in multivariate analyses of SS9405 data. Bold numbers represent pigment concentrations that accounted for 50% of the dissimilarity between that group and others in the comparison.

	North and offshore 1	South 1b	A2 C2 2	B2 3	G2 4
Chl c3	**761**	**305**	**0**	**0**	**0**
Chl c1 + c2	1,024	456	169	81	141
Peridinin	0	0	0	0	0
But-fucoxanthin	0	7	0	0	0
Hex-fucoxanthin	190	157	140	54	79
Fucoxanthin	**1,152**	527	**91**	**0**	140
Prasinoxanthin	0	**47**	**33**	0	0
Diadinoxanthin	189	103	47	**0**	51
Alloxanthin	20	54	58	0	15
Diatoxanthin	69	0	0	0	0
Lutein	0	0	0	0	0
Zeaxanthin	**0**	**20**	**56**	66	0
Chl a	1,539	1,244	1,104	549	390
Chl b	**44**	**206**	294	149	55
Phaeophytin a	0	0	0	0	**246**
Phaeophytin b	0	0	0	0	0
Pyrophytin b	0	0	0	0	0
B,e carotene	0	0	0	0	0
B,B-carotene	77	57	55	**0**	**0**
Violaxanthin	0	0	1	0	0
Number in group	6	4	2	1	1
Similarity in group	91	91	87		
Average dissimilari	26	21	25	45	32

Bermagui Inshore Station

This station has much in common with the southern inshore stations, but lacked Prasinophyceae. It was distinct from all other groups by the presence of Phaeophytin *a*, a breakdown product of Chlorophyll *a*.

SS9602

Three major groups were indicated by the multivariate analysis (Figs. 6.2.1.4 and 6.2.1.5). The two largest groups could be subdivided further. Overall dissimilarities between groups were not as strong as for SS9405.

Northern and Offshore Group

This group is primarily distinct from other groups due to the presence of Chlorophyll c3 (Table 6.2.1.3). Since 19'-Hexanoyloxyfucoxanthin was present at all stations this suggests that Chrysophyceae were present in this group but not the others.

This group could be subdivided into northern and southern offshore groups (Fig. 6.2.1.5), with the southern group having lower concentrations of all pigments except the 3 fucoxanthins.

Southern Inshore Group

This group was distinct from the northern and offshore group due to the lack of Chlorophyll c3, and higher concentrations of almost all other pigments, especially Peridinin (Dinophyta), Diatoxanthin and Zeaxanthin (Table 6.2.1.3).

Of this group, the inshore Wilson''s Promontory station had the highest levels of most pigments, especially Peridinin, but lacked Prasinoxanthin and Zeaxanthin.

Lakes Entrance Offshore Station

This station lacked Chlorophyll c3, Peridinin, Prasinoxanthin, Diatoxanthin, Lutein, Zeaxanthin, and Violaxanthin, suggesting a species poor community, lacking prymnesiophytes, Dinophyta, Prasinophyceae, and possibly Chlorophyceae.

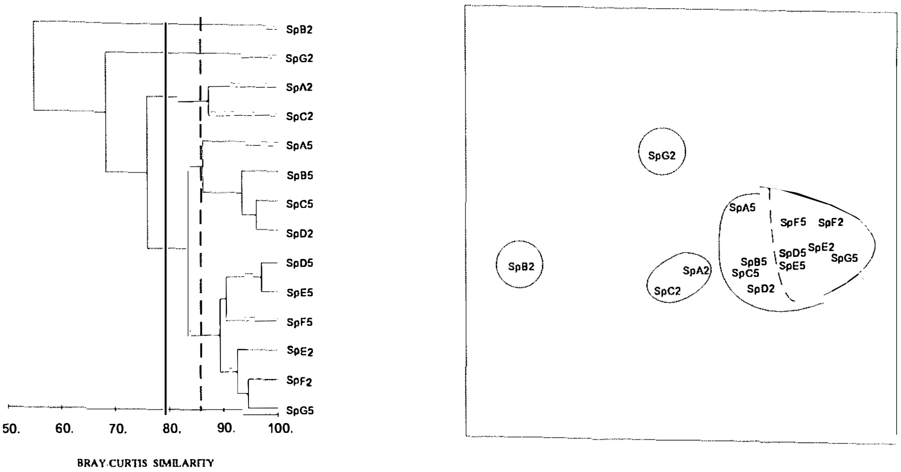
SS9606

The multivariate analyses indicates two major groups, (Figs. 6.2.1.4 and 6.2.1.5). The largest group could be further split into two subgroups. Dissimilarities between groups were comparable to SS9602, but less than for SS9405.

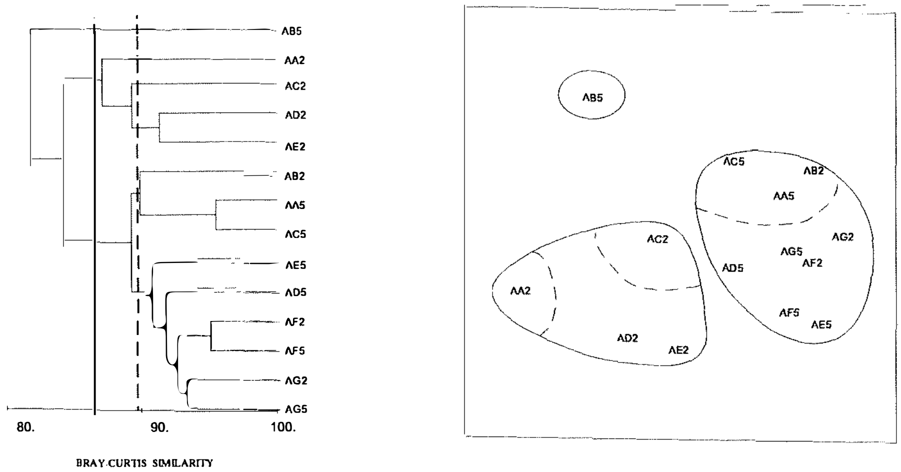
Northern Offshore Group

This group was distinct due to the lack of Chlorophyll c3, 19'-Hexanoyloxyfucoxanthin, and low concentrations of Prasinoxanthin, Alloxanthin, Chlorophyll *b* and Diatoxanthin (Table 6.2.1.4). This suggests the lack of Prymensiophyceae, and low abundances of Prasinophyceae, Chryptophyta, and other groups.

SS9405, Stress = 0.06



SS9602, Stress = 0.09



SS9606, Stress = 0.08

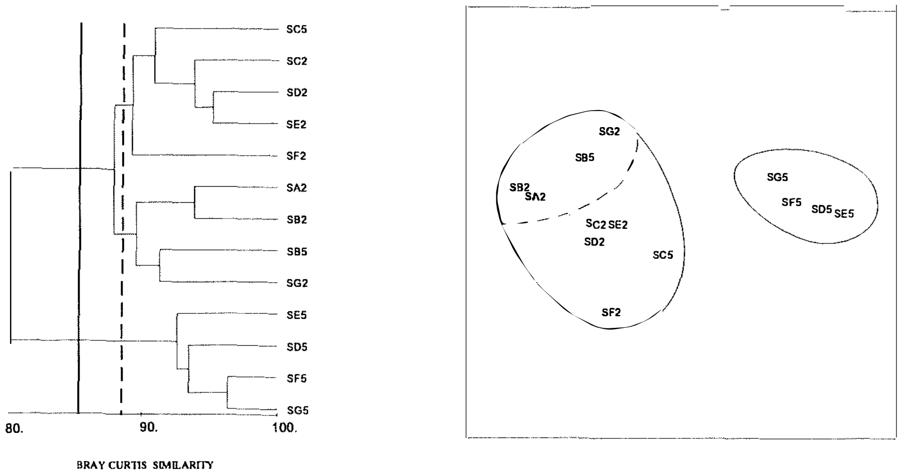


Figure 6.2.1.4 Cluster analyses and MDS plots for pigment data from combined surface and subsurface samples over three surveys (SS9405, SS9602 and SS9606). Pigment concentration data transformed with ln(x+1) before analysis.

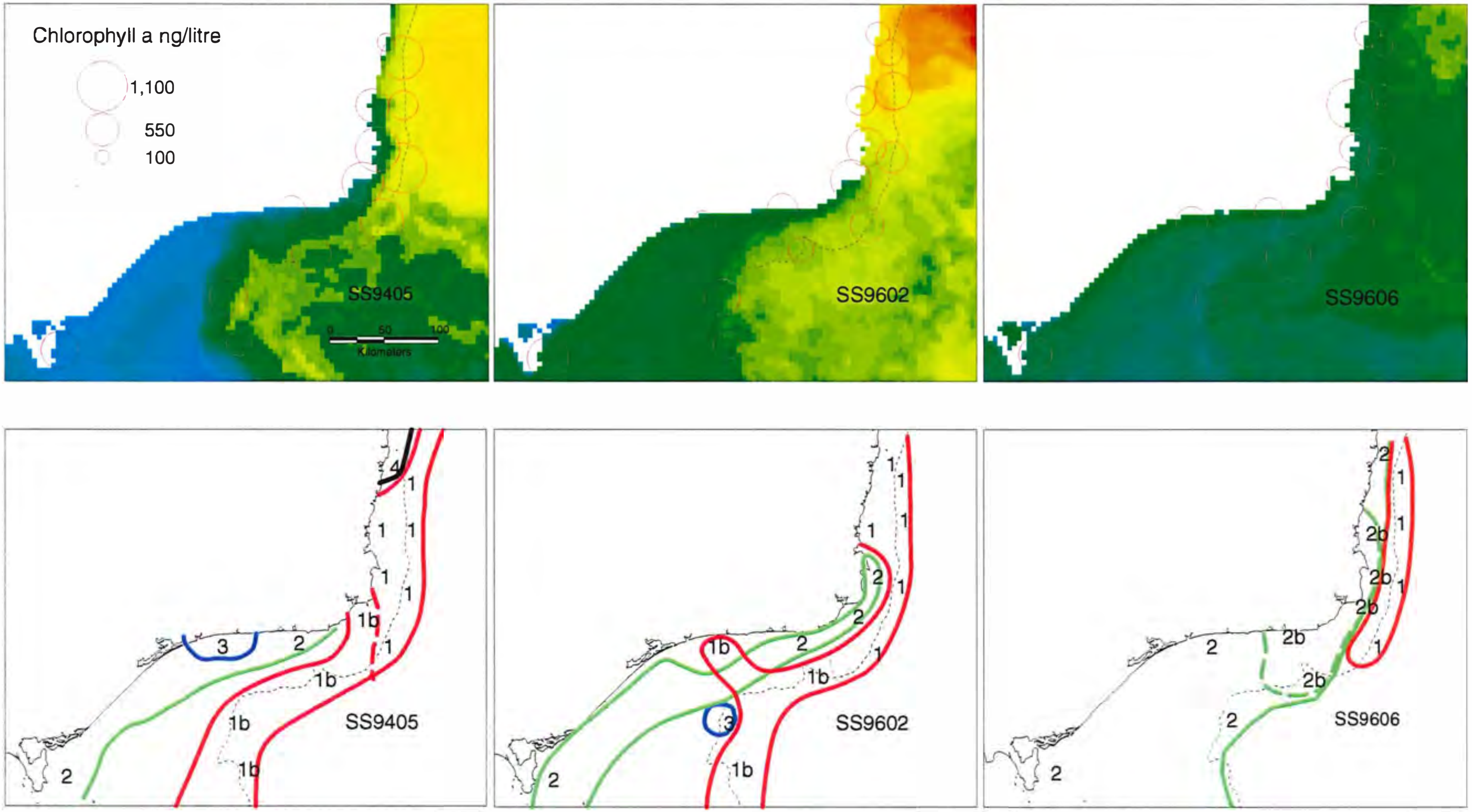


Figure 6.2.1.5 Average chlorophyll a concentrations (top) and pigment multivariate groups (bottom) in combined surface and subsurface water column samples over three surveys (SS9405, SS9602 and SS9606).

Southern and Inshore Group

The southern and central sub-groups were quite similar, although only the southern sub-group had Chlorophyll c3. The central group had higher levels of 19'-Butanoyloxyfucoxanthin and Fucoxanthin, and higher levels of Alloxanthin (Cryptophyta).

Stable isotopes

Mean $\delta^{13}C$ and $\delta^{15}N$ values for particulate organic matter (POM) in water column samples during five surveys in the study region are shown in Table 6.2.1.5. The mean $\delta^{13}C$ value for POM in this study was –21.5 ± 1.8 ‰ (range –25.2 to –16.0 ‰). Whole phytoplankton collected from the 1994 spring bloom had a similar mean $\delta^{13}C$ value of –20.5 ± 0.9‰.

The mean $\delta^{15}N$ value for water column POM for the 3 surveys was 6.1 ± 2.5 ‰. The highest and lowest values were seen during the spring survey (SS9405). High values (> 8.5 ‰) appeared in the surface samples at the inshore Point Hicks (11.7 ‰), Lakes Entrance (17.4 ‰) and Wilsons Promontory (18.2 ‰) and at the subsurface chlorophyll maximum depth at inshore Lakes Entrance. Low values (< 3 ‰) occurred at the subsurface chlorophyll maximum depth at the inshore Gabo site, at the surface and at the subsurface chlorophyll maximum depth at the offshore Point Hicks site and at the surface at the offshore Wilson''s Promontory site.

Differences in $\delta^{13}C$ values of surface and subsurface chlorophyll maximum samples

Overall, $\delta^{13}C$ and $\delta^{15}N$ values were similar at the surface and at the subsurface chlorophyll maximum depth at most sites on all surveys (paired t-tests, p>0.30; Appendix Table 6.2.1.5). Exceptions were $\delta^{13}C$ on SS9606 which were more negative at the subsurface chlorophyll maximum depth (paired t-test, n=14, p=0.011). Unfortunately, the depth of the subsurface chlorophyll maximum was not recorded on that survey so we cannot determine whether this difference was linked to a deeper subsurface chlorophyll maximum on this survey.

There were some locally consistent exceptions. At the inshore sites on the Point Hicks and Lakes Entrance transects the subsurface (25–27 m) $\delta^{13}C$ of POM was 4–5 ‰ higher than at the surface during the spring survey (SS9405). At the offshore site on the Lakes Entrance transect during the same survey the value of subsurface (38 m) POM was 2 ‰ lower than in the surface sample. There was an inverse pattern for $\delta^{15}N$ during this same survey: subsurface POM $\delta^{15}N$ values were 5 –10.5 ‰ lower than the surface at the inshore south western sites (Point Hicks, Lakes Entrance and Wilson's Promontory), while at the offshore Wilson's Promontory site, $\delta^{15}N$ at the chlorophyll maximum depth was 4.5 ‰ higher than at the surface.

Surface and subsurface chlorophyll maximum samples were pooled for the following analyses.

Differences between surveys

There was a significant difference between $\delta^{13}C$ values in water column particulates between surveys SS9405 and SS9606 (p = 0.0079, n = 91), although the mean values of $\delta^{13}C$ in water column POM differed by only 2.1 ‰ between surveys.

The mean $\delta^{15}N$ of the spring survey (SS9405) was significantly different from the autumn survey (SS9606) (p = 0.0000, n = 81). There was greater variability in $\delta^{15}N$ in SS9405 samples (2.3 to 18.2 ‰) than in the other surveys (SS9602: 3.2 to 6.4 ‰; SS9606: 4.7 to 8.4 ‰). The

Table 6.2.1.3 Average concentration of pigments at groups of stations selected in multivariate analyses of SS9602 data. Bold numbers represent pigment concentrations that accounted for 50% of the dissimilarity between that group and others in the comparison.

	North and offshore 1	South inshore 2	B5 3
Chl c3	**27**	**0**	**0**
Chl c1 + c2	113	240	220
Peridinin	**1**	**11**	0
But-fucoxanthin	42	43	12
Hex-fucoxanthin	143	194	112
Fucoxanthin	61	166	295
Prasinoxanthin	**26**	**38**	**0**
Diadinoxanthin	28	79	48
Alloxanthin	33	68	40
Diatoxanthin	**1**	**8**	0
Lutein	5	14	**0**
Zeaxanthin	**12**	**50**	**0**
Chl a	834	1,380	1,222
Chl b	208	300	158
Phaeophytin a	0	0	0
Phaeophytin b	1	0	0
Pyrophytin b	1	1	0
B,e carotene	8	8	5
B,B-carotene	30	42	33
Violaxanthin	2	2	0
Number in group	9	4	1
Similarity in group	91	89	
Average dissimilarity	16	16	18

Table 6.2.1.4 Average concentration of pigments at groups of stations selected in multivariate analyses of SS9606 data. Bold numbers represent pigment concentrations that accounted for 50% of the dissimilarity between that group and others in the comparison.

	North	South	
	offshore	Southern (+G2) sub-group	Central sub-group
	1	2	2b
Chl c3	**0**	**79**	**0**
Chl c1 + c2	269	133	264
Peridinin	2	1	4
But-fucoxanthin	70	**30**	54
Hex-fucoxanthin	0	215	268
Fucoxanthin	395	160	251
Prasinoxanthin	**5**	**28**	**31**
Diadinoxanthin	124	82	95
Alloxanthin	**8**	**34**	**67**
Diatoxanthin	**15**	20	19
Lutein	1	4	**4**
Zeaxanthin	19	40	34
Chl a	635	922	1,290
Chl b	**57**	159	180
Phaeophytin a	0	0	0
Phaeophytin b	0	0	0
Pyrophytin b	0	0	0
B,e carotene	1	2	**7**
B,B-carotene	36	32	40
Violaxanthin	1	0	1
Number in group	4	4	5
Similarity in group	87	91	91
Average dissimilarity	16	16	15

Table 6.2.1.5 Stable carbon and nitrogen values in particulate organic matter (POM) in the water column.

Survey	**n**	**$\delta^{13}C$**	**SD**	**range $\delta^{13}C$**	**n**	**$\delta^{15}N$**	**SD**	**range $\delta^{15}N$**
SS9305	5	-20.3	2	-21.9 to -17.0	0			
SS9402	5	-22.4	1.6	-24.3 to -20.8	0			
SS9405	28	-21	1.6	-24.9 to -18.7	28	7.1	3.9	2.3 to 18.2
SS9602	27	-21.2	1.2	-23.3 to -18.8	27	5.1	1	3.2 to 6.4
SS9606	26	-22.4	2.1	-25.2 to -16.0	26	6.3	0.8	4.7 to 8.4
overall	91	-21.5	1.8	-25.2 to -16.0	81	6.1	2.5	2.3 to 18.2

inshore sites of all transects on survey SS9405, except Gabo, had higher values of $\delta^{15}N$ than during the other two surveys. The inshore sites at Point Hicks and Lakes Entrance had particularly high $\delta^{15}N$ values (Fig. 6.2.1.7) during survey SS9405. Offshore sites on all three surveys had similar $\delta^{15}N$ values.

North-south trends

There were no differences in $\delta^{13}C$ values in water column particulates between transects on surveys SS9405 (2-way ANOVA on transect and station, p=0.239), but there were significant difference between transects on SS9602 (2-way ANOVA on transect and station, <0.001), and SS9606 (2-way ANOVA on transect and station, p<0.001). In both cases the northern transects were depleted compared to the southern transects, especially at inshore stations at Wilson's Promontory and Lakes Entrance (transects 1 and 2, Fig. 6.2.1.6). This trend was also seen for SS9405, although these data were not significantly different.

There were no significant differences in $\delta^{15}N$ values in water column particulates between transects on SS9405 (2-way ANOVA on transect and station, p=0.195), although a significant interaction between transect and station (p=0.037) is accounted for the stable nitrogen enrichment at inshore stations at Wilson's Promontory and Lakes Entrance (transects 1 and 2, Fig. 6.2.1.7). There were no significant differences between transects on SS9602 and SS9606 (2-way ANOVA on transect and station, p=0.156, and p-0.089, respectively), and no significant interaction effects (p=0.328 and p=0.104) (Fig. 6.2.1.7).

Cross-shelf trends

No difference was detected in POM $\delta^{13}C$ between inshore and offshore stations on SS9405 (2-way ANOVA on transects and stations, p=0.345), however on SS9602 and SS9606 inshore stations were enriched compared to offshore stations (2-way ANOVA on transect and station, p=0.0.008 and p<0.001, respectively). Interaction terms were also significant (p=0.057 and p<0.001), emphasising that the inshore enrichment was primarily on southern transects (Fig. 6.2.1.6)

There was significant enrichment of $\delta^{15}N$ at inshore stations on SS9405 and SS9602 (2-way ANOVA on transect and station, p=0.005 and 0.071, respectively), and interaction effects (p=0.037 and 0.328) indicate that this is due to inshore enrichment on the southern transects (Fig. 6.2.17). On SS9606, offshore stations may have been enriched compared to inshore stations (2-way ANOVA on transect and station, p=0.0.063). There was no significant interaction term (p=0.104).

Interpretation of primary production results

Pigments

Typical values for chlorophyll in temperate Australian waters are up to 1.5 μg L^{-1} (Jeffrey and Hallegraeff 1989), though values of up to 8.0 μg L^{-1} have been recorded in association with an upwelling area between Cape Hawke and Newcastle, NSW, during spring diatom blooms (Hallegraeff and Jeffrey 1993).

The higher values of chlorophyll *a* (up to 1.3 μg L^{-1}) in this study are higher than some values reported in earlier studies but are not remarkable when compared with other spring bloom values measured in the region. A maximum concentration of 0.89 μg L^{-1} was found in Eddy F in

November-December 1978 (Jeffrey and Hallegraeff 1980) and up to 0.9 µg L^{-1} was recorded in two warm core eddies of the East Australian current off the NSW coast in April–May 1981 (Jeffrey and Hallegraeff 1987). Up to 6 µg L^{-1} chlorophyll *a* was recorded during the October 1981 spring bloom at inshore areas off Port Hacking, Wollongong and Jervis Bay (Hallegraeff and Jeffrey 1993). Uniformly high values up to 3 µg L^{-1} were recorded between Sydney and Eden during the spring phytoplankton bloom in September 1984 and near Maria Island off the east coast of Tasmania (Hallegraeff and Jeffrey 1993).

Compared with other continental shelf regions, the waters of the shelf off south eastern Australia have low chlorophyll concentrations. Chlorophyll a values of 0.160.9 µg L^{-1} in surface waters off Cyprus (eastern Mediterranean, around 35°N) were reported by Bianchi *et al.* (1996) to be among the lowest chlorophyll values for nearshore waters.

The complexity of using pigment analysis to infer algal communities limits the interpretation. It is clear that while some algal groups (diatoms, prymnesiophytes, are chryptophytes) are distributed widely through the study area, others are more limited in space (prasinophytes), time (euglenophytes) or both (dinoflagellates). There was one instance (Disaster Bay, SS9602) of pigments consistent with terrestrial detritus, although the origin of such material is unclear.

Multivariate analyses of pigment concentrations demonstrated broad regional groupings of pigments, and presumably algae. One dominant regional group on all surveys was the northern and southern offshore group. On SS9405 and SS9602 this group was extensive and characterised by relatively high pigment levels, especially chlorophyll c3, associated with higher abundances of Chrysophyceae and/or diatoms. Temperatures and nutrients were greater than in other groups, especially at the bottom (Table 6.2.1.6).

The distribution of the northern group was restricted to northern offshore transects on SS9606, when it was lacking many pigments indicating the absence of Prymensiophyceae, and low abundances of Prasinophyceae, Chryptophyta, and other groups. Temperatures and nutrient levels were comparable to those in other groups (Table 6.2.1.6).

The second major pigment group comprised the southern inshore stations; on SS9606 this included the southern offshore stations. In SS9405 and SS9602 this group lacked chlorophyll c3, suggesting a lack of Chrysophyceae, while Prasinophyceae were present. This group had generally low temperatures and low nutrients especially at depth on those surveys (Table 6.2.1.6). On SS9606 this group expanded to include southern offshore stations, and was characterised by relatively high pigment levels indicating the presence of Chrysophyceae and Cryptophyta. Temperatures and nutrients were similar to other groups, although earlier analysis of water masses indicated water column stratification at these sites.

Several stations grouped distinctly from major groups on some surveys. The Lakes Entrance inshore station had very low, or missing, pigment levels on SS9405 indicating the lack of at least Chrysophyceae, Prasinophyceae, and Cryptophyta. Temperatures and nutrients were similar to the adjacent southern inshore stations. On the same survey, the inshore Bermagui station was distinct due to the presence of Phaeophytin *a*, a breakdown product of Chlorophyll *a*. Environmental conditions were similar to adjacent stations.

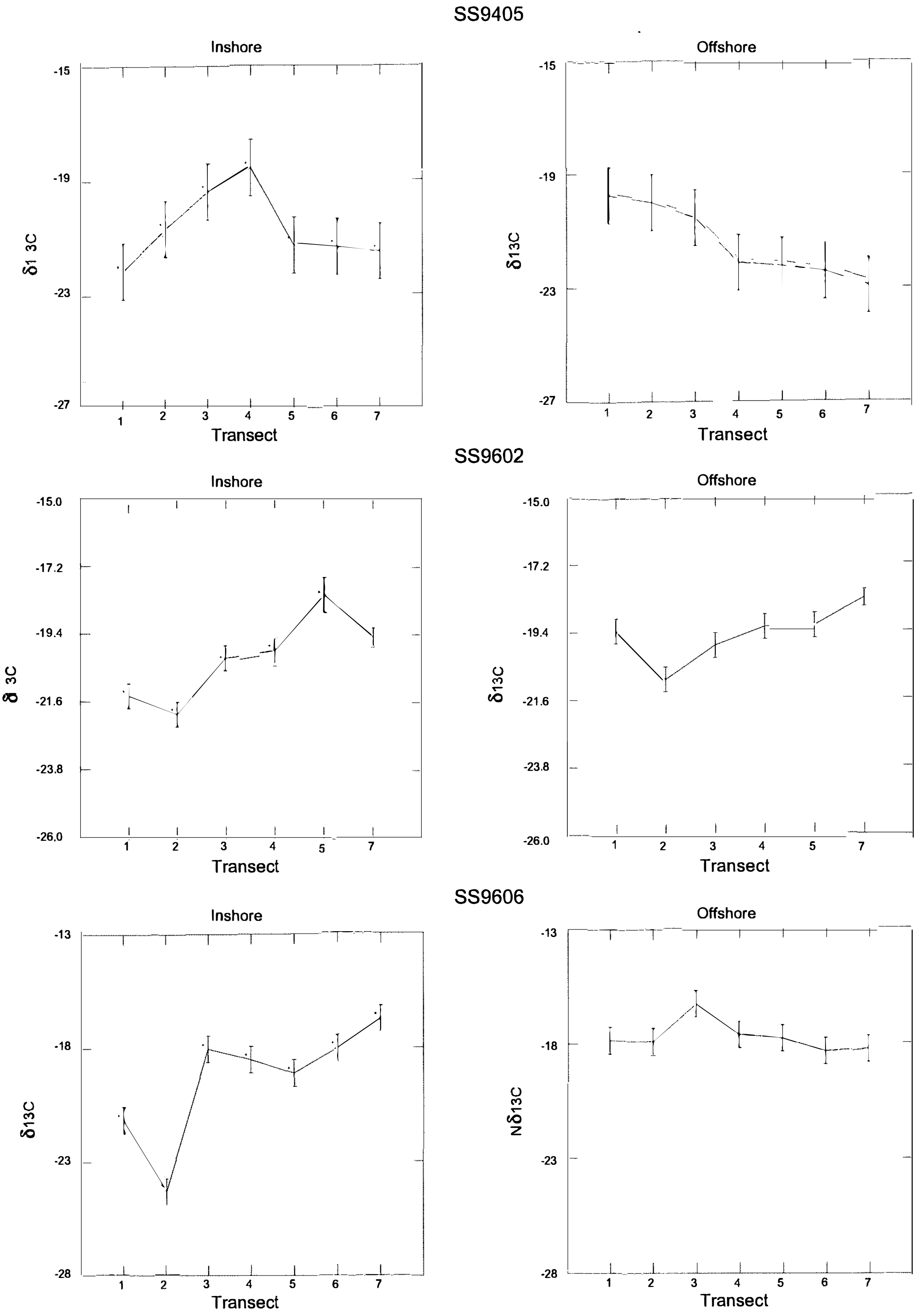


Figure 6.2.1.6 Stable carbon values in water column particulates (POM) at the inshore and offshore station on each transect for surveys SS9405, SS9602 and SS9606. Transects are numbered from south to north.

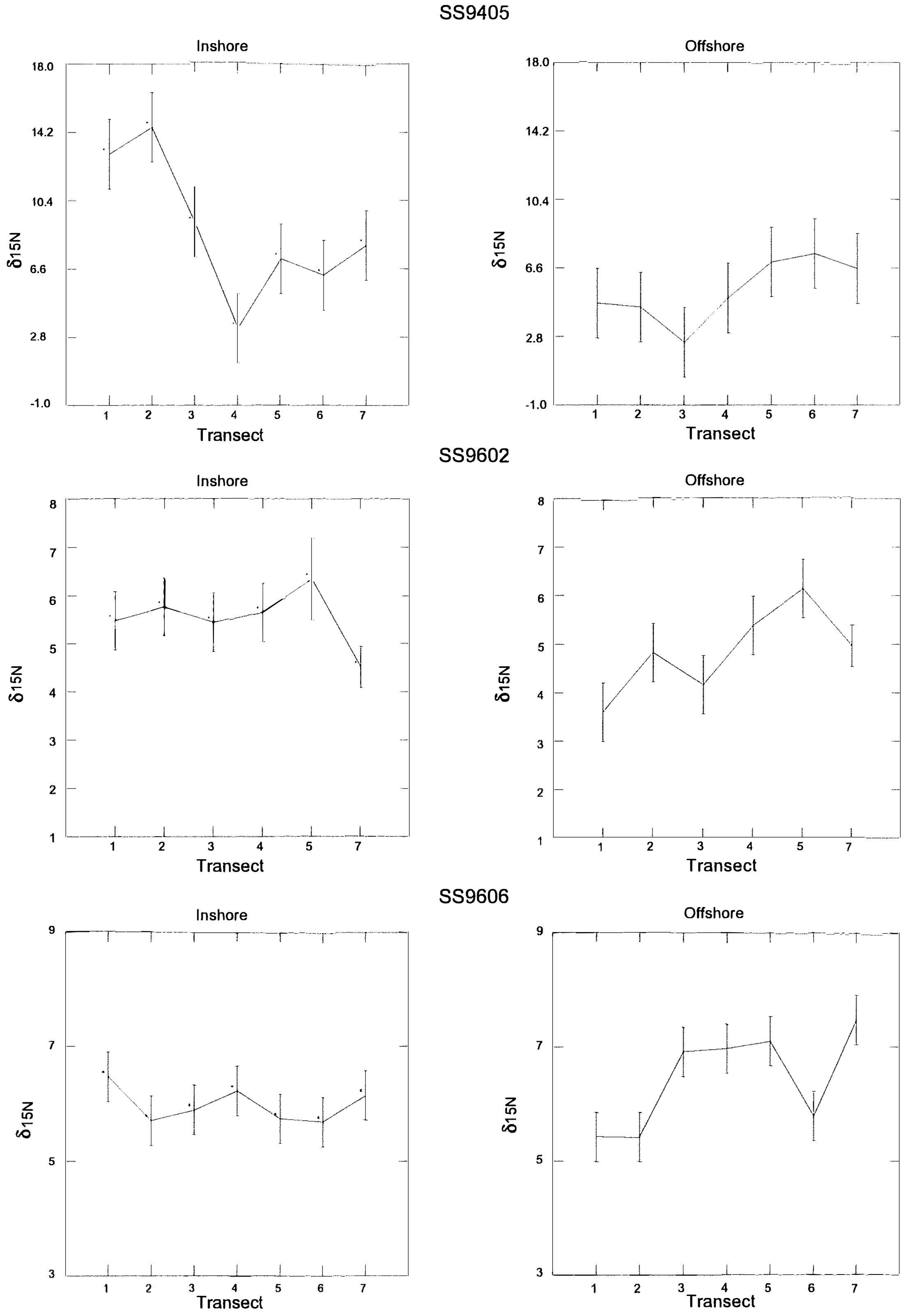


Figure 6.2.1.7 Stable nitrogen values in water column particulates (POM) at the inshore and offshore station on each transect for surveys SS9405, SS9602 and SS9606. Transects are numbered from south to north.

Table 6.2.1.6 Average oceanographic measurements for the stations in each pigment group and their significance based on individual one-way ANOVAs.

			Pigment Group				
Survey	Depth	Variable	1	2	3	4	Significance
SS9405	Surface	Temperature	15.8	12.4	12.1	15.3	0.01
		Salinity	35.6	35.4	35.5	35.5	0.13
		Dissolved O_2	264.1	274.3	266.9	263.5	0.68
		Phosphate	0.3	0.4	0.3	0.3	0.89
		Nitrate	3.2	3.0	0.2	2.2	0.82
		Silicate	1.4	1.5	0.8	1.4	0.72
	Bottom	Temperature	13.0	11.8	11.3	13.3	0.05
		Salinity	35.4	35.5	35.5	35.3	0.28
		Dissolved O_2	247.6	270.8	270.8	227.1	0.01
		Phosphate	0.6	0.3	0.3	0.7	0.07
		Nitrate	11.2	0.2	0.2	15.7	0.04
		Silicate	2.5	1.0	0.9	3.4	0.02
SS9602	Surface	Temperature	17.8	16.5	16.0		0.25
		Salinity	35.7	35.6	35.9		0.16
		Dissolved O_2	238.7	246.0	239.3		0.22
		Phosphate	0.2	0.2	0.5		0.08
		Nitrate	0.9	0.3	2.4		0.02
		Silicate	1.3	1.5	1.7		0.58
	Bottom	Temperature	15.6	16.3	12.1		0.06
		Salinity	35.5	35.6	35.1		0.02
		Dissolved O_2	226.9	239.7	215.3		0.17
		Phosphate	0.4	0.2	0.9		0.01
		Nitrate	4.8	0.6	12.5		0.01
		Silicate	2.6	1.6	5.0		0.01
SS9606	Surface	Temperature	15.8	14.8			0.12
		Salinity	35.2	35.4			0.61
		Dissolved O_2	265.7	259.5			0.06
		Phosphate	0.2	0.2			0.17
		Nitrate	0.1	0.9			0.38
		Silicate	0.3	0.9			0.03
	Bottom	Temperature	13.7	14.2			0.45
		Salinity	35.2	35.4			0.59
		Dissolved O_2	248.9	255.4			0.05
		Phosphate	0.4	0.3			0.22
		Nitrate	2.5	2.2			0.88
		Silicate	1.7	1.6			0.73

The Lakes Entrance offshore station was distinct from other southern offshore stations on SS9602, and was characterised by low or missing pigments, indicating a poor species community lacking Chrysophyceae, Dinophyta, Prasinophyceae, and possibly Chlorophyceae. Nutrients were higher at the surface and at depth than adjacent stations, and temperatures were lower at depth (Table 6.2.1.6).

Stable isotopes

The results of this study are compared with others in temperate marine ecosystems in Table 6.2.1.7. The overall mean $\delta^{13}C$ value for POM in this study (–21.5 ± 1.8‰) and most sample $\delta^{13}C$ values are typical of temperate marine phytoplankton: –24 to –18‰ (Fry & Sherr 1984), –25.3 to –19.8 ‰ (Rau *et al.* 1990), –22‰ (Boutton 1991). There were two exceptions to this:

SS9606	Lakes Entrance	inshore (40 m)	surface	–17.4‰
			subsurface chlorophyll maximum	–16.0‰

The higher $\delta^{13}C$ values at the 40 metre site on the Lakes Entrance transect in November 1996, might be due to a seagrass signature. Seagrasses grow in the vicinity of Lakes Entrance. Hydrology data show lower salinity water at the surface in 30 m depth at this time, perhaps indicating a net outflow of water from the Gippsland Lakes, perhaps carrying seagrasses or seagrass detritus with it (seagrasses typically have a higher $\delta^{13}C$ signal than marine phytoplankton–Table 6.2.1.7).

Nichols *et al.* (1985) found relatively high (–12.9 ‰) $\delta^{13}C$ values in suspended matter from Corner Inlet, near Wilson's Promontory. The authors attributed this signal to a 'seagrass contribution to the samples, either directly or indirectly through the food chain'. This conclusion was supported by seagrass-specific lipid marker compounds in the suspended matter samples.

Fig 6.2.1.8 compares the $\delta^{13}C$ results from each survey in this south eastern Australian study with typical signatures of plant sources described in a review paper by Fry and Sherr (1984) and indicates the likelihood that marine phytoplankton provide the bulk of the source material for the south east shelf ecosystem.

Variations in $\delta^{15}N$ are more difficult to explain than those for $\delta^{13}C$, and less is known of the processes at work. The mean $\delta^{15}N$ for water column particulates on the south east Australian shelf over 3 surveys was 6.1 ± 2.5 ‰ (range 2.3 to 18.2 ‰). While 'normal' $\delta^{15}N$ values for temperate marine phytoplankton/ POM are in the range 6 to 10 ‰, values as high as 46 ‰ have been found at depth in warm core rings in the Gulf Stream (Altabet & McCarthy 1985). Nitrogen isotope composition of suspended matter in the North Sea was found to be 8 ‰ (range 4 to 11.5 ‰) (Mariotti *et al.* 1984).

Significant variations in values of $\delta^{13}C$ and $\delta^{15}N$ across a range of size classes in marine suspended particulate organic matter (SPOM) have been recorded (Rau *et al.* 1990). The authors found that the smallest organisms had the lowest $\delta^{13}C$ and $\delta^{15}N$ values and that there was a significant linear relationship between the size of SPOM organisms and their $\delta^{13}C$ and $\delta^{15}N$ values.

Normal variations in the $\delta^{13}C$ and $\delta^{15}N$ values of marine phytoplankton are expected due to the different signatures of phytoplankton species contributing to the POM signal. The signal of any one species might also vary in time and space according to prevailing environmental conditions (temperature, light, nutrients etc).

A seaward enrichment in $\delta^{13}C$ has been noted in other studies in estuarine and littoral regions (Riera and Richard 1996, Fischez *et al.* 1993, Fontugne and Jouanneau 1987). The reverse was detected in this area, where $\delta^{13}C$ was slightly lower on offshore stations than inshore stations, although this appeared primarily due to $\delta^{13}C$ enrichment at the inshore stations at Wilson's Promontory and Lakes Entrance, perhaps indicating inputs of seagrass, benthic algae or C4 plants. No enrichment was detected on SS9405, when a spring bloom was underway, which appears to have led to enriched $\delta^{13}C$ at inshore and offshore sites, perhaps indicating the latter stages of the bloom. With the exception of the inshore Wilson's Promontory and Lakes Entrance sites on SS9602 and SS9606, $\delta^{13}C$ levels are typical of marine phytoplankton and suggest little terrestrial input. This is not surprising given that our sampling sites were oceanic in a region with little input from rivers.

6.2.2 Secondary Production

General description

SS9405

Algal slime (from the phytoplankton bloom, see Primary Production) dominated most plankton samples except those from the southern inshore stations (Wilson's Promontory and Lakes Entrance transects) which were free of the dense algal mats that characterised other samples. These inshore southern sites had a small zooplankton biomass and lower species diversity than the other inshore sites. The overall species diversity was greater than for the two later surveys (SS9602 and SS9606). There was a noticeable change in the composition of zooplankton samples at Gabo: samples off the NSW coast had much more crustacean zooplankton than southern sites; in some of the samples from southern sites (off Victoria), salps were abundant, unlike samples from the NSW coast where they were sparse.

Salps (particularly *Salpa fusiformis*) appeared at some southern stations; in large numbers at inshore stations (C2 and D2) on the Point Hicks and Gabo transects (647 and 723 per 100m^3). Salps may also have been present at C5, the offshore Point Hicks station, but the sample was lost when the plankton nets were pulled off their frames in rough weather. Small numbers of salps were found at most stations off the NSW coast. Except for the Merimbula transect, where very few salps were found, there were many more salps in inshore than offshore samples throughout the survey area.

Calanoid copepods were widespread (in all samples) but not as abundant as on the later surveys: largest numbers were found at offshore Disaster Bay and inshore Merimbula (4,171 and 3,665 per 100m^3 respectively). Calanoid diversity was higher during this survey than the later surveys.

Cyclopoid copepods were present in all samples except one of the three over Gabo Reef. The greatest abundance was at the offshore Disaster Bay site (1,326 per 100m^3). Except for the Gabo sites, more cyclopoids were found at offshore than inshore stations.

Table 6.2.1.7 Stable carbon values in particulate organic carbon (POC), phytoplankton and plants in temperate marine ecosystems. d13C data are presented as mean ± sd (number of samples) or as range of values.

Source		Latitude	Time of Year	d13C	Reference
Marennes-Oléron Bay, France		46–47°N			
Oceanic phytoplankton			May 92 to Oct 93	-20.6 ± 0.8 (6)	Riera & Richard 1997
Estuarine phytoplankton			May 92 to Oct 93	-23.5 ± 1.5 (4)	Riera & Richard 1997
Riverine phytoplankton			May 92 to Oct 93	-36.7 ± 2.3 (8)	Riera & Richard 1997
POM (oceanic) < 40 mm			1990-1991	-20.6 (n?) (–19.1 to -21.5)	Richard et al. 1997
Georges Bank		40–43°N	1988		
POM spring bloom				-20.9 ± 0.5 (n?)	Fry & Wainright 1991
Gironde Shelf, France		45–46°N	1977–1982		
Oceanic POC				-20.5 (mean annual av.)	Fontugne & Jouanneau 1987
Narragansett Bay, USA		41–42°N	1980-1982		
Phytoplankton				-20.6 ± 0.4 (12)	Gearing et al. 1984
Gulf of St. Lawrence, Canada		46–50°N	Aug-Sep 1979		
POC	< 50m			-25.3 to -22.3 (n?)	Tan & Strain 1983
	> 50 m			-24.4 to -19.2 (n?)	Tan & Strain 1983
Scripps Pier		~32°45'N	1968		
POC				-22.1 to -22.0 (2)	Williams & Gordon 1970
South eastern Australia		35–39°S			
Oceanic POC			1993–1996	-21.5 ± 1.8 (91)	This study
Phytoplankton: spring bloom			1994	-20.5 ± 0.9 (4)	This study
Seagrass			1996	-14.6 to -7.8 (2)	This study
Terrestrial C3 plants				-30 to -23	Fry & Sherr 1984
Terrestrial C4 plants				-14 to -10	Fry & Sherr 1984
seagrasses				-15 to -3	Fry & Sherr 1984
macroalgae				-27 to -8	Fry & Sherr 1984

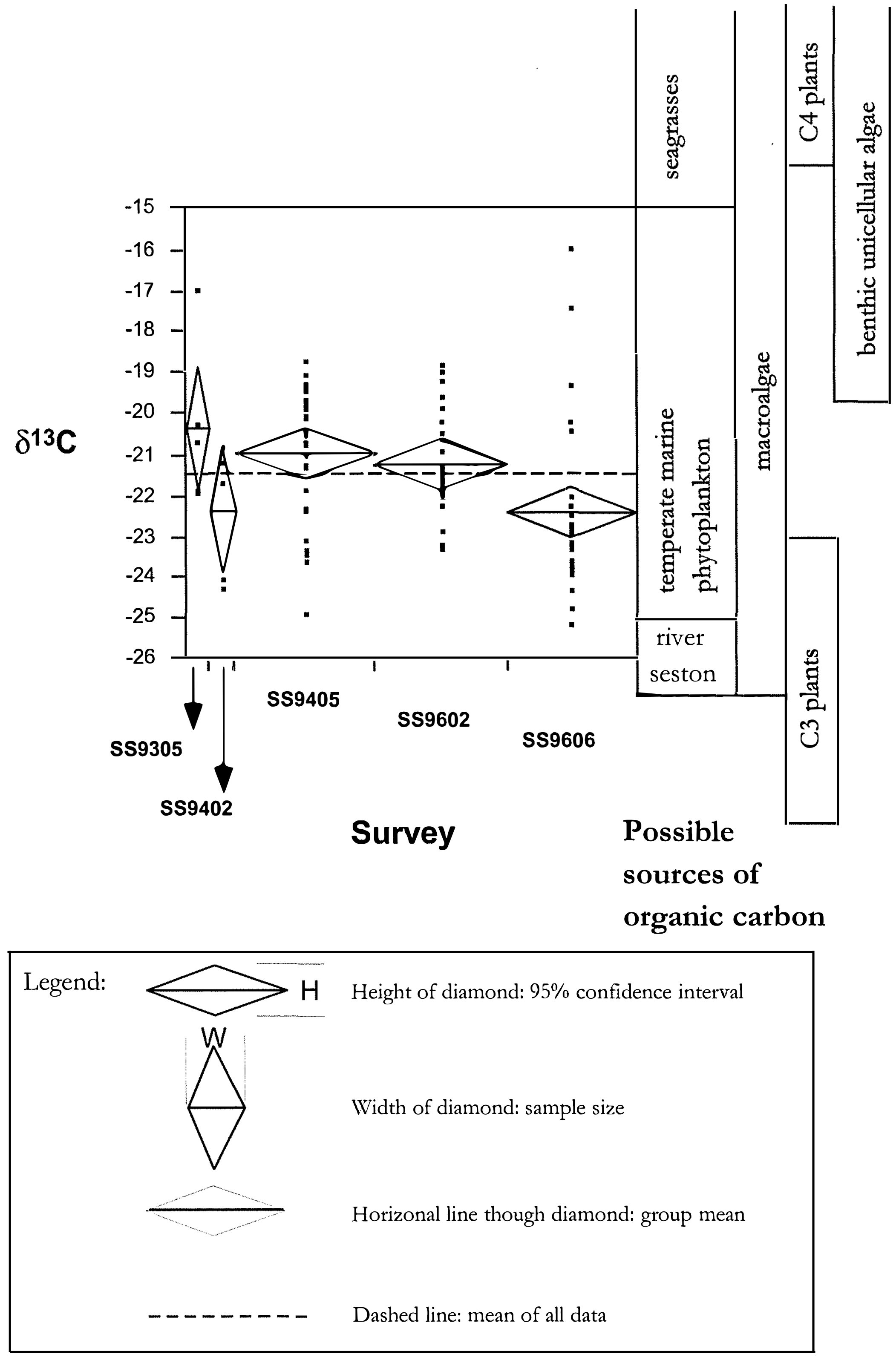


Figure 6.2.1.8 Stable carbon values in water column particulate organic matter, by survey, in south eastern Australia.

Euphausids (mostly stage 2 larvae) were widespread and found in all samples, but in lower numbers than the two later surveys. The greatest abundance of euphausids this survey was found at the inshore Merimbula site and two sites over Gabo Reef (1,282, 1,096 and 1,330 per $100m^3$ respectively).

Fish eggs and larvae were found in large numbers at the offshore Disaster Bay station (863 and 415 per $100m^3$ respectively). On southern transects off the Victorian coast, there were no larvae at inshore stations; a few at offshore stations. Fish larvae collected from eastern stations were identified as belonging to the following families and genera: Myctophidae, Carangidae, Callionymidae, Serranidae, Labridae, Macrorhamphosidae, Triglidae, Sternoptychidae, Moridae, Clupeidae, Tetragonuridae, Bothidae, *Howella* sp., and *Helicolenus* sp.

Decapod larvae were found at all except one station (offshore Wilson's Promontory) in small numbers off the Victorian coast, in larger numbers (up to 343 per $100m^3$) off the NSW coast. On all transects, more larvae were found at inshore than offshore sites.

Chaetognaths were found in all except two samples (offshore Lakes Entrance and inshore Bermagui). There were usually more in offshore than inshore samples. The greatest abundance was in offshore Merimbula and Bermagui samples (368 and 332 per $100m^3$ respectively).

Oikopleura spp. (a larvacean) were found in large numbers in the inshore Gabo sample (881 per $100m^3$) and in small numbers at other inshore sites (except Wilson's Promontory).

Obelia spp. were found in large numbers at the inshore Gabo station (996 per $100m^3$) and nowhere else.

SS9602

The highest zooplankton diversity on this survey and a large biomass were found in samples collected at the inshore and offshore Bermagui stations (> 40 species represented in each sample). The next most diverse samples came from the offshore stations on the Merimbula, Gabo and Point Hicks transects and the inshore Disaster Bay station (about 30 species per sample).

Salps contributed to a large biomass at the inshore station on the Gabo transect; large samples were also collected at the offshore Gabo and Merimbula stations. The most abundant salp collected on this survey was *Thalia democratica* (c.f. survey SS9405 where the most abundant salp was *Salpa fusiformis*).

Calanoid copepods were an especially diverse fauna at the two stations on the Bermagui transect. The greatest numbers were found at the inshore Lakes Entrance and Gabo stations (28,000 and 39,000 per $100m^3$ respectively). Calanoid abundance was boosted by very large numbers of *Tortanus barbatus* at these stations. The next most abundant calanoids found during survey SS9602 were *Calanus australis*, *Centropages australiensis* and *Rhincalanus nasutus* (c.f. survey SS9405 where *Temora* spp. and *Pleuromamma gracilis* were the most abundant copepod species).

Euphausids were widespread. Most were stage 1 larvae and were found in all samples except that from offshore Wilson's Promontory. Euphausids were particularly abundant at inshore Wilson's Promontory, Lakes Entrance, Point Hicks and Gabo stations and offshore Merimbula (1,200–5,500 per $100m^3$).

Fish eggs and larvae were found in small numbers in samples from mostly the offshore stations on each transect. The highest number of eggs and larvae were found at the inshore Bermagui station (149 and 90 per $100m^3$ respectively).

Mysids were abundant at the inshore Lakes Entrance station (746 per $100m^3$) and they were found in small numbers at a few other stations.

Decapod larvae were abundant (> 4,500 per $100m^3$) at the inshore Lakes Entrance and Gabo stations; in smaller numbers at all other inshore stations and in smaller numbers again at some offshore stations.

Chaetognaths were abundant (> 700 per $100m^3$) at both stations on the Bermagui transect, offshore Merimbula, inshore Disaster Bay and offshore Point Hicks stations. There were fewer at the southern sites: none at the inshore stations on Wilson's Promontory, Point Hicks or Gabo transects.

Oikopleura spp. was found in high numbers at the inshore Bermagui and Merimbula stations (4,597 and 1,837 per $100m^3$ respectively). Elsewhere, they were found mostly at inshore stations, though not on the Wilson's Promontory transect.

SS9606

The November-December survey had generally less diversity than the previous two surveys, but there were large numbers of a few groups, e.g. euphausids, copepods and medusae.

The bulk of gelatinous zooplankton in large samples (inshore Merimbula, samples over Gabo Reef) was made up of medusae. This survey found a few patches of abundant medusae (three sites: 2,591–6,056 per $100m^3$), three sites with fewer medusae (31–779 per $100m^3$), none at other sites, while salps were present in small numbers at a few sites only. Large samples in the earlier April-May survey (SS9602) owed their size to the large numbers of salps; no medusae were found.

Calanoid copepods were found in every sample, but there was less species diversity than in the other two surveys. A few species appeared in very large numbers, e.g. *Calanus australis* was found in every sample (> 9,000 per $100m^3$ at the inshore Bermagui site). Only 3 samples had fewer than 1,000 *C. australis* per $100m^3$: the two Lakes Entrance stations and the offshore station on the Point Hicks transect. Two other copepod species were found in large numbers (> 1,000 per $100m^3$) at the inshore Bermagui station –*Temora* spp. and *Calanoides* spp.

Euphausids were widespread and found in every sample. They were almost exclusively stage 1 larvae. Large numbers (1,233–4,200 per $100m^3$) were found at several sites (Bermagui inshore and offshore, Merimbula offshore, Disaster Bay offshore, Gabo inshore and Gabo Reef and inshore Point Hicks and Lakes Entrance).

Fish eggs and larvae were widely distributed: one or both were found in all samples. Samples with large numbers of eggs had few or no larvae; and the reverse was also true–the sites with greatest abundance of fish larvae had small numbers of, or no, fish eggs. The greatest number of eggs was found at the inshore Wilson's Promontory station (339 per $100m^3$). The greatest numbers of larvae were found in the inshore Point Hicks sample (438 per $100m^3$), inshore Bermagui (413 per $100m^3$), offshore Bermagui (298 per $100m^3$) and Gabo Reef (168 per $100m^3$)

samples. Larval fish included representative of the following families: Monacanthidae (very numerous), Bothidae, Syngnathidae and Triglidae.

Mysids were more abundant and widespread during this than during the previous (April–May) survey, although the greatest abundance (734 per 100m^3 at the inshore Bermagui station) was similar to the earlier survey. Apart from the Gabo Reef sites, mysids were more abundant at inshore than offshore sites and were absent only from three samples (offshore Bermagui, Point Hicks and Lakes Entrance).

Decapod larvae were widespread–in all samples except two (offshore Merimbula and Wilson's Promontory); and usually more abundant in inshore than offshore samples. The greatest abundance (1,055 per 100m^3) was at the inshore Bermagui site; and uniformly high numbers were found in the three Gabo samples (785–925 per 100m^3).

Chaetognaths were found in small to moderate numbers (46–463 per 100 m^3) in samples from all the offshore sites and from samples from the inshore Wilson's Promontory and Bermagui transects.

Larvaceans, *Oikopleura* spp. were not found on the Wilson's Promontory or Lakes Entrance transects, but occurred at all other sites except offshore Bermagui and Merimbula in small to moderate numbers (78–688 per 100m^3).

Zooplankton Community Analyses

The forty four samples zooplankton sample collected contained 78 taxa. Fourteen species occurred in 4 or less of the samples. Seven of these 14 species showed no spatial or temporal pattern and were removed from subsequent analyses (Table 6.2.2.1).

Following cluster analyses and MDS, there was a marked similarity in the results for all transforms, except presence/absence (Fig. 6.2.2.1). Interpretation and further analyses were based on the ln (x+1) transform as this gave the clearest geographical pattern and the transform is well recognised as having good statistical properties for abundance data..

There were four major groups (Fig. 6.2.2.2): 1) inshore samples from southern transects during SS9405 (August); 2) offshore samples from southern transects and inshore and offshore stations from northern transects during all surveys; 3) inshore samples from southern transects during SS9602 and SS9606 (April and December), and 4) the offshore station at The Horseshoe on SS9606 (December). The northern extent of the inshore samples from the southern transects changed with season and this seemed to correlate to the southern extent of the EAC eddy (Fig. 6.2.2.3). Several additional samples taken on and off Gabo Reef grouped together and in the same group as adjacent survey stations. These samples were deleted from further analysis as they placed unnecessary emphasis on one location in the broader survey area. It is interesting to note that in contrast to the daylight bongo net samples on broad scale stations, these additional samples were taken at night.

General characteristics of the groups

Groups 1 and 2 had lower numbers of individuals than groups 3 and 4, but more species. This pattern is reflected in the higher richness, diversity and evenness of the first two groups (Table 6.2.2.2).

Group 1 (Inshore south SS9405 - August)

Group 1 was dissimilar from all other groups because of the lower abundance of Euphausid larvae (1), *Nannocalanus minor*, unidentified calanoids and lack of fish larvae. It also had higher numbers of Euphausid larvae (2), *Salpa fusiformis*, unidentified salps, and Cladocera. A high abundance of *Temora* sp. further distinguished it from groups 3 and 4. Low numbers of unidentified calanoids, Family Para (Calanidae) further distinguished group 1 from group2.

Group 2 (Offshore south and all north stations–all surveys)

Group 2 was the richest of the groups with 71 species but low abundance. It had the highest diversity and evenness. Group 2 was distinguished from other groups by the higher abundances of Para (Calanidae), *Calanoides* spp., *Eucalanus hyalinus*, *Subeucalanus crassus*, *Rhincalanus nasutus*, Chaetognatha, and low numbers of decapod larvae. It was further distinguished from Group 1, by the presence of high numbers of *Nannocalanus minor* and *Pleuromamma gracilis*. High numbers of *Temora* spp., and *Pleuromamma gracilis*, and low numbers of nectophores and *Oikopleura* spp. further distinguished group 2 from 3, while high numbers of *Temora* spp. and *Nannocalanus minor* further distinguished it from group 4.

Group 3 (Inshore south SS9602 and SS9606 – April and December)

Group 3 was one of the most numerous groups but had comparatively low species numbers. It was dissimilar from the other groups due to high abundances of Euphausid larvae (1), Mysidcea, Nectophores, *Oikopleura*, and decapod larvae. Low abundances of family Para (Calanidae) and *Temora* spp. further distinguished it from groups 1 and 2

Group 4 (Offshore The Horseshoe SS9606 – summer)

Zooplankton numbers in group 4 were high. This group had the lowest species number of any group but as it consists of only one sample this is likely a sampling artefact. It was distinguished from all other stations by high numbers of *Nyctiphanes* spp., and *Pleuromamma gracilis*, but low numbers of Eupahusiid larvae (2), Nectophores, *Oikopleura* spp., *Temora* spp., *Rhincalanus nasutus*, and *Nannocalanus minor*.

Relationship of the groups to environmental factors

Environmental variables were analysed within survey to account for seasonal changes in the physical oceanography between surveys (Table 6.2.2.3).

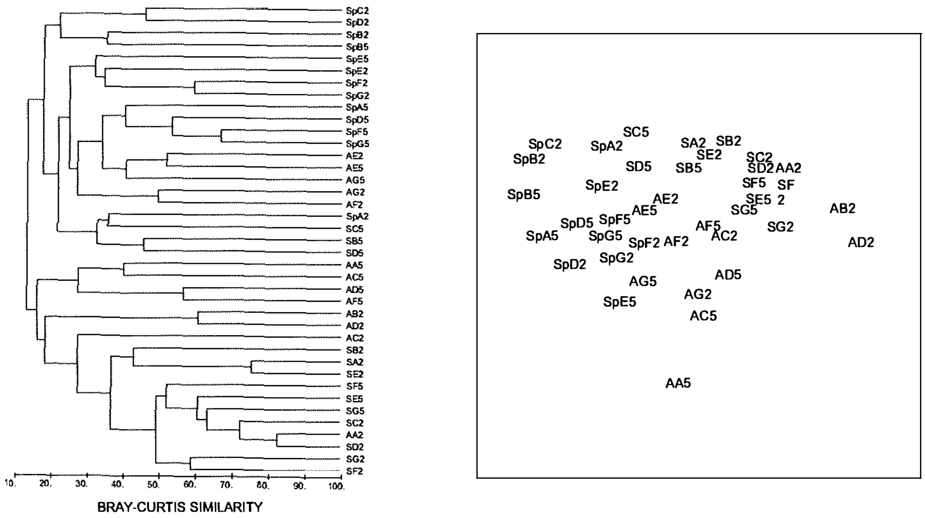
Group 2 was made up of offshore stations on southern transects and inshore and offshore stations on northern transects. On SS9405 (August) it was distinguished from the southern inshore stations by higher temperatures and salinity at the surface, higher nutrients and lower dissolved oxygen at depth, and higher depth-integrated pigments. On SS9602 (April) group 2 stations were distinguished from southern inshore stations by higher surface temperature, higher nitrates and lower dissolved oxygen at surface and depth, and lower depth-integrated pigments. On SS9606 (December), group 2 stations were distinguished form other stations by low phosphates and silicates at the surface - there were no other distinct differences, although high variability for group 2 would have obscured any differences.

Table 6.2.2.1 Zooplankton taxa occuring in 4 or less of the 44 bongo net samples

Species	Samples[a]	Action
Unidentified amphipods	SB5	Remove
Obelia	WD2	Remove
Gaetenus sp.	WGABO	Remove
Pleuormamma. xiphias	WB5, WA5	Keep as adjacent sites and season
Metridia lucens	WE5, WG2	Keep as adjacent sites and season
Mollusc larvae	AC5, AG5	Remove
Neocalanus gracilis	WA2, WGABO, AD2	Remove
Phaena sp.	WD5, WG2, AG2	Keep as northernmost site *2
Nematobrachion sp	WGABO, AD5, AG5	Remove
Gammarids	WB5, WGABO *3	Keep as 3 adjacent sites and same season
Heteropods	WA5, WD2, AG5, AF5	Keep as adjacent sites and northernmost
Pyrosoma larvae	WD2, WGABO, AA5, SB5	Remove
Centropages orsinii	SA2, SB2, SG2, SG5	Keep as adjacent sites and same season
Salpa fusiformis	WA5, WC2, WD2, WE2	Keep as adjacent sites and same season

[a] First letter codes	W,A,S	Winter (SS9405), Autumn (SS9602) and Summer (SS9606)
Second letter codes	A to G	Transect or GABO Reef
Third digit	1 to 5	Station number on transect

Raw Data, Stress=0.16



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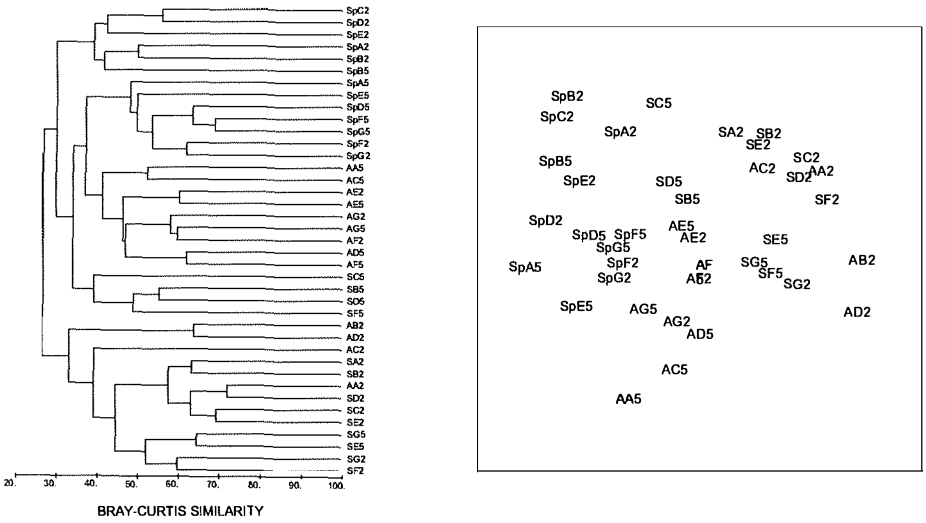


4th Root, Stress=0.20

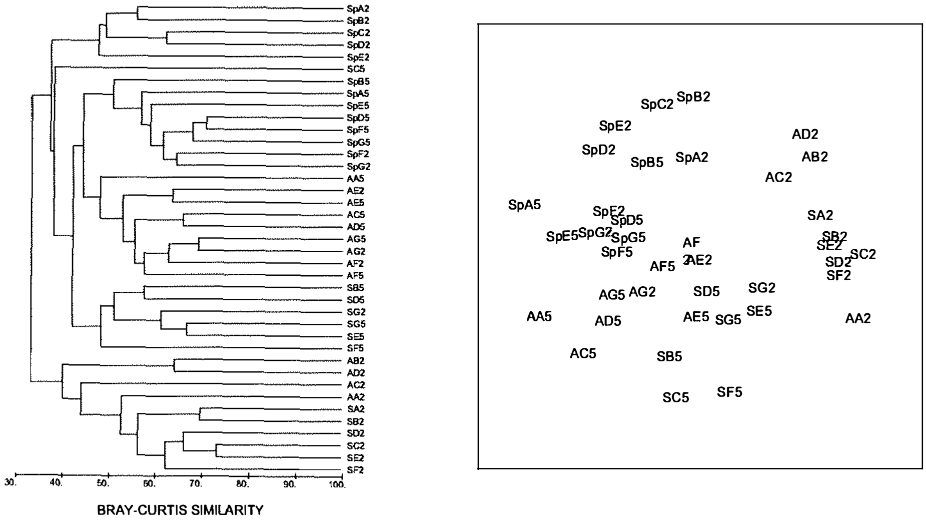
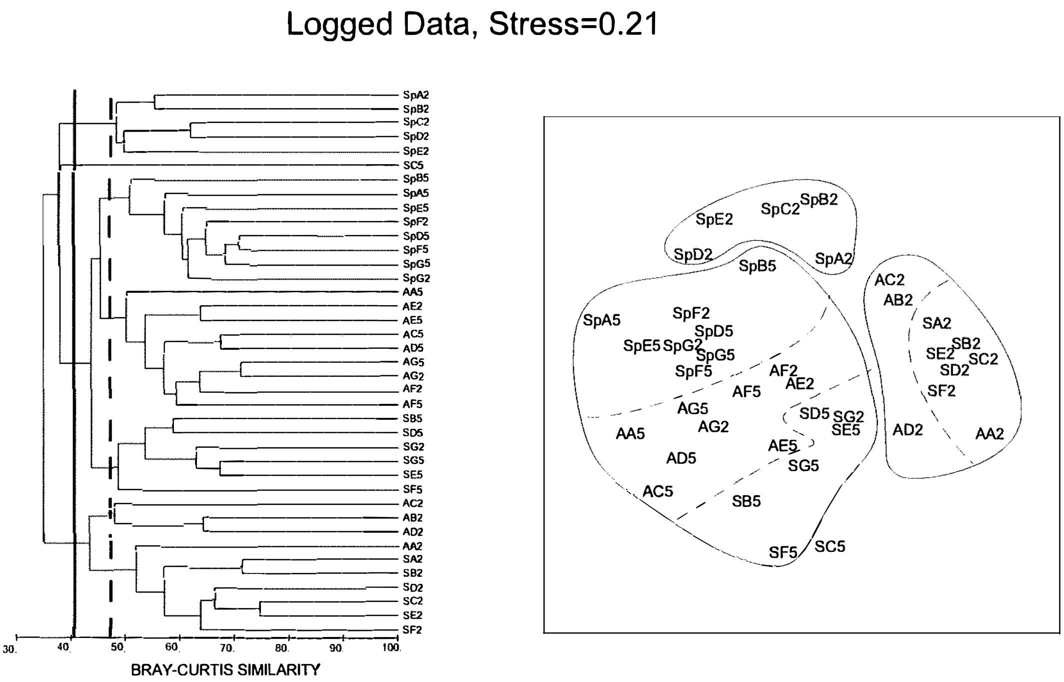


Figure 6.2.2.1 Cluster analyses and MDS plots for zooplankton abundance from all surveys under a series of transformations of increasing severity.

Logged Data, Stress=0.21



Presence/Absence Data, Stress=0.20

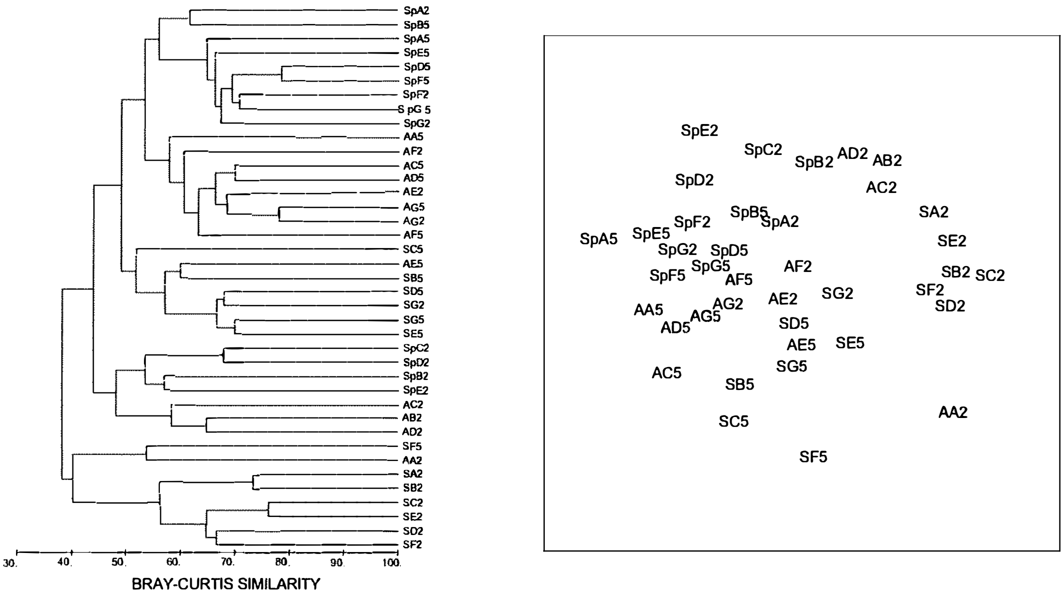


Figure 6.2.2.1 continued

Logged Data, Stress=0.21

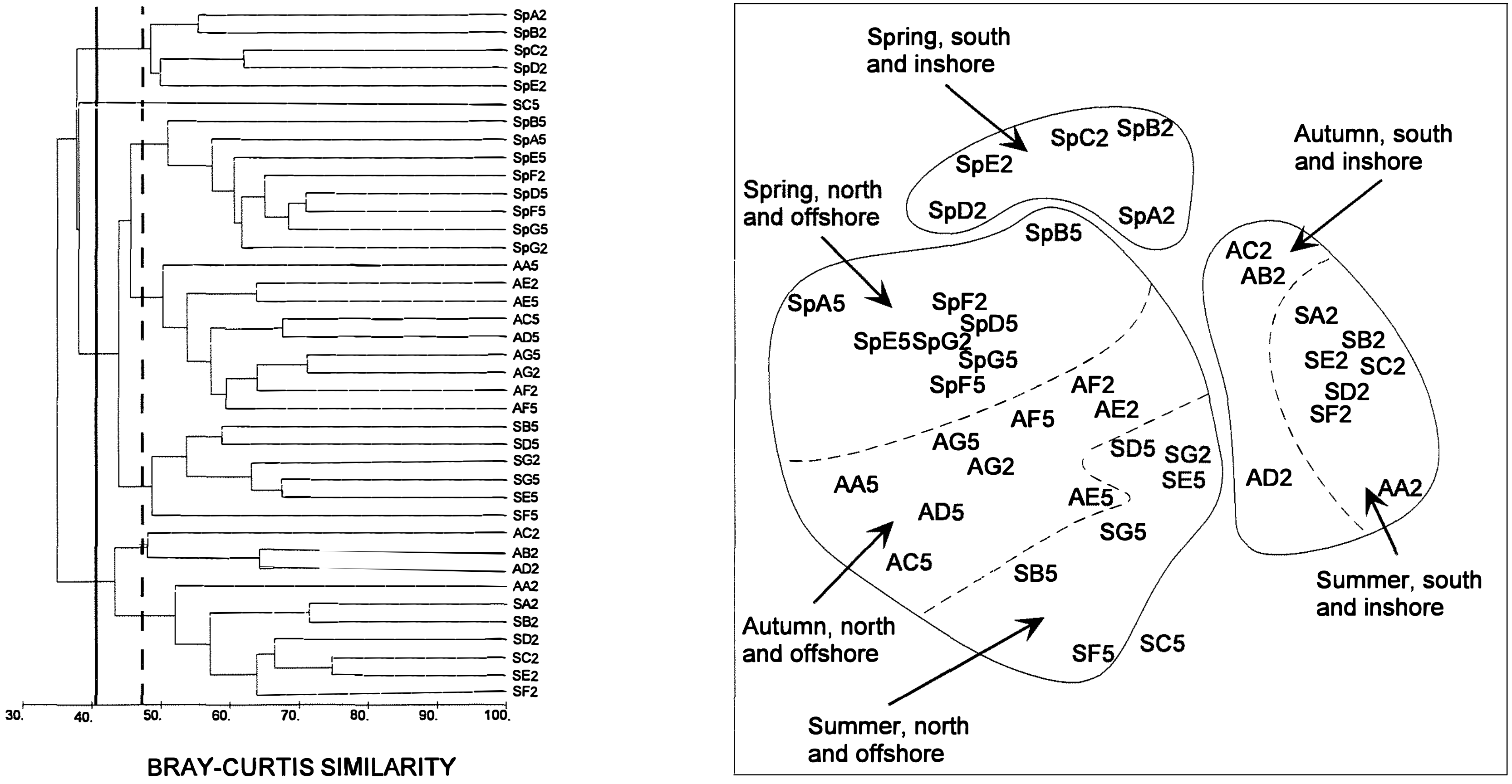


Figure 6.2.2.2 Cluster analysis and MDS plot of zooplankton abundance for all surveys with a ln(x+1) transformation. Major and secondary clusters are identified.

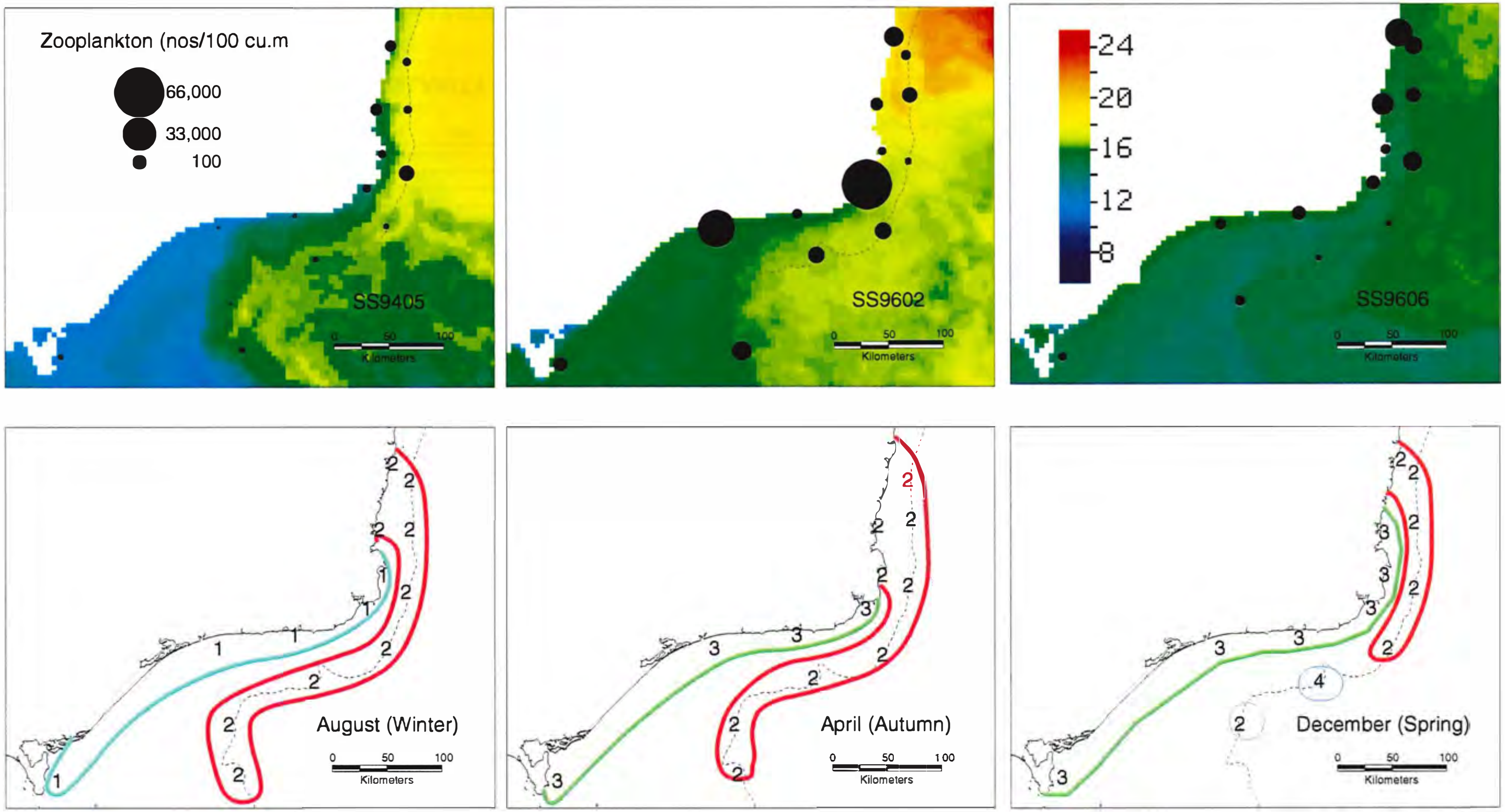


Figure 6.2.2.3 Zooplankton abundance and sea surface temerature (top) and zooplankton communities distinguished from multivariate analysis of all samples with a ln(x+1) transformation.

Table 6.2.2.2 Standardised counts (geometric mean, #/100m3) of taxa for each group defined in the multivariate analysis. Taxa that contribute to the first 30% of total dissimilarity between a group and all other samples are bolded.

Depth	Inshore	Offshore	Inshore	Offshore
Area	South	South and north	South	Big Horseshoe
Survey	SS9405	All surveys	SS9602 and SS9606	SS9606
Month	August	All surveys	April and December	December
Group number	1	2	3	4
Unidentified euphausiids	1	1	0	0
Nyctiphanes spp.	1	2	0	**457**
Stylocheiron spp.	0	0	0	5
Euphausiid larvae (1)	**6**	183	**1,501**	158
Euphausiid larvae (2)	**82**	17	**3**	**0**
Mysidacea	0	3	**76**	0
Unidentified cyclopoids	5	11	0	0
Oithonia spp.	7	1	0	0
Squareheads	0	3	0	0
L. cyclopoids	0	1	0	0
Oncaea spp.	0	3	1	0
Gammariids	0	0	0	0
Hyperiids	1	5	2	11
Fish larvae	**0**	14	8	3
Fish eggs	18	11	8	22
Ctenophores	0	2	0	0
Chaetognatha	45	**179**	**1**	46
Pteropod	1	2	0	8
Heteropod	1	0	0	0
Nectophore	10	**8**	**84**	**0**
Oikopleura spp.	**24**	**12**	**42**	**0**
Medusa	1	1	3	0
Polychaete	1	4	0	0
Polychaete larvae	0	1	0	0
Ostracoda	3	5	0	0
Cladocera	**13**	1	2	0
Unidentified calanoids	**2**	45	13	**0**
Fam. Para(Calanidae)	**3**	**83**	**2**	**5**
Temora spp.	**67**	**58**	**9**	**0**
Rhincalanus nasutus	**0**	**63**	**1**	**0**
Paraeuchaeta spp.	1	3	0	3
Calanoides spp.	1	**20**	0	3
Pleuromamma gracilis	0	**29**	0	**391**
P. abdominalis	0	4	0	0
P. xiphias	0	0	0	0
Calanus australis	134	213	1,758	370
Neocalanus tonsus	0	2	1	3
Centropages orsinii	0	0	1	0
Acartia spp.	17	15	3	0
Subeucalanus crassus	0	**18**	0	0
S. longiceps	0	1	0	3
Eucalanus hyalinus	0	**42**	0	5
Ætidus spp.	1	2	0	0

Depth	Inshore	Offshore	Inshore	Offshore
Area	South	South and north	South	Big Horseshoe
Survey	SS9405	All surveys	SS9602 and SS9606	SS9606
Month	August	All surveys	April and December	December
Group number	1	2	3	4
continued				
Heterorhabdus spp.	0	2	0	0
Centropages bradyii	0	5	1	0
C. australiensis	10	1	17	0
Cosmocalanus darwinii	0	3	0	0
Nannocalanus minor	**2**	**22**	**24**	**0**
Scaphocalanus spp.	0	2	0	0
Candacia spp.	6	17	2	35
Labidocera spp.	0	1	10	3
Paracalanus spp.	0	0	0	0
Paraeucalanus langae	0	1	0	0
Phaenaa spp.	0	1	0	0
Tortanus barbatus	0	3	9	0
Clausocalanus spp.	0	13	1	0
Euchirella spp.	0	1	0	0
Lucicutia spp.	1	0	0	0
Metridia lucens	0	0	0	0
Mesocalanus spp.	0	2	0	0
Unidentified molluscs	0	1	0	0
Gastropoda	1	3	0	14
Unidentified decapods	1	1	0	0
Decapod larvae	74	**35**	**665**	73
Long Neck	0	1	2	0
D. denticulatum	0	1	1	0
Unidentified salps	**13**	6	4	0
Salpa fusiformis	**33**	0	0	0
Ihlea magalhanica	4	1	1	0
Thalia democratica	3	3	2	3
Iasis zonaria	2	2	0	3
Total species number	48	71	39	22
Total individual numbers	1,671	6,720	15,897	1,623
Average number per statior	334	292	1,590	1,623
Richness (Margelef index)	6.33	7.94	3.93	2.84
Diversity (Shannon-Wiener	2.85	3.29	2.22	1.89
Eveness (Pielou)	0.74	0.77	0.61	0.61
Similarity (Bray-Curtis)	0.51	0.48	0.51	
Dissimilarity (Bray-Curtis)	0.63	0.64	0.65	0.64

Table 6.2.2.2 continued

Table 6.2.2.3 Average values of physical parameters and nutrients for stations identified in each zooplankton group and their signficance based on individual one-way ANOVAs.(Significant differences are highlighted)

			Zooplankton group			
Survey	Depth	Variable	Inshore South	Offshore North	Horseshoe	Significance
SS9405	Surface	Temperature	13.0	16.0		<0.01
		Salinity	35.5	35.6		0.04
		Dissolved O_2	271.6	269.7		0.82
		Phosphates	0.3	0.3		0.78
		Nitrates	2.3	3.5		0.54
		Silicates	1.4	1.4		0.83
	Bottom	Temperature	12.3	13.1		0.15
		Salinity	35.5	35.4		0.00
		Dissolved O_2	267.9	241.1		<0.01
		Phosphates	0.3	0.6		<0.01
		Nitrates	1.5	14.0		<0.01
		Silicates	1.2	2.9		<0.01
SS9602	Surface	Temperature	16.1	17.9		0.03
		Salinity	35.6	35.7		0.37
		Dissolved O_2	248.7	237.5		0.00
		Phosphates	0.2	0.2		0.98
		Nitrates	0.2	0.9		0.03
		Silicates	1.4	1.4		0.84
	Bottom	Temperature	16.0	15.7		0.72
		Salinity	35.6	35.4		0.08
		Dissolved O_2	245.5	224.3		0.00
		Phosphates	0.2	0.4		0.07
		Nitrates	0.3	4.9		0.02
		Silicates	1.5	2.7		0.02
SS9606	Surface	Temperature	15.6	15.6	15.9	0.85
		Salinity	35.7	35.1	35.5	0.36
		Dissolved O_2	258.3	264.0	257.4	0.10
		Phosphates	0.3	0.2	0.3	0.00
		Nitrates	1.4	1.2	1.7	0.78
		Silicates	1.1	0.4	1.2	<0.01
	Bottom	Temperature	14.5	13.7	14.2	0.23
		Salinity	35.7	35.1	35.4	0.42
		Dissolved O_2	249.0	251.6	244.0	0.49
		Phosphates	0.4	0.4	0.4	0.60
		Nitrates	2.7	3.2	5.0	0.77
		Silicates	1.7	1.8	2.1	0.84

Stable isotope analysis

Undifferentiated zooplankton samples had a mean δ^{13}C value of –21.3 ± 0.8 ‰ and δ^{15}N value of 7.7 ± 1.9 ‰. There was some variability in the separated zooplankton samples (Table 6.2.2.4). Fish eggs, not surprisingly had the highest δ^{15}N value at 10.2 ‰ followed by larval clupeids at 9.3 ‰. Fish eggs had a relatively low δ^{13}C value (22.1 ‰), presumably due to the presence of lipids (lipids have an isotopically 'light' stable carbon signature). The least enriched group, amphipods, had a δ^{15}N value of only 2.9 ‰ and a δ^{13}C value of –22.9 ‰.

Interpretation of secondary production results

The zooplankters in the study area were consistently divided into two communities. There was a highly diverse, species-rich, northern and offshore community associated with warmer surface waters, higher nutrients and lower dissolved oxygen especially at depth, in August 1994 and April 1996, but less distinct from other stations in December 1996. This community was dominated by calanoid copepods including *Calanus australis*, *Temora* spp. and *Rhincalanus nasutus*, Eupahusiid larvae, and chaetognaths. The calanoid copepod species that distinguish this group from the inshore groups- *Rhincalanus nasutus, Pleuoromamma gracilis, P. abdominalis* and *Eucalanus hyalinus*- are dominant members of the mid-slope plankton community (Terauds 1993). In a large scale plankton survey off the east coast of NSW, Dakin and Colefax (1940) reported finding similar species and, similarly to this study, found *Temora turbinata* and *Acartia clausii* were among the most abundant zooplankters.

Inshore of the northern and offshore community, inshore stations from Wilson's Promontory to as far north as Merimbula consistently had similar zooplankton communities, which had relatively low diversity, were species-poor, and associated with cooler surface waters, lower nutrients and higher dissolved oxygen especially at depth (although not in December 1996). In August 1994, this community had low numbers, dominated by *Calanus australis*, Euphausid larvae, decapod larvae, and *Temora* spp. In April and December 1996, the community had higher numbers than the offshore community and was dominated by *Calanus australis*, Euphausid larvae, and decapod larvae, as well as gelatinous zooplankton and mysids. In a study of the upper 200m off eastern Tasmania, Taw (1975) reported finding many of the same species, and remarked *Calanus australis, Neocalanus tonsus* were abundant, *Eucalanus hyalinus* was dominant when it occurred and *Rhincalanus nasutus* and *Pleuromamma gracilis* were common when they abundant copepods.

On the December 1996 survey, the offshore The Horseshoe station separated from all other stations. It had a few, very abundant species that were absent or of low abundance in other samples–*Nyctiphanes* spp. and *Pleuromamma gracilis*–and was missing some species common in other samples-- Nectophore, *Oikopleura* spp., *Temora* spp., *Rhincalanus nasutus* and *Nannocalanus minor*. Its oceanography did not differ noticeably from other stations.

The northern extent of the inshore zooplankton community appeared to well match the discontinuities in surface temperature associated with the EAC eddy dominating the oceanography off New South Wales. Comparison with the water masses showed a good correspondence between the northern extent of this community and changeover from southern to northern water masses at the bottom on SS9405, at the surface on SS9602 and at the surface on SS9606. There was also reasonable correspondence between the distribution of the north and offshore pigment groups and the north and offshore zooplankton groups on all surveys.

Stable nitrogen signatures showed a trophodynamically diverse group of organisms in the zooplankton community, although the lowest value (2.9 for amphipods) came from only one sample and these data are difficult to interpret.

6.3 SUMMARY AND IMPLICATIONS

Primary Production

On all surveys, the $\delta^{13}C$ levels indicated that primary production was of predominantly marine origin. The only consistent exception to this were the inshore stations at Lakes Entrance and Wilson's Promontory, where the influence of seagrasses, benthic macroalgae or C4 plants was detected. Pigments indicated the presence of algal detritus at the inshore Bermagui site on SS9405 and terrestrial detritus at Disaster Bay on SS9602, but these interpretations were somewhat subjective and were not borne out by the stable carbon results.

Compared with other continental shelf regions, the waters of the shelf off southeastern Australia have low chlorophyll concentrations. Chlorophyll *a* values of 0.160.9 µg L^{-1} in surface waters off Cyprus (eastern Mediterranean, around 35°N) were reported by Bianchi *et al.* (1996) to be among the lowest chlorophyll values for nearshore waters.

Many algal classes or divisions (diatoms, prymnesiophytes and chryptophytes) are spread widely throughout the area, while others are more limited in space (prasinophytes), time (euglenophytes) or both (dinoflagellates). There were broad regional groupings of pigments and, by implication, algal groups (since the pigments are markers for some families). A northern and offshore group was found in waters with relatively high pigment levels, nutrients and temperatures, suggesting upwelled slope water had influenced primary production. On SS9606, nutrients were not elevated on northern offshore stations, and also pigment concentrations were low, indicating low algal biomass.

Southern inshore stations were grouped together on the basis of a lack of chlorophyll c3 on SS9405 and SS9602. Concentrations of many pigments were low on SS9405, when nutrients at depth and temperatures overall were also low, while pigment concentrations were comparable or higher than the northern offshore group on SS9602, when temperatures were comparable and nutrients only slightly depressed. On SS9606 the southern inshore group expanded to include southern offshore stations that also had relatively high pigment levels indicating the presence of Chrysophyceae and Cryptophyta. Temperatures and nutrients were similar to other groups.

The inshore Lakes Entrance station in SS9405 and the offshore Lakes Entrance station in SS9602 had notably low (or missing) pigment levels. Nutrients were not lower than adjacent stations. The inshore Bermagui station on SS9405 had pigments and $\delta^{13}C$ levels consistent with a late bloom.

Secondary Production

The zooplankters in the study area were consistently divided into two communities. There was a highly diverse, species-rich, northern and offshore community associated with warmer surface waters, higher nutrients and lower dissolved oxygen (especially at depth) in August 1994 and

Table 6.2.2.4 Stable nitrogen and carbon isotope values for zooplankton collected by oblique-towed bongo nets (SS9405).

Species		$\delta^{15}N$		$\delta^{13}C$	
	n	**mean**	**SD**	**mean**	**SD**
Amphipods	1	2.9		-22.9	
Copepods	2	6.2	1.6	-21.5	1
Euphausids	2	6.5	2.3	-21.1	1.5
Megalopa larvae	1	7.9		-21	
Crustacean zooplankton	1	7.4		-20.2	
Fish eggs	1	10.2		-22.1	
Fish larvae – clupeids	1	9.3		-20.3	
Fish larvae – various species	2	7.1	0.6	-22.8	1.2
Zooplankton – undifferentiated	6	7.7	1.9	-21.3	0.5

April 1996, but this community was less distinct from those of other stations in December 1996. The most abundant species were calanoid copepods (including *Calanus australis*, *Temora* spp. and *Rhincalanus nasutus*), euphausid larvae, and chaetognaths. The calanoid copepod species (*Rhincalanus nasutus, Pleuromamma gracilis, P. abdominalis, Eucalanus hyalinus*), which distinguish this group from the inshore groups are dominant members of the mid-slope plankton community (Terauds 1993). These calanoid species migrate (diurnally or seasonally) deeper than the continental shelf-break stations on which they were caught, and must therefore have originated from slope water. This indicates the influence of slope waters on the continental shelf-break stations.

The second clearly distinguishable community was apparent at inshore stations from Wilson's Promontory to as far north as Merimbula. These zooplankton communities were consistently alike: of relatively low diversity, species poor, occurring in areas with cooler surface waters, lower nutrients and higher dissolved oxygen, especially at depth. In August 1994, this community had low numbers, dominated by *Calanus australis*, Euphausid larvae, decapod larvae and *Temora* spp. In April and December 1996, it had higher numbers than the offshore community and was dominated by *Calanus australis*, Euphausid larvae, and decapod larvae, as well as gelatinous zooplankton and mysids.

In the December 1996 survey, the offshore The Horseshoe station separated from all other stations. It had a few, very abundant, species that were either absent or of low abundance in other samples – *Nyctiphanes* spp. and *Pleuromamma gracilis* – and was missing some species common in other samples – Nectophore, *Oikopleura* spp., *Temora* spp., *Rhincalanus nasutus* and *Nannocalanus minor*. Its oceanography did not differ noticeably from other stations.

Physical Oceanography, Primary Production and Secondary Production

The northern extent of the inshore zooplankton community appeared to well match the discontinuities in surface temperature associated with the EAC eddy dominating the oceanography off New South Wales. Comparison with the water masses showed a good correspondence between the northern extent of this community and changeover from southern to northern water masses at the bottom on SS9405, at the surface on SS9602 and at the surface on SS9606 (Figs. 6.3.3.1-6.3.3.3). There was also reasonable correspondence between the distribution of the north and offshore pigment groups and the water mass distribution on all surveys.

In all three surveys the plankton communities of the inshore stations were distinct from those of the offshore stations. The exceptions were the inshore stations in the north off New South Wales where the shelf is narrower. These stations were often included in the offshore group. All inshore stations except the northernmost ones are inundated primarily with nutrient-poor Bass Strait water.

Nutrient-rich continental slope water was evident on all outer-shelf stations on all surveys, although the most northern stations were sometimes influenced by the warmer, saltier and nutrient-poor EAC water. Continental slope water was most extensive on SS9405, where it appeared even at inner-shelf stations on northern transects. Nutrients were high at these stations, and an extensive phytoplankton bloom was underway. Pigment concentrations were high but variable, with many pigments missing, indicating an abundant but species-poor phytoplankton community. The zooplankton community in subsequent surveys was distinct from the inshore community and included several continental slope species, but its overall abundance was close to the inshore community's and less than the offshore community's. The southern inshore stations, where temperatures and nutrients (especially at the bottom) were lower, had very low pigment concentrations, especially off Lakes Entrance, and much lower zooplankton numbers than in subsequent surveys. The delineation of inshore pigment groups coincided with surface water masses, while that of zooplankton groups coincided with bottom water masses.

Nutrient-rich slope water was least extensive on SS9602, when it was present only on southern transects at depth and sporadically at the surface. The algal and zooplankton communities of the inner stations were still distinct from those of the outer stations, except on northern transects. These distributions of the algal and zooplankton communities were most clearly related to the distribution of surface water masses, with lower temperatures and lower nutrients distinguishing the inshore groups. Overall, pigment concentrations were lower than on SS9405, but more diverse and this time higher on inshore stations than offshore and northern stations. The inshore stations had the highest overall zooplankton numbers (with the same group on SS9606), due to Euphausid larvae and *Calanus australis*.

On SS9606, there was a widespread intrusion of slope water onto the shelf; however, it did not appear to reach the inner-shelf stations due to a tongue of EAC water covering the middle shelf. The distinct algal community formed by the northern offshore stations matched the surface extension of the stratified EAC water at the surface. Nutrients were low overall, and pigment concentrations were also low (but diverse) especially on the northern offshore stations. Zooplankton abundance on these offshore stations was comparable with SS9602–the lowest of all zooplankton groups. Zooplankton abundance on inshore stations was close to that for SS9602.

Implications

1. Primary production in SEF shelf waters is predominantly of marine origin. Based on comparative chlorophyll concentrations, it is low in global terms. Terrestrial and estuarine inputs are small. Broad regional groupings of algal pigments suggest that upwelled slope water strongly influences primary production.

2. The scale of spatial variability narrows going from primary to secondary production, as the longer life span of the zooplankters smoothes out some of the spatial variability in primary production.

3. Zooplankton (secondary producers) consistently formed two broad communities: inshore and offshore/ northern. The composition of the latter is dominated by oceanic species, which indicates an influence of upwelled slope water. That many of these species normally make diurnal or seasonal migrations to depths greater than that of the continental shelf may indicate they are advected onto the shelf.

4. There are strong links between regional hydrology and the sources of primary and secondary production for the SEF shelf. Therefore, fishery production will be influenced by hydrological variability in time (interannually, seasonally, episodically) and space (regionally, locally).

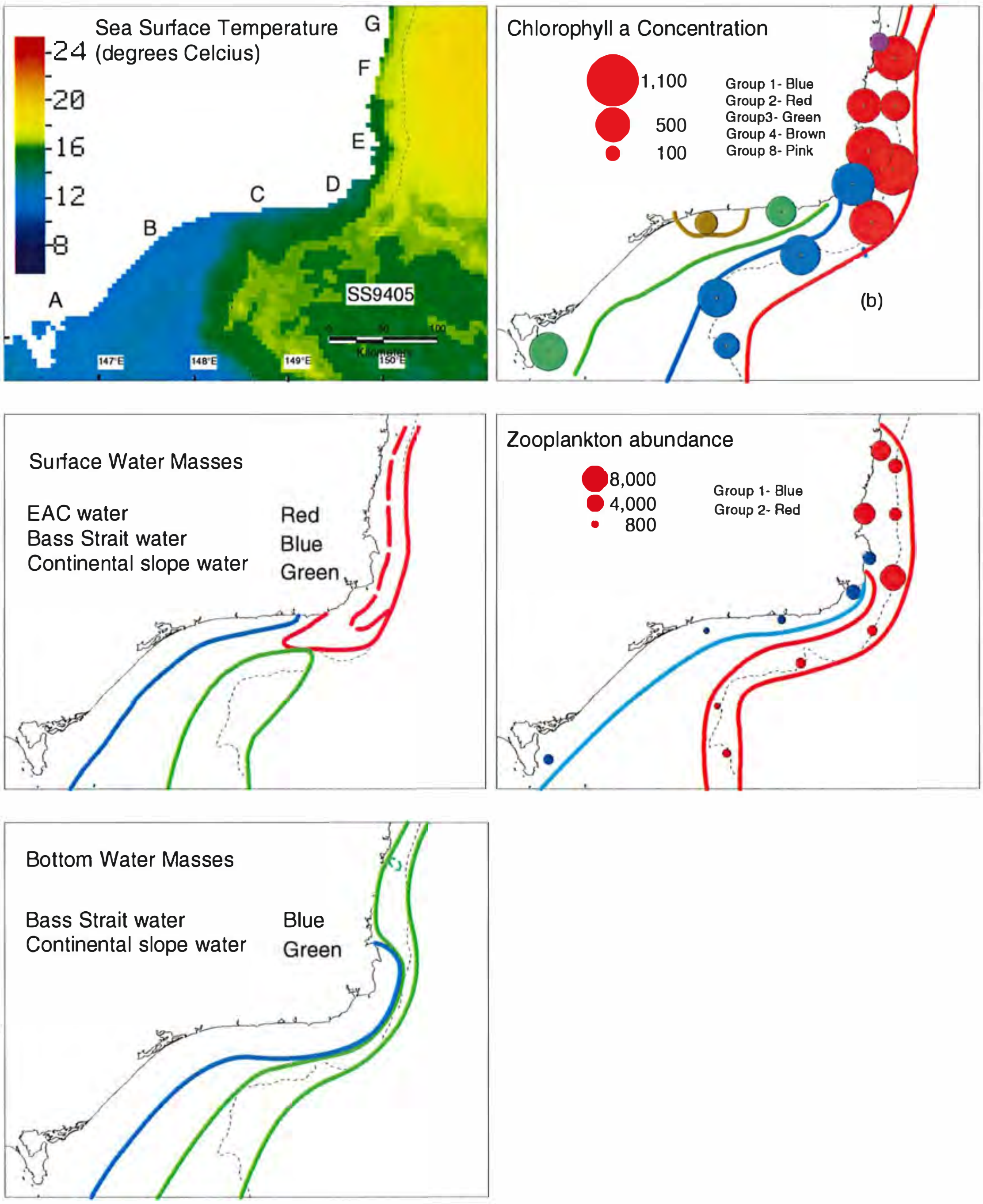


Figure 6.3.3.1 Summary of physical and biological oceanography for survey SS9405.

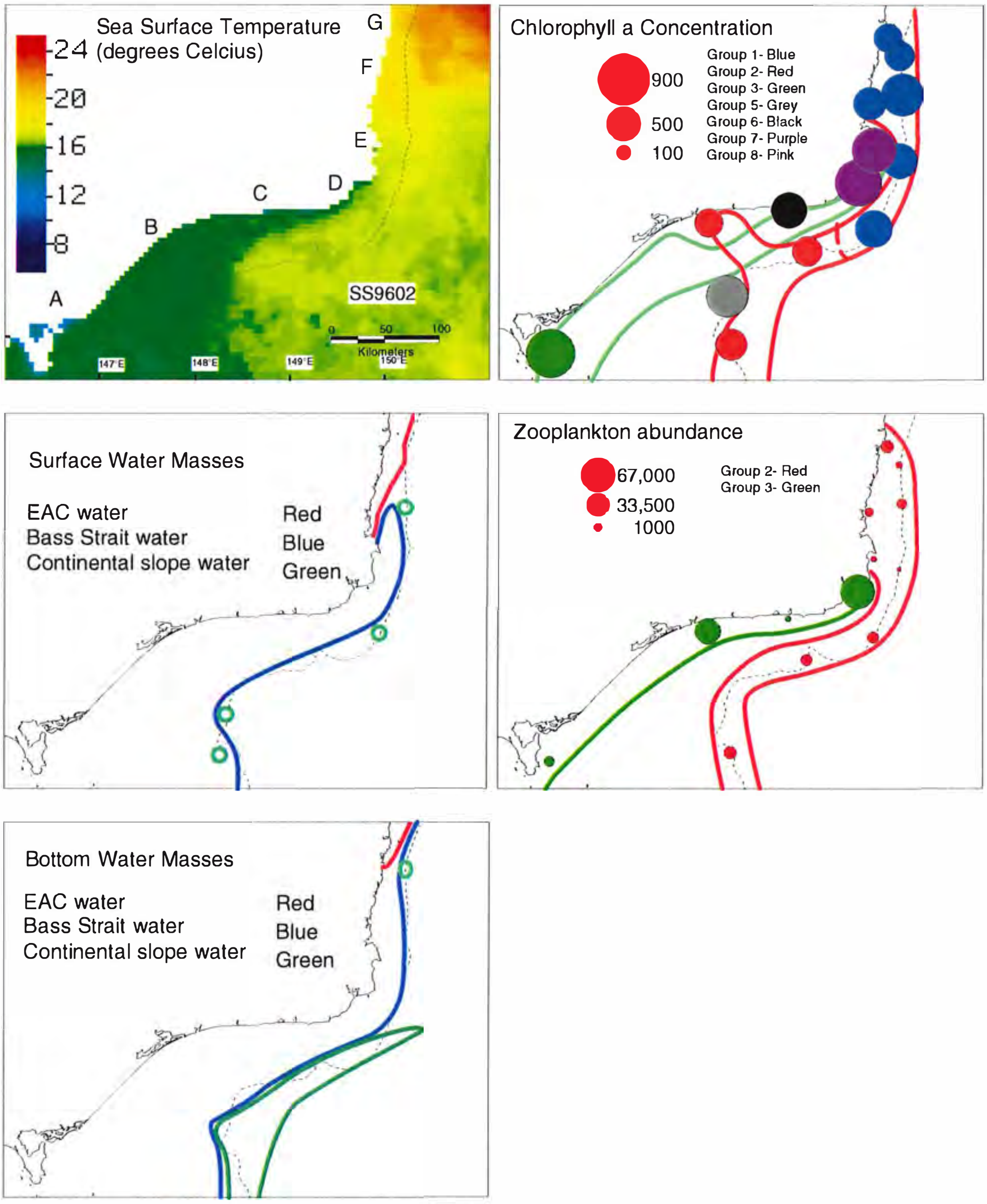


Figure 6.3.3.2 Summary of physical and biological oceanography for survey SS9602.

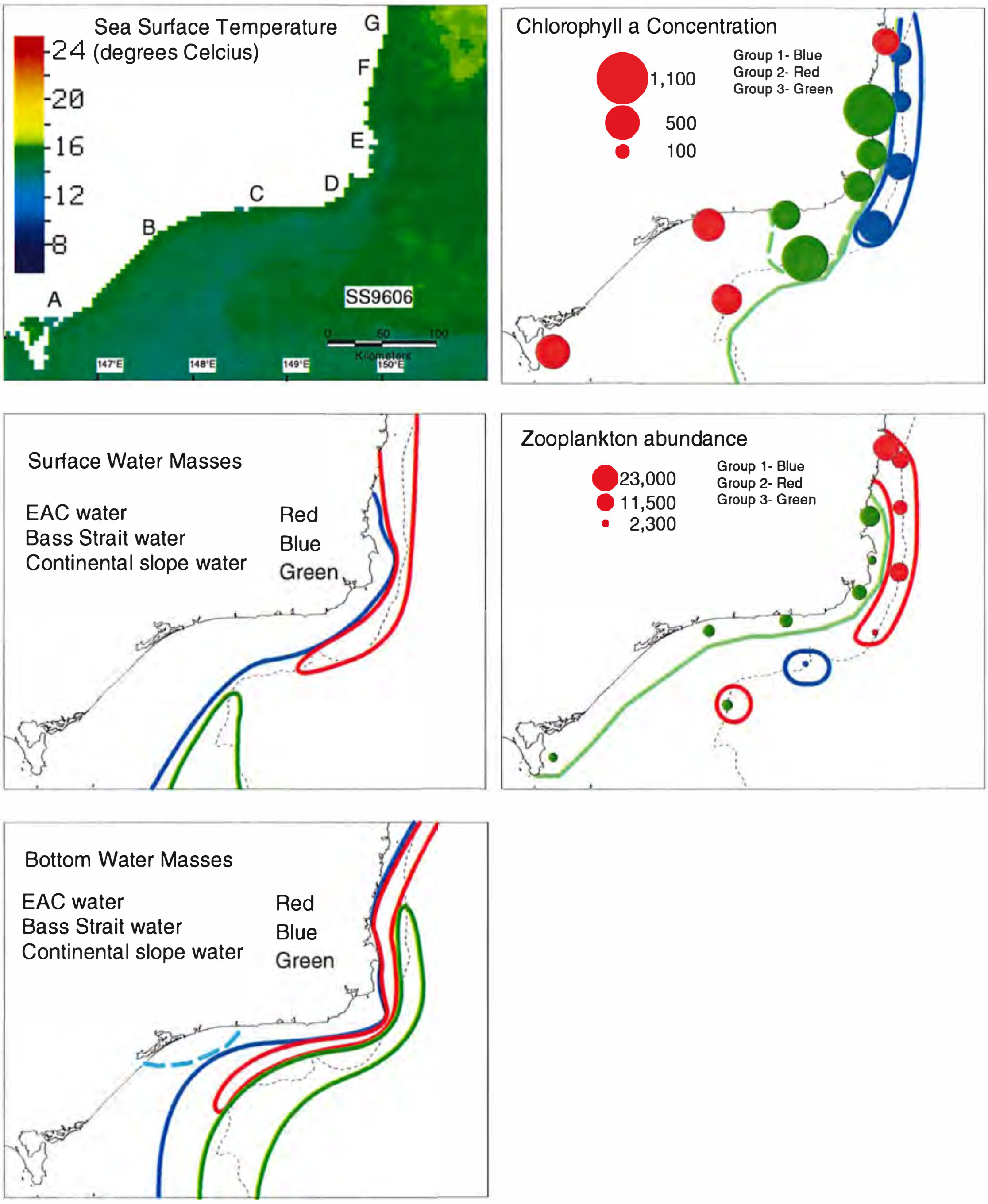


Figure 6.3.3.3 Summary of physical and biological oceanography for survey SS9606.

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7 BENTHIC HABITAT

Alan Williams, Nicholas Bax, Stevie Davenport, Rudy Kloser, Bruce Barker, Tim Ryan, Paul Sakov, Karen Gowlett-Holmes and Kim Woolley

The study of benthic habitat was directed at defining the structure and distribution of seabed types in the study area. By mapping seabed habitats, we provided a second level of spatial resolution for interpreting the ecological processes contributing to shelf productivity described in *Sections* 5 and 6. The integration of larger-scale processes in the water column with smaller-scale processes at the seabed and its interface provides the basis for understanding the ways in which the seabed is used by biological communities–particularly fishes–and by the commercial fishing fleet.

7.1 METHODS

Our benthic habitat study had two distinct components. During the first half of each survey undertaken by the research vessel we undertook a 'broad-scale' survey of benthic habitat. Distances between study sites were great (tens-hundreds of km) because we intended this sampling to be representative of large areas of the continental shelf. On the second half of research surveys, we undertook intensive mapping of specific mesohabitats (areas of spatial scales of ~tens of km^2). We directed our mesohabitat sampling using a basic map of the seabed constructed from information on fishing grounds kindly supplied by the fishing industry, and the broad-scale surveys. Mesohabitats were identified that contained heterogeneous seabed types and thereby provided contrasting macrohabitats, and were (in most instances), areas targeted by commercial fishers. Mesohabitats were acoustically surveyed at a fine scale to develop detailed maps showing topography and bottom-type. Fine-scale maps were used to indicate potentially distinct macrohabitats based on acoustic reflectivity and topography. These areas were then sampled with cameras and physical and biological samplers to confirm that macrohabitats were distinct. Finally, these fine-scale maps are interpreted in the context of regional-scale patterns in sediments and geology; sediment structures were verified from published data and with samples taken during the broad scale surveys.

7.1.1 Fishing grounds

Descriptions of seabed types and the extents of fishing grounds in the study area were recorded during the series of port visits (primarily Lakes Entrance and Eden) and trips to sea on commercial vessels. This information was combined with bathymetry and observations from early survey data and mapped in a GIS (MapInfo) to produce a 'coarse-scale' map of habitats. This composite map was then returned to local fishers for review, before reaching its current form.

7.1.2 Topography and acoustic characterisation of habitat

Acoustic data were collected continuously with the Simrad EK-500 during the four Southern Surveyor cruises, and the ship's path between sites was directed to provide as complete coverage of the sampling area as possible. The EK-500 was operated at one frequency (38 kHz) in the 1993 and 1994 surveys, but at three frequencies (12, 38 and 120 kHz) in the two 1996 surveys. Echograms were displayed and recorded after correction of one way beam spreading and two way sound absorption losses on a colour paper chart recorder and recorded digitally with a timestamp and GPS position. Data from the 1996 surveys have been processed and are presented here. Only data from the 120 kHz sounder are presented because they provided better visual discrimination in this depth range than the 12 or 38 kHz frequencies. The 120kHz sounder had a 10 degree conical beam and was operated at a 1 ms pulse length throughout the survey. All data were stored digitally and reprocessed on land. Reprocessing included checking the identified bottom echo to ensure that the correct bottom echo and therefore the correct bottom depth was identified. Bottom depths were contoured using Vertical Mapper in MapInfo.

Opportunistic acoustic sampling during the broad-scale survey and directed transects grids during the focussed habitat survey provided sufficient information to identify the boundaries of selected mesohabitats and to divide mesohabitats into contrasting macrohabitats. An example of the ship's track during sounding transects for the Disaster Bay region is shown in Fig. 7.1.2.1. Putative macrohabitats were discriminated visually from echo returns. Visual discrimination was based on the length and intensity of the tail of the first echo and the intensity of the first and second echoes (Orlowski, 1984, Chivers *et al.* 1990). This provided sufficient information to divide the mesohabitat into three macrohabitats. The macrohabitats were:

- Soft habitat–short tail on first bottom echo, low signal strength on first and second bottom echoes,
- Hard habitat–short tail on first bottom echo, high signal strength on first and second bottom echoes,
- Rough habitat–long tail on first bottom echo, moderate to high signal strength on first and second bottom echoes.

Note that the first bottom echo is the first reflection of acoustic energy from the seabed. The second bottom echo arises from acoustic energy from the first bottom echo that has been reflected from the sea-surface, and from the seabed for a second time before being received at the transducer on the vessel.

We adopted this approach mindful that acoustic scattering gives only an indirect indicator of sedimentary bottom particle size. The detailed acoustic scattering from geological seabed properties is a complex subject, and it is not clear to what extent acoustic scattering from the seabed is a useful measure of seabed properties important in determining biological assemblages, especially over a range of habitat types and depths. One of the aims of this project was to determine whether these simple acoustic indices of macrohabitat type were robust over a wide range of mesohabitats and could be used in broadscale mapping.

The EK-500 used has a wide dynamic range in comparison with commercially available acoustic bottom profilers–160 dB–and is able to record ping data digitally. Its wide dynamic range enables echoes to be recorded from weak, above-seabed features including fish and macrobenthos as well as the whole of the strong seabed echo. It thus provides a high level of information compared to typical commercially available acoustic bottom profilers, e.g. RoxAnn (Chivers et al. 1990), which was also attached to the 120 kHz echo sounder to determine its performance.

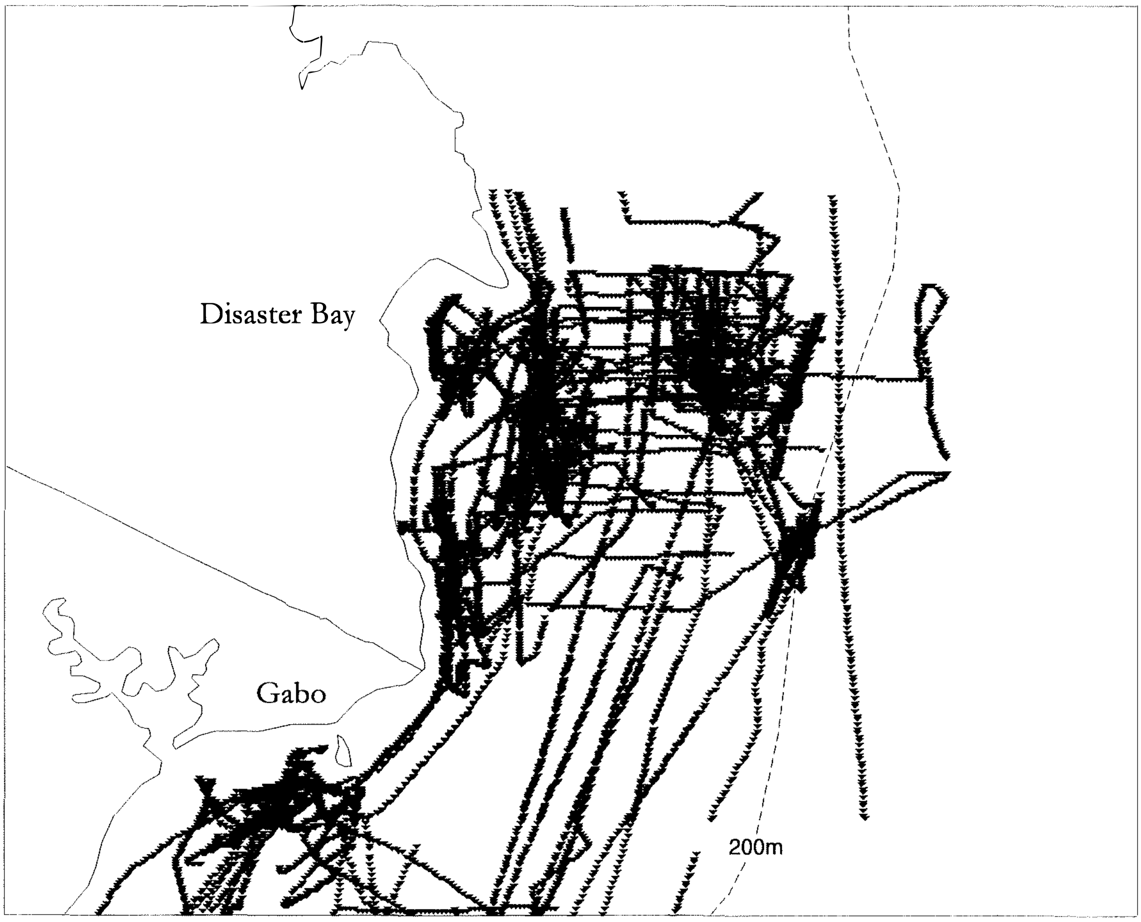


Figure 7.1.2.1 The ship's track during sounding transects for the Disaster Bay region, showing broadly spaced (~parallel) transects for broad-scale surveys and more detailed (~orthogonal) transects for fine-scale mapping.

The stored digital data were analysed after the survey to determine bias in habitat discrimination due to ship direction, ship speed and depth. Two descriptors of the return echo that corresponded with the visual discriminators used for the echograms and related to the RoxAnn system were chosen. The first descriptor (E1) is an integration of the tail of the first bottom echo, where the energy in the tail is assumed to derive from scattered reflections that increase in rough habitat. We defined the tail as between 5 and 15 m at 50 m water depth after the detection of the seabed echo as this gave the best discrimination in this study. It is important to note that this may represent acoustic contributions off the normal axis of the beam from 22.8–39.7 degrees for the 1ms pulse due to the expanding spherical wave front. The second descriptor (E2) is an integration of the entire second bottom echo and provides a measure of the total seabed energy. The second reflection theoretically has added discrimination over the energy of the first echo as it has been doubly reflected from the seabed squaring the reflection coefficient and improving discrimination power. The two indices (E1 and E2) were plotted as a scatterplot and boxes drawn around clusters of points, defined by a knowledge of the physical meaning of the E1 and E2 values. These boxes then define the different bottom types. This subjective technique is a standard approach used in delineation of RoxAnn data, and has been shown to be relatively robust compared with unsupervised cluster analysis, though prone to lower consistency between surveys (Greenstreet *et al.* 1997).

Habitat delineations from this post hoc analysis of the stored digital data were then compared with habitat delineations derived in real time from visual examination of the echograms. The two indices were depth corrected over the appropriate depth range by adjusting for sound absorption and one way spherical spreading loses. E1 was further standardised by ensuring that a similar off axis angular section was integrated by shifting the depth range of the tail integration according to depth. The E1 and E2 indices were mapped using Vertical Mapper in MapInfo (rectangular interpolation, cell size 0.005°, search radius 0.01°). Because we did not have EK-500 data coincident with trap and gillnet sets (deployed from a small commercial fishing boat), sample transects for all gear types were overlaid on the contour maps, the corresponding cross-section taken and the mean of E1 and E2 recorded for each transect.

7.1.3 Sediment composition and distribution

Survey data

Sampling gear loss and gear development led to sediments being collected by several different techniques. On the first and third cruises, SS9305 and SS9602, sediments were collected with a Smith McIntyre grab and, when the grab was lost on SS9305, a pipe dredge. For the second and fourth cruises, SS9405 and SS9606, sediments were collected with a modified 'Triple-D' demersal sled, when demersal sled samples were taken and with a Smith McIntyre grab on the limited occasions when no demersal sled samples were taken.

The modifications to the demersal sled was a short blade at the aft end of a rectangular opening on one of the sled skids which directed sediment into a removable stainless steel box on the upper surface of the skid. Benthic sled tows were typically of 20 min duration, but it is not known how quickly the sediment box filled, so sediments may be representative of a tow of much shorter duration. The box was removed at the end of each sled tow, and a sample of the sediment was immediately frozen for later analyses.

Samples were taken at five sites along each transect during the first leg of each survey and from specific habitat sites during the second leg (Fig. 7.1.3.1).

Sediments were surveyed with different gears for the SS9606 survey, and were measured at a different laboratory than earlier samples. A comparison of the sediment size for all surveys (Fig. 7.1.3.2) shows that the grainsize is multi-modal - indicating sediments with different origins - and some variation between samples for a single station from different surveys. In some cases, the sample from one survey, typically SS9602, stood out as having a poor representation of fine sediments (e.g. stations C1, D1, G1, C2, E2, C3, G3, D5 and G5). These samples were considered to be winnowed, due to flushing of fine sediments on retrieval of the sampling gear. Results that would be susceptible to winnowing - mean grain size, percents of gravel, sands and muds, variability in grain size and organic content – are not presented for these samples.

Grain size

The coarse fraction of the sediment for each site was analysed by CSIRO Marine Laboratories; the fine fraction by James Cook University. The resulting data sets were combined and mean grain size for each sample was calculated by the method of moments (Folk 1974).

Carbonate

Sediment samples were washed in distilled water and dried overnight in an oven at ~60°C. About 5 g of washed, dried sediment was weighed; 100 ml 1M HCl was gently added, agitated, then left overnight. Acid was removed and the sediment washed until neutral pH attained. Sediment was re-weighed and the difference in weights gave the amount of carbonate in the samples.

Organic content

The organic content was determined by combusting about 25 g of dried sediment at 480°C. The amount of material burnt off was considered equivalent to the organic component of the sediment.

Pigments

Samples of 1 to 2 g were chipped from the frozen sediment sample. Each sample was ultra-sonicated with a Branson microtip probe for 1 min in 100% cold methanol. Extracted samples were filtered through 25 mm diameter glass fibre filters (Whatman GF/F) to remove particulates, diluted with deionised water in a ratio of 3:1 methanol:water and injected into a Waters HPLC system. The solvent system (a modification of Wright *et al.* 1991) consisted of 2 solvent mixtures: (A) 10% water in acetonitrile, and (B) 100% ethyl acetate. These solvents were pumped in a linear gradient from 0% to 100% of solvent B in 30 min, followed by 5 min in solvent B. The solvents were run through a 250 mm x 4.6 mm Biosil C-18 HL 90-5S column (Biorad) at 1.5 ml min^{-1}.

The spectra and HPLC retention times of the various pigments were compared with those of pigments previously isolated from standard algal cultures (Burford *et al.* 1994). Phaeophytin and phaeophorbide were produced from chlorophyll a (Vernet and Lorenzen 1987). Peaks were identified by collecting them from the HPLC, evaporating the solvent and then redissolving the fractions in ethanol. The absorption spectra of the major peaks were obtained with a spectrophotometer.

Dry weights of sediment subsamples were obtained after oven-drying at 60°C for 24 hours.

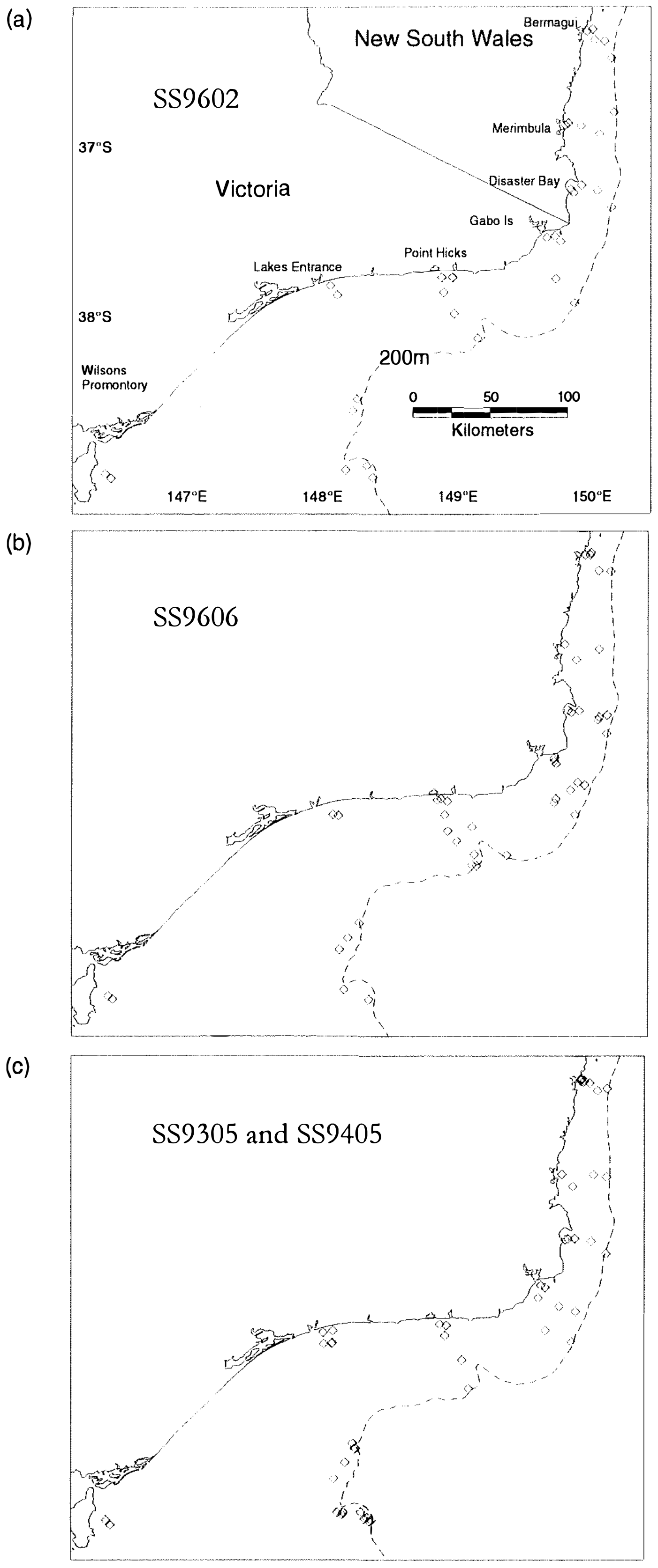


Figure 7.1.3.1 Map of study area showing sampling locations for sediment used in grain size and pigment analysis on a) SS9602, b) SS9606 and c) SS9304, SS9405.

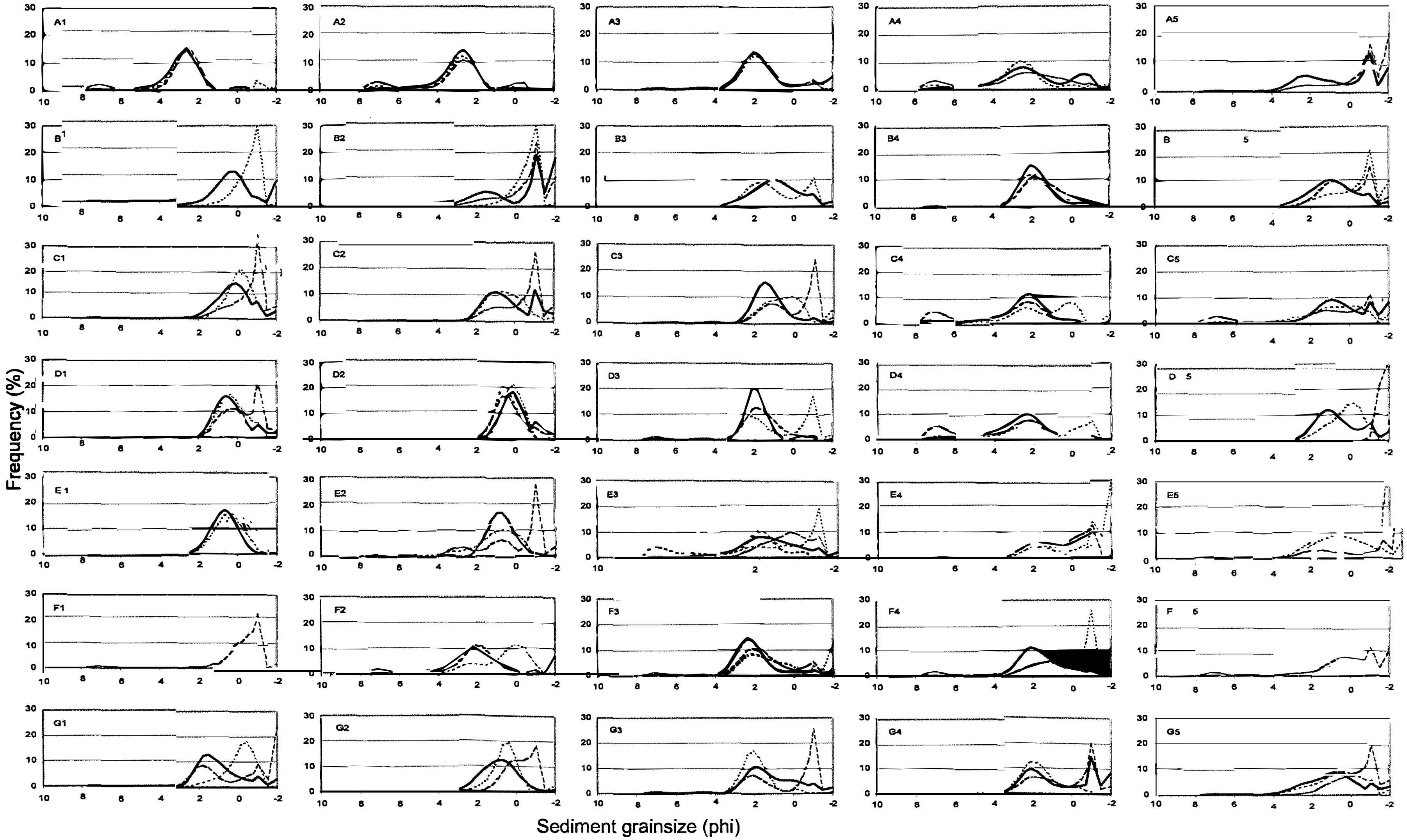


Figure 7.1.3.2 Grain size distribution of samples from different surveys used to determine samples that were winnowed and therefore to be excluded from further sampling. Solid line (SS9405), dashed line (SS9602), and dotted line (SS9606).

Stable isotope analysis

Sediments for stable isotope analysis were thawed, washed in distilled water (to remove salt), and dried. Samples for stable carbon analysis were soaked in 1M HCl overnight (to remove carbonate), rinsed several times until a neutral pH was attained, then dried.

Dried sediment was weighed into tin cups and analysed for stable carbon and stable nitrogen using methods detailed in *Section* 6.1.1, except that the analyses for carbon and nitrogen were performed separately for sediments.

Existing data

Marine geological surveys of Eastern Bass Strait (Jones and Davies 1983) and the southeast Australia continental shelf (Davies 1979) sampled sediments in 99 locations throughout the study area Fig 7.1.3.3. Data on the proportions of gravel, sand, and mud, $CaCO_3$, mean grain size and its standard deviation were taken from these reports and mapped.

Davies (1979) collected grab samples on an 18-km grid that included the northern section of our study area. The grab samples will have mixed sediments from the top 5-10 cm of bottom sediment. Samples were first wet-sieved into three fractions: greater than 2 mm (gravel); 2.0-0.062 mm (sand); and, less than 0.062 mm (mud). To increase grainsize resolution, gravel was sieved, sand was analysed using a settling tube, and mud was analysed by standard pipette analysis. The sample mean was determined by the method of moments, and inclusive graphic standard deviation was used as a measure of sorting (Folk 1974).

Jones and Davies (1983) obtained samples with a pipe dredge, or dredge of the chain-bag type with provision for retaining the fine fraction. Samples were processed using the same methods as Davies (1979).

The distribution of grainsizes depends to a large extent on present-day sediment transport and deposition. Other processes affecting grainsize distribution, especially the coarser fraction in shelf areas distant from land include presence of relict gravel, recent shells from the local benthic community, and concretionary or nodular material with authigenic components (Jones and Davies 1983).

Two sampling techniques were used in these published studies. Both the grab and pipe dredge samples integrate sediment from the top few centimetres of sediment. The pipe dredge also integrates sediments over tens of metres apart. This integration of sediments from different vertical strata or horizontal patches may cause sediments with distinct fine structure to appear poorly sorted.

7.1.4 Lithology and geomorphology

Rock samples collected opportunistically during the broad-scale and focussed habitat sampling permitted us to relate regional geomorphology to seafloor habitats based on comparison with our acoustic and sediment samples and the literature (e.g. Bernecker *et al.* 1997). Rock samples also permitted a geophysical description of some reef habitats sampled by video. Ten rock samples were slabbed and thin-section preparations made from off-cuts. Description and classification was based on colour, induration, dominant skeletal components, sorting and sedimentary structures.

7.1.5 Seabed photography

The requirements of our surveys off south-eastern Australia were to obtain high-resolution video and 35mm images to 200 m depth along transects up to 3 km in length. Relatively constant distance and aspect of the seabed relative to the cameras needed to be recorded for quantitative analysis. Because our study area was characterised by a variety of bottom topography including high-relief reef (~5 m rises), high current velocities and exposed open ocean conditions, existing systems did not meet our requirements. Diver surveys were not possible over the depth range and spatial extent of our study area and the available ROVs were unsuitable due to their limited ability in transecting, their requirement for a highly trained operator and the high cost of a motor able to work in strong currents. Sleds have been used successfully in both shallow and deep benthic surveys but cannot negotiate hard or rough bottom features without a high risk of damage or loss of the system (Holme and Barrett, 1977; Holme, 1985). As remote television systems on sleds require a multicore television cable and wire-to-depth ratios exceeding 2:1, a considerable length of expensive cable is required in shelf waters. The cable is subject to considerable strain and possible damage unless armoured, due to the weight and drag of the sled; this increases the cost and handling requirements (Holme, 1985).

Suspended camera systems, along with a variety of vehicles for towing cameras several metres above bottom, have an inherent difficulty in maintaining a constant height above bottom (Southward and Nicholson, 1985). Rough or undulating bottom topography, variable water clarity, illumination limitations, and pitch and roll of the ship may reduce the frame areas of photographs and cause resolution to vary substantially (Rosman and Boland, 1986; Boland and Lewbel, 1986). Consistently reliable results for surveys rely on keeping the camera at a constant altitude while the photographs are taken (Rosman and Boland, 1986). One solution is to attach a length of heavy chain to the underside of a slightly positively buoyant underwater platform. The chain and platform reach equilibrium as the chain settles on the bottom and can then be manoeuvred by means of remotely controlled thrusters (Barnes, 1963).

A novel camera platform, the Towed Automatically Compensated Observation System (TACOS), was designed as part of this project (Fig. 7.1.5.1). It was used successfully during surveys SS9602 and SS9606. Its design features include real-time video capability, operation at a constant height above bottom, ability to traverse a variety of bottom types including high-relief reef, and ability to calibrate the size of objects using lasers. It has considerable potential for mapping the habitat of the continental shelf, particularly where there is a need for quantitative data on the benthos of reef habitats.

The TACOS is a towed platform used to support two video cameras and flood lights, a 35 mm still camera and strobes, and ancillary equipment. We used a pan-and-tilt unit for camera direction, lasers for camera-to-subject distance estimation, a camera operation delay for deep deployments, and a between-frame interval controller for the 35 mm camera. Cameras, lights and ancillary equipment can be attached or removed from the platform with ease, to meet the specifications of individual surveys. The components and configuration of the TACOS are detailed in Barker et al. (1999).

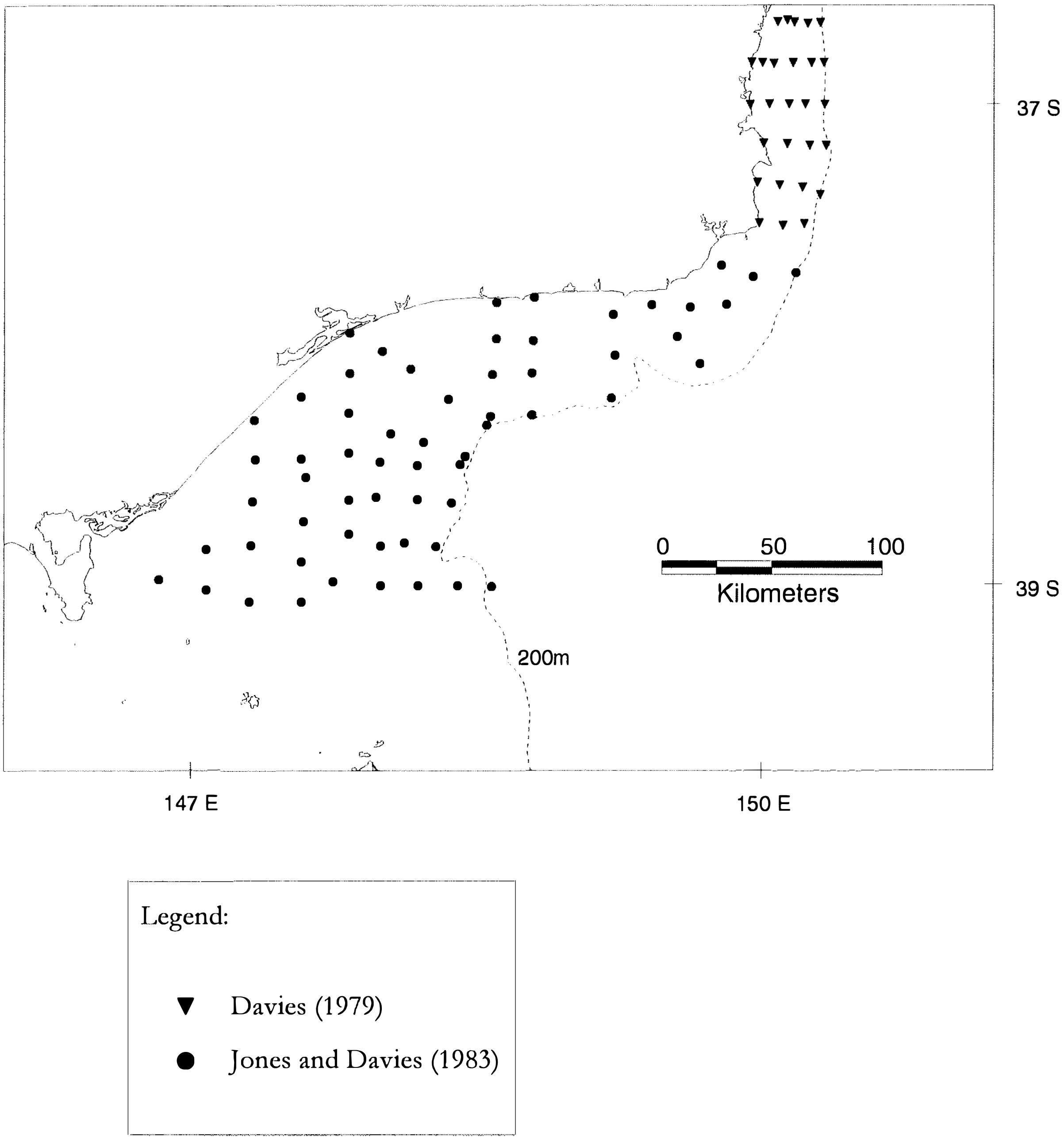


Figure 7.1.3.3 Map of study area showing locations where sediments were sampled by Davies (1979) and Jones and Davies (1983).

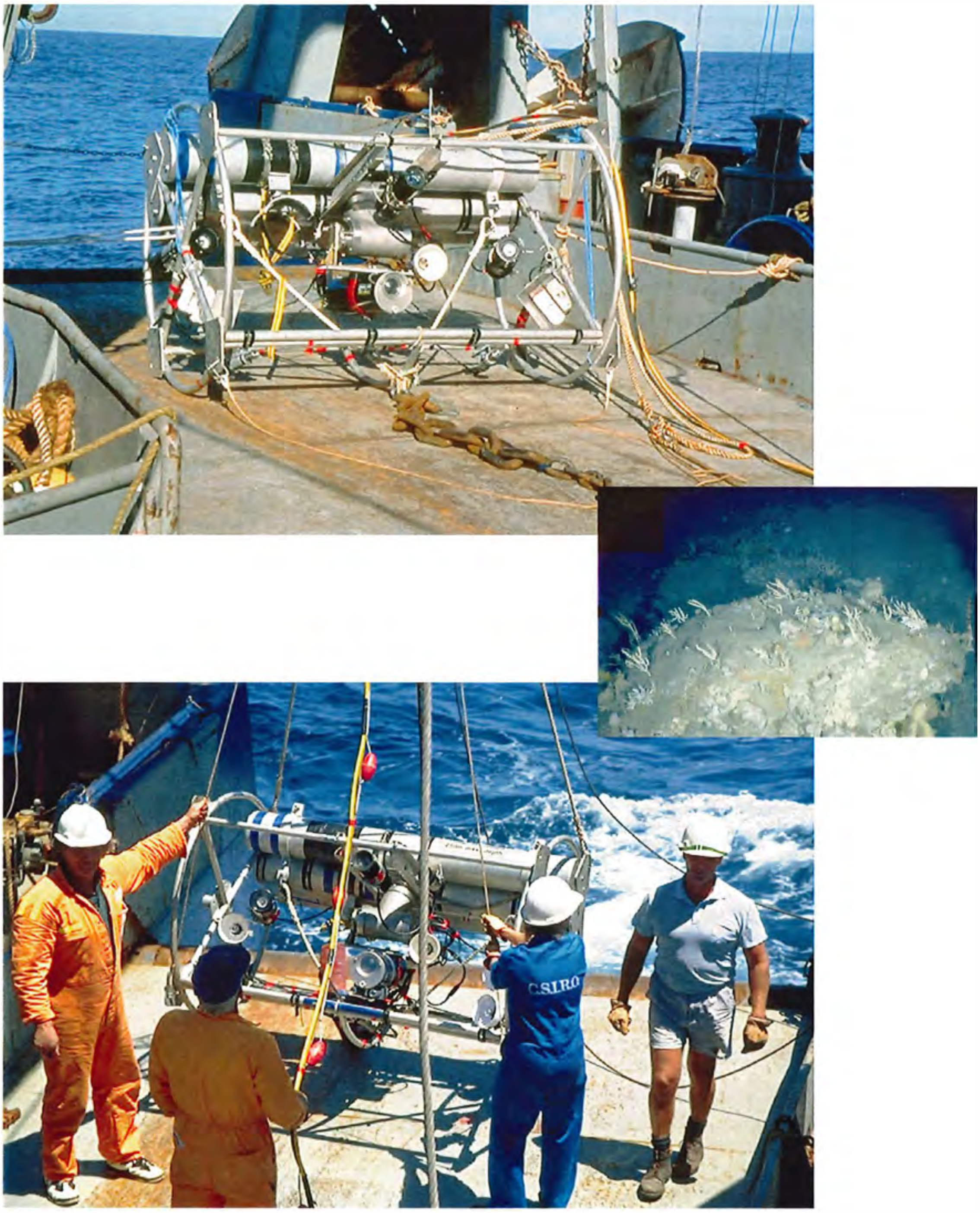


Figure 7.1.5.1 The towed camera array as developed and used in the benthic habitat surveys.

7.1.6 Broad-scale sites (‘soft-ground’ sediment flats)

A description of the geomorphology and epifauna at each of the 35 ‘soft-ground’ broad-scale sampling sites was made from photographic (35 mm and video) images. The attributes recorded were based on the scheme of Greene *et al.* (1994) in conjunction with a set of semi-quantitative qualifiers when appropriate (Fig. 7.1.6.1)

7.1.7 Focussed habitat sites (‘hard-grounds’ and adjacent areas)

Mesohabitats (areas measured in km and defined by physiography and depth) were subdivided into macrohabitats (areas measured in 100’s of m) based on indices of acoustic bottom hardness and roughness (*Section* 7.1.2).

Six study areas (the ‘primary mesohabitats’) were sampled at 17 sites (‘macrohabitats’) with a full range of gears (*Sections* 7.1.5; 8.1.1-8.2.3); another six (the ‘secondary mesohabitats’) were sampled with the towed camera array but with limited or no biological samplers. Descriptions of macrohabitats were based on the same set of attributes used to describe the broad-scale sites.

7.2 RESULTS AND DISCUSSION

7.2.1 Fishing grounds

The coarse-scale map of habitats constructed from the conjunction of information provided by the fishing industry (general substrate types and dominant invertebrates or fishes) and our early survey data (geomorphological descriptors and bathymetry) is shown in Fig. 7.2.1.1. This coarse-scale map facilitated the selection of mesohabitats, and the means to extrapolate the spatial extent of the mesohabitat types defined by our samples. Habitats at this scale are, to a large extent, synonymous with fishing grounds. A brief description of each key fishing ground, moving generally shallow to deep, west to east, is given below; full descriptions and the use of grounds by the commercial fishery are discussed in a later section (*Section* 11). Most of the names used are those of the local fishers.

‘Danish Seine grounds’

These are extensive sediment flats with low-relief sandstone/ fossiliferous reef structures (typically with a rise from flat bottom of about 1 m) in shallow regions of eastern Bass Strait.

‘South East Reef’

‘South East Reef’ is a relatively large isolated, inshore (< ~80 m), low-relief, sandstone/ limestone reef in eastern Bass Strait. It rises to some 10-15 m above the surrounding bottom at its highest point; its edges are mostly gently-shelving giving the appearance of a bank. It is the site for three oil rigs (Fortescue A, Halibut and Cobia A) and is a restricted trawl area.

Shelf-break trawl grounds

'Smithy's Corner' is a shelf-break region where flat, hard bottom drops sharply away to a bowl-shaped, more gradually sloping area of scattered broken ground. It marks the point at which one of the primary arms of the Bass Canyon opens to the shelf, and is close to the end of our transect A.

'10 x 10 Reef' is a similar 'hard bottom' shelf-break habitat south of the oil rigs near the end of Transect B. It is a north-south wall sloping down from 115 m into a basin-shaped canyon in 150 m.

'Little Horseshoe' is another of the key 'hard bottom' shelf-break grounds of eastern Bass Strait marking the opening of an arm of Bass Canyon.

'Broken Reef' complex

The 'Broken Reef' is an extensive area of hard, broken limestone and sandstone that outcrops from coarse sand between Pt. Hicks and New Zealand Star Banks.

6-Hour Reef forms the westernmost part of the Broken Reef complex and runs roughly east-west to the northwest of the 7-hour Bank (below)

'New Zealand Star Banks'

A massive, predominantly granite outcrop with debris fields, ledges and occasional intervening sand patches. Navigation charts note breaking waves in this area during conditions of large ocean swell.

'The Horseshoe'

It consists of the largest opening of the Bass Canyon onto the shelf and is bounded by a variety of substantial hard-grounds on the shelf. These run to the east and west (East Bank and West Bank), along its inner margins (particularly the west and north), and occupy areas directly inshore–the 7-hour Band and an area of associated broken-ground, and the 6-hour Reef. 7-Hour Bank is a productive 'hard bottom' trawl ground running NW-SE to the NW

'Sand Patch'

The 'Sand Patch', named after the adjacent Sand Patch Point, is an extensive deep area of generally flat bottom extending from the inside angle of the southernmost end of Gabo Reef around to the eastern perimeter of 'The Horseshoe'.

'Flower Patch'

The 'Flower Patch' is a name given to at least two different (but more or less contiguous) shelf-break areas of bryozoan-cemented hard-grounds characterised by stalked crinoids. This ground extends primarily from 'The Wall' to the eastern margin of 'The Horseshoe'. The second, smaller area is the western margin of 'The Horseshoe'; similar substrates also occur in scattered patches northwards and beyond the northern boundary of our study area, and at greater depths.

Habitat or station: name, no., location, depth and notes:

Video ID and count / film #
Echogram ref:
Page of

Gross morphology

Sediment
Bars
Banks
Channels
Crevices
Debris field
Ledges
Walls
Pinnacles
Slabs
Reefs
biogenic
nonbiogenic

Morphological modifiers

flat
regular
wavelength (use new scales)
amplitude (use new scales)
irregular (continuous, non-uniform)
hummocky (mounds/depressions)
structure (fractured/faulted)
friable
outcrop
bedding
massive

Bottom slope

flat (0-5°)
sloping (5-30°)
steep slope (30-45°)
vertical (45-90°)
overhang (>90°)

Rises/ drops (m)

pinnacles
walls
crevices

Roughness (1-5)
Hardness (1-5)

Notes (inc. estimated fractions of each)

Bottom texture

organic debris
mud (clay-silt)
sand (<2mm)
gravel (>2mm)
pebble (>10mm)
cobble (>64mm)
boulder (>256mm)
bedrock
igneous
metamorphic
sedimentary

Textural modifiers

sorting
packing
density
occasional
scattered
contiguous
pavement
lithification
jointing
rock roundness
rock shape

Bottom deposits

consolidation
not-
semi-
well-
erodability
uniform
differential
sediment cover
dusting (<1 cm)
thin (1-5 cm)
thick (>5 cm)

Process features

Physical

currents
winnowing
scouring
sediment trail
wave activity
upwelling
seismic

chemical
cementation
weathering
oxidation

Biological

bioturbation
tracks
trails
burrows
excavation
encrusters
continuous (>70%)
patchy (20-70%)
little to none (<20%)
communities

Communities

encrusting only
mollusc beds
ascidians
sea whips/sea pens
sponge gardens
crinoids
Maoricolpus

General 'quantities'

sparse (<25% cover)
intermediate (25-50% cover)
dense (>75% cover)
clumps
individuals

Misc features/ notes

trawl tracks
others.....

General 'quantities'

predominantly (>75%, many)
mostly (50-75%, several)
some (50-25%)
occasional (<25%, few)
intermittent

More notes

Fig. 7.1.6.1 Data sheet used for recording habitat attributes from seabed images; geomorphological features based on Greene et al. (1995).

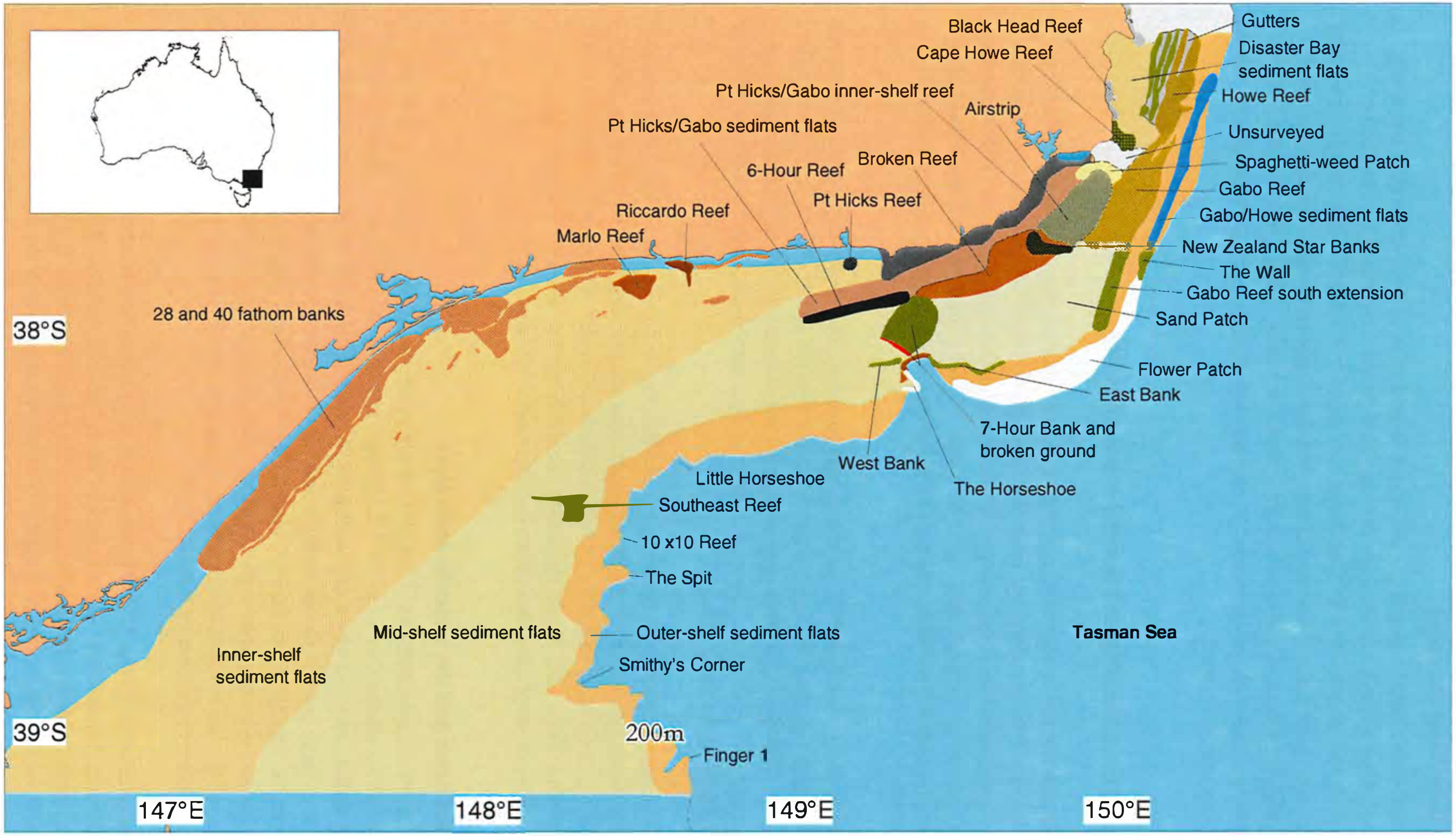


Figure 7.2.1.1 Map of coarse-scale seabed habitats on the southeastern SEF shelf region based on information supplied by the fishing industry and data from initial surveys.

'Howe Reef/ Gabo Reef' complex

The 'Howe Reef/ Gabo Reef' complex is the single largest tract of hard-ground in our study area and a key fishing ground, particularly for the Eden-based trawl fleet. It is formed of cemented, fossiliferous limestone reef that exists as a mosaic of variable size, mostly low-relief (< 3 m) patches along the inner (shoreward) margins and a generally more contiguous outer margin that is highly cemented and high relief (> 10 m) in places. 'Howe Reef' is the section north of Cape Howe and is mostly a mosaic of reef patches; 'Gabo Reef' is the southern section and is a relatively unbroken tract.

7.2.2 Acoustic characterisation of macrohabitats

Visual interpretation of the echograms (e.g. Fig. 7.2.2.1a) delineated the three macrohabitat types (Fig. 7.2.2.1b). This provided the basis for subsequent sampling. Delineation between rough and hard macrohabitats is quite distinct, but hard and soft macrohabitats are less distinct (especially on reproduced echograms). The distinction between hard and soft macrohabitats is better illustrated by plotting acoustic energy of the first bottom echo averaged over several pings (Fig. 7.2.2.2)

The two habitat indicators–E1 and E2, or rough and hard respectively–were computed from the stored digital data and plotted. The data were divided subjectively into 4 groups on the scatter plot (Fig. 7.2.2.3). These groups were then compared with the categories determined visually from the echogram (Fig. 7.2.2.1c). There was effectively a one-to-one correspondence between habitats determined by the two methods.

There was also a strong correlation between E1 and E2 (Fig. 7.2.2.3), indicating considerable overlap in the acoustic properties of the two indices. The longer length of the tail of the first bottom echo that is used as an indicator of rough habitat (E1), also results in a longer tail of the second bottom echo (Fig. 7.2.2.2). As the entire second bottom echo is used to estimate hardness (E2), it is not surprising that the two indices are correlated.

Operating conditions and the acoustic indicators

Acoustic data from the megahabitat (25 to 200 m) have been analysed to determine possible impacts of operating conditions on E1 and E2 (Kloser, unpublished data). No effects of ship direction, ship speed (up to 12 knots depending on weather), ship track (straight or curved) were found. There was linear correlation of both E1 and E2 with depth. It was necessary to correct the data for even the narrow depth range within a mesohabitat (e.g. 40–60 m) by adjusting for sound absorption and one way spherical spreading loses. E1 was further standardised by shifting the depth range of the tail integration according to depth to ensure that a similar off axis angular section was integrated regardless of bottom depth.

Acoustic data collected from the 120 kHz transducer with a RoxAnn bottom-typing package were analysed to determine depth dependency of the E1 and E2 indices. Both indices increased markedly with depth (Kloser , unpublished data). The roughness index (E1) reached a maximum at 130 m–all bottom types at depths beyond this were given the maximum E1 value. The hardness indicator (E2) reached a maximum at 70 m. Thus the depth corrections applied to the EK-500 data to account for the natural properties of acoustic wave propagation in aquatic environments did not get applied within the RoxAnn package tested. A correction for this depth correlation either by equipment setup during data collection or by post processing of data is required if these data are to provide comparison of habitat types over a wide depth range. No useful data can be retrieved once the maximum has occurred.

Maps of hardness and roughness from the stored acoustic data overlaid on the fishers' observations for the Black Head and adjacent Disaster Bay mesohabitats generally showed a good level of correspondence (e.g. Fig. 7.2.2.4). All features described by the fishers' were present, but fine scale detail was not always accurate. A failing of the acoustic maps of hardness and roughness is illustrated by the by the elongate lines of 'finger reef' (as reported by fishers) at the top of the plots, that do not match up with the 'patchy reef' detected as acoustic hardness and roughness. A video survey of the area showed that the gutters between the finger reefs were filled with gravel patches and these returned a more intense signal than the sediment covered reef and were interpreted initially as patchy reef.

Locations of benthic sled, trawl, gillnet and trap transects were overlaid on the contoured roughness and hardness indices and average (and SD) roughness and hardness for each transect determined (*Section* 8). There was a gradual increase in roughness and hardness with our visually-determined, habitat delineations of 'soft', 'hard' and 'rough'. The lower value of hardness for the gillnet transect in the rough compared to the hard macrohabitat, may be due to increased scattering, and therefore decreased normal reflection, of acoustic energy in rough habitats (Kloser, unpublished data).

7.2.3 Sediment composition and distribution

Survey data

Grainsize

Mean grain size showed a patchy distribution (Fig. 7.2.3.1). The relationship between grain size and depth showed a weak negative correlation ($r = -0.05$, $p = 0.5829$, $n = 116$) (Table 7.2.3.1). Mid-shelf sites often had finer sediments than sites inshore and offshore.

There were significant and strong relationships between grain size and the amount of organic matter in the sediment for two surveys: SS9405 and SS9602 ($r = 0.73$, $p < 0.0001$, $n = 35$; $r = 0.71$, $p < 0.0001$, $n = 41$ respectively). For survey SS9606, the pattern was similar, but the relationship weaker: $r = 0.39$, $p = 0.011$, $n = 41$. Finer sediments contained more organic matter.

Carbonate

The most consistent depth-related trend for all measured sediment characteristics was the strong correlation ($r = 0.72$, $p < 0.0001$, $n = 96$) between depth and the amount of carbonate in the sediment (Fig. 7.2.3.2). Inshore sites had as little as 1.2% carbonate and outer-shelf samples (> 200 m) contained up to 97.1% carbonate. The results for survey SS9606 show consistently lower carbonate results. We suspect that this is due to incomplete carbonate removal in the laboratory, as the elemental analysis of carbon during stable isotope analyses indicate the presence of carbonate in these samples.

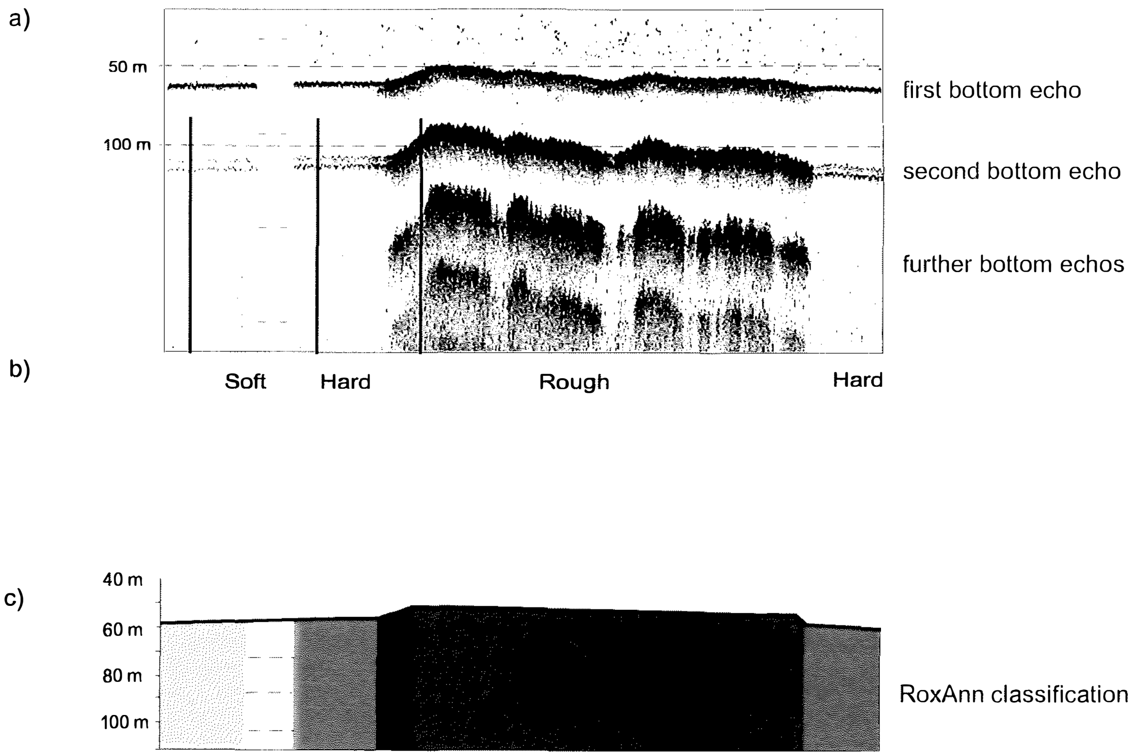


Figure 7.2.2.1 Habitat delineation of the Black Head mesohabitats along one transect, showing a) the echogram, b) real time classification and c) a posterior classification using "RoxAnn-type" hardness and roughness indicies.

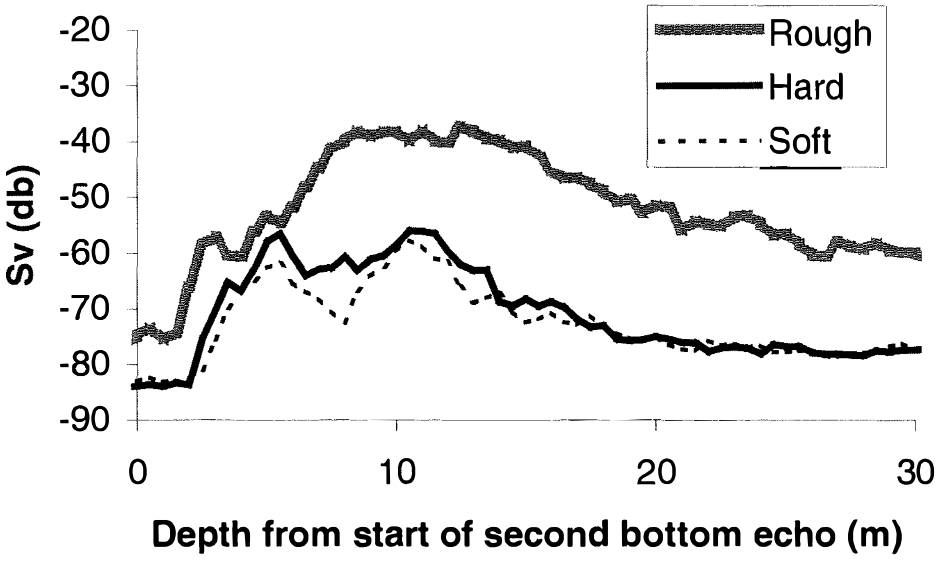


Figure 7.2.2.2 Average acoustic back scattering energy of the second bottom echo from 10 pings in the soft, hard and rough habitats of fig. 7.2.2.1. The samples are shown by the narrow vertical lines across the second bottom echo in that figure.

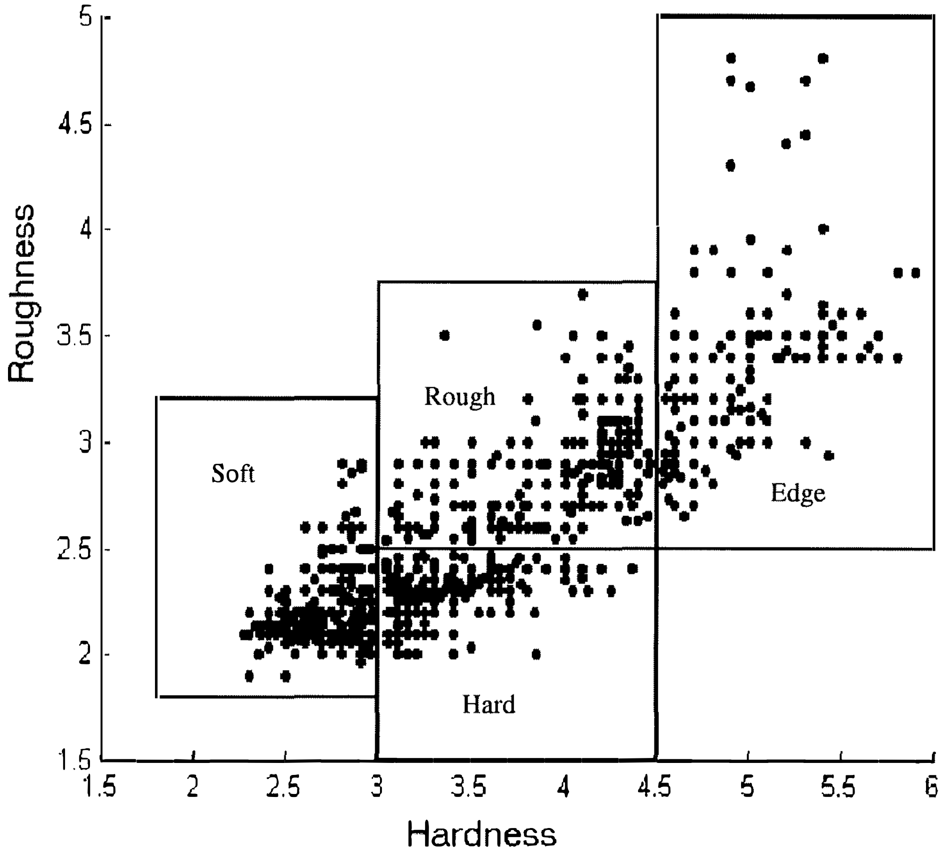


Figure 7.2.2.3 Scatterplot of "RoxAnn-type" roughness (E1) and hardness (E2) indicators and arbitary division of paired indices space into habitat types.

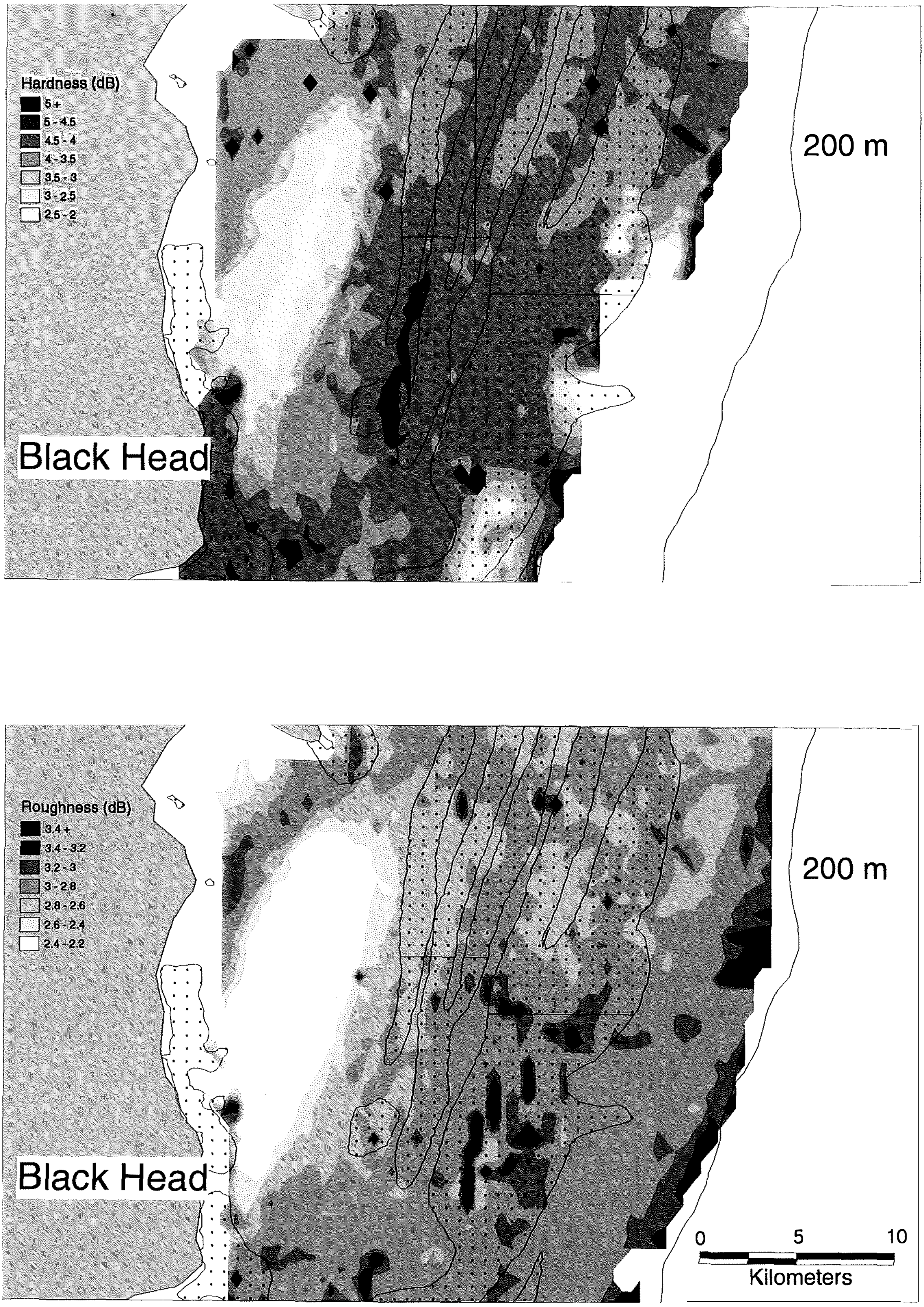


Figure 7.2.2.4 Acoustically-defined hardness (top) and roughness (bottom) indices with fishers' observations of hard and rough areas overlaid.

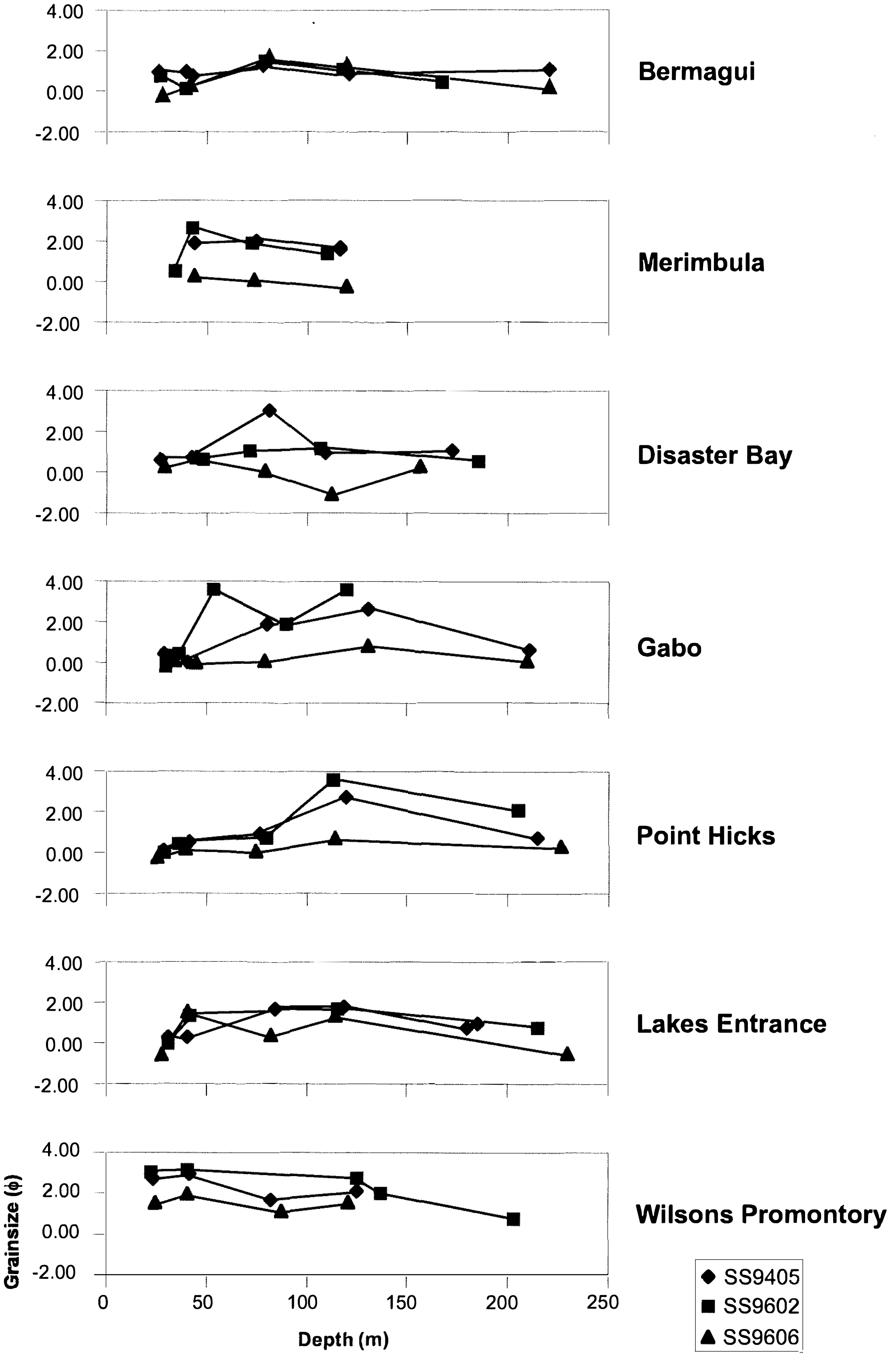


Figure 7.2.3.1 Cross-shelf sediment grainsize distribution (phi units) by transect (north to south) on the south east Australian shelf (surveys SS9405, SS9602, SS9606).

Table 7.2.3.1 Correlations between sediment characteristics for three surveys on the southeast Australian shelf (S9405, SS9602, SS9606). Most samples were from transect sites; others from the focussed habitat survey.

	Depth (m)	Latitude	Grain size	% Org	Chl *a* (ug/g)	Pbide (ug/g)	Pbide: Chl	% CO3	δ13C	δ15N
Depth (m)	1									
Latitude	0.14	1								
Grainsize	-0.05	0.20	1							
% Organic	0.51	0.31	0.29	1						
Chl a (ug/g)	-0.50	-0.08	0.07	-0.24	1					
Pbide (ug/g)	-0.28	-0.02	0.33	0.11	0.44	1				
Pbide:Chl	0.36	-0.06	0.38	0.42	-0.17	0.78	1			
% CO3	0.72	0.29	0.39	0.62	-0.21	0.09	0.27	1		
d13C	0.48	0.14	0.22	0.56	-0.20	0.02	0.18	0.55	1	
d15N	0.63	0.12	-0.16	0.27	-0.51	-0.29	0.03	0.43	0.28	1

Chl *a* = Chlorophyll *a*
Pbide = Phaeophorbide
% Org = % Organic Matter
% CO3 = % Carbonate
Grainsize in phi units

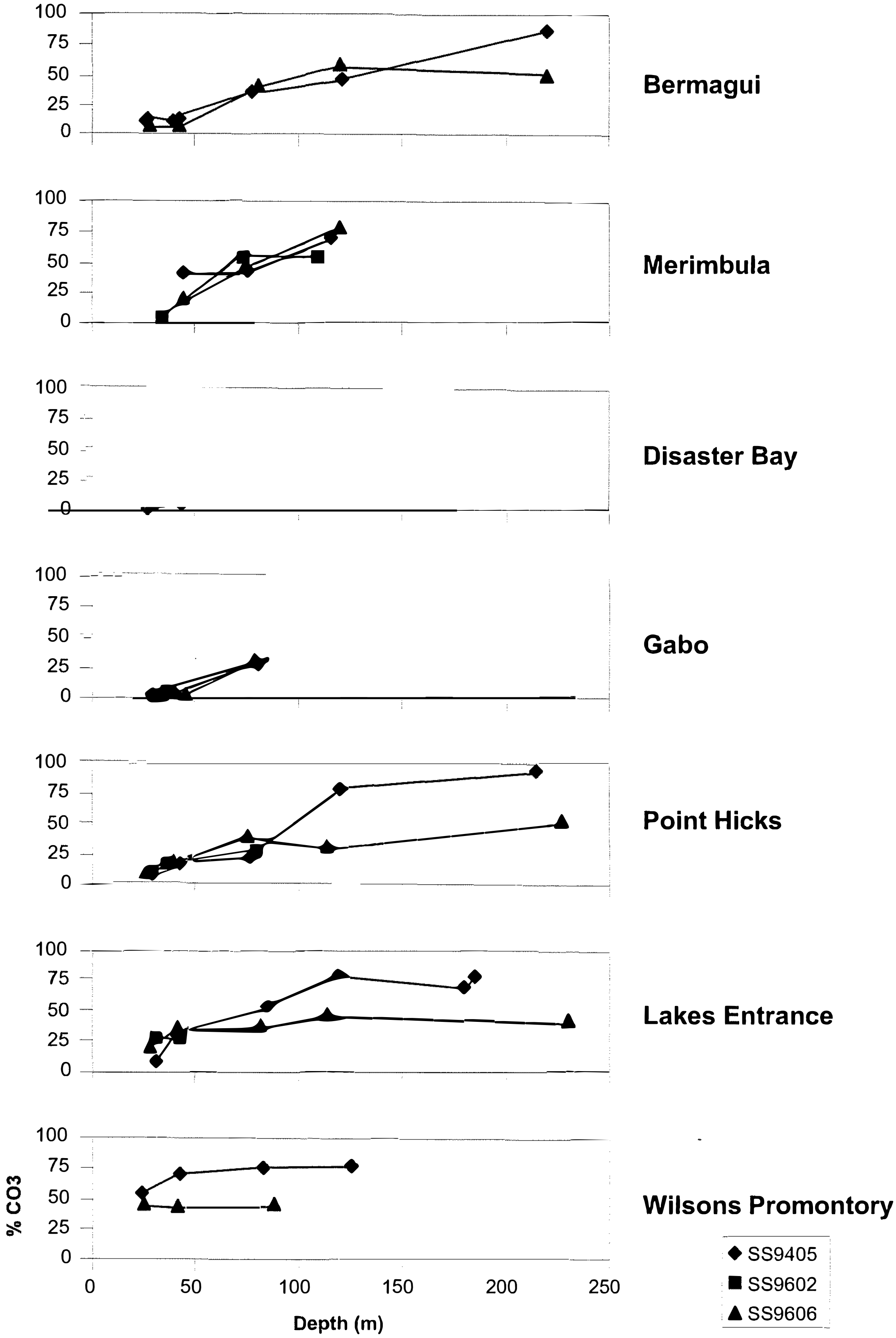


Figure 7.2.3.2 Percentage of carbonate in shelf sediments off south eastern Australia by cross-shelf transect. Transects arranged north to south down the page.

There was a strong relationship between carbonate and organic matter ($r = 0.62$, $p < 0.0001$, $n = 95$): sites with high levels of carbonate had higher levels of organic matter. The relationship between carbonate and $\delta^{13}C$ in the sediments was strong ($r = 0.55$, $p < 0.0001$, $n = 94$) and there was a weaker relationship between carbonate and $\delta^{15}N$ ($r = 0.43$, $p < 0.0001$, $n = 97$).

Organic content

The amount of organic matter in the sediment increased with depth ($r = 0.51$, $p < 0.0001$, $n = 117$). Inshore sites had as little as 0.2% organic matter in the sediment. The highest level of organic matter (5.3%) was found at the 40 m site on the Lakes Entrance transect during survey SS9606, but in general, the highest levels of organic matter on each transect were found at the 120 or 200 m site.

Sediment samples collected on survey SS9606 had higher levels of organic matter than the other 2 surveys ($p = 0.0000$) (Fig. 7.2.3.3). This difference could be explained by the fact that surveys SS9405 and SS9602 were analysed by one lab, SS9606 by another. An alternative explanation, that this survey took place in early summer and there was more organic material in the sediments during survey SS9606 (November-December 1996) due to algal fall-out from recent spring blooms, was not borne out by the sediment pigment results.

Organic matter and stable carbon were strongly related ($r = 0.56$, $p < 0.0001$, $n = 92$): values for both characteristics increasing with increasing depth.

Pigments

Pigment results were available for sediments collected on surveys SS9405 (August-September 1994), SS9602 (April-May 1996) and SS9606 (November-December 1996). The diversity of pigments in the upper water column was not reflected in the sediments. Chromatogram results for the three surveys showed the main pigments in the sediments off south eastern Australia (Appendix Table 7.2.3.1, Table 7.2.3.2) to be chlorophyll *a*, phaeophorbide *a* and other phaeophorbide *a*-like pigments. Other pigments may have been present, but masked by the presence of phaeophorbides. Chlorophyll *a* in the sediment indicates the presence of fresh algal material: autotrophic benthic algae and settling of phytoplankton and faecal pellets from the water column. Phaeophorbide *a* is a breakdown product of chlorophyll *a* through metazoan grazing.

The mean value of chlorophyll *a* in sediments sampled on the south east Australian shelf (25–220 m depth) over all surveys was 0.16 µg/g (range 0–0.85 µg/g). Concentrations of both chlorophyll *a* and phaeophorbides were higher for survey SS9405 than the other two surveys ($p = 0.0003$, $n = 133$) which were similar: not an unexpected finding since survey SS9405 coincided with the annual spring phytoplankton bloom. These annual spring blooms provide a burst of organic material to the water column, and hence to the seafloor where much of this material becomes organic detritus.

There was a significant negative correlation between chlorophyll *a* and depth ($r = -0.5$, $p < 0.0001$, $n = 125$). For each survey, the highest concentrations on each transect were usually at the 25 or 40 m site and chlorophyll *a* rarely occurred deeper than 150 metres (Figs. 7.2.3.4 and 7.2.3.5). Chlorophyll *a* was found to greater depths during Survey SS9405 (usually to >100m on all transects except Merimbula (F)) than during the other two surveys. The mean chlorophyll *a* concentration at each site for Survey SS9405 (0.27 µg/kg), was more than twice that for the other two surveys, although the range of values was similar for each survey (Table 7.2.3.2).

The chlorophyll degradation products in sediment samples from the south east Australian shelf were almost entirely phaeophorbides. The mean phaeophorbide value in sediments, across all surveys, was 5.2 μg/g (range 0–66.1 μg/g). There was some consistency in which site had the greatest phaeophorbide concentration on any transect (Fig. 7.2.3.6): on the Wilson's Promontory transect, it was at the 25 m site on every survey; and on the Lakes Entrance transect at 40 m on every survey. Little phaeophorbide, like chlorophyll *a*, was found in sediments deeper than 150 m on most transects (Figs. 7.2.3.5 and 7.2.3.6). There was a significant negative correlation between phaeophorbides in the sediments and depth ($r = -0.28$, $p = 0.0018$, $n = 125$).

The mean and range of phaeophorbide concentrations in the sediments for survey SS9405 were much greater than for the other surveys (Table 7.2.3.2).

The distribution pattern of pigment ratios chlorophyll *a*:chlorophyll *a* + phaeophorbide in shelf sediments over three surveys are shown in Figs. 7.2.3.5 and 7.2.3.7. High values indicate a high proportion of fresh (chlorophyll *a*) to degraded (phaeophorbides) material. Ratios were higher at inshore than offshore stations. This ratio was much higher in sediments collected on survey SS9405 than on the other two surveys (Table 7.2.3.2).

Stable isotopes

Complete sets of results from surveys SS9405 and SS9606, and a partial set of results from survey SS9602, were available for analysis. Discussion of survey SS9602 is treated in less detail as sediments on this survey were mostly collected by grab, and there may have been some winnowing of sediments.

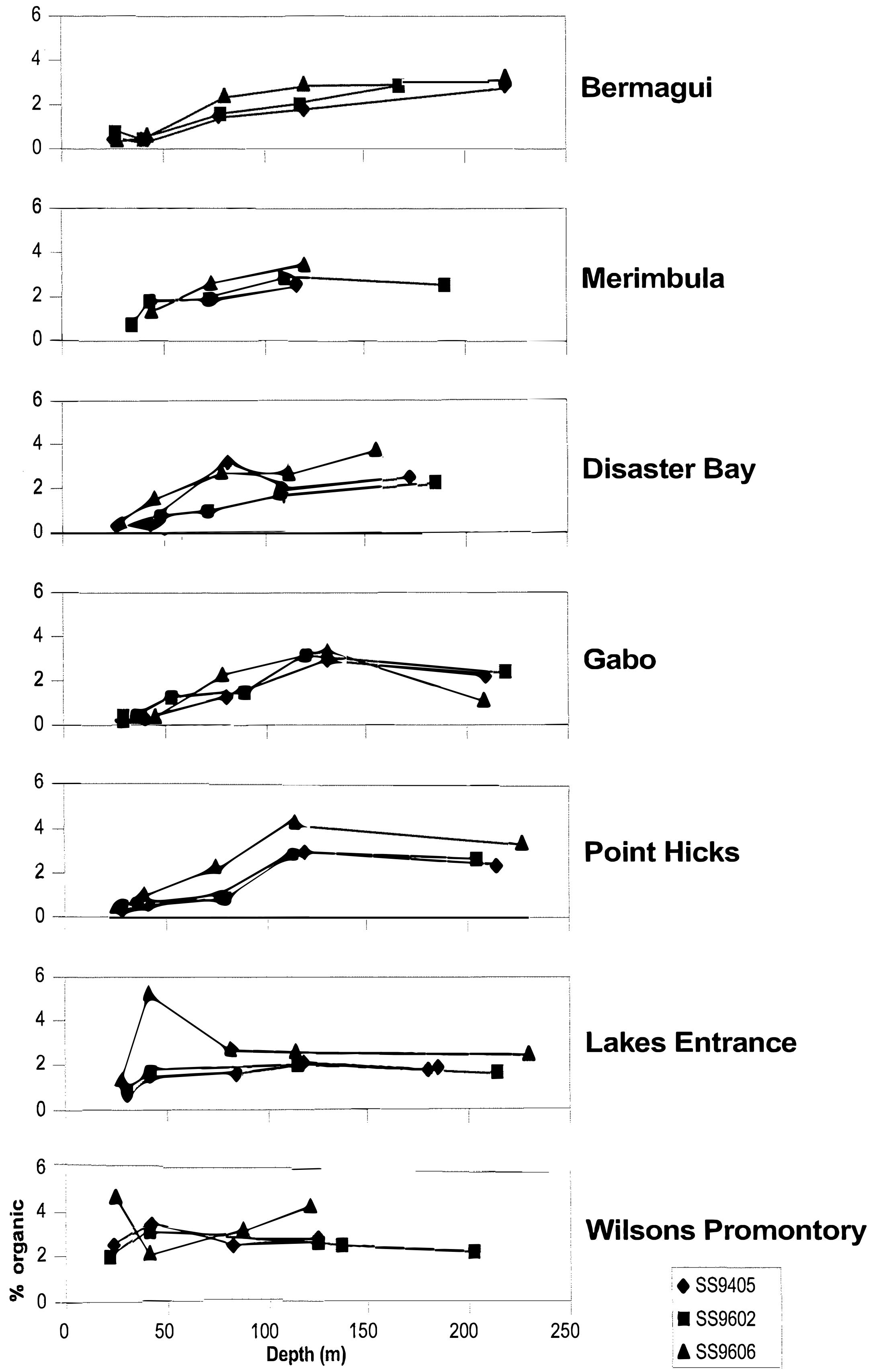


Figure 7.2.3.3 Percentage of organic matter in shelf sediments off south eastern Australia by cross-shelf transect.

Table 7.2.3.2 The main pigments (μg/g) in sediments on the continental shelf off south eastern Australia during surveys SS9405, SS9602 and SS9606 (mean ± SD, range, number in sample).

Survey	Time of year	Chlorophyll *a*	Phaeophorbides	chl *a* / (chl *a* + phbide)
SS9405	August–September	0.27 ± 0.23 0.00 – 0.84 (46)	9.55 ± 14.43 0.00 – 66.09 (46)	0.1860 ± 0.3472 (27)
SS9602	April–May	0.10 ± 0.17 0.00 – 0.85 (42)	2.17 ± 2.47 0.00 – 8.27 (42)	0.0626 ± 0.1759 (32)
SS9606	November–December	0.11 ± 0.19 0.00 – 0.81 (41)	3.15 ± 5.18 0.00 – 31.94 (41)	0.0624 ± 0.1805 (30)
Overall		0.16 ± 0.21 0.00 – 0.85 (133)	5.22 ± 9.68 0.00 – 66.09 (133)	0.0999 ± 0.2460 (89)

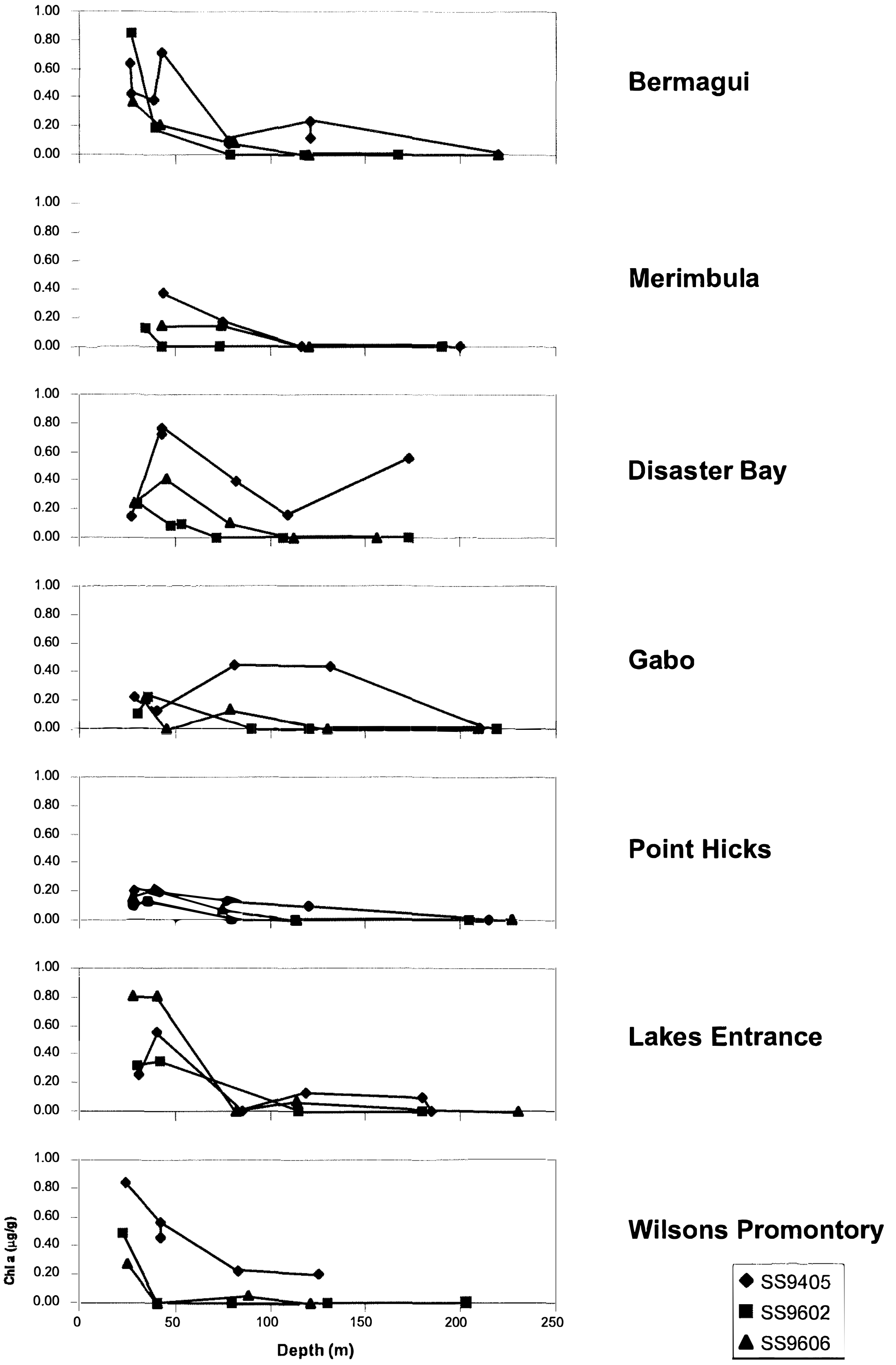
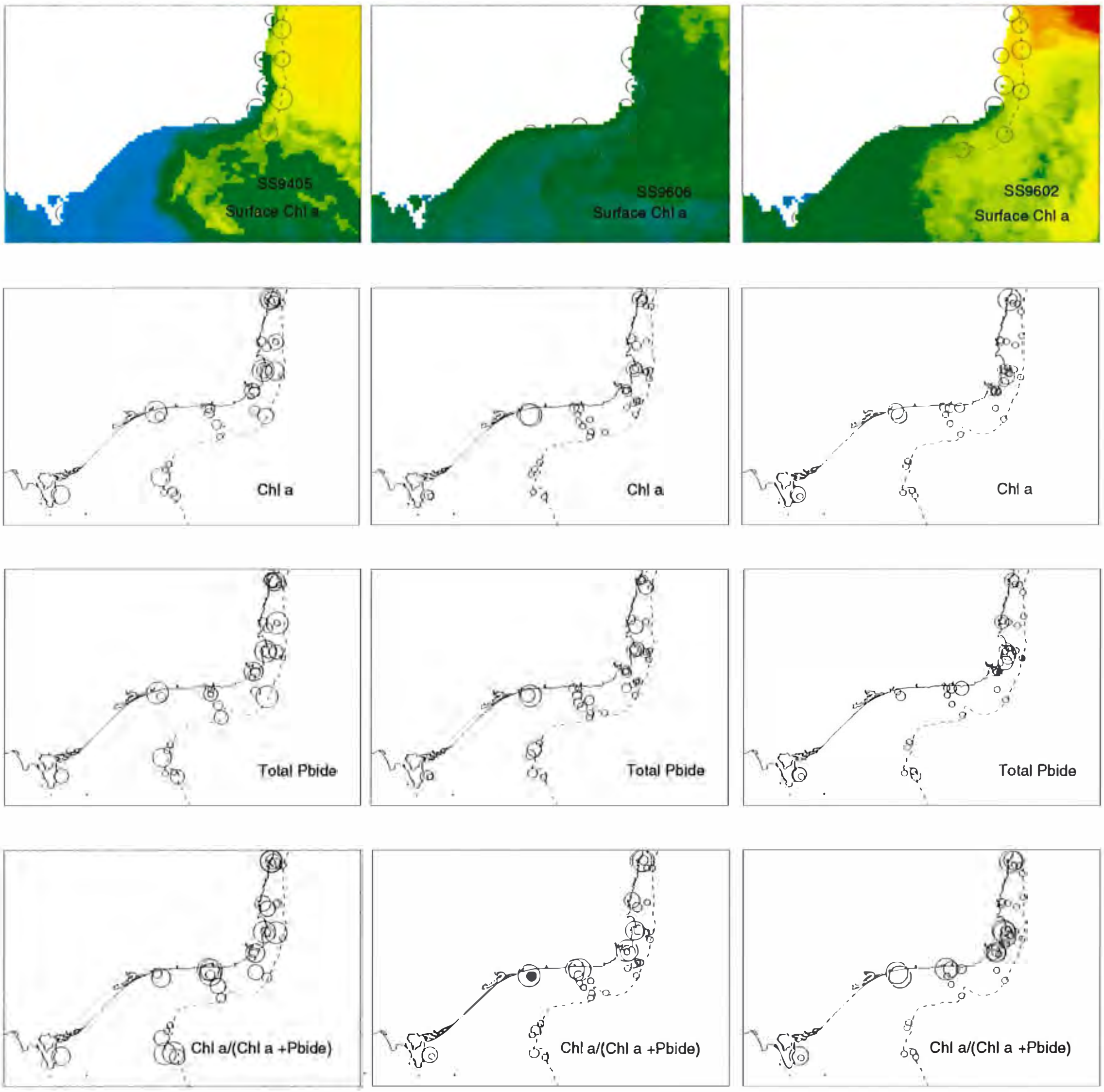


Figure 7.2.3.4 Chlorophyll a in sediments on the south east Australian shelf, by cross-shelf transect, during Surveys SS9405 (August-September 1994), SS9602 (April-May 1996) and SS9606 (November-December 1996).



Surface Chl a (ng/l)	Sediment Chl a (ppm)	Phaeophorbides (ppm)	Chl a/Total pigments (ug/l)
○ 1,000 to 1,500	○ 0.7 to 2	○ 20 to 50	○ 0.07 to 1
○ 600 to 1,000	○ 0.5 to 0.7	○ 10 to 20	○ 0.06 to 0.07
○ 300 to 600	○ 0.3 to 0.5	○ 5 to 10	○ 0.03 to 0.06
○ 100 to 300	○ 0.1 to 0.3	○ 2 to 5	○ 0.01 to 0.03
	○ 0 to 0.1	○ 0 to 2	• 0 to 0.01

Figure 7.2.3.5 Chlorophyll in water column and sediments; phaeophorbides and chlorophyll to phaeophorbide ratios in sediments on the south east Australian shelf.

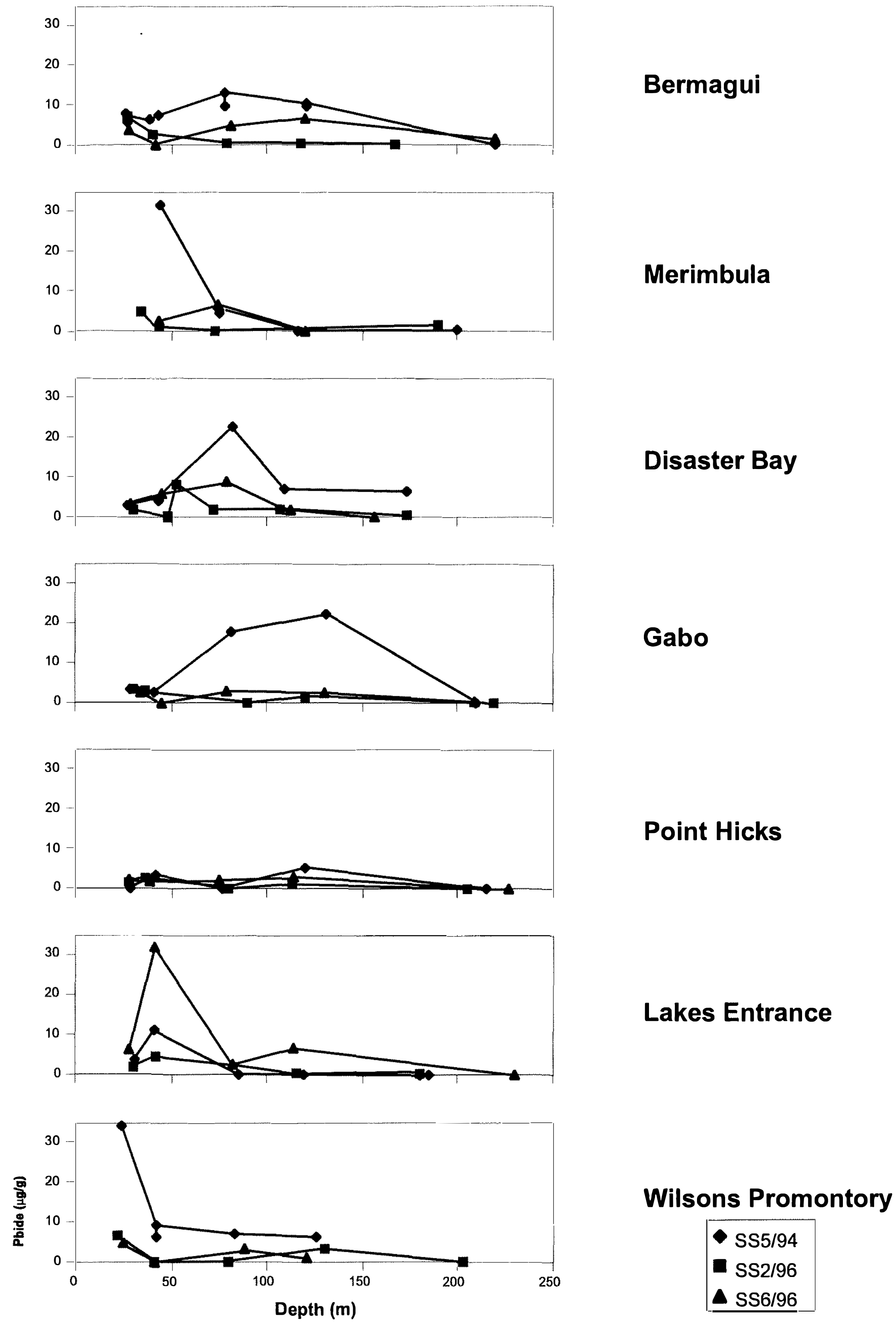


Figure 7.2.3.6 Phaeophorbides in sediments on the south east Australian shelf, by cross-shelf transect, during Surveys SS9405 (August-September 1994), SS9602 (April-May 1996), SS9606 (November-December 1996).

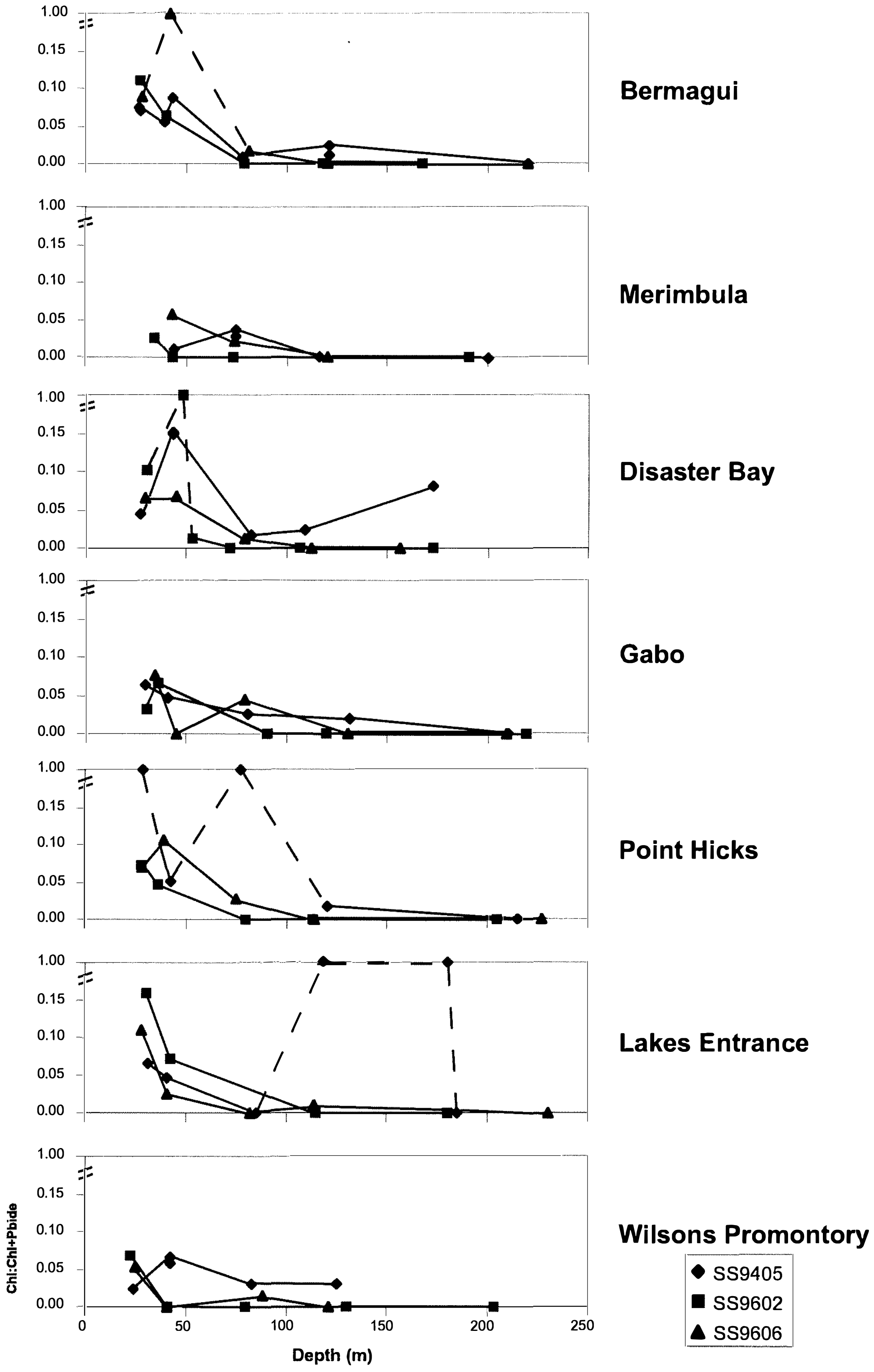


Figure 7.2.3.7 Ratio of chlorophyll to chlorophyll + phaeophorbides in SEF sediments by cross-shelf transect for surveys SS9405 (August-September1994), SS9602 (April-May 1996) and SS9606 (November-December 1996).

Stable carbon

Most sediment $\delta^{13}C$ values in this study reflect those of temperate marine phytoplankton and POC in offshore food webs: –25 to –18 ‰ (Fry & Sherr 1984 review). The mean $\delta^{13}C$ value in the sediments off south eastern Australia was –21.9 ± 1.34 ‰, range –27.9 to –19.3 ‰, $n = 80$ (surveys SS9405 + SS9606): typical values for marine sediments (Boutton 1991). Sediment $\delta^{13}C$ values reflected those of whole phytoplankton (mean $\delta^{13}C$ –20.5 ± 0.9 ‰, $n = 4$: samples from SS9405 spring bloom) and POM in the water column (mean $\delta^{13}C$ –21.5 ± 1.8 ‰, $n = 91$: surveys SS9305, SS9402, SS9405, SS9602 + SS9606).

Most transects on survey SS9405 and all transects on survey SS9606 showed a trend for seaward enrichment in $\delta^{13}C$ values (Fig. 7.2.3.8). Although there was no overall difference between the 3 surveys in the mean value of $\delta^{13}C$ in the sediments ($p = 0.52$, $n = 102$), there were differences in the relationship between $\delta^{13}C$ and depth. For surveys SS9405 and SS9606, the $\delta^{13}C$ became more enriched with depth ($r = 0.65$, $p < 0.0001$, $n = 36$; $r = 0.53$, $p = 0.0004$, $n = 39$ respectively) (Fig. 7.2.3.9); but the relationship was not significant in sediments collected during SS9602 ($r = 0.36$, $p = 0.1507$, $n = 18$).

Stable nitrogen

The mean $\delta^{15}N$ for south east Australian shelf sediments was 7.1 ± 0.9 ‰ (Table 7.2.3.2). The difference in the mean value of $\delta^{15}N$ in the sediments between the 3 surveys was not statistically significant ($p = 0.20$, $n = 101$). Most samples reflect the values for marine phytoplankton in the region. The mean $\delta^{15}N$ of water column POM from five SEF surveys (SS9305, SS9402, SS9405, SS9602, SS9606) was 6.1 ± 2.5 ‰ (range 2.3 to 18.2 ‰, $n = 81$) and for whole phytoplankton from the SS9405 spring bloom was 6.2 ± 2.3 ‰ ($n = 4$).

There was a seaward increase in $\delta^{15}N$ values in sediments across the shelf from 5–7 ‰ at inshore sites (25–40 m) to 7–9 ‰ at offshore sites (about 200 m) (Fig. 7.2.3.8). The seaward enrichment in stable nitrogen was significant for sediments collected during SS9405 ($r = 0.71$, $p < 0.0001$, $n = 36$) and SS9606 ($r = 0.75$, $p < 0.0001$, $n = 41$); but the relationship was less apparent in sediments collected during SS9602 ($r = 0.40$, $p = 0.0891$, $n = 19$).

There were no latitudinal effects detected with either stable carbon or stable nitrogen values in sediments.

Existing data

Sedimentation on Australian continental shelf reflects the continent's history of stability and relative aridity since the Oligocene: Australia is the driest continent and has low relief (Blom and Alsop 1988). Carbonate production has been little diluted by terrigenous input, even in Tasmania, where modern sediments are trapped in estuaries of the major rivers. Although modern sea level is considered to have prevailed for some 6,000 years, current sea levels are at least 67 m higher than prior to the last glacial regression, when Bass Basin was a shallow marine embayment (Blom and Alsop 1988).

Jones and Davies (1983) concluded that sand and gravel were characteristic of the entire study region south of Cape Howe, although finer scale patterns are evident from, maps of the proportions of mud, sand and gravel and the mean grain size (Fig. 7.2.3.10). Reverse-sorting (coarser grains seaward) is the regional pattern (up to Jervis Bay) with fine sand dominant along the inner-shelf, medium-grained sand further seaward and locally coarse sand or, less frequently gravel, at the shelf-break. This pattern is disrupted in the study area by several extensive areas of very fine sand and mud – one is offshore from Lakes Entrance and the others are close to the shelf-break, especially in areas such as the 'Horseshoe' situated at the head of an arm of the Bass Canyon. Much of the sediments in the area is poorly sorted (standard deviation more than 1.0 phi). This is due to the mixed origins of the sediments that derive from modern terrigenous sediment, relict sediment and reworked material.

It is necessary to understand the origins of the sediments before it is possible to infer the processes that led to its current distribution. The modern benthos is related more-or-less intimately to existing water depth, physio-chemical conditions, and the substrate, but its skeletal remains are texturally unconnected to the environment until equilibrium by sorting is reached. It is usually not practical to identify and remove the modern benthos to leave the equilibrated sediments: carbon dating of fresh-looking shells from the east Australian shelf has shown that they may date to the early Holocene. It is also not easy to distinguish between relict and modern sediments (Jones and Davies 1983). Five sediment types have been described (Fig. 7.2.3.11), although their boundaries are often not distinct–for example, there is continuous gradient between the mid- and outer-shelf fine-grained shelly sands and the shelf-edge gravels. There is also finer scale variability within the sediment types–for example, George and Black (1989) analysed 60 nearshore samples between 148° and 149°E and found a seaward gradient from coarse to medium sand, with infrequent outcrops of very coarse sand and granules.

Inner shelf quartoze sands

The well to medium sorted quartoze sands of the inner-shelf are modern and more-or-less in equilibrium with present conditions. They are dominantly unimodal suggesting a single transporting mechanism, and the carbonate component consists of fresh comminuted shell debris. They represent the sand sheet laid down during and after the postglacial marine transgression, and were probably mainly derived from outer-shelf Pleistocene beach and near-shore quartoze barrier sands.

Outer-shelf fine-grained shelly sands

Offshore of the inner-shelf quartoze sands, are poorly-sorted, slightly quartoze, fine shelly sands in which relict and modern components are present in about equal proportions. They vary greatly in textural characteristics but always contain some quartz and are nearly always polymodal with a mixed faunal assemblage that includes both modern and relict components. These sands are poorly sorted and the evidence is that they are transitional in nature, the better-sorted sampled approaching equilibrium with the present-day environment. On Australia's eastern continental shelf, south of 24°S, Foraminifera, Mollusca, Bryozoa and calcareous red algae constitute the skeletal carbonate component of outer-shelf sands; between 38° and 44°S, bryozoans become the dominant constituent of outer-shelf sands commonly exceeding 60% of overall composition (Marshall and Davies 1978). The abundance of Bryozoa on the outer-shelf in these southern latitudes is possible related to the upwelling of nutrient-rich, intermediate Antarctic water along the southern shelf (Wass *et al.* 1970). Marshall and Davies (1978) describe "forests of living Bryozoa" on the outer-shelf that continually add to the surrounding relict sediments.

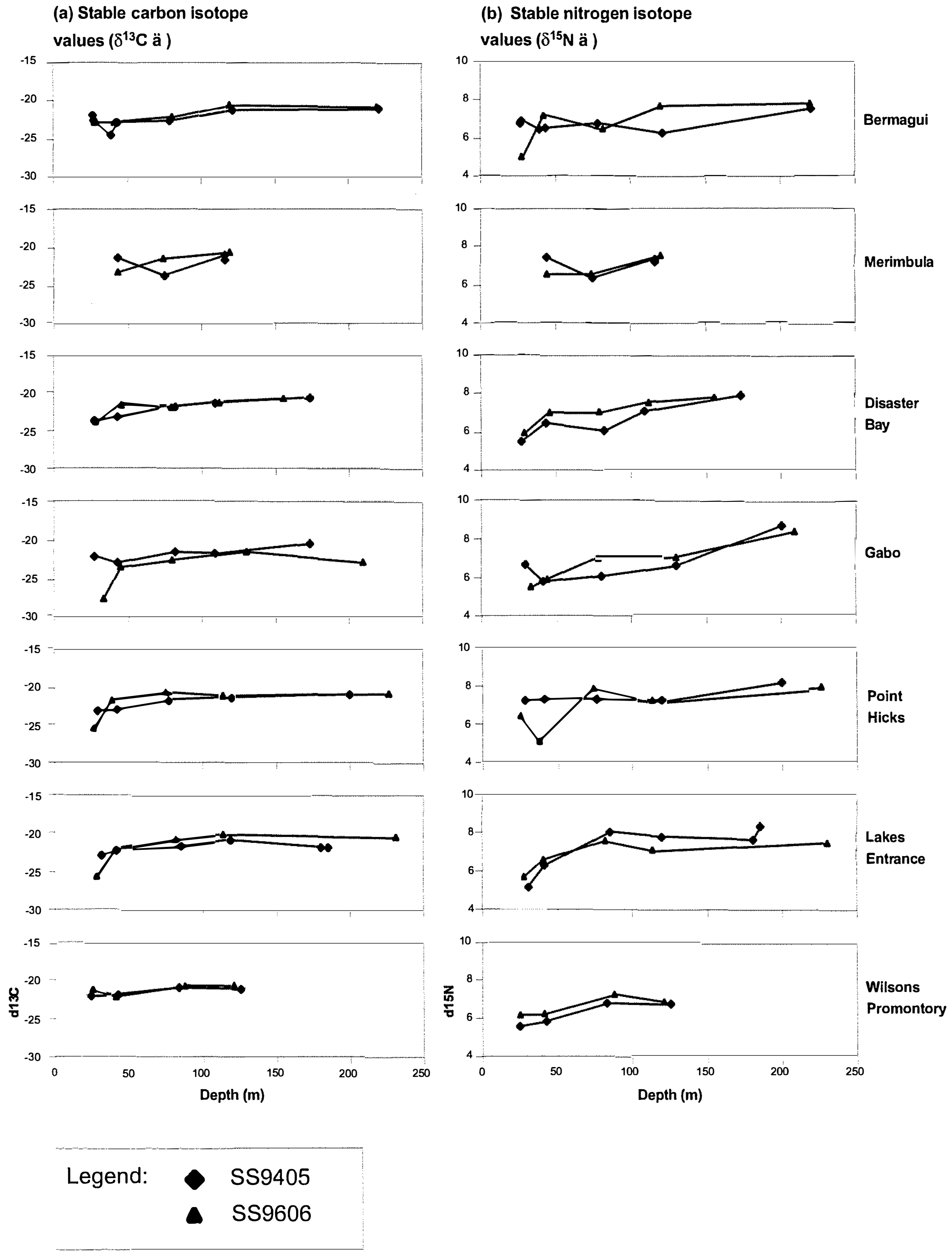


Figure 7.2.3.8 Stable carbon (a) and nitrogen (b) isotope values in sediments by cross-shelf transect for survey s SS9405 and SS9606.

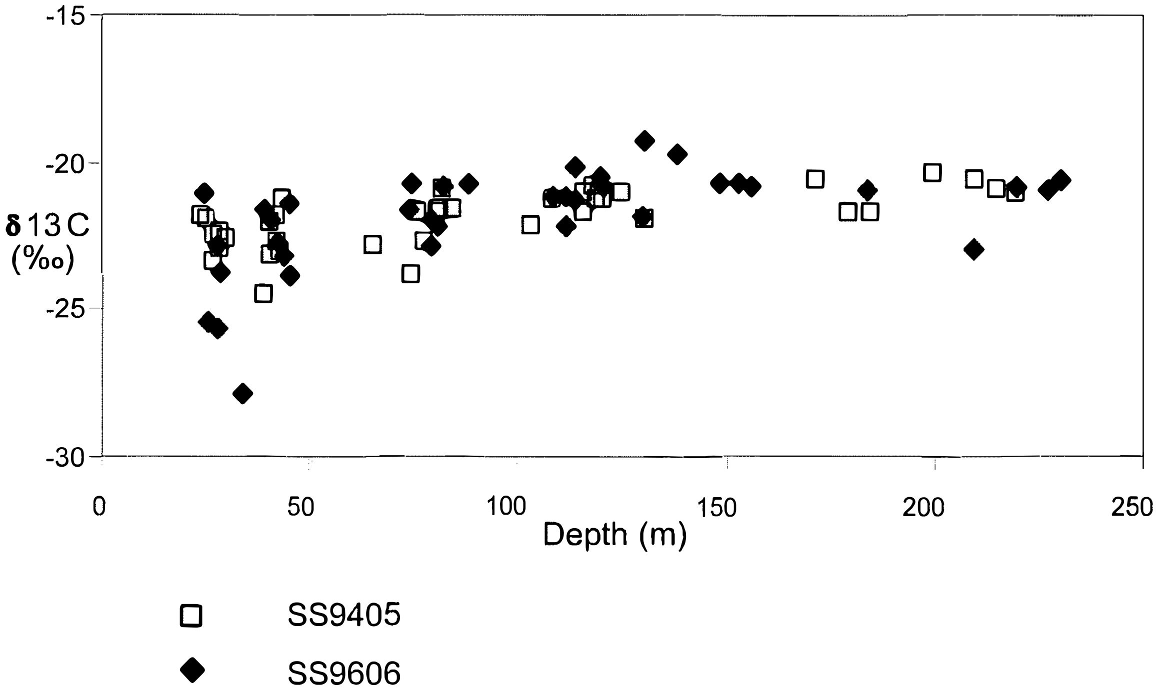


Figure 7.2.3.9 Stable carbon values in sediments on the south east Australian shelf. Sediment samples were collected in August-September 1994 (SS9405) and November-December 1996 (SS9606).

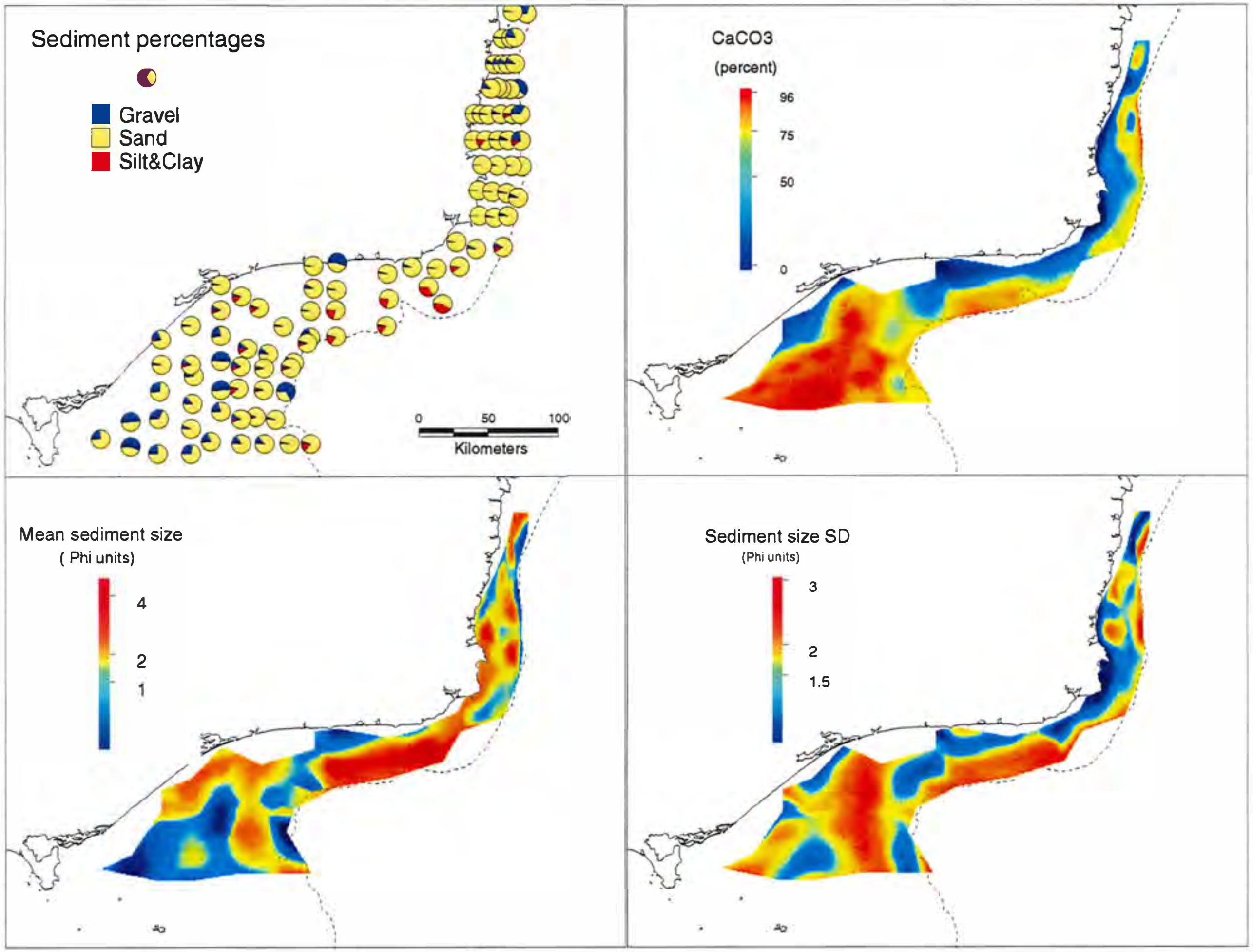


Fig. 7.2.3.10 Sediment composition, carbonate content, mean grainsize, and standard deviation of grainsize from published data (Davies 1979 and Jones and Davies 1983).

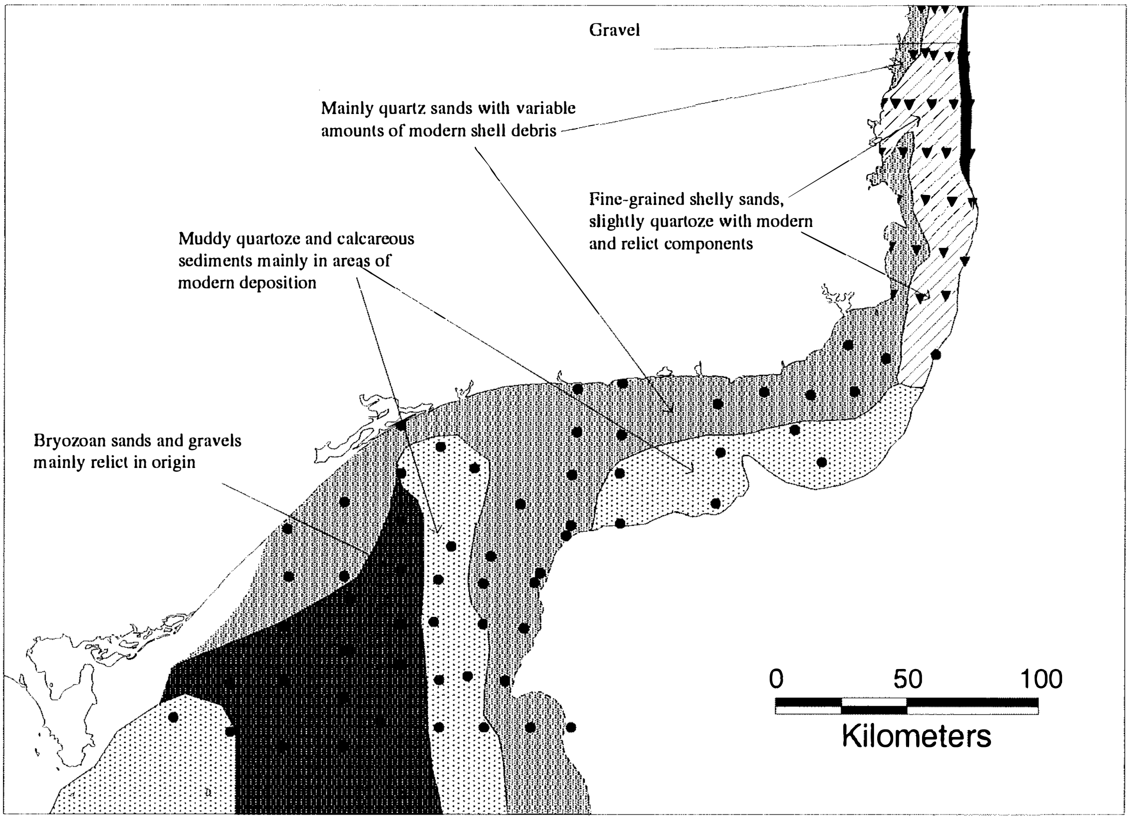


Figure 7.2.3.11 Map of sediment types in the sampling area based on published data (Davies 1979 and Jones and Davies 1983).

Bryozoan sands and gravels

Bryozoan sands and gravel cover extensive areas of the middle and outer-shelf in the southern part of the study area and are mainly relict, although a significant amount is contributed by the modern benthos. The sands are usually poorly or very poorly sorted and polymodal. Their main constituents are texturally and compositionally unrelated to the present environments.

Muddy sediments

The extremely poorly sorted muddy sediments of central Bass Strait and the southeast Victorian and Tasmanian shelves occur in water depths ranging from 44 to 212 m (Jones and Davies 1983). They are bounded by mainly terrigenous sands landwards and, where they are on the open shelf, by mainly relict sand and gravel seawards. Mud zones on the east Australian shelf, occur off river mouths (Davies 1979) and, because they are deposited on the Holocene marine transgression unconformity, date from the late Holocene or more recently. Whether the source is entirely from modern rivers or from reworking or early Holocene or Pleistocene substrates is not established.

The factors that control deposition are suspension-load concentration, bottom currents, and wave and swell-induced water movement. Jones and Davies (1983) concluded that most of the sediment carried to the sea is captured in protected estuaries of the drowned and embayed coastline. However, some reaches the open shelf at times of heavy run-off, as evidenced by surface turbidity plumes. How far this sediment, and sediment from coastal erosion and current and wave-induced seafloor winnowing is carried is unclear. Some will be transported back to land and be deposited in the coastal sediment traps. Inner shelf sands are virtually mud-free so any transported sediment must bypass the inner-shelf – limiting conditions for mud deposition occur at about 45 m water depth off eastern Tasmania (Jones and Davies 1983). The presence of pollen from recent plant introductions, for example *Pinus radiata* and agricultural weeds (Jones and Davies 1983), in mid-shelf muds suggests that hydraulically equivalent or coarser terrigenous material transported to the area would also be deposited.

Shelf-break gravels

The shelf north of Cape Howe (and south of Jervis Bay) is narrow and shallow, with the shelf-break at about 140-150m. The continental slope is steep and both slope and outer-shelf show evidence of major erosion. The coarse shelf-break gravels, the high shelf-break, the abundant evidence of erosion, and the fine-to-coarse textural gradient point to the sediments being relict from at least the last sea level low (Davies 1979).

Comparison with other areas

Pigments

On the south east Australian shelf, the mean concentration of chlorophyll *a* in sediments from 22 to 220 m depth was 0.16 μg/g (range 0–0.85 μg/g). A survey at a similar latitude in the northern hemisphere (Onslow Bay, North Carolina) found somewhat higher chlorophyll *a* concentrations in sediments (10–200 m depth) with a mean of 0.55 μg/g (range 0.06–1.87 μg/g) (Cahoon *et al.* 1990). The highest chlorophyll concentrations in Onslow Bay were found in the shallowest depth range sampled (10–19 m) and the lowest, in 50–99 m, referred to by the authors as the shelf-break zone. A similar trend was observed on the south east Australian shelf:

the highest values of chlorophyll *a* on each transect were found at depths of 25–80 m; the lowest values were mostly found at the deepest site on each transect (>150 m) towards the shelf-break.

Sediments off the coast of Madagascar had similar concentrations of chlorophyll *a*, i.e. 0.1 to 1.9 μg/g (Plante-Cuny 1978) to those off Onslow Bay. In contrast the chlorophyll *a* concentrations in the sediments in the Gulf of Carpentaria, Australia (10 to 60 m) were generally lower than those off Onslow Bay, Madagascar and south eastern Australia, at less than 0.1 μg/g at most sites (Burford *et al.* 1994).

From the finding that chlorophyll *a* concentrations in Onslow Bay sediments were equal to or greater than those of water column phytoplankton, Cahoon *et al.* (1990) concluded that benthic microalgae were probably the main primary producers in that continental shelf ecosystem. By contrast, most water column chlorophyll concentrations (mean 0.4 ppm) were greater than those in sediments (mean 0.16 ppm) on the shelf off south eastern Australia, supporting the hypothesis of greater primary production in the water column than in the sediment.

Phaeophorbide appears to be the major form of degraded chlorophyll found in faecal pellets (Patterson and Parsons 1963, Lorenzen 1967) and is an indicator of zooplankton grazing or macrobenthic breakdown of phytodetritus (Thiel *et al.* 1988/1989). Sites with high phaeophorbide values would presumably have: high zooplankton grazing activity in the water column above; detrital material advected from areas with high grazing activity; or high activity by benthic invertebrates.

Relatively high values of chlorophyll *a* (a pigment that degrades quickly) and high levels of phaeophorbides in the south east Australian shelf sediments during survey SS9405 are consistent with the survey coinciding with the annual spring phytoplankton bloom and the resulting supply of organic material as algal detritus to the seafloor. This recent rain of phytoplankton detritus was being actively broken down by pelagic and/or benthic organisms. The high concentration of chlorophyll degradation products (vs. fresh chlorophyll) where the phytoplankton bloom was most dense during this survey (i.e. on the Bermagui, Merimbula, Disaster Bay and Gabo transects and particularly on Gabo Reef) supports the hypothesis of a higher influence of water column than benthic production.

The high ratio of phaeophorbides to chlorophyll *a* (R) in sediments collected during SS9405 (mean R = 52.1; range 5.6–402.6) suggests that the phytodetritus in or on the sediment is highly degraded, although pigments indicative of zooplankton grazing (astaxanthin and phaeopigments) were not detected in the water column, sampled at the surface and subsurface (apart from phaeopigments resulting from phytoplankton death). This may reflect the daytime sampling regime when zooplankton are presumably found deeper in the water column. Thiel *et al.* (1988/1989) found values of R = 1.6 and R = 2.0 in sediment and R = 42.1 in the contents of a holothurian stomach in phytodetritus in deep ocean (4500 m) sediments at a midocean site in the northeast Atlantic. The low values of R in the sediment at the northeast Atlantic site were considered to indicate a high proportion of relatively fresh material and the result for the holothurian stomach contents to indicate well broken down material.

Stable isotopes

Sediment $\delta^{13}C$ values on the south east Australian shelf (–21.9 ± 1.3 ‰, n = 80) were very similar to values in Narragansett Bay sediments (similar latitude, 41–42°N, northern hemisphere) where Gearing *et al.* (1984) found mean values $\delta^{13}C$ in sediments of –21.8 ± 0.6 ‰, n = 26.

Although the south east Australian shelf is adjacent to a dry part of a dry continent and the rivers in the region are small, the trend for seaward enrichment in $\delta^{13}C$ values is consistent with mixing patterns described by Fry and Sherr (1984) from riverine (dominated by terrestrial plant material with $\delta^{13}C$ value of ~ –26 ‰) to offshore environments (dominated by marine phytoplankton with $\delta^{13}C$ value of ~ –21 ‰) and noted in other studies (e.g. Hedges & Parker 1976, Shultz & Calder 1976, Thornton & McManus 1994). In a study on the Great Barrier Reef Province (north eastern Australia: tropical rather than temperate), Gagan *et al.* (1987) found a linear relationship between $\delta^{13}C$ values of POM in sediments and distance from the shore. Close to the coast, $\delta^{13}C$ values were ~ –25 ‰ and increased to ~ –18 ‰, 10 km offshore.

A proxy for distance from shore is bottom depth. Fig. 7.2.3.7 combines data for two surveys (SS9405 and SS9606) where the same method for sediment collection was used. There is a clear pattern of $\delta^{13}C$ enrichment with increasing depth. The relationship here is better fitted by an asymptotic ($Y = -24.218 + 0.04 * X - 1.179E\text{-}4 * X^2$; $R^2 = 0.411$) than a linear regression.

On three adjacent transects in November–December 1996 (Gabo, Point Hicks, Lakes Entrance) (Fig. 7.2.3.6), the inshore site (~ 25 m depth) had sediment $\delta^{13}C$ values less than –25 ‰, possibly reflecting a macroalgal signal inshore or a terrestrial contribution. The findings for sediment pigments did not clarify this. Normally, if macrophytes contribute to the sediments there would be evidence of chlorophyll *b* and lutein in the sediment pigment profile. Chlorophyll *b* and lutein were not detected in the sediments. We do not know whether they were present, but masked by the strong phaeophorbide signal, or whether they really did not occur. Similarly, a terrestrial contribution would also appear as the presence of chlorophyll *b*, lutein and phaeopigments *b* in sediments.

Using stable nitrogen values in sediments, Peters *et al.* (1978) found that terrestrial and marine mixing in sedimentary organic matter in coastal Californian waters reflected the values of end member source material: marine: 7 to 10 ‰; terrestrial: 0 ‰. The same transition from a terrestrial aquatic signal to one strongly influenced by mixing with material of marine origin was seen in data for the Otsuchi River system in Japan. Wada *et al.* (1993) found $\delta^{15}N$ values for POM in the upper reaches of the Otsuchi River watershed of 0.2 to 0.7 ‰ and values of 6.4 ± 1.8 ‰ in Otsuchi Bay. In south east Australian shelf sediments, the range of $\delta^{15}N$ values in sediment was 5.0 to 9.1 ‰ with a trend for seaward enrichment in $\delta^{15}N$. The inshore values of 5-7 probably reflect some input from terrestrial and or macroalgal contributions, but the main organic contribution comes from marine phytoplankton.

The pattern of the lowest mean $\delta^{15}N$ value in the spring (SS9405) and the highest in autumn (SS9602) was similar to the pattern found by Mariotti *et al.* (1984) for $\delta^{15}N$ of suspended matter in the North Sea (mean 8 ‰; range 4–11.5 ‰) where $\delta^{15}N$ was lowest in spring and highest in summer.

7.2.4 Lithology and geomorphology

Rock types and geomorphology were identified from photographic images taken along transects, and from point samples of soft sediments and rocks. In conjunction, they were used to classify the primary seafloor hard-grounds in the study area.

Limestones

Fossiliferous limestones, composed of the hard, carbonate skeletons of dead animals (largely bivalve and bryozoan clasts), form much of the hard-ground in the study area. Skeletal elements are cemented together by fine-grained cement, often a large component of the hard matrix. The presence of glauconite and lack of burial or compaction features indicates a relatively slow rate of sedimentation and long periods of exposure to marine waters that allow precipitation of an isopachous marine cement. Bernecker *et al.* (1997) indicated that similar fossiliferous limestones are currently being deposited on much of the Gippsland Basin continental shelf. Local heterogeneities stem from variation in a number of factors including skeletal assemblages, currents, cementation, and burial rates. In addition to these 'modern' reefs, it is also likely that 'ancient' limestone outcrops through unconsolidated sediments. However, it was not possible to differentiate between the two forms from the limited number of rocks sampled or from photographic images.

Limestones are most conspicuous as relatively large (tens-thousands of metres in length), flat, raised, tabular slabs. However, cemented carbonates also form low-lying hard-grounds that are bored and encrusted by benthic organisms. These are likely to form 'patches' or mosaics of hard bottom that show little or no vertical relief. Two examples are the hard 'shoulder' off the outer edge of parts of the Gabo Reef, and 'bryozoan' reefs, formed primarily from bryozoan clasts, that form relatively small patches on mobile substrates towards the shelf-break. The latter support stands of stalked crinoids and characterise areas including the Flower Patch (see below). Limestone reefs in shallower reaches of the shelf have been exposed to the air during sea-level regressions and show signs of karstic weathering (Bernecker *et al.* 1997; Fleming & Roberts 1973). Weathered reefs have a more irregular topography with large pinnacles and depressions and are evident in sections of the Broken Reef complex.

Fossiliferous limestones comprise the majority of hard-grounds in the study area, probably often in conjunction with some sandstone. These include the following: the extensive Howe Reef/ Gabo Reef and Broken Reef complexes; the major elongate outcrops adjacent to the present day Gippsland shoreline (see under sandstone); many unnamed reef patches off the southern NSW shoreline; numerous scattered small outcrops throughout the study area, and patchy hard-grounds including at the Flower Patch.

Sandstone

Coarse grained sandstone, consisting largely of quartz grains, outcrops in tabular slabs from soft sediments on the inner to mid-shelf off the Gippsland coastline. The high degree of sorting and dominance of the quartz indicated more than one source for the grains, and that winnowing-out of other types of grains (e.g. feldspars) had occurred. Again, the presence of glauconite supports a marine origin and slow sedimentation rate, while the lack of stylolites or other compaction features indicate lack of burial. Combined, these properties suggest that this rock formed in a high-energy, coastal plain environment, a scenario consistent with Bernecker *et al.* (1997). The overall morphology of sandstone outcrops (occurring together with fossiliferous limestone)— elongate, low-relief and parallel to the present-day Gippsland shoreline— suggests that the rocks were formed in sand bodies in palaeo-shorelines. Thus, sandstone is likely to be a common constituent of 'reefs' between Wilson's Promontory and Gabo Island, particularly in those such as the mid-shelf Broken Reef complex subject to high-currents (see below).

Granite

Devonian Granite bedrock, older than the Tertiary sediments of the Gippsland Basin, outcrops from soft sediments on the inner-shelf off the Gippsland coastline. These outcrops have high-relief (> 10 m) and are distinctive in being formed of irregular, hexagonally-jointed, coarsely-crystalline granite. They form the relatively localised, hard 'reefs' at Point Hicks and the New Zealand Star Banks (see below) and are probably lateral submarine extensions of the adjacent rocky headlands composed of the same rock.

7.2.5 Seabed photography

During 51 deployments of the TACOS in the two surveys, 36 hours of video and 5200 still photographs were collected along 79 kilometres of seafloor transects. A high success rate was achieved for quality of video footage during both surveys; in the second survey, where this was quantified, 97% of seafloor footage was able to be analysed. Unusable footage resulted from areas of rapid depth change or when rapid tow cable adjustments were necessary due to changes in ship speed. Successful deployments were made in rough sea conditions (up to ~65 km h^{-1} wind-speed), and in strong ocean currents (2.8 km h^{-1}) during both surveys.

7.2.6 Broad-scale sites ('soft-ground' sediment flats)

Each of the broad-scale sites was coded by transect and depth (transects A-F, depth strata 1-5; Fig. 4.1.1.1) and samples identified by a station code or codes (below). Representative photographic images of each soft-ground site are shown in Fig. 7.2.6.1. Details of sediment composition are provided in *Section* 7.2.3 above.

A1 (SS9696 #18)

Situated on extensive sediment flat of muddy sand in an apparently thick layer. Mostly flat although some irregular sediment patterning; no appreciable slope. Occasional intermittent clumps of bushy sponges indicate an underlying harder substrate of unknown extent and type.

A2 (SS9606 #19)

Situated on extensive sediment flat of thick (>5 cm) unconsolidated muddy sand on a flatly sloping bottom. Irregular and hummocky modification (rises and depressions are ~30 cm height), with irregular bushy sponge clumps (several species) occurring in intermediate density. These are mostly in depressions, indicating scouring from currents and or wave action. There are occasional signs of bioturbation with intermittent small excavations, and noticeable suspension of sediment in the water column.

A3 (SS9606 #7)

Situated on extensive sediment flat of semi-consolidated thick (> 5 cm) mud with an overlay of organic debris on a flatly sloping bottom. Evidence of bioturbation with an intermediate cover of worm tubes and a sparse distribution of ascidians (*Polycarpa* spp.) embedded in sediment.

A4 (SS9606 #4)

Situated on extensive sediment flat of semi-consolidated thick (> 5 cm) mud with an overlay of organic debris on a flatly sloping bottom. Bioturbation evident with occasional signs of burrowing and excavation. A sparse cover of ascidians and an intermediate cover of worm tubes.

B1 (no photographic data)

B2 (SS9606 #44)

Situated on extensive sediment flat of a poorly-sorted, unconsolidated, thin (< 5 cm) muddy layer over an intermediate-density of shell fragments on a flatly sloping bottom. Mollusc beds evident, with densities ranging from dense to areas with only some individuals; dominant species include *Pecten* spp., *Chlamys* spp. and *Maoricolpus roseus*. Molluscs with a dusting of fine sediment and occasional tufts of attached brown alga.

B3 (SS9606 #32, SS9405 #43)

Situated on extensive sediment flat of a thick (> 5 cm), semi- to well-consolidated mud with organic debris on a flatly sloping bottom. Evidence of bioturbation with some burrows and excavations, and a dense cover of worm tubes and sparsely distributed ascidians and occasional alcyonarian soft coral.

B4 (SS9405 #53)

Situated on extensive sediment flat of unconsolidated mud with organic debris and intermediate-density cover of shell fragments on a flatly sloping bottom. Some bottom modification with irregular, small-scale (< 10 cm) mounding and an intermediate-density cover of worm tubes and intermittent ascidians.


A1


A2


A3

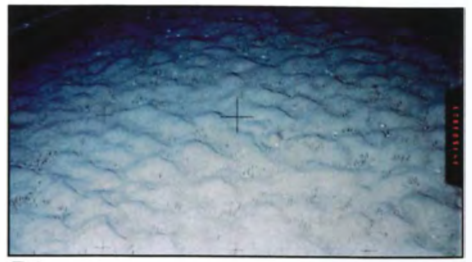

A4


A5*


B1*

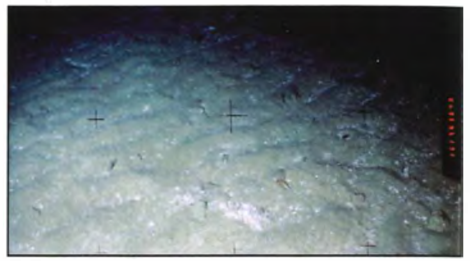

B2


B3


B4


B5


C1

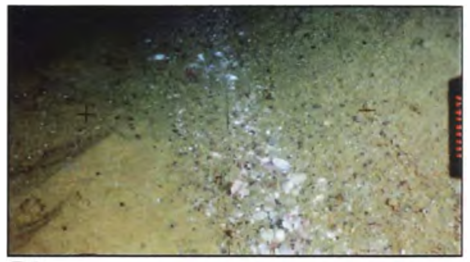

C2


C3


C4


C5


D1


D2


D3


D4*


D5


E1


E2


E3


E4


E5


F1*


F2*


F3


F4


F5


G1


G2


G3


G4


G5

B5 (SS9606 #30)

Situated on extensive sediment flat of thick (> 5 cm) semi-consolidated mud and organic debris on a flatly sloping bottom. Mostly with a thin covering of organic material and evidence of some bioturbation with small excavations (depressions). A sparse density of ascidians (*Polycarpa* spp.) and sea pens.

C1 (SS9606 #68)

Situated on extensive sand sediment flat with regular ripple formation on a flatly sloping bottom. Large (50 cm) wavelength and small (10 cm) amplitude ripples in a poorly-sorted substrate–mostly sand with some shell fragments, and a general intermediate-density of dead shells (*Pecten* spp. and glycimerid bivalves). Some bioturbation evident.

C2 (SS9405 #74 and SS9606 #66)

Situated on extensive sand sediment flat, variously modified but mostly regular, small (< 10 cm) wavelength and small (< 10 cm) amplitude ripples and some flat areas of shell bed. Noticeable variation between surveys where, in 1996, some areas of large (> 30 cm) wavelength and large (> 30 cm) amplitude sand/shell regular wave patterns were observed. An unconsolidated bottom with a noticeable degree of sorting and winnowing with shell fragments accumulated in troughs through currents and wave action. Occasional beds of *Maoricolpus roseus* with densities ranging from intermediate to sparse. Occasional signs of bioturbation with a variable, but generally sparse, density of excavations.

C3 (SS9606 #67)

Situated on extensive sediment flat of semi-consolidated thick cover (> 5cm) mud with organic debris on a flatly sloping bottom. Intermediate cover of worm tubes. Occasional sea star, ball sponge, clusters of stalked ascidians (*Pyura* spp.), soft bryozoans and hermit crabs.

C4 (SS9606 #57)

Situated on extensive sediment flat of well-consolidated thick (> 5 cm) mud on a flatly sloping bottom. No sign of modification with substrate ripples due to currents. Some bioturbation with small burrows evident and a sparse cover of worm tubes.

C5 (SS9606 #56)

Situated on extensive sediment flat with a thick (> 5cm) cover of mud with organic debris on a flatly sloping bottom. Intermittent clumps of stalked crinoids associated with small pieces of hard substrate. Occasional pancake urchins and small ascidians. Intermittent signs of bioturbation with excavations evident.

D1 (SS9405 #95)

Situated on extensive sediment flat of mostly unconsolidated sand formed into regular medium amplitude and wavelength (~10-30 cm) sand ripples, with intermittent biogenic reef (isolated hard patches with no signs of outcropping bedrock), with a dense cover of sponges and some attached brown alga (*Macrocystis*). Sediment containing some shell fragments and occasional pebbles sorted into wave troughs–presumably by winnowing in currents. Evidence of algal coating on areas of undisturbed sand. Occasional areas with re-working from excavations and burrowing.

D2 (SS9405 #96 and SS9606 #89)

Situated on extensive, unconsolidated sediment flat forming regular well-developed and symmetrical sand waves of large wavelength and amplitude (> 50cm) on a flatly sloping bottom. Coarse/medium grained sand with well-sorted grains (including mollusc shells–Pecten, mussels and other bivalves) in the ripple troughs. Area indicative of considerable wave activity (sand ripples and sorting). Occasional signs of bioturbation with a sparse cover of worm tubes and occasional *Maoricolpus roseus* communities in sparse to intermediate densities.

D3 (SS9606 #82)

Situated on extensive sediment flat of semi- to well-consolidated mud with organic debris on a flatly sloping (0-5 degree) bottom. An intermediate cover of worm tubes and intermittent individual ascidians and occasional small lumpy sponges attached to dead shell.

D4 (SS9405 #98)

Situated on extensive sediment flat of thick (> 5 cm) mud with a cover of organic debris; area mostly flat with some small (10 cm) irregular mounds and depressions on a flatly sloping bottom. Bioturbation evident from some small mounds and depressions. Occasional individual ascidians visible.

D5 (SS9606 #75)

Situated on extensive sediment flat of thick (> 5 cm), well-sorted mud with a flatly sloping bottom. A sparse cover of small, yellow ascidians (*Polycarpa* spp.) and individual sea pens.

E1 (SS9606 #98)

Situated on extensive sediment flat of sand and shell fragments with regular, well-developed medium wavelength and amplitude (10-30 cm) ripples. Shell fragments provide a sparse bottom cover in ripple troughs. Sand ripples indicate considerable wave surge or current influence. Occasional signs of bioturbation with minor re-working in sand mounds. Dead shells mostly glycimerid bivalves.

E2 (SS9606 #101)

Situated on extensive sediment flat of semi-consolidated sand/mud with regular waves of medium (10-30 cm) amplitude and wavelength on a flatly sloping bottom. Ripple formation suggests modification due to wave action/ currents but probably only during high wave/storm activity as there appears to be signs of stabilizing of the sediment with worm tubes forming on the crests. Moderate sorting with bryozoan and shell fragments in troughs of waves. Intermittent occurrence of low branching sponges and intermittent to occasional *Maoricolpus roseus* beds in intermediate densities. Possible alteration to topography due to *M. roseus* suggested in places.

E3 (SS9606 # 130)

Situated on extensive sediment flat of well-consolidated, thick (> 5cm) mud with organic debris forming a flat surface on a flatly sloping bottom. Evidence of bioturbation with some excavations. Occasional occurrence of irregular bushy and branching sponges, and intermittent occurrence of seastars, urchins and whelks. Mostly with an intermediate to dense cover of worm tubes.

E4 (SS9606 #132)

Situated on extensive sediment flat of well-consolidated, thick (> 5 cm) mud with organic debris that forms a flat surface on a flatly sloping bottom. Occasional bioturbation, and mostly with an intermediate cover of worm tubes. Occasional seastars and irregular bushy and branching sponges.

E5 (SS9606 #135)

Situated on extensive sediment flat of well-consolidated, thick (> 5 cm) mud with organic debris that forms a flat surface on a flatly sloping bottom. Evidence of bioturbation, sparse occurrence of ascidians and sea pens. Suspended particulate material (marine snow) evident near bottom.

F2 (SS9405 #134 and SS9606 #147)

Situated on extensive sediment flat of well-consolidated, thick (> 5cm) mud with organic debris that forms a flat surface on a flatly sloping bottom. Patches of medium wavelength and amplitude sand ripples (10-30 cm) with some irregular, hummocky structures (mounds and depressions). Some *Maoricolpus roseus* beds in sparse, intermediate but mostly dense patches. Occasional sponge fragments and intermittent individual yellow sponges present. Dense cover of worm tubes in places.

F3 (SS9606 #146)

Situated on extensive sediment flat of well-consolidated, thick (> 5cm) mud with organic debris that forms a flat surface on a flatly sloping bottom. Signs of bioturbation; substrate mostly with an intermediate cover of worm tubes, intermittent sponge and sea stars.

F4 (SS9405 #140)

Massive flat sediment forming a flat surface on a flatly sloping bottom and comprising of semi-consolidated thick (> 5 cm) mud/shell mix with organic debris. Evidence of bioturbation with occasional excavations. Intermittent small individual sponges.

F5 (SS9606 #155)

Situated on extensive, variable sediment flat of semi-consolidated, thick (> 5cm) mud with organic debris, and unconsolidated, poorly sorted gravel (shell and bryozoan fragments) that forms a flat surface on a flatly sloping bottom. Some evidence of bioturbation with excavations and burrows. Occasional and sparse cover of ascidians (*Polycarpa* spp.), seawhips and worm tubes. No evidence of modification by currents.

G1 (SS9606 #113)

Situated on an extensive sediment flat with variable ripple morphology on a flatly sloping bottom. This area exhibits a highly variable bottom topography over the distance of the sled tow (approx. 1 n.mile), but three types were classified. Type 1: large wavelength, medium amplitude sand/gravel ripples/dunes with shell fragments in troughs. Type 2: irregular mounds and depressions with a mud substrate and occasional *Maoricolpus roseus* individuals. Type 3: large wavelength, medium amplitude sand/gravel waves with shell fragments in troughs (same as type 1) but with *Maoricolpus roseus* communities forming an intermediate cover. Some evidence of wave surge/ current activity.

G2 (SS9606 #112)

Situated on an extensive sediment flat of semi-consolidated mud/ sand that forms regular ripples on a flatly sloping bottom. Ripples are well developed, large wavelength and medium amplitude with fine shell fragments in troughs. Sediment ripple reworking may be by high currents in wave surge or storms. Signs of bioturbation with occasional excavations.

G3 (SS9606 #114)

Situated on an extensive sediment flat of semi-consolidated thick (> 5 cm) mud with organic debris that forms a flat surface on a flatly sloping bottom. Some evidence of bioturbation with occasional excavations. Occasional occurrence of sea stars, urchins, ascidians and irregular and bushy sponges.

G4 (SS9606 # 120)

Situated on an extensive sediment flat of semi-consolidated thick (> 5 cm) mud with organic debris that forms a flat surface on a flatly sloping bottom. Some bioturbation with occasional excavations.

G5 SS9606 #124

Situated on an extensive sediment flat of well-consolidated thick (> 5 cm) mud with organic debris that forms a flat surface on a flatly sloping bottom. Intermittent signs of bioturbation with excavations. Some areas of pebble-size (> 10 mm) bryozoan clasts and mollusc shell) with small attached sponges and ascidians (*Polycarpa* spp.).

7.2.7 Focussed habitat sites ('hard-grounds' and adjacent areas)

Descriptions of each of the focussed habitat sampling areas (mesohabitats) and the contrasting bottom types within them (macrohabitats) were based on geomorphology and epifauna identified in photographic images, and from physical samples of sediments, rock and biota. Three-letter codes for each macrohabitat are based on names of local landmarks or fishing grounds plus the acoustic bottom identifier (soft, hard or rough) (*Sections* 7.2.1, 7.2.2), e.g., the soft sediment flat at the Black Head mesohabitat is coded BHS. In some cases, cross-reference is made to broad-scale sample sites by a station code or codes.

Primary mesohabitat sites (sampled with full range of samplers)

Area 1: Black Head mesohabitat (Fig. 7.2.7.1)

This study habitat lies in the 40 - 50 m depth range off the shoreline headland of the same name. Inshore it is bounded by broken hard-ground to the shoreline, and offshore by the extensive sediment flat of Disaster Bay.

'Soft' macrohabitat- BHS (station 2 on Transect E at Disaster Bay)

An extensive sediment flat of semi-consolidated sand/mud with regular ripples of medium (~10-30 cm) amplitude and wavelength, on a flatly sloping bottom. Ripple formation suggests modification due to wave action/ currents but probably only during high wave/storm activity as there appears to be signs of stabilizing of the sediment with worm tubes forming on the crests. Moderate sorting with bryozoan and shell fragments in troughs of waves. Intermittent occurrence of low branching sponges and intermittent to occasional *Maoricolpus roseus* communities in intermediate densities. Possible alteration to topography due to *M. roseus* is suggested by consecutive reference photographs. Immediately seaward, in ~80 m, there is a transition to the extensive sediment flat of Disaster Bay. It is well-consolidated mud with organic debris and evidence of bioturbation with some excavations. There is irregular occurrence of bushy and branching sponges, intermittent occurrence of seastars, urchins and whelks, and intermediate to dense patches of worm tubes.

'Hard' macrohabitat- BHH

An area of massive bedrock with a veneer of mud/sand on a slightly sloping (~5- 30 degree) bottom with intersecting patches of apparently thick (> 5 cm) unconsolidated sediment with regular non-symmetrical (current induced) ripples of small wavelength (< 10cm) and small (< 10 cm) amplitude. Mud/sand well sorted due to currents and possibly from storm surge action. Some intervening biogenic slabs of well-consolidated indurated (cemented) sediment with some jointing evidenced by regular fractures. Occasional patches of boulders with dense cover of sponge gardens. Also, intermediate to dense coverage of sponges (predominantly finger sponges) on outcrops and those areas where sediment cover is thin.

'Rough' macrohabitat- BHR

An area consisting predominantly of slabs of biogenic (fossiliferous limestone) reef with crevices and ledges, occasionally intervened by small areas of moderately sorted, unconsolidated fine sand. Reef forms pinnacles and walls (~1-3 m) with some steep to vertical slopes but otherwise with flat tops. Occasional areas with boulders. The reef has a dusting (< 1 cm) of organic debris and sediment, and is mostly covered with dense sponge gardens and occasional sea-whips. Gardens are formed from patchy encrusting sponges, intermittent cup sponges and broad irregular fronded sponges. Intervening thin (~1-5 cm) sediment areas most likely overlay massive bedrock that, where exposed, form occasional attachment points for finger sponges.

Area 2: Disaster Bay mesohabitat (Fig. 7.2.7.2)

The study area was in an eastern section of Disaster Bay in approximately 80-100 m depth, adjacent to the western margin of the northern section of the Howe Reef/ Gabo Reef complex. Inshore (westward), the bay extends for a considerable distance, gradually shallowing to meet the shoreline south of Cape Howe.

'Soft' macrohabitat- DBS

An extensive sediment flat of thick (> 5 cm) semi to well-consolidated mud with some organic debris on a flatly sloping bottom. A sparse to intermediate cover of irregular, yellow bushy sponges and intermittent occurrence of seastars, urchins and whelks at least at the inner margins (off Black Head). Evidence of bioturbation with occasional small depressions resulting from burrowing infauna. Occasional straight, parallel furrows in sediment caused by trawl gear (bobbins/ rollers and doors).

'Hard' macrohabitat- DBH

Predominantly sediment flats of a mostly thick (< 5 cm) layer of mud with organic debris and occasional slabs of biogenic reef (fossiliferous limestone) embedded in the flatly sloping bottom. Clumps of large bushy sponges and some sea-whips attached to slab outcrops, otherwise only occasional occurrence of small yellow ascidians (*Polycarpa* spp.).

'Rough' macrohabitat- DBR

Reef, composed of fossiliferous limestone slabs. Reef margins were not clearly seen with cameras but are likely to be similar to the reef at Big Gutter (part of the Howe reef complex, a few kilometres to the east). Reef with variable morphology: generally an indistinct margin composed of patches of low-relief slabs, with steep (30-45 degree) or vertical slope and overhangs in places. Some high-relief (> 3 m) reef patches with pinnacles; more generally relatively low-relief with a thin (< 5 cm) cover of mud with sparse epibenthos. Where distinct, the margin is characterised by outcropping of the hard substrate and with a dense cover of sponges and seawhips. Mud cover is well-consolidated and sorted with some evidence of bioturbation with small excavations.

Area 3: Point Hicks mesohabitat (Fig. 7.2.7.3)

The study area bounds an inner-shelf (~40 m depth) region off the Gippsland shoreline at Point Hicks. The rough macrohabitat at this site is a granite outcrop close to the shoreline, and the soft macrohabitat the adjacent seaward sediment flat. The Broken Reef complex lies further seaward of the sediment flat, with the shelf-break The Horseshoe beyond.

'Soft' macrohabitat- PHS (station 2 on Transect C at Point Hicks)

Situated on an extensive sand sediment flat, that is variously modified but mostly with regular, small (< 10 cm) wavelength and small (< 10 cm) amplitude ripples and some flat areas of shell bed. Noticeable variation (possibly storm related) with some areas of large (> 30 cm) wavelength and large (> 30 cm) amplitude sand/shell regular wave patterns were observed on one survey. An unconsolidated bottom with a noticeable degree of sorting and winnowing with shell fragments accumulated in troughs through currents and wave action. Occasional beds of *Maoricolpus roseus* with densities ranging from intermediate to sparse. Occasional signs of bioturbation with a variable, but generally sparse, density of excavations.

'Rough' macrohabitat- PHR

The 'reef' is predominantly composed of granite, mostly as boulders with rounded surfaces, creating crevices and steeply sloping topography. Margins of outcrop are predominantly a sand/ gravel sediment, well sorted, mostly well-consolidated and thick (> 5 cm) in cover with occasional biogenic reefs rising about 1 m above surrounding sediments. Sediment forming

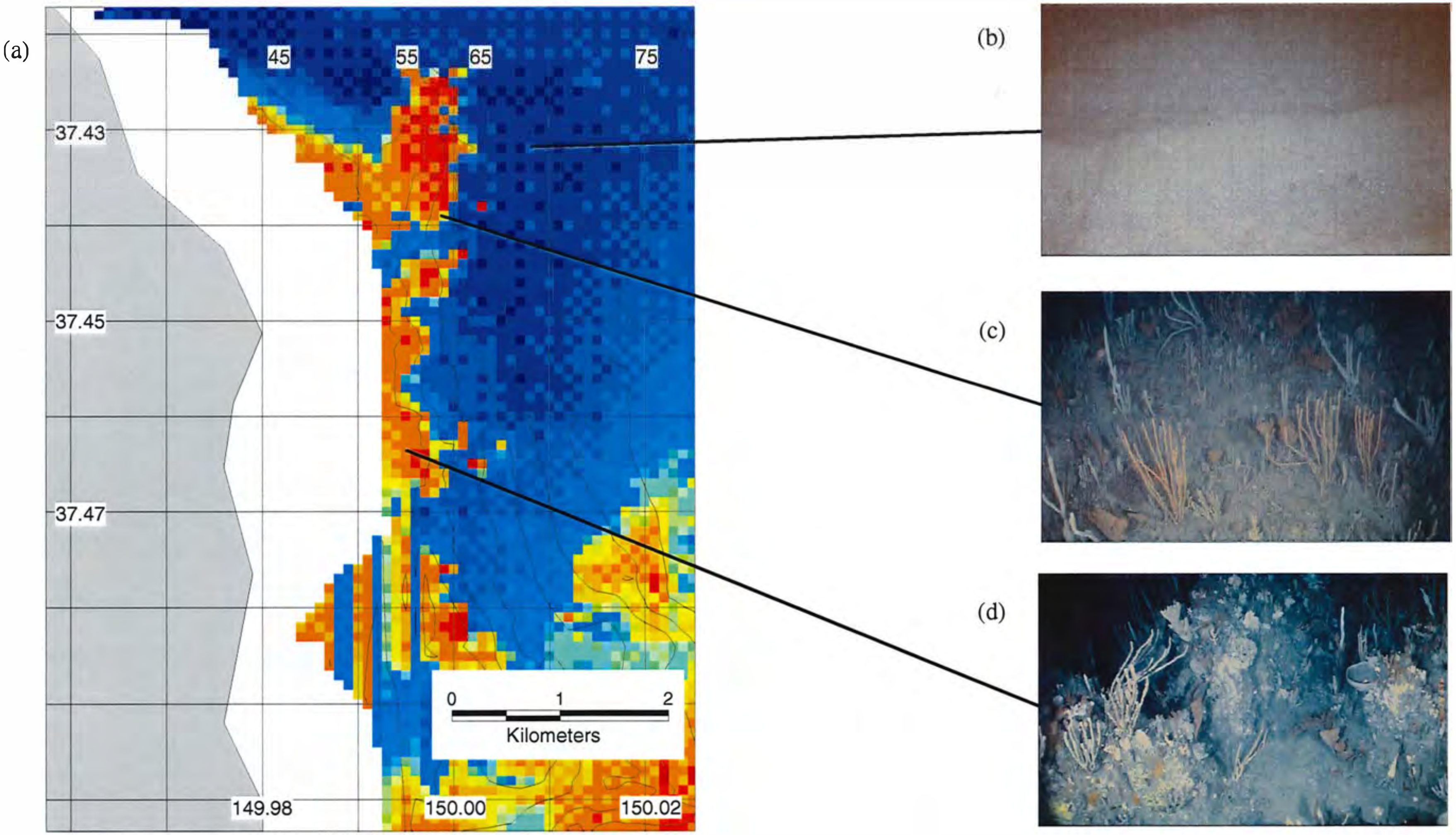


Figure 7.2.7.1 (a - d). Black Head mesohabitat showing (a) location and bathymetry overlaid on fine-scale habitat map (interpolated acoustic index of bottom roughness, red = most rough, blue = least rough). Images indicate habitat types and locations (b) soft, (c) hard and (d) rough.

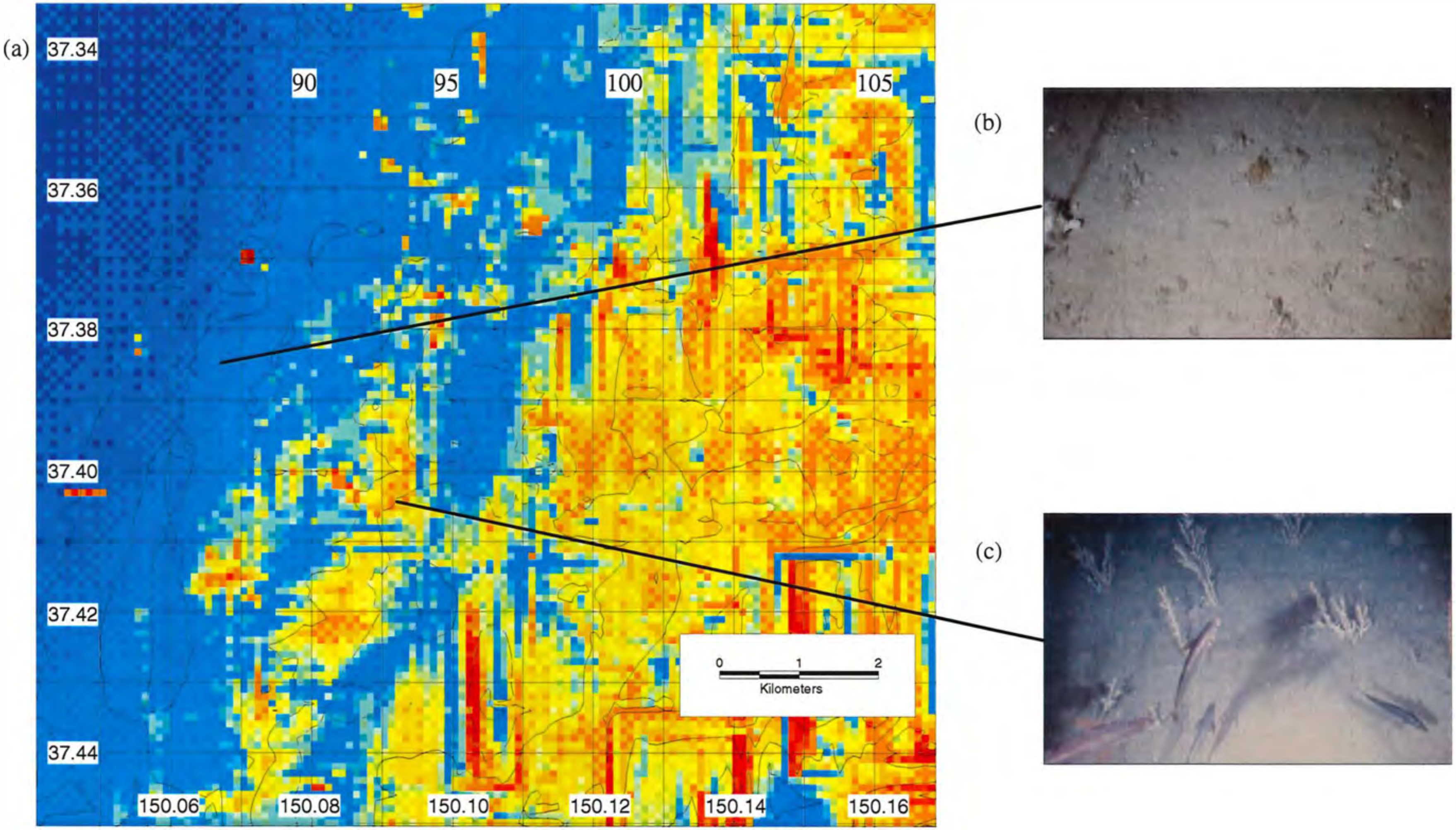


Figure 7.2.7.2 (a - c). Disaster Bay mesohabitat showing (a) location and bathymetry overlaid on fine-scale habitat map (interpolated acoustic index of bottom roughness, red = most rough, blue = least rough). Images indicate habitat types and locations (b) soft and (c) hard.

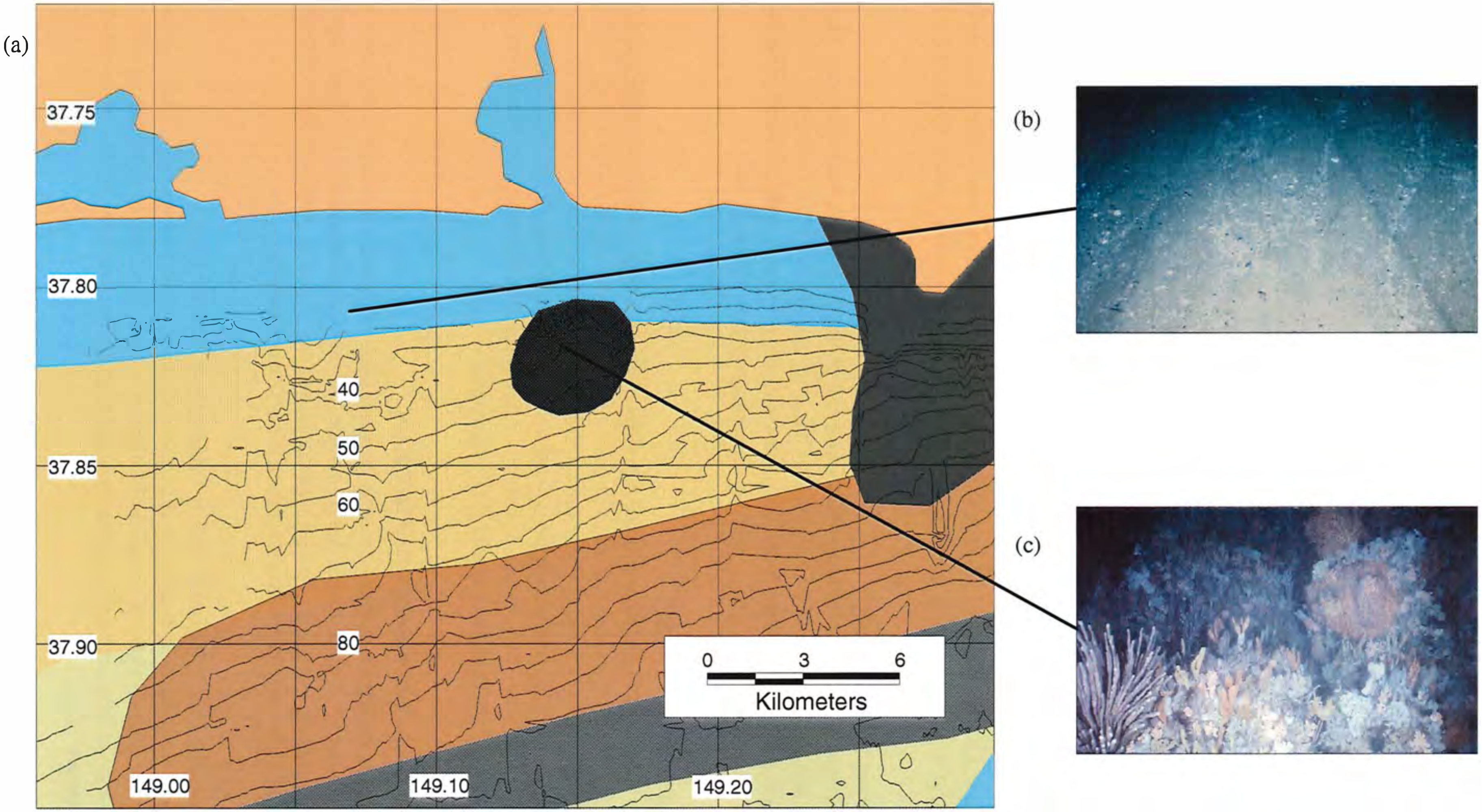


Figure 7.2.7.3 (a - c). Point Hicks mesohabitat showing (a) location and bathymetry (m) on a coarse-scale habitat map (from Plate 7.2.5.1) Images indicate habitat types and locations (b) soft and (c) rough.

regular ripples (or dunes) of medium amplitude and wavelength. Intermittent signs of scouring around reefs most likely due to wave action. A coarse, shell debris fills the ripple troughs. Reefs support dense epifaunal communities, including encrusting sponges and other taller sponges, occasional seawhips and calcareous red algae.

Area 5: Big Gutter mesohabitat (Fig. 7.2.7.4)

The study area is in a central section of the Howe Reef in ~80-100 m depth. At this latitude, the reef complex is broadly sub-divided by a number of elongate channels running approximately SSW-NNE— the commercial 'gutter tows' of which Big Gutter is one. The 'hard' macrohabitat was on the floor of Big Gutter and therefore on a commercial trawl tow. Directly inshore (westward) is Disaster Bay; offshore (eastward), the reef extends to a sediment flat that separates the reef complex from the shelf-break.

'Soft' macrohabitat- BGS

Flat sediment flat of well-sorted, semi-consolidated thick (> 5 cm) mud and organic debris. Intermediate levels of bioturbation with some burrows and trails. Occasional individual solitary ascidians. Little evidence of wave or current activity. Possible that consolidation is aided by the thin layer of surface microbial activity providing some binding. Some trawl tracks observed.

'Hard' macrohabitat- BGH

Predominantly extensive sediment flat of well sorted, unconsolidated mud with some organic debris and some low-relief (< 1 m) slabs of biogenic (fossiliferous limestone) reef out-cropping from a flatly sloping bottom. Some bioturbation with worm tubes evident. Very sparse cover of ascidians, seawhips and sponge gardens (including sea fans and bryozoan).

'Rough' macrohabitat- BGR

Reef, composed of fossiliferous limestone slabs. Reef edge with variable morphology: a distinct margin, vertical slope and overhangs in places, otherwise, less distinct with a steep slope (30-45 degree) and a thin (<5 cm) cover of mud with sparse epibenthos. Patches of high-relief (> 3 m) with pinnacles. The distinct margin is characterised by outcropping of the hard substrate and with a dense cover of sponges and seawhips. Mud cover is well-consolidated and sorted with some evidence of bioturbation with small excavations.

Area 6: Gabo Reef mesohabitat (Fig. 7.2.7.5)

The area of habitat studied was towards the outer edge of a southern section of the reef complex in the ~100-130 m depth range. At this latitude, the reef complex continues inshore (westward) for some distance where its western boundary meets the 'Airstrip' sediment flats; offshore (eastward), the shelf-break is eastwards of the soft macrohabitat.

'Soft' macrohabitat- GRS (station 5 on Transect E at Disaster Bay)

Situated on extensive sediment flat of well-consolidated, thick (> 5 cm) mud with organic debris that forms a flat surface on a flatly sloping bottom. Evidence of bioturbation with sparse occurrence of ascidians and sea pens. Suspended particulate material (marine snow) evident near bottom.

'Hard' macrohabitat- GRH (reef edge)

The reef margin has variable topography with some sections characterised by steep (45-90 degree), high-relief walls (> 3 m) with ledges, overhangs, and caves, and other sections of gradual decline over broken, boulder substrate. In places the reef edge is >10 m above the adjacent sediment flat. The reef top is mostly covered with a thin sediment cover and organic debris (evidence of background pelagic sedimentation) and occasional sponge gardens on outcrops. There is a notable increase in the abundance of sponges on the vicinity of the reef edge due probably to it being a region of exposed hard substrate for attachment and increased current. The epifauna includes occasional large cup sponges, prostrate plate sponges and highly-branched finger sponges. Off the reef edge, but immediately adjacent to it, there is a slightly thicker unconsolidated mud overlaying hard substrate. This 'reef shoulder' has a sparse to intermediate cover of sponges and with some bioturbation evident with re-working of the sediment.

'Rough' macrohabitat- GRR (reef top)

An area of flatly sloping, biogenic reef of fossiliferous limestones, mostly overlain with a thin (< 5 cm) cover of unconsolidated mud. The surface topography is of a slightly hummocky and irregular appearance with small scale pinnacles (0.5 -1 m) and the occasional small, undercut slab feature (~1 sq. m). Where overlying sediments are shallow, or where reef outcrops are exposed, there is an intermediate to dense cover of sponge garden (finger and cup sponges) and occasional pancake urchins.

Area 7: The Horseshoe mesohabitat (Fig. 7.2.7.6)

The Horseshoe is the shelf-break rim of a major arm of the Bass Canyon. Three sites around the canyon rim in ~150-180 m depth were sampled: a well defined, but small (< 2 km in length) elevated rock structure on the western margin south of the West Bank (rough macrohabitat), an area within the 'Flower Patch' characterised by stalked crinoids on the eastern margin ('crinoid-type'), and an adjacent area of sediment flat on the western margin. The Broken Reef complex lies landward (north) of The Horseshoe.

'Soft' macrohabitat- HOS (station 5 on Transect C off Point Hicks)

Situated on extensive sediment flat with a thick (> 5cm) cover of mud and organic debris on a flatly sloping bottom. Intermittent clusters of stalked crinoids associated with small pieces of hard substrate. Occasional pancake urchins and small ascidians. Intermittent signs of bioturbation with excavations evident.

'Stalked crinoid' macrohabitat- HOC

Predominantly unconsolidated mud sediment with occasional hard-grounds: low-relief slabs of indurated/ cemented limestone and bryozoan reef forming flat surfaces on a flat bottom slope. Hard-grounds with evidence of scouring around bases due to water current, but also with a dusting of sediment on exposed surfaces. Bioturbation evident with tracks, trails and burrows. An intermediate cover of stalked crinoids on most pieces of hard substrate along with sponges, ascidians and gorganacean soft corals. Areas other than the hard substrate with sparse cover of seapens and pancake urchins.

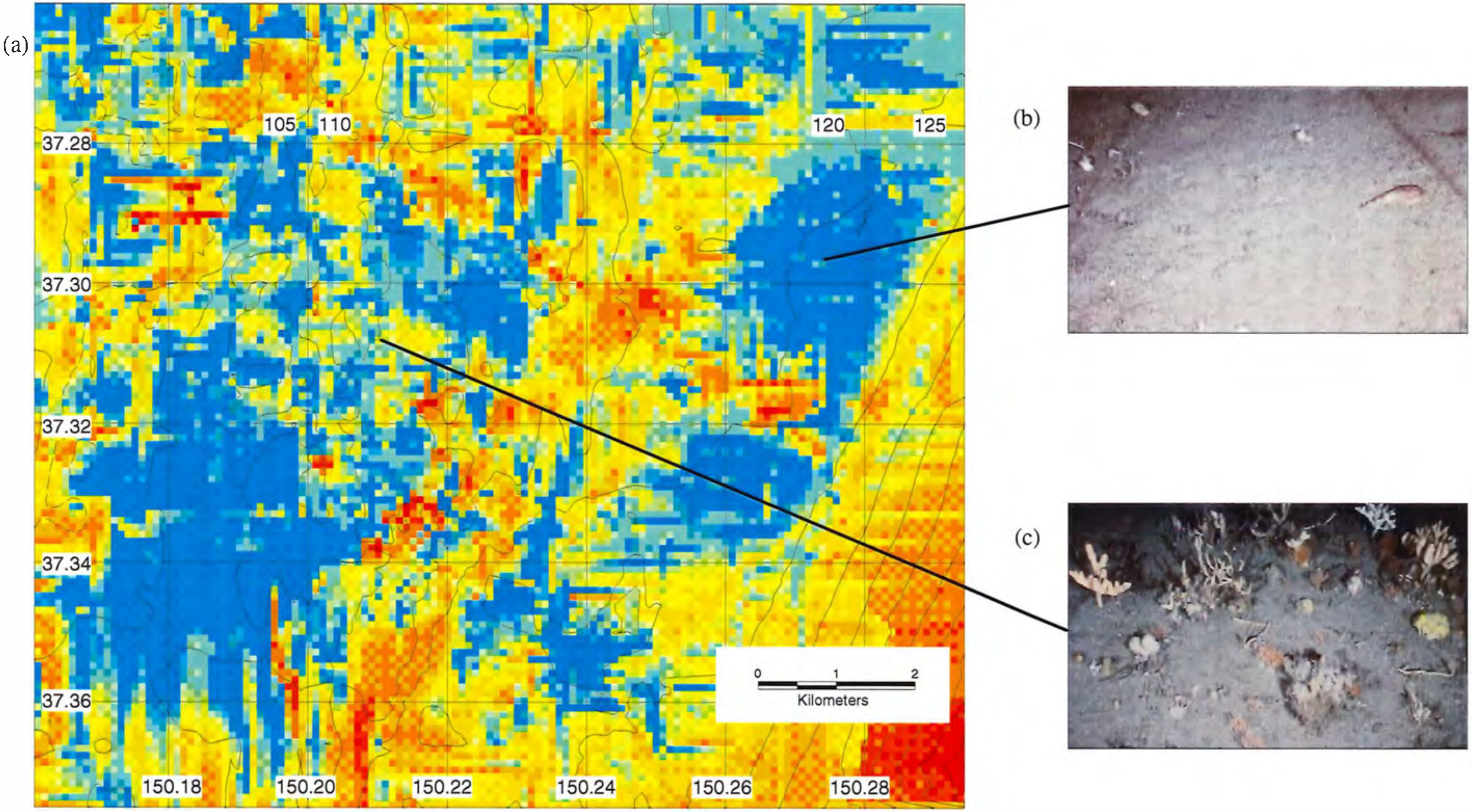


Figure 7.2.7.4 (a-c). Big Gutter mesohabitat showing (a) location and bathymetry (m) overlaid on a fine-scale habitat map (interpolated acoustic index of bottom roughness, red = most rough, blue = least rough). Images indicate habitat types and locations (b) soft and (c) hard.

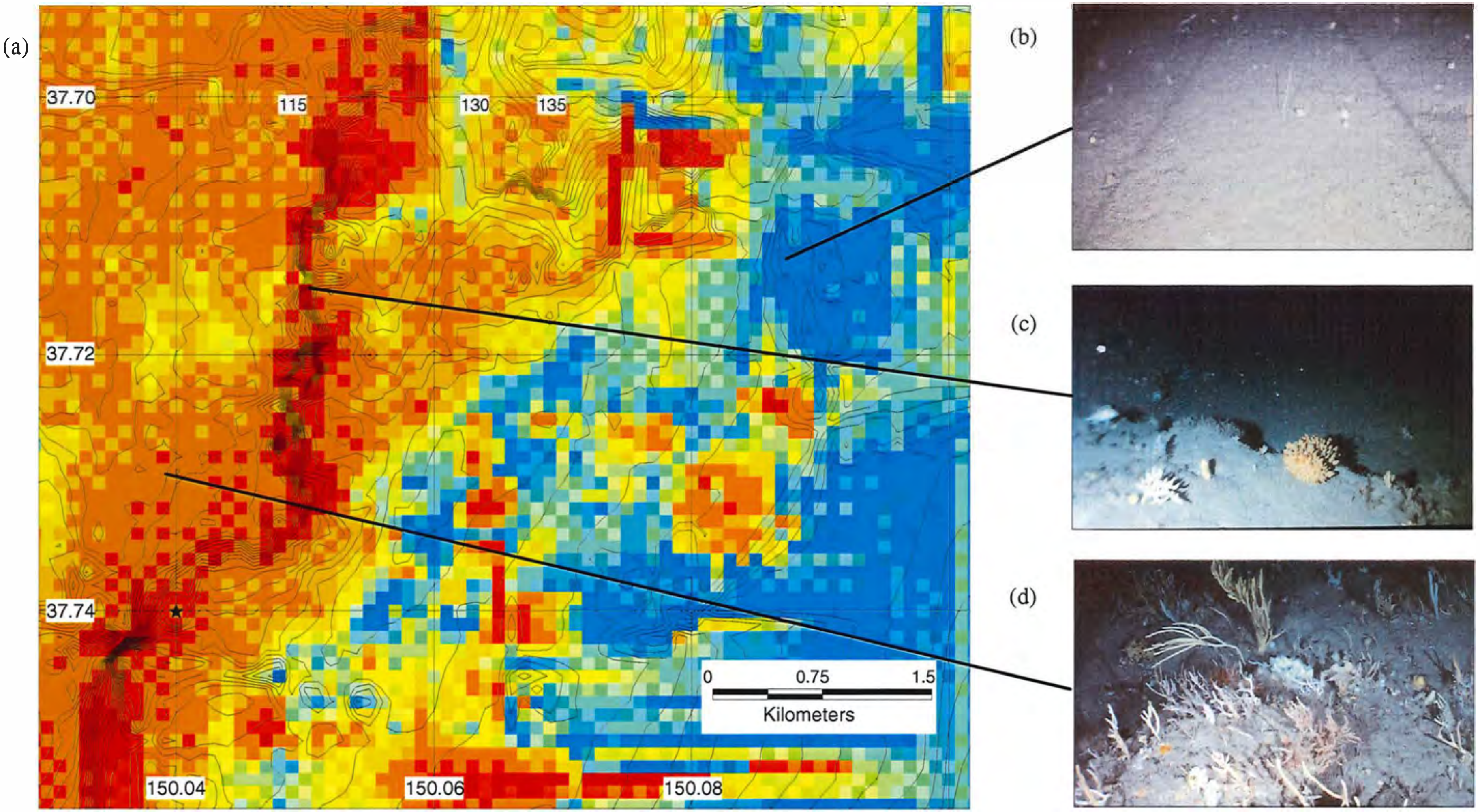


Plate 7.2.7.5 (a - d). Gabo Reef mesohabitat showing (a) location and bathymetry overlaid on fine-scale habitat map (interpolated acoustic index of bottom roughness, red = most rough, blue = least rough). Images indicate habitat types and locations (b) soft, (c) hard and (d) rough.

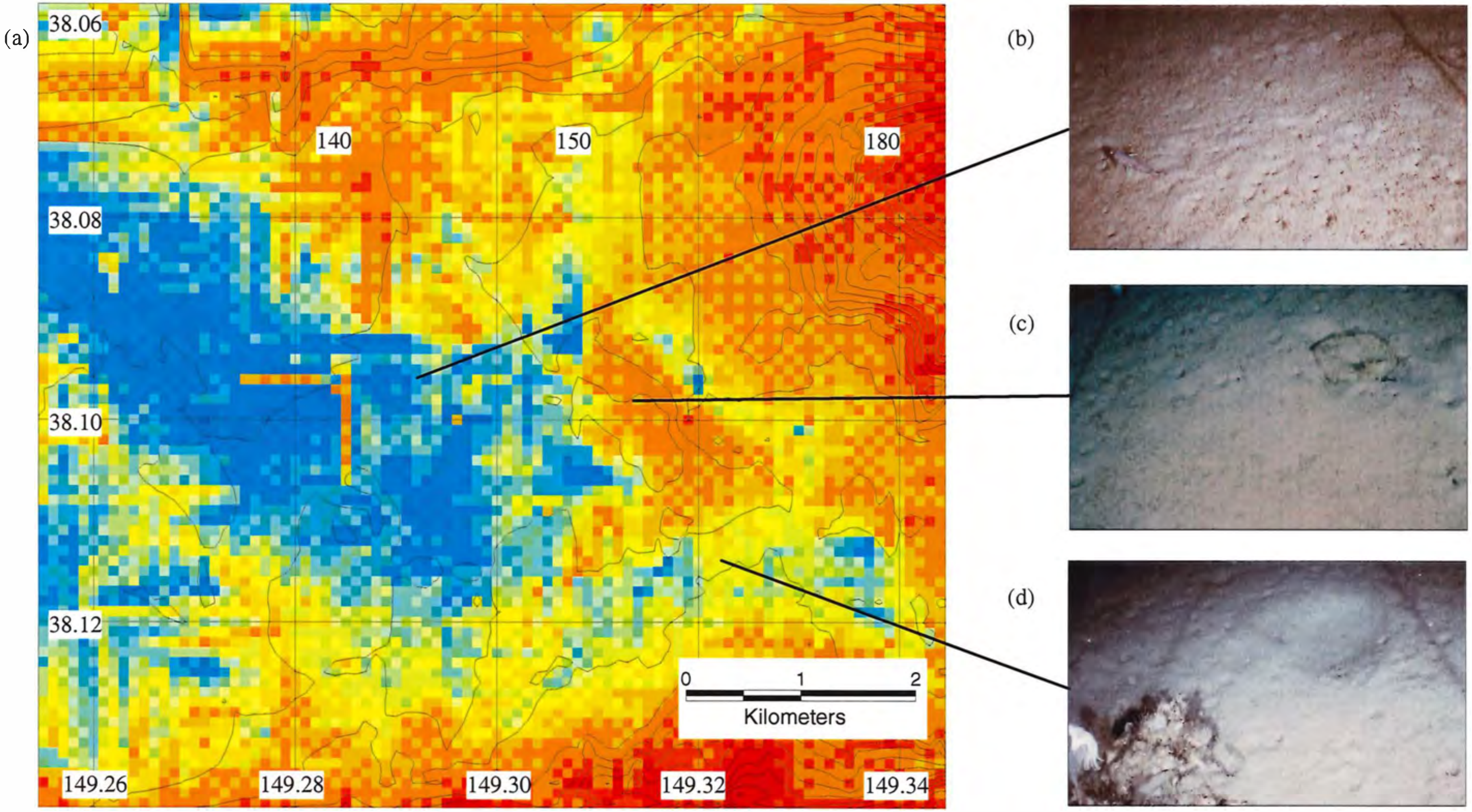


Plate 7.2.7.6 (a - d). The Horseshoe mesohabitat showing (a) location and bathymetry (m) overlaid on fine-scale habitat map (interpolated acoustic index of bottom roughness, red = most rough, blue = least rough). Images indicate habitat types and locations (b) soft, (c) hard and (d) stalked crinoid habitat.

'Rough macrohabitat' -HOR

Lithified slabs among predominantly well-sorted, unconsolidated mud sediment forming a predominantly flatly sloping bottom. Slabs with intermittent overhang features (<0.5 m), and occasional signs of sediment modification as evident by scouring due to currents. Sparse cover of sponges, seawhips and stalked crinoids on hard substrate, and some ascidians present. Intermediate bioturbation evident with excavation and hollows.

Secondary mesohabitat sites (sampled with cameras but not all samplers)

Gabo Island mesohabitat (Area 4)

'Soft' macrohabitat-GIS (station 2 on Transect D at Gabo Island, 6/96 #89)

Predominantly coarse to medium-grained sand sediment flat in ~40 m depth; sediment is well sorted, thick (> 5 cm) and unconsolidated. Sediment formed into regular, large wavelength, medium amplitude ripples with some gravel (large and coarse shell) in the troughs. Large shell fragments are mollusc remnants, mainly *Pecten* spp. and glycimerid bivalves, and *Maoricolpus roseus*. Some dense elongate patches of *M. roseus* in troughs.

'Hard' macrohabitat-GIH

An isolated area of limestone/ sandstone reef edge that outcrops from an extensive sediment flat of coarse sand formed into regular ripples with large wavelength and medium amplitude. The reef forms ledges with overhangs in places, but is mostly flat to sloping and overlain with a thin (1-5 cm) layer of sand. The reef has an intermediate to dense cover of encrusting, finger, and broad, irregular sponges. Schools of small butterfly perches, scorpaenids and other small fishes were tightly aggregated around the ledge and adjacent area.

Broken Reef (Area 8) (Fig. 7.2.7.7)

An extensive area of hard, broken limestone and coarse-grained sandstone interspersed on coarse sand sediment flats. Biogenic reef with encrusting coral and bryozoa and with some external bioturbation. Reefs on inner margin (in 75 m depth) exist as isolated patches (~200 sq. m), bulbous in shape, with boulders forming localised high relief (~1-2m) pinnacles and crevices bounded by a unconsolidated mud sediment with irregular and hummocky modification. Reef patches possibly with granite substrate. The mud sediment is affected by currents with some truncated ripples evident. Reef has a dense cover of sponges and seawhips (sponge garden) with both finger and broad irregular fronded sponges. Large numbers of juvenile redfish, as well as butterfly perch and small scorpaenids present.

South East Reef (SS9606 #237) (Fig. 7.2.7.8)

An isolated patch of inshore (< ~80 m), low-relief reef in the eastern Bass Strait region likely to have a sandstone/ limestone composition. Predominantly sediment-covered with occasional signs of exposed hard substrate that provides attachment for intermittent patches of intermediate to dense covers of finger and cup sponges. The reef is a mostly flat bottom but has some irregular raised areas (~ 40 cm in height). The degree of sediment cover is variable, but mostly thin (1-5 cm). Considerable water current was indicated by sponges vibrating and leaning in the direction of flow.

New Zealand Star Banks (SS9305 #121) (Fig. 7.2.7.9)

A massive, predominantly granite outcrop with a steep to vertical slope, crevices, debris fields and ledges and occasional intervening unconsolidated thin (~1-5cm) sand patches. Some outcrops show well developed hexagonal/ columnar jointing; some well-developed boulder fields consisting of large boulders and cobbles on granite and quartz sand. A low diversity of attached fauna and flora (compared to nearby biogenic reefs) with some low encrusting and calcareous algae, urchins, some seawhips and larger sponges at edges of reef. An apparently high energy environment with wave action and currents (noted substantial swimming activity of fishes to maintain position). Navigation chart notes breaking waves in this area during conditions of large ocean swell.

Little Horseshoe (SS9606 #236) (Fig. 7.2.7.10)

Predominantly sediment flat at the margin of the shelf-break in ~190 m depth. The shelf-break is a dramatic steep to vertical face with deep, water-worn crevices and fractures developed back from the edge. The sediment flat is mostly finely grained unconsolidated (mud), well sorted with some evidence of bottom currents and possible upwelling. At the shelf-break there are sparse ascidians, and below the drop-off some small finger sponges, ascidians (Polycarpa spp.) and pancake urchins. The high density of large particulate matter in the water column (marine-snow) was remarkable.

Smithy's Corner (Fig. 7.2.7.11)

A single photographic transect at this site across the isobaths of the canyon rim identified only soft-grounds, i.e. the reef and consolidated hard-ground was not surveyed. The soft-ground was predominantly a sediment flat of thick (> 5 cm) mud with organic debris on a flatly sloping bottom. Some areas of sediment modification due to currents were evident with distinct, well-formed, small-scale asymmetric ripples with wavelength (< 10cm) and amplitude (< 10cm). Occasional individual ascidians observed. In some areas the mud sediment appears to exist as a thinner cover (<1 cm) overlain with interspersed patches of shell (*Pecten* spp. and glycimerid bivalves), a sparse to intermediate density of small yellow ascidians (*Polycarpa* spp.), sea pens and occasional small sponge individuals. Marine snow was observed in the water column.

7.3 SUMMARY AND IMPLICATIONS

Aims of benthic habitat study

The study of benthic habitat aimed to define the structure and distribution of seabed types in a region of the South East Fishery used by the commercial fishing fleet. A basic map of the seabed was constructed from information kindly supplied by the fishing industry, and from a preliminary survey of the continental shelf between Wilson's Promontory and Bermagui. This map was developed to aid targeted sampling of specific areas with cameras, fishing gears and acoustics. Ultimately, this 'coarse-scale' map provided a complete overview of the region's seabed. Information from the targeted areas was used to produce 'fine-scale' maps, and to classify the physical and biological characteristics of the seabed at each site.

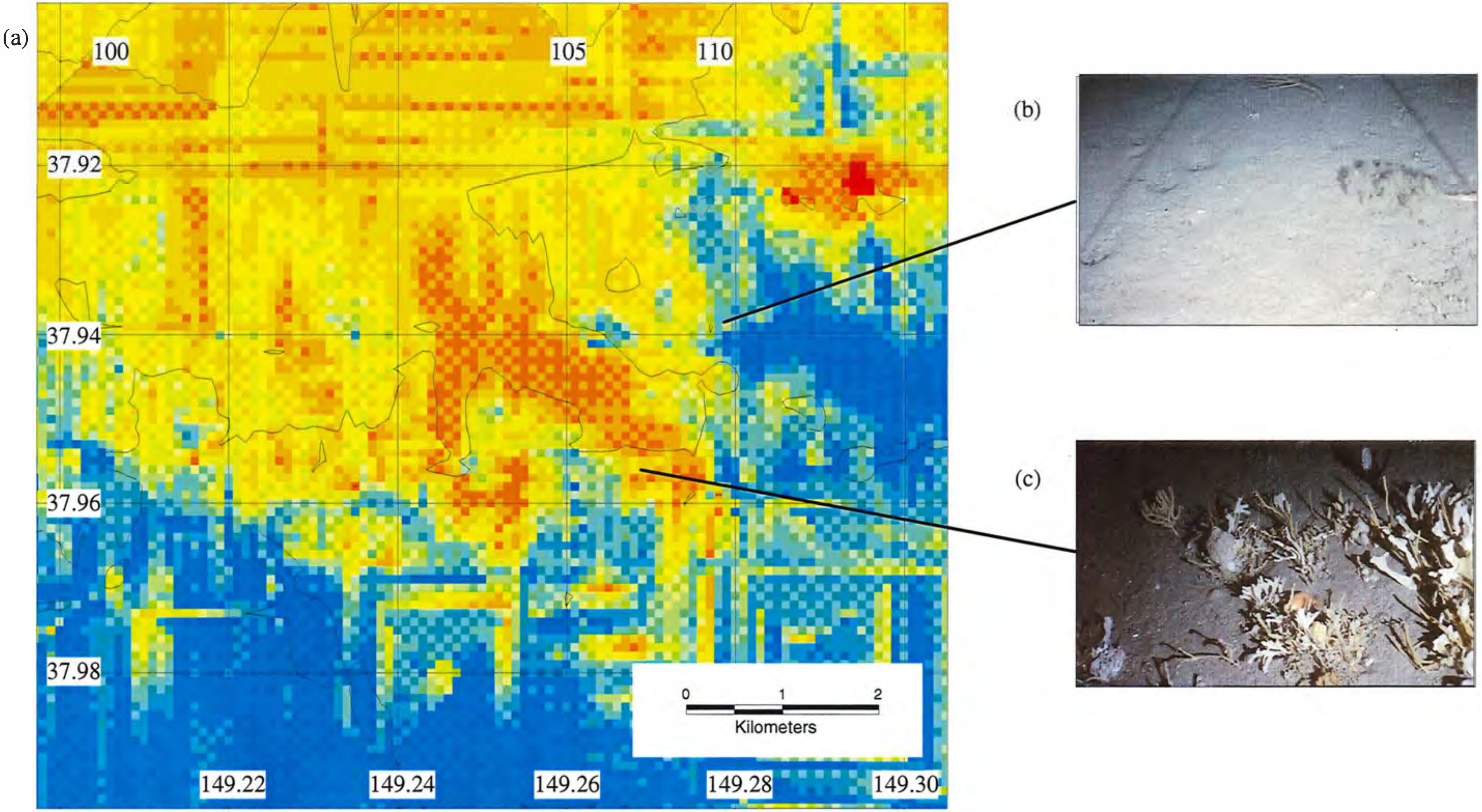


Figure 7.2.7.7 (a - c). Broken Reef mesohabitat showing (a) location and bathymetry overlaid on fine-scale habitat map (interpolated acoustic index of bottom roughness, red = most rough, blue = least rough). Images indicate habitat types and locations (b) soft and (c) hard.

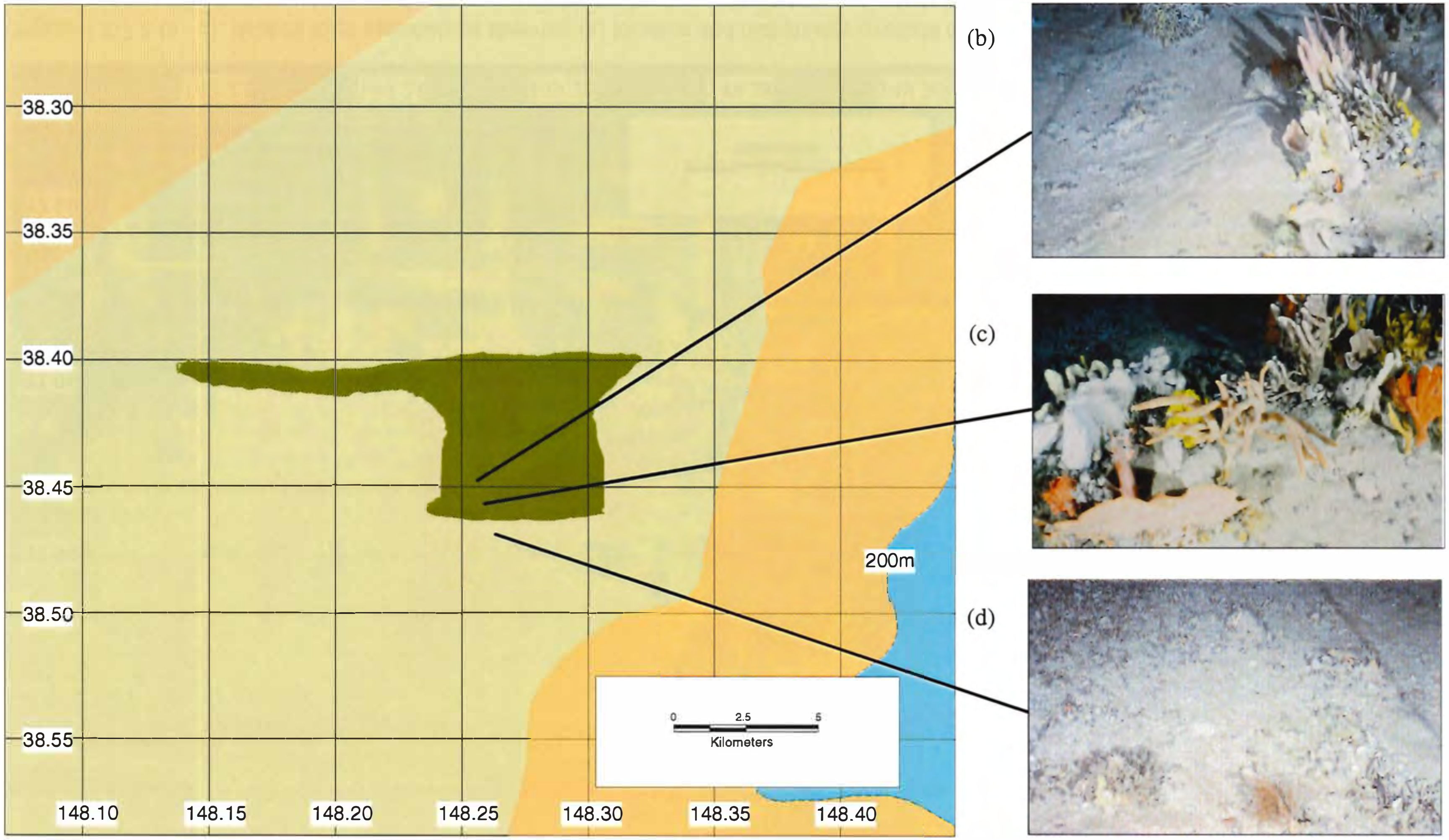


Plate 7.2.7.8 (a - d). Southeast Reef mesohabitat showing (a) location on a coarse-scale habitat map (from Plate 7.2.5.1) Images indicate habitat types and locations (b) soft, (c) hard and (d) rough.

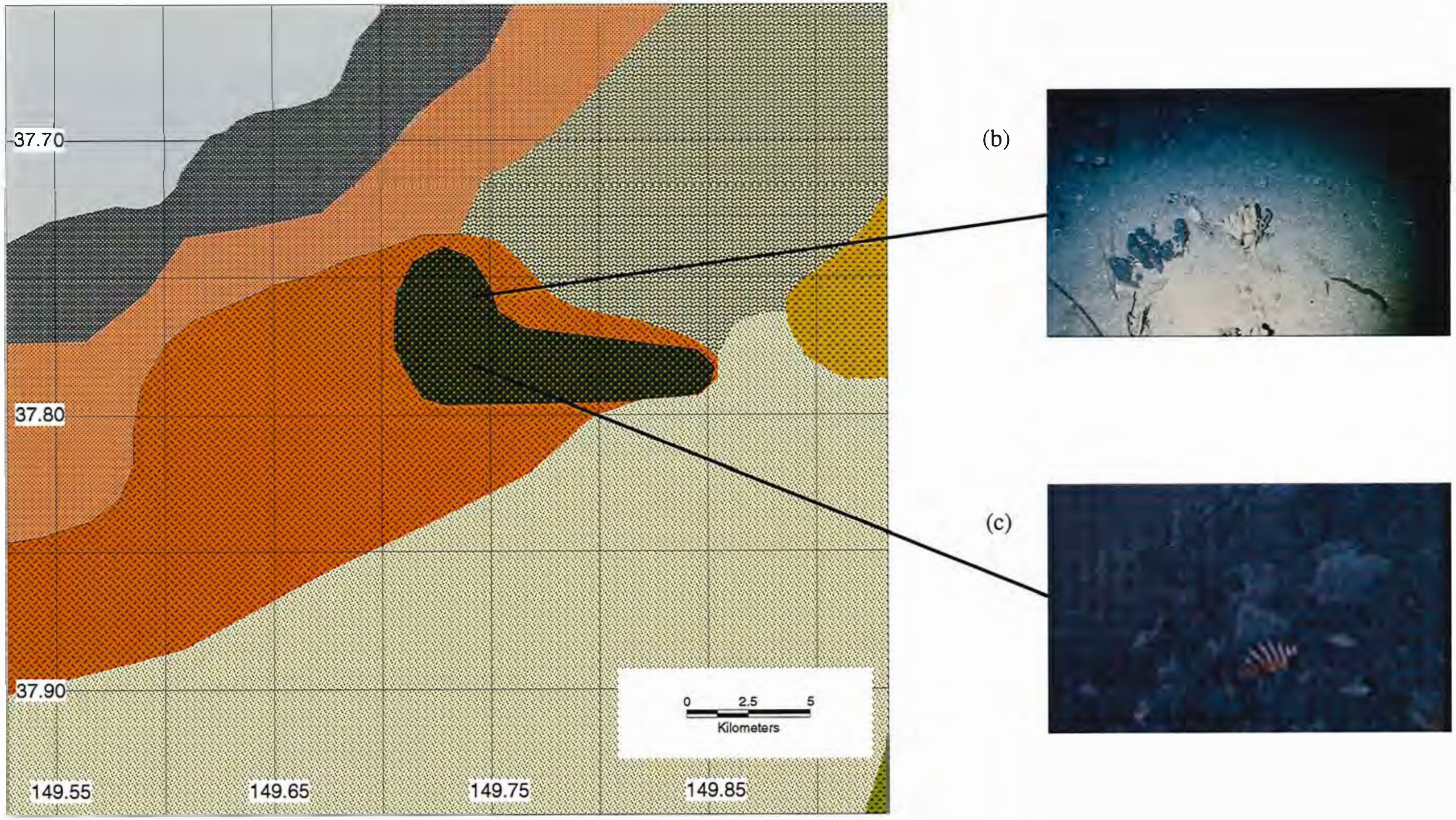


Figure 7.2.7.9 (a - c). New Zealand Star Banks mesohabitat showing (a) location on a coarse-scale habitat map (from Plate 7.2.5.1) Images indicate habitat types and locations (b) soft and (c) rough.

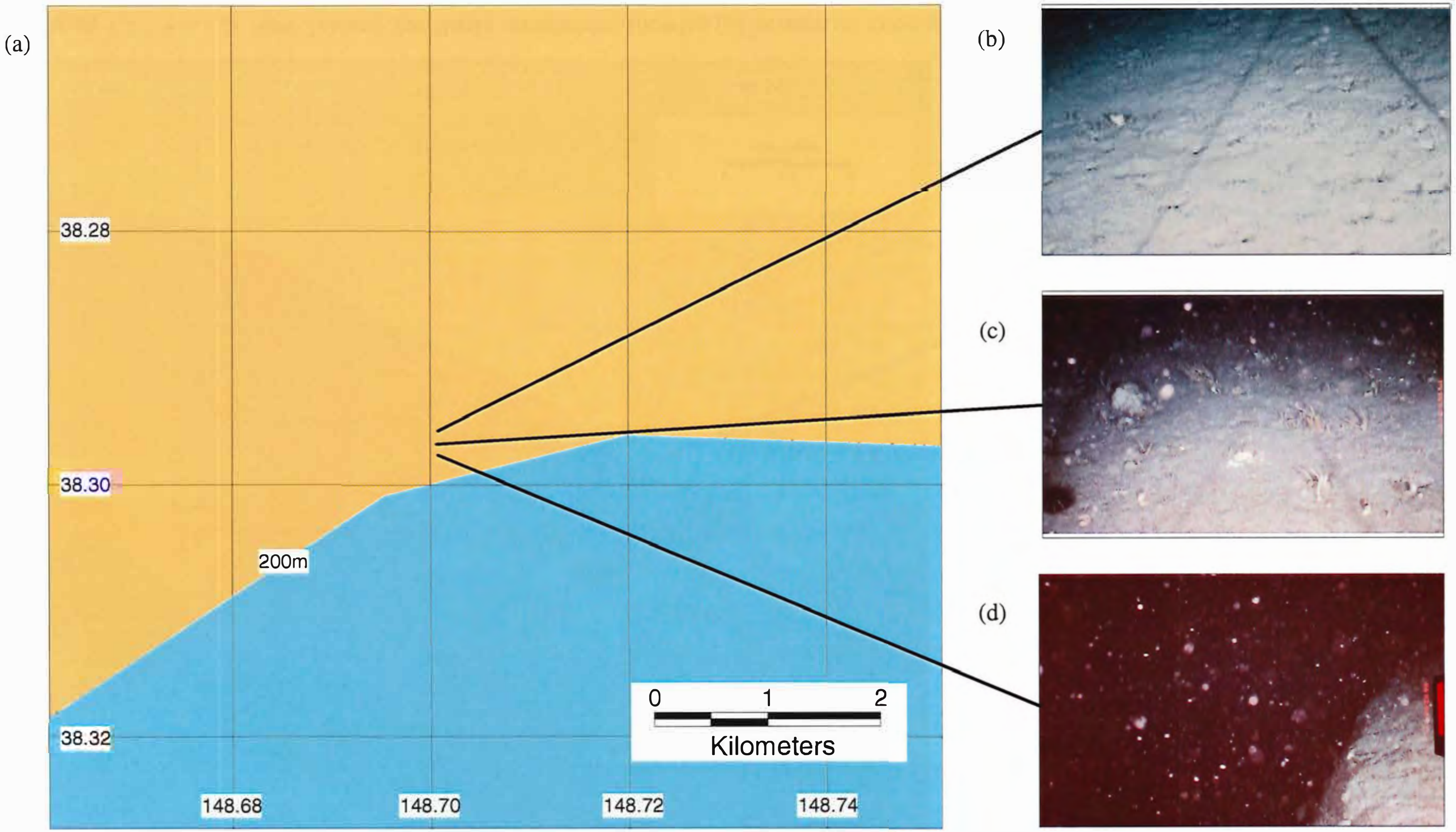


Figure 7.2.7.10 (a - d). Little Horseshoe mesohabitat showing (a) location on a coarse-scale habitat map (from figure 7.2.1.1) Images indicate habitat types and locations (b) soft, (c) hard and (d) rough.

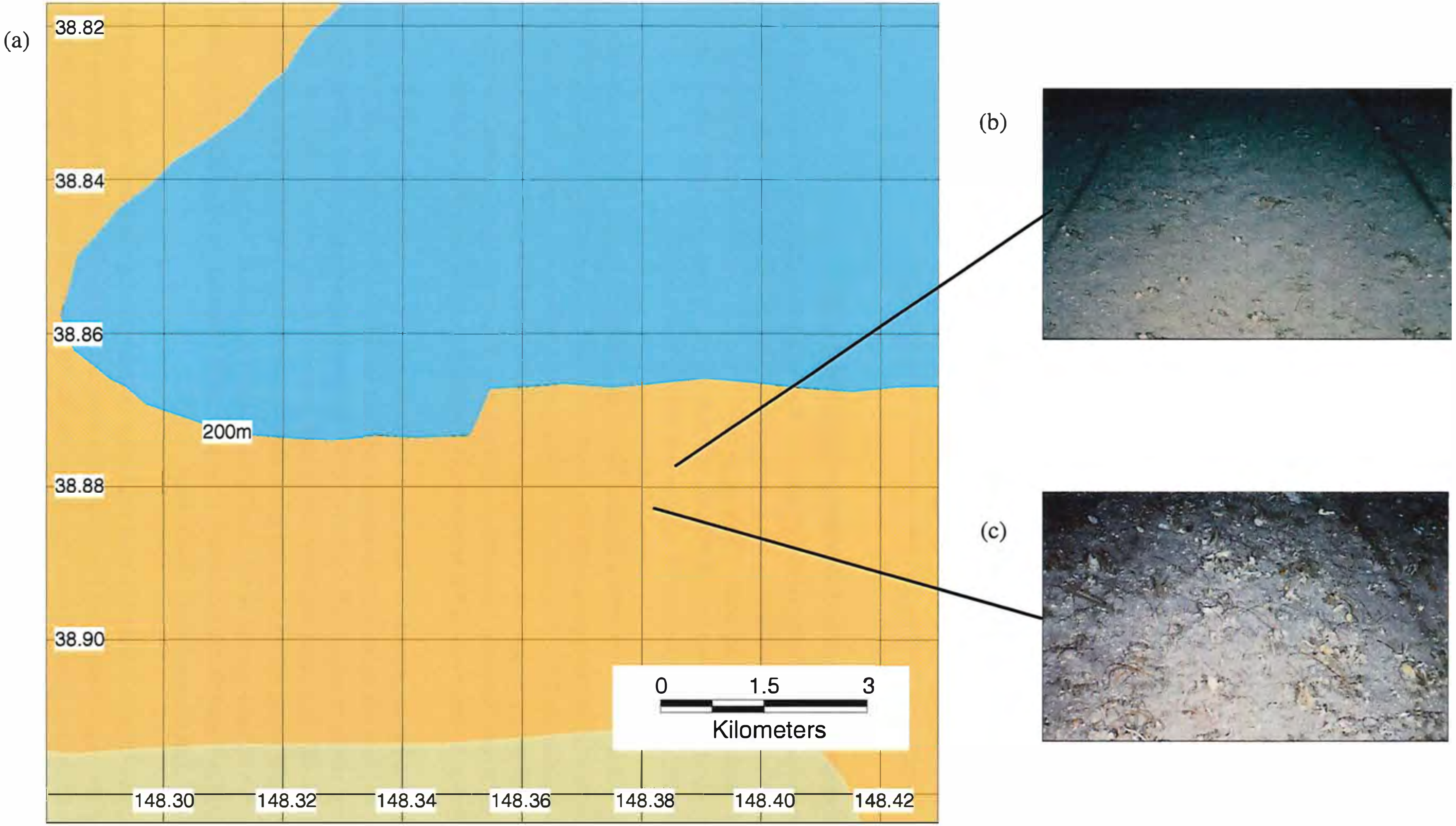


Figure 7.2.7.11 (a - c). Smithy's Corner mesohabitat showing (a) location on a coarse-scale habitat map (from figure 7.2.1.1) Images indicate habitat types and locations (b) soft and (c) hard.

Once classified, seabed types were used in conjunction with fish community information to identify the association of particular seabed types with particular fishes (i.e. to define habitats) (*Section* 8). This enabled us to assess the role of different habitat types for fishery production, (i.e. to define critical habitats).

Seabed types were also classified with respect to their vulnerability to damage from fishing gear. Their distribution was compared to the spatial distribution of commercial fishing effort to determine how the seabed is used by the fishing fleet and to evaluate the vulnerability of critical habitat (*Section* 11).

Overview of study area

The continental shelf seabed in 25-~200 m depths between Wilson's Promontory and Bermagui can be visualised as a series of extensive sediment flats ('soft-grounds') with interspersed outcrops of consolidated material ('hard-grounds'). Soft-grounds are composed of particulate material, primarily sands, muds and gravels, whereas hard-grounds include cemented sediments, reefs and bedrocks. These geological features are primary attributes of seafloor habitat for a demersal fishery, as their structure and distribution partly determines the distribution and abundance of fishes (*Section* 8), and therefore fishing effort. Most of the seabed in this region is fished commercially by board-trawling, mesh netting, Danish seining or trapping, although effort is concentrated in the most productive areas (*Section* 11).

Coarse-scale structure and distribution of benthic habitat

At a coarse-scale resolution (tens to hundreds of square kilometres) the area between Wilson's Promontory and Green Cape can be divided into 32 distinct habitat regions that represent the seabed 'landscape' at the scale of fishing grounds (Fig. 7.2.1.1). This is an appropriate scale at which to both summarise the distribution of habitat types within a regional fishery, and to examine the use of the seabed for commercial fishing (*Section* 11).

A classification of the 32 habitat regions into 'reef', 'broken-ground' or 'sediment flats' on the basis of their substrate type, contiguous extent and relief shows the vast majority (89% plan area) are sediment flats, with reefs and broken-ground making up, respectively, only 5.3% and 5.9% (*Section* 11). Finer scale resolution (hundreds of metres) would identify additional outcrops of reef (biogenic and bedrock) and patches of cemented hard-grounds in the sediment flats; however, these would not substantially change the overall proportional areas.

The soft- and hard-grounds of this region are scattered across a submarine shelf that is at present some 175 km wide in the western section adjacent to Wilson's Promontory but only about 25 km in the northern section off southern NSW. Sediment flats make up most of the wide western section off the Gippsland shoreline where hard-grounds are primarily (1) elongate, low-relief reefs parallel to the coastline on the inner-shelf (including the '40 and 28 Fathom Banks') and (2) patches of hard-ground at the shelf-break (including those at 'Smithy's Corner', 'The Spit', '10 x 10 Reef' and 'Little Horseshoe'). Isolated 'reefs' include the low-relief, outer-shelf 'South East Reef' and the near-shore 'Marlo Reef'.

Further east there is a higher overall proportion of hard-ground. Granite outcrops from sediment flats on the inner-shelf (Point Hicks and New Zealand Star Banks), and areas of low-relief, broken limestone and sandstone reef extend across the inner and mid-shelf. Shelf-break hard-grounds include 'The Horseshoe' and several adjacent hard banks, as well as patchy hard-grounds on mobile sediments through the 'Flower Patch'. Extensive sediment flats occur between the mid-shelf hard-grounds and the shelf-break.

The largest tract of hard-ground, in terms of both extent and relief, is the Howe/ Gabo Reef complex that extends north-south from the southeast corner of the shelf northwards to Cape Howe off NSW. Sediment flats east and west of the reef complex extend shoreward to inner-shelf reefs (which often extend from coastal headlands), and seaward to the shelf-break. There are numerous distinct reefs and patches of broken limestone reef occur on the relatively narrow sediment flats north of Eden.

Fine-scale structure and distribution of benthic habitat

At a finer scale (hundreds of metres to kilometers), each of the 32 habitat areas are mosaics of physical structures and biotic communities that vary in size and are patchily distributed.

The variation in the size and structure of hard-ground mosaics is illustrated by three habitats: Howe Reef, a large area (~300 sq. km) of mostly low-relief (< 3 m), scattered biogenic limestone reefs; Point Hicks Reef, an isolated high-relief (> 3 m) outcrop of granite bedrock occupying only some 11 sq. km; and the hard-grounds of the Flower Patch, cemented-sediment patches only centimeters in height and square metres in area scattered across an outer-shelf area of some 350 sq. km.

Hard-grounds provide a large surface area of attachment sites for epibenthic invertebrates that add to surface structural complexity and provide refuges for reef-associated fishes (*Section* 8). Complexity was relatively high on the limestone reefs; they often supported dense 'gardens' of sponges, seawhips and encrusting invertebrates and, particularly on the inner/ mid-shelf, had highly weathered surfaces. Community composition varied (*Section* 8), but could be simple and distinctive, for example, the clusters of large (>20 cm) stalked crinoids attached to the cemented sediment patches of the Flower Patch.

Sediment flats typically have a more repeated structure of ripples and dunes, shaped by water currents that sort the component grains. Ripples are largest (> 30 cm wavelength and amplitude) closest to shore where wind-driven currents affect the seabed in water depths of at least 60 m, and in areas prone to strong flows driven by other mechanisms. Accumulations of large grains, gravels, broken mollusc shells and live *Maoricolpus roseus* commonly fill the troughs of sand ripples. Muddy sediments, which occur in patches of varying size and shape, can support high levels of bioturbation in areas of high nutrient input.

The surface structure of soft-grounds is less complex than that of hard-grounds and offers fewer refuges for fishes. Epifaunal invertebrates such as branched sponges occur in the more muddy and sheltered sediment flats adjacent to Wilson's Promontory (western inner-shelf) and in Disaster Bay (*Section* 8), but at relatively low densities compared to hard-ground gardens. Epifauna are most scarce in the coarse-grained sediments of current-swept areas such as Gippsland inner-shelf. Low-relief (< 2 m) limestone ledges, isolated outcrops and assorted shipwrecks provide refuges in sediment flat 'landscapes', but they are separated by distances that are large relative to their size.

Composition of sediments and physical processes

The current sea level is at least 67 m higher than before the last glacial regression. This, and Australia's history of stability and relative aridity, results in continental shelf sediments that are derived from a mixture of relict and modern processes, and are often poorly sorted.

Reverse sorting is the regional pattern, with fine sand dominant along the inner-shelf, medium-grained sand further seaward, and locally coarse sand (or less frequently gravel), at the shelf-break. This pattern is disrupted in the study area by extensive areas of very fine sand and mud. These include one offshore from Lakes Entrance and others close to the shelf-break, especially around the 'Horseshoe', the shelf 'head' of the largest arm of Bass Canyon. Bryozoans commonly constitute over 60% of outer-shelf sands. This is possibly related to upwelling of nutrient-rich Antarctic water that supports "forests of living Bryozoa" in places on the outer-shelf.

Five primary types make up the massive sediments of the study area: (1) medium to well-sorted inner-shelf quartoze sands that are modern and more or less in equilibrium with present conditions; (2) poorly sorted, slightly quartoze, fine, shelly middle and outer-shelf sands that are of relict and modern origins; (3) very poorly sorted bryozoan sands forming extensive areas of middle and outer-shelf in the southern part of study area that are mainly relict; (4) extremely poorly-sorted muddy sediments off river mouths and of unknown modern and reworked relict origins; and (5) shelf-break gravels that are relict.

Modern organic matter, primarily chlorophyll *a* and, to a lesser extent, its breakdown compound phaeophorbide *a*, decrease with depth. The ratio of chlorophyll *a* to all pigments also declines with depth, indicating a decrease in the ratio of fresh to degraded material with depth. Pigment concentrations were significantly higher at the time of the plankton bloom on SS9405. There was seaward enrichment in stable carbon and stable nitrogen. Overall, these values are similar to the signature of marine phytoplankton in the area; however the trend for seaward enrichment and the particularly low values on the inshore station at Gabo, Point Hicks and Lakes Entrance on SS9606 may reflect a modest inshore macroalgal or terrestrial contribution.

In contrast, carbonate and organic matter increase with depth. So although middle and outer-shelf areas do not have the input of fresh chlorophyll found on the inner-shelf stations, they have higher biomass, as illustrated by the bryozoan forests that produced over 60% of mid- and outer-shelf sands. This higher biomass could result from less sediment sorting, generally lower metabolic rates, or deep upwelling of biomass from slope waters. It is probably a combination of all three, although the pattern of fine sands and muds at the head of arms of the Bass Canyon illustrate the contribution of deep upwelling.

Use of acoustics for fine-scale mapping

Visual observation of acoustic echograms linked with GPS provided a good initial discrimination of habitat types. Three relatively distinct macrohabitats–nominally soft, hard and rough– were clearly discriminated. The success of this method is not surprising, as it is the technique used successfully by fishers.

In this study, fine-scale mapping has been defined as hundreds of metres to kilometres; accordingly our acoustic-ping-based data processing has been summarised to this scale, using very simple indices of the complex acoustic returns (Chivers et al. 1990). Further, the acoustic hardness and roughness indices derived from the data have been treated as separate discriminators of seabed structure and overlaid with biological, photographic and video data. This, the simplest method of habitat classification, does not fully exploit the available information. It appears that the main advantage of data interpretation systems such as the one developed for RoxAnn is that they provide a shorthand notation of gross habitat types that can be mapped and recalled for future reference. They do not offer an improvement over visual examination of the echogram and would be subject to unrecognised (and therefore uncorrected) physical and electrical noise, unless raw data are also examined. The depth dependency of the RoxAnn habitat indices in this particular instance illustrates the importance of, first, looking at the raw echogram and secondly, of storing the digital data for post-processing.

The next step in the habitat classification process would be to combine the simple RoxAnn indices and perform alternative feature-extraction classifications such as Gaussian classifiers. More refined acoustic indices that use alternate feature-extraction techniques such as smooth ping analysis may offer far more information in the acoustic returns (FRDC project 93/058, Pitcher et al., 1999). A small subset of multi-frequency acoustic data collected in this study was analysed by the smooth ping method; it reduced misclassification of habitat type at fine scale from 27% to 8% (FRDC project 93/237, Kloser et al., 1998). This could be a major advance in our ability to correctly map and monitor seabed habitats with high statistical accuracy. The multi-frequency data we collected, together with the associated biological, sled, video and photographic data make up a largely unexplored data set for statistically mapping the habitat types of the SEF. These acoustic data should be analysed as a matter of high priority, using these or other advanced acoustic signal processing methods. The classification of habitat types should be explored with sophisticated discrimination systems (Gaussian, neural network, fuzzy logic classifiers) to combine the reflected acoustic, depth, biological and associated groundtruth data.

Regardless of the acoustic system used, extensive ground-truthing is required. While fishers use the composition of their catches and damage to fishing gear to "train themselves" in interpreting echograms, photographic records are indispensable in a scientific survey. Direct observation of macrohabitats by a towed video system was very useful in validating their biological significance.

From this study it is difficult to comment on the ability of acoustics to define fine scale habitat boundaries. Comparison of the separate simple acoustic indices with the fishers trawl tow data confirmed that the trawl tows are not consistent with changes in acoustic hardness and roughness indices. It would be necessary to conduct a detailed examination of the fishers' trawl lines and establish the actual seabed structure they are covering before a comparison can be made. Also it needs to be established that the fishers are using the same geo-reference we used (WGS84). Differences in the geo-reference can lead to changes in position of 150 m.

Habitats and fishing

The distribution of commercial fishing effort relative to seabed habitat is dealt with in *Section* 11; however some effects of the measured spatial variability in seabed habitat on fishing are noteworthy.

The precise locations of sampling stations in this study, as with most trawl surveys, was determined without detailed knowledge of the spatial distribution of 'untrawlable' ground (i.e. other 'hard-ground' fish habitats). Stations sampled on 'trawlable' ground vary in their proximity to other habitat types, such as reefs, so the likelihood of catching the many species that use reef and sediment flat habitats will vary. The consequence is that the effects of habitat on catch rate and catch composition may be incompletely reported or remain undetected.

The spatial variability of seabed habitat is at several different scales. The same uncertainty applies to the location of sampling stations in relation to fishing grounds. Commercial fishing grounds are fished because they are the most productive habitats, but this information was not used to determine the positions of survey stations, nor is it applied to analysis of commercial CPUE data (because the location of commercial effort cannot be compartmentalised by habitat type). It is clear that commercial fishing effort is not randomly spread across habitats of varying productivity. As new information, or new methods of collecting information, become available to fishers, their ability to concentrate on the more productive areas will increase.

The habitat-mapping process

The first map of seabed habitat in the SEF (Australia's most important trawl fishery for scalefish) was produced by this study some 100 years after fishing began in the region. However, our map covers only some 11% of the SEF continental shelf (23,950/ 222,400 sq. km), itself a small fraction of the total SEF. Construction of the map was greatly facilitated by the fishing industry, whose most-experienced operators know the seabed 'landscape' intimately. There is a great divide in knowledge of the seabed between the fishing industry and other parties (fishery scientists, fishery managers, marine cartographers, conservationists). This is clearly demonstrated by the fact that names for regions and features of the seabed 'landscape' are largely theirs.

Implications

1. The present-day form of the seabed is due to ancient geological processes, as well as ancient and modern biological and ocean processes. This has resulted in a compound mosaic of habitat types, each with different influences on biotic assemblages.

2. Relict and modern shelf-break bryozoan forests constitute much of the mid- and outer-shelf sands. Their productivity reflects (in part) deep upwelling. This enhanced productivity would also increase modern biological processes on the outer-shelf, compensating for the reduced inputs of primary production from the water column above.

3. The compound mosaic of seabed habitat types would affect the distribution of biotic assemblages and fishers' efforts to exploit them. Knowledge of this seabed landscape is necessary to interpret commercial fishing data, and to evaluate and/or alleviate anthropogenic impacts on biodiversity.

4. Mapping is needed at two scales to understand the importance of seabed habitats in the context of a regional fishery or fishery ecosystem. 'Coarse-scale' (tens to hundreds of square kilometres)— the scale at which the commercial fleet uses fishing grounds; and 'fine-scale' (hundreds of metres to kilometres)— the scale at which fishes use habitats and the physical structure of the seabed is modified by fishing. Productive hard-ground habitats for fishes on the SEF continental shelf (mainly biogenic limestone or bryozoan reefs), and productive fishing 'hot-spots' in fishing grounds exist at fine-scales. Accordingly, targeted fine-scale mapping is required to evaluate the fishery/ habitat interactions, and subsequently for effective spatial management.

5. Habitat mapping requires a toolkit consisting of acoustics to provide a map of putative habitats, cameras to describe these habitats, and physical samplers to identify the biological communities and processes associated with the features. Geological sampling of hard-grounds may also be necessary to determine their vulnerability to damage by fishing gears. Coarse-scale mapping with only acoustics and cameras can provide rapid and relatively low-cost assessments of large areas, whereas fine-scale mapping, which incorporates intensive physical sampling, is relatively time-consuming and expensive.

6. Single-beam acoustics are an effective means of mapping the seabed, but indices derived from digital data currently provide only contrast between seabed types and not identification of substrate type. Conventional (commercial) indices are also susceptible to depth-related bias. Thus, development of robust acoustic indices that can be generated from research and commercial depth-sounders remains a challenge for habitat mapping. More sophisticated feature-extraction classifications (e.g. smooth ping analysis) will enable seabed mapping with a higher reliability and statistical accuracy.

7. The physical structure and spatial integrity of reef habitats determine the extent to which they are modified by fishing gears. Large tracts of hard, high-relief, fossiliferous reef or bedrock outcrop are most resilient, smaller patches of softer, low-relief sandstone and fossiliferous reef are vulnerable to erosion, while reef-forming bryozoan beds may be completely removed. Because the seabed of the study area has been actively fished for more than a century it is not possible to evaluate the extent to which it has been modified by fishing gears. However, anecdotal evidence from the fishing industry indicates that grounds that were once productive for a variety of commercial species (e.g. 'Ten x Ten Reef', '7-Hour Bank', '6-Hour Reef) no longer support reef-associated species such as morwong, snapper, striped trumpeter and crayfish, possibly because of habitat modification.

8. Despite the clear dependence of ESD-based fishery management on maps of benthic habitats, only a small fraction (~11%) of the SEF shelf seabed has been mapped to date. It is not possible to directly extrapolate the structure and distribution of seabed features from our map to other regions of the continental shelf or the continental slope because each has a different geology, biology and hydrology. Because of the large areas involved, future mapping should be targeted, undertaken at scales appropriate to management initiatives, and use data taken by commercial vessels during fishing operations.

9. Collaboration with the fishing industry for habitat mapping is highly desirable because (1) fishers know the seabed landscape considerably better than other stakeholders (including researchers), (2) they have a broad understanding of the processes that influence fishery productivity, (3) they potentially provide the means for cost-effective acquisition of acoustic data over large areas, and (4) they have an important stake in ensuring that any spatial management of fishing effort is based on appropriate information interpreted appropriately.

10. Collaboration with industry is not limited to acquiring their data, but requires an ongoing dialogue if the data are to be interpreted judiciously, and industry is to understand the value of any proposed management measures.

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8 BIOLOGICAL COMMUNITIES

Alan Williams, Nicholas Bax and Karen Gowlett-Holmes

In this section we determine the composition and distribution of biological communities (fishes and invertebrates). We used the structure of biological communities to determine 'habitat types' with habitat defined as "simply the place where an organism lives" Hudson *et al.* (1992). Physical characteristics and productivity of habitat types were determined from the physical and biological habitat descriptors– oceanographic, production, seabed– listed in *Sections* 5 to 7. Habitats at the regional scale were determined from the broad-scale sampling and compared to water-mass structure and water-column productivity, while habitat organised at the smaller scales of seabed type and topography were determined from focussed habitat sampling. The results were used to evaluate the importance of hard-ground to the productivity of the fishery. Biological data collected from specimens provided the means to assess the size (age) distributions of quota and other key species (*Section* 9), and to define trophic linkages (*Section* 10).

8.1 METHODS

Invertebrates were sampled with a combination benthic sled that provided information on the epifaunal (surface dwelling) species and infauna (sub-surface dwelling) species. We used three gear types–trawl, gillnet and trap–to sample fish in both 'soft-ground' and 'hard-ground' habitats, and to assess the selectivity of the gears in different habitat types.

8.1.1 Invertebrate Communities

Invertebrate samples for broad scale habitat delineation were first collected on surveys SS9305 and SS9405. Invertebrate samples were to be identified to the lowest possible taxonomic level but this approach was not successful because full sorting and identification of samples could not be completed within the project resources–catches were highly diverse and contained many undescribed taxa. Partially sorted samples have been shipped to museums in Australia, New Zealand and the United States to assist their research on specific invertebrate phyla.

A more rapid invertebrate sampling procedure was required. A classification based on functional taxonomy was developed and tested on the SS9602 focussed habitat survey to provide the information on invertebrate distributions and community structure. This system was successful and used in a repeat of the broad scale sled survey on cruise SS9606 (Fig. 8.1.1.1) and the results analysed for this report. In the functional approach, biological data are categorised according to ecological attributes instead of (or in addition to) taxonomic categories. The approach was first applied to freshwater pelagic communities (Sprules and Holtby 1979). Gagnon and Haedrich (1991) applied a functional approach based on a combined feeding ecology/body size approach to the study of benthic communities on the Labrador/Newfoundland shelf, justifying this on the basis that distribution and abundance of functional groups are strongly correlated to the physical environment. They concluded that a functional approach based on the feeding ecology and body size of benthic invertebrates allows easier interpretation of community structure than the taxonomic approach based on families. In this study we used a functional approach based on the habitat requirements of benthic invertebrates (Table 8.1.1.1).

Epifauna and infauna were collected with a modified 'Triple-D' demersal sled, capable of simultaneous sediment, infaunal, epifaunal and photographic sampling. The sled is 0.65-ton, 2.9-m wide and divided into two sides–an epifaunal side with a length of heavy chain suspended cross-wise beneath a cage of 10-mm anodised steel mesh, and an infaunal side with a 8.5-cm wide plough extending 10 cm below a similar mesh cage at an angle of 32°. The sled was towed at 1 m/s for 20 minutes and invertebrates extracted by either the chain or plough were filtered by the water flow though the steel mesh cages. Individuals or pieces that did not pass through the steel mesh were collected in two 2.5-cm stretched mesh cod-ends. Finer mesh 1.0-cm stretched mesh cod-ends were used within the larger cod-ends to collect a sub-sample of smaller organisms. However, visual examination showed the samples did not provide information additional to that from the 2.5-cm mesh cod-ends and the samples were not analysed further.

Epifaunal and infaunal samples were treated separately at all stages. First, the total weight of the sample was taken. If the sample was large (> 50kg of biological material) and not dominated by one or two large specimens, a sub-sample was taken. The sub-sample was sorted to taxonomic fractions as described below and weights taken; specimen numbers were not taken as many of the organisms were colonial or modular. Dead shells and dead material were weighed and discarded, after they had been checked for hermit crabs, sipunculans or other animals. Some shells, especially gastropods like *Maoricolpus roseus*, were held in shallow dishes of water for 24 hours to separate live from dead organisms. Bivalves and gastropods collected in high numbers were measured along the longest axis with electronic calipers.

Catches or subsamples were sorted to major taxa. A major taxon could be a phylum (e.g. Porifera, Bryozoa), class (e.g. Ascidiacea), or a species for the better known organisms (e.g. within Mollusca). Where the major taxon was higher than species, it was usually divided further based on its functional characteristics that were expected to be related to habitat type (e.g. Bryozoa were divided into soft, fenestrate and massive). Representative specimens of each taxonomic or functional unit were photographed and an identification key made to ensure consistent taxonomic classification throughout the study.

Fish were caught infrequently in the infaunal but frequently in epifaunal samples and processed in the same manner as fishes from other gears described in the following sections. Fish were not included in the multivariate analyses.

Multivariate analysis of functional taxa was used to examine invertebrate assemblage structure. Catch data were analysed as weight of each functional taxon, standardised by duration of a tow. Similarities of stations based on their invertebrate assemblages were analysed using modules of the PRIMER program (Carr 1996): CLUSTER (hierarchical agglomerative clustering) was used to form groups of samples (macrohabitats) based on between-sample similarities, and MDS (non-metric multidimensional scaling) used to display between-sample similarities in 2-dimensional (2-d) space. In all analyses the Bray-Curtis similarity index (Legendre and Legendre 1973) was used. Data were analysed untransformed, and transformed with square root, double square root, and presence/absence to provide analyses that emphasised species biomass through to species richness (respectively). The transformation that led to the lowest stress in the MDS and appeared to provide the clearest assemblage structure was selected for further analysis. The contribution of each functional taxon to 1) the similarities within groups of

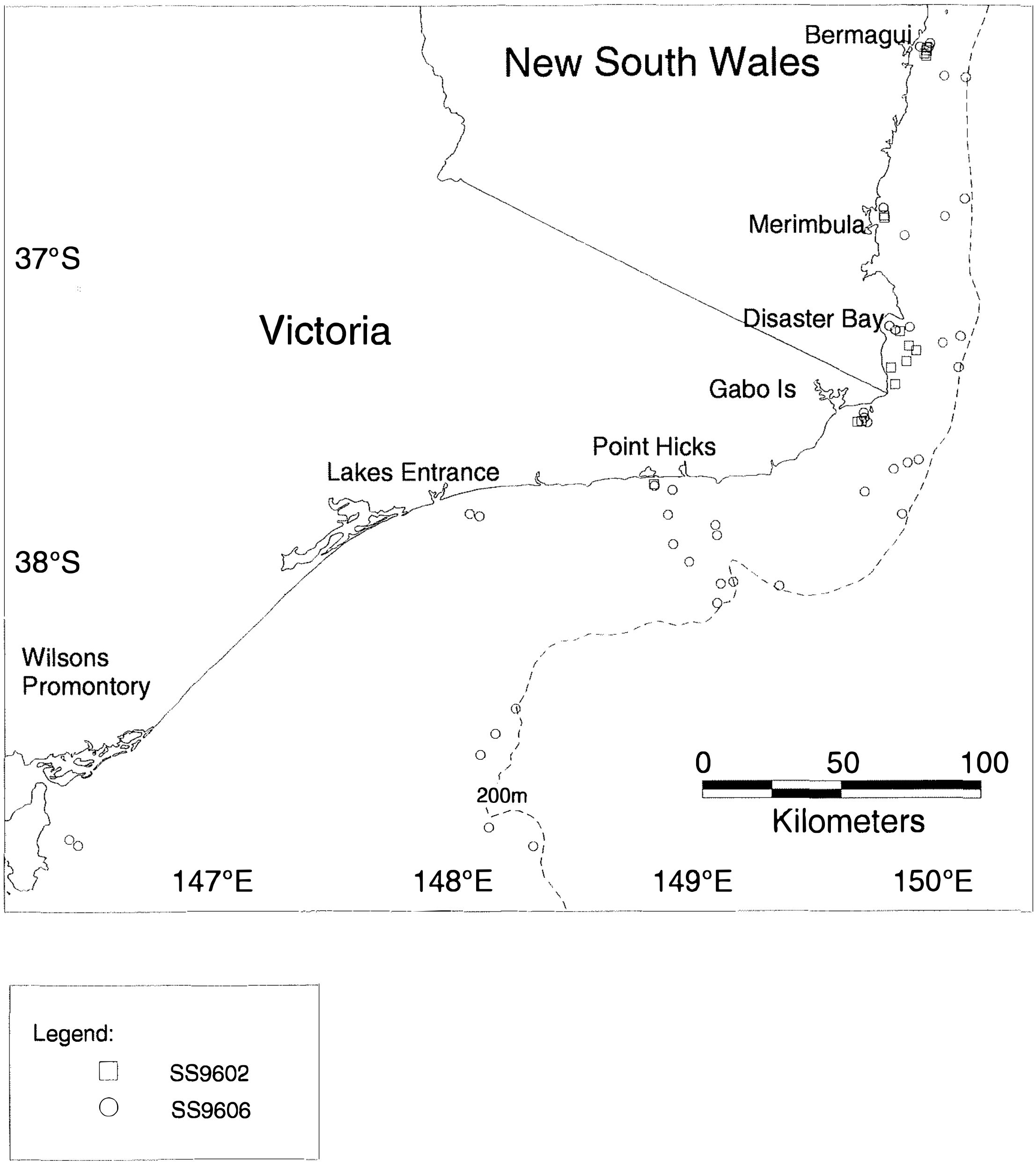


Figure 8.1.1.1 Location of invertebrate samples taken on SS9602 and SS9606. (Benthic invertebrate samples on earlier surveys were not fully analysed and are not presented here).

Table 8.1.1.1. Functional taxonomic categories used to classify invertebrate samples collected with the benthic sled.

PHYLUM	CLASS etc	SCIENTIFIC NAME	COMMON NAME	COMMENTS
Porifera		Porifera (low encrusting)	Sponges - low & encrusting	Low lumps, encrusting sheets, prostrate forms
Porifera		Porifera (in sand)	Sponges - in sand	Enbedded in sand - most of animal below sand level
Porifera		Porifera (lumpy)	Sponges - lumpy	Massive, erect lump forms
Porifera		Porifera (bushy)	Sponges - bushy	Erect bushy, branching forms, finger sponges
Cnidaria	Hydroida	Hydroida	Hydroids	Small to large colonies, usually attached to reef or other hard substrate
Cnidaria	Ceriantipatheria	Antipatharia	Black coral	Tall, branching colonies attached to reef
Cnidaria	Octocorallia	Gorgonacea (bramble coral)	Bramble coral	Low, small, rambling colonies
Cnidaria	Octocorallia	Gorgonacea (sea whip)	Sea whips	Long whip-like colonies, unbranched
Cnidaria	Octocorallia	Gorgonacea (sea fan)	Sea fans	Erect, branching colonies
Cnidaria	Octocorallia	Alcyonacea	Soft corals	Erect, bushy colonies - shape changes considerably from contracted to expanded form.
Cnidaria	Octocorallia	Pennatulacea	Sea pens	Erect colonies anchored in sand but not fixed in position
Cnidaria	Anthozoa	Anthozoa (anenomes)	Anemones	Species usually fixed to hard substrate
Cnidaria	Anthozoa	Anthozoa (burrowing anenomes)	Burrowing anemones	Sand-burrowing anemones, including cerianthids, edwardsiids etc
Cnidaria	Anthozoa	Scleractinia (colonial)	Colonial stony corals	Usually fixed to reef
Cnidaria	Anthozoa	Scleractinia (solitary)	Solitary stony corals	Usually fixed to reef
Bryozoa		Bryozoa (massive)	Massive bryozoans	Massive, erect, hard bryozoans
Bryozoa		Bryozoa (encrusting)	Encrusting bryozoans	Hard, encrusting bryozoans, not massive
Bryozoa		Bryozoa (fenestrate)	Fenestrate bryozoans or lace cora	Lace-like, hard bryozoans
Bryozoa		Bryozoa (branching)	Branching bryozoans	Erect, hard bryozoans with fine branches, mainly small
Bryozoa		Bryozoa (soft)	Soft bryozoans	Lightly calcified colonies, usually very bushy
Kamptozoa		Entoprocta-Kamptozoa	Entoprocts	Mainly small branching colonies
Brachiopoda		Brachiopoda	Lampshells	Usually attached by pedicle to hard substrate
Nemertea		Nemertea	Nemerteans or Ribbon Worms	Usually in rubble
Sipuncula		Sipuncula	Sipunculan or Acorn Worms	In sediment or rubble
Echiura		Echiura	Echiuran or Spoon Worms	In sediment or rubble
Annelida	Polychaeta	Polychaeta (tubeworms)	Tubeworms	Sessile polychaetes with tubes
Annelida	Polychaeta	Polychaeta (errant)	Errant polychaetes	Errant species - not sessile
Annelida	Polychaeta	Polynoidae	Scale worms	Usually associated with reef or other hard substrate
Mollusca	Gastropoda	Gastropoda	Snails (not otherwise specified)	Includes all gastropods other than those recognised as individual species
Mollusca	Gastropoda	Maoricolpus roseus	NZ Screw Shell	In very fine to fine sands, often in very large numbers
Mollusca	Gastropoda	Gazameda gunni	Native Screw Shell	In very fine to fine sands, not in large numbers
Mollusca	Gastropoda	Fusinus novaehollandiae	Spindle Shell	A major scavenging sand-dwelling snail
Mollusca	Gastropoda	Opistobranchia	Sea slugs, including nudibranchs	
Mollusca	Bivalvia	Bivalvia	Bivalves or cockles	Includes all bivalves other than those recognised as individual species
Mollusca	Bivalvia	Glycymeris spp.	Dog Cockles	All freeliving in sand, usually require fine-medium sands, not compacted
Mollusca	Bivalvia	Pecten fumatus	Commercial or King Scallop	Lives buried (flat side up) in sand as adult
Mollusca	Bivalvia	Chlamys asperrima	Sponge or Doughboy Scallop	Adult attached by byssus to hard substrate (e.g. rock, lg bryozoan). Swim away if threatene
Mollusca	Bivalvia	Neotrigonia margaritacea	Brooch Shell	Freeliving in fine-medium sand
Mollusca	Bivalvia	Eucrassatella kingicola	Giant Cockle	Large freeliving cockle in fine-medium sand
Mollusca	Scaphopoda	Scaphopoda	Tusk shells	Strictly sand burrowing, but sometimes found in sand pockets on reef
Mollusca	Cephalopoda	Sepia sp.	Cuttlefish	Very active species with den in reef

stations, and 2) the dissimilarities between station groups was calculated using the SIMPER (percentage similarities) module.

One sled sample was taken at each trawlable macrohabitat within the key mesohabitats (see Table 8.1.3.1).

8.1.2 Fish Communities–Broad Scale

Samples of fishes were collected by trawl at 33 stations on each seasonal survey (Fig. 4.1.1.1; A5 and F1 untrawlable). Replicate samples were taken in winter at some depths on certain transects (Table 8.1.2.1) but in other seasons a single trawl was taken at each station. Some samples were taken during the night in winter, but in other seasons all sampling was during the day. Trawls were of approximately 30 minutes duration at a speed of approximately three knots.

A commercial trawl, designed and made by McKenna net-makers of Hobart, Tasmania for the multispecies shelf fishery off southeastern Australia, was used throughout. The net is a demersal two-panel design with a total length of ~54 m, a headline of 37.6 m buoyed by 56 x 200 mm diameter floats, and a footrope of 41.3 m with ~150 mm diameter punched-disc rubber rollers. Its mesh sizes decreasing from ~220 mm (9") in the wings, square and belly to 40 mm (~2") in the cod-end liner. In operation the net had a wingspread of ~20 m and headline height of ~3 m and was fished from twin warps behind Polyvalent trawl doors.

The numbers and weights of all species were recorded from each sample. Taxonomic identifications were based primarily on Last & Stevens (1994) and Gomon *et al.* (1994) but also relied on a set of illustrated field identification sheets compiled during the study.

Multivariate analysis of species distributions was used to examine fish assemblage structure in relation to area and season. Catch data (numbers and weight of each species) were standardised to swept areas of seafloor based on the duration and speed of a tow for the standard gear configuration. Similarities of stations based on their fish assemblages were analysed using modules of the PRIMER program (Carr 1996): CLUSTER (hierarchical agglomerative clustering) was used to form groups of samples (macrohabitats) based on between-sample similarities, and MDS (non-metric multidimensional scaling) used to display between-sample similarities in 2-dimensional (2-d) space. The contribution of each species to 1) the similarities within groups of stations, and 2) the dissimilarities between station groups was calculated using the SIMPER (percentage similarities) module. In all analyses the Bray-Curtis similarity index (Legendre and Legendre 1973) was used following double square root transformation of the abundance data to stabilise its variance.

8.1.3 Fish Communities–Focussed Habitat

Survey Design

Samples of fish were collected by gillnet, trap and trawl from eight macrohabitats during two surveys in 1996 and 1997 (Table 8.1.3.1). Inner shelf sites (depths less than ~100 m) were trawled SS9602 and sampled by gillnet and trap from commercial fishing vessels (SF9602 and EJ9602). Deep sites (depths greater than ~100 m) were trawled on SS9606 and sampled by gillnet and trap on SF9701. The physical and biological attributes of each macrohabitat were assessed by acoustics, invertebrate and sediment sampling, and photographic surveys from the research vessel (*Section* 7).

The above fishing gears met our need to sample a variety of seafloor types, but not all macrohabitats could be sampled with each gear; in particular, 'rough' macrohabitats could not be trawled. Where possible, each macrohabitat was sampled with two sets of gillnets, two sets of five traps, and two or three trawls. A trap sample was taken day and night during the first survey but, due to negligible nighttime catches, this was reduced to daytime only during the second survey. A pair of gillnet samples were taken during day and night in both programs; all trawl samples were taken during the day. Gillnets and traps were deployed at sunrise and retrieved one to two hours before sunset, and at night, deployed just after dark and retrieved prior to sunrise. Trawls were of approximately 30 minutes duration at a speed of approximately three knots.

The numbers and weights of all species were recorded from each sample. Taxonomic identifications were based primarily on Last & Stevens (1994) and Gomon *et al.* (1994) but also relied on a set of illustrated field identification sheets compiled during the study.

Details of Fishing Gears

Gillnet design reflected our need to sample a wide range of species of varying sizes and vulnerability, on soft and rough substrates, often in strong currents. A suitable design for the net fleet consisted of two panels of each of six mesh sizes (50, 76, 100, 125, 150, 175 mm). A set of six panels (one of each mesh size) was ordered randomly, and then replicated by the second set. The panels had a hanging ratio 0.5, and a hanging coefficient 0.87; the monofilament line sizes were 0.62, 0.62, 0.81, 0.9, 0.9, 1.05 for the six mesh sizes respectively. Each panel measured 90 x 2.8 m and was separated by a 40 m gap giving the net a total length of ~1.5 km. The ground line was heavily weighted (38 kg per panel) and the float line buoyant (11.4 kg per panel) due to the high current speeds expected in some areas. For the same reason, 20 kg grapples were used to anchor the centre and each end of the net fleet. Two net fleets were rotated and damaged mesh mended or replaced between sets.

Our trap design was based on a commercial trap used in the region. It consisted of a rectangular hardwood frame (1.8 x 1.5 x 1.2 m) covered with 40 mm narrow-gauge wire mesh. The entrance was a single, inward facing wire mesh cone, 550 mm reducing to 300 mm, with a entrance slot of 300 x 50 mm. Each trap was baited with a fast release 500 ml berley block of minced pilchard, tuna, jack mackerel and abalone, and a whole striped tuna. The berley, contained in a slotted basket, and the tuna impaled on a skewer, were positioned in the centre of the trap (about 600 mm behind the front panel). Each trap base was weighted with ~15 kg wire and anchored with a 20 kg grapple from a polypropylene bridle. The traps were conditioned (soaked) prior to use; maintenance included re-tensioning the wire walls as necessary to prevent strumming in high currents. Typically, traps were deployed in sets of five; spacing was ~200-300 m to give a similar spatial coverage to the gillnet.

The trawl used is described in *Section* 8.1.2.

Data Analysis

Multivariate analysis of species distributions was used to examine fish assemblage structure in relation to macro- and mesohabitats. Catch data (numbers and weight of each species) were

Table 8.1.2.1 List of trawl stations from seasonal broad-scale surveys. Codes far transects and depths follow Fig. 4.1.1.1

Cruise	Station	Depth (m)	Transect code	Depth stratum	Latitude	Longitude
SS0593	72	84-92	B	3	-38.7383	148.2970
SS0593	74	106-118	B	4	-38.6400	148.3270
SS0593	76	210-245	B	5	-38.5550	148.4280
SS0593	79	84-72	A	3	-38.9317	148.3220
SS0593	81	123-125	A	4	-38.9767	148.4880
SS0593	83	200-209	A	5	-39.1033	148.5430
SS0593	84	185-151	A	5	-38.9400	149.4970
SS0593	85	25-24	A	1	-38.9838	146.5460
SS0593	87	42-41	A	2	-39.0133	146.5780
SS0593	102	42-42	B	2	-37.9250	148.2070
SS0593	104	30-32.5	B	1	-37.8650	148.8660
SS0593	106	28-28	C	1	-37.8083	149.0650
SS0593	108	49-46	C	2	-37.8250	149.0850
SS0593	110	72-78	C	3	-37.8733	149.1130
SS0593	112	114-114	C	4	-38.0150	149.2150
SS0593	114	210-230	C	5	-38.1945	149.2740
SS0593	124	172-160	E	5	-37.4083	150.2920
SS0593	127	112	E	4	-37.3317	150.1930
SS0593	129	80-80	E	3	-37.3367	150.0580
SS0593	130	40-40	E	2	-37.2950	150.0200
SS0593	132	16	E	1	-37.2767	150.9770
SS0593	140	22-31	E	1	-37.2767	149.9700
SS0593	141	115-117	E	4	-37.2983	150.2200
SS0593	142	143-169	F	5	-36.9100	150.2920
SS0593	147	38-44	F	2	-36.9133	149.9580
SS0593	150	70-68	F	3	-36.9483	150.0420
SS0593	153	115-115	F	4	-36.9417	150.1970
SS0593	160	37-43	F	2	-36.9217	149.9570
SS0593	161	205-216	E/F	5	-37.2083	150.3450
SS0593	169	26-26	C	1	-37.8067	149.0000
SS0593	172	208-234	C	6	-38.1933	149.2830
SS0593	174	230-240	C	6	-38.1983	149.2750
SS0593	175	202-280	C	6	-38.1933	149.2630
SS0593	176	204-284	C	6	-38.1917	149.2620
SS0593	177	230-248	C	6	-38.1917	149.3050
SS0593	178	240-250	C	6	-38.2067	149.2770
SS0593	179	211-293	C	6	-38.1933	149.2680
SS0593	200	216	B/C	5	-38.2800	-148.8460
SS0593	201	220-250	C/D	6	-38.1650	149.6000
SS0593	202	254-267	C/D	6	-38.1692	149.6220
SS0593	211	220-224	D	6	-37.9483	150.0350
SS0593	213	130	D	4	-37.8067	149.8980
SS0593	215	85-73	D	3	-37.6467	149.8330
SS0593	217	38-48	D	2	-37.5850	149.8430
SS0593	224	25-41	E		-37.2783	149.9870
SS0593	225	25-42	E		-37.2783	149.9920
SS0593	230	24-33	E		-37.2750	149.9850
SS0593	231	24-44	E		-37.2767	149.9850
SS0593	239	49-49	D/E	2	-37.4033	149.9820
SS0593	240	41-45	D/E	2	-37.3833	149.9730
SS0593	245	44-46	D/E	2	-37.3900	149.9770
SS0593	246	42-43	D/E	2	-37.3933	149.9620
SS0593	251	229-236	G	6	-36.4070	150.3160
SS0593	253	120-118	G	4	-36.4067	150.2480
SS0593	255	77-85	G	3	-36.3633	150.1920
SS0593	257	40-40	G	2	-36.3667	150.1450
SS0593	259	28-26.5	G	1	-36.3517	150.1230
SS0593	267	42-42	G	2	-36.4000	150.1250
SS0593	268	77-78	G	3	-36.3533	150.2030
SS0594	26	31-34	A	1	-38.9700	146.5700
SS0594	30	43-44	A	2	-39.0017	146.5970
SS0594	36	28-29	B	1	-37.8583	148.2200
SS0594	40	41-42	B	2	-37.9233	148.2480
SS0594	45	86-87	B	3	-38.7067	148.2800
SS0594	47	104-112	B	4	-38.6517	148.3300
SS0594	51	200-220	B	5	-38.5467	148.4140
SS0594	56	123-125	A	4	-38.9933	148.5200
SS0594	58	78-83	A	3	-38.9317	148.3200
SS0594	66	74-75	C	3	-37.8900	149.0650
SS0594	70	43-47	C	2	-37.8250	149.0700
SS0594	72	25-30	C	1	-37.8100	149.0180
SS0594	78	118-120	C	4	-38.0300	149.1220
SS0594	82	220-220	C	5	-38.1960	149.2770
SS0594	88	90-93	D	3	-37.6117	149.9170
SS0594	92	36-38	D	2	-37.5883	149.8500
SS0594	94	24-30	D	1	-37.5850	149.7200
SS0594	100	129-129	D	4	-37.8150	149.8880
SS0594	104	220-250	D	5	-37.9242	150.0370
SS0594	111	161-167	E	5	-37.4317	150.2730
SS0594	113	115-120	E	4	-37.3150	150.1920
SS0594	115	78-79	E	3	-37.2783	150.0770
SS0594	124	44-47	E	2	-37.3050	150.0220
SS0594	126	26-33	E	1	-37.2850	149.9900
SS0594	133	41-42	F	2	-36.9117	149.9630
SS0594	135	68-68	F	3	-36.9567	150.0430
SS0594	138	120-120	F	4	-36.9600	150.2150
SS0594	145	149-152	F	5	-36.8750	150.3020
SS0594	152	247-250	G	5	-36.5067	150.3080
SS0594	154	123-123	G	4	-36.4617	150.2180
SS0594	160	81-85	G	3	-36.4000	150.1750
SS0594	164	41	G	2	-36.3600	150.1430
SS0594	166	25-26	G	1	-36.3527	150.1220
SS9602	7	190-240	B	5	-38.5700	148.3867
SS9602	10	115-117	B	4	-38.6500	148.3317
SS9602	13	84-108	B	3	-38.6917	148.3017
SS9602	14	24-21	A	1	-38.9817	146.5300
SS9602	21	41-45	A	2	-38.9800	146.6083
SS9602	22	27-28	B	1	-37.8600	148.2113
SS9602	29	40	B	2	-37.9550	148.2317
SS9602	31	87	A	3	-38.9567	148.3517
SS9602	34	124-150	A	4	-38.9933	148.5133
SS9602	35	125-138	A	4	-38.9867	148.4983
SS9602	43	206-230	C	5	-38.2017	149.2650
SS9602	48	113-114	C	4	-38.0433	149.1450
SS9602	51	77-79	C	3	-37.9050	149.0650
SS9602	55	42-42	C	2	-37.8300	149.0950
SS9602	60	24-24	C	1	-37.8083	149.0300
SS9602	67	200-210	D	5	-37.9483	150.0317
SS9602	72	130-129	D	4	-37.8100	149.9017
SS9602	75	89-89	D	3	-37.6067	149.9183
SS9602	78	45	D	2	-37.6067	149.8400
SS9602	82	35-36	D	2	-37.5783	149.8717
SS9602	84	26-38	D	1	-37.5833	149.8033
SS9602	88	82	E	3	-37.2967	150.0783
SS9602	91	45-51	E	2	-37.2967	150.0300
SS9602	96	26-30	E	1	-37.2683	150.0033
SS9602	101	178-186	E	5	-37.4183	150.2900
SS9602	102	169-170	E	5	-37.3917	150.2983
SS9602	107	112-112	E	4	-37.3117	150.2033
SS9602	113	42-43	F	2	-36.9043	149.9672
SS9602	114	160-184	G	5	-36.4933	150.2900
SS9602	119	119-122	G	4	-36.4700	150.2367
SS9602	123	45-49	G	2	-36.3700	150.1517
SS9602	128	78-80	G	3	-36.3867	150.1800
SS9602	131	26-27	G	1	-36.3467	150.1317
SS9602	146	71-72	F	3	-36.9667	150.0517
SS9602	149	223-264	F	5	-36.8583	150.3083
SS9602	156	114-111	F	4	-36.9567	150.2100
SS9606	10	41	A	2	-38.9850	146.6150
SS9606	14	26	A	1	-38.9633	146.5750
SS9606	20	126	A	4	-38.9967	148.5234
SS9606	22	82	B	3	-38.6983	148.2717
SS9606	24	113	B	4	-38.6450	148.3333
SS9606	33	219	B	5	-38.5433	148.4167
SS9606	34	42	B	2	-37.8983	148.2833
SS9606	39	26	B	1	-37.8517	148.2367
SS9606	45	70	C	3	-37.8883	149.0717
SS9606	47	114	C	4	-38.0367	149.1067
SS9606	49	210	C	5	-38.1983	149.2617
SS9606	58	24	C	1	-37.8083	149.0383
SS9606	69	40	C	2	-37.8267	149.0883
SS9606	71	217	D	5	-37.9367	150.0317
SS9606	72	129	D	4	-37.8017	149.9017
SS9606	84	84	D	3	-37.5967	149.9133
SS9606	86	45	D	2	-37.5833	149.8950
SS9606	94	85	E	3	-37.3150	150.0800
SS9606	96	25	E	1	-37.2700	149.9967
SS9606	105	37	E	2	-37.2783	150.0317
SS9606	106	28	G	1	-36.3533	150.1283
SS9606	108	39	G	2	-36.3650	150.1450
SS9606	115	78	G	3	-36.3950	150.1800
SS9606	117	220	G	5	-36.4750	150.2133
SS9606	119	118	G	4	-36.4650	150.2167
SS9606	127	155	E	5	-37.4600	150.2583
SS9606	129	118	E	4	-37.3300	150.2133
SS9606	139	42	F	2	-36.8700	150.3117
SS9606	140	43	F	2	-36.9217	149.9633
SS9606	144	72	F	3	-36.9483	150.0483
SS9606	150	119	F	4	-36.9333	150.2217
SS9606	152	140	F	5	-36.8567	150.2983
SS9606	226	24	D	1	-37.5833	149.8067
SS9606	239	80	A	3	-38.9150	148.3000

Table 8.1.3.1 The number of samples taken by gillnet, trap, trawl and benthic sled in macrohabitats on the continental shelf of southeastern Australia. The modal depth, duration (total sampling time in minutes) and number of samples is shown for each gear at each macrohabitat as well as a three-letter macrohabitat code used in following sections.

Study area	Description	Site code	Gillnet			Trap			Trawl		
			Depth	Duratio	#nets	Depth	Duratio	#traps	Depth	Duratio	#trawls
Inner shelf											
Black Head	Flat trawl ground, soft substrate	BHS	45	1498	4	42	7450	10	52	60	2
	Flat trawl ground, hard substrate	BHH	40	1690	4	42	5590	9	60	40	2
	Rock reef	BHR	42	1480	4	40	7405	12	—	—	—
Disaster Bay	Flat trawl ground, soft substrate	DBS	78	1710	4	81	7225	10	76	90	3
	Flat trawl ground, hard substrate	DBH	91	1640	4	99	7350	10	90	45	3
	Rock reef patches	DBR	102	2348	6	106	18390	26	—	—	—
Point Hicks	Flat trawl ground, soft substrate	PHS	41	1690	4	41	7200	10	42	30	1
	Rock reef	PHR	28	1382	4	36	4050	10	—	—	—
Gabo Island	Flat trawl ground, soft substrate	GIS	—	—	—	—	—	—	38	50	2
Outer shelf											
Big Gutter	Flat trawl ground, soft substrate	BGS	121	1200	4	125	3350	5	125	65	2
	Flat trawl ground, hard substrate	BGH	118	1025	4	122	3250	5	117	95	3
	Rock reef patches	BGR	113	1038	4	108	2760	4	—	—	—
Gabo Reef	Flat trawl ground, 2 nm from reef	GRS	136	945	4	136	3150	5	137	60	2
	Flat hard ground at reef outer ed	GRH	128	1070	4	124	3225	5	132	103	3
	Reef top	GRR	112	1125	4	114	3275	5	—	—	—
The Horseshoe	Flat ground, soft substrate	HOS	149	1302	4	149	3750	5	148	60	2
	Flat trawl ground, hard substrate	HOH	157	1256	4	146	3470	5	154	60	2
	Flat trawl ground, crlnold patche	HOC	152	1055	4	163	3325	5	148	70	2
Broken Reef	Flat trawl ground, hard substrate	BRS	—	—	—	—	—	—	110	51	2
	Rock pinnacles on hard ground	BRR	114	460	2	—	—	—	—	—	—

standardised to unit time for each gear separately prior to analysis: gillnet data to a catch rate in each six-panel fleet, trap data to a catch rate per trap, and trawl data based on the duration and speed of a tow for the standard gear configuration. Where appropriate, samples were pooled to provide a mean catch rate by gear by macrohabitat. CLUSTER (hierarchical agglomerative clustering) in the PRIMER program (Carr 1996) was used to form groups of samples (macrohabitats) based on between-sample similarities, and MDS (non-metric multidimensional scaling) used to display between-sample similarities in 2-dimensional (2-d) space. In all analyses the Bray-Curtis similarity index (Legendre and Legendre 1973) was used.

Transforming multispecies abundance data prior to cluster or ordination analysis varies the relative contributions of high-abundance and low-abundance species to group formation. Essentially, the contribution of low-abundance species increases as the severity of transformation increases. In the extreme case, when the data are transformed to presence/ absence, low abundance species contribute equally to abundant ones. In order to determine an appropriate transformation for our biomass data, cluster dendrograms and 2-d MDS plots of the eleven sites sampled by all gears were compared for each gear separately after the following, increasingly severe, transformations: none, square root, double square root, and presence/absence. The double square root transformation was found to provide the lowest stress values in the MDS plots and produce clear groupings, so was used for subsequent analyses.

The species contributing to the patterns in multivariate data were identified with a similarity of percentages analysis using SIMPER (Clarke 1993). Primary species are those that contribute most to the similarities within groups of macrohabitats, and/ or the dissimilarities between macrohabitat groups. Because low abundance species with restricted biocoenotic distributions can also characterise fish assemblages but may not contribute to patterns formed by multivariate analysis, we also analysed the restriction of species to macrohabitats. Indicator species were those that were exclusive to one macrohabitat in the catches of all gears.

Different combinations of the 20 macrohabitat samples were used to examine patterns in the multispecies distribution data in three analyses; the gears were treated separately in each:

1) The effects of different transformations on the abundance data and a direct comparison of gears were based on an analysis of daytime samples from the eleven macrohabitats sampled by all gears (common macrohabitats).

2) The 20 macrohabitats were grouped according to the similarities of their fish assemblages based on all available samples for each gear (not all macrohabitats were sampled by each gear).

3) Diel changes in fish assemblages were assessed at three macrohabitats in each of five mesohabitats that were sampled by gillnet during day and night.

Summary statistics (mean and SD) of the two acoustic indices, E1 and E2, were calculated for each macrohabitat from 50 values along transects corresponding to the start and finish positions of each trawl, gillnet and trap set. This was done by using the 'cross-section' function in the Vertical Mapper module of MapInfo on contour plots of E1 and E2 formed by rectangular interpolation with a cell size of 0.005° and search radius of 0.01°.

The proportion of each species caught in 'soft' and 'rough' habitats in gillnet and trap samples was compared to determine their patterns of habitat use. Total abundance was summed over all 'soft' and 'rough' habitats, with 'hard' habitats allocated to 'soft' or 'rough' based on their acoustic roughness value, and standardised for the number of samples in each type. Trawl samples, which were taken only from 'soft' habitats, were included to indicate species that were abundant on soft-grounds. Because bottom types were not classified reliably by acoustics at The Horseshoe this mesohabitat was excluded from the analysis.

Five categories of habitat association were used: strong association with either reef or sediment flat habitat (> 95% of individuals caught in habitat by all gears); distinct association with one or other habitat (> 70% of individuals caught in habitat by all gears), and association with both (30-70% individuals caught in habitat by all gears). The degree of confidence with which species were allocated to a group was based on the proportions caught, the agreement between gears and the numbers of individuals caught. High confidence indicated agreement between gears in the proportions caught and relatively high catches (> 100 individuals in a gear). Medium confidence indicated agreement between gears in the proportions caught and relatively small catches (> 20 individuals in a gear), or if catches were smaller but literature accounts of habitat association were available for this region. Low confidence was assigned when few individuals (< 20) were caught and when supporting literature was not available.

8.2 RESULTS AND DISCUSSION

8.2.1 Invertebrates–Broad Scale

Sixty nine invertebrate functional taxa at 37 separate locations were sampled in the broadscale epifaunal invertebrate survey. Of these sixty nine taxa, 11 were found in 4 or less samples and those samples were not geographically grouped. These 11 taxa were removed before multivariate analysis and are marked with an asterisk in summary tables. There were 33 stations sampled (5 on each transect A-G, except for A5 and F1 that were not possible to sample). In addition, 4 replicate samples (at C5, D2, E3 and E5, called C52, D22, E32 and E52, respectively) were made during intensive habitat sampling.

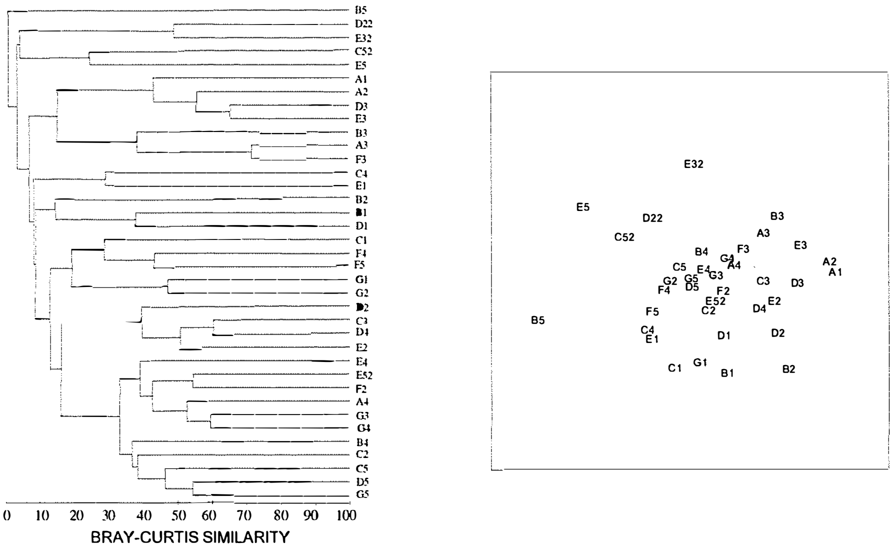
Fish were also caught in the epifaunal samples, but are not analysed here. Infaunal samples had a significant epifaunal component and were not analysed further as they were not independent of epifaunal samples.

Patterns of Assemblage Structure

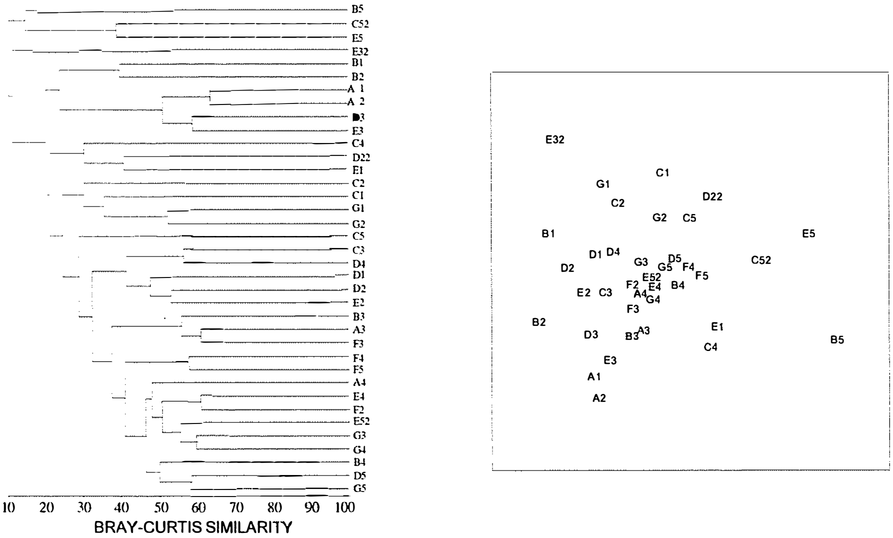
Cluster analyses and MDS plots gave quite similar groupings and stress values were very similar under all transformations (Fig. 8.2.1.1). The $\log_e(x+1)$ transformation was used in further analyses because of its desirable statistical properties for abundance data.

The first stations to separate out in the cluster analysis were B5, E5, C52 and E32. These were also the stations with the lowest biomasses (1.1, 5.9, 13.0 and 13.9 kg, respectively), compared to the range for all other broadscale samples of 31 to 3,392 kg. Stations E5 and E32 had much smaller biomasses of some of the taxa of their replicates (E52 (300 kg) and E3 (1,925 kg)) and no additional taxa, therefore they were removed from subsequent analysis on the assumption that the benthic sled did not sample properly on these occasions. Sample B5 was removed for similar reasons. Sample C52 had a smaller biomass than its replicate (C5 (66 kg)) but had a number of taxa that were missing from C52. Because of the additional taxa and the known heterogeneity of the sampling area, it was retained in subsequent analyses.

Raw Data, Stress=0.21



Square Root, Stress=0.22



4th Root, Stress=0.22

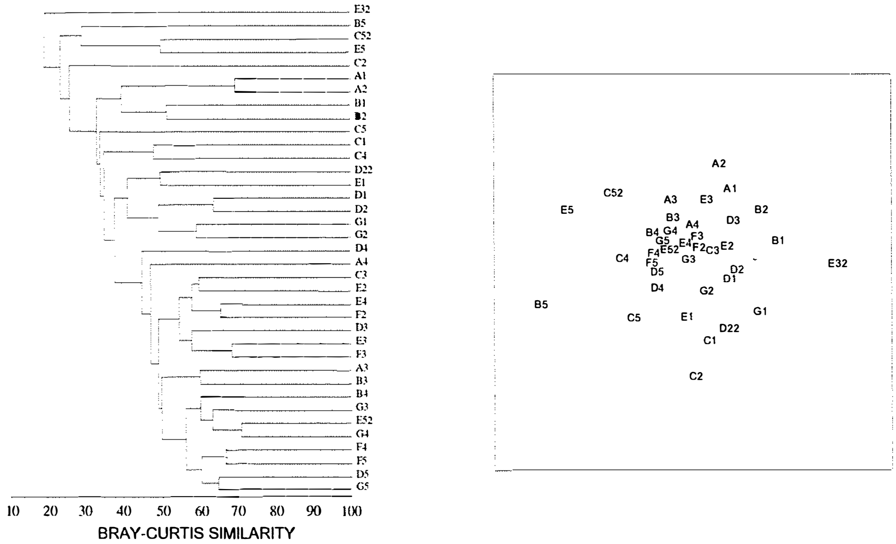
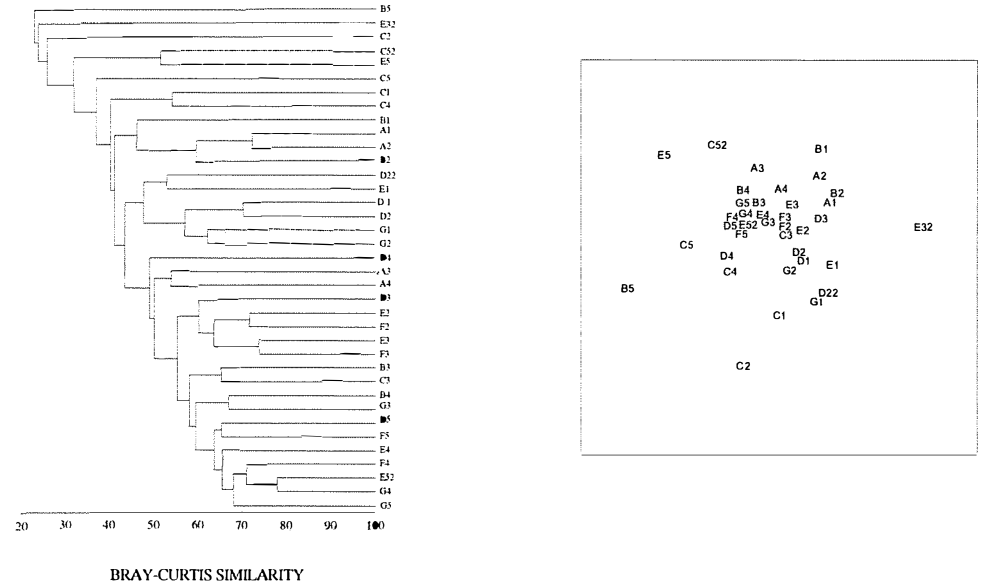


Figure 8.2.1.1 Cluster analyses and MDS plots showing grouping of broadscale invertebrate samples with increasing severity of transformation (see figure 4.1.1.1 for transect and station positions).

Logged Data, Stress=0.21



Presence/Absence, Stress=0.21

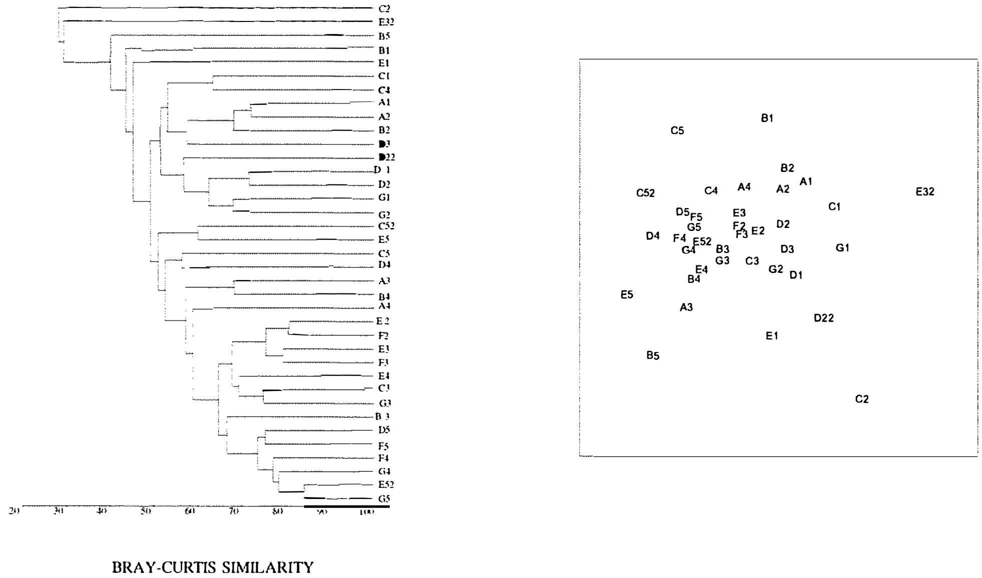


Figure 8.2.1.1 continued

The cluster analysis and MDS plot for the $\log_e(x+1)$ transformation were repeated for the reduced dataset (Fig. 8.2.1.2a). A SIMPER analysis was used to determine which taxa distinguished a group from all other stations (Table 8.2.1.1):

Group 1 South Inshore

This group comprised the 25 and 40 m depth stations on the two southern transects (A and B (Fig 8.2.1.2a). It was distinguished by a large biomass of solitary ascidians, *Chlamys asperrima* (doughboy scallop), *Coscinoasterias calamaria* (a seastar predator of bivalves), lumpy Porifera, bushy Porifera, massive/erect bryozoans, and *Maoricolpus roseus* (the introduced New Zealand screw shell), and relatively few in-sand Porifera. These abundant taxa (except possibly *Maoricolpus roseus)* are typically associated with hard substrate, or in the case of the doughboy scallops, the fauna that is attached to hard substrate.

Group 2 North Inshore

This group comprised the 25 m stations from central and northern transects (D, E, F and G) and the 40 m stations from transect D (Fig 8.2.1.2a). It was distinguished by its high biomass of tubeworm polychaetes, *Maoricolpus roseus,* massive and erect bryozoans, Asteroidea (including *Coscinoasterias calamaria*) and low biomass of lumpy Porifera. The abundant taxa suggest a softer substrate than the hard substrate of southern inshore stations.

Group 3 C2

All stations on Transect C, except C3, grouped separately from stations at the same depth on other transects, and had a lower biomass. The 40 m station, C2, was very species poor and had relatively large biomasses of only in-sand Porifera, *Maoricolpus roseus*, and paguroids (the hermit crabs presumably associated with empty *Maoricolpus roseus* shells).

Group 4 C1&C4

Stations C1 and C4 are at quite different depths (~25 and 120m), had moderate biomass and species diversity. They grouped together primarily based on a large number of *Glycymeris* spp., a diversity of ascidians and relatively low biomasses of sponge. They also had the largest biomasses of *Pecten fumatus*, although this taxon was not included in the multivariate analyses.

Group 5 C5

Station C5 had a similar biomass to other mid and outer-shelf stations. It was distinguished from these other stations by a large biomass of Brachiopoda, stalked crinoids, solitary corals. Similar to other mid and outer-shelf stations, irregular echinoids were well represented and *Sepia* sp. was also abundant.

Group 6 C52

In comparison to its replicate C5, station C52 had a lower biomass and lacked the stalked crinoids and Brachiopoda that distinguished that site. It was marked by the lack of common taxa–solitary sand-dwelling ovoid Ascidacea, Asteroida and paguroids. The station had relatively high levels biomasses of Pennatulacea, *Octopus* sp., and one species not included in the multivariate analysis–*Clypeaster australasiae*.

Group 7 Mid and outer-shelf sites

Mid and outer-shelf sites had high biomass, were speciose, with high diversity and richness. Many taxa were abundant compared with other stations, most notably soft and fenestrate Bryozoans, solitary and solitary sand-dwelling ovoids Ascidacea, asteroids, irregular echinoids and in-sand Porifera. The stations were quite diverse and a second analysis was conducted on this group of stations (Fig 8.2.1.2b, Table 8.2.1.2)

Group 7a South midshelf

This group consisted of the midshelf stations on transect A (A3 and A4). The outer-shelf transect is not sampled on this transect. It was distinguished from the other mid- and outer-shelf stations by relatively fewer taxa, lower diversity and moderate biomass. Solitary ascidians, irregular echinoids, and tubeworm Polychaeta were abundant compared to other groups, while solitary sand-dwelling ovoid ascidians, fenestrate and massive/erect bryozoans and bushy Porifera were of relatively low abundance.

Group 7b Midshelf

The midshelf group consisted of station 3 (~80m) on transects B, C, D, E & F and station 2 (~40m) on transects E and F. This group had the largest overall biomass but had fewer species and lower diversity than the outer-shelf group. Abundances of soft, fenestrate and massive/erect bryozoans, lumpy and bushy Porifera, regular echinoids, the introduced *Maoricolpus roseus* were relatively high.

Group 7c Outershelf

Station 4 (~120m) on transects B, E, F & G, station 5 (~200m) on transects D, E, F & G and station G3 comprised this outershelf group. Biomass was relatively low, but species numbers and diversity were the highest of the mid- and outer- shelf groups. Alcyonacea and Gorgonian seawhips were more abundant than in other groups, while sand-dwelling solitary ascidians, soft, fenestrate and massive/erect bryozoans and bushy and lumpy Porifera were less abundant than in the midshelf group.

Group 7d D4

This group contained only one station. Biomass was very high and species number appear low. Biomass was dominated by in-sand Porifera, sand-dwelling solitary, compound and ovoid ascidians. It was also distinguished from other groups by a large biomass of gastropods, Entoprocta Kamptoza, and Peronella peronii. Regular and irregular echinoids were lacking.

Correlation with Physical Variables

Physical sediment characteristics–grain size, proportions of gravel, sand and silt, standard deviation of grain size–and biochemical attributes–stable isotopes, percent carbon and nitrogen, concentration of chlorophyll *a* and its breakdown product phaeophorbides–were examined for their relationship with the grouping of stations based on the preceding community analyses (Table 8.2.1.3).

Table 8.2.1.1 Average biomass in cluster groups determined from multivariate analyses of invertebrate biomass data. Bolded numbers are those that contribute 30% of the dissimilarity between the group and all other samples.

	South inshore	North inshore	C2	C1 & C4	C5	C52	Mid- and outer shelf
Alcyon acea	0	0	0	0	0	0	1,043
* Anthozoa anenomes	0	0	0	0	0	0	234
* Anthozoa burrowing_anenomes	0	0	0	0	0	0	0
Ascidacea compound	10,533	3,234	0	**4,575**	1,598	900	25,597
Ascidacea dogturds	0	**6,267**	0	1,465	0	**0**	**19,087**
Ascidacea sandsolitary	0	0	90	**2,105**	0	0	**17,633**
Ascidacea solitary	**116,959**	0	0	0	0	0	870
* Ascidacea stalked	0	0	0	0	0	0	258
Asteroidea	3,485	**17,344**	0	15	0	**0**	**6,001**
Bivalvia	449	474	40	165	129	0	265
Brachiopoda	63	56	0	5	**15,670**	0	168
Bryozoa branching	0	0	0	0	0	10	635
Bryozoa encrusting	115	10	0	55	0	60	1,020
Bryozoa fenestrate	300	287	0	0	0	10	**2,528**
Bryozoa massiveerect	**21,000**	**53,662**	0	50	0	0	2,097
Bryozoa soft	25,506	2,631	0	0	0	5,570	**208,036**
Chlamys asperrima	**336,432**	23	0	0	0	0	99
* Clypeaster australasiae	0	602	0	0	0	2,230	0
Coscinasterias calamaria	**34,197**	**6,119**	0	0	0	0	224
Crab spider	1,157	234	0	25	77	470	3,921
Crinoid	5	0	0	0	**9,407**	0	7
Crustacea amphipoda	5	0	0	15	52	10	57
Crustacea paguroids	12,747	14,449	37,000	5,405	387	**0**	10,122
Crustacea prawn_shrimp	0	20	0	5	103	10	405
Crustacea rockcrabs	1,163	456	0	70	26	10	506
Crustacea sandburrowingcrabs	0	104	0	40	0	0	259
Echinoidea irregular	410	13	0	0	**2,139**	0	5,346
Echinoidea regular	5,055	35	0	75	0	10	**5,598**
* Echiura	0	0	0	0	0	0	0
Entoprocta Kamptozoa	167	0	0	5	0	0	181
Eucrassatella kingicola	3,995	1,460	0	10	0	0	0
Fusinus novaehollandiae	0	47	0	0	0	0	659
Gastropoda	8,230	2,653	20	4,890	3,325	630	1,231
Gazameda gunni	0	4	0	15	0	0	51
Glycymeris spp.	0	2,330	0	**15,450**	0	0	13
Gorgonacea bramble_coral	728	12	0	0	0	0	66
Gorgonacea seafan	0	0	0	0	0	0	49
Gorgonacea seawhip	0	0	0	0	0	**300**	649
Holothurian	133	0	0	0	0	0	0
Hydroida	332	2	0	15	0	50	918
* Ibacus peronii	130	2,377	0	0	0	0	0
Maoricolpus roseus	**40,882**	**158,792**	**23,200**	25	0	0	**10,126**
Nectria sp.	156	0	0	0	155	0	29
* Nemertina Rhynchocoela	11	0	0	0	0	0	1
Neotrigonia margaritacea	0	12	0	0	0	20	10
Octopus sp.	211	16	0	**360**	0	**2,360**	878
Ophiuroidea	1,445	28	0	40	0	40	464
Opistobranchia	2,574	89	0	50	26	40	467
* Pecten fumatus	44	0	0	2,315	0	0	0
Pennatulacea	0	0	0	0	0	**90**	68
Peronella peronii	0	0	0	0	0	0	463
Polychaeta errant	5	13	0	0	26	0	96
Polychaeta tubeworms	0	**19,473**	0	0	0	0	613
Polynoidae	0	0	0	0	0	70	90
Porifera bushy	**30,500**	90	0	**7,865**	0	0	**24,022**
Porifera in_sand	**2,250**	**76,052**	**45,000**	**0**	29,253	**0**	**114,989**
Porifera low_encrusting	44,535	0	**4,320**	**0**	0	**2,200**	6,417
Porifera lumpy	**1,111,611**	**1,913**	0	25,550	0	0	**94,224**
Pycnogonida	0	4	0	0	0	10	109
* Pyura spinifera	18,050	0	0	0	0	0	0
Scaphopoda	0	0	0	5	26	0	0
* Scleractinia colonial_corals	100	167	0	95	0	0	0
Scleractinia solitary_corals	0	39	0	0	**1,624**	0	879
Scyllaridae	0	0	0	0	26	0	145
Sepia sp.	303	229	0	0	**1,881**	140	168
* Sepiolidae	0	0	0	0	0	0	0
Sipuncula	0	0	0	0	26	0	19
Squillidae	0	0	0	0	0	0	51
Surime starfish	0	0	0	0	0	20	59
Total taxa number	40	41	7	30	20	24	58
Average biomass per station	1,835,972	371,823	109,670	70,760	65,954	15,260	570,221
Richness (Margelef index)	5.43	6.65	1.19	5.58	3.94	5.10	9.21
Diversity (Shannon-Wiener)	0.61	0.77	0.52	0.79	0.71	0.76	0.90
Eveness (Pielou)	0.39	0.49	0.62	0.54	0.54	0.57	0.52
Average Dissimilarity	62	61	74	62	65	65	61

* Rare taxa not included in multivariate analysis

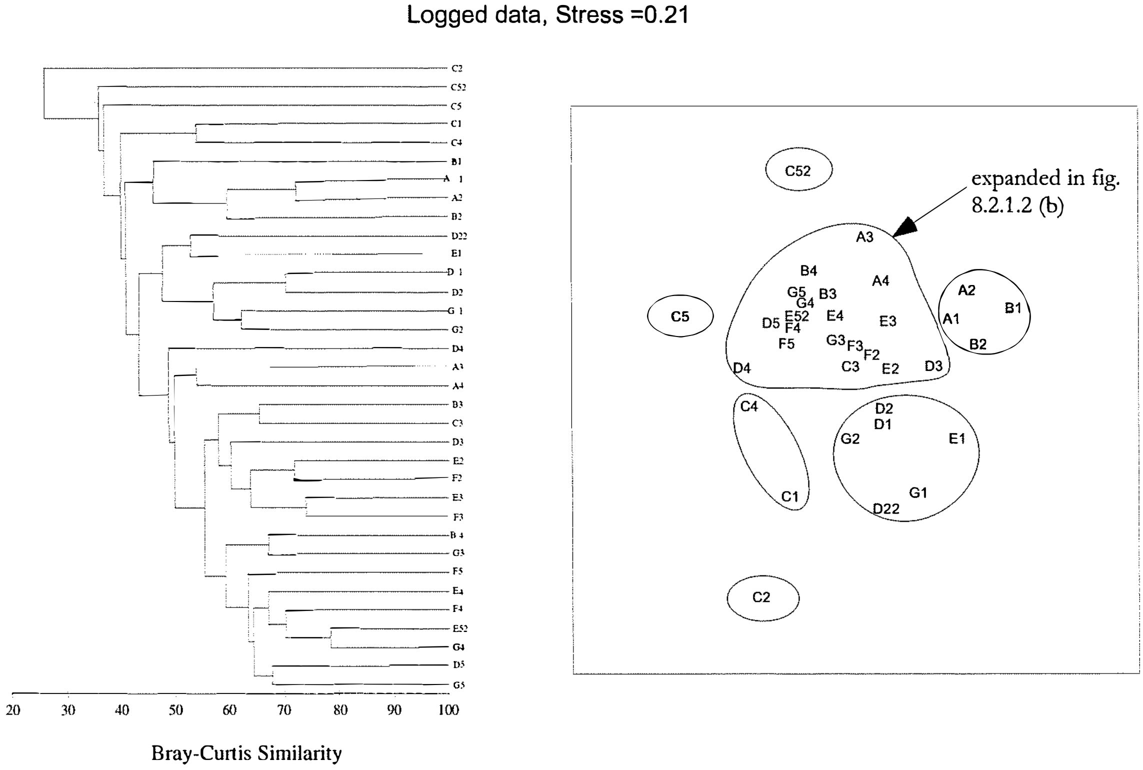


Figure 8.2.1.2 (a) Cluster analyses and MDS plots of broad-scale invertebrate samples with non-representative samples removed. Log transformation used.

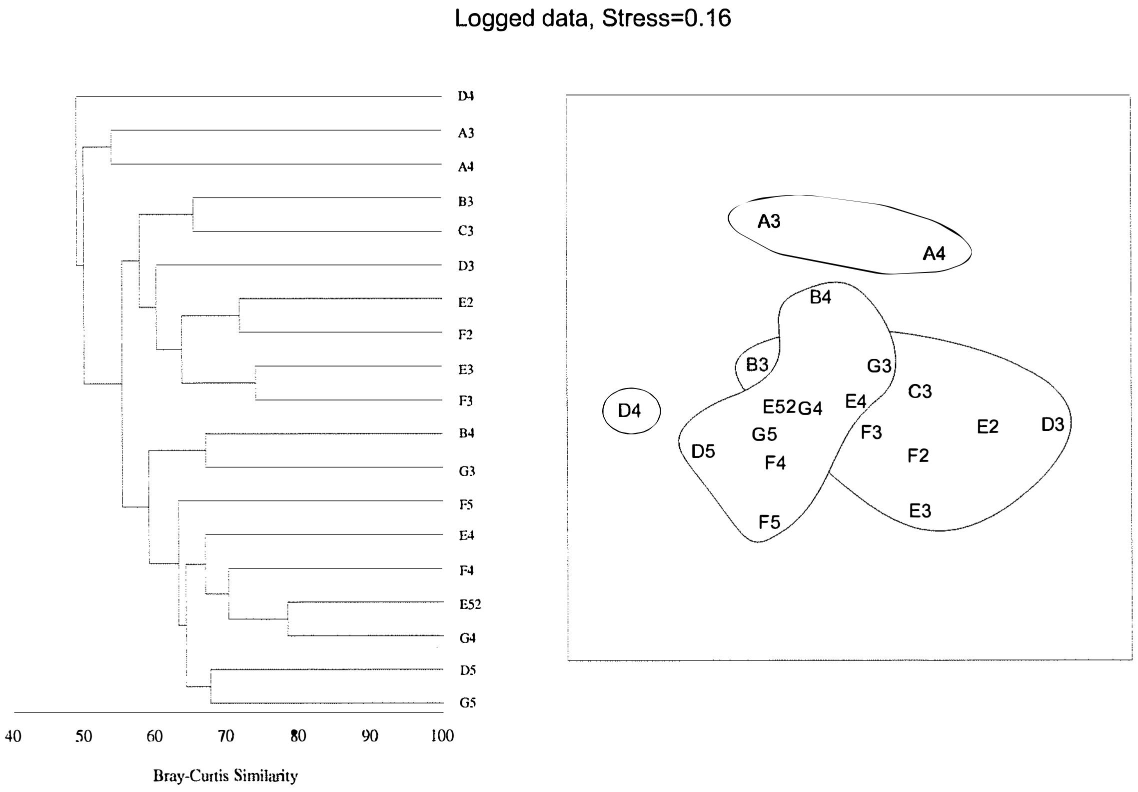


Figure 8.2.1.2 (b) Cluster analysis and MDS plot for mid and outer-shelf samples. Log transformation used.

Table 8.2.1.2 Average biomass in cluster groups determined from multivariate analyses of invertebrate biomass data on mid- and outer-shelf. Bolded numbers are those that contribute 30% of the dissimilarity between the group and all other samples.

	South midshelf 7a	Midshelf 7b	Outer Shelf 7c	D4 7d
Alcyon acea	**0**	**76**	**2,143**	0
* Anthozoa anenomes	0	0	494	0
* Anthozoa burrowing_anenomes	0	0	0	0
Ascidacea compound	1,070	45,102	7,924	97,160
Ascidacea dogturds	**120**	**21,932**	**18,237**	44,750
Ascidacea sandsolitary	**12,020**	**13,054**	**7,345**	**153,500**
Ascidacea solitary	**4,343**	1,119	0	0
* Ascidacea stalked	0	49	507	0
Asteroidea	698	9,628	4,376	5,850
Bivalvia	5	392	191	560
Brachiopoda	0	0	355	0
Bryozoa branching	658	474	826	0
Bryozoa encrusting	530	728	1,424	400
Bryozoa fenestrate	**0**	**6,245**	**480**	**0**
Bryozoa massiveerect	0	**5,673**	**15**	0
Bryozoa soft	295,939	**467,009**	**10,194**	**0**
Chlamys asperrima	10	216	40	0
* Clypeaster australasiae	0	0	0	0
Coscinasterias calamaria	0	608	0	0
Crab spider	27,497	1,965	632	60
Crinoid	15	0	6	50
Crustacea amphipoda	5	23	102	0
Crustacea paguroids	3,548	9,575	12,202	8,380
Crustacea prawn_shrimp	0	513	446	100
Crustacea rockcrabs	818	693	342	50
Crustacea sandburrowingcrabs	10	187	400	0
Echinoidea irregular	**9,112**	3,273	6,716	**0**
Echinoidea regular	746	**10,103**	**3,794**	**0**
* Echiura	0	0	0	0
Entoprocta Kamptozoa	0	0	33	**3,150**
Eucrassatella kingicola	0	0	0	0
Fusinus novaehollandiae	1,240	433	778	0
Gastropoda	15	957	685	**10,500**
Gazameda gunni	27	74	44	0
Glycymeris spp.	0	0	27	0
Gorgonacea bramble_coral	0	91	69	0
Gorgonacea seafan	0	0	103	0
Gorgonacea seawhip	0	151	**1,220**	300
Holothurian	0	0	0	0
Hydroida	658	275	1,578	0
* Ibacus peronii	0	0	0	0
Maoricolpus roseus	0	**27,486**	**0**	0
Nectria sp.	0	79	0	0
* Nemertina Rhynchocoela	0	2	0	0
Neotrigonia margaritacea	0	17	7	0
Octopus sp.	75	2,310	41	0
Ophiuroidea	713	794	204	0
Opistobranchia	0	942	248	50
* Pecten fumatus	0	0	0	0
Pennatulacea	0	182	2	0
Peronella peronii	64	336	64	**5,740**
Polychaeta errant	46	117	101	0
Polychaeta tubeworms	**1,357**	922	275	0
Polynoidae	0	131	83	50
Porifera bushy	**0**	**62,223**	**2,317**	0
Porifera in_sand	62,228	163,939	50,529	458,000
Porifera low_encrusting	0	3,454	10,859	0
Porifera lumpy	0	**251,313**	**3,451**	0
Pycnogonida	698	25	55	0
* Pyura spinifera	0	0	0	0
Scaphopoda	0	0	0	0
* Scleractinia colonial_corals	0	0	0	0
Scleractinia solitary_corals	**0**	829	1,212	0
Scyllaridae	0	0	306	0
Sepia sp.	5	73	277	180
* Sepiolidae	0	0	0	0
Sipuncula	40	0	32	0
Squillidae	0	0	107	0
Surime starfish	0	0	124	0
Total taxa number	31	48	53	19
Average biomass per station	424,310	1,115,792	154,022	788,830
Richness (Margelef index)	2.32	3.23	4.10	1.33
Diversity (Shannon-Wiener)	1.12	1.81	2.49	1.27
Eveness (Pielou)	0.33	0.47	0.64	0.43
Average Dissimilarity	51	47	46	51

* Rare taxa not included in multivariate analysis

Table 8.2.1.3 Average value for environmental variables in cluster groups determined from multivariate analysis of invertebrate infauna and signficance from Kruskal-Wallis one-way analysis of variance.

	South inshore	North inshore	C2	C1&C4	C5	Mid- and outer shelf	p
Mean depth	38.25	36.80	43.00	75.00	196.00	112.21	0.003
Mean Phi Size	1.15	0.11	0.24	0.28	0.34	0.51	0.465
Percent Gravel	10.08	4.74	5.62	5.97	8.58	11.48	0.866
Percent Sand	75.39	95.14	94.22	85.62	80.73	82.16	0.02
Percent Silt	14.53	0.12	0.15	8.41	10.72	6.36	0.011
Min Sediment SD	0.32	0.41	0.75	0.48	1.18	0.55	0.064
Max Sediment SD	1.39	0.56	0.75	1.43	1.18	1.48	
Mean δ13C	-22.64	-24.20	-21.56	-23.34	-20.97	-21.39	0.044
Mean δ15N	6.22	5.93	4.99	6.67	7.89	7.34	0.004
Percent Carbon	1.04	0.17	0.22	1.62	5.17	0.76	0.007
Percent Nitrogen	0.05	0.01	0.01	0.05	0.07	0.05	0.02
Chl *a* (ug/g)	0.48	0.21	0.21	0.08	0.00	0.07	0.088
Total Phaeophorbides	10.84	1.94	1.75	2.50	0.00	3.42	0.487
R							0.041

Northern inshore stations were distinguished from southern inshore stations by a higher proportion of sand, and less silt and gravel (Table 8.2.1.3). Thus the southern inshore stations had a more varied grain size than the northern inshore stations. The northern inshore stations had lower carbon and nitrogen concentrations and δ13C was less enriched.

Inshore stations were distinct from mid and outer-shelf stations, by having better-sorted sediments, with less enriched δ13C and δ15N, and higher concentrations of chlorophyll *a*.

Some of the reasons for the C-transect stations grouping separately from stations at the same depth on other transects may be found in their sediment characteristics. Stations C1, C4 and C5 had the highest proportions of silt and the highest levels of carbon of any stations, suggesting biogenic sediments.

Differences in sediments within the mid- and outer-shelf group of stations, are less clear. Southern stations are characterised by higher carbon, D4 is characterised by poorly sorted sediments, while midshelf stations had some of the highest chlorophyll *a* levels (Table 8.2.1.4).

8.2.2 Invertebrates–Focussed Habitat

Seventy invertebrate functional taxa at 20 separate locations were sampled in the focussed habitat survey (Table 8.1.3.1). In addition, 3 other locations that served as replicates (because of proximity and similarity of roughness/hardness to an existing sample) were culled from the broadscale survey.

Fish formed a minor part of the catches in the infaunal samples, but a substantial proportion of the catches in the epifaunal samples. Fish were removed from the data before multivariate analyses as it was considered that these mobile fauna might mask the distribution patterns of the more sedentary invertebrates.

Patterns of Assemblage Structure

Stress values decreased from 0.20 to 0.16 as the severity of transformation increased from none to presence absence. There were several groups that appeared consistently in all analyses (Fig. 8.2.2.1), although exact membership changed with the transformation. These groupings were:

Group 1a Point Hicks Soft

This group sometimes included Horseshoe Soft 2 with less severe transformation. It was characterised by large biomasses of low Porifera and Paguroids (Table 8.2.2.1).

Group 1b Gabo Island Soft

This group comprised the two Gabo Island Soft sites, but with less severe transformation was split between Groups 2 and the rest. It was characterised by high biomasses of in-sand Porifera, *Maoricolpus roseus*, *Ibacus peroni*, and massive Bryozoa.

Group 2 Black Head and Disaster Bay Soft/Hard

This group comprised the Black Head and Disaster Bay soft and hard sites and included Gabo Island soft with less severe transformation. The group was characterised by soft Bryozoa, *Pecten fumatus*, compound Ascidacea and Asteroidea.

Group 3 Outer Shelf Hard/Soft/Rough

This group comprised 11 sites ranging from soft to rough and including groups 3 and 4a of the infaunal analyses. It was characterised by high biomasses of low, bushy, and lumpy Porifera. This group was reanalysed by itself to provide 3 groups (Table 8.2.2.2, Fig. 8.2.2.2).

Group 3a Outer Shelf Rough

This group contained Disaster Bay Rough, Gabo Reef Rough and Broken Reef Rough and was characterised by high biomasses of low, bush and lumpy Porifera and massive Bryozoa.

Group 3b Broken Reef Soft/Hard

This group contained the two Broken Reef sites that sampling indicates are better described as soft/hard with patch reef. The sites were characterised by high biomasses of solitary sand-dwelling and solitary sand-dwelling ovoid Ascidacea and Surime starfish.

Group 3c Outer Shelf Soft

This group comprised Big Gutter soft and hard and Gabo Reef soft and hard. It was characterised by high biomasses of in-sand Ascidacea.

Group 4 Horseshoe

The Horseshoe sites were quite variable. There were no taxa evident for which they had particularly high biomasses, although they had moderate biomasses of low Porifera, compound Ascidacea, soft Bryozoa and stalked crinoids.

8.2.3 Fish Communities–Broad Scale

Sample overview

A list of the species caught during the survey, showing scientific and common names is given in Table 8.2.3.1: for this reason, common names only are used in this section. This list also identifies marketable species (SEF quota and secondary commercial species), shown hatched (dark and light respectively); this scheme is used in all tables in this *Section* 8.

Several of the broad-scale samples were represented by small catches (< 100 kg) containing relatively low numbers of species. Because they may affect the analysis of inter-station similarity as outliers they are identified separately: early winter (G2), late winter (G2), spring (B3, C1, E1, F4, G1,G2, G4) and autumn (B5, D1, E4, G5).

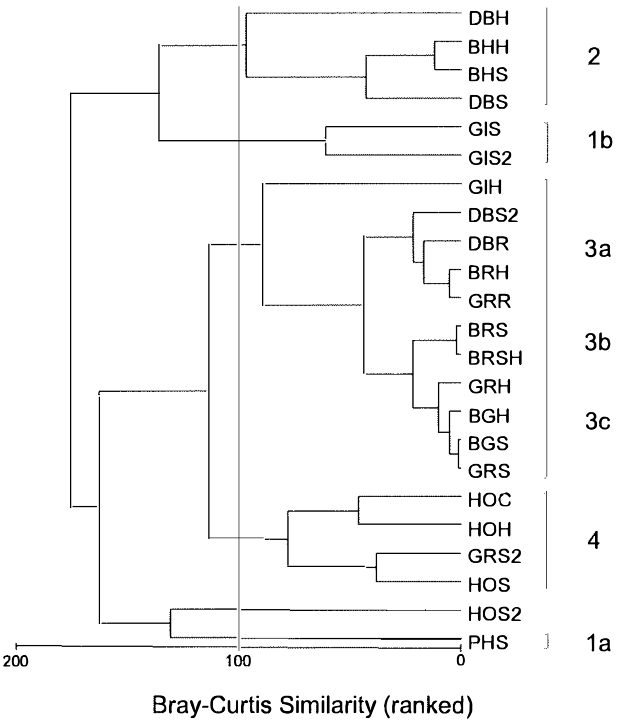
Table 8.2.1.4 Average value for environmental variables in cluster groups determined from multivariate analysis of invertebrate infauna and signficance from Kruskal-Wallis one-way analysis of variance.

	South	Mid-shelf	Outer-shelf	D4	p
Mean depth	106.50	71.14	143.67	128.00	0.03
Mean Phi Size	1.37	0.27	0.47	0.81	0.29
Percent Gravel	4.14	12.00	13.35	7.48	0.64
Percent Sand	81.04	82.65	82.56	77.81	0.87
Percent Silt	14.81	5.34	4.09	14.72	0.15
Min Sediment SD	0.87	0.84	0.55	1.48	0.06
Max Sediment SD	1.24	1.41	1.04	1.48	
Mean δ13C	-20.76	-21.78	-21.16	-21.78	0.35
Mean δ15N	7.12	7.15	7.59	7.13	0.36
Percent Carbon	1.41	0.40	0.91	0.84	0.04
Percent Nitrogen	0.08	0.05	0.04	0.08	0.15
Chl *a* (ug/g)	0.03	0.15	0.02	0.00	0.04
Total Phaeophorbides	2.36	4.54	2.80	2.69	0.55
R					0.193

Table 8.2.2.1 Epifaunal invertebrate taxa that contribute at least 3% of the dissimilarity between sites in SIMPER pairwise comparisons, and species richness of the different sites.

Taxa		Number of comparisons with greater than 3% dissimilarity				
		Black Head & Disaster Bay	Pt Hicks Soft	Gabo Is. soft	Mid Shelf	Horseshoe
Porifera	low		4		4	2
	bushy				4	
	lumpy				4	
	in sand		3	4	2	
Gastropoda				2		
	Maoricolpus roseus	1	3	4		
Bivalvia				2		
	Eucra kingicola					
	Pecten fumatus	3				
Ascidacea	Sand					
	dogturds			2	3	
	compound	3		1	3	2
Crustacea	Paguroids	1	4	2	2	
	sand					
	prawns					
	Ibacus peroni			4		
Bryozoa	Soft	4		1	1	2
	Massive			4		
	Alcyo acea	1				
Hydroida						2
Crinoids	stalked					1
Asteroidea		3		3		
Echinoidea	regular	2				1
	irregular				2	1
	Sepia sp.					
	Octop sp					
Polychaete	tubes					
Brachiopoda						
	Glycy spp.					
Ophiuroide		1				

a)



b)

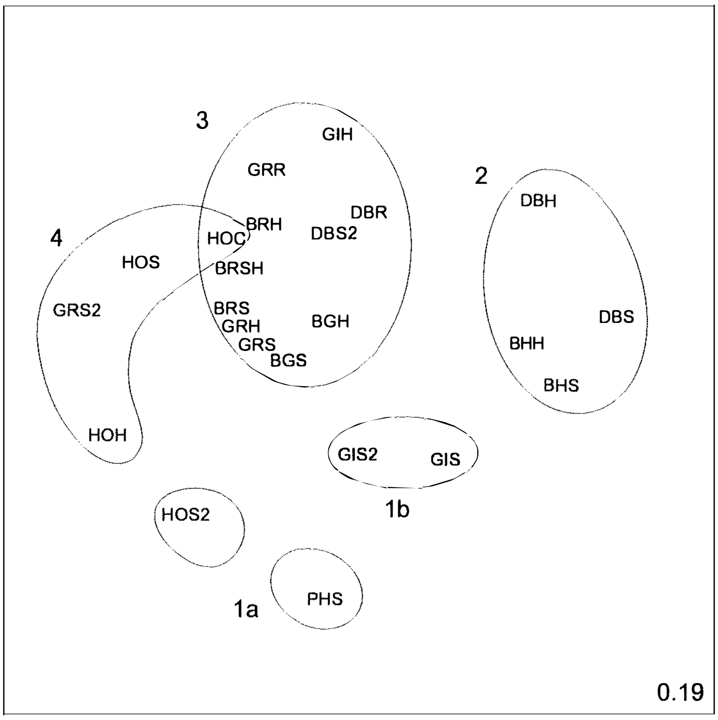
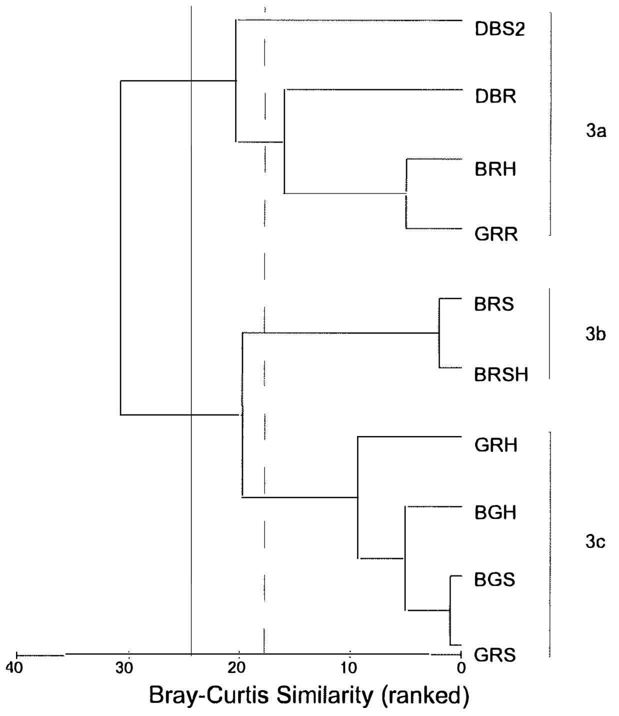


Figure 8.2.2.1 Heirarchical cluster analysis and MDS plot of epifaunal samples collected with the epibenthic sled in focussed habitat sampling. Biomasses of functional taxa were root transformed before applying the Bray-Curtis similarity matrix.

Table 8.2.2.2 Epifaunal invertebrate taxa that contribute at least 3% of the dissimilarity between 3 Outer Shelf sites in SIMPER pairwise comparisons, and species richness of the different sites.

Taxa		Number of comparisons with greater than 3% dissimilarity		
		Offshore rough	Broken Reef S/H	Offshore soft
SIMPER OUTPUT GROUP		1	2	3
Porifera	low	2	1	
	bushy	2		
	lumpy	2	1	
	in sand	1		1
Gastropoda				
	Maoricolpus roseus			
Bivalvia				
	Eucra kingicola			
	Pecten fumatus			
Ascidacea	Sand			2
	dogturds		2	1
	compound			
	solitary		2	
Crustacea	Paguroids			
	sand			
	prawns			
	Ibacus peroni			
Bryozoa	Soft			
	Massive	2		
	Alcyo acea	1		1
Hydroida				
Crinoids	stalked			
Asteroidea				
	Surime starfish		2	
Echinoidea	regular			
	irregular			1
	Sepia sp.			
	Octop sp		1	
Polychaete	tubes			
Brachiopoda				
	Glycy spp.			
Ophiuroide				

a)



b)

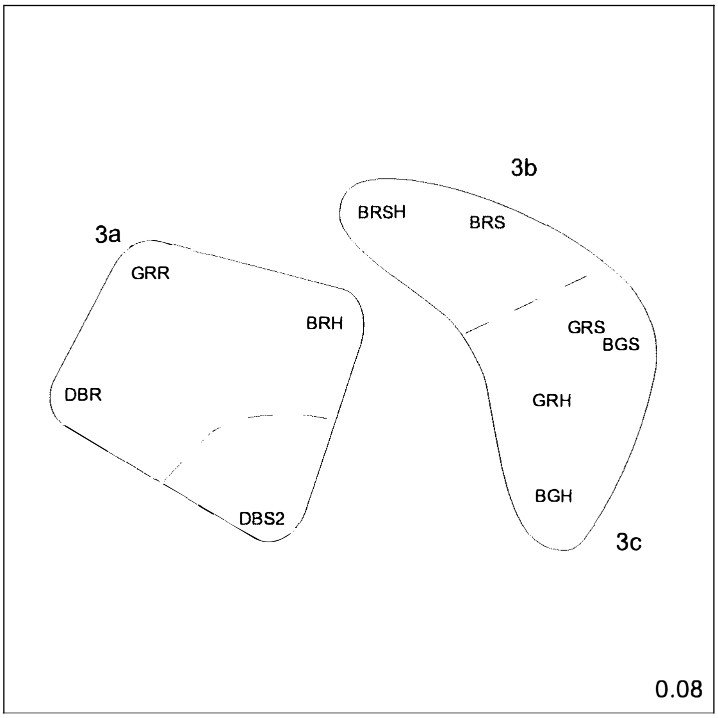


Figure 8.2.2.2 Expanded heirarchical cluster analysis and MDS plot of outer shelf epifaunal samples (group 3) collected with the epibenthic sled. Biomasses of functional taxa were root transformed before applying the Bray-Curtis similarity matrix.

Table 8.2.3.1 List of species taken by fishing gears on broad-scale trawl survey and focussed habitat study. Quota species and secondary commercial species hatched (dark and light respectively).

Common Name	*Scientific name*	Code	Common Name	*Scientific name*
Sevengill shark	*Heptranchias perlo*	288006	Latchet	*Pterygotrigla polyommata*
Broadnose sevengill shark	*Notorynchus cepedianus*	288007	Minor gurnard	*Lepidotrigla modesta*
Port Jackson shark	*Heterodontus portusjacksoni*	288008	Deepwater gurnard	*Lepidotrigla mulhalli*
Mako shark	*Isurus oxyrinchus*	288010	Argus gurnard*	*Lepidotrigla argus*
Thresher shark	*Alopias vulpinus*	288020	Little red gurnard	*Lepidotrigla grandis*
Rusty carpetshark	*Parascyllium ferrugineum*	288030	Crocodilefish	*Satyrichthys lingi*
Draughtboard shark	*Cephaloscyllium laticeps*	296001	Tiger flathead	*Neoplatycephalus richardsoni*
Sawtail shark	*Galeus boardmani*	296003	Sand flathead	*Platycephalus bassensis*
Whitefin swellshark	*Cephaloscyllium sp A*	296007	Blue-spotted flathead	*Platycephalus caeruleopunctatus*
Dwarf catshark	*Asymbolus sp A*	296021	Northern sand flathead	*Platycephalus arenarius*
Orange-spotted catshark	*Asymbolus sp D*	296035	Toothy flathead	*Neoplatycephalus aurimaculatus*
Grey spotted catshark	*Asymbolus analis*	296036	Long-spined flathead	*Platycephalus longispinis*
Northern draughtboard shark	*Cephaloscyllium sp C*	296037	Southern Flathead	*Platycephalus speculator*
Gummy shark	*Mustelus antarcticus*	296038	Marbled flathead	*Platycephalus marmoratus*
School shark	*Galeorhinus galeus*	297001	Deepsea flathead	*Hoplichthys haswelli*
Smooth hammerhead	*Sphyma zygaena*	311001	Eastern orange perch	*Lepidoperca pulchella*
Longsnout dogfish	*Deania quadrispinosa*	311002	Butterfly perch	*Caesioperca lepidoptera*
Spikey dogfish	*Squalus megalops*	311003	Barber perch	*Caesioperca rasor*
Southern dogfish	*Centrophorus uyato*	311006	Hapuku	*Polyprion oxygeneios*
Southern sawshark	*Pristiophorus nudipinnis*	311036	Halfbanded seaperch	*Hypoplectrodes maccullochi*
Common sawshark	*Pristiophorus cirratus*	311053	Threespine cardinalfish	*Apogonops anomalus*
Eastern sawshark	*Pristiophorus sp A*	311055	Splendid perch	*Callanthias australis*
Australian angel shark	*Squatina australis*	311091	Blackbanded seaperch	*Hypoplectrodes annulata*
Eastern angel shark	*Squatina sp A*	326002	Bigeye	*Cookeolus japonicus*
Western shovelnose ray	*Aptychotrema vincentiana*	327002	Longfin pike	*Dinolestes lewini*
Southern fiddler ray	*Trygonorrhina fasciata*	330001	King George whiting	*Sillaginodes punctata*
Eastern fiddler ray	*Trygonorrhina sp A*	330014	Eastern school whiting	*Sillago flindersi*
Eastern shovelnose ray	*Aptychotrema rostrata*	337002	Jack mackerel	*Trachurus declivis*
Coffin ray	*Hypnos monopterygium*	337003	Yellowtail scad	*Trachurus novaezelandiae*
Tasmanian numbfish	*Narcine tasmaniensis*	337006	Yellowtail kingfish	*Seriola lalandi*
Short-tail torpedo ray	*Torpedo macneilli*	337062	White trevally	*Pseudocaranx dentex*
Sydney skate	*Raja australis*	337063	Skipjack trevalley	*Pseudocaranx wrighti*
White spotted skate	*Raja cerva*	337077	Peruvian jack mackerel	*Trachurus murphyi*
Longnose skate	*Raja sp A*	345001	Redbait	*Emmelichthys nitidus nitidus*
Melbourne skake	*Raja whitleyi*	349001	Silverbelly	*Parequula melbournensis*
Peacock skate	*Pavoraja nitida*	353001	Snapper	*Pagrus auratus*
Bight skate	*Raja gudgeri*	355029	Red mullet	*Upeneichthys vlamingii*
Smooth stingray	*Dasyatis brevicaudata*	357001	Common bullseye	*Pempheris multiradiata*
Black stingray	*Dasyatis thetidis*	357002	Slender bullseye	*Parapriacanthus elongatus*
Sandyback stingaree	*Urolophus bucculentus*	357003	Rough bullseye	*Pempheris klunzingeri*
Banded stingaree	*Urolophus cruciatus*	361009	Silver sweep	*Scorpis lineolata*
Sparsely-spotted stingaree	*Urolophus paucimaculatus*	361010	Mado	*Atypichthys strigatus*
Yellowback stingaree	*Urolophus sulflavus*	366001	Old wife	*Enoplosus armatus*
Common stingaree	*Trygonoptera testacea*	367002	Giant boarfish	*Paristiopterus labiosus*
Greenback stingaree	*Urolophus viridis*	367003	Boarfish	*Pentaceropsis recurvirostris*
Eastern shovelnose stingaree	*Trygonoptera sp B*	367005	Longfin boarfish	*Zanclistius elevatus*
Western shovelnose stingaree	*Trygonoptera mucosa*	372005	White ear	*Parma microlepis*
Kapala stingaree	*Urolophus sp A*	377002	Grey morwong	*Nemadactylus douglasi*
Coral sea stingaree	*Urolophus sp B*	377003	Morwong	*Nemadactylus macropterus*
Southern eagle ray	*Myliobatis australis*	377006	Banded morwong	*Cheilodactylus spectabilis*
Ogilbys ghostshark	*Hydrolagus ogilbyi*	378001	Striped trumpeter	*Latris lineata*
Blackfin ghostshark	*Hydrolagus lemures*	378002	Bastard trumpeter	*Latridopsis forsteri*
Elephantfish	*Callorhinchus milii*	382002	Shortfin seapike	*Sphyraena novaehollandiae*
Green moray	*Gymnothorax prasinus*	384001	Foxfish	*Bodianus vulpinus (frenchii?)*
Pike eel	*Muraenesox bagio*	384003	Bluethroat wrasse	*Notolabrus tetricus*
Conger	*Gnathophis longicauda*	384023	Rosy wrasse	*Pseudolabrus psittaculus*
Southern conger	*Conger verreauxi*	384040	Maori wrasse	*Ophthalmolepis lineolata*
Swollenhead conger	*Bassanago bulbiceps*	384043	Eastern blue grouper	*Achoerodus viridis*
Giant snake eel	*Ophisurus serpens*	384061	Eastern blackspot pigfish	*Bodianus unimaculatus*
Siverside	*Argentina australiae*	384062	Pigfish	*Bodianus sp. 1 (Gomon)*
Sergeant Baker	*Aulopus purpurissatus*	384149	Redband wrasse	*Pseudolabrus biserialis*
Cucumberfish	*Chlorophthalmus nigripinnis*	390001	Barred grubfish	*Parapercis allporti*
Largescale new lanternfish	*Neoscopelus macrolepidotus*	390012	Grubfish*	*Parapercis binivirgata*
Beaked salmon	*Gonorynchus greyi*	400001	Bulldog stargazer	*Gnathagnus innotabilis*
Coffinfish	*Chaunax endeavouri*	400002	Fringed stargazer	*Ichthyscopus barbatus*
Bearded rock cod	*Pseudophycis barbata*	400003	Common stargazer	*Kathetostoma laeve*
Largetooth beardie	*Lotella rhacinus*	400018	Speckled stargazer	*Kathetostoma canaster*
Red cod	*Pseudophycis bachus*	427001	Common stinkfish	*Synchiropus calauropomus*
Tasmanian cod	*Austrophycis marginata*	427015	Spotted stinkfish	*Repomucenus calcaratus*
Bastard red cod	*Pseudophycis breviuscula*	439001	Barracouta	*Thyrsites atun*
Blue grenadier	*Macruronus novaezelandiae*	439002	Gemfish	*Rexea solandri*
Pink Ling	*Genypterus blacodes*	440002	Ribbonfish	*Lepidopus caudatus*
Southern whiptail	~~*Caelorinchus australis*~~	441001	Blue mackerel	*Scomber australasicus*
Banded whiptail	*Caelorinchus fasciatus*	441020	Australian bonito	*Sarda australis*
Gargoylefish	*Caelorinchus mirus*	445001	Blue-eye trevalla	*Hyperoglyphe antarctica*
Toothed whiptail	*Lepidorhynchus denticulatus*	445005	Blue warehou	*Seriolella brama*
Small banded whiptail	*Caelorinchus parvifasciatus*	445006	Silver warehou	*Seriolella punctata*
Sandpaper fish	*Paratrachichthys sp 1*	460001	Crested flounder	*Lophonectes gallus*
Violet roughy	*Optivus sp 1*	460002	Smalltooth flounder	*Pseudorhombus jenynsii*
Redfish	*Centroberyx affinis*	461001	Longsnout flounder	*Ammotretis rostratus*
Swallowtail	*Centroberyx lineatus*	461002	Bandedfin flounder	*Azygopus pinnifasciatus*
Yelloweye redfish	*Centroberyx australis*	461003	Greenback flounder	*Rhombosolea tapirina*
Silver dory	*Cyttus australis*	462010	Manybanded sole	*Zebrias scalarias*
Mirror dory	*Zenopsis nebulosus*	465002	Toothbrush leatherjacket	*Acanthaluteres vittiger*
John dory	*Zeus faber*	465003	Mosaic leatherjacket	*Eubalichthys mosaicus*
New Zealand Dory	*Cyttus novaezelandiae*	465005	Velvet leatherjacket	*Meuschenia scaber*
Flutemouth	*Fistularia petimba*	465006	Ocean jacket	*Nelusetta ayraudi*
Banded bellowsfish	*Centriscops humerosus*	465007	Rough leatherjacket	*Scobinichthys granulatus*
Common snipefish	*Macroramphosus scolopax*	465008	Brownstriped leatherjacket	*Meuschenia australis*
Crested bellowsfish	*Notopogon lilliei*	465024	Little leatherjacket*	*Paramonacanthus filicauda*
Bellowsfish	*Notopogon fernandezianus*	465025	Southern pygmy leatherjacket	*Brachaluteres jacksonianus*
Bigbelly seahorse	*Hippocampus abdominalis*	465036	Sixspine leatherjacket	*Meuschenia freycineti*
Spiny pipehorse	*Solegnathus spinosissimus*	465037	Degens leatherjacket	*Thamnaconus degeni*
Ocean perch	*Helicolenus percoides*	465039	Black reef leatherjacket	*Eubalichthys bucephalus*
Gurnard perch	*Neosebastes pandus*	465060	Stars-and-stripes leatherjacket	*Meuschenia venusta*
Ruddy gurnard perch	*Neosebastes scorpaenoides*	466001	Ornate cowfish	*Aracana ornata*
Thetis fish	*Neosebastes thetidis*	466002	Eastern smooth boxfish	*Anoplocapros inermis*
Southern rock cod	*Scorpaena papillosa*	466003	Shaws cowfish	*Aracana aurita*
Western gurnard perch	*Neosebastes entaxis*	467001	Barred toadfish	*Contusus richei*
Soldierfish	*Gymnapistes marmoratus*	467002	Ringed toadfish	*Omegophora armilla*
Northern' gurnard perch	*Neosebastes incisipinnis*	467004	Pufferfish*	*Sphoeroides pachygaster*
Whitleys scorpionfish	*Maxillicosta whitleyi*	467005	Starry toadfish	*Arothron firmamentum*
Fortesque	*Centropogon australis*	467050	Halstead's toadfish	*Reicheltia halsteadi*
Red rock cod	*Scorpaena cardinalis*	469001	Globefish	*Diodon nicthemerus*
Deep ocean perch	*Helicolenus barathri*	469002	Australian burrfish	*Allomycterus pilatus*
~~Red gurnard~~	*Chelidonichthys kumu*	999997	Unidentified 3	Unidentified 3
Spiny gurnard	*Lepidotrigla papilio*	999998	Unidentified 2	Unidentified 2
Butterfly gurnard	*Lepidotrigla vanessa*	999999	Unidentified 1	Unidentified 1
Painted latchet	*Pterygotrigla andertoni*			

Effects of Data Transformation

The formation of similar groups of samples by cluster and ordination following each transformation indicated that the emerging patterns, related to depth and latitude, were robust (Fig. 8.2.3.1). Stress decreased with increasing severity of transformation from 0.20 (untransformed) to 0.13 (double square-root) but was not further reduced by the presence/ absence transform. The differentiation of three depth-related groups was strong for all transforms (depths 1+2, 3+4 and 5), whereas the gradient with latitude (transect A= most southwesterly, G= most northeasterly) was most distinct in the intermediate transforms. Based on these observations, the double square-root transformation was used for subsequent analyses.

Diel Effects

Time constraints on the first survey (SS0593, early-winter), when days were shortest and the sampling sites were sounded for the first time, required 12 of the standard trawls to be completed at night. Thus, it was necessary to determine if there was a diel signal in these samples that would influence our interpretation of depth and latitude effects across seasons using the full seasonal dataset. As there were not replicate day samples for the 12 samples in question, a limited test of day/ night and local spatial effects was possible by using replicate samples (four day and four night) from the C5 station, and the corresponding day samples from adjacent transects at the same depth (B5, D5) (Fig. 8.2.3.2a) and adjacent depths (B4, C4, D4) (Fig. 8.2.3.2b). Cluster and ordination plots showed that local spatial differences were marked but that there was no differentiation of day and night samples. Seven of the C5 samples formed a group while one C5 night sample and all the adjacent samples were separated— those from the adjacent depth stratum most clearly. On this basis the 12 night-time standard trawls were included in the full dataset, although noting that there had been no test for a diel signal in the shallower samples ($\leq$ 120 m).

Patterns of similarity among soft-ground sites

Depth and spatial (latitude/ longitude) trends were most dominant in the groups formed by stations (Fig. 8.2.3.3). Multivariate (classification and ordination) analysis of separate seasonal data sets showed consistent groups formed by sites from inner-shelf depths 1 and 2 (25+40 m), mid-shelf depths 3 and 4 (80+120 m), and outer-shelf depth 5 (~150-200 m) with very few 'cross-overs' between groups (Fig. 8.2.3.3a-d). Southwesterly to northeasterly (clinal) patterns were also evident, to varying degrees, within depth-related groups in all seasons (A= southwesterly to G= northeasterly). Stress values showed that the overall representation of between-site similarity in 2-d MDS plots was adequate, although stress in the early-winter plot was relatively high (0.20). Four outliers (late-winter G2, spring G1 & G2, autumn G5) were sites represented by small catches (<100 kg unstandardised total weight). The strong and consistent relationship with depth across seasons enabled us to re-aggregate the data to examine clinal and seasonal effects with the depth effect removed (Fig. 8.2.3.4).

Clinal patterns were most distinct on the inner-shelf and least distinct on the outer-shelf (Figs. 8.2.3.3, 4). Sites from transects A and B ('southwest') generally had high similarity to each other, as did those from transects F and G ('northeast'). Sites from the central transects, C, D and E ('central-region') generally grouped together but were variously combined with the southwest and northeast groups, particularly transect E with northeast transects.

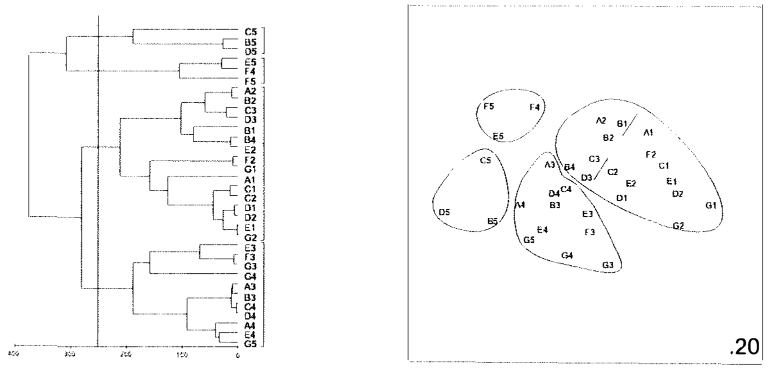
Southwest sites (transects A and B) on the inner-shelf formed a discrete group (group 1, Fig. 8.2.3.4), but on the mid-shelf grouped together within a larger southwest/ central-region group (group 3, Fig. 8.2.3.5). Three early-winter mid-shelf sites (A3, B3, B4) grouped separately (group 1, Fig. 8.2.3.5). Our analysis provided less contrast on the outer-shelf because transect A was not sampled. Transect B grouped with central-region transects C and D in spring and autumn, but separately in winter (Fig. 8.2.3.6).

Central-region sites (transects C, D and E) on the inner-shelf grouped together but formed two sub-groups: most C and D sites in one, and most E sites together with some northeast sites in the other (group 2, Fig. 8.2.3.4). On the mid-shelf, most central-region sites grouped together and formed a large group with the southwest sites (group 3, Fig. 8.2.3.5). The notable exceptions were transect E sites that grouped with northern sites in autumn and winter (group 4, Fig. 8.2.3.5). At the outer-shelf, sites C and D combined with B and were separated from E, although early-winter and spring C sites were outliers (Fig. 8.2.3.6).

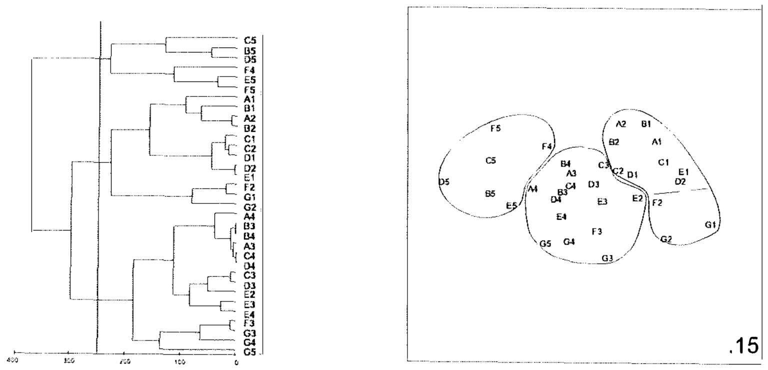
Northeast sites (transects F and G) were generally less-distinctly grouped than southwest sites (transects A and B). Six of 12 inner-shelf samples formed a discrete group (group 3, Fig. 8.2.3.4), four contributed to a sub-group with transect E sites (group 2, Fig. 8.2.3.4), and two were outliers. Northeast sites on the mid-shelf, in combination with transect E sites from autumn and winter, formed three groups that had a weak seasonal structure. Outer northeast shelf sites mostly grouped together with transect E sites (Fig. 8.2.3.6), although a second group was formed by F (early winter) and G (autumn) (group 4, Fig. 8.2.3.6).

Only weak seasonal signals were evident in the patterns formed by soft-ground sites. They were indistinct relative to depth and spatial trends, and inconsistent across depth or clinal site groups. Overall, dendrograms showed that in late-winter (1994) and autumn (1996), shallower groups (inner and mid-shelf) were more similar to each other than the outer-shelf (Fig. 8.2.3.3b, d), whereas in early winter (1993) and spring (1996) the deeper groups (mid-shelf and outer-shelf) were most similar (Fig. 8.2.3.3a, c). Spring samples showed the most distinct depth structure overall. Most ‘cross-overs’ were outer-shelf sites grouping with the mid-shelf. Cross-overs occurred in early winter (E5 and F5) and in late winter (B5 and F5) but not in spring; the autumn G5 ‘cross-over’ was an unreliable (< 100 kg) sample. Otherwise, C3, grouped with the inner-shelf in spring, and E2 with the mid-shelf in autumn.

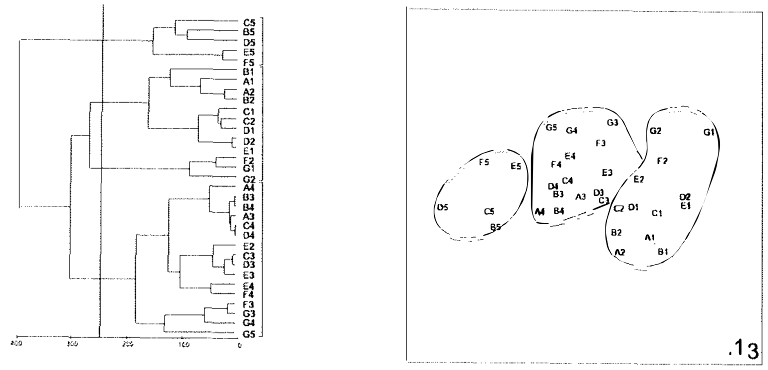
Among depth groups, inner-shelf sites showed no seasonal signal (Fig. 8.2.3.4). Mid-shelf sites showed a weak seasonal signal with some early-winter sites grouping separately (Fig. 8.2.3.4). In addition, southwest sites from early and late winter were separated from spring and autumn in group 3, and northeast sites from winter separated from spring and autumn in groups 2 and 5 (Fig. 8.2.3.5). A weak seasonal separation was also apparent at the outer-shelf where winter sites from southern transects (B, C and D) tended to separate from spring and autumn in groups 1 and 2 (Fig. 8.2.3.6). Within depth-groups, stations on Transect E (Disaster Bay) appeared to be most seasonally variable in their affinities with adjacent stations. E2 grouped with inner-shelf stations from C and D in late-winter and spring, but northern stations in autumn and early winter. This is largely consistent with the northward penetration of Bass Strait water on the seabed: to or beyond Disaster Bay in late-winter and spring, but only to Cape Howe in early winter (*Section* 5). (In autumn when all inner-shelf stations south of transect G (Bermagui) were inundated with warm water (presumably EAC), the E2 autumn sample was an outlier being more similar to the adjacent mid-shelf.) However, the affinities of mid-shelf stations on transect E were not consistent with water mass distribution. Thus, E3 and E4 grouped with northern stations in autumn (and winter) when Bass Strait water extended over and northwards of the



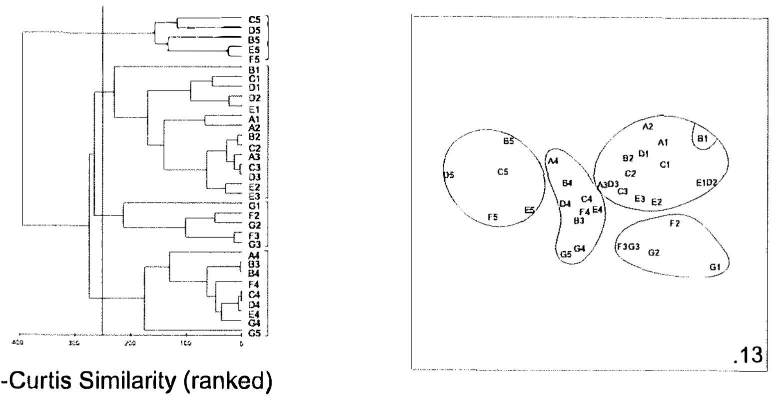
(a) None



(b) Square root



(c) Root-root



(d) Presence/ absence

Figure 8.2.3.1. Cluster and ordination plots showing the effects of different transformations of species biomass data on the grouping of the 33 standard stations sampled in autumn. Transect codes, A-G, follow Figure 4.1.1.1.

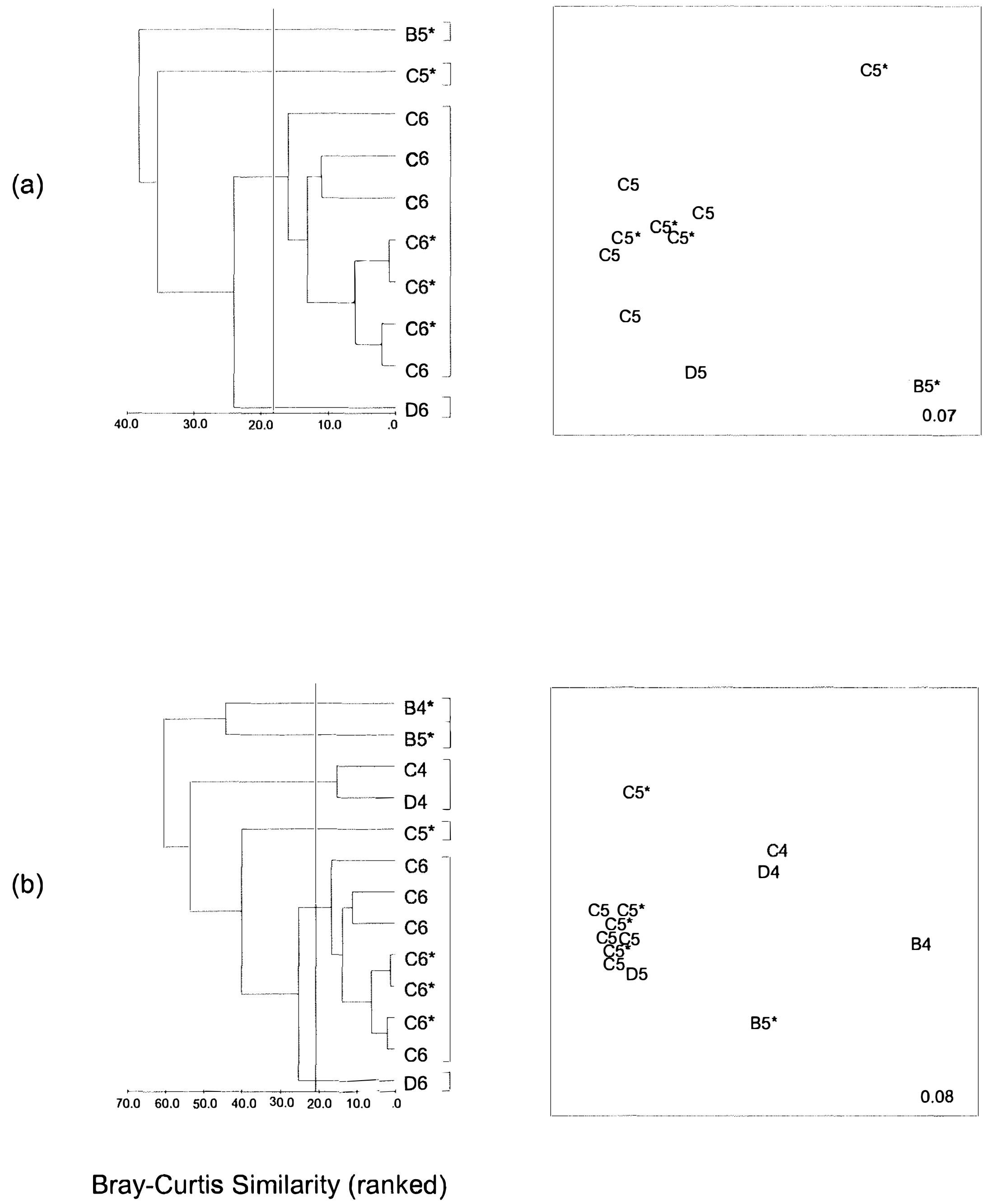
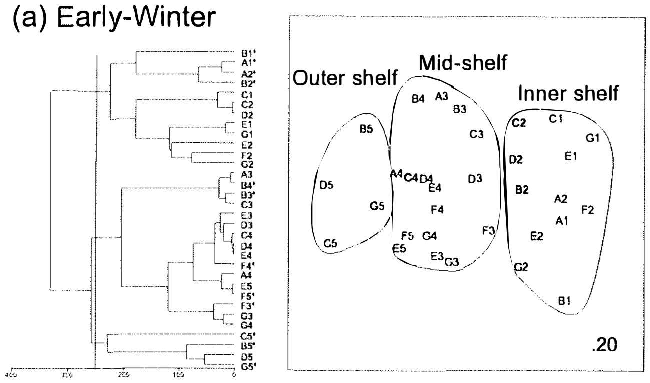
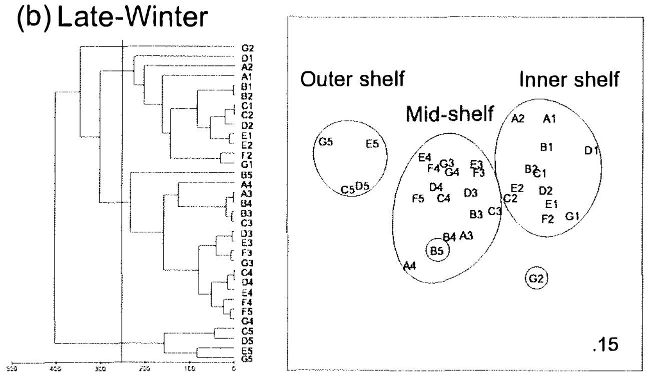


Figure 8.2.3.2 Cluster and ordination plots showing patterns among replicate day/ night samples at C5 station, together with the corresponding day samples from (a) adjacent transects at the same depth (B5, D5) and (b) adjacent depths (B4, C4, D4). * indicates night samples.

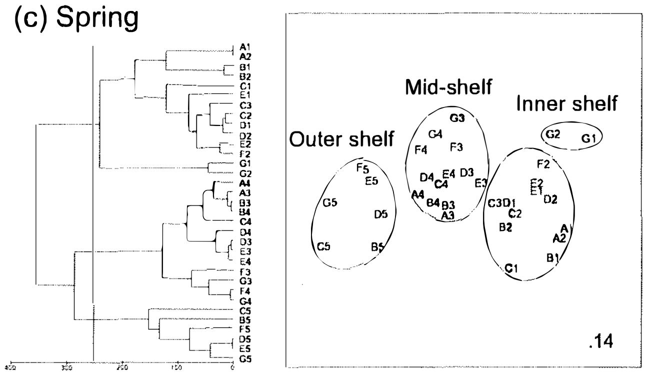
(a) Early-Winter



(b) Late-Winter



(c) Spring



(d) Autumn

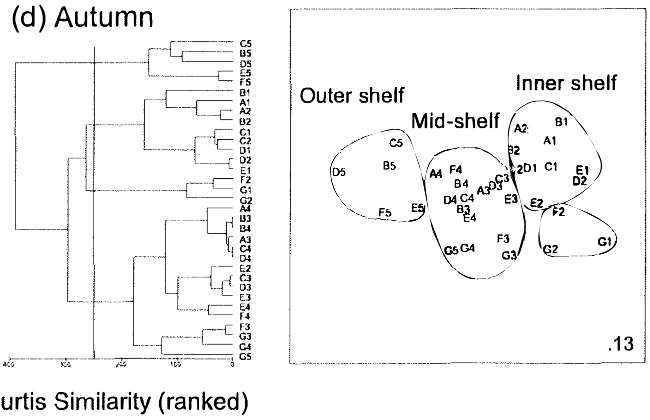


Figure 8.2.3.3 Cluster and ordination plots showing the primary depth and clinal patterns among the stations sampled in each of the seasonal cruises. Transect codes, A-G, follow Figure 4.1.1.1.

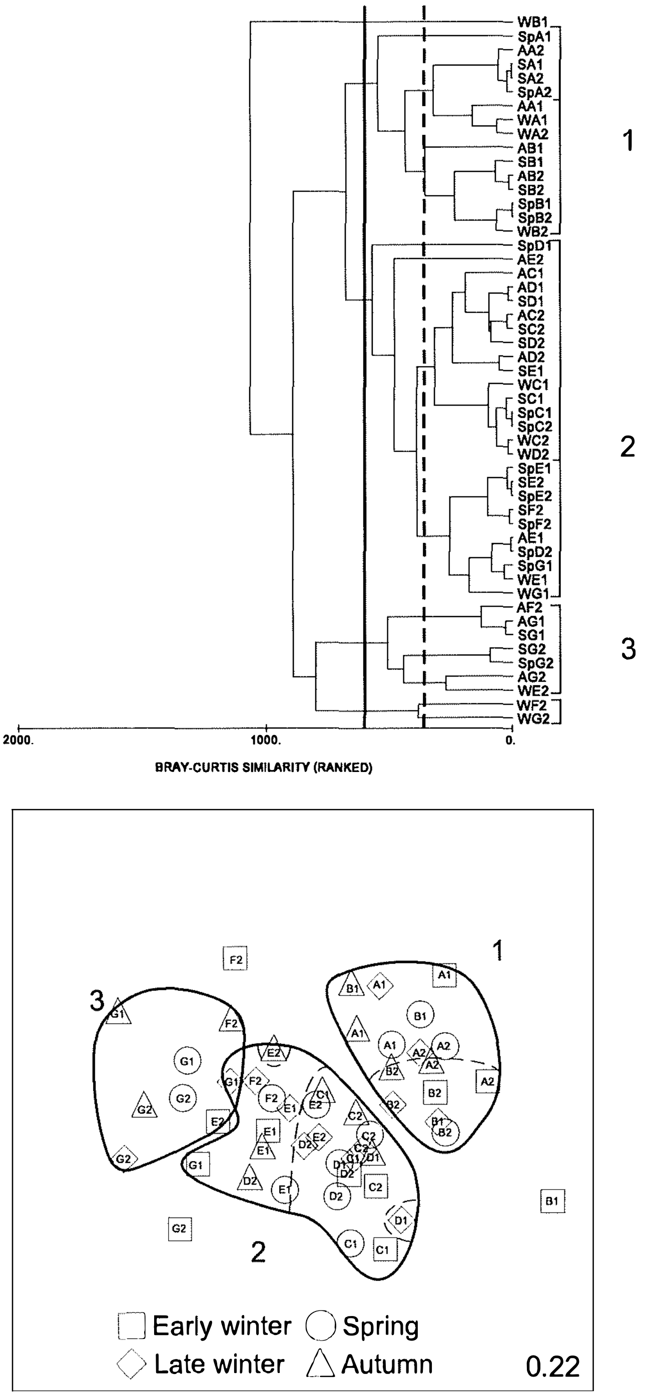


Figure 8.2.3.4 Cluster and ordination plots showing similarities of stations from broad-scale trawl survey: combined seasonal patterns of stations at 25 m and 40 m depths. Transect codes A-G follow fig. 4.1.1.1.

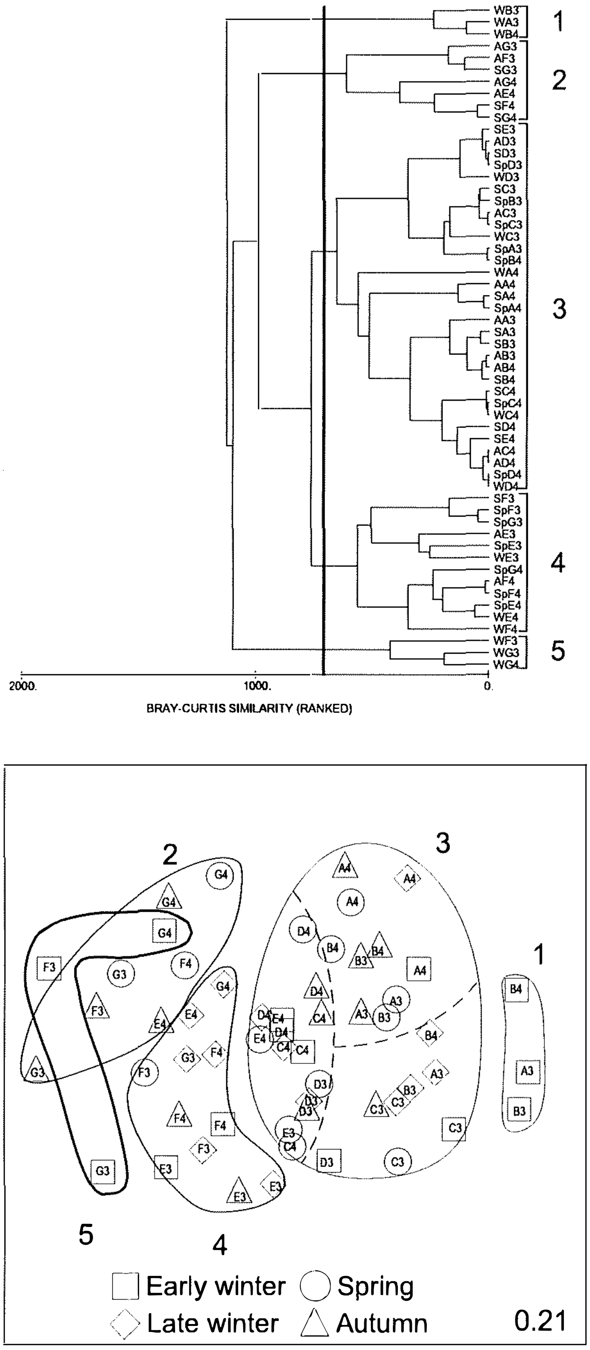


Figure 8.2.3.5 Cluster and ordination plots showing similarities of stations from broad -scale trawl survey: overall patterns of stations at 80m and 120m depths. Transect codes A -G follow fig. 4.1.1.1.

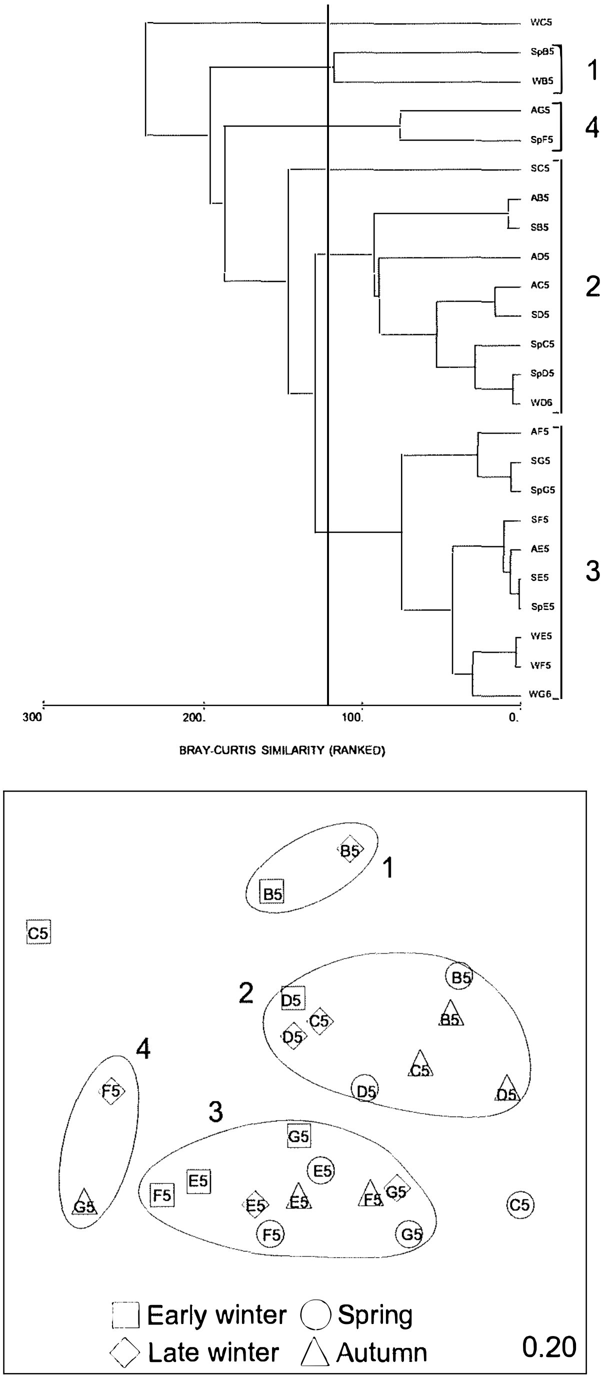


Figure 8.2.3.6 Cluster and ordination plots showing similarities of stations from broad-scale trawl survey: seasonal patterns of stations at 200m depths. Transect codes, A - G, follow fig 4.1.1.1.

Disaster Bay mid-shelf; they grouped with southern stations in spring when a distinct tongue of EAC water inundated the mid-shelf as far south as transect B.

A further disaggregation of the data, with depth-groups examined within season repeated clinal patterns without a distinct or consistently different seasonal signal (Figs. 8.2.3.7-8.2.3.9).

Thus, based on fish community composition at soft-ground sites, seven habitat regions were identified based primarily on depth and location (southwest/ northeast cline) with weak seasonal signals indicating subtle shifts in winter-time community boundaries on the mid- and outer-shelf, particularly on Transect E.

1) ISW = A1-2, B1-2 (inner-shelf, southwest)

2) IC = C1-2, D1-2, [E1-2] (inner-shelf, central region)

3) INE = F1-2, G1-2 (inner-shelf, northeast)

4) MSWC = A3-4, B3-4, C3-4, D3-4, [E3-4] (mid-shelf, southwest/ central region)

5) MNE = F3-4, G3-4 (mid-shelf, northeast region)

6) OSWC = B5, C5, D5 (outer-shelf, southwest/ central region)

7) ONEC = E5, F5, G5 (outer-shelf, northeast/ central region)

Species characterising soft-ground habitats

Species contributing to the differentiation of southwest and northeast inner-shelf stations were compared using combined seasonal catches from transects A and B (ISW), and F and G (INE). Of the 128 fishes caught, 58 (45%) were shared, 46 (36%) restricted to the southwest, and 24 (19%) restricted to the northeast. Among the 10 most-typical species in each area (contributing most similarity) only two (jack mackerel and sparsely-spotted stingaree) were shared (Table 8.2.3.2). Tiger flathead and white trevally were the only quota species highly typical of either area (in top-ranked 10 northeast species), although John dory and eastern school whiting were in the top 20 northeast species, and tiger flathead, eastern school whiting and blue warehou in the top 20 southern species.

Most dissimilarity between areas was contributed by shared species with relatively high abundance (rather than uncommon, restricted species), of which most were species with relatively high abundance in the southwest. These trends are evident in the ten species, including the quota species eastern school whiting, that contributed most dissimilarity (Table 8.2.3.2).

Species contributing to the differentiation of southern and northeast mid-shelf stations were compared using combined seasonal catches from transects A to D (MSWC), and F and G (MNE). Transect E was excluded due to its variable grouping pattern. Of the 121 species caught, 71 (59%) were shared, 32 (17%) restricted to the southern stations, and 18 (15%) to the northeast. Among the 10 most-typical species in each area (contributing most similarity) five species (cucumberfish, tiger flathead, velvet leatherjacket, silver dory and deepwater gurnard) were shared (Table 8.2.3.3). Quota species that were in the top-ranked group were tiger flathead in both areas, and John dory and ocean perch in the northeast. Also highly ranked (in the top 20 most typical species) were John dory, ocean perch and morwong in the southern area, and redfish and morwong in the northeast. As was the case on the inner-shelf, most dissimilarity between areas was contributed by shared species with relatively high abundance, of which most were species with relatively high abundance in the southwest. Redfish and common snipefish were highly ranked but most abundant in the northeast. These trends are evident in the ten species that contributed most dissimilarity (Table 8.2.3.3).

Species contributing to the differentiation of southwest and northeast outer-shelf stations were compared using combined seasonal catches from transects B to D (OSWC), and E to G (ONEC). Of the 93 species caught, 53 (57%) were shared, 22 (24%) restricted to the southwest stations, and 18 (19%) to the northeast. Among the 10 most-typical species in each area (contributing most similarity) five species (3-spined cardinalfish, cucumberfish, spikey dogfish, jack mackerel and mirror dory) were shared (Table 8.2.3.4). More quota species were in the top-ranked groups relative to the inner and mid-shelf: morwong and mirror dory in the southwest, and redfish, ocean perch, pink ling, tiger flathead and mirror dory in the northeast. Also highly ranked (in the top 20 most typical species) were tiger flathead, ocean perch and pink ling in the southern area, and silver warehou, morwong and deep ocean perch in the northeast. As was the case on the inner and mid-shelf, most dissimilarity between areas was contributed by shared species with relatively high abundance, of which most were species with relatively high abundance in the southwest. Redfish, jack mackerel and ocean perch were highly ranked but most abundant in the northeast. These trends are evident in the ten species that contributed most dissimilarity (Table 8.2.3.4).

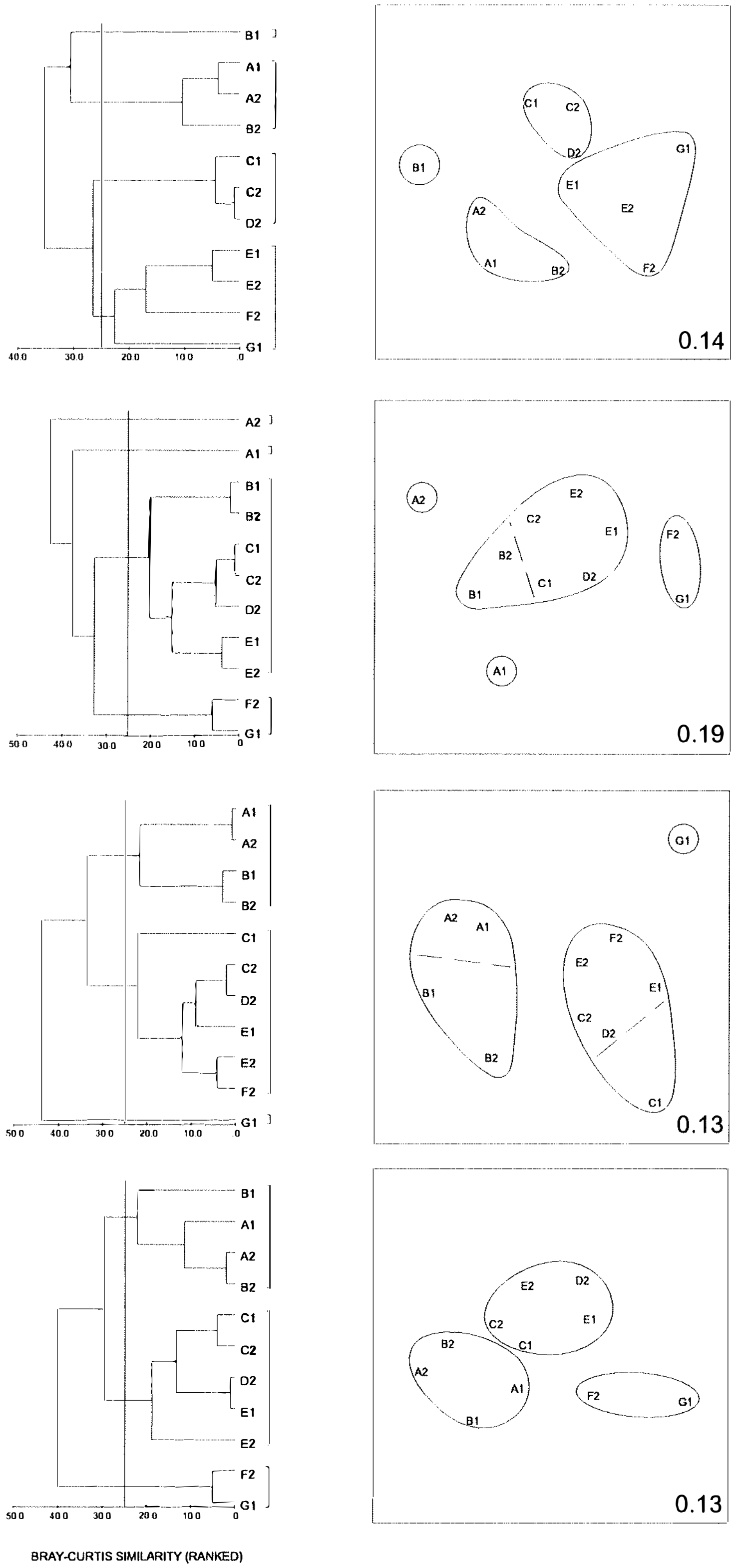
Dominant species in soft-ground habitats

Dominant fishes were identified as those highest ranked by geometric mean abundance and making up 80% untransformed biomass in the catch of each gear in each habitat (Table 8.2.3.5). The proportions of marketable species (quota and commercial) and non-commercial species are shown in Table 8.2.3.6.

The number of dominant species in soft-ground habitats was generally high due to the high species-richness of trawl catches. However, they varied considerably as exemplified by the two outer-shelf regions: only six species in the northeast (ONEC) compared to 25 in the southwest/ central (OSWC).

A diverse mix of primarily non-commercial species dominate the three inner-shelf habitats with jack mackerel making up the highest proportion of biomass in each (Table 8.2.3.5). Eastern school whiting was the most important of the commercially marketable species in each habitat accounting for the vast majority of their combined biomass. In the northeast (INE), where total marketable species was highest (33.3%), eastern school whiting made up 7.8% biomass, but redfish (5.7% biomass), white trevally (5.7%) and Australian angelshark (9.0%) were also important.

In mid-shelf habitats, redfish were conspicuous among dominant species in the northeast (MNE) in making up 35.3% of overall biomass; they account for the large difference in the proportion of marketable species between MNE and the southwest central region (MSWC) (Table 8.2.3.6). The ubiquitous jack mackerel made up substantial proportions of biomass in both mid-shelf habitat regions, along with cucumberfish and barracouta in the southwest/ central region (Table 8.2.3.5).



(a) Early-Winter

(b) Late-Winter

(c) Spring

(d) Autumn

Figure 8.2.3.7 Cluster and ordination plots showing similarities of stations from broad-scale trawl survey:patterns of stations at 25 m and 40 m depths by season. Transect codes, A - G, follow fig 4.1.1.1.

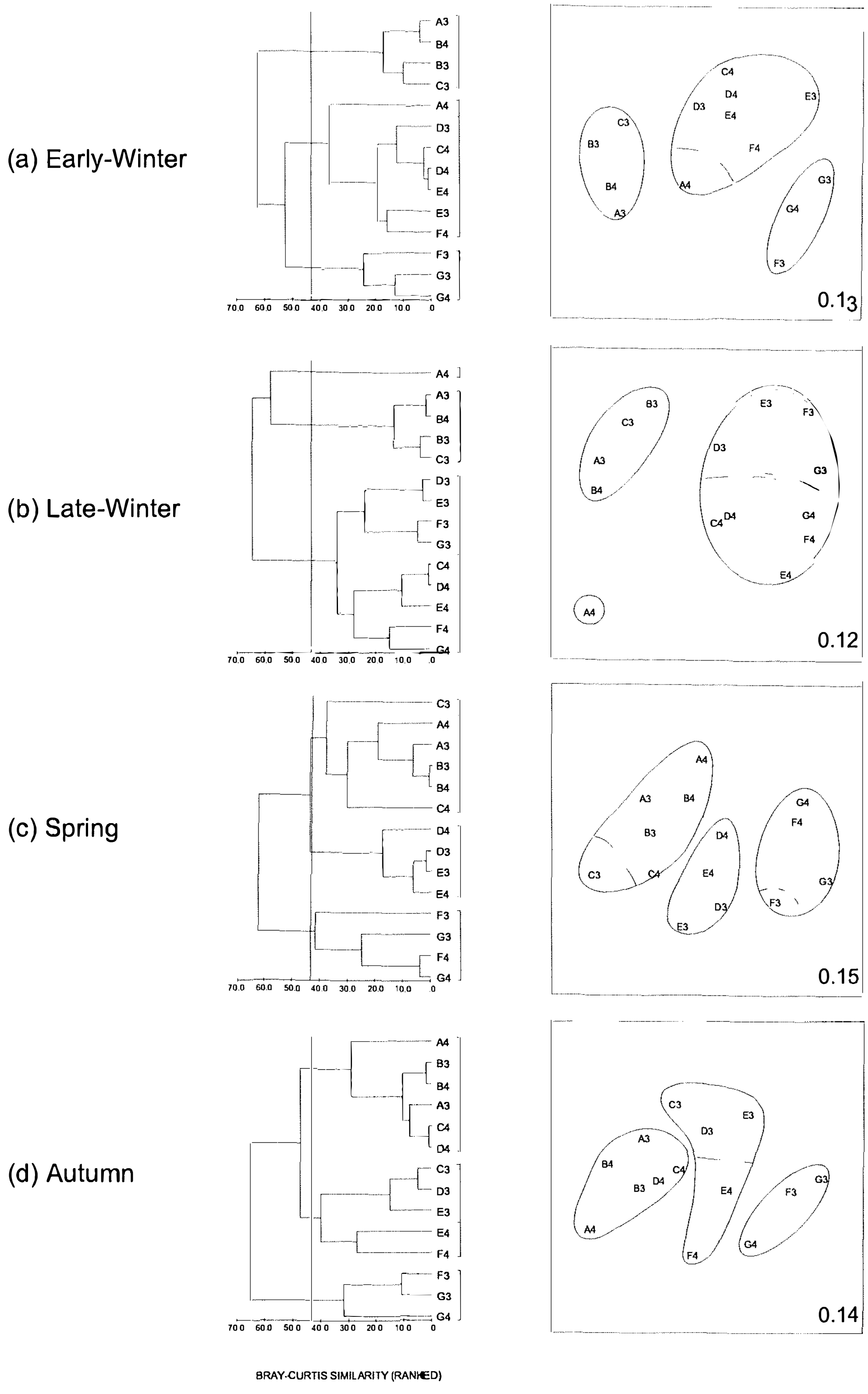
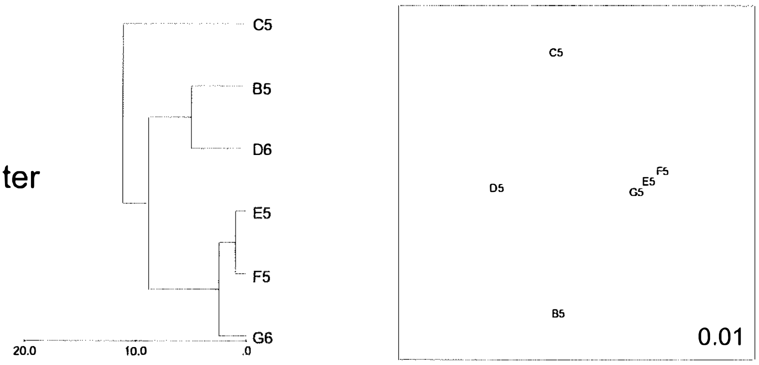
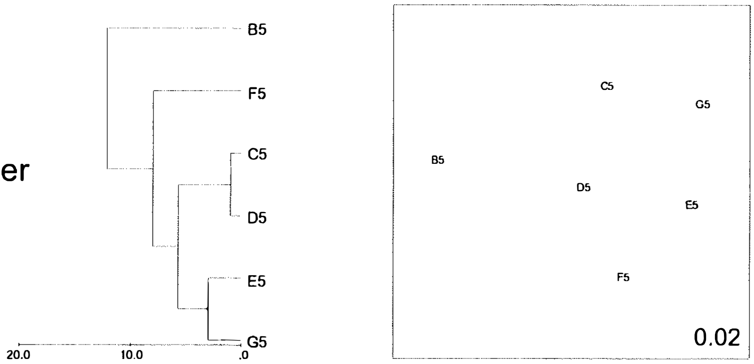


Figure 8.2.3.8 Cluster and ordination plots showing similarities of stations from broad-scale trawl survey: patterns of stations at 80 m and 120 m depths by season. Transect codes, A-G, follow Figure 4.1.1.1.

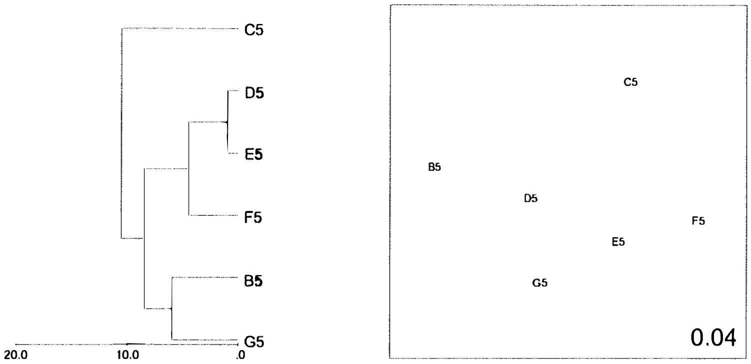
(a) Early-Winter



(b) Late-Winter



(c) Spring



(d) Autumn

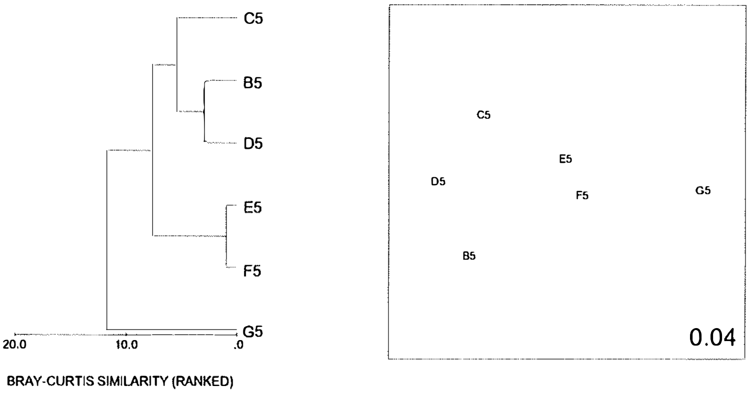


Figure 8.2.3.9 Cluster and ordination plots showing similarities of stations from broad-scale trawl survey: patterns of stations at 200 m depths by season. Transect codes, A-G, follow Figure 4.1.1.1.

Table 8.2.3.2 Top-ten ranked species typifying (high similarity) and discriminating (high dissimilarity) broad-scale trawl stations in similarity percentage analysis: inner shelf

INNER SHELF Northeast typical species		Average abundance	Average similarity	Ratio	Percentage similarity	Cumulative percent
Sparsely-spotted stingaree	*Urolophus paucimaculatus*	259.23	5	3.95	11.79	11.79
Australian angel shark	*Squatina australis*	330.88	3.8	1.2	8.95	20.73
Deepwater gurnard	*Lepidotrigla mulhalli*	124.99	3.2	2	7.49	28.22
Eastern smooth boxfish	*Anoplocapros inermis*	42	2.8	2.96	6.51	34.73
Jack mackerel	*Trachurus declivis*	543.89	2.4	1.6	5.65	40.38
Australian burrfish	*Allomycterus pilatus*	54.47	2	1.04	4.58	44.96
Tiger flathead	*Neoplatycephalus richardsoni*	31.35	1.8	0.97	4.14	49.09
White trevally	*Pseudocaranx dentex*	207.07	1.6	0.79	3.78	52.87
Sixspine leatherjacket	*Meuschenia freycineti*	67.92	1.6	0.83	3.71	56.58
Southern eagle ray	*Myliobatis australis*	361.93	1.5	0.7	3.59	60.17
Southwest typical species						
Jack mackerel	*Trachurus declivis*	6139.96	4.8	1.43	10.76	10.76
Globefish	*Diodon nicthemerus*	484.44	3.6	5	8.06	18.81
Draughtboard shark	*Cephaloscyllium laticeps*	453.9	2.5	1.26	5.72	24.53
Common stinkfish	*Synchiropus calauropomus*	345.63	2.2	2.2	5.02	29.55
Sparsely-spotted stingaree	*Urolophus paucimaculatus*	137.11	2.2	2.07	4.86	34.41
Red mullet	*Upeneichthys vlamingii*	168.27	2.1	3.23	4.79	39.2
Silverbelly	*Parequula melboumensis*	285.76	2.1	1.56	4.65	43.86
Degens leatherjacket	*Thamnaconus degeni*	487.54	1.8	1.33	4.17	48.02
Banded stingaree	*Urolophus cruciatus*	101.92	1.7	1.46	3.88	51.91
Longnose skate	*Raja sp A*	147.67	1.6	1.05	3.59	55.49

Southwest/ northeast discriminating species		Average abundance (southwest)	Average abundance (northeast)	Average dissimilarity	Ratio	Percentage dissimilarity	Cumulative percent
Jack mackerel	*Trachurus declivis*	6139.96	543.89	3.02	1.02	4.16	4.16
Australian angel shark	*Squatina australis*	23.51	330.88	1.92	1.52	2.65	6.82
Degens leatherjacket	*Thamnaconus degeni*	487.54	0	1.88	1.62	2.59	9.4
Silverbelly	*Parequula melboumensis*	285.76	0	1.86	1.94	2.56	11.96
Draughtboard shark	*Cephaloscyllium laticeps*	453.9	127.3	1.8	1.33	2.48	14.44
Eastern school whiting	*Sillago flindersi*	1093.41	282.96	1.78	1.22	2.46	16.9
Globefish	*Diodon nicthemerus*	484.44	38.91	1.7	1.61	2.34	19.24
Common stinkfish	*Foetorepus calauropomus*	345.63	3.75	1.69	1.56	2.33	21.56
Southern eagle ray	*Myliobatis australis*	250.3	361.93	1.6	1.12	2.21	23.77
Red mullet	*Upeneichthys vlamingii*	168.27	0.64	1.59	2.14	2.19	25.96

Table 8.2.3.3 Top-ten ranked species typifying (high similarity) and discriminating (high dissimilarity) broad-scale trawl stations in similarity percentage analysis: mid-shelf

MID-SHELF Southern typical species		Average abundance	Average similarity	Ratio	Percentage similarity	Cumulative percent
Cucumberfish	*Chlorophthalmus nigripinnis*	708.44	4.6	2.21	9.12	9.12
Minor gurnard	*Lepidotrigla modesta*	204.75	3.8	3.55	7.53	16.65
Longnose skate	*Raja sp A*	173.47	3.8	4.51	7.52	24.17
Tiger flathead	*Neoplatycephalus richardsoni*	222.84	3.7	4.16	7.32	31.49
Velvet leatherjacket	*Meuschenia scaber*	359.09	3.1	1.88	6.22	37.71
Spikey dogfish	*Squalus megalops*	211.48	2.7	1.32	5.45	43.17
Draughtboard shark	*Cephaloscyllium laticeps*	340.89	2.7	1.21	5.34	48.5
Silver dory	*Cyttus australis*	119.87	2	1.56	3.95	52.46
Deepwater gurnard	*Lepidotrigla mulhalli*	138.12	1.9	1.28	3.71	56.16
Australian burrfish	*Allomycterus pilatus*	79.39	1.8	1.11	3.61	59.78
Northeast typical species						
Jack mackerel	*Trachurus declivis*	1284.24	5.5	2.67	11.67	11.67
Common snipefish	*Macroramphosus scolopax*	413.22	5.1	2.49	10.95	22.61
Velvet leatherjacket	*Meuschenia scaber*	245.84	4.3	2.94	9.2	31.81
Tiger flathead	*Neoplatycephalus richardsoni*	287.31	4.3	4.29	9.2	41.01
Cucumberfish	*Chlorophthalmus nigripinnis*	107.12	2.8	1.55	5.99	47
Deepwater gurnard	*Lepidotrigla mulhalli*	46.01	2.7	2.05	5.69	52.69
Grey morwong	*Nemadactylus douglasi*	115.8	2.5	1.92	5.42	58.11
John dory	*Zeus faber*	60	2.5	2.07	5.26	63.36
Ocean perch	*Helicolenus percoides*	276.56	2.3	1.15	4.83	68.2
Silver dory	*Cyttus australis*	39.23	2.1	1.48	4.47	72.66

Southern/ northeast discriminating species		Average abundance (northeast)	Average abundance (southwest)	Average dissimilarity	Ratio	Percentage dissimilarity	Cumulative percent
Jack mackerel	*Trachurus declivis*	1284.24	1042.31	2.35	1.5	3.87	3.87
Spikey dogfish	*Squalus megalops*	0	211.48	2.13	1.73	3.51	7.38
Redfish	*Centroberyx affinis*	2350.2	4.11	2.05	0.99	3.38	10.75
Draughtboard shark	*Cephaloscyllium laticeps*	68.52	340.89	2.01	1.45	3.3	14.06
Common snipefish	*Macroramphosus scolopax*	413.22	50.53	1.74	1.47	2.86	16.92
Cucumberfish	*Chlorophthalmus nigripinnis*	107.12	708.44	1.63	1.32	2.69	19.6
Barracouta	*Thyrsites atun*	30.08	640.34	1.59	0.97	2.62	22.22
Sandyback stingaree	*Urolophus bucculentus*	15.71	217.1	1.58	1.23	2.6	24.82
Minor gurnard	*Lepidotrigla modesta*	19.12	204.75	1.5	1.46	2.47	27.3
Greenback stingaree	*Urolophus viridis*	96.38	198.34	1.42	1.24	2.34	29.63

Table 8.2.3.4 Top-ten ranked species typifying (high similarity) and discriminating (high dissimilarity) broad-scale trawl stations in similarity percentage analysis: shelf-break

SHELF-BREAK Southern typical species		Average abundance	Average similarity	Ratio	Percentage similarity	Cumulative percent
Threespine cardinalfish	*Apogonops anomalus*	2917.27	4.1	1.92	10.41	10.41
Cucumberfish	*Chlorophthalmus nigripinnis*	201.56	3.2	3.09	8.04	18.45
Spikey dogfish	*Squalus megalops*	587.55	2.9	1.29	7.28	25.73
Speckled stargazer	*Kathetostoma canaster*	199.89	2.5	1.04	6.35	32.08
Jack mackerel	*Trachurus declivis*	1880.98	2	0.98	5.07	37.15
Silver warehou	*Seriolella punctata*	1920.21	2	0.75	5.06	42.21
Morwong	*Nemadactylus macropterus*	1077.94	1.8	0.76	4.41	46.62
Longnose skate	*Raja sp A*	59.56	1.7	1.05	4.37	50.99
Mirror dory	*Zenopsis nebulosus*	133.52	1.6	0.97	4.04	55.03
Southern whiptail	*Caelorinchus australis*	68.15	1.5	1.04	3.85	58.88
Northern typical species						
Redfish	*Centroberyx affinis*	2071.28	6	1.72	12.66	12.66
Cucumberfish	*Chlorophthalmus nigripinnis*	509.41	5.8	6.47	12.28	24.94
Ocean perch	*Helicolenus percoides*	340.54	5	3.85	10.61	35.55
Jack mackerel	*Trachurus declivis*	2307.23	4.5	1.29	9.4	44.95
Threespine cardinalfish	*Apogonops anomalus*	1195.9	2.3	0.86	4.92	49.87
Pink Ling	*Genypterus blacodes*	54.04	2.1	1.32	4.45	54.32
Spikey dogfish	*Squalus megalops*	93.12	2	1.35	4.28	58.6
Barred grubfish	*Parapercis allporti*	7.66	1.6	2	3.28	61.89
Tiger flathead	*Neoplatycephalus richardsoni*	42.15	1.5	1.02	3.19	65.08
Mirror dory	*Zenopsis nebulosus*	112.06	1.5	0.77	3.08	68.15

Southern/ northern discriminating species		Average abundance (northern)	Average abundance (southern)	Average dissimilarity	Ratio	Percentage dissimilarity	Cumulative percent
Redfish	*Centroberyx affinis*	2071.28	722.34	3.42	1.95	5.35	5.35
Jack mackerel	*Trachurus declivis*	2307.23	1880.98	2.61	1.33	4.08	9.43
Threespine cardinalfish	*Apogonops anomalus*	1195.9	2917.27	2.26	1.27	3.54	12.97
Silver warehou	*Seriolella punctata*	69.6	1920.21	2.22	1.2	3.48	16.45
Morwong	*Nemadactylus macropterus*	28.54	1077.94	1.91	1.28	2.99	19.44
Ocean perch	*Helicolenus percoides*	340.54	250.87	1.84	1.42	2.88	22.31
Speckled stargazer	*Kathetostoma canaster*	64.14	199.89	1.71	1.42	2.68	24.99
Spikey dogfish	*Squalus megalops*	93.12	587.55	1.56	1.25	2.44	27.43
Barracouta	*Thyrsites atun*	29.14	203.54	1.36	1.17	2.13	29.56
Redbait	*Emmetichthys nitidus nitidus*	22.73	1716.47	1.36	0.67	2.12	31.68

Table 8.2.3.5 Dominant species in 'soft-ground' habitats sampled by broad-scale trawl survey: species ranked geometric mean abundance with cut-off at 80% of total untransformed biomass. Habitat codes follow Section 8.2.3.

Habitat type	Common name	Species name	Geo. mean biomass	% raw biomass	Cum % biomass
INE	Sparsely-spotted stingaree	*Urolophus paucimaculatus*	187.3	7.1	7.1
	Australian angel shark	*Squatina australis*	100.8	9.1	16.2
	Deepwater gurnard	*Lepidotrigla mulhalli*	56.6	3.4	19.7
	Jack mackerel	*Trachurus declivis*	32.7	14.9	34.6
	Eastern smooth boxfish	*Anoplocapros inermis*	22.8	1.2	35.8
	White trevally	*Pseudocaranx dentex*	22.5	5.7	41.4
	Southern eagle ray	*Myliobatis australis*	19.3	9.9	51.4
	Port Jackson shark	*Heterodontus portusjacksoni*	18.4	4.4	55.8
	Australian burrfish	*Allomycterus pilatus*	17.9	1.5	57.3
	Eastern school whiting	*Sillago flindersi*	16.7	7.8	65.1
	Sixspine leatherjacket	*Meuschenia freycineti*	15.2	1.9	67.0
	Tiger flathead	*Neoplatycephalus richardsoni*	11.5	0.9	67.8
	Eastern fiddler ray	*Trygonorrhina sp A*	11.0	1.4	69.2
	Kapala stingaree	*Urolophus sp A*	10.3	4.9	74.2
	Globefish	*Diodon nicthemerus*	9.4	1.1	75.2
	Draughtboard shark	*Cephaloscyllium laticeps*	8.0	3.5	78.7
	Red gurnard	*Chelidonichthys kumu*	7.6	0.4	79.2
	Butterfly gurnard	*Lepidotrigla vanessa*	5.7	0.4	79.6
	Velvet leatherjacket	*Meuschenia scaber*	4.8	0.9	80.5
IC	Sparsely-spotted stingaree	*Urolophus paucimaculatus*	640.9	17.5	17.5
	Draughtboard shark	*Cephaloscyllium laticeps*	300.8	12.3	29.8
	Banded stingaree	*Urolophus cruciatus*	155.5	5.9	35.7
	Globefish	*Diodon nicthemerus*	111.2	3.1	38.8
	Jack mackerel	*Trachurus declivis*	60.6	20.0	58.8
	Ruddy gurnard perch	*Neosebastes scorpaenoides*	51.2	2.3	61.1
	Common stinkfish	*Synchiropus calauropomus*	43.0	4.4	65.5
	Butterfly gurnard	*Lepidotrigla vanessa*	33.0	1.0	66.5
	Longnose skate	*Raja sp A*	28.1	2.4	68.9
	Deepwater gurnard	*Lepidotrigla mulhalli*	27.4	1.4	70.3
	Common stargazer	*Kathetostoma laeve*	15.1	1.1	71.3
	Velvet leatherjacket	*Meuschenia scaber*	14.8	0.9	72.3
	Red gurnard	*Chelidonichthys kumu*	11.6	0.8	73.0
	Sandyback stingaree	*Urolophus bucculentus*	10.1	3.5	76.6
	Southern eagle ray	*Myliobatis australis*	9.4	4.0	80.6
ISW	Jack mackerel	*Trachurus declivis*	1063.9	39.5	39.5
	Globefish	*Diodon nicthemerus*	299.9	3.1	42.6
	Draughtboard shark	*Cephaloscyllium laticeps*	119.0	2.9	45.5
	Silverbelly	*Parequula melbournensis*	70.1	1.8	47.4
	Common stinkfish	*Synchiropus calauropomus*	63.2	2.2	49.6
	Sparsely-spotted stingaree	*Urolophus paucimaculatus*	62.9	0.9	50.5
	Degens leatherjacket	*Thamnaconus degeni*	61.5	3.1	53.6
	Red mullet	*Upeneichthys vlamingii*	52.3	1.1	54.7
	Longnose skate	*Raja sp A*	39.3	0.9	55.6
	Yellowtail horse mackerel	*Trachurus novaezelandiae*	36.5	0.9	56.6
	Banded stingaree	*Urolophus cruciatus*	36.2	0.7	57.2
	Ruddy gurnard perch	*Neosebastes scorpaenoides*	35.3	1.0	58.2
	Eastern school whiting	*Sillago flindersi*	34.2	7.0	65.2
	Sand flathead	*Platycephalus bassensis*	23.2	1.0	66.2
	Barracouta	*Thyrsites atun*	23.2	15.1	81.3
MNE	Jack mackerel	*Trachurus declivis*	395.4	19.3	19.3
	Common snipefish	*Macroramphosus scolopax*	216.6	6.2	25.5
	Tiger flathead	*Neoplatycephalus richardsoni*	130.0	4.3	29.8
	Velvet leatherjacket	*Meuschenia scaber*	122.8	3.7	33.5
	Redfish	*Centroberyx affinis*	39.6	35.3	68.8
	Cucumberfish	*Chlorophthalmus nigripinnis*	34.5	1.6	70.4
	Ocean perch	*Helicolenus percoides*	32.5	4.2	74.6
	Grey morwong	*Nemadactylus douglasi*	28.3	1.7	76.3
	Deepwater gurnard	*Lepidotrigla mulhalli*	23.3	0.7	77.0
	John dory	*Zeus faber*	22.4	0.9	77.9
	Australian burrfish	*Allomycterus pilatus*	19.8	1.6	79.5
	Silver dory	*Cyttus australis*	15.3	0.6	80.0

Table 8.2.3.5 continued. Dominant species in 'soft-ground' habitats sampled by broad-scale trawl survey: species ranked geometric mean abundance with cut-off at 80% of total untransformed biomass.

Habitat type	Common name	Species name	Geo. mean biomass	% raw biomass	Cum % biomass
MSWC	Cucumberfish	*Chlorophthalmus nigripinnis*	329.9	11.2	11.2
	Minor gurnard	*Lepidotrigla modesta*	136.5	3.2	14.4
	Tiger flathead	*Neoplatycephalus richardsoni*	134.7	3.5	18.0
	Longnose skate	*Raja sp A*	129.0	2.7	20.7
	Velvet leatherjacket	*Meuschenia scaber*	111.5	5.7	26.4
	Draughtboard shark	*Cephaloscyllium laticeps*	86.5	5.4	31.8
	Spikey dogfish	*Squalus megalops*	62.0	3.3	35.1
	Sandyback stingaree	*Urolophus bucculentus*	28.5	3.4	38.6
	Silver dory	*Cyttus australis*	27.8	1.9	40.5
	Deepwater gurnard	*Lepidotrigla mulhalli*	25.6	2.2	42.7
	Jack mackerel	*Trachurus declivis*	25.5	16.5	59.2
	Australian burrfish	*Allomycterus pilatus*	23.1	1.3	60.4
	Greenback stingaree	*Urolophus viridis*	17.5	3.1	63.5
	Barracouta	*Thyrsites atun*	15.9	10.1	73.7
	Orange-spotted catshark	*Asymbolus sp D*	11.8	0.7	74.4
	Ocean perch	*Helicolenus percoides*	11.1	1.0	75.4
	John dory	*Zeus faber*	10.9	0.4	75.9
	Morwong	*Nemadactylus macropterus*	9.6	1.2	77.1
	Common snipefish	*Macroramphosus scolopax*	9.1	0.8	77.9
	Tasmanian numbfish	*Narcine tasmaniensis*	6.6	0.3	78.1
	Sparsely-spotted stingaree	*Urolophus paucimaculatus*	6.2	1.8	79.9
	Latchet	*Pterygotrigla polyommata*	5.8	0.6	80.6
ONEC	Redfish	*Centroberyx affinis*	676.4	26.2	26.2
	Cucumberfish	*Chlorophthalmus nigripinnis*	396.6	6.4	32.6
	Jack mackerel	*Trachurus declivis*	291.5	29.1	61.7
	Ocean perch	*Helicolenus percoides*	230.7	4.3	66.0
	Threespine cardinalfish	*Apogonops anomalus*	57.8	15.1	81.1
OSWC	Threespine cardinalfish	*Apogonops anomalus*	314.9	20.8	20.8
	Spikey dogfish	*Squalus megalops*	91.1	4.2	25.0
	Cucumberfish	*Chlorophthalmus nigripinnis*	80.7	1.4	26.5
	Silver warehou	*Seriolella punctata*	68.2	13.7	40.2
	Jack mackerel	*Trachurus declivis*	55.1	13.4	53.6
	Speckled stargazer	*Kathetostoma canaster*	54.8	1.4	55.0
	Morwong	*Nemadactylus macropterus*	51.7	7.7	62.7
	Mirror dory	*Zenopsis nebulosus*	23.0	1.0	63.7
	Longnose skate	*Raja sp A*	18.7	0.4	64.1
	Tiger flathead	*Neoplatycephalus richardsoni*	17.3	0.6	64.6
	New Zealand Dory	*Cyttus novaezelandiae*	16.9	0.7	65.3
	Ocean perch	*Helicolenus percoides*	16.6	1.8	67.1
	Southern whiptail	*Caelorinchus australis*	16.2	0.5	67.6
	Barracouta	*Thyrsites atun*	10.9	1.5	69.0
	Deepsea flathead	*Hoplichthys haswelli*	9.7	0.2	69.2
	Pink Ling	*Genypterus blacodes*	9.6	0.3	69.6
	Gemfish	*Rexea solandri*	6.5	3.1	72.7
	Whitefin swellshark	*Cephaloscyllium sp A*	6.4	0.8	73.4
	Ogilbys ghostshark	*Hydrolagus ogilbyi*	6.2	1.0	74.5
	Silver dory	*Cyttus australis*	5.8	0.3	74.7
	Painted latchet	*Pterygotrigla andertoni*	5.3	0.2	74.9
	Sawtail shark	*Galeus boardmani*	5.3	0.1	75.1
	Banded stingaree	*Urolophus cruciatus*	5.2	0.1	75.2
	Sandpaper fish	*Paratrachichthys sp 1*	5.2	0.2	75.5
	Redfish	*Centroberyx affinis*	5.0	5.2	80.6

Table 8.2.3.6. Proportions of quota and commercial species in 'soft-ground' habitats sampled by broad-scale trawl survey total untransformed biomass of all species in each habitat.

Habitat code	Habitat region	No samples	% quota	% commercial	% non-commercial
ISW	inner shelf, southwest	16	9.5	4.0	86.5
IC	inner shelf, central	15	3.0	7.0	90.0
INE	inner shelf, northeast	12	20.3	13.0	66.7
MSWC	mid-shelf, southwest/ central	32	8.0	7.1	84.9
MNE	mid-shelf, northeast	16	51.7	4.1	44.2
OSWC	outer shelf, southwest/ central	12	35.0	3.1	61.9
ONEC	outer shelf, northeast/ central	12	36.1	2.9	61.0

At the outer-shelf, the higher degree of dominance in the northern habitat region (ONEC) was attributable to large proportions made up by three species, jack mackerel (29.1% biomass), redfish (26.2%) and threespine cardinalfish (15.1%) (Table 8.2.3.5). In the southern region (OSWC), threespine cardinalfish (20.8% biomass) and jack mackerel (13.4%) were also dominant, but other species with high average (geometric) abundance made up relatively small proportions of overall biomass (Table 8.2.3.5). The proportion of marketable species was high in both outer-shelf habitat regions (~38-39%) (Table 8.2.3.6). Silver warehou (13.7% biomass), morwong (7.7%) and redfish (5.2) were important in the southern region, and redfish (26.2%) and ocean perch (4.3%) in the northern region.

Seasonal influence on species compositions

The apparent seasonal difference between the winter vs. spring + autumn groups in the outer-shelf stations was evaluated by comparing the average abundances of the most important northern/ southern discriminators during these two periods. Our hypothesis was that a seasonal difference would include a north/ south shift of some species coincident with the seasonal influence of dominant water masses, EAC in spring-summer and Bass Strait water in winter.

A seasonal north/ south shift was apparent for two species. Redfish, the single most important north/ south outer-shelf discriminator and primarily a 'northern' species, was caught at the southern stations only in spring/ autumn when catches were lower at the northern stations. Ocean perch, another 'northern' species, was more abundant at southern stations during spring/ autumn when abundance was slightly lower at northern stations.

Other species showed seasonal shifts in abundance that did not have a north/ south component. Silver warehou (primarily a 'southern' species) was most abundant in winter at both southern and northern stations whereas threespined cardinalfish (also more abundant at southern stations) was most abundant in spring/ autumn at both southern and northern stations. Morwong, which were also caught mostly at the southern stations, were more abundant in spring/ autumn at the southern stations and more abundant in winter at the northern stations—although the difference in the relatively very low abundance in the north may not be significant. Spurdog and barracouta (also primarily 'southern' species) showed the reverse, being more abundant in winter at the southern stations and more abundant in spring/ autumn at the northern stations.

Jack mackerel and redbait contributed to northern/ southern discrimination but their seasonal patterns of abundance are difficult to evaluate in our data because they are schooling benthopelagics with complex seasonal and inter-annual variability in abundance. In jack mackerel, which were ubiquitous and highly abundant in the study area, seasonal migrations also have a strong cross-shelf component. Redbait occurred in high abundance at southern stations during one winter survey only and it remains possible that this was the appearance of an annually variable and ephemeral species rather than seasonal migration into the area.

There were few examples of seasonal emigration of less-common species into the study area. One, caught in appreciable quantities in autumn across the shelf on Transect G and at F4, was starry toadfish. It is primarily a pelagic species (Kuiter, 1993) and our samples presumably indicated a southwards movement of individuals in EAC water.

Relationships of fish community structure to hydrology

The dominant features of water masses in the study area— interacting subtropical and temperate currents with often well-defined longshore, cross-shelf and vertical interfaces (*Section* 5)—show some correspondence with the primary bathymetric and clinal patterns in demersal fish communities.

Regions of correspondence between water mass interfaces and fish community boundaries occurred across the shelf (bathymetric boundaries) between the inner- and mid-shelf (at about 100 depth), and at the outer-shelf (~200 m). Longshore correspondence (locational boundaries) was primarily the distinction between the south (Victorian) and east (NSW) coasts with a main area of overlap between Point Hicks and Green Cape. The affect of water mass structure on community structure was related more to location on the inner-shelf and to bathymetry on the mid-shelf/ shelf-break.

Inner shelf fish communities reside primarily within two well-defined water masses with different origins: cold, fresh Bass Strait water from the south coast and warm, salty EAC water from the east coast—although note that Newell's work suggests that Eden Water has its origins in Bass Strait. These water masses are similar in being generally well-mixed (extending from surface to the seabed) and nutrient-poor, but differ markedly in temperature and salinity. Their overlap brings regional faunas together in a regional zootone that has strong clinal structure. Overlap of both water masses and fish communities was better-defined than in deeper water where there is a greater influence by intermittent or episodic cross-shelf wedges of slope water, and vertical stratification. Interestingly, however, the marked seasonality in the longshore interface of the two water masses had only subtle effects on the overall structure of inner-shelf communities. The distribution and abundance of individual species may change seasonally but, at the community-level, a clinal pattern with distinct southern, central and northern groupings appears stable despite profound changes in water masses.

Mid-shelf fish communities also reside within Bass Strait and EAC water but are more strongly influenced by cross-shelf wedges of slope water. The seasonal signal in community structure at the northern transects corresponded with north/ south water mass shifts. As appears to be the case on the inner-shelf, however, the clinal pattern in fish communities appears quite stable despite profound changes in water masses. Distinct emigrations of individual species were not obvious.

There were seasonal signals in both community structure and hydrology at the outer-shelf but limited correspondence in their patterns. Community groups reflected north/ south structure with spring and autumn samples generally separated from winter samples. However, bottom water masses differed between spring and autumn, with all stations except G5 inundated with cold slope water in spring but northern stations (E, F, G) influenced by warm water in autumn. In winter, north/ south patterns in community structure persisted while cold slope water inundated the entire study area outer-shelf (strongly in late winter with early winter uncertain due to incomplete data). Again, it appears that while the distribution and abundance of some outer-shelf species has a seasonal component, there is not a strong community-level response to changing water mass structure.

8.2.4 Fish Communities–Focussed Habitat

A summary of the species caught by each gear and their percent contribution to the total catch by each gear over all macrohabitats is given in Table 8.2.4.1.

Table 8.2.4.1 Checklist of species caught by gillnet, trap and demersal trawl during this study. Figures are the percentage biomass of each species in the total catch of each gear pooled over all sites.

Species	Gillnet		Trap		Trawl		Species	Gillnet		Trap		Trawl	
	% abund	Occurs	% abund	Occurs	% abund	Occurs		% abund	Occurs	% abund	Occurs	% abund	Occurs
Heterodontus portusjacksoni	5.192	7	0.591	1	0.806	5	*Neoplatycephalus richardsoni*	2.354	12			1.469	13
Isurus oxyrinchus	0.263	4					*Platycephalus bassensis*	0.013	1			0.053	1
Alopias vulpinus	0.023	2					*Platycephalus caeruleopunctatus*					0.011	2
Parascyllium ferrugineum	0.174	5					*Platycephalus arenarius*					0.009	1
Cephaloscyllium laticeps	15.286	17	12.160	8	3.252	14	*Neoplatycephalus aurimaculatus*					0.059	2
Galeus boardmani					0.031	2	*Platycephalus longispinis*					0.006	1
Cephaloscyllium sp A			0.119	1	0.355	6	*Platycephalus speculator*	0.032	2			0.001	1
Asymbolus sp A					0.008	1	*Hoplichthys haswelli*	0.003	1			0.010	3
Asymbolus sp D	1.019	13	0.466	7	0.333	11	*Lepidoperca pulchella*	0.091	6	1.835	7	0.182	5
Asymbolus analis	0.172	5	0.562	7	0.206	4	*Caesioperca lepidoptera*	0.595	7	0.063	3	1.200	4
Mustelus antarcticus	7.536	10	0.315	1	0.175	3	*Caesioperca rasor*	0.001	1	0.034	1		
Galeorhinus galeus	0.062	1			0.018	1	*Polyprion oxygeneios*	0.118	1				
Sphyrna zygaena	0.142	1			0.015	1	*Hypoplectrodes maccullochi*	0.004	2			0.002	1
Squalus megalops	20.942	15	1.492	7	0.938	6	*Apogonops anomalus*					4.540	9
Centrophorus uyato	0.097	1					*Callanthias australis*	0.011	3			0.048	3
Pristiophorus nudipinnis	0.361	6			0.273	4	*Hypoplectrodes annulata*	0.002	1	0.026	2		
Pristiophorus cirratus	0.096	3					*Dinolestes lewini*	0.070	3				
Pristiophorus sp A	0.268	6			0.019	1	*Sillago flindersi*	0.001	1			0.045	3
Squatina australis					0.025	1	*Trachurus declivis*	17.235	17	0.263	1	21.243	15
Squatina sp A					0.066	2	*Trachurus novaezelandiae*					0.097	3
Trygonorrhina sp A					0.167	1	*Seriola lalandi*	0.028	1				
Narcine tasmaniensis					0.502	9	*Pseudocaranx dentex*	0.392	6			0.149	4
Torpedo macneilli					0.175	1	*Trachurus murphyi*	0.191	5				
Raja australis					0.021	1	*Emmelichthys nitidus nitidus*	0.807	11			0.210	9
Raja sp A	0.028	1			1.325	12	*Parequula melbournensis*					0.004	1
Raja whitleyi					1.958	6	*Pagrus auratus*	0.025	2	0.013	1	0.023	2
Pavoraja nitida					0.128	5	*Upeneichthys vlamingii*					0.094	3
Raja gudgeri					0.159	1	*Pempheris multiradiatus*	0.029	3				
Dasyatis brevicaudata					0.946	3	*Scorpis lineolatus*			0.087	2		
Dasyatis thetidis					0.206	2	*Atypichthys strigatus*	0.001	1	0.338	2		
Urolophus bucculentus					0.978	5	*Paristiopterus labiosus*	0.017	2			0.059	4
Urolophus cruciatus	0.002	1			1.603	13	*Pentaceropsis recurvirostris*	0.004	1			0.051	2
Urolophus paucimaculatus					2.711	7	*Zanclistius elevatus*					0.043	7
Urolophus viridis	0.003	1			0.756	9	*Parma microlepis*	0.002	1	0.016	2		
Myliobatis australis					0.900	4	*Nemadactylus douglasi*	0.610	7	0.090	1	1.012	8
Callorhinchus milii	0.119	2			0.120	1	*Nemadactylus macropterus*	3.099	16	33.634	12	1.627	10
Gymnothorax prasinus			0.182	1			*Cheilodactylus spectabilis*	0.041	2				
Conger verreauxi			1.544	2			*Latris lineata*	0.349	5	15.209	6		
Bassanago bulbiceps					0.000	1	*Latridopsis forsteri*	0.737	6	0.100	1	0.024	1
Ophisurus serpens	0.051	1					*Notolabrus tetricus*	0.098	2	0.365	2		
Argentina australiae					0.001	4	*Pseudolabrus psittaculus*	0.007	3	0.174	3	0.042	3
Aulopus purpurissatus	0.063	4	0.013	1	0.013	1	*Ophthalmolepis lineolatus*	0.067	2	0.152	2		
Chlorophthalmus nigripinnis	0.033	5			9.159	12	*Achoerodus viridis*	0.079	2				
Gonorynchus greyi					0.008	3	*Bodianus unimaculatus*			0.032	1		
Pseudophycis barbata	0.156	5	5.373	12			*Bodianus sp*	0.061	3	0.075	1		
Lotella rhacinus	0.006	2	0.191	3			*Parapercis allporti*	0.001	1			0.166	13
Pseudophycis bachus	0.608	10	9.828	12	0.256	5	*Gnathagnus innotabilis*					0.014	2
Pseudophycis breviuscula					0.003	1	*Kathetostoma laeve*					0.440	3
Macruronus novaezelandiae	0.132	2			0.004	1	*Synchiropus calauropomus*	0.001	1			5.828	8
Genypterus blacodes	3.446	13	0.337	2	0.938	11	*Thyrsites atun*	4.903	15			0.768	10
Caelorinchus australis	0.004	1			0.127	2	*Rexea solandri*	0.224	2			0.247	3
Caelorinchus mirus	0.003	1			0.011	1	*Lepidopus caudatus*	0.022	1			0.027	2
Paratrachichthys sp 1	0.109	3			0.050	2	*Scomber australasicus*	1.882	12			0.121	5
Centroberyx affinis	0.830	13			5.751	10	*Sarda australis*	0.031	1				
Centroberyx lineatus	0.048	3					*Seriolella brama*	6.901	14			2.477	6
Centroberyx australis					0.015	1	*Seriolella punctata*	0.441	4			0.311	7
Cyttus australis	0.042	8	0.056	1	1.230	15	*Lophonectes gallus*					0.002	4
Zenopsis nebulosus					0.370	6	*Ammotretis rostratus*					0.006	1
Zeus faber	0.013	1			1.031	11	*Eubalichthys mosaicus*	0.054	3			0.761	6
Cyttus novaezelandiae					1.151	8	*Meuschenia scaber*	0.080	8	9.218	11	2.274	13
Macroramphosus scoiopax					2.263	10	*Nelusetta ayraudi*	0.006	1	1.985	6	0.005	1
Hippocampus abdominalis					0.000	1	*Meuschenia freycineti*	0.016	1	0.254	4	0.392	3
Solegnathus spinosissimus					0.007	5	*Thamnaconus degeni*	0.002	1	1.169	3	0.043	3
Ophisternon candidum	0.001	1					*Eubalichthys bucephalus*					0.004	2
Helicolenus percoides	0.715	14	1.585	12	7.572	13	*Anoplocapros inermis*					0.027	3
Neosebastes scorpaenoides	0.047	3	0.054	1	0.308	5	*Aracana aurita*					0.019	2
Neosebastes thetidis	0.014	2			0.067	4	*Omegophora armilla*					0.004	1
Scorpaena papillosa	0.006	4			1.675	6	*Diodon nicthemerus*					0.634	5
Maxillicosta whitleyi					0.004	1	*Allomycterus pilatus*					0.327	11
Chelidonichthys kumu	0.017	2			0.069	4							
Lepidotrigla vanessa					0.151	3	Total no. sites		18		16		15
Pterygotrigla polyommata	0.118	8			0.101	5	Total no. species	91		39		113	
Lepidotrigla modesta	0.003	2			0.672	12	Total wt. fish (kg, unstandardised)	9,498		1,484		6,974	
Lepidotrigla mulhalli	0.014	1			0.607	12	Total no. fish (unstandardised)	11,904		2,499		65,989	

Acoustic bottom-typing of sample transects

There was reasonable overall correspondence between the nominal macrohabitat bottom-type determined visually from echograms and contour plots of E1 and E2, the acoustic indices of roughness and hardness— in other words, sampling had successfully targeted contrasting macrohabitats within mesohabitats. However, quantified measures of roughness and hardness along sample transects, based on the interpolated data in contour plots (Table 8.2.4.2), showed both expected and unexpected patterns with respect to macrohabitats and gears. Data from Black Head and Disaster Bay were generally in line with expectation—roughness and hardness were relatively low for 'soft' transects and relatively high for 'hard' and 'rough' transects for all gears. Other macrohabitats that contrasted visually on echograms affected the behaviour of E1 (roughness) and/ or E2 (hardness) unexpectedly. The contrast at Point Hicks between 'soft' and 'rough' macrohabitats (coarse sand in pronounced waves and high elevation 'granite' reef, respectively) was only apparent in roughness data. Thus, coarse sand 'soft' substrate at Point Hicks, and at Gabo Island, appeared relatively hard compared to the 'soft' substrates at Black Head and Disaster Bay. Data were unavailable for some gillnet and trap transects that did not overlap the contoured areas, e.g., Gabo Reef 'soft', and were not used for transects at some plot boundary regions where contouring was unsuccessful, e.g. The Horseshoe. Interpretation of these indices is discussed elsewhere (*Section* 7) and is the subject of ongoing work.

Comparison of catch composition and selectivity of gears

A quantitative comparison of the catch rates of each gear was not possible because sampling effort and selectivity could not be standardised across gears. However, there were clear patterns in the number of species, species composition, and size spectrum of individuals caught by each (Table 8.2.4.1).

Overall, the trawl caught most species (113 of the total 143) despite a smaller number of samples which did not include any 'rough' macrohabitat samples (Table 8.1.3.1). Gillnet catches contained more than double the number of species caught by trap (91 vs. 39) in relatively few additional samples (one additional macrohabitat plus night samples from the outer-shelf macrohabitats). The overlap between the passive gears (gillnet and trap) was high (34 species) with most (87%) of trap caught species also caught by gillnet. Twenty four species were taken by all three gears whereas 64 species (45%) were caught by only one— 46 by trawl, 14 by gillnet and four by trap.

Gear selectivity was markedly different in terms of the relative abundances of species caught by more than one gear (Table 8.2.4.1). Clear demonstrations are provided by three abundant and broadly distributed species caught by all gears: spikey dogfish— highly vulnerable to gillnet, ocean perch— vulnerable to trawl, and morwong— highly vulnerable to trap. The total catch weight and total individuals caught by each gear across all macrohabitats indicated the trawl caught a considerably higher proportion of smaller individuals than either gillnet or trap (Table 8.2.4.1). This results from both the retention of smaller individuals (from packing in the cod end) and the capture of many small-bodied species that are ineffectively caught by the passive gears, e.g. cucumber fish, snipefish and stinkfish. Patterns of size selectivity in the variable-mesh gillnet also varied widely between species: intra-species patterns included restriction to one or two mesh sizes, size corresponding to mesh size, or broad overlap in sizes in a range of mesh sizes (*Section* 9).

Information on selectivity for quota species is contained in Table 8.2.4.1 (overall comparison of gears) and *Section* 9 (size selection in gillnet meshes); the interactions of these features with habitat types form part of the analysis of fish assemblage structure in the following sections.

Macrohabitats sampled by three fishing gears

Analysis of species biomass and numbers showed only minor differences in the grouping of the 11 common macrohabitats (sampled during the day by all three gears) by cluster and MDS. Accordingly, only biomass was used in subsequent analysis as we considered it to be ecologically more meaningful to this study than numerical abundance.

Two-dimensional (2-d) ordination plots of samples showed a clear delineation of macrohabitats from the inner-shelf (labels A-D) and outer-shelf (labels E-J), and isolation of Point Hicks (label K) (Fig. 8.2.4.1). Increasing severity of transformation reduced the isolation of macrohabitats represented by small samples with few species or one dominant species, e.g. BGH and GRS (gillnet), HOC (trawl) and DBS (trap). It also produced better representations of sample similarity in 2-d MDS plots as indicated by lower stress values. Double square-root transformation produced the most consistent grouping across gears and the lowest stress in 2-d MDS plots, and was therefore used in subsequent analyses.

Overall, gillnet and trawl samples formed similar groupings of macrohabitats to each other, and most clearly grouped inner and outer-shelf macrohabitats. There was little overlap between the species that delineated the common inner and outer-shelf macrohabitats in gillnet and trawl catches. Among the 19 species contributing most importantly to the dissimilarity, only grey morwong was common to gillnet and trawl catches (Table 8.2.4.3). Such a difference in species composition indicated both the high degree of difference in the selectivity of each gear, and the robustness of the inner and outer-shelf grouping.

Patterns of similarity among macrohabitats

The clear delineation of inner and outer-shelf macrohabitats among the 11 common macrohabitats was repeated in analysis of daytime catches from all 20 macrohabitats (Fig. 8.2.4.2.) Again, the degree of separation was more clear in samples from gillnet and trawl than from trap. Stress levels for the plots were moderately low— 0.12 (gillnet), 0.08 (trawl), 0.10 (trap)— indicating an adequate representation of the data in two dimensions. For this reason, and because the inner/ outer-shelf groupings were consistent, further analysis treated the inner and outer-shelf macrohabitats separately.

Inner shelf macrohabitat groups showed patterns related to mesohabitat location (Fig. 8.2.4.3) and acoustic bottom type (Table 8.2.4.2). Although the patterns varied between gears, partly because each gear sampled a slightly different set of macrohabitats, mesohabitat similarity tended to be expressed on the vertical axes of MDS-plots and bottom-type similarity on the horizontal axes. While the inner-shelf Black Head and Disaster Bay mesohabitats tended to separate from one another, gillnet samples indicated a strong association of the hard macrohabitat at Black Head (BHH) with rough macrohabitats (BHR, DBR), whereas the hard Disaster Bay samples (DBH) grouped with soft macrohabitats (BHS, DBS). Both Point Hicks macrohabitats (PHR, PHS) were distinct and their high dissimilarity to the remaining sties and to each other was sufficient to collapse MDS-plots of gillnet and trap catches (removed from Fig. 8.2.4.3). The Gabo Island soft macrohabitat (GIS), sampled only by trawl, was most similar to Point Hicks.

Table 8.2.4.2 Mean (SD) of acoustic indices along sampling transects for fishing gears at each macrohabitat (* indicates no acoustic data available; shading indicates data from poorly contoured area)

Mesohabitat	**Macrohabitat code**	**Roughness**			**Hardness**		
		Gillnet	**Trap**	**Trawl**	**Gillnet**	**Trap**	**Trawl**
Point Hicks	PHR	3.54 (0.64)	3.79 (1.02)	No sample	4.55 (0.12)	4.58 (0.18)	No sample
	PHS	2.96 (0.08)	2.97 (0.08)	* *	4.52 (0.53)	4.49 (0.49)	* *
Gabo Island	GIH	No sample	No sample	3.22 (0.05)	No sample	No sample	4.26 (0.29)
	GIS	No sample	No sample	3.12 (0.01)	No sample	No sample	4.04 (0.02)
Black Head	BHR	2.92 (0.15)	3.02 (0.28)	No sample	4.22 (0.32)	4.47 (0.51)	No sample
	BHH	2.91 (0.44)	2.83 (0.37)	2.48 (0.22)	4.46 (0.55)	4.05 (0.58)	3.49 (0.36)
	BHS	2.20 (0.19)	2.12 (0.06)	2.25 (0.20)	3.16 (0.28)	3.58 (0.10)	2.78 (0.20)
Disaster Bay	DBR	2.94 (0.12)	3.44 (0.60)	No sample	4.16 (0.14)	4.16 (0.10)	No sample
	DBH	2.78 (0.04)	2.87 (0.16)	2.63 (0.08)	3.90 (0.34)	4.19 (0.10)	4.15 (0.62)
	DBS	2.24 (0.03)	2.27 (0.04)	2.29 (0.03)	2.65 (0.13)	2.85 (0.11)	3.46 (0.26)
Broken Reef	BRR	2.74 (0.18)	No sample	3.49 (0.09)	4.30 (0.17)	No sample	2.49 (0.02)
	BRS	No sample	No sample	2.82 (0.12)	No sample	No sample	3.94 (0.23)
Big Gutter	BGR	3.03 (0.40)	2.93 (0.26)	No sample	3.94 (0.15)	3.91 (0.14)	No sample
	BGH	2.80 (0.03)	2.81 (0.04)	2.80 (0.04)	4.39 (0.56)	3.82 (0.11)	4.13 (0.42)
	BGS	2.80 (0.03)	2.81 (0.02)	2.85 (0.08)	4.57 (0.70)	4.52 (0.40)	4.15 (0.46)
Gabo Reef	GRR	3.02 (0.07)	3.20 (0.05)	No sample	4.03 (0.06)	4.10 (0.09)	No sample
	GRH	3.47 (0.46)	3.45 (0.48)	2.91 (0.36)	4.46 (0.33)	4.54 (0.21)	4.79 (0.49)
	GRS	* *	2.82 (0.02)	2.79 (0.02)	* *	* *	* *
Horseshoe	HOR	2.84 (0.30)	3.22 (0.10)	No sample	3.75 (0.69)	4.08 (0.39)	No sample
	HOH	No sample	No sample	2.84 (0.21)	No sample	No sample	3.26 (1.08)
	HOC	2.74 (0.19)	2.74 (0.19)	No sample	5.45 (0.16)	5.45 (0.19)	No sample
	HOS	2.57 (0.13)	* *	2.49 (0.08)	3.40 (0.36)	* *	3.34 (0.40)

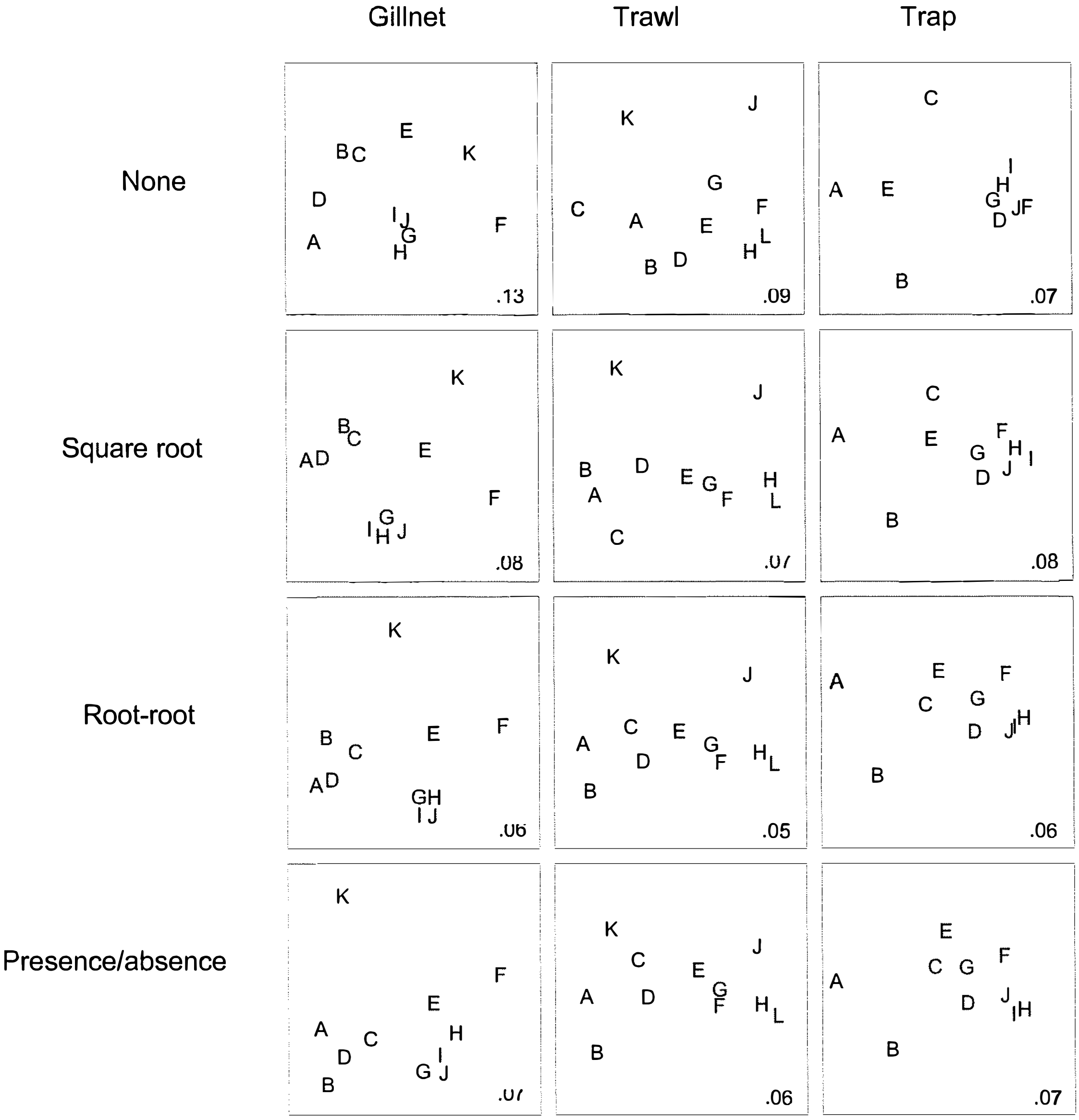


Fig. 8.2.4.1 MDS plots of gillnet, trap and trawl samples from eleven sites on the southeastern Australian continental shelf sampled by all three gears and the effects of data transformation.

Table 8.2.4.3 The 19 species making the greatest contribution to the dissimilarity of the common inner and outer shelf sites. A cutoff at 33% of total dissimilarity for both gears retained 13 trawl caught species and 7 gillnet caught species.

Gear	Inner shelf	Outer shelf
Trawl	*Synchiropus calauropomus*	*Chlorophthalmus nigripinnis*
	Eubalicthys mosaicus	*Apogonops anomolus*
	Namadactylus douglasi	*Centroberyx affinis*
	Scorpaena papillosa	*Zenopsis nebulosus*
	Caesioperca lepidoptera	*Nemadactylus macropterus*
	Meuschenia scaber	*Cyttus novaezelandiae*
	Macroramphosus scolopax	
Gillnet	*Cephaloscyllium laticeps*	*Squalus megalops*
	Mustelus antarcticus	
	Heterodontus portusjacksoni	
	Pristiophorus nudipinnis	
	Seriolella brama	
	Nemadactylus douglasi	

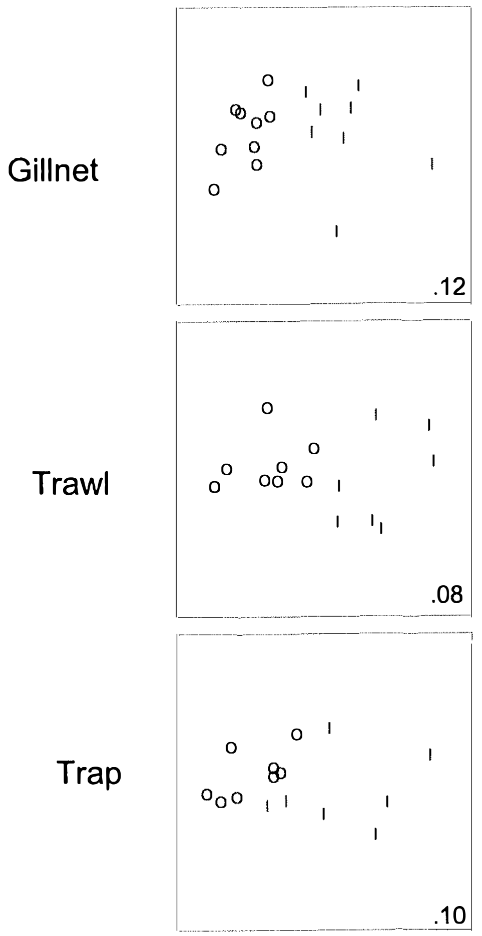


Fig. 8.2.4.2 MDS plots of daytime samples from gillnet, trawl and trap labelled to indicate inner and outer shelf sites (I=inner, O=outer). Stress values for each plot shown inside plot boundary.

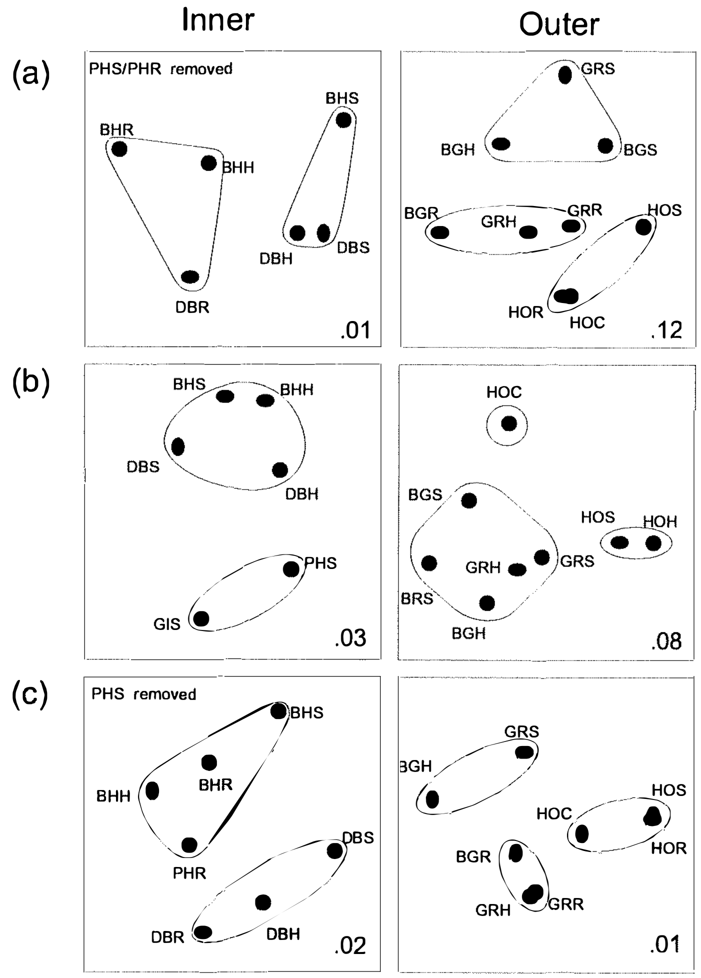


Fig. 8.2.4.3 MDS plots of gillnet, trawl and trap daytime samples from sites on the inner and outer southeastern Australian continental shelf. Note that a slightly different suite of sites were sampled by each gear; (a) gillnet, (b) trawl, (c) trap. Stress values shown inside plot boundaries.

Similar, but less defined, trends were evident for outer-shelf macrohabitats where the dissimilarity of the Horseshoe mesohabitat was the dominant feature (Fig. 8.2.4.3). It was delineated by each gear, although the trawl samples from the macrohabitat characterised by stalked crinoids (HOC) were isolated due to relatively small catches containing few species. Gillnet and trap catches clearly grouped the rough macrohabitats at Big Gutter and Gabo Reef (BGR, GRR) with the hard macrohabitat at Gabo Reef (GRH), and the hard macrohabitat at Big Gutter (BGH) with soft macrohabitats from Big Gutter and Gabo Reef (BGS, GRS)— although traps failed to catch fish at BGS. Trawl catches showed less discrimination, with soft and hard macrohabitats from Big Gutter and Gabo Reef grouped together, i.e. GRH was not separated (Fig. 8.2.4.3c). This is likely to be attributable to both the lower contrast of the macrohabitats sampled by trawl (no rough-ground), and to the GRH trawl samples being taken further from the Gabo Reef than either the gillnet or trap samples. Soft-ground at Broken Reef (BRS), a macrohabitat sampled only by trawl, grouped with the Big Gutter and Gabo Reef trawl samples.

These groups of macrohabitats defined the primary ‘habitat types’ in the study area and formed the basis for the description of fish community types and the physical environments in which they exist. The grouping of sites was generally consistent between gears despite broad differences in the species caught by each gear. The gillnet proved to be the most effective fishing gear overall because it fished successfully on all bottom types, and caught a relatively large number of species and a wide range of sizes compared to traps. Most reliance was placed on the gillnet (being most versatile and less selective than traps) when patterns varied between gears. Seven community types (habitats) were identified from focussed habitat sampling:

1) PHS = PHS, GIS, GIH (inner-shelf, soft/ hard, Point Hicks to Gabo Island)

2) PHR = PHR (inner-shelf, rough, Point Hicks)

3) IS = BHS, DBS, DBH (inner-shelf, soft/ hard, Black Head/ Disaster Bay)

4) IR = BHR, BHH, DBR (inner-shelf, hard/ rough, Black Head/ Disaster Bay)

5) OS = BRS, BGS, BGH, GRS (mid/ outer-shelf, soft/ hard, Broken Reef, Big Gutter, Gabo Reef)

6) OR = BGR, GRH, GRR (mid/ outer-shelf, hard/ rough, Big Gutter, Gabo Reef)

7) H = HOS, HOH, HOR (outer-shelf, soft/ hard/ rough, Horseshoe)

Species characterising macrohabitat groups

The similarities analysis (SIMPER) identified species making the greatest contributions to the grouping of macrohabitats: to within-habitat similarity (‘typifying’ species), and between-habitat dissimilarity (‘discriminating’ species). Because the number of species contributing to within-habitat and between-habitat comparisons was usually large, and varied between gear types (Tables 8.2.4.4-8.2.4.6), we chose arbitrary cut-off values of similarity to retain the few most-important typifying or discriminating species for each analysis.

Typifying species for each gear were those that contributed >5% of total within-habitat similarity, while the cut-off for discriminating species was variable (>2% for trawl, >3% for gillnet, >4% trap) to account for the fewer species, respectively, contributing to each analysis. How consistently a species contributed to each analysis was measured by the ratio of the mean/

standard deviation of its contributions to the samples comprising each habitat type. Larger ratios indicated a greater consistency of contribution and therefore a higher confidence in the identification of typifying or discriminating species. Again, arbitrary cut-offs were selected to simply designate large from small ratios: for similarity and dissimilarity respectively, these were 10 and 3 (gillnet), 10 and 3 (trap), 5 and 3 (trawl). A summary of the information on typifying and discriminating species is presented together with the species restricted to single habitat types (indicator species) for the inner-shelf and outer-shelf in Figs. 8.2.4.4-8.2.4.5.

In accordance with the overall numbers of species caught by each gear, a greater number contributed to analysis of trawl samples than gillnet, and fewest to trap samples. Also, the important species were largely different for each gear: 32 of 41 typifying species and 35 of 51 discriminating species were important to one gear only. As would be expected, a greater number of species contributed to between-habitat dissimilarity than to within-habitat similarity. Where fewer species were caught, for example in trap catches, they each tended to contribute a relatively higher fraction of total similarity/ dissimilarity than when many species were involved. Within-habitat similarities and between-habitat dissimilarities were highly variable and showed no clear relationship with gear, depth or acoustic bottom type.

The most abundant species tended to have high within-habitat similarities and therefore comprised many of the fishes that typified habitat types. However, many moderately abundant species were also typical. Most species typified only one or two habitat types, but since some abundant species were also widespread, individual species were often typical of several habitat types, e.g. jack mackerel–which was caught in gillnets and trawls at >90% macrohabitats and was typical in most habitats. Species that were highly vulnerable to a particular gear type, e.g. the velvet leatherjacket to traps, could also be typical in several habitat types.

Because uncommon (rarely caught) species have high discriminating power, habitat discrimination can be driven by a few low abundance species and therefore by chance captures. In our data, discrimination was by both abundant and uncommon species (Tables 8.2.4.4-8.2.4.6). However, two factors–the low vulnerability of highly abundant species to a particular gear, and the chance capture of transient (highly mobile) or benthopelagic species–both produced some anomolous results. Examples of the 'low-vulnerability effect', where a species appeared to have discriminating power in the catches one gear but not in the catches of the gears that caught it most effectively, were the discrimination of outer soft from the Horseshoe by spikey dogfish in traps (compared to gillnet and trawl catches), the Horseshoe from outer rough by cucumberfish in the gillnet (compared to trawl catches), and habitats discriminated by tiger flathead in the gillnet (compared to trawl catches). Uncertainties due to transient species included between-habitat discrimination by jack mackerel and barracouta, two species which are highly mobile (undertaking horizontal and vertical migrations), densely-schooling and ubiquitous off southeastern Australia. The differential selectivity's of the gears are discussed further in the 'habitat preferences' section below and 'gear selectivity's' sections (9.2.1) of this report.

Fifty-three of the 120 species caught by the three gears on the inner-shelf were important as typifying, discriminating or indicator species for the four habitat types (Fig 8.2.4.4). Relatively high numbers of species characterised the Inner Soft (IS), Inner Rough (IR) and Pt. Hicks/ Gabo Is Soft (PHS/GIS) habitats in contrast to the Pt. Hicks Rough (PHR) habitat which had a relatively depauperate fauna and no indicator species. There were also distinct contrasts in the composition of the assemblages characterising the IR, IS and PHS/GIS habitats, including the occurrence of several indicator species in each. Overall, most discriminating species contrasted

Table 8.2.2.4 Percentage contributions of typifying species (> 5%) and discriminating species (>3%) to within-group similarity (WGS) and between-group dissimilarity (BGD), respectively, identified by SIMPER analysis of macrohabitat groupings formed by MDS of GILLNET samples. Note: ranks are substituted for % similarity for typifying species at the two isolated Point Hicks macrohabitats since similarity can only be calculated for groups of three or more macrohabitats. Relative (untransformed) abundances shown in parentheses; commercial species shaded.

Typifying species		IS	IR	OS	OR	H	PHS	PHR
Port Jackson shark	*Heterodontus portusjacksoni*	7.3 (223)	8.8 (1773)					2 (3907)
Draughtboard shark	*Cephaloscyllium laticeps*	9.5 (1311)	10.2 (3432)				1 (4930)	1 (5020)
Orange-spotted catshark	*Asymbolus* sp D	5.7 (92)			8.3 (146)			
Gummy shark	*Mustelus antarcticus*						6 (99)	4 (144)
School shark	*Galeorhinus galeus*						5 (134)	
Spikey dogfish	*Squalus megalops*			25.8 (731)	14.2 (2051)	15.5 (1838)	2 (1200)	
Southern sawshark	*Pristiophorus nudipinnis*	7.9 (237)					3 (174)	7 (53)
Elephant fish	*Callorinchus milli*						4 (169)	6 (89)
Bearded rock cod	*Pseudophycis barbata*							5 (89)
Ocean perch	*Helicolenus percoides*				6.2 (53)			
Latchet	*Pterygotrigla polyommata*			5.5 (30)				
Tiger flathead	*Neoplatycephalus richardsoni*	5.5 (293)		5.8 (76)		11.9 (1920)		
Eastern orange perch	*Lepidoperca pulchella*				8.2 (109)			
Butterfly perch	*Caesioperca lepidoptera*		6.1 (289)					3 (228)
Jack mackerel	*Trachurus declivis*	11.8 (3700)	6.0 (1056)	34.4 (3143)	13.4 (980)	8.8 (1130)		
Grey morwong	*Nemadactylus douglasi*	5.2 (70)	7.7 (512)					
Morwong	*Nemadactylus macropterus*			17.2 (57)	14.2 (1566)	12.6 (845)		
Bastard trumpeter	*Latridopsis forsteri*		7.0 (614)					
Barracouta	*Thyrsites atun*	13.7 (2274)	7.5 (1392)	5.0 (53)	10.2 (708)	12.4 (1553)		
Blue mackerel	*Scomber australasicus*	6.6 (611)						
Blue warehou	*Seriolella brama*	6.0 (2005)	10.7 (2730)			15.7 (2841)		
Silver warehou	*Seriolella punctata*					6.6 (321)		
	Total species	18	24	8	17	13	~	~
	Within-group similarity	59	59.2	47.8	60.9	64	~	~
	Contribution to WGS (%)	71.9	64	93.7	74.4	83.5	~	~

Discriminating species		IS vs IR	IS vs PHS	IS vs PHR	IR vs PHS	IR vs PHR	OS vs OR	H vs OS	H vs OR
Port Jackson shark	*Heterodontus portusjacksoni*		4.2	4.6	5.4				
	Isurus oxyrinchus		3	3.0					
Draughtboard shark	*Cephaloscyllium laticeps*			3.7					
Orange-spotted catshark	*Asymbolus sp D*		3.3	3.3			6.6		5.4
Gummy shark	*Mustelus antarcticus*	4.3	3.7	3.1		3.5			
School shark	*Galeorhinus galeus*		4.1		3.3			3.7	
Spikey dogfish	*Squalus megalops*		5.3		3.3		3.8		
Southern sawshark	*Pristiophorus nudipinnis*	3.2							
Common sawshark	*Pristiophorus cirratus*						3.7		3.5
Eastern sawshark	*Pristiophorus sp A*						4		3.3
Elephant fish	*Callorinchus milli*		4.7	4	3.8	3.8			
Cucumberfish	*Chlorophthalmus nigripinnis*								3.1
Bearded rock cod	*Pseudophycis barbata*			3.2					
Red cod	*Pseudophycis bachus*							3.3	
Pink Ling	*Genypterus blacodes*								
Redfish	*Centroberyx affinis*							3.5	3.3
Ocean perch	*Helicolenus percoides*						3.7		
Tiger flathead	*Neoplatycephalus richardsoni*	3.8	3.8	3.8			3.2	8.2	6.2
Eastern orange perch	*Lepidoperca pulchella*						6.2		4.4
Butterfly perch	*Caesioperca lepidoptera*	3.6		4.2	3.5		5.7		4.7
Jack mackerel	*Trachurus declivis*	3	5.4	7.8		5.1	3.4	4.4	
Redbait	*Emmelichthys nitidis*						3.4	5.0	
Grey morwong	*Nemadactylus douglasi*		3	3.1	4.2	4.9			
Morwong	*Nemadactylus macropterus*		3.4	3.4		3.4	6.6	5	
Striped trumpeter	*Latris lineata*						4.4	3.9	
Bastard trumpeter	*Latridopsis forsteri*	4.1			4.2	4.9	3.9		3.3
Pigfish	*Bodianus sp*							3.5	3.1
Barracouta	*Thyrsites atun*		7.5	7.4	4.8	5.7	6	7.8	
Gemfish	*Rexea solandri*							4	3.5
Blue mackerel	*Scomber australasicus*	3.7	4.8	4.8			3.3	3.1	
Blue warehou	*Seriolella brama*	3.2	5.6	5.5	6.2	7.3	5.4	13.2	6.8
Silver warehou	*Seriolella punctata*							6.7	5.7
	Total species	57	41	42	52	48	29	28	37
	Between-group dissimilarity	51.0	73.8	74.3	79.6	67.2	57.2	59.3	50.0
	Contribution to BGD (%)	28.9	58.8	64.9	38.7	38.6	73.3	75.3	56.3

Table 8.2.4.5. Percentage contributions of typifying species (> 5%) and discriminating species (>4%) to within-group similarity (WGS) and between-group dissimilarity (BGD), respectively, identified by SIMPER analysis of macrohabitat groupings formed by MDS of TRAP samples. Note: ranks are substituted for % similarity for typifying species at the outer-soft macrohabitat since similarity can only be calculated for groups of three or more macrohabitats. Relative (untransformed) abundances shown in parentheses; commercial species shaded.

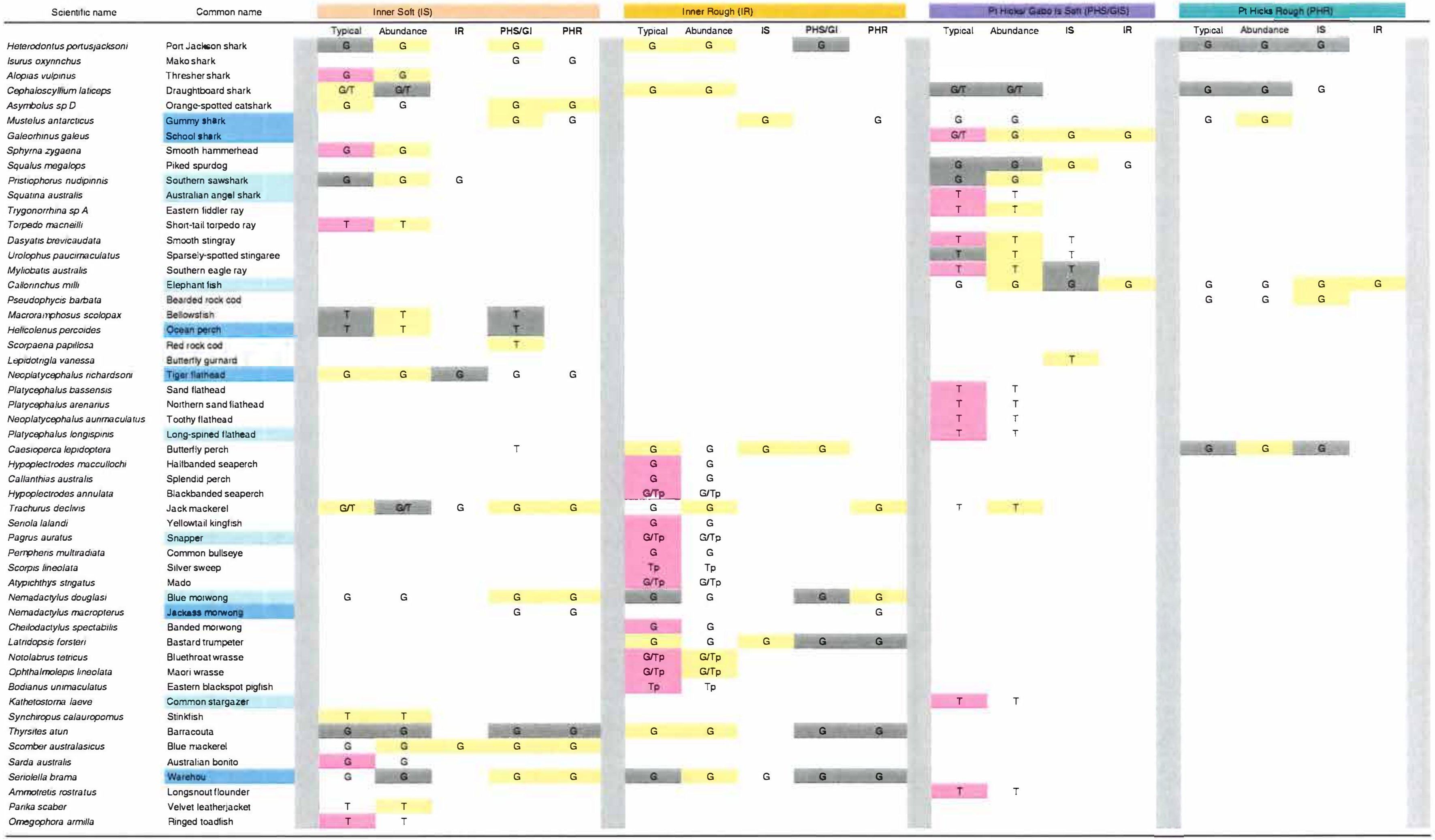
Typifying species	BH	DB	OS	OR	H
Cephaloscyllium laticeps	22.5 (274)				
Asymbolus sp D				7.4 (19)	
Asymbolus analis		14.9 (23)			
Squalus megalops			2 (53)		
Conger verreauxi		7.8 (58)			
Pseudophycis barbata		7.9 (100)			27.5 (66)
Pseudophycis bachus		7.8 (47)		12.1 (268)	29.3 (130)
Helicolenus percoides	5.5 (9)	15.6 (46)	5 (25)	8.2 (32)	
Lepidoperca pulchella				9.8 (74)	
Nemadactylus macropterus		19.1 (477)	1 (290)	20.5 (1147)	37.8 (352)
Latris lineata				16.0 (783)	
Pseudolabrus psittaculus	6.6 (16)				
Meuschinia scaber	29.3 (300)	23.2 (107)	3 (28)	11.8 (289)	
Nelusetta ayraudi			4 (26)	10.7 (96)	
Meuschenia freycineti	16.2 (23)				
Total species	13	7	~	8	3
Within-group similarity	41.1	39.8	57.9	75.1	71.7
Contribution to WGS (%)	80.11	96.3	~	96.39	94.6

Discriminating species	BH vs DB	OS vs OR	OS vs H	OR vs H
Cephaloscyllium laticeps	6.9			
Asymbolus sp D		4.8		8.8
Asymbolus analis	4.5	4.4	5.6	
Squalus megalops		7.8	14.5	
Conger verreauxi	5.0			
Pseudophycis barbata	4.8	6.7	10.0	5.3
Pseudophycis bachus	4.9	15.5	18.0	4.7
Helicolenus percoides			9.3	7.5
Lepidoperca pulchella	4.1	11.5	6.4	7.1
Nemadactylus macropterus	8.7	8.1	7.0	7.0
Latris lineata		20.2	5.6	17.1
Meuschenia scaber		10.3	7.0	16.4
Nelusetta ayraudi			12.0	13.1
Meuschenia freycineti	5.4			
Thamnaconus degeni	4.4			
Total species	32	13	10	13
Between-group dissimilarity	73.8	50.8	65.1	49.9
Contribution to BGD (%)	48.7	89.3	95.4	87.0

Table 8.2.4.6. Percentage contributions of typifying species (> 5%) and discriminating species (>2%) to within-group similarity (WGS) and between-group dissimilarity (BGD), respectively, identified by SIMPER analysis of macrohabitat groupings formed by MDS of TRAWL samples. Note: ranks are substituted for % similarity for typifying species at the Pt Hicks/ Gabo Is macrohabitats since similarity can only be calculated for groups of three or more macrohabitats. Relative (untransformed) abundances shown in parentheses; commercial species shaded.

Typifying species	IS	PHS/GI	OS	H
Cephaloscyllium laticeps	5.3 (1780)	3 (3350)		
Raja sp A			5.7 (995)	
Dasyatis brevicaudata		4 (3333)		
Urolophus paucimaculatus		1 (6011)		
Myliobatis australis		5 (2968)		
Chlorophthalmus nigripinnis			8.9 (9779)	9.4 (6188)
Centroberyx affinis				5.4 (7229)
Zenopsis nebulosus				5.2 (673)
Cyttus novaezelandiae				6.1 (2978)
Macroramphosus scolopax	6.1 (3434)		5.2 (808)	
Helicolenus percoides	7.1 (9779)		6.7 (2512)	
Apogonops anomalus				8.3 (11515)
Trachurus declivis	7.3 (16240)	2 (3559)	9.6 (12163)	7.6 (11259)
Nemadactylus macropterus				6.0 (2230)
Synchiropus calauropomus	5.1 (7562)			
Meuschenia scaber	5.8 (2885)			
Total species	52	~	41	32
Within-group similarity	57.1	55.1	64.3	59.4
Contribution to WGS (%)	36.7	~	36.1	48

Discriminating species	IS vs PHS/GI	OS vs H
Heterodontus portusjacksoni		2.2
Cephaloscyllium laticeps		2.1
Asymbolus sp D		2.5
Squalus megalops		2.5
Raja whitleyi		3.0
Dasyatis brevicaudata	2.3	
Urolophus paucimaculatus	2.4	
Urolophus viridis		2.2
Myliobatis australis	2.9	
Caelorinchus australis		2.0
Centroberyx affinis		3.1
Zenopsis nebulosus		2.1
Cyttus novaezelandiae		3.4
Macroramphosus scolopax	3.4	3.4
Helicolenus percoides	4.2	
Scorpaena papillosa	2.6	
Lepidotrigla vanessa	2.1	
Lepidotrigla modesta		2.3
Caesioperca lepidoptera	2.4	
Apogonops anomalus		4.7
Trachurus declivis		2.0
Rexea solandri		3.3
Seriolella brama		4.0
Meuschenia scaber		2.9
Total species	93	66
Between-group dissimilarity	57.9	47.8
Contribution to BGD (%)	22.3	47.7



Scientific name	Common name	Inner Soft (IS)					Inner Rough (IR)					Pt Hicks/ Gabo Is Soft (PHS/GIS)				Pt Hicks Rough (PHR)			
		Typical	Abundance	IR	PHS/GI	PHR	Typical	Abundance	IS	PHS/GI	PHR	Typical	Abundance	IS	IR	Typical	Abundance	IS	IR
Heterodontus portusjacksoni	Port Jackson shark	G	G		G		G	G		G						G	G	G	
Isurus oxyrinchus	Mako shark				G	G													
Alopias vulpinus	Thresher shark	G	G																
Cephaloscyllium laticeps	Draughtboard shark	G/T	G/T				G	G				G/T	G/T			G	G	G	
Asymbolus sp D	Orange-spotted catshark	G	G		G	G													
Mustelus antarcticus	Gummy shark				G	G			G		G	G	G			G	G		
Galeorhinus galeus	School shark											G/T	G	G	G				
Sphyrna zygaena	Smooth hammerhead	G	G																
Squalus megalops	Piked spurdog											G	G	G	G				
Pristiophorus nudipinnis	Southern sawshark	G	G	G								G	G						
Squatina australis	Australian angel shark											T	T						
Trygonorrhina sp A	Eastern fiddler ray											T	T						
Torpedo macneilli	Short-tail torpedo ray	T	T																
Dasyatis brevicaudata	Smooth stingray											T	T	T					
Urolophus paucimaculatus	Sparsely-spotted stingaree											T	T	T					
Myliobatis australis	Southern eagle ray											T	T	T					
Callorhinchus milii	Elephant fish											G	G	G	G	G	G	G	G
Pseudophycis barbata	Bearded rock cod															G	G	G	
Macroramphosus scolopax	Bellowsfish	T	T		T														
Helicolenus percoides	Ocean perch	T	T		T														
Scorpaena papillosa	Red rock cod				T														
Lepidotrigla vanessa	Butterfly gurnard													T					
Neoplatycephalus richardsoni	Tiger flathead	G	G	G	G	G													
Platycephalus bassensis	Sand flathead											T	T						
Platycephalus arenarius	Northern sand flathead											T	T						
Neoplatycephalus aurimaculatus	Toothy flathead											T	T						
Platycephalus longispinis	Long-spined flathead											T	T						
Caesioperca lepidoptera	Butterfly perch				T		G	G	G	G						G	G	G	
Hypoplectrodes maccullochi	Halfbanded seaperch						G	G											
Callanthias australis	Splendid perch						G	G											
Hypoplectrodes annulata	Blackbanded seaperch						G/Tp	G/Tp											
Trachurus declivis	Jack mackerel	G/T	G/T	G	G	G	G	G			G	T	T						
Seriola lalandi	Yellowtail kingfish						G	G											
Pagrus auratus	Snapper						G/Tp	G/Tp											
Pempheris multiradiata	Common bullseye						G	G											
Scorpis lineolata	Silver sweep						Tp	Tp											
Atypichthys strigatus	Mado						G/Tp	G/Tp											
Nemadactylus douglasi	Blue morwong	G	G		G	G	G	G		G	G								
Nemadactylus macropterus	Jackass morwong				G	G					G								
Cheilodactylus spectabilis	Banded morwong						G	G											
Latridopsis forsteri	Bastard trumpeter						G	G	G	G	G								
Notolabrus tetricus	Bluethroat wrasse						G/Tp	G/Tp											
Ophthalmolepis lineolata	Maori wrasse						G/Tp	G/Tp											
Bodianus unimaculatus	Eastern blackspot pigfish						Tp	Tp											
Kathetostoma laeve	Common stargazer											T	T						
Synchiropus calauropomus	Stinkfish	T	T																
Thyrsites atun	Barracouta	G	G		G	G	G	G		G	G								
Scomber australasicus	Blue mackerel	G	G	G	G	G													
Sarda australis	Australian bonito	G	G																
Seriolella brama	Warehou	G	G		G	G	G	G	G	G	G								
Ammotretis rostratus	Longsnout flounder											T	T						
Parika scaber	Velvet leatherjacket	T	T																
Omegophora armilla	Ringed toadfish	T	T																

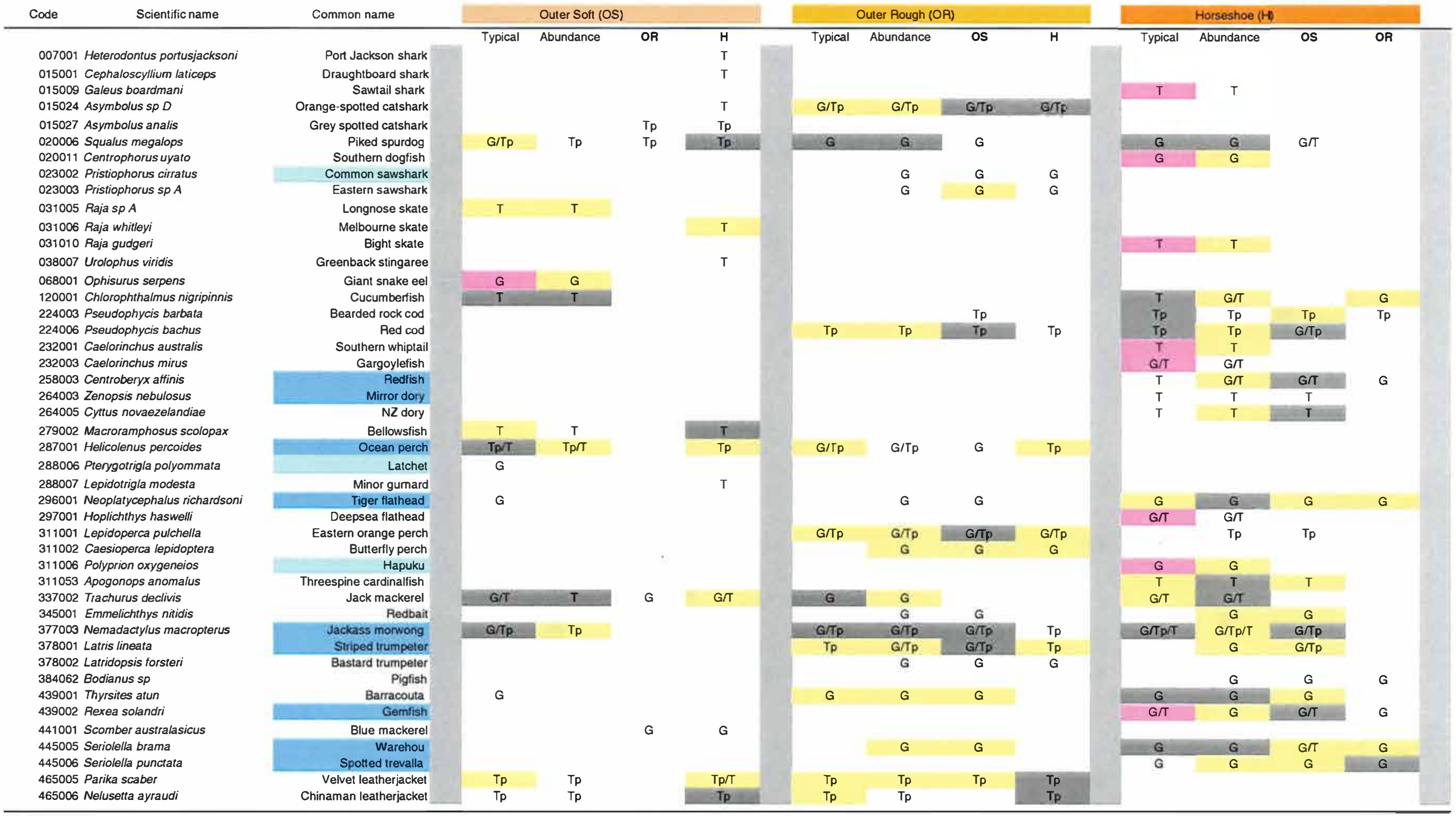
Fig. 8.2.4.4 Typifying, indicator and discriminating fish species from continental shelf habitat types off southeastern Australia shown by method of capture (G= gillnet, Tp= trap, T= trawl). The relative abundance (Abundance) of typica and indicator species (Typical), and discriminating species (discriminated habitats shown), follow the colour scheme in the legend and summarise the data from SIMPER analysis (Tables GN, trap, trawl simpers). Primary and secondary commercial species indicated.

Similarity or dissimilarity & corresponding ratio

Both low	Onehigh	Both high
☐	🟨	⬛
<100	<1000	>1000

Relative abundance

🟥 Indicator species
🟦 Primary commercial species
🟦 Secondary commercial species



Code	Scientific name	Common name	Outer Soft (OS)				Outer Rough (OR)				Horseshoe (H)			
			Typical	Abundance	**OR**	**H**	Typical	Abundance	**OS**	**H**	Typical	Abundance	**OS**	**OR**
007001	*Heterodontus portusjacksoni*	Port Jackson shark				T								
015001	*Cephaloscyllium laticeps*	Draughtboard shark				T								
015009	*Galeus boardmani*	Sawtail shark									T	T		
015024	*Asymbolus sp D*	Orange-spotted catshark				T	G/Tp	G/Tp	G/Tp	G/Tp				
015027	*Asymbolus analis*	Grey spotted catshark			Tp	Tp								
020006	*Squalus megalops*	Piked spurdog	G/Tp	Tp	Tp	Tp	G	G	G		G	G	G/T	
020011	*Centrophorus uyato*	Southern dogfish									G	G		
023002	*Pristiophorus cirratus*	Common sawshark						G	G	G				
023003	*Pristiophorus sp A*	Eastern sawshark						G	G	G				
031005	*Raja sp A*	Longnose skate	T	T										
031006	*Raja whitleyi*	Melbourne skate				T								
031010	*Raja gudgeri*	Bight skate									T	T		
038007	*Urolophus viridis*	Greenback stingaree				T								
068001	*Ophisurus serpens*	Giant snake eel	G	G										
120001	*Chlorophthalmus nigripinnis*	Cucumberfish	T	T							T	G/T		G
224003	*Pseudophycis barbata*	Bearded rock cod							Tp		Tp	Tp	Tp	Tp
224006	*Pseudophycis bachus*	Red cod					Tp	Tp	Tp	Tp	Tp	Tp	G/Tp	
232001	*Caelorinchus australis*	Southern whiptail									T	T		
232003	*Caelorinchus mirus*	Gargoylefish									G/T	G/T		
258003	*Centroberyx affinis*	Redfish									T	G/T	G/T	G
264003	*Zenopsis nebulosus*	Mirror dory									T	T	T	
264005	*Cyttus novaezelandiae*	NZ dory									T	T	T	
279002	*Macroramphosus scolopax*	Bellowsfish	T	T		T								
287001	*Helicolenus percoides*	Ocean perch	Tp/T	Tp/T		Tp	G/Tp	G/Tp	G	Tp				
288006	*Pterygotrigla polyommata*	Latchet	G											
288007	*Lepidotrigla modesta*	Minor gurnard				T								
296001	*Neoplatycephalus richardsoni*	Tiger flathead	G					G	G		G	G	G	G
297001	*Hoplichthys haswelli*	Deepsea flathead									G/T	G/T		
311001	*Lepidoperca pulchella*	Eastern orange perch					G/Tp	G/Tp	G/Tp	G/Tp		Tp	Tp	
311002	*Caesioperca lepidoptera*	Butterfly perch						G	G	G				
311006	*Polyprion oxygeneios*	Hapuku									G	G		
311053	*Apogonops anomalus*	Threespine cardinalfish									T	T	T	
337002	*Trachurus declivis*	Jack mackerel	G/T	T	G	G/T	G	G			G/T	G/T		
345001	*Emmelichthys nitidis*	Redbait						G	G			G	G	
377003	*Nemadactylus macropterus*	Jackass morwong	G/Tp	Tp			G/Tp	G/Tp	G/Tp	Tp	G/Tp/T	G/Tp/T	G/Tp	
378001	*Latris lineata*	Striped trumpeter					Tp	G/Tp	G/Tp	Tp		G	G/Tp	
378002	*Latridopsis forsteri*	Bastard trumpeter						G	G	G				
384062	*Bodianus sp*	Pigfish										G	G	G
439001	*Thyrsites atun*	Barracouta	G				G	G	G		G	G	G	
439002	*Rexea solandri*	Gemfish									G/T	G	G/T	G
441001	*Scomber australasicus*	Blue mackerel			G	G								
445005	*Seriolella brama*	Warehou						G	G		G	G	G/T	G
445006	*Seriolella punctata*	Spotted trevalla									G	G	G	G
465005	*Parika scaber*	Velvet leatherjacket	Tp	Tp		Tp/T	Tp	Tp	Tp	Tp				
465006	*Nelusetta ayraudi*	Chinaman leatherjacket	Tp	Tp		Tp	Tp	Tp		Tp				

Fig. 8.2.4.5 Typifying, indicator and discriminating fish species from continental shelf habitat types off southeastern Australia shown by method of capture (G= gillnet, Tp= trap, T= trawl). The relative abundance (Abundance) of typical and indicator species (Typical), and discriminating species (discriminated habitats shown), follow the colour scheme in the legend and summarise the data from SIMPER analysis (Tables GN, trap, trawl simpers). Primary and secondary commercial species indicated.

Similarity or dissimilarity & corresponding ratio

Both low	One high	Both high
☐	🟨	▨
<100	<1000	>1000

Relative abundance

🟪 Indicator species
🟦 Primary commercial species
▭ Secondary commercial species

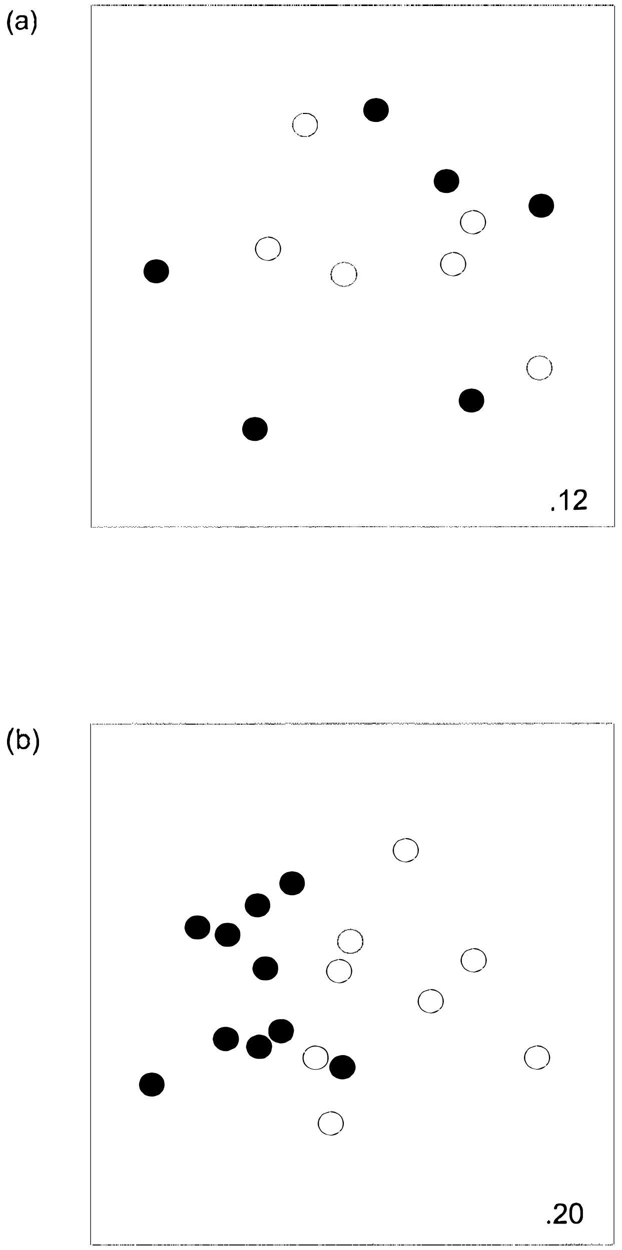


Figure 8.2.4.6 MDS plots of day and night gillnet samples from inner and outer shelf sites on the southeastern Australian continental shelf; (a) inner shelf (b) outer shelf.
(Open circles= day, filled circles=night; stress values shown inside plot boundary).

the IR and IS habitats with the PHR, PHS/GIS— a result consistent with the ordinations of macrohabitats.

A relatively high number of typical species was identified in the inner soft habitat— in part because it was also sampled with the trawl. These included orange-spotted catshark, southern sawshark, tiger flathead, blue mackerel and blue warehou in gillnet catches, and snipefish, ocean perch and velvet leatherjacket in the trawl. Several wide-ranging species were also typical in this habitat including Port Jackson and draughtboard sharks, jack mackerel and barracouta. Indicator species were the thresher shark, smooth hammerhead shark, short-tailed torpedo ray, Australian bonito and ringed toadfish. Three species–southern sawshark, tiger flathead and blue mackerel–reliably discriminated inner soft from inner rough habitat. A fourth (jack mackerel) appeared to discriminate inner soft from the other three inner-shelf habitats, however, its low reliability is discussed above. Inner soft, like inner rough, was discriminated from the PHS/GIS and PHR habitats by numerous species that included orange-spotted catshark, gummy shark, snipefish, ocean perch, red rock cod, tiger flathead, blue and morwong, blue mackerel and blue warehou.

Fishes typical of inner rough habitat were caught by gillnet and trap, and included butterfly perch, grey morwong, bastard trumpeter and blue warehou, as well as the widespread Port Jackson and draughtboard sharks, jack mackerel and barracouta. A further twelve species, caught by gillnet and trap, occurred only in this habitat type: three wrasses (Labridae), three perches (Serranidae), two sweeps (Scorpidae) and yellowtail kingfish, snapper, common bullseye, and banded morwong. Most discriminating species in this assemblage provided a contrast with the PHS/GIS and PHR habitats (grey morwong, bastard trumpeter and blue warehou), while gummy shark, butterfly perch and bastard trumpeter contrasted the inner soft habitat.

The fish assemblage of the PHS/GIS habitat was highly distinctive in both the dominance by elasmobranchs and the high number of indicators. Elasmobranchs accounted for all the typical species, except for jack mackerel, and included gummy and school shark, spikey dogfish, southern sawshark, sparsely spotted stingaree, and elephant fish. Again, the abundant and widespread draughtboard shark featured among typical species but had no discriminating power. The indicators, which were primarily trawl-caught, comprised four species of flathead (Platycephalidae), three rays, Australian angel shark, school shark, common stargazer and longnose flounder. Among discriminating species, three provided reliable contrasts with both inner soft and rough habitats: school shark, which was moderately abundant and restricted to this site; spikey dogfish, which was highly abundant and otherwise restricted mainly to the outer-shelf; and elephant fish, which was moderately abundant but found elsewhere only at the PHR habitat. The value of smooth stingray and southern eagle ray as discriminators is less reliable because they are relatively large-bodied species that were caught less frequently.

The Pt. Hicks rough habitat was characterised by only six species, none of which were indicators. Four of these, Port Jackson shark and butterfly perch (high abundance) and elephant fish and bearded rock cod (low abundance) were typical and good discriminators with inner soft habitat. Elephant fish were also good discriminators with inner rough habitat. The widespread draughtboard shark was highly abundant in this habitat, as it is across the inner-shelf.

In outer-shelf habitats, there were fewer species overall and fewer indicator species than in inner-shelf habitats; 45 of the 81 species caught were important as typifying, discriminating or indicator species for the three habitat types (Fig 8.2.4.5). The Horseshoe habitat was characterised by the greatest number of species, due in part to the relatively high number of indicators that occurred there (eight compared to none in either the outer soft or rough habitats). A similar number of species characterised each of the outer rough and soft habitats but fewer soft habitat species had discriminating power.

The outer soft habitat was characterised by species caught primarily by trap and trawl. Abundant and typical species included longnose skate, cucumberfish, snipefish, ocean perch, morwong, velvet leatherjacket and ocean jacket, as well as the widespread and abundant spikey dogfish and jack mackerel. Four species provided only weak discrimination between outer soft and outer rough habitats. Blue mackerel and grey-spotted catshark discriminated at the low level, while the reliability of the other two is questionable: jack mackerel due to the factors discussed above, and spikey dogfish which was caught by all gears but was only important in traps–undoubtably an ineffective gear for this species. There was greater discrimination of inner soft from the Horseshoe provided by Melbourne skate, snipefish, ocean perch, velvet leatherjacket and ocean jacket, and at a lower level by Port Jackson shark, orange and grey-spotted catsharks, greenback stingaree, minor gurnard and blue mackerel. Jack mackerel and spikey dogfish are unreliable discriminators for the reasons outlined above.

The abundant and typical fishes in the outer rough habitat, taken by gillnet and trap, were orange-spotted catshark, spikey dogfish, red cod, ocean perch, eastern orange perch, jack mackerel, morwong, striped trumpeter, barracouta, and velvet leatherjacket and ocean jacket. The outer rough habitat had many discriminating species including several that contrasted both the outer soft and Horseshoe. The most important in discriminating from the outer soft habitat were orange-spotted catshark, eastern sawshark, red cod, eastern orange perch, butterfly perch, morwong, striped trumpeter, blue warehou and velvet leatherjacket. Unreliable discriminators here included spikey dogfish and barracouta, as well as tiger flathead and ocean perch that likely had a low vulnerability to the gillnet. Discrimination from the Horseshoe was provided most importantly by orange-spotted catshark, ocean perch, eastern orange perch, butterfly perch, striped trumpeter, velvet leatherjacket and ocean jacket.

Many species were abundant and typical of the Horseshoe habitat, with the most important being spikey dogfish, cucumberfish, bearded rock cod, red cod, tiger flathead, threespine cardinalfish, jack mackerel, morwong, gemfish, barracouta, blue warehou and silver warehou. The greater discrimination between this habitat and the outer soft compared to outer rough was due to several important species including bearded rock cod, red cod, redfish, NZ dory, threespine cardinalfish, redbait, morwong, striped trumpeter, gemfish, blue warehou and silver warehou. Discrimination between the Horseshoe and outer rough habitats was due to cucumberfish, blue warehou and silver warehou, with lesser contributions from bearded rock cod, redfish, pigfish and gemfish. Tiger flathead were considered unreliable discriminators because of their uncertain vulnerability to the gillnet. Indicator species proved particularly useful in characterising the Horseshoe, where the eight indicators caught are more typical of the upper slope than the shelf. Their presence at the Horseshoe is consistent with the relatively steep gradient between the mid- and outer-shelf in this region, and the intrusion of the Bass Canyon into the shelf margin at this point. Its depth drops rapidly to ca. 400 m and continues to the abyssal plain.

Dominant species in habitat types

Dominant fishes were identified as those highest ranked by geometric mean abundance and making up 80% untransformed biomass in the catch of each gear (gillnet, trap and trawl) in each habitat (Table 8.2.4.7a-c, respectively). Total and average catch rates and the proportions of quota, commercial and non-commercial species (based on untransformed biomass) are shown in Table 8.2.4.8.

The number of dominant species was generally least in trap catches and greatest in trawl catches reflecting the selectivity and total number of species caught by each gear. The degree of species overlap between gears and the number of dominants per habitat was variable. This was clear at the three habitats sampled and consistently defined by all gears (H, OS and PHS): only morwong contributed to the catch of more than one gear from 10 dominant species at the Horseshoe, only draughtboard shark and sliver dory overlapped from the 12 dominants at Point Hicks soft, while jack mackerel, spikey dogfish and ocean perch overlapped among six dominants at the outer soft habitat.

Although it was not possible to directly compare the catch rates between gears, catch data (Table 8.2.4.8) showed that, for time-standardised soaks of the static gears, many traps would be needed to produce an equivalent total catch biomass to the gillnet. For a relatively short deployments (1 hour vs. 10 hours) the mobile trawl caught a correspondingly large biomass. There was no general relationship between the size of catches for any gear and habitats defined by bottom type (soft or rough). Relatively large and small gillnet catches were taken in both types, while trap catches did not discriminate the inner-shelf soft and hard-grounds, and trawls only sampled soft bottom-types. However, catch rates varied greatly between specific habitats with relatively large catches taken by gillnet and trap on particular reefs (inner rough and outer rough, respectively).

The relative proportions of marketable species (quota and commercial) varied between gears and habitats (Table 8.2.4.8). In gillnet catches, the proportions of marketable species were greatest in habitats with reef (OR, IR and H; 37%, 48%, 57% respectively)— although the biomass of marketable species was negligible at PHR. Blue warehou, morwong and tiger flathead comprised most biomass, with smaller proportions made up by gummy shark and grey morwong at IR. Small proportions of marketable species (< 30%) were caught on soft-ground habitats, particularly at OS (~7%). Trap catches, although generally smaller in size, contained relatively high proportions of marketable species (mostly morwong and striped trumpeter). A high proportion (73%) coincided with the highest catch rate (6 kg per trap per soak) on the outer rough (Gabo- Howe Reef) where morwong (~41%) and striped trumpeter (~28%) comprised most biomass. morwong was also the top-ranked species in the other habitats (H, OS and DB) where marketable species proportion was high (67%, 77%, 50% respectively). In trawls, the proportion of marketable species was highest (35%) at the Horseshoe where redfish (12%) and blue warehou (10%) were most important. At other soft-ground habitats, ocean perch, silver dory and redfish were the most important species.

Habitat association

The patterns of habitat preference for all species caught in the three gears are shown in Table 8.2.4.9 and Fig. 8.2.4.7. Of the total 95 species caught by gillnet and trap, 86 were in macrohabitats that could be categorised as either predominantly reef (acoustically rough or hard-type bottom) or sediment flats (acoustically soft-type). The nine remaining species were restricted to the Horseshoe.

Comparison of the numbers of individuals caught showed near-equal proportions of species associated with reef, with sediment flats or using both habitat types. The reef-associated group included 19 species (22%) caught only on reef and nine species (11%) caught mostly (>70% individuals) on reef. Sediment flat dwellers were nine species (11%) caught only in sediment flat habitats and 20 species (23%) that were caught mostly on sediment flats. The remaining 29 species (34%) were caught in relatively large proportions (30-70%) in both habitat types in one or more gears. Most determinations were made with a high or medium degree of confidence indicating good agreement in the catches of different gears and sufficiently large catch sizes.

Commercial species occurred in each of the five groups of habitat association. Striped trumpeter were strongly associated with reef, while snapper showed a distinct reef association. School whiting were strongly associated with sediment flat habitats and there was a distinct association with this habitat for John dory, silver dory, white trevally, gummy shark, tiger flathead and school shark. Seven other species (silver warehou, pink ling, ocean perch, grey morwong, morwong, redfish and blue warehou) were associated with reefs and sediment flats.

Diel differences in macrohabitat similarities

Because gillnet samples were collected from all macrohabitats during day and night they were analysed for diel differences. Ordination of day and night single-net samples together showed a pronounced separation of day and night on the outer-shelf that was not evident on the inner-shelf (Fig. 8.2.4.6). The outer-shelf difference was due mostly (65% total dissimilarity) to higher species' abundances at night, rather than a difference in the species caught. Thus, while only 26 of the total 49 species were caught during the day and night, they included the 19 most abundant species that contributed 72% of dissimilarity. The most important contributor, the commercially important pink ling, is noteworthy because catches at night considerably exceeded those during the day; it is highly characteristic of the Horseshoe but was not included in the list of characteristic species (Fig. 8.2.4.5) due to relatively very low daytime catches. However, the next four most important contributors with higher nighttime abundance were low-reliability (widespread and/ or transient) discriminators: draughtboard shark, jack mackerel, spikey dogfish and redbait. Important species that had higher abundance in daytime catches included blue warehou, morwong, striped trumpeter, and butterfly perch, as well as the low-reliability discriminators barracouta and tiger flathead.

Day/ night differences in catches caused some changes to macrohabitat groupings. On the outer-shelf, the outer soft and outer rough habitats failed to group distinctly but this was due primarily to the great dissimilarity of the Gabo Reef hard macrohabitat that was represented by small samples with few species. The Horseshoe grouped more distinctly, due in part to the influence of large pink ling catches. Among inner-shelf samples, the Disaster Bay rough macrohabitat grouped with the inner soft macrohabitats at night due to lower species abundances in night samples and relatively low overall catches. More species were caught during the day (27 vs. 21), of which 22 had higher daytime abundance and contributed 83% of total dissimilarity between day and night catches in this macrohabitat. Diel differences in abundance showed several parallels with the outer-shelf: striped trumpeter and blue warehou were the most important daytime discriminators with butterfly perch and morwong highly ranked (7 and 9 respectively).

Table 8.2.4.7a Dominant species in macrohabitat groups sampled by **gillnet:** species ranked by geometric mean abundance with cut-off at 80% of total untransformed biomass. Habitat codes follow Section 8.2.3.

Habitat type	Common name	Species name	Geo. mean biomass	% raw biomass	Cum % biomass
PHR	Draughtboard shark	*Cephaloscyllium laticeps*	6.14	55.6	55.6
	Port Jackson shark	*Heterodontus portusjacksoni*	4.17	35.0	90.6
PHS	Draughtboard shark	*Cephaloscyllium laticeps*	2.70	52.5	52.5
	Spikey dogfish	*Squalus megalops*	1.55	29.1	81.7
IR	Draughtboard shark	*Cephaloscyllium laticeps*	3.10	19.2	19.2
	Blue warehou	*Seriolella brama*	2.43	22.5	41.7
	Bastard trumpeter	*Latridopsis forsteri*	0.63	4.0	45.7
	Grey morwong	*Nemadactylus douglasi*	0.61	3.5	49.2
	Jack mackerel	*Trachurus declivis*	0.54	7.1	56.3
	Port Jackson shark	*Heterodontus portusjacksoni*	0.47	10.3	66.6
	Barracouta	*Thyrsites atun*	0.39	7.9	74.5
	Butterfly perch	*Caesioperca lepidoptera*	0.32	1.8	76.3
	Orange-spotted catshark	*Asymbolus sp D*	0.07	0.5	76.8
	Morwong	*Nemadactylus macropterus*	0.04	1.9	78.7
	Sergeant Baker	*Aulopus purpurissatus*	0.04	0.4	79.1
	Spikey dogfish	*Squalus megalops*	0.04	1.0	80.1
IS	Barracouta	*Thyrsites atun*	2.09	17.2	17.2
	Jack mackerel	*Trachurus declivis*	1.84	28.0	45.2
	Draughtboard shark	*Cephaloscyllium laticeps*	0.37	9.9	55.1
	Southern sawshark	*Pristiophorus nudipinnis*	0.21	1.8	56.9
	Blue mackerel	*Scomber australasicus*	0.17	4.6	61.5
	Gummy shark	*Mustelus antarcticus*	0.08	8.4	69.9
	Tiger flathead	*Neoplatycephalus richardsoni*	0.08	2.2	72.2
	Blue warehou	*Seriolella brama*	0.07	15.2	87.3
OR	Spikey dogfish	*Squalus megalops*	1.42	28.8	28.8
	Morwong	*Nemadactylus macropterus*	1.34	22.0	50.7
	Jack mackerel	*Trachurus declivis*	0.64	13.7	64.4
	Barracouta	*Thyrsites atun*	0.24	9.9	74.4
	Orange-spotted catshark	*Asymbolus sp D*	0.06	2.0	76.4
	Ocean perch	*Helicolenus percoides*	0.04	0.7	77.2
	Eastern orange perch	*Lepidoperca pulchella*	0.02	1.5	78.7
	Tiger flathead	*Neoplatycephalus richardsoni*	0.02	1.3	80.0
OS	Jack mackerel	*Trachurus declivis*	0.45	69.8	69.8
	Spikey dogfish	*Squalus megalops*	0.22	16.2	86.0
H	Spikey dogfish	*Squalus megalops*	1.76	15.7	15.7
	Blue warehou	*Seriolella brama*	1.50	24.3	40.1
	Tiger flathead	*Neoplatycephalus richardsoni*	0.88	16.4	56.5
	Morwong	*Nemadactylus macropterus*	0.79	7.2	63.7
	Barracouta	*Thyrsites atun*	0.48	13.3	77.0
	Jack mackerel	*Trachurus declivis*	0.40	9.7	86.7

Table 8.2.4.7b Dominant species in macrohabitat groups sampled by **trap;** species ranked by geometric mean abundance with cut-off at 80% of total untransformed biomass. Habitat codes follow Section 8.2.3.

Habitat type	Common name	Species name	Geo. mean biomass	% raw biomass	Cum % biomass
BH	Velvet leatherjacket	*Meuschenia scaber*	198.6	35.3	35.3
	Draughtboard shark	*Cephaloscyllium laticeps*	111.4	32.2	67.6
	Sixspine leatherjacket	*Meuschenia freycineti*	15.9	2.7	70.2
	Rosy wrasse	*Pseudolabrus psittaculus*	8.1	1.9	72.1
	Bluethroat wrasse	*Notolabrus tetricus*	6.8	3.7	75.9
	Mado	*Atypichthys strigatus*	6.4	4.9	80.7
DB	Morwong	*Nemadactylus macropterus*	112.1	38.1	38.1
	Velvet leatherjacket	*Meuschenia scaber*	87.9	8.5	46.6
	Ocean perch	*Helicolenus percoides*	27.4	3.7	50.3
	Bearded rock cod	*Pseudophycis barbata*	24.9	8.0	58.3
	Southern conger	*Conger verreauxi*	18.6	4.6	63.0
	Grey spotted catshark	*Asymbolus analis*	16.7	1.9	64.8
	Red cod	*Pseudophycis bachus*	15.4	3.8	68.6
	Eastern orange perch	*Lepidoperca pulchella*	8.4	5.0	73.5
	Degens leatherjacket	*Thamnaconus degeni*	6.3	10.5	84.0
OS	Morwong	*Nemadactylus macropterus*	142.6	65.3	65.3
	Piked spurdog	*Squalus megalops*	46.2	11.9	77.2
	Ocean perch	*Helicolenus percoides*	24.5	5.7	82.9
OR	Morwong	*Nemadactylus macropterus*	1015.1	40.8	40.8
	Striped trumpeter	*Latris lineata*	512.4	27.9	68.7
	Velvet leatherjacket	*Meuschenia scaber*	174.0	10.3	79.0
	Red cod	*Pseudophycis bachus*	168.9	9.6	88.5
H	Morwong	*Nemadactylus macropterus*	271.8	57.1	57.1
	Red cod	*Pseudophycis bachus*	96.6	21.1	78.3
	Bearded rock cod	*Pseudophycis barbata*	60.5	10.7	89.0
PHS	Silver dory	*Cyttus australis*	15.6	100.0	100.0

Table 8.2.4.7c Dominant species in macrohabitat groups sampled by **trawl**; species ranked by geometric mean abundance with cut-off at 80% of total untransformed biomass. Habitat codes follow Section 8.2.3.

Habitat type	Common name	Species name	Geo. mean biomass	% raw biomass	Cum % biomass
PHS	Jack mackerel	*Trachurus declivis*	743.1	17.4	17.4
	Sparsely-spotted stingaree	*Urolophus paucimaculatus*	614.9	11.7	29.1
	Banded stingaree	*Urolophus cruciatus*	563.7	4.8	34.0
	Common stinkfish	*Synchiropus calauropomus*	358.0	5.9	39.9
	Draughtboard shark	*Cephaloscyllium laticeps*	353.7	6.4	46.3
	Silver dory	*Cyttus australis*	297.4	0.8	47.1
	Velvet leatherjacket	*Meuschenia scaber*	245.8	0.9	48.1
	Barracouta	*Thyrsites atun*	227.3	4.1	52.2
	Tasmanian numbfish	*Narcine tasmaniensis*	218.8	1.4	53.6
	Southern eagle ray	*Myliobatis australis*	190.3	4.2	57.7
	Globefish	*Diodon nicthemerus*	153.2	2.3	60.0
	Ruddy gurnard perch	*Neosebastes scorpaenoides*	150.1	1.5	61.5
	Longnose skate	*Raja sp A*	143.7	2.4	63.9
	Butterfly gurnard	*Lepidotrigla vanessa*	104.5	0.9	64.8
	Deepwater gurnard	*Lepidotrigla mulhalli*	93.9	0.8	65.7
	Red gurnard	*Chelidonichthys kumu*	51.8	0.4	66.0
	Tiger flathead	*Neoplatycephalus richardsoni*	45.3	0.4	66.5
	~~Minor gurnard~~	*Lepidotrigla modesta*	43.5	0.5	67.0
	Smooth stingray	*Dasyatis brevicaudata*	34.4	4.1	71.1
	Melbourne skake	*Raja whitleyi*	31.8	2.8	73.9
	Mosaic leatherjacket	*Eubalichthys mosaicus*	27.8	0.2	74.0
	Common stargazer	*Kathetostoma laeve*	22.1	0.8	74.8
	Grey morwong	*Nemadactylus douglasi*	21.3	0.2	75.0
	Cucumberfish	*Chlorophthalmus nigripinnis*	20.5	4.0	79.0
	Silver warehou	*Seriolella punctata*	19.9	1.1	80.1
IS	Ocean perch	*Helicolenus percoides*	5923.4	15.5	15.5
	Common snipefish	*Macroramphosus scolopax*	2824.7	4.9	20.3
	Jack mackerel	*Trachurus declivis*	2608.5	22.6	43.0
	Velvet leatherjacket	*Meuschenia scaber*	2147.5	4.1	47.1
	Draughtboard shark	*Cephaloscyllium laticeps*	1546.3	2.7	49.7
	Silver dory	*Cyttus australis*	1260.2	2.4	52.1
	John dory	*Zeus faber*	921.7	1.9	54.0
	Common stinkfish	*Synchiropus calauropomus*	747.1	10.8	64.8
	Grey morwong	*Nemadactylus douglasi*	599.5	2.6	67.4
	Southern rock cod	*Scorpaena papillosa*	528.0	5.9	73.3
	Mosaic leatherjacket	*Eubalichthys mosaicus*	280.4	2.1	75.5
	Barred grubfish	*Parapercis allporti*	101.5	0.3	75.8
	Greenback stingaree	*Urolophus viridis*	97.1	1.9	77.7
	Cucumberfish	*Chlorophthalmus nigripinnis*	93.9	2.0	79.7
	Deepwater gurnard	*Lepidotrigla mulhalli*	72.4	0.8	80.4
OS	Cucumberfish	*Chlorophthalmus nigripinnis*	6949.4	22.3	22.3
	Jack mackerel	*Trachurus declivis*	3254.1	29.0	51.3
	Ocean perch	*Helicolenus percoides*	1962.8	5.8	57.0
	Common snipefish	*Macroramphosus scolopax*	653.5	1.8	58.8
	Longnose skate	*Raja sp A*	522.6	2.4	61.2
	Tiger flathead	*Neoplatycephalus richardsoni*	335.0	1.5	62.7
	Velvet leatherjacket	*Meuschenia scaber*	294.6	2.1	64.8
	Pink Ling	*Genypterus blacodes*	232.4	1.1	65.9
	John dory	*Zeus faber*	169.4	1.5	67.4
	Silver dory	*Cyttus australis*	100.9	0.7	68.1
	Draughtboard shark	*Cephaloscyllium laticeps*	94.1	3.6	71.7
	Minor gurnard	*Lepidotrigla modesta*	91.4	1.0	72.7
	Orange-spotted catshark	*Asymbolus sp D*	70.4	0.6	73.3
	Redfish	*Centroberyx affinis*	65.0	10.1	83.4
H	Cucumberfish	*Chlorophthalmus nigripinnis*	4563.7	10.5	10.5
	Jack mackerel	*Trachurus declivis*	3752.3	19.2	29.7
	Threespine cardinalfish	*Apogonops anomalus*	2160.4	19.6	49.4
	New Zealand Dory	*Cyttus novaezelandiae*	1999.9	5.1	54.4
	Redfish	*Centroberyx affinis*	904.6	12.3	66.8
	Morwong	*Nemadactylus macropterus*	651.0	3.8	70.6
	Mirror dory	*Zenopsis nebulosus*	496.0	1.1	71.7
	Silver dory	*Cyttus australis*	256.8	0.5	72.2
	Pink Ling	*Genypterus blacodes*	233.9	1.8	74.0
	Ocean perch	*Helicolenus percoides*	221.1	2.9	76.9
	Gemfish	*Rexea solandri*	186.1	1.1	78.0
	Spikey dogfish	*Squalus megalops*	94.8	1.6	79.6
	Blue warehou	*Seriolella brama*	72.1	9.8	89.4

Table 8.2.4.8 Daytime catch rates by gear type in each habitat. Total and arithmetic mean catch rate based on standardised data: gillnet (kg per 6-panel net, 10-hour set); trap (kg per trap, 10-hour set); trawl (kg per 60 min tow @ 3 knots). Proportions of quota species and commercial species are based on the geometric mean abundance of all species in each habitat. Habitat codes follow section 8.2.4.

	Habitat type	No samples	Total catch	Average catch	% quota	% commercial	% non-commercial
Gillnet	H	6	351	59	53.6	3.7	42.7
	OR	6	214	36	28.8	7.9	63.3
	OS	6	135	23	4.0	3.3	92.7
	IR	6	573	96	25.6	22.1	52.3
	IS	6	397	66	20.1	9.1	70.8
	PHR	2	121	61	0.0	0.6	99.4
	PHS	2	54	27	1.8	14.9	83.3
Trap	H	15	18	1	57.9	9.0	33.1
	OR	15	84	6	42.0	31.4	26.6
	OS	15	9	1	70.9	5.9	23.2
	BH/PHR	20	34	2	1.4	5.6	93.0
	DB	15	38	3	41.8	8.6	49.6
	PHS	5	<1	<1	#	#	#
Trawl	H	6	352	59	34.9	0.7	64.4
	OS	11	470	43	23.7	1.2	75.1
	IS	10	661	66	21.7	8.3	70.0
	PHS/GIS	4	167	42	6.5	4.4	89.1

Table 8.2.4.9 Habitat associations of 95 fishes caught by gillnet and trap based on acoustic separation of macrohabitats into reef habitat or sediment flats; samples from the Horseshoe excluded and shown separately. n= raw total individuals caught by each gear; code= degree of association (RR, >95% on reef; R, >70% on reef; S, >70% on sediment flats; SS, >95% on sediment flats; B, 30-70% on either habitat type). Abund= scaled, standardised, log abundance (1= 1, 2= 2-10, 3= 11-100, 4= 101-1000, etc). Confidence interval based on the proportions caught, the agreement between gears and the numbers of individuals caught.

			GILLNET			TRAP			TRAWL		
Habitat association	**Common Name**	**Name**	**n**	**Use code**	**Abund**	**n**	**Use code**	**Abund**	**n**	**Abund**	**confidence level**
Sediment flat, strong											
	Smooth hammerhead	*Sphyma zygaena*	2	SS	2						low
	Giant snake eel	*Ophisurus serpens*	2	SS	2						medium
	Cucumberfish	*Chlorophthalmus nigripinnis*	19	SS	3				11468	6	high
	Deepwater gurnard	*Lepidotrigla mulhalli*	31	SS	3				459	5	high
	Sand flathead	*Platycephalus bassensis*	3	SS	2				5	2	medium
	Southern flathead	*Platycephalus speculator*	5	SS	2						medium
	Eastern school whiting	*Sillago flindersi*	2	SS	2				26	4	high
	Common stinkfish	*Foetorepus calauropomus*	1	SS	1				1728	5	high
	Australian bonito	*Sarda australis*	2	SS	2						low
Sediment flat, distinct											
	Banded slingaree	*Urolophus cruciatus*	1	RR	1				216	4	medium
	Greenback stingaree	*Urolophus viridis*	1	RR	1				185	4	medium
	John dory	*Zeus faber*	1	RR	2				102	4	high
	Minor gurnard	*Lepidotrigla modesta*	2	RR	2				725	5	high
	Silver dory	*Cyttus australis*	13	B	3	15	SS	3	463	5	high
	Southern rock cod	*Scorpaena papillosa*	6	B	2				3666	6	high
	Red gurnard	*Chelidonichthys kumu*	2	B	2				11	3	low
	White trevally	*Pseudocaranx dentex*	28	B/S	3				24	3	medium
	Gummy shark	*Mustelus antarcticus*	266	S	4	4	SS	2	4	3	medium
	Spikey dogfish	*Squalus megalops*	3300	S	5	76	R/B	3	301	4	high
	Southern sawshark	*Pristiophorus nudipinnis*	33	S	3				4	2	medium
	Elephantfish	*Callorhinchus milii*	5	S	2				2	2	medium
	Ruddy gurnard perch	*Neosebastes scorpaenoides*	9	S	2	3	SS	2	33	3	medium
	Tiger flathead	*Neoplatycephalus richardsoni*	244	S	4				230	4	high
	Jack mackerel	*Trachurus declivis*	3266	S	5	2	RR	2	5948	6	high
	Peruvian jack mackerel	*Trachurus murphyi*	10	S	2						low
	Blue mackerel	*Scomber australasicus*	250	S	4				22	3	high
	School shark	*Galeorhinus galeus*	10	SS	2				2	2	medium
	Blue grenadier	*Macruronus novaezelandiae*	6	SS	2				1	H	low
	Degens leatherjacket	*Thamnaconus degeni*	1	SS	1	138	S	4	21	3	high
Both											
	Sandpaper fish	*Paratrachichthys sp 1*	29	RR	3				25	H	medium
	White ear	*Parma microlepis*	2	RR	2	3	RR	2	26		medium
	Silver warehou	*Seriolella punctata*	39	RR	2				40	3	high
	Sixspine leatherjacket	*Meuschenia freycineti*	7	RR	2	14	B	3	16	2	medium
	Mako shark	*Isurus oxyrinchus*	4	R/B	2						low
	Common sawshark	*Pristiophorus cirratus*	5	R	2						low
	Pink Ling	*Genypterus blacodes*	112	R	3	5	RR	2	147	4	medium
	Ocean perch	*Helicolenus percoides*	249	R	4	94	R	4	5398	6	high
	Thetis fish	*Neosebastes thetidis*	4	R	2				17	3	medium
	Grey morwong	*Nemadactylus douglasi*	97	R	3	2	RR	2	421	5	high
	Morwong	*Nemadactylus macropterus*	608	R	4	669	R	4	279	4	high
	Velvet leatherjacket	*Meuschenia scaber*	50	R	3	665	R	5	936	5	high
	Port Jackson shark	*Heterodontus portusjacksoni*	79	B/R	3	1	SS	2	10	3	medium
	Rusty carpetshark	*Parascyllium ferrugineum*	15	B	3						medium
	Draughtboard shark	*Cephaloscyllium laticeps*	684	B	4	88	B	4	191	4	high
	Orange-spotted catshark	*Asymbolus sp D*	231	B	4	15	R	3	83	4	medium
	Grey spotted catshark	*Asymbolus analis*	25	B	3	18	B	3	28	4	high
	Eastern sawshark	*Pristiophorus sp A*	11	B	3						low
	Red cod	*Pseudophycis bachus*	40	B	3	123	R	4	23	3	high
	Redfish	*Centroberyx affinis*	228	B	4				1858	5	high
	Latchet	*Pterygotrigla polyommata*	12	B	2				25	3	medium
	Redbait	*Emmelichthys nitidus nitidus*	352	B	4				47	4	medium
	Rosy wrasse	*Pseudolabrus psittaculus*	6	B	2	23	RR	3	8	3	high
	Barracoula	*Thyrsites atun*	326	B	4				54	3	high
	Blue warehou	*Seriolella brama*	523	B	4				99	3	high
	Mosaic leatherjacket	*Eubalichthys mosaicus*	7	B	2				107	4	medium
	Giant boarfish	*Paristiopterus labiosus*	3	S/B	2				10	3	medium
	Boarfish	*Pentaceropsis recurvirostris*	1	SS	1				5	3	medium
	Whitefin swellshark	*Cephaloscyllium sp A*				1	RR	1	10	3	low
Reef, distinct											
	Bearded rock cod	*Pseudophycis barbata*	8	RR	2	76	R	3			high
	Butterfly perch	*Caesioperca lepidoptera*	338	RR	4	13	RR	3	1314	5	high
	Barber perch	*Caesioperca rasor*	3	RR	2	5	RR	2			medium
	Halfbanded seaperch	*Hypoplectrodes maccullochi*	2	RR	2				6	3	medium
	Splendid perch	*Callanthias australis*	8	RR	2				10	3	medium
	Yellowtail kingfish	*Seriola lalandi*	1	RR	1						medium
	Snapper	*Pagrus auratus*	3	RR	2	1	RR	2	4	2	medium
	Ocean jacket	*Nelusetta ayraudi*	1	RR	1	51	R	3	3	2	high
	Eastern orange perch	*Lepidoperca pulchella*	47	R	3	172	RR	4			high
Reef, strong											
	Thresher shark	*Aloplas vulpinus*	5	RR	2						low
	Sergeant Baker	*Aulopus purpurissatus*	9	RR	2	1	RR	2	1	2	medium
	Largetooth beardie	*Lotella rhacinus*	2	RR	2	13	RR	3			high
	Swallowtail	*Centroberyx lineatus*	10	RR	2						medium
	Blackbanded seaperch	*Hypoplectrodes annulata*	1	RR	1	2	RR	2			medium
	Longfin pike	*Dinolestes lewini*	19	RR	3						medium
	Common bullseye	*Pempheris multiradiata*	23	RR	3						medium
	Mado	*Atypichthys strigatus*	2	RR	2	87	RR	4			high
	Banded morwong	*Cheilodactylus spectabilis*	4	RR	2						medium
	Striped trumpeter	*Latris lineata*	19	RR	2	76	RR	4			high
	Bastard trumpeter	*Latridopsis forsteri*	65	RR	3	1	RR	2	1	2	high
	Bluethroat wrasse	*Notolabrus tetricus*	7	RR	2	7	RR	3			high
	Maori wrasse	*Ophthalmolepis lineolata*	15	RR	3	8	RR	3			high
	Eastern blue grouper	*Achoerodus viridis*	3	RR	2						medium
	Pigfish	*Bodianus sp. 1*	9	RR	2	1	RR	2			medium
	Green moray	*Gymnothorax prasinus*				4	RR	2			medium
	Southern conger	*Conger verreauxi*				12	RR	3			medium
	Silver sweep	*Scorpis lineolata*				9	RR	3			medium
	Eastern blackspot pigfish	*Bodianus unimaculatus*				1	RR	2			medium
Horseshoe											
	Southern dogfish	*Centrophorus uyato*	1	H							
	Longnose skate	*Raja sp A*	1	H					77	4	
	Southern whiptail	*Caelorinchus australis*	1	H					30	H	
	Gargoylefish	*Caelorinchus mirus*	2	H					2	H	
	Deepsea flathead	*Hoplichthys haswelli*	3	H					5	H	
	Hapuku	*Polyprion oxygeneios*	5	H							
	Barred grubfish	*Parapercis allporti*	1	H					117	4	
	Gemfish	*Rexea solandri*	12	H					29	H	
	Frostfish	*Lepidopus caudatus*	1	H					2	2	

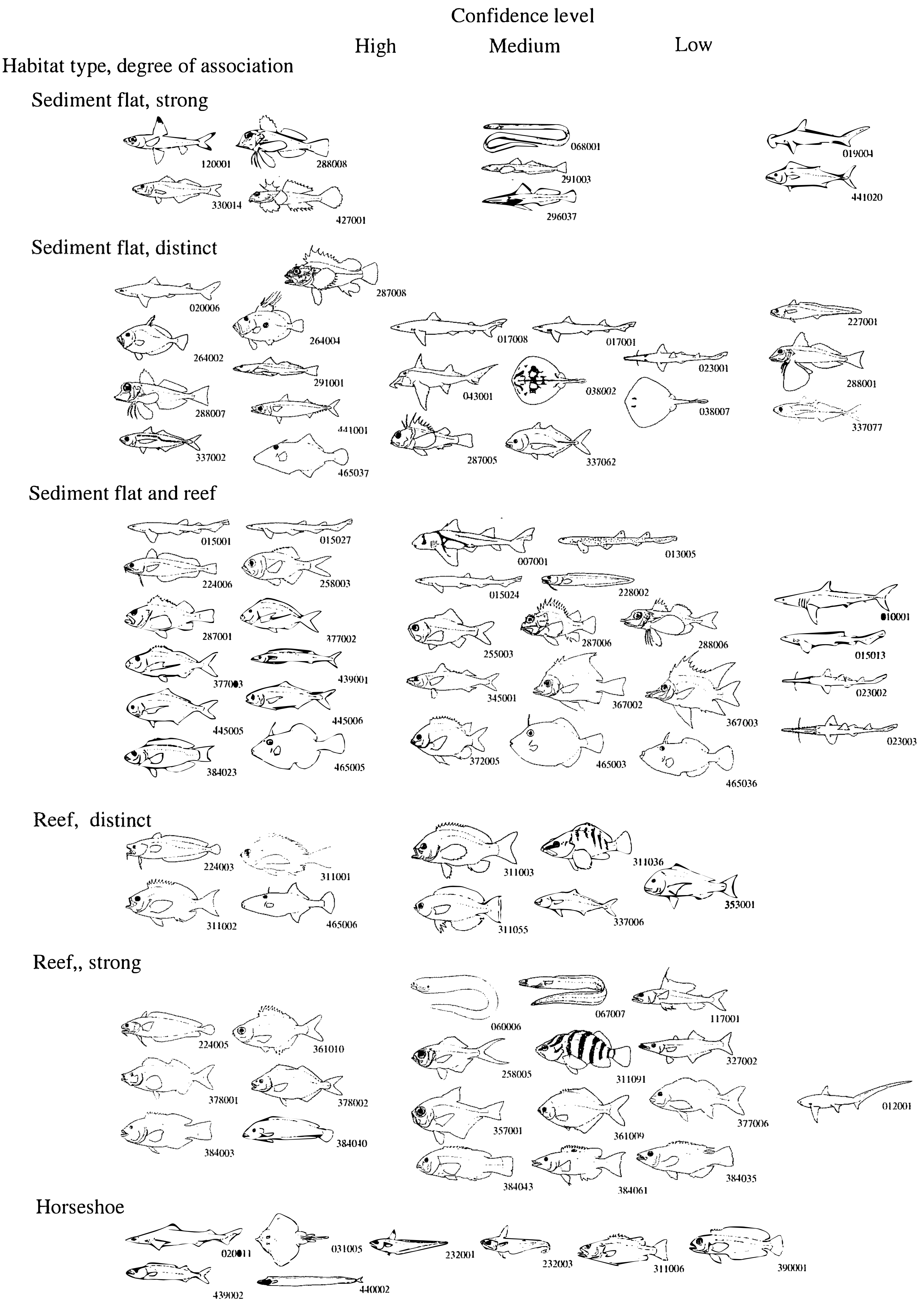


Fig. 8.2.4.7 Habitat association of fishes caught in focussed habitat samples. Categories of habitat association are: strong (> 95% of individuals caught in habitat by all gears); distinct (> 70% of individuals caught in habitat by all gears), and association with both (30-70% individuals caught in habitat by all gears). Confidence interval based on the proportions caught, the agreement between gears and the numbers of individuals caught.

8.3 SUMMARY AND IMPLICATIONS

Aims of survey of biological communities

Biological communities (fishes and invertebrates) were sampled at a variety of seabed types (*Section* 7) to determine their structure and thereby determine the broad distribution of habitat types in this region of the SEF ecosystem. We used three gear types–gillnet, trap and trawl–to enable sampling of fishes in both 'soft-ground' and 'hard-ground' habitats, and to assess the selectivity of the gears in different habitat types. The seasonal stability in community structure was assessed by systematic trawl sampling of soft-ground habitats at times when regional hydrology differed. Invertebrates were sampled with a combination benthic sled that provided information on the epifaunal(surface-dwelling) species and infauna (subsurface-dwelling) species. Biological information was used in conjunction with details of the physical structure of the seabed types (*Section* 7) to evaluate the importance of hard-ground to the productivity of the fishery. Biological data collected from specimens provided the means of defining trophic linkages, and assessing the age (size) composition of quota and other key species. Sites representing the range of seabed types in our study area were effectively sampled by the program of targeted sampling with multiple fishing gears. The use of four gear types, with traps and gillnets fished by experienced fishers from commercial vessels, provided sufficiently large and representative samples of invertebrates and fishes to describe the composition and structure of communities at each site. The description of invertebrates in hard-ground habitats relied to some extent on photography, because we did not develop a reliable and robust hard-ground sampler.

Invertebrate communities

Distinct differences in invertebrate communities were found in different habitats, although they had many taxa in common. Two clear trends were observed in the broad-scale survey: changes in community with depth, and changes in the inshore community between southern and northern sites. The complication in this overall pattern was transect C: generally the stations on this transect grouped separately from stations at a similar depth on adjacent transects. These trends in the invertebrate communities correlated with changes in sediment characteristics (grain size, degree of sorting and biological activity) superimposed on the trend with depth. The distinct invertebrate communities found on transect C can be related to the poorly sorted sediments of high biogenic activity on these stations. Broadscale mapping of sediments in previous sections suggested that these sediments result from localised upwelling at a major arm of the Bass Canyon.

A stronger influence of bottom type on invertebrate communities is clear from the focussed habitat study. Again, there is a distinct change in community structure with depth, and inshore communities are distributed according to broad regional trends. The relationship between invertebrate fauna and habitat type is clearest for the offshore, focussed habitat sites, where rough habitat is associated with a high coverage of sponges and bryozoans, whereas softer habitat is associated with bivalves and echinoids.

Average macrobenthic biomass and species diversity decrease with depth (Karakassis and Eleftheriou 1998). Previous authors have found that shelf invertebrate communities form a continuum with environmental variables (Gagnon and Haedrich 1991) or distinct groups superimposed on the continuum (Karakassis and Eleftheriou 1998). Even when distinct groups are found, they are based on quantitative differences in species rather than in the presence of unique species, again suggesting a continuum rather than a distinct delineation as found in this study.

Invertebrate communities are commonly characterised according to depth and sediment type (e.g. Basford *et al.* 1989, Rabalais 1990). For example, depth alone appeared to explain 89% of the variance in macrofauna distribution on the Cretian shelf (Karakassis and Eleftheriou 1998). However, as depth can often be associated with other variables such as grain size, redox potential and the quantity and condition of sedimenting organic material, these authors concluded that macrobenthic communities on the nearshore Cretian shelf were structured by hydrodynamic processes and their effect on sedimentary processes, while offshore shelf communities were structured by food availability in qualitative and quantitative terms. In our study area, nearshore communities divided into southern and northern subgroups, associated with different sediment characteristics, in turn reflecting local currents. Midshelf and offshore communities were less clearly delineated by sediment structure, apart from the sites on transect C where deep upwelling increased the amount of fine biogenic sediments. Rough and hard habitats, however, did delineate distinct communities. While habitat type may influence food availability through changing boundary-layer conditions, it seems more probable that the structural properties of rough/ hard habitats enable a community with larger epifauna to settle and develop than could do so on the softer habitat, where there is little structure that could support it.

Exotic Marine Pests

The New Zealand screw shell *Maoricolpus roseus* was almost certainly introduced to Australian waters in the 1940s, as an inadvertent consequence of the then-prevalent trade of bringing oysters from New Zealand to Tasmania for sale. The live animals from New Zealand were hung in the Derwent until they were sold, which resulted in a number of New Zealand species being introduced into southern Australian waters.

Maoricolpus roseus has been by far the most successful of these invaders. It has spread from the Derwent and along Tasmania's east coast, crossing Bass Strait in the 1980s. A specimen was recently found in Sydney harbour (Winston Ponder, Australian Museum, pers. comm.). It inhabits depths from the shoreline to at least 80 m (in this study; it is reported down to 130 m in New Zealand), and reaches densities in excess of 1000 individuals per square metre. It is the only known introduced marine species, anywhere in the world, that has successfully invaded the continental shelf from a port environment, and the only common marine introduction that inhabits areas (the shelf beyond 3 nautical miles) managed by the Commonwealth.

Very little is known about the biology of *Maoricolpus roseus*, its impacts on sediment structure or its competition with other invertebrates. Even the empty shells may have substantial impact as homes for hermit crabs, as indicated by the crabs' large biomass in areas where *Maoricolpus roseus* is abundant. Discussions with local natural historians and State biologists suggest that, as its distribution has widened and its numbers increased, several native gastropods have declined sharply. Moreover, the vast numbers and widespread distribution of the species on the shelf suggest that its impacts on ecosystem dynamics are likely to have been substantial, if to date almost entirely unstudied. From its densities, it is likely that *Maoricolpus roseus* may well be the environmentally most damaging of the introduced marine species, though largely out-of-sight and hence unknown to the general public or conservation managers.

In this survey *Maoricolpus roseus* was a major component of the fauna at most stations between 25 and 80 m throughout the study area. It constituted half the sampled biomass on northern inshore stations.

Association of fishes with different seabed types

The strength of association with reef ('hard-ground') or sediment flat ('soft-ground') seabed types was assessed by comparing the abundance of each of the 95 species caught in gillnet and trap samples. Five categories of habitat association were used: strong association with either (> 95% of individuals caught in habitat by all gears); distinct association with either one (> 70% of individuals caught in habitat by all gears), and association with both (30-70% individuals caught in habitat by all gears).

Near-equal proportions of species were associated with reef, with sediment flats or with both habitat types. The reef-associated group included 19 species (22%) caught only on reef and 9 species (11%) caught mostly (>70% individuals) on reef. Sediment-flat dwellers were 9 species (11%) caught only in sediment flat habitats and 20 species (23%) caught mostly on sediment flats. The remaining 29 species (34%) were caught in relatively large proportions (30-70%) in both habitat types by one or more gears. Most determinations were made with a high or medium degree of confidence indicating good agreement in the catches of different gears and sufficiently large catch sizes.

Commercial species occurred in each of the five groups of habitat association. Striped trumpeter was strongly associated with reef, while snapper showed a distinct reef association. School whiting were strongly associated with sediment flat habitats and there was a distinct association with this habitat for John dory, silver dory, white trevally, gummy shark, tiger flathead and school shark. Seven other species (silver warehou, pink ling, ocean perch, grey morwong, morwong, redfish and blue warehou) were associated with both reefs and sediment flats.

Broad-scale fish communities

Sediment-flat fish communities on this section of continental shelf are primarily structured along depth and locational (latitudinal/ longitudinal) gradients; seven community types were delineated. Depth-related patterns were most dominant, with cross-shelf samples between the nearshore (~25 m) and outer-shelf (~200 m) showing strong and consistent similarities among inner-shelf (25 and 40 m) samples, mid-shelf (80 and 120 m) samples, with outer-shelf samples (~200 m) mostly distinct. The consistency of depth-related patterns over the study area indicated that at the community-level, sediment-flat fishes were not strongly affected by the variable width of the continental shelf, and were stable through time (therefore not greatly affected by profound changes in long-shore and cross-shelf water-mass structure) (*Section* 5).

A large number of fishes (> 200 species) live on the sediment flats of the study area, and typically many (> 90) contributed to the clinal differentiation of station groups within depth ranges. Species that were most important to defining spatial patterns were relatively abundant and broadly distributed across the study area. They included several quota species: eastern school whiting (inner-shelf) and silver trevally and morwong (outer-shelf)– most abundant in the southern region; and redfish (mid-shelf and outer-shelf) and ocean perch (outer-shelf)– most abundant in the northern region.

Locational gradients were strongly clinal in following the southwest/ northeast order of transects. Clinal patterns were very clear on the inner and mid-shelf, but less so at the six outer-shelf locations. These clinal patterns are consistent with the bioregionalisation (Lyne et al. 1997) that describes the region as a zootone (South Eastern Zootone) where there is overlap of elements of the Central Eastern, Bass Strait and Tasmanian Provinces. It also confirms those authors' report that a major faunal disjunction occurs near Cape Howe. Some seasonal changes in the distributions of individual species were noted, but these may have reflected seasonally-variable availability to demersal trawl gear or inadequate sampling density. Patterns were indistinct in species such as morwong that are reported by fishers to have complex and strong interactions with seabed habitat, time of day and depth. Intensive but infrequent scientific survey data is not adequate to resolve the complex seasonal distribution patterns of individual species.

Hard-ground fish community structure

Fish communities were used to define 'habitat types'. Seven communities were delineated from focussed habitat samples in this region of the SEF by patterns related to depth, seabed type, south coast/ east coast location and overlying water column. Community structure was described from the catches of all gears in terms of the most typical species, the species contributing the greatest dissimilarity between habitats, indicator species, and the most abundant species.

A relatively high number of species typify the 'IS' community (inner-shelf sediment flats of Disaster Bay), including the wide-ranging Port Jackson and draughtboard sharks, jack mackerel and barracouta, as well as orange-spotted catshark, southern sawshark, tiger flathead, blue mackerel and blue warehou (in gillnet catches), and snipefish, ocean perch and velvet leatherjacket (in trawl catches). Indicator species were the thresher shark, smooth hammerhead shark, short-tailed torpedo ray, Australian bonito and ringed toadfish. Numerous species discriminated this from other communities.

Fishes typical of the 'IR' community (inner-shelf, low-relief, biogenic limestone reefs at the inner and outer boundaries of Disaster Bay) included butterfly perch, grey morwong, bastard trumpeter and blue warehou, as well as the widespread Port Jackson and draughtboard sharks, jack mackerel and barracouta (caught by gillnet and trap). Three wrasses (Labridae), three perches (Serranidae), two sweeps (Scorpidae) and yellowtail kingfish, snapper, common bullseye, and banded morwong comprised a suite of twelve indicator species. Most discriminating species provided a contrast with the 'PHR' and 'PHS/GIS' habitats (granite outcrops off Point Hicks and current-swept sediments from Point Hicks to Gabo Island) (grey morwong, bastard trumpeter and blue warehou), while gummy shark, butterfly perch and bastard trumpeter contrasted the 'IS' community.

The fish community of the 'PHS/GIS' habitat (inner-shelf Point Hicks/ Gabo Island sediment flats) was highly distinctive in both the dominance by elasmobranchs and the high number of indicators. Elasmobranchs accounted for all the typical species, except for jack mackerel, and included gummy and school shark, spikey dogfish, southern sawshark, sparsely spotted stingaree, and elephant fish. The indicators, which were primarily trawl-caught, comprised four species of flathead (Platycephalidae), three rays, Australian angel shark, school shark, common stargazer and longnose flounder. Several discriminating species provided contrasts with both 'IS' and 'IR' habitats.

The 'PHR' community (inner-shelf, high-relief granite outcrops off Point Hicks) was characterised by only six species, none of which was an indicator. Four of these-- Port Jackson shark and butterfly perch (high abundance), and elephant fish and bearded rock cod (low abundance)-- were typical and good discriminators from the 'IS' habitat, while elephant fish provided discrimination from the 'IR' habitat.

The 'OS' community (outer-shelf Gabo/ Howe sediment flats) was characterised by species caught primarily by trap and trawl. Abundant and typical species included longnose skate, cucumberfish, snipefish, ocean perch, morwong, velvet leatherjacket and ocean jacket, as well as the widespread and abundant spikey dogfish and jack mackerel. Again, a suite of discriminating species contrasted this with other communities.

At 'OR' (outer-shelf Gabo/ Howe limestone reef habitat), abundant and typical fishes were orange-spotted catshark, spikey dogfish, red cod, ocean perch, eastern orange perch, jack mackerel, morwong, striped trumpeter, barracouta, and velvet leatherjacket and ocean jacket. There were discriminating species, including several that contrasted both 'OS' and 'H'. The most important were orange-spotted catshark, eastern sawshark, red cod, eastern orange perch, butterfly perch, morwong, striped trumpeter, blue warehou and velvet leatherjacket.

Many species were abundant and typical of the 'H' community (mixed substrate types at the Horseshoe Canyon neck), with the most important being spikey dogfish, cucumberfish, bearded rock cod, red cod, tiger flathead, threespine cardinalfish, jack mackerel, morwong, gemfish, barracouta, blue warehou and silver warehou. Many species contributed to the discrimination of this from other outer-shelf habitats. Eight indicator species typical of the upper slope were useful in characterising the Horseshoe.

Gillnet and trap catches indicated there were diel differences in fish community composition. Gillnet data showed differences were more pronouced on the outer than inner shelf and resulted mostly from higher abundances of certain species at night. We have restricted our analysis to day-time community patterns, in part because no night-time data were collected during the complementary broad-scale survey of soft-grounds. Data from hard-ground indicate there is a need for diel stratification in sampling, and that survey results will be gear-dependent (in contrast to abundance patterns in the gillnet data, trap catches were negliable at night).

Proportional abundance of marketable (quota and commercial) species in habitats

Fish community structure was also examined in terms of the proportional abundance of marketable (quota and commercial) species. The proportion was relatively high in habitats with limestone reefs, with blue warehou, morwong and tiger flathead most important in gillnet catches, and morwong and striped trumpeter in trap catches. Among trawl catches from the focussed habitat sampling, the proportion of marketable species was highest at the Horseshoe, where redfish and blue warehou were the main species.

Broad-scale trawl sampling showed that eastern school whiting was the most important commercially marketable species in inner-shelf habitats. Redfish, white trevally and Australian angelshark were also important on the northeast inner-shelf, where the proportion of marketable species was higher than in other inner-shelf communities. Redfish was one of the principal species in mid-shelf habitats, particularly in the northeast, where it accounted for the large difference in the proportion of marketable species between the northeast and southwest/ central mid-shelf communities. The proportion of marketable species was relatively high overall in outer-shelf soft-ground habitats, with silver warehou, morwong and redfish most important in the southern region, and redfish and ocean perch in the northern region.

Relationships of fish community structure to hydrology

The dominant features of water masses in the study area— interacting subtropical and temperate currents with often well-defined longshore, cross-shelf and vertical interfaces (*Section* 5)—show some correspondence with the primary bathymetric and clinal patterns in demersal fish communities.

Regions of correspondence between water-mass interfaces and fish community boundaries occurred across the shelf (bathymetric boundaries) between the inner- and mid-shelf (<100 m>), and at the outer-shelf (~200 m). Longshore correspondence (locational boundaries) was primarily the distinction between the south (Victorian) and east (NSW) coasts with the main overlap between Point Hicks and Green Cape. The effect of water-mass structure on community structure was related more to location on the inner-shelf and to bathymetry on the mid-shelf/ shelf-break.

The overlap of water masses and fish communities was better defined on the inner-shelf than in deeper water, where intermittent or episodic cross-shelf wedges of slope water and vertical stratification had a greater influence. However, the marked seasonality in the longshore interface of the two water masses had only subtle effects on the overall structure of inner-shelf communities. The distribution and abundance of individual species may change seasonally but, at the community level, a clinal pattern with distinct southern, central and northern groupings appears stable, despite profound changes in water masses.

Mid-shelf fish communities are more strongly influenced by cross-shelf wedges of slope water. The weak seasonal signal in community structure at the northern transects corresponded with north-south water-mass shifts. However, the clinal pattern in fish communities seems quite stable on the inner-shelf despite profound changes in water masses. Distinct emigrations of individual species were not obvious. There were seasonal signals in both community structure and hydrology at the outer shelf but limited correspondence in their patterns. Again, it appeared that while the distribution and abundance of some outer-shelf species had a seasonal component, there was not a strong community-level response to changing water mass structure.

Implications

Success of sampling program

1. The use of multiple fishing gears, with some types fished by experienced fishers from commercial vessels, successfully provided the data necessary to describe the composition and structure of fish communities in a variety of seabed habitat types.

2. Replicate, systematic biological and hydrological sampling over much of the study area successfully provided the data necessary to describe fish and invertebrate communities on soft-grounds and their relation to environmental factors. However, because the hydrology of the region is heavily influenced by boundary conditions of EAC eddies, it is highly variable at the scale of weeks (sometimes days) and between years. While intensive scientific sampling can determine the mechanisms of changes in the fish communities, it must be interpreted within the context of the extensive information generated by commercial fishers to provide an accurate picture of the region.

Invertebrate communities

1. Distinct epifaunal invertebrate communities exist on the SEF shelf seabed. They can be divided into shallow, midshelf and outershelf communities. Within those categories, communities are related to sediment characteristics, with larger forms and higher biomasses occurring in relatively poorly sorted sediments.

2. Bottom type and depth of specific macrohabitats strongly influences invertebrate community structure. The relationship is clearest at the offshore focussed habitat sites, where hard-ground habitat is associated with a high coverage of sponges and bryozoans, whereas soft-ground habitat is associated with bivalves and echinoids.

3. Stations on transect C (and D4) influenced by localised upwelling at "The Horseshoe" inshore of the main arm of Bass Canyon stand out distinctly from adjacent stations at the same depth. These stations typically have poorly sorted biogenic sediments with a high proportion of silt. Biomasses and diversity are relatively low, with the major groups– sponges, ascidians and bryozoans– poorly represented; however, some species (e.g. stalked crinoids and brachiopods) appear on one of these stations (C5) and almost nowhere else. The area's long history of high fishery productivity (catches) indicates it is a primary foraging ground for commercial fishes.

4. Fishing impacts on invertebrate communities will be highly specific to macrohabitat. Conservation of invertebrate biodiversity would need to take account of the risks of impacts by fishing in different habitats and the patchy mosaic of those habitats on the shelf. Of most concern are activities that permanently alter the structural properties of the seabed, and consequently the type of epifauna that can settle and survive there.

5. The largest biomass on northern inshore stations, and a substantial biomass on other inshore and some midshelf stations, is the introduced New Zealand screwshell *Maoricolpus roseus*. This shellfish is unavailable to most predators because of its heavy shell. As it takes up the habitat of other seabed shellfish, it reduces the availability of edible shellfish to commercial fish populations, and reduces fishery productivity of this area. Its empty shells persist long after death of the animal and provide extensive habitat for hermit crab species that can use its shell for protection. The impacts of this shellfish on the invertebrate fauna of the shelf and on the productivity of particular species could be severe. It is continuing to spread northward along Australia's east coast

Fish communities of soft-grounds (sediment flats)

1. Demersal fish communities of southeastern continental shelf sediments are highly structured by depth and location (latitude/ longitude); to a lesser extent, their boundaries are determined by seabed habitat and modified by local hydrodynamics and seasonal hydrography.

2. Seasonal changes in the distribution and abundance of individual species (often well known to experienced fishers) do not show clearly in community-level analyses of survey data because of the difficulty of timing 'seasonal' cruises, and because survey samples are not targeted at the aggregations or physical features that attract particular species. This exposes the limitations of intensive but infrequent scientific surveys to study the complex seasonal distribution patterns of individual species.

3. Our broad-scale trawl survey, in common with many that are used for fisheries assessments, sampled fish communities of sediment flat habitats without knowledge of the other seabed habitats that surround them or of the productivity regimes that affect them. Ignorance of either may result in unbalanced survey designs. In the absence of fully representative pre-survey data, valuable insights into survey design can often be provided by the fishing industry.

4. The broad-scale spatial structure of fish communities provides opportunities for spatial management of fishing effort and other anthropogenic uses. In conjunction with information on the spatial distribution of size (age) classes (*Section* 9), this could provide a basis for improving the fishery's selectivity for species groups and sizes within particular species.

Fish communities of hard-grounds (bedrocks, reefs, consolidated sediments)

1. Distinct fish communities are associated with different types of seabed on the SEF shelf, and can be used to define 'habitat types'. Individual species and species groups can be classified on their strength of association, or dependence, on different seabed types. Several key commercial species (striped trumpeter, snapper, silver warehou, pink ling, ocean perch, grey morwong, morwong, redfish and blue warehou) have an association with 'hard-ground', although the strength of association (based on relative abundance) varies between species.

2. Fish community structure, including the proportional abundance of commercial species, is related to particular physical features of the seabed and overlying water column (habitats). In this region of the SEF, communities and habitats form a patchy mosaic but show strong patterns related to depth, seabed type and location (south or east coast). The spatial extent of communities and habitats can be mapped by spatially extrapolating the corresponding physical features (*Section* 7). A similar method may be used to extend the results of this study to broader areas of the temperate Australian shelf.

3. The habitats used by fish communities often exist at fine spatial scales (hundreds of metres to kilometres) (*Section* 7), and the way in which they are used may be species-specific (refuges, spawning areas, aggregation sites for benthopelagic species). Thus, techniques for rapidly assessing habitat or community distributions that sample at coarse scales (tens to hundreds of km) may not be sufficient for defining the boundaries of ecologically significant areas. Fine-scale sampling will be necessary in future studies of temperate fishery ecosystems, as that is the scale at which important ecological and fishing processes operate.

4. 'Hard-ground' habitats are used by important commercial fishes, but make up less than 11% of our study area, and some are vulnerable to physical damage, including damage by fishing activity. Some hard-ground habitats are being 'opened-up' (*Sections* 7 and 11). This will, in some instances, reduce their value in supporting or aggregating fish species with the result that fishery catches will decline. Management strategies that effectively conserve significant areas of importance to commercial fish species while minimising the loss of access to fishing grounds need to be developed.

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9 FISH BIOLOGY (LENGTH AND AGE)

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We have delineated fish and invertebrate comminutes and used the structure and properties of water column processes and seabed types to develop a description of biological habitat. We now examine the distributions of fish lengths and age groups over the same habitats. The aim of this section is to find out whether there is ontogenetic variation in habitat use and whether this provides an opportunity for improving selectivity of the fishery or management processes. As otoliths were used for building age/ length keys and for identifying prey in the diets of piscivores, we present those data here as well.

9.1 METHODS

Size and age compositions were examined in relation to depth using the broad-scale trawl samples. Size composition only was examined in relation to habitat type for each of three gear types (gillnet, trap and trawl). In addition, mesh selectivity was assessed for the six different mesh sizes used in the gillnets.

9.1.1 Fish Sampling

Fish from all successfully completed trawls, gillnets and trap shots were sorted to species and total counts and weights recorded. Lengths were measured for up to 100 fish per sample. Biological data (including length, weight and sex) and samples (including stomach, otolith and muscle) were collected from up to ten fish/ species/ trawl for SEF quota species and other potentially important prey and predator species (Table 9.1.1.1).

Where the catch was too large for complete enumeration, it was sub-sampled before sorting, noting the weight of fish retained and the weight of fish discarded, to determine the proportion of the catch processed. The subsampled portion of the catch was then processed as for a standard catch. Where rare species occurred, all were retained from the total catch, and recorded as such on the catch composition sheets.

All trawl catches were converted to total numbers/standardised trawl (standardised to 30 minutes duration by 3 knots tow speed), accounting for subsampling to allow direct comparison between tows. Gillnet and trap catches were standardised for sampling duration (10 hour soak of the gillnet fleet or set of 5 traps).

9.1.2 Length Frequency Sampling

Fish lengths were measured from the tip of the snout to the tip of the medial caudal-fin ray, with the caudal fin in its natural position, and recorded as Fork Length (FL). The exceptions were blue grenadier (*Macroronus novaezelandiae*) which was measured to the tip of the last caudal vertebra and recorded as Standard Length (SL), and whiptails (Macrouridae) which were measured as Total Length (TL). Shark and ray species were measured from the tip of the snout to the upper caudal-fin lobe, with the caudal-fin in an extended position, and also recorded as Total Length. The caudal filament of Chimaeras was not included in the TL.

With the exception of lengths obtained from biological samples, length measures were made using an electronic length measuring board with a 1mm resolution, developed by CSIRO. The system comprised a linear distance transducer together with an analogue-to-digital converter which allowed fish measures to be stored and, if required, edited electronically. Although portable, the system was linked through a specialist program for Southern Surveyor use, which allowed data to be downloaded at sea to the Oracle database in a form appropriate for our data manipulation.

For each species with more than five (5) representatives within a trawl, length frequencies for a maximum of one hundred fish (or 200 fish where the distribution was obviously multimodal) were recorded as FL or SL as specified. Length frequencies were standardised with regard to the total catch in trawls, as not all individuals of each species were measured. This was unnecessary for gillnet and trap catches in which all individuals were measured.

Standardised length data were analysed to examine the size (length) of fish in relation to depth, habitat type and gear type. Depth-related patterns in body size could then be considered in relation to the broad-scale sampling data (*Section* 4.1.1) and the focused habitat sampling data (*Section* 4.1.2).

Two subsets of the focused-habitat length dataset were examined:

1) Standardised length frequencies for species and assemblages from targeted trawl, trap and gillnet sampling in mesohabitats were examined for the relationship between fish size and habitat attributes, and to compare size compositions taken with different gears.

2) Standardised length frequencies from gillnet catches were examined to determine the importance of mesh selectivity.

A computer program ("VeryFishy") was developed to plot length data by species and other selected variables.

9.1.3 Otolith Sampling and Age Determination

Reference otoliths (sagittae only), used to identify fish species from partly digested remains, were collected from 67 fish species (Table 9.1.1.1). Samples were stored in numbered envelopes with biological details supplied for each. Otoliths were cleaned, stub-mounted and platinum spatter-coated in preparation for SEM viewing. SEM images were stored digitally using PowerPoint and Photoshop software.

Otolith samples for ageing were retained from target species (Table 9.1.1.1) and from fish used for stomach samples. For elasmobranchs, a section of vertebrae was retained for ageing. For several species where otoliths proved unreadable for age determination, the spines were sampled. Otoliths were stored as for reference otoliths; vertebrae and spines were frozen. Otoliths (789 pairs from 67 species), dorsal spines (44 from 2 species) and vertebrae (168 from 20 species) were sent to the Central Ageing Facility of MAFRI, Victoria (CAF), for estimation of age.

At the CAF laboratory, unbroken otoliths were weighed to the nearest milligram prior to further examination. Age estimations were attained from whole, ground or sectioned otoliths,

Table 9.1.1.1 Summary of fish species, measures and samples collected during the SEF Ecosystem study.

Family	Species	Common name	Code	No. Fish Measured	Min. Length(mm) Measured	Max. Length(mm) Measured	Min. Weight(gm) Measured	Max. Weight(gm) Measured	No. of Gonads Measured	Reference Otolith Collected	Max. Age (yrs)	Max. Aged Fish Length(mm)	No. of Stomachs Sampled	No. of Isotopes Sampled
Hexanchidae	*Notorynchus cepedianus*	Tasmanian Tiger Shark	5002											
Heterodontida	*Heterodontus portusjacksc*	Port Jackson Shark	7001	177	299	1250	750	2030			6	646	14	6
Lamnidae	*Isurus oxyrinchus*	Shortfin Mako Shark	10001	4	780	1042								3
Alopiidae	*Alopias vulpinus*	Common Thresher Shark	12001	4	240	2910							1	2
Parascyllidae	*Parascyllium ferrugineum*	Rusty Carpetshark	13005	29	660	905					8	760	2	2
Scyliorhinidae	*Cephaloscyllum laticeps*	Draughtboard Shark	15001	1949	192	1019	125	5520			8	930	104	30
	Galeus boardman	Sawtail Shark	15009	65	245	560								
	Cephaloscyllium sp A	Whitefin Swellshark	15013	2	1020	1030								
	Apristurus sp F	Spadenose Catshark	15019	6	475	510								
	Asymbolus sp. D	Orange-spotted Catsha	15024	758	153	630	27	162					9	
	Asymbolus sp E	Pale Spotted Catshark	15025	21	400	450								
	Asymbolus analis	Grey-spotted Catshark	15027	488	183	600					NR		2	7
Triakidae	*Mustelus antarcticus*	Gummy Shark	17001	297	119	1390	387	1030			5	1022	17	14
	Galeorhinus galeus	School Shark	17008	18	408	864	300	410			2	925	12	13
	Mustelus spp	**???**	17901	7	470	710								
Carcharhinida	*Carcharhinus brachyurus*	Bronze Whaler	18001	1	2350	2350								1
Sphyrnidae	*Sphyrna zygaena*	Smooth Hammerhead	19004	2	580	1540								1
Squalidae	*Squalus megalops*	Spikey Dogfish	20006	5692	200	1108	50	1575			30	446	190	6
Pristiophoridae	*Pristiophorus nudipinnis*	Southern Sawshark	23001	45	590	1170								
	Pristiophorus cirratus	Common Sawshark	23002	58	530	1320								
	Pristiophorus sp. A	Eastern Sawshark	23003	13	595	1150								
	???	**???**	23200	38	18	107	1	21						
Squatinidae	*Squatina australis*	Australian Angel Shark	24001	126	278	1100	790	12800			NR		47	5
	Squatina tergocellata	Ornate Angelshark	24002										1	
	Squatina sp. A	Eastern Angel shark	24004	21	472	1040	900	10770			24	104	6	3
Rhinobatidae	*Trygonorhina fasciata*	Southern fiddler ray	27002	16	655	1100	2000	10000			22	1077	9	
	Trygonorhina sp. A	Eastern fiddler ray	27006	17	102	1040	330	7000					6	9
Torpedinidae	*Hypnos monopterygium*	Coffin ray (Aust. Numbfis	28001	141	73	513								
	Narcine tasmaniensis	Tasmanian Numbfish	28002	238	205	431	133	493			NR		37	15
Rajidae .	*Raja australis*	Sydney Skate	31002	20	255	578	119	868					7	
	Raja sp.A	Longnose Skate	31005	443	185	850	200	1812					63	6
	Raja whitleyi	Melbourne Skate	31006	8	423	798								
	Pavoraja nitida	Peacock Skate	31009	48	255	377								
Dasyatididae	*Dasyatis brevicaudata*	Smooth Stingray	35001	3	1060	1250		18300			10	1250	1	1
Urolophidae	*Urolophus bucculentus*	Sandyback Stingaree	38001	134	210	816	1110	7400			14	816	5	
	Urolophus cruciatus	Banded Stingaree	38002	1085	163	410	50	804			8	357	132	13
	Urolophus gigas	Spotted Stingaree	38003	6	283	333								
	Urolophus paucimaculat	Sparsely-spotted Stingar	38004	3543	110	503	70	800			11	442	154	23
	Urolophus sufflavus	Yellowback Stingaree	38005	1	257	257								
	Trygonoptera testace	Common Stingaree	38006	16	228	618								
	Urolophus viridis	Green-back Stingaree	38007	1401	151	738	44	1200			8	330	120	11
	Trygonoptera sp.B	Eastern Shovelnose Sting	38014	37	225	720								
	Trygonoptera mucos	Western Stingaree	38015	5	440	643								
	Urolophus sp A	Kapala Stingaree	38018	133	183	565	279	662					7	
	Urolophus sp B	Coral Sea Stingaree	38019	10	270	590					8	437		
Myliobatidae	*Myliobatis australis*	Southern Eagle Ray	39001	51	197	808	439	8000			12	775	8	
Chimaeridae	*Hydrolagus ogilbyi*	Ogilby's Ghost Shark	42001	13	495	760								
	Hydrolagus lemures	Bight Ghostshark	42003	7	890	1100								
Callorhynchida	*Callorhinchus milli*	Elephantfish	43001	28	482	957	848	2756			NR		12	2
Muraenidae	*Gymnothorax prasinus*	Green Moray	60006	6	83	840								4
Congridae	*Conger verreaux*	Southern Conger Eel	67007	12	970	1360								6

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	Bassanago bulbiceps	Swollenhead Conger	67012	58	290	533		134						
Ophichthidae	*Muraenichthys sp.*	Worm Eels (4 fish)	68000											3
	Ophisurus serpens	Giant Snake Eel	68001	2	1060	2040								
Clupeidae	*Sardinops neopilchardus*	Pilchard	85002											10*
Argentinidae	*Argentina australiae*	Silverside	97001	2	100	100	7	7					1	
Sternoptychido	*Maurolicus muelleri*	Pennant Lightfish	107002											5
Aulopodidae	*Aulopus purpurissatus*	Sergeant Baker	117001	10	228	470								
Chlorophthalm	*Chlorophthalmus nigripinn*	Cucumberfish	120001	10116	85	1921	10	173		*	10	246	242	18
Neoscopelidae	*Neoscopelus macrolepidc*	Largescaled Lanternfish	121001	127	168	413								
Myctophidae	*Lampanyctodes hectoris*	Hectors’ Lanternfish	122002											10*
	Symbolophorus barnardi	Bullseye Lanternfish	122007											5
	Gymnoscopelus piabilis		122018											1
Antennariidae	*Echinophryne reynoldsi*	Sponge Anglerfish	210023	1	110	110								
Moridae	*Mora moro*	Deepsea Cod	224002	3	418	590								
	Pseudophycis barbata	Bearded Rock Cod	224003	164	31	660							3	
	Lotella rhacinus	Largetooth Beardie	224005	26	27	414								6
	Pseudophycis bachus	Red Cod	224006	296	100	604	177	508		*	21	490	10	9
Merlucciidae	*Macruronus novaezelandi*	Blue Grenadier	227001	93	368	970								
Ophidiidae	*Genypterus blacodes*	Pink Ling	228002	700	103	1180	124	7400		*	12	1060	111	18
	Ophidion muraenolepis	Black-edged Cusk-eel	228006	1	260	260								
Macrouridae	*Caelorinchus australis*	Southern Whiptail	232001	160	100	585	64	574		*	6	483	24	5
	Caelorinchus fasciatus	Banded Whiptail	232002	103	118	790	30	460					36	
	Caelorinchus mirus	Gargoyle Fish	232003	558	45	544	1	116	7		6	294	58	5
	Lepidorhynchus denticula	Toothed Whiptail	232004	1670	43	563				*				
	Malacocephalus laevis	Smooth Whiptail	232007	12	310	700								
	Caelorinchus maurofasciatus		232045	740	38	430		480		*			159	
	Caelorinchus parvifasciatus		232047	283	120	280	17	75					13	
	Ventrifossa nigrodorsalis		232074	14	173	293								
Atherinidae	*Leptatherina presbyteroid*	Silverfish	246002	2	140	180								
Trachichthyida	*Hoplostethus intermedius*		255001	43	28	120								
	Paratrachichthys sp 1	Sandpaperfish	255003	141	138	273	76	425			21	210	19	
	Optivus sp 1		255007	74	75	135							1	
Berycidae	*Beryx decadactylus*	Imperador	258001	22	270	390								
	Beryx splendens	Alfonsino	258002	1										
	Centroberyx affinis	Redfish (Nannygai)	258003	10014	48	413	15	970		*	37	302	485	68
	Centroberyx gerrardi	Red Snapper	258004	1	94		27			*				
	Centroberyx lineatus	Swallowtail	258005	9	230	312								
	Centroberyx australis	Yelloweye Redfish	258006	3	265	285	475	620						
Zeidae	*Cyttus traversi*	King Dory	264001	95	103	558								
	Cyttus australis	Silver Dory	264002	2250	75	500	17	780	2	*	4	372	149	43
	Zenopsis nebulosus	Mirror Dory	264003	350	203	646				*	4	366	59	3
	Zeus faber	John Dory	264004	707	98	505	18	2954	6	*	11	450	209	40
	Cyttus novaezelandiae	New Zealand Dory	264005	1400	99	313	24	145		*	5	197	40	5
Oreosomatida	*Neocyttus rhomboidalis*	Spiky Dory	266001	230	175	393								
Fistulariidae	*Fistularia petimba*	Rough Flutemouth	278002											
Macroramphos	*Centriscops humerosus*	Banded bellowsfish	279001	776	146	260	30	123					250	
	Macrorhamphosus scolop	Snipefish	279002	7988	55	173		35	8	*	NR		268	19
	Notopogon sp.		279004	10	165	203	40	90						
Synbranchidae	*Ophisternon candidum*		285003	2	135	141								
Scorpaenidae	*Helicolenus percoides*	Ocean perch	287001	7405	49	740	3	2100	5	*	22	294	848	58
	Neosebastes nigropuncta	Blackspotted Gurnard P	287002	26	113	375								
	Neosebastes pandus	Gurnard Perch	287003											
	Neosebastes scorpaenoid	Ruddy Gurnard Perch	287005	666	141	388	68	820			27	375	30	5
	Neosebastes thetidis	Thetis Fish	287006	71	178	426								

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	Scorpaena papillosa	Red Rock Cod	287008	2028	60	607							11	
	Neosebastes incisipinnis		287019	12	88	178								
	Maxillicosta whitleyi	Whitleys Scorpionfish	287045	70	45	95								
	Centropogon australis	Eastern Fortesque	287048	18	80	110								
	Scorpaena cardinalis	Cardinal Scorpionfish	287066	13	213	398								
	Helicolenus barathri	Deep Ocean Perch	287093	369	51	494	2	835		*	20	346	63	
Triglidae	*Chelidonichthys kumu*	Red Gurnard	288001	156	210	480	277	1520		*	11	441	25	
	Lepidotrigla vanessa	Butterfly Gurnard	288003	348	48	320	63	418		*	14	270	20	
	Pterygotrigla andertoni	Spotted Gurnard	288005	14	134	238								
	Pterygotrigla polyommata	Latchet	288006	119	220	465	340	1571		*	16	440	22	
	Lepidotrigla modesta	Grooved Gurnard	288007	4328	78	240	25	153		*	13	200	154	29
	Lepidotrigla mulhalli	Round-snouted Gurnard	288008	5910	64	616	19	96		*	10	187	192	11
	Pterygotrigla hemisticta	Half-spotted Gurnard	288009	10	218	305								
	Lepidotrigla argus	Long-finned Gurnard	288010	98	100	190								
	Lepidotrigla grandis	Supreme Gurnard	288020	145	95	323								
	Satyrichthys lingi	Crocodilefish	288030	30	190	295								
Platycephalida	*Neoplatycephalus richard*	Tiger Flathead	296001	3342	105	779	25	1708	1	*	15	605	404	58
	Platycephalus bassensis	Sand Flathead	296003	159	178	528	85	1420		*	13	518	43	23
	Platycephalus caeruleopu	Blue-spotted Flathead	296007	4	303	425								
	Neoplatycephalus aurima	Toothy Flathead	296035	11	335	540	300	1180		*			5	4
	Platycephalus longispinis	Long-spined Flathead	296036	289	155	455							15	
	Platycephalus speculator	Southern Flathead	296037	5	400	515								
Hoplichthydae	*Hoplichthys haswelli*	Deepsea Flathead	297001	162	195	451	48	335		*	9	366	20	
Serranidae	*Lepidoperca pulchella*	Eastern Orange Perch	311001	698	74	280	408	526		*	15	205	25	13
	Caesioperca lepidoptera	Butterfly Perch	311002	1459	74	290	21	330		*	29	261	65	19
	Caesioperca rasor	Barber Perch	311003	608	73	283	99	268		*	18	238	18	8
	Polyprion oxygeneios	Hapuku	311006	6	582	660		3350		*			1	
	Hypoplectrodes maccullo	Halfbanded Seaperch	311036	2	145	154								2
	Apogonops anomalus	Threespine Cardinalfish	311053	5983	40	168	5	200		*	NR		115	25
Callanthiidae	*Callanthias australis*	Splendid Perch	311055	10	145	273	47	300			13	268	3	
	Hypoplectrodes annulata	Blackbanded Seaperch	311091	5	201	210	212	222		*	32	201	3	3
Apogonidae	*Epigonus lenimen*	Bigeyed Cardinalfish	327001	713	145	225								
	Dinolestes lewini	Longfin Pike	327002	89	280	443				*	15	436	10	10
	Epigonus denticulatus	White Cardinalfish	327010	67	80	173								
Sillaginidae	*Sillago schomburgkii*	Yellowfin Whiting	330012	181	155	208								
	Sillago flindersi	Eastern School Whiting	330014	3983	75	302	9	191		*	6	239	222	28
Carangidae	*Trachurus declivis*	Jack Mackerel	337002	14447	50	943	6	1280		*	16	392	594	52
	Trachurus novaezelandiae	Yellowtail Horse Macker	337003	814	60	341	50	115			3	202	21	
	Seriola lalandi	Yellowtail Kingfish	337006	1	570	570								
	Pseudocaranx dentex	White Trevally	337062	609	64	980	121	1980		*	15	476	72	21
	Trachurus murphyi	Peruvian Mackerel	337077	18	470	565								
Emmelichthyid	*Emmelichthis nitidus nitidus*	Redbait	345001	1248	143	335	38	356		*	10	282	89	25
Gerreidae	*Parequula melbournensis*	Silverbelly	349001	1434	60	200	20	29		*			10	
Sparidae	*Pagrus auratus*	Snapper	353001	138	140	560	87	341		*	3	247	17	5
Mullidae	*Upeneichthys lineatus*	Goatfish	355001	26	117	268								
	Upeneichthys vlamingii	Red Mullet	355029	488	92	560							10	
Pempherididae	*Pempheris multiradiata*	Common Bullseye	357001	295	60	193	35	100		*	19	169	26	10
	Parapriacanthus elongatu	Slender Bullseye	357002	100	100	145								
Scorpididae	*Scorpis lineolatus*	Silver Sweep	361009	17	177	240	137	287		*	12	227	8	8
	Atypichthys strigatus	Mado	361010	137	118	200	51	133		*	18	184	31	9
Pentacerotidae	*Paristiopterus labiosus*	Giant Boarfish	367002	3	286	385								
	Pentaceropsis recurvirostris	Boarfish	367003	64	181	474								
	Zanclistius elevatus	Long-finned Boarfish	367005	16	118	366								
Pomacentridae	*Parma microlepis*	White Ear	372005	9	131	160	100	130		*	47	143	5	5

Family	Species	Common name	Code	No. Fish Measured	Min. Length(mm) Measured	Max. Length(mm) Measured	Min. Weight(gm) Measured	Max. Weight(gm) Measured	No. of Gonads Measured	Reference Otolith Collected	Max. Age (yrs)	Max. Aged Fish Length(mm)	No. of Stomachs Sampled	No. of Isotopes Sampled
Cheilodactylid	*Nemadactylus douglasi*	Grey Morwong	377002	1445	35	545	29	1574		*	18	415	22	7
	Nemadactylus macropter	Morwong	377003	3841	66	487	46	1778	8	*	28	416	548	43
	Cheilodactylus spectabilis	Brown Banded Morwong	377006	4	297	435								
Latridiidae	*Latris lineata*	Striped Trumpeter	378001	109	394	833	6570	9230		*	26	810	22	19
	Latridopsis forsteri	Bastard Trumpeter	378002	76	396	573		2102	1	*	14	468	15	10
Cepolidae	*Cepola australis*	Bandfish	380001											1
Labridae	*Bodianus vulpinus*	Wrasse	384001	1	290	290								
	Notolabrus tetricus	Bluethroat Wrasse	384003	13	288	470	437	2057		*	15	458	9	12
	Pseudolabrus psittaculus	Rosy Wrasse	384023	51	126	242	123	255		*	15	240	14	10
	Bodianus sp	Eastern Foxfish	384035	11	202	388								
	Ophthalmolepis lineolatus	Maori Wrasse	384040	32	271	350	229	512		*	16	339	13	13
	Achoerodus viridis	Eastern Blue Groper	384043	3	274	617								
	Bodianus unimaculatus	Eastern Blackspot Pigfish	384061	1	320	320								
	Bodianus sp	Pigfish	384062	10	281	373								
Pinguipedidae	*Parapercis allporti*	Barred Grubfish	390001	131	89	255	6						1	
Uranoscopidae	*Gnathagnus innotabilis*	Bulldog Stargazer	400001	3	308	343								
	Ichthyscopus barbatus	Fringed Stargazer	400002							*				1
	Kathetostoma laeve	Common Stargazer	400003	31	172	600	144	7920		*	35	610	16	5
	Kathetostoma canaster	Speckled Stargazer	400018	68	173	680	283	7270	2	*	11	580	23	6
Callionymidae	*Synchiropus calauropomu*	Common Stinkfish	427001	4035	52	550		180		*	10	280	142	28
Gempylidae	*Thyrsites atun*	Barracouta	439001	1858	193	1097	130	3400		*	5	980	204	36
	Rexea solandri	Gemfish	439002	280	297	840	337	3750		*	9	810	12	9
Trichiuridae	*Lepidopus caudatus*	Ribbonfish	440002	117	59	1380				*			12	
	Trichiurus lepturus	Largehead Hairtail	440004	79	110	268								
Scombridae	*Scomber australasicus*	Blue Mackerel	441001	536	160	870	44	700		*	9	373	59	10
	Gasterochisma melampus	Butterfly Mackerel	441019											10*
	Sarda australis	Australian Bonito	441020	2	490	491								
Centrolophidae	*Hyperoglyphe antarctica*	Deep Sea Trevalla	445001	2	553	693								
	Seriolella brama	Blue Warehou	445005	1298	41	590	94	3210	15	*	5	500	130	28
	Seriolella punctata	Silver Warehou	445006	2125	110	580	89	2370		*	9	520	462	40
	Seriolella caerulea	White Trevalla	445011	5	308	663								
Bothidae	*Lophonectes gallus*	Crested Flounder	460001	13	68	105								2
	Pseudorhombus jenynsii	Smalltooth Flounder	460002	5	190	220								
Pleuronectidae	*Azygopus pinnifasciatus*	Banded-fin Flounder	461002	30	83	130	4	23					20	
Monacanthida	*Eubalichthys mosaicum*	Mosaic Leatherjacket	465003	145	97	478								
	Meuschenia scaber	Velvet Leatherjacket	465005	6694	43	300	44	395		*	NR		87	10
	Nelusetta ayraudi	Ocean Jacket	465006	52	249	396								
	Paramonocanthus filicauc	Leatherjacket	465024							*	35 Day	142	10	
	Meuschenia freycineti	Sixspine Leatherjacket	465036	243	170	448	101	1420	2	*	12	421	72	8
	Thamnoconus degeni	Degens Leatherjacket	465037	1211	19	306								
			465801	10	97	129	17	25						
Aracanidae	*Anoplocapros inermis*	Eastern Smooth Boxfish	466002	105	113	263				*				
Tetraodontidae	*Contusus richei*	Barred Toadfish	467001	59	119	261								
	Arothron firmamentum	Starry Toadfish	467005	65	287	408	654	1147			NR		11	
Diodontidae	*Diodon nichthemerus*	Globefish	469001	9917	90	905	100	1600	1	*	15	260	114	12
	Allomycterus pilatus	Deepwater Burrfish	469002	382	163	354	310	1337	1				24	

NR = ageing sample not readable.

determined by prior experience with the species, and morphology of the sagittae. Depending on preparation type, otoliths were viewed using a dissecting microscope with reflected light, or a compound scope under transmitted light. Magnification varied with the size of the otolith. Age estimations were gained by repeated counts of incremental structures along a transect from primordia to edge of otolith proximal surface. Age estimates are unverified, but based on the assumption that the identified incremental structures are laid down annually. Full details of methodologies are included in the CAF Reports 1, 2 and 3.

Age estimations from spines and vertebrae were also gained, but later determined to be of lesser importance. Specific methodologies and results are tabled in the CAF reports.

9.2 RESULTS AND DISCUSSION

9.2.1 Spatial distribution of size groups

The lengths of >200 fish species were collected during the study; measures, including minimum and maximum lengths, are summarised in Table 9.1.1.1.

Broad-scale samples (size distribution by depth)

Broad-scale length-frequency data was analysed to determine intra-specific patterns of size distribution by the five depths (25 m, 40 m, 80 m, 120 m and ~200 m) sampled. Fifty species— those with >200 sampled fish as well as quota species— were used for this analysis (Table 9.2.1.1). Four distinct depth-related patterns were present in 27 species, while 23 species showed no discernible distribution patterns. Length-depth plots, using standardised sample numbers, are provided for a sub-set of the species with depth-related patterns: quota species and species representing the primary pattern types (Figs. 9.2.1.1—9.2.1.15).

The four patterns were classified by the following definitions:

- bigger-deeper (B/D)— a progressive increase in size with increasing depth: 16 species;
- smaller-shallower (S/S)— a smaller size range in shallower depths with little variation in large size ranges across depths: 3 species;
- bigger-shallower (B/S)— largest size range in shallower depths with little variation in other size ranges across depths: 1 species;
- restricted range (RR)— narrow depth range or with near-shore (<25 m) or upper-slope (>200 m) centres of distribution: 7 species.

All 12 quota species showed depth-related distribution patterns; a distinct bigger-deeper distribution pattern was shown in nine species (*Centroberyx affinis*, *Genypterus blacodes*, *Helicolenus percoides*, *Nemadactylus macropterus*, *Neoplatycephalus richardsoni*, *Pseudocaranx dentex*, *Seriolella brama*, *S. punctata* and *Zeus faber*), smaller-shallower in one species (*Sillago flindersi*), and a restricted range with distribution largely restricted to 200 m depth in two species (*Rexea solandri* and *Zenopsis nebulosus*). Other important (abundant or commercial) species with distinct bigger-deeper distribution patterns included *Nemadactylus douglasi*, *Squalus megalops* and *Trachurus declivis*.

Focused habitat (size distribution by habitat type by gear)

Focused habitat length-frequency data from three gear types (*Section* 4.1.2) were analysed in relation to habitat type and depth from three gear types. Habitats, component macro-habitats and corresponding depth ranges are given in Table 9.2.1.2. Results of the fish assemblage analysis (*Section* 8.2.4) provided the habitat divisions used in grouping length-frequency data for further analysis. This analysis was restricted to thirty-four species (species with >200 sampled fish and quota species) (Table 9.2.1.3) and was compared to the results from the broad-scale analyses. Intra-specific differences in catch selectivity, between gear types, was also considered.

A species by species account follows for the twelve quota species, and for a further eleven important species. Length-frequency plots of standardised sample numbers, by habitat type and gear type, are attached for each of these 23 species (Appendix Figures 9.2.1.1—9.2.1.23).

Redfish (*Centroberyx affinis*) were caught by gillnet and trawl only, although gillnet sample sizes were comparatively small (n=8 to 87). The size structure of catches by each gear were similar in corresponding habitats. Gillnet catches showed that redfish occurred on both rough and soft ground both as juveniles and adults. The bigger/deeper distribution-pattern of the broad-scale sampling was also evident in focused-habitat catches, with the smallest fish occurring at IS and GI/PHS (45 and 110 mm respectively), and the largest fish (340 mm) at HO. Within gears, size structure and catch were comparable between habitats in similar depths.

Pink ling (*Genypterus blacodes*) were caught by all gear types, although trap catches were low (n=4). Gillnet sampling showed that pink ling catches sizes were comparable on both soft and rough- ground (IR-OR and IS-OS). A relatively large number of fish (n=21) were caught in the single BRR gillnet sample. The bigger/deeper distribution-pattern of the broad-scale analysis was also evident in focused-habitat catches, but less defined, with small fish (<390 mm) occurring on soft-grounds over a greater depth range. The smallest fish (280—350 mm) were caught by trawl (with greatest numbers at OS) and the largest fish by gillnet (940 mm at HO).

Ocean perch (*Helicolenus percoides*) were susceptible to all gear types, but highly susceptible to trawl. Gillnet and trap caught mid size-range fish (130—250 mm), while the smallest and largest ocean perch (70 and 340 mm respectively) were caught by trawl. Gillnet catches on rough-ground were comparatively larger than on soft-ground, particularly at OR (mid-size to larger fish), while trawl numbers were comparatively higher at IS. The bigger/deeper pattern of the broad-scale data was evident, although not as well defined in gillnet samples. In gillnets, the smallest fish caught at the shallow habitats of BRR and IR were larger than trawled fish at corresponding depths.

Morwong (*Nemadactylus macropterus*) were caught by all gears at all sizes. Although size separation between gears was not marked, gillnet took relatively more small fish than trap at OR, and broad-scale trawl samples caught the smallest individuals. morwong occurred at habitats IS, IR, OS, OR, and HO, but not PHR, GI/PHS, or BRR (though BRR was only lightly sampled). The bigger/deeper pattern in broad-scale data was not found when

Table 9.2.1.1 Species list for broad-scale size-distribution analysis, ordered by raw-data fish numbers.

(B/D = Bigger/deeper, S/S = Smaller/shallower, B/S = Bigger/shallower, R/R = Restricted range, / = No pattern)

Species List from Broadscale Sampling (*quota species)			Broadscale fish numbers		Dist'n Pattern Type				
Species name	Species code	Common name	Raw data	Standardised	B/D	S/S	B/S	RR	/
**Genypterus blacodes*	37228002	Pink ling	123	179.09	x				
Platycephalus longispinis	37296036	Long-spined flathead	208	218.17					x
Lepidoperca pulchella	37311001	Eastern orange perch	217	425.90					x
**Zenopsis nebulosus*	37264003	Mirror dory	226	375.85				x	
**Rexea solandri*	37439002	Gemfish	261	527.86				x	
Pempheris multiradiatus	37357001	Common bullseye	262	427.28					x
Lepidotrigla vanessa	37288003	Butterfly gurnard	267	281.13				x	
Scomber australasicus	37441001	Blue mackerel	268	360.65					x
Allomycterus pilatus	37469002	Australian burrfish	302	441.36	x				
Helicolenus barathri	37287093	Deep Ocean perch	310	368.94					x
Raja sp A	37031005	Longnose skate	338	393.08			x		
**Zeus faber*	37264004	John dory	387	500.77	x				
Asymbolus analis	37015027	Grey spotted catshark	392	508.36					x
Caelorinchus mirus	37232003	Gargoylefish	408	1103.57					x
Asymbolus sp D	37015024	Orange-spotted catshark	425	459.27					x
Upeneichthys vlamingii	37355029	Red mullet	471	1178.82				x	
Caesioperca rasor	37311003	Barber perch	473	2002.19	x				
**Pseudocaranx dentex*	37337062	White trevally	514	739.69	x				
Caesioperca lepidoptera	37311002	Butterfly perch	530	1656.73					x
Neosebastes scorpaenoides	37287005	Ruddy gurnard perch	573	756.01					x
**Seriolella brama*	37445005	Blue Warehou	576	1118.78	x				
Emmelichthys nitidus nitidus	37345001	Redbait	623	4667.04					x
Trachurus novaezelandiae	37337003	Yellowtail scad	733	1720.26					x
Urolophus cruciatus	37038002	Banded stingaree	783	1188.06					x
Cyttus novaezelandiae	37264005	New Zealand dory	790	1056.29				x	
Nemadactylus douglasi	37377002	Grey morwong	808	1451.11	x				
Diodon nicthemerus	37469001	Globefish	844	1450.23					x
Cephaloscyllium laticeps	37015001	Draughtboard shark	892	1120.18					x
Thamnaconus degeni	37465037	Degens leatherjacket	996	4700.30				x	
Urolophus viridis	37038007	Greenback stingaree	1018	1811.16					x
**Seriolella punctata*	37445006	Silver warehou	1021	2284.82	x				
Scorpaena papillosa	37287008	Red rock cod	1210	4367.18					x
Thyrsites atun	37439001	Barracouta	1231	17926.20	x				
Parequula melbournensis	37349001	Silverbelly	1333	5562.98					x
Cyttus australis	37264002	Silver dory	1523	2566.00					x
**Nemadactylus macropterus*	37377003	Morwong	1549	3632.15	x				
**Neoplatycephalus richardsoni*	37296001	Tiger flathead	2322	3002.10	x				
Squalus megalops	37020006	Spikey dogfish	2352	4793.04	x				
Synchiropus calauropomus	37427001	Common stinkfish	3070	8054.18					x
Lepidotrigla modesta	37288007	Minor gurnard	3106	5505.11					x
Urolophus paucimaculatus	37038004	Sparsely-spotted stingaree	3244	5087.01		x			
**Helicolenus percoides*	37287001	Ocean perch	3315	6351.82	x				
**Sillago flindersi*	37330014	Eastern school whiting	3377	36435.61		x			
Apogonops anomalus	37311053	Threespine cardinalfish	3708	190630.92				x	
Meuschenia scaber	37465005	Velvet leatherjacket	4381	12005.77	x				
Lepidotrigla mulhalli	37288008	Deepwater gurnard	4418	11718.78		x			
Macroramphosus scolopax	37279002	Snipefish	4732	28289.82					x
Chlorophthalmus nigripinnis	37120001	Cucumberfish	6480	26863.11					x
**Centroberyx affinis*	37258003	Redfish	7468	85148.66	x				
Trachurus declivis	37337002	Jack mackerel	9389	111498.54	x				

Figure 9.2.1.1

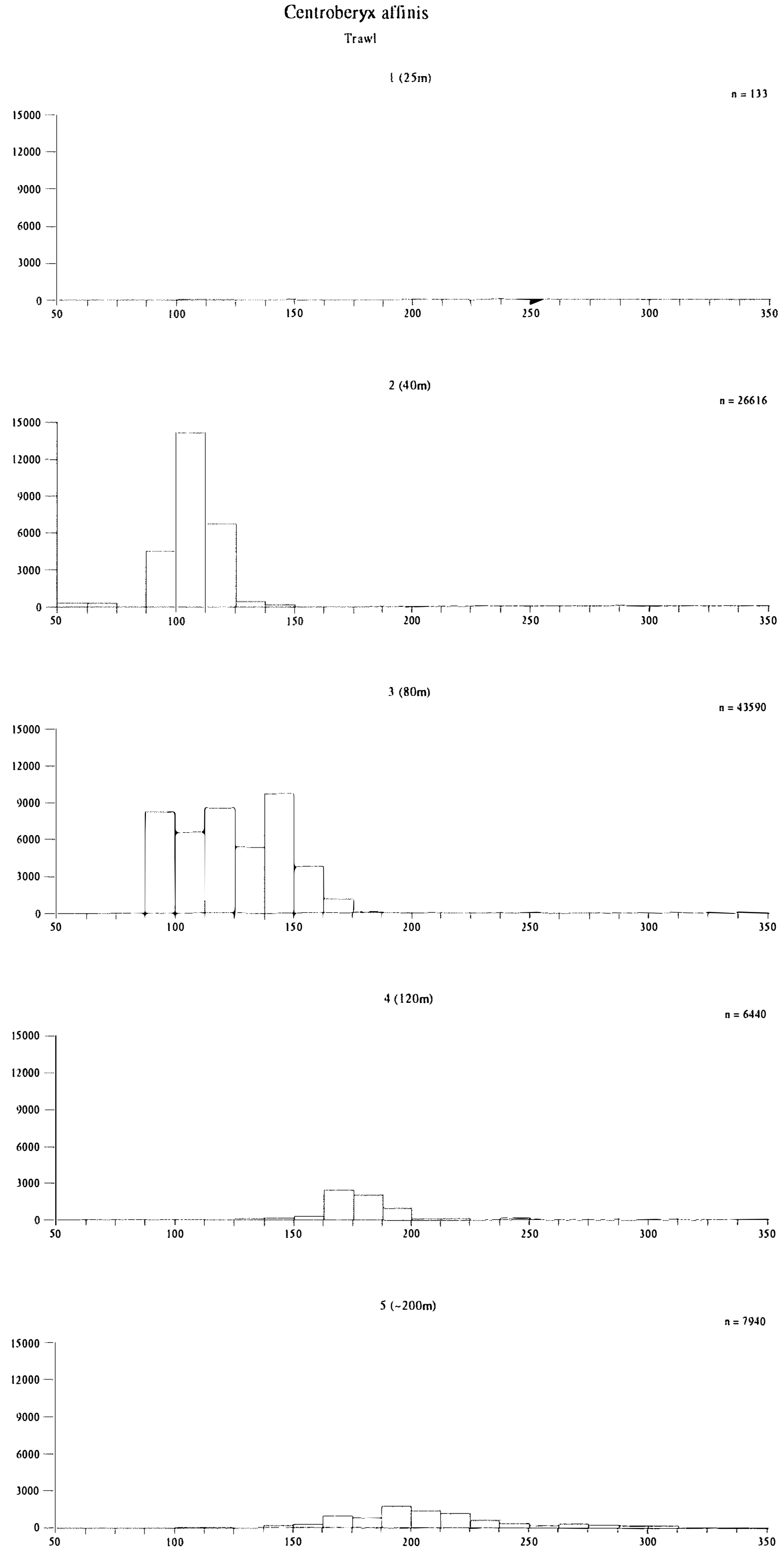

Centroberyx affinis
Trawl
1 (25m)
n = 133
2 (40m)
n = 26616
3 (80m)
n = 43590
4 (120m)
n = 6440
5 (~200m)
n = 7940
15000
12000
9000
6000
3000
0
50
100
150
200
250
300
350

Figure 9.2.1.2

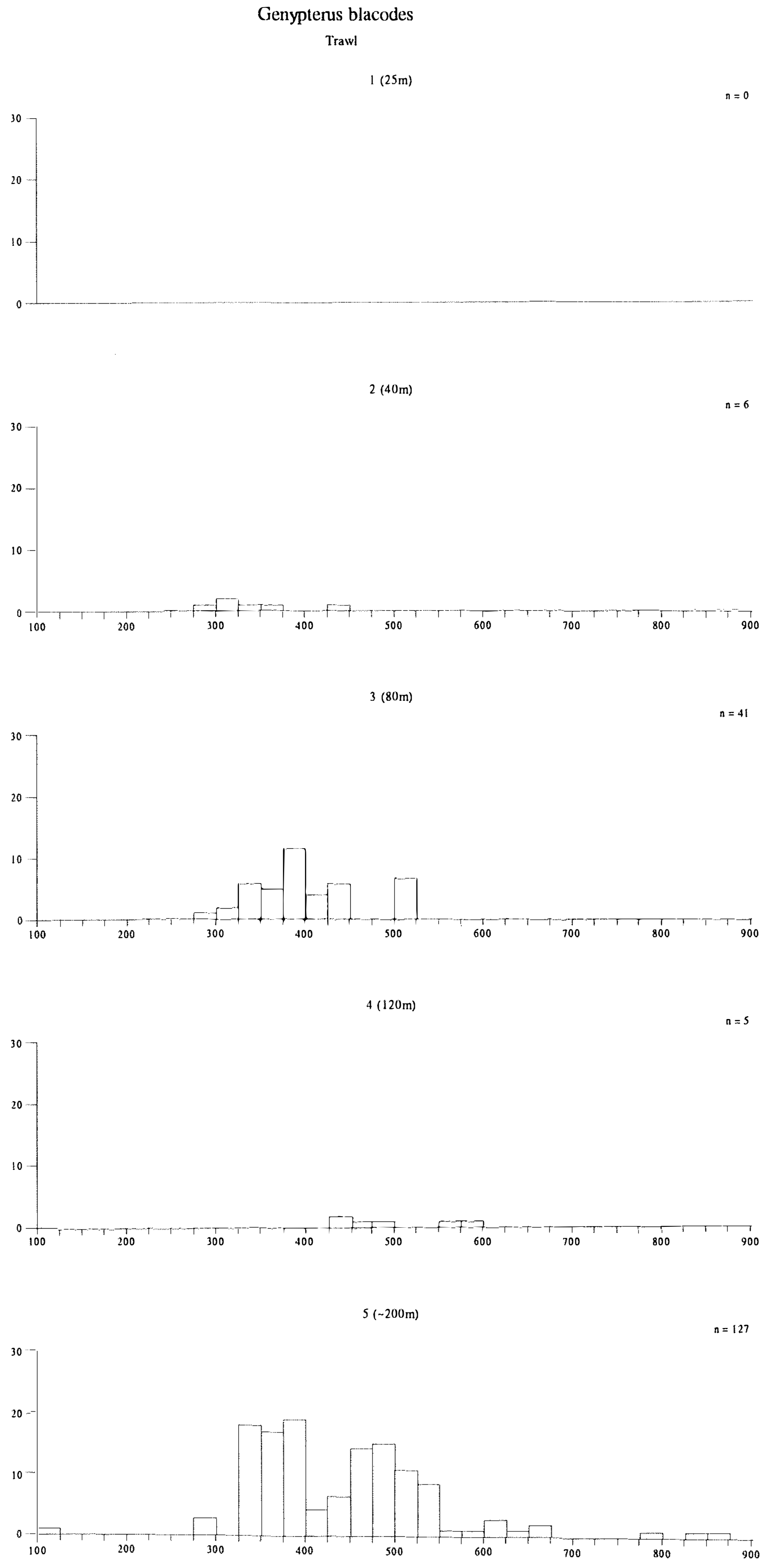

Genypterus blacodes
Trawl
1 (25m)
n = 0
30
20
10
0
2 (40m)
n = 6
30
20
10
0
100
200
300
400
500
600
700
800
900
3 (80m)
n = 41
30
20
10
0
100
200
300
400
500
600
700
800
900
4 (120m)
n = 5
30
20
10
0
100
200
300
400
500
600
700
800
900
5 (~200m)
n = 127
30
20
10
0
100
200
300
400
500
600
700
800
900

Figure 9.2.1.3

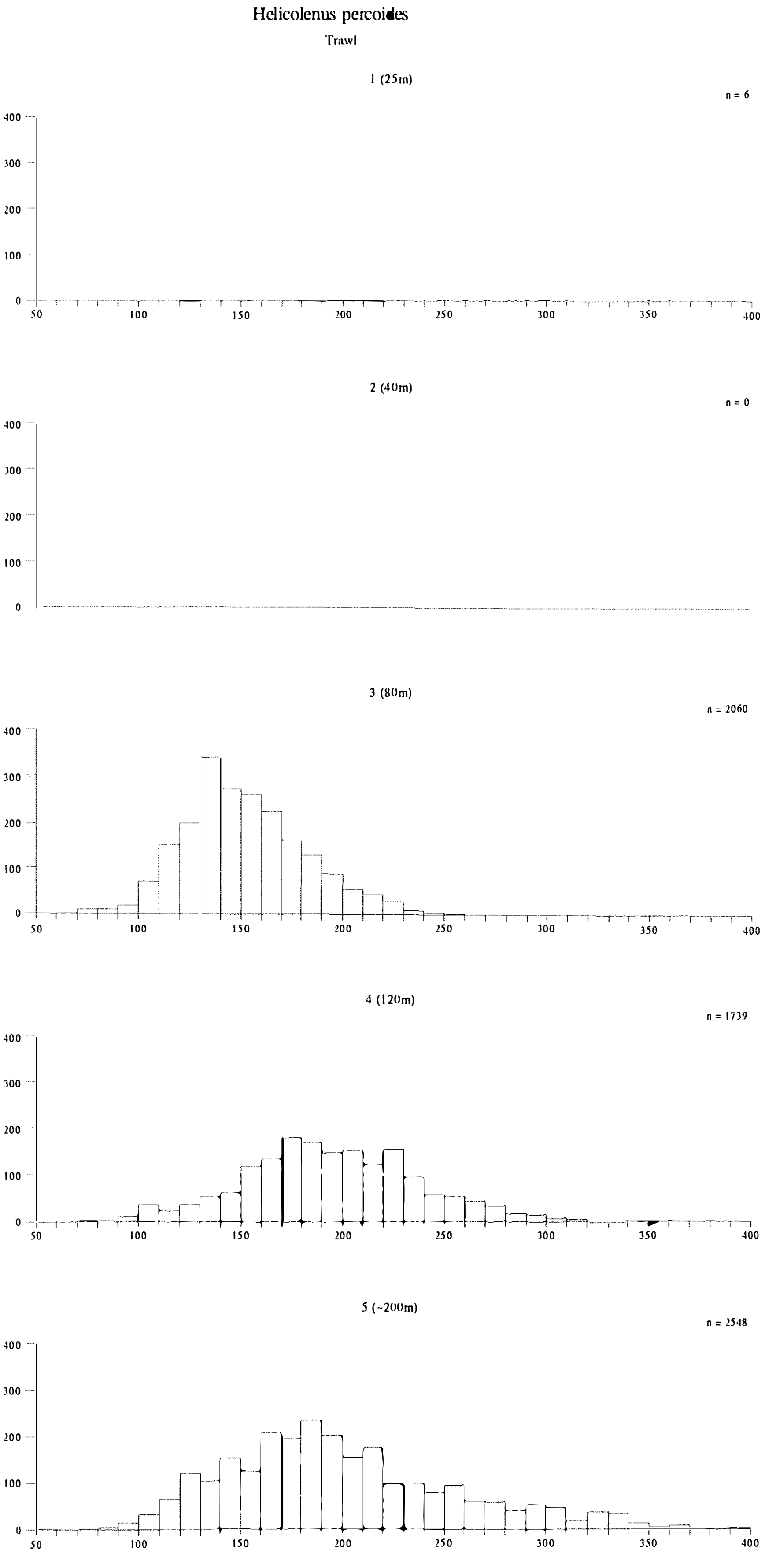

Helicolenus percoides
Trawl
1 (25m)
n = 6
2 (40m)
n = 0
3 (80m)
n = 2060
4 (120m)
n = 1739
5 (~200m)
n = 2548
0
100
200
300
400
50
100
150
200
250
300
350
400

Figure 9.2.1.4

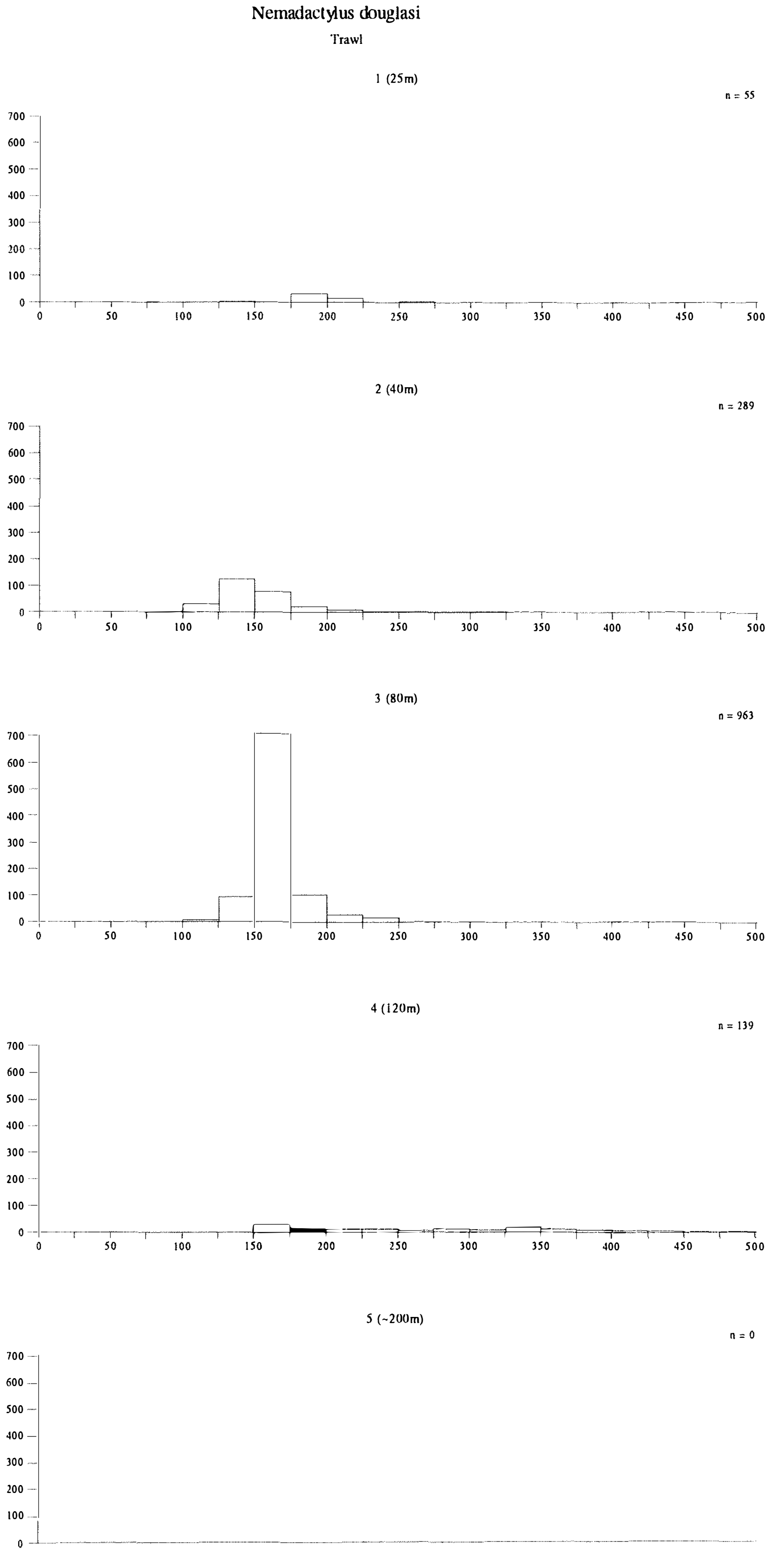

Nemadactylus douglasi
Trawl
1 (25m)
n = 55
2 (40m)
n = 289
3 (80m)
n = 963
4 (120m)
n = 139
5 (~200m)
n = 0
0
100
200
300
400
500
600
700
0
50
100
150
200
250
300
350
400
450
500

Figure 9.2.1.5

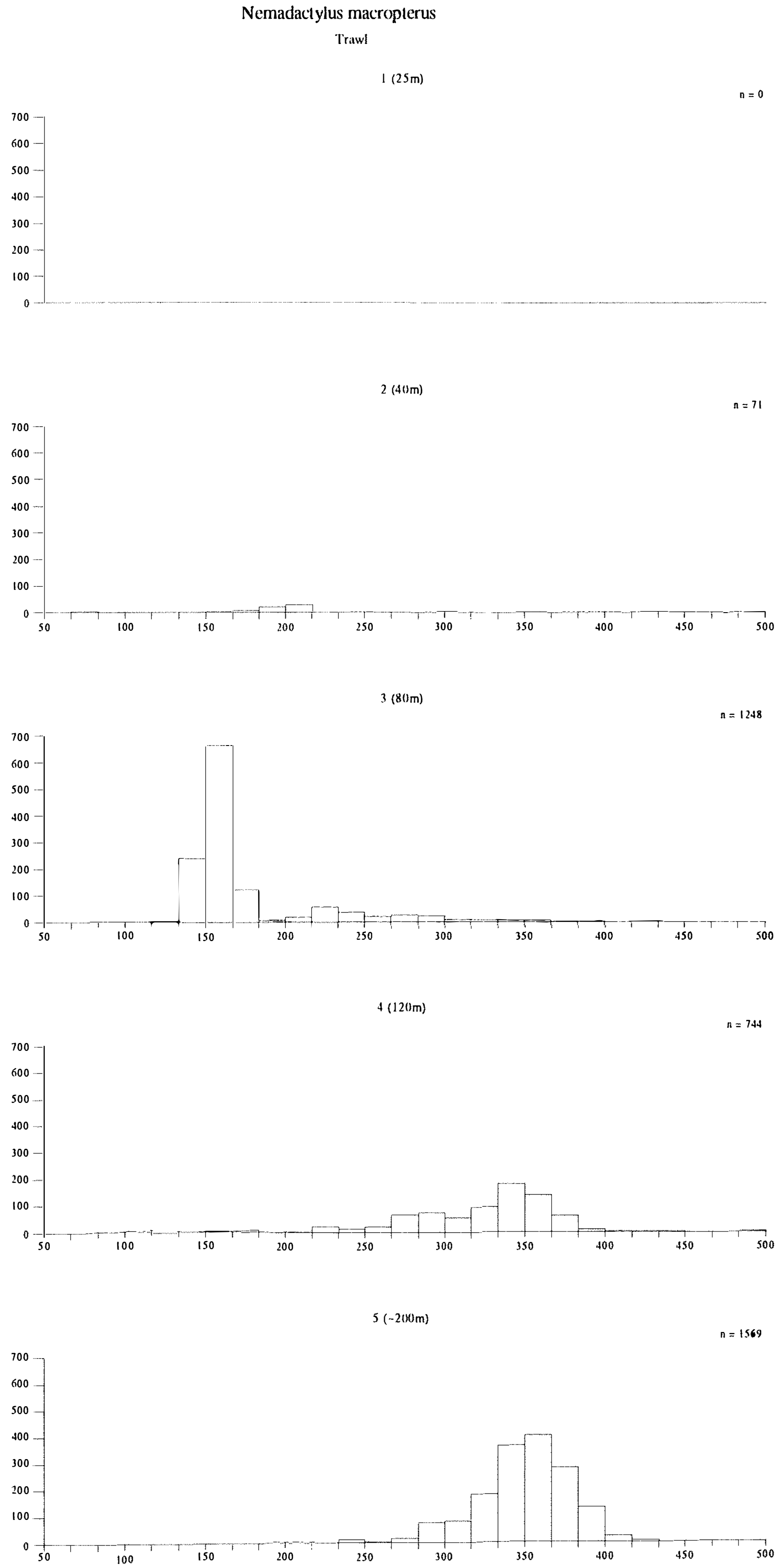

Nemadactylus macropterus
Trawl
1 (25m)
n = 0
2 (40m)
n = 71
3 (80m)
n = 1248
4 (120m)
n = 744
5 (~200m)
n = 1569
0
100
200
300
400
500
600
700
50
100
150
200
250
300
350
400
450
500

Figure 9.2.1.6

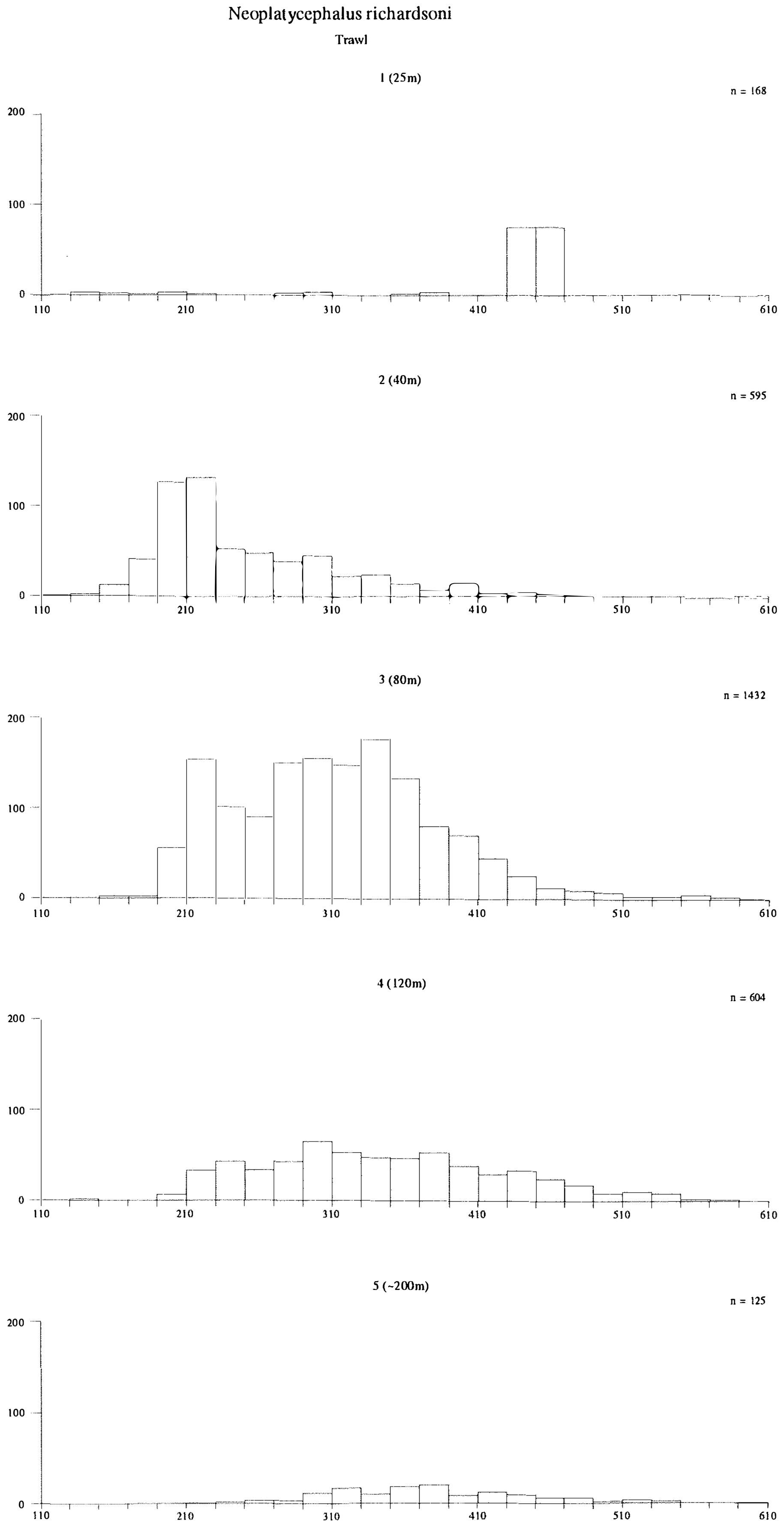

Neoplatycephalus richardsoni
Trawl
1 (25m)
n = 168
2 (40m)
n = 595
3 (80m)
n = 1432
4 (120m)
n = 604
5 (~200m)
n = 125
200
100
0
110
210
310
410
510
610

Figure 9.2.1.7

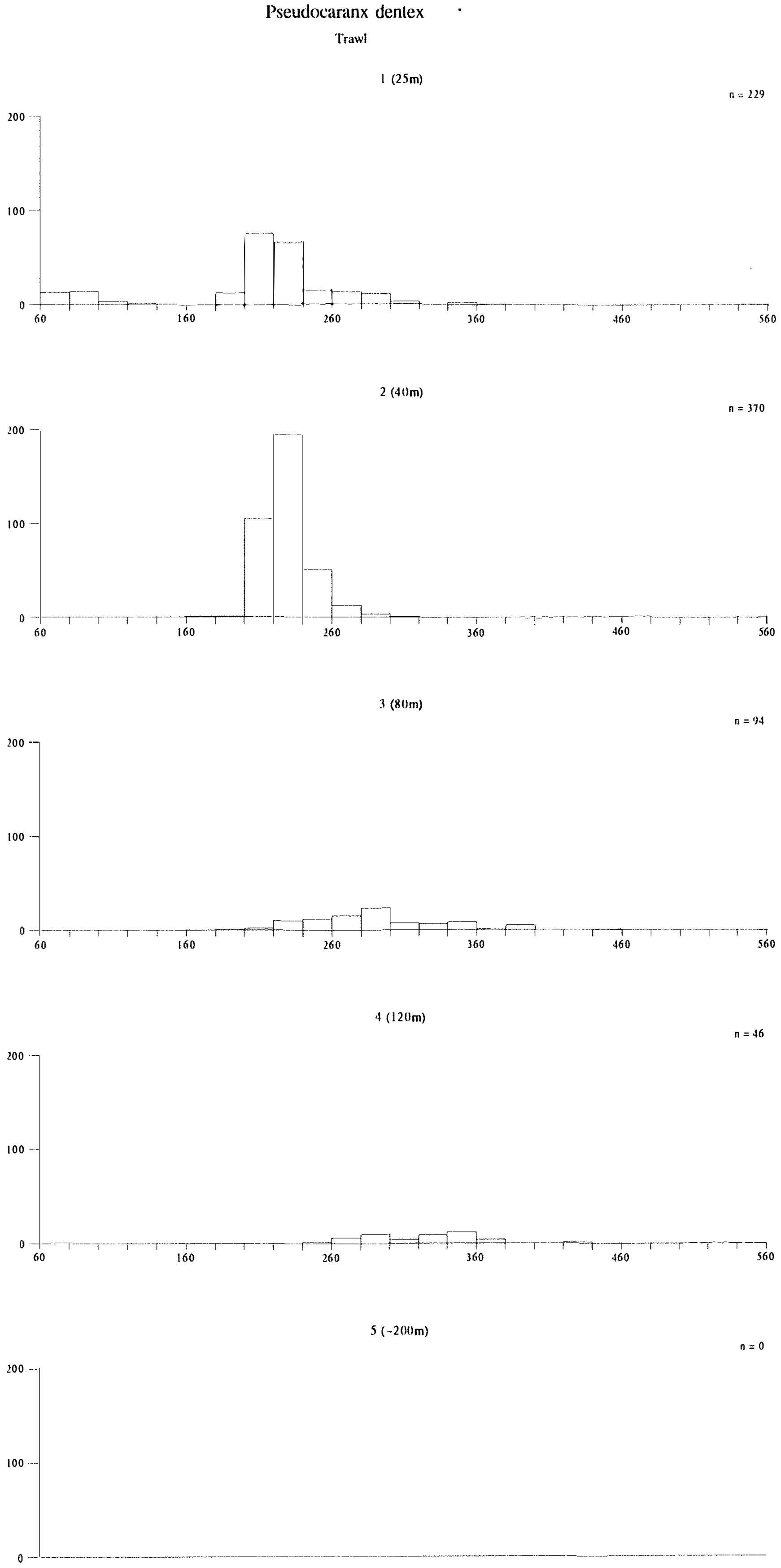

Pseudocaranx dentex
Trawl
1 (25m)
n = 229
2 (40m)
n = 370
3 (80m)
n = 94
4 (120m)
n = 46
5 (~200m)
n = 0
200
100
0
60
160
260
360
460
560

Figure 9.2.1.8

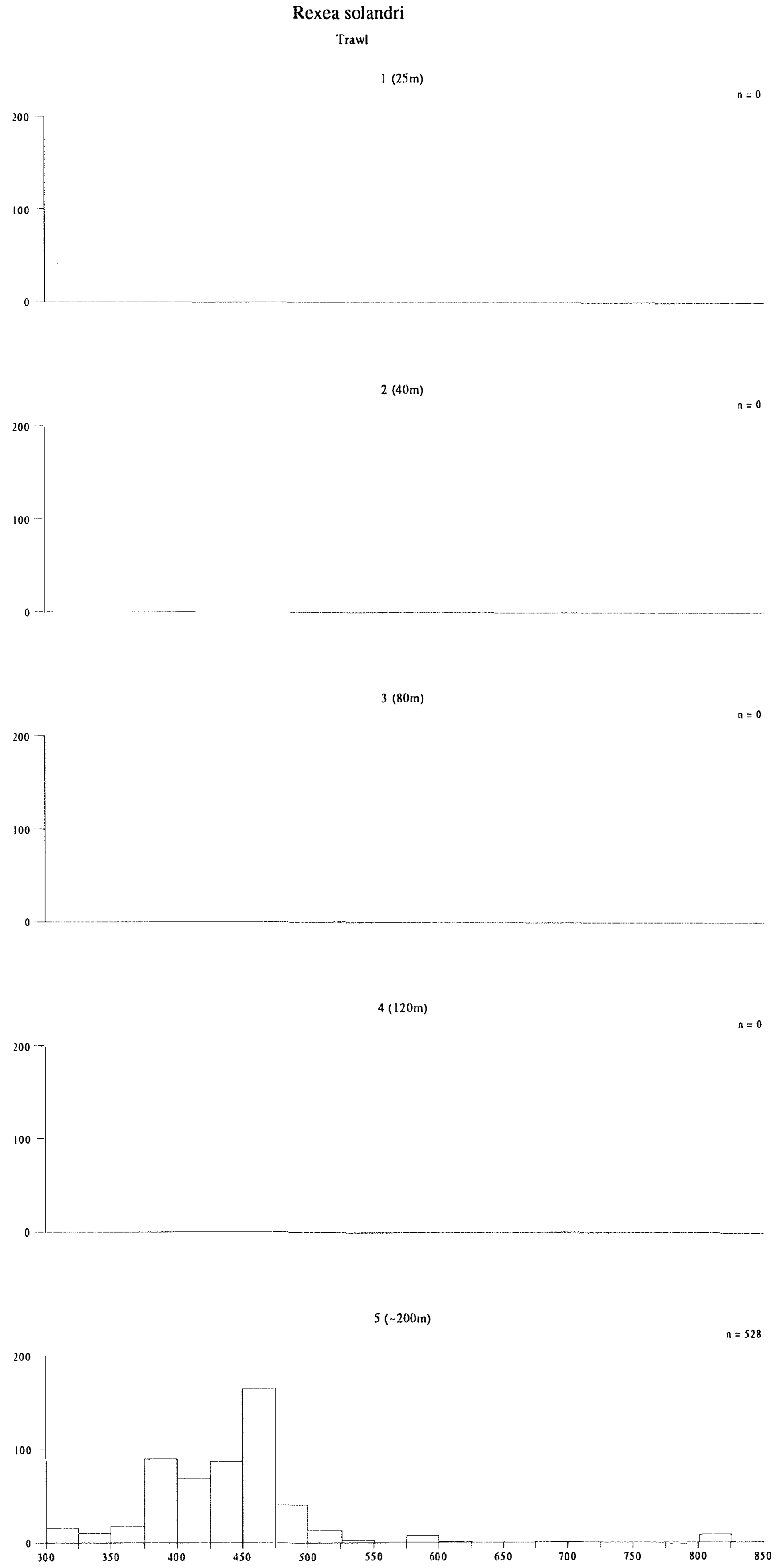

Rexea solandri
Trawl
1 (25m)
n = 0
2 (40m)
n = 0
3 (80m)
n = 0
4 (120m)
n = 0
5 (~200m)
n = 528
200
100
0
300
350
400
450
500
550
600
650
700
750
800
850

Figure 9.2.1.9

Seriolella brama

Trawl

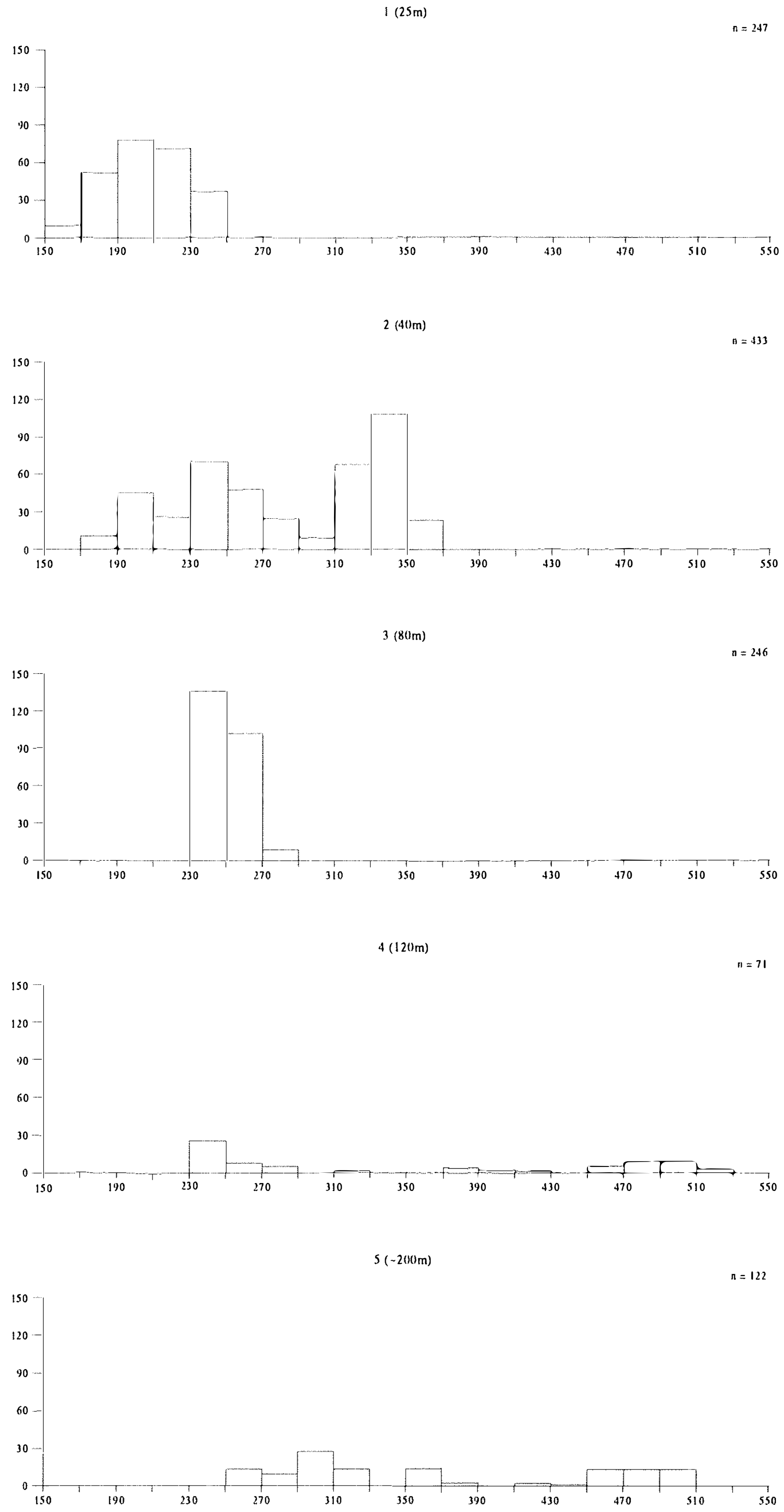
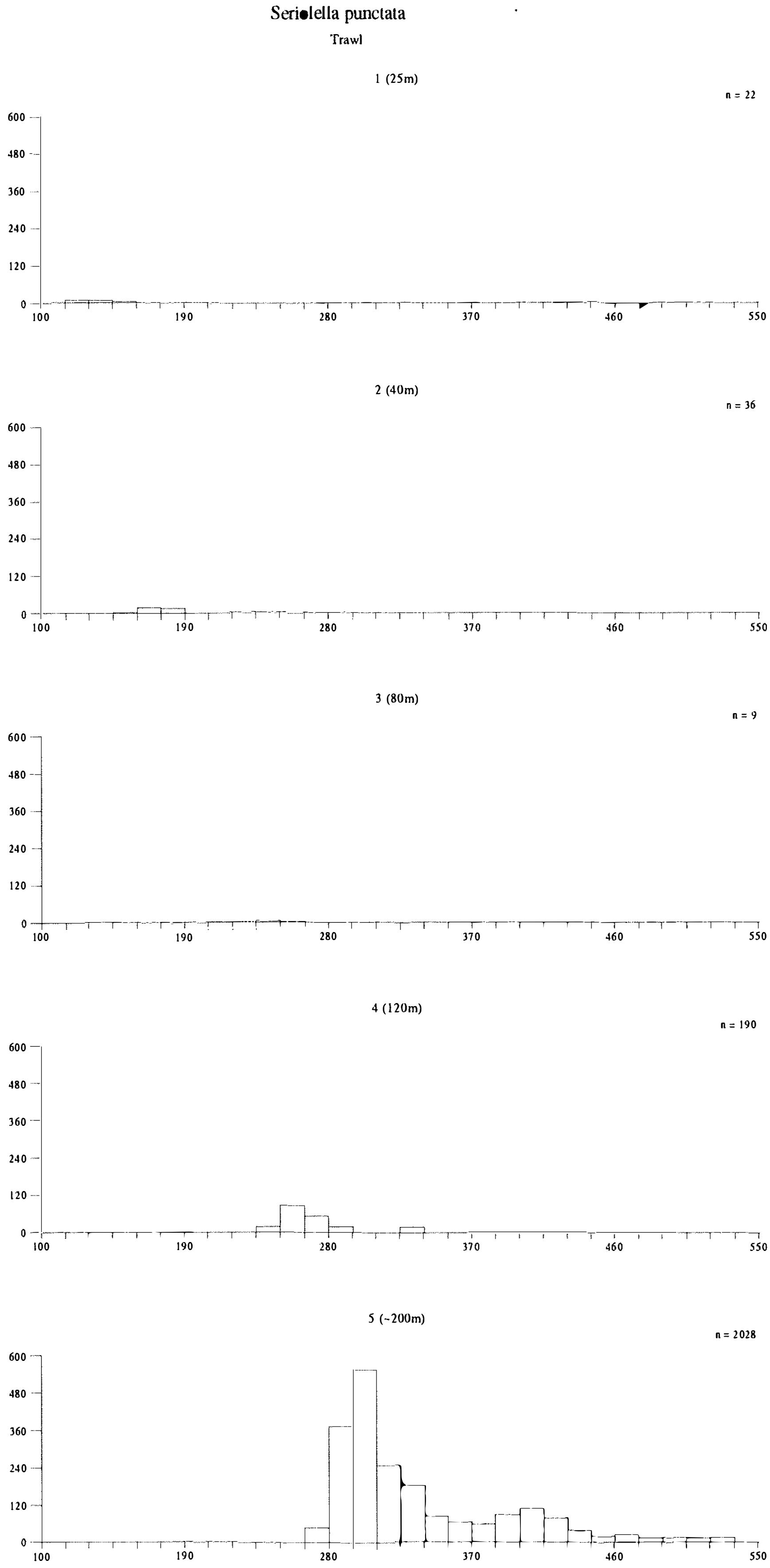


Figure 9.2.1.10



Seriolella punctata

Trawl

1 (25m)

2 (40m)

3 (80m)

4 (120m)

5 (~200m)

Figure 9.2.1.11

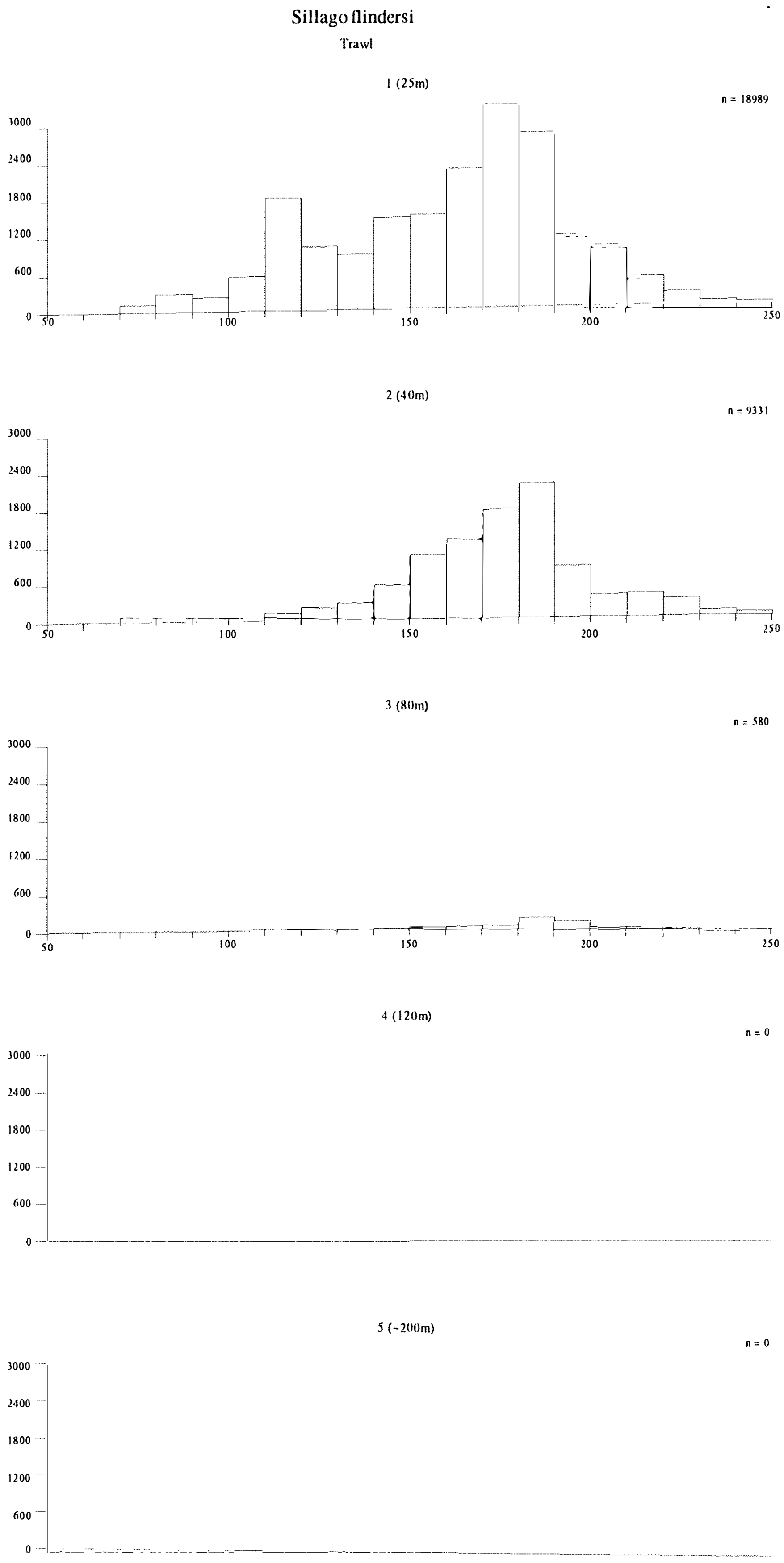
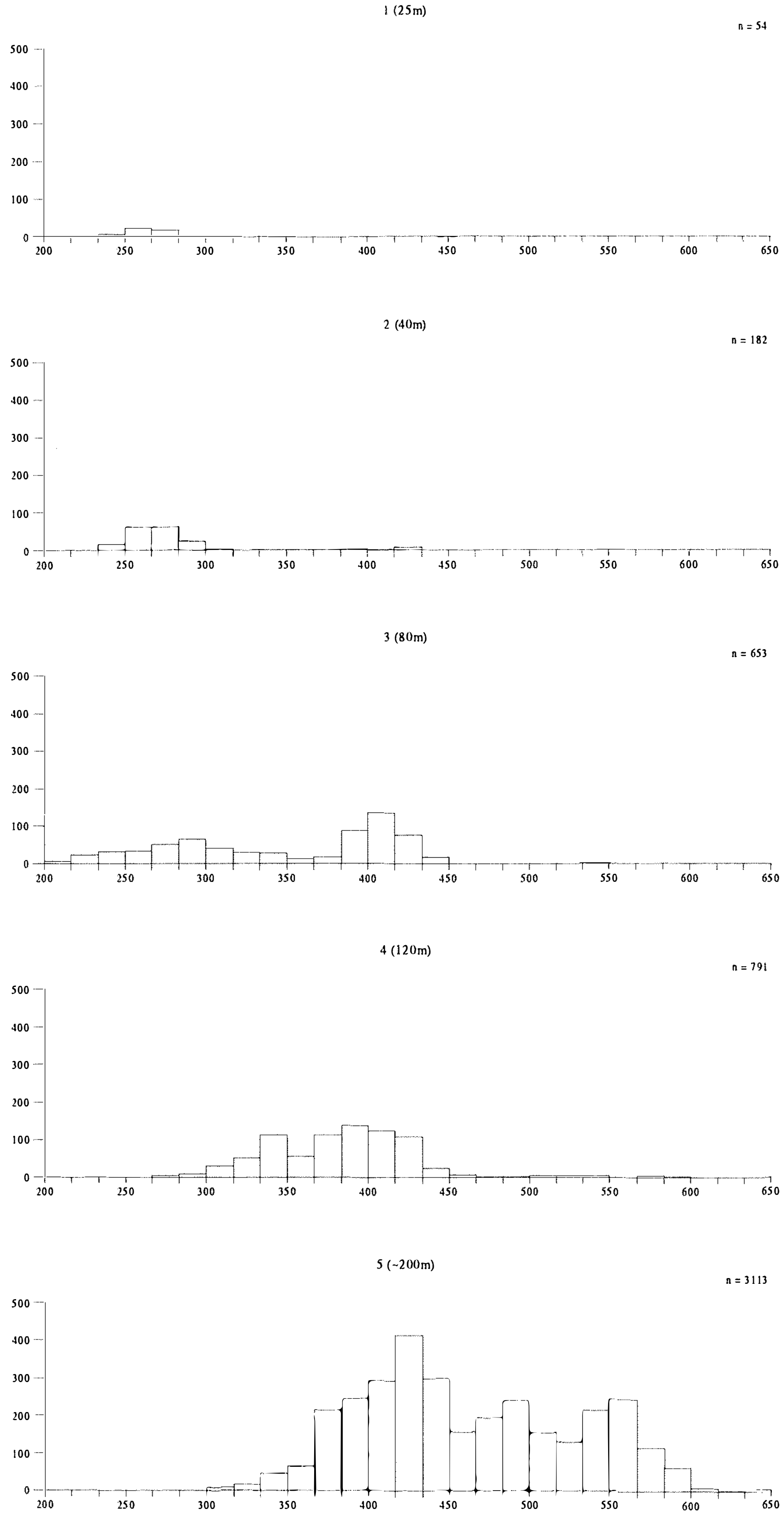


Figure 9.2.1.12



Squalus megalops

Trawl

Figure 9.2.1.13

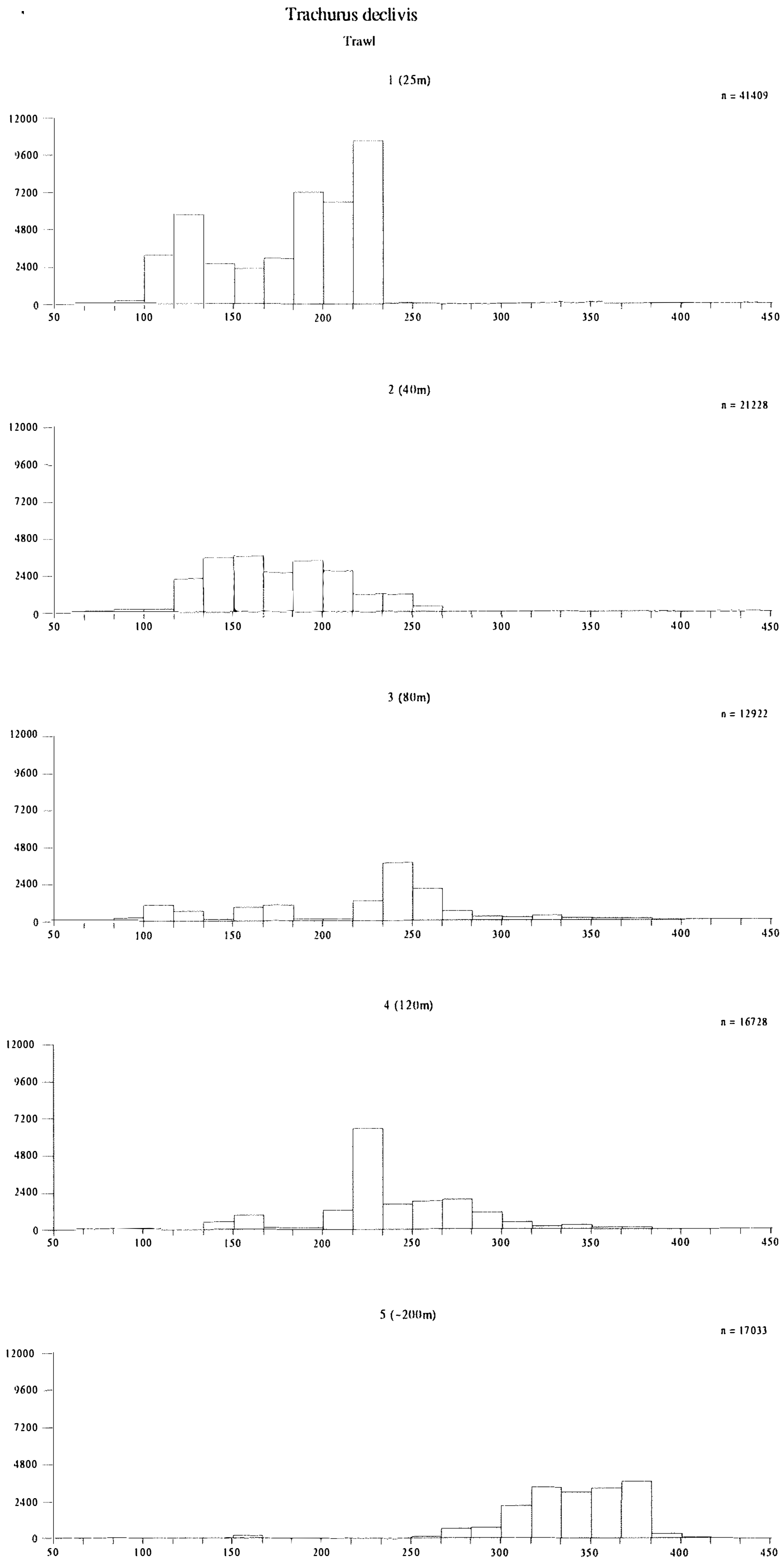


Figure 9.2.1.14

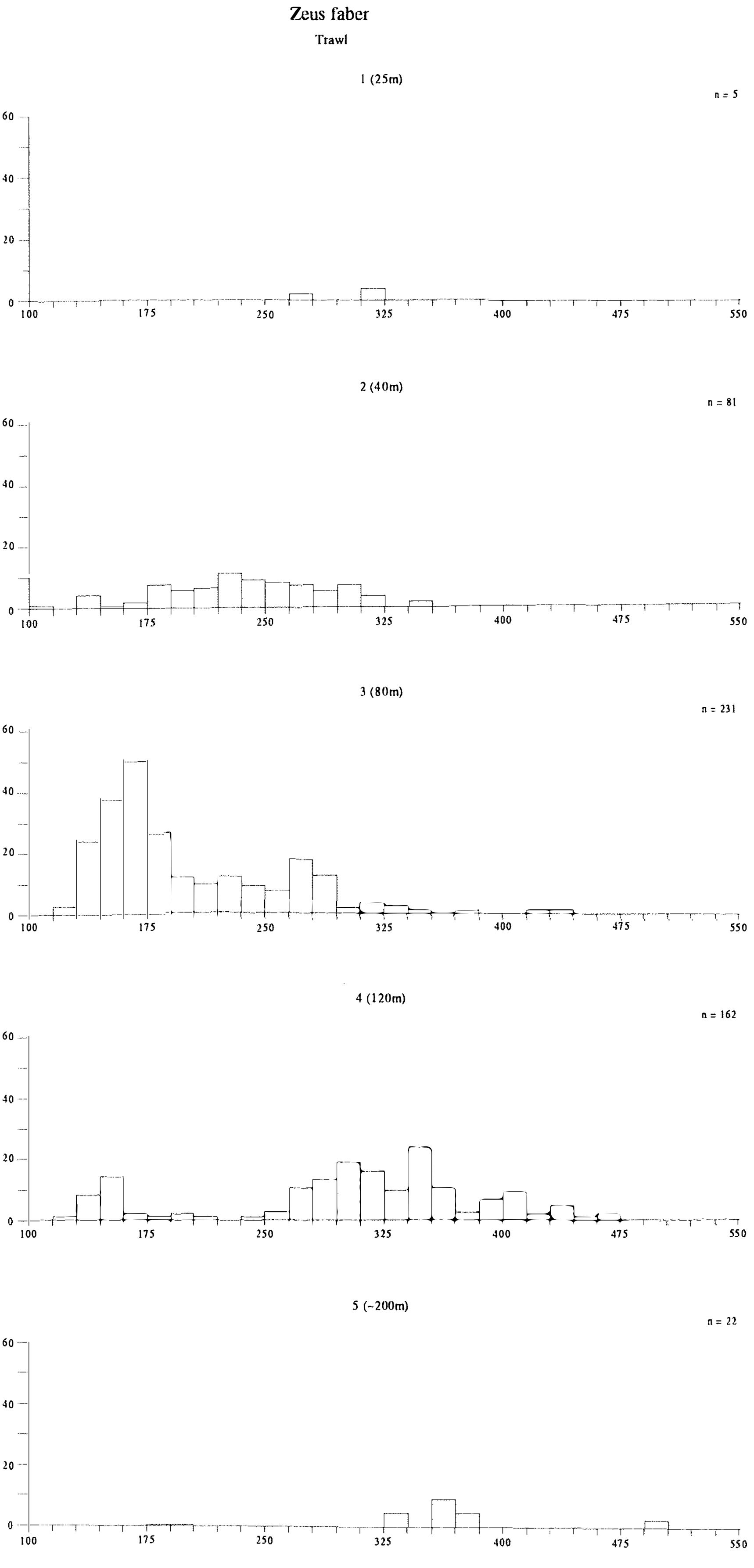


Figure 9.2.1.15

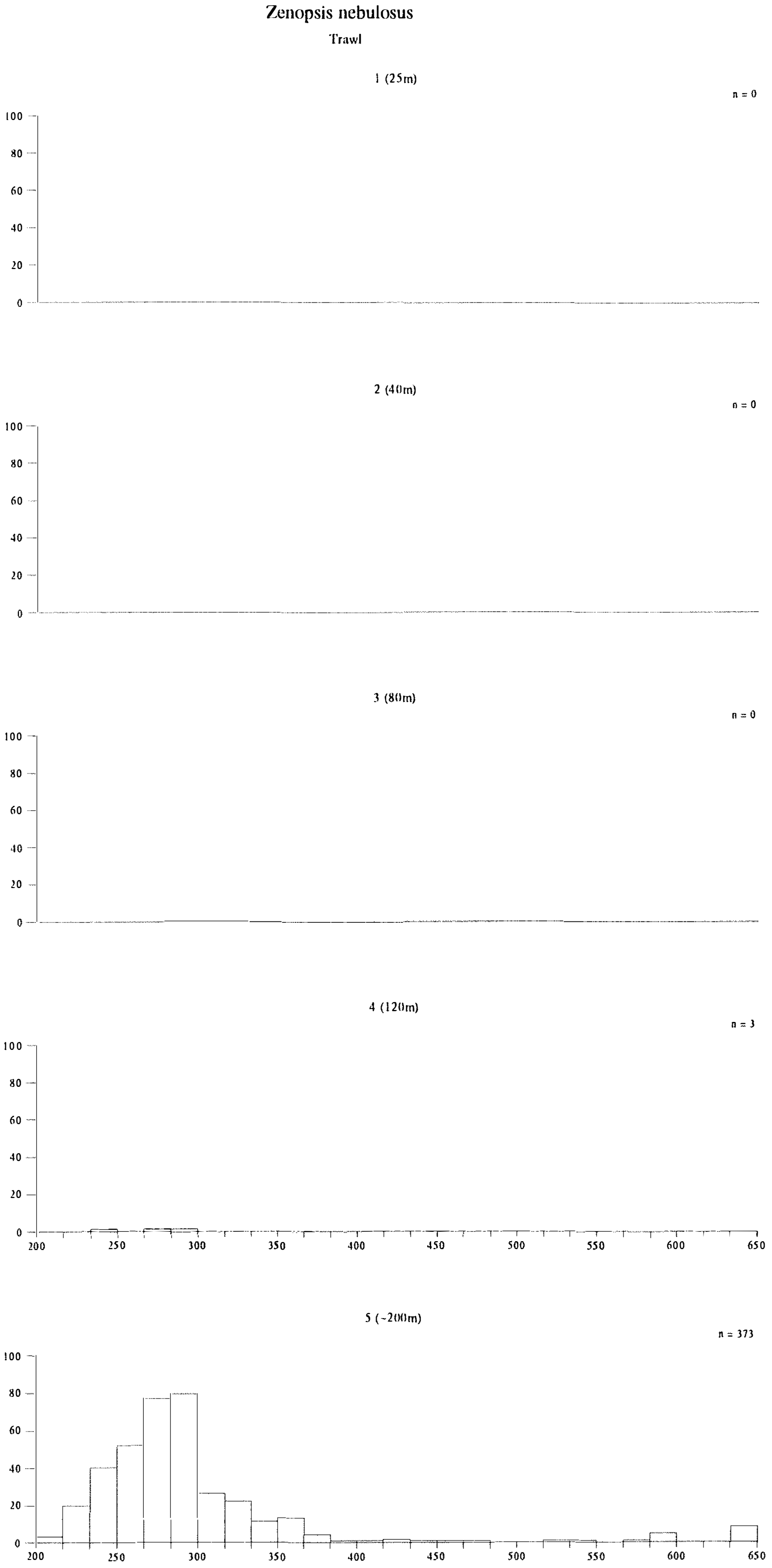


Table 9.2.1.2 Summary of focused habitat codes and descriptors, and sampling effort by gear types.

Habitats	Macro-habitat codes	Habitat name/Descriptor	Depth (metres)	Samples by gear type		
				Gillnet	Trap	Trawl
PHR	PHR	Pt. Hicks reef	28-36	4	10	/
GI/PHS	GIS, PHS	Pt. Hicks-Gabo sediment flat	38-42	4	10	3
GH	GIH	Gabo Is. Reef	48	/	/	1
IS	BHS	Disaster Bay sediment flats	42-99	4	10	2
BRR	BRR	Broken Reef	114	2	/	/
IR	BHR, DBR, BHH	Disaster Bay reef	40-42, 102-106	8, 6	21, 26	2, /
OS	BGS, GRS, BGH	Outer shelf sediment flats	117-137	12	15	7
OR	BGR, GRR, GRH	Gabo-Howe reef	108-132	12	14	3
HO	HOS, HOH, HOC	Horseshoe	148-163	12	15	6

Table 9.2.1.3 Species list for focussed habitat size-distribution analysis, including gear type and habitat data, ordered by raw-data fish numbers.

(Habitat codes as given in Table 9.2.1.2)

Species List from Habitat Sampling (*Quota/commercial species)			Habitat fish Numbers		Effective gear type			Habitat(GIH trawl only)(BRR gillnet only)								
Species name	Species code	Common name	Raw data	Standardised	Gillnet	Trap	Trawl	PHR	GI/PHS	GIH	IS	BRR	IR	OS	OR	HO
**Rexea solandri*	37439002	Gemfish	12	12.23	x											x
**Sillago flindersi*	37330014	Eastern school whiting	19	20.71	x		x				x					
**Pseudocaranx dentex*	37337062	White trevally	47	41.82	x		x	(x)	(x)		(x)		(x)	(x)	(x)	
**Zenopsis nebulosus*	37264003	Mirror dory	51	39.55			x							x		x
**Seriolella punctata*	37445006	Silver warehou	59	58.89	x		x							x	x	x
**Zeus faber*	37264004	John dory	107	105.26			x				x			x		(x)
**Genypterus blacodes*	37228002	Pink ling	227	251.57	x	(x)	x				x	x	(x)	x	(x)	x
Scomber australasicus	37441001	Blue mackerel	249	266.82	x		(x)		x		x	(x)	(x)	x	(x)	(x)
Mustelus antarcticus	37017001	Gummy shark	268	205.62	x	(x)		(x)	(x)		x		(x)	(x)	(x)	
Asymbolus sp D	37015024	Orange-spotted catshark	283	280.64	x	(x)	x		x		x	x	x	x	x	
Lepidoperca pulchella	37311001	Eastern orange perch	310	269.89	x	x	x				x		x	x	x	x
Thyrsites atun	37439001	Barracouta	333	278.17	x		x		x		x		x	x	x	x
Emmelichthys nitidus nitidus	37345001	Redbait	394	424.66	x		x				x			x	x	x
Urolophus paucimaculatus	37038004	Sparsely-spotted stingare	401	549.95			x		x	x	x					
**Neoplatycephalus richardsoni*	37296001	Tiger flathead	463	455.99	x		x				x			x	x	x
Cyttus novaezelandiae	37264005	New Zealand dory	495	1004.06			x							(x)		x
Lepidotrigla mulhalli	37288008	Deepwater gurnard	520	472.22	(x)		x		x		x			x		x
Cyttus australis	37264002	Silver dory	550	467.85	x	(x)	x		x		x		(x)	x	(x)	x
Scorpaena papillosa	37287008	Red rock cod	554	3439.93	(x)		x				x					
Nemadactylus douglasi	37377002	Grey morwong	593	480.35	x	(x)	x		x		x		x		x	
**Seriolella brama*	37445005	Blue Warehou	609	491.65	x		x		(x)		x	(x)	x	(x)	(x)	x
Lepidotrigla modesta	37288007	Minor gurnard	611	696.22			x		x		x			x		x
Caesioperca lepidoptera	37311002	Butterfly perch	854	1702.09	x	(x)	x	x		x	(x)		x		x	
Cephaloscyllium laticeps	37015001	Draughtboard shark	905	748.52	x	x	x	x	x	x	x	x	x	x	x	x
**Centroberyx affinis*	37258003	Redfish	975	2053.75	x		x		x		x		(x)	x	x	x
Synchiropus calauropomus	37427001	Common stinkfish	1125	2367.44			x		x	x	x			(x)		
Apogonops anomalus	37311053	Threespine cardinalfish	1294	15832.88			x				(x)			x		x
**Nemadactylus macropterus*	37377003	Morwong	1534	1421.38	x	x	x	x			x	(x)	x	x	x	x
Meuschenia scaber	37465005	Velvet leatherjacket	1548	1581.76	(x)	x	x	x	x	x	x		x	x	x	
Chlorophthalmus nigripinnis	37120001	Cucumberfish	2069	10895.09	(x)		x				x			x		x
Macroramphosus scolopax	37279002	Snipefish	2365	9270.85			x				x			x		
**Helicolenus percoides*	37287001	Ocean perch	2615	6860.43	(x)	(x)	x			x	x	x	x	x	x	x
Squalus megalops	37020006	Spikey dogfish	3110	3557.13	x	(x)	(x)	(x)	x		x	x	x	x	x	x
Trachurus declivis	37337002	Jack mackerel	4156	8310.73	x		x		x		x	(x)	x	x	x	x

sampling across all habitat types: small fish occurred in relatively high numbers on outer reef areas (OR, OS and HO).

Tiger flathead (*Neoplatycephalus richardsoni*) were caught by gillnet and trawl. The smallest fish were in trawl catches, particularly at IS and in broad-scale trawl samples. Larger fish were proportionately more numerous in gillnet. The bigger/deeper pattern of broad-scale data was evident but less defined in focused habitat samples. The small number of fish that occurred at the deeper reef habitat, OR, were mid size-range fish. The smallest and largest tiger flathead (150 and 800 mm) occurred at IS. Comparatively large fish (320—650 mm) were taken by gillnet at HO.

White trevally (*Pseudocaranx dentex*) were caught by gillnet and trawl, on soft and rough-grounds, but all catches numbers were very low.

Gemfish (*Rexea solandri*) catches were very low, being caught only at HO (~150 m) by gillnet. The restricted-range distribution pattern (broad-scale analysis) resulted from having sampled this upper-slope species at its shallow limits of distribution (May and Maxwell 1986).

Blue warehou (*Seriolella brama*) were caught in large numbers in broad-scale samples, and by gillnet and, in low numbers only, by trawl in focussed habitat sampling. Smaller individuals were taken by trawl. Gillnet numbers were comparable at IS, IR and HO, with low numbers elsewhere. No clear evidence of the broad-scale bigger/deeper pattern was found, but predominantly large fish were caught by gillnet in the focused habitat sampling. No size difference occurred between blue warehou at inner and outer habitats.

Silver warehou (*Seriolella punctata*) were caught in low numbers (n=39) by gillnet and trawl only. Fish size was generally smaller in gillnet catches. The bigger/deeper broad-scale pattern was weakly evident considering the constraints of low sample numbers and restricted depth range of capture habitats (120—150 m).

Eastern school whiting (*Sillago flindersi*) were caught by gillnet and trawl, in very low numbers (n=21), only at IS (40-100 m). Broadscale catches also occurred only in 25-80 m depth.

Mirror dory (*Zenopsis nebulosus*) were only caught by trawl, at OS and HO, in low numbers (n=40). Its restricted-range distribution pattern (broad-scale analysis) can be attributed to sampling only the shallow extreme of the distribution for this species (May and Maxwell (50—550 m) (1986)).

John dory (*Zeus faber*) were caught by trawl in low numbers only, at IS, OS and HO. The broad-scale distribution pattern of bigger/deeper is weak within the focused habitat data, but broad-scale trawl catches contain comparably more smaller fish than focused habitat catches.

Other important species

Threespine cardinalfish (*Apogonops anomalus*) were caught by trawl only, predominantly at OS and HO (125—150 m depth). Its restricted range in both broad-scale and focused habitat samples is consistent with an outer-shelf/ upper slope distribution (May and Maxwell, 1986: 100—400 m depth). A bigger/deeper pattern was also indicated, with only small individuals at IS (<90 mm) in comparatively low numbers (n=17), and progressively larger fish at OS and HO respectively.

Grey spotted catshark (*Asymbolus sp. D*) were caught by all gears, although gillnet catches were consistently greater than catches from trap or trawl. Catches were made on soft and rough -grounds. Apart from the largest individuals being consistently caught by gillnet, size segregation of fish between gears was not well defined. Within gears, gillnet catches were comparatively higher at OR. No patterns of size to depth or habitat distribution were evident in broad-scale or focused habitat data, though distribution is restricted to ~40—120 m depth in both.

Butterfly perch (*Caesioperca lepidoptera*) were caught predominantly by gillnet and trawl, with low trap numbers only (n=11). Size segregation was consistent, with the smallest fish (<130 mm) caught by trawl and the largest fish (>200 mm) by gillnet. The 'inner' habitat catches were predominantly on soft-ground (trawl at IS, gillnet at PHR, IR) and 'outer' habitat catches were predominantly on rough-grounds (gillnet at OR). No size-related broad-scale distribution pattern was identified apart from a centre of distribution at 40 m depth on soft-ground. The focused habitat data indicated a bigger/deeper distribution on soft and rough-grounds, inner and outer (IS, IR and OR).

Draughtboard shark (*Cephaloscyllium laticeps*) were caught by all gears, but gillnet was consistently more effective than other gears within comparable habitats. Within gear types, soft and rough-ground catches were comparable. The largest individuals were predominantly caught by gillnet in inner habitat areas (IR, IS and PHR, 910—1000 mm) and the smallest fish (<400 mm) on soft-grounds of GI/PHS, IS and OS. Catches at IS and GI/PHS habitats were bi-modal, with large and small fish. No size-related pattern of distribution was evident in broad-scale or focused habitat data.

Cucumberfish (*Chlorophthalmus nigripinnis*) were predominantly caught by trawl, at IS, OS and HO, with low catches also by gillnet at OS and HO. Catches at OS were relatively large. No size-related pattern of distribution was evident in broad-scale or focused habitat data.

Eastern orange perch (*Lepidoperca pulchella*) were caught in relatively low numbers by all gear types. Fish occurred on soft and rough-grounds (IS, IR, OS, OR and HO), although catches were greater on rough-ground for gillnet and trap. Catches were predominantly from OR (gillnet) and IR and OR (trap). The smallest and largest fish were in trawl catches. No size-related distribution pattern was identified. Distribution was restricted to outer-shelf (>100 m depth), consistent with published records (60—350 m, May and Maxwell (1986)).

Velvet leatherjacket (*Meuschenia (Parika) scaber*) were caught by all gears, but gillnet numbers were relatively very low across similar habitats (n=38). Within gears, the numbers at 'inner' habitats were greater than 'outer' habitats (IS>OS, IR>OR). The smallest fish (<170 mm) were only caught by trawl. Most of the largest fish were trap caught on rough-ground (IR, OR), but also occurred in trawl catches at OS. Trap catches on rough-grounds were comparatively higher than on soft-ground, for both inner and outer habitats. The bigger/deeper pattern from broad-scale data is evident in trap and trawl focused habitat data.

Gummy shark (*Mustelus antarcticus*) were mostly caught by gillnet, although low numbers (n=3) were also taken by trap at IS. Gillnet catches occurred at all sampled habitats, except BRR and HO. With the exception of IS (where n=168), catch rates were low (n<19). Although individuals at IS covered a wide size range (100—1300 mm), the largest fish occurred at IR (1400 mm). No size-related distribution pattern was evident.

Grey morwong (*Nemadactylus douglasi*) were caught by all gears, but in relatively low numbers by trap (n=3). Fish occurred on soft and rough-grounds (GI/PHS, IS, IR and OR). The smallest fish (<150 mm) occurred in trawl catches at the inner, soft-grounds of GI/PHS and IS. The largest fish (>400 mm) occurred on rough-grounds (IR and OR). Within gillnet, catches were comparatively greater at IR, and cover a wide size-range (180—550 mm).

Spikey dogfish (*Squalus megalops*) were caught by all gears; where gears could be compared within habitats, catches were greatest in gillnet. Gillnet catch numbers were greatest at OS (n=1458) and OR (n=752) where fish sizes were similar (~300—600 mm). Smaller fish (<300 mm) occurred at inner (GI/PHS, IR) and outer (HO) habitats. The largest fish (>550 mm) occurred at the deepest habitats (OS, OR and HO). The bigger/deeper distribution pattern of the broad-scale data was evident but less pronounced.

Jack mackerel (*Trachurus declivis*) were caught by gillnet and trawl at all habitats except PHR. Within all habitats, the smaller fish were consistently caught by trawl. Catches from gillnet and trawl were greatest at OS. Gillnet catches at IS and OS were comparatively greater than IR and OR (i.e. soft >rough) although the size composition of the catches were similar. The bigger/deeper distribution pattern of the broad-scale data was also evident in the focused habitat data, with the largest fish (420—470 mm) caught by gillnet at the outer habitats of OS and OR.

Mesh selectivity in gillnet

A variable-mesh (2", 3", 4", 5", 6" and 7" mesh) net was used for gillnet sampling, to assess selectivity. As sampling effort was identical, i.e. all panels were incorporated into the net for every sample, direct comparison between catches of each mesh could be made. Data from this study has also been used in the FRDC study "Evaluation of selectivity in the South East Fishery to determine its sustainable aggregate yield" (FRDC 96/140)

Redfish (*Centroberyx affinis*) (Fig. 9.2.1.16) catches show mesh selectivity throughout all mesh sizes, with increasing fish size from 2" through to 4", with larger fish (>200 mm) caught by all mesh sizes > 4". A degree of overlap in fish < 200 mm is evident in 3", 4" and 5" mesh, with ~50% of total individuals being in 3" mesh. Some tangling of large fish in small mesh occurs: fish >200 mm and >250 mm in the 2" and 3" mesh respectively.

Ling (*Genypterus blacodes*) (Fig. 9.2.1.17) catches indicate mesh selectivity particularly in the 3" to 5" meshes (containing 90% of the total pink ling individuals). Within these three meshes, a large overlap in fish size occurs, but size segregation is evident with the smallest fish (<500 mm) in 3" mesh and largest fish (>750 mm) in the 5" mesh. Fish greater than 700 mm in 3" mesh may be due to tangling. Small catches in the 2" and 6" meshes (n=4, and n=8 respectively) are consistent with small and large fish-size catches respectively, plus some large fish tangling in small mesh, and small fish tangling in large mesh.

Ocean perch (*Helicolenus percoides*) (Fig. 9.2.1.18) catches predominantly indicate mesh selectivity in 2", 3" and 4" mesh, with the 2" and 3" meshes catching 80% of total individuals and 99% of the size range. Fish sizes within individual meshes were <240 mm in 2" mesh, 190—320 mm in 3" mesh, and 280—330 in 4" mesh. Although an overlap in fish-size occurred in the 3" and 4" mesh, catches in the 4" mesh were less. Similarly, an overlap in fish-sizes in the 2" and 3" mesh is evident in 190—240 mm fish, but 2" mesh catches are predominantly fish <190 mm. Larger individuals may indicate tangling. Some evidence of small fish tangling in large mesh is seen in the catches of the 6” mesh, although this represents 2% of the total catch only.

Morwong (*Nemadactylus macropterus*) (Fig. 9.2.1.19) catches occurred predominantly in the 3”, 4” and 5” mesh, with strong mesh selectivity for increasingly larger fish. The 3” and 4” mesh took 60% of total morwong individuals in gillnet catches. Some overlap in fish >260 mm is evident between the 3” and 4” mesh, but the low representation of these fish in 3” mesh, in comparison to fish <260 mm, may indicate a greater degree of tangling as opposed to mesh selectivity. Overlap in fish sizes between the 4” and 5” mesh also occurs (>320 mm), but this size range is more prevalent in the 5” mesh.

Tiger flathead (*Neoplatycephalus richardsoni*) (Fig. 9.2.1.20) catches occurred predominantly in 2”—4” mesh (95% of total individuals), with mesh selectivity indicated within the 2”—5” mesh sizes. An overlap in fish sizes extends to the upper ~60—70% of the size range within each mesh, but smaller fish are selected in progressively smaller mesh. Tangling of smaller fish in the larger mesh is indicated in 6” and 7” mesh, although numbers are very low (n=5, and n=1 respectively).

White trevally (*Pseudocaranx dentex*) (Fig. 9.2.1.21) numbers in gillnet samples were low (n=24), but catches indicated mesh selectivity in 3’—6’ mesh, with fish sizes progressively larger in larger mesh. Some indication of large fish tangling in small mesh is evident (980 mm in 4” mesh).

Gemfish (*Rexea solandri*) (Fig. 9.2.1.22) numbers in gillnet samples were very low (n=12), and occurred in 2”, 3” and 4” mesh only.

Blue warehou (*Seriolella brama*) (Fig. 9.2.1.23) catches occurred in 4”, 5” and 6” mesh, with progressively larger mean fish sizes as mesh sizes increased. Although mesh selectivity is indicated (smaller fish in smaller mesh and larger fish in larger mesh), an overlap of fish sizes of ~>50% individuals occurred between the 4” and 5” mesh, and a complete overlap of 370—450 mm individuals between the 5” and 6” mesh. Tangling of larger fish in smaller mesh is evidenced in the 2” and 3” mesh. The 5” mesh caught 50% of the blue warehou catch and a further 25% in the 4” mesh.

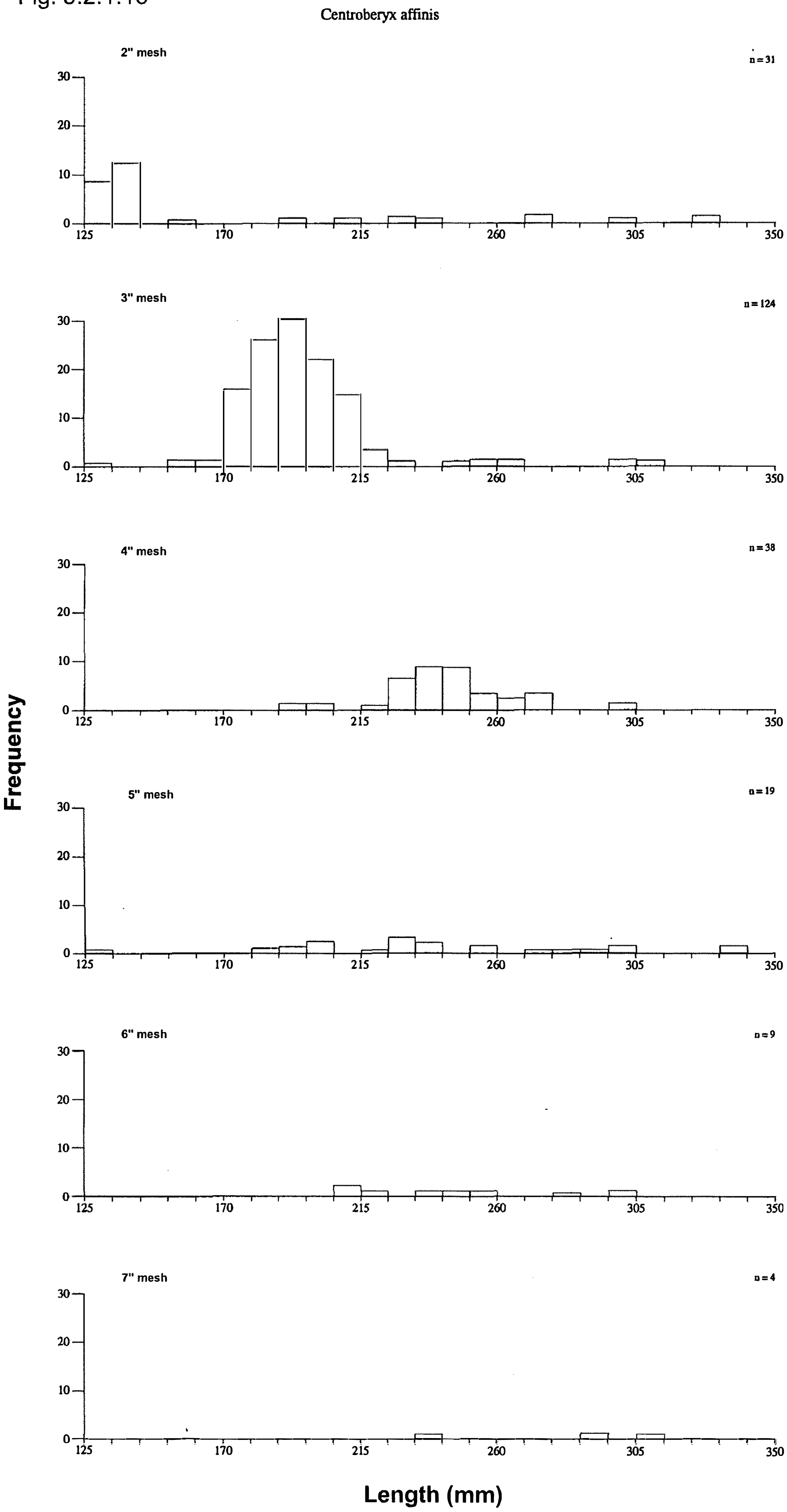
Silver warehou (*Seriolella punctata*) (Fig. 9.2.1.24) catches were low in number (n=39), occurring in 3” and 4” mesh only, with fish more susceptible to the 4” mesh (n=35). Although small fish were present in both mesh sizes, the 4” mesh also contained larger fish.

Eastern school whiting (*Sillago flindersi*) and John dory (*Zeus faber*) numbers in gillnet samples were too low to assess (n=2, and n=1 respectively). Mirror dory (*Zenopsis nebulosus*) were not caught by gillnet.

9.2.2 Otolith Sampling and Age Determination

Age estimates for 71 fish species were made. Maximum ages for these species have been given (Table 9.1.1.1) together with the corresponding length of the aged fish. Species-specific mortality estimates were calculated from this information, and used in the FRDC ecomorphology study (FRDC96/275).

Fig. 9.2.1.16



Centroberyx affinis
2" mesh
n=31
3" mesh
n=124
4" mesh
n=38
5" mesh
n=19
6" mesh
n=9
7" mesh
n=4
30
20
10
0
125
170
215
260
305
350
Frequency
Length (mm)

Fig. 9.2.1.17

Genypterus blacodes

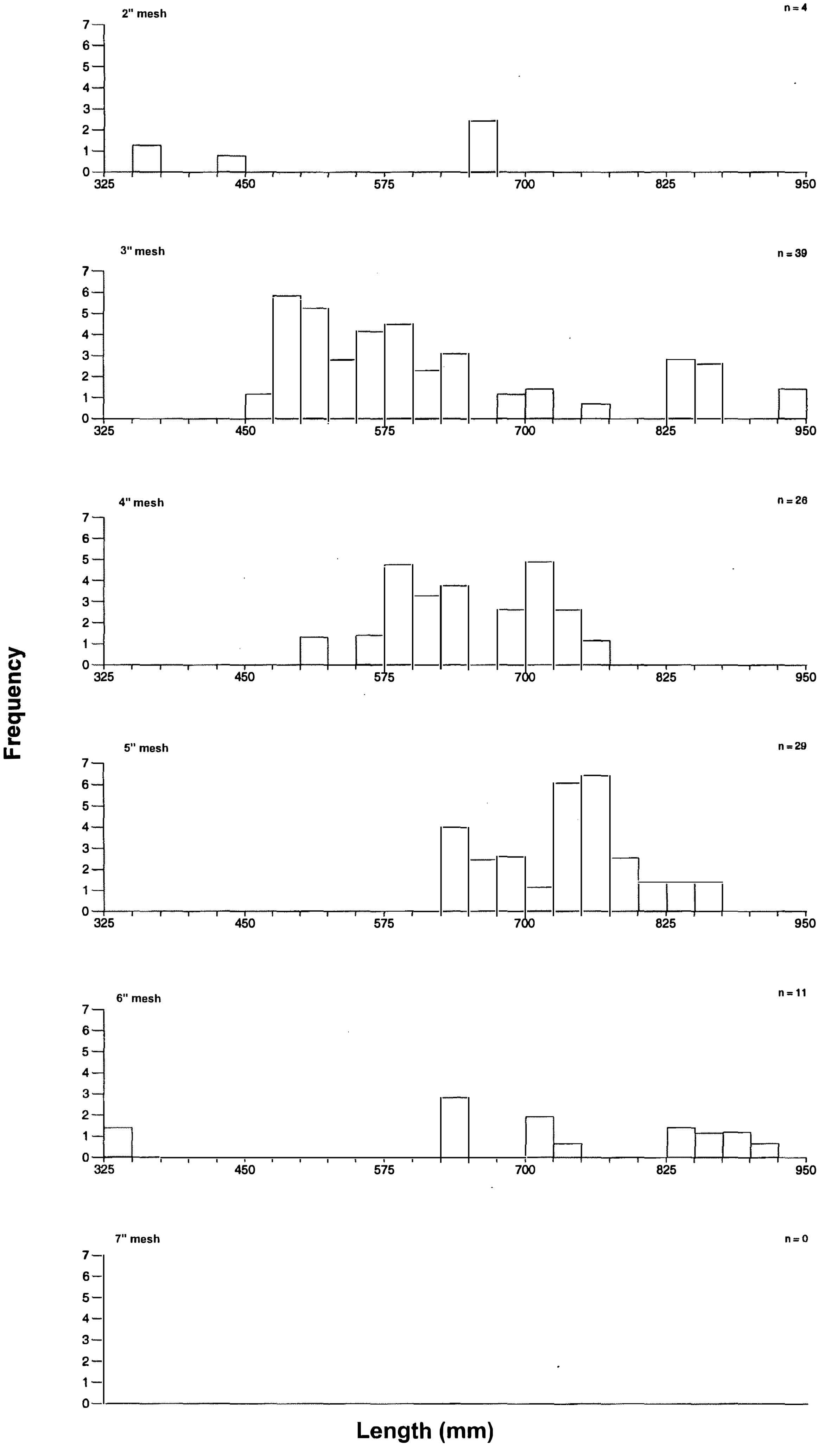


Fig. 9.2.1.18

Helicolenus percoides

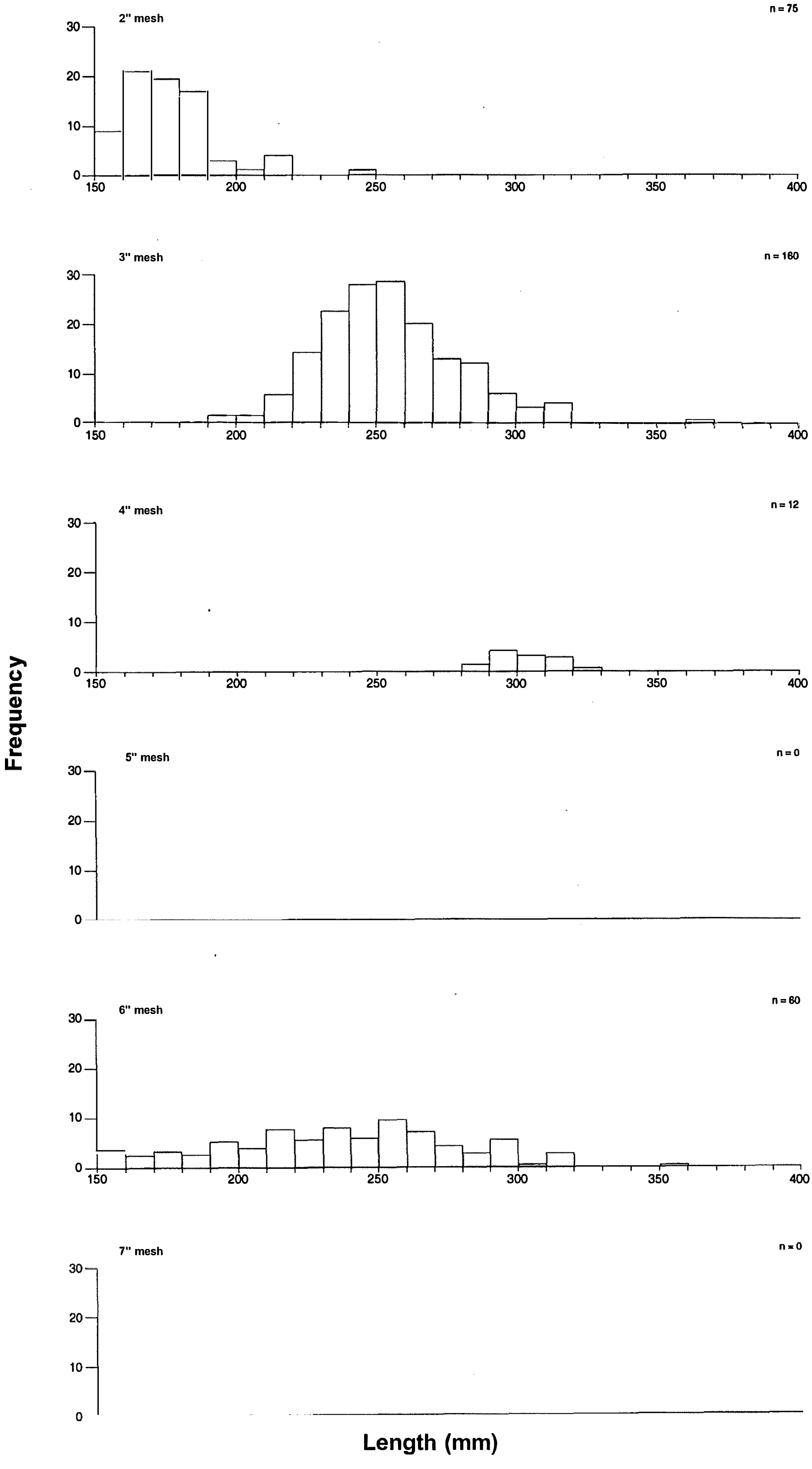


Fig. 9.2.1.19 Nemadactylus macropterus

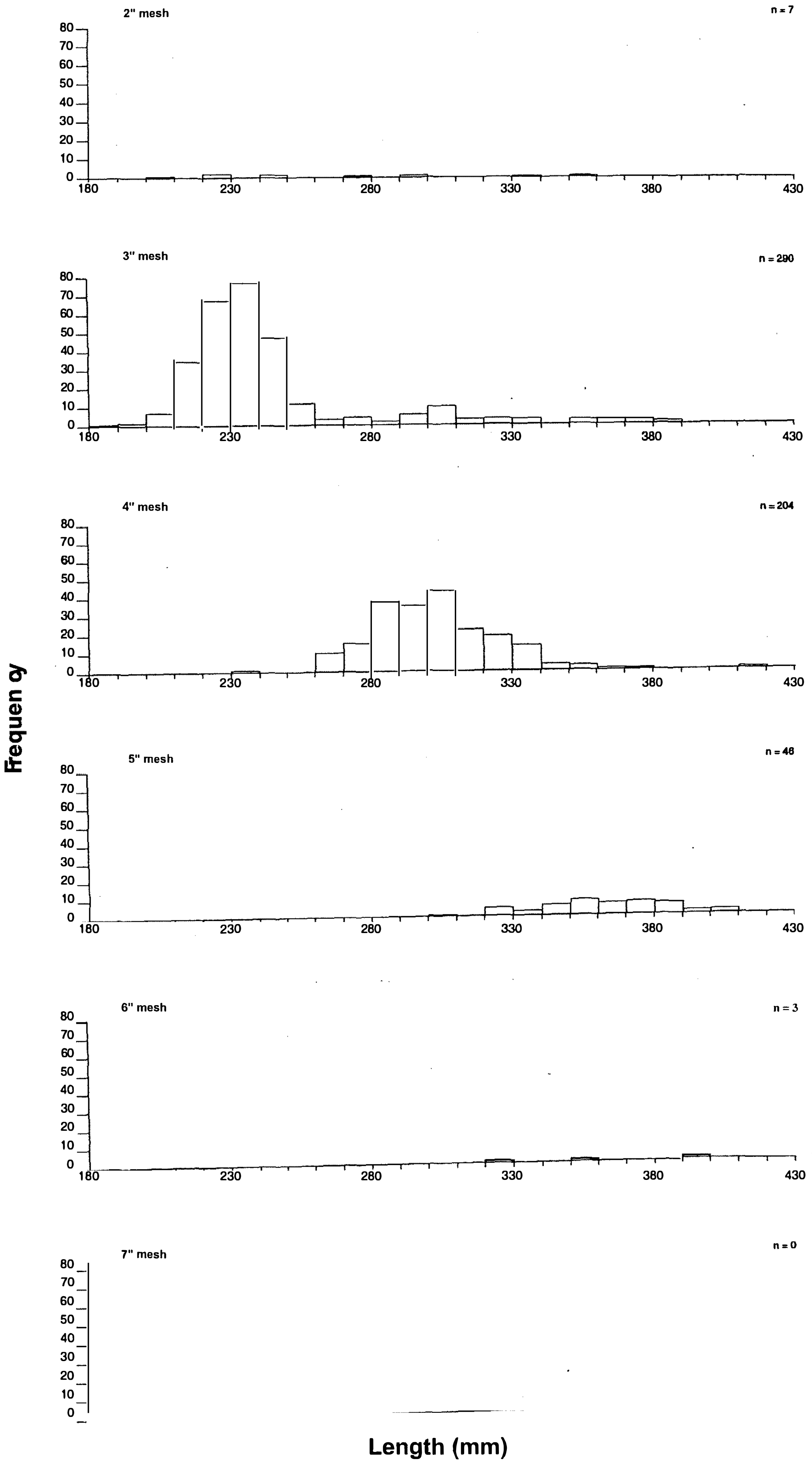


Fig. 9.2.1.20

Neoplatycephalus richardsoni

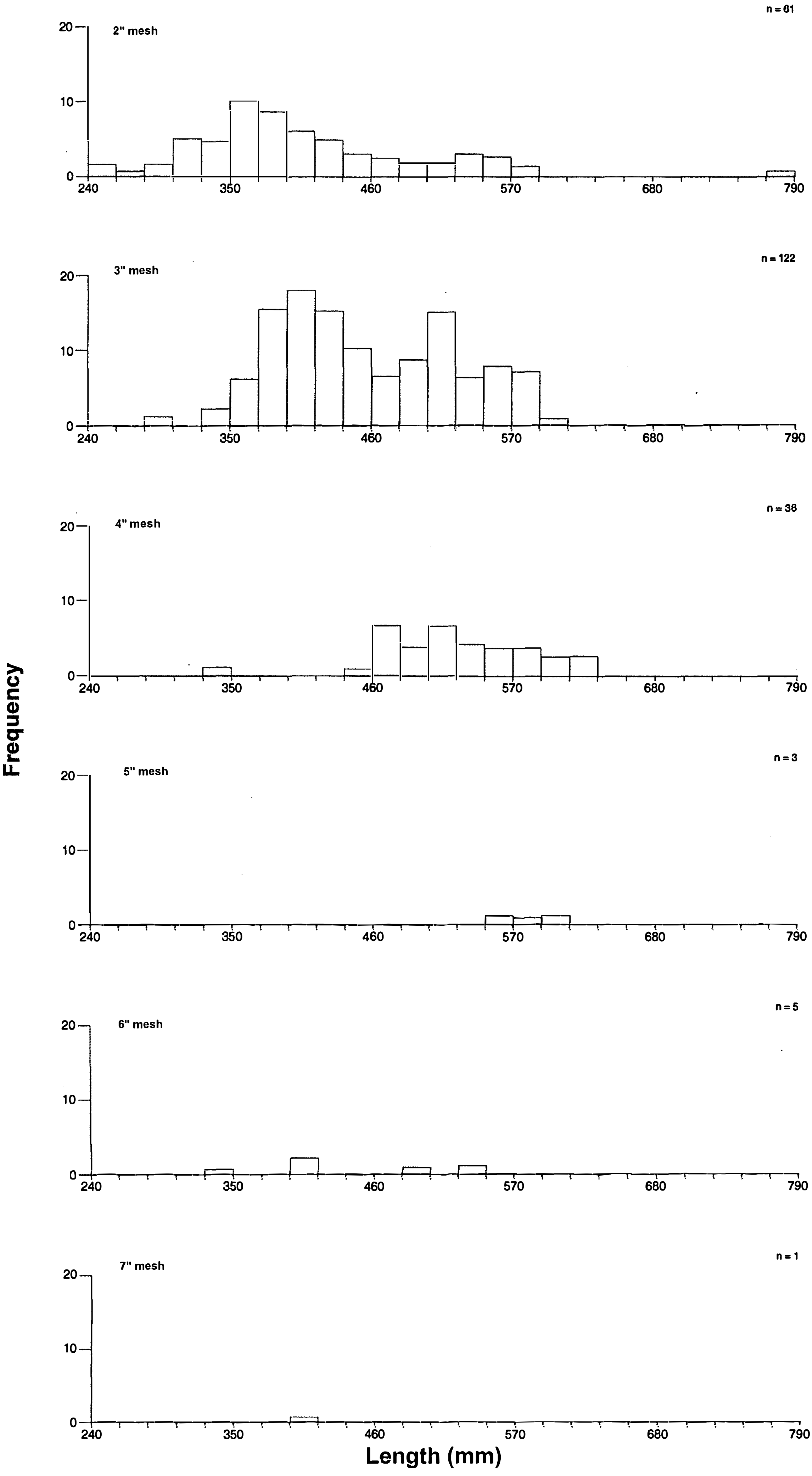


Fig. 9.2.1.21

Pseudocaranx dentex

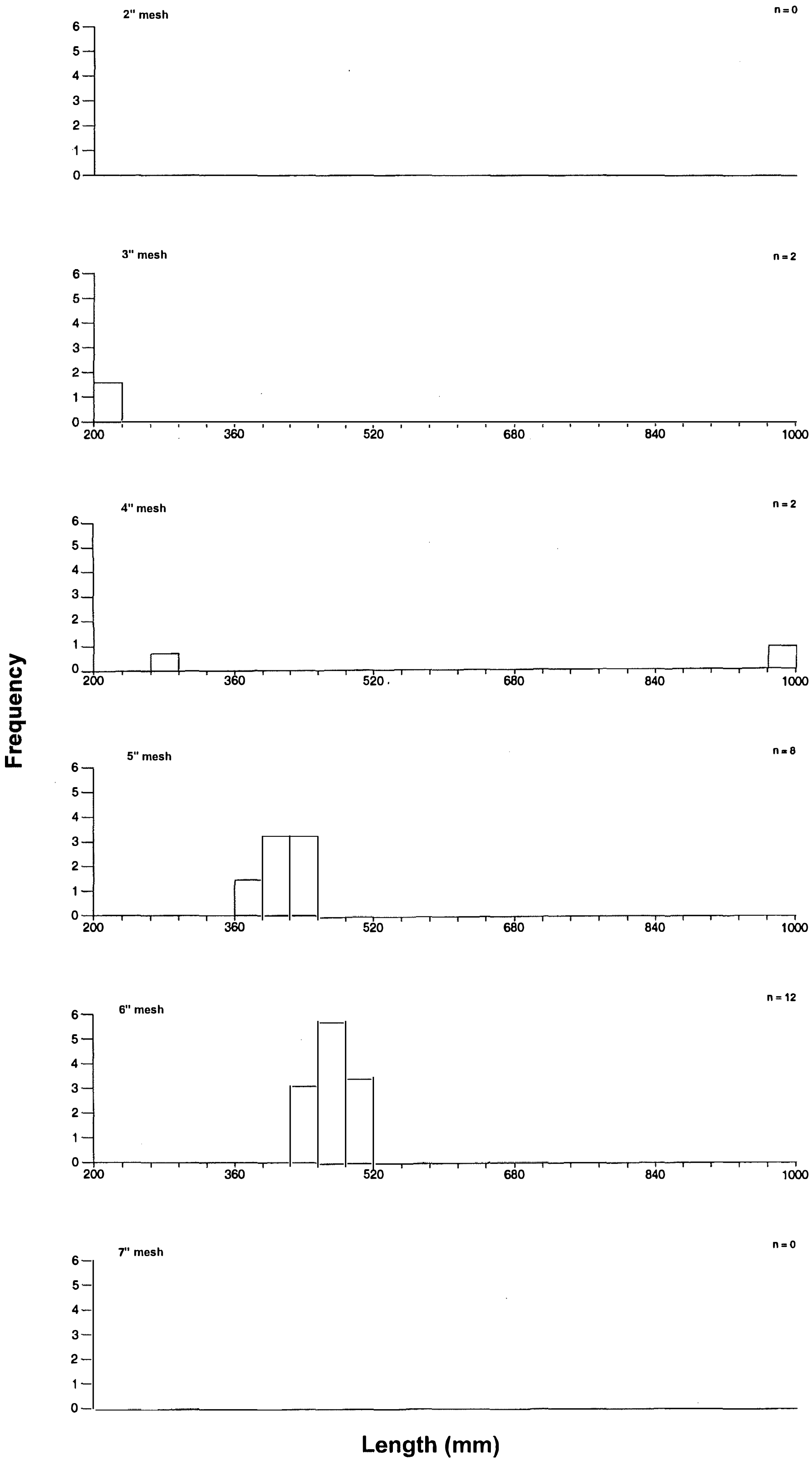


Fig. 9.2.1.22

Rexea solandri

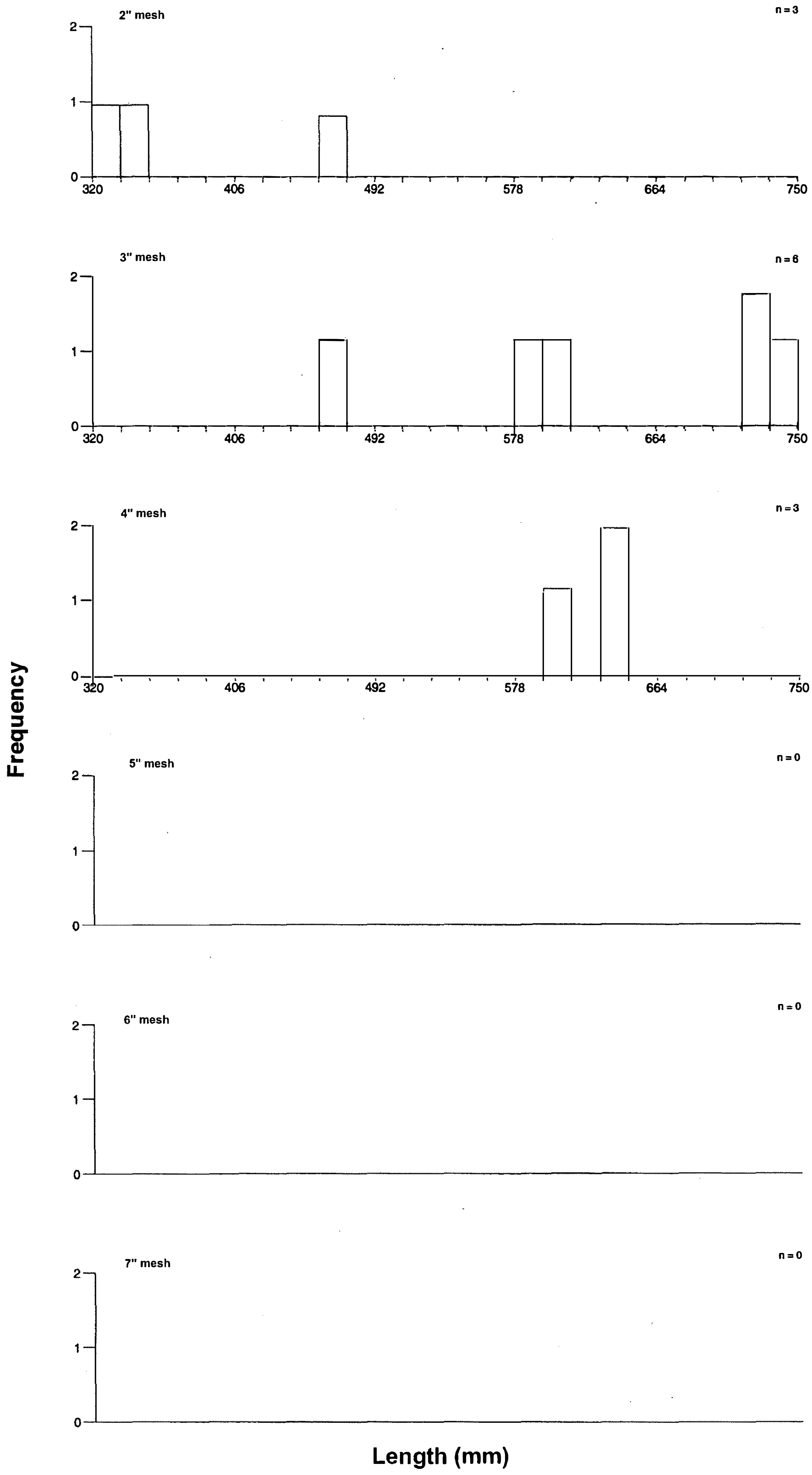


Fig. 9.2.1.23

Seriolella brama

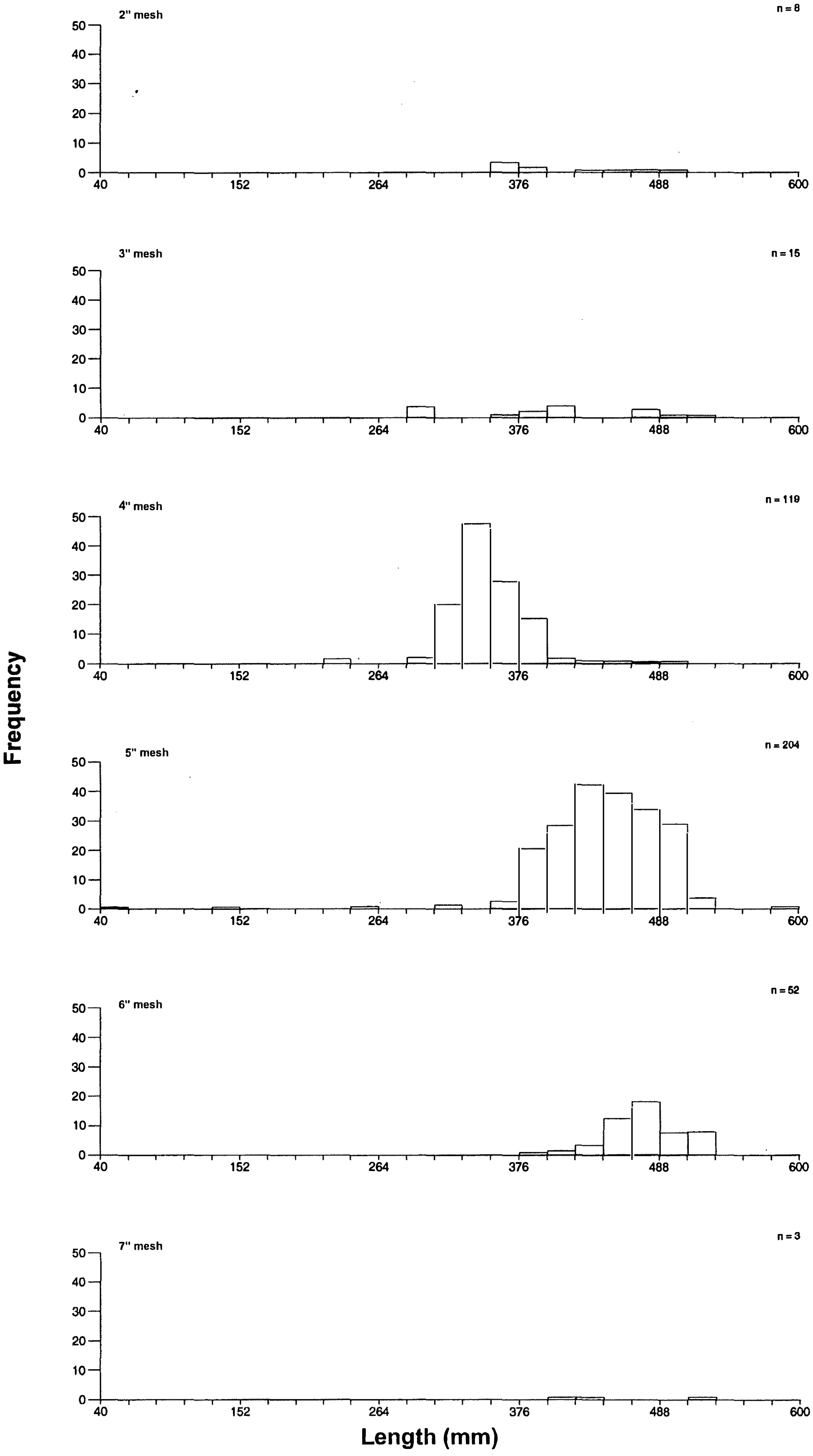
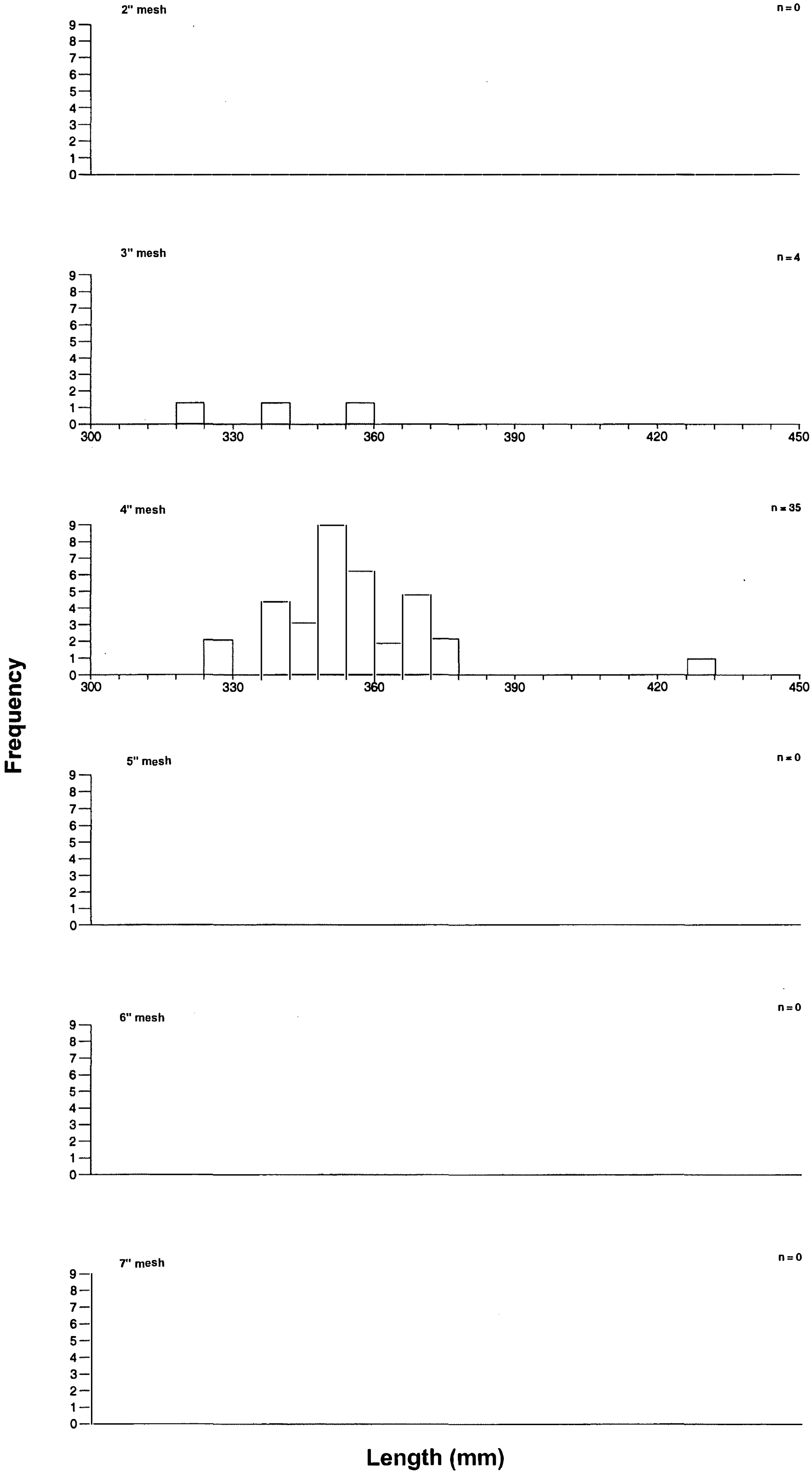


Fig. 9.2.1.24 *Seriolella punctata*



SEM images of reference otoliths were used in dietary content analysis, by comparing a combination of distinctive features of reference otoliths with otoliths from within stomachs content samples, to determine fish predator-prey relationships. Otolith images (Fig. 9.2.2.1) illustrate the variability of size and shape of otoliths, with similarities between taxonomic groupings also apparent. Descriptions of otolith morphology, relational graphs of otolith weight by fish age, and SL by fish age, together with SEM images for all reference otoliths (67 species) are included in the Otolith Guide, nearing completion as a joint publication with the Tasmanian Museum.

9.3 SUMMARY AND IMPLICATIONS

Spatial distribution of fish size by depth

The spatial distributions of demersal marine fishes which are related to many physical variables, can be examined at the level of community or species or intra-specifically. Depth is commonly, and often distinctly, related to the distribution of communities and species, and possibly also individuals of a species, based on body size. For example, increasing size with increasing depth ("bigger-deeper") is a common relationship for mesopelagic and continental-slope fishes, and some shelf fishes.

Most of the temperate Australian continental-shelf fishes susceptible to trawl sampling were insufficiently abundant to evaluate (150 of 200 species). Among the remaining 50 species, 23 showed no depth-related pattern in size structure. Of the 27 species that showed depth-related patterns, most (16) were 'bigger-deeper'. In the context of life history, this pattern indicates a cross-shelf ontogenetic migration— the progressive movement of juveniles from inner-shelf nursery areas to foraging areas on the outer-shelf and outer-shelf used by adults.

Importantly, the 16 'bigger-deeper' species included many of the key commercial species, including 9 of the 12 SEF shelf quota species: redfish, pink ling, ocean perch, morwong, tiger flathead, white trevalley, blue warehou, silver warehou and John dory. Two of the remaining quota species--gemfish and mirror dory--also show this pattern, but were classified here as 'restricted range' because the adults are most abundant in upper-slope depths (>200 m), which we did not sample. Two other bigger-deeper species are the abundant jack mackerel (*Trachurus declivis*) and spikey dogfish (*Squalus megalops*).

We conclude that ontogenetic cross-shelf migration is a successful life-history strategy that provides partitioning of habitat (depth range) and trophic resources between size (age) groups within species. It also provides adult individuals access to the most-productive shelf foraging grounds--those of the outer-shelf/ shelf-break. Here, nutrient-enrichment and transport of particulate organic material in shelf-slope upwelling are higher than in shallow water, but is localised around particular seabed topography (*Sections* 5 and 6). Cross-shelf migration also gives adults access to key forage fishes whose distributions do not extend shorewards of the outer-shelf: threespine cardinalfish (*Apogonops anomolous*) and lanternfish (*Lampanyctodes hectoris, Hygophum hanseni).*

The size structure of individuals in a species may also be incorporated in analyses of fish community structure, which typically use only the similarities in species abundances between samples to describe the spatial location and extent of communities. Species abundance, whether measured as number or weight, does not provide information on the relative size of individuals within species and therefore within communities. Substitution of simple within-species size-category variables would provide more insight to community structure in areas such as the SEF continental shelf. Size-depth relationships are of particular interest, since depth is the main variate that explains the structure of SEF shelf fish communities based on distribution of biomass (*Section* 8).

Spatial distribution of fish size by bottom type (habitat type)

Our evaluation of size distribution by depth did not consider the role of seabed type, because all samples were trawled on 'soft-ground' sediment flats. The focussed habitat sampling provided within-species size distribution data for different seabed types, particularly reefs.

Size-distribution patterns were more difficult to classify in focussed-habitat data than in broad-scale data, mainly because the numbers of individuals were small. This was particularly true for 'rough- ground' habitats sampled by gillnet and trap; for example, the sample sizes of silver warehou and white trevally were too small to evaluate. In addition, depth was a confounding variable with habitat, and habitats were sampled with multiple gears that had different selectivities.

Of interest was whether the bigger-deeper pattern common to quota species on sediment flats was also evident in samples from focussed habitat sampling, which included hard-ground ('rough') habitat types. The pattern appeared to be preserved in redfish, pink ling, ocean perch and tiger flathead, although sample sizes were small. In blue warehou, where the sample size was intermediate, the pattern was unclear. In contrast, in morwong (where the sample size was relatively large), proportionally more small individuals (< 250 mm) were found deeper on reef habitat than sediment-flat habitats. The life-history pattern of ontogenetic cross-shelf migration common to these species is, therefore, affected by habitat in different ways. All the above species use both sediment-flat and hard-ground habitats (Table 8.2.4.9), which possibly represents the use of flats for foraging and the hard ground for refuge. In morwong, however, it appears that smaller individuals use hard-grounds to safely penetrate deeper (Appendix Figure 9.2.1.12) where foraging grounds are most productive (*Sections* 5 and 6).

Selectivity: gear and habitat

The three gears used had markedly different selectivities for most species. Trawl was most effective overall for quota species (redfish, pink ling, ocean perch, morwong, tiger flathead and blue warehou), with traps the least effective (catching only morwong in quantity). Tiger flathead, pink ling and blue warehou, and to a lesser extent redfish, were vulnerable to gillnet, but only morwong were vulnerable to all three gears. Size selectivity was not strong between gears for redfish or morwong, but the trawl caught more smaller pink ling and flathead than the gillnet. Mesh selectivity of the gillnet, which was strong for all species, is being evaluated as a separate project.

Length-frequency profiles by depth combined with length-age relationships shows that most individuals of quota species caught at shallower than 120 m depth are immature (Table 9.3.1.1). The patterns vary between species, but all show that few large, mature fish are caught shoreward of this depth. In species that migrate to upper slope waters (e.g. pink ling), all individuals on the shelf are immature. Our data are combined across seasons and therefore do not represent the spatial variations of species through time; it is known that larger fish migrate to shallow waters under certain environmental conditions (e.g. blue warehou in Disaster Bay).

Figure 9.2.2.1 Reference otoliths

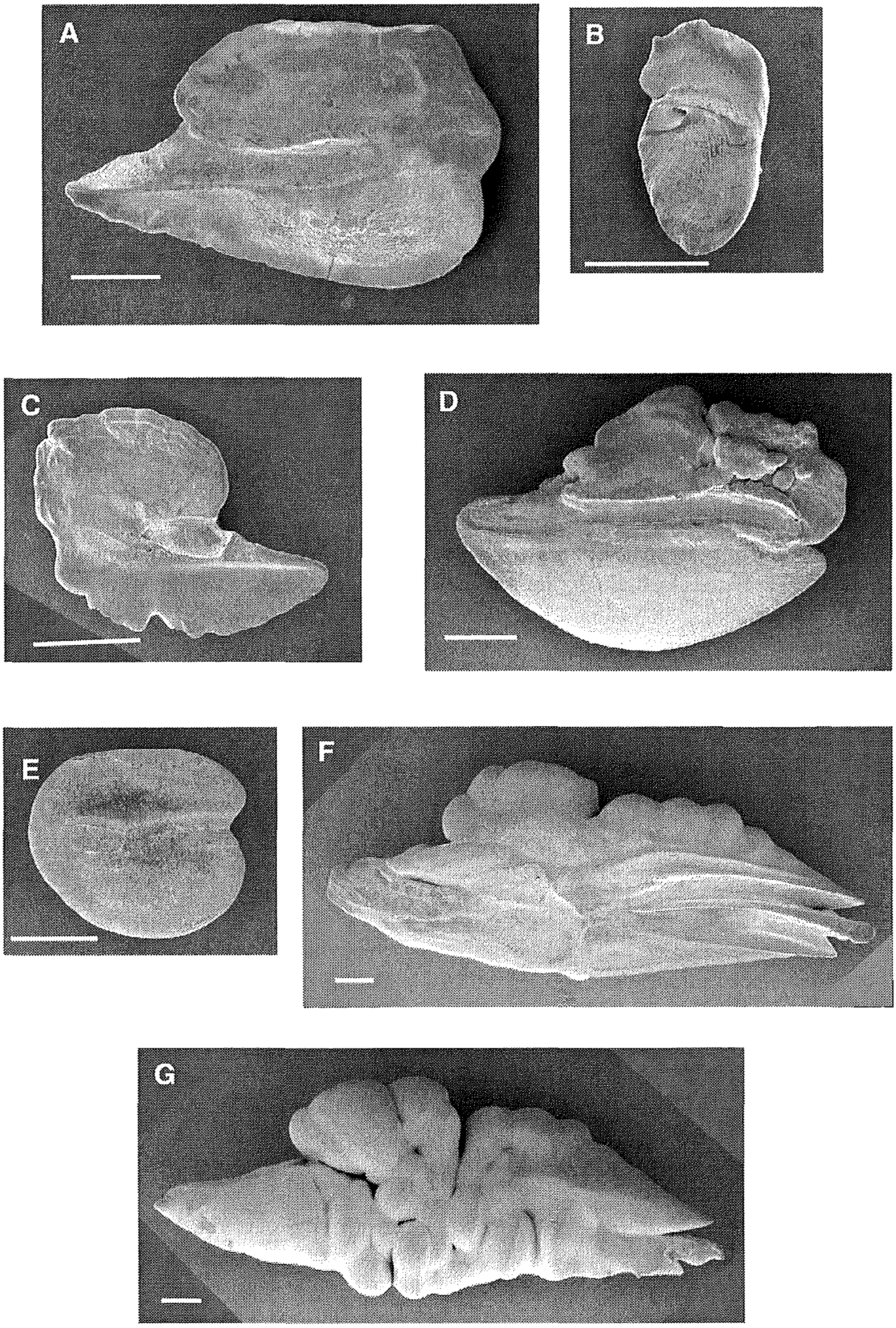


Table 9.3.1.1 Summary of spatial distribution of quota species by body size. General distribution pattern on sediment flat habitats (broad-scale sampling showing outer bathymetric boundary of immature size classes, and influence of bottom type. For length/depth patterns: B/D = Bigger/deeper; R/R = Restricted range.
For location of juvenile fish: refer section 8.2.4.

Common name	Species	Age at maturity (years)	Length at maturity* (cm)	Length/depth patterns	Depth at which 95% and 50% of population is immature: ~95%	~50%	Is length/depth pattern influencec by bottom type?	Primary location of juvenile fish
Redfish	*Centroberyx affinis*	5 to 7	17-21	B/D	≤120	≤200	NO	I, (OS)
Ling	*Genypterus blacodes*		72	B/D	<200	~200	NO	Shelf
Ocean perch	*Helicolenus percoides*		30	B/D	<120	~200	NO	Shelf
Morwong	*Nemadactylus macropterus*	3	25	B/D	<80	80	YES	IS, OR
Tiger flathead	*Neoplatycephalus richardsoni*	3 to 5	30-35	B/D	≤40	80	YES	IS, (OS)
Trevally	*Pseudocaranx dentex*	4 to 5	32-37	B/D ***	<80	120	YES	IS ***
Blue Warehou	*Seriolella brama*	3	40	B/D	<120	~200	YES	IS, IR, OR
Silver warehou	*Seriolella punctata*	3 to 4	40	B/D	≤120	~200	NO	O
John dory	*Zeus faber*	3 to 5	20-30	B/D	≤80	≤120	NO	?
Gemfish	*Rexea solandri*	5	60	R/R (≥200 m) ***	N/A **	N/A	***	Shelf
Mirror dory	*Zenopsis nebulosus*	5	35	R/R (>120 m)	≤120 **	<200		Shelf
Eastern school whiting	*Sillago flindersi*	2	10	R/R (≤80)	N/A	N/A	***	?

* Maximum length of both sexes at maturity

** Small numbers of immature fish at shelf-break

*** Small sample size only

Large numbers of smaller specimens of commercial fish are discarded in certain areas of the SEF. This could be reduced if trawlers avoided shallower habitats. However, in some areas or conditions (e.g., periods of poor weather), this would result in the loss of marketable sizes of other species. While projects are underway to reduce discarding in the SEF through gear design, it is clear that there is also the potential to reduce discarding by redirecting effort away from areas or periods where smaller (non-marketable) fish are abundant.

Implications

1. Over the trawl-grounds (sediment flats) of this area of the SEF shelf, a 'bigger-deeper' pattern of size distribution with depth is common to the main quota and commercial shelf species that extend across the shelf (redfish, pink ling, ocean perch, morwong, tiger flathead, white trevalley, blue warehou, silver warehou and John dory). We interpret this ontogenetic cross-shelf migration as a successful life-history strategy that provides (1) partitioning of habitat (depth range) and trophic resources between size (age) groups within species, and (2) gives adult individuals access to the most-productive shelf foraging grounds at the outer-shelf and shelf-break.

2. The way in which the bigger-deeper pattern was influenced by including hard-ground samples varied between species. While the pattern appeared to be preserved in redfish, pink ling, ocean perch and tiger flathead, proportionally more small morwong occurred on deep reef than sediment-flat habitats. This indicates that hard-grounds may be important to smaller individuals of some species by enabling them to penetrate deeper to the most-productive shelf foraging grounds offshore.

3. There is a strong size-structured spatial distribution common to the primary commercial species in the SEF: 95% of each quota species caught on these surveys at less than 40 m depth were immature, 50% caught at less than 80 m depth were immature.

4. The change in size with depth provides an opportunity to reduce the probability of trawl nets capturing or damaging juvenile fish. While technical measures to reduce the capture of smaller fish are being developed in a multi-agency FRDC project, they are unlikely to be successful for all species in this complex multispecies fishery. A combination of technology and avoidance of waters where juveniles are abundant could further reduce capture or damaging of small fish.

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Figure legends

Fig. 9.2.1.1	*Centroberyx affinis*: plot of length-frequency distribution by depth (25 m to ~200 m depth range) from broad-scale sampling data. (n = standardised numbers)
Fig. 9.2.1.2	*Genypterus blacodes*: plot of length-frequency distribution by depth (25 m to ~200 m depth range) from broad-scale sampling data. (n = standardised numbers)
Fig. 9.2.1.3	*Helicolenus percoides*: plot of length-frequency distribution by depth (25 m to ~200 m depth range) from broad-scale sampling data. (n = standardised numbers)
Fig. 9.2.1.4	*Nemadactylus douglasi*: plot of length-frequency distribution by depth (25 m to ~200 m depth range) from broad-scale sampling data. (n = standardised numbers)
Fig. 9.2.1.5	*Nemadactylus macropterus*: plot of length-frequency distribution by depth (25 m to ~200 m depth range) from broad-scale sampling data. (n = standardised numbers)
Fig. 9.2.1.6	*Neoplatycephalus richardsoni*: plot of length-frequency distribution by depth (25 m to ~200 m depth range) from broad-scale sampling data. (n = standardised numbers).
Fig. 9.2.1.7	*Pseudocaranx dentex*: plot of length-frequency distribution by depth (25 m to ~200 m depth range) from broad-scale sampling data. (n = standardised numbers)
Fig. 9.2.1.8	*Rexea solandri*: plot of length-frequency distribution by depth (25 m to ~200 m depth range) from broad-scale sampling data. (n = standardised numbers)
Fig. 9.2.1.9	*Seriolella brama*: plot of length-frequency distribution by depth (25 m to ~200 m depth range) from broad-scale sampling data. (n = standardised numbers)
Fig. 9.2.1.10	*Seriolella punctata*: plot of length-frequency distribution by depth (25 m to ~200 m depth range) from broad-scale sampling data. (n = standardised numbers)
Fig. 9.2.1.11	*Sillago flindersi*: plot of length-frequency distribution by depth (25 m to ~200 m depth range) from broad-scale sampling data. (n = standardised numbers)
Fig. 9.2.1.12	*Squalus megalops*: plot of length-frequency distribution by depth (25 m to ~200 m depth range) from broad-scale sampling data. (n = standardised numbers)
Fig. 9.2.1.13	*Trachurus declivis*: plot of length-frequency distribution by depth (25 m to ~200 m depth range) from broad-scale sampling data. (n = standardised numbers)
Fig. 9.2.1.14	*Zeus faber*: plot of length-frequency distribution by depth (25 m to ~200 m depth range) from broad-scale sampling data. (n = standardised numbers)

Fig. 9.2.1.15 *Zenopsis nebulosus*: plot of length-frequency distribution by depth (25 m to ~200 m depth range) from broad-scale sampling data. (n = standardised numbers)

Fig. 9.2.1.16 *Centroberyx affinis*: plot of length-frequency distribution by mesh-size (2" to 7" mesh) from gillnet sampling data. (n = standardised numbers).

Fig. 9.2.1.17 *Genypterus blacodes*: plot of length-frequency distribution by mesh-size (2" to 7" mesh) from gillnet sampling data. (n = standardised numbers).

Fig. 9.2.1.18 *Helicolenus percoides*: plot of length-frequency distribution by mesh-size (2" to 7" mesh) from gillnet sampling data. (n = standardised numbers).

Fig. 9.2.1.19 *Nemadactylus macropterus*: plot of length-frequency distribution by mesh-size (2" to 7" mesh) from gillnet sampling data. (n = standardised numbers).

Fig. 9.2.1.20 *Neoplatycephalus richardsoni*: plot of length-frequency distribution by mesh-size (2" to 7" mesh) from gillnet sampling data. (n = standardised numbers).

Fig. 9.2.1.21 *Pseudocaranx dentex*: plot of length-frequency distribution by mesh-size (2" to 7" mesh) from gillnet sampling data. (n = standardised numbers).

Fig. 9.2.1.22 *Rexea solandri*: plot of length-frequency distribution by mesh-size (2" to 7" mesh) from gillnet sampling data. (n = standardised numbers).

Fig. 9.2.1.23 *Seriolella brama*: plot of length-frequency distribution by mesh-size (2" to 7" mesh) from gillnet sampling data. (n = standardised numbers).

Fig. 9.2.1.24 *Seriolella punctata*: plot of length-frequency distribution by mesh-size (2" to 7" mesh) from gillnet sampling data. (n = standardised numbers).

Fig. 9.2.2.1 Reference otoliths: (A) *Photicthys argenteus* otolith from fish of standard length 223 mm; (B) *Argyropelecus gigas* otolith, standard length not recorded; (C) *Persparsia kopua* otolith from fish of standard length 122 mm; (D) *Chloropthalmus nigripinnis* otolith ; (E) *Lampanyctus australis* otolith from fish of standard length 103 mm; (F) *Pseudophycis bacchus* otolith from fish of standard length 356 mm; proximal surface; (G) *Pseudophycis bacchus* otolith, distal surface.

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10 TROPHODYNAMICS

Cathy Bulman, Stevie Davenport and Franzis Althaus

In the previous sections, we have established that the fishes on the southeast Australian shelf form distinct consistent communities, are associated with particular habitat types, and undergo ontogenetic shifts in at least one habitat variable–depth. Consistent adaptations must have a selective advantage, such as refuge from predators, reduced of competition through specialised feeding opportunities, hydrodynamic advantage caused by habitat topography, or just a point to aggregate with others of the same species. Our aim in this section is to examine two possible selective pressures, competition and predation.

10.1 METHODS

Two data types were collected to achieve the goals of this section. First, a broad-scale collection of fish stomachs and fish tissue was used to generate an overall picture of the dominant dietary trends in the study area, and how these related to primary production through isotopic pathways. These broad-scale data were also used to examine whether the observed ontogenetic changes in depth distribution for many fish species were reflected in ontogenetic changes in diet. Second, stomachs from a select group of abundant fish, covering several feeding types were collected from different habitat types to determine if diet was linked to habitat.

10.1.1 Fish Diets–Broad Scale Surveys

The broad-scale surveys provided samples for seasonal and geographical comparisons of diet as well as overall diet descriptions (refer *Section* 4.1.1). Collections for the specific habitat surveys are described below. Overall, 70 species were examined for broad dietary descriptions (see Table 9.1.1.1. for species listing). The 12 SEF quota species and another 16 abundant species were targeted for more detailed diet analyses. Collections were made throughout each survey, so that where possible, a range of depths, time, geographical locations and size of fish were sampled for each species. From each tow, stomachs were removed from up to ten fish per selected species. A maximum of 50 stomachs per species per cruise was taken. Large stomachs were frozen at -20°C and small stomachs were preserved in 10% formalin. Biological details such as length, weight and sex of donor fish were recorded.

In the laboratory, stomachs were assessed for fullness and then dissected. Prey items were identified to the lowest possible taxon. Items were counted, blotted on absorbent paper to remove excess moisture and weighed (to 0.001 g in the case of very small items). Fish digested beyond recognition, were identified from otoliths if possible (see *Section* 9.1.2). Squid beaks were identified by Dr C.C. Lu. No attempts were made to back-calculate sizes of animals from otolith or beak sizes.

Diets were described by determining the proportions of prey by wet weight in stomachs containing food. Prey items were aggregated to form categories on which further analyses were performed. The categories were:

- benthic invertebrates e.g. echinoderms, benthic ascidians, ectoprocta
- polychaetes
- benthic crustaceans e.g. isopods, some shrimps, amphipods
- megabenthos e.g. crabs, molluscs including octopus
- benthic fish
- benthopelagic fish
- pelagic fish
- pelagic invertebrates e.g. tunicates, squid, pelagic ascidians
- pelagic crustaceans e.g. shrimps, euphausids, copepods
- other e.g. sediment, macroalgae, seagrasses
- unknown fish
- unknown crustaceans
- unknown invertebrates
- unknown.

None of the unknown categories was used in the cluster analyses and species were deleted from the analysis if these categories constituted more than 60% of their diet. The remaining species were clustered on Bray-Curtis dissimilarity coefficients and an average linkage clustering algorithm (UPMGA) (SPSS v 6.1 1994).

The diets of a subset of 28 species, including the 12 SEF quota species and 16 species of commercial or ecological interest, were examined to determine the importance of benthic and pelagic sources of prey, and the importance of quota fish species as prey. Benthopelagic prey were classed as pelagic sources as they too probably derived their food sources from pelagic sources. Ontogenetic variations in diets of the species in this group were investigated using Kendall's concordance tests (Zar 1984).

10.1.2 Fish Diets–Focussed Habitat Surveys

To characterise fish diet in the different macrohabitats (see *Section* 4.1.2. & Fig. 4.1.2.1.), five species were chosen that were most likely available in most macrohabitats and were thought a priori to represent a range of feeding habits. The species chosen were John dory (*Zeus faber*), ocean perch (*Helicolenus percoides*), common snipefish (*Macroramphosus scolopax*), morwong

(*Nemadactylus macropterus*) and redfish (*Centroberyx affinis*). Collections for this study were made similarly to the broad-scale survey during SS9602 and SS9606. On board commercial boats, (SF9701 and EJ9602), whole fish were collected and frozen. Later, in the laboratory, stomachs were removed from these fish and biological details of donor fish recorded. The data were analysed specifically to determine whether the same fish species had a significantly different diet in the different habitats using Kendall's concordance W (Zar 1984). Fish diets between macrohabitats were also compared by clustering the dietary data on Bray Curtis dissimilarity coefficients and an average linkage clustering algorithm (UPGMA) (SPSS Inc, 1994).

Common or important commercial species which could not be caught by trawls, were often caught with gillnets and were also collected and sampled for diet in the same manner as described for the broad scale survey (previous section). These data were added to the data set of the broad scale survey in order to give an overall dietary description.

10.1.3 Stable Isotopes and Trophic Levels

Samples of fishes, invertebrates, phytoplankton and seals were collected during the CSIRO surveys in the SEF for stable nitrogen and stable carbon isotope analyses. These samples were supplemented to include species that were not collected by *Southern Surveyor* during the SEF surveys e.g. inshore pelagics (*Sardinops neopilchardus*) provided by MAFRI; offshore pelagics (*Gasterochisma melampus*) provided by CSIRO colleagues; seabirds (little penguins) provided by Dr Peter Dann of the Phillip Island Penguin Reserve, and Dr David Obendorf following the Iron Baron oil spill off northern Tasmania in 1995; cetacean samples (from species that occur in the SEF) from strandings around Tasmania provided by Deborah Thiele and Karen Evans. Marine mammal and bird samples were collected opportunistically from animals that had died of natural causes. Samples were frozen following collection until prepared for analysis.

Muscle tissue was taken from the vertebrates (from fish: white muscle from the caudal region); in the case of invertebrates, the whole animal was used unless it was too large or had a hard shell or test. Samples were thawed, all surfaces were trimmed of outside tissue to reduce possible contamination, and the remaining tissue was cut into small pieces, dehydrated (in an oven at 60°C for 2 days), and ground into a fine powder. The samples were then analysed for stable isotopes of carbon and nitrogen according to the methods outlined in *Section* 6.1.1.

10.2 RESULTS AND DISCUSSION

10.2.1 Fish Diets–Broad Scale Surveys

General description

Diets of the fishes examined are represented graphically by survey in Appendix Tables 10.2.1.1-42. Composite diets for all species are shown in Fig. 10.2.1.1. In many cases the diets appear to differ greatly between surveys which is usually due to low numbers caught during those cruises and possibly to different habitats and methods of capture.

Of the 70 species, about one third were piscivorous. Within families, diets could vary markedly. Three of the four dories (Appendix Tables 10.2.1.13 & 14) were piscivores whereas the New Zealand dory *Cyttus novaezelandiae* (Appendix Tables 10.2.1.14) ate only pelagic crustaceans. In the Triglidae, three species, *Chelidonichthys kumu, Lepidotrigla vanessa* and *Pterygotrigla polyommata* (Appendix Tables 10.2.1.18 & 19) ate mainly benthic fish whereas two other were invertebrate feeders: *L. mulhalli* was a benthopelagic feeder and *L. modesta* was a benthic feeder (Appendix Table 10.2.1.19). In the Scorpaenidae, ocean perch *Helicolenus percoides* (Appendix Table 10.2.1.16) and the closely-related perch species, *H. barathri* (Appendix Table 10.2.1.17), ate fish, pyrosomes, crabs, cephalopods and shrimps but the former ate a larger proportion of pelagic prey. In contrast, the ruddy gurnard perch *Neosebastes scorpaenoides* ate more benthic prey such as crabs, gastropods and benthic fish (Appendix Table 10.2.1.17). In the serranid family, the butterfly perch *Caesioperca lepidoptera* (Appendix Table 10.2.1.23) ate benthic prey such as ascidians, coral and polychaetes and pelagic shrimps, copepods and pyrosomes. In contrast, the barber perch *C. rasor* (Appendix Table 10.2.1.23) and *L. pulchella* (Appendix Table 10.2.2.22) were piscivores, probably benthopelagic, and *Apogonops anomalus* was a pelagic piscivore (Appendix Table 10.2.1.22).

Both tiger and sand flathead, *Neoplatycephalus richardsoni* and *Platycephalus bassesnis*, were piscivores (Appendix Tables 10.2.1.20 & 21) but the former ate benthopelagic fish while the latter ate benthic fish. Pink ling *Genypterus blacodes*, barracouta *Thyrsites atun* and gemfish *Rexea solandri* all ate fish predominantly (Appendix Tables 10.2.1.10 & 36). Jack mackerel *Trachurus declivis* and yellowtail scad *T. novaezelandiae* (Appendix Table. 10.2.1.25) ate fish and pelagic crustaceans such as euphausid. Similarly, redfish *Centroberyx affinis* (Appendix Table 10.2.1.12) ate pelagic fish and crustacea. The spikey dogfish *Squalus megalops* (Appendix Table 10.2.1.3) and draughtboard shark *Cephaloscyllium laticeps* (Appendix Table 10.2.1.1) both ate fish and cephalopods predominantly. Both warehous ate mostly pyrosomes (Appendix Tables 10.2.1.37 & 38).

The remaining species were mostly benthic or benthopelagic omnivores or invertebrate feeders. Two of the leatherjackets *Mueschenia scaber* and *M. freycineti* (Appendix Table 10.2.40) and the common stinkfish *Synchiropus calauropomus* (Appendix Table 10.2.1.35) were among the most benthic predators eating mostly corals, ectoprocta (bryozoa), echinoderms crabs and gastropods. The diodontids fed mostly on crabs, bivalves and gastropods (Appendix Table 10.2.1.42). Similarly, the starry toadfish *Arothron firmamentum* (Appendix Table 10.2.1.42) was largely an epibenthic invertebrate feeder. All four whiptails (Appendix Table 10.2.1.11) fed predominantly on polychaetes, echinoderms and gastropods. The common snipefish *Macrorhamphosus scolopax* (Appendix Table 10.2.1.15) ate mostly copepods and amphipods. The four stingarees, *Urolophus* species, ate polychaetes and a mixture of benthic and pelagic crustacea (Appendix Tables 10.2.1.5-8).

Guild structure

Overall diets were calculated, and amalgamated into the broad prey categories for cluster analysis (Fig. 10.2.1.1). The following guilds were identified from the dendrograms and MDS scatterplots produced from the cluster analysis of the 70 species for which the diets were mostly known, (Fig. 10.2.1.2 & 3):

benthic piscivores–ate predominantly fish of benthic origin

benthopelagic piscivores–ate predominantly fish of benthopelagic origin

pelagic piscivores and omnivores-ate predominantly pelagic fish and other pelagic prey

benthic invertebrate feeders & omnivores–ate predominantly invertebrates living on or just above the bottom including fish

benthopelagic omnivores–ate a wide variety of prey types of benthopelagic origin, including less than 30% fish

pelagic invertebrate feeders–ate predominantly invertebrates of pelagic origin e.g. pyrosomes

pelagic crustacean feeders & omnivores–ate predominantly pelagic crustaceans and sometimes fish.

mixed group whose diet consisted predominantly of unknown prey and therefore were not grouped.

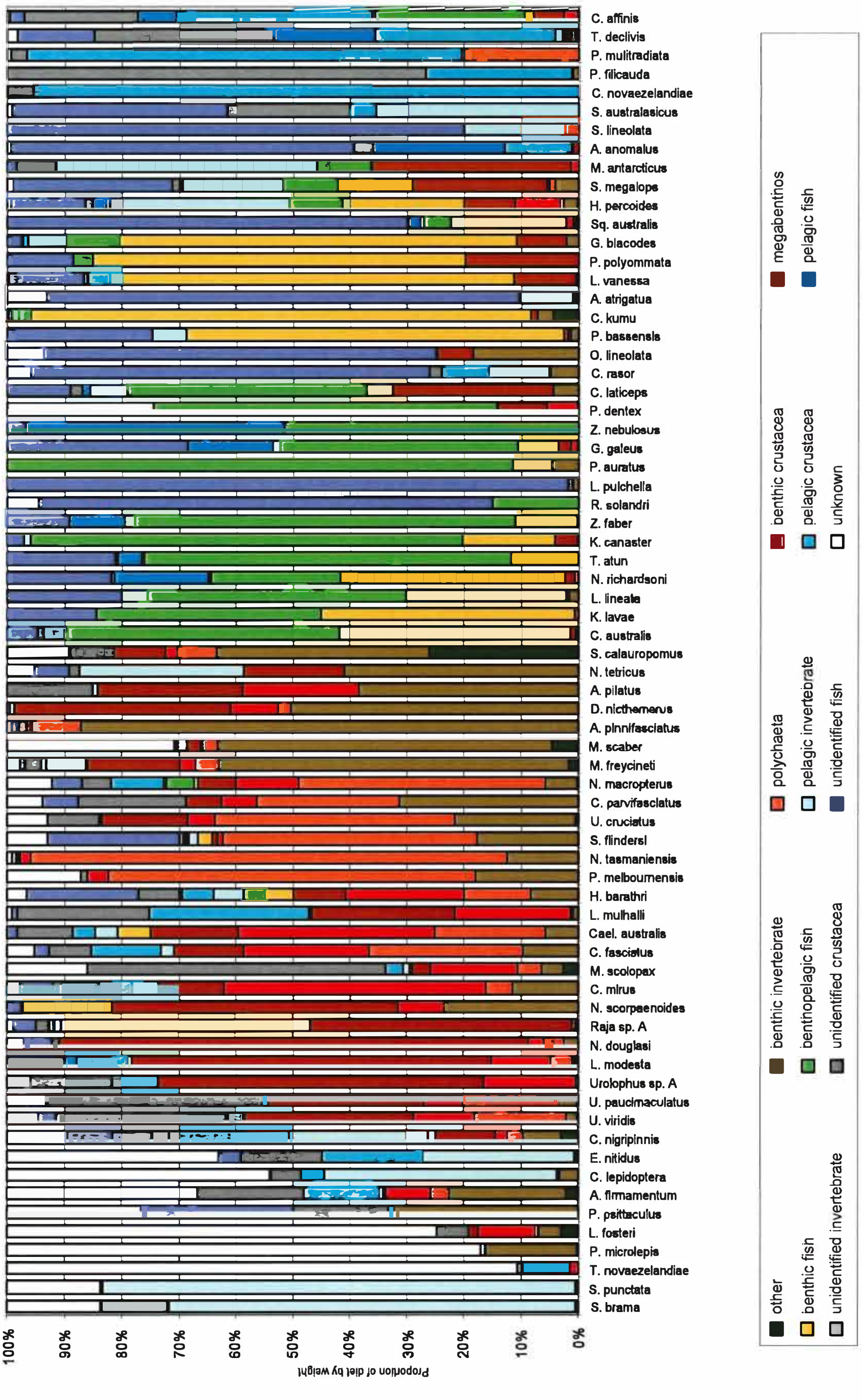


Fig 10.2.1.1. Overall diet composition (% weight) of 70 species in the South East Fishery, with prey grouped in functional categories.

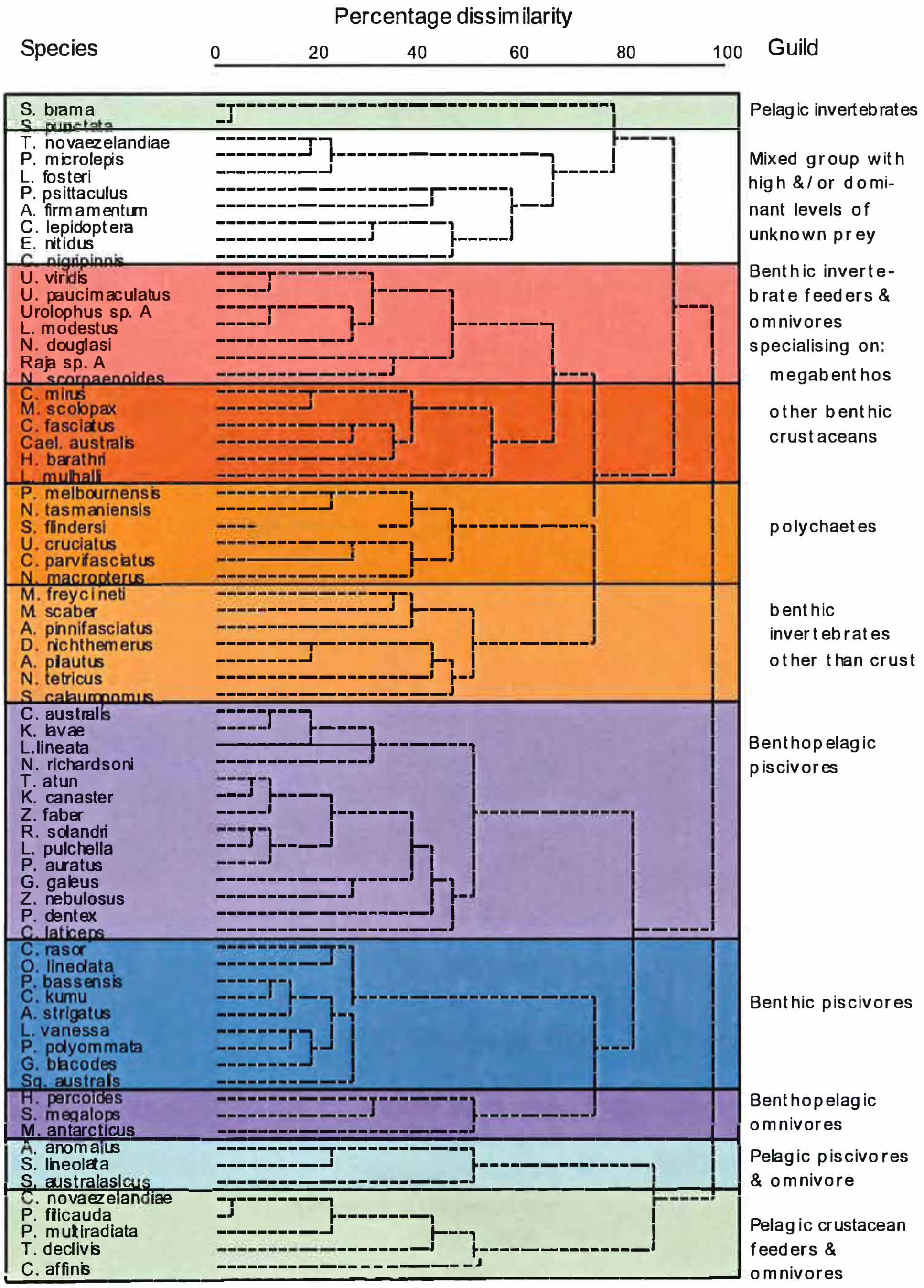


Figure 10.2.1.2. Dendrogram of the cluster analysis based on the diet composition of 70 species in the SEF ecosystem.

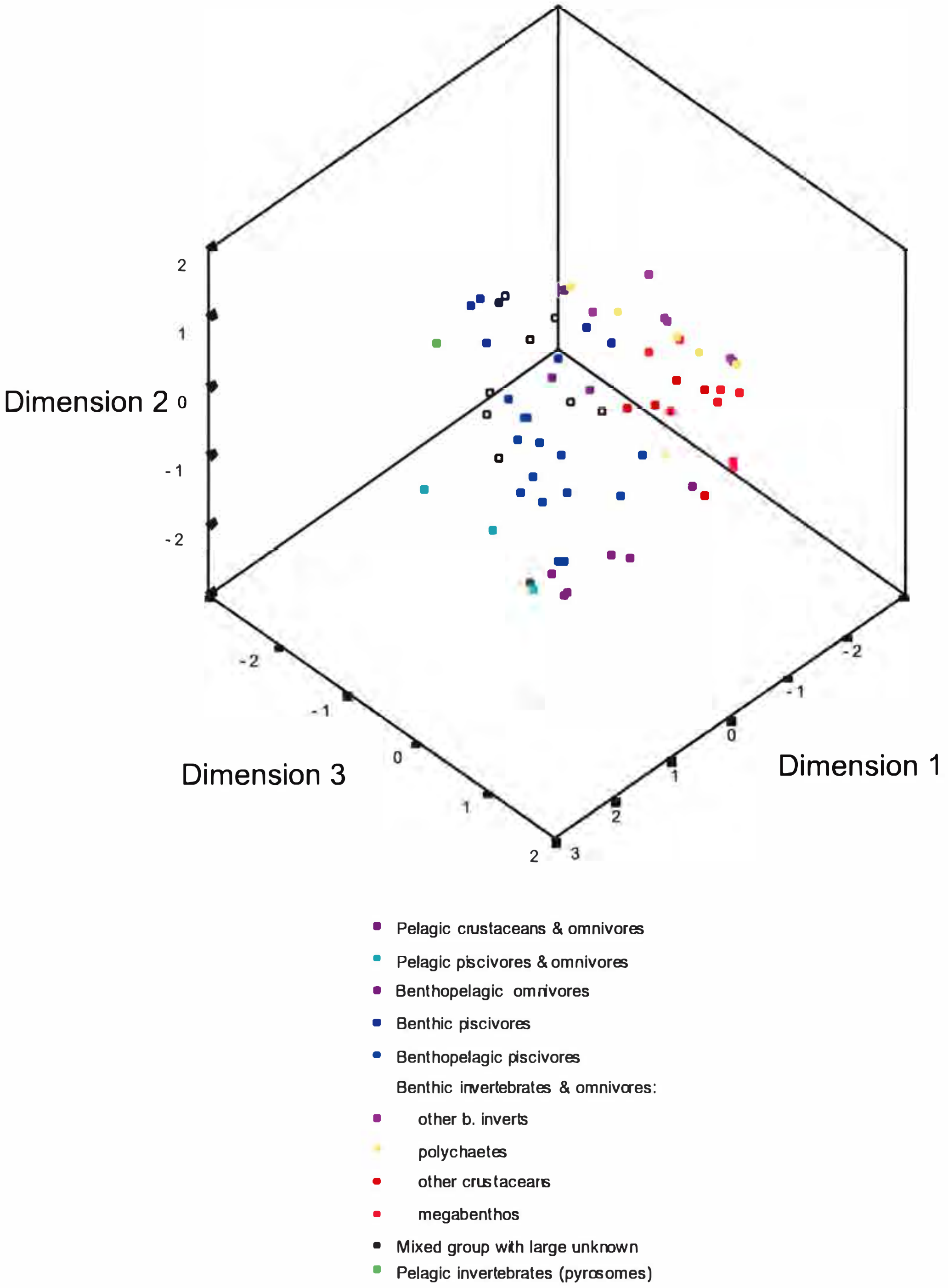


Figure 10.2.1.3. Three-dimensional scatterplot of 70 SEF species based on a cluster analysis of diet composition. Functional prey categories used were: other, pelagic invertebrates, pelagic crustaceans, pelagic fish, benthopelagic fish, benthic fish, megabenthos, other benthic crustaceans, benthic invertebrates, polychaetes, unknown. Legend indicates the groups identified by the cluster analysis.

The dendrogram arrangement largely agreed with the 3-dimensional MDS plots but the complexity determining the grouping of some of the omnivorous or invertebrate feeding species was not always as obvious as in the cluster analysis. The multidimensional scatterplots confirmed the interpretation of species guilds and the analysis was robust (Kruskal stress factor=0.17, R2=0.79).

Some species were grouped inappropriately because not enough data were available to properly describe their diets and correctly classify them. These species clustered in the "mixed group". A few species could be misappropriately clustered because the reproportioned data might misrepresent their real feeding preferences, i.e. benthic, benthopelagic or pelagic. Also, these data are based on proportion by weight, which might overemphasise larger, rarer prey items or underemphasise smaller, more common prey items, and perhaps give a false impression of the guild to which the fish actually belongs.

The groups containing the benthopelagic and benthic piscivores clearly differentiated in both the dendrogram grouping and the MDS plot grouping. These groups ate more than 50% fish and in most cases more than 80%. *Zeus faber*, *Zenopsis nebulosus*, *Pseudocyttus auratus*, *Kathetostoma lavae* and N. *richardsoni* were virtually exclusive piscivores.

Benthopelagic omnivores, species that ate a variety of prey including fish, were *H. percoides*, *S. megalops* and *Mustelus antarcticus.* Benthic omnivores were *H. barathri*, *S. flindersi, Nemadactylus macropterus, Raja* sp. A, *N. scorpaenoides*, and *Pseudolabrus psittaculus.* These species ate mostly invertebrates, either pelagic or benthic or both in varying proportions, and fish in low proportions (between 10% and 50%). The benthic omnivores were not differentiated from the epibenthic invertebrate feeders in the analyses because the proportions of fish eaten were quite low and other prey categories were dominant.

Benthic invertebrate feeders grouped into sub-groups based on the dominant prey category eaten. For instance, the *Urolophus* species ate largely megabenthos, *Caelorinchus* species ate other benthic crustaceans, *Parequula melbournensis, N. macropterus* ate mostly polychaetes and *M. freycineti*, *M. scaber*, *S. calauropomus* ate invertebrates other than crustaceans and polychaetes.

Pelagic invertebrate feeders, *Seriolella punctata* and *S. brama*, fed mostly on pyrosomes. Pelagic omnivores, *S. australasicus* could also be classified as an omnivore although it ate mostly pelagic invertebrates such as ascidians, pyrsomes and salps. *C. novaezelandiae* and *Paramonacanthus filicauda* and P. *multiradiata* were pelagic crustacean feeders while *T. declivis* and *C. affinis,* also included fish in their diets, and were classed as omnivores. Pelagic piscivores were *A. anomalus* and *S. lineolata.*

Prey sources

In the full data set, more than half the species–37 out of 70–relied on benthic food types as their primary food source (Fig. 10.2.1.1). In contrast, pelagic prey sources dominated in 18 of the 28 commercial or abundant species (Fig. 10.2.1.4). Furthermore, the diets of nine of the 12 quota species, i.e. *R. solandri, Z. nebulosus, S. brama, S. punctata, C. affinis, Z. faber, P. dentex, H. percoides* and *N. richardsoni,* were dominated by pelagic prey sources. The species that ate predominantly benthic prey were: *S. flindersi, N. macropterus, G. blacodes, L. mulhalli, U. paucimaculatus, H. barathri, M. scaber, P. bassensis, S. calauropomus* and *N. douglasi*, of which the first three were quota species. Prey of *M. scolopax* was largely unidentified (70%) but likely to have also been benthic.

Piscivory on quota species

Nearly half of the species in the subset were highly piscivorous, i.e. more than 50% of their diet was fish and half ate over one third fish (Fig. 10.2.1.4). However, of all the fish-eaters–27 of the 28 species–only a few ate quota species (Fig. 10.2.1.5). The highest proportion was found in the diet of striped trumpeter *L. lineata* where 17% of the diet was ocean perch *Helicolenus* species. In John dory *Z. faber*, 10% of the diet was redfish *C. affinis* and minor quantities of others. Tiger flathead *N. richardsoni* ate over 5% of school whiting *S. flindersi* and 2% of pink ling *G. blacodes*. These three species were highly piscivorous so that the proportions of quota species in the fish component is similar to those in total diet as illustrated in Fig 10.2.1.5. Also of interest was that jack mackerel *T. declivis,* a non-quota species, was eaten in large amounts by John dory (43%), mirror dory *Z. nebulosus* (50%) and the draughtboard shark *C. laticeps* (34%).

Ontogeny in quota species

Ontogenetic changes in diet were found in *H. percoides* (Fig. 10.2.1.6). The diet of the smallest size class was largely pelagic invertebrates. As size increased, from the 200mm class, the proportion of benthic prey types decreased while pelagic prey increased. The proportion of fish remained nearly equal in all but the smallest size classes but the proportion of benthic fish decreased while the proportion of pelagic fish increased. The differences in diet between the size classes were significant (Kendall's W=0.4243, p=0.01).

G. blacodes subadults (<70 cm) ate more benthic and benthopelagic than larger sizes up to the size class representing maturation (>70 cm) (Fig. 10.2.1.7). Only a few adults were examined (n=6). They ate pelagic invertebrates and megabenthos but with so few data, any continuing trends were not found. Agreement between the size classes was not very high indicating only some, although significant, difference (Kendall's W=0.5057, p<0.001).

S. flindersi ate more fish, benthic invertebrates and polychaetes as they grew larger (Fig. 10.2.1.8) but again the differences were not large (Kendall's W= 0.4564, p=0.01).

Differences in diets of *R. solandri* and *P. dentex* were observed but the data were too few to be significant (Kendalls W= 0.1625, p=0.44 and W= 0.296, p=0.300 respectively). Ontogenetic diet differences in the remainder of the quota species were either not found or not significant.

In one of the non-quota species, *T. declivis,* larger fish ate more fish but less pelagic crustaceans (Fig 10.2.1.9). The unknown prey categories also increased in larger classes.

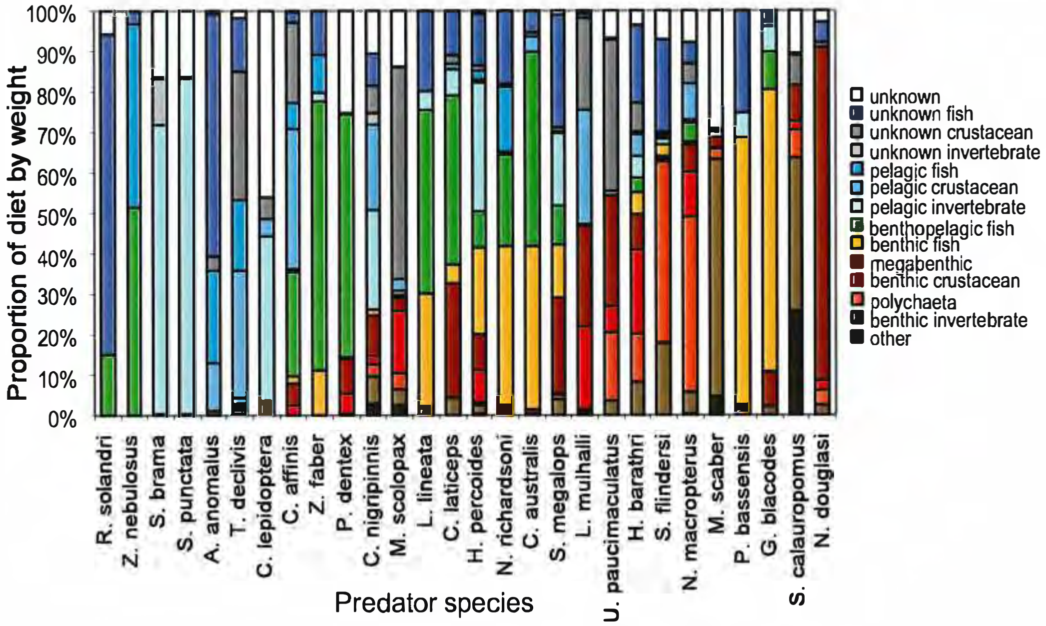


Fig. 10.2.1.4. Diet of 28 species that were of commercial interest or abundant in the SEF, showing importance of pelagic and benthic production.

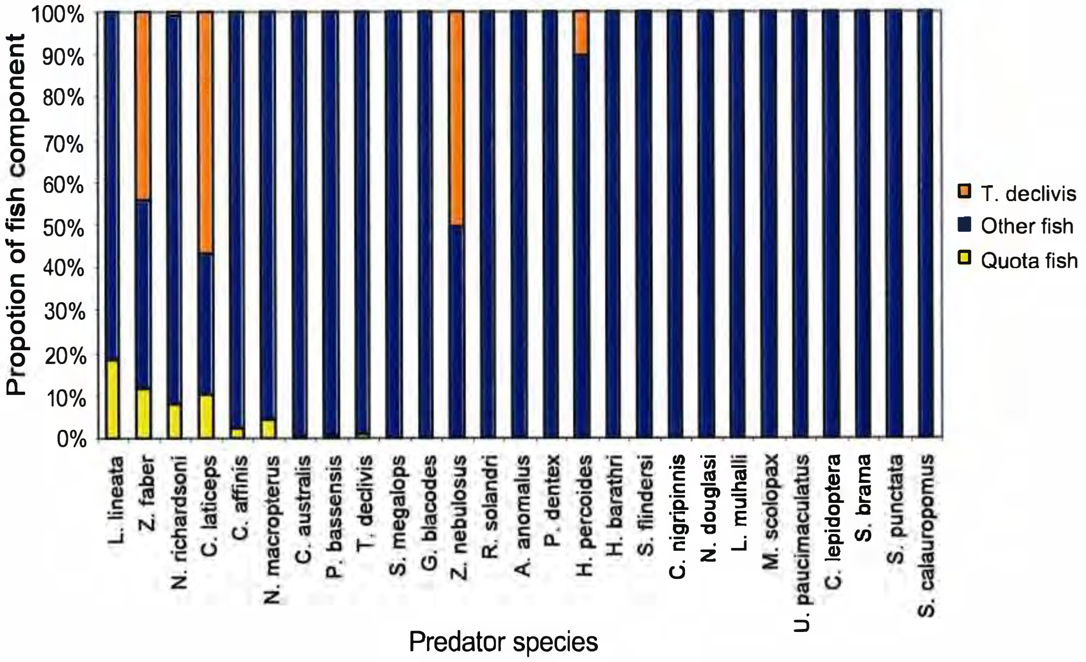


Fig. 10.2.1.5. Proportion of quota species and *T. declivis* in the fish component of the diets of the 27 piscivores in the subset of 28 species of commercial interest or abundant.

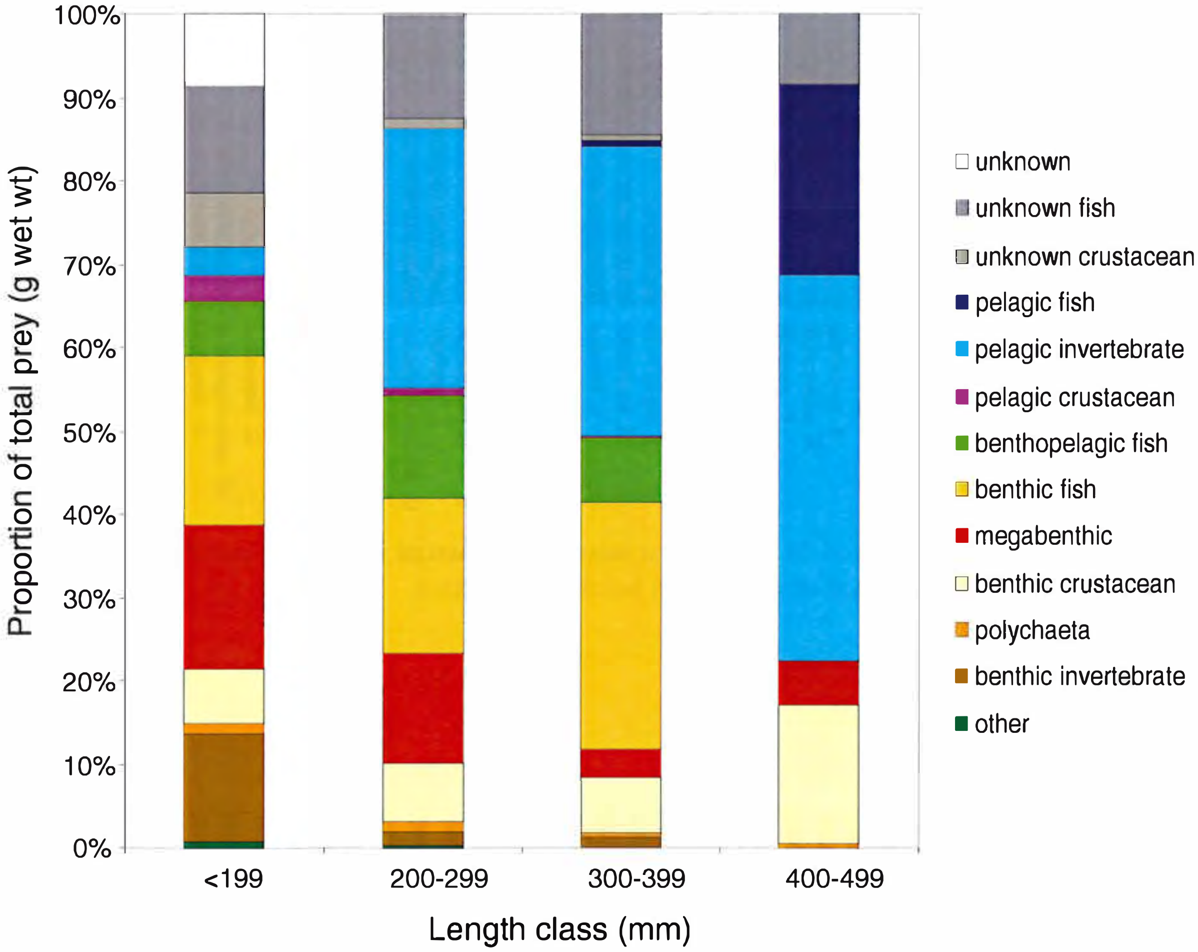


Fig 10.2.1.6. Ocean perch *Helicolenus percoides* diet in proportions of prey in functional groups by size classes.

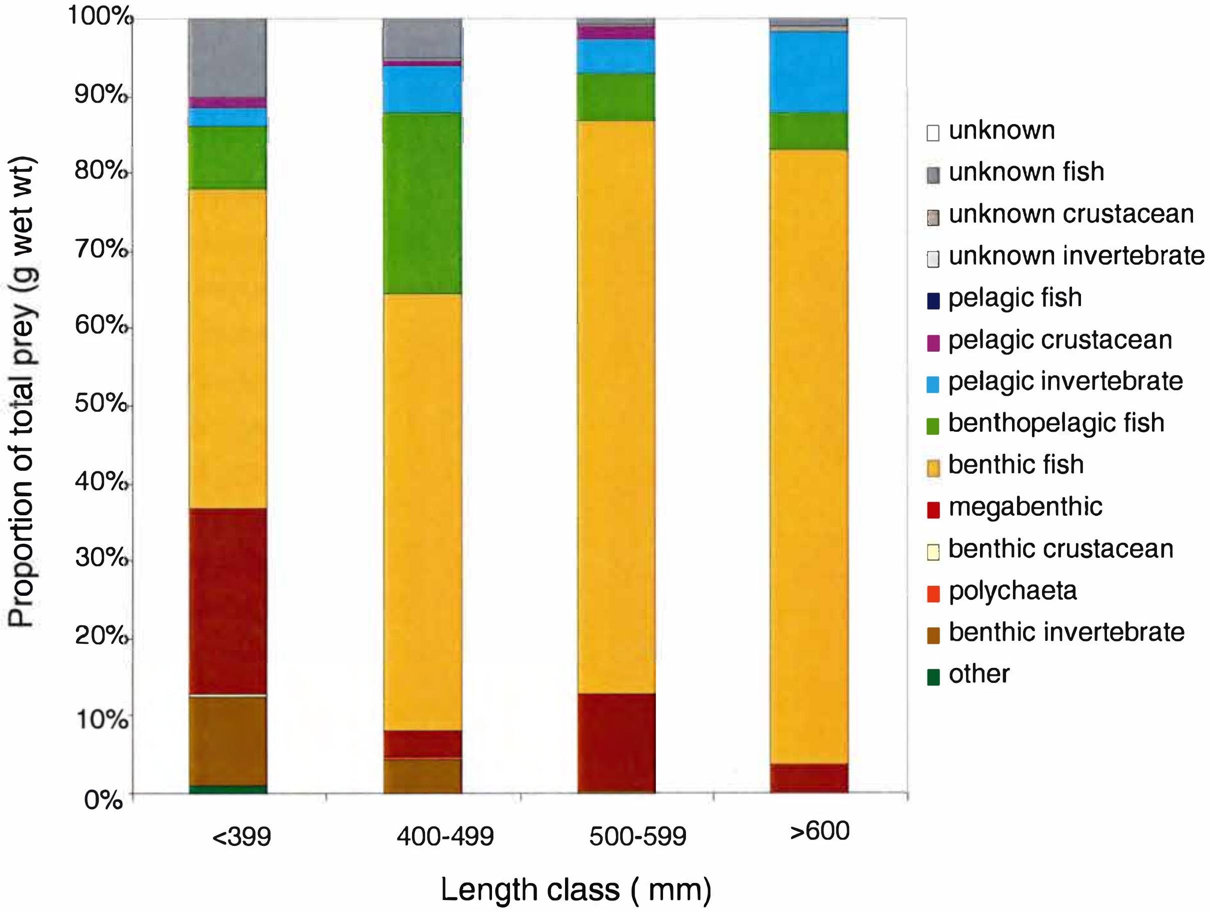


Fig 10.2.1.7. Pink ling *Genypterus blacodes* diet in proportions of prey in functional groups by size classes.

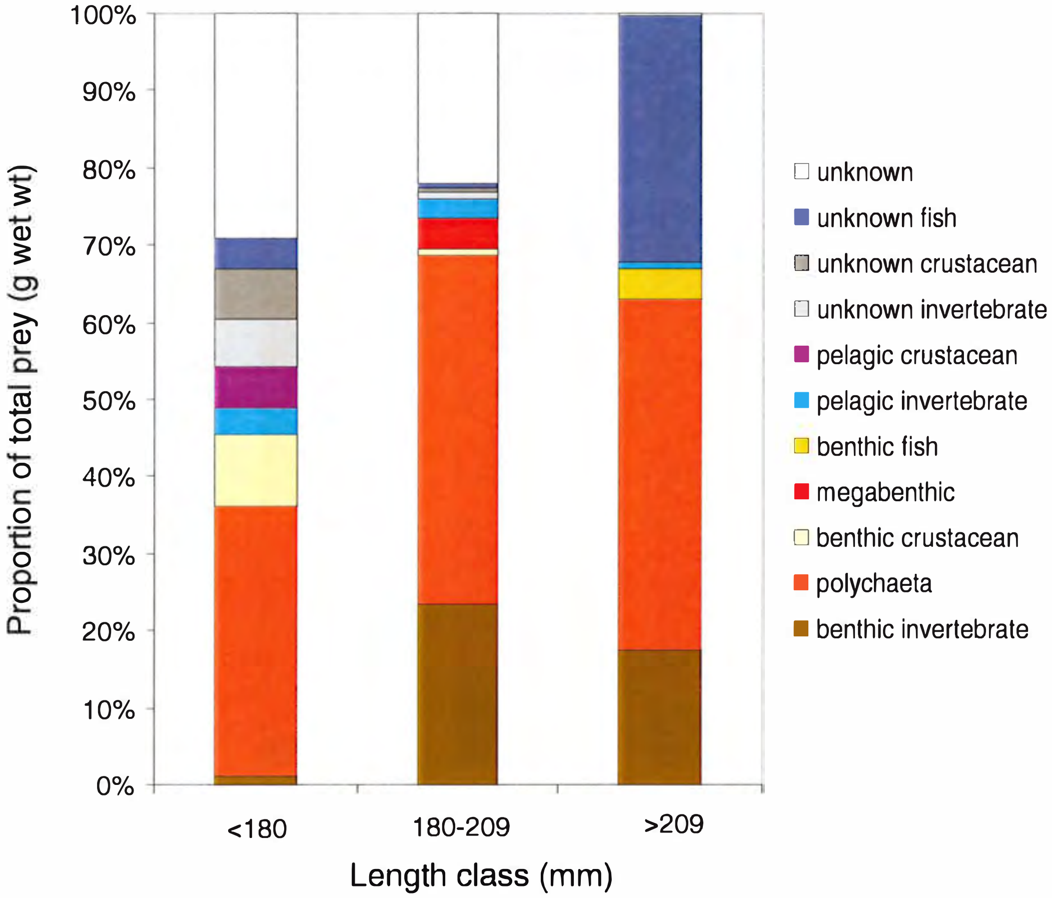


Fig 10.2.1.8. Eastern school whiting *Sillago flindersi* diet in proportions of prey in functional groups by size classes.

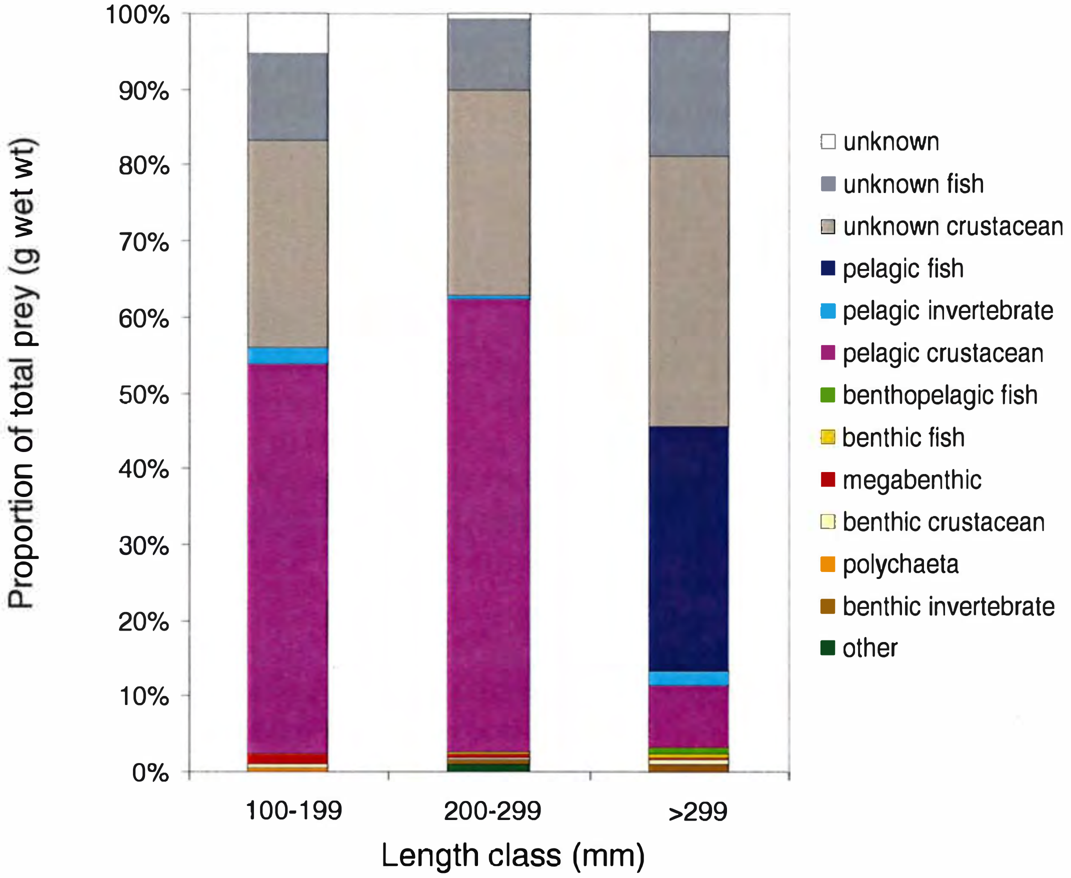


Fig 10.2.1.9. Jack mackerel *Trachurus declivis* diet in proportions of prey in functional groups by size classes.

10.2.2 Fish Diets–Habitat Surveys

John Dory *(Zeus faber)*

Z. faber was a benthopelagic piscivore, which ate a very high proportion of fish, minor portions of crustacea and cephalopods and a trace of polychaetes in one area (Fig 10.2.2.1). The diet was similar between areas (W=0.68, P=0.002), however cluster analysis indicated that the fish from around Gabo Reef (soft) GRS, ate more cephalopods, distinguishing that area from the others from which dory were caught (Fig 10.2.2.2).

Ocean Perch *(Helicolenus percoides)*

H. percoides was a benthopelagic omnivore that ate fish, crustacea such as gammarid amphipods, isopods, crabs and prawns, squid, brittle stars and seastars, and pyrosomes (Fig 10.2.2.3). Diet variations between fish from the macrohabitats were the largest of the species in this study (W=0.39, P>0.0001), which suggested that it is highly opportunistic and takes advantage of any available prey. Prey was largely pelagic which also contributes to the lack of association of macrohabitats. Consequently, cluster analyses showed no obvious associations between macrohabitats (Fig 10.2.2.4).

Common snipefish *(Macroramphosus scolopax)*

M. scolopax was a benthopelagic omnivore which ate ascidians, gammarid and hyperiid amphipods, calanoid and cyclopoid copepods, crabs, polychaetes, bivalves and gastropods (Fig 10.2.2.5). However, a large proportion of crustacea was unidentifiable. Foraminiferans occurred regularly but contributed little by weight. Diet was largely similar between habitats (W=0.59, P>0.0001). Ascidians were prominent components of fish diets at Gabo Reef (soft) and Disaster Bay (hard), this being the feature that seemed to separate these sites from the others in the cluster analysis (Fig 10.2.2.6).

Morwong *(Nemadactylus macropterus)*

N. macropterus is an opportunistic benthopelagic omnivore which eats mostly polychaetes, gammarid amphipods and euphausids, and to a lesser extent crabs, shrimps, isopods, fish, bivalves, and ophiuroids (Fig 10.2.2.7). Its diet varied between habitats (W= 0.41, P>0.0001). For example, euphausids were commonly eaten by fish from the crinoid area of the Horseshoe (HOC),polychaetes were eaten predominantly by fish from the rough and soft areas, and *Apogonops anomalus* were eaten by fish from the hard area. Cluster analysis revealed little meaningful association between fish from the macrohabitats (Fig 10.2.2.8).

Redfish *(Centroberyx affinis)*

C. affinis was a pelagic omnivore that fed mainly on fish, euphausids, amphipods and shrimps (Fig 10.2.2.9). Its diet varied between habitats (W= 0.47, P>0.0001). The cluster analyses divided the fish from the various habitats into two main groups based on the presence or absence of euphausids in the diets. The group without euphausids appeared to be subdivided based on the size of fish component, i.e. either >75% or < 20%. There was no obvious association between the groupings of habitats (Fig 10.2.2.10) suggesting that redfish feed opportunistically.

Kendalls' concordance tests, W, showed low agreement in diet between habitats of most of the five species, indicating that there were differences in diets of fish between macrohabitats. However, complicating the interpretation of the results is the level of identification to which prey could be identified. Where the same prey has been identified at several levels of taxonomy in different fish, i.e. a euphausid might be identified at its specific level or as a eucarid or as a decapod depending on its degree of digestion, the results might indicate differences where in fact there aren't any. The cluster analyses grouped fish from macrohabitats based on the proportion of prey by weight but there appeared to be little explanation to the groupings i.e. not all the habitats of the same type or depth would group together.

10.2.3 Stable Isotopes and Trophic Levels

During the SEF survey series stable nitrogen and stable carbon isotopes were analysed in 1,214 fish (teleost and elasmobranch) samples representing 87 species; 153 samples of benthic and pelagic invertebrates from 8 Phyla; 10 species of marine mammal; 1 seabird; 9 species of algae; 91 samples of particulate organic matter in the water column from 4 surveys and 103 samples of sediment from 3 surveys (Figs. 10.2.3.1 and 10.2.3.2, Appendix Table 10.2.3.1).

Stable isotope results indicate a complexity of relationships that relate more to functional patterns of feeding rather than to taxonomic links. The foundations of the ecosystem in the study region are marine phytoplankton. Trophic paths diverge early in the food web into benthic and pelagic patterns (Fig. 10.2.3.1). Within a single taxonomic group there is often a wide range of isotopic signatures and feeding mechanisms.

Two groups of invertebrates (polychaetes and gastropods) were examined in detail as there were several species among the samples collected for isotope analysis. When their stable nitrogen signature was compared to what is known of their feeding behaviour (P. Hutchins 1982, K. Gowlett-Holmes, pers. comm.), there is an obvious trend (Figs. 10.2.3.3 (a) & (b)). The species with a higher $\delta^{15}N$ signal are more carnivorous, and in the case of polychaetes, have large jaws. The species with lower signals tend to be suspension or detrital feeders.

Fig. 10.2.3.1 includes cetaceans stranded in the study region, but not necessarily feeding in it. The single baleen whale (minke) examined has a very different signature from the other vertebrates. It's diet had presumably been antarctic krill that feed on antarctic phytoplankton. Antarctic phytoplankton have a much lower $\delta^{13}C$ signal than temperate marine phytoplankton.

Stable isotope data with reference to stomach content analysis

Each of the techniques used here for determining a fish's diet –stable isotope and stomach content analysis–provides information of different resolution.

Stomach content analysis indicates what the animal has ingested very recently (there are biases related to what material is identifiable in the stomach, i.e. different prey types are digested at different rates and it is possible to underestimate the importance of prey that are digested rapidly). Stomach contents information was available for 57% of fish (50 of 87 species) for which there were isotope data (Table 10.2.3.1). Although stomach contents provide just a snapshot of items eaten by each species, they provide a base for building knowledge of an animal's diet.

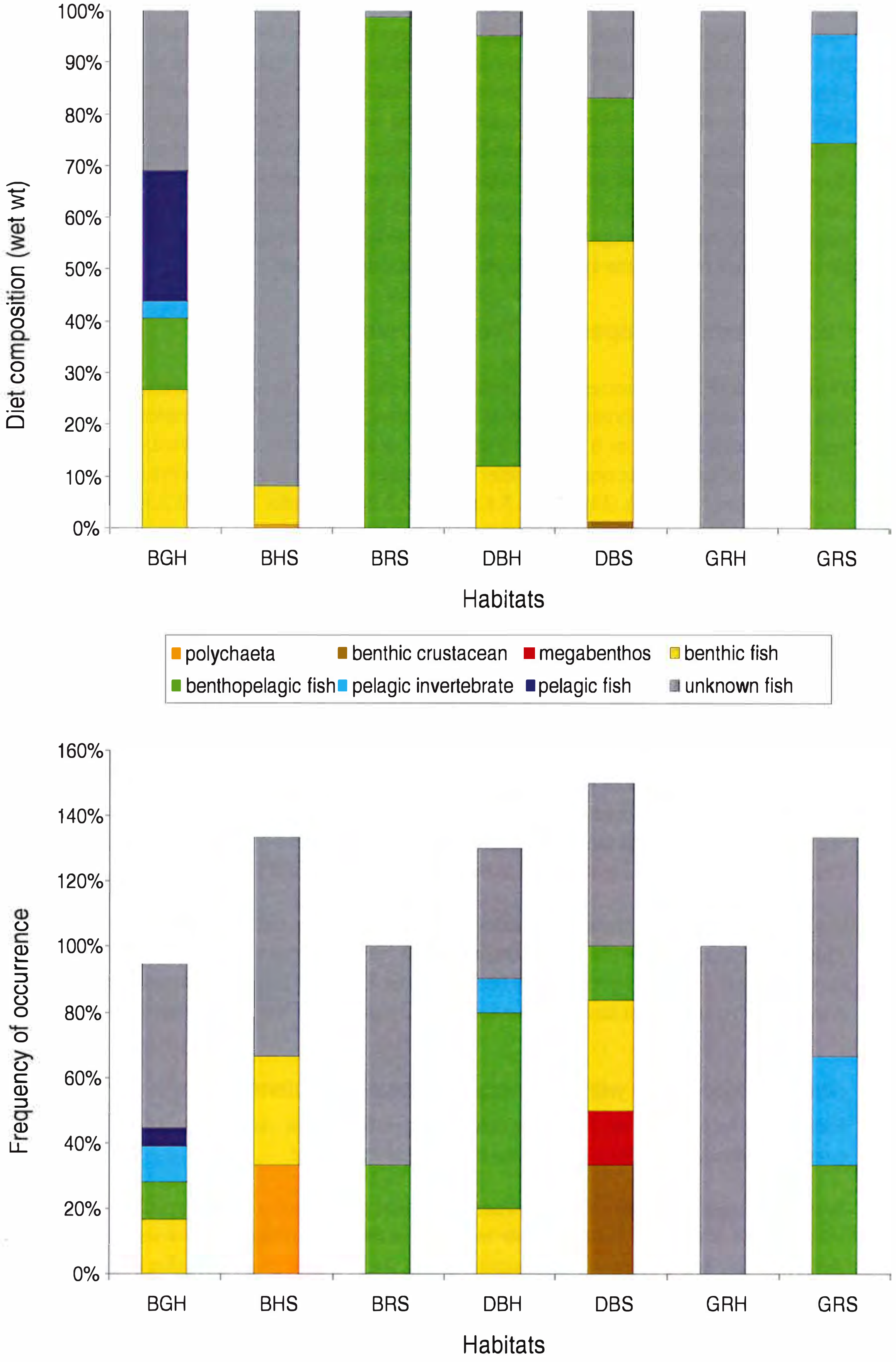


Fig 10.2.2.1. John dory *Zeus faber* diet in functional prey groups by wet weight and frequency of occurrence in the macrohabitats.

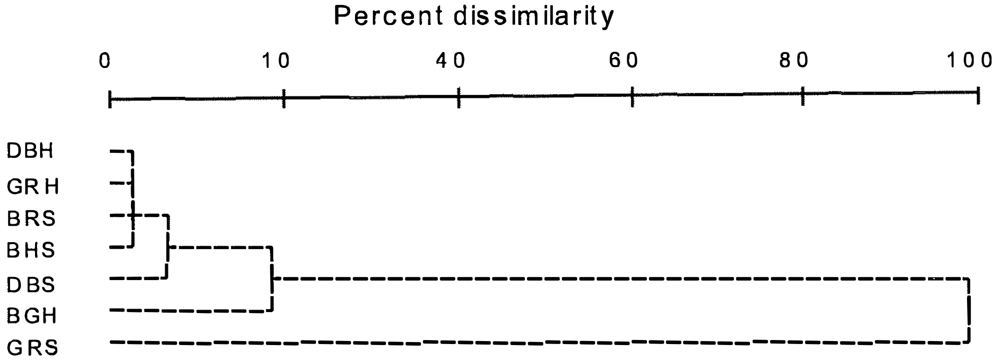


Figure 10.2.2.2 Dendrogram from cluster analysis of diets in various habitats for *Zeus faber*.

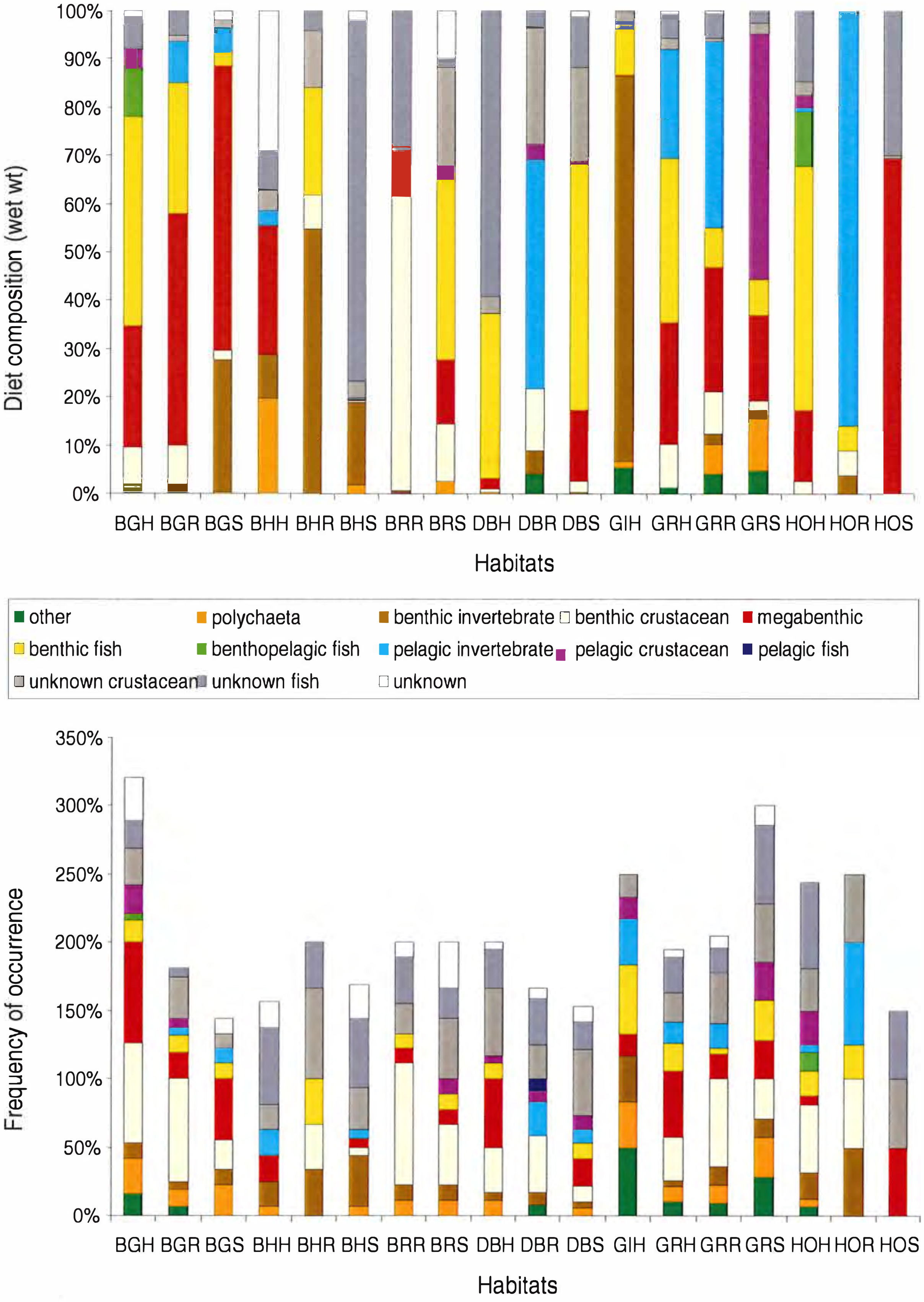


Fig 10.2.2.3. Ocean perch *Helicolenus percoides* diet in macrohabitats by proportion of prey by functional groups by weight and frequency of occurrence.

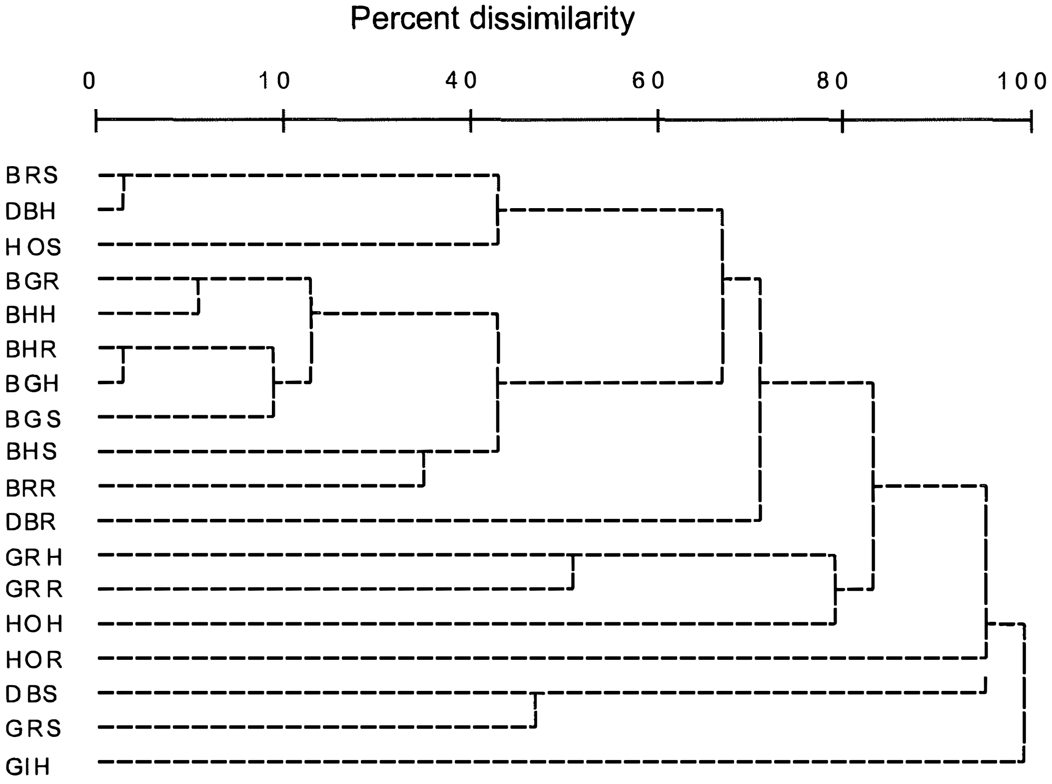


Figure 10.2.2.4. Dendrogram from cluster analysis of diets in various habitats for *Helicolenus percoides*.

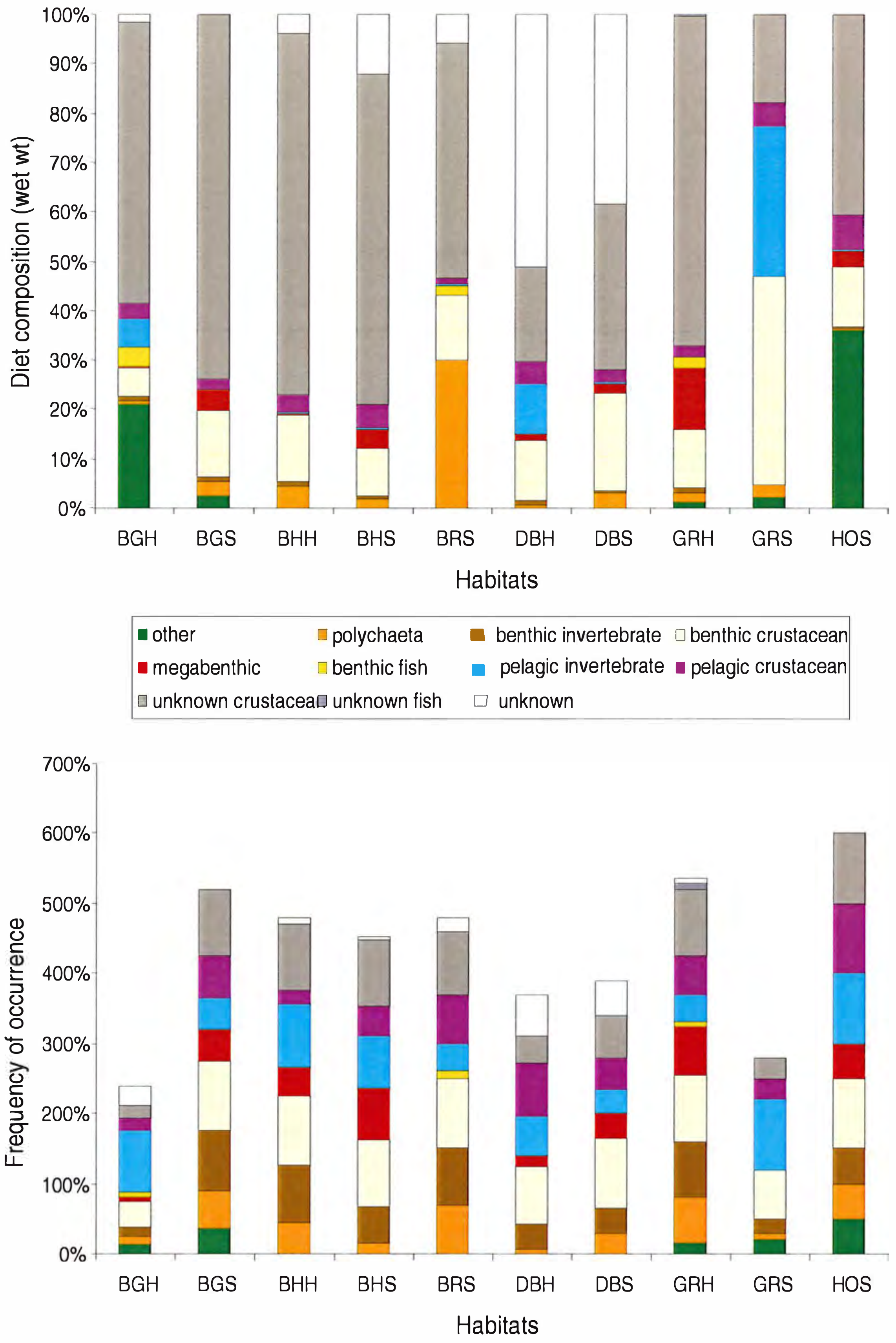


Fig 10.2.2.5. Common snipefish *Macrorhamphosus scolopax* diet in macrohabitats by proportion of prey by functional groups by weight and frequency of occurrence.

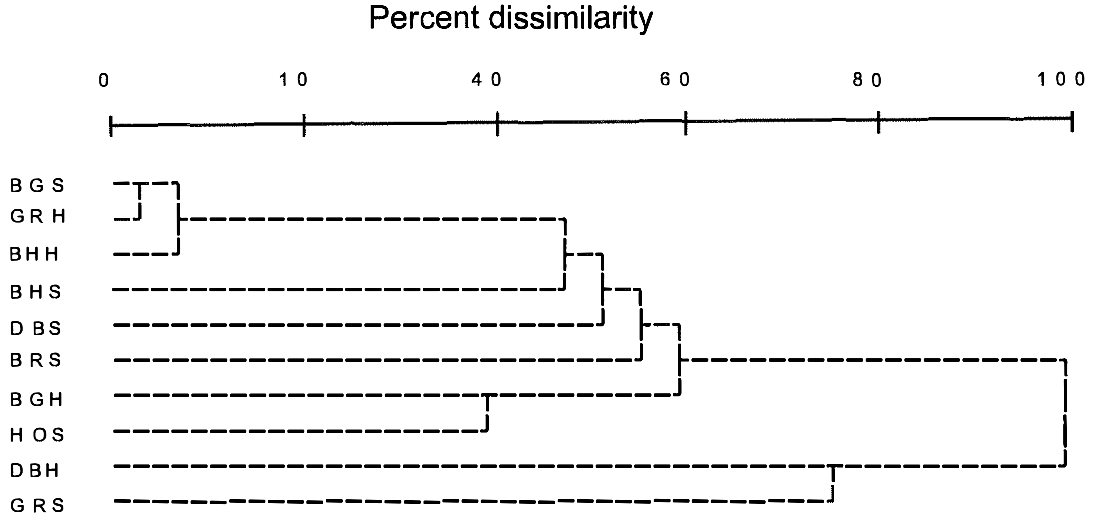


Figure 10.2.2.6. Dendrogram from cluster analysis of diets in various habitats for *Macroramphosois scolopax*.

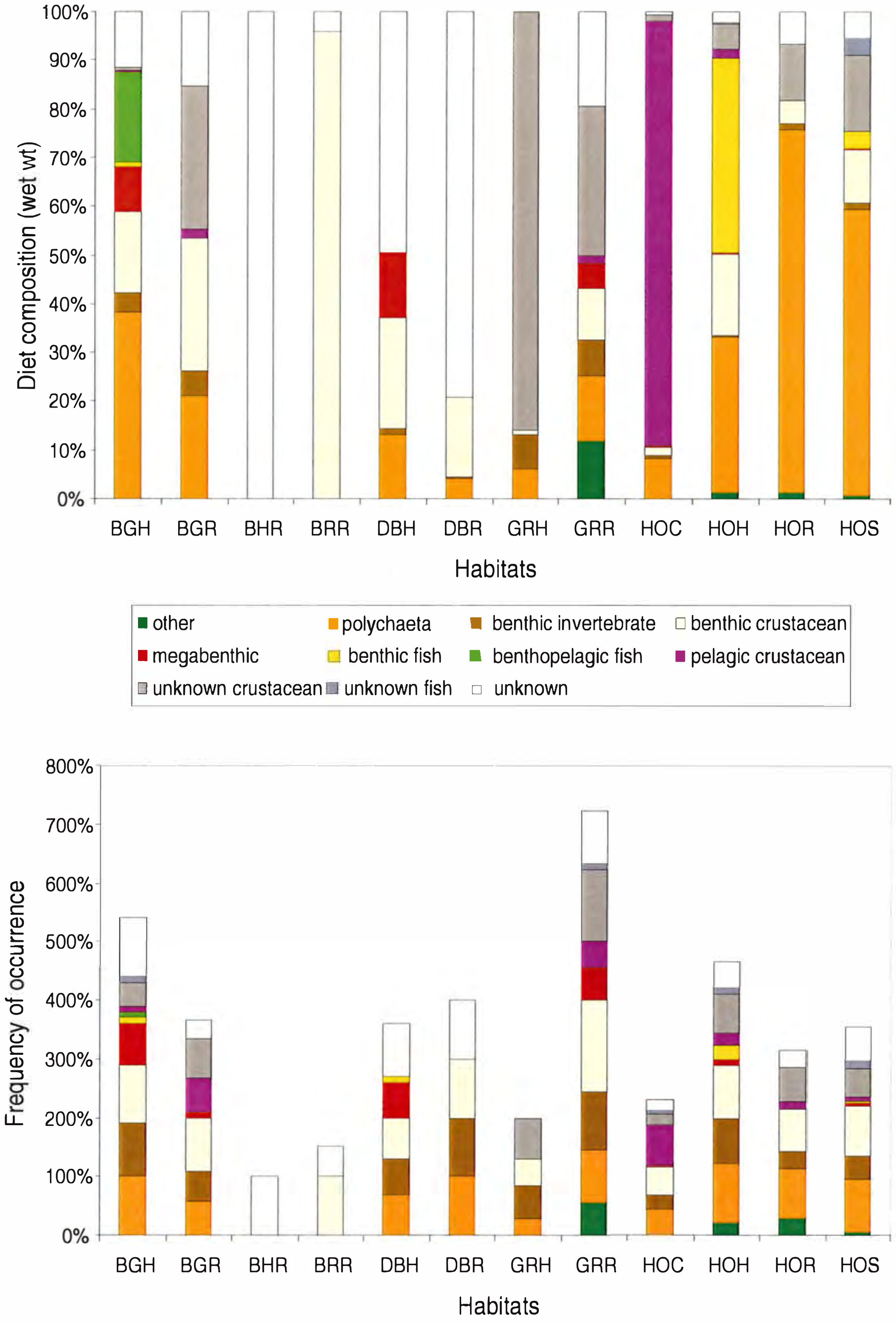


Fig 10.2.2.7. Morwong *Nemadactylus macropterus* diet in macrohabitats by proportion of prey by functional groups by weight and frequency of occurrence.

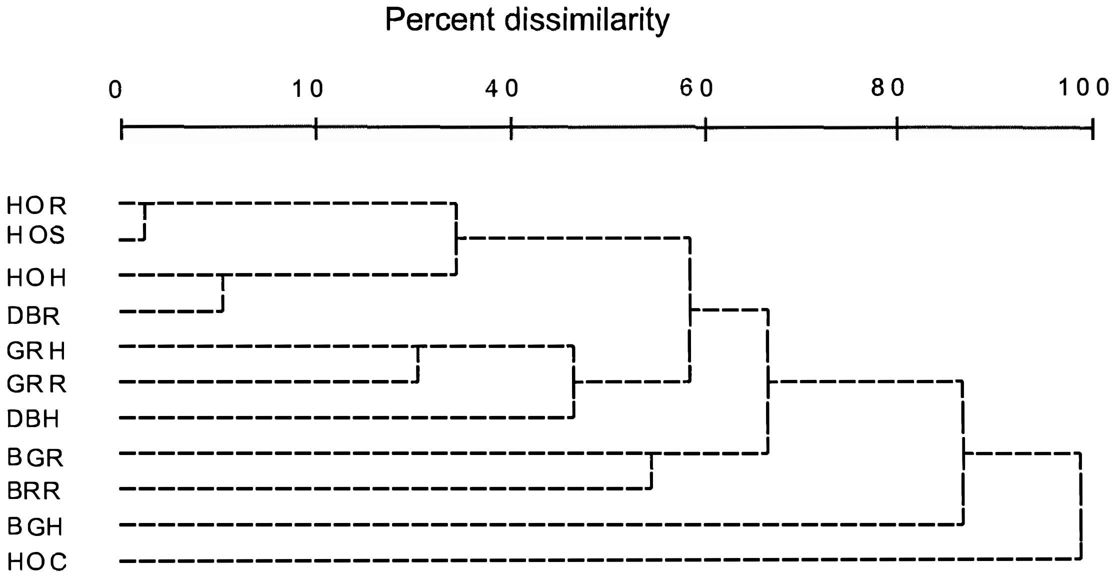


Figure 10.2.2.8. Dendrogram from cluster analysis of diets in various habitats for *Nemadactylus macropterus*.

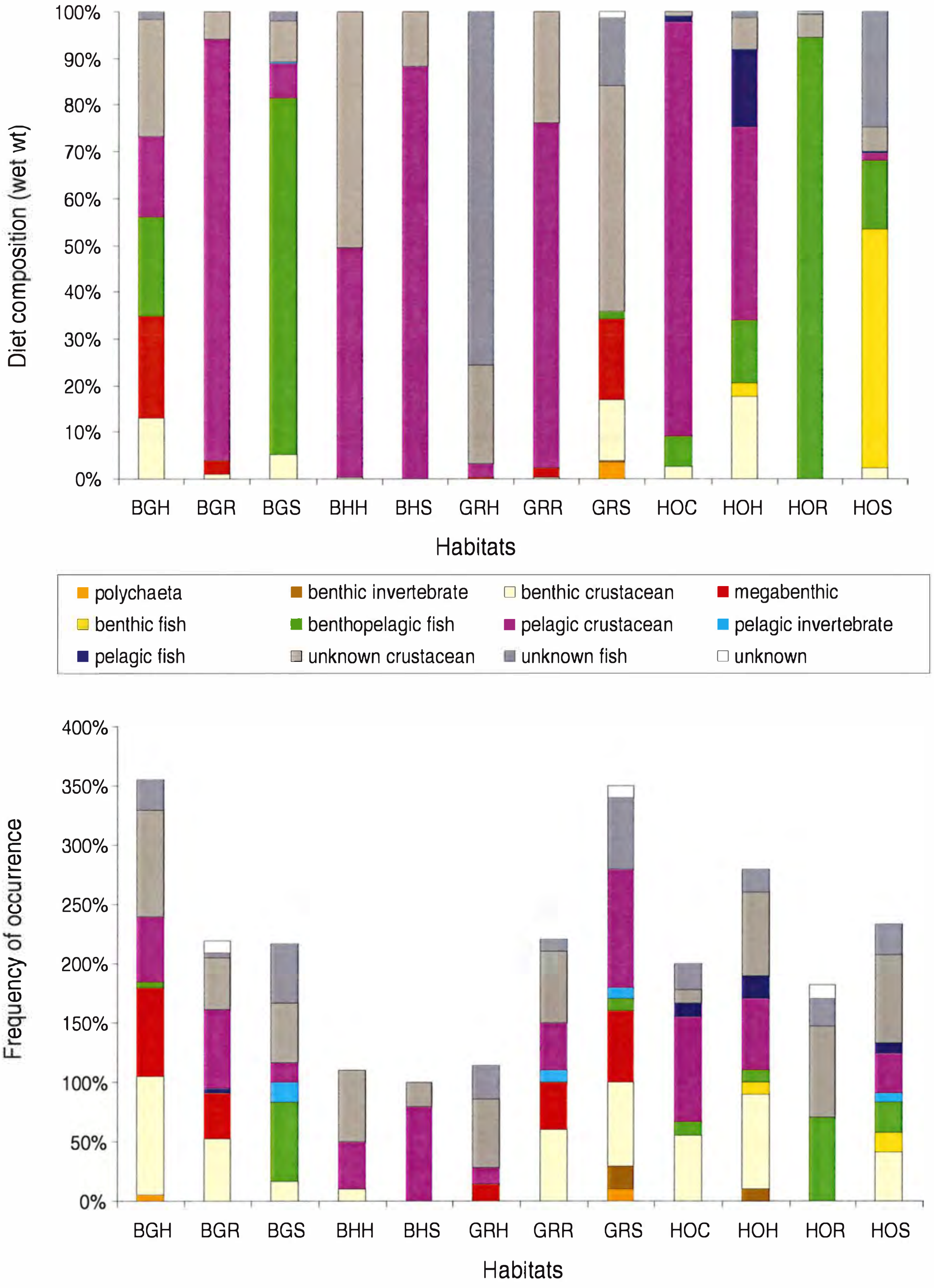


Fig 10.2.2.9. Redfish *Centroberyx affinis* diet in macrohabitats by proportion of prey by functional groups by weight and frequency of occurrence.

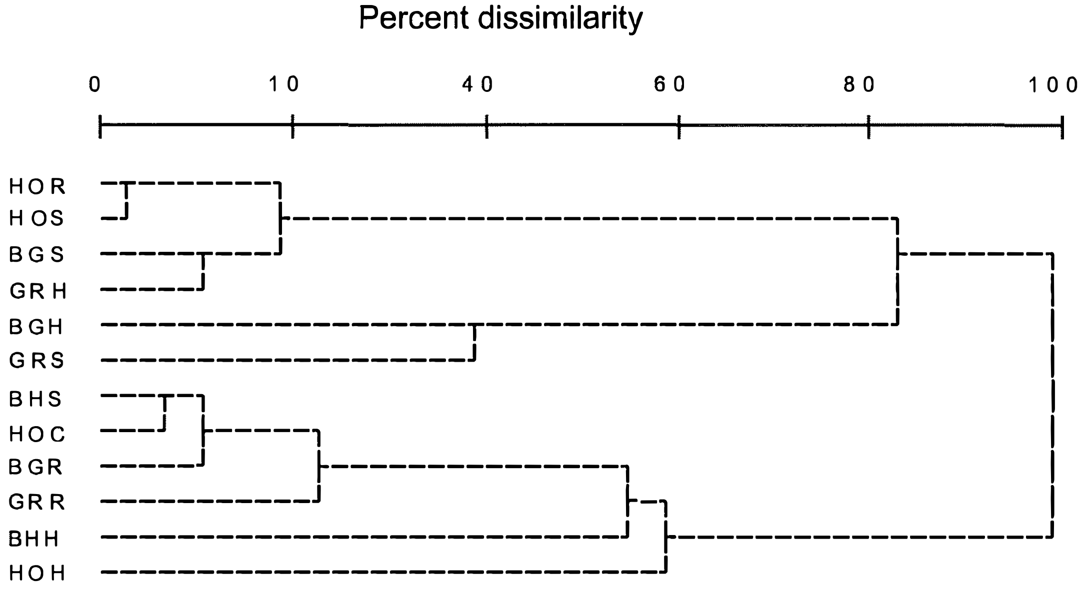
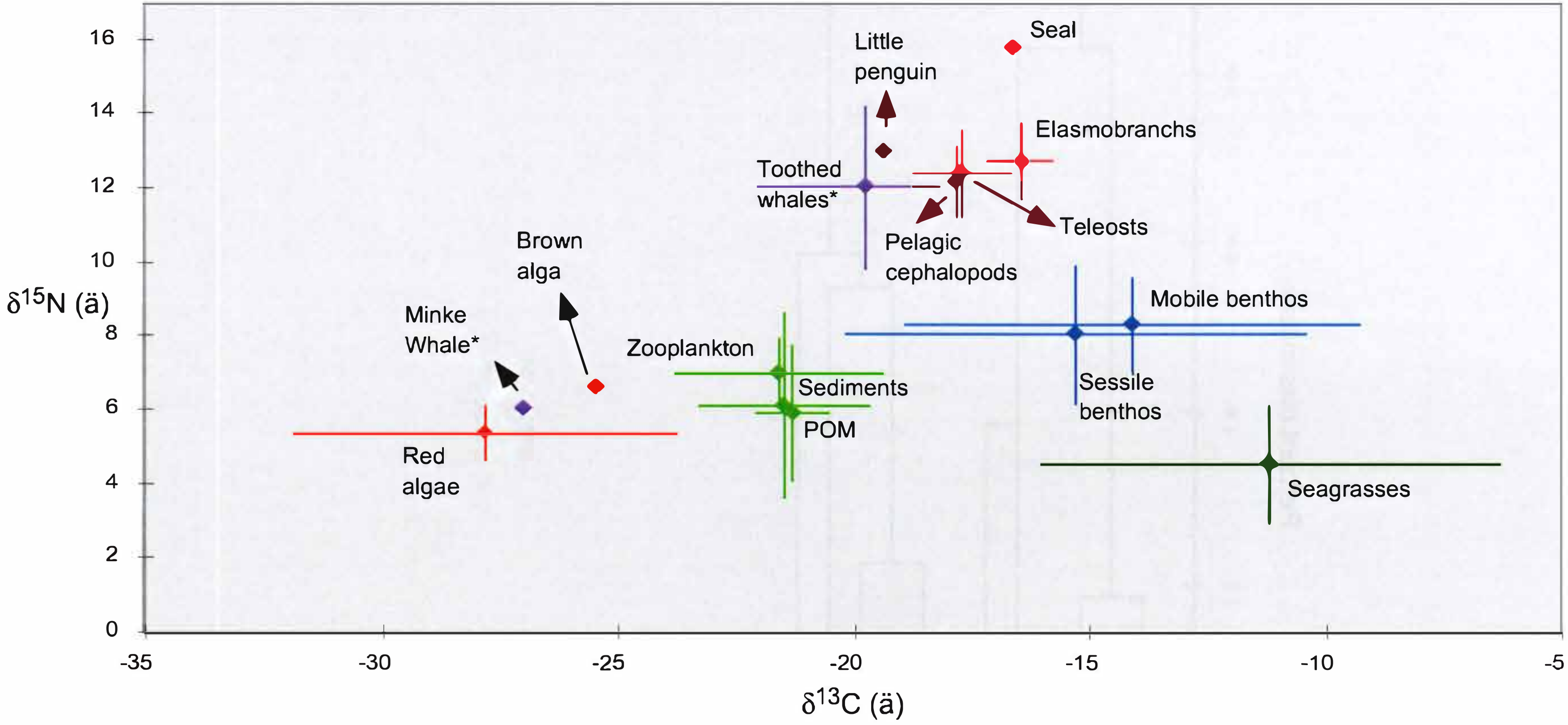


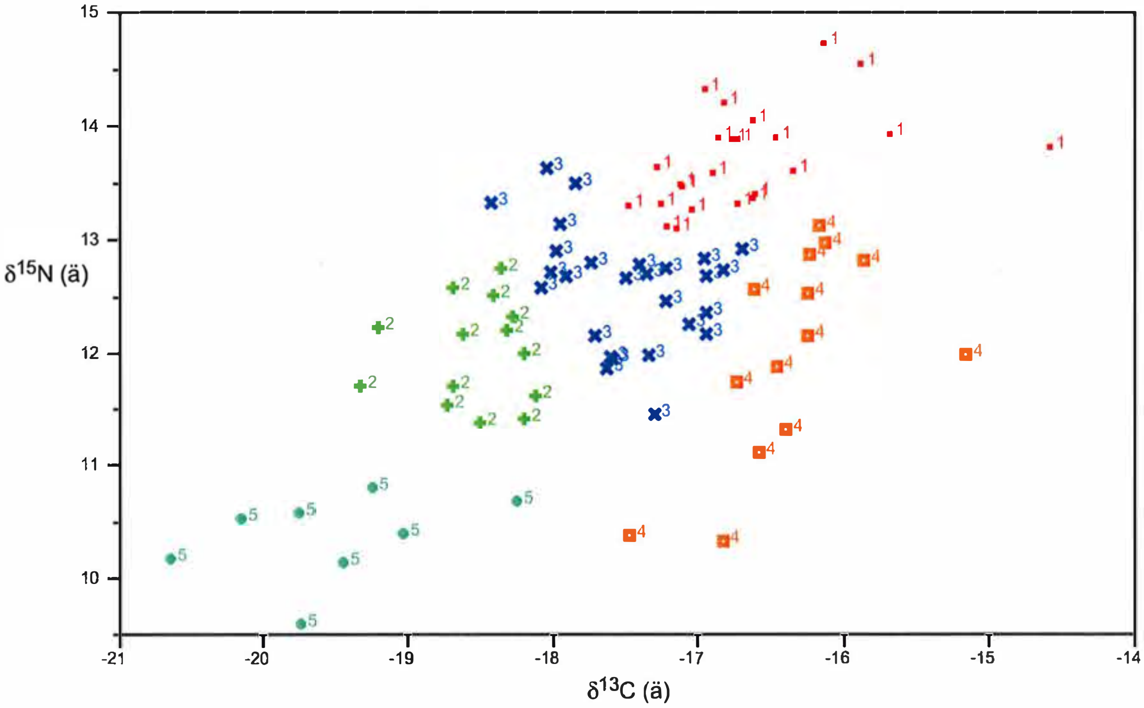
Figure 10.2.2.10. Dendrogram from cluster analysis of diets in various habitats for *Centroberyx affinis*.



* cetaceans stranded in this region, but not necessarily feeding in it

Mobile benthos includes: asteroids, bivalves, crustaceans, echinoids, gastropods, octopus, ophiuroids
Sessile benthos includes: anemones, ascidians, bryozoans, crinoids, soft corals, sponges

Fig. 10.2.3.1 Mean stable isotope values (±1SD) for primary producers to higher consumers from the South East Australian continental shelf 1993-1996



Five groups (Ward's minimum variance method) emerge based on δ^{15}N and δ^{13}C:

Group 1: Piscivory common: include benthic and pelagic predators that consume prey with a high trophic position

Group 2: Pelagic feeders: most eat pelagic zooplankton and fish

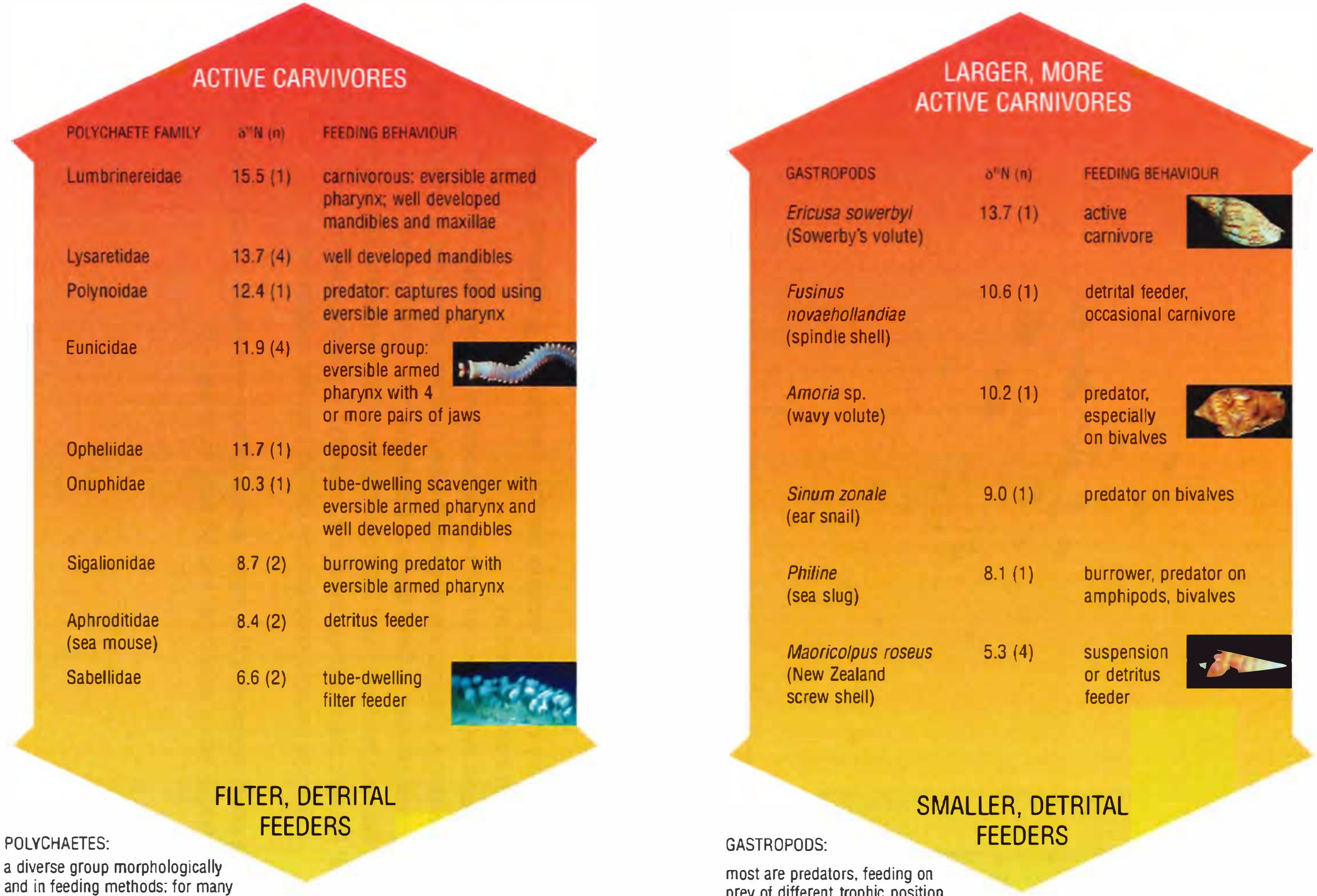
Group 3: Benthic & pelagic feeders: most take a variety of benthic & pelagic prey (invertebrates & fish); there are overlaps with other groups

Group 4: Benthic feeders: most take benthic prey (invertebrates, fish, cephalopods)

Group 5: Pelagic planktivores: most are small fish (including several lanternfish) that eat small pelagic zooplankton or fish that eat zooplankton

Each data point represents the mean stable carbon and stable nitrogen value for a single species. Sample sizes vary from 1 to 68 fish; most are > 5 .

Figure 10.2.3.2 Stable isotope values for 87 species of fish (teleosts & elasmobranchs) from the South East Australian shelf.



POLYCHAETE FAMILY	$\delta^{15}N$ (n)	FEEDING BEHAVIOUR
Lumbrinereidae	15.5 (1)	carnivorous: eversible armed pharynx; well developed mandibles and maxillae
Lysaretidae	13.7 (4)	well developed mandibles
Polynoidae	12.4 (1)	predator: captures food using eversible armed pharynx
Eunicidae	11.9 (4)	diverse group: eversible armed pharynx with 4 or more pairs of jaws
Opheliidae	11.7 (1)	deposit feeder
Onuphidae	10.3 (1)	tube-dwelling scavenger with eversible armed pharynx and well developed mandibles
Sigalionidae	8.7 (2)	burrowing predator with eversible armed pharynx
Aphroditidae (sea mouse)	8.4 (2)	detritus feeder
Sabellidae	6.6 (2)	tube-dwelling filter feeder

POLYCHAETES:
a diverse group morphologically and in feeding methods: for many there is little information on diet.

GASTROPODS	$\delta^{15}N$ (n)	FEEDING BEHAVIOUR
Ericusa sowerbyi (Sowerby's volute)	13.7 (1)	active carnivore
Fusinus novaehollandiae (spindle shell)	10.6 (1)	detrital feeder, occasional carnivore
Amoria sp. (wavy volute)	10.2 (1)	predator, especially on bivalves
Sinum zonale (ear snail)	9.0 (1)	predator on bivalves
Philine (sea slug)	8.1 (1)	burrower, predator on amphipods, bivalves
Maoricolpus roseus (New Zealand screw shell)	5.3 (4)	suspension or detritus feeder

GASTROPODS:
most are predators, feeding on prey of different trophic position.

Figure 10.2.3.3 Stable nitrogen trends within invertebrate taxa.

Table 10.2.3.1 Main dietary components of fish from the south east Australian continental shelf. Fish species are arranged in groups as defined by cluster analysis of stable isotope data (Fig. 10.2.3.2).

Species	Common Name	Spp cod	n	Group	GL:FL*	Main diet components (Dietary components are only listed if they comprised > 1% in stomach content analyses)
Alopius vulpinus	Thresher shark	012001	2	1		
Cephaloscyllium laticeps	Draughtboard shark	015001	30	1	0.86	59.4% pisces, 26.8% cephalopoda, 7.4% crabs, 3.6% gastropoda, 2.1% unid crust,
Caelorinchus australis	Southern whiptail	232001	5	1	1.02	23.7% polychaete, 21.6% crabs, 21.3% pisces, 11.8% benthic amphipod, 8.9% thaliacea, 7.5% unid crust, 3.2% Shrimps, 1.2% isopod,
Caelorinchus mirus	Gargoylefish	232003	5	1		59.4% pisces, 12.5% unident., 11.3% unid. crust, 5.9% shrimps, 3.4% crabs, 2.9% benthic amphipods, 1.5% isopod, 1.1% polychaete,
Conger verreauxi	Southern conger	067007	6	1		
Dasyatis brevicaudata	Smooth stingray	035001	1	1		
Dinolestes leweni	Longfin pike	327002	10	1		
Galeorhinus galeus	School shark	017008	13	1		
Genypterus blacodes	Pink ling	228002	18	1	0.98	82.7% pisces, 8% cephalopods, 5.8% ascidacea, 1.2% shrimps, 1.1% crabs,
Gymnothorax prasinus	Green moray	060006	4	1	0.19	
Hypoplectrodes annulata	Blackbanded seaperch	311091	3	1		
Hypoplectrodes maccullochi	Halfbanded seaperch	311036	2	1		
Ichthyscopus barbatus	Fringed stargazer	400001	1	1		
Isurus oxyrinchus	Mako shark	010001	3	1		
Kathetostoma canaster	Speckled stargazer	400018	6	1	1.14	94.7% pisces, 5.1% cephalopoda,
Latris lineata	Striped trumpeter	378001	19	1	1.20	93.5% pisces, 4.4% thaliacea, 1.5% unid mollusca,
Lotella rhacinus	Largetooth beardie	224005	6	1	1.02	
Narcine tasmaniensis	Tasmanian numbfish	028002	15	1	0.45	84.3% polychaeta, 12.3% sipuncula, 1.7% isopods,
Notolabrus tetricus	Bluethroat wrasse	384003	12	1	0.61	
Pseudophycis bachus	Red cod	224006	9	1	1.22	
Sphyrna zygaena	Smooth hammerhead	019004	1	1	0.90	
Squalus megalops	Spikey dogfish	020006	6	1	0.55	50.8% pisces, 39.4% cephalopods, 2.2% gastropoda, 1.8% crabs, 1.5% unid crust, 1.2% polychaeta, 1% unid
Squatina sp. A	Eastern angel shark	024004	3	1		
Zeus faber	John dory	264004	40	1	1.12	97.9% pisces, 1.9% cephalopods,
Apogonops anomalus	Threespine cardinalfish	311053	25	2	1.00	83.1% pisces,11.1% euphausids, 3.6% unid. crust, 1.3% shrimps
Caesioperca lepidoptera	Butterfly perch	311002	19	2	1.84	45.9% unid., 30.6% thaliacea, 12.6% asidacea, 5.6% unid. crustacea, 3% copepods
Centroberyx affinis	Redfish	258003	68	2	1.37	37% pisces, 31.6% euphausid, 21.1% unid crust, 5.9% shrimp, 1.5% amphipoda
Chlorophthalmus nigripinnis	Cucumberfish	120001	18	2	1.03	20% euphausids,16.9% ascidacea, 11.6% cnidaria, 10.6% unident, 9.6% shrimps, 9.2% pisces, 7% inid crust, 3.3% thaliacea, 2.9% polychaeta, 2.9% sediment, 1.8% cephalopods, 1.3% crabs, 1.2% ostracods
Cyttus novaezelandiae	New Zealand dory	264005	5	2	0.98	95.4% euphausids, 4.5% unid crust,
Emmelichthys nitidus	Redbait	345001	25	2	1.45	36.9% unident, 20.1% thaliacea, 14.1% euphausid, 13.7% unid crust, 5.7% cnidaria, 4.1% pisces, 4% copepod
Gymnoscopelus piabilis	Fam. Myctophidae	122018	1	2		
Lepidoperca pulchella	Eastern orange perch	311001	13	2	1.16	
Mueschenia scaber	Velvet leatherjacket	465005	10	2	2.09	17.6% ectoprocta (bryozoa), 12.6% ascidia, 12.1% benthic amphipods, 8.8% polychaete, 8% gastropods, 6.3% porifera, 6.3% cnidaria, 4.2% ostracods, 4.2% echinoderm, 2.9% bivalves, 2.5% isopods, 2.5% crabs, 2.5% unid crust, 2.1% unid, 1.7% foram,

Stable isotope analysis indicates the diet assimilated over a much longer period, up to several weeks, possibly longer, from analysis of muscle tissue. This technique doesn't indicate specifically what an animal has been feeding on (it needs to be 'ground-truthed'), but does suggest the trophic niche(s) that an organism is feeding in.

Cluster analysis of isotope data

From a cluster analysis (Ward's minimum variance method) of the stable carbon and stable nitrogen results for the 87 species of teleosts and elasmobranchs, five groups emerged (Figs. 10.2.3.2 and 10.2.3.4). Generalisations can be made about each of these groups, although in each group there are apparent departures.

Group 1 includes several large sharks and rays, eels, whiptails, pike, pink ling, sea perches, stargazers, striped trumpeter, cods and John dory. In general, this group has the most enriched stable nitrogen and stable carbon values of any, indicating that fish in this group feed on prey with a high trophic position. This is supported by the data from stomach content analysis.

For the 9 of 24 species in the group where stomach content data are available, fish contributed about 70% of the diet (21-95%), except for the numbfish (*Narcine tasmaniensis*) whose diet comprised 84% polychaetes. The important diet components for this group (fish, cephalopods, polychaetes) have high stable nitrogen signals. No euphausids were found in the stomachs of fish examined from this group.

Many of the **Group 2** fish (8 of 14 species) have an elongate shape and pelagic habit. The group includes warehous, jack mackerel, blue mackerel, redfish, redbait, threespine cardinal fish, butterfly perch, orange perch, cucumber fish, New Zealand dory, a myctophid, velvet leatherjacket and sweep. Fish, if present in the stomach contents generally comprised < 50%; most species had a high proportion of pelagic zooplankton (euphausids and/or thalacians: 11-95%) in the stomachs. Exceptions to these generalisations were the velvet leatherjacket (*Meuschenia scaber)* which had a diverse, largely benthic diet, the main component of which was bryozoan; and the threespine cardinal fish (*Apogonops anomalus*) which had a high proportion of fish (83%) in the stomach contents. Where the fish prey species of *Apogonops* could be identified, all were myctophids–small pelagic fish. The other species in this group for which stomach contents were examined and that had fish in the stomachs: redfish (*Centroberyx affinis*), blue mackerel (*Scomber australasicus*), jack mackerel (*Trachurus declivis*), cucumber fish (*Chlorophthalmus nigripinnis*), redbait (*Emmelichthys nitidis*), blue warehou (*Seriolella brama*); showed a similar pattern i.e. where the fish prey species could be identified, they were small pelagic fish such as *Apogonops* and Myctophids.

Group 3 was the largest (27 species) and middle group (Fig. 10.2.3.2), contained the greatest variability of any group and is probably the most difficult group to describe. There are obvious overlaps with the groups around it. Group 3 comprises 24 teleost and 3 ray species. Many species showed high diversity in the diet; some species had very low diversity and might be expected to fall into other groups: e.g. gemfish (*Rexea solandri*), barracouta (*Thyrsites atun*), mirror dory (*Zenopsis nebulosus*) and tiger flathead (*Neoplatycephalus richardsoni*) all contained > 95% fish in the stomach contents and would intuitively fall into group 1.

Some group 3 fish stomachs (e.g. common bullseye (*Pempheris multiradiatus*) and mirror dory (*Zenopsis nebulosus*)) contained organisms of mainly pelagic origin; others (e.g. globefish (*Diodon nichthemerus*), eastern school whiting (*Sillago flindersi*) and sand flathead

(*Platycephalus bassensis*)) contained mainly benthic prey. With a high proportion of euphausids in the stomachs (74%), the bullseye reflects a group 2 pattern except that it also contained about 20% polychaetes, a prey group (Fig. 10.2.3.3) with a potentially enriched stable nitrogen signal.

Several group 3 fish took a mixture of benthic and pelagic prey: e.g. tiger flathead (*Neoplatycephalus richardsoni*) had 96% fish in the stomachs; a mixture of benthic (48%) and pelagic (10%) fish.

Overall the stomach contents data suggest that 13 species in this group are mainly benthic feeders, 2 were mainly pelagic feeders, 7 were mixed benthopelagic feeders (5 with a higher benthic component, 2 with higher pelagic component) and there are 5 species for which we have no stomach contents data.

Group 4 contains 14 species: 5 sharks, 3 skates or rays, 5 teleosts and 1 chimaerid. Most of these fish display a strong benthic habit.

Three of the four species for which we have stomach contents data indicate a benthic diet: Port Jackson shark (*Heterodontus portusjacksoni*) with 99% gastropods (n=11); the Maori wrasse (*Opthalmolepis lineolata*) with 72% fish, 10% ophiuroids, 6% crabs and 3% gastropods; and banded stingaree (*Urolophus cruciatus*) with 45% polychaetes, 10% shrimps, 10% sipunculids.

The fourth species for which we have stomach data, the snapper (*Pagrus auratus)*, appears to be an exception to the pattern: stomachs of the 10 fish in the sample contained 96% fish, most of which was *Apogonops*, a pelagic species.

Another species in this group that might intuitively fall into group 1 is the bronze whaler shark (*Carcharhinus brachyurus*). We caught only one fish and have no stomach content data from Australian waters. The literature (Last & Stevens 1994, Cliff & Dudley 1992, Bass *et al.* 1973) suggests that they are largely fish eaters and many prey species are benthic in habit; they also feed to a lesser extent on elasmobranchs and cephalopods. At times bronze whalers are known to feed on schools of pelagic fish such as Australian salmon (*Arripis* spp.), and off South Africa on the South African pilchard (*Sardinops ocellatus*). Perhaps there is a seasonal aspect to the diet of bronze whalers and the one shark in our isotope samples reflects a recent diet that was predominately benthic.

Group 5 with one exception, butterfly mackerel (*Gasterochisma melampus*), contained small fish (mostly lanternfish) that feed mostly on zooplankton or on fish that feed on zooplankton. There were stomach contents data for only one species: barber perch (*Caesioperca rasor*)–fish made up 70% of the diet, the rest was mostly mixed zooplankton. The presence of the butterfly mackerel in this group superficially appears to be anomalous because of its much larger size than the other fish in the group. Little is known of its biology (Collette & Nauen 1983), but it is thought to be a planktonic feeder. This hypothesis is supported by the stable isotope results.

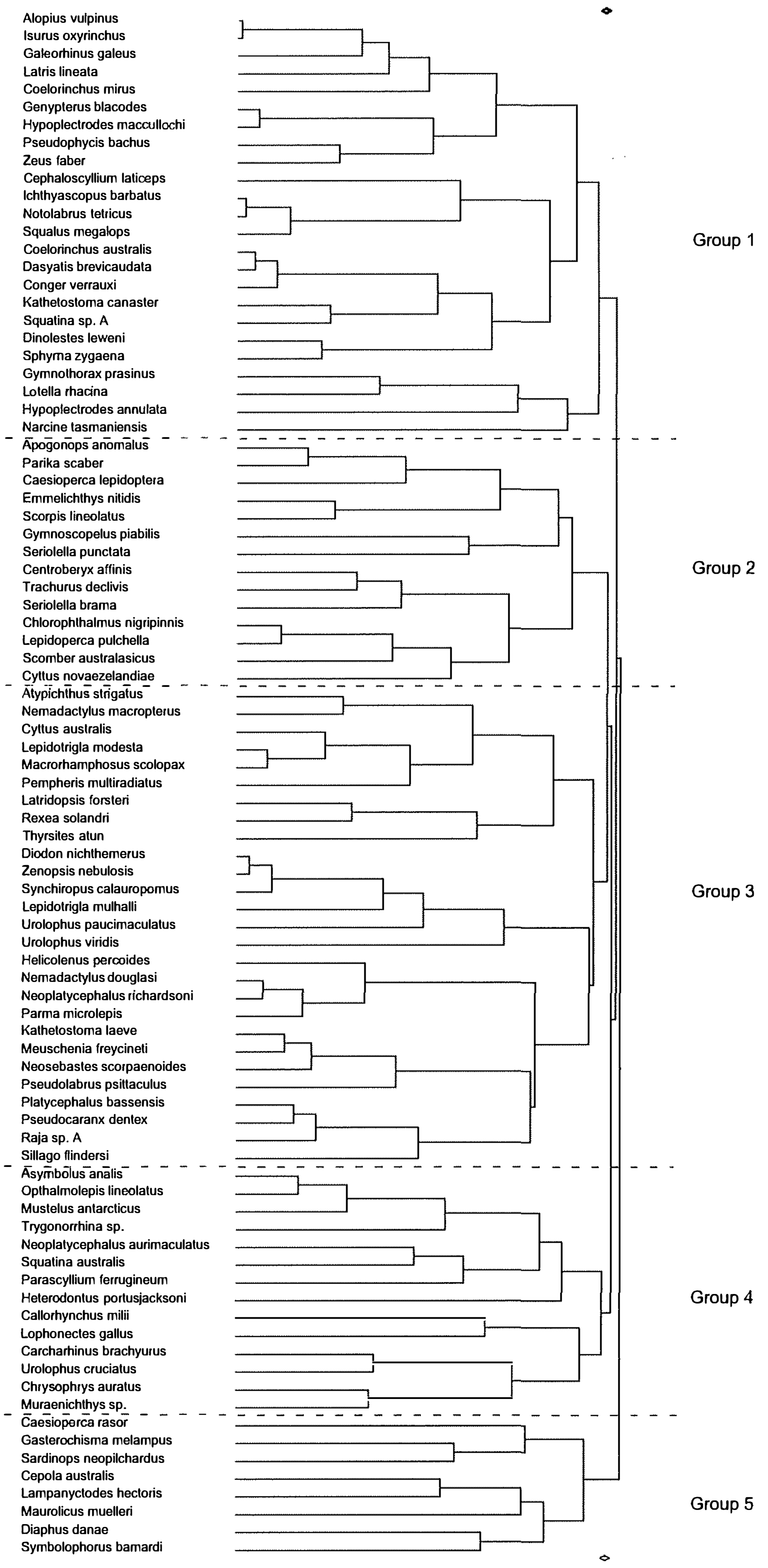


Figure 10.2.3.4 Hierarchical clustering (Ward's minimum variance method) of stable nitrogen and stable carbon results for SEF fish species.

Table 10.2.3.2 SEF fish species listed in decreasing order of stable nitrogen signal

Species	**Common Name**	**Spp code**	**n**	δ^{15}N
Lotella rhacinus	Largetooth beardle	224005	6	**14.74**
Gymnothorax prasinus	Green moray	060006	4	**14.55**
Dinolestes leweni	Longfin pike	327002	10	**14.33**
Sphyrna zygaena	Smooth hammerhead	019004	1	**14.21**
Kathetostoma canaster	Speckled stargazer	400018	6	**14.05**
Hypoplectrodes annulata	Blackbanded seaperch	311091	3	**13.94**
Conger verrauxi	Southern conger	067007	6	**13.91**
Squatina sp. A	Eastern angel shark	024004	3	**13.90**
Caelorinchus australis	Southern whiptail	232001	5	**13.88**
Dasyatis brevicaudata	Smooth stingray	035001	1	**13.88**
Narcine tasmaniensis	Tasmanian numbfish	028002	15	**13.81**
Caelorinchus mirus	Gargoylefish	232003	5	**13.64**
Latridopsis forsteri	Bastard trumpeter	378002	10	**13.63**
Cephaloscyllium laticeps	Draughtboard shark	015001	30	**13.61**
Latris lineata	Striped trumpeter	378001	19	**13.59**
Rexea solandri	Gemfish	439002	9	**13.50**
Isurus oxyrinchus	Mako shark	010001	3	**13.49**
Alopius vulpinus	Thresher shark	012001	2	**13.48**
Ichthyscopus barbatus	Fringed stargazer	400002	1	**13.40**
Notolabrus tetricus	Blue throat wrasse	384003	12	**13.38**
Squalus megalops	Spikey dogfish	020006	6	**13.32**
Thyrsites atun	Barracouta	439001	36	**13.32**
Zeus faber	John Dory	264004	40	**13.32**
Pseudophycis bachus	Red cod	224006	9	**13.30**
Galeorhinus galeus	School shark	017008	13	**13.28**
Nemadactylus macropterus	Morwong	377003	43	**13.13**
Genypterus blacodes	Pink ling	228002	18	**13.12**
Opthalmolepis lineolata	Maori wrasse	384040	13	**13.12**
Hypoplectrodes macculochi	Halfbanded seaperch	311036	2	**13.11**
Asymbolus analis	Grey spotted catshark	015002	7	**12.97**
Pseudolabrus psittaculus	Rosy wrasse	384023	10	**12.92**
Atypichthus strigatus	Mado	361010	9	**12.90**
Mustelus antarcticus	Gummy shark	017001	14	**12.86**
Neosebastes scorpaenoides	Ruddy gurnard perch	287005	5	**12.83**
Trygonorrhina sp.	Fiddler ray	027006	9	**12.82**
Pempheris multiradiata	Common bullseye	357001	10	**12.79**
Neoplatycephalus richardson	Tiger flathead	296001	58	**12.78**
Helicolenus percoides	Ocean perch	287001	58	**12.75**
Centroberyx affinis	Redfish	258003	68	**12.74**
Kathetostoma laeve	Common stargazer	400003	5	**12.73**
Macrorhamphosus scolopax	Common snipefish	279002	19	**12.71**
Nemadactylus douglasi	Grey morwong	377002	7	**12.69**
Lepidotrigla modesta	Minor gurnard	288007	29	**12.68**
Meuschenia freycineti	Sixspine leatherjacket	465036	8	**12.68**
Parma microlepis	White ear	372005	5	**12.66**
Seriolella brama	Blue warehou	445005	28	**12.58**
Cyttus australis	Silver dory	264002	43	**12.57**
Neoplatycephalus aurimacul	Toothy flathead	296035	4	**12.56**
Squatina australis	Australian angel shark	024001	5	**12.53**
Trachurus declivis	Jack mackerel	337002	52	**12.50**
Sillago flindersi	Eastern school whiting	330014	28	**12.45**
Raja sp. A	Longnose skate	031005	6	**12.35**
Chlorophthalmus nigripinnis	Cucumber fish	120001	18	**12.32**
Pseudocaranx dentex	White trevally	337062	21	**12.25**
Seriolella punctata	Silver warehou	445006	40	**12.21**
Lepidoperca pulchella	Eastern orange perch	311001	13	**12.20**
Cyttus novaezelandiae	New Zealand dory	264005	5	**12.17**
Platycephalus bassensis	Sand flathead	296003	23	**12.17**
Lepidotrigla mulhalli	Deepwater gurnard	288008	11	**12.15**
Parascyllium ferrugineum	Rusty carpetshark	013005	2	**12.15**
Scomber australasicus	Blue mackerel	441001	10	**11.99**
Urolophus paucimaculatus	Sparsely-spotted stingare	038004	23	**11.98**
Heterodontus portusjacksoni	Port Jackson shark	007001	6	**11.97**
Zenopsis nebulosus	Mirror dory	264003	3	**11.96**
Diodon nichthemerus	Globefish	469001	12	**11.94**
Urolophus cruciatus	Banded stingaree	038002	13	**11.87**
Synchiropus calauropomus	Common stinkfish	427001	28	**11.85**
Carcharhinus brachyurus	Bronze whaler	018001	1	**11.74**
Gymnoscopelus piabilis	Fam. Myctophidae	122018	1	**11.71**
Meuschenia scaber	Velvet leatherjacket	465005	10	**11.70**
Emmelichthys nitidus	Redbait	345001	25	**11.62**
Apogonops anomalus	Threespine cardinalfish	311053	25	**11.54**
Urolophus viridis	Greenback stingaree	038007	11	**11.45**
Scorpis lineolata	Sliver sweep	361009	8	**11.42**
Caesioperca lepidoptera	Butterfly perch	311002	19	**11.39**
Pagrus auratus	Snapper	353001	5	**11.31**
Muraenichthys sp.	Worm eel (4 fish)	068000	3	**11.11**
Sardinops neopilchardus	Pilchard	085002	10	**10.81**
Caesioperca rasor	Barber perch	311003	8	**10.68**
Lampanyctodes hectoris	Hector's lanternfish	122002	10	**10.59**
Cepola australis	Bandfish	380001	1	**10.53**
Gasterochisma melampus	Butterfly mackerel	441019	10	**10.40**
Lophonectes gallus	Crested flounder	460001	2	**10.37**
Callorhinchus milii	Elephantfish	043001	2	**10.33**
Maurolicus muelleri	Pennant lightfish	107002	5	**10.17**
Symbolophorus barnardi	Bullseye lanternfish	122007	5	**10.14**
Diaphus danae	Dana lanternfish	122001	7	**9.59**

Are there other generalisations from the stable isotope data for SEF fish?

Stable nitrogen $\delta^{15}N$ is typically used as an indicator of trophic level: broadly, the higher the $\delta^{15}N$ value, the higher the trophic position. The 87 fish species were sorted in order of their $\delta^{15}N$ signal (Table 10.2.3.2), and this data set was compared with that from stomach contents analysis.

In general, fish with a higher $\delta^{15}N$ signal have, in stomach contents, a high proportion of fish and/or other species (e.g. polychaetes) that probably have a high stable nitrogen signature. Fig. 10.2.3.3 shows that within invertebrate groups such as polychaetes and gastropods, there is a wide range of $\delta^{15}N$ signal, apparently related to the mode of feeding, likely choice of food, and hence trophic position.

Some fish lower down the $\delta^{15}N$ hierarchy also have a high proportion of fish in the diet, e.g. mirror dory (*Zenopsis nebulosus*) has a $\delta^{15}N$ value of 11.96 ‰, and contained 99.9% fish in the diet, predominantly pelagic fish such as cardinal fish (*Apogonops anomalus*) that had a $\delta^{15}N$ value of 11.54 ‰. The stomachs of *Apogonops* contained 83% fish, mostly lantern fish $\delta^{15}N \leq 10.6$ ‰). These results suggest that the mirror dory heads a short pelagic food chain.

Trophic level

The literature (e.g. Wada *et al.* 1993) commonly refers to a difference of 3 to 4 ‰ (average about 3.4 ‰) as the difference in stable nitrogen values between adjacent trophic levels. For stable carbon, where the predator's signal is much closer to that of its diet, and there is less consistency in ^{13}C enrichment between trophic levels, this difference averages about 1 ‰ (Fry & Sherr 1984).

In the SEF ecosystem, the level of enrichment in ^{15}N between adjacent trophic levels does not always match the difference quoted above. If a trophic level is the distance in ^{15}N between a predator and its main prey, at the lower end of the 'food chain' very much smaller differences than 3.4 ‰ in $\delta^{15}N$ appear in SEF species.

Examples low in food chain:

(1) pelagic:

predator/prey	$\delta^{15}N$ ‰	Difference $\delta^{15}N$ ‰	$\delta^{13}C$ ‰	Difference $\delta^{15}N$ ‰
cardinal fish *Apogonops anomalus*	11.5		–18.7	
Myctophids e.g.	10.6	0.9	–19.8	1.1
Lampanyctodes hectoris				
Zooplankton	7.7	2.9	–21.3	1.5
Phytoplankton	6.2	1.5	–20.5	-0.8

(2) benthic:

Three species of bivalves, thought to be filter feeders, and the corresponding POM and sediment (if detritus feeding) stable isotope values in the region where the bivalves were collected (inshore Point Hicks transect, survey SS9602).

δ^{15}N ‰ enrichments

bivalve ‰	δ^{15}N ‰	POM δ^{15}N ‰	difference δ^{15}N ‰	sediment δ^{15}N ‰	difference δ^{15}N ‰
Glycymeris striatularis	6.76	5.44	1.32	5.22	1.54
Tucetona flabellata	6.24	5.44	0.8	5.22	1.02
Venericardia amabilis	6.47	5.44	1.03	5.22	1.25

δ^{13}C ‰ enrichments

bivalve ‰	δ^{13}C ‰	POM δ^{13}C ‰	difference δ^{13}C ‰	sediment δ^{13}C ‰	difference δ^{13}C ‰
Glycymeris striatularis	–18.02	–20.81	2.79	–22.46	4.44
Tucetona flabellata	–18.45	–20.81	2.36	–22.46	4.01
Venericardia amabilis	–18.92	–20.81	1.89	–22.46	3.54

If the assumption that these bivalves are filter feeders is correct, the difference in δ^{15}N between bivalve and POM is 0.8 to 1.32 ‰ and for δ^{13}C this difference is 1.89 to 2.79 ‰. In the less-likely scenario where these bivalves were deposit feeders, the difference in δ^{15}N between bivalve and sediment is 1.02 to 1.54 ‰, and in δ^{13}C, 3.54 to 4.44 ‰. Another possibility is that our assumptions about the food of these bivalves, are incorrect.

In the earlier example of mirror dory (*Zenopsis nebulosus*), δ^{15}N 11.96 ‰, its main prey cardinal fish (*Apogonops anomalus*) δ^{15}N 11.5 ‰, myctophids δ^{15}N $\leq$ 10.6 ‰, the differences in δ^{15}N values between predator and main prey are 0.5 ‰ and $\geq$ 0.9 ‰ respectively. Stable carbon differences between predator and main prey are 1.13 ‰ and 0.71 to 2.03 ‰ respectively.

At the higher end of the food chain in the SEF ecosystem, e.g. Australian fur seal, there are larger differences between trophic levels. Australian fur seals prey mainly on jack mackerel, redbait, leatherjackets and Gould's squid (Gales and Pemberton 1994).

To calculate the difference in trophic position between the seal and its prey, it is necessary to make a few assumptions: (1) equal portions of the main four ingredients (redbait, leatherjackets, jack mackerel and Gould's squid) in the diet, (2) ignore, for the purposes of this exercise, other species that make up smaller portions of the diet of Australian fur seals (3) let leatherjackets be represented by the velvet leatherjacket (*Meuschenia scaber*), the leatherjacket that was most often caught in the SEF surveys. This gives an average $\delta^{15}N$ value of 12.2 ‰ and $\delta^{13}C$ value of –18.3 ‰ for the prey of the seal, and represents a trophic distance of 3.6 ‰ for $\delta^{15}N$ and 1.6 ‰ for $\delta^{13}C$ between predator and prey.

In general, the higher up the food chain a predator is (as defined by its stable nitrogen signal: Appendix Tables 10.2.3.1 & 10.2.3.2) the more opportunity it has to feed on organisms at different trophic levels below it.

In the SEF, the differences in trophic level appear not to be constant across the food chain. It is possible that the differences low in the food chain are small and get larger with progress up the food chain. It is also likely that there are processes that we do not yet understand that influence the changes in stable isotope ratios between an animal and its food, e.g. in the case of the 3 species of bivalve above, the differences in stable nitrogen are smaller than those for stable carbon in both the filter feeding and detrital feeding scenarios (c.f. typical figures in the literature for trophic level differences: 3.4 ‰ for $\delta^{15}N$, 1 ‰ for $\delta^{13}C$).

When the organisms collected from the SEF (our collections are representative but not exhaustive)–fish, mammals, birds, invertebrates, POM etc–are listed in order of decreasing $\delta^{15}N$ signal (Appendix Table 10.2.3.2), and this is compared with stomach content data (Table 10.2.3.1), it is clear that there is a great complexity in these food web relationships.

The $\delta^{13}C$ signal is useful in providing a rough guide to separating fish according to primarily benthic or pelagic feeding behaviours. A comparison of Tables 10.2.3.1 & 10.2.3.3 shows that 53 of the 61 species (87%) with a $\delta^{13}C$ signal > –18 ‰ have a partly to largely benthic habit and their diets contain a significant portion of benthic prey (e.g. polychaetes, molluscs etc). Of the 26 species whose $\delta^{13}C$ signal was less than –18 ‰, twenty (77%) take mainly pelagic prey, two take mainly small benthic organisms and there are four species where samples sizes were small and there are insufficient diet data to determine whether they are mainly benthic or pelagic feeders.

Ecomorphological evidence

From an extensive database of morphological measurements made for SEF species (FRDC project # 96/230), we examined measurements that might provide useful support for the groupings established using cluster analysis of the stable isotope results. Of the measurements examined: ratio of intestinal length to body length; number of pyloric caecae (spiral valves were counted in elasmobranchs); and the length of the longest caecum; the only measurement that showed a significant relationship with stable isotope clusters, was the intestinal length to body length ratio (Tables 10.2.3.4 & 10.2.3.5). The relationship between $\delta^{13}C$ and intestinal length to fish length ratio shows a significant negative regression ($r = -0.43$, $n = 58$, $p = 0.0008$) i.e. a smaller intestinal length to fish length ratio was correlated with more enriched $\delta^{13}C$ values; but there was not a corresponding relationship with $\delta^{15}N$.

The individual species summarised in Table 10.2.3.4, are shown in Table 10.2.3.5.

In a section on intestinal structure and function in fish, Jobling (1995) discussed the interpretation of the ratio of intestinal length to body length. In carnivorous species, this ratio is usually less than one; it is lower for piscivores than for carnivores whose diet is more diverse and includes worms, molluscs, crustaceans, etc. In omnivorous fish this ratio may be as high as 2–3 and in herbivorous fish and fish whose diet includes a lot of roughage (e.g. detritivorous fish) the ratio may be even higher.

From Jobling's (1995) account, the data in Table 10.2.3.4 suggest that Groups 1 and 4 are strongly piscivorous; Groups 2 and 3 include some piscivores but more omnivores and detritivores. We have no ecomorphological data for any of the fish in Group 5. From Table 10.2.3.5, the species with the highest intestinal to body length ratio: the globefish (*Diodon nichthemerus*) (4.04), mado sweep (*Atypichthys strigatus*) (2.75), sixspine leatherjacket (*Meuschenia freycineti*) (2.63), silver warehou (*Seriolella punctata*) (2.54), velvet leatherjacket (*Meuschenia scaber*) (2.09); eat either a very varied diet (*Diodon* and *Meuschenia*) or, as in the case of *Seriolella*, the bulk of the stomach contents were made up of thaliaceans (mostly pyrosomes), that presumably contain a high proportion of bulky, indigestible material. From the stomach content data, the mado (*Atypichthys)* took mostly fish and some pelagic invertebrates (n=24). Perhaps the stomach contents we found do not reflect the typical longer term diet of this species; perhaps this species is an exception, having a relatively longer intestine for its diet: Jobling (1995) notes that not all species conform to the broad patterns.

Trends in stable isotope data for SEF fish

Seasonal trends

Data for all species where there were $\geq$ 25 stable isotope samples were examined for seasonal trends (Table 10.2.3.6). Seasons were allocated as indicated in Table 10.2.3.7. Sample sizes were mostly small (as few as five per season), so caution should be used in assessing the biological significance of the results

There were no seasonal differences observed in $\delta^{13}C$ or $\delta^{15}N$ values for redfish, ocean perch, John dory, barracouta, eastern school whiting and swell shark.

Seasonal differences in $\delta^{13}C$ values were found for tiger flathead (differences between spring/summer and spring/winter); morwong (difference between spring/autumn); silver warehou (differences between autumn/spring, autumn/winter, autumn/summer, spring/summer); grooved gurnard (difference between autumn/winter, but only 3 fish in winter sample); threespine cardinal fish (differences between autumn/spring and autumn/summer); redbait (only have data for winter and spring).

Seasonal differences in $\delta^{15}N$ values were found for tiger flathead (difference summer/winter); jack mackerel (difference autumn/winter); silver dory (difference spring/summer); morwong (the seasonal pattern for stable nitrogen was very similar to that for stable carbon, except that spring/summer are the least alike seasons); silver warehou (winter is different from the other three seasons); grooved gurnard (differences winter/spring and winter/autumn, although the winter sample only contains 3 fish); blue warehou (difference spring/autumn); stinkfish (winter is different from the other three seasons, but only three fish in winter sample); threespine

Table 10.2.3.3 SEF fish species listed in decreasing order of stable carbon signal

Species	**Common Name**	**Spp code**	**n**	**$\delta^{13}C$**
Narcine tasmaniensis	Tasmanian numbfish	028002	15	**-14.58**
Heterodontus portusjacksoni	Port Jackson shark	007001	6	**-15.15**
Hypoplectrodes annulata	Blackbanded sea perch	311091	3	**-15.67**
Trygonorrhina sp.	Fiddler ray	027006	9	**-15.85**
Gymnothorax prasinus	Green moray	060006	4	**-15.88**
Asymbolus analis	Grey spotted catshark	015002	7	**-16.11**
Lotella rhacinus	Largetooth beardie	224005	6	**-16.13**
Opthalmolepis lineolata	Maori wrasse	384040	13	**-16.15**
Mustelus antarcticus	Gummy shark	017001	14	**-16.22**
Parascyllium ferrugineum	Rusty carpetshark	013005	2	**-16.24**
Squatina australis	Australian angel shark	024001	5	**-16.24**
Cephaloscyllium laticeps	Draughtboard shark	015001	30	**-16.34**
Pagrus auratus	Snapper	353001	5	**-16.38**
Urolophus cruciatus	Banded stingaree	038002	13	**-16.45**
Squatina sp. A	Eastern angel shark	024004	3	**-16.46**
Muraenichthys sp.	Worm eel (4 fish)	068000	3	**-16.56**
Ichthyscopus barbatus	Fringed stargazer	400002	1	**-16.61**
Neoplatycephalus aurimaculat	Toothy flathead	296035	4	**-16.61**
Kathetostoma canaster	Speckled stargazer	400018	6	**-16.62**
Notolabrus tetricus	Bluethroat wrasse	384003	12	**-16.62**
Pseudolabrus psittaculus	Rosy wrasse	384023	10	**-16.68**
Caelorinchus australis	Southern whiptail	232001	5	**-16.72**
Squalus megalops	Spikey dogfish	020006	6	**-16.72**
Carcharhinus brachyurus	Bronze whaler	018001	1	**-16.73**
Dasyatis brevicaudata	Smooth stingray	035001	1	**-16.77**
Kathetostoma laeve	Common stargazer	400003	5	**-16.81**
Callorhinchus milii	Elephantfish	043001	2	**-16.82**
Sphyrna zygaena	Smooth hammerhead	019004	1	**-16.82**
Conger verrauxi	Southern conger	067007	6	**-16.85**
Latris lineata	Striped trumpeter	378001	19	**-16.89**
Platycephalus bassensis	Sand flathead	296003	23	**-16.93**
Meuschenia freycineti	Sixspine leatherjacket	465036	8	**-16.94**
Raja sp. A	Longnose skate	031005	6	**-16.94**
Dinolestes lewini	Longfin pike	327002	10	**-16.95**
Neosebastes scorpaenoides	Ruddy gurnard perch	287005	5	**-16.95**
Galeorhinus galeus	School shark	017008	13	**-17.04**
Pseudocaranx dentex	White trevally	337062	21	**-17.06**
Alopias vulpinus	Thresher shark	012001	2	**-17.11**
Isurus oxyrinchus	Mako shark	010001	3	**-17.12**
Hypoplectrodes maccullochi	Halfbanded seaperch	311036	2	**-17.15**
Helicolenus percoides	Ocean perch	287001	58	**-17.21**
Sillago flindersi	Eastern school whiting	330014	28	**-17.21**
Genypterus blacodes	Pink ling	228002	18	**-17.22**
Zeus faber	John Dory	264004	40	**-17.26**
Caelorinchus mirus	Gargoylefish	232003	5	**-17.28**
Urolophus viridis	Greenback stingaree	038007	11	**-17.29**
Urolophus paucimaculatus	Sparsely-spotted stingar	038004	23	**-17.33**
Nemadactylus douglasi	Grey morwong	377002	7	**-17.35**
Neoplatycephalus richardsoni	Tiger flathead	296001	58	**-17.40**
Lophonectes gallus	Crested flounder	460001	2	**-17.46**
Pseudophycis bachus	Red cod	224006	9	**-17.48**
Parma microlepis	White ear	372005	5	**-17.49**
Diodon nichthemerus	Globefish	469001	12	**-17.58**
Zenopsis nebulosus	Mirror dory	264003	3	**-17.60**
Synchiropus calauropomus	Common stinkfish	427001	28	**-17.63**
Lepidotrigla mulhalli	Deepwater gurnard	288008	11	**-17.71**
Pempheris multiradiata	Common bullseye	357001	10	**-17.73**
Rexea solandri	Gemfish	439002	9	**-17.84**
Lepidotrigla modesta	Minor gurnard	288007	29	**-17.91**
Nemadactylus macropterus	Morwong	377003	43	**-17.94**
Atypichthus strigatus	Mado	361010	9	**-17.97**
Macrorhamphosus scolopax	Common snipefish	279002	19	**-18.01**
Latridopsis forsteri	Bastard trumpeter	378002	10	**-18.04**
Cyttus australis	Silver dory	264002	43	**-18.07**
Emmelichthys nitidus	Redbait	345001	25	**-18.11**
Scomber australasicus	Blue mackerel	441001	10	**-18.20**
Scorpis lineolata	Sweep	361009	8	**-18.20**
Caesioperca rasor	Barber perch	311003	8	**-18.25**
Chlorophthalmus nigripinnis	Cucumber fish	120001	18	**-18.28**
Lepidoperca pulchella	Eastern orange perch	311001	13	**-18.32**
Centroberyx affinis	Redfish	258003	68	**-18.36**
Trachurus declivis	Jack mackerel	337002	52	**-18.41**
Thyrsites atun	Barracouta	439001	36	**-18.42**
Caesioperca lepidoptera	Butterfly perch	311002	19	**-18.50**
Cyttus novaezelandiae	New Zealand dory	264005	5	**-18.62**
Meuschenia scaber	Velvet leatherjacket	465005	10	**-18.69**
Seriolella brama	Blue warehou	445005	28	**-18.69**
Apogonops anomalus	Threespin cardinalfish	311053	25	**-18.73**
Gasterochisma melampus	Butterfly mackerel	441019	10	**-19.03**
Seriolella punctata	Silver warehou	445006	40	**-19.20**
Sardinops neopilchardus	Pilchard	085002	10	**-19.25**
Gymnoscopelus piabilis	Fam. Myctophidae	122018	1	**-19.32**
Symbolophorus barnardi	Bullseye lanternfish	122007	5	**-19.44**
Diaphus danae	Dona lanternfish	122001	7	**-19.73**
Lampanyctodes hectoris	Hector's lanternfish	122002	10	**-19.75**
Cepola australis	Bondfish	380001	1	**-20.15**
Maurolicus muelleri	Pennant lightfish	107002	5	**-20.64**

Table 10.2.3.4 The ratio of intestinal length to body length in SEF fish by isotope group (defined by cluster analysis)

Group	mean ± s.d.	range	n
1	0.89 ± 0.32	0.19 – 1.22	14
2	1.44 ± 0.52	0.87 – 2.54	12
3	1.33 ± 0.84	0.55 – 4.05	24
4	0.61 ± 0.16	0.37 – 0.81	8
5			0

Table 10.2.3.5 Intestinal length to body length ratio in SEF fish species for which there were stable isotope data.

Species	Common Name	Spp code	intestine to body length ratio*	n	Isotope group
Diodon nichthemerus	Globefish	469001	4.05	12	3
Atypichthus strigatus	Mado	361010	2.75	1	3
Meuschenia freycineti	Sixspine leatherjacket	465036	2.63	10	3
Seriolella punctata	Silver warehou	445006	2.54	9	2
Meuschenia scaber	Velvet leatherjacket	465005	2.09	11	2
Nemadactylus douglasi	Grey morwong	377002	1.88	9	3
Synchiropus calauropomus	Common stinkfish	427001	1.86	12	3
Caesioperca lepidoptera	Butterfly perch	311002	1.84	10	2
Seriolella brama	Blue warehou	445005	1.79	14	2
Nemadactylus macropterus	Morwong	377003	1.72	12	3
Zenopsis nebulosus	Mirror dory	264003	1.68	12	3
Emmelichthys nitidus	Redbait	345001	1.45	10	2
Neosebastes scorpaenoides	Ruddy gurnard perch	287005	1.44	8	3
Centroberyx affinis	Redfish	258003	1.37	12	2
Pseudophycis bachus	Red cod	224006	1.22	5	1
Helicolenus percoides	Ocean perch	287001	1.21	12	3
Latris lineata	Striped trumpeter	378001	1.20	1	1
Scomber australasicus	Blue mackerel	441001	1.19	7	2
Pagrus auratus	Snapper	353001	1.18	8	4
Lepidoperca pulchella	Eastern orange perch	311001	1.16	18	2
Kathetostoma canaster	Speckled stargazer	400018	1.14	10	1
Lepidotrigla modesta	Minor gurnard	288007	1.14	12	3
Zeus faber	John Dory	264004	1.12	11	1
Neoplatycephalus richardso	Tiger flathead	296001	1.09	11	3
Kathetostoma laeve	Common stargazer	400003	1.05	1	3
Macrorhamphosus scolopax	Common snipefish	279002	1.04	12	3
Chlorophthalmus nigripinnis	Cucumber fish	120001	1.03	12	2
Caelorinchus australis	Southern whiptail	232001	1.02	10	1
Lotella rhacinus	Largetooth beardie	224005	1.02	1	1
Apogonops anomalus	Threespine cardinalfish	311053	1.00	12	2
Platycephalus bassensis	Sand flathead	296003	1.00	5	3
Lepidotrigla mulhalli	Deepwater gurnard	288008	1.00	12	3
Genypterus blacodes	Pink ling	228002	0.98	13	1
Cyttus novaezelandiae	New Zealand dory	264005	0.98	11	2
Pempheris multiradiata	Common bullseye	357001	0.94	1	3
Sphyrna zygaena	Smooth hammerhead	019004	0.90	1	1
Pseudocaranx dentex	White trevally	337062	0.87	10	3
Trachurus declivis	Jack mackerel	337002	0.87	12	2
Cyttus australis	Silver dory	264002	0.86	10	3
Cephaloscyllium laticeps	Draughtboard shark	015001	0.86	10	1
Sillago flindersi	Eastern school whiting	330014	0.85	8	3
Mustelus antarcticus	Gummy shark	017001	0.81	2	4
Neoplatycephalus aurimacu	Toothy flathead	296035	0.79	8	4
Asymbolus analis	Grey spotted catshark	015002	0.69	10	4
Rexea solandri	Gemfish	439002	0.66	5	3
Lophonectes gallus	Crested flounder	460001	0.65	6	4
Urolophus cruciatus	Banded stingaree	038002	0.63	12	4
Notolabrus tetricus	Bluethroat wrasse	384003	0.61	1	1
Thyrsites atun	Barracouta	439001	0.58	12	3
Urolophus viridis	Greenback stingaree	038007	0.57	10	3
Urolophus paucimaculatus	Sparsely-spotted stingar	038004	0.56	10	3
Squalus megalops	Spikey dogfish	020006	0.55	12	1
Raja sp. A	Longnose skate	031005	0.55	7	3
Squatina australis	Australian angel shark	024001	0.49	3	4
Trygonorrhina sp.	Fiddler ray	027006	0.47	1	4
Narcine tasmaniensis	Tasmanian numbfish	028002	0.45	9	1
Callorhinchus milii	Elephantfish	043001	0.37	2	4
Gymnothorax prasinus	Green moray	060006	0.19	1	1

* this ratio uses FL in most fish species (SL in S. calauropomus); TL in elasmobranchs

Table 10.2.3.6 Seasonal trends in fish stable isotope data

Species	**Common Name**	**Spp code**	**n**	**Seasonal differences and significance** $\delta^{13}C$	$\delta^{15}N$
Apogonops anomalus	Threespine cardinalfish	311053	25	p=0.0004 autumn/spring autumn/summer	p=0.0015 winter/spring winter/summer winter/autumn
Centroberyx affinis	Redfish	258003	68	n.s.	n.s.
Cephaloscyllium laticeps	Draughtboard shark	015001	30	n.s.	n.s.
Cyttus australis	Silver dory	264002	43	n.s.	p=0.0442 spring/summer
Emmelichthys nitidus	Redbait	345001	25	p=0.0154 winter/spring (2 seasons only)	p=0.0001 winter/spring (2 seasons only)
Helicolenus percoides	Ocean perch	287001	58	n.s.	n.s.
Lepidotrigla modesta	Minor gurnard	288007	29	p=0.0468 autumn/winter (winter sample=3)	p=0.03 winter/autumn winter/spring (winter sample=3)
Nemadactylus macropterus	Morwong	377003	43	p=0.0014 spring/autumn	p=0.0081 spring/summer
Neoplatycephalus richardsoi	Tiger flathead	296001	58	p=0.0041 spring/summer spring/winter	p = 0.0169 summer/winter
Seriolella brama	Blue warehou	445005	28	n.s. (3 seasons only)	p=0.019 spring/autumn
Seriolella punctata	Silver warehou	445006	40	p=0.0033 autumn/spring autumn/winter autumn/ summer spring/summer	p=0.0003 winter/spring winter/autumn winter/summer
Sillago flindersi	Eastern school whiting	330014	28	n.s.	n.s.
Synchiropus calauropomus	Common stinkfish	427001	28	n.s.	p=0.0096 winter/autumn winter/summer winter/spring (winter sample=3)
Thyrsites atun	Barracouta	439001	36	n.s.	n.s.
Trachurus declivis	Jack mackerel	337002	52	n.s.	p=0.0231 autumn/winter
Zeus faber	John Dory	264004	40	n.s.	n.s.

Table 10.2.3.7 Seasonal allocation of commercial vessel and research vessel surveys

Spring	Summer	Autumn	Winter
IM9501	SS9402	SS9602	BB9401
SF9401	SS9606		IM9601
SS9405			SS9305

cardinal fish (winter is different from the other three seasons); and redbait (data were available only for spring and winter).

Ontogenetic changes

For species where there were $\geq$ 20 isotope samples (19 species), the data were examined for evidence of changes in stable isotope values with fish length (Table 10.2.3.8).

There was no evidence of any change in $\delta^{13}C$ or $\delta^{15}N$ with fish length in silver warehou or stinkfish.

In 6 species, both $\delta^{13}C$ and $\delta^{15}N$ values changed with fish length: redfish, ocean perch, tiger flathead, silver dory, barracouta and grooved gurnard.

In 6 species, $\delta^{13}C$ changed with fish length, but $\delta^{15}N$ did not (jack mackerel, morwong, eastern school whiting, threespine cardinal fish, redbait, silver trevally); and in 5 species $\delta^{15}N$ changed with fish length but $\delta^{13}C$ did not (John dory, swell shark, blue warehou, sand flathead and sparsely spotted stingaree).

All changes in stable isotope values with fish length are in the same direction: i.e. increasing fish length is positively correlated with enriched stable isotope signature. This indicates that for species with fish length/stable isotope (particularly $\delta^{15}N$) correlations, bigger fish are feeding higher in the food chain.

10.3 SUMMARY AND IMPLICATIONS

Dietary studies

In all, the diets of 70 species from the SEF were examined. Quite different types of feeding strategies were found within some families or genera. About a third of the total were piscivorous, (more than half their diet was fish). Of the original 70 species, 56 that were well-sampled were selected for further analyses of guild structure. Prey were amalgamated into functional categories for analysis. Interpretation of the dendrograms produced from cluster analysis and multi-dimensional scatterplots identified six main feeding guilds.

In the whole data set, benthic sources of prey dominated. Interestingly, when the data set was reduced to only fishes of commercial or ecological interest (28 in all) pelagic prey sources dominated: most SEF quota species fell into this group.

Ontogenetic changes in some species were observed, although only the data set for ocean perch *H. percoides* was significant. For most species there were too few data to be reliable.

In the focussed habitat studies, ocean perch *H. percoides* and morwong *N. macropterus* (benthopelagic omnivores) and redfish *C. affinis* (a pelagic omnivore) showed significant differences in diet between the different macrohabitats studied. However, John dory *Z. faber,* a benthopelagic piscivore, and snipefish *M. scolopax*, a benthopelagic omnivore, showed little difference between areas. Since some species relied on pelagic food, it is not surprising to find that their diets did not vary according to the macrohabitat in which they were captured. However, the results of these habitat-prey associations were not conclusive suggesting that the rough, reefy areas of the macrohabitats might be used for purposes, other than foraging, such as refuge.

Isotope studies

Stable isotope analysis of muscle tissue gives an estimate of the food assimilated over weeks or months, whereas stomach-contents analysis gives an idea of the the food eaten over the past few hours. Isotope ratios do not identify prey taxa, but rather the trophic niche(s) that an animal is feeding in. In the SEF, stable isotope results showed complex dietary relationships more closely related to functional patterns of feeding than to taxonomic relationships; within a single taxonomic group there may be a variety of isotopic signatures and feeding mechanisms.

In general, fishes with a high $\delta^{15}N$ signal eat a high proportion of fish and/or other species (e.g. polychaetes) that probably have a high stable nitrogen signal. The $\delta^{13}C$ signal provides a rough guide to separating fish by whether they have eaten mainly benthic or pelagic prey. Of the 61 species, 53 (87%) with a $\delta^{13}C$ signal more than –18‰ have a partly to largely benthic habit, as their diets contain a large portion of benthic prey (e.g. polychaetes, molluscs). Of the 26 species whose $\delta^{13}C$ signal was less than –18‰, 20 (77%) take mainly pelagic prey; 2 take mainly small benthic; 4 were caught in insufficient numbers for diet analysis.

SEF fishes can be classified into five broad trophic categories: Group 1 species with highly enriched stable nitrogen and stable carbon values indicating a diet of prey with a high trophic position; Group 2 species with a relatively low (< 50%) proportion of fish and high proportion of pelagic zooplankton; Group 3 species with variable signatures (stomach contents analysis showed a variety of feeding types: 13 benthic feeders, 2 pelagic feeders, 7 benthopelagic feeders, and 5 species with unknown diets); Group 4 species with strong benthic feeding links, and Group 5 species that are mostly small zooplanktivores or feed on zooplanktivores.

In the SEF, the differences in trophic level did not appear to be constant across the food chain. Moreover, the level of enrichment in ^{15}N between adjacent trophic levels (defined as the distance in ^{15}N between a predator and its main prey) did not always match the differences found in other studies (~3.4 ‰ in $\delta^{15}N$). In some instances, very much smaller differences appeared in SEF species at the lower end of the 'food chain'. At the higher end of the food chain there were some greater differences between trophic levels. Possibly, the differences low in the food chain are small and get larger with progress up the food chain. It is also possible that processes we do not yet understand influence the changes in stable isotope ratios between an animal and its food: e.g. in three species of bivalve in this study, the differences in stable nitrogen were smaller than those for stable carbon in both filter-feeders and detritus-feeders (c.f. typical figures in the literature for trophic level differences: 3.4‰ for $\delta^{15}N$, 1‰ for $\delta^{13}C$). When the organisms collected from the SEF are listed in order of decreasing $\delta^{15}N$ signal, and this is compared with stomach content data (Table 10.2.3.1), it is clear that there is great complexity in these food web relationships.

The isotope signatures of SEF species were cross-referenced to an extensive database of morphological measurements (including the ratio of intestine length to body length; number of pyloric caecae or spiral valves; and the length of the longest caecum). The only measurement that showed a significant relationship with stable isotope clusters was the intestine length to body length ratio.

Table 10.2.3.8 Ontogenetic trends observed in stable isotope data (data for all surveys pooled).

Species	**Common Name**	**Spp code**	**n**	**Length correlated with $\delta^{13}C$**	**Length correlated with $\delta^{15}N$**
Centroberyx affinis	Redfish	258003	68	r = 0.73, p < 0.0001	r = 0.44, p = 0.0042
Helicolenus percoides	Ocean perch	287001	58	r = 0.40, p = 0.0015	r = 0.36, p = 0.005
Neoplatycephalus richardsor	Tiger flathead	296001	58	r = 0.33, p = 0.01	r = 0.36, p = 0.0052
Trachurus declivis	Jack mackerel	337002	65	r = 0.35, p = 0.0037	n.s.
Cyttus australis	Silver dory	264002	43	r = 0.76, p < .0001	r = 0.58, p < 0.0001
Nemadactylus macropterus	Morwong	377003	43	r = 0.70, p < .0001	n.s.
Seriolella punctata	Silver warehou	445006	40	n.s.	n.s.
Zeus faber	John Dory	264004	40	n.s.	r = 0.64, p < 0.0001
Thyrsites atun	Barracouta	439001	36	r = 0.65, p < 0.0001	r = 0.46, p = 0.0039
Cephaloscyllium laticeps	Draughtboard shark	015001	30	n.s.	r = 0.73, p < 0.0001
Lepidotrigla modesta	Minor gurnard	288007	29	r = 0.42, p = 0.0222	r = 0.41, p = 0.0252
Seriolella brama	Blue warehou	445005	38	n.s.	r = 0.49, p = 0.0015
Sillago flindersi	Eastern school whiting	330014	28	r = 0.6, p = 0.0005	n.s.
Synchiropus calauropomus	Common stinkfish	427001	28	n.s.	n.s.
Apogonops anomalus	Threespine cardinalfish	311053	23	r = 0.65, p = 0.0005	n.s.
Emmelichthys nitidus	Redbait	345001	25	r = 0.68, p < 0.0001	n.s.
Platycephalus bassensis	Sand flathead	296003	21	n.s.	r = 0.53, p = 0.0116
Urolophus paucimaculatus	Sparsely-spotted stingaree	038004	23	n.s.	r = 0.61, p = 0.0032
Pseudocaranx dentex	White trevally	337062	21	r = 0.49, p = 0.0247	n.s.

Ontogenetic patterns (change in relation to fish length) varied: no change in $\delta^{13}C$ or $\delta^{15}N$ (silver warehou and stinkfish); change in $\delta^{13}C$ and $\delta^{15}N$ (redfish, ocean perch, tiger flathead, silver dory, barracouta and grooved gurnard); change in $\delta^{13}C$ only (jack mackerel, morwong, eastern school whiting, threespine cardinal fish, redbait, silver trevally) and change in $\delta^{15}N$ only (John dory, swell shark, blue warehou, sand flathead and sparsely spotted stingaree). In all cases, increasing fish length was positively correlated with enriched stable isotope signature, showing that bigger fish feed higher in the food chain.

Implications

1. The diets of the 70 species of fish caught with demersal gear on the southeast Australian shelf in sufficient quantities to examine were dominated by benthic items. However, pelagic prey sources dominated in highly abundant species and those of commercial interest. Stable isotope data show that marine phytoplankton provides the basic nutrients for both benthic and pelagic components of the ecosystem. Therefore most fish production on the shelf is driven directly by pelagic production. Indirect pelagic production (cycled through the benthos) supports a more diverse, but less abundant, fish fauna.

2. Most important commercial fish in the demersal trawl fishery in the SEF feed on pelagic or benthopelagic prey. Since there were no top predators identified, we suggest that the SEF is structured by food availability rather than by predation. It follows that there would be little to gain from selective harvesting of SEF species to increase total fishery production. However, we note that the fish communities on the shelf have been fished for close to 100 years, and selective harvesting of species such as tiger flathead may already have removed top predators.

3. We cannot confirm there is competition between species, as we do not have the data to show that either pelagic or benthopelagic prey are limiting. However, any reduction in prey, such as midwater fish removed by environmental factors or harvesting, is likely to have cascading impacts on the production of the currently exploited fish species.

4. The habitat study did not reveal any consistent dietary trends, which leads us to suspect that habitat may be used for refuge rather than for foraging exclusively. From the previous sections, we know that certain fish species are associated with particular habitat types, but the dietary results presented here do not support any particular feeding basis for the association.

5. Stomach contents and isotope data show that, for many fish, when they increase in size and move into deeper water, their diet switches to higher trophic levels, especially more pelagic items and especially fish. This suggests that one reason for larger fish moving to deeper waters is the increased availability of pelagic prey. These prey are often associated with the shelf-break, where deep upwelling brings organic matter and prey communities from the slope.

6. Because deep upwelling is a variable process in space and time, the distribution of commercial fish utilising this source of production is also likely to be variable through space and time. However, as shown in earlier sections, structural habitat also affects their distribution. It seems reasonable, therefore, to hypothesise that structural habitat has a role in modifying local hydrography to either enhance the availability of pelagic and benthopelagic prey, or reduce the expenditure of energy required to obtain these prey.

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11 DISTRIBUTION OF COMMERCIAL FISHING EFFORT ON FISHING GROUNDS

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11.1 METHODS

The southeast Australian shelf is organised at multiple scales of spatial complexity. Seasonal variations in water masses and deep upwelling drive production and availability of the pelagic and benthopelagic prey that constitute the diet of the main commercial species. At a smaller scale, slope and shelf-break topography enhances deep upwelling and increases the availability of prey. At a still smaller scale, seabed structures aggregate fish, perhaps by increasing the availability of pelagic and benthopelagic prey items, or reducing the energy expenditure to obtain these prey items. We now examine how the fishers respond to these features.

11.1.1 Fishing grounds: location and spatial extent

Descriptions of seabed types and the extents of fishing grounds in the study area were recorded during the series of port visits (primarily Lakes Entrance and Eden) and trips to sea on commercial vessels. This information was combined with bathymetry and observations from early survey data and mapped in a GIS (MapInfo) to produce a 'coarse-scale' map of habitats (*Section* 7). The composite map (Fig. 7.2.1.1) was used here as, 1) a visual reference to descriptions of fishing grounds, 2) as a template for an overlay of geological characteristics to estimate the plan-areas of grounds, and 3) as a template for an overlay of trawl effort.

11.1.2 Distribution of commercial fishing effort (temporal and spatial)

Species-by-shot data from commercial fishers recorded on the SEF1 logbooks between 1985 and 1996 were obtained from the AFMA database (Phil Stewart BRS, pers. comm.) and filtered to remove:

- Method not equal to 27 (trawling) or 33 (Danish seine),
- Activities not equal to 0 (fishing),
- Shots starting north of 35°S, south of 40°S or west of 146°E.

This left 1,082,286 observations. The data were then aggregated by boat, year, month, day and operation number, leaving 241,607 observations of individual shots. The hours of fishing, start location, end location, and start time of each shot were retained.

Subsets of the data for each gear and each year, and for each gear and quarter were generated and imported to MapInfo where the total effort for all shots in individual 0.05° squares in a given year was computed, using data aggregation in Vertical Mapper. This process assigns all of a shot's effort to the recorded start location, even though average tow length for trawlers would take the vessel outside of the 0.05° square that it started in. It was not possible to apportion effort from individual shots between 0.05° squares, because the longitude and latitude at the end of a shot were not consistently recorded. Thematic maps of total effort by 0.05° square by year were generated and overlaid on the coarse-scale map of habitats. Effort data were square-root transformed for thematic mapping so that the area of the circular symbols directly represents aggregated trawl hours.

11.2 RESULTS AND DISCUSSION

11.2.1 Fishing grounds: location and spatial extent

A geologically based classification of fishing grounds, based largely on substrate type, contiguous extent and relief, shows the vast majority (89% plan area) are sediment flats, with reefs and broken-ground making up only 11% (Table 11.2.1.1).

A description of the key fishing grounds shown in the coarse-scale map (Fig. 7.2.1.1) is given below (moving generally shallow to deep, west to east). We use units of both metres and fathoms to describe depth features, reflecting common usage by, respectively, scientists and fishers. (One fathom is approximately two metres.) The background information on associations of fishes with habitats was provided by the fishing industry.

'Danish Seine grounds'

These are extensive sediment flats with low-relief sandstone/ fossiliferous reef structures (typically with a rise from flat bottom of about 1 m) in shallow regions of eastern Bass Strait. The '28 Fathom Bank' and '40 Fathom Bank' are elongate patches of harder bottom following these contours in the vicinity of Lakes Entrance. Catches by Danish seine vessels off Lakes Entrance indicate the key target species with depth stratification: school whiting mainly in depths to 26 fathoms, with some taken between 26 and 28 fathoms. In this range the flathead catch comprises mainly southern, toothy and sand flathead. Beyond 24 fathoms, and particularly between 28 fathoms and about 80 fathoms the catch is predominantly tiger flathead.

'South East Reef'

'South East Reef' is a relatively large isolated, inshore (< ~80 m), low-relief reef in eastern Bass Strait. It rises to some 10-15 m above the surrounding bottom at its highest point; its edges are mostly gently-shelving giving the appearance of a bank. It is likely to have a sandstone/ limestone composition–in common with other hard-grounds off the eastern Bass Strait/ Gippsland shoreline region–with an area of relatively hard bottom along its southern perimeter. It is the site for three oil rigs (Fortescue A, Halibut and Cobia A) and in a restricted trawl area.

'South East Reef' was fished consistently from the early 70s and produced large catches of blue warehou in mesh nets for several (at least four to five) years in the late eighties and early nineties. It is of great interest that no commercial catches have been taken from it in recent years despite continued low-level effort. The reason for the demise of fishing is unknown; the plausible, but uninvestigated, influences cited by fishers include habitat modification (considerable but unquantified volumes of large epibenthic invertebrates were removed), stock over-fishing and seismic testing.

Table 11.2.1.1 Fishing grounds in continental shelf study area (25 to ~200m, Wilsons Promontory, VIC to Green Cape, NSW): plan area, plan percent of study area and approximate cross-shelf location.

Fishing ground	Area (sq km)	% of study area	Inner shelf/ mid-shelf/ shelf break
Reef and broken ground	**2631**	**11.1**	
Low relief, broken, sandstone/ limestones	*1442*	*6.1*	
28 and 40 fathom Banks	532	2.3	I
Southeast Reef	52	0.2	I
Broken Reef	281	1.2	I
Six-hour Reef	83	0.4	I
Seven-hour Bank	8	0.0	M
Seven-hour Bank (rough ground)	160	0.7	M
Black Head Reef	8	0.0	I
Howe Reef	318	1.3	M
High/ low relief limestone complex	*510*	*2.2*	
West Bank	11	0.0	M
East Bank	33	0.1	M
Horseshoe Reef	14	0.1	M
Gabo Reef	340	1.4	M
Gabo Reef (south extension)	92	0.4	M
The Wall	20	0.1	M
High relief granite	*55*	*0.2*	
Point Hicks Reef	11	0.0	I
New Zealand Star Banks	44	0.2	I
Cemented carbonates/ sediment flats	*364*	*1.5*	
Flower Patch	351	1.5	SB
Flower Patch (west extension)	13	0.1	SB
Unsurveyed	*260*	*1.1*	
Cape Howe Reef	26	0.1	I
Marlo Reef	52	0.2	I
Riccardo Reef	5	0.0	I
Inshore Mallacouta	48	0.2	I
Point Hicks-Gabo Island inshore reef	129	0.5	I
Sediment flat mosaics	**20979**	**88.9**	
Airstrip	234	1.0	I
Sand Patch	1055	4.5	M
Eastern Bass Strait shelf edge	1537	6.5	SB
East coast shelf edge	722	3.1	SB
Pt Hicks-Gabo Island inner shelf	464	2.0	I
Disaster Bay	265	1.1	I
Spaghetti-weed Patch	38	0.2	I
Eastern Bass Strait inner-shelf	9045	38.3	I
Eastern Bass Strait outer-shelf	7619	32.3	M

Outer-shelf trawl grounds

'Smithy's Corner' is a shelf-break region where flat, hard bottom drops sharply away to a bowl-shaped, more gradually sloping area of scattered broken-ground. It marks the point at which one of the primary arms of the Bass Canyon opens to the shelf, and is close to the end of our transect A. Historically, fishing was by trawling along the top rim in about <130 m but over the last 5-6 years tows have been developed over the rim and down the slope. It is still a productive ground for flathead and blue warehou but species that used to be abundant there— striped trumpeter, morwong and redfish, and pink ling at the deeper margin— apparently no longer occur commonly.

'10 x 10 Reef' is a similar 'hard bottom' shelf-break habitat south of the oil rigs near the end of Transect B. It is a north-south wall sloping down from 115 m into a basin-shaped canyon in 150 m. Historically it was a productive ground for crayfish, pink ling, striped trumpeter, morwong, yellowtail kingfish, shark and blue-eye in the deeper sections but it is now relatively poor fishing. Some operators attribute its decline to habitat removal and burial by sediment in the prevailing eastwards-moving current. However, it is not known whether this results from sediment disturbance by trawling along the canyon rim or from natural hydrodynamic processes. Areas for trawling are reported to have been opened-up in places off the shelf-edge.

'Little Horseshoe' is another of the key 'hard bottom' shelf-break grounds of eastern Bass Strait marking the opening of an arm of Bass Canyon. There is a productive section in 140 m that is currently gillnetted but not trawled— although there are trawl shots on either side.

'Broken Reef' complex

The 'Broken Reef' covers an area from Cape Conrad to Little Rae Head. An extensive area of hard-broken-ground runs from 58-61 fathoms west of Pt. Hicks and from ~58 to 64 fathoms between Pt. Hicks and 'New Zealand Star Banks'. The area is a mix of hard, broken limestone and sandstone outcropping from coarse sand and is bordered by granite outcrops inshore at Pt. Hicks and to the east at the 'New Zealand Star Banks'.

'6-Hour Reef' forms the westernmost part of the 'Broken Reef 'complex in depths of ~62-63 fathoms; it runs roughly east-west to the northwest of the '7-hour Bank' (below). Some reports suggest that it has been eroded by trawling and is now towable further to the east than in the early 1990s. It is a productive for warehous, with noted spots for gillnetting and trawling.

'New Zealand Star Banks'

A massive, predominantly granite outcrop with debris fields, ledges and occasional intervening sand patches. Navigation charts note breaking waves in this area during conditions of large ocean swell. Historically it was a good ground for striped trumpeter and other species but is no longer regarded as a good commercial ground.

'The Horseshoe'

Also commonly known as 'Everard' after the shoreline point, Cape Everard, this has been one of the most productive and heavily fished grounds in the SEF. It consists of the largest opening of the Bass Canyon onto the shelf and is bounded by a variety of substantial hard-grounds on the shelf. These run to the east and west ('East Bank' and 'West Bank'), along its inner margins (particularly the west and north), and occupy areas directly inshore–the '7-hour Bank' and an area of associated broken-ground, and the '6-hour Reef'.

The many trawl tows that run through or adjacent to the East and West Banks and the reef at the margin of the canyon mouth are important for a variety of species including large blue warehou, large redfish, flathead and morwong.

'7-Hour Bank' is a productive 'hard bottom' trawl ground running NW-SE to the NW of Everard Canyon. The hardest bottom is on the inside (NE) edge; the rise of the bank is small, only 1-2 fathoms. The area of hard-ground to the NE is trawled but has isolated patches of reef that cannot be trawled over. Both this and '6-hour Reef' have historically produced large quantities of morwong (Easter) and snapper (July) but catches are reported to have declined.

'Sand Patch'

The 'Sand Patch', named after the adjacent Sand Patch Point, is an extensive deep plateau of generally flat bottom extending from the inside angle of the southernmost end of Gabo Reef around to the eastern perimeter of 'The Horseshoe'. It runs roughly in 69-77 fathoms and is shallowest in the middle. A slender, tube-like, spongy 'weed', generally 4-6" in length but up to 8-9" in height, characterises the area. It is a consistently productive ground for a variety of species— flathead, morwong, snapper, silver and blue warehou— with occasional very large shots of blue warehou taken.

'Flower Patch'

The 'Flower Patch' is a name given to at least two different (but more or less contiguous) shelf-break areas of consolidated sediment hard-grounds characterised by attached stalked crinoids. This ground extends primarily from 'The Wall', a sheer section of the shelf-break adjacent to the southern end of 'Gabo Reef' to the eastern margin of 'The Horseshoe' and extends onto the upper slope. The second, smaller area is the western margin of 'The Horseshoe'; similar substrates apparently also occur in scattered patches northwards and beyond the northern boundary of our study area.

Both board trawlers and Danish seiners have fished these productive grounds for a variety of species–predominantly morwong, large redfish, warehou species, snapper and John dory. Skippers have the impression that crinoids recolonise rapidly because they reappear over the same tows.

'Howe Reef/ Gabo Reef' complex

The 'Howe Reef/ Gabo Reef' complex is the single largest tract of hard-ground in our study area and a key fishing ground, particularly for the Eden-based trawl fleet. It is formed of cemented, fossiliferous limestone reef that exists as a mosaic of variable size, mostly low-relief (< 3 m) patches along the inner (shoreward) margins and a generally more contiguous outer margin that is highly cemented and has high relief (> 10 m) in places. 'Howe Reef' is the section north of Cape Howe and is mostly a mosaic of reef patches; 'Gabo Reef' is the southern section and is a relatively unbroken tract. Several elongate 'gutters' that run roughly north-south (mostly through the 'Howe Reef patches) are important trawl tows and include the 'Big Gutter', 'Little Gutter', the 'Snake Track', and 'Curley's Hole'. 'Gutter fishing', that has two seasonal peaks, is primarily for morwong, redfish and, increasingly, blue warehou.

'Spaghetti Weed' patch

The 'Spaghetti Weed' patch is an area adjacent to Gabo Is., the 'Airstrip' and the 'Sand Patch' in ~25-50 fathoms characterised by a small, soft, tubular, brown 'weed' (presumably polychaete tubes) and large quantities of dead small bivalve shells. It is a productive area at times for a mix of species including morwong, bastard trumpeter, silver trevally, octopus, leatherjackets and blue and silver warehou 'on the move'.

11.2.2 Distribution of commercial fishing effort (temporal and spatial)

Temporal distribution

Reported commercial trawl effort- as measured by both trawl hours and individuals shots- increased substantially during the last 12 years (to 1997) in the study area (35 to 40°S and east of 146°E) (Table 11.2.2.1, Fig. 11.2.2.1). The overall trend resulted mostly from increases during the latter six years (1992 to 1997).

From 1992 to 1997, total effort increased by ~60% on the continental shelf (depths < 250 m): trawl hours from ~20,500 to 34,500, and shots from ~6,600 to 10,800 (Table 11.2.2.1a). The average duration of shots also increased marginally during this time (3.09 to 3.18 hours), up from 2.78 hours in 1986. Over the same six-year period, the increase in effort was greater on the slope (depths > 250 m) where the total effort doubled: hours increasing from ~13,000 to 26,000, and shots from ~3,900 to 7,800 (Table 11.2.2.1a). These trends (both shelf and slope) contrast to patterns over the previous six-year period (1986 to 1991) when the overall level of effort was relatively steady despite some inter-annual variability (Fig. 11.2.2.1a,b).

Danish seine effort has decreased by a little over 10% over the same period (Table 11.2.2.1b and Fig. 11.2.2.1c).

Spatial distribution

The spatial distribution of effort showed several distinct patterns with respect to both habitat (depth and seabed type), and time. Annual distributions of effort over this period (1986 to 1997) are shown overlaid on the coarse-scale map of seabed habitat (Fig. 11.2.2.2).

The consistent picture over these years is a widespread distribution of trawl effort in the study area. The most recent data (1997) indicate that trawling on the shelf occurs primarily on the outer-shelf region (>100 m) with most effort at the shelf-break (~200 m) (Fig. 11.2.2.2). Trawl effort is particularly concentrated at the shelf-break off Victoria where the shelf is relatively wide and the proportion of hard-ground relatively low (Fig. 11.2.2.2). Effort on the slope is mainly on the upper slope–a relatively narrow band of seabed extending down to ~700 m depth. Because this region was outside our study area we have not included detailed bathymetry in Fig. 11.2.2.2.

In the deeper outer-shelf and shelf-break regions (~>150 m), most fishing is on the sediment flats north of Cape Howe, seaward of the Gabo-Howe Reef complex, and off eastern Bass Strait, as well as on the consolidated sediment mosaic of the Flower Patch. Concentrations of effort occur close to Eden, around canyon necks (especially the hard-grounds of the Horseshoe and Little Horseshoe) and at habitat boundaries- particularly those between sediment flats and limestone reefs such as the outer edge of the Gabo-Howe Reef.

On the mid-shelf shoreward of these grounds (~100-150 m), fishing occurs mostly at the margins and gutters of Howe Reef, the inner and outer margins of Gabo Reef, outer reaches of the Sand Patch, shoreward reaches of canyon necks (especially 7-Hour Bank and the East West Bank) and across the massive sediment flats of eastern Bass Strait. Large parts of Gabo Reef, Broken Reef and 6-Hour Bank appear to be untrawled (based on 'start-position' data).

Inner-shelf grounds (<100 m) are relatively lightly fished except for the outer reaches of Disaster Bay and grounds close to Eden. The near-shore effort close to Lakes Entrance is probably mis-coded Danish Seine effort. (Other obvious errors in the database, e.g. shots reported over land, are left in to give some idea of the precision of individual data points.)

An important feature of effort distribution was the change in spatial resolution at which trawl shot positions were recorded in logbooks. This was most evident between 1994 and 1995 when the resolution increased considerably due, presumably, to a switch to recording by GPS position rather than grid-square. The degree of disaggregation prevents direct comparison of spatially distributed effort (in different habitats) before and after 1995.

During the period 1995 to 1997, the increases in total effort on both shelf and upper-slope were distributed across many of the key grounds but also showed areas of concentration at habitat boundaries. These include the outer margin of Gabo Reef (including The Wall and Gabo Southern Extension), and the East and West Banks. In some other grounds, particularly Broken Reef, effort appears to have declined. The relatively high effort off Cape Howe in the southern reaches of Disaster Bay in 1995 compared to subsequent years may be an artefact arising from the mis-reporting of catches taken offshore.

Interpretation of effort data in relation to seabed habitat is limited both by the spatial resolution of seabed maps and by the spatial representation of trawls. We used aggregated trawl hours based on start positions with a coarse-scale map but recognise that these provide only approximate representations for trawl shots that are typically several (>10) nautical miles in length. However, the currently available logbook data (trawl start and end positions) are not amenable to spatial analysis at fine-scales. Analysis based on shot mid-points provides a closer spatial approximation of effort by including end-points, but suffers from the introduction of unknown errors because trawl tows do not follow straight lines. Fishers report that tow tracks follow physical boundaries- most often depth contours, reef margins and gutters or 'paths' through 'broken-ground' (limestone mosaics). For example, the important, and aptly named, 'Snake Track' tow used by Eden fishers involves several direction changes to navigate around limestone patches comprising part of the Howe-Gabo Reef complex.

Danish seine effort is far more restricted (Fig. 11.2.2.3), with concentration on school whiting and flathead species on the inner-shelf off Lakes Entrance, and tiger flathead on the outer-shelf off Lakes Entrance.

11.3 SUMMARY AND IMPLICATIONS

Characteristics of fishing grounds

At a resolution of tens of kilometres, the SEF continental shelf 'seabed landscape' used by the commercial fishery can be visualised as massive sediment flats ('soft-grounds') with reefs, bedrocks and consolidated sediment ('hard-grounds') outcrops

Table 11.2.2.1a Reported commercial fishing effort by trawlers off Eastern Victoria and Southern New South Wales. (Data from SEF1 logbook data through AFZIS database and BRS)

Depth	Year	Total effort	
		Hours	Shots
<250 m	1986	24,571	8,826
	1987	19,005	6,447
	1988	24,747	8,219
	1989	21,970	7,435
	1990	22,219	7,249
	1991	21,809	6,982
	1992	20,537	6,642
	1993	25,771	8,414
	1994	29,504	9,517
	1995	29,780	9,216
	1996	33,618	10,253
	1997	34,551	10,841
>250m	1986	15,707	5,205
	1987	14,643	4,779
	1988	15,462	5,794
	1989	13,037	4,603
	1990	11,914	3,917
	1991	13,833	4,281
	1992	13,196	3,898
	1993	17,255	5,154
	1994	16,813	5,424
	1995	20,045	6,455
	1996	23,684	7,649
	1997	26,356	7,803

Table 11.2.2.1 b Reported commercial fishing effort by Danish seiners off Eastern Victoria and Southern New South Wales. (Data from SEF1 logbook data through AFZIS database and BRS

		Total effort		
Depth	Year		Hours	Shots
<250 m	1986	1	11,451	8,947
	1987	1	10,937	7,710
	1988	1	11,323	8,001
	1989	1	10,979	7,695
	1990	1	11,510	8,037
	1991	1	10,232	7,161
	1992	1	9,984	7,038
	1993	1	8,620	6,107
	1994	1	9,146	6,466
	1995	1	8,513	6,026
	1996	1	9,092	7,329
	1997	1	9,807	7,907

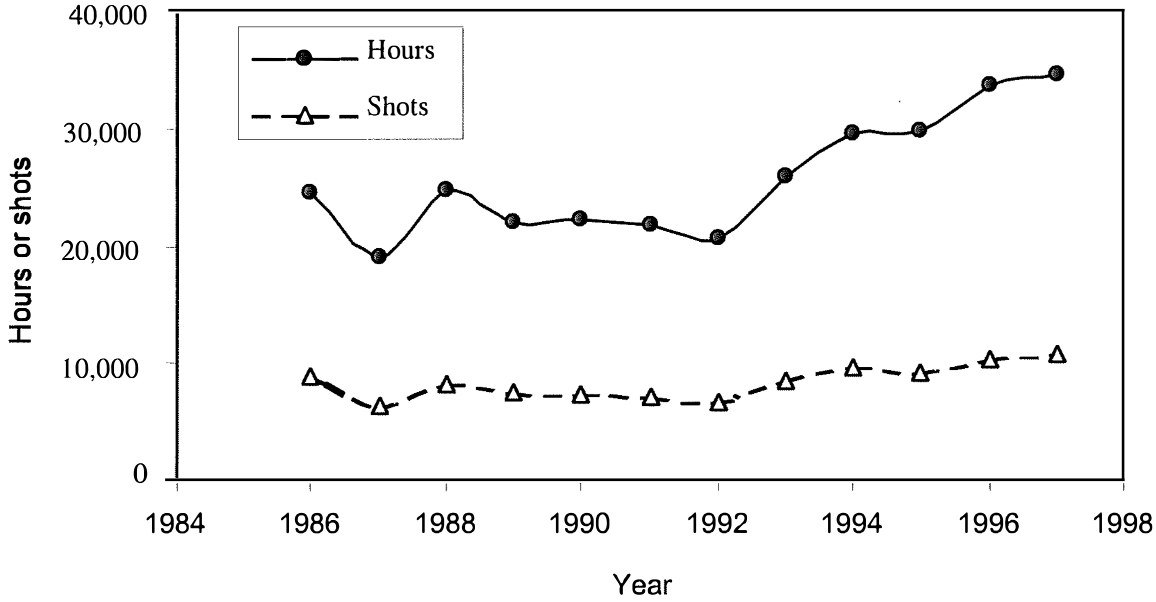

Figure 11.2.2.1 (a) Annual trawl effort on shelf less than 250 m deep between 35 to 40°S and east of 146°E.

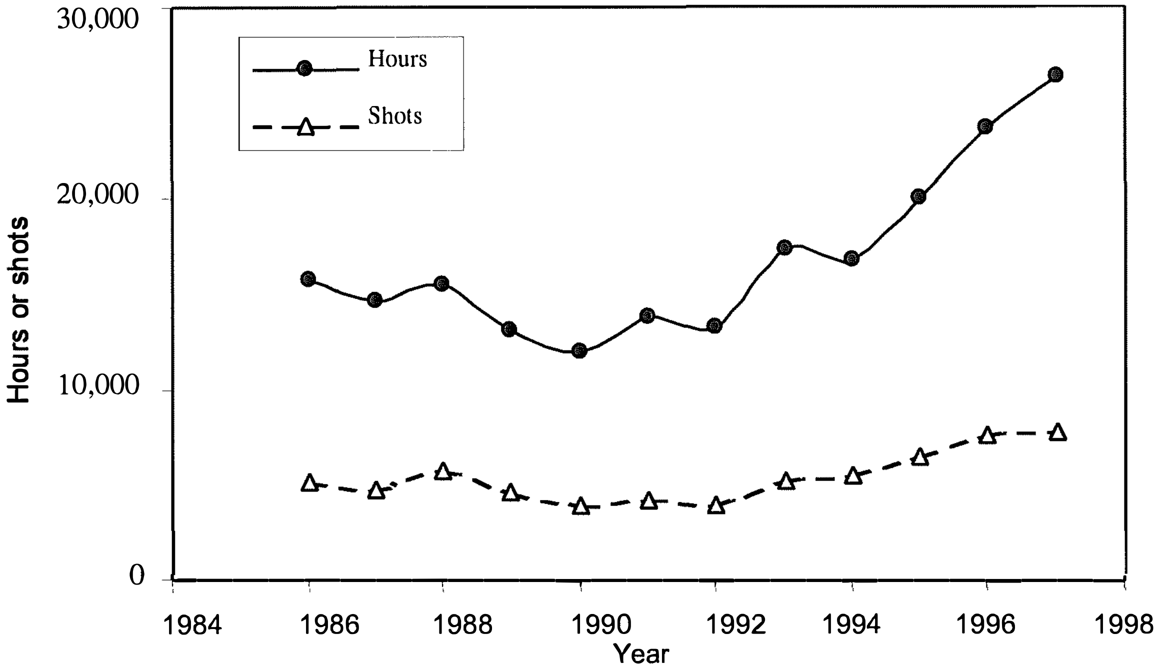

Figure 11.2.2.1 (b) Annual trawl effort on shelf more than 250 m deep between 35 to 40°S and east of 146°E.

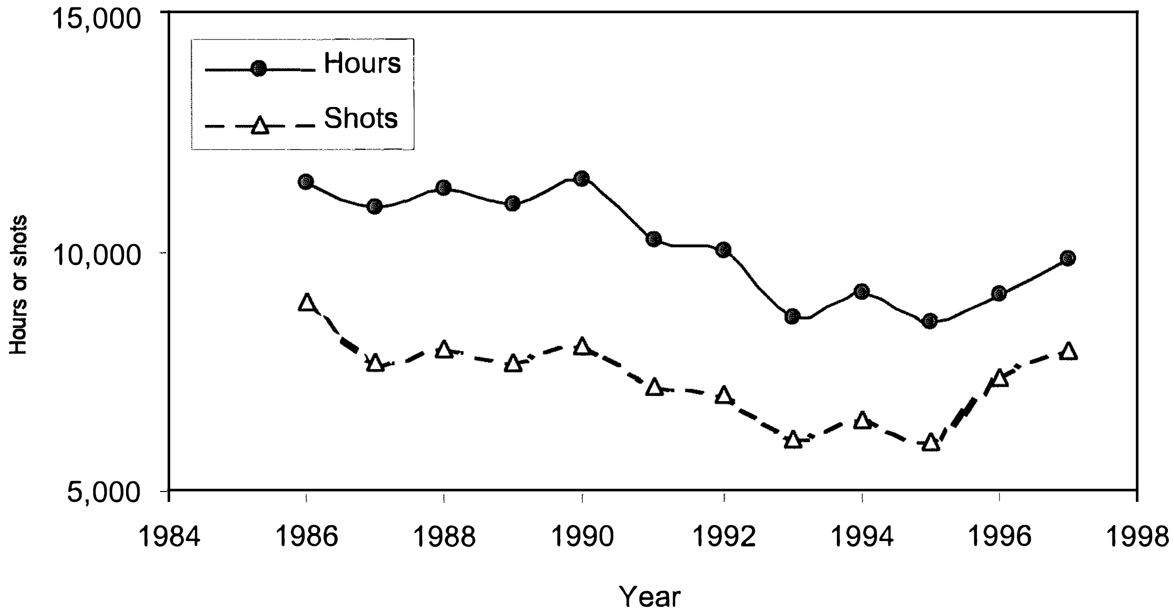

Figure 11.2.2.1 (c) Annual Danish seine effort between 35 to 40°S and east of 146°E.

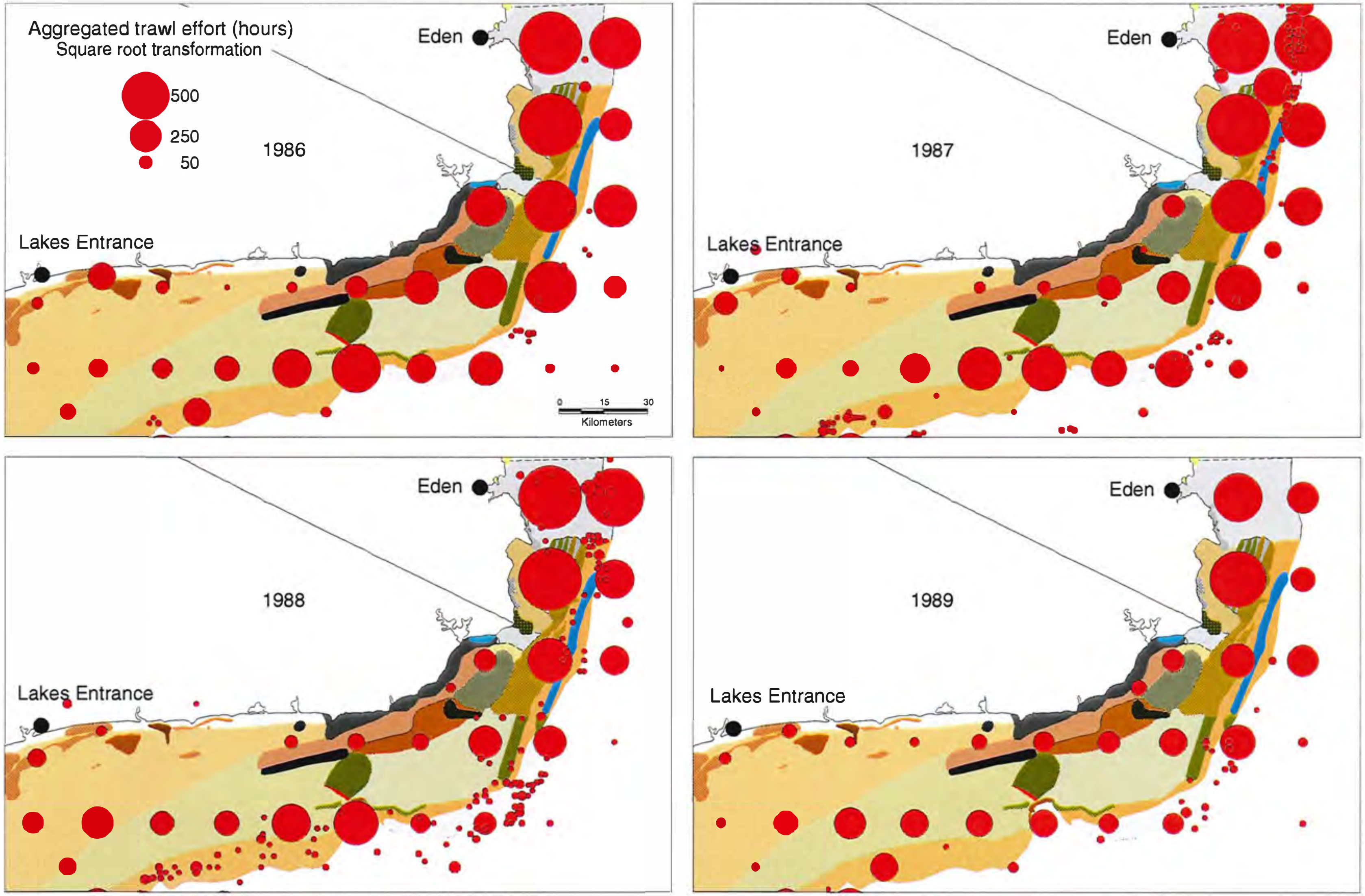

Figure 11.2.2.2 Thematic map of commercial trawl effort overlaid on coarse-scale map of habitats. Grid cells containing less than 10 hours effort excluded.

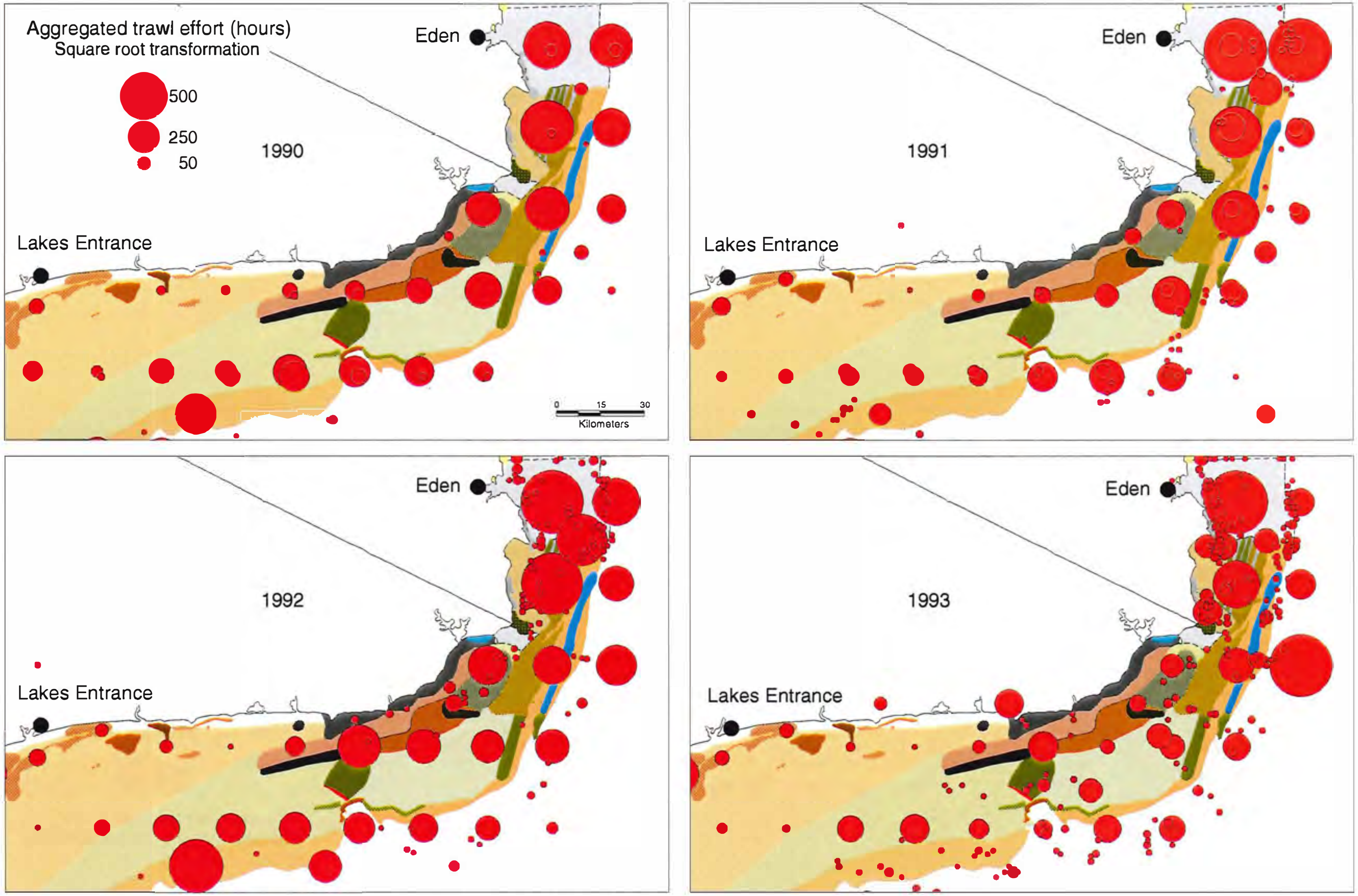

Figure 11.2.2.2 (continued) Thematic map of commercial trawl effort overlaid on coarse-scale map of habitats. Grid cells containing less than 10 hours effort excluded.

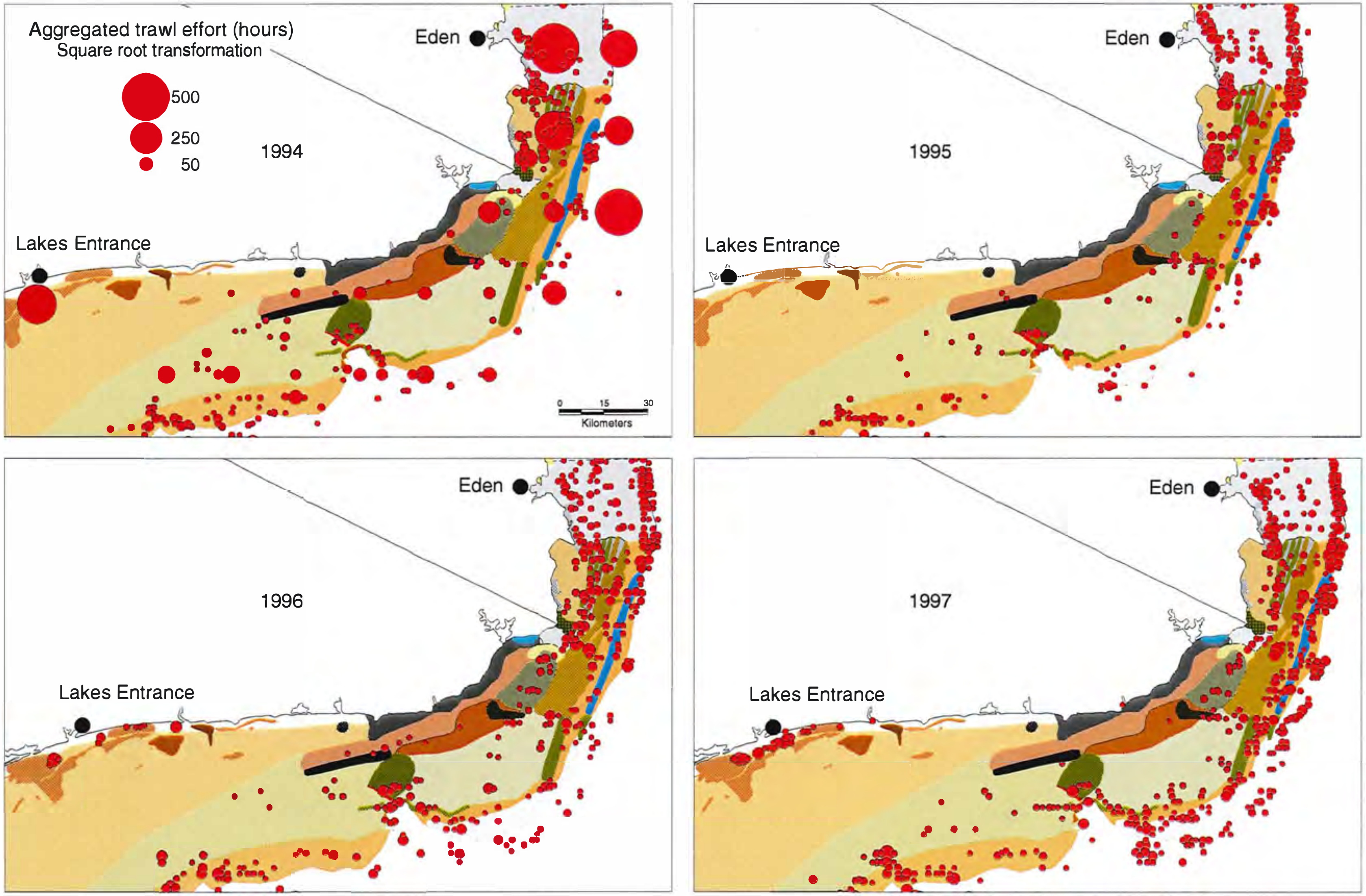

Figure 11.2.2.2 (continued) Thematic map of commercial trawl effort overlaid on coarse-scale map of habitats. Grid cells containing less than 10 hours effort excluded.

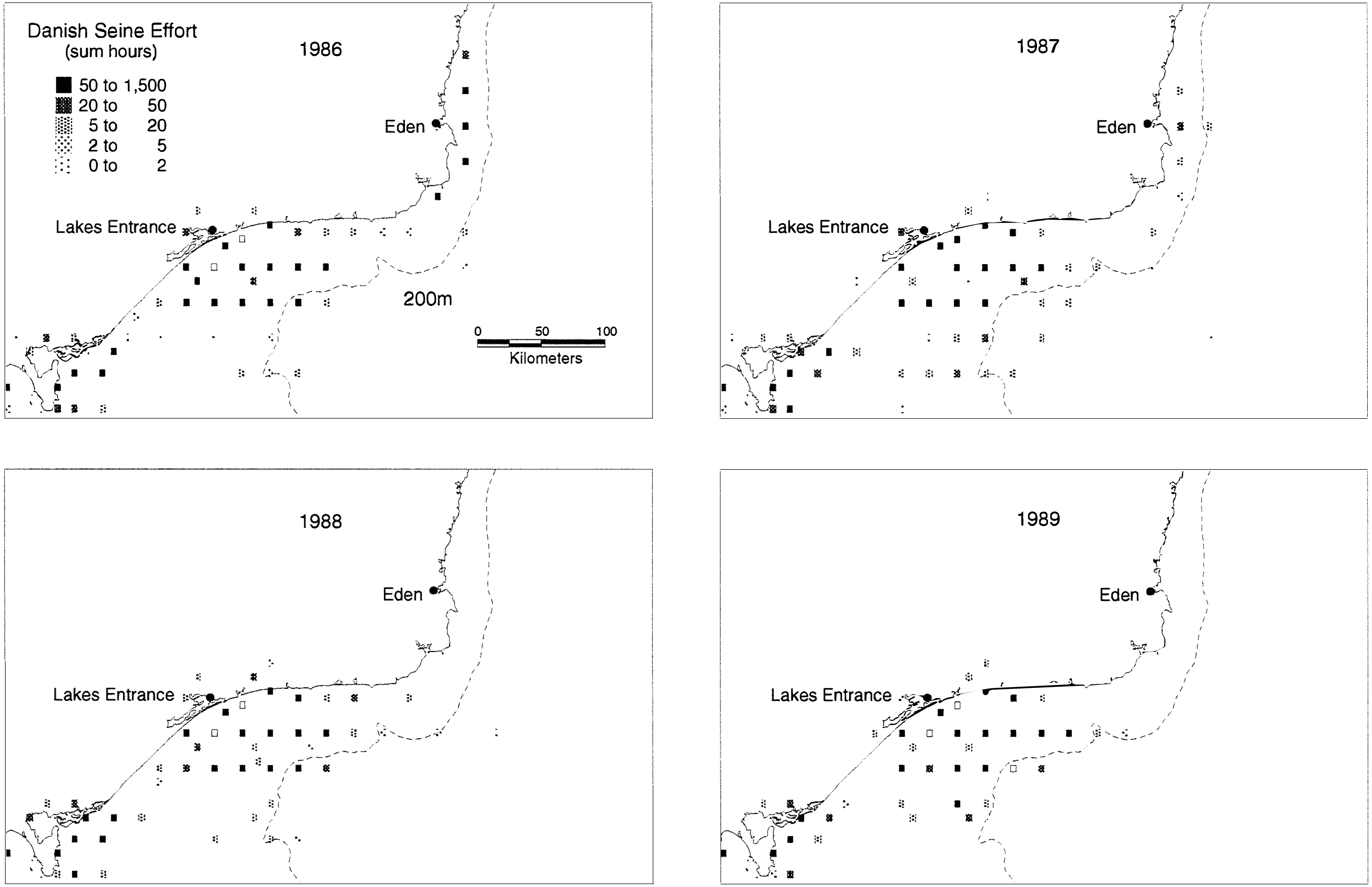

Figure 11.2.2.3 Distribution of Danish seine fishing effort in study area from 1986 - 1997, all depths.

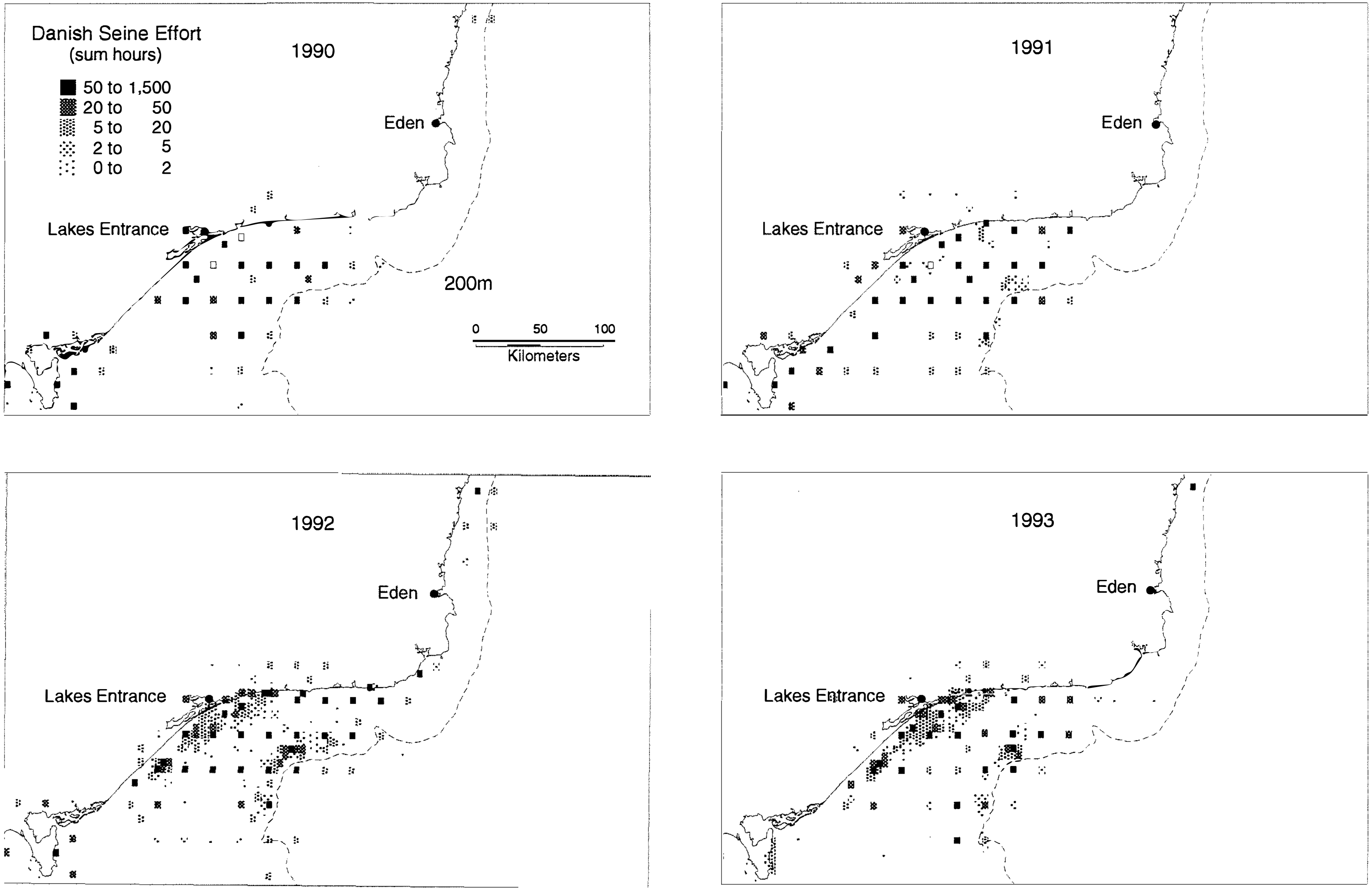

Figure 11.2.2.3 continued

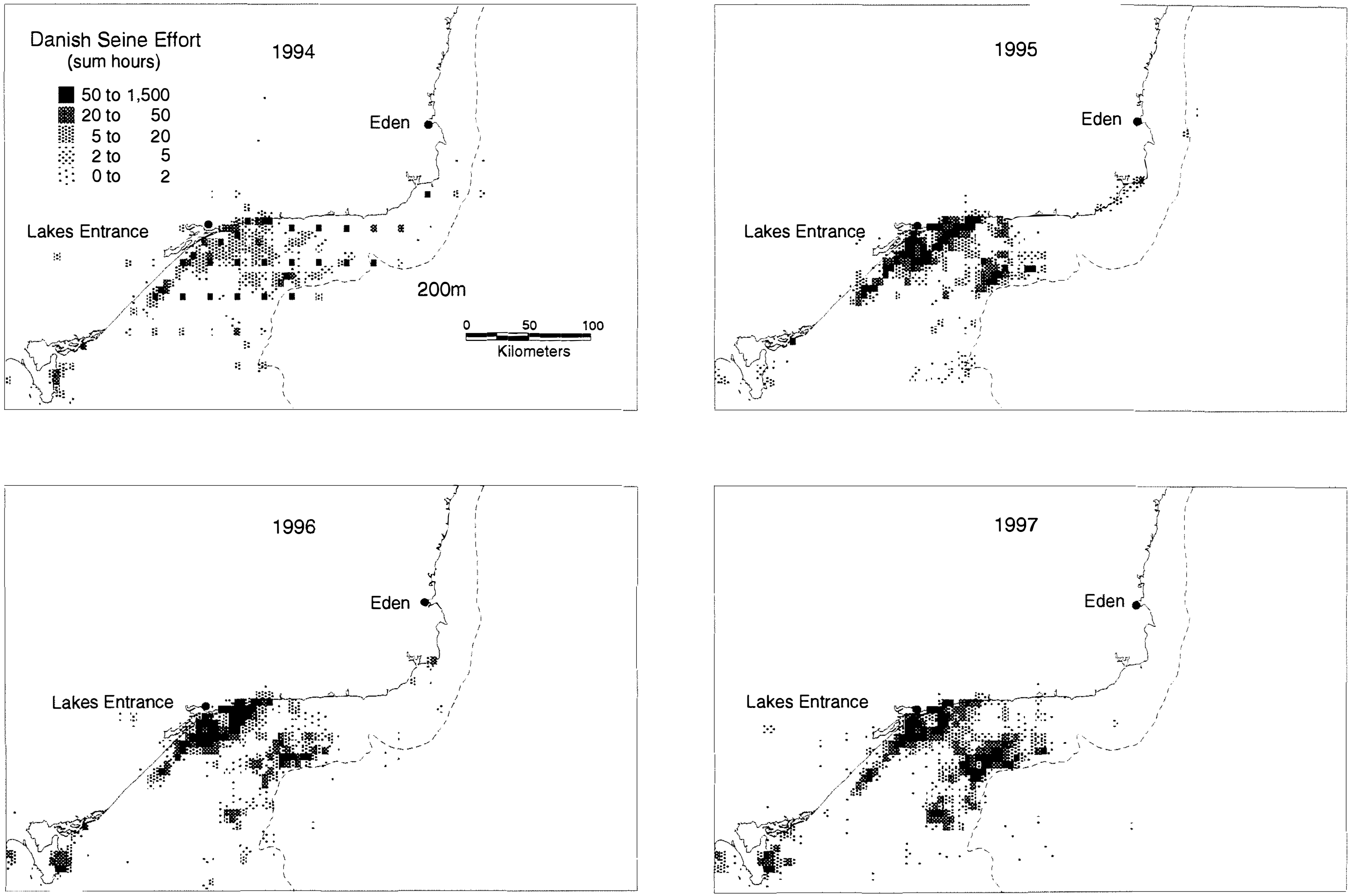

Figure 11.2.2.3 continued

(*Section* 7). In our study area, most of the seabed (89%) is sediment flats, with hard-grounds making up only 11% (Table 11.2.1.1). Finer-scale resolution (hundreds of metres) would identify additional outcrops of reef (biogenic and bedrock) and patches of cemented hard-grounds in the sediment flats, particularly at the shelf-break. However, while these are important features of fishing grounds, they would not substantially change the overall proportions.

As all ground types are habitats for commercial species, fishing effort covers a wide area. However, effort is concentrated in small areas where productivity is greatest. In this context, 'productivity' includes the likelihood of finding commercial species, their density or abundance, their size, and their availability. Productive areas such as the margins of 'hard-grounds' and the outer-shelf/ shelf-break are fished repeatedly. Key productive areas that are untrawlable (such as the outer Gabo Reef platform) may be effectively fished with gillnets, for blue warehou, for example.

Many shelf-edge sediment flats are productive fishing grounds for a variety of species because the flats are near to the source of upwelled nutrients and advected oceanic pelagic prey (*Sections* 5 and 6). In these environments, commercial species are larger fractions of the total fish communities (*Section* 8), are often aggregated, and have a greater mean size than in shallower depths (*Section* 10). Hard-grounds, particularly reefs, provide productive grounds for a different suite of species; it includes fishes that use soft- and hard-grounds but also those that just use hard-grounds (*Section* 8). Productivity in hard-grounds is high because they provide refuges, hunting grounds, aggregation points and modify current flows.

Overall, the most productive regions of the seabed for fishes and fishers are where these attributes of high production occur together. These are the prime fishing grounds (as shown by maps of effort), which include the shelf-break canyon necks (Horseshoe, Little Horseshoe and Smithy's Corner), outer-shelf/ shelf-break limestone reefs (East and West Banks, 7-Hour Bank, Gabo-Howe Reef complex) and consolidated sediment mosaics (Flower Patch). These habitats, together with nursery and spawning areas, are therefore critical habitats for fishery production.

The value of fishing grounds to the fishery

In spatial terms, key fishing grounds make a disproportionately high contribution to overall fishery productivity by providing the habitat in which commercial fishes 'grow-on', and by aggregating key species in commercial quantities at particular times. This is particularly true of the hard-grounds in our study area, which make up only about 11% of the seabed. Many key fishing grounds–hard-grounds or particular parts of large soft-grounds–exist at smaller spatial scales than can be easily mapped or managed (*Section* 7). Future spatial management plans must recognise the importance of fine-scale critical habitat distributions to the fishery. Well-informed planning will be needed to ensure that intervention does not unnecessarily restrict current fishing activities or curtail the development of new areas. Spatial boundaries may also need temporal components to give access to species in sensitive areas during particular seasons, for example the blue warehou migration across inner-shelf sediment flats off Disaster Bay.

The vulnerability of grounds to fishery impact

Are there habitats that are significant to the fishery that have been, or will be, adversely impacted by fishing activity?

Some fishers report erosion and disappearance of some offshore features in recent years, but this is difficult to verify. There is no doubt that adoption of advanced navigational aids (track plotters and GPS), and gears that fish rough-ground effectively, has enabled effort in trawl and non-trawl sectors to be increasingly targeted at the fine-scale habitat features that attract fish. But, while spatial management has the potential to redirect fishing effort and reduce the local effort to preserve significant habitat, the definition of 'significant habitat' is vague.

Here we define significant habitats in terms of vulnerability and resilience. Significant habitats are those that are targeted by fishing and vulnerable to erosion or removal unless effort is managed. They are habitats that once eroded may never recover (short of the next ice age). Resilient habitats are those unlikely to be eroded by current fishing practices.

Our rock, sediment and photographic sampling (*Section* 7) show that 'hard-ground' habitats are fossiliferous limestone reefs formed of bivalve and bryozoan clasts, sediments consolidated by reef-forming bryozoans, indurated (cemented) sediments, and outcrops of granite and sandstone bedrocks. Their vulnerability to modification by fishing gears varies, depending on the hardness, degree of weathering, relief, area extent and spatial integrity. 'Soft-ground' habitats, which form most of the shelf seafloor, are massive sediments, primarily sands but with gravels and mud in some areas.

The most vulnerable habitats are shelf-break bryozoan reefs (e.g. those of the Flower Patch) which are soft and lightly-attached, have little vertical relief (< 30 cm) and exist as small patches (of the order of square metres). Bryozoan reefs may be completely removed by fishing gear, but nothing is known about their recovery times in this area. Once dead, bryozoans are also the main constituent of outer-shelf sands (often > 60%, *Section* 7).

Many inner-shelf fossiliferous limestone/ sandstone reefs are also vulnerable because they are relatively soft, strongly-weathered, have little vertical relief (< 2 m) and exist in isolation or as patches intersected by gutters (e.g. Broken Reef). This means their structure can be damaged by tow wires (sawing) or removed by nets. Their spatial structure, often consisting of multiple reef patches, can be 'opened up' or subdivided by trawl tows. Having no jutting rocks means that areas can be towed over by robust ground-gear fitted with rollers or bobbins. It is likely that carefully targeted preservation or controlled opening-up of these habitats has the potential to enhance fishery productivity— but current activities are undocumented.

The most resilient habitat are highly cemented, deep, high-relief (to 10 m), large and undivided fossiliferous limestone reefs such as Gabo Reef, and granite outcrops. Opening-up of habitats, especially in areas of extensive hard-ground such as western Bass Strait, or even Gabo Reef, may increase fishery productivity. Howe Reef, a northern extension of Gabo Reef, has been opened-up over decades and continues to be a productive fishing area. However, it is too early to say to what extent hard-ground areas can be opened up without reducing overall fishery productivity. Again, there is much to be learned through monitoring current activities.

Impacts of fishing on the structure and stability of sediment flats in this predominantly high-energy, current-swept shelf environment are unknown, but may not cause permanent modifications (on a geological time scale). Many sediment flats have been fished for decades and are still productive. The long period over which they have been fished also means that impacts are difficult to evaluate.

Implications

1. Trawl effort on the continental shelf seabed of our study area is widely distributed and occurs in all habitat types, except on platforms of limestone reef and bedrock. However, trawl effort is concentrated at small, productive areas such as the margins of 'hard-grounds' that are fished repeatedly. Some untrawlable areas, such as the outer Gabo Reef platform, are effectively fished with gillnets, particularly for blue warehou.

2. The commercial imperative will always encourage operators to 'open up' new areas in the expectation of better catches, and to be 'first in' to maximize catch before tows becomes common knowledge. It has been possible to substantially 'open-up' the hard-grounds (~11% of our study area) during the last decade due to the skill of fishers in using new navigational technology (primarily GPS and trackplotters) together with greater fishing power (primarily bigger boats, heavier trawl wires, better trawl ground-gear and improved gillnets). 'Opening-up' of the most vulnerable habitats could lead to erosion or complete removal of reef substrate and invertebrate cover, and therefore the subdivision of larger reef areas into smaller patches. There is no documentation or regulation of this use. The likely result is that some hard-grounds would no longer be critical habitats to increase fishery catches. However, it is also possible that in areas of extensive hard-ground (e.g. western Bass Strait) 'opening-up' could increase fishery productivity.

3. Geological properties partly determine the vulnerability or resilience of hard-grounds to modification or permanent damage by fishing gear. Indicators include hardness, relief, degree of weathering and patch-size.

4. Habitat vulnerability may not involve direct impact by fishing gear; some operators believe that certain areas, such as the shelf-break 'Ten x Ten Reef', are susceptible to burial by sediment carried by prevailing currents from adjacent areas. It is not known whether this results from sediment disturbance by trawling or from natural hydrodynamic processes. The effect of trawling on sediment stability also remains unknown.

5. The cooperation of the fishing industry is highly desirable for effective spatial management, because vulnerable seabed features often exist at fine-scales. In practical terms, it would be difficult–and potentially counter-productive–to enforce effort restriction on such a small-scale without industry cooperation. Alternative approaches, such as restricting effort over larger areas by using spatial buffers, could reduce fishery productivity and cause fishers to fish harder in unrestricted areas. A requirement to use trawl gear that rides high off the seabed, facilitating trawling on hard-ground habitats without removing substrate or benthos, is an option worthy of further consideration. However, it would first be necessary to compare the benefits of reducing removals in fished areas with the benefits of leaving the areas unfishable.

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12 CONCLUSIONS

"Ecosystem Management" is a commonly stated goal of marine fisheries management in Australia and overseas, but what does it mean? Ecosystem properties, as distinct from the properties of individual species, are those that relate to the ecosystem as a whole and are not reducible to their individual components (Odum 1953). Ecosystem properties are rarely proposed for use in marine fisheries management (though see Caddy 1993). Instead, it has been frequently proposed that traditional marine fisheries management can been extended by amalgamating single-species models linked by predation into multispecies models (e.g. Laevastu and Larkins 1981, Gislason and Helgason 1985). These multispecies models have frequently been considered a form of ecosystem management, despite ignoring the ecosystem as a whole.

Ecosystem approaches in marine fisheries have concentrated on species interactions firstly, because the multispecies models were a logical adaptation of familiar single-species models; secondly, because the models have an extensive theoretical background; and thirdly, because they use the sorts of data (species, abundance, diets, growth, and natural mortality rates) that are the fodder of fisheries science (they can be collected from fishing vessels or fish markets). These models have been used to correct misconceptions of processes at the single-species level and to provide advice on managing multispecies communities (e.g. Gislason and Helgason 1985).

But species interactions, and associated energy flows, are only one facet of ecosystem functioning. Recent technological advances in remote sensing and geographic positioning systems are changing the ways in which we can study the marine environment and therefore the ways in which we can monitor and manage ecosystem processes. We are now no longer absolutely limited by technology in our choice of which aspect of the marine ecosystem to study, but can now choose aspects of marine ecosystems that are likely to benefit most from management intervention.

Our aim in this project was to determine which new management measures could usefully supplement the current single-species management of the South East Fishery. One approach to managing complex systems is to begin by determining where the "leverage" is greatest (Senge 1990). Leverage is based on the notion that small, well-focussed actions can produce enduring improvements if they are directed at sensitive system components. We used the notion of leverage to direct our research.

The area of the SEF shelf off northeast Victoria and south New South Wales contains many important fishery grounds; its an area where current single-species fisheries management practices could be enhanced through knowledge of the supporting ecosystem. A 1993 CSIRO research survey of the shelf area between Wilson's Promontory and Bermagui was used to develop a conceptual model (Fig. 12b) and design a research strategy for the area. The research strategy focussed on key factors and their potential as leverage points for management of fish resources. In this way we planned to reduce the complexity of ecosystem management to one or two pertinent operational procedures that are represented as conceptual models.

Our sampling program combined broad-scale surveys of general ecosystem processes and focussed studies on specific habitats identified through liaison with the local fishers. Three broad-scale research surveys aboard the RV *Southern Surveyor* were followed by three focussed habitat surveys from smaller industry vessels. The use of multiple fishing gears (trawls, variable mesh gillnets, traps and benthic sleds), with some types fished by experienced fishers from commercial vessels, successfully provided the data to describe the composition and structure of fish and invertebrate communities over a range of scales and habitat types *(Objective 1: Survey the structure and broad distributions of habitat types and associated fish assemblages in the SEF shelf ecosystem).* Habitat types were successfully distinguished by acoustics, verified by photographic, sediment and geological characterisation. Distinct invertebrate and fish communities were identified across the SEF shelf, structured by bottom depth and latitude. Within those categories, communities are distributed in a compound mosaic defined by seabed habitat, modified by local hydrodynamics and (in the case of fish) seasonal hydrography.

The exotic marine pest *Maoricolpus roseus* is a dominant component of most nearshore and mid-shelf habitats. Its impacts on invertebrate and possibly fish communities and ecosystem processes are unknown.

The three gear types used (trawl, gillnet and trap) had markedly different selectivities for most species. The trawl was most effective overall for quota species (redfish, pink ling, ocean perch, morwong, tiger flathead and blue warehou), with traps the least effective (catching only morwong in quantity). *(Objective 2: Assess the selectivity of different commercial gear types [demersal trawl, gillnet and trap] for quota species in different habitats).* Tiger flathead, pink ling and blue warehou, and to a lesser extent redfish, were vulnerable to gillnet, but only morwong were vulnerable to all three gears. Size selectivity between gears was not strong for redfish or morwong, but the trawl caught more small pink ling and flathead than did the gillnet. Mesh selectivity of the gillnet was strong for all species; it is being evaluated as a separate project (FRDC Project 96/140).

Selectivity of fishing gear depends on the characteristics of the gear and the fish. Distinct fish communities are associated with different habitat types; distinct sizes of fish are associated with different depths *(Objective 3: Assess the relative abundance, age composition, distribution and vulnerability to fishing gear of key commercial species, primarily redfish and warehous).* All the main quota and commercial species in the survey area (redfish, pink ling, ocean perch, morwong, tiger flathead, white trevalley, blue warehou, silver warehou and John dory) have a "bigger-deeper" pattern of size distribution with depth–at least 95% of each quota species caught at less than 40 m depth were immature; at less than 80 m depth the percentage of immature dropped to 50%. However, these are aggregate data and do not account for migrations of larger fish to shallower water, which happens in certain environmental conditions, e.g. blue warehou in Disaster Bay. Selectivity of fishing gear for species depends directly on the availability of species and size classes, and therefore depends directly on the depths and seabed type fished.

Individual species and species groups can be classified on their strength of association, or dependence, on different seabed habitat types. Several key commercial species (striped trumpeter, snapper, silver warehou, pink ling, ocean perch, grey morwong, morwong, redfish and blue warehou) have an association with "hard-ground"; the strength of this association varies between species *(Objective 4: Evaluate the importance of hard-ground as refuge for commercial fish species.)* In some instances (e.g. morwong), hard-grounds at depth contain proportionally more small fish than open sediment flats which are further from the more productive outer-shelf foraging grounds. We could find no consistent dietary trends in fish species that lived in different habitats, which leads us to suspect that habitat may be used at least as much for refuge as for foraging.

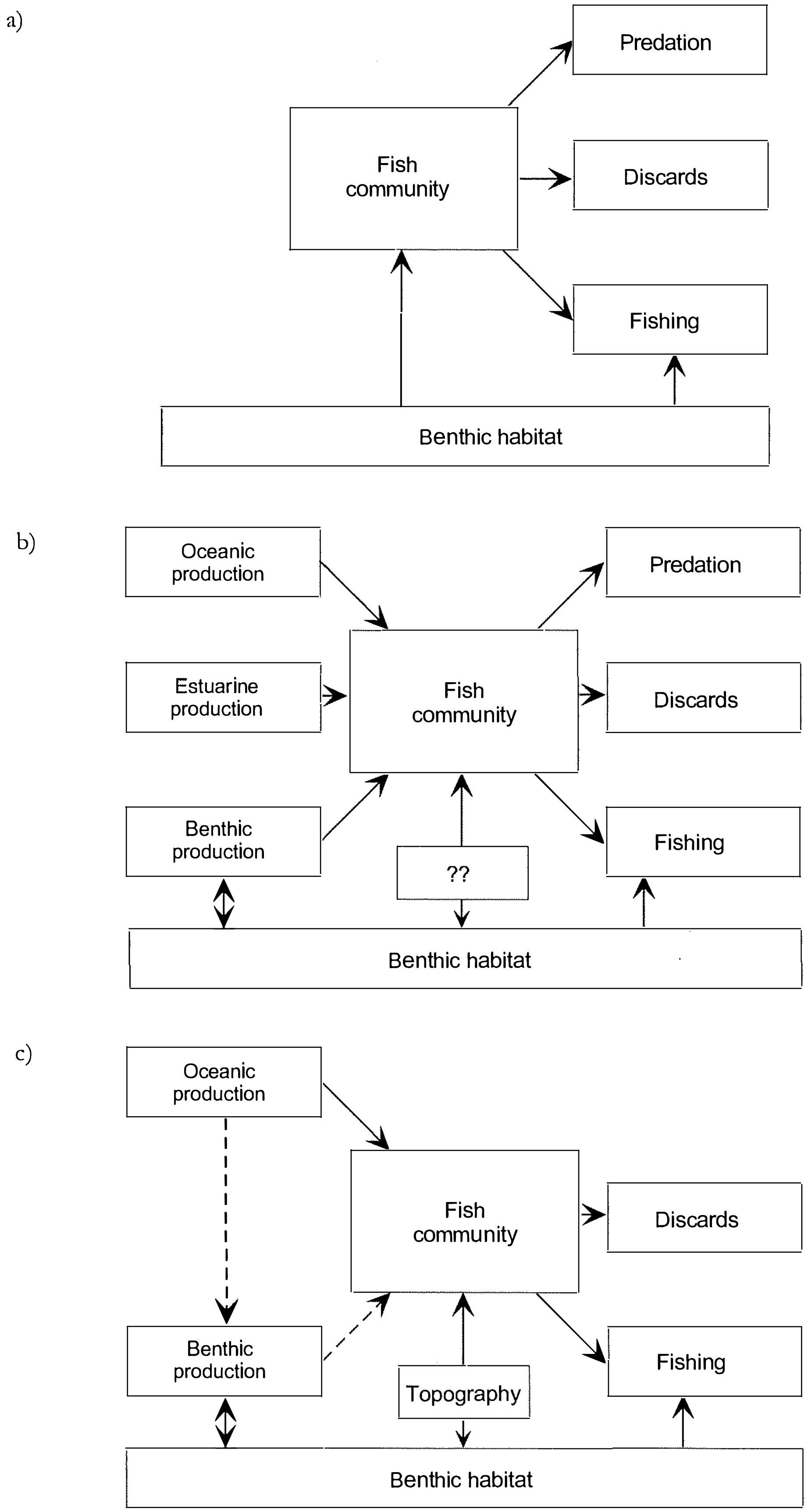

Figure 12 Development of conceptual model of potential leverage points for productivity of the southeast continental shelf fishery ecosystem: a) prior to first survey; b) expanded after results of first survey; and c) updated to show lack of influence of estuarine primary production and piscivory, importance of discarding, and role of habitat in fisheries productivity.

The distribution of commercial fish, which is variable in space and time, is linked to deep upwelling processes at the shelf-break. Structured habitat ("hard-ground") also affects their distribution and it seems reasonable to hypothesise that structured habitats modify local hydrography to either enhance the availability of pelagic and benthopelagic prey, or reduce the energy expenditure required to obtain these prey.

The 70 fish species caught most frequently with demersal fishing gear ate mainly benthic items. However, the most abundant and the commercially valuable species ate pelagic prey. Therefore, production of the major fish groups on the shelf is driven directly by pelagic production. Benthic production supports a more diverse, but less abundant, fauna *(Objective 5: Define the major trophic linkages [including predators] of SEF quota species by habitat type and identify the relative importance of benthic, pelagic, and inshore [e.g. seagrass, macroalgae] sources of production to quota fish species).* No top predators were identified (or at least none that were sufficiently abundant to dominate prey dynamics); we suggest that the SEF fish community is currently structured by food availability rather than predation. A hundred years ago, before selective harvesting of the shelf community started, species such as tiger flathead may have had a greater role in community dynamics.

The ontogenetic cross-shelf migration of most species partitions trophic resources for the different life-history stages. Adults have access to the most productive foraging grounds at the outer-shelf and shelf-break, and their diet switches to higher trophic levels. Deep upwelling of high-nutrient sub-Antarctic water drives productivity on the outer-shelf; there is little input from terrestrial or estuarine sources or from nearshore macroalgae. The mechanisms that drive the deep upwelling–an interaction of East Australia Current eddies, wind and topography–result in an uneven and seasonally variable enrichment. Local topography at the shelf-break influences the hydrology–deep upwelling is particularly strong at the Big Horseshoe; the "Bass Strait Cascade" is at its maximum at the Little Horseshoe. These areas are among the most productive commercial fishing areas.

A goal of this project was to determine which "ecosystem-level" processes had potential to be harnessed to improve current fisheries management, which is currently centred on single-species processes. Ecosystem management requires a model of system structure and processes *(Objective 6: Develop hierarchical models based on the fishery and on the fishery's ecology)*. Our first conceptual model of the southeast Australian shelf ecosystem was that the demersal trawl fishery caught demersal fish and that benthic habitat was essential to these fish communities (Fig. 12a). On our first demersal trawl survey we caught a high proportion of pelagic and benthopelagic fish – for example the very abundant carangid, jack mackerel. It was clear that our conceptual model was wrong or incomplete. We therefore extended the model to coarsely represent production sources as well as extractive processes (Fig. 12b), but we left the link between benthic habitat and fish communities unspecified. Given the broadened scope, it was clear that we did not have sufficient resources to study all aspects of system structure, so we concentrated on those we thought had leverage potential. For our purposes we defined potential leverage points as system structures or processes to which our chosen output measure (fisheries production) was sensitive and, as importantly, structures or processes that were amenable to management intervention.

The first potential leverage point that we identified was the input of primary production from seagrass. Estuarine and terrestrial sources of primary production, including seagrasses, have been identified as contributing to production over the entire continental shelf for 110 km off northeast Australia (Risk et al. 1994), and seagrass is important in the trophic ecology of juvenile blue grenadier off southeast Australia (Thresher et al. 1992). Thus it seemed plausible that seagrass production was an important source of primary production for the southeast shelf. Seagrass conservation also provided an attractive management option, because seagrass acreage in Australia has been greatly reduced (Poiner and Peterken 1995), seagrass coverage is easily monitored, and seagrass conservation could involve fishers in ecosystem management without affecting their own livelihoods. However, analyses of stable isotopes and photoreactive pigments (Chapters 6 and 7) could detect no contribution of seagrass or terrestrial production to the continental shelf food webs. Shallow-water red and brown algae may contribute to local primary production, but sources are local and not amenable to management intervention. The primary source of production for the shelf ecosystem is pelagic phytoplankton in the open ocean. This production source is also not amenable to management intervention at the local scale. Estuarine production was removed from our conceptual model of this ecosystem (Fig. 12c).

Our second potential leverage point was predation on fish, a well-studied aspect of ecosystem interactions (e.g. Bax 1998). It has been suggested that the abundance of desirable fish species could be increased by removing their predators (Gulland 1982, Harwood and Greenwood 1985). Marine mammals and birds in the area are strongly piscivorous, as indicated by their enriched $\delta^{15}N$ ratios (Chapter 10). Diet studies, however, show that they eat mainly surface and midwater pelagic species, including jack mackerel and Australian pilchard (*Sardinops neopilchardus*). These species are part of the midwater prey community, sustained by euphausiids and lanternfish, and exploited by many taxa including tuna and pelagic sharks (e.g. Young et al. 1997). Some of the fish species caught with demersal nets were piscivorous, but ate few commercial species. If the more abundant piscivorous species, such as jack mackerel, eat commercial fish (even occasionally), they could have a marked impact. However, the abundant piscivores had essentially no commercial species in their diets, although unidentified fish in stomach contents could have hidden predation on the larvae of commercial species. Therefore there is no indication that predation is directly limiting the productivity of commercial species in this ecosystem, as currently configured. Typically as ecosystems are fished, the larger more piscivorous species are removed first, so predation may have played a larger role at the start of this fishery. Many taxa feed on the midwater food and there may be competitive interactions among them, but in practice it would be very difficult to demonstrate that resources were limiting to the extent that competition was occurring. Monitoring and managing competitive interactions would prove even harder. Predation was removed as a key factor in our conceptual model of this ecosystem (Fig. 12c).

The third potential leverage point was the direct impacts of fishing on fish populations; indirect impacts, for example fish feeding on discards, has yet to be addressed for this system. Direct impacts are well covered in annual assessment reports (summarized in Caton et al. 1997) and in focussed discarding studies (Liggins 1996). Discarding of commercial species can be high, either because they are too small for the market or because market prices are temporarily too low to cover transport costs. Discarding of juvenile redfish (*Centroberyx affinis*), for example, can exceed 90% of catch in some ports (Liggins 1996). There is an ontogenetic change in habitat with movement to greater depth for many commercial species on the southeast Australian continental shelf (Chapter 9). Therefore most discards of many commercial species are caught in shallow waters, typically either when sea conditions prevent vessels from fishing offshore, or when they are targeting marketable commercial species whose adults occur in shallow waters. This is an obvious leverage point. Modifications to gear and fishing practices have the potential to reduce discarding (Bax 1997) and thereby affect fish populations, but the implications for fishers' activities and financial return have not been determined. Direct impacts of fishing (including discards) were retained in our conceptual model of this ecosystem (Fig. 12c). Management of fishing practices to reduce pressure on areas containing predominantly immature (non-marketable) fish would require the spatial (and perhaps seasonal) management of fishing effort.

The link between the fish community and habitat was one potential leverage point we identified. The impacts of demersal trawling on benthic organisms, habitat, and fish communities have been well documented (e.g. Jones 1992, Schwinghammer et al. 1996, Sainsbury et al. 1997). Comparisons of the diets of fish species caught in different habitats did not indicate any particular trophic link with habitat (Chapter 11). However, multispecies abundances clearly delineated fish communities associated with distinct habitats (Chapter 8). Individual species were mostly either obligate or facultative users of particular habitat types, and rarely ubiquitous. Analysis of the shape and morphology of obligate and facultative habitat users suggested that the relationship between habitat and fish might be mediated through fish seeking refuge from prevailing currents. Fish found in current-swept sediment flat habitats were frequently dorso-ventrally flattened for low drag, or were burrowers or sustained swimmers. Fishes found in topographically complex reef areas were mostly deep-bodied, with specializations such as fin shape and positioning that would confer good maneuverability. Although we cannot determine the full scope of relationship between benthic habitat and fish community, the distribution of morphotypes together with measurements of water chemistry and currents around reefs, indicate that habitat topography has a role through changing current flow. It may not be necessary to define the link between benthic habitat and fish populations precisely because the association of many taxa with structural habitat implies an increase in individual fitness that would be lost if the structural features were lost (Auster and Malatesta 1995). Additionally, even if particular benthic habitat conferred no increase in individual fitness, the role of particular habitat types in aggregating particular species would increase fishers' effectiveness. Topography was identified as the link between benthic habitat and the fish community in the conceptual model (Fig. 12c).

Fishers target very specific habitats on the southeast Australian shelf (Chapter 11). Ancient geological processes, ancient and modern biological processes and modern oceanography have resulted in a compound mosaic of habitat types on this shelf, each having particular biotic assemblages and different susceptibilities to mechanical disturbance. The physical structure and spatial integrity of reef habitats determine the extent to which they are modified by fishing gears (Chapter 7). Large tracts of hard, high-relief, fossiliferous reef on bedrock outcrop are most resilient; smaller patches of softer, low-relief sandstone and fossiliferous reef are vulnerable to erosion; reef-forming bryozoan beds may be completely removed. Some fishers report that once-productive grounds (e.g. "Ten x Ten Reef ", "7-Hour Bank", "6-Hour Reef") no longer support reef-associated species such as morwong, snapper, striped trumpeter and crayfish, possibly because of habitat modification. Patchy mosaics of low-relief reef are particularly vulnerable to being 'opened-up' as vessels become more powerful and use thicker warps and heavier bottom gear on trawls. The gear development that has made precise targeting possible is the combination of GPS and electronic trackplotters, which enable skippers to plot obstacles precisely and to either avoid or remove them.

The commercial imperative will always encourage operators to "open up" new areas in the expectation of better catches. The skill of the fishers, combined with new navigation technology and greater fishing power, means that it is increasingly possible to open up the hard-grounds (<11% of the survey area). Opening up the most vulnerable habitats may result in the loss of reef substrate and invertebrate cover, and in the subdivision of larger reefs into smaller patches that may no longer act as critical habitat to sustain fisheries production. Opening-up of less vulnerable habitats, especially in areas of extensive hard-ground such as western Bass Strait, or even Gabo Reef, may increase fishery productivity–Howe Reef, a northern extension of Gabo Reef has been opened up for decades and continues to be a productive fishing area. It is too early to say to what extent hard-ground areas can be opened up without reducing overall fishery productivity–there is much to be gained through monitoring current activities.

The links between fish communities and benthic habitat suggests that habitat preservation could be a strong leverage point. Some fishers have spoken out on the need to preserve habitat, but may be reluctant to diminish their own catching efficiency unless other fishers also avoid – and are seen to avoid – the sensitive habitat. For fishers to agree to limitations on their fishing practices they must see the potential benefits clearly and also accept that any restrictions are not excessive. For example, although some topographically complex habitats are vulnerable to fishing impacts, other complex habitats (for example those based on granite or large contiguous areas of fossiliferous limestone) are less vulnerable (Chapter 7). At the moment they are considered untrawlable. However, trawlable areas close to these complex habitats are prime fishing grounds. Restricting fishing on all complex habitat, regardless of its vulnerability to fishing, would unnecessarily impede fishing on these prime grounds. Other topographically complex habitats are vulnerable to fishing and it is these that should be targeted by habitat-based management. Habitat-based management need not require that habitats be closed to all fishing, so long as management objectives are clearly specified and outcomes monitored. Satellite-linked vessel monitoring systems, as used to manage effort in the Australian orange roughy fishery, provide one means of monitoring.

Spatial management of fishing effort is required to avoid continued loss of vulnerable habitat. Spatial management of fishing effort is now technically feasible through vessel monitoring systems. We conclude that it provides the best opportunity to supplement the current single-species management of the SEF shelf fishery. But it is also clear that uninformed spatial management could unnecessarily restrict current fishing activities and curtail the development of new areas. We describe habitat on the southeastern continental shelf as a patchy mosaic, with significant features at scales of hundreds of metres to kilometres. This is the scale at which biotic assemblages are distributed and the scale at which fishers use the habitats. It is the scale that spatial management of fishing effort will need to address if it is to be successful.

Lastly, it is worth stressing the importance of the fishing industry to the outcomes of this project. The industry has mapped the area–they are out there most days and they have named the significant seabed features. The active involvement of the fishing industry is a prerequisite to developing, implementing and monitoring successful spatial management in this area.

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13 BENEFITS

13.1 BENEFITS AS STATED IN PROPOSAL

This project is of direct benefit to all users of the SEF, including commercial fishers, recreational fishers, and the general public concerned about the sustainability and biodiversity of Australian marine resources. Techniques and insights gained during this research will be of direct benefit to the development and management of other Australian fishery ecosystems.

Estimate, as percentages of total benefit, the flow of benefits to fisheries, regions, States, Territory and/or other beneficiaries (specify). Careful consideration must be given to the distribution as the FRDC shall seek ratification.

State	%	**Fishery(ies)/Other beneficiaries**	%
NSW	25	SEF	100
QLD	0		
NT	0		
WA	0		
SA	0		
VIC	25		
TAS	20		
COMMONWEALTH	30		
TOTAL	**100%**	**TOTAL**	**100%**

Benefits for the SEF and other fishery ecosystems generated by this project are diffuse and wide ranging. The project has identified the ecosystem features that are important in sustaining fisheries productivity on the southeast Australian shelf and, as importantly, elucidated the features of less importance. This is the information required to start managing the SEF shelf ecosystem in an ecologically sustainable manner as required by the 1991 Fisheries Management Act. Through focussing on ecosystem features that are amenable to management intervention, the study has provided direction to the vexed issue of ecosystem management that has been often discussed but rarely implemented.

More specifically, the study has shown the dependence of the demersal trawl caught quota species on the pelagic food web, the lack of inputs from estuarine or nearshore sources, the current lack of significant apex predators, the significant ontogenetic cross-shelf movement and its implications for availability of immature fish to the commercial fishery and the importance of habitat to fisheries productivity. This is the information found to be lacking in a recent FRDC review of Australian fish habitat, and the information likely to be incorporated in the imminent SE Australia Regional Management Plan.

Industry interaction during the project (for example, over 120 days at sea on industry vessels) not only helped the project attain its goals, but has also provided a conduit to distribute the findings to the local industry and, as importantly, has provided a mechanism to incorporate at least some of industry's knowledge into the scientific and, hopefully, management process.

13.2 COMMUNICATION, MEDIA AND DATA

As the project progressed, feedback and results were presented at industry meetings, research vessel open days, and through local and national media. Cruise plans, and reports of each of the cruises of FRV *Southern Surveyor,* were provided to interested parties such as fishing cooperatives, commercial fishers, FRDC, AFMA etc. Further details of these reporting activities are provided below.

Results from this study were presented to industry, managers, and scientists at the 1995 and 1996 SEF workshops. At the request of SETFIA, a presentation of project results and in particular the implications for spatial management of habitat was given to industry members in March 1999. A video summarising project results including video footage of key commercial fishing grounds in the study area was presented at the 1999 SEF Workshop. This video, earlier videos compiling 15 years of satellite sea-surface temperatures in the region, and other published materials have consistently been distributed to key industry members in the study area for their comment and in gratitude for their cooperation on this project.

An open day on the *Southern Surveyor* was held for fishers and the general public on each survey. About 30-40 people attended each of the three open days, which were publicised by local and national print and television media.

Data on fish distribution and length composition (especially for redfish and flathead) have been used in stock assessments. Small individuals of quota species collected with the trawl or benthic sled have been provided to the central ageing facility (CAF) and Tasmania Department of Primary Industry and Fisheries (TDPIF) to assist interpretation of growth in these species.

Collected fish and invertebrates have been provided to the South Australia Museum, the Museum of Victoria, the Australian Museum, the NIWA invertebrate collection in New Zealand, the British Museum of Natural History and to AIMS for a bioprospecting project.

Biological data and specimens have supported FRDC Projects: 94/152–"Resolution of taxonomic problems and preparation of a user-friendly guide to whole fish and fillets for the quota species of the South East Fishery"; 96/140–"Evaluation of selectivity in the South-East fishery to determine its sustainable aggregate yield."; 96/275–"Development of a rapid-assessment technique to determine biological interactions between fish, and their environment, and their role in ecosystem functioning."

Specimens of the exotic New Zealand screwshell, *Maoricolpus roseus,* were provided to the CSIRO Center for Research into Marine Pests. Live handfish, *Brachionichthyidae*, were captured and provided to the CSIRO handfish project for development of breeding protocols.

Digital acoustic data used by FRDC Project 93/058: "Development of an acoustic system for remote sensing of benthic fisheries habitat for mapping, monitoring and impact assessment."

The extensive database developed from this project is being used in a joint FRDC/CSIRO project with AUSLIG to develop a common data model (and database) to access these data (perhaps with some restrictions) across the WWW.

14 INTELLECTUAL PROPERTY

The intellectual property arising from this work is the property of both CSIRO and FRDC.

15 FURTHER DEVELOPMENT

HABITAT

Mapping

The fishing grounds for board-trawlers and mesh-netters catching scalefishes on the SEF continental shelf (~25-200 m) between Wilson's Promontory and Eden include many areas around 'hard-bottom' (reef) habitats. As reef habitats vary in their physical structure (e.g. rock type, spatial extent, height and sand cover), their role for the fish species varies. Historically, the physical structure of reefs largely determined where and how they were fished: trawlers fished perimetres and 'gutter tows' running through mosaics of rock outcrop, while only mesh-netters could fish the rougher and less-dispersed reef areas.

Recently, two factors have fundamentally changed the distribution and effort levels of fishing on reef habitat. The first, was the rapid adoption of advanced navigational aids (track plotters and GPS) which greatly increased the ability of trawl operators to explore and re-navigate reef mosaics. The skills to target tows with minimal gear damage are now finely honed and widespread through the SEF fleet. The second, was that the precise locations of productive and safe trawls have dispersed throughout the fleet on computer discs from track-plotters, which are less secure and more portable than traditional paper charts. Both factors have resulted in greatly expanded and largely unquantified levels of fishing effort targeted on reefs.

Several recent initiatives in the SEF have the potential to provide the long-term stability and sustainability that this fishery requires, but the benefits of spatial management of habitat (or the costs of inappropriate spatial management) are unknown and unconsidered. The government-sponsored buy-back to reduce dormant capacity and compensate fishers penalised by the quota system, the management measures and research to reduce discarding of non-marketable fish, and the integration of research and management for the trawl and non-trawl sectors, are all steps towards ensuring long-term sustainability. But meanwhile, fishing effort continues to grow and to be increasingly targeted on specific habitats, while the new gears favour the exploitation of new habitats. These sources of effective effort remain largely unquantified, and are not available to measures of CPUE.

The capacity of particular shelf-reef habitats to aggregate fish, and potentially to sustain fish stocks, is being reduced. Operators are aware of this, and many we talked to were concerned about the consequences for the shelf fishery of habitat loss. Nonetheless, commercial pressures will always encourage operators to open up new areas in the expectation of better catches, and to be 'first in' to maximise catch before tows become common knowledge. However, unexplored areas are becoming fewer and the locations of many individual critical habitats are now widely known. These habitats are vulnerable to modification by fishing gear, so are likley to become unsuitable for the target fish. When critical fish habitat is removed, operators will have to fish harder and longer to catch the same amount of fish–and in doing so will hasten the rate of habitat degradation–a vicious circle.

Mapping of habitat throughout the South East Fishery is a prerequisite to ensuring its maintenance. It may also create new opportunities for increasing fishery productivity. The habitat-mapping techniques developed in this study should be extended to the remainder of the SEF with industry cooperation and support.

Fish Aggregation

Habitat supports unique invertebrate and fish communities, provides shelter for juveniles of a few fish species and in aggregates fish of many species. The economic importance of hard-ground as a 'fish-aggregating-device' to the commercial fisheries is considerable. The targeting of hard-ground is also potentially has consequences for the environment; when fishers target fish more effectively, their overall effort can be reduced, which reduces impacts on the environment.

We speculate that the mechanism of this aggregation is through the local concentration of benthopelagic and pelagic food sources, or through providing flow refuges for fish. However, we cannot document the precise mechanism(s), and therefore cannot estimate the impact of its modification. For example, while we suggest that the opening-up of weathered inner-shelf reefs, such as Broken Reef, may reduce fishery productivity, Howe Reef has been opened up for many years and remains a productive fishing ground. We suspect that the selective opening-up of large-scale hard-grounds may increase local catches by enabling fishers to target aggregations of fish, which are replaced. But after some point, the reefs would aggregate fewer fish and productivity would decline. Similarly, areas that are reported to have once had a dense cover of invertebrates before they were opened-up, for example the 'Flower Patch', could profit from a selective closure of specific areas to rebuild the overall aggregating properties, which fishers could target in adjacent areas.

Further studies of the mechanisms, and limits, of the aggregating properties of hard-ground are necessary to take full advantage of these properties to increase fishery productivity.

Vulnerability

Analysis of the geology and spatial distribution of habitat indicates its relative vulnerability to physical disturbance. Rock and sediment samples showed that 'hard-ground' habitats are fossiliferous limestone reefs formed of bivalve and bryozoan clasts, sediments consolidated by reef-forming bryozoans, indurated (cemented) sediments, and outcrops of granite and sandstone bedrocks. Their vulnerability to modification by fishing gears is highly variable and determined by the degree of hardness, degree of weathering, relief, area extent and spatial integrity. 'Soft-ground' habitats, which form most of the shelf seafloor, are massive sediments, primarily sands but with gravels and mud in some areas.

The most vulnerable habitats are shelf-break bryozoan reefs, which are soft and lightly attached, have a low vertical relief (< 30 cm) and exist as small patches (1-10 sq. m). Many inner-shelf fossiliferous limestone/ sandstone reefs are also vulnerable because they are relatively soft, highly-weathered, have low relief (< 2 m) and exist in isolation or as patchworks intersected by gutters. Least vulnerable are highly cemented, deep, high-relief (to 10 m), large and undivided fossiliferous limestone reefs, and granite outcrops. Fishing impacts on the structure and stability of sediment flats in this predominantly high-energy, current-swept shelf environment are unknown but may not cause permanent modifications (on a geological time scale). Most sediment flats have been fished for decades, so impacts are difficult to evaluate–although fishers' report smothering of upper-slope reefs by current-borne sediment disturbed on the shelf.

These measures of habitat vulnerability are relative measures only. We do not know the impact of fishing gears, natural sand movements, and other physical disturbances on these habitats, although we have surmised some of the impacts of fishing gear from fishers' reports. It is difficult to rank the importance of different habitat modifiers. One approach is to base importance on rate of recovery from their modification. For example, disturbance resulting from storm events, burial by sand, or removal of invertebrates by fishing gear can be considered temporary events. However, modification of the geologic structures on which the invertebrates grow and around which the fish aggregate are permanent events, at least until the next ice age. Modification may result from mining, fishing on susceptible structures, or through colonisation by the New Zealand screwshell, *Maoricolpus roseus*.

Research is needed to determine the impacts of the different habitat modifiers, so that they can be ranked in order of importance and resources for their management directed accordingly.

Acoustic Bottom-Typing

Acoustic bottom-typing is an integral part of habitat mapping. In this study, fine-scale mapping (hundreds of metres to kilometres) was achieved with simple (RoxAnn) indices of the complex acoustic returns (Chivers et al. 1990). This, the simplest method of habitat classification, does not fully exploit the available information.

The next step in habitat classification would be to combine the RoxAnn indices and extract additional features from the data using, for example, Gaussian classifiers. Acoustic indices that use alternate feature extraction techniques such as smooth ping analysis have shown that there may be far more information in the acoustic returns; FRDC project 93/058, Pitcher et al. (1999). A small subset of multifrequency acoustic data collected in this study was analysed by the smooth ping method. It showed that misclassification of habitat type at fine scale can be reduced from 27% to 8%; FRDC project 93/237, Kloser et al. (1998). This could lead to a major advance in our ability to map and monitor seabed habitats with high statistical accuracy. The multifrequency data collected for the present study, together with the associated biological, sled, video and photographic material is a largely unexplored data set for statistically mapping the habitat types of the SEF. As a matter of high priority, these acoustic data should be analysed by advanced acoustic signal processing methods. The classification of habitat types should be explored through sophisticated discrimination systems (Gaussian, neural network, fuzzy logic classifiers) to combine the reflected acoustic, depth, biological and ground-truth data.

TROPHODYNAMICS

Extensive study of the main shelf species failed to find a key predator. We concluded that this system was not structured by predation, but rather by the availability of food. This conclusion appears at odds with many continental shelf ecosystems (reviewed by Bax 1999), where predation has a major role in structuring fish communities.

One hypothesis is that selective reduction of predators (e.g. tiger flathead) since the start of the fishery in the early part of this century has changed the community. This is worthy of further observation, as it will provide the best indication of how we might expect the community to respond to further selective harvesting.

Midwater fish species are important to production of the shelf 'demersal-fish' community. They are also important to other (pelagic) fish, seabirds and marine mammals. However, they are not targeted by commercial fisheries, although this may change with the advent of larger, more efficient midwater trawls. One reason given for the shift in the Northeast U.S. shelf ecosystem from one dominated by commercially valuable species to one dominated by 'trash' species is that the ecosystem was harvested selectively; there has been no similar shift in the North Sea ecosystem which has been harvested harder but less selectively. This raises the question of what the potential impacts might be of continued selective harvesting of the SEF. Trophodynamic data from this project, combined with that collected in other FRDC projects of the inner-shelf, mid-slope, seamounts and pelagic fisheries, should be assembled in a trophodynamic model of the SEF, so that impacts of selective harvesting of particular trophic guilds can be examined.

MANAGEMENT OPPORTUNITIES

Spatial Management of Fishing Effort

The links between fish communities and benthic habitat indicate that to maintain fishery productivity, it is necessary to maintain habitat. Some fishers have spoken out on the need to preserve habitat, but may be reluctant to diminish their own catching efficiency unless other fishers also avoid – and are seen to avoid – the sensitive habitat. For fishers to agree to limitations on their fishing practices they must see the potential benefits clearly and also accept that any restrictions are not excessive. For example, although some topographically complex habitats are vulnerable to fishing impacts, other complex habitats (for example those based on granite or large contiguous areas of fossiliferous limestone) are less vulnerable. At the moment they are considered untrawlable. However, trawlable areas close to these complex habitats are prime fishing grounds. Restricting fishing on all complex habitat, regardless of its vulnerability to fishing, would unnecessarily impede fishing on these prime grounds. Other topographically complex habitats are vulnerable to fishing and it is these that should be targeted by habitat-based management. Habitat-based management need not require that habitats be closed to all fishing, so long as management objectives are clearly specified and outcomes monitored. Satellite-linked vessel monitoring systems, as used to manage effort in the Australian orange roughy fishery, provide one means of monitoring.

Transferable Ecological Stock Rights

An alternative to closing particular habitats is to limit their use through economic means. Fishers in the South East Fishery pay an annual levy for fishery management based on the estimated market value of their individual transferable quota (ITQ) holdings. No account is taken of the biological or environmental impacts of their fishing practices, although managing biological impacts is the goal of single-species management, and managing broader environmental impacts is one goal of Ecologically Sustainable Development – a legislative requirement for the Australian Fisheries Management Authority. As Alain Laurec of the European Union said in reference to sustainable fisheries: "Limiting catches is a symptom of the disease rather than the cure" (Senior 1996). One proposed alternative to ITQs is transferable dynamic stock rights based on a fraction of a year class rather than a set tonnage, enabling a fisher to profit from catching his/her fraction of the year class at an appropriate biological (or economic) age (Townsend 1995). Future stock rights could also be dependent on the opportunity a fisher's year class fraction has had to contribute to future generations before being caught.

Transferable dynamic stock rights have attractions, but because they require monitoring of catch and discarded catch to be effective, they would be cumbersome to monitor and enforce in most fisheries. We propose a modification of these rights: transferable ecological stock rights. In this instance a fisher would be given the right to harvest a certain fraction of a year-class subject to the perceived ecological damage associated with harvesting. Monitoring (satellite-derived positions for fishing vessels) and enforcement would be based on the distribution of fishing effort in relation to habitat as a proxy for the likelihood of catching (and discarding) immature fish or causing ecological damage. If fishing in shallow waters where smaller fish reside would be expected to lead to higher discarding, then landed catch would count more against stock rights than a similar tonnage landed in deeper waters. In a similar fashion, fish caught from fishing in sensitive areas or with gear that damages benthic habitat would attract a higher deduction from that year's stock rights. Transferable ecological stock rights would provide managers an instrument more clearly linked with the goals of ecosystem management and ecologically sustainable development than ITQs are – and would treat the problem, not the symptoms.

Improvements in remote sensing and satellite-tracking technology have enabled scientists to cost-effectively research new features of marine ecosystems. The same technology has enabled fishers to target particular habitats more precisely, increasing their impact on particular productive habitats. Limiting landed catch no longer meets the requirements of managers attempting to satisfy goals of ecosystem management and ecologically sustainable development. Management of marine ecosystems requires more than management of landed catches. "Fisheries management is environmental management" (Martin Cabot, head Newfoundland Inshore Fishermen's Association, quoted in Griffin 1993). If fisheries managers are to become environmental managers, then fisheries (environmental?) scientists must provide them with the appropriate concepts, tools and information. In a complex system it will be essential to understand where the leverage points are. We have identified one such point for the continental shelf off southeast Australia, but it remains for managers and fishers, supported by scientists to determine how this particular leverage point can be used profitably.

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16 STAFF

(% of time)**		CSIRO	FRDC	Final FTEs
Dr N. Bax[1]	Modelling of habitat and fish interaction; trophic relations	30	0	1.60
Dr S. Rainer[1]	Benthic habitat description; invertebrate taxonomy; statistical design	25	0	0.75
Dr A. Williams[2]	Survey design; fish taxonomy; structure of fish assemblages; field operations	40	0	1.75
Dr J.A. Koslow[1]	Biological oceanography; statistical design	10	0	0.00
Mr R. McLoughlin[2]	Industry liaison & UW video	10	0	0.10
Mr B. Barker[2]	Gear specialist; cameras & UW video; field operations	50	0	3.00
Mr D. Evans[2]	Invertebrate taxonomy; field operations	50	0	0.75
Ms S. Davenport[2]	Trophic linkages; field operations	50	0	4.00
Ms C. Bulman [2]	Fish trophodynamics	30	0	1.00
Mr M. Lewis[2]	Fish trophodynamics support; field operations; gear specialist	25	0	0.75
Mr R. Kloser[2]	Acoustic data acquisition and analysis	5	0	0.40
Dr P. Last[1]	Fish taxonomy	2	0	0.30
Dr S. Jeffrey[1]	Primary prodn pathways	2	0	0.06
Ms K. Haskard	Statistical advice	5	5	0.05
Mr T. Ryan	Acoustic/ database support	0	25	0.75
Ms K. Gowlett-Holmes	Invertebrate support	0	50	1.50
CSOF5	Hydrological support	5	10	0.50
Dr V Wadley	Video Analysis/ Ind.Liaison	0	0	3.0
Ms D. Furlani	Fish biology	0	0	1.0
Total FTE's (4 yr project)		10.17	2.70	21.26

Substantial contributions were also made by a number of CSIRO staff: Ian Helmond and the Moorings Group; the Electronics group, especially Matt Sherlock, Jeff Cordell and Lindsay MacDonald; the CSIRO Workshop; CSIRO OMS, especially Brian Griffiths and Dave Terhell; the Fish Taxonomy group, especially Gordon Yearsley, Alistair Graham and Ross Daley; the Data Centre, especially Miroslaw Ryba; the Administration group, especially Greg Lyden; the masters and crew of the RV *Southern Surveyor*, especially first mates Roger Pepper and John Boyse, and the vessel operations managers John Wallace and Clive Liron. Martin Gomon (Museum of Victoria), Penny Barents (Australian Museum) provided additional taxonomic advice. Vivienne Mawson edited introductory and concluding sections, but cannot be held responsible for what lies in between. Ron Thresher initiated the project and Keith Sainsbury supported its successful conclusion.

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Williams, A. and Bax, N. (in review) Delineating fish-habitat associations for spatially-based management: an example from the south-eastern Australian continental shelf. Marine and Freshwater Research.

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Bulman, C. and Althaus, F. Trophic interactions of major fish species in the South East Fishery. Poster presented at the Australian Society for Fish Biology annual meeting, Hobart, 1998.

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APPENDIX I PRESENTED POSTERS

Seabed habitat on the SE Australian continental shelf

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*Geology Department, University of Tasmania, Sandy Bay, Tasmania

This research was funded by the Fisheries Research and Development Corporation

Study area and sampling

The continental shelf seabed in the region between eastern Bass Strait (Victoria) and Bermagui (NSW) was sampled at 35 depth-stratified sites and 15 additional sites during a study of the region's fishery ecosystem. A towed camera system (Figure 1), a sediment grab and a benthic sled provided the information on lithology, geomorphology and biota used to classify habitat types. A representative image of the seabed at each site is shown here on a coarse-scale map of habitats (Figure 2).

The seabed: what it is and where it is

In this region the seabed may be visualised as a series of extensive sediment flats ('soft-grounds') with interspersed outcrops of consolidated material ('hard-grounds').

Soft grounds consist primarily of sands, with gravels making up a higher fraction in the south. Mud is present in localised areas, often close to the shelf edge (The Horseshoe). Generally, inner-shelf sediments (< 40 m) are less stable, more sorted, and rippled by water currents. Mid-shelf sediments (> 60 m) are more stable, have higher levels of bioturbation and are less rippled by water currents.

Hard grounds include cemented sediments, biogenic reefs (mostly fossiliferous limestones) and bedrocks (granite and sandstone). The fossiliferous limestones are composed largely of bivalve and bryozoan skeletons cemented together by fine-grained cement, and form relatively large (10s-1000s of metres in length), flat, raised, tabular slabs (Black Head, the Howe and Gabo Reef complexes). Cemented carbonates also form hard patches that show little or no vertical relief; these are bored and encrusted by a variety of benthic animals and provide attachment for larger organisms such as stalked crinoids (The Flower Patch; The Horseshoe). Coarse-grained sandstone, consisting largely of quartz grains, also outcrops in tabular slabs. It may have formed as sand bodies in high-energy, paleo-shorelines and is a constituent of inner and mid-shelf hard-grounds off the Gippsland coastline (Broken Reef complex). Granite, distinguished by its irregular, hexagonally-jointed, coarsely-crystalline structure, outcrops as high-relief 'reefs' on the inner-shelf off the Gippsland coastline (Point Hicks, New Zealand Star Banks).

The irregular morphology (pinnacles and crevices) of inner and mid-shelf limestone reefs results from weathering when exposed during sea-level regressions, eg. as recently as ~10,000 years ago (Broken Reef complex).

Invertebrate communities

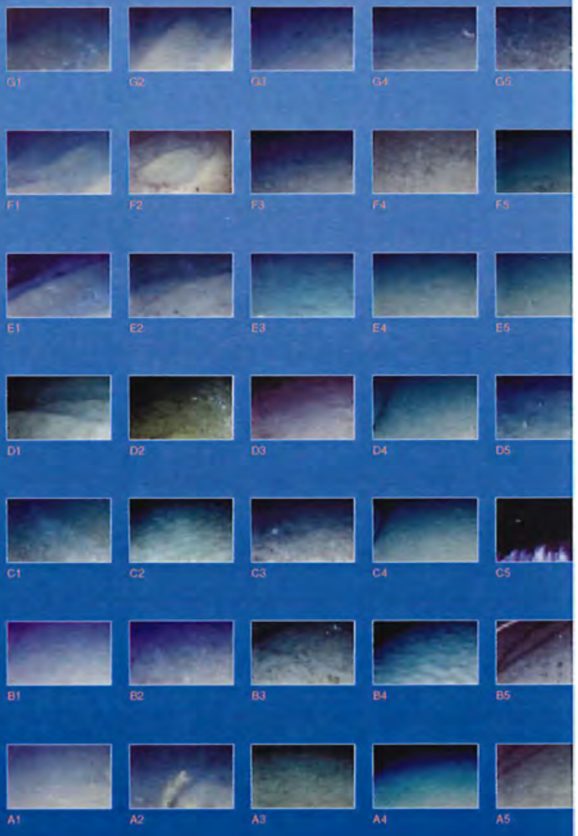
Gastropods and bivalves (principally *Maoricolpus roseus* and the large bivalves *Eucrassatella kingicola* and *Glycymeris* spp.), massive bryozoans, infaunal and low-profile sponges, hermit crabs and bugs (*Ibacus peronii*) are the most abundant groups in inner-shelf soft-ground communities where sediments are unconsolidated and sorted. Soft-grounds in greater depths with more-stable sediments are inhabited mostly by solitary sand-dwelling ascidians, polychaetes (sometimes detectable as patches of high-density surface tubes), sea pens, soft bryozoans and erect sponges attached to shell or stone fragments; mobile groups include asteroids, urchins, whelks and hermit crabs. Low-profile sponges, compound ascidians, soft bryozoans, seapens and pancake urchins dominate soft-grounds at the shelf-break.

Hard-ground communities at all depths are composed mostly of low-profile, bushy and lumpy sponges, seawhips and massive bryozoans, with sponges and seawhips forming patchy to dense 'gardens'. Low-profile sponges, compound ascidians and octocorals dominate the shelf-break hard-grounds, with stalked crinoids attached to localised patches of cemented sediments.

Figure 1
Towed camera system

Figure 2
Coarse-scale map of habitats

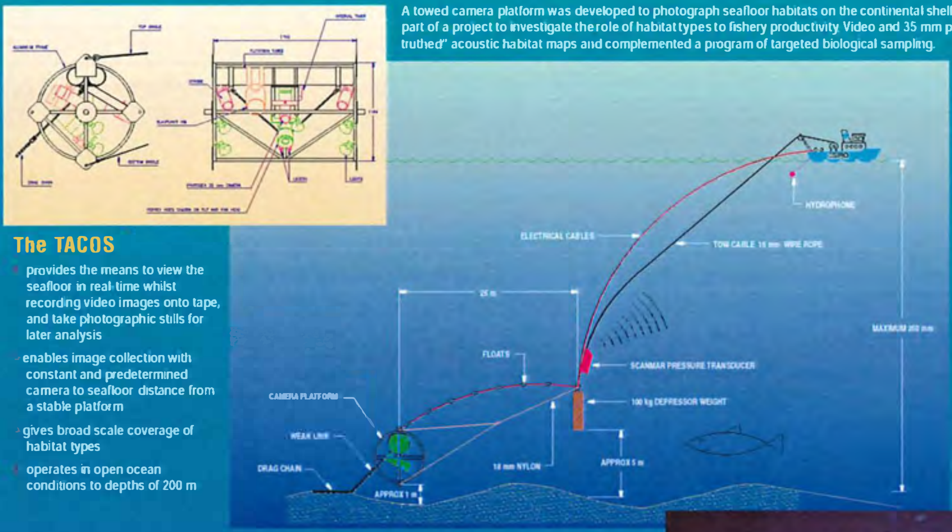
Depth-stratified sites at transect positions as shown in Figure 2



A vessel-towed camera platform for seafloor surveys of the continental shelf

Bruce Barker, Ian Helmond, Nicholas Bax, Alan Williams,
Stephanie Davenport and Victoria Wadley
CSIRO Division of Marine Research, GPO Box 1538 Hobart, Tasmania 7001, Australia

A towed camera platform was developed to photograph seafloor habitats on the continental shelf fishery off southeastern Australia as part of a project to investigate the role of habitat types to fishery productivity. Video and 35 mm photographic still images "ground truthed" acoustic habitat maps and complemented a program of targeted biological sampling.



The TACOS

- provides the means to view the seafloor in real-time whilst recording video images onto tape, and take photographic stills for later analysis
- enables image collection with constant and predetermined camera to seafloor distance from a stable platform
- gives broad scale coverage of habitat types
- operates in open ocean conditions to depths of 200 m

The Towed Automatically Compensating Observation System (TACOS), has successfully photographed the seafloor over a range of bottom types from flat soft substrates, to hard and high relief reef areas.

Survey of reef habitats is particularly important because advances in technology and fishing gears have increased the ability of commercial fishers to target such habitats.

High relief rock reef in 110 m

The platform is an open cylinder constructed from aluminium tubing and consists of two transverse flotation tubes which gives it positive buoyancy. A frame provides protection and mounting points for the cameras and lights as well as attachment points for the towing bridle and drag chain. The platform is connected by the towing bridle to a heavy depressor weight, which in turn is towed behind the ship by wire rope. Separate conducting cables are used for video and power transmission. A drag chain attached to the platform maintains a constant camera height off bottom through balance of the platform's buoyancy and the weight of the chain. The drag of the chain on the bottom also orientates the platform in the direction of tow and largely negates the effect of cross-currents. Since water current speed can be similar to tow speed, this alignment with tow direction is important to enable the cameras to look ahead.

High relief rock reef in 40 m

Hard bottom in 110 m

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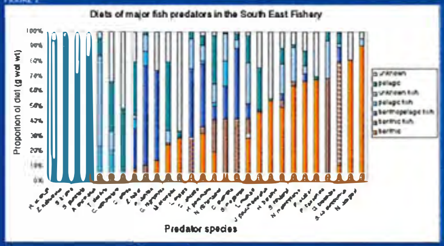
Trophic interactions of major fish species in the South East Fishery

C. M. Bulman and F. Althaus
CSIRO Marine Research

Objectives

The South East Fishery (SEF) is based on more than 80 regularly caught fish species of which about 16 species constitute the majority of the landed catch. We investigated the diets of over 80 fish species with the aim of defining the major trophic linkages of SEF quota species and identifying the relative importance of benthic, pelagic, and inshore (*i.e.* seagrass, macroalgae) sources of production to quota fish species. We also determined the level of predation on quota species.

FIGURE 2



The study

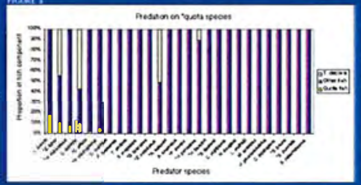
The area from Wilsons Promontory to Bermagui was surveyed. Demersal trawls were made at depths of 25, 40, 80, 120, and ~200 m on each of seven cross-shelf transects (see map). Samples were collected on four cruises of the RV *Southern Surveyor* in July 1993 (winter), August 1994 (spring), April 1996 (autumn) and November 1996 (summer). Additional samples were collected by commercial gill-netters during winter and summer from "reefs". Seasonal and geographical comparisons of diet have been made as well as overall diet descriptions but are not described here.

The SEF quota species and 16 other species were targeted because of their commercial or ecological importance (see Fig 2). Collections were made throughout each cruise, so that, where possible, a range of depths, time, geographical locations and size of fish were sampled for each species. From each tow, stomachs were removed from up to ten fish per selected species. Stomach contents were identified to the lowest possible taxon, counted and weighed.

Diets were described in terms of wet weight of prey. Prey were grouped into 14 broad categories: other (sediment, algae), benthic invertebrates, polychaetes, benthic crustaceans, megabenthos, benthic fish, benthopelagic fish, pelagic invertebrates, pelagic crustaceans, pelagic fish, unknown invertebrates, unknown crustaceans, unknown fish and unknown. Guild structure was determined by clustering the species based on the proportions of all but the unknown prey categories using a Bray-Curtis dissimilarity coefficient and an agglomerative clustering routine based on average linkage (UPMGA) (SPSS).

Results

FIGURE 3



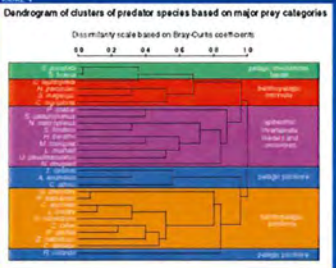
Nearly half of the species were highly piscivorous, *i.e.* more than 50 % of their diet was fish. Half ate over one third fish (Fig 2).

However of all the fish-eaters —27 of the 28 species—only a few ate quota species (Fig 3). The highest proportion was found in the diet of Stripey trumpeter *L. lineata*. 17% was Ocean Perch *Helicolenus* species. John Dory *Z. faber* ate 10% of Redfish *C. affinis* and minor quantities of others. Tiger flathead *N. richardsoni* ate over 5% of School whiting *S. flindersi* and 2% of Ling *G. blacodes*. Also of interest was that Jack mackerel *T. declivis*, a non-quota species, was eaten in large amounts by John Dory *Z. faber* (43%), Mirror Dory *Z. nebulosus* (50%) and the swell shark *C. laticeps* (34%). However Jack mackerel is not a particularly important commercial species at present .

The species we studied here resulted in the following guilds (see Fig 4):

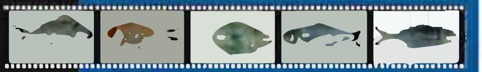
- Benthopelagic omnivores & pelagic invertebrate feeders
- Epibenthic invertebrate feeders & omnivores
- Pelagic piscivores
- Benthopelagic piscivores

FIGURE 4



Conclusion

The majority of important commercial fish in the demersal trawl fishery in the SEF feed on pelagic or benthopelagic prey, therefore the fishery is largely pelagically driven. Since there were no top predators identified, we suggest that the SEF is structured by competition rather than by predation. This might have implications for competition between different fisheries if the same source of prey, such as midwater fishes, is targeted by those fisheries.



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FISHERIES
RESEARCH &
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CORPORATION

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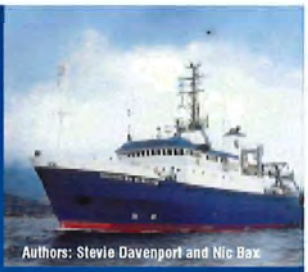
Fisheries Research &
Development Corporation

CSIRO Marine Research

A glimpse into a marine ecosystem off SE Australia using stable isotopes



Authors: Stevie Davenport and Nic Bax

DESCRIPTION OF STUDY AREA

From 1993 to 1996 CSIRO made four, month-long surveys on the south east Australian continental shelf, in depths of 20-250 metres. Seven transects across the shelf were sampled each survey. In addition, specific habitats were sampled intensively. Each survey covered a different season.

The objectives of the study include identifying the relationships between the habitat type and the fish assemblages (especially commercial fish) and important trophic links and sources of production.

Stable isotope analyses of carbon and nitrogen in phytoplankton, sediments, flora and fauna was one of the tools used in this study to identify sources of productivity and trophic links.

A complex, multispecies fishery - the South East Fishery - operates on the south east Australian continental shelf. Over the 4 surveys we caught 200 fish species by trawl (an average of about 30 species per trawl), and about 70 invertebrate functional groups by benthic sled (about 25-30 groups per sled).

PROVENANCE: WATER COLUMN AND SEDIMENTS

Q. What are the sources of productivity in this ecosystem? Are terrestrial and inshore sources important?

The overall mean value for δ^{1}C in Particulate Organic Matter (POM) in the water column varied little between surveys (-21.5 ± 1.8‰) and is typical of marine phytoplankton.

Sediments on the continental shelf also reflected marine signatures with a mean δ^{1}C of -21.8‰ (± 1.7‰). For each survey, overall mean sediment δ^{1}C was 0.4 to 0.9‰ more negative than mean POM.

A. The survey lies off a dry corner of a dry continent. Sea floor sediments and water column particulates show stable isotope signatures that are predominantly oceanic with little terrestrial or estuarine input.

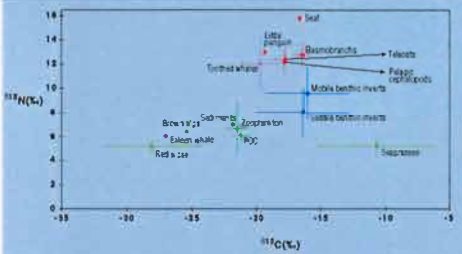


Fig. 1 Mean stable isotope values (±1 SD) for primary producers to higher consumers from the South East Australian continental shelf 1993 — 1996.

• cetaceans stranded in this region, but not necessarily feeding in it

Stable isotope results indicate a complexity of relationships that relate to functional patterns of feeding rather than to taxonomic links. The foundations of this ecosystem are marine phytoplankton. Trophic paths diverge early in the food web into benthic and pelagic patterns. Within a single taxonomic group there is often a wide range of isotopic signatures and feeding mechanisms.

TROPHIC RELATIONSHIPS

Q. Who's further up the trophic ladder... snail, seal or shark?. .worm or warehou?

A. d15N: seal15.8, snail 13.7, gummy shark 12.9; worm 12.2, warehou 12.2

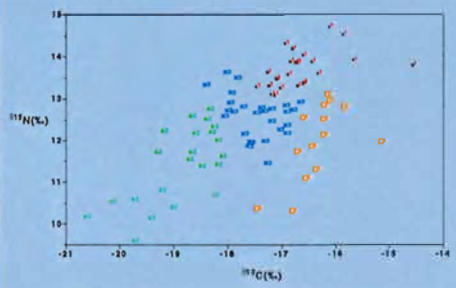


Fig 2 Stable isotope values for 87 species of fish (teleosts & elasmobranchs) from the South East Australian Shelf. Five groups (Ward's minimum variance method) emerge based on $\delta^{15}N$ and $\delta^{13}C$.

Group 1. Piscivory common: include benthic and pelagic predators that consume prey with a high trophic position
Group 2: Pelagic feeders: most eat pelagic zooplankton and fish
Group 3. Benthic and pelagic feeders. most take a variety of benthic & pelagic prey (invertebrates & fish), there are overlaps with other groups
Group 4: Benthic feeders: most take benthic prey (invertebrates, fish, cephalopods)
Group 5: Pelagic planktivores: most are small fish (including several lanternfish) that eat small pelagic zooplankton or fish that eat zooplankton

Each data point represents the mean stable carbon and stable nitrogen value for a single species. Sample sizes vary from 1 to 60 fish, most are > 5.

For the 86 fish species sampled (teleosts and elasmobranch cluster analysis of δ13C and δ15N identified 5 basic groups t reflect prevailing patterns of feeding behaviour

CSIRO MARINE RESEARCH
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This research was funded by the Fisheries Research and Development Corporation
Poster designed by [illegible]

Authors: Dianne Furlani,
Alan Williams and Nic Bax

DOES SIZE MATTER?

Depth-patterns in SE Australian shelf fishes

Juvenile Redfish in 70 m depth

Introduction

The spatial distributions of demersal marine fishes are related to many physical variables and may be examined at the level of community, species or intra specifically. Depth is commonly, and often distinctly, related to community and species distributions, and may also be related to the distribution of individuals within species based on body size. For example, increasing size with increasing depth is a common intra specific pattern in mesopelagic and continental slope fishes, and is reported for some shelf fishes. This poster describes the size depth relationships of temperate southeastern Australian continental shelf fishes and their relevance to a study of the regional fishery ecosystem.

Methods

Fishes were sampled by trawl at 25, 40, 80, 120 and ~200 m depths on 7 transects between Wilsons Promontory and Bermagui (Map 1). Lengths were recorded for all species with > 5 individuals per trawl in a total of 147 trawls taken at four different times of the year, and recorded together with a suite of variables including depth, transect, season, and habitat type. A subset of 54 species represented by > 250 lengths were analysed from the 153 species and 151,074 individual lengths recorded. Length frequencies (LFs) were subsequently standardised by the species composition of each trawl to account for sub sampling of large catches, and by tow time and tow speed to permit comparison between trawls.

The patterns

There were four intra specific patterns of distribution with depth, three of which are shown in Figure 1.

These patterns are:

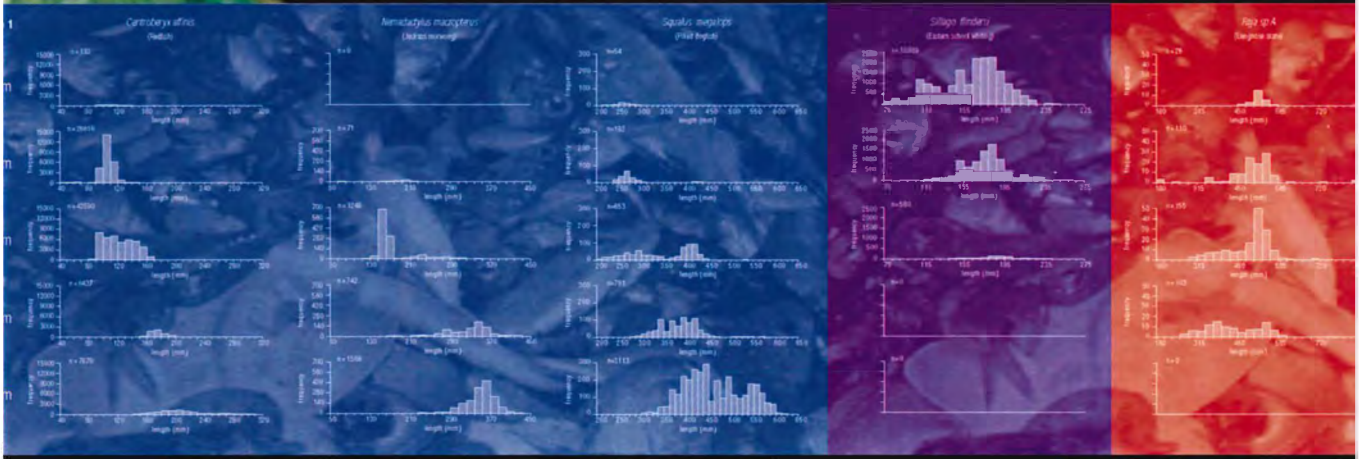
1. Bigger deeper — progressive increase in size with increasing depth
2. Smaller shallower — smallest size range in shallower depths with little variation in large size ranges across depths
3. Bigger shallower — largest size range in shallower depths with little variation in other size ranges across depths
4. Restricted range — narrow depth range or with near-shore (< 25 m) or upper-slope (>200 m) centres of distribution

Twenty one of the 54 species analysed (LFs > 250) had a distinct depth related pattern of distribution (Table 1). The majority are 'bigger deeper' species, and ten are of commercial importance in the South East Fishery (SEF): redfish, ling, ocean perch, jackass morwong, blue morwong, tiger flathead, white trevally, warehou, spotted warehou and John dory.

Table 1

The numbers of species with distribution pattern types 1 to 3 (b
on 54 species
with LF > 250)

Pattern	*All species*	*Comm spec*
1. Bigger/deeper	*16*	*1*
2. Smaller/shallower	*3*	*1*
3. Bigger/shallower	*1*	*0*
4. Restricted range	*8*	*2*
No discernible pattern	*26*	*0*



Bigger deeper

Allomycterus pilatus
Caesioperca rasor
**Centroberyx affinis*
**Genypterus blacodes*
**Helicolenus percoides*
**Nemadactylus macropterus*
**Nemadactylus douglasii*
**Neoplatycephalus richardsoni*
Parika scaber
**Pseudocaranx dentex*
**Seriolella brama*
**Seriolella punctata*
Squalus megalops
Thyrsites atun
Trachurus declivis
**Zeus faber*

Smaller shallower

Lepidotrigla mulhalli
Urolophus paucimaculatus
**Sillago flindersi*

Bigger shallower

Raja sp A

Discussion

Many temperate Australian continental shelf fishes available to trawl sampling showed no depth related pattern in size structure. The 'bigger deeper' pattern [illegible]

[illegible]

communities. As size is a major determinant of predation success and predator avoidance, key biological factors will be important in any study of community composition. [illegible] Shelf.

The landing of smaller specimens [illegible] smaller and marketable fish are abundant.

Fish lengths recorded using an electronic fish measuring board

Fishery impacts on trophic structure: Comparisons between three marine systems

Xi He[1], Alex B. Huang[2], James F. Kitchell[3], Catherine M. Bulman[1], Nic Bax[1], and Christofer H. Boggs[4]

Ecopath models were used to examine changes in the trophic structure of three marine systems: the Central North Pacific, and Australia's South East Shelf and Gulf of Carpentaria. As there are no keystone predators in these systems, fisheries play an important role in shaping trophic structure by removing biomass from different trophic levels.

MAIN CHARACTERISTICS OF FISHERIES AND FOOD WEB STRUCTURE FOR THREE MARINE SYSTEMS EXAMINED

System	Central North Pacific	South East Shelf	Gulf of Carpentaria
Main feature	Temperate pelagic	Temperate shelf	Tropic shelf
Main species harvested	Large apex predators (large tunas, billfishes, sharks)	Mixed predators and planktivores (suite of demersal fishes)	Most planktivores (prawn, small plantivores)
Main fishing gear	Longline	Demersal trawl	Demersal trawl
Fishery status	Uncertain	Some fully exploited	Fully exploited
Fishery mean trophic level	4.81	4.40	4.06
Fishery efficiency	0.0001	0.0031	0.0429
Number of cycle pathways	3	0 (uncertain)	23
System omnivory index	0.218	0.262	0.080

CHANGES IN TROPHIC STRUCTURE REQUIRED TO SUPPORT INCREASES IN FISHERY PRODUCTION BY 50%

System	Central North Pacific	South East Shelf	Gulf of Carpentaria
Increase primary production by	50.1%	37.3%	0.5%
Changes in total system biomass	50.0%	34.6%	1.0%
Changes in fishery efficiency	0.1%	10.1%	51.1%
Changes in system omnivory index	0.0%	1.3%	0.0%
Changes in trophic efficiency	Mostly unchanged	Mostly unchanged	+10% (low trophic levels) to +45% (high)

Summary

When large apex predators are removed by fishing, such as in the Central North Pacific, fishery efficiency is low and significant increases in system production are required to support increases in fishery production. In contrast, when prawns and small planktivory fishes are removed by fishing, such as in the Gulf of Carpentaria, fishery efficiency is high. Increases in fishery production can be supported by increases in trophic efficiency without significant increases in system production.

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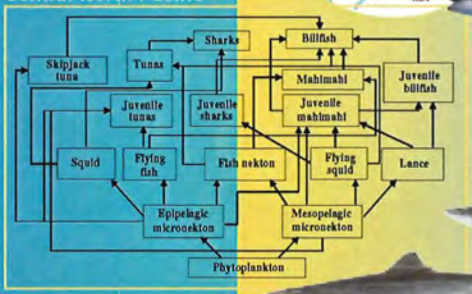
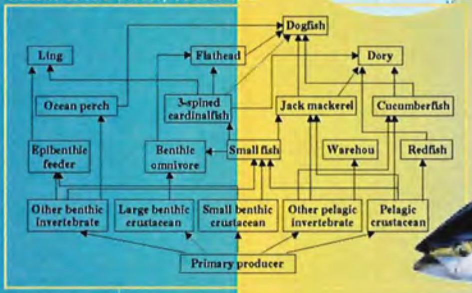
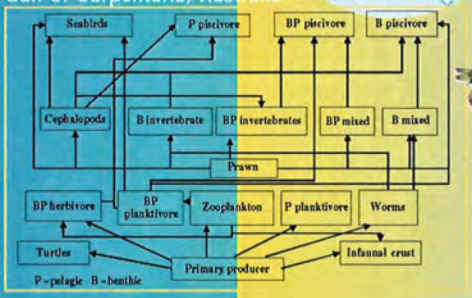
Central North Pacific



South East Shelf, Australia



Gulf of Carpentaria, Australia



Mapping the seafloor for spatial management of fishing effort and impact assessment

Alan Williams and Nic Bax
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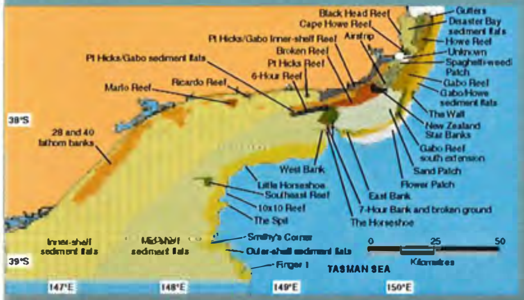
Figure 1. The SEF is Australia's largest scalefish fishery and the most important source of scalefish for domestic markets.

The continental shelf off southeast Australia (Figure 1) is the area of the greatest fishing effort within the South East Fishery (SEF). Trawling started in the early 1900s, and today a large fleet is made up of otter-trawlers, Danish seiners, demersal longline and dropliners, gillnetters and trappers. Both trawl and non-trawl sectors target a similar suite of valuable abundant fishes (below), however, their modes of fishing and habitat impacts are quite different. Effort in the fishery continues to rise, despite recent management attempts to reduce it. Adoption of advanced navigational aids (track plotters and GPS), and gears that fish rough-ground effectively, has enabled effort in both sectors to be increasingly targeted at the fine-scale 'hard-ground' habitat features that attract fish. Fishers report substantial erosion and disappearance of some features in recent years as a result. Spatial management has the potential to redirect fishing effort and effect the local effort-reduction necessary to sustain productivity of this fishery by preserving significant habitat.

But what is significant habitat? We present three levels for mapping the seafloor and identifying significant habitat from a case study in the SEF.



Level 1: coarse-scale mapping using fisher's information

Fisher's information on seafloor areas at scales of 10s- 100 sq. km was digitised and collated into a coarse-scale map of seafloor types and primary fishing grounds (Figure 2). We gathered the information during port visits and sea voyages as part of a liaison program to establish links with key fishers from different sectors of the fishery. Their observations, typically based on many years of exploring and sampling our study area, were provided as a series of charts, sketches, notes and marks from track-plotters.

The scale of this map is appropriate for scientists to understand the interaction of the commercial fishing fleet with the seafloor landscape (effort and catch), and to direct scientific sampling of habitats. Collaborating with fishers acknowledges their broad and often detailed knowledge of the seafloor, exemplified by their provision of 'place-names' for maps.

Figure 2 A coarse-scale map gives the first level of visualization of the shelf seafloor as a series of extensive sediment flats ('soft-grounds') with interspersed outcrops of consolidated material ('hard-grounds'). Practically all grounds are fished commercially but fishing effort is particularly targeted at 'hard-grounds'— bedrock and reef outcrops, consolidated sediments, their perimeters and the gutters that divide them.

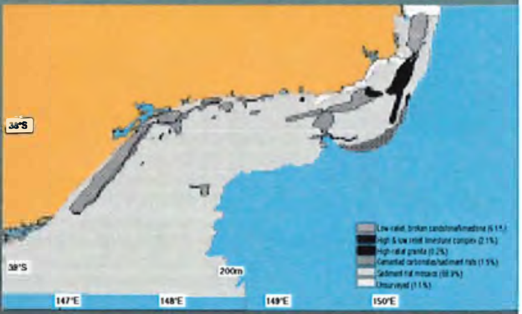
Level 2: addition of geological and biological attributes to define significant habitats

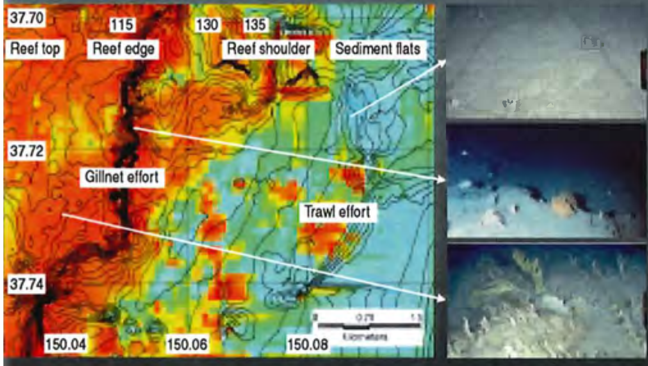
Rock and sediment samples showed that 'hard-ground' habitats are fossiliferous limestone reefs formed of bivalve and bryozoan clasts, sediments consolidated by reef forming bryozoans, indurated (cemented) sediments, and outcrops of granite and sandstone bedrocks (Figure 3). Their vulnerability to deleterious modification by fishing gears is highly variable and determined by the degree of hardness, degree of weathering, relief, areal extent and spatial integrity. 'Soft-ground' habitats, that form most of the shelf seafloor, are massive sediments, primarily sands but with gravels and mud in specific areas.

The most vulnerable habitats are shelf break bryozoan reefs that are soft and lightly attached, have minimal vertical relief (< 30 cm) and exist as small patches (1s-10s sq. m). Many inner-shelf fossiliferous limestone/ sandstone reefs are also vulnerable because they are relatively soft, highly weathered, have low-relief (< 2 m) and exist in isolation or as patchworks intersected by gutters. Least vulnerable are highly cemented, deep, high-relief (to 10 m), large and undivided fossiliferous limestone reefs, and granite outcrops. Fishing impacts on the structure and stability of sediment flats in this predominantly high-energy, current-swept shelf environment are unknown but may not cause permanent modifications (on a geological time scale). Most sediment flats have been fished for decades making impacts difficult to evaluate — although fishers report smothering of upper-slope reefs by current-borne sediment disturbed on the shelf.

Significant habitats are those that are targeted by fishing and vulnerable to erosion or removal unless effort is managed. Some, such as limestone reefs, are habitats that once eroded may never recover (short of the next ice age). Resilient habitats are those unlikely to be eroded by current fishing practices.

Figure 3. Geological and biological attributes added to the coarse-scale map provide the means of broadly differentiating vulnerable and resilient habitats.





Level 3: fine-scale mapping

Fine-scale mapping (10s-1000s sq. m) is necessary at the scale that fishing occurs. It is therefore a prerequisite to monitoring any management intervention. In the SEF, we identified and mapped the fine-scale features at which fishers target their effort (Bax *et al.*, in press, a) using acoustics, video on a towed camera platform (Barker *et al.*, in press), and a benthic sled. Examples from three important fishing grounds show (1) a region of concentrated effort on a largely resilient, outer-shelf, fossiliferous limestone reef (Gabo Reef, Figure 4), (2) a vulnerable shelf-break bryozoan reef (Flower Patch, Figure 5), and (3) a vulnerable inner-shelf limestone reef (Broken Reef, Figure 6).

To be effective, and accepted, spatial management must not unnecessarily impede fishing practices (Bax *et al.*, in press, b). Fine-scale mapping of significant habitats is necessary to determine where fishing can occur while still meeting management objectives.

Figure 4 Gabo Reef: a highly cemented, high-relief, limestone reef of some 430 sq. km on the outer shelf. Gillnet and trawl effort for aggregated blue warehou (*Seriolella brama*) is concentrated where a steep outer edge meets a flat 'shoulder' of cemented sediment at its base. A fine-scale survey was required to identify and map features critical to monitoring the possible impacts of fishing. (Raster image of 'acoustic roughness index' with red = most rough, blue = least rough; bathymetry in metres).

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Acknowledgements

Rudy Kloser developed acoustic processing techniques; more information available from http://www.marine.csiro.au/
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Figure 5. Flower Patch: shelf-break bryozoan reefs provide structured foraging areas by stabilizing sediments and permitting attachment of organisms including stalked crinoids.

Figure 6. Broken Reef: weathered, low-relief, limestone reef on the inner shelf provides highly structured habitats for many species, including nursery areas for the commercial redfish

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APPENDIX II STABLE ISOTOPE ANALYSIS AND ECOSYSTEM STUDIES

Most elements exist in nature in more than one form; i.e. they have different isotopes. An isotope is a member of a chemical-element family: the same number of protons, a different number of neutrons. Isotopes of an element have the same chemical attributes, but often display different physical attributes. e.g. C^{14}, C^{13} , C^{12}.

C^{14} is a radioactive isotope; C^{13}, C^{12} are stable isotopes of carbon.

Ecosystem studies using stable isotopes have concentrated on the biologically important elements: carbon (C^{13}, C^{12}), nitrogen (N^{15}, N^{14}), oxygen (O^{18}, O^{16}), hydrogen (H^2, H^1) and sulphur (S^{34}, S^{32}).
Isotopic compositions are usually expressed in terms of δ values, which are parts per thousand differences from a standard. The formula used to express stable isotope ratios (a measure of the heavy isotope to the light isotope) is:

$$\delta X‰ = (R_{sample} - R_{standard}) / R_{standard} * 1000$$

where X is ^{13}C, ^{15}N or ^{34}S, and R is the corresponding ratio $^{13}C/^{12}C$, $^{15}N/^{14}N$ or $^{34}S/^{32}S$.

By definition, standards have 0‰ δ values. The δ values are measures of the amounts of heavy and light isotopes in a sample. Increasing δ values denote increasing amounts of the heavy isotope component.
The standards used are Pee Dee limestone for carbon, nitrogen gas in the atmosphere for nitrogen, and the Canyon Diablo meteorite for sulphur.

HOW STABLE ISOTOPE RATIOS CHANGE

Many reactions alter the ratio of heavy to light isotopes (ie. they ‘fractionate’ stable isotopes), but the degree of fractionation is typically quite small.
The most commonly-used stable isotopes in ecosystem work are carbon, nitrogen and sulphur. Stable carbon is most often used to provide provenance information (information about the source or origins of samples); sulphur is used in tracing sources of sewage and pollution, and sulphur requirements of marine organisms; and nitrogen provides trophic information.
The stable carbon ratios of animal tissues reflect the isotopic compositions of plants at the base of the food chain in an ecosystem. Plant stable carbon ratios values vary in response to physiological and environmental parameters.

Animals are similar in isotopic compositions to their diets for carbon and sulphur, but are on average 3 to 5 ‰ heavier than their diet for nitrogen. The ^{15}N enrichments vs diet are largely due to excretion of isotopically light nitrogen in urine. The urinary losses of ^{14}N are offset by ^{15}N enrichments in other nitrogen pools (eg. milk and blood are +4 δ ‰ enriched in ^{15}N). There is also increasing evidence that an animal's physiological status may affect its stable nitrogen signature.

Carbon shows modest increases, between 0 and 1 ‰ per trophic level. This small enrichment may be due to carbon isotopic fractionation during assimilation or respiration.

While diet controls the overall isotopic composition of animals, considerable isotopic variation occurs between different tissues and metabolites within individual animals, eg. the bone protein, collagen, is 2 to 6 ‰ enriched in ^{13}C compared to the diet, while lipids in fat reserves are 2 to 8 ‰ depleted in ^{13}C.

More metabolically active tissues turn over more quickly. Depending on the tissue, stable isotope (carbon, nitrogen) values are biased towards feeding patterns of the recent past. For example, in gerbils switched from a C^4 corn to a C^3 wheat diet (Tieszin et al. 1983), ^{13}C enrichment for individual tissues fell:

hair > brain > muscle > liver > fat

fat being the fastest turnover tissue and the quickest to reflect the new diet.

The use of stable isotopes to study diets is based on the use of animal tissues that bear a fixed isotopic enrichment or depletion vs the diet. Sometimes whole animals are used, otherwise analyses of muscle or protein fractions have shown to be adequate indicators of diet.

These analyses are complementary to other methods of studying diet. Stable isotope compositions of tissues are a measure of the assimilated (not just ingested) diet, reflecting both long-term and short-term diets in slow and fast-turnover tissues.

APPENDIX TABLES

(Appendix table numbers correspond to the relevant chapter and section number)

SURVEY SS9405 August - September 1994

Concentrations (ng/L)

Station	Transect	Lat	Long	Water Depth(m)	Sample Depth(m)	Chl. c3	Chl c1+c2	19'-but	Fucox	19'-hex	cis-fuc	Prasin	Viola	Diadino	Allox	Zeax	Chl b	Chl a	Phytin a	B,B-car
161	Bermagui	36.39	150.1	46	0	0.0	93.9	0.0	58.9	78.9	0.0	0.0		51.0	15.1	0.0	54.6	273.9	0.0	0.0
					33	0.0	46.7	0.0	81.4	0.0	0.0	0.0		0.0	0.0	0.0	0.0	115.6	245.7	0.0
149	Bermagui	36.52	150.3	201	0	368.3	533.3	0.0	429.1	111.1	81.2	0.0		121.3	0.0	0.0	0.0	410.9	0.0	29.8
					25	724.5	1010.8	0.0	879.2	166.2	153.3	0.0		94.9	0.0	0.0	0.0	1316.9	0.0	44.9
130	Merimbula	36.92	150	45	0	0.0	131.8	0.0	102.5	74.9	0.0	0.0		52.9	0.0	0.0	0.0	203.6	0.0	0.0
					22	410.7	536.5	0.0	558.5	29.5	86.7	0.0		85.7	0.0	0.0	0.0	861.3	0.0	85.4
141	Merimbula	36.91	150.3	152	0	336.2	538.6	0.0	269.6	170.7	71.9	0.0		127.7	0.0	0.0	53.6	376.7	0.0	30.7
					29	117.5	141.6	0.0	190.3	42.7	28.5	0.0		17.8	0.0	0.0	35.9	458.6	0.0	0.0
120	Disaster B	37.29	150	44	0	455.3	536.6	0.0	630.9	51.2	111.2	0.0		124.5	26.8	0.0	0.0	1261.1	0.0	67.1
					25	117.7	125.1	0.0	215.9	0.0	35.7	0.0		30.4	0.0	0.0	0.0	501.4	0.0	24.7
108	Disaster B	37.46	150.3	245	0	208.2	312.0	0.0	360.1	61.9	58.3	0.0		33.5	0.0	0.0	0.0	893.5	0.0	22.4
					25	771.1	1060.1	0.0	990.2	249.0	195.6	0.0		233.9	67.1	0.0	119.9	1302.5	0.0	77.9
89	Gabo Is	37.59	149.9	43	0	285.2	384.7	0.0	490.7	71.8	110.2	60.1		87.5	30.4	13.8	132.8	1035.2	0.0	52.9
					25	178.3	258.9	0.0	299.4	61.5	83.2	50.4		86.6	35.7	17.7	118.3	531.6	0.0	44.1
101	Gabo Is	37.91	150.1	225	0	404.2	492.9	0.0	415.9	77.5	83.3	0.0		124.8	28.6	0.0	0.0	328.8	0.0	31.1
					20	650.8	726.9	0.0	831.2	104.1	129.8	0.0		85.1	0.0	0.0	55.7	1321.6	0.0	45.9
67	Pt Hicks	37.82	149.1	42	0	0.0	71.6	0.0	36.4	42.5	0.0	34.5	*	25.4	31.9	30.8	138.1	494.6	0.0	28.6
					15	0.0	45.0	0.0	0.0	44.2	0.0	32.3	*	0.0	0.0	39.7	121.7	351.1	0.0	19.1
79	Pt Hicks	38.2	149.3	236	0	147.2	205.7	0.0	140.8	93.7	41.4	23.3		42.0	30.4	17.3	120.3	773.6	0.0	28.7
					25	169.8	229.4	0.0	191.7	104.7	48.4	30.2		36.4	23.6	15.5	103.2	599.6	0.0	27.2
37	Lakes Ent	37.93	148.3	42	0	0.0	32.6	0.0	0.0	0.0	0.0	0.0		0.0	0.0	37.9	60.2	241.4	0.0	0.0
					27	0.0	48.3	0.0	0.0	53.8	0.0	0.0		0.0	0.0	28.1	89.0	307.9	0.0	0.0
48	Lakes Ent	38.55	148.3	210	0	101.5	173.0	0.0	128.8	85.7	0.0	0.0		63.6	45.4	15.2	93.4	590.8	0.0	23.7
					25	146.2	264.9	0.0	280.4	85.9	0.0	0.0		39.6	25.8	0.0	128.5	776.6	0.0	31.4
27	Wilsons P	39.01	146.6	45	0	0.0	109.8	0.0	77.1	99.7	0.0	0.0		33.1	42.6	22.0	164.5	696.2	0.0	33.3
					18	0.0	110.8	0.0	67.9	93.3	0.0	0.0		34.6	42.2	19.3	163.0	667.1	0.0	29.1
63	Wilsons P	38.94	148.5	200	0	88.7	177.9	29.0	138.3	74.2	0.0	24.7		38.5	23.6	0.0	65.9	314.8	0.0	19.4
					44	106.1	130.5	0.0	156.5	52.4	0.0	0.0		17.5	0.0	0.0	60.6	353.3	0.0	0.0

* = presence of violaxanthin

Appendix Table 6.2.1.2 Water column pigments Survey SS9602

Survey SS9602 16 April to 12 May 1996

Pigment concentrations (ng/L)

Station	Date	Transect	Lat	Long	Water Depth (m)	Sample Depth	Chl c3	Chl c1+c2	Perid	19'-but	Fuco	19'-hex	c-Fuco	Pras	Viola	Diadino	Allo	Diato	Lut	Zea	Chl b	Chl a-like	Chl a allom	Chl a	Chl a epim	Tot Chl a	Phytin b	Pyro phytin b	B,e car	B,B-car
124	4/28/92	Bermagui	36.36	150.2	40	4	17.4	34.7	0.0	11.3	13.9	37.4	3.9	2.5	*	12.5	12.3	0.0	2.1	39.0	47.6	8.5	12.8	265.3	7.9	294.4	0.0	0.0	4.6	12.5
						19	19.2	46.6	2.5	18.8	18.7	50.3	0.0	6.7	*	8.3	12.1	0.0	1.9	29.0	67.8	8.2	15.6	287.5	9.6	320.8	0.0	0.0	4.9	9.8
115	4/27/92	Bermagui	36.54	150.3	180	4	23.1	47.7	0.0	19.9	18.8	65.6	7.6	3.7	*	26.0	13.3	4.0	3.6	68.8	39.3	10.1	10.6	316.5	9.4	346.6	0.0	0.0	4.5	13.5
						40	30.0	51.5	0.0	37.1	29.0	67.9	0.0	8.4	*	8.2	6.6	0.0	2.6	41.6	99.5	10.4	12.7	320.8	12.8	356.7	0.0	0.0	9.9	10.2
140	4/29/92	Merimbula	36.92	150	44	3.5	21.8	51.3	0.0	10.7	19.8	47.0	0.0	12.5	*	12.1	14.9	0.0	3.7	54.4	83.9	10.1	18.1	375.4	13.9	417.5	0.0	0.0	4.0	16.6
						23	17.9	46.5	0.0	9.9	23.7	70.9	0.0	18.6	*	9.2	17.8	0.0	1.3	47.7	123.8	0.0	16.4	409.7	9.2	435.3	0.0	0.0	5.5	17.2
150	4/29/92	Merimbula	36.86	150.3	206	3	15.6	55.7	0.0	12.8	24.1	80.9	0.0	38.8	*	0.0	24.9	0.0	2.4	76.0	191.9	0.0	16.6	559.3	10.0	585.9	0.0	0.0	3.8	28.6
						18	24.0	82.7	0.0	16.7	29.8	97.1	0.0	45.1	*	14.0	29.8	0.0	3.6	82.0	232.1	0.0	24.1	670.5	12.9	707.5	0.0	0.0	4.7	33.4
92	4/25/92	Disaster B	37.32	150	49	3	37.1	84.9	0.0	15.5	23.6	55.8	4.0	43.2	*	23.5	45.7	4.0	7.8	60.8	179.4	15.2	27.9	583.7	14.5	641.2	0.0	1.4	5.2	26.0
						19	0.0+	107.9	0.0	18.8	45.2	94.6	0.0	53.1	*	18.2	48.5	0.0	8.8	59.5	230.6	21.0	37.0	686.4	20.2	764.5	0.0	1.7	6.3	24.7
103	4/26/92	Disaster B	37.42	150.3	~200	5	16.4	60.2	0.0	10.0	30.7	39.2	3.8	21.6	*	15.2	31.7	0.0	4.8	50.6	104.9	14.4	27.5	423.7	16.1	481.7	0.0	2.2	5.0	19.6
						19	0.0+	57.3	0.0	9.3	33.1	38.0	3.7	0.0	*	11.6	26.9	0.0	5.1	43.5	103.8	11.7	22.5	387.4	16.7	438.2	5.8	2.2	4.7	18.7
79	4/24/92	Gabo	37.58	149.9	36	4	0.0+	125.8	9.8	16.1	86.9	94.3	13.6	23.5	*	55.6	30.4	7.1	7.3	29.6	150.4	13.5	33.3	614.9	12.5	674.2	0.0	0.0	2.8	19.0
						14	0.0+	166.7	7.6	21.0	129.8	122.7	0.0	24.7	*	50.8	28.5	7.4	7.6	26.1	212.3	22.8	56.4	759.5	37.6	876.4	0.0	0.0	5.4	23.2
68	4/23/92	Gabo	37.95	150	~200	3	0.0+	94.3	1.7	36.2	43.8	122.8	0.0	16.6	*	28.5	34.9	3.5	3.1	19.6	137.3	11.7	29.0	534.2	18.4	593.3	0.0	0.0	4.8	16.8
						24	16.2	63.2	0.0	31.6	34.0	91.5	0.0	13.3	*	12.0	19.6	0.0	2.0	14.7	115.7	8.7	11.0	431.4	5.2	456.2	0.0	0.0	3.6	13.7
56	4/22/92	Pt Hicks	37.82	149.1	36	4	0.0	111.5	0.0	20.0	116.9	80.7	0.0	0.0	*	47.5	10.4	5.3	3.4	13.0	65.6	8.9	36.3	496.6	13.9	555.7	0.0	0.0	0.0	20.4
						23	0.0	67.9	2.0	13.7	54.4	74.5	0.0	9.1	*	12.6	6.6	0.0	3.4	10.0	76.9	6.7	14.2	377.8	5.5	404.3	0.0	0.0	2.3	11.3
44	4/21/92	Pt Hicks	38.18	149.3	191	3	0.0+	58.1	0.0	26.9	29.0	84.4	8.1	11.5	*	16.0	9.1	0.0	0.0	10.8	78.1	7.1	20.8	307.7	7.4	343.0	0.0	0.0	1.9	8.5
						24	0.0+	51.8	0.0	27.0	29.3	82.4	10.3	9.5	*	17.3	11.2	0.0	0.0	12.6	80.2	0.0	16.6	316.7	5.3	338.7	0.0	0.0	1.7	9.0
25	4/19/92	Lakes Entr	37.92	148.3	42	4	17.6	50.2	0.0	12.7	36.0	68.8	0.0	0.0	*	20.1	10.5	0.0	5.5	17.2	86.1	0.0	11.3	332.5	5.2	349.0	0.0	0.0	1.7	12.3
						26	13.7	44.4	0.0	11.2	34.2	62.0	0.0	0.0	*	10.1	5.0	0.0	4.0	12.0	75.3	0.0	7.4	288.5	4.0	299.8	0.0	0.0	1.4	7.7
8	4/17/92	Lakes Entr	38.55	148.4	191	4	0.0+	103.9	0.0	5.7	127.9	53.9	0.0	0.0	*	23.3	20.2	0.0	0.0	0.0	59.0	0.0	25.1	538.8	0.0	563.9	0.0	0.0	2.8	16.0
						38	0.0+	116.5	0.0	6.5	149.7	58.2	17.3	0.0	*	25.1	19.7	0.0	0.0	0.0	99.1	0.0	51.7	599.7	6.8	658.2	0.0	0.0	2.5	16.5
18	4/18/92	Wilsons P	38.99	146.5	40	2	0.0+	138.5	11.9	29.5	89.3	120.1	0.0	0.0	*	59.6	53.4	7.7	9.5	0.0	133.3	0.0	15.5	738.8	12.2	766.5	0.0	0.0	4.8	21.8
						19	0.0+	155.5	13.7	36.5	101.9	132.8	0.0	0.0	*	48.4	49.3	0.0	10.0	0.0	150.2	0.0	40.1	777.7	17.4	835.2	0.0	0.0	6.5	22.9
41	4/20/92	Wilsons P	38.92	148.5	205	4	0.0+	61.0	0.0	34.6	24.6	91.2	0.0	13.1	*	15.4	10.5	0.0	0.0	14.8	100.6	6.6	9.5	365.3	5.0	386.4	0.0	0.0	2.2	10.2
						23	14.3	54.8	0.0	37.2	24.7	91.1	12.9	12.9	*	13.3	9.1	0.0	0.0	13.3	102.6	6.8	8.2	350.6	5.8	371.4	0.0	0.0	1.9	9.7

* = presence of violaxanthin   + = chl 3/chlorophyllide mix

Appendix Table 6.2.1.3 Water column pigments Survey SS9606

Stn	Transect	Lat	Long	Depth	Depth	Chl c3	C1+C2	Perid	19'-but	Fuco	19'-hex	c-fuco	Pras	Viola	Diadino	Allo	Diato	Lut	Zea	Chl b	allom	Chl a	ep	B,e	B,B-
78	Gabo	37.91	150.04	218	3.8	0.0	203.6	0.0	33.4	378.2	56.2	21.7	0.0		140.8	0.0	31.8	0.0	11.6	10.9	16.7	375.3	19.5	0.0	19.8
					9.6	0.0	252.0	0.0	37.3	430.9	62.0	27.1	0.0		177.8	0.0	30.1	0.0	18.0	12.3	10.8	457.0	15.9	0.0	19.7
					28.5	0.0	466.5	0.0	38.3	616.3	87.0	54.1	0.0		100.5	0.0	13.9	0.0	6.2	25.0	20.2	537.6	20.2	0.0	27.7
					50.8	0.0	194.3	0.0	20.1	339.0	24.3	29.7	0.0		24.0	0.0	8.0	0.0	1.9	12.2	21.4	454.8	6.5	0.0	12.2
					74.7	0.0	89.8	0.0	15.6	200.4	14.4	20.7	0.0		17.6	0.0	6.4	0.0	0.0	5.4	16.4	331.8	0.0	0.0	8.5
					103.8	0.0	43.8	0.0	9.3	89.1	21.6	0.0	0.0		11.0	0.0	6.9	0.0	0.0	0.0	4.9	151.4	0.0	0.0	4.0
65	Pt Hicks	37.82	149.08	40	4.5	0.0	5.0	0.0	8.4	18.0	44.3	0.0	3.1	*	33.3	9.8	9.5	2.5	19.0	17.1	0.0	165.1	0.0	0.0	7.2
					10.3	0.0	28.1	0.0	9.1	19.8	47.1	0.0	3.2	*	33.6	10.7	9.1	2.7	21.3	18.6	0.0	184.9	3.5	0.0	11.4
					30.3	0.0	162.4	0.0	12.0	121.4	198.8	0.0	28.3	*	30.8	29.4	5.8	2.0	21.3	138.5	12.7	616.4	12.6	4.0	19.6
					36.2	0.0	15.3	5.4	10.3	124.4	175.7	0.0	25.9	*	24.1	26.9	3.5	0.0	19.4	132.8	0.0	606.6	0.0	4.5	19.2
52	Pt Hicks	38.2	149.31	280	2.8	0.0	135.4	0.0	28.0	156.1	104.5	0.0	9.9	*	122.1	39.4	30.0	6.0	19.6	66.9	23.9	622.7	16.1	0.0	26.5
					10.7	0.0	241.0	0.0	48.5	330.1	75.5	0.0	11.2	*	197.7	45.3	34.3	4.4	30.9	90.2	36.0	860.7	29.7	0.0	48.3
					25.0	0.0	326.5	0.0	39.5	394.5	125.2	0.0	16.6		55.3	28.6	8.4	0.0	17.7	112.4	51.4	1031.0	22.0	0.0	32.6
					45.5	0.0	199.4	0.0	32.2	288.9	127.0	0.0	15.4	*	39.0	18.8	4.9	0.0	11.8	83.9	38.5	781.5	18.3	0.0	23.9
					74.3	22.3	24.5	0.0	5.1	38.4	31.2	0.0	6.6		6.2	3.5	0.0	0.0	5.2	36.7	0.0	162.1	0.0	1.5	4.9
					101.0	7.6	15.2	0.0	3.3	24.9	24.2	0.0	6.7		4.5	2.8	0.0	0.0	4.6	30.4	0.0	119.8	0.0	1.4	3.5
35	Lakes Entr	37.91	148.26	41	3.1	0.0	0.0	0.0	0.0	44.4	73.6	0.0	20.7	*	38.1	12.2	10.1	4.8	26.7	77.6	0.0	319.6	0.0	0.0	13.1
					24.7	66.5	103.4	5.1	0.0	89.9	129.5	0.0	31.8	*	22.7	14.7	0.0	0.0	16.4	142.5	7.1	567.1	7.8	3.9	14.2
43	Lakes Entr	37.92	148.25	41	2.3	0.0	35.0	0.0	0.0	33.4	60.1	0.0	15.5	*	36.0	13.8	12.8	7.3	29.0	52.3	0.0	242.3	10.6	0.0	7.8
					10.3	0.0	14.3	0.0	0.0	41.9	73.2	0.0	20.0	*	30.6	0.0	8.2	6.4	26.1	81.3	0.0	322.4	0.0	0.0	10.2
					30.3	111.4	36.4	0.0	5.9	155.5	216.8	0.0	37.1	*	22.7	19.8	0.0	0.0	18.7	183.7	0.0	763.4	0.0	4.1	16.3
					42.2	13.7	8.7	0.0	0.0	71.0	50.7	0.0	13.0	*	7.5	4.5	0.0	0.0	7.1	66.5	0.0	269.5	0.0	1.9	6.2
27	Lakes Entr	38.55	148.43	251	2.6	66.7	77.8	0.0	26.9	86.2	55.5	0.0	6.3	*	62.3	16.9	25.5	3.5	11.8	33.9	8.8	342.8	7.7	0.0	10.0
					12.0	0.0	99.6	0.0	34.3	99.3	68.6	0.0	6.9	*	74.9	27.5	24.2	4.0	13.0	47.3	18.6	435.1	11.2	0.0	11.7
					25.5	0.0	125.1	4.4	31.0	127.1	64.4	0.0	8.4	*	57.2	24.0	14.9	2.1	10.9	56.2	12.0	462.6	8.7	2.0	9.9
					46.5	0.0	91.2	0.0	16.1	125.8	34.8	0.0	6.6	*	18.6	5.5	4.6	0.0	5.8	35.2	15.7	303.1	0.0	0.0	6.7
					101.8	9.1	25.0	0.0	5.1	45.3	15.6	0.0	9.2		7.3	2.0	0.0	0.0	2.8	9.0	0.0	115.9	0.0	0.0	3.0
17	Wilsons Pr	38.96	146.57	23	2.6	29.2	58.5	0.0	6.3	46.5	85.2	0.0	9.5	*	37.6	17.2	10.8	4.5	45.5	74.0	8.7	373.7	7.2	0.0	15.3
					10.5	43.0	65.0	0.0	8.0	49.1	91.5	0.0	15.0	*	40.8	18.4	12.1	4.8	47.4	79.7	9.9	402.9	8.2	0.0	15.0
					20.7	37.6	76.0	3.0	6.7	51.6	96.2	0.0	17.8	*	28.3	17.5	7.5	3.4	49.8	99.7	9.6	440.6	8.8	2.8	20.9
11	Wilsons Pr	39	146.6	40	5.1	57.9	92.0	0.0	6.6	65.4	136.3	0.0	18.0	*	35.8	26.2	10.9	2.8	33.2	107.2	0.0	553.3	0.0	0.0	30.0
					10.7	40.0	83.8	0.0	5.2	29.9	133.1	0.0	16.2	*	33.6	24.8	5.9	0.0	33.6	112.7	0.0	566.9	0.0	0.0	32.2
					25.1	46.0	83.5	0.0	10.6	62.0	128.4	0.0	19.0	*	33.3	24.1	7.6	2.1	30.5	99.4	0.0	522.1	5.8	0.0	28.6
					38.0	58.4	87.9	0.0	7.4	63.4	130.1	0.0	19.8	*	30.3	25.3	7.3	2.1	32.9	104.8	0.0	526.5	0.0	4.0	25.7

* = presence of violaxanthin

SURVEY SS9606 **20 November to 18 December 1996**

				Water	Sample		Chl		Pigment concentrations ng/L												Chl a		Chl a		
Stn	Transect	Lat	Long	Depth	Depth	Chl c3	C1+C2	Perid	19'-but	Fuco	19'-hex	c-fuco	Pras	Viola	Diadino	Allo	Diato	Lut	Zea	Chl b	allom	Chl a	ep	B,e	B,B-
109	Bermagui	36.36	150.15	40	3.5	0.0	8.9	0.0	28.2	61.7	86.9	0.0	0.0	*	64.1	9.9	11.1	0.0	13.8	24.6	0.0	312.4	6.9	0.0	10.8
					10.2	26.0	50.2	0.0	25.9	60.9	88.2	0.0	5.7	*	60.9	9.8	10.7	0.0	13.9	29.0	4.4	324.8	7.0	0.0	11.6
					25.1	34.0	59.0	0.0	23.2	54.7	103.4	0.0	9.6	*	36.5	8.0	5.5	0.0	9.7	40.1	0.0	320.4	4.4	2.0	9.5
					42.3	41.2	73.4	0.0	15.6	80.9	108.3	0.0	9.3	*	16.7	0.0	0.0	0.0	8.8	64.7	3.7	388.0	0.0	2.8	12.9
118	Bermagui	36.48	150.3	240	2.3	0.0	40.3	0.0	30.2	123.6	70.7	0.0	0.0		79.9	0.0	10.6	0.0	12.7	10.6	9.8	157.5	24.0	0.0	14.0
					10.3	0.0	57.6	0.0	28.6	112.1	65.6	0.0	0.0		67.6	0.0	10.8	0.0	14.6	11.5	8.6	151.0	21.5	0.0	11.5
					24.7	0.0	62.4	0.0	28.6	110.0	69.5	0.0	0.0		58.3	0.0	18.2	0.0	14.9	12.9	10.0	154.6	23.0	0.0	11.0
					49.6	0.0	141.5	0.0	47.5	224.6	143.0	0.0	0.0		58.0	0.0	4.1	0.0	9.5	25.8	6.9	273.4	8.2	0.0	17.6
					75.0	0.0	168.0	0.0	35.1	300.5	35.9	0.0	0.0		26.9	0.0	0.0	0.0	2.5	16.3	11.1	254.9	8.6	0.0	18.0
					100.0	0.0	79.1	0.0	16.2	150.4	14.2	0.0	0.0		13.3	0.0	0.0	0.0	0.0	11.6	8.3	185.0	0.0	0.0	9.2
141	Merimbula	36.95	149.98	50	3.0	0.0	197.9	0.0	25.8	78.6	169.1	0.0	23.1	*	44.4	88.5	4.4	0.0	18.0	135.0	55.4	998.7	22.8	14.3	24.0
					10.3	0.0	209.0	0.0	34.8	115.2	208.5	0.0	29.4	*	49.5	73.7	4.1	0.0	18.8	164.2	55.5	1055.7	0.0	11.6	28.9
					26.4	0.0	95.9	0.0	8.0	112.5	77.8	0.0	16.4	*	13.0	0.0	0.0	0.0	0.0	90.5	20.8	358.6	7.2	0.0	12.3
					53.2	0.0	62.9	0.0	10.7	76.0	97.4	0.0	0.0		9.8	0.0	0.0	0.0	0.0	50.9	7.2	283.3	0.0	2.0	6.7
151	Merimbula	36.84	150.31	147	2.3	0.0	61.2	0.0	28.4	82.9	66.1	0.0	0.0	*	58.4	0.0	15.8	0.0	4.7	12.4	10.1	161.0	9.2	0.0	12.1
					10.2	0.0	74.3	0.0	35.3	99.2	73.1	0.0	0.0	*	58.5	0.0	15.7	0.0	7.5	15.4	8.0	167.3	7.9	0.0	13.0
					43.3	0.0	285.6	0.0	44.2	352.6	182.9	0.0	0.0		47.3	0.0	14.3	0.0	7.2	28.6	17.2	283.6	17.7	0.0	26.2
					50.3	0.0	254.7	0.0	38.0	385.3	96.9	26.3	0.0		40.9	0.0	0.0	0.0	4.4	17.9	9.1	224.6	10.6	0.0	24.2
					74.9	0.0	39.2	0.0	3.8	77.1	3.1	0.0	0.0		10.0	0.0	0.0	0.0	0.0	0.0	0.0	88.9	0.0	0.0	4.6
					100.2	0.0	0.0	0.0	0.0	9.1	0.0	0.0	2.0		2.3	0.0	0.0	0.0	0.0	0.0	0.0	20.5	0.0	0.0	0.0
104	Disaster B	37.32	150	40	3.3	0.0	54.8	0.0	16.8	41.4	73.3	0.0	4.7	*	47.1	16.8	13.5	4.5	14.5	35.7	4.5	245.1	5.8	0.0	12.8
					10.2	0.0	84.3	0.0	22.3	68.6	104.0	0.0	12.9	*	57.9	19.5	12.2	3.3	17.1	51.4	6.5	353.8	7.9	0.0	18.0
					37.1	0.0	185.5	12.0	42.0	145.6	195.0	0.0	21.4	*	33.6	19.7	3.3	0.0	15.7	116.8	15.2	543.5	14.3	0.0	22.2
					41.9	0.0	158.8	7.7	37.0	126.0	176.5	0.0	17.0	*	28.5	0.0	0.0	0.0	12.5	98.8	12.0	521.4	13.2	3.6	14.3
128	Disaster B	37.44	150.27	156	9.7	0.0	206.5	0.0	27.4	223.4	142.0	0.0	0.0		92.2	0.0	0.0	0.0	11.1	19.4	16.9	288.3	13.9	0.0	17.0
					24.1	0.0	295.6	0.0	37.4	386.9	173.5	0.0	0.0		103.4	0.0	0.0	0.0	8.7	18.6	23.7	338.8	19.7	0.0	29.0
					49.3	0.0	264.5	0.0	27.9	395.1	119.8	0.0	0.0		58.9	0.0	0.0	0.0	5.6	13.3	22.1	290.2	12.9	0.0	23.7
					74.1	0.0	95.6	0.0	9.0	171.3	18.5	0.0	0.0		20.2	0.0	0.0	0.0	2.8	10.7	43.4	282.9	8.9	0.0	10.7
					157.9	0.0	2.5	0.0	0.0	49.6	30.4	0.0	1.7		8.0	4.1	0.0	0.0	3.9	20.5	0.0	139.4	0.0	1.3	5.2
87	Gabo	37.6	149.87	58	5.8	0.0	21.4	4.6	31.3	84.6	101.2	0.0	7.2	*	52.1	16.4	9.5	2.5	11.5	50.6	0.0	421.8	0.0	1.9	11.2
					11.1	0.0	100.6	0.0	29.5	81.6	96.7	0.0	7.0	*	48.9	13.0	7.4	2.4	10.9	51.0	0.0	382.3	4.6	0.0	12.9
					25.5	0.0	22.2	4.3	32.0	100.0	121.5	0.0	12.5	*	5.1	14.2	7.0	2.6	11.8	60.5	0.0	437.0	0.0	2.2	16.5
					61.1	0.0	72.3	0.0	14.9	74.1	105.6	0.0	13.4	*	12.9	9.2	0.0	0.0	9.3	67.7	0.0	354.5	0.0	2.9	9.5

Appendix Table 6.2.1.4 Pigment abbreviations used in SEF pigment results

Abbreviation	**Pigment**
Chl C3	Chlorophyll c3
Chl c1+c2	Chlorophyll c1+c2
Perid	Peridinin
19’-but	19’-Butanoyloxyfucoxanthin
Fuco	Fucoxanthin
19’-hex	19’-Hexanoyloxyfucoxanthin
cis-fuco	Cis-fucoxanthin
Pras	Prasinoxanthin
Viola	Violaxanthin
Diadino	Diadinoxanthin
Allo	Alloxanthin
Diato	Diatoxanthin
Lut	Lutein
Zea	Zeaxanthin
Chl b	Chlorophyll b
Chl a-like	Chlorophyll a-like
Chl a allom	Chlorophyll a allomer
Chl a	Chlorophyll a
Chl a ep	Chlorophyll a epimer
Phytin b	Phaeophytin b
Phytin a	Phaeophytin a
Pyrophytin b	Pyrophaeophytin b
B,e-car	B,e-carotene
B,B-car	B,B-carotene
Chlide	Chlorophyllide

Appendix Table 6.2.1.5 Stable isotope results for particulate organic matter (POM) in water column samples collected on the south east Australian shelf.

Survey	Stn	Transect	Tr #	Lat	Long	Btm depth	Sample depth	$\delta^{15}N$	$\delta^{13}C$
SS9305	170	Pt Hicks	3	38.19	149.28	236	0		-20.24
SS9305	170	Pt Hicks	3	38.19	149.28	236	50		-21.91
SS9305	170	Pt Hicks	3	38.19	149.28	236	100		-21.87
SS9305	170	Pt Hicks	3	38.19	149.28	236	150		-20.68
SS9305	170	Pt Hicks	3	38.19	149.28	236	200		-16.97
SS9402	143	Pt Hicks	3	38.20	149.29	250	0		-21.72
SS9402	143	Pt Hicks	3	38.20	149.29	250	50		-24.03
SS9402	143	Pt Hicks	3	38.20	149.29	250	100		-21.21
SS9402	143	Pt Hicks	3	38.20	149.29	250	150		-20.83
SS9402	143	Pt Hicks	3	38.20	149.29	250	200		-24.26
SS9405	161	Bermagui	7	36.39	150.13	46	0	8.19	-21.22
SS9405	161	Bermagui	7	36.39	150.13	46	33	7.61	-19.65
SS9405	149	Bermagui	7	36.52	150.30	201	0	6.06	-18.70
SS9405	149	Bermagui	7	36.52	150.30	201	25	7.07	-19.84
SS9405	130	Merimbula	6	36.92	149.97	45	0	5.66	-20.51
SS9405	130	Merimbula	6	36.92	149.97	45	22	6.85	-20.70
SS9405	141	Merimbula	6	36.91	150.30	152	0	6.46	-19.40
SS9405	141	Merimbula	6	36.91	150.30	152	28	8.33	-20.05
SS9405	120	Disaster Bay	5	37.29	150.03	44	0	6.39	-20.40
SS9405	120	Disaster Bay	5	37.29	150.03	44	25	7.96	-21.03
SS9405	108	Disaster Bay	5	37.46	150.27	245	0	6.05	-20.08
SS9405	108	Disaster Bay	5	37.46	150.27	245	25	7.80	-19.73
SS9405	89	Gabo	4	37.59	149.85	43	0	4.37	-23.56
SS9405	89	Gabo	4	37.59	149.85	43	25	2.25	-23.31
SS9405	101	Gabo	4	37.91	150.05	225	0	5.60	-19.04
SS9405	101	Gabo	4	37.91	150.05	225	20	4.27	-20.98
SS9405	67	Pt Hicks	3	37.82	149.10	42	0	11.68	-24.87
SS9405	67	Pt Hicks	3	37.82	149.10	42	25	6.72	-20.09
SS9405	79	Pt Hicks	3	38.20	149.27	236	0	2.38	-21.84
SS9405	79	Pt Hicks	3	38.20	149.27	236	25	2.57	-21.30
SS9405	37	Lakes Entranc	2	37.93	148.25	42	0	17.40	-23.09
SS9405	37	Lakes Entranc	2	37.93	148.25	42	27	11.56	-19.24
SS9405	48	Lakes Entranc	2	38.55	148.29	210		3.64	-20.75
SS9405	48	Lakes Entranc	2	38.55	148.29	210		5.22	-23.44
SS9405	27	W Prom	1	39.01	146.60	45	0	18.21	-20.00
SS9405	27	W Prom	1	39.01	146.60	45	18	7.75	-19.34
SS9405	63	W Prom	1	38.94	148.51	200	0	2.37	-22.38
SS9405	63	W Prom	1	38.94	148.51	200	44	6.92	-22.28

Appendix Table 6.2.1.5 Stable isotope results for particulate organic matter (POM) in water column samples collected on the south east Australian shelf.

Survey	Stn	Transect	Tr #	Lat	Long	Btm depth	Sample depth	$\delta^{15}N$	$\delta^{13}C$
SS9602	124	Bermagui	7	36.36	150.15	40	0	3.89	-21.65
SS9602	124	Bermagui	7	36.36	150.15	40	25	3.62	-21.61
SS9602	115	Bermagui	7	36.54	150.30	180	0	4.11	-22.23
SS9602	115	Bermagui	7	36.54	150.30	180	40	3.56	-22
SS9602	140	Merimbula	7	36.92	149.97	44	0	5.21	-21.53
SS9602	140	Merimbula	7	36.92	149.97	44	25	5.34	-21.29
SS9602	150	Merimbula	7	36.86	150.32	206	0	5.97	-23.28
SS9602	150	Merimbula	7	36.86	150.32	206	20	6.25	-23.2
SS9602	92	Disaster Bay	5	37.32	150.01	49	0	6.33	-22.86
SS9602	103	Disaster Bay	5	37.42	150.29	200	0	6.11	-21.83
SS9602	103	Disaster Bay	5	37.42	150.29	200	25	6.17	-21.71
SS9602	79	Gabo	4	37.58	149.87	36	0	5.34	-21.48
SS9602	79	Gabo	4	37.58	149.87	36	25	5.95	-20.63
SS9602	68	Gabo	4	37.95	150.03	200	0	4.91	-21.7
SS9602	68	Gabo	4	37.95	150.03	200	25	5.87	-21.84
SS9602	56	Pt Hicks	3	37.82	149.11	36	0	4.51	-19.86
SS9602	56	Pt Hicks	3	37.82	149.11	36	25	6.37	-21.75
SS9602	44	Pt Hicks	3	38.18	149.29	191	0	4.35	-21.41
SS9602	44	Pt Hicks	3	38.18	149.29	191	25	3.99	-20.9
SS9602	25	Lakes Entranc	2	37.92	148.26	42	0	5.75	-18.78
SS9602	25	Lakes Entranc	2	37.92	148.26	42	25	5.76	-19.19
SS9602	8	Lakes Entranc	2	38.55	148.41	191	0	4.37	-20.45
SS9602	8	Lakes Entranc	2	38.55	148.41	191	40	5.29	-19.61
SS9602	18	Wilsons Prom	1	38.99	146.52	40	0	5.46	-20.19
SS9602	18	Wilsons Prom	1	38.99	146.52	40	20	5.49	-18.96
SS9602	41	Wilsons Prom	1	38.92	148.47	205	0	4.01	-21.92
SS9602	41	Wilsons Prom	1	38.92	148.47	205	25	3.19	-21.46

Appendix Table 6.2.1.5 Stable isotope results for particulate organic matter (POM) in water column samples collected on the south east Australian shelf.

Survey	**Stn**	**Transect**	**Tr #**	**Lat**	**Long**	**Btm depth**	**Sample depth**	**$\delta^{15}N$**	**$\delta^{13}C$**
SS9606	109	Bermagui	7	36.36	150.15	40	0	6.36	-24.77
SS9606	109	Bermagui	7	36.36	150.15	40		5.93	-23.68
SS9606	118	Bermagui	7	36.48	150.30	240	0	6.51	-22.82
SS9606	118	Bermagui	7	36.48	150.30	240		8.44	-23.22
SS9606	141	Merimbula	6	36.95	149.98	50	0	5.89	-23.16
SS9606	141	Merimbula	6	36.95	149.98	50	25	5.46	-22.73
SS9606	151	Merimbula	6	36.84	150.31	147	0	5.29	-23.22
SS9606	151	Merimbula	6	36.84	150.31	147		6.3	-22.45
SS9606	104	Disaster Bay	5	37.32	150.00	40	0	5.67	-23.31
SS9606	104	Disaster Bay	5	37.32	150.00	40		5.8	-20.4
SS9606	128	Disaster Bay	5	37.44	150.27	156	0	7.02	-23.9
SS9606	128	Disaster Bay	5	37.44	150.27	156		7.19	-22.79
SS9606	87	Gabo	4	37.60	149.87	58	0	5.96	-22.7
SS9606	87	Gabo	4	37.60	149.87	58		6.49	-22.23
SS9606	78	Gabo	4	37.91	150.04	218	0	6.99	-23.6
SS9606	78	Gabo	4	37.91	150.04	218		6.95	-23.31
SS9606	65	Pt Hicks	3	37.82	149.08	40	0	5.47	-23.81
SS9606	65	Pt Hicks	3	37.82	149.08	40		6.32	-22.03
SS9606	52	Pt Hicks	3	38.20	149.31	280	0	7.14	-24.28
SS9606	52	Pt Hicks	3	38.20	149.31	280		6.69	-25.16
SS9606	35	Lakes Entranc	2	37.91	148.26	41	0	5.66	-17.42
SS9606	35	Lakes Entranc	2	37.91	148.26	41	40	5.75	-15.99
SS9606	27	Lakes Entranc	2	38.55	148.43	251	0	6.11	-23.12
SS9606	27	Lakes Entranc	2	38.55	148.43	251	25	4.74	-22.9
SS9606	11	Wilsons Prom	1	39.00	146.60	40	0	6.72	-20.17
SS9606	11	Wilsons Prom	1	39.00	146.60	40		6.22	-19.29

Appendix Table 7.2.3.1 Sediment characteristics

Transect	Survey	Stn No	Methoc colln	Tr#	Nomina Depth	Av. depth (m)	Lat	Long	mean ϕ grainsize	% Org	Chl *a* (ug/g)	Pbide c (ug/g)	Other Pbide	Total Pbide	Pbide : Chl	% CO3	δ13C	δ15N
Bermagui	9405	167	sled	G1	25	26	36.37	150.11	0.98	0.42	0.64	7.88	0	7.88	12.37	10.21	-21.92	6.79
	9405	168	sled	G1	25	27	36.36	150.12			0.42	5.59	0	5.59	13.24	12.91	-22.54	6.92
	9405	169	sled	G2	40	39	36.38	150.11	0.96	0.46	0.38	6.44	0	6.44	16.77	10.81	-24.47	6.52
	9405	158	sled	G2	40	42.5	36.38	150.13	0.77	0.47	0.71	7.43	0	7.43	10.40	11.83	-22.75	6.57
	9405	156A	sled	G3	80	77.5	36.39	150.18	1.27	1.50	0.10	12.98	0	12.98	129.82	35.89	-22.70	6.79
	9405	156B	sled	G3	80	77.5	36.39	150.18			0.08	9.50	0	9.50	120.23			
	9405	155A	sled	G4	120	120.5	36.43	150.24	0.84	1.84	0.23	9.71	0	9.71	41.67	45.11	-21.25	6.32
	9405	155B	sled	G4	120	120.5	36.43	150.24			0.12	10.35	0	10.35	87.72			
	9405	148	sled	G5	200	220	36.42	150.31	1.01	2.79	0.00	0.00	0	0.00		86.63	-21.03	7.56
	9405	170	sled	cross-shelf		65.5	36.38	150.14	0.49	0.44	0.09	3.47	0	3.47	37.73	5.95	-22.84	6.98
	9405	171A	sled	transects		103.5	36.38	150.19			0.07	11.62	3.12	14.74	201.90	33.42	-22.22	6.99
	9405	171B	sled			103.5	36.38	150.19			0.11	13.14	3.74	16.88	156.31			
	9405	172	sled			200	36.38	150.25			0.00	0.00	0	0.00		73.37	-20.35	8.38
Merimbula	9405	134	sled	F2	40	44	36.93	149.97	1.93	1.78	0.37	24.88	6.89	31.77	85.41	42.34	-21.31	7.49
	9405	129A	sled	F3	80	75	37	150.05	2.01	1.88	0.17	4.41	0	4.41	26.55	44.14	-23.82	6.45
	9405	129B	sled	F3	80	75	37	150.05			0.15	5.14	0	5.14	34.48			
	9405	140A	sled	F4	120	116	36.93	150.2	1.56	2.68	0.00	0.00	0	0.00		70.30	-21.74	7.39
	9405	140B	sled	F4	120	116	36.93	150.2	1.65	2.50	0.00	0.00	0	0.00		70.55	-21.04	7.27
Disaster Bay	9405	127	sled	E1	25	27	37.32	149.99	0.67	0.27	0.15	3.12	0	3.12	20.96	1.91	-23.39	5.54
	9405	123A	sled	E2	40	43	37.31	150.01	0.72	0.43	0.77	4.42	0	4.42	5.74	5.45	-23.02	6.49
	9405	123B	sled	E2	40	43	37.31	150.01			0.73	4.07	0	4.07	5.61			
	9405	119	sled	E3	80	81.5	37.31	150.07	3.08	3.17	0.39	6.18	16.71	22.89	58.54	47.00	-21.63	6.13
	9405	116	sled	E4	120	108.5	37.32	150.19	0.98	2.02	0.16	3.71	3.23	6.94	43.67	56.19	-21.29	7.14
	9405	107	sled	E5	200	172.5	37.4	150.3	1.05	2.49	0.55	6.29	0	6.29	11.47	85.16	-20.58	7.94
Gabo	9405	95	sled	D1	25	28.5	37.59	149.81	0.38	0.22	0.23	3.33	0	3.33	14.75	2.74	-22.36	6.68
	9405	96	sled	D2	40	40.5	37.6	149.84	-0.03	0.31	0.12	2.58	0	2.58	20.81	3.33	-23.15	5.79
	9405	86	sled	D3	80	80.5	37.66	149.79	1.92	1.24	0.45	8.45	9.31	17.76	39.54	28.41	-21.71	6.11
	9405	98	sled	D4	120	130.5	37.85	149.85	2.62	2.92	0.43	10.85	11.5	22.35	51.73	66.59	-21.91	6.69
	9405	105	sled	D5	200	210	37.92	150.04	0.62	2.18	0.00	0.00	0	0.00		94.89	-20.64	8.79
Gabo Reef	9405	195A	sled	habitat sites			37.71	149.95			0.16	38.04	26.37	64.41	402.56	55.92	-21.59	6.67
	9405	195B	sled				37.71	149.95			0.37	28.13	37.96	66.09	180.08			
	9405	194	sled				37.74	150.07			0.41	9.48	7.51	16.99	41.94	66.57	-21.38	7.30
Pt Hicks	9405	73A	sled	C1	25	28.5	37.81	149.05	0.16	0.35	0.10	0.00	0	0.00	0.00	9.28	-22.97	7.18
	9405	73B	sled	C1	25	28.5	37.81				0.20	0.00	0	0.00	0.00			
	9405	73C	sled	C1	25	28.5	37.81				0.13	0.00	0	0.00	0.00			

Appendix Table 7.2.3.1 Sediment characteristics

Transect	Survey	Stn No	Methoc colln	Tr#	Nomina Depth	Av. depth (m)	Lat	Long	mean φ grainsize	% Org	Chl a (ug/g)	Pbide c (ug/g)	Other Pbide	Total Pbide	Pbide : Chl	% CO3	δ13C	δ15N
	9405	74	sled	C2	40	42	37.82	149.1	0.48	0.49	0.19	3.54	0	3.54	18.61	17.03	-22.77	7.23
	9405	64	sled	C3	80	76.5	37.88	149.09	0.95	0.95	0.13	0.00	0	0.00	0.00	23.03	-21.68	7.34
	9405	76	sled	C4	120	119.5	38.03	149.22	2.72	2.92	0.10	0.00	5.33	5.33	54.39	78.32	-21.31	7.23
	9405	83	sled	C5	200	215	38.2	149.05	0.69	2.27	0.00	0.00	0	0.00		94.65	-20.95	8.26
Lakes Entrance	9405	34	sled	B1	25	30.5	37.87	148.18	0.35	0.62	0.25	3.64	0	3.64	14.32	8.68	-22.65	5.13
	9405	41	sled	B2	40	41	37.93	148.25	0.35	1.50	0.56	11.32	0	11.32	20.36	30.53	-22.09	6.27
	9405	43	sled	B3	80	84.5	38.73	148.26	1.72	1.55	0.00	0.00	0	0.00		53.70	-21.60	8.08
	9405	53	sled	B4	120	118.5	38.64	148.35	1.83	2.06	0.13	0.00	0	0.00	0.00	78.08	-20.79	7.86
	9405	54	sled	B5	200	180	38.98	148.46	0.79	1.84	0.10	0.00	0	0.00	0.00	70.44	-21.71	7.70
	9405	52	sled	B5	200	185	38.56	148.41	0.98	1.93	0.00	0.00	0	0.00		79.61	-21.69	8.40
	9405																	
Wilsons Prom	9405	32	sled	A1	25	24	38.97	146.56	2.79	2.49	0.84	14.80	19.32	34.12	40.71	55.22	-21.81	5.69
	9405	31A	sled	A2	40	42	39	146.6	2.96	3.43	0.56	9.12	0	9.12	16.23	69.35	-21.78	5.91
	9405	31B	sled	A2	40	42	39	146.6			0.46	6.49	0	6.49	14.23			
	9405	59	sled	A3	80	82.5	38.94	148.32	1.70	2.58	0.22	0.00	6.99	6.99	31.77	75.90	-20.92	6.87
	9405	60	sled	A4	120	125	38.99	148.53	2.05	2.88	0.20	0.00	6.44	6.44	32.36	77.19	-21.09	6.83
Bermagui	9602	133	Grab	G1	25	27	36.38	150.11	0.79	0.70	0.85	6.9	0	6.9	8.12			
	9602	125	Grab	G2	40	40	36.36	150.15	0.08	0.40	0.19	2.75	0	2.75	14.47			
	9602	130	Grab	G3	80	79	36.42	150.17	1.48	1.61	0	0	0.28	0.28				
	9602	120	Grab	G4	120	118	36.43	150.24	1.09	1.99	0	0	0.31	0.31				
	9602	116	Grab	G5	200	167	36.53	150.29	0.47	2.82	0	0	0	0				
Merimbula	9602	145	Grab	F1	25	34	36.93	149.95	0.58	0.76	0.13	1.6	3.4	5	38.46	5.82	-22.46	6.80
	9602	141	Grab	F2	40	43	36.92	149.97	2.60	1.80	0	0	1.07	1.07				
	9602	148	Grab	F3	80	73	36.93	150.07	1.88	1.91	0	0	0	0		54.08	-20.96	7.01
	9602	157	Grab	F4	120	110	36.98	150.2	1.34	2.84	0	0	0.88	0.88		53.61	-18.88	6.89
	9602	151	Grab	F5	200	190	36.85	150.31	0.98	2.52	0	0	1.43	1.43				
Disaster Bay	9602	93	Grab	E2	40	48	37.32	150.01	0.61	0.74	0.09	0	0	0	0.00	17.25	-21.44	7.03
	9602	90	Grab	E3	80	72	37.28	150.07	1.03	0.99	0	0	1.99	1.99		29.87	-21.27	8.24
	9602	109	Grab	E4	120	107	37.31	150.19	1.15	1.65	0	0	1.74	1.74				
	9602	104	Grab	E5	200	185	37.41	150.3	0.53	2.35	0	0	0.46	0.46				
Gabo	9602	86	Grab	D1	25	30	37.6	149.81	-0.23	0.24	0.11	1.36	2.02	3.38	30.73	1.24	-21.43	6.55
	9602	98	Grab	D1	25	30	37.3	149.99	0.36	0.37	0.23	0	2	2	8.70			
	9602	80	Grab	D2	40	36	37.58	149.87	0.37	0.37	0.22	3.14	0	3.14	14.27	4.81	-21.89	7.49
	9602	99	Sled	D2	40	53	37.3	150.03	3.62	1.25	0.1	4.02	4.25	8.27	82.70			
	9602	77	Grab	D3	80	90	37.61	149.52	1.89	1.43	0	0	0	0				
	9602	74	Grab	D4	120		37.83	149.88	3.61	3.19	0	0	1.67	1.67				
	9602	69	Grab	D5	200	219	37.96	150.03		2.46	0	0	0	0		97.09	-19.22	8.94

Appendix Table 7.2.3.1 Sediment characteristics

Transect	Survey	Stn No	Methoc colln	Tr#	Nomina Depth	Av. depth (m)	Lat	Long	mean ϕ grainsize	% Org	Chl *a* (ug/g)	Pbide c (ug/g)	Other Pbide	Total Pbide	Pbide : Chl	% CO3	δ13C	δ15N
Point Hicks	9602	62	Grab	C1	25	28	37.81	149.02	-0.04	0.49	0.11	1.39	0	1.39	12.64	10.29	-22.46	7.23
	9602	57	Grab	C2	40	36	37.82	149.11	0.37	0.60	0.13	1.76	0.83	2.59	19.92	17.01	-23.19	7.41
	9602	53	Grab	C3	80	80	37.91	149.04	0.69	0.85	0	0	0	0		27.86	-28.85	9.08
	9602	49	Grab	C4	120	113	38.03	149.12	3.53	2.79	0	0	1.3	1.3				
	9602	45	Grab	C5	200	205	38.17	149.3	2.12	2.58	0	0	0	0				
Lakes Entrance	9602	24	Grab	B2	40	30	37.87	148.2	-0.04	0.83	0.32	1.68	0	1.68	5.25	27.85	-20.86	
	9602	26	Grab	B2	40	42	37.92	148.26	1.37	1.69	0.35	2.15	2.3	4.45	12.71	28.5	-21.52	7.60
	9602	12	Grab	B4	120	115	38.6	148.37	1.66	1.99	0	0	0.26	0.26				
	9602	7	Grab	B5	200	215	38.53	148.41	0.71	1.73	0	0	0.29	0.29				
Wilsons Prom	9602	15	Grab	A1	25	22	38.97	146.55	3.02	2.01	0.49	4.78	1.84	6.62	13.51			
	9602	20	Grab	A2	40	41	39	146.59	3.13	3.14	0	0	0	0				
	9602	34/33	Grab	A3	80	137	38.95	148.32	2.05	2.56	0	0	0	0				
	9602	36/37	Grab	A4	120	125	38.99	148.52	2.76	2.59	0	0	3.17	3.17				
	9602	40	Grab	A5	200	203	38.92	148.48	0.72	2.26	0	0	0	0				
Area 1 50m Pos	9602	159	Sled	Habitat	25	51	37.42	149.99	3.31	2.73	0.19	2.82	4	6.82	35.89	43.61	-22.07	6.72
Area 1 80m 'har	9602	176	Sled	sites	25	84	37.39	150.06	3.22	2.25	0.34	2.46	4.14	6.6	19.41	39.55	-19.83	6.22
Area 1 Pos 2	9602	164	Sled	(DB)	40	59.5	37.46	150.01	2.76	2.34	0.14	2.77	2.69	5.46	39.00	37.56	-21.81	6.88
Area 2 'soft'	9602	178	Sled		40	82	37.34	150.07	3.67	3.18	0	1.65	5.43	7.08		41.76		6.55
Area 2 80m 'rou	9602	185	Sled		80	92	37.35	150.1	1.29	1.40	0	0	0.75	0.75		38.08		8.08
Area 4 36m 'sof	9602	199	Sled	Gabo	40	36	37.58	149.87	0.45	0.30	0.11	1.53	0	1.53	13.91	5.98	-25.69	8.45
Area 4 'rough'	9602	205	Sled	Gabo	80	48.3	37.6	149.86	0.06	0.79	0	0	0	0		5.45	-24.63	7.37
	9602	4								3.24								
Bermagui	9606	113	Sled	G1	25	28	36.37	150.12	-0.18	0.47	0.37	3.79	0	3.79	10.24	6.84	-22.85	5.01
	9606	112	Sled	G2	40	42	36.37	150.15	0.32	0.61	0.21	0	0	0	0.00	6.94	-22.74	7.26
	9606	114	Sled	G3	80	81	36.36	150.16	1.70	2.39	0.09	2.51	2.38	4.89	54.33	40.49	-22.11	6.46
	9606	120	Sled	G4	120	120	36.46	150.22	1.26	3.00	0	4.41	2.47	6.88		58.6	-20.54	7.73
	9606	124	Sled	G5	200	220	36.47	150.3	0.26	3.23	0	1.42	0	1.42		49.42	-20.85	7.82
Merimbula	9606	147	Sled	F2	40	44	36.9	149.96	0.32	1.42	0.15	2.49	0	2.49	16.60	21.48	-23.22	6.63
	9606	146	Sled	F3	80	74	36.99	150.05	0.09	2.63	0.15	4.09	2.58	6.67	44.47	48.13	-21.61	6.63
	9606	156	Sled	F4	120	120	36.92	150.22	-0.18	3.48	0	0	0	0		79.32	-20.67	7.58
Disaster Bay	9606	98	Sled	E1	25	29	37.28	149.99	0.32	0.52	0.24	3.4	0	3.4	14.17	4.82	-23.74	6
	9606	101	Sled	E2	40	45	37.3	150.01	0.74	1.54	0.42	5.83	0	5.83	13.88	19.6	-21.39	7.07
	9606	130	Sled	E3	80	79	37.29	150.07	0.09	2.69	0.11	3.87	4.89	8.76	79.64	35.6	-21.90	7.08
	9606	132	Sled	E4	120	112	37.34	150.21	-1.02	2.73	0	2.02	0	2.02		48.81	-21.16	7.62
	9606	135	Sled	E5	200	156	37.42	150.28	0.32	3.82	0	0	0	0		39.79	-20.82	7.88

Appendix Table 7.2.3.1 Sediment characteristics

Transect	Survey	Stn No	Methoc colln	Tr#	Nomina Depth	Av. depth (m)	Lat	Long	mean ϕ grainsize	% Org	Chl *a* (ug/g)	Pbide c (ug/g)	Other Pbide	Total Pbide	Pbide : Chl	% CO3	δ13C	δ15N
Gabo	9606	91	Sled	D1	25	34	37.57	149.88	0.08	0.39	0.21	2.53	0	2.53	12.05	4.06	-27.86	5.49
	9606	89	Sled	D2	40	45	37.59	149.89	0.01	0.37	0	0	0	0		3.65	-23.81	5.91
	9606	82	Sled	D3	80	79	37.6	149.9	0.12	2.32	0.14	3.05	0	3.05	21.79	32.15	-22.86	7.09
	9606	79	Sled	D4	120	130	37.81	149.9	0.81	3.38	0	2.69	0	2.69		41.69	-21.78	7.13
	9606	75	Sled	D5	200	209	37.9	150.04	0.09	1.16	0	0	0.43	0.43		43.36	-22.92	8.45
Point Hicks	9606	60	Sled	C1	25	26	37.81	149.01	-0.16	0.50	0.16	2.14	0	2.14	13.38	11.11	-25.42	6.35
	9606	66	Sled	C2	40	39	37.82	149.09	0.24	1.01	0.21	1.75	0	1.75	8.33	18.45	-21.56	4.99
	9606	67	Sled	C3	80	75	37.9	149.07	0.13	2.34	0.07	2.37	0	2.37	33.86	40.27	-20.69	7.91
	9606	57	Sled	C4	120	114	38.06	149.16	0.72	4.31	0	1.55	1.31	2.86		30.94	-21.27	7.20
	9606	56	Sled	C5	200	227	38.2	149.27	0.34	3.35	0	0	0	0		52.9	-20.97	7.89
Lakes Entrance	9606	40	Sled	B1	25	28	37.9	148.24	-0.54	1.38	0.81	6.48	0	6.48	8.00	20.61	-25.59	5.70
	9606	44	Sled	B2	40	41	37.91	148.28	1.54	5.30	0.81	14.53	17.41	31.94	39.43	36.94	-21.95	6.64
	9606	32	Sled	B3	80	82	38.7	148.29	0.41	2.78	0	1.93	0.7	2.63		38.61	-20.80	7.67
	9606	31	Sled	B4	120	114	38.63	148.35	1.33	2.68	0.07	2.7	4.08	6.78	96.86	47.28	-20.17	7.15
	9606	30	Sled	B5	200	230	38.54	148.43	-0.53	2.57	0	0	0	0		42.26	-20.60	7.58
Wilsons Prom	9606	18	Sled	A1	25	25	38.97	146.57	1.58	4.71	0.28	4.95	0	4.95	17.68	46.07	-21.07	6.28
	9606	19	Sled	A2	40	41	38.99	146.61	2.04	2.24	0	0	0	0		43.91	-21.97	6.29
	9606	7	Sled	A3	80	88	38.93	148.32	1.12	3.30	0.05	1.64	1.81	3.45	69.00	45.09	-20.74	7.29
	9606	4	Sled	A4	120	121	38.99	148.51	1.62	4.33	0	1.26	0	1.26			-20.78	6.94
Area 6 pos 3	9606	212	Sled	Habitat sites:		109	37.75	150.01	0.47	3.31	0	0	0	0		40.78	-21.18	7.59
Area 6 pos 2	9606	193	Sled	Gabo		131	37.71	150.06	-0.20	3.43	0	0	0	0		41.03	-19.30	8.52
Area 6 off, pos 1	9606	171	Sled			138	37.72	150.11	0.07	3.33	0	0	0	0		38.79	-19.65	8.40
Area 7 pos 1	9606	202	Sled	Habitat sites:		149	38.13	149.29	0.47	4.39	0	0.81	0	0.81		43.71	-20.75	7.38
Area 7 pos 2	9606	201	Sled	Point Hicks		153	37.32	150.22	1.48	4.11	0	1.04	0.26	1.3		34.66	-20.69	7.83
Area 7 pos 4	9606	203	Sled			184	38.14	149.53	-0.25	4.13	0	0	0	0		45.56	-20.99	8.37
Area 8 pos 1	9606	227	Sled	Habitat sites:		111	38	149.09	1.62	3.82	0	2.06	1.03	3.09		39.26		7.52
Area 8 pos 1/2	9606	222	Sled	Point Hicks		112	37.97	149.27	0.08	3.76	0	1.93	0.51	2.44		40.91	-22.15	7.72
	9606	188	Sled	GC		124	37.31	150.28	0.43	2.96	0	0	0	0		38.35		8.11

% Org = % organic matter
Chl *a* = Chlorophyll *a*
Pbide = Phaeophorbide

Table 10.2.1.1. Diet of *Cephaloscyllium laticeps* draughtboard shark by survey.

Prey (% wet wt)	EJ9601	SS9305	SS9402	SS9405	SS9602	SS9606
Sediment	-	-	-	-	-	0.45
Sipunculida	-	3.30	-	-	-	0.58
Ectoprocta	-	0.33	-	-	-	-
Unid. crustacea	-	18.82	0.85	0.01	6.14	0.03
Reptantia	0.07	26.55	-	2.24	-	16.18
Stomatopoda	-	-	-	-	-	0.08
Mollusca	-	0.33	-	-	-	-
Bivalvia	-	-	-	0.01	-	0.08
Cephalopoda	7.02	41.87	-	32.75	16.42	13.85
Gastropoda	0.25	8.18	-	-	-	13.46
Pisces	92.67	0.61	99.15	64.99	77.44	55.28

Table 10.2.1.2. Diets of *Mustelus antarcticus* gummy shark and *Galeorhinus galeus* school shark by survey.

	M. antarcticus		*G. galeus*	
Prey (% wet wt)	EJ9601	SS9405	EJ9601	SS9602
Echinodermata	-	0.14	-	-
Unid. crustacea	-	44.18	-	-
Reptantia	25.22	53.84	-	2.49
Stomatopoda	7.26	-	-	-
Ostracoda	0.06	-	-	-
Isopoda	-	-	2.06	0.91
Bivalvia	-	-	1.59	-
Cephalopoda	54.49	-	8.02	-
Pisces	12.97	1.84	88.32	96.59

Table 10.2.1.3. Diet of *Squalus megalops* spikey dogfish by survey.

Prey (% wet wt)	SS9305	SS9405	SS9602	SS9606
Ascidiacea	-	-	-	0.09
Thaliacea	1.12	-	-	0.04
Cnidaria	-	0.01	-	0.01
Ectoprocta	0.02	-	-	-
Porifera	-	-	0.63	-
Sipunculida	0.36	-	-	1.27
Polychaeta	0.77	0.41	0.06	3.72
Unid. crustacea	0.24	1.51	0.30	4.23
Reptantia	1.60	0.62	3.86	1.35
Natantia	0.17	-	0.19	0.07
Euphausiacea	0.01	-	0.03	-
Stomatopoda	-	-	0.58	-
Amphipoda-benthic	0.04	-	-	0.05
Amphipoda-Hyperiidae	-	-	0.01	-
Isopoda	0.34	0.10	-	0.16
Mysidacea	-	-	-	-
Ostracoda	0.09	-	0.04	0.06
Mollusca	1.06	-	-	0.84
Bivalvia	-	-	-	0.01
Cephalopoda	43.03	27.64	40	44.26
Gastropoda	-	-	-	9.54
Polyplacophora	-	-	-	0.03
Pisces	51.14	67.14	54.26	32.08
Unidentified	-	2.56	0.03	2.18

Table 10.2.1.4. Diet of *Squatina australis* Australian angel shark by survey.

Prey (% wet wt)	SS9305	SS9405	SS9602	SS9606
Macrophyta	-	-	0.38	-
Ascidiacea	-	-	0.60	-
Echinodermata	-	-	0.38	-
Polychaeta	-	-	0.25	0.12
Unid. crustacea	-	-	0.41	0.17
Natantia	-	0.12	0.15	-
Stomatopoda	-	-	1.96	-
Amphipoda-benthic	-	-	-	0.01
Isopoda	-	-	-	-
Bivalvia	-	-	-	0.01
Cephalopoda	0.23	2.59	0.23	1.43
Gastropoda	-	-	-	-
Pisces	99.77	97.28	95.64	98.20
Unidentified	-	-	-	0.06

Table 10.2.1.5. Diets of *Raja* sp. A and *Narcine tasmaniensis* Tasmanian numbfish by survey.

	Raja sp. A			*N. tasmaniensis*		
Prey (% wet wt)	SS9405	SS9602	SS9606	SS9305	SS9602	SS9606
Sediment	0.14	-	0.00	-	-	-
Foraminiferida	-	-	0.00	-	-	-
Porifera	-	1.22	0.00	-	-	-
Ectoprocta	-	-	-	0.00	0.00	0.08
Sipuncula	-	-	-	36.82	0.00	2.84
Polychaeta	-	-	0.37	62.21	90.61	93.73
Unid. crustacea	1.24	2.01	7.82	0.00	0.00	0.02
Reptantia	4.55	13.08	13.22	-	-	-
Natantia	0.07	25.84	0.25	0.00	4.99	0.10
Stomatopoda	-	12.92	2.59	0.00	0.88	0.00
Amphipoda	-	-	0.01	0.00	0.00	0.05
Isopoda	-	-	-	0.97	0.00	2.35
Cephalopoda	51.22	1.51	5.47	-	-	-
Pisces	42.78	34.04	69.75	-	-	-
Unidentified	-	9.38	0.51	0.00	3.52	0.81

Table 10.2.1.6. Diet of *Urolophus cruciatus* banded stingaree by survey.

Prey (% wet wt)	SS9305	SS9402	SS9405	SS9602	SS9606
Sediment	-	-	0.43	0.98	0.29
Ascidiacea	-	-	0.07	-	-
Cnidaria	-	-	1.26	-	0.05
Ophiuroidea	-	-	-	-	0.01
Echiura	-	-	-	2.94	5.45
Ectoprocta	-	0.10	0.02	-	-
Sipunculida	7.60	34.52	1.78	15.58	2.61
Nemertea	-	-	-	1.67	2.08
Polychaeta	79.18	19.66	40.24	41.57	55.10
Unid. crustacea	7.85	27.98	2.91	1.68	7.90
Reptantia	-	3.89	-	17.06	2.24
Natantia	0.48	0.20	46.17	1.23	1.27
Stomatopoda	-	0.01	-	-	0.02
Amphipoda-benthic	3.88	0.24	0.98	0.71	1.34
Amphipoda-Hyperiidae	-	-	0.03	-	-
Isopoda	0.05	1.61	0.09	1.55	6.99
Copepoda	0.05	-	-	-	-
Ostracoda	-	-	0.02	0.02	-
Mollusca	0.91	0.16	-	0.59	1.97
Bivalvia	-	5.18	3.15	4.29	0.01
Octopoda	-	-	-	-	0.09
Gastropoda	-	0.06	-	0.98	3.27
Unidentified	-	6.38	2.85	9.16	9.33

Table 10.2.1.7. Diet of *Urolophus paucimaculatus* sparsely-spotted stingaree by survey.

Prey (% wet wt)	SS9305	SS9402	SS9405	SS9602	SS9606
Sediment	-	-	1.08	-	-
Ascidiacea	0.12	-	0.01	-	0.06
Cnidaria	-	-	0.17	-	-
Porifera	-	-	-	-	0.66
Polychaeta	75.51	0.68	17.65	22.62	10.57
Unid. crustacea	5.19	34.07	48.30	20.89	58.81
Reptantia	8.10	53.15	0.87	34.47	5.10
Natantia	-	3.53	9.13	6.27	12.21
Amphipoda-benthic	10.16	0.77	10.45	3.11	4.69
Amphipoda-Hyperiidae	-	0.09	1.71	0.01	-
Cumacea	-	-	0.53	-	-
Isopoda	-	0.60	2.73	1.47	0.17
Mysidacea	-	-	0.44	-	-
Copepoda	0.33	-	0.22	-	-
Ostracoda	0.10	0.03	-	-	0.07
Mollusca	-	-	0.32	0.27	-
Gastropoda	-	-	-	0.38	0.51
Pisces	0.50	0.45	-	0.04	0.23
Unidentified	-	6.62	6.37	10.46	6.93

Table 10.2.1.8. Diet of *Urolophus viridis* greenback stingaree and *Urolophus* sp. A Kapala stingaree by survey.

	U. viridis				*Urolophus* sp. A
Prey (% wet wt)	SS9305	SS9405	SS9602	SS9606	SS9602
Sediment	-	-	-	0.57	-
Hymenostomatia	-	0.04	-	-	-
Cnidaria	-	-	-	0.09	-
Echiura	-	-	2.71	0.57	-
Porifera	-	-	-	0.25	-
Sipunculida	-	0.31	-	-	-
Polychaeta	43.94	20.95	4.24	17.95	0.44
Unid. crustacea	11.84	39.06	41.88	41.45	14.36
Reptantia	-	1.86	1.47	4.47	72.23
Natantia	26.02	17.02	24.46	15.76	5.32
Euphausiacea	10.85	-	-	-	-
Stomatopoda	-	-	0.59	-	-
Amphipoda-benthic	6.75	3.65	11.78	6.91	3.15
Amphipoda-Hyperiidae	-	2.29	0.64	-	-
Cumacea	-	0.24	-	0.06	-
Isopoda	-	10.05	2.70	0.70	0.35
Ostracoda	-	-	0.01	0.05	-
Cephalopoda	0.60	-	-	0.11	-
Gastropoda	-	0.05	-	0.54	0.06
Pisces	-	0.15	5.56	3.06	-
Unidentified	-	4.33	3.96	7.47	4.10

Table 10.2.1.9. Diet of *Chlorophthalmus nigripinnis* cucumberfish by survey.

Prey (% wet wt)	IM9501	IM9601	SS9305	SS9402	SS9405	SS9602	SS9606
Sediment	61.62	2.84	-	-	-	-	5.29
Foraminiferida	-	-	-	-	-	-	0.04
Cnidaria	5.19	78.16	29.41	10.83	0.43	28.54	0.50
Ectoprocta	-	-	-	-	-	-	0.44
Ascidiacea	2.33	-	-	-	46.58	8.52	20.24
Thaliacea	-	-	5.34	2.69	9.90	-	1.98
Polychaeta	-	0.48	0.22	0.08	-	3.98	7.36
Unid. crustacea	9.22	10.25	10.97	5.39	11.01	10.87	1.31
Reptantia	-	1.64	-	1.09	0.38	3.94	0.32
Natantia	-	-	-	0.99	0.92	37.72	3.03
Euphausiacea	-	-	-	4.69	24.61	0.74	51.38
Stomatopoda	-	-	-	0.88	-	0.40	-
Amphipoda	0.89	-	2.34	0.52	0.05	0.61	0.71
Cumacea	-	-	-	-	-	-	0.04
Isopoda	-	-	-	0.63	-	0.64	0.45
Mysidacea	-	-	-	-	-	0.02	-
Copepoda	-	-	0.01	-	-	-	-
Ostracoda	0.86	0.01	0.57	4.45	-	0.16	0.11
Mollusca	-	-	2.96	0.98	-	-	-
Cephalopoda	-	-	0.34	6.19	-	0.63	0.40
Gastropoda	4.19	0.12	-	0.09	-	-	-
Pisces	11.56	2.70	45.09	24.11	3.45	0.26	5.31
Unidentified	4.13	3.80	2.75	36.40	2.66	2.96	1.08

Table 10.2.1.10. Diet of *Genypterus blacodes* pink ling by survey.

Prey (% wet wt)	SS9305	SS9405	SS9602	SS9606
Sediment	-	-	-	0.18
Ascidiacea	12.96	14.50	3.50	4.72
Ectoprocta	-	-	-	0.06
Polychaeta	0.03	-	-	0.08
Unid. crustacea	-	0.69	0.01	0.47
Reptantia	-	-	0.93	1.70
Natantia	1.20	-	0.40	1.62
Stomatopoda	-	-	1.71	-
Amphipoda-benthic	-	-	-	0.07
Isopoda	-	-	-	0.08
Tanaidacea	-	-	-	-
Cephalopoda	7.80	-	11.53	6.23
Pisces	78.01	84.40	81.89	84.71
Unidentified	-	0.41	0.01	0.07

Table 10.2.1.11. Diets of *Caelorinchus australis* southern whiptail, *C. mirus* gargoylefish, *C. fasciatus* banded whiptail and *C. parvifasciatus* small-banded whiptail by survey.

	C. australis			*C. mirus*			*C. fasciatus*	*C. parvifasciatus*
Prey (% wet wt)	SS9405	SS9602	SS9606	SS9305	SS9405	SS9602	SS9405	SS9305
Foraminiferida	-	-	-	0.05	-	-	0.02	-
Ascidiacea	-	-	-	-	0.32	-	-	-
Thaliacea	20.32	-	-	-	-	-	-	-
Cnidaria	-	-	0.05	0.05	-	-	0.28	-
Porifera	-	-	-	-	-	-	-	-
Echinodermata	-	-	0.32	0.11	-	-	13.47	3.01
Ectoprocta	-	-	-	-	0.38	0.33	-	-
Echiura	-	-	-	-	-	-	-	-
Sipunculida	-	-	-	-	-	-	-	2.39
Polychaeta	42.37	1.07	15.90	13.06	-	0.82	32.34	79.90
Unid. crustacea	3.44	6.55	14.24	53.33	51.99	3.50	13.04	7.38
Reptantia	10.02	67.32	-	1.08	25.16	0.38	18.58	-
Natantia	-	11.96	0.46	-	-	7.05	1.48	-
Euphausiacea	-	-	-	-	4.15	0.27	0.55	-
Amphipoda-benthic	-	13.10	27.64	10.70	11.89	1.22	0.99	-
Amphipoda-Hyperiidae	-	-	0.02	-	-	0.04	0.03	-
Isopoda	-	-	3.96	2.52	5.51	0.87	3.63	0.64
Tanaidacea	-	-	-	-	-	0.08	-	-
Copepoda	-	-	-	-	0.07	-	-	0.21
Cumacea	-	-	-	-	-	-	-	-
Ostracoda	-	-	0.03	4.45	0.05	-	-	-
Unid. mollusca	-	-	0.06	-	-	-	-	-
Bivalvia	-	-	-	0.85	-	-	-	-
Cephalopoda	-	-	1.79	0.32	-	-	-	-
Gastropoda	-	-	-	7.96	0.22	-	3.03	1.71
Pisces	23.85	-	35.53	4.14	0.26	70.56	0.05	1.69
Unidentified	-	-	-	1.39	-	14.87	12.52	3.07

Table 10.2.1.12. Diet of *Centroberyx affinis* redfish by survey.

Prey (% wet wt)	EJ9401	IM9501	IM9601	SF9701	SS9305	SS9402	SS9405	SS9602	SS9606
Sediment	-	-	0.03	-	-	-	-	-	-
Polychaeta	-	0.05	-	-	0.11	1.21	-	-	0.13
Cnidaria	-	-	-	0.01	0.12	-	-	-	0.28
Echinodermata	-	-	-	-	-	-	-	-	0.01
Unid. crustacea	74.74	43.64	14.54	5.84	5.79	36.31	14.31	60.56	13.45
Reptantia	-	0.15	1.68	0.36	1.73	1.81	-	0.05	0.62
Natantia	-	19.90	10.53	1.43	0.42	37.34	9.03	0.23	7.62
Euphausiacea	-	2.58	69.33	66.58	-	17.16	-	9.14	7.56
Stomatopoda	-	-	-	-	-	-	-	-	0.05
Amphipoda	22.89	0.76	2.80	0.38	0.67	0.35	6.53	0.13	3.01
Cumacea	-	-	-	0.01	0.01	-	-	0.33	0.02
Isopoda	-	0.16	0.48	0.94	-	-	1.01	0.25	1.29
Ostracoda	-	0.02	0.22	0.04	0.17	0.20	0.44	0.09	1.43
Cephalopoda	-	3.29	0.02	-	-	-	-	0.39	0.89
Gastropoda	-	-	-	-	0.04	-	-	-	-
Pisces	2.37	29.47	0.37	24.36	88.52	3.63	67.87	28.38	63.54
Unidentified	-	-	0.01	0.05	2.42	1.99	0.81	0.46	0.09

Table 10.2.1.13. Diet of *Cyttus australis* silver dory and *Zenopsis nebulosus* mirror dory by survey.

	C. australis					*Z. nebulosus*	
Prey (% wet wt)	SS9305	SS9402	SS9405	SS9602	SS9606	SS9602	SS9606
Sediment	-	-	-	-	0.22	-	-
Ascidiacea	-	-	-	-	0.04	-	-
Hymenostomatia	-	-	0.06	-	-	-	-
Cnidaria	-	-	-	-	0.12	-	-
Ectoprocta	-	-	-	-	0.42	-	-
Unid. crustacea	0.24	0.07	6.60	1.00	1.53	0.01	-
Reptantia	-	-	-	0.29	-	-	-
Natantia	-	0.22	3.39	9.72	1.87	-	-
Euphausiacea	-	2.52	5.46	0.13	1.09	-	-
Stomatopoda	-	-	-	-	0.33	-	-
Copepoda	0.08	-	0.16	-	-	-	-
Unid. mollusca	-	-	-	-	0.01	-	-
Cephalopoda	-	-	-	0.04	-	-	-
Pisces	99.69	97.19	84.23	88.83	94.36	99.98	100
Unidentified	-	-	0.10	-	0.02	-	-

Table 10.2.1.14. Diets of *Zeus faber* John dory and *Cyttus novaezelandiae* New Zealand dory by survey.

	Z. faber					*C. novaezelandiae*		
Prey (% wet wt)	SS9305	SS9402	SS9405	SS9602	SS9606	SS9405	SS9602	SS9606
Sediment	-	-	-	0.03	-	-	-	-
Cnidaria	-	-	-	0.01	-	-	-	-
Ectoprocta	-	-	-	-	-	-	-	-
Polychaeta	-	-	0.01	0.08	-	-	-	
Unid. Crustacea	-	0.04	0.03	-	-	34.58	2.20	-
Reptantia	-	-	-	0.01	-			
Euphausiacea	-	0.12	-	-	-	65.42	97.80	99.96
Amphipoda-Hyperiidae						-	-	0.04
Isopoda	-	-	-	0.03	-	-	-	-
Ostracoda	-	-	0.01	-	-	-	-	-
Mollusca	-	-	-	0.05	-	-	-	-
Bivalvia	-	0.49	-	-	-	-	-	-
Cephalopoda	-	11.59	-	0.16	3.19	-	-	-
Pisces	100	87.77	99.95	99.63	96.81	-	-	-

Table 10.2.1.15. Diet of *Macrorhamphosus scolopax* common snipefish by survey.

Prey (% wet wt)	SS9405	SS9602	SS9606
Sediment	15.56	0.35	2.80
Foraminiferida	0.15	0.06	0.25
Ascidiacea	1.13	1.99	0.48
Ectoprocta	0.26	-	0.01
Cnidaria	-	-	0.27
Echinodermata	-	0.03	-
Polychaeta	-	1.88	6.34
Unid. crustacea	32.46	34.82	67.23
Reptantia	-	0.99	5.38
Pasiphaeidae	-	-	0.03
Amphipoda	15.88	17.00	13.42
Cumacea	-	0.02	0.01
Isopoda	1.16	1.17	1.43
Tanaidacea	-	0.18	0.04
Phyllocarida	-	0.13	-
Copepoda	6.84	4.97	-
Ostracoda	0.10	1.19	0.13
Bivalvia	-	0.22	-
Gastropoda	0.07	7.82	0.18
Pisces	-	0.16	1.13
Unidentified	26.40	27.00	0.86

Table 10.2.1.16. Diet of *Helicolenus percoides* ocean perch by survey.

Prey (% wet wt)	EJ9601	IM9501	IM9601	SF9701	SS9305	SS9402	SS9405	SS9602	SS9606
Sediment	2.52	0.36	0.12	0.34	-	-	-	0.50	0.77
Macrophyta	-	-	-	0.85	-	-	-	-	-
Foraminiferida	-	-	-	-	-	-	-	-	-
Ascidiacea	-	0.16	-	0.53	-	-	1.99	0.07	-
Thaliacea	-	52.30	1.22	35.21	16.28	0.05	79.98	-	0.21
Cnidaria	0.50	0.42	0.02	0.01	0.05	0.15	-	0.09	1.40
Echinodermata	-	-	-	0.06	-	-	-	-	-
Asteroidea	-	-	-	-	-	-	-	0.01	-
Ophiuroidea	20.89	-	-	0.26	3.06	2.23	-	1.23	0.91
Ectoprocta	-	-	-	0.09	-	-	-	-	0.03
Porifera	-	-	-	-	-	-	-	0.01	-
Platyhelminthe	-	-	-	-	-	-	-	-	-
Echiura	-	-	-	-	-	-	-	-	0.01
Sipunculida	-	-	-	-	-	-	-	-	-
Polychaetes	-	-	0.07	1.59	2.87	1.55	0.06	0.60	0.46
Unid. crustacea	11.37	0.64	1.60	0.75	1.69	3.22	0.46	2.84	2.92
Reptantia	1.90	0.58	52.97	18.28	12.40	8.27	1.51	1.04	7.01
Natantia	8.10	0.22	3.67	1.32	1.03	3.98	0.66	2.31	3.04
Scyllaridae	-	-	-	-	-	-	-	-	-
Euphausiacea	-	-	-	0.01	0.26	0.10	-	0.02	0.42
Stomatopoda	-	-	10.59	5.21	-	-	0.19	0.23	8.22
Amphipoda	3.98	-	0.40	0.34	-	0.11	-	0.04	0.48
Isopoda	5.82	-	0.13	13.50	12.33	1.31	0.09	0.23	1.58
Copepoda	-	-	-	-	-	-	-	-	-
Ostracoda	0.65	-	-	0.12	-	0.10	0.02	0.01	-
Brachiopoda	-	-	-	0.31	-	-	-	-	0.04
Mollusca	-	-	-	1.07	0.55	-	0.43	6.64	-
Bivalvia	2.99	-	-	-	1.93	-	-	0.12	0.01
Cephalopoda	28.95	-	-	-	-	-	-	4.80	13.12
Gastropoda	-	-	-	0.03	0.01	-	-	0.22	0.04
Pisces	12.19	45.27	29.20	19.99	41.28	77.89	14.35	78.49	58.87
Unidentified	0.14	0.05	-	0.13	6.26	1.02	0.25	0.50	0.48

Table 10.2.1.17. Diets of *Helicolenus barathri* deep ocean perch and *Neosebastes scorpaenoides* ruddy gurnard perch by survey.

	H. barathri				*N. scorpaenoides*	
Prey (% wet wt)	SS9305	SS9402	SS9602	SS9606	SS9405	SS9602
Sediment	0.33	-	-	-	-	-
Foraminiferida	0.01	-	-	-	-	-
Thaliacea	-	19.38	-	-	-	-
Echiura	-	-	-	-	-	9.51
Echinodermata	5.57	-	-	4.58	-	-
Ectoprocta	0.13	4.53	-	-	-	-
Polychaeta	2.59	0.72	7.72	2.66	-	-
Unid. crustacea	1.77	0.36	0.91	7.21	-	-
Reptantia	-	-	10.66	1.26	5.60	12.42
Euphausiacea	-	-	0.02	14.21	-	-
Stomatopoda	0.57	-	-	3.81	-	-
Amphipoda-benthic	1.50	-	0.10	0.94	-	-
Amphipoda-Hyperiidae	0.40	-	-	-	-	-
Isopoda	-	7.97	1.33	41.97	21.59	0.29
Ostracoda	-	-	0.40	-	-	-
Unid. mollusca	0.55	-	-	-	-	-
Bivalvia	-	-	-	0.18	6.02	0.50
Cephalopoda	-	-	-	12.73	1.34	36.62
Gastropoda	0.31	-	-	0.16	56.73	-
Pisces	86.29	66.11	78.38	10.26	8.71	40.65
Unidentified	-	0.92	0.48	0.04	-	-

Table 10.2.1.18. Diets of *Chelidonicthys kumu* red gurnard and *Pterygotrigla polyommata* latchet by survey.

	C. kumu		*P. polyommata*	
Prey (% wet wt)	SS9305	SS9602	EJ9401	SS9305
Sediment	25.15	-	-	-
Ascidiacea	-	-	-	-
Polychaeta	-	0.06	-	-
Reptantia	1.69	0.59	-	-
Natantia	-	0.37	-	-
Unid. crustacea	-	-	-	0.04
Bivalvia	8.50	0.40	-	-
Cephalopoda	9.89	-	-	29.48
Gastropoda	0.35	0.65	-	-
Pisces	54.42	97.75	100	70.48
Unidentified	-	0.18	-	-

Table 10.2.2.19. Diets of *Lepidotrigla vanessa* butterfly gurnard, *L. modesta* minor gurnard and *L. mulhalli* deepwater gurnard by survey.

	L. vanessa	*L. modesta*					*L. mulhalli*				
Prey (% wet wt)	SS9602	SS9305	SS9402	SS9405	SS9602	SS9606	SS9305	SS9402	SS9405	SS9602	SS9606
Sediment	-	0.29	2.48	-	-	-	-	-	-	-	-
Ascidiacea	0.01	-	1.07	-	-	-	-	-	0.01	-	-
Cnidaria							-	-	-	-	0.35
Polychaeta	-	2.08	21.59	0.70	0.03	1.11	0.48	0.96	1.36	0.12	0.05
Cumacea	0.07	-	0.04	-	-	0.05	-	-	3.91	0.60	-
Ectoprocta	-	-	0.16	-	-	-	-	0.24	0.02	-	-
Euphausiacea	-	0.24	-	-	0.41	2.90	-	-	16.53	0.81	36.40
Isopoda	-	-	1.74	2.48	0.15	4.06	13.84	1.02	2.45	4.34	1.02
Tanaidacea	-	-	-	0.09	-	-	-	-	3.15	0.14	-
Phyllocarida	-	-	-	-	0.15	-					
Ostracoda	-	0.93	4.20	0.93	-	1.64	2.32	1.40	3.05	1.84	1.21
Brachiopoda							-	-	0.09	-	-
Mysidacea	0.50	-	-	-	-	-	0.58	-	-	-	-
Copepoda	-	-	-	-	-	-					
Amphipoda-benthic	0.09	2.48	8.33	12.73	0.77	11.37	10.61	8.79	26.75	4.33	7.92
Amphipoda-Hyperiidae	-	-	-	-	-	0.21	-	2.49	-	2.46	0.04
Reptantia	12.14	93.71	14.36	13.72	5.92	6.79	54.69	21.93	2.21	6.23	0.17
Natantia	2.08	0.26	14.90	49.66	76.17	43.46	0.98	1.02	5.07	61.04	13.72
Unid. crustacea	0.67	-	31.13	11.81	16.40	20.81	12.26	36.70	32.88	16.63	38.87
Bivalvia	-	-	-	-	-	-	0.16	-	-	-	-
Cephalopoda	0.02	-	-	-	-	-					
Gastropoda	0.30	-	-	-	-	0.82	0.05	-	1.59	-	-
Unid. mollusca							1.56	-	-	0.49	-
Pisces	83.93	-	-	7.87	-	6.77	-	22.28	-	0.97	-
Unidentified	0.19	-	-	-	-	0.02	2.47	3.17	0.92	-	0.26

Table 10.2.1.20. Diet of *Neoplatycephalus richardsoni* tiger flathead by survey.

Prey (% wet wt)	IM9501	IM9601	SS9305	SS9402	SS9405	SS9503	SS9602	SS9606
Sediment	0.10	-	-	-	-	-	-	0.01
Porifera	-	-	-	-	-	-	0.04	-
Ascidiacea	0.06	0.01	-	-	-	-	0.04	0.09
Cnidaria	-	0.01	-	-	-	-	-	-
Polychaeta	0.07	-	-	-	-	-	-	-
Unid. crustacea	2.76	3.39	8.69	1.78	0.18	8.69	0.19	2.62
Reptantia	-	-	-	-	-	-	-	0.20
Natantia	10.83	0.02	0.48	-	-	0.48	0.22	0.59
Euphausiacea	-	-	-	-	0.10	-	0.02	0.22
Stomatopoda	-	-	-	-	3.14	-	-	-
Gammaridae	-	-	-	-	-	-	0.01	-
Isopoda	-	-	-	-	-	-	2.01	0.10
Cephalopoda	-	-	-	-	0.01	-	0.34	0.02
Gastropoda	-	-	-	1.71	-	-	-	-
Pisces	86.18	96.57	90.83	96.51	96.56	90.83	97.14	96.16

Table 10.2.1.21. Diet of *Platycephalus bassensis* sand flathead by survey.

Prey (% wet wt)	SS9305	SS9405	SS9503
Polychaeta	-	7.17	-
Echiura	-	10.73	-
Ascidiacea	-	0.07	-
Thaliacea	8.61	-	5.03
Hydrozoa	-	-	-
Reptantia	1.06	0.10	0.62
Mollusca	0.09	-	0.05
Bivalvia	0.33	-	0.39
Gastropoda	0.71	-	0.41
Pisces	89.20	81.94	93.49

Table 10.2.1.22. Diets of *Lepidoperca pulchella* eastern orange perch and *Apogonops anomalus* threespine cardinal fish by survey.

	L. pulchella			*A. anomalus*			
Prey (% wet wt)	EJ9601	SF9601	SF9701	SS9305	SS9405	SS9602	SS9606
Sediment	-	-	-	-	-	-	0.13
Ascidiacea	-	-	-	-	0.79	-	-
Polychaeta	-	-	-	0.07	-	-	-
Cnidaria	0.03	0.30	1.97	-	-	-	-
Unid. crustacea	0.06	0.01	80.33	1.04	25.87	8.89	2.87
Euphausiacea	-	-	-	-	66.67	15.63	18.56
Mysidacea	-	-	-	-	0.09	-	-
Natantia	-	-	0.50	0.99	6.04	-	0.86
Copepoda	-	-	-	0.01	0.54	0.61	0.01
Mollusca	-	8.00	-	-	-	-	-
Pisces	99.91	91.69	16.32	97.88	-	-	77.57
Unidentified	-	-	0.87	-	-	74.87	-

Table 10.2.1.23. Diets of *Caesioperca lepidoptera* butterfly perch and *C. rasor* barber perch by survey.

	C. lepidoptera					*C. rasor*	
Prey (% wet wt)	EJ9601	SF9601	SF9701	SS9405	SS9602	SF9601	SS9602
Cnidaria	1.12	-	8.01	-	-	-	3.71
Ascidiacea	0.50	-	45.79	-	62.71	-	12.00
Thaliacea	80.07	-	-	-	-	-	18.53
Porifera	-	-	-	-	-	-	2.52
Polychaeta	-	-	-	-	0.46	-	-
Unid. crustacea	0.47	0.04	28.06	0.01	26.03	-	5.42
Reptantia	-	-	1.30	-	0.75	-	-
Natantia	0.88	-	-	-	-	-	-
Euphausiacea	0.32	-	-	-	-	-	0.94
Amphipoda	-	-	0.81	0.08	1.65	-	11.41
Cumacea	-	-	-	-	0.07	-	-
Isopoda	-	-	0.31	0.02	-	-	-
Mysidacea	-	-	-	-	0.38	-	-
Copepoda	4.43	-	-	0.04	7.93	-	16.28
Ostracoda	-	-	-	-	-	0.02	0.10
Gastropoda	-	-	-	-	-	-	13.34
Pisces	0.49	-	-	0.01	0.01	99.98	2.47
Unidentified	11.73	99.96	15.72	99.85	-	-	13.28

Table 10.2.1.24. Diet of *Sillago flindersi* eastern school whiting by survey.

Prey (% wet wt)	SS9305	SS9402	SS9405	SS9602	SS9606
Ascidiacea	-	-	-	2.27	-
Cnidaria	-	-	13.24	0.40	32.19
Echinodermata	-	-	-	9.23	-
Echiura	-	0.67	-	-	-
Porifera	-	-	22.99	-	-
Polychaeta	41.52	66.20	63.77	13.03	32.67
Unid. crustacea	4.12	0.03	-	0.33	2.07
Reptantia	-	-	-	1.72	-
Natantia	4.03	-	-	0.73	-
Euphausiacea	-	0.90	-	-	-
Stomatopoda	-	-	-	0.18	-
Amphipoda	0.18	-	-	1.81	7.97
Isopoda	-	-	-	0.06	-
Tanaidacea	-	-	-	0.04	-
Copepoda	0.46	-	-	-	0.08
Mollusca	-	15.20	-	6.37	-
Bivalvia	-	-	-	0.12	-
Cephalopoda	-	1.62	-	-	-
Pisces	4.67	7.13	-	61.90	-
Unidentified	45.02	8.25	-	1.81	25.02

Table 10.2.1.25. Diet of *Trachurus declivis* Jack mackerel and *Trachurus novaezelandiae* yellowtail scad by survey.

	T. declivis								*T. novaeze-landiae*
Prey (% wet wt)	IM9501	IM9601	SS9305	SS9402	SS9405	SS9503	SS9602	SS9606	SS9602
Sediment	4.13	0.16	-	-	-	-	-	-	-
Porifera	-	-	-	-	-	-	-	0.07	-
Polychaeta	-	-	-	-	0.76	-	-	0.01	-
Ascidiacea	0.07	2.09	0.03	-	1.21	0.36	0.01	-	0.11
Thaliacea	-	-	0.02	-	-	-	-	-	-
Cnidaria	0.86	3.73	0.11	-	1.43	1.29	3.58	1.58	-
Echinodermata	0.13	-	-	-	-	-	8.01	-	-
Ectoprocta	-	-	-	-	-	-	0.59	-	-
Unid. crustacea	34.42	71.38	25.37	3.78	27.00	17.29	2.37	33.08	1.00
Reptantia	-	-	0.14	0.41	0.84	-	0.75	0.05	1.07
Natantia	-	-	1.64	-	0.88	-	0.02	-	4.67
Scyllaridae	-	-	-	0.56	-	-	-	-	-
Euphausiacea	5.09	16.08	15.08	88.75	1.80	-	30.25	56.81	1.20
Stomatopoda	-	-	-	-	0.75	-	-	-	-
Amphipoda	0.04	0.07	0.48	-	0.18	-	0.05	0.03	0.13
Cumacea	-	-	-	-	-	-	0.04	-	-
Isopoda	0.14	-	0.01	-	-	-	0.02	-	1.13
Mysidacea	-	-	-	-	0.01	-	-	-	-
Copepoda	1.52	0.01	4.45	-	36.00	26.33	0.03	1.38	1.30
Ostracoda	-	-	0.01	-	0.03	-	-	0.04	-
Unid. Mollusca	-	-	-	-	0.03	-	0.36	-	-
Bivalvia	-	-	-	-	0.03	-	-	-	-
Gastropoda	0.73	0.01	0.59	-	0.07	0.68	0.08	0.17	-
Pisces	52.86	6.46	52.06	5.37	16.37	54.06	18.31	6.38	-
Unidentified	-	-	0.01	1.13	12.61	-	35.53	0.40	89.39

Table 10.2.1.26. Diet of *Pseudocaranx dentex* white trevally by survey.

Prey (% wet wt)	SS9305	SS9405	SS9503	SS9602
Ectoprocta	-	0.41	-	0.09
Polychaeta	-	0.26	-	0.09
Unid. Crustacea	0.05	-	0.05	0.08
Reptantia	-	47.85	-	19.32
Natantia	-	-	-	4.61
Amphipoda-benthic	-	2.58	-	2.94
Amphipoda-Hyperiidae	-	0.05	-	-
Cumacea	-	-	-	0.09
Isopoda	-	0.63	-	0.13
Tanaidacea	-	-	-	0.32
Ostracoda	-	-	-	0.17
Bivalvia	-	0.44	-	0.31
Gastropoda	-	-	-	0.03
Pisces	99.95	47.77	99.95	0.73
Unidentified	-	-	-	71.09

Table 10.2.1.27. Diet of *Emmelichthys nitidus nitidus* redbait by survey.

Prey (% wet wt)	SS9305	SS9405	SS9602	SS9606
Appendicularia (Larvacea)	0.02	-	-	-
Ascidiacea	0.42	0.06	26.77	0.38
Thaliacea	18.54	33.55	-	-
Cnidaria	8.21	1.09	-	11.65
Chaetognatha	0.37	-	-	-
Annelida	-	-	0.39	-
Unid. Crustacea	57.38	0.25	22.80	7.00
Reptantia	-	0.02	0.73	-
Natantia	0.05	-	-	-
Euphausiacea	3.79	0.16	-	44.06
Amphipoda-benthic	0.29	0.02	0.01	0.06
Hyperiidae	0.02	-	-	0.02
Isopoda	-	0.05	-	0.01
Mysidacea	-	-	0.04	-
Copepoda	4.67	5.42	29.75	0.38
Mollusca	-	-	-	-
Teuthoidea	0.66	-	-	-
Gastropoda	1.41	0.37	-	-
Pisces	3.24	6.37	12.81	0.56
Unidentified	0.93	52.63	6.71	35.86

Table 10.2.1.28. Diets of *Parequula melbournensis* silverbelly, *Pempheris multiradiata* common bullseye and *Pagrus auratus* snapper by survey.

	P. melbournensis		*P. multiradiatus*	*P. auratus*	
Prey (% wet wt)	SS9602	EJ9601	SS9405	SS9405	SS9602
Ascidiacea	-	-	-	99.26	-
Polychaeta	64.42	-	93.78	-	-
Cnidaria	-	-	2.06	0.05	-
Unid. Crustacea	0.98	3.45	0.17	0.06	-
Reptantia	-	2.20	0.22	-	-
Euphausiacea	-	94.31	-	-	-
Natantia	0.02	-	-	-	-
Ostracoda	-	-	-	-	-
Amphipoda-Gammaridae	0.03	0.02	-	0.60	-
Cumacea	1.37	-	-	-	-
Isopoda	0.08	0.01	-	-	-
Tanaidacea	2.17	-	-	-	-
Unid. Mollusca	6.53	-	-	-	0.18
Polyplacophora	11.43	-	-	-	-
Pisces	-	-	-	0.04	99.82
Unidentified	12.95	-	3.78	-	-

Table 10.2.1.29. Diets of *Scorpis lineolata* silver sweep, *Atypichthys strigatus* mado and *Parma microlepis* white ear by survey.

	S. lineolata	*A. strigatus*	*P. microlepis*	
Prey (% wet wt)	SF9601	SF9601	EJ9601	SF9601
Macrophyta	0.20	0.04	-	0.41
Porifera	-	-	-	20.74
Ascidiacea	1.57	17.55	2.18	-
Thaliacea	6.95	-	-	-
Polychaeta	-	2.18	0.39	-
Cnidaria	0.76	0.28	1.17	-
Ectoprocta	0.01	-	2.22	-
Unid. Crustacea	0.30	-	-	-
Isopoda	0.02	-	-	-
Insecta	0.02	-	-	-
Cephalopoda	0.21	-	-	-
Gastropoda	0.20	-	-	-
Pisces	82.78	79.95	-	-
Unidentified	6.99	-	94.03	78.85

Table 10.2.1.30. Diet of *Nemadactylus douglasi* grey morwong by survey.

Prey (% wet wt)	EJ9601	SS9602
Sediment	0.09	-
Macrophyta	0.01	-
Foraminiferida	0.02	-
Ophiuroidea	14.40	0.01
Echiura	2.57	-
Ectoprocta	0.11	-
Polychaeta	12.78	2.32
Unid. crustacea	12.57	0.01
Reptantia	2.87	92.67
Shrimp	-	0.03
Euphausiacea	0.34	-
Amphipoda	2.88	1.71
Isopoda	0.29	-
Bivalvia	1.17	-
Gastropoda	3.99	-
Pisces	45.91	-
Unidentified	-	3.24

Table 10.2.1.31. Diet of *Nemadactylus macropterus* morwong by survey.

Prey (% wet wt)	EJ9401	EJ9601	IM9501	IM9601	SF9701	SS9305	SS9402	SS9405	SS9602	SS9606
Sediment	-	-	1.39	5.51	0.47	0.14	-	-	-	0.15
Macrophyta	-	-	-	-	-	0.01	-	-	-	-
Ascidiacea	-	-	-	-	-	-	-	-	-	0.01
Cnidaria	-	-	0.05	0.03	0.05	0.12	-	-	-	0.20
Echinodermata	-	-	1.32	0.17	0.27	8.69	8.38	0.15	4.42	1.27
Ectoprocta	-	0.15	0.07	0.05	0.08	0.09	0.22	0.64	-	0.79
Platyhelminthes	-	-	-	-	-	-	-	-	-	0.11
Foraminiferida	-	-	-	0.07	0.03	-	-	0.01	-	0.01
Polychaeta	100	13.01	10.52	2.45	9.73	64.29	41.61	92.82	12.40	35.63
Unid. crustacea	-	3.55	2.08	46.61	5.47	2.50	23.78	1.32	12.12	6.79
Reptantia	-	6.49	0.20	4.91	0.03	1.04	1.92	0.91	12.40	8.99
Natantia	-	6.44	-	1.49	0.31	0.02	-	0.31	7.53	3.99
Euphausiacea	-	-	-	-	47.97	-	0.12	-	-	-
Stomatopoda	-	-	-	-	-	-	-	-	-	0.31
Amphipoda	-	19.15	2.70	26.15	1.36	0.78	5.89	1.61	6.05	15.33
Cumacea	-	-	-	-	0.01	-	-	-	-	-
Isopoda	-	0.11	-	11.39	0.78	3.02	0.06	0.11	0.04	0.24
Tanaidacea	-	0.21	-	0.04	-	-	-	-	0.40	0.03
Ostracoda	-	-	0.14	0.28	0.13	8.21	0.19	-	0.07	0.05
Copepoda	-	-	-	-	-	-	-	-	-	0.01
Mollusca	-	-	-	-	-	0.61	0.19	0.15	-	0.22
Bivalvia	-	0.83	-	-	0.11	0.04	-	0.37	-	0.49
Cephalopoda	-	-	-	-	-	7.94	15.68	-	-	0.93
Gastropoda	-	0.48	0.24	0.01	0.09	0.09	-	0.02	-	0.56
Pisces	-	0.03	79.49	0.84	28.25	0.89	-	0.01	0.05	14.57
Unidentified	-	49.55	1.81	-	4.88	1.52	1.95	1.59	44.52	9.32

Table 10.2.1.32. Diets of *Latris lineata* striped trumpeter, *Latridopsis forsteri* bastard trumpeter

	L. lineata				*L. forsteri*
Prey (% wet wt)	EJ9601	SF9701	SS9305	SS9503	EJ9601
Macrophyta	-	-	-	-	2.92
Echinodermata	-	-	-	-	4.08
Polychaeta	-	-	-	-	0.65
Thaliacea	-	24.77	24.21	24.21	-
Amphipoda	-	-	-	-	5.18
Cumacea	-	-	-	-	0.51
Tanaidacea	-	-	-	-	2.91
Ostracoda	-	-	-	-	0.26
Unid. Crustacea	-	-	-	-	5.55
Reptantia	-	-	-	-	1.58
Shrimp	0.36	-	-	-	-
Isopoda	0.02	-	-	-	0.93
Unid. Mollusca	-	-	9.76	9.76	-
Cephalopoda	0.23	-	-	-	-
Pisces	99.39	75.23	66.03	66.03	-
Unidentified	-	-	-	-	75.43

Table 10.2.1.33. Diets of *Notolabrus tetricus* bluethroat wrasse, *Pseudolabrus psittaculus* rosy wrasse and *Ophthalmolepis lineolata* Maori wrasse by survey.

	N. tetricus		*P. psittaculus*	*O. lineolata*	
Prey (% wet wt)	EJ9601	SF9601	SF9601	EJ9601	SF9601
Ascidiacea	-	-	-	-	-
Ophiuroidea	-	-	3.63	-	10.63
Echinodermata	22.33	-	-	-	-
Ectoprocta	3.19	-	-	-	-
Unid. Crustacea	1.42	13.77	16.71	3.54	-
Reptantia	18.24	-	1.07	4.42	6.23
Mollusca	2.09	-	8.52	-	-
Bivalvia	2.35	12.11	-	-	3.37
Cephalopoda	29.47	-	-	-	-
Gastropoda	5.78	72.12	19.87	2.65	3.42
Polyplacophora	4.10	-	-	-	1.96
Pisces	6.10	-	26.85	59.29	69.28
Unidentified	4.93	2.00	23.35	30.09	5.12

Table 10.2.1.34. Diets of *Kathetostoma laeve* common stargazer and *K. canaster* speckled stargazer by survey.

	K. laeve				*K. canaster*		
Prey (% wet wt)	SS9305	SS9405	SS9602	SS9606	SS9305	SS9602	SS9606
Ectoprocta	-	-	-	0.14	-	-	-
Annelida	-	-	-	-	3.19	-	-
Ostracoda	-	-	-	-	0.05	-	-
Unid. crustacea	-	-	-	0.01	-	-	-
Anomura	-	-	0.68	0.05	-	-	-
Isopoda	-	0.36	-	-	-	-	-
Cephalopoda	0.44	-	-	0.70	1.14	5.88	-
Bivalvia	-	-	-	-	-	0.03	-
Pisces	99.56	99.64	99.32	99.09	95.62	94.00	100
Unidentified	-	-	-	-	-	0.09	-

Table 10.2.1.35. Diet of *Synchiropus calauropomus* common stinkfish by survey.

Prey (% wet wt)	SS9305	SS9402	SS9405	SS9602	SS9606
Sediment	54.65	26.16	-	43.69	13.97
Macrophyta	0.17	-	-	-	0.01
Foraminiferida	0.01	0.03	-	0.12	0.09
Porifera	-	-	0.23	-	-
Ascidiacea	-	-	4.13	0.77	1.21
Cnidaria	-	-	-	0.18	-
Echinodermata	0.90	18.50	1.02	0.18	0.53
Ectoprocta	0.84	0.74	0.36	0.34	0.34
Sipunculida	0.21	-	-	-	-
Polychaeta	7.65	1.23	10.42	7.15	13.32
Unid. crustacea	2.04	7.45	1.90	20.73	1.59
Reptantia	0.67	7.30	2.35	4.57	26.64
Natantia	-	-	1.13	-	-
Amphipoda-benthic	0.19	0.23	0.81	0.84	0.67
Amphipoda-Hyperiidae	-	0.01	-	-	-
Cumacea	-	-	0.06	-	-
Isopoda	0.19	0.20	0.16	1.09	2.63
Tanaidacea	-	-	0.43	-	-
Phyllocarida	-	-	0.06	-	-
Copepoda	0.02	0.01	-	0.02	-
Ostracoda	0.30	0.28	0.23	1.09	0.23
Unid. mollusca	1.90	2.27	0.10	0.21	0.05
Bivalvia	16.87	23.90	33.62	16.34	28.02
Gastropoda	7.64	5.91	2.29	2.18	2.72
Scaphopoda	-	-	0.05	-	-
Pisces	-	-	-	-	0.39
Unidentified	5.75	5.77	40.66	0.49	7.58

Table 10.2.1.36. Diets of *Thyrsites atun* barracouta and *Rexea solandri* gemfish by survey.

	T. atun						*R. solandri*
Prey (% wet wt)	SS9305	SS9402	SS9405	SS9503	SS9602	SS9606	SS9602
Cnidaria	-	-	-	-	-	-	-
Unid. crustacea	0.21	0.37	0.42	0.14	-	0.06	-
Euphausiacea	-	-	0.66	-	-	7.58	-
Amphipoda	-	-	-	0.10	-	-	-
Pisces	99.79	99.63	98.91	99.76	99.89	92.20	94.44
Unidentified	-	-	-	-	0.10	0.16	5.56

Table 10.2.1.37. Diet of *Scomber australasicus* blue mackerel by survey.

Prey (% wet wt)	SS9202	SS9305	SS9402	SS9602
Appendicularia (Larvacea)	-	0.72	-	-
Ascidiacea	15.97	-	-	0.31
Thaliacea	-	-	8.61	38.21
Siphonophora	32.69	-	2.50	0.22
Chaetognatha	-	0.13	-	-
Polychaeta	4.77	-	-	0.01
Unid. crustacea	0.75	67.13	30.00	19.49
Reptantia	-	0.08	-	-
Euphausiacea	-	-	46.94	0.01
Cladocera	-	0.16	-	-
Amphipoda-Hyperiidae	-	-	-	-
Isopoda	-	-	-	-
Copepoda	1.40	19.61	-	0.01
Ostracoda	-	0.16	-	-
Gastropoda	-	-	-	0.02
Pisces	4.49	-	11.94	41.17
Unidentified	39.93	12.00	-	0.54

Table 10.2.1.38. Diet of *Seriolella brama* blue warehou by survey .

Prey (% wet wt)	EJ9601	SS9305	SS9405	SS9503	SS9606
Macrophyta	0.08	-	0.03	-	-
Ascidiacea	-	-	0.28	-	14.55
Thaliacea	97.98	-	44.69	-	6.97
Cnidaria	1.23	-	0.01	-	76.92
Platyhelminthes	-	-	0.19	-	0.34
Unid. crustacea	-	0.17	-	0.04	0.70
Euphausiacea	0.55	-	-	-	-
Amphipoda	-	0.02	0.02	0.01	0.28
Copepoda	-	-	-	-	0.02
Ostracoda	0.02	-	-	-	-
Cephalopoda	-	-	38.75	-	-
Gastropoda	-	-	-	-	0.02
Pisces	-	1.96	0.04	74.83	0.20
Unidentified	0.14	97.85	15.98	25.12	-

Table 10.2.1.39. Diet of *Seriolella punctata* silver warehou by survey.

Prey (% wet wt)	SS9305	SS9402	SS9405	SS9503	SS9602	SS9606
Foraminiferida	-	-	-	-	0.02	-
Ectoprocta	-	-	-	-	0.04	-
Ascidiacea	-	0.16	0.01	-	1.30	17.56
Thaliacea	63.33	6.03	99.34	62.89	64.78	-
Cnidaria	-	-	0.16	-	12.59	14.51
Echinodermata	0.01	-	-	0.01	0.01	-
Polychaeta	0.02	0.09	-	0.02	0.02	-
Unid. crustacea	0.74	0.01	0.04	0.74	0.01	-
Amphipoda	0.02	0.22	0.01	0.02	0.09	0.51
Copepoda	-	-	0.01	-	0.01	-
Cephalopoda	3.54	-	0.40	3.52	-	-
Pisces	0.64	-	0.02	0.62	0.28	24.76
Unidentified	31.69	93.48	0.01	32.18	20.84	42.66

Table 10.2.1.40. Diet of *Azygopus pinnifasciatus* banded-fin flounder by survey.

Prey (% wet wt)	SS9305
Echinodermata	77.47
Ectoprocta	5.37
Polychaeta	8.38
Unid. Crustacea	1.23
Amphipoda-benthic	0.95
Ostracoda	0.03
Gastropoda	4.30
Pisces	1.15
Unidentified	1.12

Table 10.2.1.41. Diet of *Meuschenia scaber* velvet leatherjacket, *Paramonacanthus filicauda* little leatherjacket and *M. freycineti* sixspine leatherjacket by survey.

	M. scaber				*P. filicauda*	*M. freycineti*			
Prey (% wet wt)	SS9305	SS9405	SS9602	SS9606	SS9602	SS9305	SS9405	SS9602	SS9606
Sediment	2.13	-	-	-	-	-	0.54	-	3.66
Macrophyta	2.13	-	-	-	-	-	0.05	-	0.09
Foraminiferida	2.13	1.89	1.37	1.54	-	-	-	-	0.01
Ascidiacea	10.64	18.87	6.85	15.38	0.07	8.65	8.36	-	7.57
Thaliacea	2.13	-	-	-	-	21.29	-	-	-
Cnidaria	-	5.66	10.96	6.15	-	-	1.33	40.93	0.19
Echinodermata	6.38	1.89	5.48	3.08	-	15.62	21.84	51.62	19.09
Ectoprocta	27.66	15.09	15.07	15.38	-	-	3.90	0.01	0.22
Sipuncula	-	-	-	-	-	-	0.96	-	-
Porifera	4.26	7.55	8.22	4.62	-	-	-	0.29	15.47
Platyhelminthes	2.13	-	-	-	-				
Polychaeta	4.26	7.55	12.33	9.23	0.02	-	6.73	0.12	5.98
Unid. crustacea	6.38	1.89	1.37	1.54	74.20	-	0.06	-	6.98
Reptantia	2.13	-	5.48	1.54	-	-	22.41	4.15	22.22
Amphipoda-benthic	4.26	11.32	10.96	20	-	0.04	0.01	-	-
Amphipoda-Hyperiidae	-	-	1.37	1.54	0.14	-	-	-	-
Isopoda	-	7.55	-	3.08	-	-	3.40	-	-
Mysidacea	4.26	-	-	-	-	0.09	0.05	-	0.01
Cirripedia	-	-	-	1.54	-	-	6.14	-	-
Copepoda	2.13	-	-	1.54	24.55	-	-	-	-
Ostracoda	2.13	5.66	5.48	3.08	-	-	-	-	-
Mollusca	2.13	-	-	1.54	-	40.82	0.88	-	1.16
Bivalvia	4.26	3.77	1.37	3.08	-	0.97	0.33	0.02	1.26
Gastropoda	6.38	7.55	12.33	4.62	0.82	8.81	4.52	0.68	7.41
Cephalopoda	-	-	-	-	-	0.09	11.62	2.18	4.53
Pisces	-	-	-	-	-	-	1.14	-	2.81
Unidentified	2.13	3.77	1.37	1.54	0.20	3.59	5.75	-	1.34

Table 10.2.1.42. Diets of *Diodon nicthemerus* globefish, *Allomycterus pilatus* Australian burrfish and *Arothron firmamentum* starry toadfish by survey.

	D. nicthemerus						*A. pilatus*				*A. firmamentum*
Prey (wet wt)	SS9202	SS9305	SS9405	SS9503	SS9602	SS9606	SS9202	SS9305	SS9602	SS9606	SS9602
Sediment	-	-	0.03	-	-	-	-	-	-	-	-
Marine Angiosperm	-	-	-	-	-	-	-	-	-	-	0.21
Macrophyta	-	0.03	-	0.03	-	-	-	-	-	-	1.87
Foraminiferida	-	-	-	-	-	-	-	-	-	-	-
Cnidaria							-	-	-	-	0.62
Ascidiacea	1.64	-	-	-	1.64	-	-	0.15	-	-	4.34
Thaliacea	-	1.87	-	1.87	-	-	-	3.25	-	0.88	-
Echinodermata	-	0.69	-	0.69	-	-	-	-	-	7.72	-
Ectoprocta	0.13	-	0.03	-	0.13	-	-	-	-	-	6.00
Polychaeta	-	0.01	9.01	0.01	-	1.10	-	-	-	-	3.19
Unid. crustacea	-	-	-	-	-	0.57	26.38	-	26.38	-	18.59
Ostracoda	-	-	-	-	-	-	-	-	-	91.13	0.02
Reptantia	64.08	14.57	52.01	14.57	64.08	73.51	30.74	37.48	30.74	-	13.92
Natantia	-	-	-	-	-	-	-	-	-	-	0.21
Gammaridae	-	11.49	-	11.49	-	-	-	-	-	-	0.69
Hyperiidae	-	-	-	-	-	-	-	-	-	-	0.13
Stomatopoda	-	-	-	-	-	-	-	-	-	-	2.47
Isopoda	-	0.79	1.97	0.79	-	0.06	-	-	-	0.27	3.98
Mollusca	4.27	26.21	1.26	26.21	4.27	0.34	-	40.88	-	-	9.59
Bivalvia	19.76	40.29	10.79	40.29	19.76	3.08	-	-	-	-	0.19
Gastropoda	7.36	4.06	24.40	4.06	7.36	21.04	42.88	18.21	42.88	-	-
Pisces	-	-	-	-	-	-	-	0.04	-	-	0.52
Unidentified	2.77	-	0.51	-	2.77	0.30	-	-	-	-	33.44

Appendix Table 10.2.3.1 Stable nitrogen and stable carbon isotope results for all species analysed in SEF ecosystem surveys.

Species	Common Name	Spp cod	n	$\delta^{15}N$	s.d.	min	max	$\delta^{13}C$	s.d.	min	max
Teleosts and Elambobranchs											
Alopius vulpinus	Thresher shark	012001	2	**13.48**	0.10	13.41	13.55	**-17.11**	0.06	-17.15	-17.07
Apogonops anomalus	Threespine cardinalfish	311053	25	**11.54**	0.63	10.53	13.11	**-18.73**	1.05	-21.02	-16.00
Asymbolus analis	Grey spotted catshark	015002	7	**12.97**	0.27	12.56	13.46	**-16.11**	0.16	-16.25	-15.80
Atypichthus strigatus	Mado	361010	9	**12.90**	0.38	12.41	13.63	**-17.97**	0.78	-19.46	-16.80
Caesioperca lepidoptera	Butterfly perch	311002	19	**11.39**	0.30	10.79	11.95	**-18.50**	0.36	-19.18	-17.87
Caesioperca rasor	Barber perch	311003	8	**10.68**	0.20	10.38	10.94	**-18.25**	0.42	-19.04	-17.75
Callorhinchus milii	Elephantfish	043001	2	**10.33**	0.21	10.18	10.47	**-16.82**	0.10	-16.89	-16.75
Carcharhinus brachyurus	Bronze whaler	018001	1	**11.74**				**-16.73**			
Centroberyx affinis	Redfish	258003	68	**12.74**	0.47	11.80	13.75	**-18.36**	0.69	-19.93	-17.07
Cephaloscyllium laticeps	Draughtboard shark	015001	30	**13.61**	0.56	12.08	14.40	**-16.34**	0.38	-17.54	-15.55
Cepola australis	Bandfish	380001	1	**10.53**				**-20.15**			
Chlorophthalmus nigripinnis	Cucumber fish	120001	18	**12.32**	0.44	11.58	13.30	**-18.28**	0.35	-19.09	-17.59
Caelorinchus australis	Southern whiptail	232001	5	**13.88**	0.33	13.42	14.18	**-16.72**	0.45	-17.35	-16.14
Caelorinchus mirus	Gargoylefish	232003	5	**13.64**	0.29	13.31	14.01	**-17.28**	0.37	-17.83	-16.85
Conger verrauxi	Southern conger	067007	6	**13.91**	0.10	13.79	14.03	**-16.85**	1.36	-19.59	-15.96
Cyttus australis	Silver dory	264002	43	**12.57**	0.75	10.19	13.72	**-18.07**	0.97	-19.92	-16.55
Cyttus novaezelandiae	New Zealand dory	264005	5	**12.17**	0.36	11.59	12.55	**-18.62**	0.47	-19.31	-18.15
Dasyatis brevicaudata	Smooth stingray	035001	1	**13.88**				**-16.77**			
Diaphus danae	Dana lanternfish	122001	7	**9.59**	0.71	8.84	10.73	**-19.73**	0.82	-20.96	-19.00
Dinolestes lewini	Longfin pike	327002	10	**14.33**	0.22	13.86	14.75	**-16.95**	0.32	-17.50	-16.5
Diodon nichthemerus	Globefish	469001	12	**11.94**	0.82	10.23	13.23	**-17.58**	0.76	-19.22	-16.81
Emmelichthys nitidus	Redbait	345001	25	**11.62**	0.45	10.98	13.08	**-18.11**	0.53	-19.05	-17.17
Galeorhinus galeus	School shark	017008	13	**13.28**	0.49	12.64	14.16	**-17.04**	0.61	-18.03	-15.86
Gasterochisma melampus	Butterfly mackerel	441019	10	**10.40**	0.31	9.80	10.77	**-19.03**	0.91	-20.84	-17.92
Genypterus blacodes	Pink ling	228002	18	**13.12**	0.69	12.12	14.34	**-17.22**	0.57	-18.86	-16.67
Gymnoscopelus piabilis	Fam. Myctophidae	122018	1	**11.71**				**-19.32**			
Gymnothorax prasinus	Green moray	060006	4	**14.55**	0.37	14.11	15.02	**-15.88**	0.30	-16.24	-15.52
Helicolenus percoides	Ocean perch	287001	58	**12.75**	0.73	11.03	14.33	**-17.21**	0.42	-18.88	-16.42
Heterodontus portusjacksoni	Port Jackson shark	007001	6	**11.97**	0.37	11.61	12.65	**-15.15**	0.33	-15.56	-14.56
Hypoplectrodes annulata	Blackbanded seaperch	311091	3	**13.94**	0.15	13.76	14.03	**-15.67**	0.13	-15.75	-15.51
Hypoplectrodes maccullochi	Halfbanded seaperch	311036	2	**13.11**	0.11	13.02	13.19	**-17.15**	0.35	-17.39	-16.91
Ichthyscopus barbatus	Fringed stargazer	400002	1	**13.40**				**-16.61**			
Isurus oxyrinchus	Mako shark	010001	3	**13.49**	0.25	13.22	13.71	**-17.12**	0.26	-17.37	-16.85
Kathetostoma canaster	Speckled stargazer	400018	6	**14.05**	0.83	13.11	15.36	**-16.62**	0.41	-17.30	-16.14
Kathetostoma laeve	Common stargazer	400003	5	**12.73**	0.75	11.98	13.57	**-16.81**	0.42	-17.24	-16.24
Lampanyctodes hectoris	Hector's lanternfish	122002	10	**10.59**	0.38	10.09	11.25	**-19.75**	1.19	-21.24	-18.35
Latridopsis forsteri	Bastard trumpeter	378002	10	**13.63**	0.44	12.74	14.50	**-18.04**	1.73	-19.83	-14.14
Latris lineata	Striped trumpeter	378001	19	**13.59**	0.81	11.40	14.95	**-16.89**	1.19	-18.12	-12.38
Lepidoperca pulchella	Eastern orange perch	311001	13	**12.20**	0.29	11.81	12.86	**-18.32**	0.54	-19.41	-17.51
Lepidotrigla modesta	Minor gurnard	288007	29	**12.68**	0.50	11.79	14.04	**-17.91**	0.48	-18.61	-16.55
Lepidotrigla mulhalli	Deepwater gurnard	288008	11	**12.15**	0.61	11.12	13.15	**-17.71**	0.25	-18.12	-17.12
Lophonectes gallus	Crested flounder	460001	2	**10.37**	0.16	10.26	10.48	**-17.46**	0.67	-17.93	-16.98
Lotella rhacinus	Largetooth beardie	224005	6	**14.74**	0.62	13.58	15.21	**-16.13**	0.51	-17.07	-15.63
Macrorhamphosus scolopax	Common snipefish	279002	19	**12.71**	0.55	11.21	13.62	**-18.01**	0.48	-19.40	-17.46
Maurolicus muelleri	Pennant lightfish	107002	5	**10.17**	0.28	9.76	10.42	**-20.64**	0.25	-20.96	-20.34
Meuschenia freycineti	Sixspine leatherjacket	465036	8	**12.68**	1.12	10.83	14.22	**-16.94**	0.79	-18.76	-16.34
Meuschenia scaber	Velvet leatherjacket	465005	10	**11.70**	0.26	11.18	12.12	**-18.69**	0.75	-19.82	-17.76
Muraenichthys sp.	Worm eel (4 fish)	068000	3	**11.11**	1.20	10.16	12.46	**-16.56**	0.96	-17.61	-15.73
Mustelus antarcticus	Gummy shark	017001	14	**12.86**	0.47	12.02	13.44	**-16.22**	0.31	-16.80	-15.74
Narcine tasmaniensis	Tasmanian numbfish	028002	15	**13.81**	0.54	13.02	14.80	**-14.58**	0.41	-15.72	-14.04
Nemadactylus douglasi	Grey morwong	377002	7	**12.69**	0.30	12.15	12.95	**-17.35**	0.40	-17.86	-16.58
Nemadactylus macropterus	Morwong	377003	43	**13.13**	0.56	11.94	14.37	**-17.94**	0.87	-19.56	-16.47
Neoplatycephalus aurimaculatus	Toothy flathead	296035	4	**12.56**	0.41	11.99	12.96	**-16.61**	0.21	-16.81	-16.32
Neoplatycephalus richardsoni	Tiger flathead	296001	58	**12.78**	0.51	11.81	13.99	**-17.40**	0.53	-18.91	-16.51
Neosebastes scorpaenoides	Ruddy gurnard perch	287005	5	**12.83**	0.28	12.44	13.16	**-16.95**	0.34	-17.40	-16.49
Notolabrus tetricus	Bluethroat wrasse	384003	12	**13.38**	0.55	12.09	14.07	**-16.62**	0.36	-17.26	-15.94
Opthalmolepis lineolata	Maori wrasse	384040	13	**13.12**	0.27	12.55	13.43	**-16.15**	0.30	-16.86	-15.75
Pagrus auratus	Snapper	353001	5	**11.31**	0.28	10.88	11.57	**-16.38**	1.20	-18.31	-15.12
Parascyllium ferrugineum	Rusty carpetshark	013005	2	**12.15**	0.09	12.09	12.21	**-16.24**	0.16	-16.35	-16.13
Parma microlepis	White ear	372005	5	**12.66**	0.36	12.16	13.12	**-17.49**	1.01	-18.95	-16.74
Pempheris multiradiata	Common bullseye	357001	10	**12.79**	0.37	12.05	13.30	**-17.73**	0.42	-18.87	-17.43
Platycephalus bassensis	Sand flathead	296003	23	**12.17**	0.84	9.95	13.27	**-16.93**	1.23	-20.31	-13.55
Pseudocaranx dentex	White trevally	337062	21	**12.25**	0.65	10.58	13.11	**-17.06**	0.68	-18.72	-15.81

Appendix Table 10.2.3.1 Stable nitrogen and stable carbon isotope results for all species analysed in SEF ecosystem surveys.

Species	Common Name	Spp cod	n	δ^{15}N	s.d.	min	max	δ^{13}C	s.d.	min	max
Pseudolabrus psittaculus	Rosy wrasse	384023	10	**12.92**	0.28	12.41	13.29	**-16.68**	0.28	-16.99	-16.16
Pseudophycis bachus	Red cod	224006	9	**13.30**	0.28	12.70	13.57	**-17.48**	0.17	-17.73	-17.11
Raja sp. A	Longnose skate	031005	6	**12.35**	0.79	11.07	13.25	**-16.94**	0.80	-18.49	-16.27
Rexea solandri	Gemfish	439002	9	**13.50**	0.42	12.91	13.95	**-17.84**	0.33	-18.32	-17.41
Sardinops neopilchardus	Pilchard	085002	10	**10.81**	0.80	9.66	12.36	**-19.25**	0.72	-20.15	-17.67
Scomber australasicus	Blue mackerel	441001	10	**11.99**	0.58	11.31	13.11	**-18.20**	0.67	-19.26	-17.56
Scorpis lineolata	Sweep	361009	8	**11.42**	0.49	10.42	11.87	**-18.20**	0.32	-18.49	-17.54
Seriolella brama	Blue warehou	445005	28	**12.58**	0.52	11.67	13.81	**-18.69**	0.99	-20.84	-15.28
Seriolella punctata	Silver warehou	445006	40	**12.21**	0.76	11.07	13.91	**-19.20**	0.93	-21.28	-16.3
Sillago flindersi	Eastern school whiting	330014	28	**12.45**	1.01	10.16	15.49	**-17.21**	0.73	-18.93	-15.26
Sphyrna zygaena	Smooth hammerhead	019004	1	**14.21**				**-16.82**			
Squalus megalops	Spikey dogfish	020006	6	**13.32**	0.40	12.77	13.85	**-16.72**	0.72	-17.85	-15.68
Squatina australis	Australian angel shark	024001	5	**12.53**	0.73	11.44	13.41	**-16.24**	0.39	-16.54	-15.63
Squatina sp. A	Eastern angel shark	024004	3	**13.90**	0.53	13.45	14.49	**-16.46**	0.22	-16.72	-16.33
Symbolophorus barnardi	Bullseye lanternfish	122007	5	**10.14**	0.82	8.96	11.11	**-19.44**	0.68	-20.19	-18.42
Synchiropus calauropomus	Common stinkfish	427001	28	**11.85**	0.61	10.96	13.57	**-17.63**	0.60	-18.73	-16.52
Thyrsites atun	Barracouta	439001	36	**13.32**	0.75	11.68	14.49	**-18.42**	1.02	-20.23	-16.84
Trachurus declivis	Jack mackerel	337002	52	**12.50**	0.68	11.48	14.49	**-18.41**	1.11	-20.45	-12.76
Trygonorrhina sp.	Fiddler ray	027006	9	**12.82**	0.76	11.38	14.01	**-15.85**	0.20	-16.16	-15.58
Urolophus cruciatus	Banded stingaree	038002	13	**11.87**	0.51	11.21	12.93	**-16.45**	0.37	-17.18	-15.92
Urolophus paucimaculatus	Sparsely-spotted stingaree	038004	23	**11.98**	0.48	11.01	12.81	**-17.33**	0.65	-18.68	-16.23
Urolophus viridis	Greenback stingaree	038007	11	**11.45**	0.43	10.80	12.48	**-17.29**	0.47	-17.82	-16.06
Zenopsus nebulosis	Mirror dory	264003	3	**11.96**	0.28	11.64	12.15	**-17.60**	0.12	-17.70	-17.46
Zeus faber	John Dory	264004	40	**13.32**	0.74	11.79	15.09	**-17.26**	0.75	-19.20	-15.78

Appendix Table 10.2.3.2 Species from the south east Australian shelf arranged in decreasing order of stable isotope signature.

$\delta^{15}N$	n	Mammals, birds	Teleosts	Elasmobranchs	Invertebrates	Algae, sediments	Common Name
15.81	2	Arctocephalus p. pusillus					Australian fur seal
15.48	1				Fam. Lumbrineris		polychaete
15.17	1	Orcinus orca					killer whale
14.96	2				Fam. Oenone		polychaete
14.74	6		Lotella rhacinus				largetooth beardie
14.60	1				Fam. Polyodontida		polychaete
14.55	4		Gymnothorax prasinus				green moray
14.41	5	Tursiops truncatus					bottlenose dolphin
14.33	10		Dinolestes leweni				longfin pike
14.21	1			Sphyrna zygaena			smooth hammerhead
14.05	6		Kathetostoma canaster				speckled stargazer
13.94	3		Hypoplectrodes annulata				blackbanded
13.91	6		Conger verrauxi				southern conger
13.90	3			Squatina sp. A			eastern angel shark
13.88	5		Caelorinchus australis				southern whiptail
13.88	1		Dasyatis brevicaudata				smooth stingray
13.81	15			Narcine tasmaniensis			Tasmanian numbfish
13.71	1				Ericusa sowerbyi		spindle-shaped volute
13.64	5		Caelorinchus mirus				gargoylefish
13.63	10		Latridopsis forsteri				bastard trumpeter
13.61	30			Cephaloscyllium laticeps			draughtboard shark
13.59	19		Latris lineata				striped trumpeter
13.50	9		Rexea solandri				gemfish
13.49	3			Isurus oxyrinchus			mako shark
13.48	2			Alopius vulpinus			thresher shark
13.40	1		Ichthyscopus barbatus				fringed stargazer
13.38	12		Notolabrus tetricus				bluethroat wrasse
13.38	5				Jasus sp.		rock lobster
13.33	3	Delphinus delphis					common dolphin
13.32	6			Squalus megalops			spikey dogfish
13.32	36		Thyrsites atun				barracouta
13.32	40		Zeus faber				John dory
13.30	9		Pseudophycis bachus				red cod
13.28	13			Galeorhinus galeus			school shark
13.13	43		Nemadactylus macropterus				morwong
13.12	18		Genypterus blacodes				pink ling
13.12	13		Opthalmolepis lineolata				Maori wrasse
13.11	2		Hypoplectrodes maccullochi				halfbanded seaperch
13.00	19	Eudyptula minor					little penguin
12.97	7			Asymbolus analis			grey spotted catshark
12.92	10		Pseudolabrus psittaculus				rosy wrasse
12.90	9		Atypichthus strigatus				mado
12.90	1	Mesoplodon grayi					Gray's Scamperdown beaked whale
12.87	8				Nototodarus gouldi		Gould's squid

Appendix Table 10.2.3.2 Species from the south east Australian shelf arranged in decreasing order of stable isotope signature.

$\delta^{15}N$	n	Mammals, birds	Teleosts	Elasmobranchs	Invertebrates	Algae, sediments	Common Name
12.86	14			Mustelus antarcticus			gummy shark
12.83	5		Neosebastes scorpaenoides				ruddy gurnard perch
12.82	9			Trygonorrhina sp.			fiddler ray
12.79	10		Pempheris multiradiata				common bullseye
12.78	58		Neoplatycephalus richardsoni				tiger flathead
12.75	58		Helicolenus percoides				ocean perch
12.74	68		Centroberyx affinis				redfish
12.73	5		Kathetostoma laeve				common stargazer
12.71	19		Macrorhamphosus scolopax				common snipefish
12.69	7		Nemadactylus douglasi				grey morwong
12.68	29		Lepidotrigla modesta				minor gurnard
12.68	8		Meuschenia freycineti				sixspine leatherjacket
12.66	5		Parma microlepis				white ear
12.64	1				Dardanus sp.		hermit crab
12.62	4				Octopus maorum		Maori octopus
12.58	28		Seriolella brama				blue warehou
12.57	43		Cyttus australis				silver dory
12.56	4		Neoplatycephalus aurimaculatus				toothy flathead
12.53	5			Squatina australis			eastern angel shark
12.50	52		Trachurus declivis				jack mackerel
12.45	28		Sillago flindersi				eastern school
12.42	2				Fam. Lysaretinae		polychaete
12.41	1				Fam. Polynoid		polychaete
12.35	6			Raja sp. A			longnose skate
12.32	18		Chlorophthalmus nigripinnis				cucumber fish
12.25	21		Pseudocaranx dentex				white trevally
12.21	40		Seriolella punctata				silver warehou
12.20	13		Lepidoperca pulchella				eastern orange perch
12.17	5		Cyttus novaezelandiae				New Zealand dory
12.17	23		Platycephalus bassensis				sand flathead
12.15	11		Lepidotrigla mulhalli				deepwater gurnard
12.15	2			Parascyllium ferrugineum			rusty carpetshark
11.99	10		Scomber australasicus				blue mackerel
11.98	23			Urolophus paucimaculatus			sparsely-spotted stingaree
11.97	6			Heterodontus portusjacksoni			Port Jackson shark
11.96	3		Zenopsis nebulosus				mirror dory
11.94	12		Diodon nichthemerus				globefish
11.87	13			Urolophus cruciatus			banded stingaree
11.85	28		Synchiropus calauropomus				common stinkfish
11.77	1				Ibacus alticrenatus		shovel-nosed lobster
11.74	1			Carcharhinus brachyurus			bronze whaler
11.74	1				Anemone		
11.72	1				Fam. Opheliidae		polychaete
11.71	1		Gymnoscopelus piabilis				Fam. Myctophidae

Appendix Table 10.2.3.2 Species from the south east Australian shelf arranged in decreasing order of stable isotope signature.

δ^{15}N	n	Mammals, birds	Teleosts	Elasmobranchs	Invertebrates	Algae, sediments	Common Name
11.70	10		Meuschenia scaber				velvet leatherjacket
11.62	25		Emmelichthys nitidus				redbait
11.54	25		Apogonops anomalus				threespine
11.54	5				Sepia sp.		cuttlefish
11.54	1				Scyllarides sp.		flat lobster
11.45	11			Urolophus viridis			greenback stingaree
11.42	8		Scorpis lineolata				sweep
11.39	19		Caesioperca lepidoptera				butterfly perch
11.31	5		Pagrus auratus				snapper
11.11	3		Muraenichthys sp.				worm eel
11.11	5				Aristaeomorpha foliacea		giant red prawn
10.88	1				Petalomera sp. (Fam. Dromiidae)		crab
10.81	10		Sardinops neopilchardus				pilchard
10.81	1				Jasus edwardsii		southern rock lobster
10.69	1				Fam. Dromiidae		sponge crabs
10.68	8		Caesioperca rasor				barber perch
10.67	94	Globicephala melas					pilot whale
10.62	1				Fusinus novaehollandiae		gastropod
10.59	10		Lampanyctodes hectoris				Hector's lanternfish
10.58	1	Lissodelphis peronii					southern right whale dolphin
10.53	1		Cepola australis				bandfish
10.40	10		Gasterochisma melampus				butterfly mackerel
10.38	3				Strigopagrus strigimanus		hermit crab
10.37	2		Lophonectes gallus				crested flounder
10.33	2			Callorhinchus milii			elephantfish
10.27	1				Fam. Rhanphobranchium		polychaete
10.17	5		Maurolicus muelleri				pennant lightfish
10.17	1				Amoria sp.		gastropod
10.16	1		Fish eggs				
10.14	5		Symbolophorus barnardi				bullseye lanternfish
10.00	1				Mursia sp. (Fam. Calappidae)		crab
9.93	2				Sicyonia australiense		carid prawn
9.90	1				Fam. Alpheidae		snapping shrimp
9.87	1	Phocoena dioptrica					spectacled porpoise

Appendix Table 10.2.3.2 Species from the south east Australian shelf arranged in decreasing order of stable isotope signature.

$\delta^{15}N$	n	Mammals, birds	Teleosts	Elasmobranchs	Invertebrates	Algae, sediments	Common Name
9.75	2				Pontophilus sp.		carid prawn
9.73	5				Aegaean locazei		carid prawn
9.69	2				Order Stomatopoda		mantis shrimps
9.59	7		Diaphus danae				Dana lanternfish
9.59	2				Fam. Palaemonida		shrimp
9.52	1				Fam. Dorididae		opisthobranch (Nudibranch)
9.49	1				Fam. Raninidae		spanner crab
9.43	1	Mesoplodon sp. 1					beaked whale
9.42	1				Opisthobranc		gastropod
9.42	3				Class Ophiuroidea		ophiuroids
9.41	1				Latreillopsis petterdi?(Fam. Latreillidae)		crab
9.36	1				Ovalipes molleri (Fam. Portunidae)		crab
9.27	1		Clupeid fish larvae				
9.22	1				Ophiocrossota multispina		ophiuroid
9.03	1				Sinum zonale		gastropod
9.01	1				Octopus berrima		octopus
8.87	5				Eucrassatella kingicola		bivalve
8.85	1				Australiaster dubia		asteroid
8.83	1				Carid shrimp		unidentified species
8.82	1				Coscinasterias		starfish
8.77	1				Paguridae larva		hermit crab
8.76	1				Capnella sp. (Fam. Nephtheidae)		soft coral
8.74	2				Sigalionidae		polychaete
8.58	4				Munida c.f. haswelli		craylets
8.57	1				Crinoid (parts)		
8.39	2				Aphrodite australis		polychaete
8.28	1				Clypeaster viriscens		sea biscuit
8.2	2				Polycarpa sp.		ascidian

Appendix Table 10.2.3.2 Species from the south east Australian shelf arranged in decreasing order of stable isotope signature.

$\delta^{15}N$	n	Mammals, birds	Teleosts	Elasmobranchs	Invertebrates	Algae, sediments	Common Name
8.13	1				Seriolidae		isopod
8.11	1				Bryozoa		soft bryozan
8.07	1				Philine		gastropod
7.94	1				Megalopa		larval crab
7.90	1				Crab (Fam. Goneplacida		Carcinoplax sp.
7.89	1				Sarcoptilus grandis		sea pen
7.80	1				Myochamia anomioides		bivalve
7.7	1				Crinoid		
7.69	6				Zooplankton		from surface tows
7.68	1				Polycarpa rigida?		ascidian
7.64	1				Sphaeromatidae		isopod
7.61	2				Order Amphipoda		various amphipods
7.59	1				Order Mysidacea		
7.57	4				Sponges		
7.43	1				Crustacean zooplankton		
7.22	1				Holothurian		
7.10	2		Larval fish				
7.07	42					Sediments SS9606	
7.05	28					POM SS9405	
7.03	19					Sediments SS9602	
6.97	42					Sediments SS9405	
6.91	2				Chlorotocus sp.		carid shrimp
6.76	4				Glycymeris striatularis		bivalve
6.64	1					Phaeophyte alga	
6.58	2				Sabellidae		polychaete
6.51	2				Euphausids		
6.49	1					Red algae sp. 6 (Platoma australica)	
6.47	1				Venericardia amabilis		bivalve
6.27	26					POC SS0696	
6.24	1				Tucetona flabellata		bivalve
6.21	4					Phytoplankton	from SS9405 bloom

Appendix Table 10.2.3.2 Species from the south east Australian shelf arranged in decreasing order of stable isotope signature.

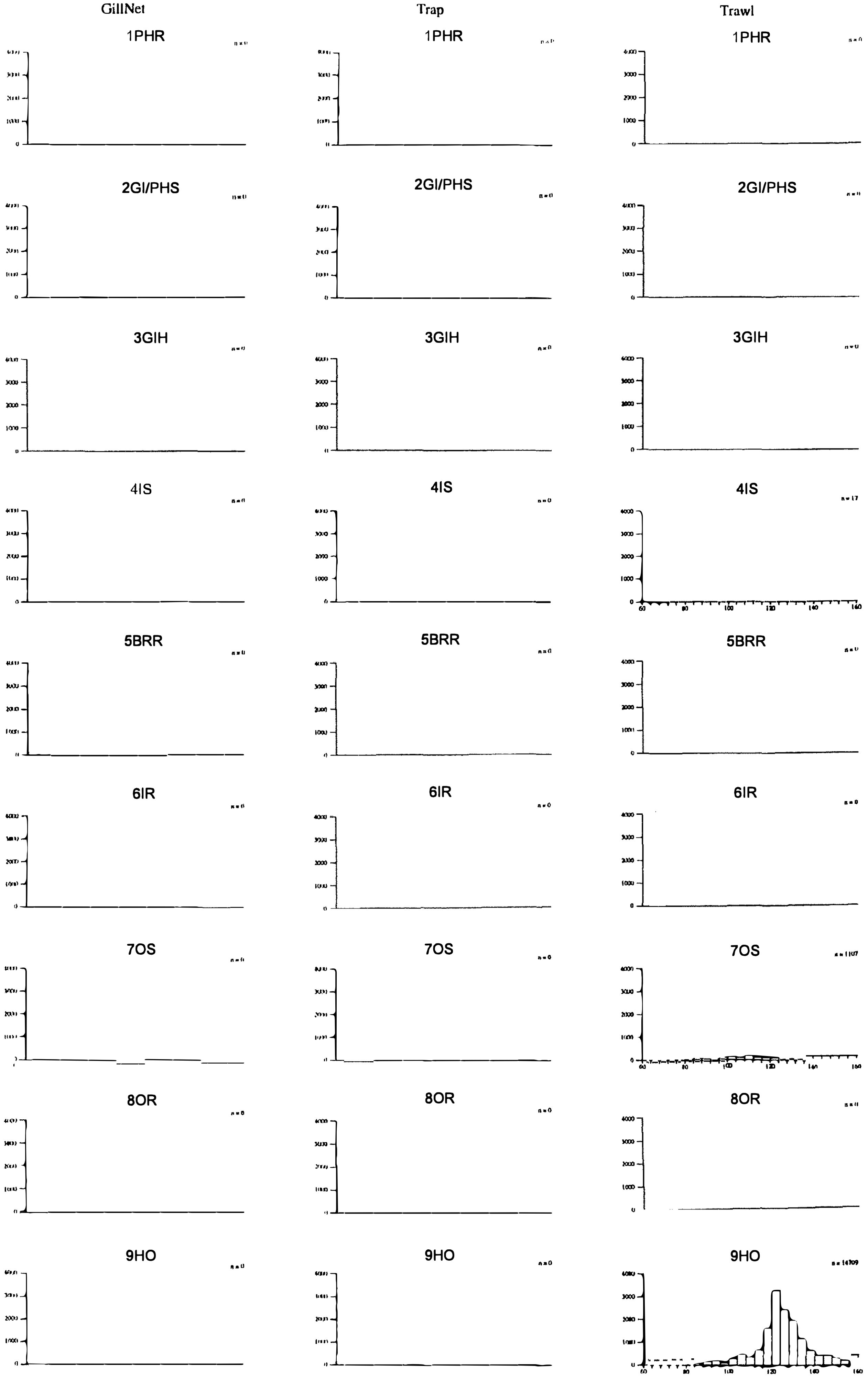
$\delta^{15}N$	n	Mammals, birds	Teleosts	Elasmobranchs	Invertebrates	Algae, sediments	Common Name
6.19	2				Copepods		
6.04	1	Balaenoptera acutorostrata					Minke whale
5.87	1					Red algae sp. 2 (Craspedocarpus	
5.67	1					Seagrass sp. 2 (Fam. Zosteraceae)	
5.57	1				Echinoidea		
5.54	1					Red algae sp. 5 (poss 4 spp.)	
5.32	4				Mauricolpus roseus		New Zealand screw shell
5.15	1					Red algae sp. 4 (Gracilaria sedundata)	
5.08	27					POM SS9602	
4.78	1					Red algae sp. 1 (Ptilonia australasica)	
4.56	1					Red algae sp. 3 (Rhodymenia australis)	
4.27	3				Pyrosome		Pyrosome
3.96	1				Bryozoa		Bryozoan
3.72	1				Prawn		out of pyrosome
3.45	1					Seagrass sp. 1 (Fam. Zosteraceae)	
2.92	1				Amphipods		

APPENDIX FIGURES

(Appendix figure numbers correspond to their chapter and section numbers).

App. 9.2.1.1

Apogonops anomalus



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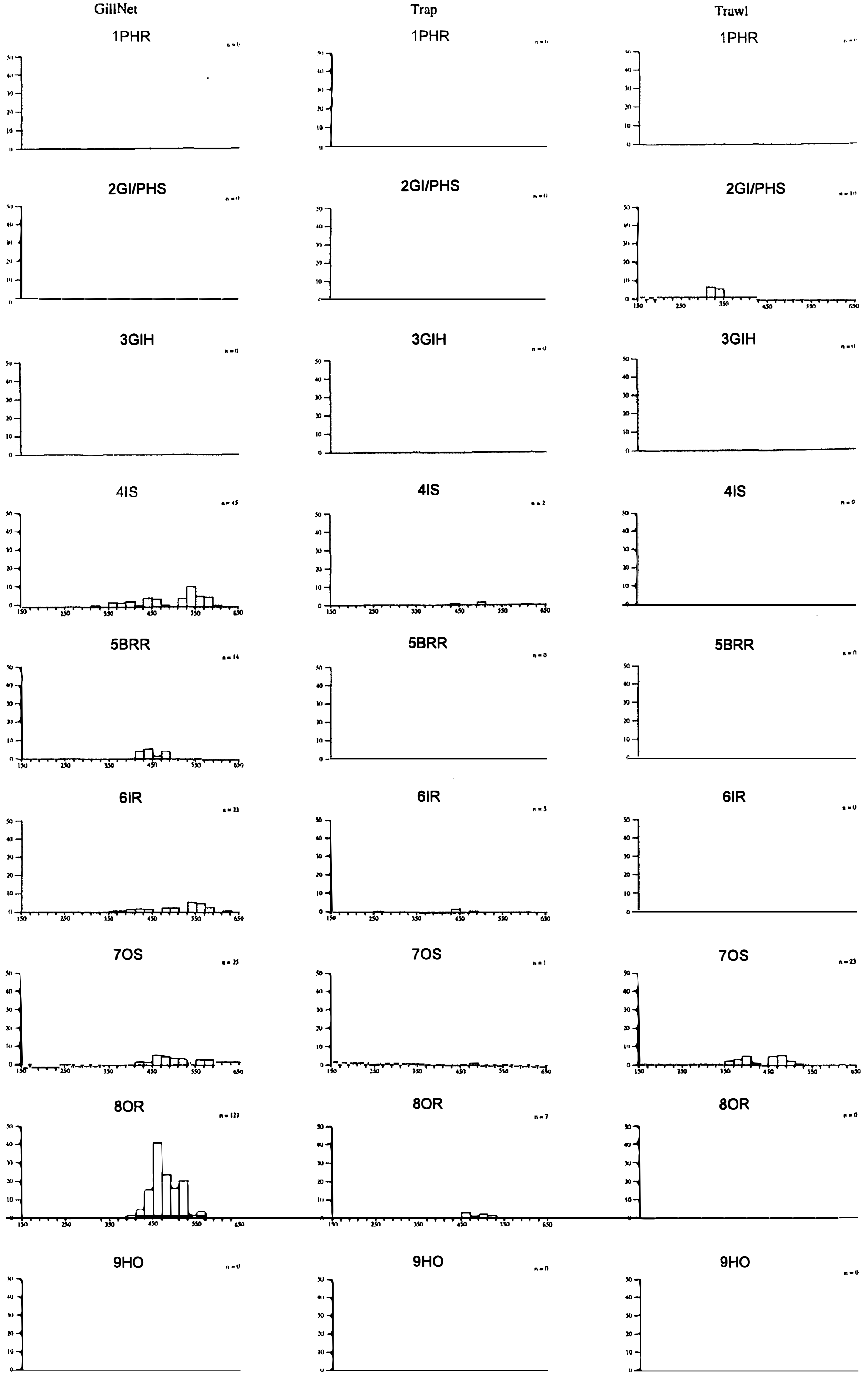
Asymbolus sp D



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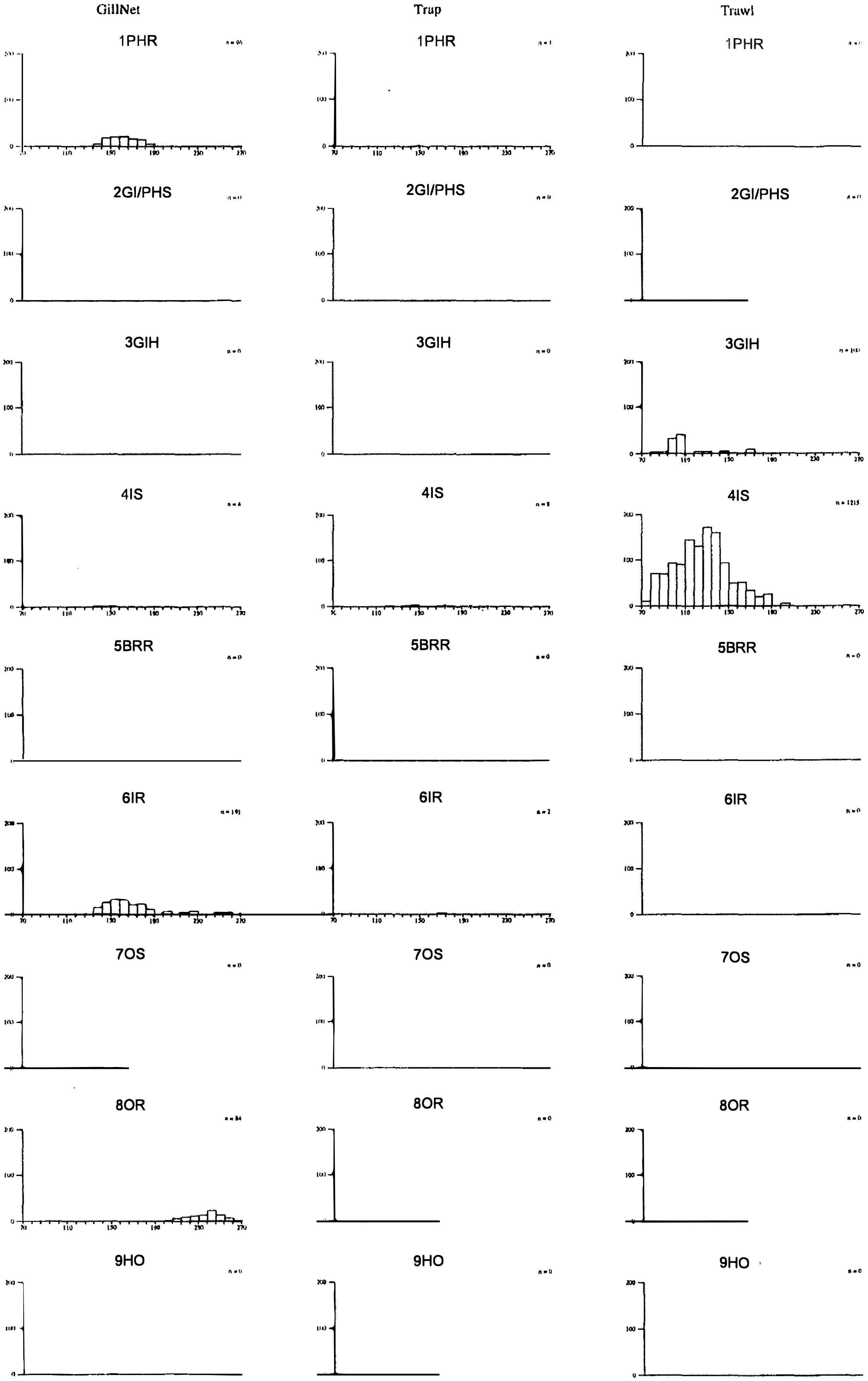
Caesioperca lepidoptera



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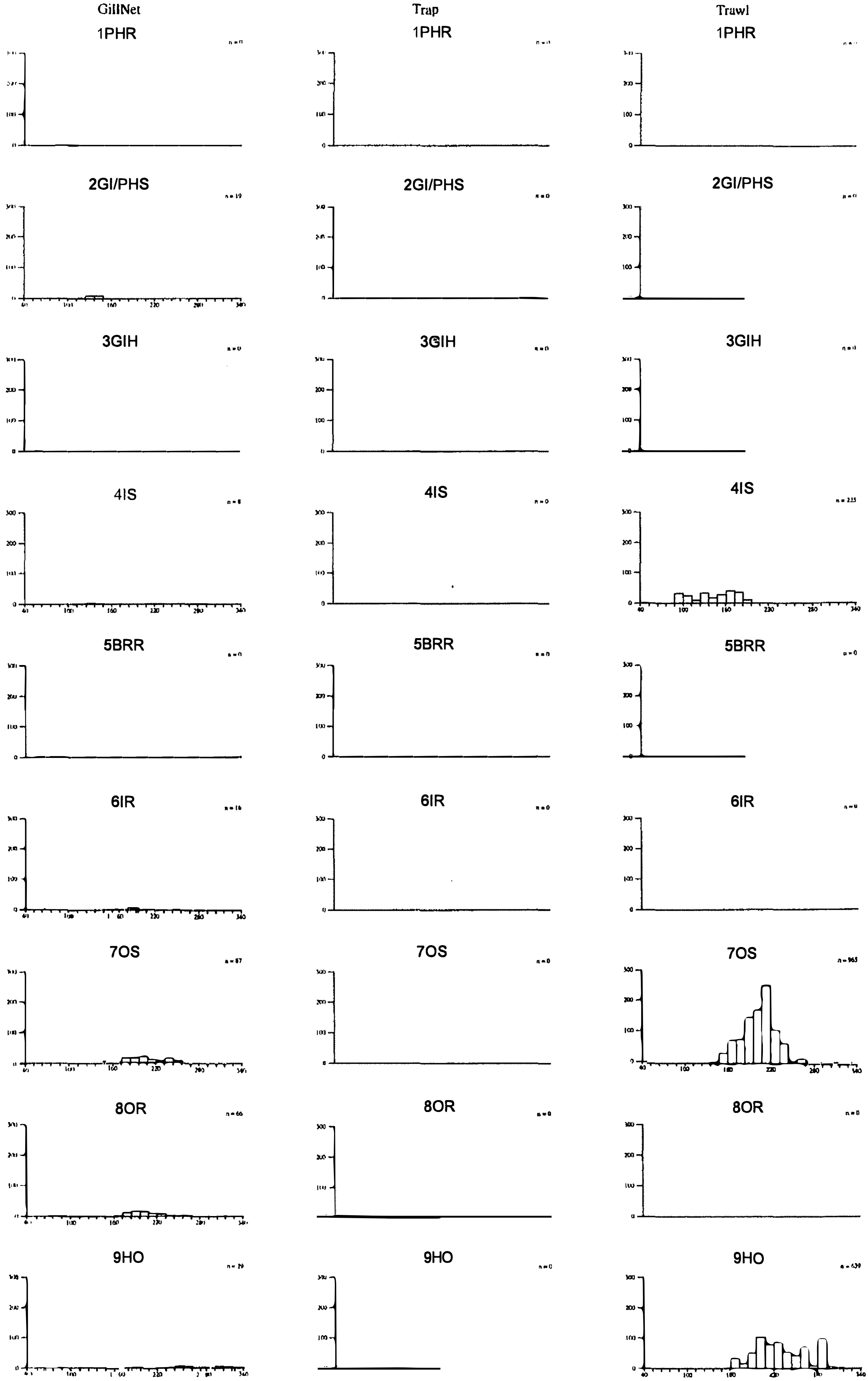
Centroberyx affinis



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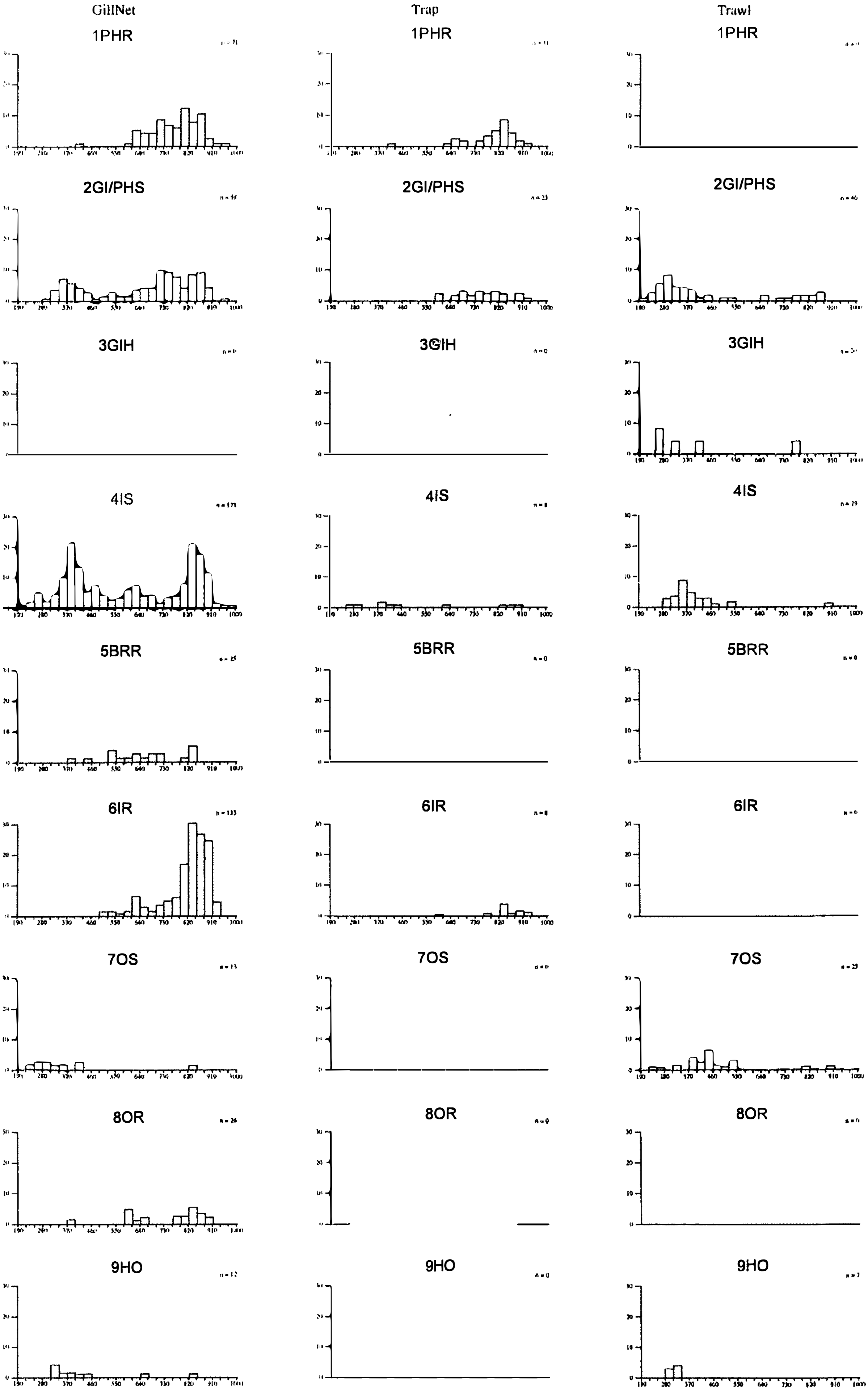
Cephaloscyllium laticeps



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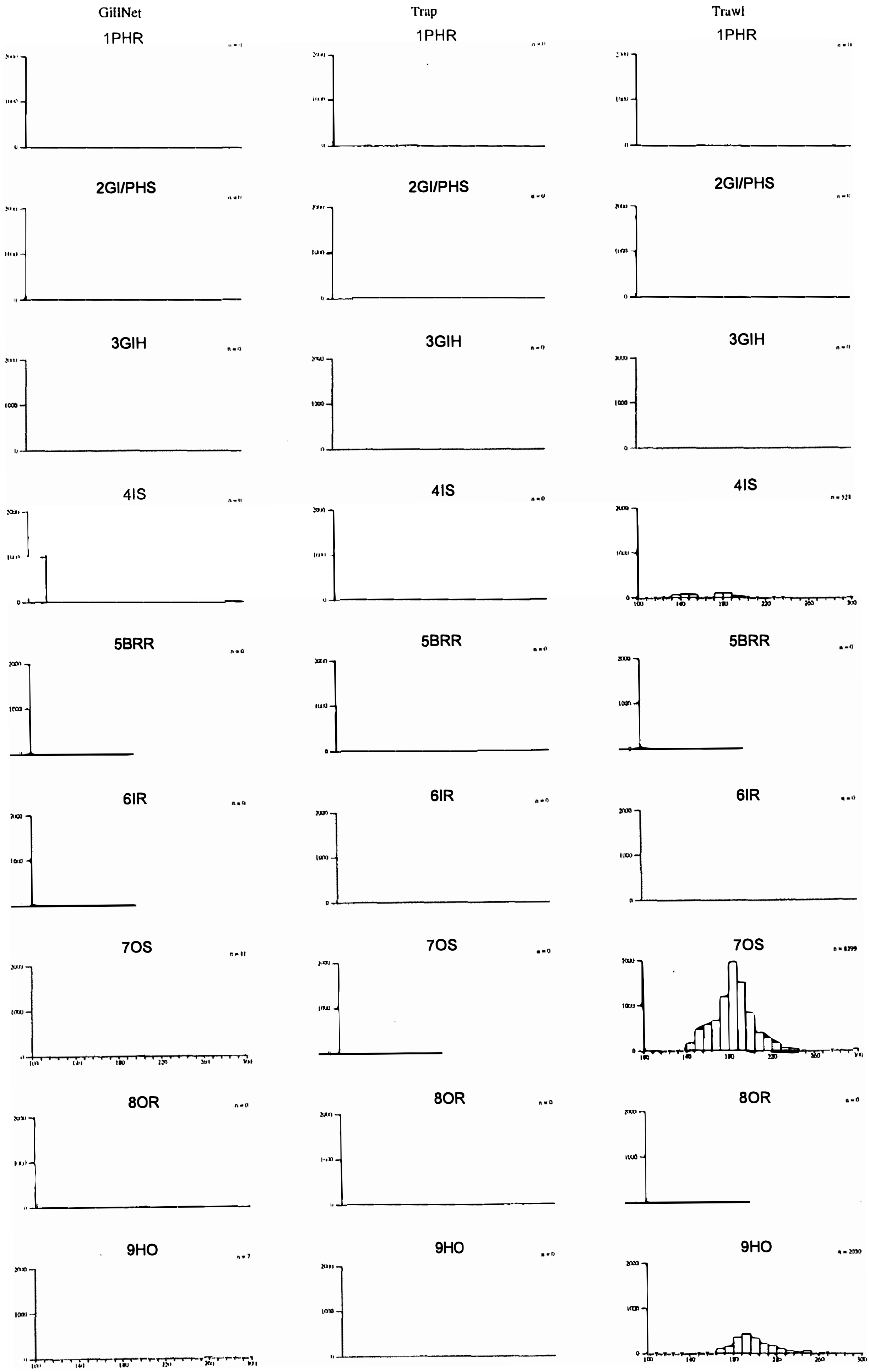
Chlorophthalmus nigripinnis



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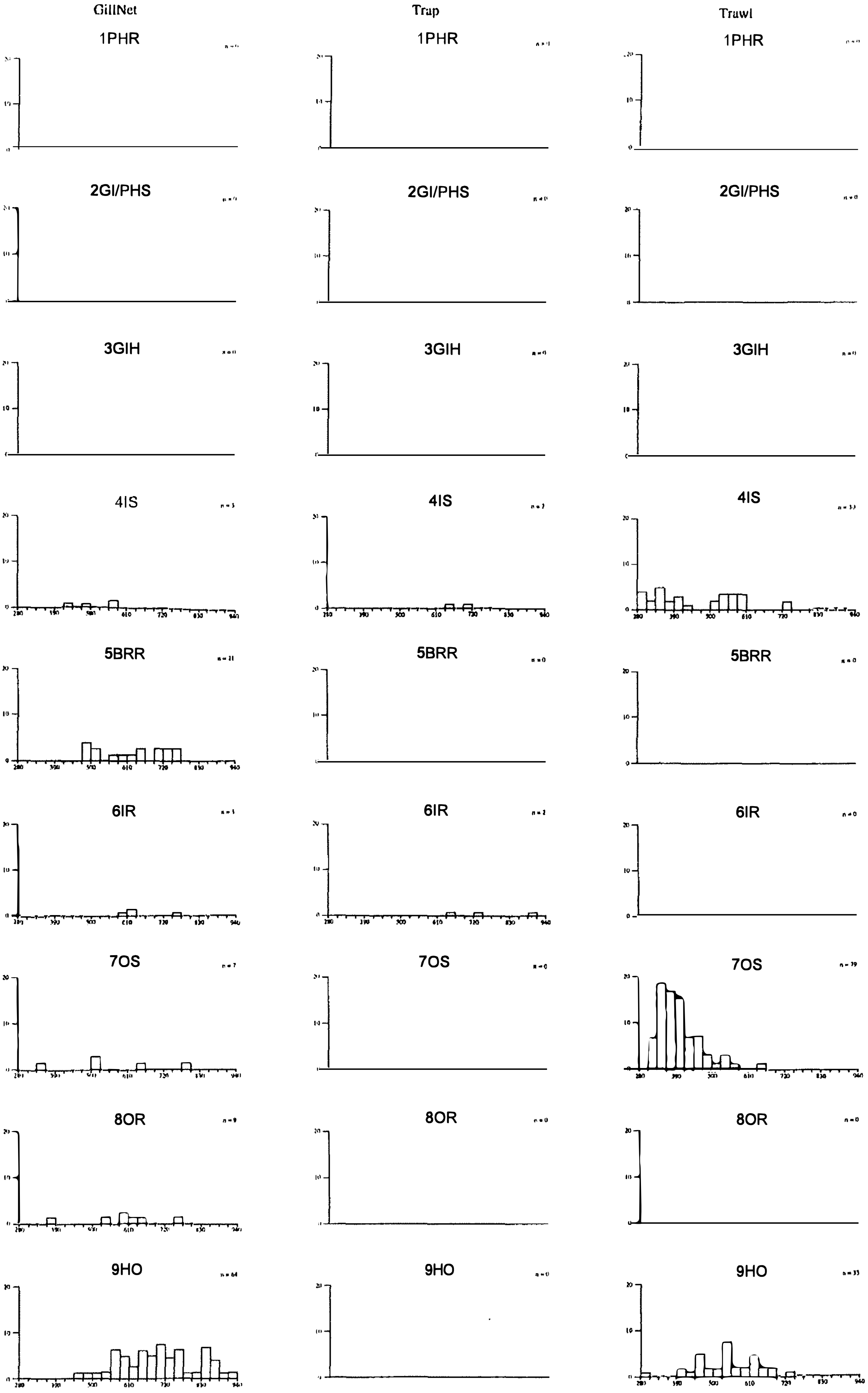
Genypterus blacodes



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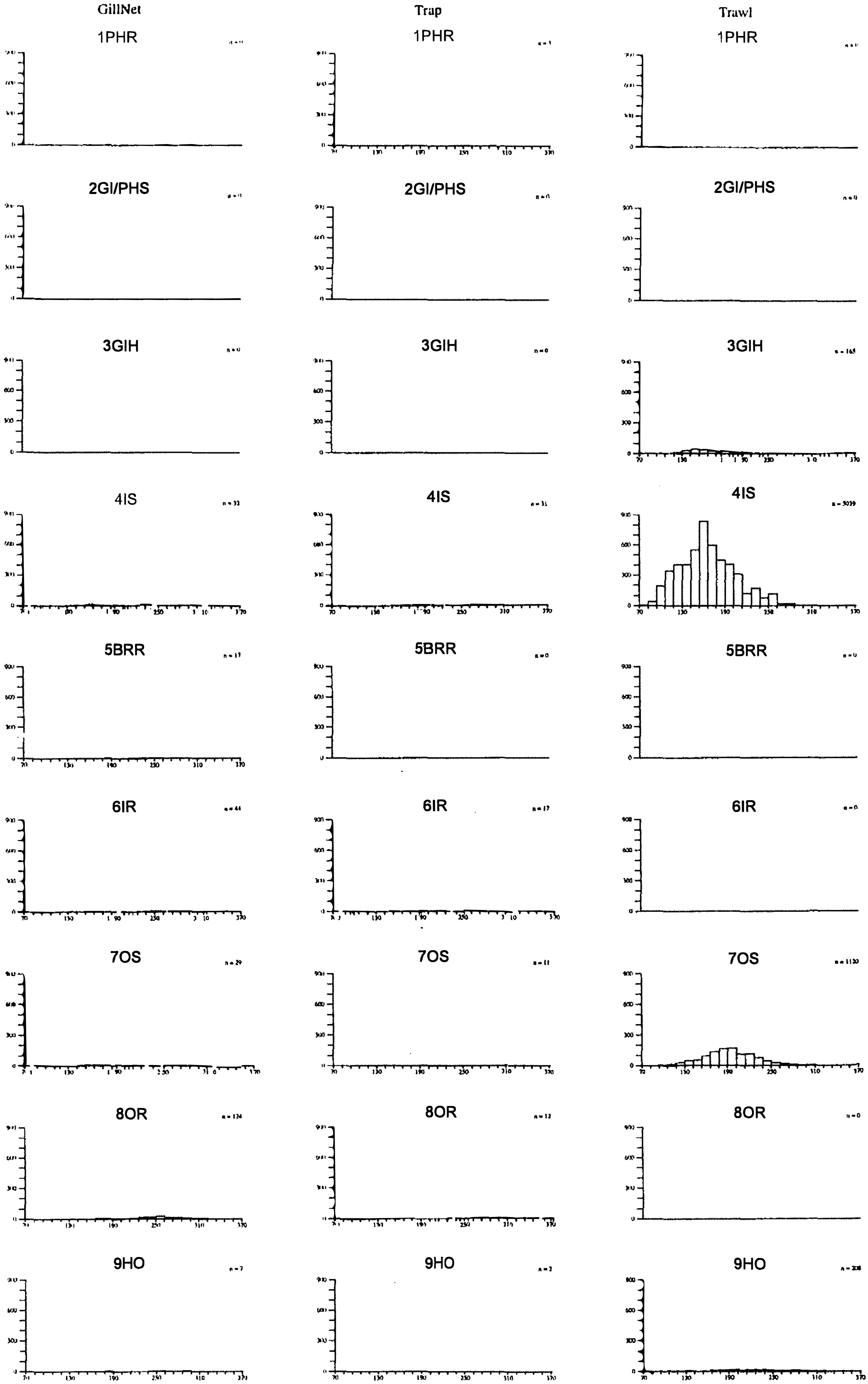
Helicolenus percoides



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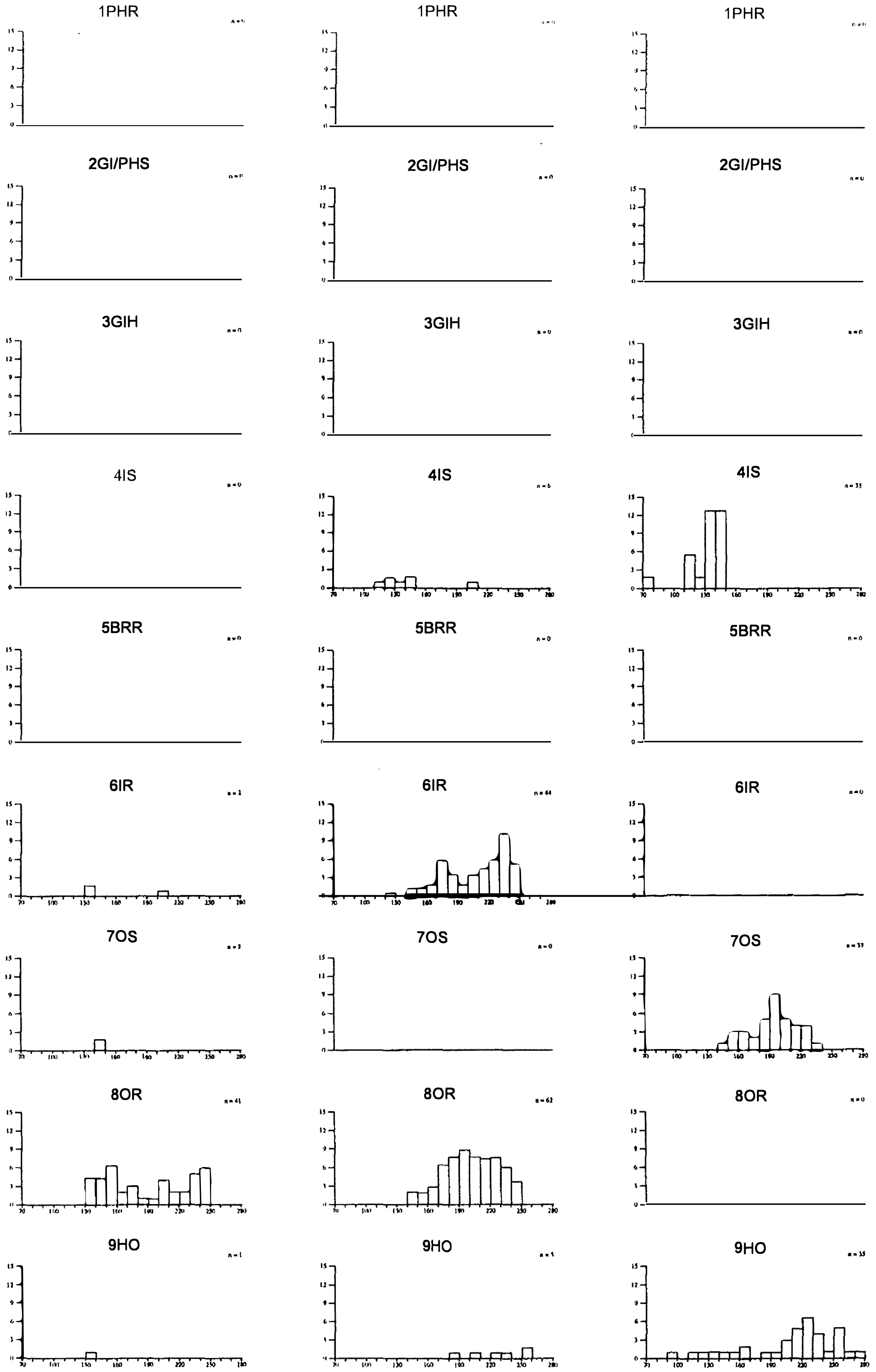
Lepidoperca pulchella

GillNet Trap Trawl



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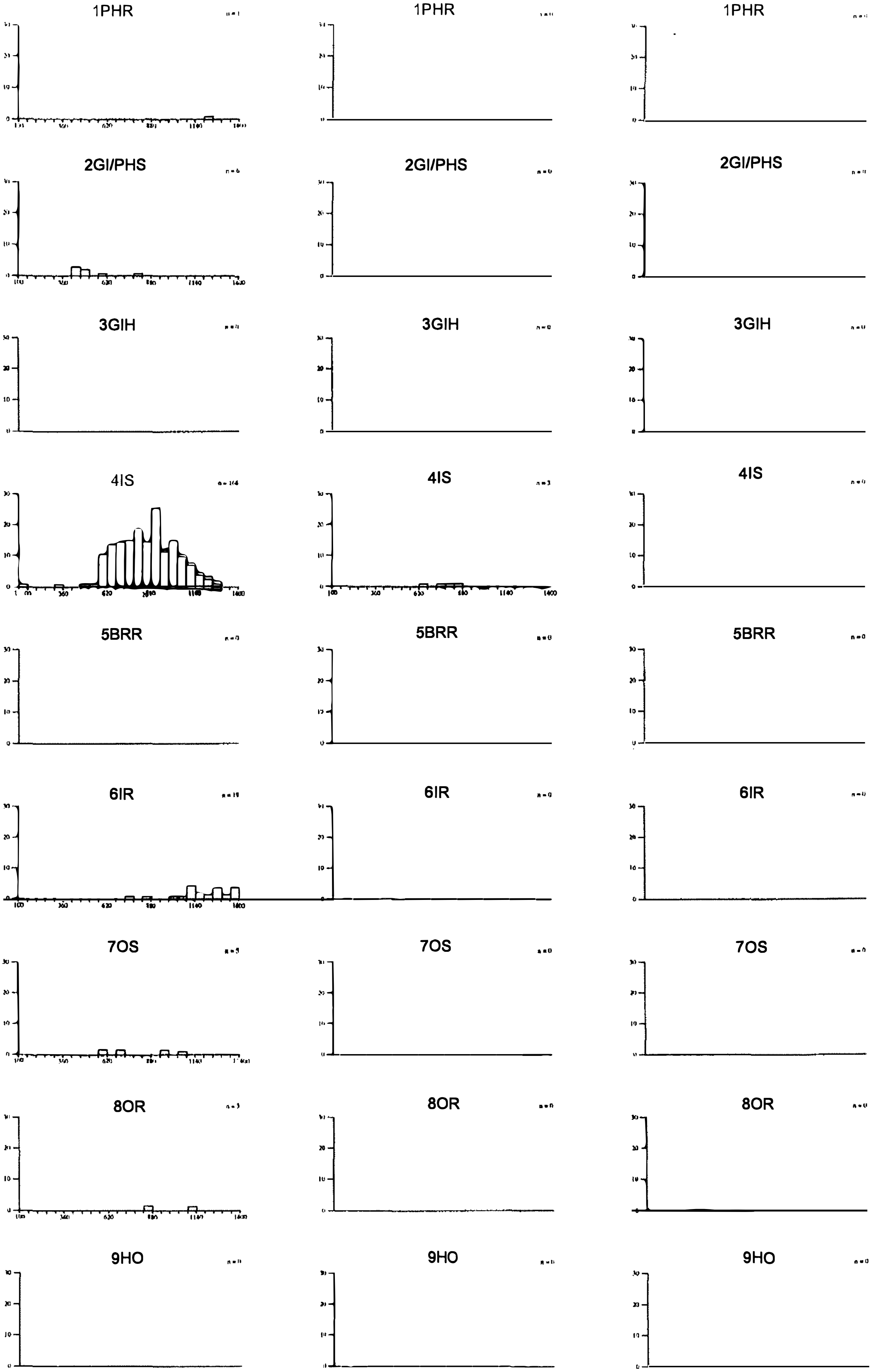
Mustelus antarcticus

GillNet Trap Trawl



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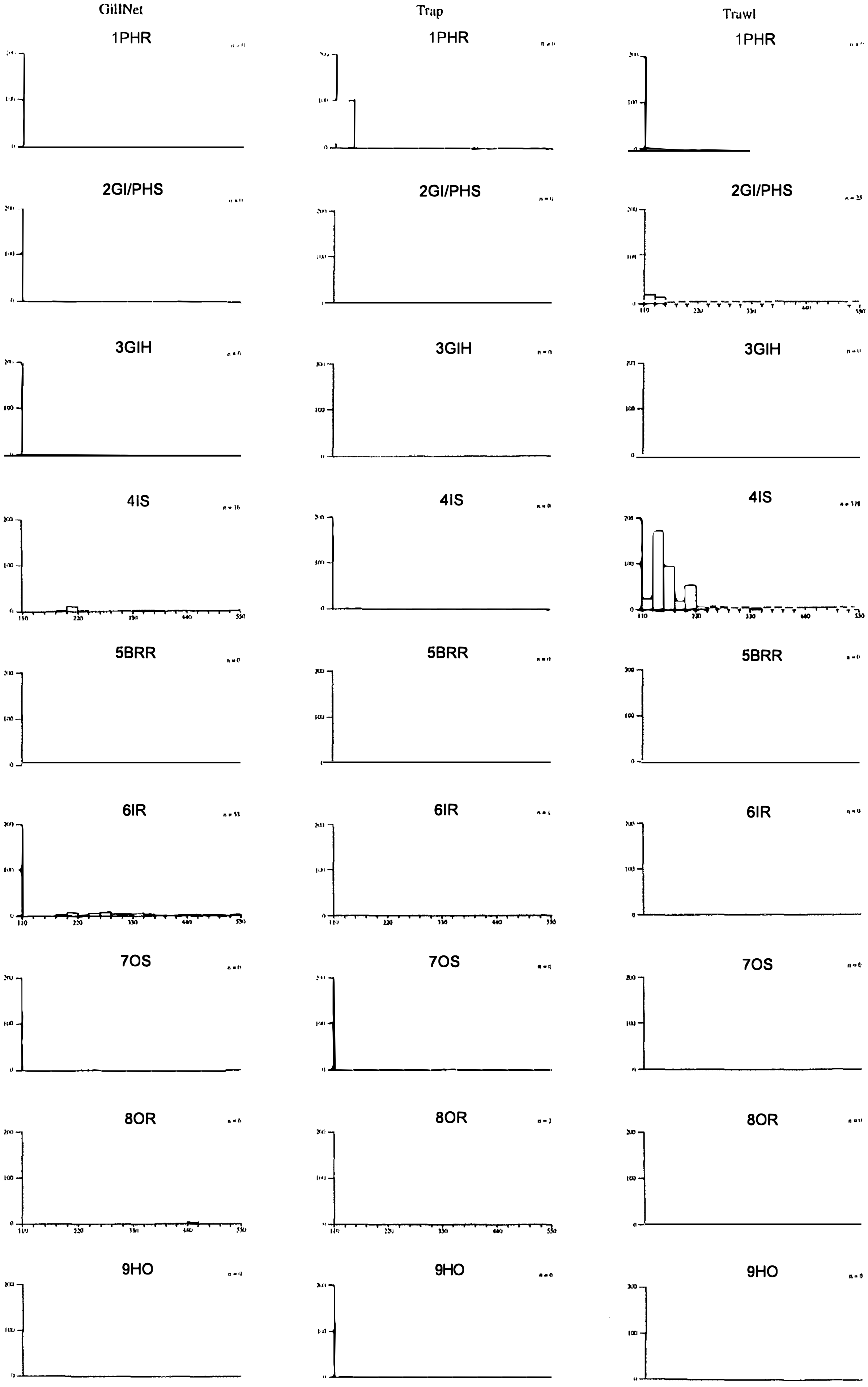
Nemadactylus douglasi



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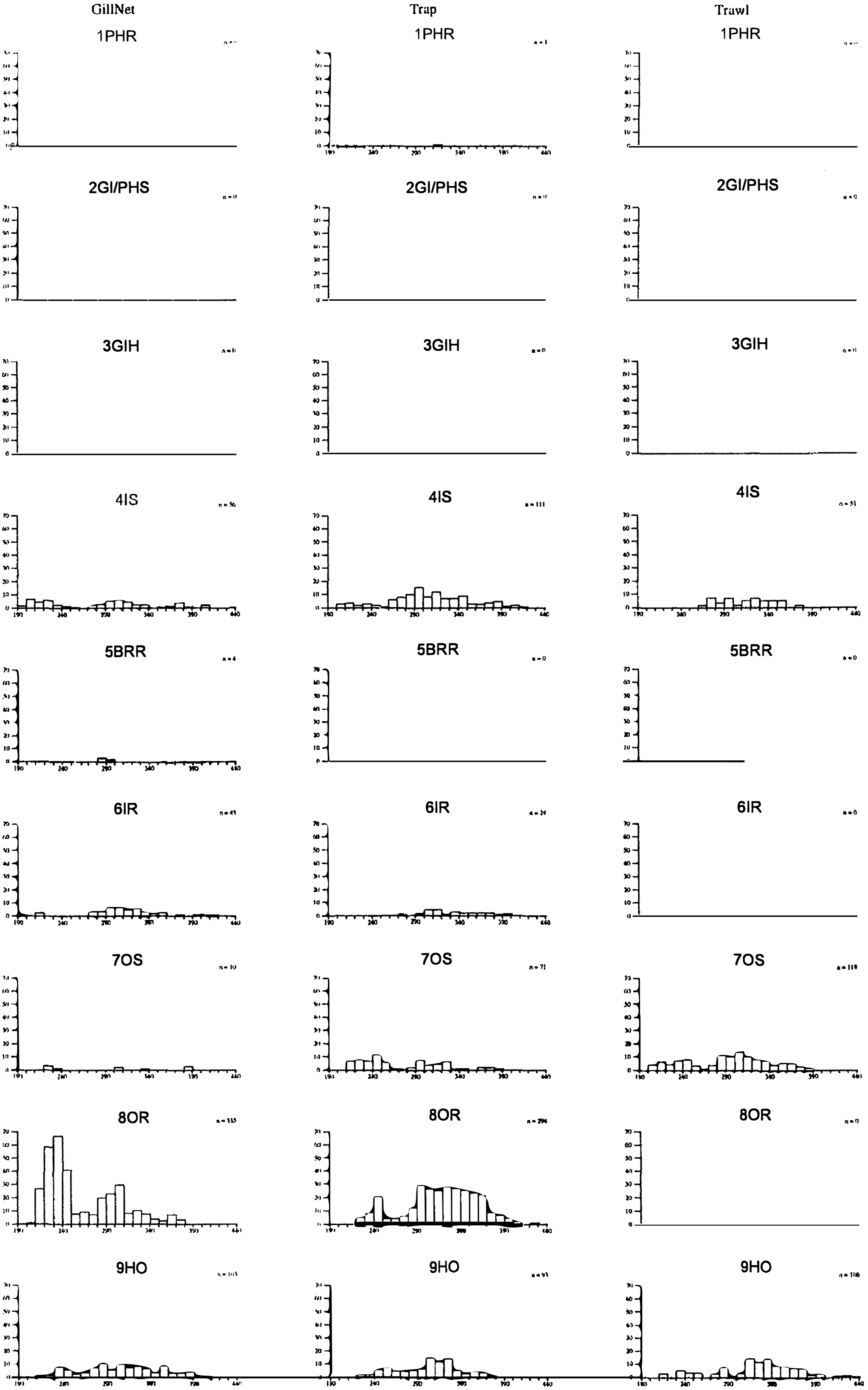
Nemadactylus macropterus



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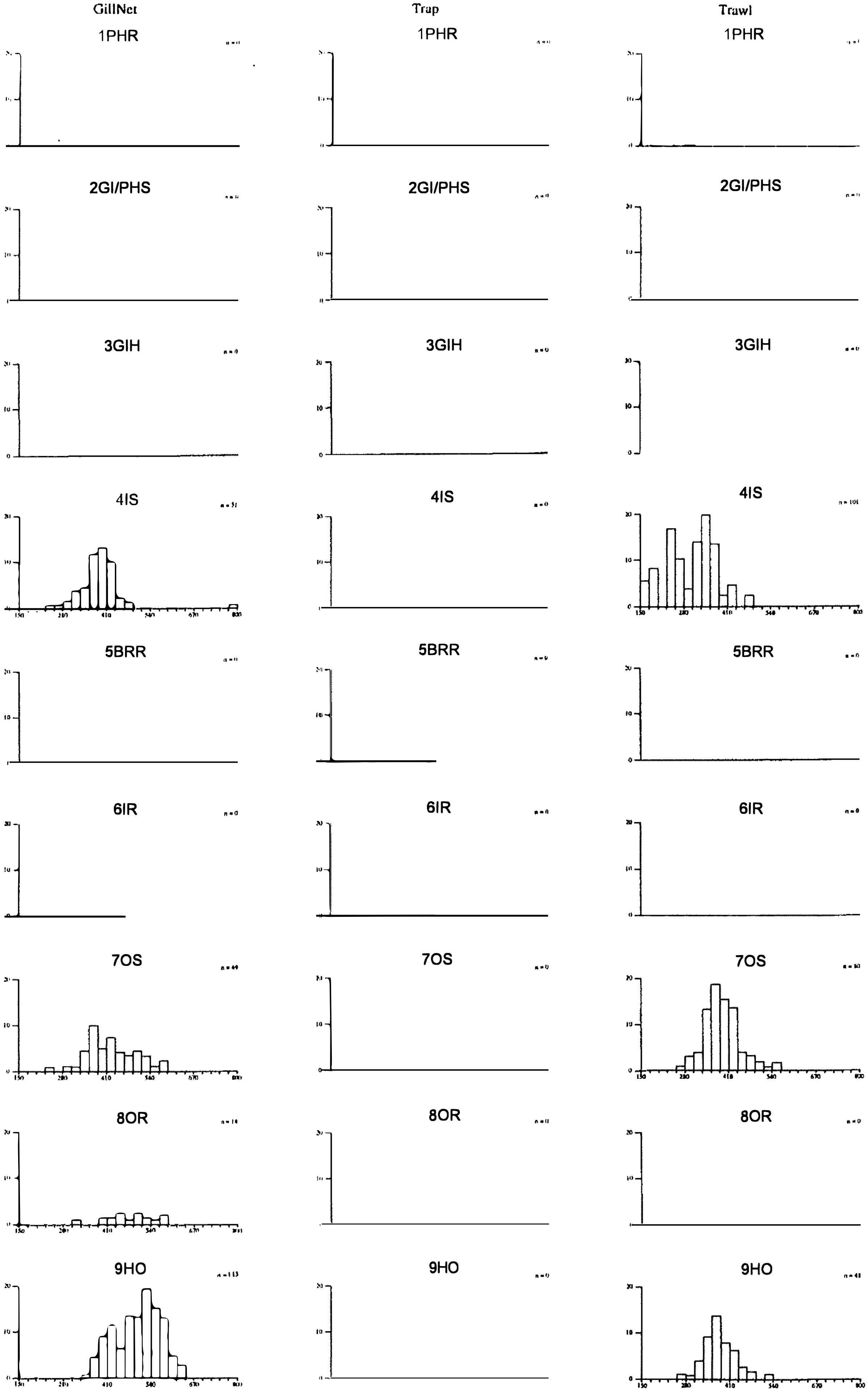
Neoplatycephalus richardsoni



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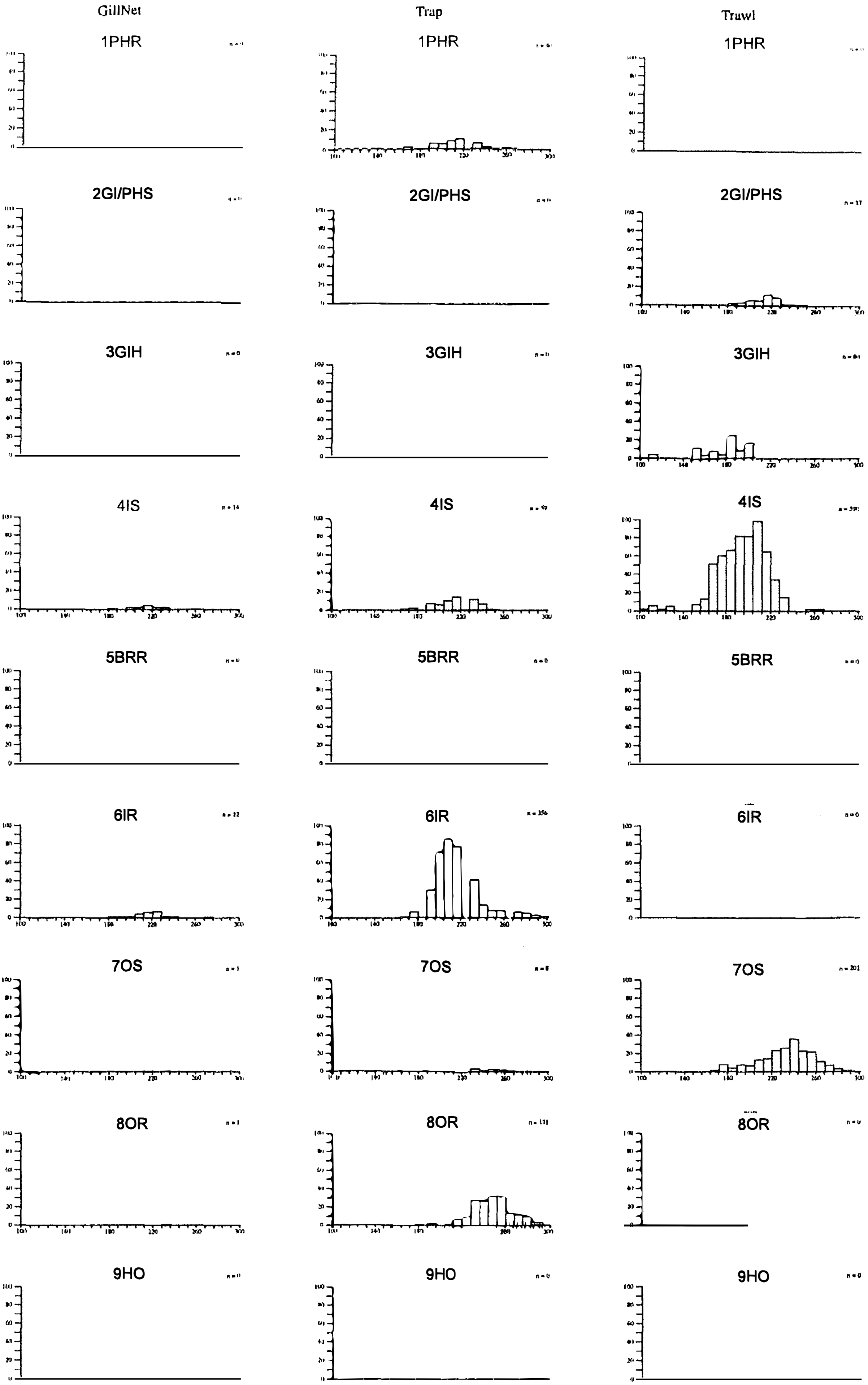
Parika scaber



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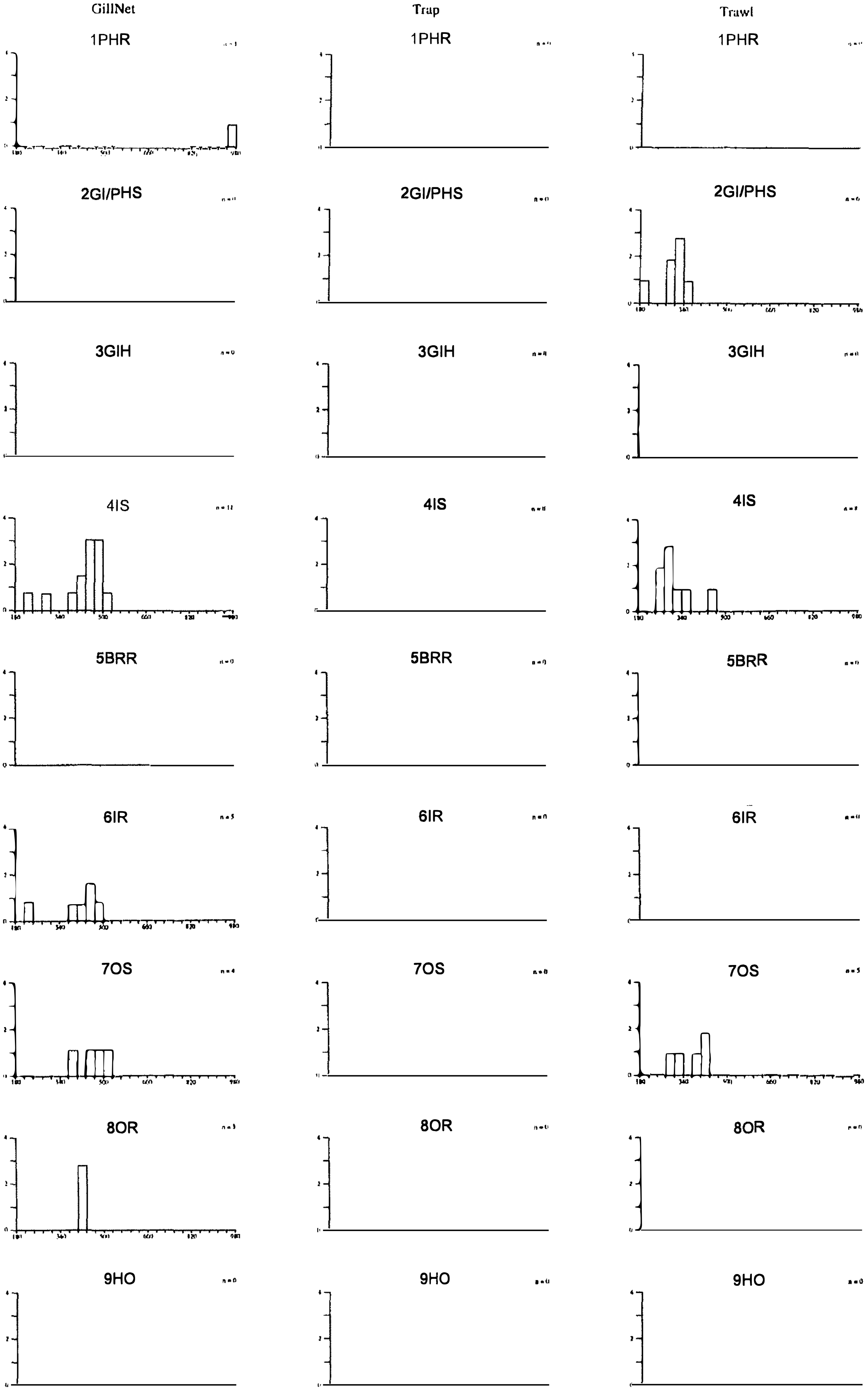
Pseudocaranx dentex



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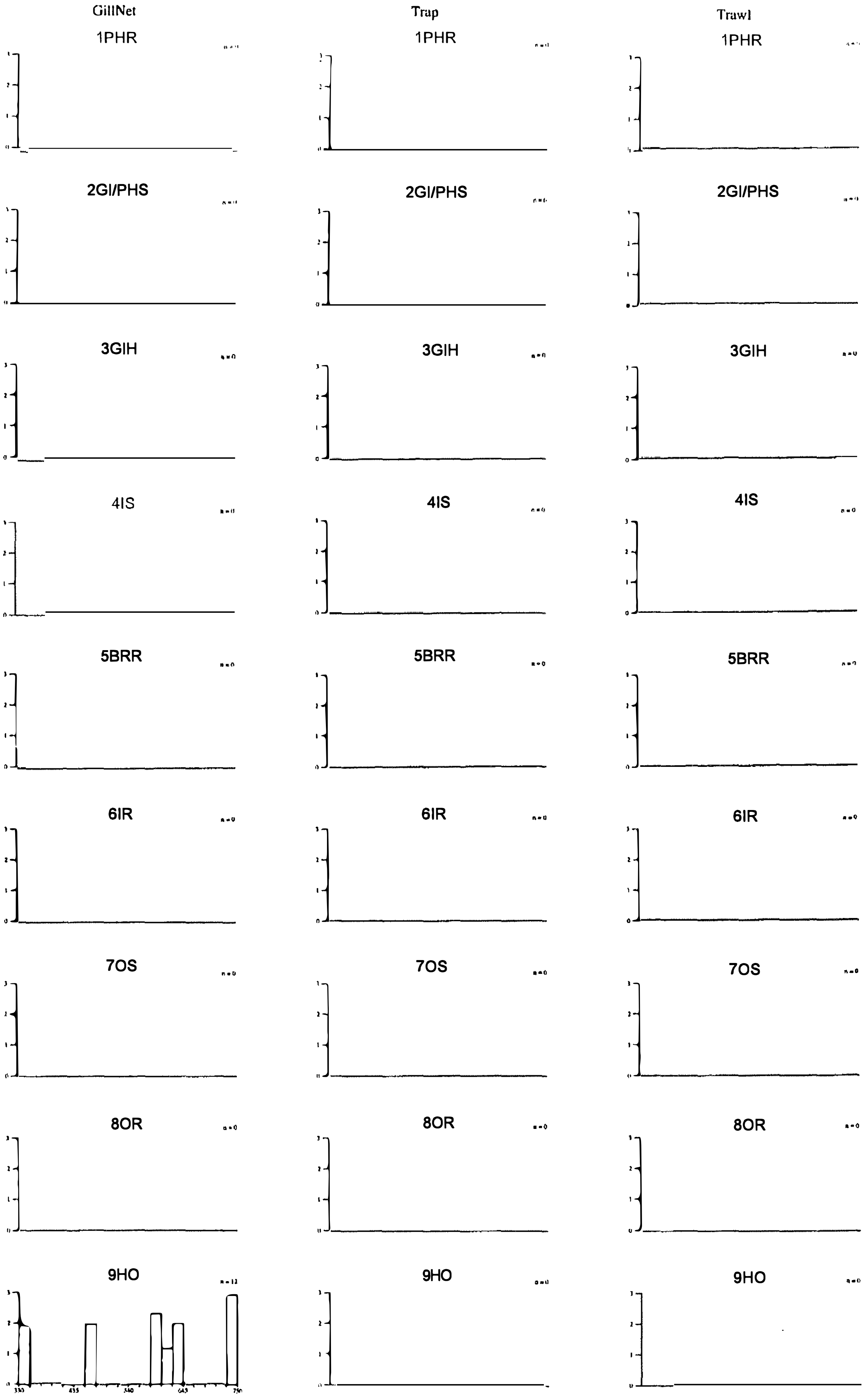
Rexea solandri



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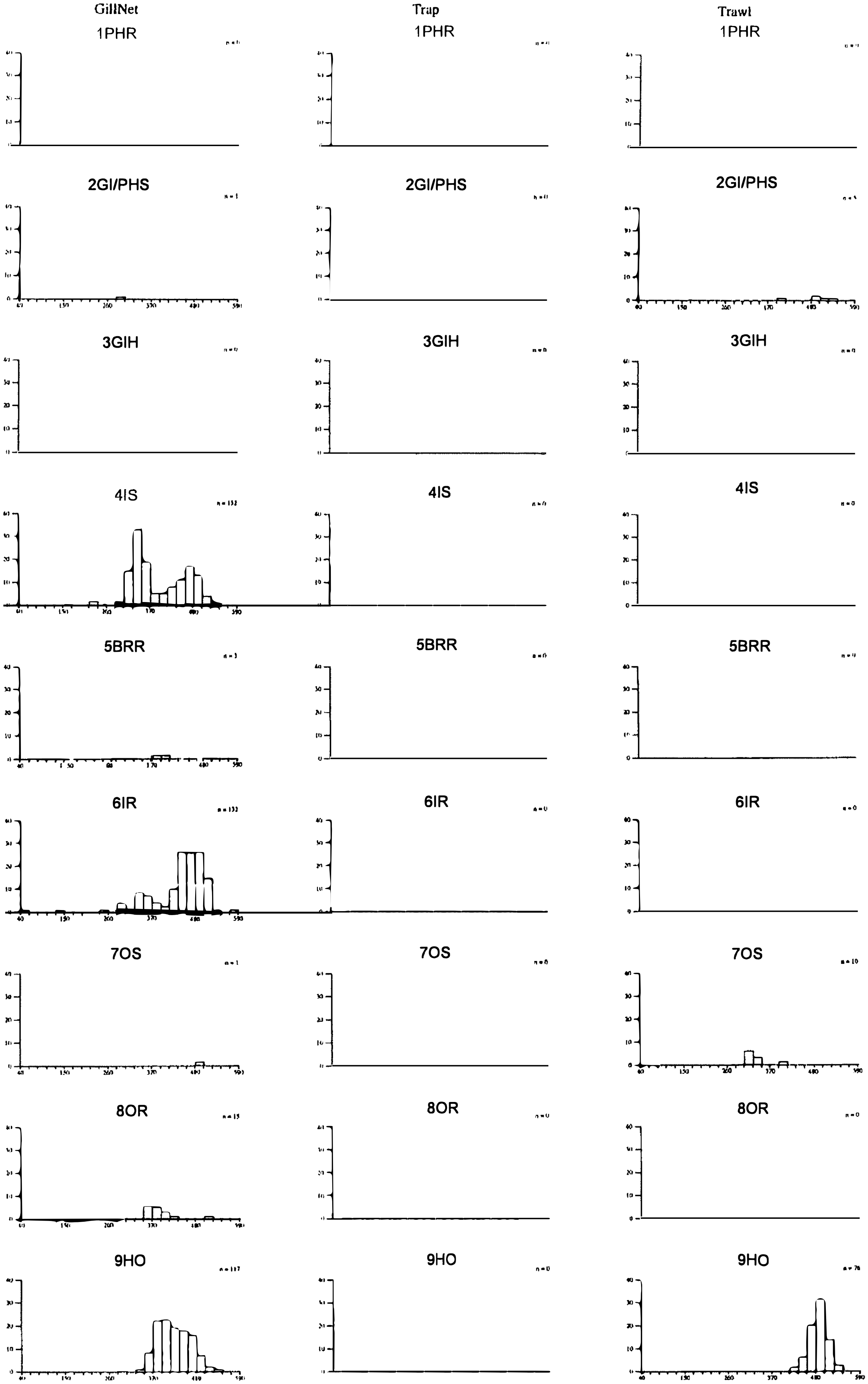
Seriolella brama



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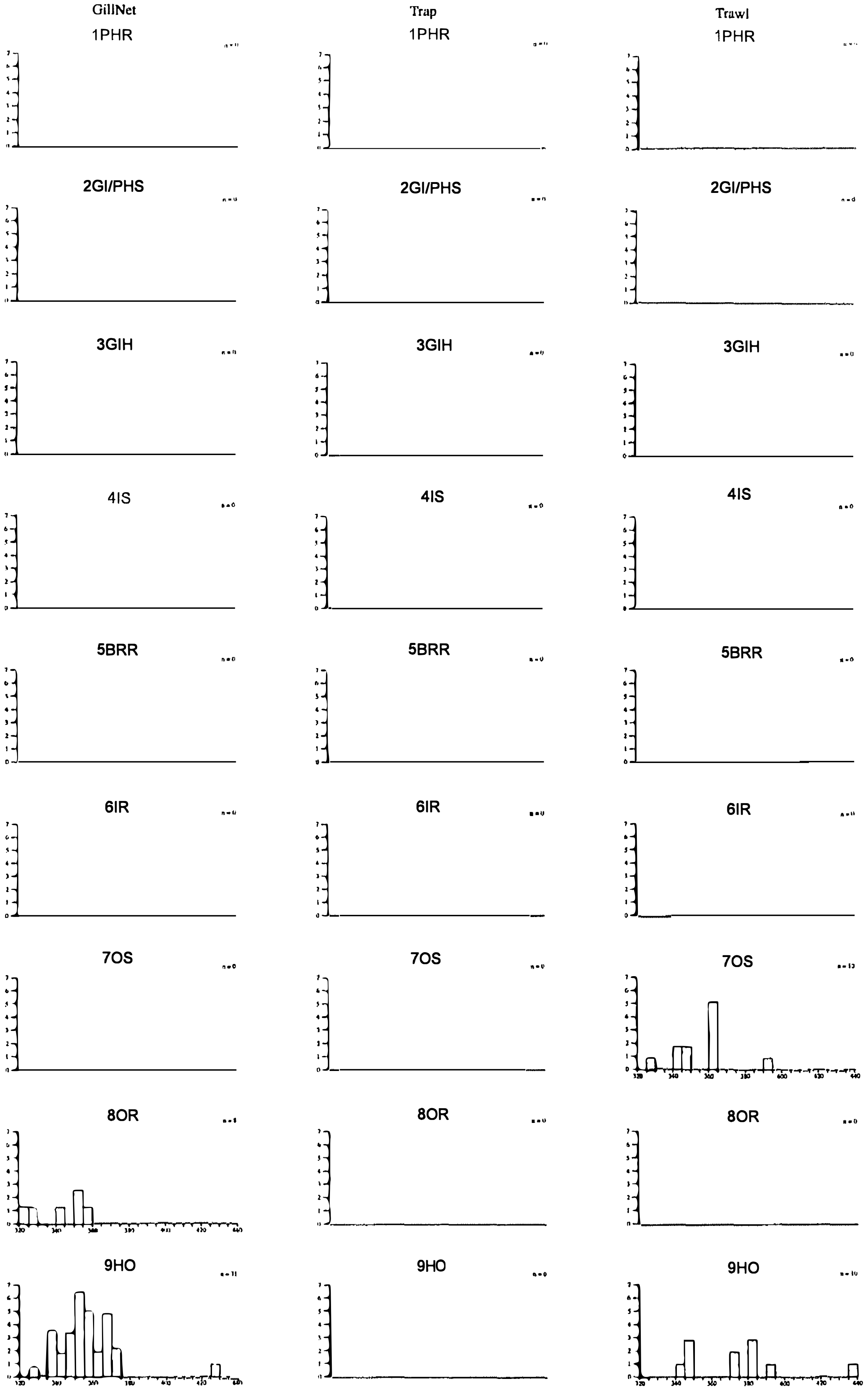
Seriolella punctata



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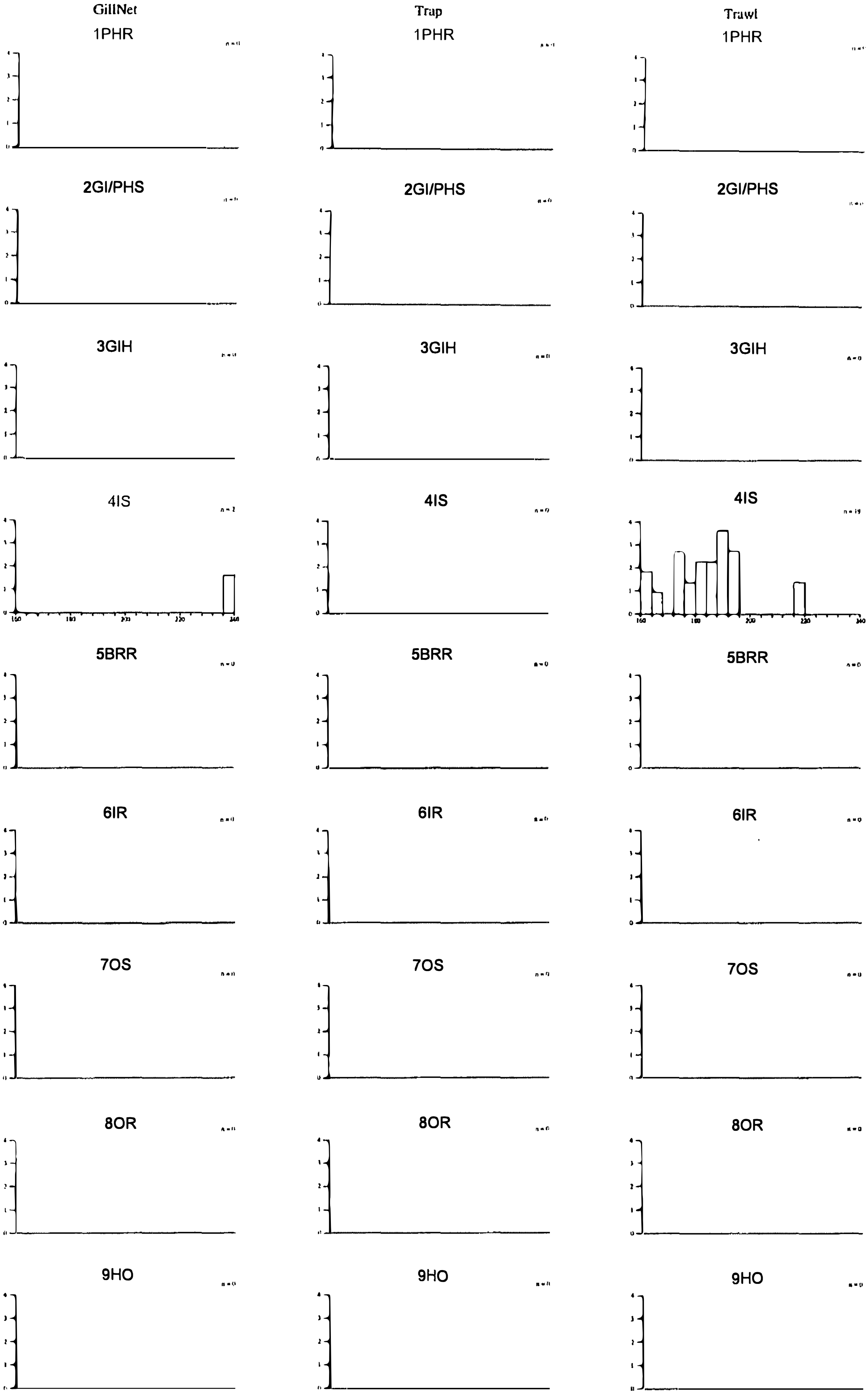
Sillago flindersi



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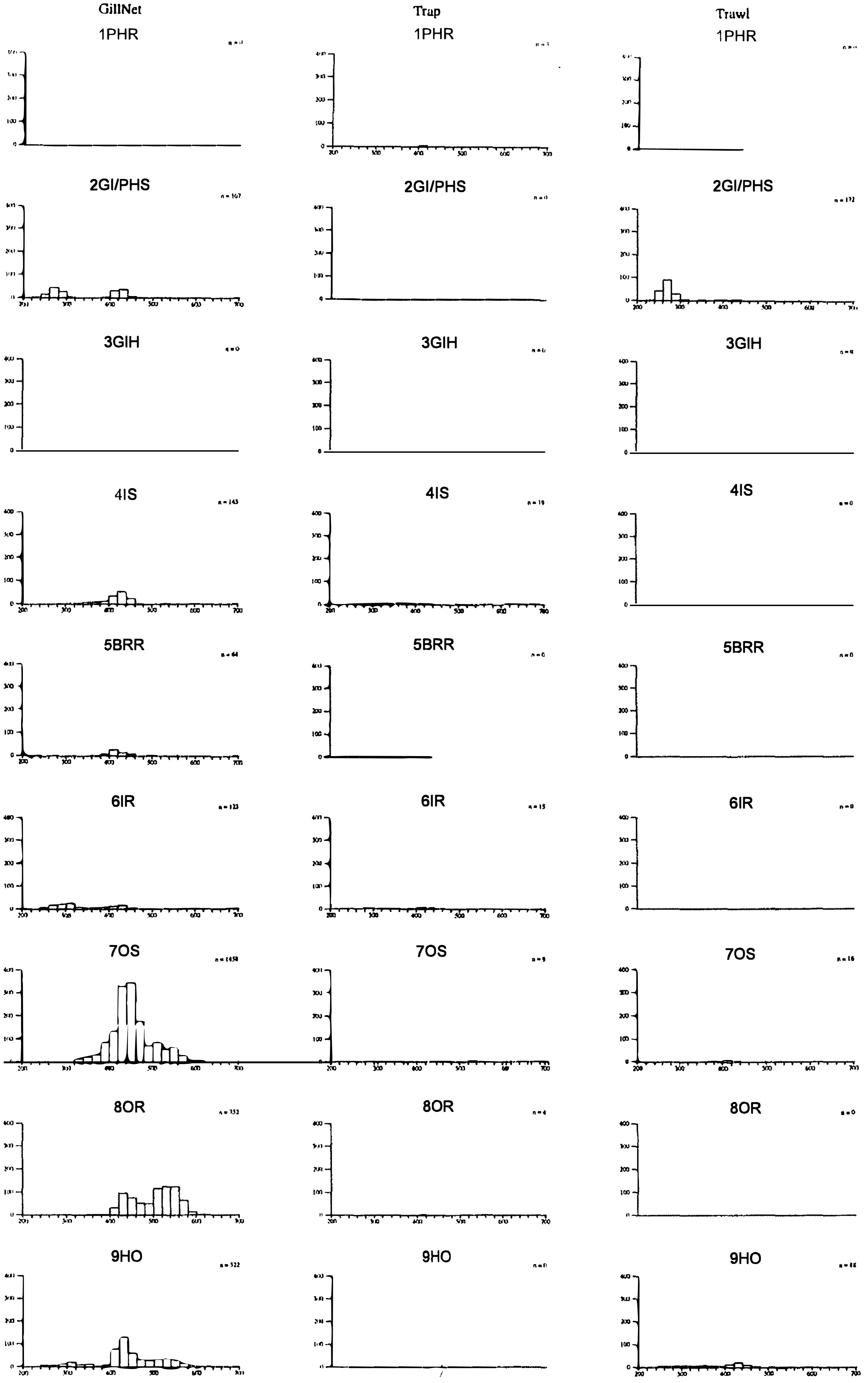
Squalus megalops



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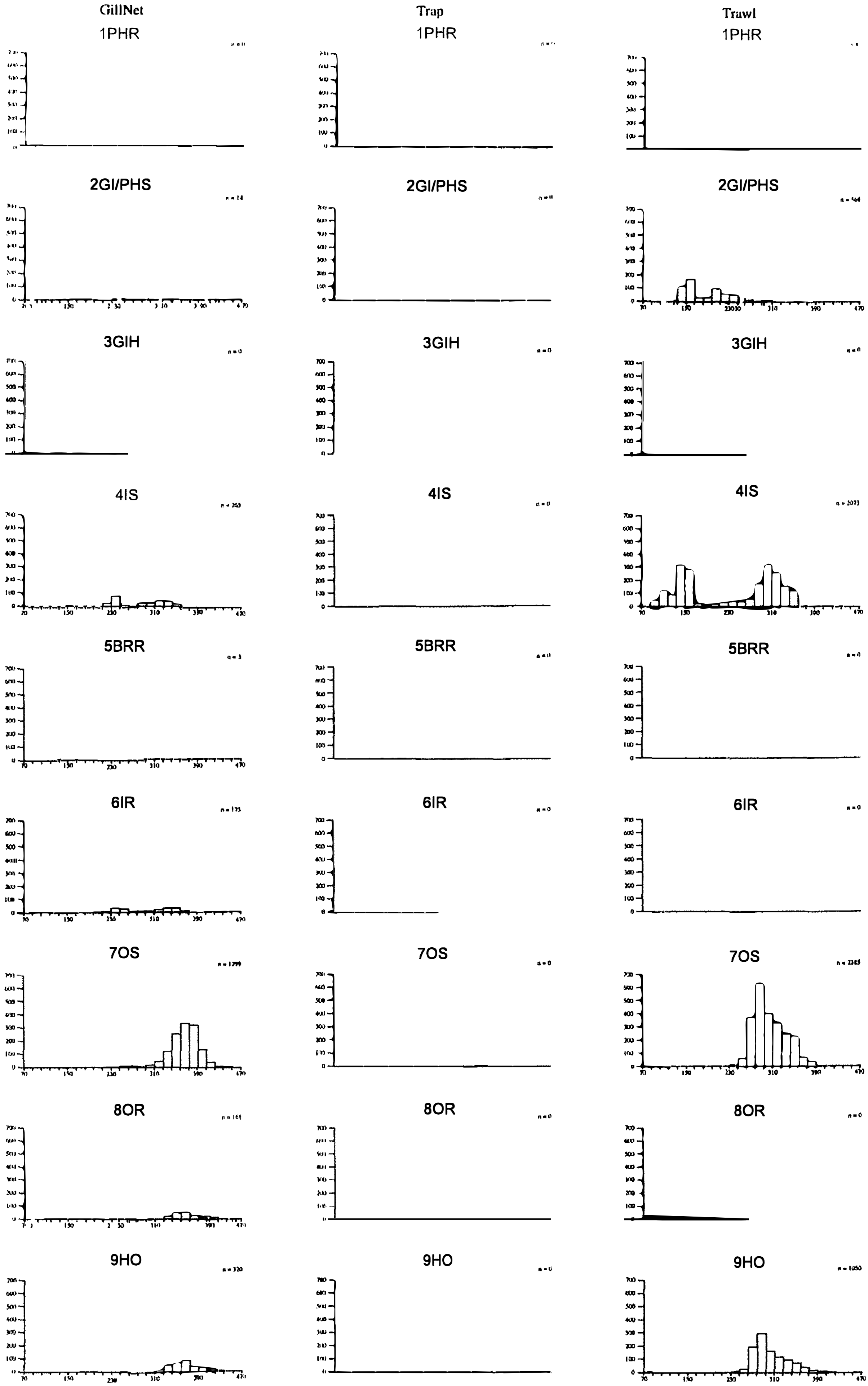
Trachurus declivis



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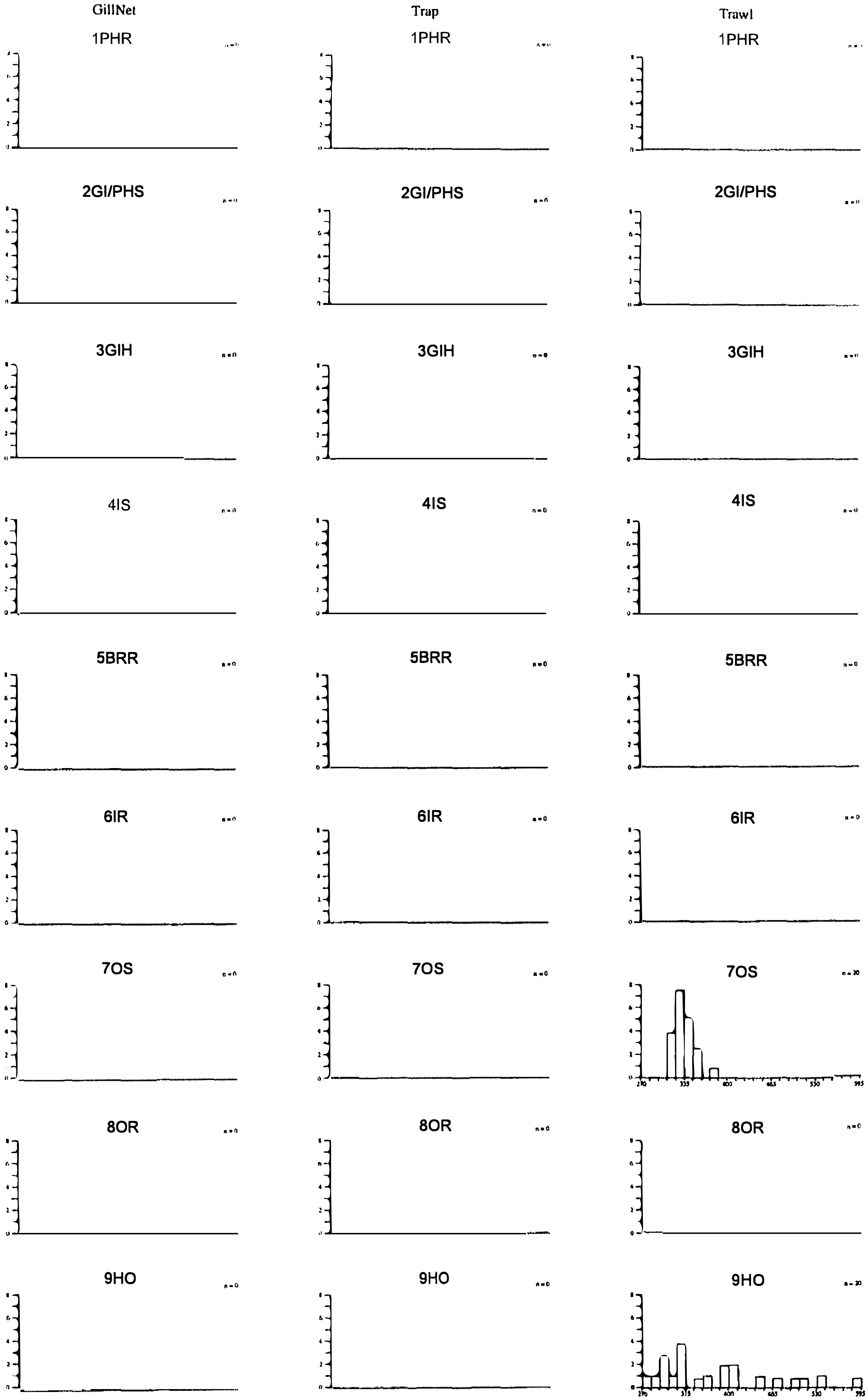
Zenopsis nebulosus



App. 9.2.1.23

Zeus faber