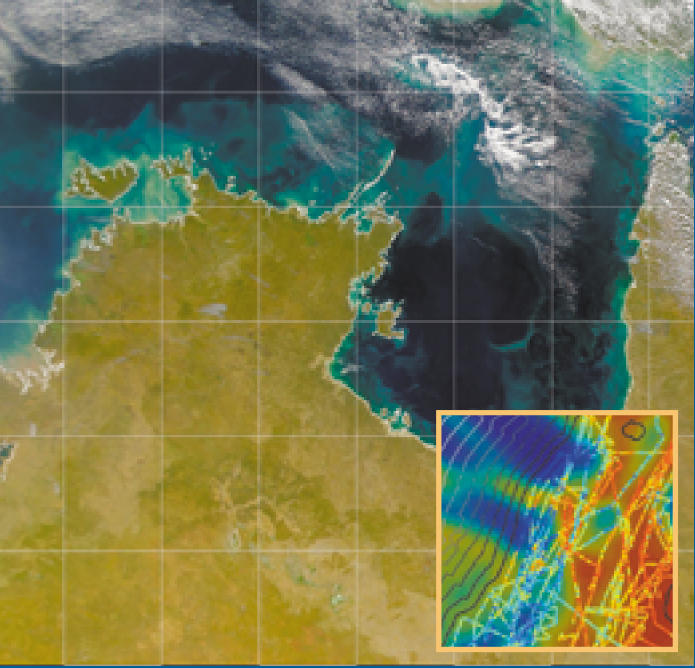

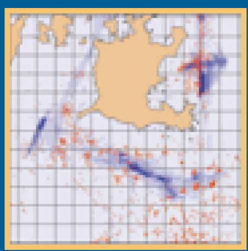

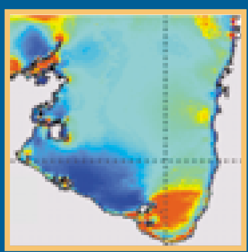

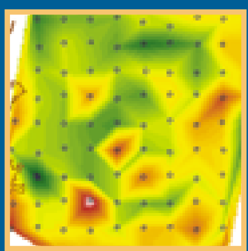

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Surrogates I – Predictors, impacts, management and conservation of the benthic biodiversity of the Northern Prawn Fishery

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SURROGATES I – PREDICTORS, IMPACTS, MANAGEMENT AND CONSERVATION OF THE BENTHIC BIODIVERSITY OF THE NORTHERN PRAWN FISHERY

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CONTENTS

NON-TECHNICAL SUMMARY

Non Technical Summary

FRDC Project 2000/160

Surrogates I – Predictors, impacts, management and conservation of the benthic biodiversity of the Northern Prawn Fishery

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OBJECTIVES

1. Assess the potential of physical, research and fishery data to classify benthic species assemblages within the NPF
2. Develop maps of benthic species assemblages, fine–scale patterns of trawling intensity and the untrawlable grounds for key areas in the NPF
3. Assess the sampling strategies required to extend the coverage of data on benthic species assemblages and untrawlable grounds in the NPF
4. Apply the existing CSIRO/GBRMPA East Coast Trawl Fishery management scenario evaluation model to evaluate the impacts of trawling on benthic species assemblages under a number of likely scenarios for several regions of the NPF
5. Develop a planning tool that will assist in identifying different reserve configurations to achieve specified biodiversity and other environmental targets, while maximising the value of the commercial fishery

NON TECHNICAL SUMMARY:

Need

Under the Commonwealth Fisheries Management Act (1991), the new Environmental Protection and Biodiversity Conservation (EPBC) Act (effective July 2000) and the Wildlife Protection (regulation of Exports and Imports) Acts 1982, fisheries have to demonstrate their ecological sustainability. In addition the Commonwealth government is committed to setting up a National Representative System of Marine Protected Areas throughout Australia's entire marine environment that will protect areas representative of all major ecological regions and the communities of plants and animals found there. NORMAC has responded by actively supporting research that investigates the ecological sustainability of the fishery. NORMAC 45 also agreed that a pro-active approach to assessing potential areas for designation as MPAs, and the impact of their potential designation on the fishery, would benefit the NPF and should be given a high priority.

The Surrogates project addresses both of these two new demands on fisheries. Firstly, it is clear that identification of areas for MPAs is complex and requires knowledge of the biological attributes of an enormous area. Surrogates offers a way of expediting this process, if physical attributes can be linked to biological ones it may be feasible to use the former to predict with reasonable accuracy the latter. Generally information on physical attributes can be collected more rapidly and cheaply than can that for biological attributes. The need for fisheries to demonstrate their ecological sustainability is dealt with in the Surrogates project in two ways. Firstly by using a variety of information to estimate the sustainability of animals captured in prawn trawls. Secondly, the project has modelled the impacts of trawling on seabed fauna using realistic management interventions.

Biological data

We reviewed existing data sets from 16 research cruises in the NPF but found that the majority were very restricted in their coverage because they were targeted at prawns not general biology. Biological coverage was limited to two cruises in the Gulf of Carpentaria (GoC); except for fish trawls there is very limited data for the NPF outside of the GoC. The first of the two data sets was collected in 1990 and involved fish trawl and dredge samples collected from 107 stations across the GoC. The second is a set of 1076 prawn trawl bycatch samples collected in 1997 and 1998 by research and commercial trawlers. This data is restricted to the commercial trawl grounds; we have no comparable prawn trawl samples from off the grounds.

Physical and chemical data

We had data on 15 different environmental variables. Acoustic data (used for describing seabed structure) has been collected for the Groote Eylandt and Wellesley Island area. Sediment data was available for many areas but the only adequate coverage was for the GoC. We found a strong relationship between acoustic data and sediment characteristics (sand and mud) indicating that acoustic data could be used to describe seabed sediments. The coverage for water quality data (oxygen, nitrate etc) was also adequate only in the GoC; reliability fell in the western part of the NPF. We developed models that describe hydrodynamics for the entire NPF. We also modelled the sediments for the GoC. These models together with the other data made it possible to examine seabed animal distributions in the GoC in relation to the physical environment.

Fine scale maps of trawl effort

We analysed over 100,000 VMS records for the NPF fleet and used the data to partition effort into 1 nautical mile grid squares. This is a 36 times higher resolution than available from the commercial logbook data. The fine-scale effort patterns reveal that the distribution of fishing effort within the 6 nautical mile grids squares is highly variable; in some areas it is relatively evenly spread across the 6 nm grid, but in other areas effort is highly aggregated in small parts of the 6 nm grid square. In some parts of the fishery, trawl effort is very much focused around the edges of patches of untrawlable ground. In contrast, in areas where the untrawlable ground is more fragmented there is no clear spatial relationship between the two.

Surrogates

Our analysis of the relationships between a wide range of environmental variables (n = 28) and biological attributes of the fish and invertebrate fauna suggests some important factors that are common to all groups. These are mud or sand and oxygen. The latter probably results from the formation of a thermocline in the Gulf in summer and this appears to affect both fish and invertebrates but because it is a seasonal event its application as a surrogate is limited. Other factors of importance are a range of water column properties but there isn't any consistent one that applies across all sampling groups.

Sustainability

Sustainability of benthic fauna was assessed on the basis of their susceptibility to being caught in a trawl and their ability to recover from any trawl impacts. The most sustainable groups included bivalves, crabs, hermit crabs and starfish. The least sustainable groups included echinoids (mainly heart urchins), soft corals, squid and sea pens. Many of the least sustainable animals are found on and off the trawl grounds and so are probably not threatened by trawling. The area between Groote and Gove has the highest number of least sustainable invertebrates, teleosts and elasmobranchs.

Threats to the seabed fauna

We undertook a review of a wide range of threats ranging from mining to agriculture. The threats were evaluated using a process developed as part of the Ecological Sustainability and using two axes – Consequences of the threat and Likelihood of the threat occurring. Estimates of these two factors for each threat were combined into a Risk factor. The threats were ranked on the basis of risk.

- Two threats were scored as being Extreme Risk – these are the introduction of a serious marine pest, and changes in rainfall.
- Five threats were scored as High Risk. These included three climate change effects (rise in sea level, rise in sea temperature and increased frequency of cyclones), changes in water flows in estuaries and the direct impacts on the benthos from prawn trawling

Impacts of trawls on seabed fauna

We estimated the impacts of prawn trawling on the seabed fauna to the GoC using data on clearance rates by trawls and recovery data derived from our previous work in the GBR region and the susceptibility of various groups estimated in this project. We then tested various management options involving different strategies for reduction in effort. An instantaneous reduction in effort by 25% (the management measure applied in 2002) had similar outcomes to a reduction over 5 years. A 50% reduction over 5 years resulted in greater relative biomass of benthos. Medium effort grids showed the greatest responses to changes in effort

Marine Protected Areas

We have set out a framework for the identification of potential MPAs. We did not attempt to identify MPAs because of a lack of adequate information and because wide stakeholder consultation is needed as part of the process. A flow chart for the process is presented. The starting point of the process is seen as adequate stakeholder consultation. Stakeholders would be asked to identify objectives and values to be used in the process. There are serious shortcomings in the data presently available for the NPF managed area. It has high biodiversity with 15 IMCRA bioregions identified but most of these have not been surveyed. Apart from the prawn trawl fishery, there is a lack of available economic data that could be used in the process.

OUTCOMES ACHIEVED

- The project has demonstrated that the recent major reduction in trawl effort undertaken by NORMAC will have positive effects on the seabed fauna. We can expect substantial recovery of this fauna over the next decade. This information will assist AFMA and NORMAC in meeting their obligations under the EPBC Act in demonstrating the sustainability of the fishery.
- The project has summarised the issues surrounding establishment of marine protected areas in the NPF. It also provides advice to managers on the techniques that should be used in the identification of suitable areas including extensive stakeholder consultation, information needed and suitable computer software for the analyses needed to optimise reserve selection.
- The finding in the project that a high proportion of the seabed fauna most susceptible to trawling occurs in the north-west part of the Gulf of Carpentaria will contribute to strategic planning for spatial management of the NPF with respect to Marine Protected Areas
- The NPF now has a substantial Threat Analysis for the seabed fauna as well as a method that can be used for evaluating threats. The results of this evaluation will be valuable in strategic planning for the NPF.
- Detailed information on distribution of wave height, seabed current stress, seabed substrate composition and fine scale distribution of effort has been used in identifying suitable areas for establishing experimental plots in the new Effects of Trawling project (FRDC 2002/102). The information enabled the selection of two areas with high environmental contrast and which are unlikely to be trawled commercially during the course of the experiment.
- The results of the project have been used in planning a joint CSIRO-Geosciences Australia project using the Southern Surveyor National Facility to explore the geological and biological structure of the western Gulf of Carpentaria. Specifically information on fine scale distribution of trawling, untrawlable grounds, sediment distribution and seabed current stress was used to identify a suitable area for the study.
- The inadequate biological coverage of the NPF outside of the Gulf of Carpentaria has been drawn to the attention of the National Oceans Office and discussions are underway to collect additional data to fill the gaps. The relationships identified in the project between physical environmental factors and biodiversity will assist in the planning of this additional data gathering.

KEYWORDS: Surrogates for biodiversity, Sustainability of benthos in the Northern Prawn Fishery, Modelling of physical attributes of the NPF region, Hydrodynamic Modelling, Acoustics as surrogates, Marine Protected Areas, Fine scale mapping of trawl effort, Modelling impacts of trawling on seabed fauna, Threat assessment for the NPF.

CHAPTER 1

INTRODUCTION

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Burke Hill

CHAPTER 1

INTRODUCTION

Burke Hill

> Surrogate, n Deputy, esp of bishop or his chancellor [Latin: Sur (rogare ask) elect as substitute (Concise Oxford English Dictionary)

While the above definition is reasonably clear, the term surrogate has developed a far wider meaning in the modern world outside the ecclesiastical one. An Internet search for example, reveals a wealth of sites dealing with surrogacy as relating to child bearing. In ecology, although the term carries the connotation of a substitute, it also involves some degree of simplification – something that does not apply to surrogate mothers. Ecologically, surrogates attempt to use a relatively easily measurable property or properties of the environment as a substitute for more complex – and more accurate – measures of the real situation. In the USA for example, the number of reports of contamination of water supplies in a catchment, is used as a surrogate of overall water quality. Frequently, ecological surrogates combine information from more than one source. The distribution of many plants can be described by a combination of rainfall, annual temperature and soil type. Information on this physical environment can be gathered over large areas at a far lower cost than can vegetation surveys. Surrogates can be biological as well as physical or chemical - the distribution of a particular species may be an accurate predictor of the distribution of a certain habitat. Factors that are key drivers in an ecological system will often be the best surrogates – in the sense of being the most reliable predictors.

Unfortunately, the real situation is often complex and there may for example be interactions between temperature and rainfall such that a particular plant species or group can survive at different temperatures depending on rainfall and soil. In reality then, identification of surrogates is frequently quite difficult and requires a great deal of background information.

The complexity and cost of ecological surveys of the seabed has been a major limitation in exploration of an environment that encompasses two thirds of our planet. Seabed classification is at a far earlier stage than classification of terrestrial ecosystems where many hundreds of vegetation types alone are usually commonly distinguished. Our lack of detailed knowledge of the seabed results in an oversimplified system of classification into broad categories such as reefs, sandy plains or muddy plains. These categories are comparable to using descriptors such as forests, swamps or deserts on land. Collecting data to provide more accurate and useful descriptors is not only expensive, it is also time consuming and so unlikely to be achieved in reasonable time frames.

This is especially true of the area chosen for this study – the Northern Prawn Fishery. It is large, remote and there is little available information. Clever use of surrogates would appear to offer a feasible solution to the problem. Anon (1999) for example selected two taxonomic groups – corals and echinoderms – as indicators of reef habitats around the Wellesley Islands in the southern Gulf of Carpentaria. A study by Ward et al., (1999) suggests that indicator groups may be useful in identifying potential reserves. Gladstone (2002) found for example that molluscs appeared to be a reliable indicator for the occurrence of other species of intertidal fauna and could possibly be used as an indicator or surrogate. Surrogates are frequently used to characterise biodiversity since this is generally accepted as a key property that needs to be taken into account when identifying reserves. Biodiversity itself is not an easy property to measure especially if it is based on numbers of species. The marine environment is rich in species many of which are undescribed. The data sets available for the present project were not collected with any biodiversity objective in mind and many groups were identified to levels higher than species (see Chapter 3.1 – Sources of Data). In addition, different sampling gears have been used to sample different components of the seabed fauna. A fish trawl may for example yield a low number of species of benthic invertebrates whereas a dredge sample from the same site may indicate a rich infauna. We have illustrated this and discussed the implications in Chapter 5.

The project described in this report was designed to identify surrogates that could be used to characterise the biological communities of the NPF managed area (Fig 1.1). This vast area that stretches from Cape York in Queensland across northern Australia to Cape Londonderry in Western Australia encompasses an area of 771,121 km^2 and includes around 6,000 km of coastline. The commercial prawns of the region have been studied intensively since the early 1960s but we have little information on the seabed fauna other than prawns. The original research proposal included collecting of additional field samples but, following negotiations between FRDC and CSIRO it was decided to undertake a two year desk top study that would use existing data.

The project set out to address five objectives:

Objective 1

Assess the potential of physical, research and fishery data to classify benthic species assemblages within the NPF

This was seen as a key objective of the study. The first step was to identify useful data. We reviewed all the available sets of biological data and found two sets of cruises that proved invaluable. The first of these consisted of a Gulf of Carpentaria-wide study using a fish trawl as we as a dredge. The second dealt with a major set of prawn trawl bycatch samples collected on the trawl grounds in the Gulf of Carpentaria. There was unfortunately a major gap in that no comparable data was available for the western sections of the NPF. We also identified suitable physical and chemical datasets; these are described in Chapter 3.1 (*Sources of Data*). In most cases this information had been collected at sites different to the biological samples. To overcome this mismatch, we developed two major models, one dealing with seabed water current stress and the second with sediment distribution. These are described in Chapters 3.2 (*Hydrodynamic Models*) and 3.3 (*Interpolation of sediment data in the Gulf of Carpentaria*). We had continuous acoustic data for the inshore biological sampling, this is described in Chapter 3.4 (*Acoustic Data*). The analyses of these data to classify benthic species assemblages – essentially to search for surrogates – are described in Chapter 5 (*Surrogates and Assemblages*).

Objective 2

Develop maps of benthic species assemblages, fine–scale patterns of trawling intensity and the untrawlable grounds for key areas in the NPF

Assemblages identified in Objective 1 were mapped and the results are also given in Chapter 5 (*Surrogates and Assemblages*). We used data supplied by AFMA from the satellite-based Vessel Monitoring System (VMS) to partition 6 nautical mile grid logbook effort data into 1 nautical mile squares – a 36 fold increase in resolution. The methods and results are given in Chapter 4 (*Fine scale distribution of trawl effort*) together with maps of the untrawlable grounds to show the relationship between the two. The availability of this fine scale effort data will considerably enhance future research in the NPF.

Objective 3

Assess the sampling strategies required to extend the coverage of data on benthic species assemblages and untrawlable grounds in the NPF.

We reviewed the available biological and physical data in relation to the fifteen Bioregions identified in the NPF managed area. This showed considerable gaps in both datasets as reported in Chapter 3.5. The importance of filling in these gaps and commitment of funds to do the work needs to be assessed by stakeholders. Broadly, there are two groups of stakeholders with interests in this information. One is the fishing industry, the other is conservation groups and managers. Trawling does not take place in many of the bioregions and so there is little interest from the prawn trawl industry in supporting research in these unfished areas. Conservation interests include all the bioregions but at least in the past have not had the resources necessary to carry out surveys in them. We have discussed future data collection in Chapter 3.5.

Objective 4

Apply the existing CSIRO/GBRMPA East Coast Trawl Fishery management scenario evaluation model to evaluate the impacts of trawling on benthic species assemblages under a number of likely scenarios for several regions of the NPF.

Information on clearance rates of seabed fauna by prawn trawls, recovery rates of seabed fauna following trawl impacts and the fine scale distribution of trawling was used as inputs to the model. We do not have measurements of the first two parameters for the NPF seabed fauna and so we have used data derived from the northern Great Barrier Reef. This is not a satisfactory compromise given the differences between the two regions and it is hoped that this gap in information will be filled in the near future. A range of effort reduction scenarios including the one currently being applied, were tested for effects on individual taxa and the results are presented in Chapter 8 (*Modelling of the impacts of prawn trawls on seabed fauna*).

Objective 5

Develop a planning tool that will assist in identifying different reserve configurations to achieve specified biodiversity and other environmental targets, while maximising the value of the commercial fishery

Establishment of Marine Protected Areas should be based on adequate information and extensive stakeholder consultation. We have reasonable scientific information for part of the NPF and we also have economic information for a major stakeholder namely the prawn trawl fishery. We do not have biological information for the entire western half of the NPF. We also do not have economic or social information in relation to other stakeholders in the region. Given these major gaps, it was not appropriate for the Surrogates project to attempt to identify marine reserves in the NPF. Our approach has rather been to address this objective by describing the process that needs to be followed in identifying marine reserves in the NPF.

Experience in Australia and overseas has shown that one of the major pitfalls in the establishment of Marine Protected Areas (MPAs) is inadequate stakeholder consultation. In Chapter 9 (*A process for the identification of marine reserves within the NPF Managed Area*) we have identified stakeholders and have provided a list of scientific databases relevant to the NPF. We have also suggested a software package for carrying out the complex computations for optimising reserve configuration. Finally we identified the inputs needed for the model and the type of output that would be generated.

Additional work

During the course of the project, we identified some additional aspects that would contribute to the study. The first was to expand one of the performance indicators relating to sustainability of the seabed fauna. We have included all invertebrate groups caught as bycatch in prawn trawls, not only attached fauna as required. We have also presented maps of the distribution of the least sustainable teleosts by species rather than by group, we feel this considerably increases the value of the information. The results are presented in Chapter 6 (*Sustainability of animals captured in prawn trawls*) and were used as one of the inputs in the trawl impacts model.

Prawn trawling is seen by some as a threat to the seabed fauna but the various other threats to this fauna in the NPF have never been evaluated. We reviewed the threats and assessed the consequences and likelihood of each and scored them using the National ESD reporting framework for Australian Fisheries. The review and assessment of risk are given in Chapter 8 (*Threats to the seabed fauna of the NPF Managed Area*).

Finally, we have documented and archived the data that we have used in the project to assist any subsequent studies (Chapter 3.7 – *Archiving of data from the project*).

Background

Mapping of trawl effort

The Northern Prawn Fishery (NPF) is Australia's most valuable prawn fishery and has been well managed for much of its history, particularly over the last 15 years. Research has been directed towards understanding the biology of the banana and tiger prawns, the habitats they use throughout their life cycle, and the dynamics of the fishery. More recently, research has examined other components of the ecosystem, particularly vertebrate bycatch and mitigating the impacts of trawling on sea turtles and other large animals. The fishery is now subject to a sophisticated Vessel Monitoring System (VMS) in which the position of every vessel in the fleet is recorded at intervals using satellite links. This information, primarily used for surveillance was recognised by NORMAC as opening up possibilities for greater information on fleet dynamics and assisting in research. In the present project we propose to use this VMS data to produce fine-scale maps of fishing grounds NPF. This has never before been achieved for an Australian fishery. The maps will provide a better understanding of the impacts of trawling on prawn stocks and a basis for assessing the impacts of trawling on biodiversity.

Protection of biodiversity

Australia's Oceans Policy and changes to the Commonwealth environmental legislation (Environmental Protection and Biodiversity Conservation Bill 1998 and Wildlife Protection (Regulation of Exports and Imports) Acts 1982) require ecosystem level approaches to managing our marine living resources. These changes pose new challenges to researchers and managers of the NPF. All Commonwealth managed fisheries must be assessed on their 'ecological sustainability', by the Minister for the Environment. Environment Australia (EA), in consultation with AFMA and the various Commonwealth Management Advisory Committees, is developing criteria to assess the ecological sustainability of commercial fisheries. The draft criteria include those for the target species, bycatch, and the environment. For example, Principle 2 states that "Fishing operations should safeguard the structure, productivity, function and diversity of the ecosystem (including habitat and associated dependent and ecologically related species)". In the present project we propose to review all of the currently available information on the seabed fauna in the NPF. We will review the quality and geographical coverage of the data and we will evaluate the sustainability of the benthic invertebrate fauna with respect to prawn trawling. We also propose use a model originally developed by CSIRO for the Queensland East Coast to evaluate the effect on the seabed fauna of changes to the management regime of the NPF (see also ‘Effects of Trawling’ below).

Marine Protected Areas

The NPF and other Australian fisheries are required to meet the commitment of the Commonwealth Government to creating a National Representative System of Marine Protected Areas (NRSMPA) throughout Australia's marine environment. These areas are designed to protect representative areas of all major ecological regions and the animal and plant communities found in them (IMCRA 1998). Representative systems will be assessed on the basis of ecosystems and the biodiversity they support. However, it is not clear how best to identify ecosystems and candidate representative areas or how fishing will be incorporated into the selection and management of representative areas or how to monitor components of the ecosystem to demonstrate that fishing is sustainable.

A difficulty in proceeding with MPA identification is a lack of data and stakeholder consultation. We are therefore not in a position to progress to actual identification of candidate MPAs in the NPF. In order to assist the process for establishment of MPAs in northern Australia, we propose to review the present situation regarding MPAs in Australia and to describe the process that is needed including the information that is needed and what components are or are not available. We will also identify stakeholders that need to be consulted as part of the process. Once suitable information is available, the drawing of possible boundaries for MPAs is a complex task. We will recommend suitable computer software that can be used in this process.

Ecosystems/bioregions of northern Australia

The diversity of habitats in the managed area of the NPF is demonstrated by the identification of 15 bioregions in this region (IMCRA 1998). These bioregions were identified from information on climate, oceanography, geology, geomorphology, biota and estuaries, collected by marine management and research agencies within the Australian States and Territories, and the Australian Commonwealth. The quality and quantity of data varied greatly between subjects and organisations and does not include the more recent CSIRO studies in the region (e.g. see related projects FRDC 95/14, FRDC 96/257, FRDC 98/109). Because of its tropical location, and isolation, the managed area of the NPF is likely to contain areas with very high values for biodiversity. Although trawling is an important activity within the managed area of the NPF, current information indicates that Northern Australia remains pristine by world standards.

The primary goal of the NRSMPA is to conserve marine biodiversity (ANZECC Task Force on Marine Protected Areas 1998). However, this requires extensive information on species distributions and abundance; information which in many marine ecosystems is incomplete. Gaps in information on species distributions have often been addressed by predictive techniques that use other more readily available biological or physical information (surrogates). This assumes that there is a quantifiable link between each of these surrogate measurements and the species of interest. To be effective in reserve planning surrogate variables should be clearly defined and available over much of the area of interest.

In the NPF we have comprehensive data from three sources: (1) physical data such as sediment type, areas of untrawlable ground, depth, currents and bottom stresses; (2) biological data on prawn species and associated bycatch populations in different areas and benthic communities; and (3) log book data on prawn catch and effort from the Northern Prawn Fishing fleet (recorded on a daily basis and within 6 x 6 nautical mile grid squares). This type of logbook data is available for many Australian commercial fisheries. We propose to evaluate the effectiveness of surrogates for biodiversity developed from a combination of all or some of these data.

Effects of trawling

Trawling clearly affects prawn stocks, some bycatch populations and some of the organisms attached to the bottom (Taylor and Die 1999; Stobutzki et al 2000; Poiner and Harris 1996; Poiner et al 1999). AFMA and NORMAC have successfully implemented management measures to control the impacts of trawling on target stocks and sea-turtles and have started to implement measures to manage impacts on bycatch. The impacts of trawling on attached organisms also need to be managed.

Research on the effects of trawling on the Great Barrier Reef (GBR) has shown that the impacts of trawling on benthic habitats, target species, bycatch and biodiversity depend on two factors: (1) the intensity of trawling; and (2) the vulnerability of the biota in the area being trawled (Poiner et al. 1999). The vulnerability of a species to trawling depends not only on the quantity removed by a trawl, but also on the recovery rate between trawls and the location of trawling in relation to where the organisms live. The most vulnerable species are those that are easily removed or killed in trawls and/or are slow to recover and/or live in areas of high trawling intensity.

Research on vertebrate bycatch in the NPF and on a range of taxa in the GBR has provided information on their vulnerability (Stobutzki et al. 2000). In this new project we propose to assess the vulnerability of the seabed invertebrate fauna in the NPF. We will use this information together with data on vulnerability and recovery rates derived from our studies in the GBR, in a model to help develop and evaluate the environmental performance of different management strategies and identify critical information needs.

Threats to the seabed fauna of the NPF

Although this was not part of the original proposal, we intend to identify those processes that pose some threat to the seabed fauna of the NPF. We will describe the nature of the threat in each case. We will then undertake an evaluation of the threats in order to provide a ranking of the importance of each.

Need

In the past fisheries research and management focussed on the target species of the fishery. Two recent policy developments by the Commonwealth government have broadened this focus considerably. Firstly, the Commonwealth government is committed to setting up a National Representative System of Marine Protected Areas throughout Australia's entire marine environment that will protect areas representative of all major ecological regions and the communities of plants and animals found there. Secondly, under the Commonwealth Fisheries Management Act (1991), the new Environmental Protection and Biodiversity Conservation (EPBC) Act (effective July 2000) and the Wildlife Protection (regulation of Exports and Imports) Acts 1982, fisheries have to demonstrate their ecological sustainability. Fisheries will be assessed to ensure that they are conducted in accordance with the EPBC Act. Fisheries that cannot do so will not be allowed to export product. This is a serious threat to an export-oriented fishery like the NPF. NORMAC has responded by actively supporting research that investigates the ecological sustainability of the fishery. NORMAC 45 also agreed that a pro-active approach to assessing potential areas for designation as MPAs, and the impact of their potential designation on the fishery, would benefit the NPF and should be given a high priority.

The Surrogates project addresses both of these two new demands on fisheries. Firstly, it is clear that identification of areas for MPAs is complex and requires knowledge of the biological attributes of an enormous area. Surrogates offers a way of expediting this process, if physical attributes can be linked to biological ones it may be feasible to use the former to predict with reasonable accuracy the latter. Generally information on physical attributes can be collected more rapidly and cheaply than can that for biological attributes. A major part of the project deals with identification of surrogates using existing data sets. The project also discusses the process for identifying MPAs and makes recommendations on this for the NPF, The need for fisheries to demonstrate their ecological sustainability is dealt with in the Surrogates project in two ways. Firstly by using a variety of information to estimate the sustainability of animals captured in prawn trawls. Secondly, the project has modelled the impacts of trawling on seabed fauna using realistic management interventions.

The challenges facing industry, managers and researchers in meeting the requirements of government are complex but are generally accepted as being necessary. Unsustainable fisheries are collapsing around the world. We hope that the results of the Surrogates study will assist in ensuring the sustainability of the Northern Prawn Fishery.

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CHAPTER 2

CONCLUSIONS AND OUTCOMES

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CHAPTER 2

CONCLUSIONS

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Availability of biological data

We reviewed 16 research cruises in the NPF and found the majority were very restricted in their coverage and generally limited in terms of the types of data they collected because they were targeted at prawns not at the general seabed fauna. (Chapter 3.1). Biological coverage was limited largely to the Gulf of Carpentaria. After completion of the project we became aware of a series of fish trawl research cruises undertaken in 1980-81 that included other parts of the NPF (Okera and Gunn, 1986). This data should be used in future analysis of the biota of the region. There appears to be no dredge or prawn trawl samples of benthic fauna data at all for Joseph Bonaparte Gulf and very limited data for the top end region between the two Gulfs. The first of the two data sets used in the project was collected in 1990 and involved fish trawl and dredge samples collected from 107 stations across the Gulf of Carpentaria. The second is a set of 1012 prawn trawl bycatch samples collected in 1997 and 1998 by a research trawler. This data is largely restricted to the commercial trawl grounds, we have no comparable prawn trawl samples from off the grounds. These two sets of data had little spatial overlap, consequently we do not have fish trawl data for the commercial fishing grounds and we do not have prawn trawl data for most of the Gulf of Carpentaria. In Chapter 3.5 we assessed the gaps in data for each of the 16 bioregions that cover the NPF, this showed that most bioregions have been inadequately sampled. Even in the Gulf of Carpentaria, our analysis of the adequacy of sampling (Chapter 5) shows that except for fish captured in prawn trawls, other groups including fish from fish trawls, invertebrates from prawn trawls and the fauna collected by dredge have been inadequately sampled.

Conclusion

The biological data for a full analysis of surrogates is inadequate for most of the NPF. The focus of future general biological surveys should be on collecting an adequate description of biota from the bioregions presently incompletely described. The following biological data is recommended as top priority:

- Prawn trawl bycatch especially in bioregions not presently adequately sampled - this should be regarded as the minimum biological collection. Identification of the invertebrates should be to species wherever feasible otherwise at least to family level
- Biological dredge samples - samples should overlap with those collected in prawn and fish trawls
- Fish trawl samples – the existing data needs to be assessed for completeness before additional sampling is undertaken

Physical and chemical data

As is the case for biological data, most of the physical and chemical data for the NPF has been collected in the Gulf of Carpentaria. The only comprehensive acoustic data (used for describing seabed structure) is for the Groote Eylandt and Wellesley Island area. Sediment data was available for many areas but the data are sparse outside of the Gulf of Carpentaria.. The coverage for water quality data (oxygen, nitrate etc) was also adequate only in the Gulf of Carpentaria, reliability fell in the western part of the NPF.

We found a strong relationship between acoustic data and sediment characteristics (sand and mud) indicating that acoustic data could be used to describe seabed sediments. This can be done at far lower cost than sediment sampling (Chapter 3.4). We developed models in order to overcome the point source nature of our information for some of the physical data. These included the sediments (Chapter 3.3) and hydrodynamics (Chapter 3.2). The hydrodynamic model showed that extensive areas of high bottom stress occur in Joseph-Bonaparte Gulf, around Melville Island, south of Irian Jaya, and the southeast Gulf of Carpentaria. However, more localized zones are evident, such as Torres Strait, west of Groote Eylandt, and around the Wessel Islands. The NPF model was also used to provide the boundary forcing for three smaller scale regions near Groote, the Vanderlins, and Mornington. These sub-region models provided higher spatial resolution (0.01°) in areas where other relevant physical and biological datasets are available. The three areas revealed contrasting bottom stress distributions. The waters around Groote were characterised by very high stresses in straits and channels, falling rapidly towards more open water. The relatively open waters to the northeast of the Vanderlins were characterised by weaker currents and relatively low bottom stresses. While the Mornington region was also relatively open, currents and bottom stresses were much higher off the eastern side of the island. Although our surrogates analyses have shown some properties to be more useful than others, we do not recommend using this as a guide for future data collection because of the special nature of the Gulf of Carpentaria.

Conclusion

The bias in the present data set should be corrected by collection of additional samples in Joseph Bonaparte Gulf and off Arnhem Land with some targeted sampling in the Gulf of Carpentaria. The following information is required for the ‘gap’ areas:

- Seabed structure – can be collected using normal incidence acoustic tracks over as much area as possible
- Sediments - grain size data from selected areas to increase reliability of the information
- VMS data on a continuing basis - data is already being collected by AFMA but needs to be analysed
- Bottom current stress - field data is needed to validate the hydrodynamic model
- Chemical and physical water column data – Additional measurements are needed to improve the reliability of the existing data set
- Remote sensing (SeaWIFS) should be continued in order to provide relatively low cost supplementary data

Biodiversity

Biodiversity is a measure of the number of species (ideally) or taxa (less ideally) present in an area. Like many biological terms it has an extensive history of speculation and even dissent. There are two main components of community structure that contribute to biodiversity: i.) Species richness which is simply the number of species present and ii.) Equitability, which expresses how evenly the individuals are distributed amongst the species. A wide range of diversity indices have been developed and different indices emphasise the species richness or equitability components to differing degrees. Given the already low level of information that we are dealing with in the NPF, we have not used any of these modified measures of biodiversity but simply relied on number of species or taxa. This simple approach is however not completely straightforward because in order to count the number of species you have to catch them. It is obvious that success in catching is related to the type of gear used. Since we are dealing with three different sampling gears – fish trawls, prawn trawls and dredge – ideally we should compare the measurement of biodiversity by each type. Unfortunately we have paired samples only for fish trawl and dredge. The number of species or taxa caught by each gear is very different. We have a total of 289 species of finfish from the fish trawl and 849 species of invertebrates from the dredge. The prawn trawl yielded 234 taxa of invertebrates, 390 species of teleosts and 43 species of elasmobranchs. Plots of the number of species or taxa versus the number of samples suggests that except for fish caught in fish trawls, sampling is not adequate (Chapter 5.1). This is especially clear in the case of the invertebrates.

High biodiversity in one group does not necessarily imply high biodiversity in other groups at the same site. Our analysis shows that biodiversity as measured by two different gears – fish trawl and dredge – is not the same (Chapter 5.3). This means that assessment of biodiversity requires sampling with a range of gears.

The distribution of biodiversity varied across the Gulf of Carpentaria. Biodiversity of the seabed invertebrate fauna was higher in the eastern and northern Gulf of Carpentaria whereas that of the fish trawl-caught fish was fairly uniform over much of the central area with a different grouping more inshore. The area with the highest biodiversity of teleosts is the north-east of the Gulf of Carpentaria and there is a clear separation of fish into deeper and a shallower water components.

Analyses of fish trawl samples from 107 stations across the GoC yielded a total of 289 species Ten species were common occurring at 70% of more of the stations but most of the rest were rare. We identified seven major fish assemblages, the one with the widest distribution across the Gulf of Carpentaria was made up of species associated with reefs suggesting that reef structures may be widespread across the GoC. This assemblage may be useful as a form of indicator for reef ecosystems.

Conclusion

- The measurement of biodiversity is affected by the gear used for collecting samples as well as the variation in biodiversity across groups at the same site.
- Sampling for most groups is presently insufficient to describe biodiversity in the NPF outside of the Gulf of Carpentaria and even the latter has not been sampled adequately.

Surrogates

We investigated the relationship between the biological data and 15 different environmental variables to establish whether the latter could be used to predict biological properties or attributes. The environmental variables were tested as a mean value and its standard deviation giving a total of 28 variables.

We used two different datasets to examine the nature of relationships between benthic invertebrates and environmental variables – those from dredge samples taken in offshore waters of the Gulf of Carpentaria and those from a set of prawn trawls taken on the near-shore fishing grounds. We found only limited relationships between the invertebrate fauna from the dredge samples and the environmental variables available for analysis. We attribute this to the limited range of samples available – all from offshore in the Gulf of Carpentaria, and the limited type of environmental factors that could be tested. We tested the relationship between biodiversity and a range of physical and chemical factors (depth, bottom current stress, chlorophyll, K490 absorption, NO_3, PO_4, salinity, O_2, temperature, Si, and the percentages of cobble, granules, mud, pebble and sand). The most significant generalized linear model contained two terms – oxygen and temperature. This probably results from thermocline formation in the GoC and the narrow range of other terms in the region.

Similarly, the predictive capacity of the environmental variables for the invertebrates caught in the prawn trawls was not particularly strong. A combination of oxygen, median wave height, phosphorous, sand, gravel and chlorophyll could be used to predict membership of a station group, but the error rate was very high (57%). Also, a group of variables related to the nature of the substrate (mud.SE, sand.SE and acoustic hardness) were useful in predicting the distribution of a limited number of individual species caught by the prawn trawls.

We also had two different sets of data for fish – those captured in fish trawls and those captured in prawn trawls. The α-biodiversity of the fish fauna is much less, and much less variable, than for the dredge data. The connection between the fish fauna and available environmental variable information is relatively weak.

A tree analysis of the fish captured in fish trawls indicated that salinity SD, nitrate SD and oxygen were the split variables with the highest frequency of occurrence. In the case of fish captured in prawn trawls, the most important surrogates for biodiversity were temperature and salinity. These water quality properties are probably also linked to thermocline formation in summer in the Gulf of Carpentaria and the associated water quality changes are probably key drivers in determining the distribution of mobile species such as most teleosts.

At first sight the results of the surrogate analysis suggests that the most important environmental factors are not the same for each faunal group. However, when we consider that 28 different environmental factors were tested, there is a degree of commonality in the highest scoring 9 or 10. Sand and mud appear in all cases as does oxygen. Aspects of water chemistry such as silica, phosphorus, nitrate and salinity each appear in at least three of the four faunal samples. We suggest that these factors may be the best surrogates for the marine fauna derived from the present analysis.

Conclusion

The most common environmental driver for the deciding the biodiversity of the seabed fauna is the substrate – sand or mud. Oxygen also appears to be important and this may be related to the formation of a thermocline in summer and this appears to affect both fish and invertebrates.

Although the main drivers for the different faunal groups are different there is a high degree of commonality. Sand and mud as well as oxygen are important to all groups. We suggest that these factors may be the best surrogates for the seabed fauna.

Indicator species

In the case of the dredge fauna, a species of spider crab (*Micippa excavata*) had the highest number of associated species (128) and might be regarded as an indicator species for biodiversity of the fauna sampled by the dredge. The next highest indicator species was a small shrimp (*Sicyonia cristata= lancifer*) which was associated with 98 species.

Three species of teleost were associated with the highest biodiversity of fish caught in fish trawls: *Pseudorhombus diplospilus*, *Lagocephalus sceleratus* and *Gerres macracanthus*. The eight stations with all three of these species had a mean of 54 species of fish.

The most significant indicator species for teleosts in the prawn trawl bycatch were *Nemipterus peronii*, *Lethrinus genivittatus* and *Echeneis naucrates*. Although they were found together at only a few stations, these stations had a mean species count of 78.4. This difference in fish indicators is probably attributable to the differences in composition of the catch of prawn and fish trawls.

Indicator species probably have less value in this environment than they do on land because they do not provide a short cut to sampling. A species collected in trawl samples for example requires that trawl sampling be carried out in order to establish whether or not it is present.

Conclusion

Although we identified indicator species for biodiversity, they are different depending on the sampling gear used. Even in the case of fish, they were different in prawn and fish trawls. This once more emphasises the importance of having a broad range of sampling gear when measuring biodiversity. The performance of indicator fish species for biodiversity is poor, we suspect this is largely because the variation in α-biodiversity is very small in the first place.

Sustainability

Sustainability of the benthic invertebrate fauna on trawl grounds was assessed on the basis of their susceptibility to being caught in a trawl and their ability to recover from any trawl

impacts (Chapter 6). The general approach followed that developed by Stobutzki et al (2000 and 2001) for finfish. The following twelve taxa were identified as the most sustainable:
Pectinids (bivalve), Venerids (bivalve), Xenophorids (gastropod), Holothuroids, Mactrids (bivalve), Corystids (crab), Gonoplacids (crab), Cardiids (bivalve), Pagurids (hermit crab), Portunids (crab), Scyllarids (bug), and Asteroids (starfish).
The twelve least sustainable animals groups identified were:
Soft corals, Bryozoans, Echinoids, Octopods, Olivids (gastropod), Palinurids (lobster), Parthenopids (pea crab), Pennatulids (sea pen), Sepiolids (cephalopod) Solemyids (bivalve), Solenids (bivalve) and Teuthoids (squid).
Distribution maps showed that some of the least sustainable species have a very wide distribution. This suggests that despite their vulnerability to trawling, they are probably not threatened by trawling. The area between Groote Eylandt and Gove had the highest concentration of least sustainable species in the Gulf of Carpentaria.

Conclusion

- The echinoids appear to have low overall sustainability as they are highly susceptible and have a low ability to recover.
- The asteroids and holothuroids appear to be the most sustainable groups as they have a high recovery and a moderate susceptibility score.
- The more delicate families of Crustacea such as crangonids, carids and parthenopid crabs have low sustainability.
- The most robust Crustacea are the hermit crabs, portunid crabs and the bugs (Scyllarids).

The wide distribution of some species/taxa identified as having low sustainability with respect to trawling suggests they are not threatened by trawling.

Fine-scale patterns of trawl effort

During the project, over 100,000 VMS records for the NPF fleet for the period August – October 2000 were made available by AFMA. Analysis of the data allowed trawl effort to be partitioned into 1 nautical mile grid squares. This is a 36 times higher resolution than available from the commercial logbook data. The fine-scale effort pattern has revealed for the first time the distribution of fishing effort within the 6 nautical mile grids squares and how it is affected for example by reefs. Trawling is clearly highly targeted and concentrated in relatively limited areas. The data will be extremely valuable in relating trawl effort to the effects of trawling and the measurement of the real area that is trawled. At this stage release of maps showing the fine-scale distribution of fishing effort to the fishing industry is restricted by a confidentiality agreement between AFMA and CSIRO.

Conclusion

VMS data has allowed a 36 times improvement in resolution in the mapping of trawl effort in the NPF.
This data will be of considerable value in future research planning in the NPF and in obtaining more accurate estimates of the effects of trawling.

Threats to the seabed fauna

A review of a wide range of threats was undertaken and is presented in Chapter 7. The following threats were described:

- Fishing (Prawn trawling, line fishing, net fishing, fish trawling, recreational fishing and traditional fishing
- Mining (Mining of bauxite, lead and zinc, manganese, gas, oil, seismic exploration, port facilities for export, siltation from mining)
- Shipping (Introduction of marine pests, antifouling paint, oil pollution, chemical pollution, shipping accidents)
- Agriculture (Land clearing, water diversion, acid sulphate soils, pesticide and herbicide runoff)
- Aquaculture (Introduction of diseases, pollution and habitat destruction)
- Global warming - increasing sea temperature, rise in sea level, changes in rainfall and increased frequency of cyclones

We evaluated each potential threat using a process developed as part of the Ecologically Sustainable Development process. This uses two axes – Consequences of the threat and Likelihood of the threat occurring. Estimates of these two factors for each threat were combined into a Risk factor that was used to rank the threats.

Two threats were scored as having a risk greater than 19 and are classified as Extreme Risk – these are the introduction of a serious marine pest, and changes in rainfall. Five threats were scored as High risk (scores 13-18.9). These included three climate change effects (rise in sea level, rise in sea temperature and increased frequency of cyclones), altered water flows in estuaries because of agriculture and the direct impacts on the benthos from prawn trawling.

Thus out of the top highest risks, four deal with the consequences of climate change and are realistically beyond the power of the NPF management to deal with. Introduction of a serious marine pest is a important threat since once it becomes established there is probably nothing that can be done to either remove it or possibly even to mitigate the effects. Port Phillip Bay is an unfortunate example of this situation. In view of the high risk from this source, the NPF industry should support measures to prevent the introduction of marine pests. This includes consideration of new methods of preventing of hull fouling – a problem exacerbated for many vessels by the long periods for which the NPF is closed. The fifth most serious risk results from the alteration of water flows in rivers and estuaries because of agricultural needs for water. The sixth serious risk is the direct effects of prawn trawling. One of the actions that follows from identification of a High or Extreme Risk is to focus attention on it in an attempt to quantify the risk. At present we cannot evaluate the real risk of prawn trawling. We have some of the information and Chapter 8 (Modelling the Impacts of Prawn Trawls on Seabed Fauna) summarises this. Some of the key inputs to the modelling use data collected in the Great Barrier Reef region and this undermines the value of the model. A new research project on the Effects of Trawling will address this gap and hopefully be able to provide us with a higher degree of confidence in our knowledge of the impacts of trawling – most importantly – whether or not trawling is really a high risk activity for the seabed fauna.

The scoring presented in this chapter was done by scientists involved in the project and they are not representative of major stakeholders. We also found some problems with the present framework and its scoring. AFMA has commissioned a review of the ESD framework and the weaknesses are presently being addressed. We recommend that once this is complete and a new version of the framework is available, a broader range of stakeholders should be used to score the threats.

Conclusion

The introduction of a serious marine pest and changes in rainfall resulting from climate change were identified as extreme risks

Three other climate change effects (rise in sea level, rise in sea temperature and increased frequency of cyclones), altered water flows in estuaries because of agriculture and the direct impacts on the benthos from prawn trawling were identified as high risk

A scoring of threats by a wider group of stakeholders is recommended

Impacts of trawls on seabed fauna

We applied a model that estimates prawn trawl impacts on the seabed fauna to the Gulf of Carpentaria using data on clearance rates by trawls and recovery data derived from research on the Great Barrier Reef (Chapter 9). We used sustainability data reported in this project (Chapter 6). We demonstrated the value of the model by testing various management options involving different strategies for reduction in effort.

Conclusion

An instantaneous reduction in effort by 25% (the management measure applied in 2002) had similar outcomes to a reduction over 5 years. A 50% reduction over 5 years resulted in greater relative biomass of benthos, more grids exceeded 20% of initial biomass and there was a higher median biomass.
Groups that were impacted the most were gastropods and echinoids. Asteroids were impacted the least. Medium effort grids showed the greatest responses to changes in effort

Marine Protected Areas

Chapter 9 sets out the background to the establishment of marine protected areas under Commonwealth legislation. The primary objective of the Commonwealth system of Marine Protected Areas (MPAs) is protection of biodiversity, following the principles of comprehensiveness, adequacy, and representativeness. We have described the framework for the identification of potential MPAs. We did not attempt to identify MPAs in the NPF region because of a lack of biological and economic information and the need to undertake wide stakeholder consultation. A flow chart for the process is presented. The starting point of the process is seen as adequate stakeholder consultation. Stakeholders would be asked to identify objectives and values to be used in the process.
The chapter also points out that there are serious shortcomings in the data presently available for the NPF managed area. It has high biodiversity with 15 IMCRA bioregions identified but most of these have not been surveyed. There is good economic data for the Northern Prawn Fishery (ABARE) but little accessible data for other stakeholders in the NPF. This information is critical to any serious analysis for establishment of marine parks. Some of the information could be accessed through public channels, for example financial reports of mining and shipping companies. Other information may be difficult to access, for example from privately held companies involved in activities such as fishing, agriculture and tourism. The identification of marine protected areas should be done using an optimisation process that maximises biological attributes but minimises economic costs. This is a complex process and in Chapter 9 we have discussed presently available state of the art computer software for identification of MPAs.

Conclusion

There are three major gaps in information that need to be addressed before any identification of MPAs in the NPF. These are

- More adequate biological data is needed – many bioregions have not been sampled at all
- Economic data needs to be collected for all the major stakeholders
- The stakeholders need to be consulted

Outcomes

The following outcomes were identified at the conclusion of the project, we expect that others will be identified as the results of the project become more widely known:

- The project has demonstrated that the major reduction in trawl effort undertaken by NORMAC will have positive effects on the seabed fauna. We can expect substantial recovery of this fauna over the next decade. This prediction will contribute to strategic planning of the NPF region. This information will assist AFMA and NORMAC in meeting their obligations under the EPBC Act in demonstrating the sustainability of the fishery.
- The project has summarised the issues surrounding establishment of marine protected areas in the NPF. It also provides advice to managers on the techniques that should be used in the identification of suitable areas including extensive stakeholder consultation, information needed and suitable computer software for the complex analyses.
- The finding in the project that a high proportion of the seabed fauna most susceptible to trawling occurs in the north-west part of the Gulf of Carpentaria will contribute to strategic planning for spatial management of the NPF with respect to Marine Protected Areas
- The NPF now has a substantial Threat Analysis for the seabed fauna as well as a method that can be used for evaluating threats. It is expected that NORMAC will use the information and procedure presented in the report to carry out a Threat Evaluation. The results of this evaluation would be valuable in strategic planning for the NPF.
- Detailed information on distribution of wave height, seabed current stress, seabed substrate composition and fine scale distribution of effort has been used in identifying suitable areas for establishing experimental plots in the new Effects of Trawling project (FRDC 2002/102). The information enabled the selection of two areas with high environmental contrast and which are unlikely to be trawled commercially during the course of the experiment.
- The results of the project have been used in planning a joint CSIRO-GSA project using the Southern Surveyor National Facility to explore the geological and biological structure of the western Gulf of Carpentaria. Specifically information on fine scale distribution of trawling, sediment distribution and seabed current stress was used to identify a suitable area for the study.
- The inadequate biological coverage of the NPF outside of the Gulf of Carpentaria has been drawn to the attention of the National Oceans Office and discussions are underway to collect additional data to fill the gaps. The relationships identified in the project between physical environmental factors and biodiversity will assist in the planning of this additional data gathering.

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CHAPTER 3

DATA USED IN THE PROJECT

CHAPTER 3.1

SOURCES OF DATA

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CHAPTER 3.1

SOURCES OF DATA

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Summary

Biological Data

- Data from dredge and fish trawl samples were available from a 1990 survey of 107 stations across the Gulf of Carpentaria
- Data from 1076 prawn trawl samples and 44 dredge samples were available from 1997 and 1998 surveys carried out mainly on the commercial trawl grounds
- These two sets of data had little spatial overlap, consequently we do not have fish trawl data for the commercial fishing grounds and we do not have prawn trawl data for most of the Gulf of Carpentaria. This limits the analysis.
- Fish trawl and dredge samples had been identified to species but in the prawn trawl bycatch only Crustacea were identified to species, other groups were identified to Family level.

Hydrographic Data

- A comprehensive dataset of conductivity-temperature-depth (CTD) and hydrographic casts was assembled from all known sources.
- Seasonal maps of the seafloor distributions of temperature, salinity, dissolved oxygen, nitrate, phosphate and silicate were developed by interpolating the historical data in space and time. Sample results are presented for summer and winter conditions.

Satellite Ocean Colour Data

- Ocean colour data was taken from the satellite SeaWiFS instrument (1997-2001) and seasonal maps of chlorophyll concentration and turbidity were developed by interpolating in space and time. Sample results are again presented for summer and winter conditions.

Hydrodynamic Model Data

- A new hydrodynamic model was developed for the NPF and the results are presented in detail in Chapter 3.2.

Sediments & Sediment Model Data

- We describe the sediment data used and the development of an interpolated model of sediments for the Gulf of Carpentaria in Chapter 3.3.

Acoustic Data

- Acoustic data (seabed acoustic depth, roughness and hardness) was available from three research cruises and is presented in Chapter 3.4.

Introduction

We had three types of data for analysis. First biological data collected from various CSIRO survey cruises in the NPF; second a range of physical and chemical data some of which was collected on the biological research cruises, while other data came from a variety of sources including oceanographic cruises; and thirdly remote sensed satellite and underwater acoustic data. Because much of the physical and chemical data was collected at points other than the biological data, we developed models that could be used to interpolate physical and chemical conditions at the biological sampling sites. The latter are reported in Chapter 3.2 (Hydrodynamic Model) and Chapter 3.3 (Modelling of Sediments). The acoustic data are dealt with in Chapter 3.4.

Biological data

Mick Haywood, Scott Gordon

We were aware that a considerable number of research collecting cruises had been carried out in the NPF region. We did not attempt to extract all data because much of it is very limited in scope – especially geographically. We were also constrained by whether or not the data was available. Okera and Gunn (1986) for example carried out extensive fish trawling in the Timor-Arafura Seas and in the Gulf of Carpentaria but we could not locate their data and so could not use it.. We decided to concentrate on 16 cruises undertaken by CSIRO in northern waters in recent years for which all the data was available. Some of these were very specialised (e.g. testing of TEDs and BRDs) or limited to specific areas such as Albatross Bay. We identified four key cruises that should yield useful information. The first of these was cruise SS9003[1]. This covered 107 stations in a grid pattern across the entire Gulf of Carpentaria and collected fish trawl, dredge and grab samples. Unfortunately this cruise did not sample waters much shallower than 20 m, it also did not use prawn trawls. Secondly we have three cruises carried out in 1997 and 1998 from Cape York round the [1]southern end of the Gulf of Carpentaria and then north of Arnhem Land to Darwin. The most intensively sampled areas were the southern and western Gulf of Carpentaria and the area north of Mellville-Essington. The main sampling device was a prawn trawl (over 1000 samples) but dredge samples were also taken at 44 stations. The fish from the three research cruises in the southern and western Gulf were analysed as part of the Bycatch Sustainability Project FRDC 96/257) but the invertebrate material was only logged and identified and had not been used for any analysis. These datasets were not ideal for the analyses proposed in this project. Cruise SS9003 was designed to survey the fish and benthic animals of the central Gulf. Comparisons made by CSIRO in northern GBR regions have shown that fish trawls and dredges do not sample the same fauna as that sampled by a prawn trawl. In addition this cruise did not collect acoustic data. Because the data on fish and benthic organisms was worked up, analysed and published and because of the date of the cruise, the data was not archived as stringently as presently required by CSIRO Marine. We found different copies of the data and no meta-data to explain what processing has been done on the data. A considerable effort was put into cleaning up the datasets. A cleaned-up version together with documentation has been lodged in the Divisional data centre (See below – Chapter 3.7 Archiving of data from project). The three later cruises were designed to study bycatch and so a prawn trawl was used throughout as the main sampling gear and the sampling areas were either on or adjacent to commercial prawn grounds. These cruises also collected RoxAnn acoustic data. All of this data was correctly archived and is accessible. This means that our biological samples are limited to the Gulf of Carpentaria, we do not have samples for the

[1] Note that the convention used by CSIRO to number research cruises consists of an acronym of the vessel name followed by the year and then the month of the cruise. Thus SS9003 refers to a cruise by the Research Ship *Southern Surveyor* in March 1990.

western part of the NPF and the two major areas of interest – prawn grounds and offshore – have little overlapping sampling.

Prawn trawl bycatch samples

These were collected on research cruises using the 66m stern trawler RV Southern Surveyor in the main fishing grounds of the NPF (Stobutzki et al., 2000). Details of the sampling are given by Stobutzki et al., 2000) and a summary is given in Table 3.1.1. There is no standard net used in the commercial fishery but the net used by the Southern Surveyor was consistent with those used by commercial trawlers except that in this fishery, the vessels tow two at a time. The position of the trawls is shown Fig 3.1.1.

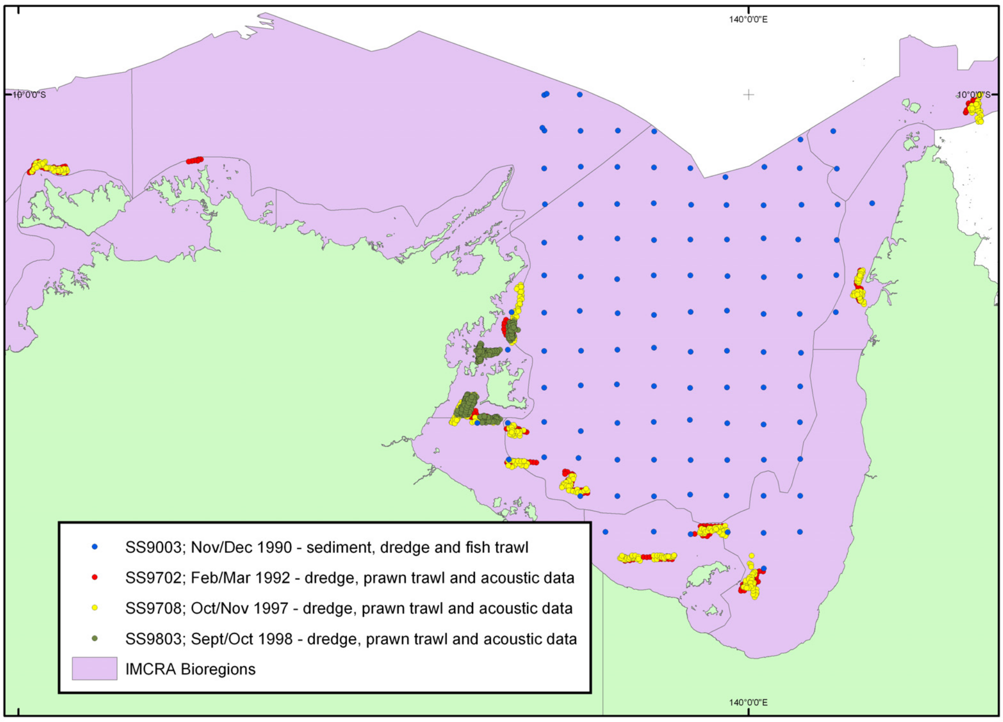

Figure 3.1.1 Sampling sites of Southern Surveyor cruises SS9003, SS9702, SS9708 and SS9803

Dredge samples

Most (107) of the dredge samples used in the study were collected in 1990 (cruise SS9003) with a further 44 collected in 1997 (SS9702 and SS9708) and 1998 (SS9803). The methods used in cruise SS03/90 are described in detail in Long et al. (1995) and are summarised in Table 3.1.1. The dredge sampled approximately the top 150 mm of substrate as well as associated benthos and fish. Dredge samples were identified by taxonomists at the Queensland Museum. Sediment samples were collected at each dredge site with a 0.1 m^2 Smith-McIntyre grab.

Dredge samples taken on subsequent cruises were collected using the same gear and procedures but only Crustacea were identified to species, the rest of the invertebrates were identified to family.

Fish trawl samples

The fishes of the Gulf of Carpentaria were collected on a research cruise (SS9003) carried out in 1990. The stations were the same as those described above for the dredge samples and details are given in Blaber et al.(1994) and are summarised in Table 3.1.1. The net was fitted with a SCANMAR system for recording net opening height, wingspread and spread between the boards. The SCANMAR system also recorded actual time on the bottom and the length of the track on the bottom.

Table 3.1.1 Description of the gear together with data on samples used in the Surrogates study

	Prawn trawl	Dredge	Fish trawl
Name of gear	Florida Flyer	Church Dredge	Frank and Bryce demersal fish trawl
Size of gear	Single 14 fathom (26.5 m) demersal prawn trawl	3.0 m wide by 1.2 m high beam trawl	26 m headrope and a 32 m foot rope fitted with chain. SCANMAR showed average opening of 15.6 m
Mesh size	Body of 57 mm stretched mesh, codend of 45 mm stretched mesh	30 mm stretched mesh net bag	Wings of 225 mm stretched mesh, body of 150 mm stretched mesh gradually reducing to 100 mm, codend of 50 mm stretched mesh
Length and speed of tow	30 mins at 5.9 km h^{-1}	15 min at 5.8 km h^{-1}	30 min at 5.8 km h^{-1}
Length of tow	30 mins at 3.2 knots	15 min at 6 km $^{h-1}$	30 min
Cruises	SS9702, SS9708 and SS9803	SS9003, SS9702, SS9708 and SS9803	SS9003
Number of samples	232 (SS9702) 467 (SS9708) 377 (SS9803)	107 (SS9003) 7 (SS9702) 18 (SS9708) 19 (SS9803)	107
Level of identification of samples	Invertebrates to Family	Invertebrates to species in SS9003. Some to species but many only to family in SS9803	Fish to species
Number of species or taxa collected	210 taxa	846	>300

Taxonomy

All of the material that we have used in this study was collected for other studies with different objectives. Unfortunately most invertebrate taxa were not identified to species level mostly because the information may not have been required in the original study. It is difficult to identify many species of marine invertebrates fauna and so it is not done unless the information is needed by the project collecting the samples. A consequence is that many of the taxa that we have in our records are identified only to family and this caused us some serious taxonomic problems. For example, 25 families of sponges were identified in the bycatch samples collected by Stobutzki et al (2000) but 85% of the samples (by weight) were identified only as Phylum Porifera. Part of the problem in this case is that much of the sponge material landed on deck is fragmented. Crustaceans had been identified to species level but molluscs and echinoderms only to the family level. In order to overcome the difficulty of using data identified to different taxonomic levels, in the sustainability analysis we reluctantly decided to use family as the lowest taxonomic level. This gave us 115 taxa. Taxonomic aggregation was not used in other analyses in the project such as measurements of biodiversity.

The animals on which the present study is based were collected in cruises in 1990 and 1997/98. At that time the Octocorals (formerly Alcyonaria) were divided into Penatulacea, Gorgonacea (gorgonians) and Alcyonacea (soft corals). The latter two taxa are now regarded as one group, the Alcyonacea, because morphological intermediates exist (Fabricius and Alderslade, 2001). For convenience we have retained the separation into gorgonians and soft corals as typifying the distinctive types of Octocorals found as bycatch in trawls.

Hydrographic data

Scott Condie, Jeff Dunn

The physical and chemical water properties across the NPF can be characterised in terms of the distributions of temperature, salinity, dissolved oxygen, and major nutrients such as nitrate, phosphate, and silicate. The seasonal distributions close to the seafloor are likely to be the most relevant to epibenthic communities. Each of these quantities can be mapped on the basis of historical hydrographic data collected by research vessels. However, the data is scattered unevenly through time and space, and there are significant seasonal variations across the NPF. Sophisticated mapping techniques have therefore been used to capture the seasonal signal, while excluding many of the biases associated with historical sampling patterns.

A comprehensive dataset of conductivity-temperature-depth (CTD) and hydrographic casts was assembled from all known sources, including the World Ocean Database (WOD98; Conkright et al., 1998) and CSIRO archives. Stringent quality control procedures rejected corrupted data, duplicated data, and data which departed excessively from a first pass mapping. In the case of temperature and salinity, data which departed excessively from known temperature-salinity trends was also rejected.

Individual casts were interpolated vertically onto standard depth levels down to the seafloor, before being horizontally interpolated onto a uniform grid of resolution 0.125° using a locally-weighted least squares, or "loess", filter (Cleveland and Devlin, 1988). This involved projecting the data onto quadratic functions of latitude and longitude while simultaneously fitting annual and semiannual harmonics by weighted least squares. A significant advantage of the simultaneous fitting of temporal and spatial functions is that seasonal biases in sampling are less likely to introduce biased mean fields or aliased spatial structure.

The spatial resolution or smoothness scale of the mapping was dependent on the data ellipse radius, which was allowed to vary with data density to produce gridded estimates with maximum achievable resolution. A minimum limit of 200 km was used to ensure that mesoscale eddy fluctuations were appropriately smoothed in regions where data was abundant. Distortion of fields by clusters of high data density was avoided by thinning these clusters to a set of monthly averages of the data. This process preserved the seasonal information, while allowing the data ellipse radius to expand over a more representative sample. Special schemes were also adopted to reduce smearing of the tracer structure across land barriers such as islands and capes (Dunn and Ridgway 2002).

Uncertainties in the seasonal mappings associated with low data density can be measured in terms of the data ellipse radius described above. However, even in regions of adequate data density, there may be significant uncertainty in the seasonal patterns due to:

i. High levels of interannual variability.
ii. Small-scale variability arising from unresolved ocean processes, such as mesoscale eddies and internal waves.
iii. Errors associated with the data collection methods.

The root-mean-square (rms) of residuals between the mapped fields and original data has been used as a relative measure of these errors.

Seafloor distributions of temperature, salinity, and dissolved oxygen are shown under summer and winter conditions (Fig 3.1.2). Temperatures decreased monotonically with depth, with sharp gradients evident at the edge of the shelf. The highest summertime temperatures (~ 30°C) and largest temperature fluctuations (~ 9°C) occur in the shallow waters of the southern Gulf of Carpentaria. While these regions also have high salinities in early summer due to evaporation, coastal levels diminish over the monsoon due to riverine inputs. Dissolved oxygen diminishes with depth and therefore exhibits similar spatial patterns to temperature. However, since equilibrium concentrations fall with increasing temperature, peak levels occur in winter.

Seafloor distributions of the most significant nutrients, nitrate, phosphate, and silicate are shown under summer and winter conditions (Fig 3.1.3). They all increase with depth, particularly below the euphotic depth where biological consumption diminishes (~ 40 m). However, some enhancement of phosphate and silicate are evident in the coastal zone of the southern Gulf of Carpentaria. These are again likely to be associated with riverine inputs during the monsoon.

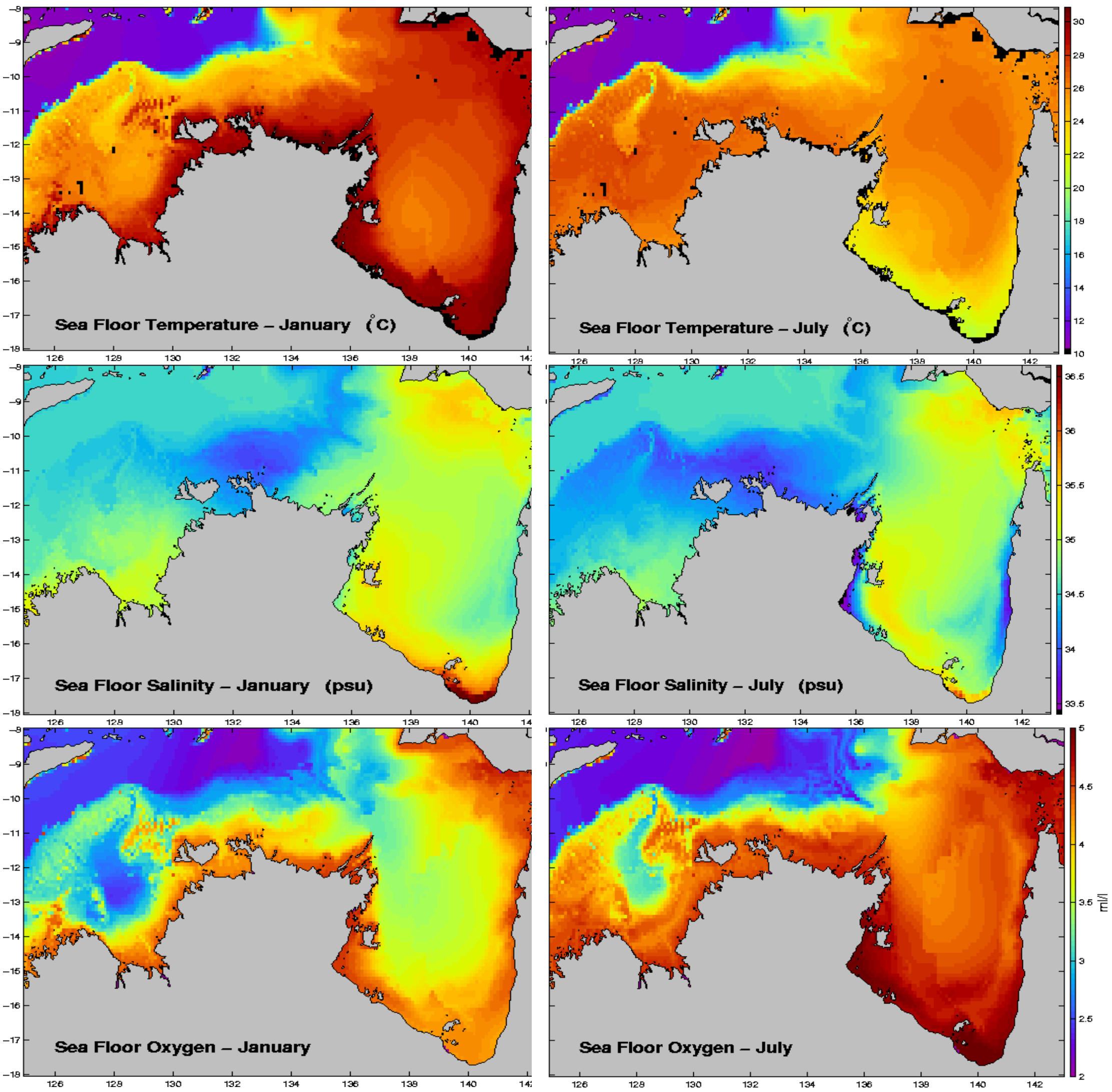

Figure 3.1.2 Seasonal fields for January and July of temperature (°C), salinity (PSU), and dissolved oxygen (ml l^{-1}) at the seafloor. Scales are given on right hand axis

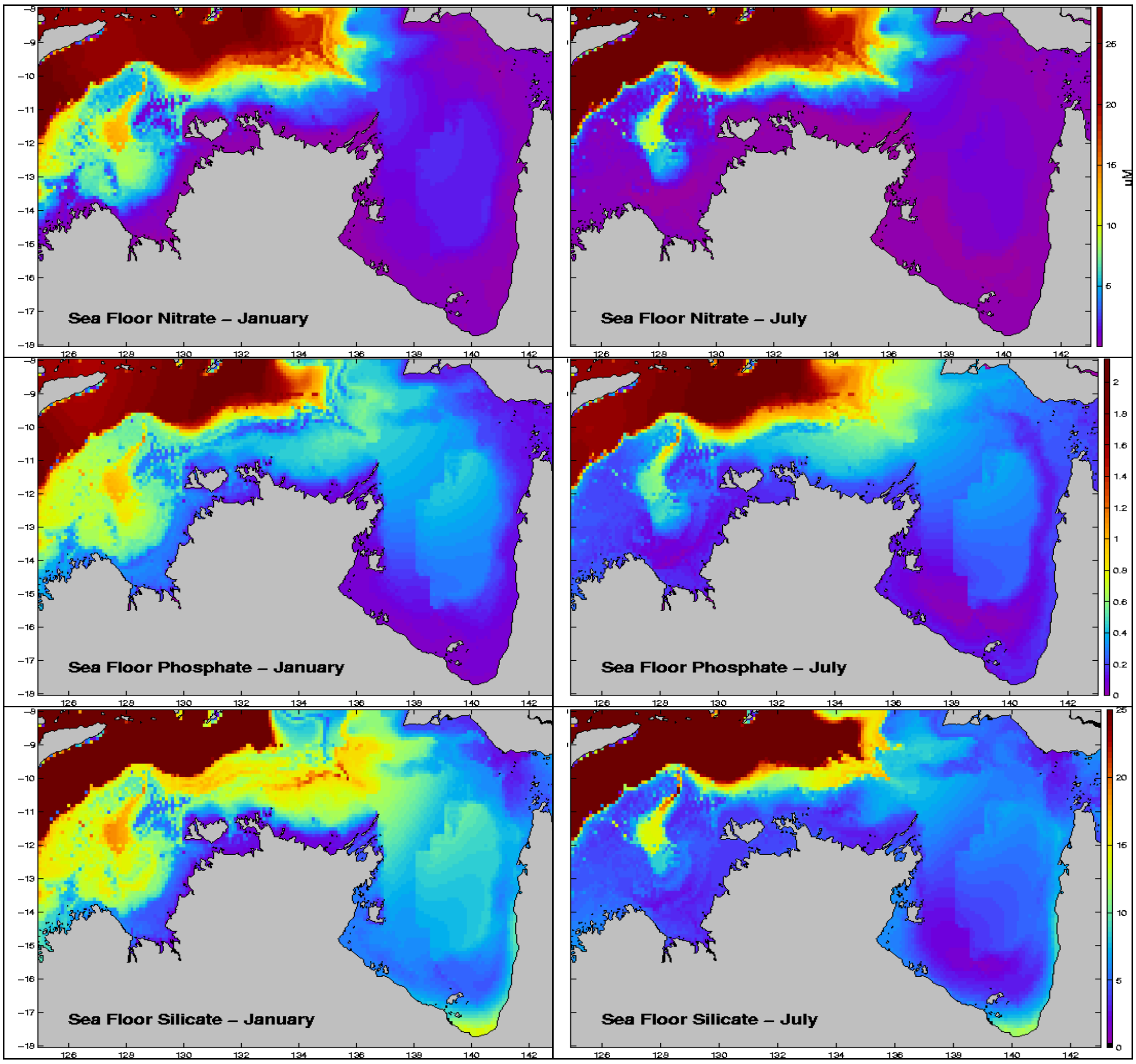

Figure 3.1.3 Seasonal fields for January and July of nitrate (µM), phosphate (µM), and silicate (µM) at the seafloor. Scales are given on right hand axis.

Uncertainties in the tracer fields were quantified in terms of the mapping radius (reflecting data density) and rms residuals (reflecting data deviations from the mapped fields). The mapping radius patterns were similar for most tracers, revealing relatively high data densities (i.e. small mapping radii) around the coastal waters of the Gulf of Carpentaria, lower densities in the central Gulf of Carpentaria and Joseph Bonaparte Gulf, and very sparse coverage to the north around the Timor Trough (Fig 3.1.4). Phosphate is the exception to these trends, with relatively sparse coverage across the entire region.

The rms residuals generally increase with the amplitude of the annual cycles (compare Fig 3.1.5 with Figs 3.1.2 and 3.1.3). For example, while dissolved oxygen levels along the Gulf of Carpentaria seafloor are highest in shallow water, both the annual variations and rms residuals peak in the central western half of the basin. Exceptions to this trend are evident in the Gulf of Carpentaria salinity and silicate fields, where there are large interannual variations in coastal values associated with rainfall and terrestrial runoff.

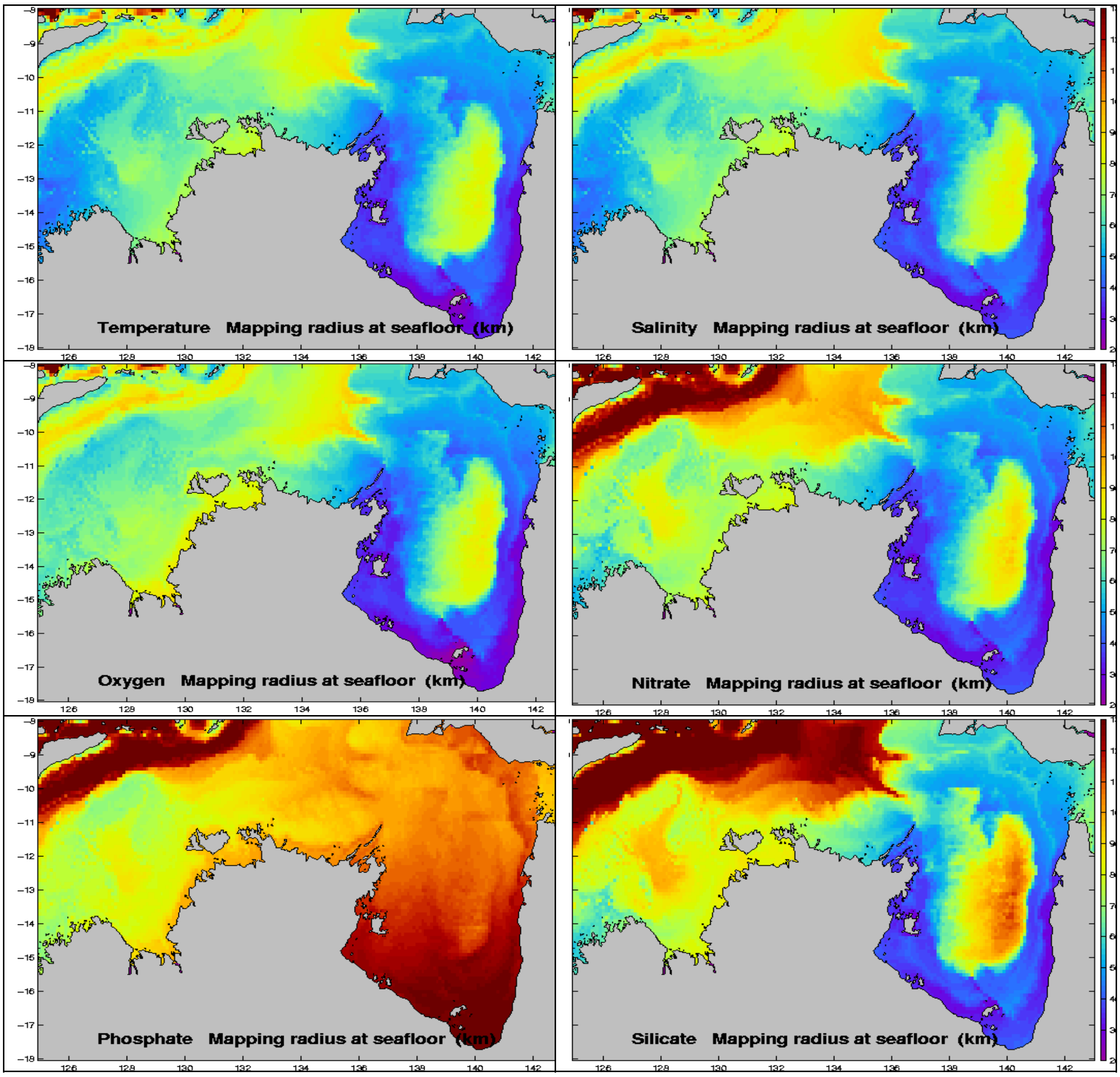

Figure 3.1.4 Mapping radius (km) for temperature and nitrate at the seafloor (note that the scales in the two plots are different). Scales are given on right hand axis.

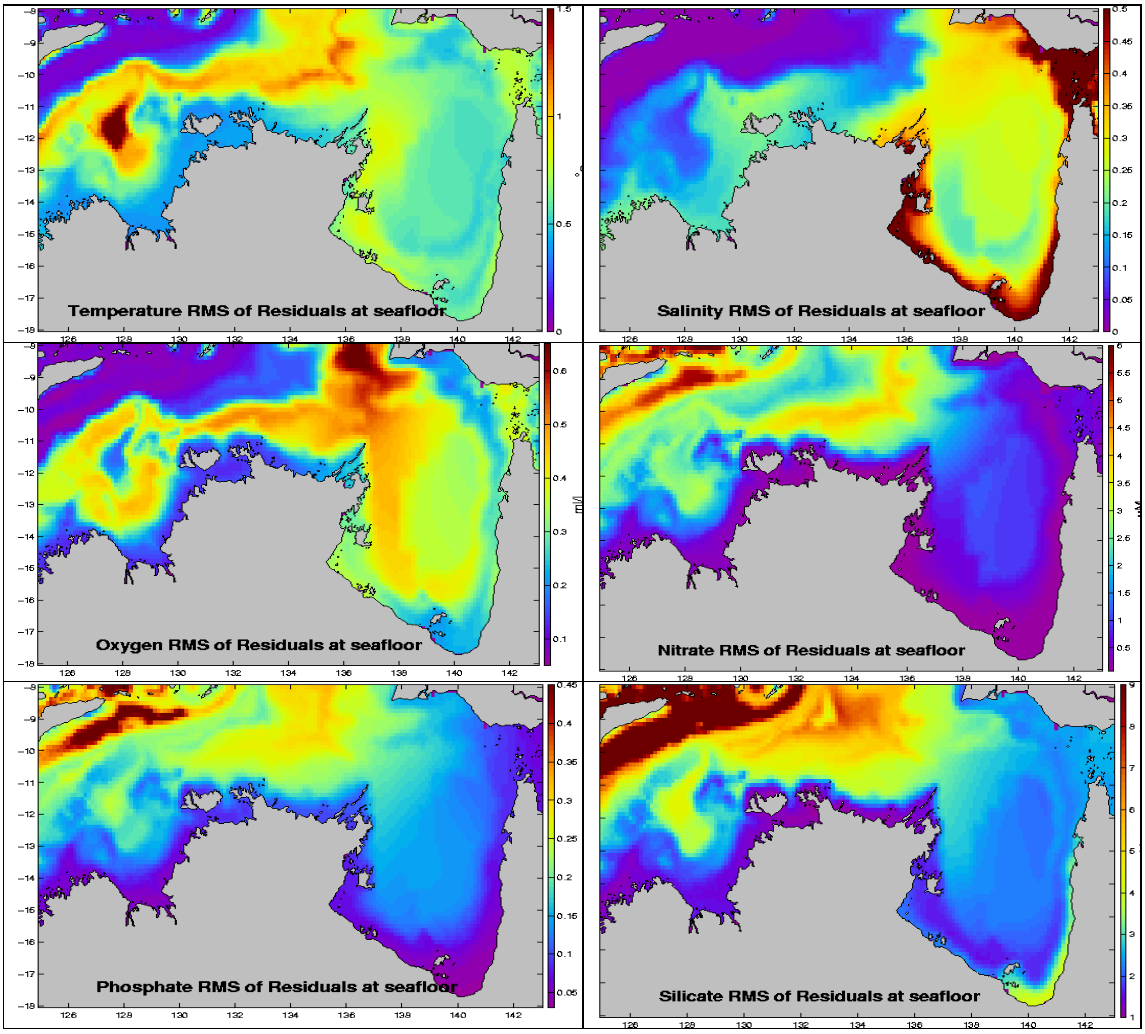

Figure 3.1.5 Root-mean-square residuals for temperature (°C) and nitrate (μM) at the seafloor. Scales are given on right hand axis.

Satellite ocean colour data

Scott Condie, Jeff Dunn

Satellite measurements of ocean colour can provide a measure of chlorophyll concentration in surface waters. In the relatively turbid waters of the NPF, suspended sediments introduce a significant uncalibrated contribution to the ocean colour signal. Under these conditions, the absolute chlorophyll levels tend to be unreliable. However, the information associated with their temporal and spatial patterns provides a potentially useful surrogate for biological communities.

Ocean colour data was taken from the SeaWiFS instrument (1997-2001). Seasonal climatologies were developed by fitting annual and semi-annual harmonics using a similar methodology to the hydrographic data. This helped eliminate biases associated with persistent seasonal cloud cover in some areas. The only additional processing was a spatially weighted averaging to reduce the horizontal resolution to 0.125° consistent with the hydrographic fields.

Chlorophyll concentrations are shown under summer and winter conditions (Fig 3.1.6). Highest concentrations (> 3 mg m^{-3}) occur in the coastal zone, where the contribution from suspended sediments is also likely to peak. While summer concentrations were generally higher in the coastal zone, values were higher in winter further offshore. The offshore seasonal cycle may be influenced by the development of thermal stratification and nutrient limitation in the surface mixed layer over summer (Rothlisberg et al. 1994).

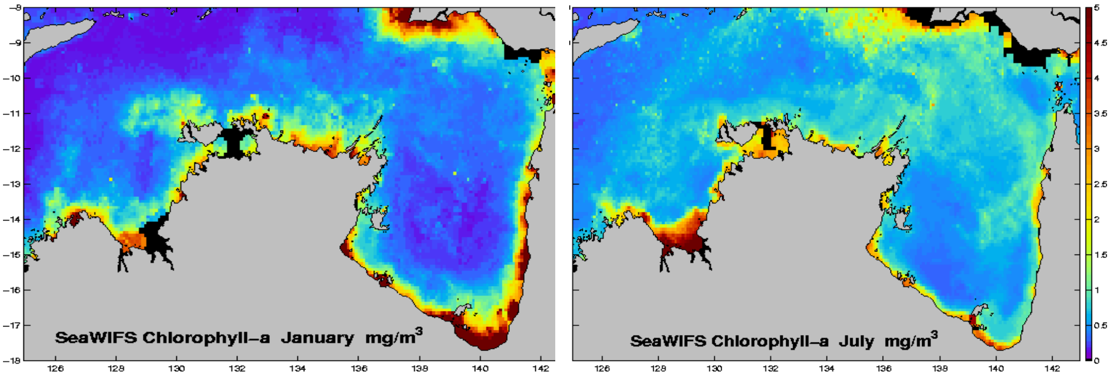

Figure 3.1.6 Seasonal fields for January and July of chlorophyll-a concentration as derived from the SeaWiFS ocean colour signal. Scales are given on right hand axis.

Conclusion

Sophisticated mapping techniques have been used to integrate available hydrographic and ocean colour data into seasonal descriptions suitable for incorporating into statistical surrogate analyses. The spatial and temporal coverage of the raw hydrographic data is highly variable, with most sampling concentrated in the coastal waters of the Gulf of Carpentaria. While the main restriction on the satellite ocean colour measurements is cloud cover, associated chlorophyll estimates tend to be confounded by the high levels of other suspended matter in the NPF. It should also be emphasised that the resolution of the mappings is limited to spatial scales of 0.125° with annual and semi-annual temporal components. These scales are appropriate for a seasonal mapping of water properties and have revealed significant spatial and seasonal variability in the NPF. However, they can only be expected to correlate with relatively large-scale variations in the distributions of benthic communities. The smaller scale patchiness evident in some benthic datasets is generally not reflected in water column properties.

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CHAPTER 3.2

HYDRODYNAMIC MODELS

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CHAPTER 3.2

HYDRODYNAMIC MODELS

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Summary

- A new hydrodynamic model was developed for the NPF, with realistic seasonal wind, wave, tidal, and open-ocean boundary forcing. The model has been run over a period of one year to provide information on seasonal variability. Comparisons with observed tides are very satisfactory, particularly given the extended regions of shallow water within the model. Description of the model output has focused on the bottom stress distribution due to its hypothesised relation to the distribution of benthic habitat. Extensive areas of high bottom stress occur in Joseph-Bonaparte Gulf, around Melville Island, south of Irian Jaya, and the southeast Gulf of Carpentaria. However, more localized zones are also evident, such as Torres Strait, west of Groote Eylandt, and around the Wessel Islands.
- The NPF model was also used to provide the boundary forcing for three smaller scale regions near Groote, the Vanderlins, and Mornington. These sub-region models provided higher spatial resolution (0.01°) in areas where other relevant physical and biological datasets are available. The three areas revealed contrasting bottom stress distributions. Groote was characterised by very high stresses in straits and channels, falling rapidly towards more open water. The relatively open waters to the northeast of the Vanderlins were characterised by weaker currents and relatively low bottom stresses. While the Mornington region was also relatively open, currents and bottom stresses were much higher off the eastern side of the island.

Introduction

In shallow waters with strong current regimes, the stresses exerted on the seafloor by deep currents are known to influence the distribution of bottom sediments. They are also postulated to influence the distribution of benthic organisms. For example, strong currents may inhibit settlement and recruitment or even cause physical damage to mature organisms. Alternatively, in a region of weak currents some plants and filter-feeders may be limited by the low influx of nutrients and other suspended food material.

Bottom stress cannot be measured directly in the field, but must be inferred from current meter measurements in the water column. Since this is only ever practical at a small number of sites, we must rely on hydrodynamic models to provide current and bottom stress distributions over large areas. Because these estimates tend to be sensitive to local bathymetry, high spatial resolution is desirable in regions of complex bathymetry. A nested modelling approach was therefore adopted in which fine scale models were developed for regions of particular interest and then forced by outputs from a regional model of the NPF.

This section of the report describes results from the NPF regional model and three higher resolution models for the Groote Eylandt, Vanderlin Island, and Mornington Island regions.

Hydrodynamic model of the NPF region

A three-dimensional hydrodynamic model was developed to describe the tidal and wind driven circulation over the entire NPF. The main purposes of the model were to:

i. Provide estimates of currents and bottom stresses over the NPF for assessment as surrogates for species assemblages.
ii. Provide boundary forcing for finer scale circulation models developed for key areas in the NPF.

Model description

The structure of the model is similar to that developed by Condie et al. (1999) for the Gulf of Carpentaria. This model provided essential components such as resolution of the three-dimensional flow structure and inclusion of a sophisticated bottom boundary layer module. It will also support potential future developments such as dispersion, sediment transport, and biological productivity studies. Past experience further indicates that the model performs very well in tidally dominated coastal environments (Walker 1999, Condie et al. 1999).

The model covers the Gulf of Carpentaria and extends over much of the Arafura and Timor Seas, including Joseph Bonaparte Gulf. The model bathymetry was derived from a 30 second gridded product developed by Geosciences Australia (Fig 3.2.1). The horizontal resolution of the model was 0.05° in both latitude and longitude (approximately 5 km), while the vertical grid expanded with depth from 3 m near the surface to 18 m at the maximum depth of 150 m.

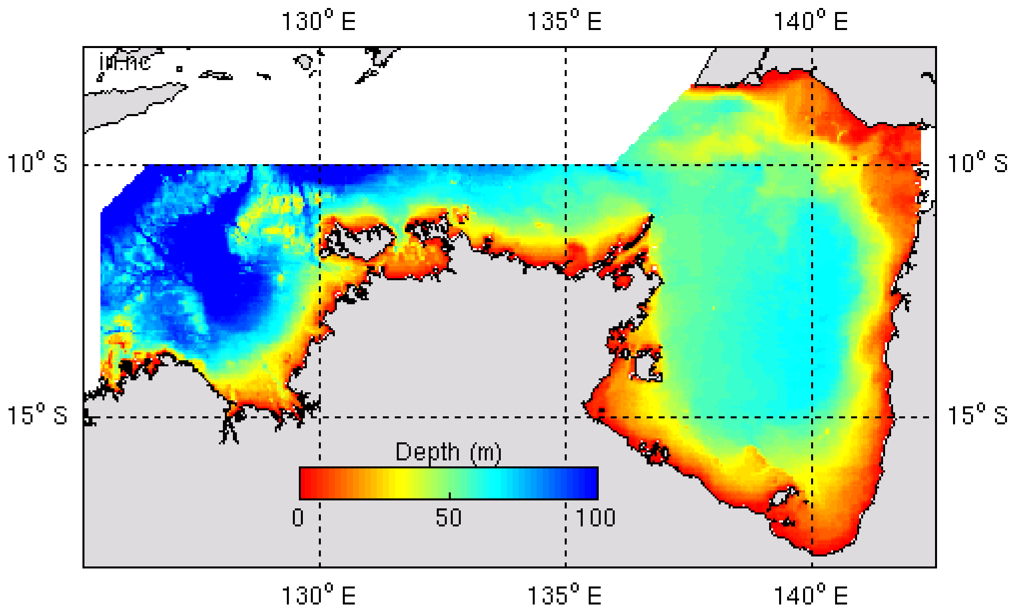


Figure 3.2.1 The model bathymetry derived from the 30 second gridded product developed by Geosciences Australia. This figure also demonstrates the horizontal coverage of the model grid.

The temperature and salinity fields over the model domain were initialized using the average seasonal patterns obtained from the CSIRO Atlas of Regional Seas (CARS) described in Chapter 3.1. Throughout the model runs, these fields were also weakly relaxed towards the seasonal average to ensure that the density fields were always consistent with historical data.

The circulation was forced by:
i. Tidal sea-level around the open ocean boundaries.
ii. Temperature and salinity fields around the open ocean boundaries.
iii. Wind stress and atmospheric pressure at the sea-surface.

iv. Surface wave fields.

Tidal sea-level, incorporating the M2, S2, K1 and O1 components, was interpolated from coastal and offshore tide-gauge data. This data was available at all the localities indicated in Fig 3.2.2, except False Cape for which initial estimates were taken from Condie et al. (1999). Estimates of dynamic height based on CARS indicate that the longer-term seasonal gradients in sea-level along the open ocean boundaries are relatively small and unlikely to contribute significantly to circulation in such a shallow system with high tidal dissipation. The temperature and salinity fields at the open ocean boundaries were also provided by CARS, and therefore varied with a seasonal pattern consistent with historical data.

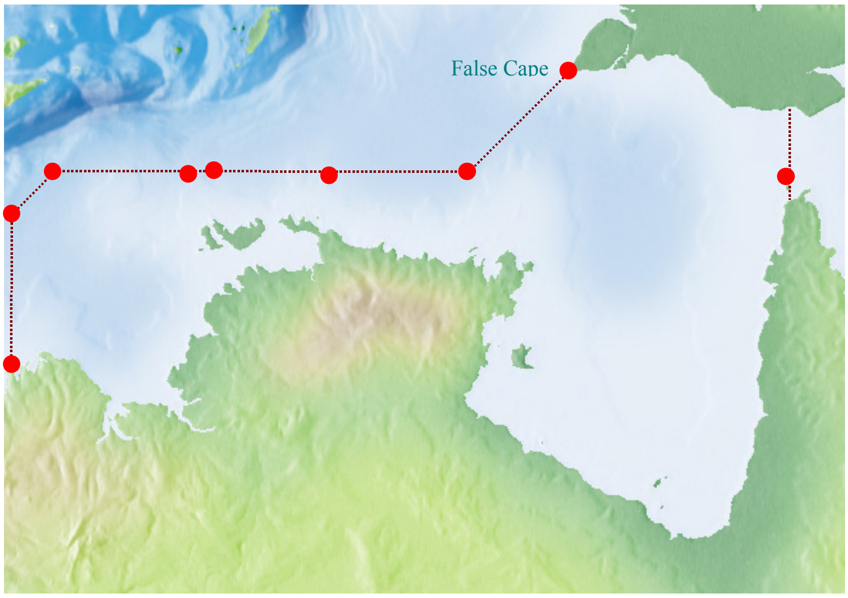


Figure 3.2.2 Map showing the location of tide-gauge stations (red dots) used to force sea-level along the open ocean boundaries.

Wind fields and atmospheric pressure were interpolated from the NCEP-NCAR 40-year Reanalysis dataset (Kalnay et al. 1996). Twelve hourly winds and pressures on a 1.9° grid were averaged over the years 1982 to 1997, to provide the seasonal patterns. These fields were then interpolated in space and time onto the model grid and model timestep. Comparisons across years indicate that the seasonal wind cycles are quite regular over the NPF (Fig 3.2.3), so that seasonally averaged wind forcing should result in valid estimates of seasonal circulation patterns.

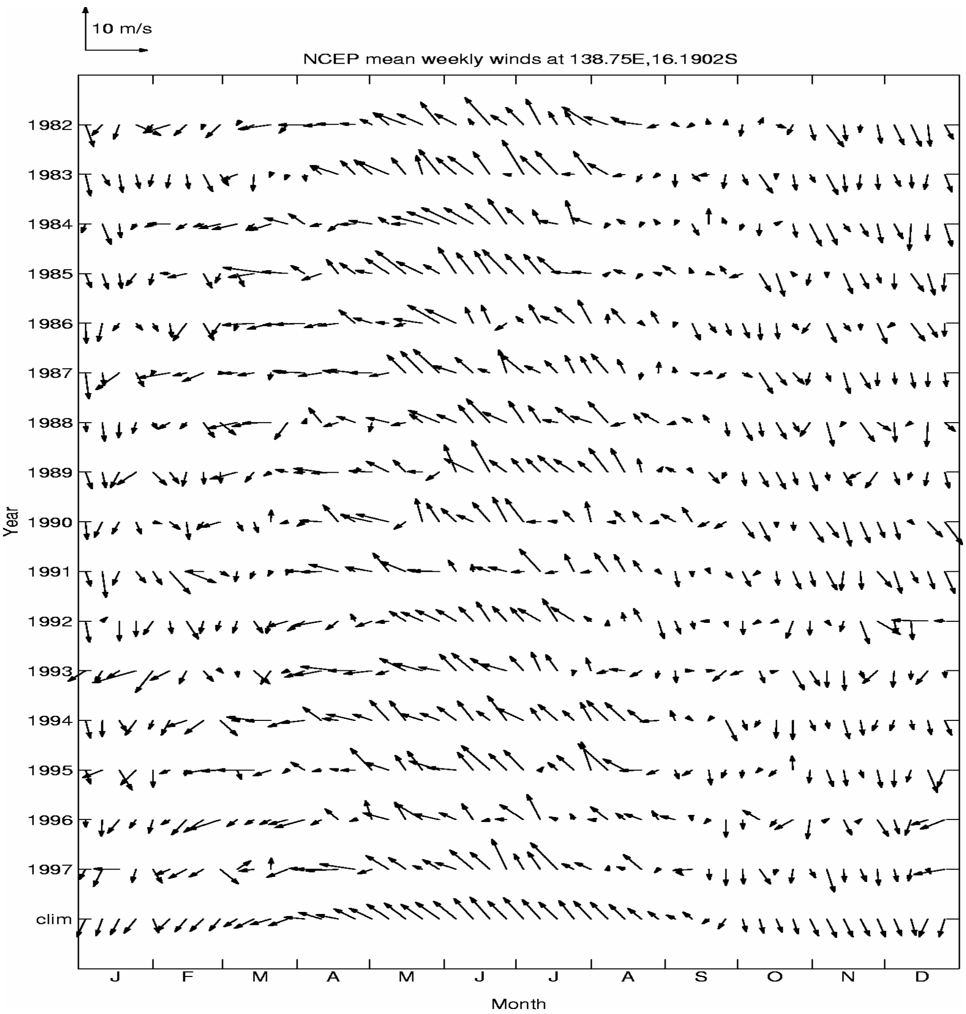


Figure 3.2.3 NCEP-NCAR Reanalysis wind vectors at 138.75°E, 16.19°S, and a height of 10 m above sea-level, for the years 1982 to 1997. The climatological winds (vector average over all these years) are indicated by "clim" near the bottom of the plot.

In shallow water (< 50 m) the orbital motions generated by surface waves can significantly enhance bottom stress. Since bottom stress is a potential surrogate for sediment type and/or benthic community type, wave enhancement was parameterised in the model using the Grant and Madsen (1979) scheme. This requires specification of the wave field in terms of significant wave height, period and direction, all of which vary in space and time. Since there are very few wave-rider buoy measurements available, it was necessary to develop a separate wave model for the region. Fortunately, the NPF is dominated by local "sea" rather than swell propagating in from the open ocean, so that a relatively simple empirical model provided adequate wave predictions for our purpose (U.S. Army Coastal Engineering Research Center, 1979). This model assumed a fully developed sea state in which the dissipation through white-capping and other processes is in equilibrium with the energy input by the wind. It used only the wind speed from the NCEP-NCAR Reanalysis, fetch derived from coastline locations, and water depths from the Geosciences Australia dataset. The model outputs were significant wave height (average height of the highest 1/3 of waves), wave period, wave direction, and orbital velocity at the seafloor. All outputs were saved on a 12 hourly timestep for the climatological year on both the 0.05° and 0.01° hydrodynamic model grids. The orbital velocity, period, and direction were used directly in the circulation model runs to calculate the wave enhanced bottom stress based on the methodology of Grant and Madsen (1979).

Model validation

The hydrodynamic model was first run with zero windstress in order to validate the tidal circulation. The temperature and salinity stratification and surface waves were not removed, since these influences are not excluded when tidal constituents are estimated. Time-series from the model output were then compared with tides measured at coastal stations within the NPF (Fig 3.2.4). Correlations between the modelled and observed tides, and the mean ratio of the hourly tide data are summarised in Table 3.2.1. The agreement at most stations is quite good, with an average correlation of 0.78 and an average modelled to observed ratio of 0.91. Because the tidal signal tends to propagate clockwise around the Gulf of Carpentaria, there is a notable degradation along the complex coastline between Milner Bay and Gove Harbour. However, further west the comparisons again improve due to the closer influence of the open boundary (Cape Croker, Darwin). Given the large shallow region and associated remoteness of many of the stations from the boundary forcing, these results can generally be considered as very satisfactory.

The sea-level results showed no significant sensitivity to any internal model parameters, such as horizontal viscosity or bottom roughness scale. The only other tunable factor in the model was the tidal constituents at False Cape (Papua New Guinea). These are important to the boundary forcing, but have never been directly measured. As in previous modelling studies of the Gulf of Carpentaria (Church and Forbes 1981, Wolanski 1993, Rothlisberg et al. 1996, Condie et al. 1999), these were adjusted to optimize the agreement with observations at other tidal stations in the Gulf. The final set of constituents were very similar to those obtained previously by Condie et al. (1999), the only change being an increase in amplitude of M2, K1, and O1 by 0.1 m. This increase tends to offset the enhanced bottom friction associated with the inclusion of surface waves in the new model.

Results

Following validation of the tidal component, pressure and wind stress forcing were added and the model was run over a full year. Not surprisingly, the tidal component continues to dominate the sealevel and current fields (Fig 3.2.5). The largest variations occur in Joseph Bonaparte Gulf, where the tidal range approaches 7 m and depth averaged currents peak at around 1.5 m s^{-1} or 3 knots. However, substantial tides occur throughout the NPF, with currents of 0.5 m s^{-1} commonplace.

The bottom stress distribution is determined by bathymetry, currents, and surface waves. It reflects the strong tidal oscillations evident in the currents, but tends to be further enhanced in shallow waters and narrow straits (Fig 3.2.6). Large areas of high bottom stress occur in Joseph Bonaparte Gulf, around Melville Island, and in the shallow waters south of Irian Jaya and the southeast Gulf of Carpentaria. However, more localized zones are also evident, such as Torres Strait, west of Groote Eylandt, and around the Wessel Islands.

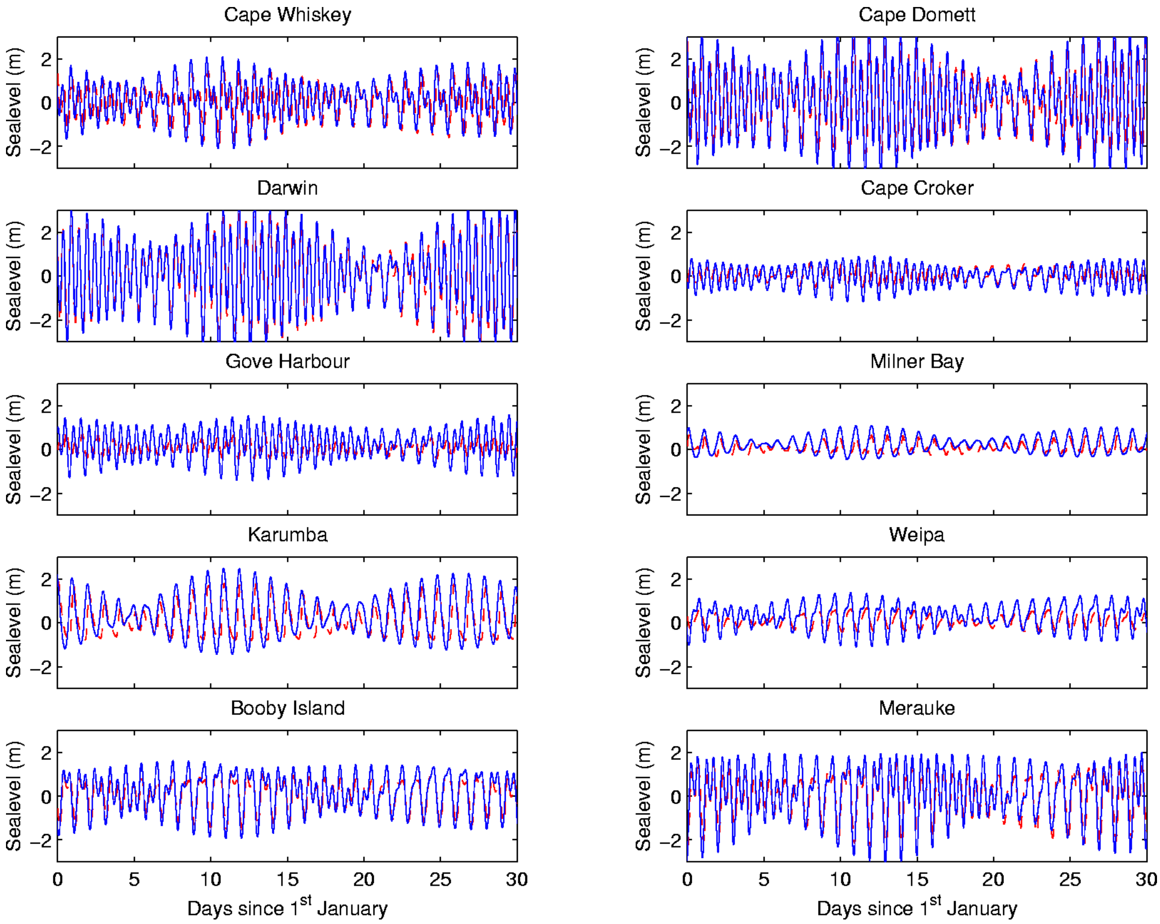


Figure 3.2.4 Comparison of measured tides (solid blue lines) and tides from the hydrodynamic model (dashed red lines) at ten locations within the NPF.

Table 3.2.1 Correlations and time averaged ratios of observed and modelled tides (both calculated from hourly records).

Tidal Station	Correlation	modelled/observed
Cape Whiskey	0.63	1.39
Cape Domett	0.91	0.96
Darwin	0.98	0.97
Cape Croker	0.73	0.83
Gove Harbour	0.51	0.80
Milner Bay	0.76	0.73
Karumba	0.73	1.04
Weipa	0.72	0.72
Booby Island	0.93	0.80
Merauke	0.89	0.87
Average over all stations	0.78	0.91

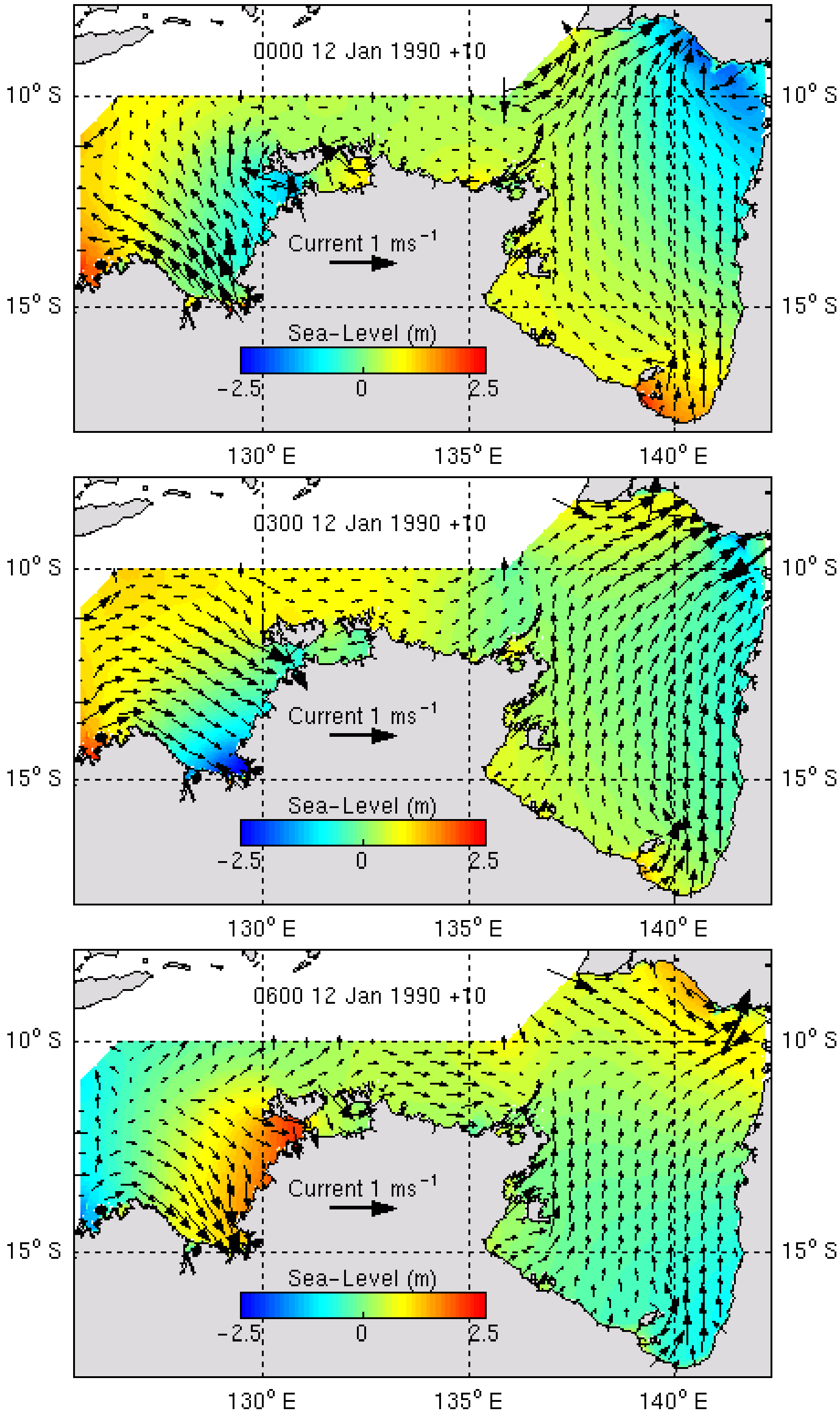


Figure 3.2.5 Sea-level computed by the hydrodynamic model at midnight, 3:00 am, and 6:00 am on January 12, overlain by the depth averaged current vectors.

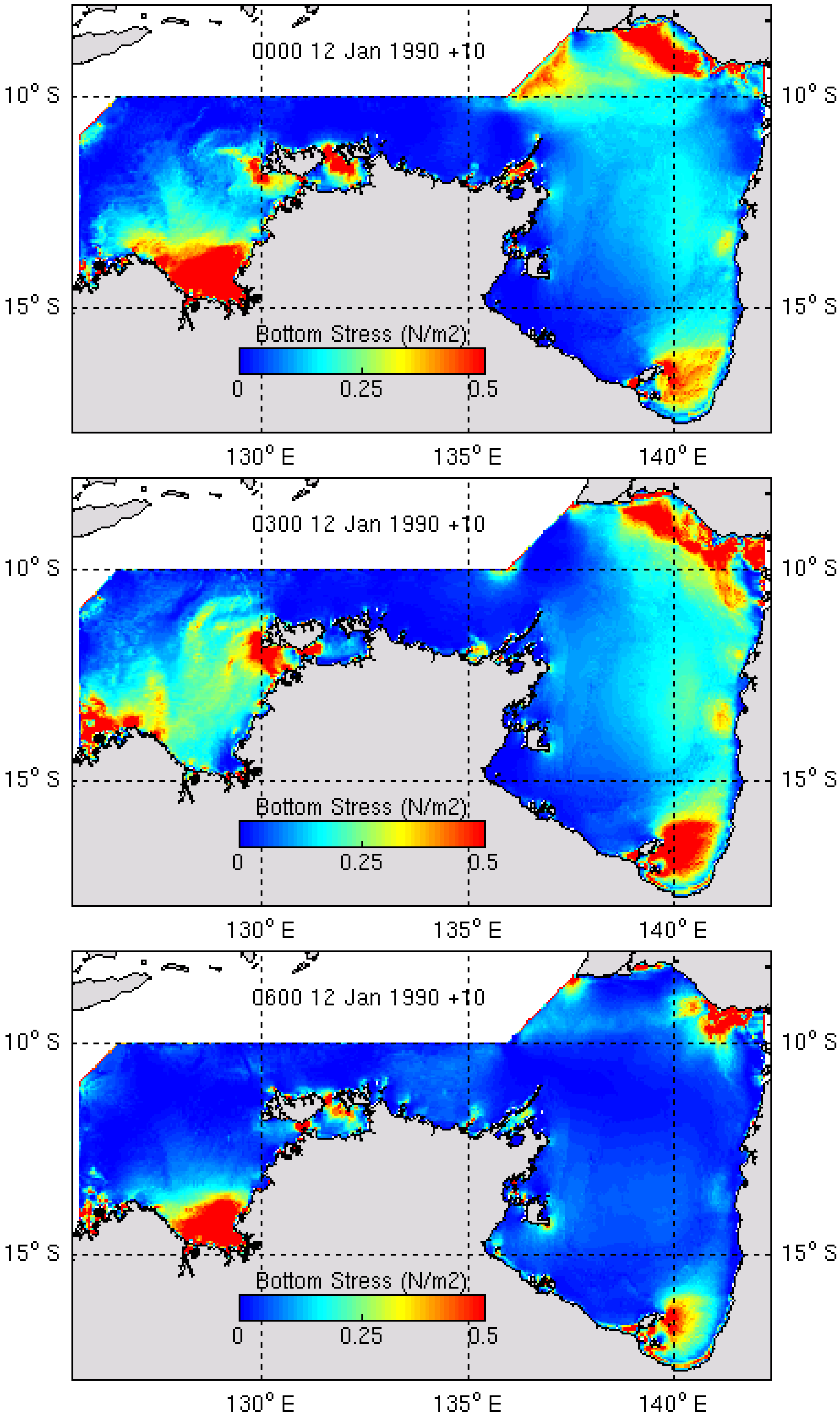


Figure 3.2.6 Bottom stress (N m^{-2}) computed by the hydrodynamic model at midnight, 3:00 am, and 6:00 am on January 12.

To use bottom stress as a surrogate for ecosystems, we must first determine its temporal statistics at each model grid cell. The mean, standard deviation, and maximum (mean of upper 10%) were calculated from hourly model output over the whole year (Fig 3.2.7). Because the signal is predominantly due to oscillatory tides, the spatial distribution of each of these fields is very similar. They again illustrate the impact of strong tidal flows in the south and west of Joseph Boneparte Gulf and Torres Strait. However, significant contrasts can be seen in other regions, such as Groote and Mornington.

Much of the surface wave influence has already been captured in the computation of bottom stress. However, the sloshing motions associated with the passing of each wave crest may have specific impacts on benthic communities independent of the lower frequency background currents. Temporal statistics from the output of the wave model may therefore provide another potential surrogate variable. The mean, standard deviation, and maximum (mean of upper 10%) values of significant wave height have been calculated from the 12 hourly model output over the whole year (Fig 3.2.8). Since the winds are climatological there is no representation of strong storm events, such as tropical cyclones, in these results. It should also be noted that during any period there is a spectrum of wave heights present and individual waves of two to three times the significant wave height can be encountered. Annually averaged significant wave heights exceed 1.5 m in the northwestern Gulf of Carpentaria and maximum values are almost twice this value. Smaller waves are predicted in the southern Gulf with substantial differences in the wave environments north and south of Groote Eylandt. Smaller waves (< 1 m) also predominate off Arnhem Land and in Joseph-Bonaparte Gulf.

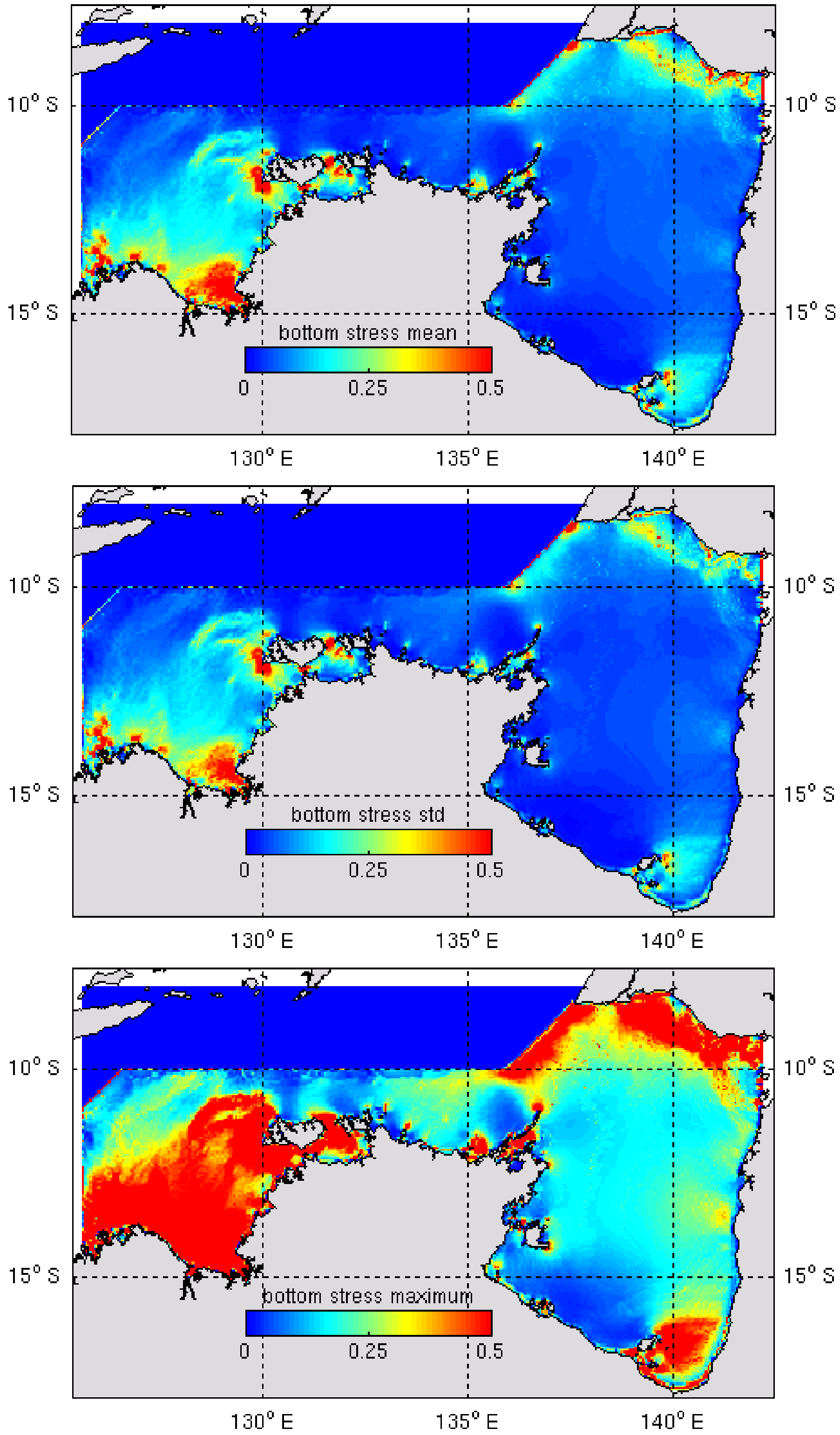


Figure 3.2.7 Bottom stress statistics (N m^{-2}) based on hourly output fields covering the entire year: mean (top), standard deviation (centre), and maximum - defined here as the mean of the upper 10% (bottom).

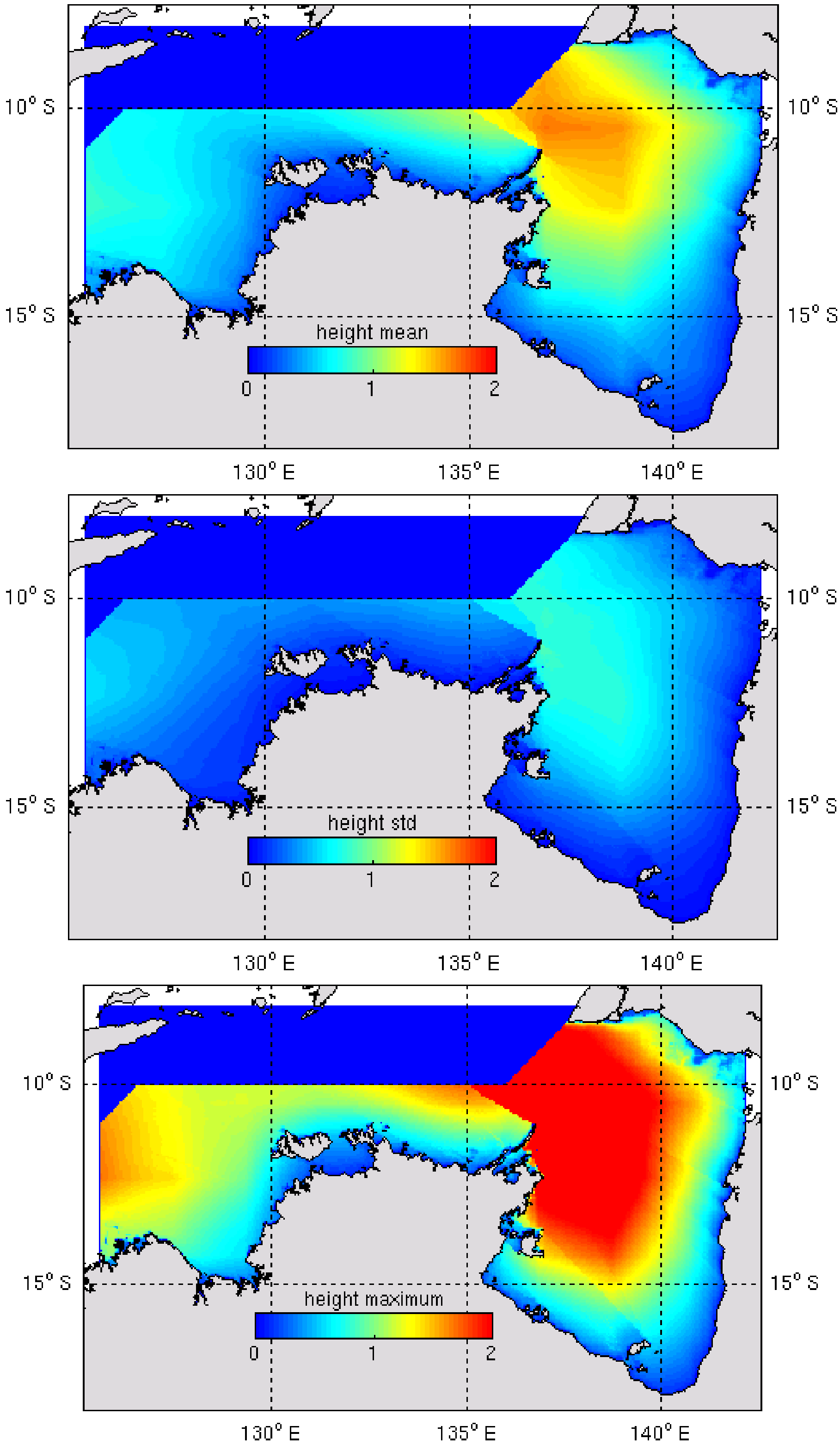


Figure 3.2.8 Significant wave height statistics (m) based on 12 hourly output fields covering the entire year: mean (top), standard deviation (centre), and maximum (bottom).

Fine-scale hydrodynamic models for sub-regions within the NPF

The model described above provides comprehensive coverage of the NPF at a resolution of 0.05°. This is better than the resolution of available fisheries and research trawl data. However, much of the other geological and biological data is taken from point sources in environments that are heterogeneous in their physical characteristics and likely to be characterized by patchy biological distributions. While it is impractical to run a finer scale hydrodynamic model over the entire NPF, nested models have been developed for three sub-regions within the Gulf of Carpentaria. These were selected to coincide with the locality of other available physical and biological data.

Model description

For each of the sub-region models, the horizontal resolution was increased by a factor of five to 0.01° in both latitude and longitude (approximately 1 km). The vertical grid was the same as that used for the 0.05° NPF model. However, since the deepest water in any of the three models was less than 60 m, the vertical grid spacing did not exceed 5 m. Bathymetries were again derived from the 30 second gridded product developed by Geosciences Australia.

The selected sub-regions were:

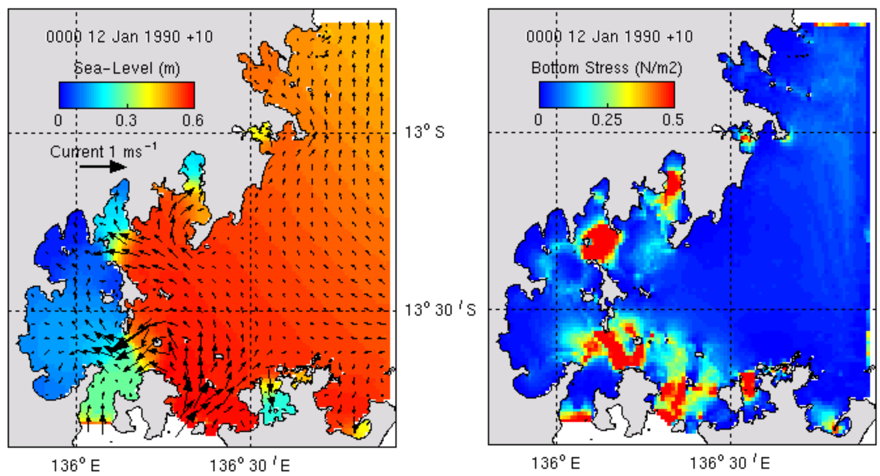
i.	North of Groote Eylandt	(135.83°E 13.86°S to 136.90°E 12.69°E)
ii.	Northeast of Vanderlin Island	(136.98°E 15.72°S to 138.02°E 14.68°E)
iii.	North of Mornington Island	(138.98°E 16.32°S to 140.02°E 15.68°E)

Each of the sub-region models were forced by:

i. Sea-level around the open ocean boundaries from the NPF model (0.05°).
ii. Temperature and salinity around the open ocean boundaries from the NPF model.
iii. The wind stress and atmospheric pressure fields used to force the NPF model interpolated onto the finer grids.
iv. Surface wave fields produced by the wave model on the finer grids.

Model results

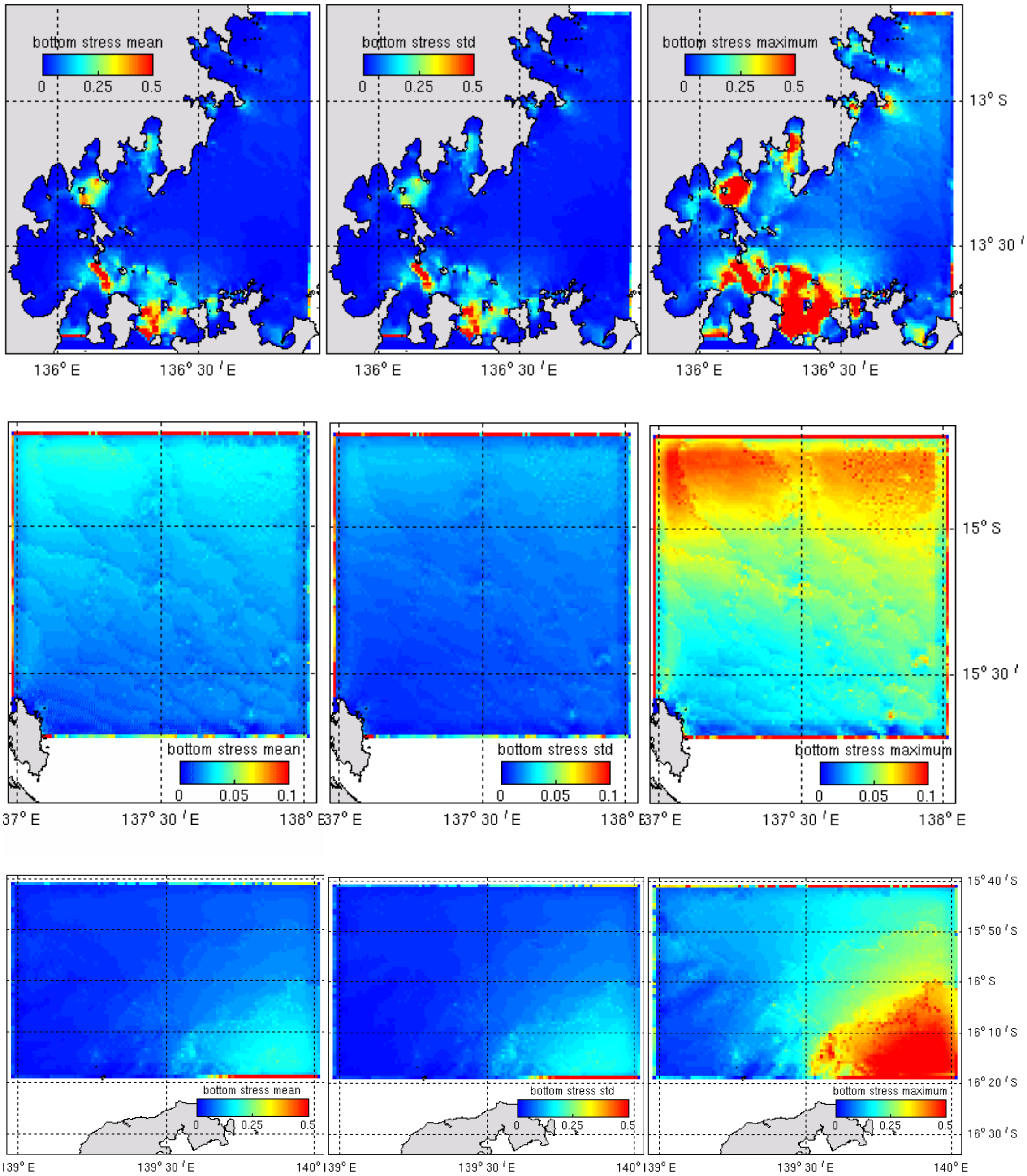
The sealevel, currents, and bottom stress fields around Groote demonstrate the higher level of detail provided by the fine-scale model (Fig 3.2.9). This is particularly significant in regions of complex bathymetry, such as narrow channels and headlands, where strong tidal currents and high bottom stresses are most evident.



(a) (b)

Figure 3.2.9 Examples from north of Groote of (a) sealevel and depth-averaged currents and (b) bottom stress distribution.

Summary statistics for the bottom stress distribution in each of the three regions were computed as for the NPF model. The mean, standard deviation, and maximum (mean of upper 10%) are shown for the Groote, Vanderlins, and Mornington regions (Fig 3.2.10). North of Groote the bottom stress distribution is again characterised by high values within straits and channels, and much lower values in open waters. However, the other two sub-regions are relatively free of complex bathymetric features. The Vanderlins sub-region has relatively low bottom stresses throughout the selected domain, with a gradual increase from south to north. Values are generally higher around Mornington, with a significant increase towards the southeast associated with strong tidal flows on the eastern side of the island. Comparing Fig 3.2.10 with Fig. 3.2.7 suggests that enhanced spatial resolution reveals significant additional structure around Groote, but had less impact around the Vanderlins and Mornington.



(a) (b) (c)

Figure 3.2.10 Bottom stress statistics (N m^{-2}) from north of Groote (upper), northeast of Vanderlin (center), and north of Mornington (lower). (a) Mean, (b) standard deviation, and (c) maximum or mean of the upper 10% of values. Note that the colourbar range for the Vanderlin plots is only 20% of the other two areas.

Conclusion

With a focus on developing surrogates for distributions of benthic organisms, the main outputs of the hydrodynamic modelling are spatial statistics for the bottom stress fields. There is clearly substantial spatial and temporal variability in bottom stress across the NPF. In regions with limited bathymetric variation, such as Mornington, only very limited additional information was generated by increasing the resolution from 0.05° to 0.01°. However, in regions of complex bathymetry, such as Groote, there is significant fine-scale structure down to the kilometre scale of the model and it is likely that still finer structure exists in the real system. When statistically evaluating the surrogate value of the model output, it is therefore essential to match the scales of the surrogate and the habitat information.

The coverage of existing habitat data across areas of variable bottom stress is likely to be inadequate for a proper surrogate evaluation. However, the model fields may provide a valuable guide for the design of future field programs. For example, to test if bottom stress influences the distribution of benthic communities around Mornington, sampling could be aimed at contrasting the environments northeast and northwest of the island (Fig. 3.2.10). High variability in bottom stress levels could similarly provide a basis for biological sampling in the Groote region.

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CHAPTER 3.3

INTERPOLATION OF SEDIMENT DATA IN THE GULF OF CARPENTARIA

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Nick Ellis

CHAPTER 3.3

INTERPOLATION OF SEDIMENT DATA IN THE GULF OF CARPENTARIA

Nick Ellis

Summary

- We describe how to carry out spatial interpolation of sediment data using the techniques of Akima, local regression smoothing and universal kriging. Our preferred choice is kriging, because it takes into account small-scale spatial dependence and provides a measure of the error in the interpolated values.
- By interpolating onto a fine grid, we have produced maps of the sediment over the entire Gulf of Carpentaria. We have also produced interpolated values at the biological sites, and these values have been used elsewhere in this report as explanatory variables, or surrogates, for the biota.

Introduction

Elsewhere in this report we describe methods and results of predicting benthic biota from physical covariates or surrogates. In order to relate biota to covariates, the biological and physical data need to be measured at the same location. However, for logistical reasons it is often not possible to collect the physical data as well as the biological data at the same site. It is therefore necessary to provide an estimate of the physical data at the biological site; this is done by interpolation from physical data measured at nearby sites. These sites could be

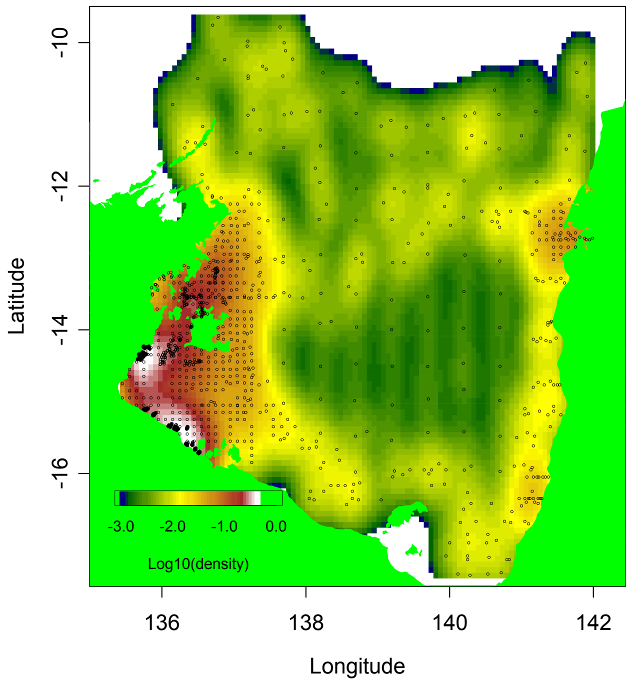

Figure 3.3.1. Kernel density plot showing the density of sediment sample points on a log_{10} scale. Sample locations are shown as black points. The kernel function is normal surface with variances 0.17 and 0.29 degrees in the longitude and latitude directions respectively.

special sites in the same survey where physical data were measured, or they could come from a completely unrelated survey or from a commercial vessel.

Moreover, even if physical data have been measured at the biological site, such measurements may be subject to error. Also, the physical data, being the result of grabs, are point measurements, whereas the biological data, being the result of trawls, are an aggregate measurement over an extended area. Therefore, the point measurement of the physical covariate, being more variable, may be less reliable than an estimate arising from averaging over nearby sites.

In this section we describe how we performed spatial interpolation for sediment data. The data are percentages of sediment at three different grain sizes (gravel, sand and mud). Although the main reason for interpolating was to provide estimates at biological sites, we have also generated, as a by-product of the process, sediment maps by interpolating onto a very fine grid and displaying the result.

Methods

We had data from 1900 sediment samples (% mud, sand and gravel) collected over 18 research cruises and from several commercial vessels. There was a high density of sampling around Weipa and Groote Eylandt, and a very high density along the south-western corner of the Gulf. There was sparser sampling in the middle of the Gulf, but the sampling is sufficiently extensive to develop a map of sediment over the entire Gulf by interpolation. Figure 3.3.1 shows a kernel density plot of the sampling. One method of interpolation, due to Akima (1978), is to perform a Delaunay triangulation and then fit a fifth-order polynomial to the triangles spanning the data points. For this to work, replicate values (of which there are 390 in this case) must be averaged to provide a unique value at each location. This method provides a reasonable first impression of the spatial behaviour. However, it tends to be rather noisy and looks somewhat artificial because the surface is forced to go through the actual data values at the sample points. Also it does not provide an indication of the error in the interpolation. An example for percentage sand is shown in Figure 3.3.2.

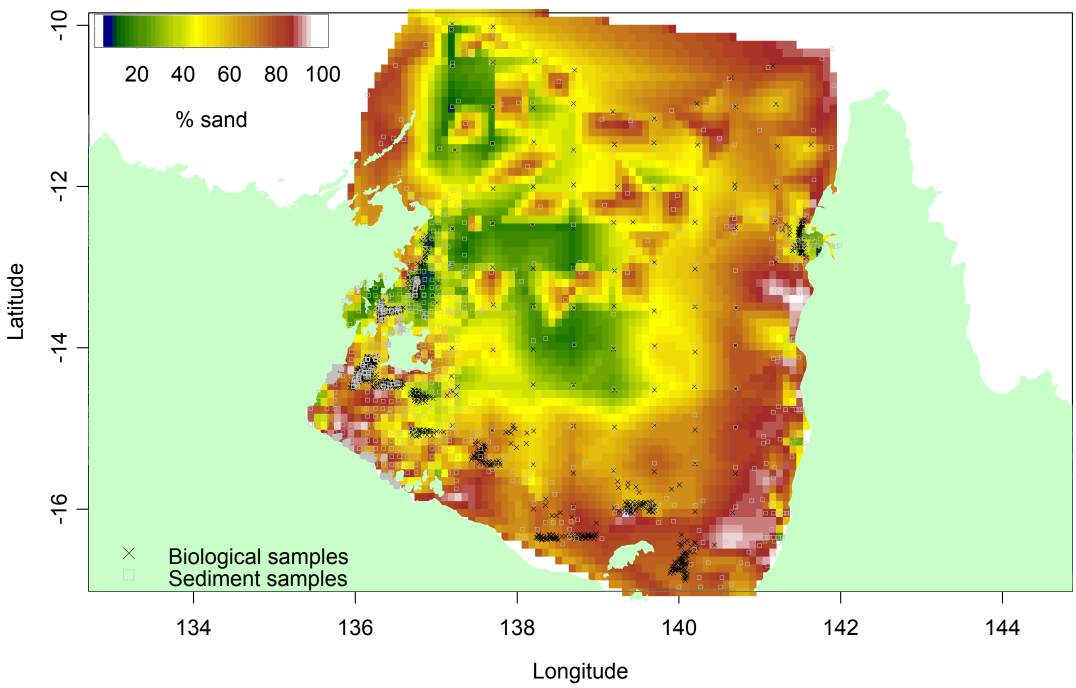

Figure 3.3.2. Akima interpolation of raw percentage sand. Replicate values at the same location have been averaged. Only the region inside the convex hull of the sediment sample locations has been interpolated.

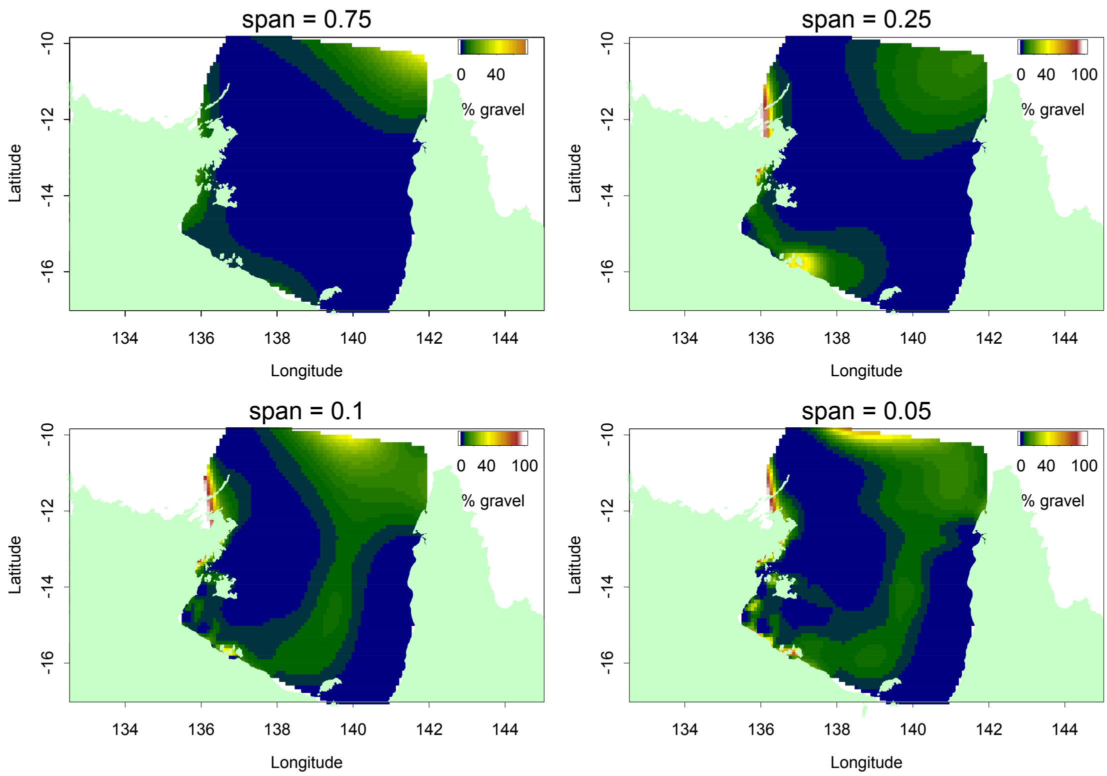

Figure 3.3.3. Local regression (loess) fits to the gravel data for 4 different span values.

A second method of interpolation is to apply a local regression (loess) model to the data. Here, the surface is modelled locally as a second-order polynomial in longitude and latitude, chosen to minimize the weighted sum of square residuals in the local neighbourhood. This method can handle replicate values. The modelled surface tends to be smooth and so looks more natural than the Akima surfaces. The degree of smoothness is controlled by the span parameter which must be chosen. In principle, the span could be determined by cross-validation, but, as this is computationally intensive, it is usually chosen to give the 'best-looking' fit. Again, apart from cross-validation, the method does not provide an indication of the error in the interpolation. Examples of loess smoothing for 4 different spans are shown in Figure 3.3.3. The span value is the fraction of data included in the local neighbourhood.

The third method is universal kriging. The method is similar to loess in that it provides a smoothing to the data, but it uses a global second-order polynomial instead of a local model. However, it differs from loess in the way it models the local-scale behaviour. Whereas loess regards the data values as independent, and so minimizes a weighted sum of squares, universal kriging takes into account the correlation between neighbouring sample points, and so minimizes a generalized sum of squares that involves cross products between residuals at different points. The kriged value is that which minimizes the expected squared error in the prediction. For detail on the theory of kriging see, for example, Cressie (1993).

The theory of kriging is based on normal distributions, and so it is reasonable to transform the data onto a scale that extends to infinity in both directions. Such a transformation is

$$\text{log-ratio}(x) = \log(x/(100-x)).$$

In order to quantify the correlation between neighbouring points, we compute the empirical variogram of the transformed data. Empirical variograms are shown in Figure 3.3.4. The data are first fitted to a global second-order polynomial, and the residuals are then used to compute the variogram. The value in a distance bin is the mean of the squared difference in residual between all pairs of points lying in that distance bin.

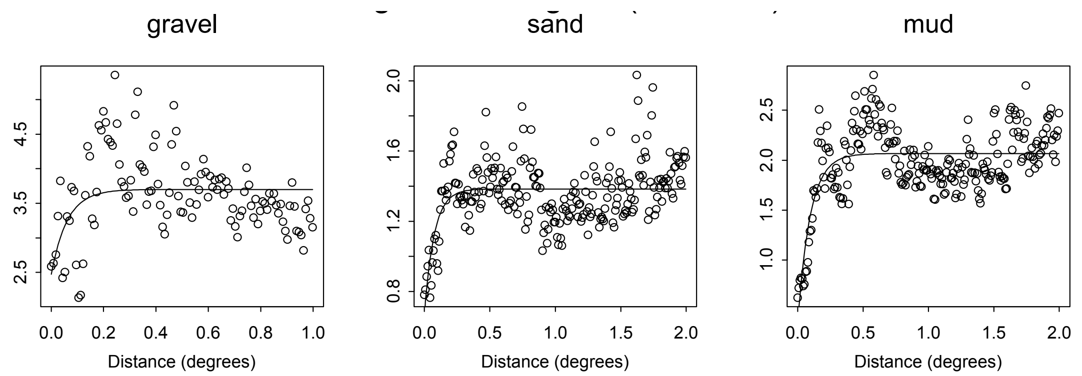

Figure 3.3.4. Empirical variograms for de-trended log-ratio-transformed sediment data.

It is clear that the variance is smaller for shorter distances, but there is still some variation even at very small distances. This is called a nugget effect: it can be due either to measurement error (that is variation in repeated measurements at the same location), or to small-scale variation (neighbouring points are to a certain extent dissimilar no matter how close they are). We assume a functional form for the variogram, in this case an exponential form

$N+S(1-\exp(-3h/R))$,

where h is the distance, N is the nugget, S is the partial sill and R is the range. Points with separation greater than about R are uncorrelated under this model. We have fitted the variogram model to the empirical values, and the fitted line is shown overlaid in the Figure. The range is about 0.2–0.3 degrees for each sediment type. This means that, to interpolate at some point, we need only consider a neighbourhood of about 0.3 degrees around that point. This suggests that, for the loess method, a span of at most 0.05 (0.3 degrees) is required, and so the other cases may have been over-smoothed.

Current kriging software does not handle replicate values at the same location, because the kriging equations become singular. One proposal is to use averaged data but modify the diagonal of the covariance matrix. (Generalized least squares use a covariance matrix formulation instead of a variogram formulation; the two are interchangeable.) The modification is to divide the diagonal by the vector k, which is the number of replicates at each location. This correctly provides the added weight that an averaged value should have and will also reduce the standard error of the estimate. This modification will require a recoding and recompilation of the Venables and Ripley spatial library. A second proposal, which would also require such modification, is to find the generalized inverse of the covariance matrix.

An alternative work-around is to jitter the locations so that they are all unique. This makes the system nearly singular and, for small systems, is usually enough to cure the problem. However for our relatively large system this work-around does not work.

We have resorted to simply taking averages and using the usual kriging equations as if the averages were single observations. There remains the issue of how much averaging to do, that is, how large a cell size to average over. We took the practical step of rounding all points to a grid, averaging and attempting to krige on the gridded data. We gradually increased the grid separation until the system became non-singular. This occurred at a separation of 0.01 degrees, when the number of grid points was 1082.

The results of kriging are shown in Figures 3.3.5–3.3.7. The results are intermediate between the roughness of the Akima method and the smoothness of the loess method. A further benefit of kriging is that we obtain standard errors for the predictions. The standard errors (which are on the transformed scale) tend to be higher in the middle of the Gulf where the sampling is coarser and lower in the south-west corner where the sampling is much finer. If the diagonal modification described earlier were implemented, the standard errors in the south-west corner would be lower still. They would be bound below by the nugget.

The sediment fractions have been analysed independently, whereas they are in fact constrained to sum to 100. An independent check shows that the predicted values do indeed sum to approximately 100, except in the region just below the chain of Wessel Islands in the north-west, where the predictions are all extrapolations (see Figure 3.3.1).

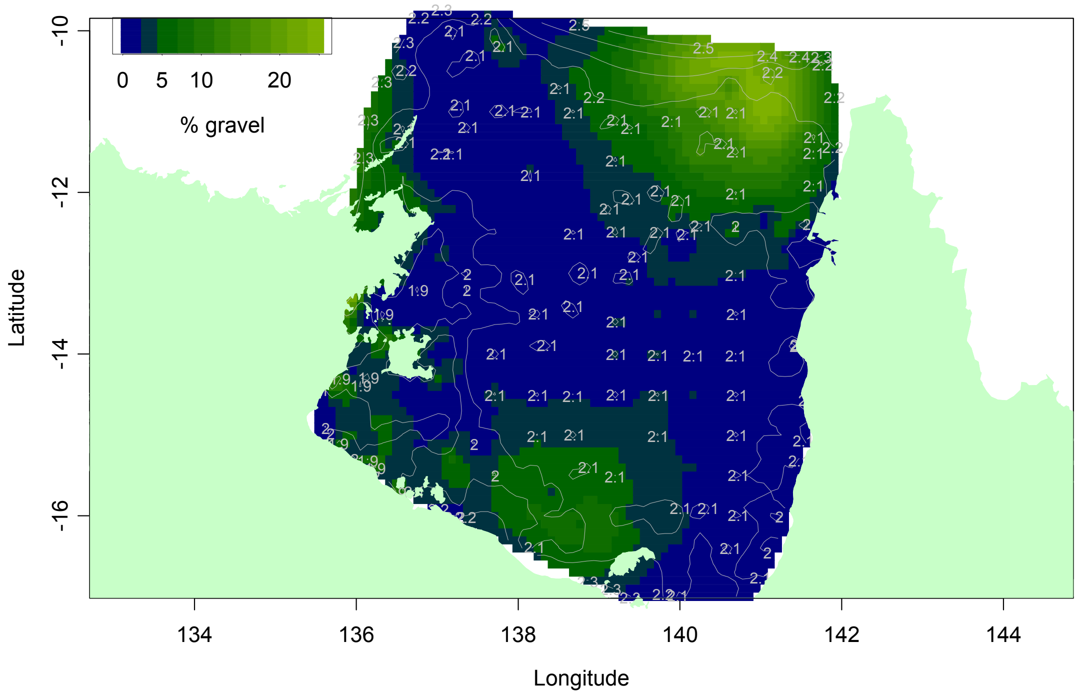

Figure 3.3.5. Kriged surface for percentage gravel with standard errors on log-ratio scale shown by contours.

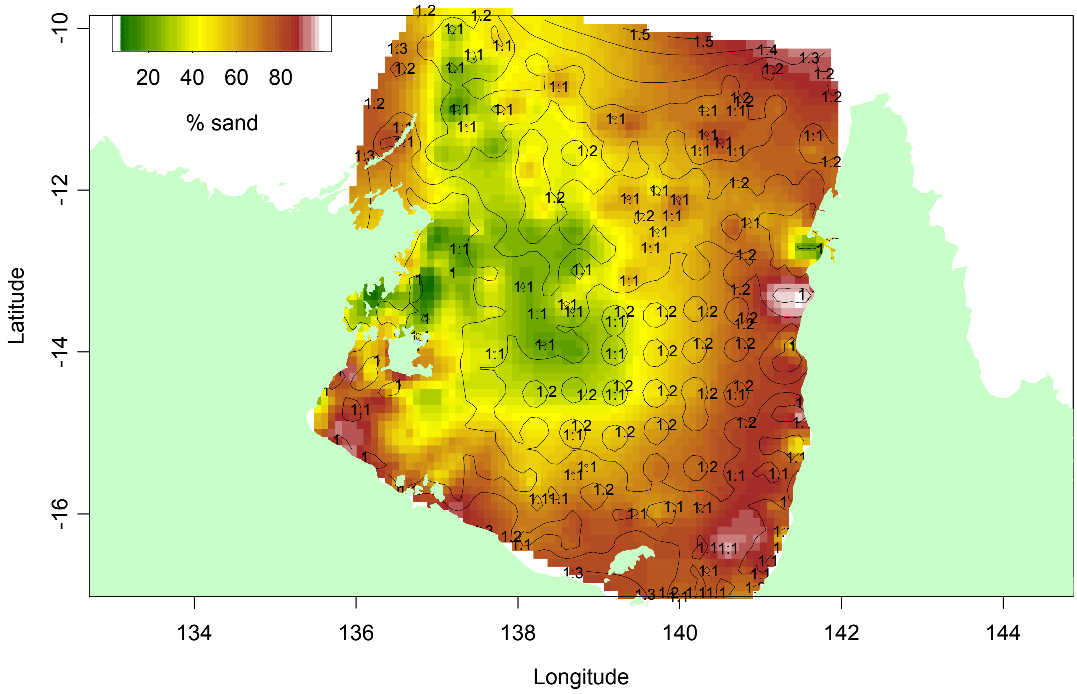

Figure 3.3.6. Kriged surface for percentage sand with standard errors on log-ratio scale shown by contours.

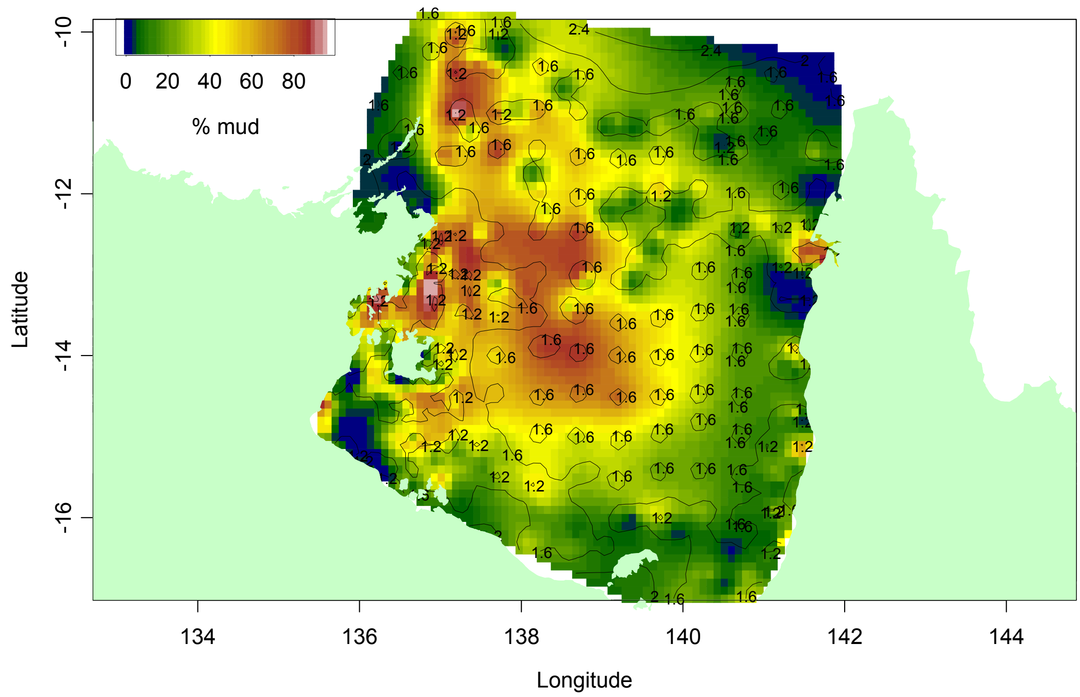

Figure 3.3.7. Kriged surface for percentage mud with standard errors on log-ratio scale shown by contours.

Strictly, the process of estimating the variogram ought to be iterated by analysing the residuals from the polynomial trend from the kriging. The variograms do look similar to those generated from the residuals of the preliminary polynomial fit (Figure 3.3.4).

Conclusion

We tried various methods for interpolating spatial data and discuss the merits of each. Since the variograms show definite small-scale correlation, we believe the kriging results are the most reliable, since they take this correlation into account. What is more, it is clear from the variograms that there is a distinct nugget effect, meaning that there is considerable small-scale variation. It is therefore necessary to smooth (i.e. krige) the data even at sites where physical data *have been* measured. We have provided predictions at these sites; these predictions have been used as covariates in several of the analyses elsewhere in this report.

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CHAPTER 3.4

ACOUSTIC DATA

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CHAPTER 3.4

ACOUSTIC DATA

Scott Gordon
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Summary

Acoustic data (seabed acoustic depth, roughness and hardness) was available from three research cruises as well as corresponding bycatch data from 689 prawn trawls

The data set is complex and a large amount of filtering was necessary

Comparison of data from two cruises 6 months apart (SS9702 and SS9708) showed that acoustic depth and hardness were strongly positively correlated between cruises but acoustic roughness was not

There is a strong relationship between acoustic hardness and the sediment property percentage sand for the area north of Mornington Island, where high sand content sediments result in a harder acoustic signal. This is due to the sand providing an excellent reflective surface for the acoustic energy, resulting in stronger 2nd echo which is the basis of the acoustic hardness parameter

In the area to the north and south of Groote Eylandt there is a strong relationship between acoustic roughness and the sediment property percentage mud. There is a link between high mud content sediments and low acoustic roughness signals. This is due to the mud being a poor reflector for acoustic energy, resulting in a weak 1st echo

Comparison of a low biodiversity, low biomass transect with a high biodiversity, low biomass transect suggests that overall hardness values are much higher for the high biodiversity transect. Also in the higher biodiversity transect there seems to be increased bathymetric structure and distinct groupings of data in the roughness/hardness space plots possibly indicating different habitats - which in turn may be an indicator of biodiversity.

Introduction

In this part of the study, we have attempted to relate the available physical data derived from acoustics to biological information as measured by samples collected from a prawn trawl. Although the trawl samples were collected over a wide geographic area in the NPF there were restricted to near shore areas around the Gulf of Carpentaria, Torres Strait, and Melville Island to the North (see Figure 3.1.1 in Chapter 3.1). This prawn trawl data provided extensive spatial coverage, though not as comprehensive as the available dredge samples. The information derives from three research cruises SS9702, SS9708, and SS9803 and includes data from 689 prawn trawls (96 trawls on SS9702, 339 trawls on SS9708, and 254 trawls on SS9803).

Summary of available Acoustic Information

Information about the seabed was obtained from underwater acoustic sound pulses emitted from an echo sounder, then reflected by the seafloor and collected by the seabed classification instrument RoxAnn (Chivers et.al., 1990). The RoxAnn instrument produces three streams of information: seabed depth, seabed acoustic roughness and seabed acoustic hardness. The roughness and hardness measures are on a numeric scale ranging from 0 to 4096. Once calibrated over known seabed type and with appropriate "ground truthing", the RoxAnn indices may provide continuous classification of basic physical seabed habitat types. Seabed acoustic roughness and hardness data were collected along with depth information approximately twice a second for the duration of three cruises of interest to this project (SS9702, SS9708, and SS9803). When sampled during trawl, dredge or grab stations, this acoustic information was available for analysis as a potential surrogate for seabed geophysical properties, biological parameters such as species biomass, and ecological parameters such as biodiversity. Acoustic data was also collected when the vessel was steaming between stations throughout the entire cruise providing broad-scale information on the structure and physical characteristics of the seabed over a large area.

The SS9702 and SS9708 cruises were mainly in the Gulf of Carpentaria but also extended to Torres Strait in the east and Melville Island in the west. In the Gulf the survey area was restricted to the near-shore with no coverage of the central region. The SS9803 cruise concentrated on areas to the north and south of Groote Eylandt. Consequently these first two cruises were not directly geographically comparable. There was also a large variation in acoustic roughness and hardness parameters between these sets of cruises (see Figure 3.4.1). That is, the SS9803 cruise has a much larger range of acoustic roughness and a far smaller range of acoustic hardness. The depth range differences are explainable due to the geographic differences. However the acoustic parameters are not as easily explained and may be due to different instrument settings between cruises. Changes in instrument settings would affect the results of any subsequent analysis.

The acoustic sampling was carried as an adjunct to existing research programs. There was no dedicated acoustic expertise assigned to the collection of the data during the 3 cruises and so no one ensured that there were no changes to the settings of the echo sounder / RoxAnn over a cruise and between cruises. In addition there was no acoustic calibration and so poor data quality has to be considered. As a consequence, careful filtering and interpretation was required to remove erroneous data (e.g. the effect of poor weather influencing acoustic information, depth outliers due to noise spikes in readings) where possible and take into account possible influencing factors or biases (e.g. effects of depth and vessel speed). This data filtering precluded some large sections of acoustic data completely from further analysis e.g. acoustic / trawl transects with less than 300 acoustic samples were not analysed, as previous filtering due to erroneous data had reduced the data to such low levels that the entire transect was considered suspect. In these cases however there was no evidence that there was any systematic reason for the problem and hence probably no bias over an entire cruise. We compared the acoustic parameters from the SS9702 and SS9708 cruises by geographic area (Cobourg, Melville, Weipa, Torres Strait, East Mornington, North Mornington, West Mornington, South Groote, North Groote and the Vanderlins) covering the Gulf of Carpentaria, Torres Strait and Melville Island to the north (see Figure 3.4.2). The SS9803 cruise was excluded as it is significantly different acoustically (see Figure 3.4.1) and geographically from the other two cruises.

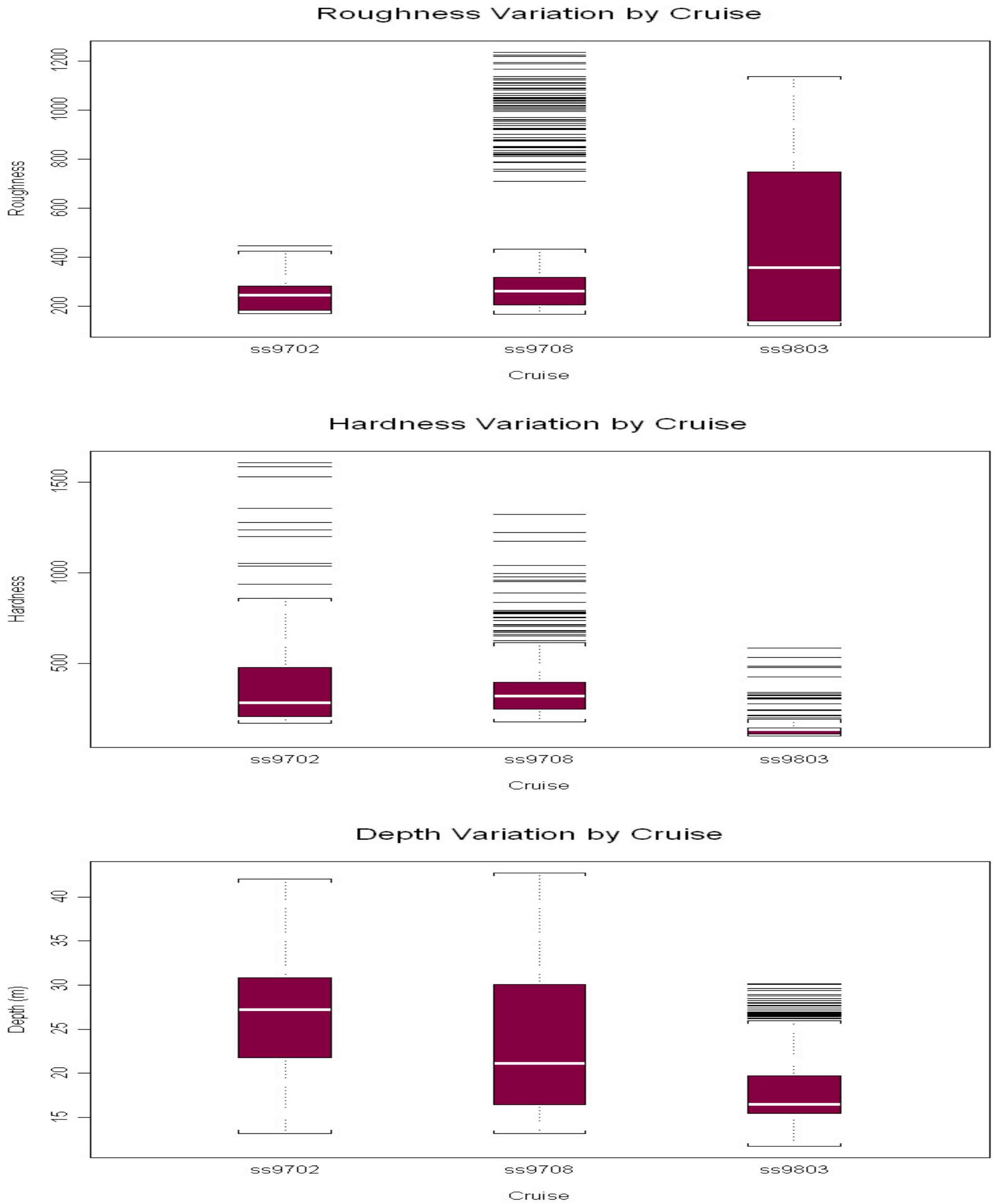


Figure 3.4.1 Acoustic parameter (roughness, hardness and depth) variation over the three cruises. The figures show the distribution of data along the Y axis and provide an indication of the homogeneity of the data. Thus data for depth was tightly clustered for SS9702 and SS9708 but was bimodal for SS9803.

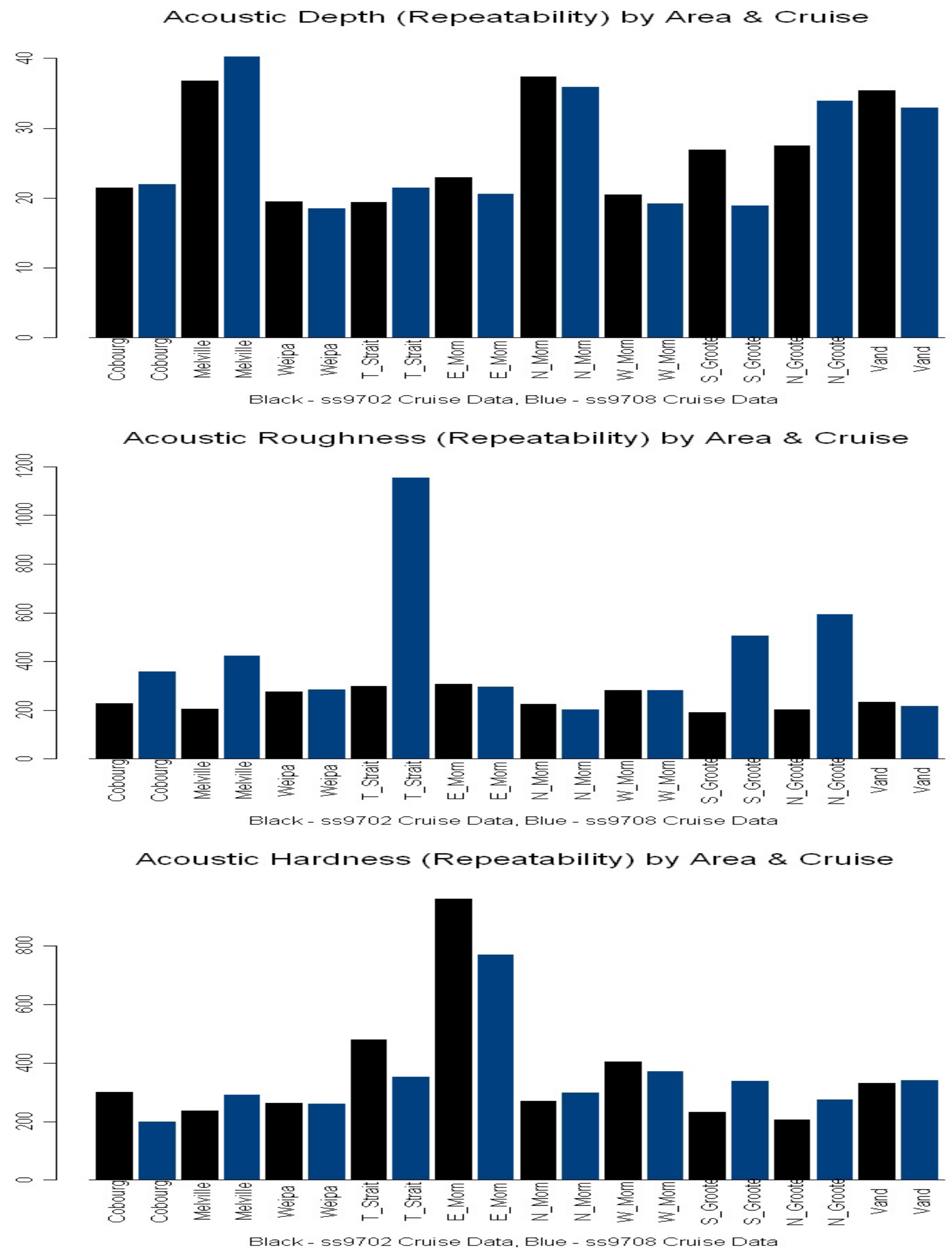


Figure 3.4.2 Acoustic parameter (depth, roughness and hardness) summaries for SS9702 and SS9708 cruises by geographic area, and repeatability between cruises.

The range of mean depths for the geographic areas ranges between approximately 20 meters and 40 metres and compared well between cruises. Areas surveyed around Melville Island, the Vanderlins, and to north of Mornington are deeper than other areas which tended to be more in-shore. The areas surveyed near the Vanderlins and off Melville Island also had a large depth variance.

The acoustic roughness measured ranges mostly from 150 to 400 over both cruises with the SS9708 cruise showing roughness measures up to 1200. The SS9708 cruise has higher overall acoustic roughness measures for most areas, especially for Torres Strait, which was significantly rougher acoustically (along with north and south Groote and Melville to a lesser extent). However the mean roughness and roughness variance for the different geographic areas did not agree well between cruises.

The acoustic hardness measures between the two cruises and geographic areas showed similar relative variations. The acoustic hardness measured ranged mostly between 150 and 700 for both cruises with measures up to 1500. It is worth noting that the area east of Mornington Island is significantly (and consistently) acoustically harder than other areas throughout the Gulf. East Mornington had a large hardness variance; consistent between the two cruises, along with (though to a lesser extent) the Vanderlins.

The correlation between SS9702 and SS9708 cruises was calculated for mean and standard deviation statistics of the acoustic parameters (depth, roughness and hardness) by geographic area. Even though ship tracks were different between cruises they surveyed similar areas and the acoustic measures of depth and hardness exhibited a strong positive correlation between cruises (see Table 3.4.1).

Table 3.4.1 Correlation of mean and variance acoustic parameters (depth, roughness, hardness) between SS9702 and SS9708 cruises by geographic area.

Acoustic Parameter	Mean Correlation Coefficient	Variance Correlation Coefficient
Depth	0.93	0.64
Roughness	0.32	0.26
Hardness	0.96	0.85

Acoustic roughness was not significantly correlated between the cruises, which may be due to tuning settings changing for the RoxAnn instrument between cruises, causing the measured roughness to alter. The roughness parameter may be more sensitive to instrument tuning than depth or hardness. It relies on correct identification of the 1st seabed echo in the acoustic signal, compared to the hardness signal which is derived from a wider integration interval encompassing the 2nd seabed echo which is subsequently more robust to instrument tuning (though in some cases this hardness index may be biased with depth) . In this case where acoustic instrumentation measurements may be erroneous, it is useful to refer to the full digital acoustic signal from the echo sounder in order to investigate whether there is a real acoustic phenomenon, or instrument calibration problem causing the altered acoustic parameter, however this data was unavailable.

Relationship between Acoustics and Sediments

Acoustics is a physically remote sensed surrogate for potential seabed physical surrogates of biological and ecological parameters. With each level of abstraction the link becomes more uncertain and since the relationship between acoustic parameters and other physical parameters such as sediment properties is complex (and not well understood - e.g. acoustic roughness, does not necessarily mean, physical roughness, which is more likely linked to bathymetric roughness). Acoustic data provides `some useful information about sediment properties, as demonstrated in the following examples (see Figure 3.4.2 and Figure 3.4.3).

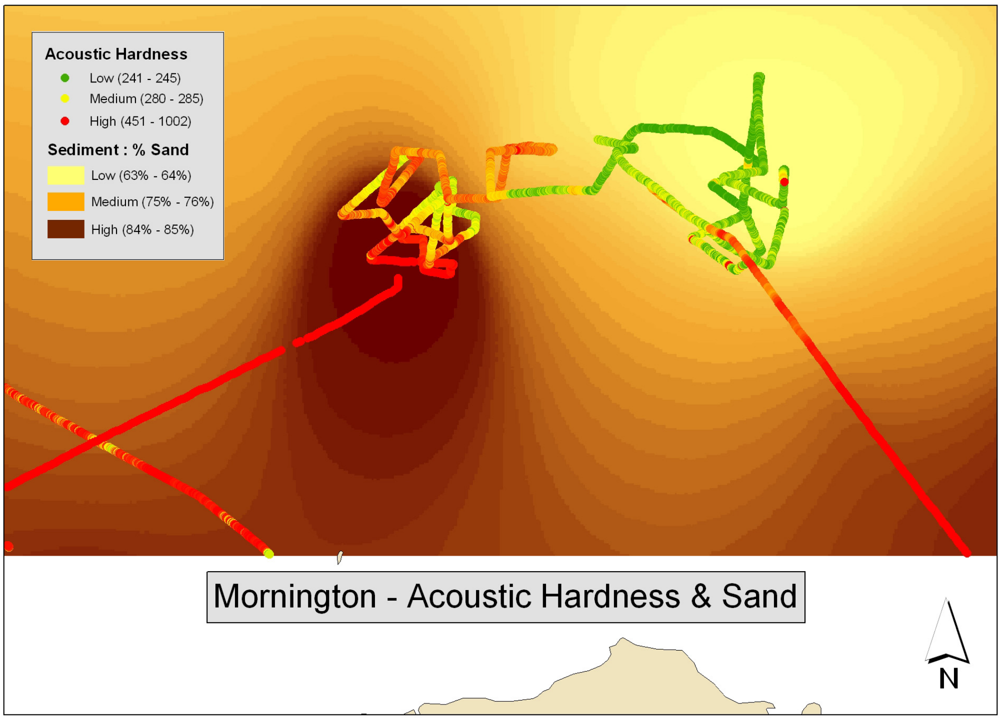


Figure 3.4.3 Variation of the acoustic hardness parameter with the percent sand sediment property in the area north of Mornington Island

There is a strong relationship between acoustic hardness and the sediment property percentage sand for the area north of Mornington Island, where high sand content sediments result in a harder acoustic signal (Figure 3.4.3). This is due to the sand providing an excellent reflective surface for the acoustic energy, resulting in stronger 2nd echo which is the basis of the acoustic hardness parameter.

The area to the north and south of Groote Eylandt (see Figure 3.4.4) provides an example of the related but complimentary phenomenon where there is a strong relationship between acoustic roughness and the sediment property percentage mud. From Figure 3.4.4 we can see that there is a link between high mud content sediments and low acoustic roughness signals. This is due to the mud being a poor reflector for acoustic energy, resulting in a weak 1st echo.

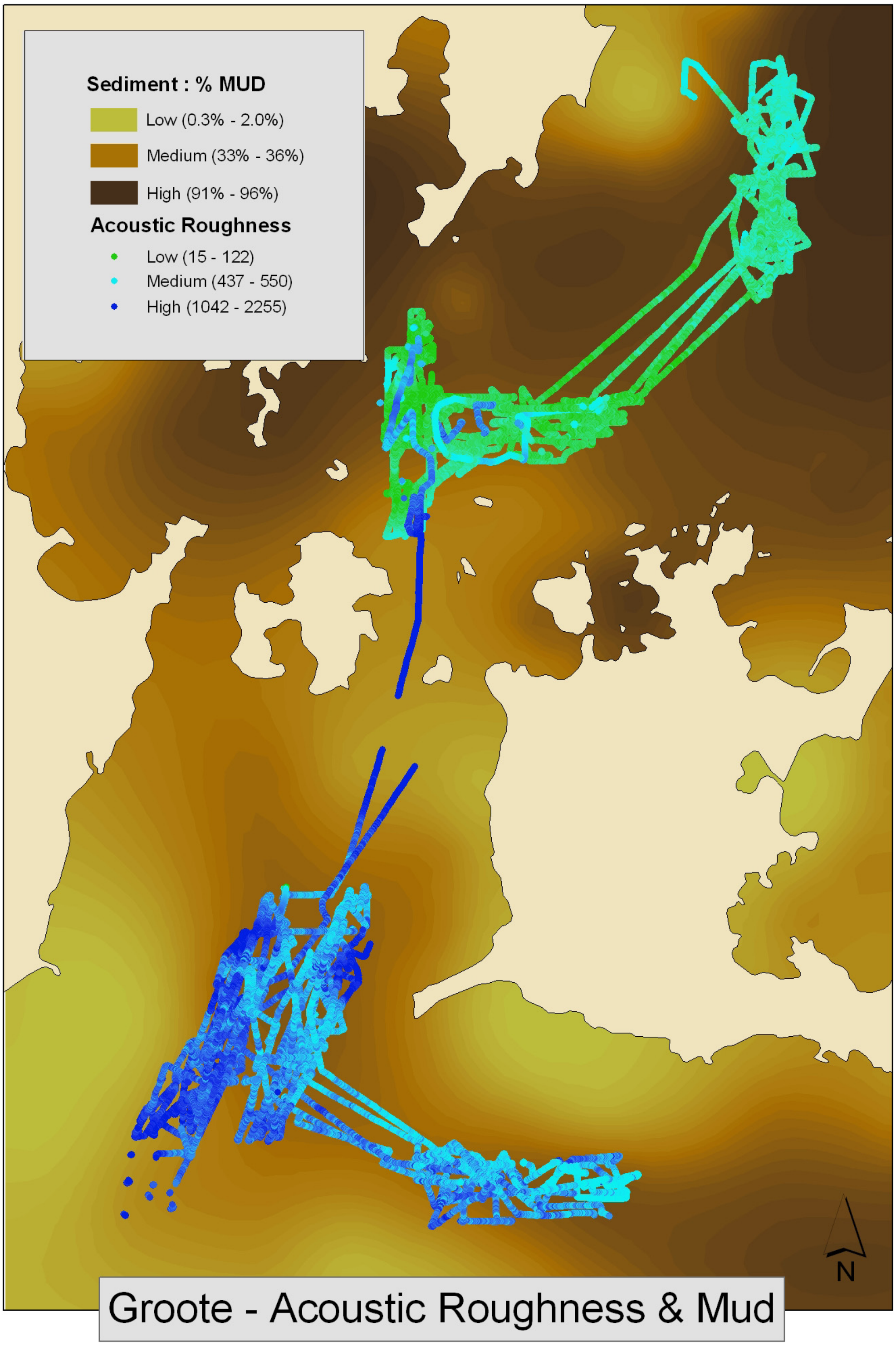


Figure 3.4.4 Variation of the acoustic roughness parameter with the percent mud sediment property in the Groote Eylandt area.

Geospatial Modeling of Acoustic Parameters

For areas where there was adequate spatial coverage of acoustic information we modeled the acoustic parameters to produce spatially interpolated surfaces of acoustic information. The data used also included acoustic information collected while the vessel was between sample stations.

Areas of particular interest that also provided a high spatial density (on a fine scale) of acoustic sampling were to the north and south of Groote Eylandt, particularly for data from the SS9803 cruise. These areas were selected as they had excellent coverage of other physical covariates (including the high resolution current stress model), as well as a wide range in values (see percentage mud map in Figure 3.4.4). There were a large number (254) of prawn trawl sites in this area, providing biological information.

We modeled acoustic roughness and hardness with trend surfaces fitted using the universal kriging technique. There was a lot of fine scale ping-to-ping variability (and measurement error – due to the nature of the acoustic sampling i.e. small transducer beam pattern beam widths and vessel motion) making modeling difficult. We subsequently used nearest spatial neighbor mean smoothed versions of the kriged trend surfaces. The resulting modeled surface of acoustic roughness is shown for South Groote in Figure 3.4.5. The kriging technique also provided an indication of the prediction error for our fitted surface; this is shown in Figure 3.4.5 as contours (the error increases with distance from an actual acoustic sample point).

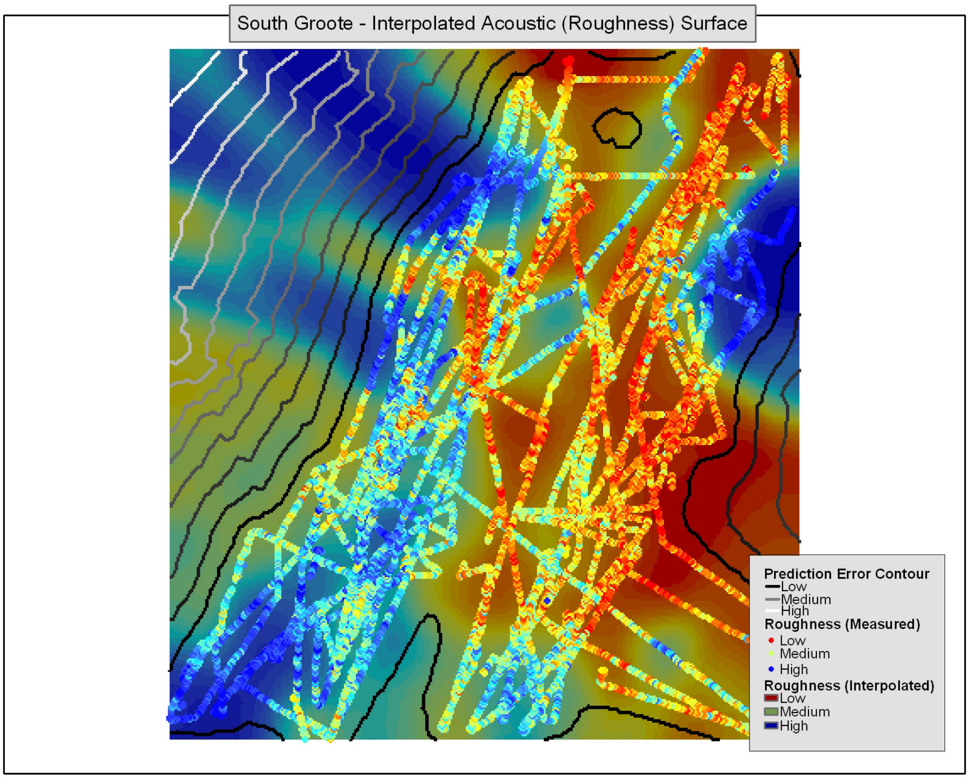


Figure 3.4.5 Modelled acoustic roughness surface in the area south of Groote Eylandt, measured acoustic information is shown as transect lines as well as contours of model prediction error.

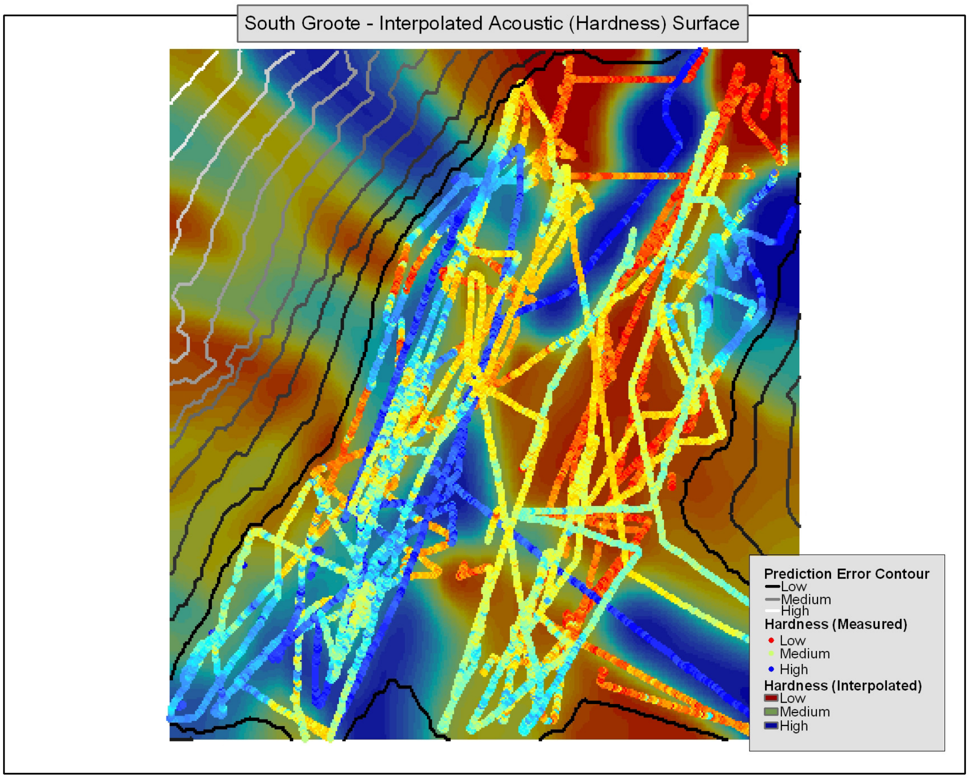


Figure 3.4.6 Modelled acoustic hardness surface in the area south of Groote Eylandt, measured acoustic information is shown as transect lines as well as contours of model prediction error.

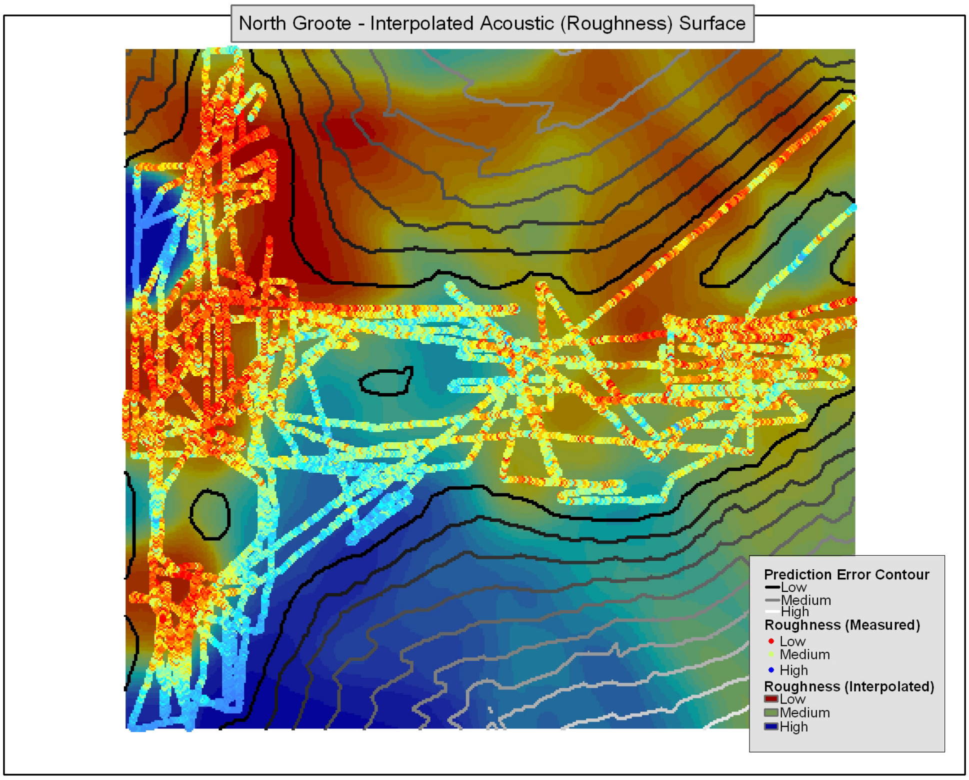


Figure 3.4.7 Modelled acoustic roughness surface in the area nouth of Groote Eylandt, measured acoustic information is shown as transect lines as well as contours of model prediction error.

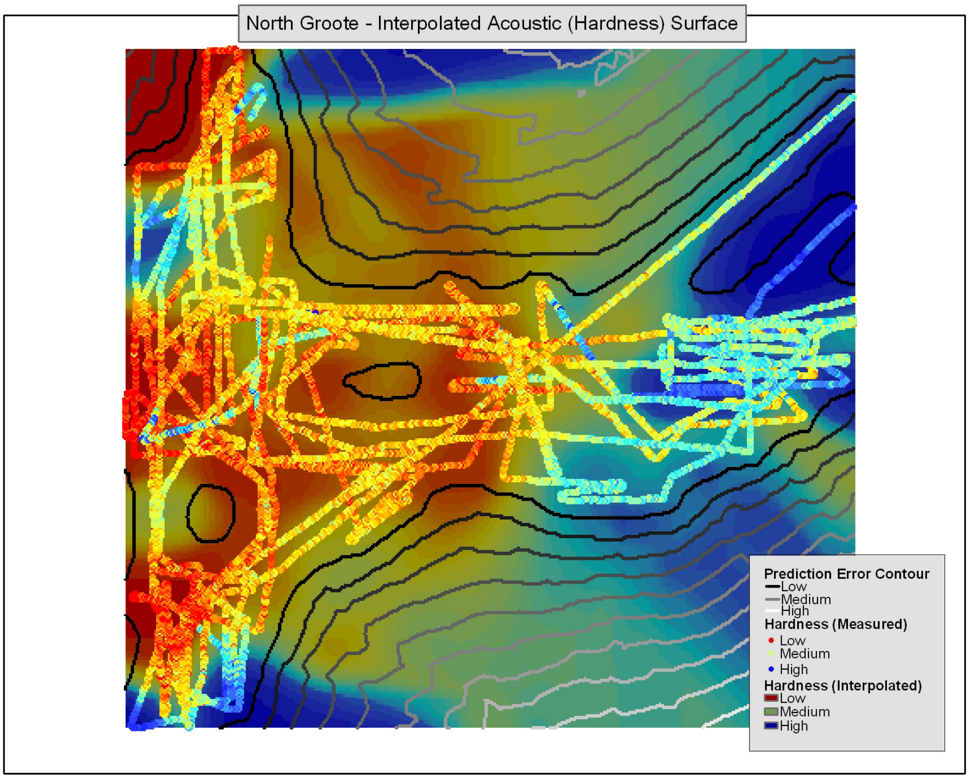


Figure 3.4.8 Modelled acoustic hardness surface in the area nouth of Groote Eylandt, measured acoustic information is shown as transect lines as well as contours of model prediction error.

Acoustic Transect Profile Information for Trawl Stations

A very large number of acoustic samples are recorded over the course of a trawl transect because the equipment logs data approximately twice a second (see Figure 3.4.6 – 9). The acoustic information is three indices, or depth, roughness and hardness profiles covering the whole trawl. However biological information comes from the end result of a trawl. Hence the biological information over the trawl is an integration (or the sum of) of the organisms sampled during the station. Thus for each trawl shot there was a large amount of acoustic data compared to a single integrated biological parameter. This means that the biological information can only be related to aggregate properties of the acoustic information.

To address this issue of data matching, summary statistics for the acoustic parameters were used to test their utility as a surrogate for biodiversity. Simple measures of a trimmed mean (removing 5% of outliers); mean absolute deviation (a measure of variance); and 95% quantile (a measure of the maximum) where calculated for the depth, roughness and hardness measures. These trimmed mean, mean absolute deviation and 95th quantile were used to represent acoustic information for the transect. Some investigation in further research may yield better acoustic summary features which provide improved performance as biological surrogates or that provide an improved insight into interpreting the physical phenomenon underlying the acoustic surrogate. For example, threshold transformed integrations where acoustic information is only included above or below a certain threshold, or summary features that emphasize changes (i.e. differentials) in acoustic parameters along the transect.

In this section we highlight examples of the type of information collected across a trawl transect for a number of biologically distinct habitats, using low/high biomass and low/high biodiversity examples. Acoustic transect 9708091 (see Figure 3.3.6) is a trawl station with both low biodiversity and low biomass; acoustic transect 9708317 (see Figure 3.4.7) is a trawl station with low biodiversity and high biomass. In contrast, acoustic transect 9708393 (see

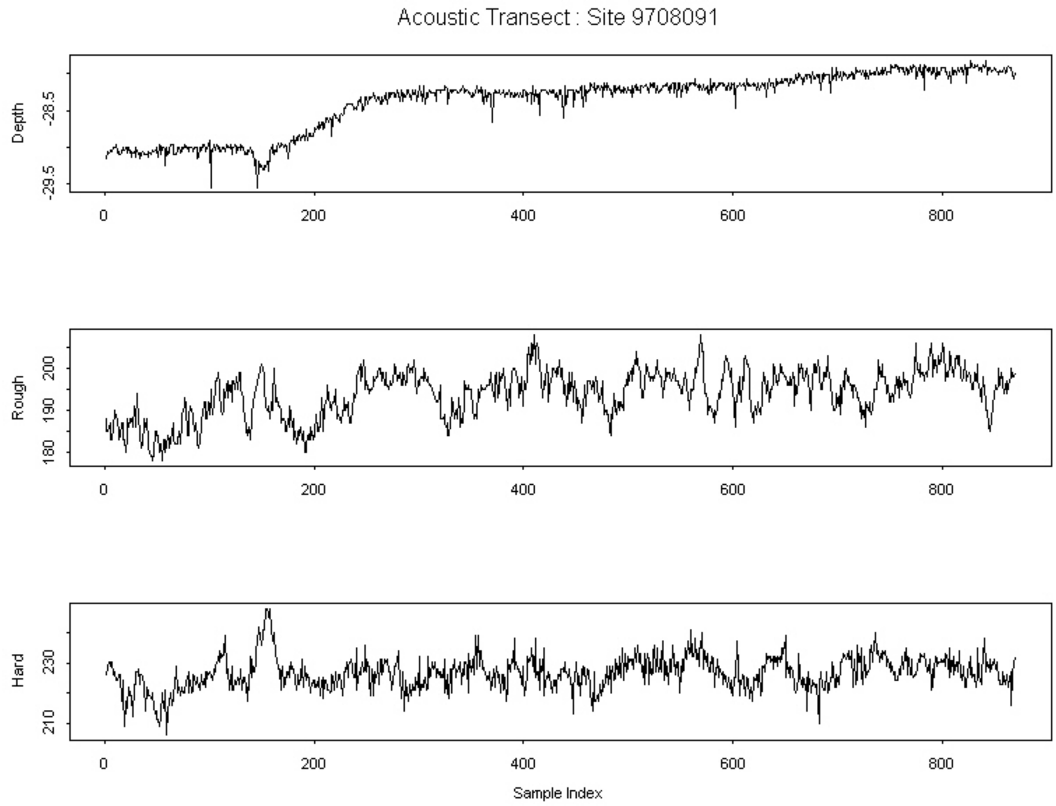
Figure 3.4.8) is a trawl station with high biodiversity and low biomass; acoustic transect 9803624 (see Figure 3.4.9) is a trawl station with both high biodiversity and high biomass.

Comparing the low biodiversity, low biomass transect 9708091 (see Figure 3.4.6) to the low biodiversity, but high biomass transect 9708317 (see Figure 3.4.7) it can be seen that the range of data and probably the information contained within the acoustic hardness parameter has increased significantly, as does the depth profile (though on the small scale there is little variation for both transects). This may indicate that hardness or the range over which it varies may be important in determining biomass.

Comparing the low biodiversity, low biomass transect 9708091 (see Figure 3.4.6) to the high biodiversity, low biomass transect 9708393 (see Figure 3.4.8) it can be seen that overall hardness values are much higher for the high biodiversity transect. Also in the higher biodiversity transect there seems to be increased bathymetric structure and also distinct groupings of data in the roughness/hardness space plots possibly indicating different habitats (which in turn may be an indicator of biodiversity).

While the acoustic transect 9803624 with both high biodiversity and high biomass (see Figure 3.4.9) is not directly comparable to the other transects (as there were acoustic differences between the cruises), it indicates that this characteristic is not necessarily related to depth structure because there is little change in the profile. However the range of roughness for this transect is significant which may indicate a possible surrogate for either biodiversity or biomass.

It may be possible to make inferences regarding where along an acoustic transect a particular biological or geophysical phenomenon occurred (or was likely to occur). This would provide finer spatial scale information, however there are issues with this information because it cannot be verified as there is no data with which to test the inference.



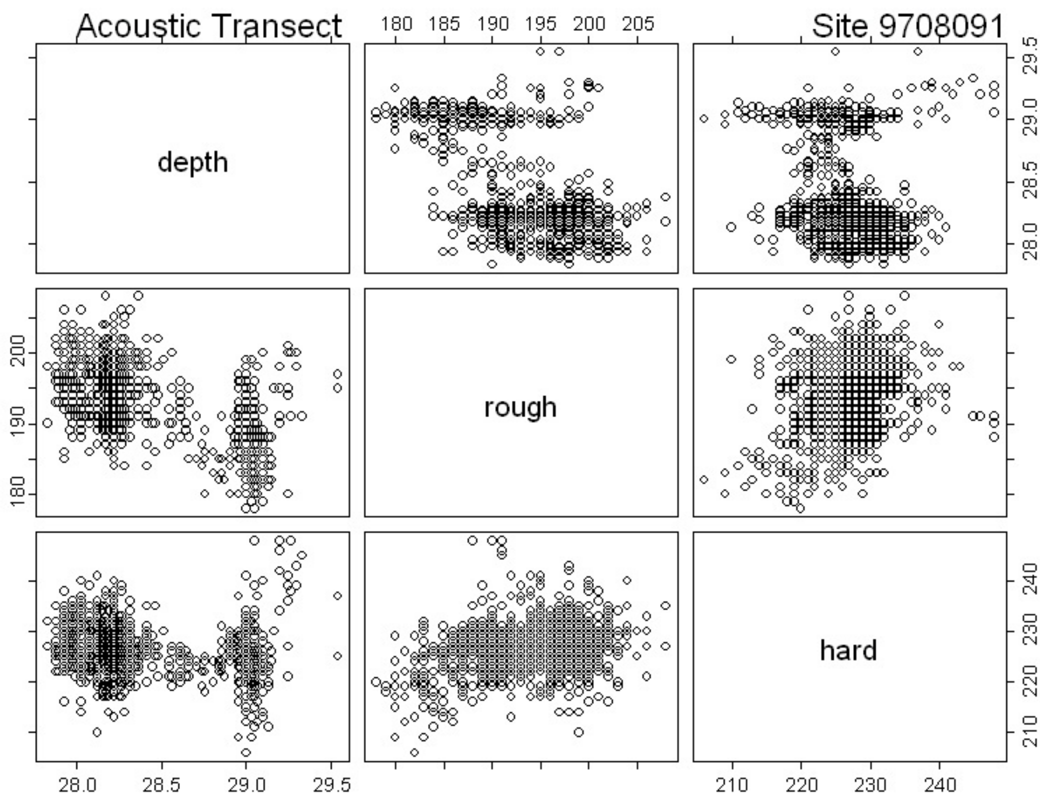


Figure 3.4.9 Acoustic transect profile and parameter (depth, roughness and hardness) space plots for trawl station 9708091 – low biodiversity and low biomass.

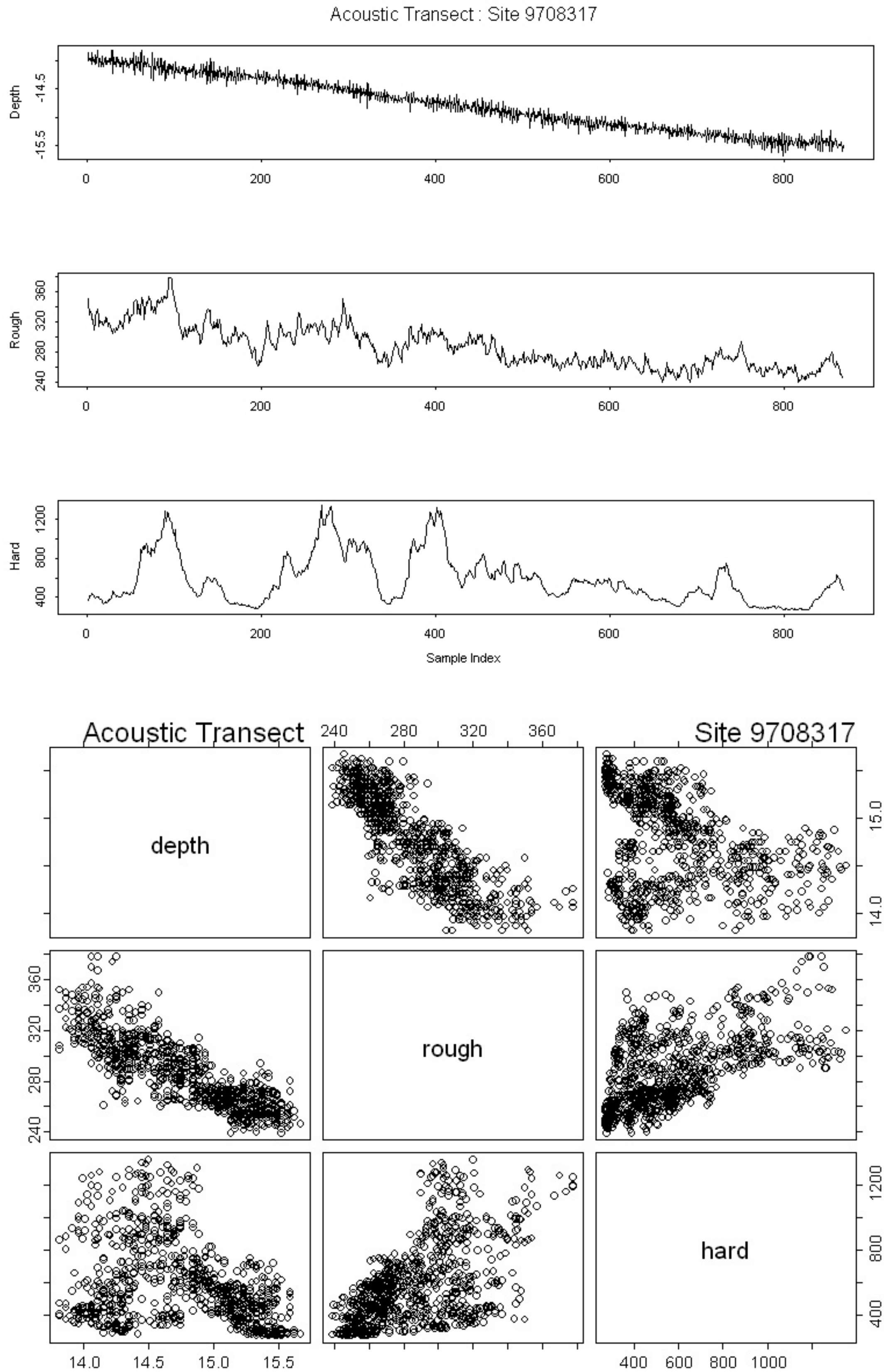


Figure 3.4.10 Acoustic transect profile and parameter (depth, roughness and hardness) space plots for trawl station 9708317 – low biodiversity and high biomass.

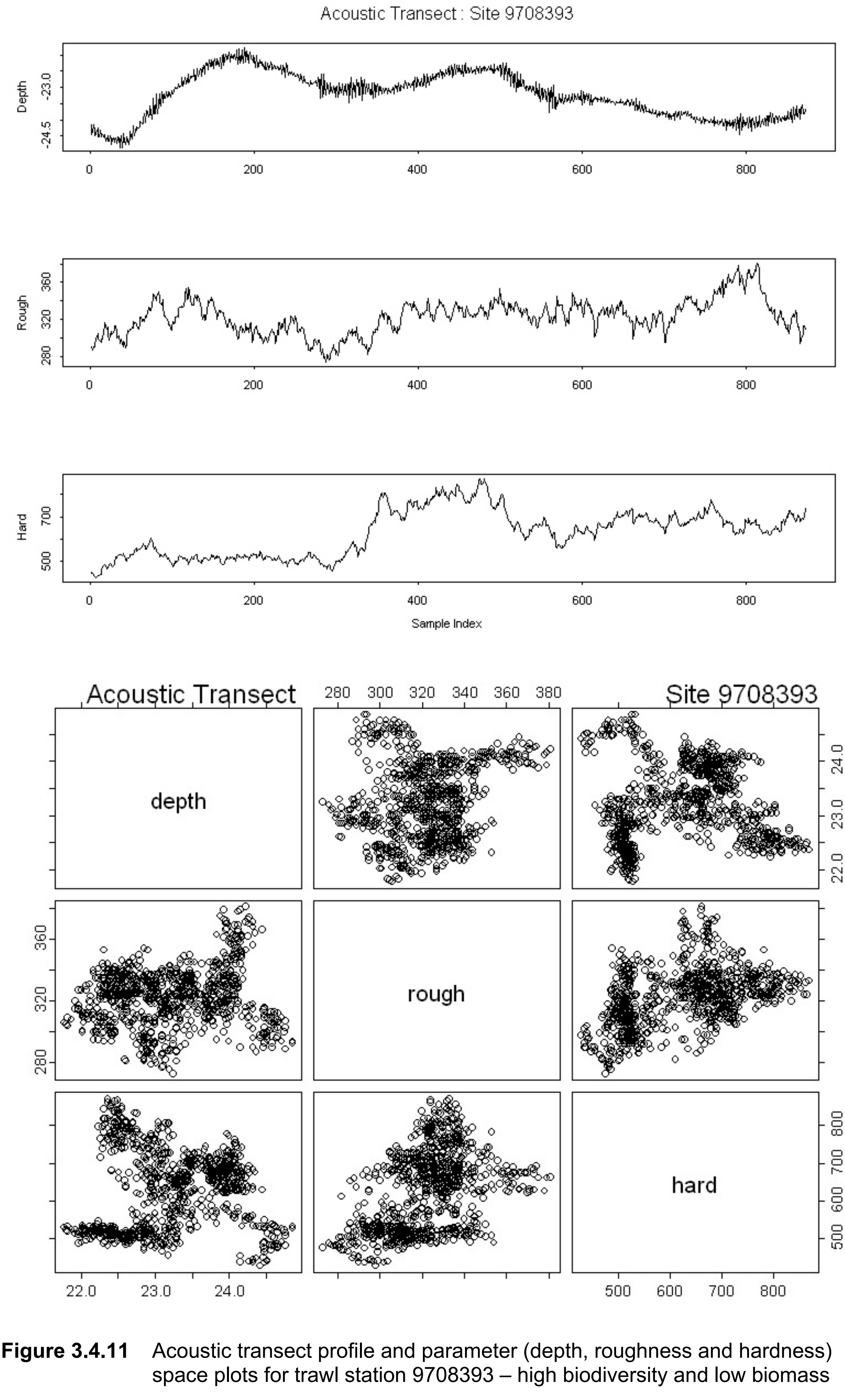


Figure 3.4.11 Acoustic transect profile and parameter (depth, roughness and hardness) space plots for trawl station 9708393 – high biodiversity and low biomass

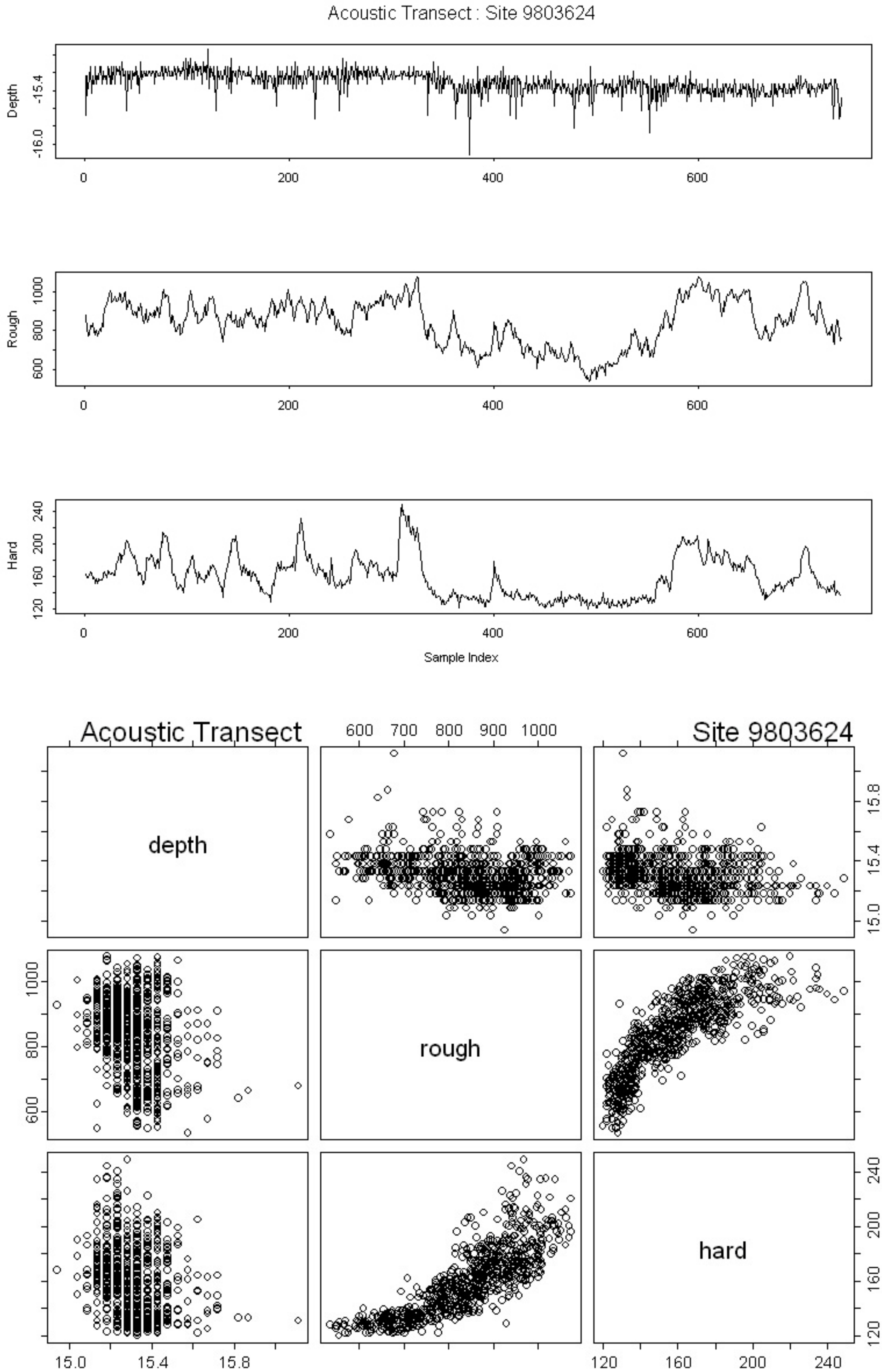


Figure 3.4.12 Acoustic transect profile and parameter (depth, roughness and hardness) space plots for trawl station 9803624 – high biodiversity and high biomass.

Discussion

Acoustics offer a way of finding out about the structure of the seabed at far lower cost than other technologies. There are a number of ways in which this can be achieved from simple echo-sounders through to sophisticated seabed mapping systems. In the present study we had available to us data collected by a commercial RoxAnn instrument. This is a relatively low level acoustic instrument that collects data for depth, seabed roughness and seabed hardness. As records are taken twice every second while the ship is underway, a considerable number of data points are collected very rapidly. The data subsequently requires a considerable amount of filtering because of errors or biases introduced by factors such as sea state. In addition, it is essential that there is some form of ground truthing to provide a calibration for the acoustic signals (Pitcher et.al., 1999) .

We found a strong relationship between acoustic hardness and the sediment property percentage sand for the area north of Mornington Island, where high sand content sediments result in a harder acoustic signal. This is due to the sand providing an excellent reflective surface for the acoustic energy, resulting in stronger 2nd echo which is the basis of the acoustic hardness parameter. In the area to the north and south of Groote Eylandt we found a strong relationship between acoustic roughness and the sediment property percentage mud. There is a link between high mud content sediments and low acoustic roughness signals. This is due to the mud being a poor reflector for acoustic energy, resulting in a weak 1st echo
Comparison of a low biodiversity, low biomass transect with a high biodiversity, low biomass transect suggests that overall hardness values are much higher for the high biodiversity transect. Also in the higher biodiversity transect there seems to be increased bathymetric structure and distinct groupings of data in the roughness/hardness space plots possibly indicating different habitats - which in turn may be an indicator of biodiversity.

Langstreth (1999) attempted to relate biological properties of flatfish (Pleuronectidae) to acoustic properties of the seabed using the same acoustic data set available to us. Flatfish have close association with the seabed and were thought to be likely to show a relationship with the benthic habitat. Langstreth (1999) found that acoustically distinct seabed habitats supported distinct flatfish assemblages. This distinction was clear however only in areas of high acoustic variability but flatfish appeared to be responding to changes in the seabed habitat that were detectable by RoxAnn. Langstreth pointed out that in some areas, acoustic roughness and hardness and thus sediment composition were highly variable on fine spatial scales. This highlights a problem in relating acoustic information to biological samples. Acoustic data is extremely fine resolution spatially. Trawl samples by contrast are collected from 30 min duration tows and so provide only a single aggregated or averaged data point. This makes it difficult to compare data from the two sources.

The relationship between acoustic data and prawn trawl data in the Gulf of Carpentaria is addressed in Chapter 5.3.

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Chivers, R.C., Emerson, N., and Burns, D.R. (1990) New Acoustic Processing for Underway Surveying. The Hydrographic Journal. (56):9-17.

Langstreth J (1999). Prawn trawl fishery bycatch study: An acoustic investigation of benthic habitat associations of flatfish (Pleuronectiformes) assemblages in Northern Australia. BSc Hons Thesis, James Cook University. 88pp.

Pitcher, C.R., Gordon, S.R., Kloser, R., Jones, P. (1999) Development of an Acoustic System for Remote Sensing of Benthic Fisheries Habitat for Mapping, Monitoring and Impact Assessment, Final Report to FRDC (Project 93/058), CSIRO Marine Research Report, 103pp. ISBN 0 643 06196 7.

CHAPTER 3.5

IDENTIFICATION OF GAPS IN SPATIAL COVERAGE OF DATA

AND

RECOMMENDATIONS ON FUTURE DATA COLLECTION

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CHAPTER 3.5

IDENTIFICATION OF GAPS IN SPATIAL COVERAGE OF DATA

AND

RECOMMENDATIONS ON FUTURE DATA COLLECTION

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Summary

Identification of Gaps in spatial coverage of Data

- We reviewed 16 research cruises in the NPF but found that the biological coverage was limited to the Gulf of Carpentaria. There is no data at all for Joseph Bonaparte Gulf and very limited data for the top end region between the two Gulfs
- Fish trawls, prawn trawls and dredges sample different components of the biota and a description of the biota/biodiversity needs to have data from all three. Unfortunately our data sets do not overlap – we have fish and dredge samples from the central Gulf of Carpentaria and prawn trawl bycatch samples from the more inshore regions. This is a serious drawback
- There are 15 bioregions in the NPF, for four of these we have no prawn trawl, fish trawl or dredge samples at all. Many of the others are inadequately sampled, for example 10 bioregions have less than 10 dredge samples, this is insufficient for a description of the benthic biota
- Acoustic data (used for describing seabed structure) is similarly limited in area with only the Groote Eylandt –Wellesley region being adequately covered, though aggregated.
- Sediment data is available for the whole NPF but the density of sampling outside of the Gulf of Carpentaria is low and needs to be supplemented
- Water column chemical and physical data is also available for the entire NPF but because of a wide distribution of sampling stations outside of the Gulf of Carpentaria, reliability of the data over much of the region is low
- Economic data on prawn trawling is available to assess opportunity costs of MPA establishment in parts of the NPF region, but there is no readily available data on other resource uses.

Recommendations of future data collection

The focus should be on collecting an adequate description of the bioregions presently inadequately described. The following data is regarded as top priority:

- Prawn trawl bycatch especially in bioregions not presently adequately sampled - this should be regarded as the minimum biological collection
- Biological dredge samples - samples should overlap with those collected in prawn and fish trawls
- Fish trawl samples - should be collected if funding is available to obtain a more complete biological record
- Range of seabed mapping techniques including normal incidence acoustic tracks over as much area as possible
- Sediments - percent mud, grain size in selected areas to increase reliability of information

- VMS data on a continuing basis - data is already being collected by AFMA but needs to be analysed
- Bottom current stress - field data is needed to validate the CSIRO model
- Chemical and physical water column data – Additional measurements are needed to improve the reliability of the existing data set
- Remote sensing (SeaWIFS) should be continued in order to provide relatively low cost supplementary data
- Literature reviews of ABARE statistics for other fisheries in the region, or field surveys of economic costs should be carried out for resource uses identified by stakeholders.

Introduction

Objective 3 of the project required us to:

> *Assess the sampling strategies required to extend the coverage of data on benthic species assemblages and untrawlable grounds in the NPF.*

In order to meet this objective we have reviewed the data that is presently available and identified the gaps in the data set. We decided to do this on a spatial basis and to use the present bioregions as the framework. The identification of gaps was very relevant to the rest of the project as we were using these data sets in our analysis.

Identification of gaps in spatial coverage of data

Biological and acoustic data

The coverage of data used in this project is limited spatially in two ways – actual spatial coverage of samples and an unequal spatial coverage of the various sampling gears used. We have samples from two sources:

- Firstly Southern Surveyor cruise SS 90/03. This covered 107 stations in a grid pattern across the entire Gulf of Carpentaria and collected fish trawl, dredge and grab samples.
- Secondly we have cruises SS02/97, SS08/97 and SS03/98 carried out in 1997 and 1998 from Cape York round the southern end of the Gulf of Carpentaria and then north of Arnhem Land to Darwin. The most intensively sampled areas were the southern and western Gulf of Carpentaria and the area north of Mellville-Essington. The main sampling device was a prawn trawl but dredge samples were also taken at some stations. Acoustic data was also collected on this second set of cruises.

The distribution of the sampling is shown in Fig 3.5.1. In order to assess the extent of coverage of the NPF we have used the IMCRA Bioregionalisation for the region (Fig 3.5.2). The NPF region has been divided into 15 bioregions which are meant to reflect biological attributes. We have included the acoustic data with the biological data because they were collected on the same cruises unlike the remaining physical and chemical data.

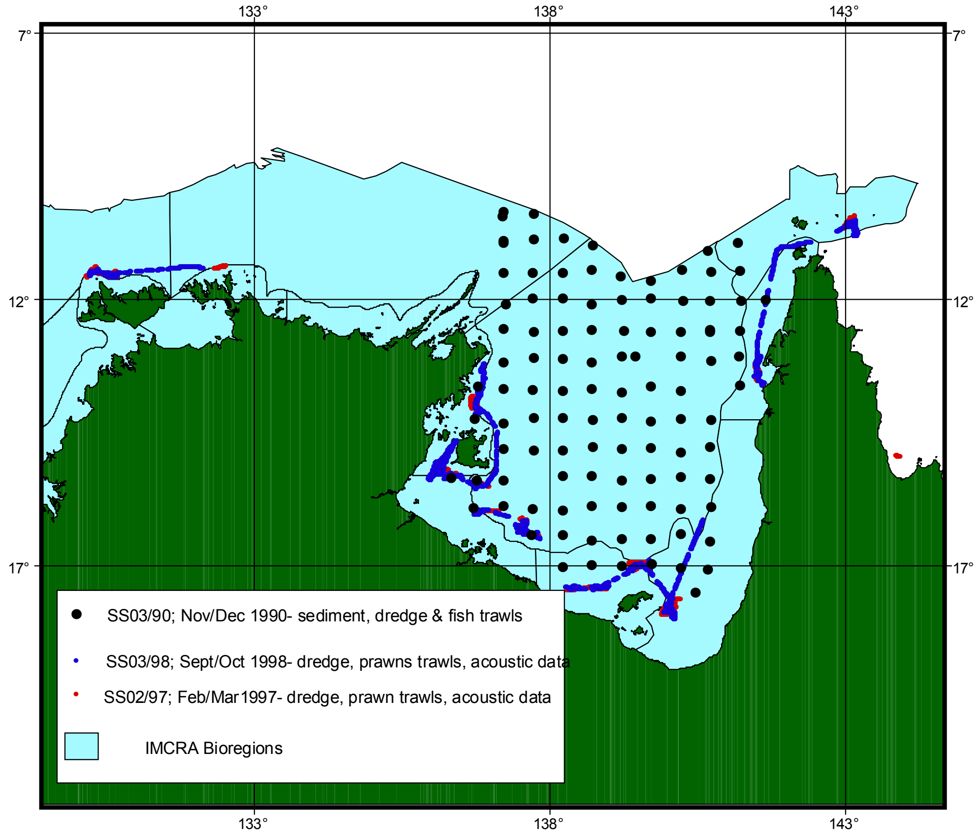

Figure 3.5.1 Sampling sites in the NPF for data on benthic species

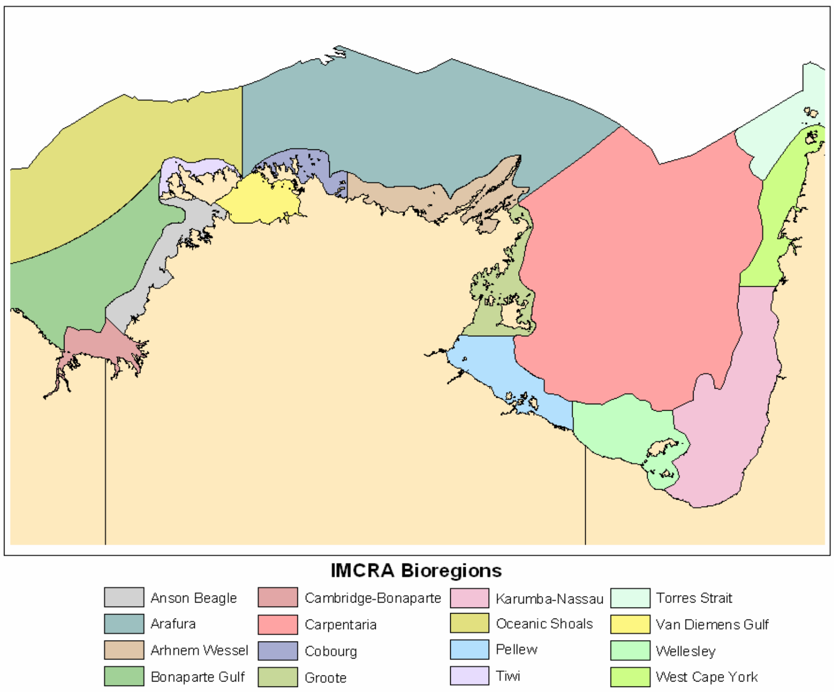

Figure 3.5.2 Marine bioregions of Australia. Source: (Interim Marine and Coastal Regionalisation for Australia Technical Group 1998)

The IMCRA bioregions are very unequal in area and reflect the information that was available at the time the bioregionalisation was carried out. We have two categories of information that can be used for describing the seabed environment and its fauna. Firstly point-source data derived from samples or actual measurements at sea. Secondly information derived by extrapolation of point source data using modelling techniques. The number of samples in the first category is given by bioregion in Table 3.5.1.

Table 3.5.1. The area, fishing effort in boat days (mean and range for 1995 - 1999) and the number of biological and physical samples collected in each IMCRA bioregion. The number of acoustic data refers to individual RoxAnn samples.

Bioregion	Area km^2	Mean effort	Range of Effort	Percent of NPF effort	Dredge samples	Prawn trawl samples	Fish trawl samples	Sediment samples	Acoustic data
West Cape York	22269	1845	497 – 3569	9.1	4	59	13	55	106264
Karumba - Nassau	56701	2887	1364 – 4291	14.2	8	76	20	99	132043
Wellesley	26771	3405	2220 – 4473	16.7	6	107	12	25	164429
Pellew	21494	1803	1168 – 2782	8.8	8	83	0	649	142774
Groote	16718	3468	2401 – 4360	17.0	26	459	2	605	871845
Carpentaria	229974	3421	2580 – 4279	16.8	82	158	98	335	335440
Arnhem - Wessel	22752	271	204 –350	1.3	0	0	0	0	0
Cobourg	8380	479	350 – 717	2.4	2	7	1	5	8971
Arafura	155114	204	312 – 279	1.0	9	0	8	33	49034
Oceanic Shoals	253343	412	247 – 752	2.0	0	63	12	4	126765
Tiwi	5134	370	281 – 536	1.8	0	7	1	2	12761
Anson-Beagle	17527	337	212 – 458	1.7	0	0	0	3	0
Bonaparte Gulf	58189	1468	912 – 2626	7.2	0	0	0	5	0
Torres Strait	36525	2	2 – 2	0.0	3	62	11	4	59479
Van Diemens Gulf	12800	5	2 – 11	0.0	0	0	0	0	0

Table 1 shows that the present biological data sets are highly skewed towards bioregions in the Gulf of Carpentaria (GoC). We have dredge and fish trawl data collected on a 30 nm grid across the entire Gulf but only a few samples were collected on prawn trawl grounds. There is a substantial amount of data on the seabed fauna of the commercial prawn trawl grounds but this comes almost entirely from prawn trawl bycatch samples. This is illustrated in Fig 3.5.3 which show that the distribution of stations for dredge samples, fish trawls and sediments is mainly in the central (Carpentaria) bioregion outside the prawn fishing grounds, compared to prawn trawl bycatch samples which come mainly from the bioregions around the perimeter of the GoC and are generally within the prawn fishing grounds.

The acoustic data was collected on the 1997 and 1998 cruises and so follows the pattern of the prawn trawl bycatch samples and consequently the resulting coverage is highly aggregated (Fig 3.5.4). While there may be a large number of samples/readings from some bioregions they do not have a uniform (or even well distributed) coverage across the bioregion (e.g. Carpentaria - there are over 300 000 samples/readings, but these are limited to the south-western margin of the bioregion). There is no acoustic data from the earlier SS90/03 cruise, which has good Gulf of Carpentaria wide spatial coverage. The Groote bioregion and areas of Carpentaria and Wellesley close to Groote Island have the largest number of samples (See Table 3.5.1.) and widest spatial coverage for the acoustic data (as they do for most other sampling devices) (Fig 3.5.5).

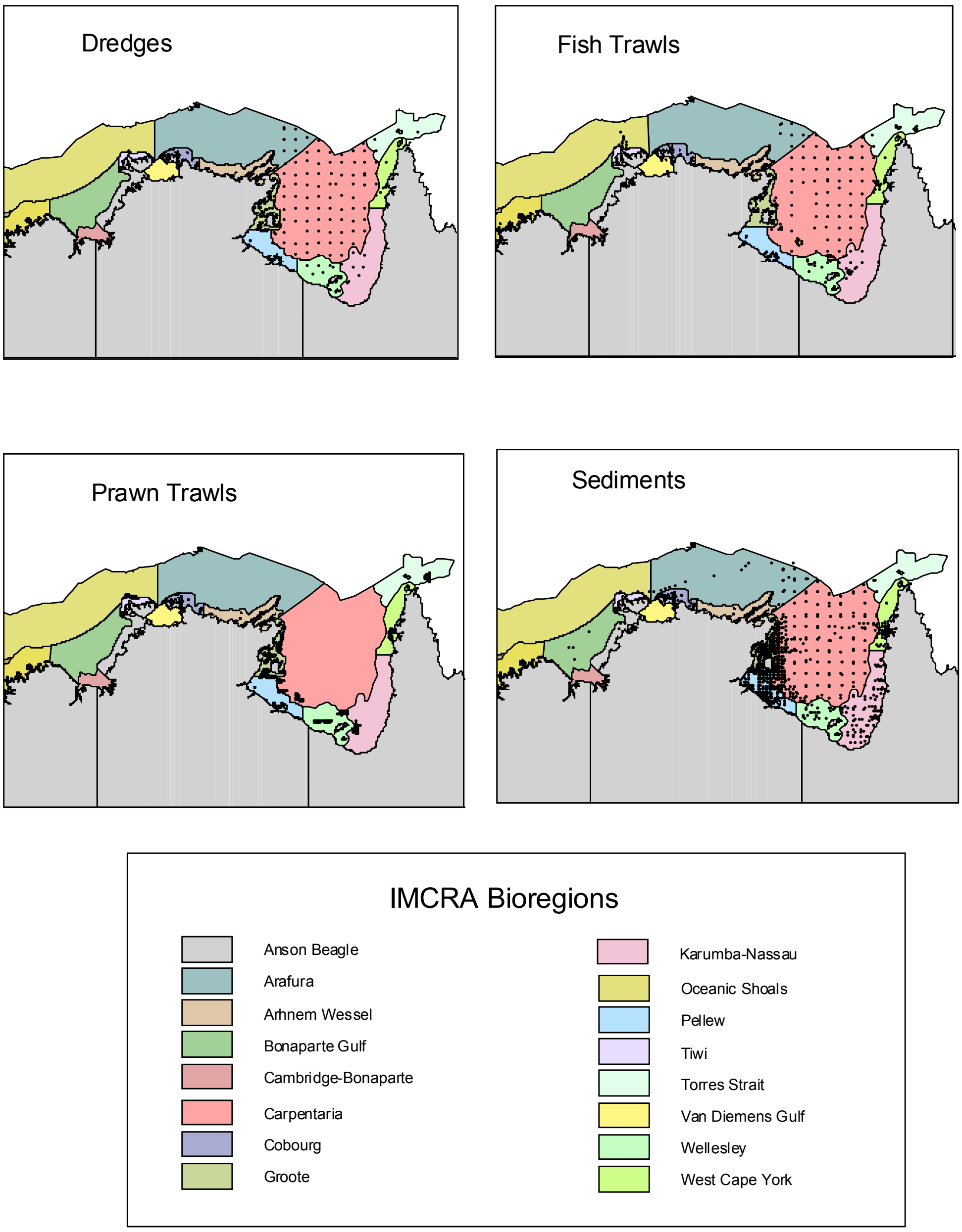

Figure 3.5.3 Extent of coverage of dredge, fish trawl, prawn trawl and sediment samples used for the analyses in this study

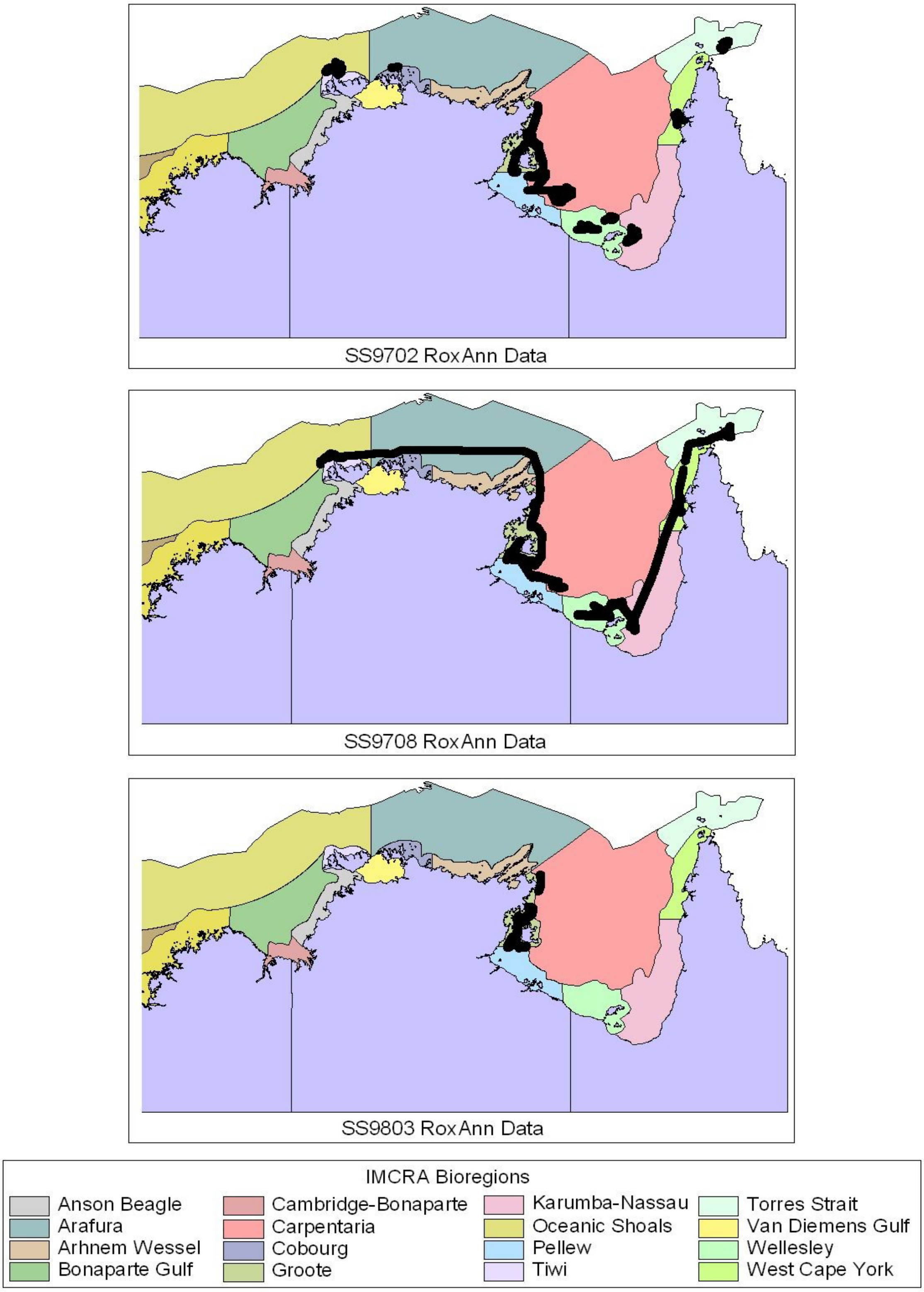

Fig 3.5.4 Acoustic tracks (heavy black lines) in the NPF overlaid on the IMCRA bioregions

Acoustic sampling

This was carried out as an adjunct to the research programs conducted during the SS97/02, SS97/08 and SS98/03 cruises. As a result data quality may be an issue. We suspect that crew or scientists may have changed echosounder/RoxAnn settings over the cruise and between cruises as part of their calibration. These changes were not logged because there was no dedicated acoustics expertise assigned to the collection of the data during the 3 cruises. Acoustic readings can also be biased depth and vessel speed i.e. samples recorded while the vessel is steaming may not be comparable to samples taken while the vessel is at working speed or on station.

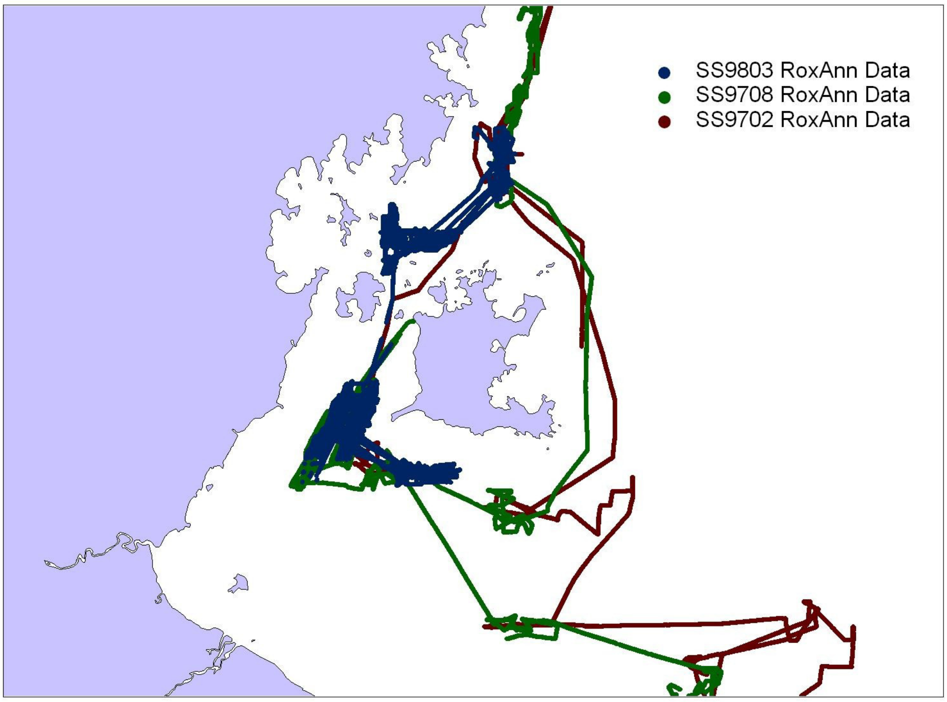

Fig 3.5.5 Acoustic tracks in the Groote Eylandt region

Physical and Chemical Data

Information on the physical and chemical environment covers the entire NPF largely because the available point source data has been extrapolated in models (Table 3.5.2). Figure 3.5.6 is a spatial representation of the reliability of the Coastal Atlas of Regional Seas (CARS) data set. As explained previously, although the models provide information on physical and chemical parameters of the water column, they are based on samples taken at stations in the NPF. The further the measurement stations are from an estimation point, the lower the reliability of the model estimate. For all parameters apart from phosphate, reliability is highest in the near shore areas around the GoC, but less so in the centre of the Gulf and in the western part of the NPF. As is the case for the biological samples, the amount of information for Joseph Bonaparte Gulf is sparse and hence the reliability of estimates for this region is low.

A comprehensive hydrodynamic current model has been developed for the entire NPF as part of the present project (Chapter 3.2 Hydrodynamic Models). This has a resolution of 5 km overall and 1 km for selected areas. The model requires ground truthing in order to validate it.

We used the depth data from the 30 arc second gridded bathymetry of Australia produced by the Australian Geographical Survey (AGSO). This data set has been compiled from AGSO surveys combined with data from various other sources. While this is believed to be one of the best bathymetric datasets for the Australian region it is still only at 30 second (about 1 km) resolution and this may not be sufficient in areas where depth changes are rapid. For these areas of rapid depth change and for those of particular interest where higher resolution bathymetry is required, swath sonar bathymetry may be used.

Many studies have shown that sediment is an important factor driving the distribution of seabed faunas. There are several data sets on sediments in the NPF but our coverage of sediment data is variable across the NPF; we have a high density of samples from the western GoC to the north and south of Groote Eylandt and in Albatross Bay. Elsewhere in the GoC the coverage is more sparse, but covers most of the Gulf. There are very few sediment samples for the remainder of the NPF. We have carried out a detailed assessment of the sediment data to map the distribution of sediments in the Gulf of Carpentaria; this is presented separately in Chapter 3.3 (Interpolation of Sediment Data in the Gulf of Carpentaria).

Table 3.5.2: Source and coverage of physical and chemical data for the NPF

Parameter	Coverage of NPF	Source of information	Comments
Hydrodynamic current model	Entire NPF at 5 nm and selected areas at 1 nm	CSIRO Model (see Chapter 3.2)	Has not been verified with field data except for tide height
Depths	Entire NPF	1 km resolution model developed by AGSO	
Sediments	Entire NPF	Point source samples	
Mean bottom: temperature, salinity, oxygen, silicate, nitrate, phosphate	Entire NPF	CSIRO model and CARS. Based on point source samples	Reliability varies over NPF and generally is less reliable in western sections
Turbidity and chlorophyll	Entire NPF	SeaWIFS satellite data	Analysis of the data shows a relationship between turbidity and chlorophyll that may be due to inappropriate algorithms.
Wave Height	Entire NPF	CSIRO model (See Chapter 3.2)	

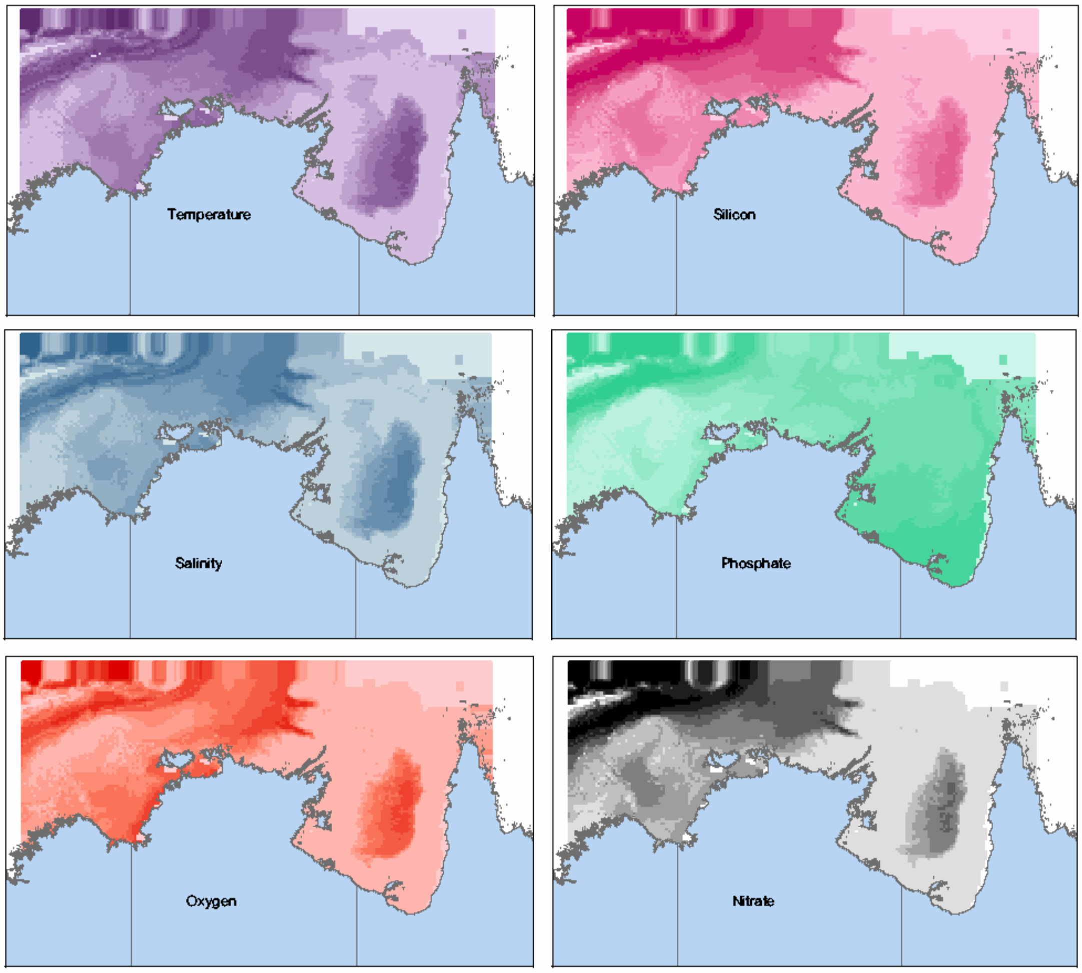

Figure 3.5.6 Reliability maps for the physical water column data (Coastal Atlas of Regional Seas [CARS] dataset). Large values (dark shading) indicate sparse data and consequently the model has applied a higher degree of smoothing at these locations.

Data for Identification of Marine Protected Areas

There are two types of basic information required to identify Marine Protected Areas using the process outlined in Chapter 9. The first are biological or physical data to characterise the habitats and biodiversity of the region. These types of data were described above, and the only additional point to note for MPA identification is that whatever biophysical data are used must be continuous, or assumed to be continuous, across the entire region at the scale of the planning units used to design the MPA system. For example, if MPA designs used the fish trawl data from cruise SS90/03 to identify fish communities, we would have to assume that each sample was representative of the large area around each station.

The second type of information required is economic data on the costs and benefits of different uses of the NPF region. The process outlined in Chapter 9 will use this data to identify MPA systems that meet the conservation goals of the National Representative System of Marine Protected Areas at a minimum opportunity cost for human uses. At present the main use of the region is the NPF, and we have excellent (by comparison with other datasets) records of the spatial distribution of the catch at a spatial resolution of six nautical miles. These data represent the benefit side of the opportunity cost equation. ABARE has carried out economic surveys of the NPF to obtain a detailed picture of the costs associated with fishing

(ABARE 2000), and together these two datasets can be used to calculate the opportunity cost of not having access to a portion of the trawl grounds. The most significant limitation of this data is that the trawled areas cover only a small portion of the entire NPF region; thus we have no information on the potential costs of MPAs outside the trawl grounds. A second problem is that the benefits (i.e. the catch) in a single six nautical mile grid cell can vary from year to year, sometimes by a large amount.

The opportunity costs of untrawled areas in the NPF region would have to be identified by stakeholders. In the absence of detailed economic data a range of scenarios could be explored where costs are assumed to take values relative to the prawn catch, and these scenarios evaluated by stakeholders. Issues associated with the costs of MPA establishment are dealt with in more detail in Chapter 9.

Recommendations for future data collection

Basic data set by region

In this section we have attempted to identify the basic – or minimum – data set by region that should be available for further work in the NPF region. The actual data needs are of course strongly influenced by the use of the data. Fisheries managers for example require different information from that required by environmental managers. This difference becomes very clear when we consider the area that is trawled.

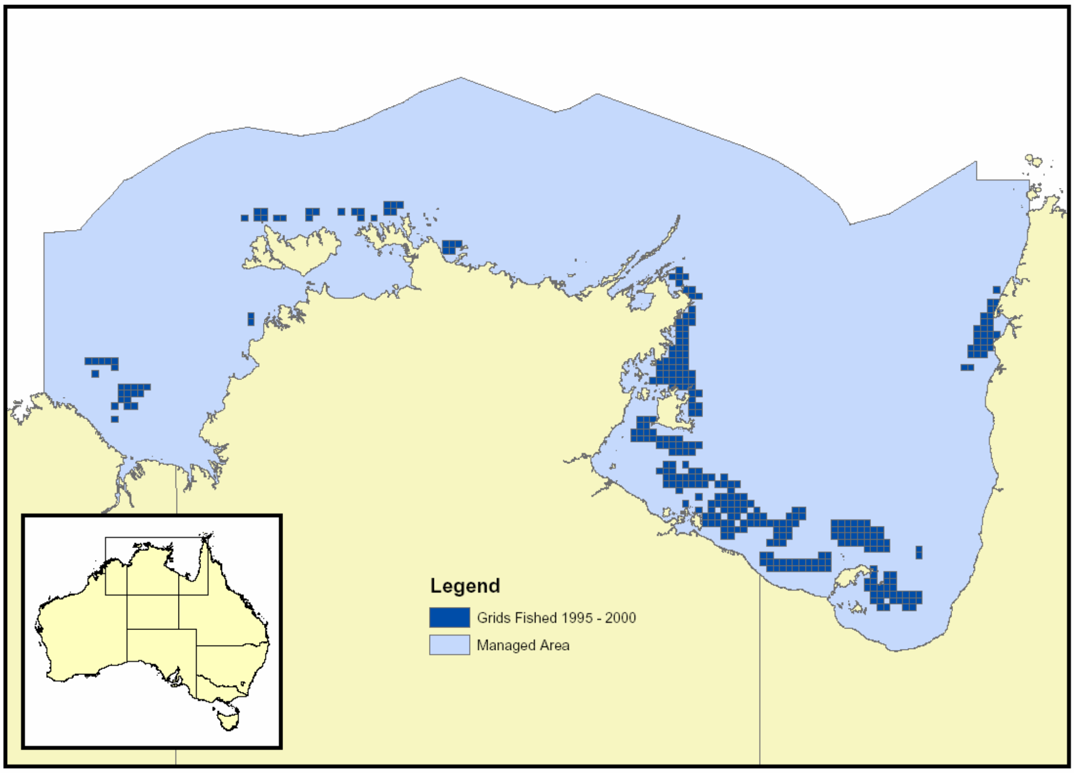

Figure 3.5.7 Six nm grids (dark blue) that were fished in the NPF Managed area (light blue) between 1996 and 2000. Data from AFMA.

The area outside of the GoC contributes less than 15% of the total NPF prawn catch and the trawl grounds cover a small proportion of the area (Fig. 3.5.7). Extending the coverage of data on benthic species into these areas would be of little interest to the fishing industry but would be important to environmental managers. We have tried to keep a broad approach and assumed that an adequate data set is required not only for topics such as the sustainability of the trawl industry but also for assessing the boundaries of bioregions and possibly identifying marine protected areas. We have therefore taken not restricted our recommendations on further data acquisition to trawl grounds.

The need for additional information by bioregion can be judged from an examination of Table 3.5.1 which clearly shows how the present data sets are biased towards the GoC. The spatial resolution of samples needs to be calculated using a power analysis as mentioned below and so the number of samples by bioregion is not dealt with here. The sampling needs have been summarised in Table 3.5.3 and are explained below. We suggest that ideally we should have the following basic information for each region:

- Quantitative samples of seabed macro benthos with invertebrates identified at least to family level. The level of taxonomic identification is a compromise between what is practical and what provides a reasonably reliable indication of the taxonomic composition of the catch. Vanderklift et al (1998) have shown that family level data provides nearly as much information as species or genus data for invertebrates and fish and given the higher costs of finer resolution we believe that this compromise is justified. Priority areas are those outside of the GoC. Two sampling gears have been used to sample this component – prawn trawls and benthic dredges. We already have a large number of prawn trawl samples mainly from the Gulf of Carpentaria and it would be advantageous for sampling of areas outside of the GoC to use the same gear to facilitate comparisons. Similarly we have a comprehensive dredge survey of the central GoC and again it would be advantageous to use the same sampling gear for other areas. The important difference between the two gears is that prawn trawls sample mainly the epibenthos and animals that live close to the seabed, they are not particularly efficient at catching attached animals unless these break off easily. They are also effective at catching the slower moving mobile animals such as echinoderms and especially crustaceans. Prawn trawls catch a wide variety of animals – over 400 taxa of invertebrates and over 500 species of fish in the case of the GoC The mesh size (usually 37.5 mm) can catch small animals. Prawn trawl bycatch also identifies which species are vulnerable to prawn trawling. West (2002) has shown that overall, prawn trawls are a good method of sampling seabed benthos. Standard prawn trawl gear is used and so sampling can be carried out by commercial trawlers as well as research vessels. The dredge we have used is a 3.0 m wide by 1.2 m high beam trawl (Church dredge) rigged with a 30 m mesh net bag. Because of its heavy weight and because it scrapes the seabed, it samples animals that live in surface sediments as well as those that are attached. It can be towed from a standard prawn trawler.
- Quantitative samples of fish identified to species level. Priority areas are those outside of the GoC. Ideally these samples should be collected using a fish trawl. This is towed faster than a prawn trawl and so is more effective at catching the more active fish. A fish trawl has a higher opening than a prawn trawl and so can catch fish that swim off the seabed. It has a larger mesh (usually 100 mm) than a prawn trawl (37.5 mm) and so does not catch small animals. A comparison between the catch of fish and prawn trawls in the northern Great Barrier Reef showed that although there was an overlap in species, each gear caught a different component of the fish fauna and that both gears were needed in order to obtain a complete picture of the fish fauna (Wassenberg et al, 1997). Because of the large size of fish trawls, they cannot be handled from a standard prawn trawler. In the past we have either used the RS Southern Surveyor or chartered prawn trawlers that have been specially modified to use fish trawls
- In Chapter 4 (Fine-scale distribution of trawl effort) we have presented maps of the so-called untrawlable grounds. These areas are thought to be reefs but we have no confirmation of this. We consider that maps of the three dimensional structure of the NPF should be treated as a priority area since they will enable us to visualize the seabed for the first time and will assist in future planning of both research and management in the area. Practical limitations due to time and cost limits the use of cameras, dredges, and grabs for mapping the seabed. Consequently broad-scale maps of seabed type are difficult to produce because only a fraction of a study area can be

sampled. Above-water remote sensing tools (e.g. satellite data) allow broad-scale mapping, however they are severely limited for sampling deeper seabeds and especially so in high turbidity water. In order to address these limitations, CSIRO has been developing and using techniques to remotely sense the seabed using acoustic signals from instruments such as sonars or echo sounders. The collection and analysis of underwater sound pulses emitted from these instruments and reflected by the seabed provides the potential to differentiate seabed types because different seabed types produce different echoes. These acoustic techniques provide information on fine scale ocean depth as well as acoustic backscatter, seabed acoustic roughness and hardness. Combined with traditional sampling methods, this acoustic information permits rapid broad-scale and continuous mapping of seabed type even over rugged terrain, such as reefs. Description of seabed structure can be based on data from normal incidence echo sounder acoustics as well as bathymetry and backscatter data from high-resolution side-scan acoustics in areas of particular interest. Basic depth data can be obtained from any vessel fitted with an echo sounder. RoxAnn, Swath and Side-scan sounder data require special gear and an acoustics specialist. This data can be collected while the ship is underway making it possible to map large areas between stations and areas of particular interest. Swath mapping is a very effective way of mapping the seabed but it has the limitation that it operates on a 5:1 ratio. In 30 m of water, the swath is only 150 m wide which, given the high cost, is very little advance on the coverage of side scan sonar. An important aspect of the acoustics work would be to extend knowledge of the distribution of seabed reef structure outside of the GoC trawl grounds. Biological information on distribution of fish communities in the GoC suggests that reef structures exist in the deeper waters of the GoC. We have no information at all from north of Arnhem Land and in the Joseph Bonaparte Gulf.

- Sediments – percent mud, grain size of sand and gravel. Priority areas are those outside of the GoC. These samples can be collected by a grab that can be handled from any vessel with a suitable winch. CSIRO, AGSO and the University of Sydney already hold a considerable amount of information on sediments and additional sampling needs to take existing data into account to maximise its value.
- VMS data for the whole fishery. AFMA has now given CSIRO access to all VMS data for the NPF. The data is complex because of the use of different polling frequencies but it provides high-resolution data on the distribution of effort. Examples of the use of a subset of the VMS data are given in Chapter 4. Its main use has been to increase the mapped resolution of fishing effort by a factor of 36x – from 6 x 6 nm fishing grids to 1 x 1 nm grids.
- Bottom current stress. The hydrodynamic model developed as part of the Surrogates Project includes the entire NPF but needs ground-truthing. Although this has not proved to be a surrogate in the central GoC we consider that this might be a consequence of the low range in that region. We know that bottom current stress is important in Torres Strait and the northern GBR and we consider that it may be important in the western NPF where current speeds are higher than in the GoC.
- Mean bottom physical and chemical parameters. Data on these parameters have been collected from sites at points in the NPF and used for modelling their values over the entire NPF (CARS). Additional measurements are needed to fill in gaps and to obtain seasonal information on those factors (oxygen, nitrate) that appear to have a role in determining distribution of seabed fauna. Specialised water sampling equipment is required as well as a ship-based laboratory for handling and processing water samples so in practice this work has to be done from a research vessel.
- Remote sensed satellite data such as SeaWIFS where appropriate to enhance existing data sets.
- Video and still photography of the seabed where visibility allows. We are not optimistic whether water visibility in the NPF is adequate for these techniques to be used, opportunistic field trials are needed and targeting times of the year when water

is clearer may be successful. We presently have no images of the NPF seabed including the untrawlable grounds. Even a limited coverage would give everyone a much greater understanding of the seabed habitat

- Spatially referenced economic data on the benefits and costs resource uses other than prawn trawling are required to properly assess the costs of implementing a system of MPAs in the NPF region. Estimates of costs may already be available from the ABARE reports on Australian fisheries, and catch data are held by the relevant management authorities.

Table 3.5.3 Summary of sampling that needs to be carried out in the NPF to provide a more complete data set. The emphasis should be on collection of data in bioregions not presently adequately sampled

Nature of data	Comment
Prawn trawl bycatch	This should be regarded as the minimum biological collection
Biological dredge samples	Samples should overlap with those collected in prawn and fish trawls
Fish trawl samples	Should be collected if funding is available to obtain a more complete biological record
Range of seabed mapping techniques including normal incidence acoustic tracks over as much area as possible	Acoustic sampling should be combined with biological sampling in order to relate the two
Sediments	Percent mud, grain size in selected areas to increase reliability of information
VMS data on a continuing basis	Data is already being collected by AFMA but analysis is needed
Bottom current stress	Field data to validate model
Chemical and physical water column data	Improve reliability of existing data set
Remote sensing	SeaWIFS data
Seabed video	Opportunistic depending on water visibility and availability of gear and ship time
Economic data on resource uses other than prawn trawling	From literature reviews or planned surveys, following on from stakeholder consultations

Discussion

We recognise that a full data set would be expensive to obtain. Some of the data that are needed may come from other projects but much will have to be specially collected. Key points in the collection of this data would be that where possible, data from different gears should be co-located in order to increase the power of analysis. We have had a major problem with the present project in that biological samples from the central Gulf of Carpentaria were collected with different gear from that around the margins of the GoC. Secondly the sampling should cover areas that are different physically and biologically. For example we have no information from the deep waters of Joseph Bonaparte Gulf but we have many replicates covering similar grounds from within the GoC. Thirdly there should be an attempt to complete the GoC data sets by obtaining overlapping samples. For example we have no prawn trawl bycatch samples from the central GoC, this make it difficult to compare this region and others where we have only prawn trawl samples.

Sampling strategies need to be developed using power analysis to obtain a statistically rigorous design for the collection of additional data. This would need to take into account properties of biota such as the high biodiversity, the dominance of the fauna by a few species, species assemblages as well as relationship between animals and physical environment. We have not undertaken such a design as part of the present project because the vessel and the gear that are available as well as the amount of time available for sampling would affect it. In addition sample design needs to take into account the amount of relevant data that is already available.

There is the possibility that appropriate data might be collected as part of other research projects. While apparently attractive, we recognise that the cost to an existing project of obtaining additional samples can be substantial and in a climate of containing costs, may be unacceptably high. For example in the case of prawn trawl bycatch samples collected from commercial vessels, the cost of collecting, holding, transporting and storing each sample is estimated to be around $30 with a further $30 for sorting, identifying and entering data for each sample, While this cost may appear low, to cover the commercial trawl grounds in the western half of the NPF would require several hundred samples and this means a non-trivial additional cost. A limitation on this approach is that the commercial trawl grounds cover only a minor proportion of the western NPF and so most areas would not be visited or sampled by commercial vessels as part of their normal fishing. This means that very extensive areas cannot be sampled simply by collecting samples from commercial trawlers. Despite these reservations, we recommend strongly that the planners of future research projects in the NPF consider the scope for additional targeted data collection since it may be possible to obtain this at a moderate additional cost.

References

ABARE 2000, Australian Fisheries Statistics 1999, Canberra.

Poiner I, Glaister J, Pitcher R, Burridge C, Wassenberg T, Gribble N, Hill B, Blaber S, Milton D, Brewer D, Ellis N. (1998). Environmental Effects of Prawn Trawling in the Far Northern Section of the Great Barrier Reef: 1991-1996. Final Report to the Great Barrier Reef Marine Park Authority and the Fisheries Research and Development Corporation

Vanderklift MA, Ward TJ and Phillips JC. (1998). Use of assemblages derived from different taxonomic levels to select areas for conserving marine biodiversity. Biological Conservation 86: 307-315

Wassenberg TJ, Blaber SJM, Burridge CY, Brewer DT, Salini JP and Gribble N (1997) The effectiveness of fish and shrimp trawls for sampling fish communities in tropical Australia. Fisheries Research 30: 241-251

West R (2002) Comparison of fish and shrimp trawls for sampling deep-water estuarine fish in a large coastal river in eastern Australia. Fisheries Research 54, 409-417

CHAPTER 3.6

ARCHIVING OF DATA FROM THE PROJECT

Chapter Authors:

Chris Moesender, Mick Haywood, Scott Gordon, Bill Venables, Dave Vance

CHAPTER 3.6

ARCHIVING OF DATA

Chris Moeseneder
Scott Gordon
Mick Haywood
Bill Venables
Dave Vance

Summary

Content

Introduction

The Surrogates project relied on using existing data sets. We had considerable problems with some of these particularly those from the 1990 Southern Surveyor Cruise. In order to assist future workers we have documented here which files were used and the methods used to extract the data.

File locations

All files refered to in this chapter are stored on the file server “Anchovy” in a share named “WorkGroups\GoC Surrogates”. The files containing data that has been used to produce the final report will be stored in the directory “Data\Final Report” of this share.

Marlin metadata record

A record for this project has been created in the “Marlin” (CSIRO Marine Laboratories Information Network) database. Following is the content of this record.

Developing Surrogates for Ecosystems, Assessing the Impacts of Trawling and Modelling the Performance of Spatial Closures on the Northern Prawn Fishery
Short title: GoC Surrogates MarLIN record number: 5918

Data Type
Observed Data - field
Observed Data - laboratory
GIS
Aggregated/Derived Data
Model Data

Local Custodian Organisation: CSIRO Division of Marine Research - Cleveland

Originator Organisation: CSIRO Division of Marine Research - Cleveland

Contributors: Neil Loneragan, Mick Haywood, Ilona Stobutzki, David Vance, Cathy Dichmont, Scott Gordon, Christian Moeseneder, Nick Ellis, Scott Condie, Jim Mansbridge, Bill Venables, Kenton Lawson (ABARE), Ian Poiner Acknowledgements: Fisheries Research and Development Corporation References: Long BG, Poiner IR (1994) Infaunal Benthic Community Structure and Function in the Gulf of Carpentaria, Northern Australia, Aust. J. Mar. Freshwater Res. 1994, 45, 293-316 Blaber SJM, Brewer DT, Harris AN (1994) Distribution, Biomass and Community Structure of Demersal Fishes of the Gulf of Carpentaria, Australia, Aust. J. Mar. Freshwater Res. 1994, 45, 375-396 Publication date : Not Known

Abstract:
This chapter lists the cruises from which we derived the data used in the project. It provides the metadata that future users will need if they wish to work on the files. Much of the analyses in the project resulted in the formation of derived files. We have listed these and their contents. We have also described the methods used to create the final tables.

Location Keywords
Pacific Ocean
Arafura Sea
Australia > Gulf of Carpentaria
Australia > Gulf of Carpentaria > Albatross Bay
Australia > Gulf of Carpentaria > Groote Eylandt
Australia > Joseph Bonaparte Gulf

Geographic Extent

10.0 S

120.0 E 141.5 E

17.0 S

Dataset contains GIS spatial data in format World Geodetic.

Subject Categories and Search Word(s)

MarLIN Subject Categories
1181a. Biodiversity
1242. Aquatic invertebrates (excl. molluscs/crustaceans/insects) - geographical distribution
1262. Aquatic molluscs - geographical distribution
1282. Aquatic crustaceans - geographical distribution

1342. Marine and freshwater fishes - geographical distribution
1383. Biogeography and biogeographic regions
1522/2123. Aquatic environment protection
2201. Underwater acoustics
2264. Sediments and sedimentation

Habitat Keywords
EARTH SCIENCE > Biosphere > Aquatic Habitat > Benthic Habitat

Taxonomy Keywords
EARTH SCIENCE > Biosphere > Zoology > Anemones
EARTH SCIENCE > Biosphere > Zoology > Corals
EARTH SCIENCE > Biosphere > Zoology > Crustaceans
EARTH SCIENCE > Biosphere > Zoology > Echinoderms
EARTH SCIENCE > Biosphere > Zoology > Fish
EARTH SCIENCE > Biosphere > Zoology > Invertebrates
EARTH SCIENCE > Biosphere > Zoology > Molluscs
EARTH SCIENCE > Biosphere > Zoology > Segmented Worms
EARTH SCIENCE > Biosphere > Zoology > Sponges

GCMD Keywords
EARTH SCIENCE > Oceans > Bathymetry/Seafloor Topography > Water Depth
EARTH SCIENCE > Oceans > Marine Biology > Fish
EARTH SCIENCE > Oceans > Marine Biology > Marine Habitat
EARTH SCIENCE > Oceans > Marine Biology > Marine Invertebrates
EARTH SCIENCE > Oceans > Marine Sediments > Sedimentary Textures
EARTH SCIENCE > Oceans > Ocean Acoustics > Acoustic Frequency
EARTH SCIENCE > Oceans > Ocean Chemistry > Nitrogen
EARTH SCIENCE > Oceans > Ocean Chemistry > Oxygen
EARTH SCIENCE > Oceans > Ocean Chemistry > Phosphate
EARTH SCIENCE > Oceans > Ocean Chemistry > Silicate
EARTH SCIENCE > Oceans > Ocean Circulation > Ocean Currents
EARTH SCIENCE > Oceans > Ocean Temperature > Water Temperature
EARTH SCIENCE > Oceans > Ocean Waves > Wave Height
EARTH SCIENCE > Oceans > Salinity/Density > Salinity

ANZLIC Search Words
ECOLOGY
ECOLOGY Habitat
FAUNA Invertebrates
FAUNA Vertebrates
MARINE Biology
MARINE Geology and Geophysics
MARINE Human Impacts
OCEANOGRAPHY Physical
OCEANOGRAPHY Chemical

Equipment
Acoustic Equipment/Echo Sounders
Boats and Small Vessels
Dredges
Grabs
Logbook/Catch Data

Satellites
Demersal Trawls
Prawn Trawls

Additional keywords
Human Dimensions > Environmental Impacts > Fisheries

Originating Research Project
Not Entered

Research Platform, Site or Source
Southern Surveyor

Research Voyage/Survey Details

Voyage/Survey Name
SS 03/90 [*SS199003*]

Voyage/Survey Leader(s)
I. Poiner & S. Blaber (CSIRO)

Voyage/Survey Region
Gulf of Carpentaria, W Torres Strait

Voyage/Survey Description
Southern Surveyor cruise SS 03/90 was undertaken to carry out the first fisheries survey, and benthic sampling in the Gulf of Carpentaria, the south eastern Arafura Sea and western Torres Strait Protection Zone. The primary aim of the cruise was to determine the commercial finfish recourses and the distribution of the demersal fish fauna in relation to: the distribution of the benthos, sediments and depth in these areas. Secondary aim was to determine which species of fish feed on penaeid prawns in selected prawn-trawl areas of the GOC; to describe the
bycatch and determine the fate of bycatch of commercial fish trawls and differences in the fish communities of areas of high and low prawn trawl effort.

Voyage Track
View voyage track

Voyage/Survey Name
SS 02/97 [*SS199702*]

Voyage/Survey Leader(s)
J. Salini (CSIRO)

Voyage/Survey Region
Torres Strait, Gulf of Carpentaria, Arafura Sea

Voyage/Survey Description
Southern Surveyor cruise SS 02/97 was the first in a series of three cruises for the Bycatch Sustainability project in the areas of the northern prawn fishery of the Torres Strait and the Gulf of Carpentaria. The aims of the cruise were to identify all vertebrate and invertebrate bycatch species in prawn trawls in the northern prawn fishery and the Torres Strait; to sort one total catch from each of nine areas; to complete sub sampling prawn trawl experiments; to collect RoxAnn and EK500 acoustic data to help discriminate bottom environments, accompanied by dredge tows and abiotic

samples; to collect saurid specimens for phylogenetic analyses; and to collect and photograph specimens of commercial fishes. Sea snakes were also tested for post-trawl survival, and leiognathids (pony fish) chemically treated for otolith marking.

Voyage Track
View voyage track

Voyage/Survey Name
SS 08/97 [*SS199708*]

Voyage/Survey Leader(s)
J. Salini (CSIRO)

Voyage/Survey Region
Torres Strait, Gulf of Carpentaria, Arafura Sea

Voyage/Survey Description
Southern Surveyor cruise SS 08/97 was the second in a series of three cruises for the Bycatch Sustainability project in the areas of the northern prawn fishery of the Torres Strait and the Gulf of Carpentaria. The aims of the cruise were to identify all vertebrate and invertebrate bycatch species in 468 prawn trawls in the northern prawn fishery and the Torres Strait; to sort one total catch from each of nine areas (seven were successfully sampled); to sample inside and outside prawn closure areas north west of Groote Eylandt; and to collect RoxAnn and EK500 acoustic data to help discriminate bottom environments, accompanied by dredge tows and abiotic samples. Sea snakes were also tested for post-trawl survival, and leiognathids (pony fish) chemically treated for otolith marking.

Voyage Track
View voyage track

Voyage/Survey Name
SS 03/98 [*SS199803*]

Voyage/Survey Leader(s)
J. Salini (CSIRO)

Voyage/Survey Region
Gulf of Carpentaria, Arafura Sea

Voyage/Survey Description
Southern Surveyor cruise SS 03/98 is the final of three cruises for the Bycatch Sustainability project in the region of the northern prawn fishery in the Gulf of Carpentaria, north-east of Mornington and around Groote Eylandt. The objectives of this cruise are to identify all vertebrate and invertebrate bycatch species in prawn trawls inside and outside closed areas of the fishery; to sort one total catch from each area; and to collect RoxAnn and EK500 acoustic data on bottom environments, complemented by dredge tows, grab samples and abiotic data. The survival of trawl-caught sea snakes will also be monitored.

Voyage Track
View voyage track

Beginning date : 1990 Ending date : Not Known Progress : In Progress Maintenance and Update Frequency : As Required

Stored Data Format(s)

DIGITAL - Database Files - MS Access
DIGITAL - Database Files - Oracle
DIGITAL - GIS - ARC/INFO
DIGITAL - GIS - ARCVIEW

Stored Data Volume
10 gigabyte

Specific Software Requirements
ARC/Info, Oracle, SAS

Stored Data Documentation
argyrops\NT-shares\Public\GoC Surrogates\Data

Stored Data Location
Oracle area 'Surrogates' on Forty2

Available Format Type(s)
Same As Stored

Access constraint
Fisheries-derived data (VMS and logbook) is confidential

Data Source, Processing and Quality Control Information
see http://www.bne.marine.csiro.au/wwwsite/surrogates/Analysis of the Surrogates tables

Positional accuracy
+/- 200m

Parameter accuracy
weights +/- 50g

Logical consistency report
see http://www.bne.marine.csiro.au/wwwsite/surrogates/Analysis of the Surrogates tables

Completeness
Data collected is largely complete and accurate. An exception is the species identification of invertebrates.

Contact
Position: ...
CSIRO Division of Marine Research - Cleveland
Person: Mick Haywood
mick.haywood@csiro.au

Metadata Access
Internal

Metadata Entry Created
01-Mar-2002 by Chris Moeseneder

Metadata Updateable By
TCSE Group

Important files used in the project

File Name and address	Description	Source	Notes
GoC surrogates\Data\Sustainability cruises\Sus_pt_iv.xls	This file is the numbers and kg per hour of each species caught in the sustainability prawn trawls from cruises: SS0702, SS9708, SS9803	Generated from \\conger\c:\surrogates\data\prawn_trawl\read_invert_species.sas	This file gives the names used in classifying each species at five taxon levels - used in the Sustainability spreadsheet
GoC surrogates\Sustainability spreadsheet\Sustainability.xls	This file is the working document in which we estimated Susceptibility and Recovery for all of the Invertebrate taxa used	See Worksheet Source of information	There are 17 worksheets in this file. The worksheet named Summary for Nick is the sustainability values used by Nick in his Impacts Model (Chapter 8)
GoC surrogates\Data\Sustainability cruises\Prawn_trawl\Sustainability_trawl_position_.xls	1176 records of prawn trawl (most), fish trawl and try net shots on cruises SS97/02, SS97/08, SS 98/03 Gives gear, lat, long and depth		
Goc Surrogates\Data\Sustainability_cruises\sus_pt_fish.xls	34332 records of fish caught in 97/02, 97/08 and 98/03. Gives Species code, Family, Location, Count/hr, Wt/hr, Newopno, Opno, Cruise, Station, Scientific name		
GoC surrogates\Data\Sustainability cruises\Inverts\inverts_pri.xls	Sustainability cruises - 1070 records of invertebrate catches weight per hr		Catch rates for Invertebrates families (in alphabetical order) for each operation on 97/02, 97/08 and 98/03
GoC surrogates\Data\Sustainability cruises\Inverts\opcl500.xls	407 records of trawl length (check) for cruises 97/02, 97/08 and 98/03. Gives Newopno, area of trawl and whether it is in open or closed zone		
GoC surrogates\Data\Sustainability cruises\Inverts\opcl500_factors.xls	407 records of trawl length (check), Newopno, area, start (S) and end (E) position, distance to closure for cruises 97/02, 97/08 and 98/03		
GoC surrogates\Data\Sustainability cruises\Inverts\OPCL500Pri.xls	3722 records of Catch rates (wt and count) for invert families. Gives start and end position, length and duration of trawl and area		
GoC surrogates\Data\Sustainability cruises\Inverts\OPCL500Pri2.xls	Appears to be the same information as GoC surrogates\Data\Sustainability		

	cruises\Inverts\OPCL500Pri.xls		
GoC surrogates\Data\Sustainability cruises\Inverts\sus_inverts_catches.xls	10165 records of catch rates (wt hr, count hr), newopno by region for invertebrate families		

Analysis and restructure of the Surrogate tables

An analysis of the tables, which were produced at the times of the cruises resulted in the following logic:

Table new_cruise defines the sites that were visited.

Every dredge shot produces one entry in the table dredge_log.

The large fish (“monsters”) which are removed from the net produce one entry in dredge_catch per species with t_field = "T".

The rest of the catch is divided into subsamples. Only one subsample is analyzed, the rest are dumped.

For invertebrates, one entry in dredge_catch was made for each invertebrate species with t_field = "S".

Field cgf (Catch grossing factor) in dredge_log is the proportion of the catch weight that was sorted. Used as a multiplication factor.

Field sample in dredge_log is the weight of the sample of the total catch that was sorted from each dredge.

Field restsam in dredge_log is the weight of the subsamples, which were discarded.

Field totcatch in dredge_log is restsam + sample + t_catch (Monsters). The value is often 0.

Table dredge_catch should contain only invertebrates. However there are also fish-records in this table. These are identified by the field SPCODE beginning with "fis*" or field NAME being anything with "fish" or "teleost".

Fish in the subsample produce one entry in dredge_catch_fish for each fish species.

Field NOS in dredge_catch_fish shows the number of specimens, which were caught of this species (identifed by this record).

If the catch was sub sampled then t_field = “S”. If the total catch was sorted (no sub sampling) then t_field = “T” (therefore CGF =1).

Dredge_catch contains all invertebrates. A fish produces a single record in dredge_catch.

When comparing the tables at hand, the following similarities became apparent.

Group	"cruise_dredge"	"dredge_catch" The catch. One record for each invertebrate species (monsters and rest)	"all_dredge_log"	"dredge_fish" The catch. One record for each fish species	"dredge_log" Dredge details. The entire content of the net	"ascspp" Definitions of species	"new_cruise" Definitions of the areas dredged
Similar 1	ss03_90_dredge	dredge_catch (1)	all_dredge_log	all_dredge_fish	ss0193_dredge_log (1)	ascspp	new_cruise
Similar 2	ss05_91_dredge (1)	dredge_catch_backup		goc_dredge_fish	dredge_log_s5 (1)		
Similar 3		dredge_catch_fish			dredge_log_hist (1)		
Similar 4		dredge_catch_fish_hist			dredge_log_bak		
Similar 5		dredge_catch_hist			dredge_log		
Similar 6		dredge_catch_hist_backup					
Similar 7		dredge_catch_s5 (1)					
Similar 8		ss0193_dredge_catch (1)					
Proposed name	sur_dre	sur_cat	sur_log all	sur_fis	sur_log	ascspp	sur_cru

(1) indicates differences in field structures

IDENTIFYING DERIVED TABLES.

1. New_cruise Group

Table new_cruise is unique

2. Dredge_log Group

A program was written which compares record of two tables. It is called CompareRecords.
Dredge_log and dredge_log_bak are identical as distinct dredge_log.sql and CompareRecords proves. Therefore dredge_log_bak is not considered.
Dredge_log_hist seems to be a more detailed version of some of the records of dredge_log. CompareRecords was run after field depth had been removed from dredge_log and fields up_date and quality_control had been removed from dredge_log_hist. Furthermore, there were records with a single quote (') in dredge_hist which caused the compare to fail (as the quote is a reserved character). Quotes were then removed manually from the data imported into Access. CompareRecord proves that about 40% of the records match when comparing in both directions.
Dredge_log_s5 seems to be a valid dredge log for cruise SS0592. As CompareRecords proves, there are no matches for any records of dredge_log_s5 in dredge_log (with field depth removed) and vice

versa. The table should be combined with table dredge_ log. Field depth is missing in dredge_log_s5. Therefore values for records from dredge_log_s5 will be NULL in the final table.
Comparing dredge_log_hist (without fields up_date and quality_control) with dredge_logs5 and vice versa shows that there are no records that match in either direction.
SS0193_dredge_log seems to be a valid dredge log for cruise SS0592. CompareRecords shows that there are no matching records when comparing in both directions. The table should be combined with table dredge_ log. Field depth is missing in ss0193_dredge_log. Therefore values for records from ss0193_dredge_log will be NULL in the final table.
When comparing dredge_log_s5 to ss0193_dredge_log with CompareRecords no records match in any direction.
When comparing ss0193_dredge_log to dredge_log_hist (without fields up_date and quality_control) with CompareRecords no records match in any direction.

Result of the comparison

from / to ->	dredge_ log	dredge_ log_bak	dredge_ log_hist	dredge_ log_s5	ss0193_ dredge_log
dredge_log		A	41	N	N
dredge_log_bak	A		41	N	N
dredge_log_hist	46	46		N	N
dredge_log_s5	N	N	N		N
ss0193_dredge_log	N	N	N	N	

Legend: N - No matches, A- All match, 99 - Number of records that match.
Some fields have been removed for compare.

Conclusions from the comparison
Dredge_log remains unchanged.
Dredge_log_bak can be ignored.
All data from dredge_log_s5 and ss0193_dredge_log will be appended to dredge_log. Field depth will contain NULL values for these records.
Data in dredge_log_hist needs further analysis further to find if it is derived from dredge_log. Major problem being the two additional fields up_date and quality_control.

3. Dredge_fish Group

Comparison of all_dredge_fish and goc_dredge_fish with CompareRecords and sql-statements shows that there is a record in all_dredge_fish for each record in goc_dredge_fish. See also comp rows all_dredge_fish & goc_dredge_fish 1.sql and comp rows all_dredge_fish & goc_dredge_fish 2.sql for reference.

Results

Table goc_dredge_fish is a subset of table all_dredge_fish. There is a match for every row of goc_dredge_fish in all_dredge_fish. Goc_dredge_fish should therefore be ignored.
Change datatype of field station in the tables all_dredge_fish and goc_dredge_fish from varchar2 (4)/(7) to number(3) as the field contains numeric values only and no numbers over 999. See
check values in all_drege_fish.sql
check values in goc_drege_fish.sql

4. ascspp Group

Table ascspp is unique

5. cruise_dredge Group

When comparing tables ss03_90_dredge and ss05_91_dredge with CompareRecords no matching records were found in either directions.

Results

As both tables have the same structures, the records from tables ss03_90_dredge and ss05_91_dredge should be combined in one table.

6. all_dredge_log Group <needs further analysis>

Purpose of this table is unknown.

Results

Change datatype of field station in tables all_dredge_log from varchar2 (4)/(7) to number(3) as the field contains numeric values only and no numbers over 999. See check values in all_dredge_log.sql

7. dredge_catch Group

Note: "'" (single quotes) in entries were eliminated in dredge_catch_backup

Results

No record in dredge_catch_fish matches with any record in dredge_catch. All records of table dredge_catch_fish should be appended to dredge_catch. The table dredge_catch_fish can then be ignored
About half the records in dredge_catch_backup are matched in dredge_catch. Dredge_catch_backup should be ignored until someone can make a statement about its origin/purpose.

Except for one record, dredge_catch_fish_hist has no matches in dredge_catch_fish. However, until someone can make a statement about its origin/purpose the table should be ignored due to its name.
There are no matches for the rows in dredge_catch_hist with the rows in dredge_catch.
Dedge_catch_hist has about 40% less records thank dredge_catch. Until someone can make a statement about its origin/purpose the table should be ignored due to its name.
Dredge_catch_hist_backup has fewer rows than dredge_catch_hist. 3070 Rows in Dredge_catch_hist_backup match in Dredge_catch_hist, 34 do not match. The table can probably be ignored.
Dredge_catch_s5 seems to be a valid data set for SS0591. The data should be appended to dredge_catch.
SS0193_dredge_catch seems to be a valid data set for SS0193. The data should be appended to dredge_catch.

General Results of the comparison:
Change field cruise from varchar2(6) to varchar2(7) in all tables which contain this field, because the field is up to 7 characters long in some tables
All records with value "SS03" in field cruise should be changed to "SS0390".
Put a NOT NULL constraint on all cruise fields in all tables as there are no NULL values present.
Put a NOT NULL constraint on all station fields in all tables. Existing NULL values are present in these tables:

table	number of NULL values in field 'station'
dredge_log_hist	2
dredge_catch_fish_hist	2
dredge_catch_hist	1
dredge_catch_hist_backup	1

These records must be cleaned.

Missing values in field station should be filled in with the correct value or with a pseudo-value, which is well documented.
Data inconsistencies that need to be rectified
Field t_field may contain letter in capitals or lower case. Change all to uppercase.
All "SS03" values in field "cruise" in all tables which have this field should be changed to "SS0390".

Suggested new table structure based on findings outlined above.

New table name	Group	Copy all rows from	Comment
SUR_DRE	cruise_dredge	ss03_90_dredge	
		ss05_91_dredge	
SUR_CAT	dredge_catch	dredge_catch	
		dredge_catch_fish	
		dredge_catch_s5	
		ss0193_dredge_catch	
SUR_LOGALL	all_dredge_log	all_dredge_log	Table may be eliminated
SUR_FIS	dredge_fish	all_dredge_fish	
SUR_LOG	dredge_log	dredge_log	
		dredge_log_s5	
		ss0193_dredge_log	
SUR_CRU	new_cruise	new_cruise	
ASCSPP	- as is -	- as is -	

These tables can be ignored

dredge_catch_backup
dredge_catch_fish_hist
dredge_catch_hist
dredge_catch_hist_backup
goc_dredge_fish
dredge_log_bak
dredge_log_hist

Activities performed to create the final tables

Created new area Surrogates in Oracle.
Copied tables dredge_log, dredge_log_s5 and ss0193_dredge_log from Gulfish to the Surrogates area.
Updated all rows in dredge_log and set cruise field to SS0390 for all records (were all SS03).
Created table sur_dredge_log (see CREA_SUR_DREDGE_LOG).
Added column depth to tables dredge_log_s5 and ss0193_dredge_log. All NULL values.
Copied all rows from dredge_log, dredge_log_s5 and ss0193_dredge_log to sur_dredge_log.
Manually compared the rows in the source table with rows in destination table to ensure success of copy operation.
Deleted tables dredge_log, dredge_log_s5 and ss0193_dredge_log from Surrogates area.
Copied Gulfish.station_log to Surrogates area and changed all entries in cruise field from SS03 to SS0390.
Added column STARTDATETIME of type date to SUR_DREDGE_LOG. This gives a new create table statement for SUR_DREDGE_LOG: CREA_SUR_DREDGE_LOG 2.
Updated column STARTDATETIME in SUR_DREDGE_LOG with a derived date/time combination from the same table and STATION_LOG (see STARTTIMEDATE_SUR_DREDGE_LOG). As STATION_LOG only contains records for cruise SS0390, the update produced only valid date/time entries for SUR_DREDGE_LOG entries with cruise SS0390.
Dropped table STATION_LOG in area Surrogates.
A comparison of tables all_dredge_log and sur_dredge_log shows:

All_dredge_log has 271 records. When ignoring records for cruise GBR0192, sur_dredge_log has 266 records. The additional 5 rows in all_dredge_log are either duplicates of existing rows in the same table (can be ignored) or rows with same cruise/station and most other fields with NULL values. All values in all_dredge_log seem to be derived from the records in dredge_log/dredge_log_s5/ss0193_dredge_log with the same value in fields cruise and station except for the fields start_time and the_date which are probably from table station_log (the_date was taken directly, start_time seems to be the start time rounded to the nearest hour (minutes 1 to 29: same hour; minutes 30-59: next hour)).

Suggestion: Ignore table all_dredge_log if data for cruise GBR0192 is not needed.

Altered table SUR_DREDGE_LOG. Set NOT NULL constraint on column STATION.
Created index ISUR_DREDGE_LOG1 on fields CRUISE, STATION on table SUR_DREDGE_LOG. See ISUR_DREDGE_LOG.
Added Primary Key constraint to table SUR_DREDGE_LOG on fields CRUISE, STATION. This gives a new create table statement for SUR_DREDGE_LOG:
CREA_SUR_DREDGE_LOG 3.
There are 3 records in SUR_DREDGE_LOG which have NULL values in field STARTDATETIME. This is due to NULL values in STARTTIME in table DREDGE_LOG. The solution is to check in table NEW_CRUISE by searching for the appropriate station and checking the date.
For all records in SUR_DREDGE_LOG tables grab_log and trawl_log were checked if the date in SUR_DREDGE_LOG is correct.
Table ALL_DREDGE_LOG will be ignored.
Copied table NEW_CRUISE to Surrogates area. It will be called SUR_CRUISE_LOG.
Added field CRUISE to this table and set to SS0390 for all records.
Each tables was assigned to one of four groups:
CRUISE: 4 cruises
ACTIVITY_LOG: dredge_log, prawn trawl logs, fish trawl logs, grab_log
CATCH: species, total weight, number, min length, max length
UNKNOWN: tables of unknown purpose
Identified which tables are relevant for the analysis.
Imported the identified tables (SUR_DREDGE_LOG and SUR_GEAR) into Oracle

Structure of the final tables in Oracle

SUR_DREDGE_LOG

Field name	Type	Description
STARTDATETIME	VARCHAR2 (30)	dredge start time
REP	NUMBER (1,0)	dredge replicate number
HEADLINEH	NUMBER (5,3)	height (m) of the head rope above the substrate
WINGSP	VARCHAR2 (10)	Distance between the wings of the net (m)
DOORSP	NUMBER (5,2)	Distance between the trawl doors (m)
WARPL	NUMBER (3,0)	Length of the trawl warps (m)
CRUISE	VARCHAR2 (6)	Cruise identification number
STATION	NUMBER (3,0)	Station number
DUR	NUMBER (3,0)	Duration of trawl (minutes)
SPEED	NUMBER (8,5)	speed of trawl (knots)
RESTSAM	NUMBER (8,4)	Weight of the catch that was weighed and discarded i.e. not sorted at all
CGF	NUMBER (6,3)	Catch grossing factor
GEAR	VARCHAR2 (10)	Gear code
NOTES	VARCHAR2 (100)	Notes
SAMPLE	NUMBER (8,3)	Weight of the sub sampled catch
TOTCATCH	NUMBER (8,3)	Sum of(restsam, sample, t_catch)
T_CATCH	NUMBER (8,3)	weight of "monsters" (large sharks & rays etc) that were weighed and discarded i.e. not included in the sub sampling procedure
STARTTIME	NUMBER (5,0)	Time at start of trawl/dredge
ENDTIME	VARCHAR2 (10)	Time at end of trawl/dredge
SLAT	NUMBER (2,0)	Latitude (degrees) start of trawl/dredge
SLATMIN	NUMBER (6,4)	Latitude (minutes) start of trawl/dredge
SLATSEC	NUMBER (8,3)	Latitude (seconds) start of trawl/dredge
SLON	NUMBER (3,0)	Longitude (degrees) start of trawl/dredge
SLONMIN	NUMBER (6,4)	Longitude (minutes) start of trawl/dredge
SLONSEC	NUMBER (8,3)	Longitude (seconds) start of trawl/dredge
ELAT	NUMBER (2,0)	Latitude (degrees) end of trawl/dredge
ELATMIN	NUMBER (6,4)	Latitude (minutes) end of trawl/dredge
ELATSEC	NUMBER (8,3)	Longitude (seconds) end of trawl/dredge
ELON	NUMBER (3,0)	Longitude (degrees) end of trawl/dredge
ELONMIN	NUMBER (6,4)	Longitude (minutes) end of trawl/dredge
ELONSEC	NUMBER (8,3)	Longitude (seconds) end of trawl/dredge
DEPTH	NUMBER (6,2)	Depth (m)

SUR_GEAR

Field name	Type	Description
BTL_SPECIES_COUNT	NUMBER (4,0)	Count of the number of species at this station. Less detailed.
DESCRIPTION_SPECIES_COUNT	NUMBER (3,0)	Count of the number of species at this station. More detailed.
CRUISE_ID	VARCHAR2 (6)	Cruise number
OPERATION_NO	NUMBER (4,0)	Sequential number allocated to each trawl/dredge/grab etc.
OPERATION_NAME	VARCHAR2 (35)	Description of the operation
START_DATE	VARCHAR2 (50)	Date of the operation
START_TIME	VARCHAR2 (50)	Start time of the operation
END_DATE	VARCHAR2 (50)	End date of the operation
END_TIME	VARCHAR2 (50)	End time of the operation
DATA_SET	NUMBER (3,0)	Box number. Used in BTl (Box-the-lot).
GEAR_NO	NUMBER (2,0)	A code which usually describes a cod-end cover
GEAR_CODE	NUMBER (3,0)	Code for the net type
GEAR_PART_NO	NUMBER (2,0)	Distinction within gear code (sub code)
GEAR_NAME	VARCHAR2 (40)	Text description of the fishing gear
SLAT	NUMBER (8,5)	Latitude (degrees) start of trawl/dredge
SLON	NUMBER (8,5)	Longitude (degrees) start of trawl/dredge
ELAT	NUMBER (8,5)	Latitude (degrees) end of trawl/dredge
ELON	NUMBER (8,5)	Longitude (degrees) end of trawl/dredge
DEPTH_M	NUMBER (6,2)	Depth during the operation (m)
SDEPTH	NUMBER (6,2)	Depth at the start of the operation (m)
EDEPTH	NUMBER (6,2)	Depth at the end of the operation (m)
SPEED	NUMBER (4,2)	Vessel speed during the operation (knots)
DUR_H	NUMBER (5,4)	Duration of the operation (min)
TRANSECT_NAME	VARCHAR2 (35)	Text description of the region
TIME_OF_DAY	VARCHAR2 (5)	Day or night
DISCARDED_CATCH_WT	NUMBER (7,3)	Weight of the 'monsters' that were weighed and discarded (kg)
SAMPLED_CATCH_WT	NUMBER (7,3)	Weight of the catch that was weighed and discarded i.e. not sorted at all (Does not include DISCARDED_CATCH_WT)
SUBSAMPLED_CATCH_WT	NUMBER (7,3)	Weight of the sub sampled catch that was sorted
TOTAL_CATCH_WT	NUMBER (7,3)	sum of (DISCARDED_CATCH_WT, SAMPLED_CATCH_WT, SUBSAMPLED_CATCH_WT)
FRACTION_SAMPLED	NUMBER (4,3)	Proportion of the catch that was sub sampled
SPECIES_COUNT	NUMBER (3,0)	The number of species seen the catch for that

		station (in the subsample)
FISH_COUNT	NUMBER (6,0)	The number of fish seen in the catch for that sample
INDIVIDUALS_CATCH_WT	NUMBER (7,3)	

VMS data

The VMS (Vessel Monitoring System) data, which was used in the Surrogates project originated from AFMA (Australian Fisheries Management Authority). It is stored at J:\WorkGroups\GoC Surrogates\Data\VMS\npf_vms.mdb

The work database used is located at J:\WorkGroups\GoC Surrogates\Data\VMS\VMSACC97.mdb. It contains the following programs, which were used to analyse and prepare the VMS data.

```
Function Add10Hrs()
'This function adds 10 hours to the time stored in sent_date_utc to make it local time

Dim db As Database
Dim rs As Recordset

Set db = CurrentDb()
Set rs = db.OpenRecordset("VMS01_NoDups", dbOpenDynaset)

rs.MoveFirst
Do Until rs.EOF
   rs.Edit
   rs!SentDatePlus10hrs = DateAdd("h", 10, rs!sent_date_utc)
   rs.Update
   rs.MoveNext
Loop

End Function

Function DetAvgPoll()
'This function determines the average poll rate.
Dim db As Database
Dim rs As Recordset
Dim rsp As Recordset
Dim vesselid As String
Dim curtime As Date
Dim xnight As Date
Dim pollnum As Integer 'Poll counted
Dim pollmin As Long 'Poll in minutes

Set db = CurrentDb()
Set rs = db.OpenRecordset("select vessel, long, lat, pdate from VMS01_NightTrawlers order by
vessel, pdate", dbOpenDynaset)
Set rsp = db.OpenRecordset("PollAvg", dbOpenDynaset)

DoCmd.RunSQL "delete from pollavg"
rs.MoveFirst

vesselid = rs!vessel
'Determine which night we are in (next day determines this)
If Format(rs!pdate, "h") >= 18 And Format(rs!pdate, "h") <= 23 Then
   xnight = DateAdd("d", 1, Format(rs!pdate, "dd/mm/yyyy"))
Else
```

```
    xnight = Format(rs!pdate, "dd/mm/yyyy")
End If
curtime = rs!pdate
pollnum = 0

Do Until rs.EOF
    If vesselid <> rs!vessel Then
        rsp.AddNew
        rsp!vessel = vesselid
        If pollmin <> 0 And pollnum <> 0 Then
            rsp!PollAvg = pollmin / pollnum
            rsp!pollamt = pollnum
        End If
        rsp.Update
        vesselid = rs!vessel
        If Format(rs!pdate, "h") >= 18 And Format(rs!pdate, "h") <= 23 Then
            xnight = DateAdd("d", 1, Format(rs!pdate, "dd/mm/yyyy"))
        Else
            xnight = Format(rs!pdate, "dd/mm/yyyy")
        End If
        curtime = rs!pdate
        pollnum = 0
        pollmin = 0
    Else
        If rs!pdate > DateAdd("h", -6, xnight) And rs!pdate < DateAdd("h", 8, xnight) Then
            'Still in this night
            If rs!pdate <> curtime Then
                pollnum = pollnum + 1
                pollmin = pollmin + (60 * (Format(rs!pdate - curtime, "h")) + Format(rs!pdate - curtime,
"n"))
                curtime = rs!pdate
            End If
        Else 'Now in new night
            If Format(rs!pdate, "h") >= 18 And Format(rs!pdate, "h") <= 23 Then
                xnight = DateAdd("d", 1, Format(rs!pdate, "dd/mm/yyyy"))
            Else
                xnight = Format(rs!pdate, "dd/mm/yyyy")
            End If
            curtime = rs!pdate
        End If
    End If

    rs.MoveNext

    If rs.EOF Then 'We are at the last record
        rsp.AddNew
        rsp!vessel = vesselid
        If pollmin <> 0 And pollnum <> 0 Then
            rsp!PollAvg = pollmin / pollnum
            rsp!pollamt = pollnum
        End If
        rsp.Update
    End If
```

```
Loop

End Function

Function DetOutliers()
'This function determines the outliers which are 50% or more outside the average poll frequency

Dim db As Database
Dim rs As Recordset
Dim rsp As Recordset
Dim rso As Recordset
Dim vesselid As String
Dim curtime As Date
Dim xnight As Date
Dim pollnum As Integer 'Poll counted
Dim pollmin As Long 'Poll in minutes
Dim xin50 As Integer
Dim xout50 As Integer
Dim stdin50 As Double

Set db = CurrentDb()
Set rs = db.OpenRecordset("select vessel, long, lat, pdate from VMS01_NightTrawlers order by
vessel, pdate", dbOpenDynaset)
Set rsp = db.OpenRecordset("PollAvg", dbOpenDynaset)
Set rso = db.OpenRecordset("PollAvgOutliers", dbOpenDynaset)

rso.MoveFirst
Do Until rso.EOF
   rso.Edit
   rso!InPM50 = Null
   rso!OutPM50 = Null
   rso.Update
   rso.MoveNext
Loop
rso.MoveFirst

rs.MoveFirst

vesselid = rs!vessel
rsp.FindFirst "vessel = " & vesselid
stdin50 = rsp!PollAvg

'Determine which night we are in (next day determines this)
If Format(rs!pdate, "h") >= 18 And Format(rs!pdate, "h") <= 23 Then
   xnight = DateAdd("d", 1, Format(rs!pdate, "dd/mm/yyyy"))
Else
   xnight = Format(rs!pdate, "dd/mm/yyyy")
End If
curtime = rs!pdate
pollnum = 0

Do Until rs.EOF
   If vesselid <> rs!vessel Then
```

```
        rso.FindFirst "vessel = " & vesselid
        rso.Edit
        rso!InPM50 = xin50
        rso!OutPM50 = xout50
        rso.Update
        xin50 = 0
        xout50 = 0

        vesselid = rs!vessel
        rsp.FindFirst "vessel = " & vesselid
        stdin50 = rsp!PollAvg
        If Format(rs!pdate, "h") >= 18 And Format(rs!pdate, "h") <= 23 Then
            xnight = DateAdd("d", 1, Format(rs!pdate, "dd/mm/yyyy"))
        Else
            xnight = Format(rs!pdate, "dd/mm/yyyy")
        End If
        curtime = rs!pdate
        pollnum = 0
        pollmin = 0
    Else
        If rs!pdate > DateAdd("h", -6, xnight) And rs!pdate < DateAdd("h", 8, xnight) Then
            'Still in this night
            If rs!pdate <> curtime Then
                pollnum = pollnum + 1
                pollmin = 60 * (Format(rs!pdate - curtime, "h")) + Format(rs!pdate - curtime, "n")

                If pollmin > 1.5 * stdin50 Or pollmin < 0.5 * stdin50 Then
                    xout50 = xout50 + 1
                Else
                    xin50 = xin50 + 1
                End If

                curtime = rs!pdate
            End If
        Else 'Now in new night
            If Format(rs!pdate, "h") >= 18 And Format(rs!pdate, "h") <= 23 Then
                xnight = DateAdd("d", 1, Format(rs!pdate, "dd/mm/yyyy"))
            Else
                xnight = Format(rs!pdate, "dd/mm/yyyy")
            End If
            curtime = rs!pdate
        End If
    End If

    rs.MoveNext

    If rs.EOF Then 'We are at the last record
        rso.FindFirst "vessel = " & vesselid
        rso.Edit
        rso!InPM50 = xin50
        rso!OutPM50 = xout50
        rso.Update
        xin50 = 0
```

```
      xout50 = 0
   End If
Loop

End Function

Function DetAvgPos()
'Determines the average position for each vessel in each night .The night that is reported is not the
date of the next day (00:00) but rather the day of the first record

Dim db As Database
Dim rs As Recordset
Dim rsp As Recordset
Dim vesselid As String
Dim curtime As Date
Dim xnight As Date
Dim firstdate As Date
Dim avglat As Double
Dim avglong As Double
Dim avgctr As Integer

Set db = CurrentDb()
Set rs = db.OpenRecordset("select vessel, long, lat, pdate from VMS01_NightTrawlers order by
vessel, pdate", dbOpenDynaset)
Set rsp = db.OpenRecordset("AvgPosPerVesselPerNight", dbOpenDynaset)

DoCmd.RunSQL "delete from AvgPosPerVesselPerNight"
rs.MoveFirst

vesselid = rs!vessel
firstdate = rs!pdate
'Determine which night we are in (next day determines this)
If Format(rs!pdate, "h") >= 18 And Format(rs!pdate, "h") <= 23 Then
   xnight = DateAdd("d", 1, Format(rs!pdate, "dd/mm/yyyy"))
Else
   xnight = Format(rs!pdate, "dd/mm/yyyy")
End If
curtime = rs!pdate

Do Until rs.EOF
   If vesselid <> rs!vessel Then
      rsp.AddNew
      rsp!vessel = vesselid
      rsp!Lat = -1 * avglat / avgctr
      rsp!long = avglong / avgctr
      rsp!pdate = firstdate
      rsp.Update
      avglat = 0
      avglong = 0
      avgctr = 0


      vesselid = rs!vessel
```

```
        If Format(rs!pdate, "h") >= 18 And Format(rs!pdate, "h") <= 23 Then
            xnight = DateAdd("d", 1, Format(rs!pdate, "dd/mm/yyyy"))
        Else
            xnight = Format(rs!pdate, "dd/mm/yyyy")
        End If
        curtime = rs!pdate
        firstdate = rs!pdate
        avglat = avglat - rs!Lat
        avglong = avglong + rs!long
        avgctr = avgctr + 1
    Else
        If rs!pdate > DateAdd("h", -6, xnight) And rs!pdate < DateAdd("h", 8, xnight) Then
            'Still in this night
            If rs!pdate <> curtime Then
                curtime = rs!pdate
            End If
            avglat = avglat - rs!Lat
            avglong = avglong + rs!long
            avgctr = avgctr + 1
        Else 'Now in new night
            rsp.AddNew
            rsp!vessel = vesselid
            rsp!Lat = -1 * avglat / avgctr
            rsp!long = avglong / avgctr
            rsp!pdate = firstdate
            rsp.Update
            avglat = 0
            avglong = 0
            avgctr = 0

            If Format(rs!pdate, "h") >= 18 And Format(rs!pdate, "h") <= 23 Then
                xnight = DateAdd("d", 1, Format(rs!pdate, "dd/mm/yyyy"))
            Else
                xnight = Format(rs!pdate, "dd/mm/yyyy")
            End If
            curtime = rs!pdate
            firstdate = rs!pdate
            avglat = avglat - rs!Lat
            avglong = avglong + rs!long
            avgctr = avgctr + 1
        End If
    End If

    rs.MoveNext

    If rs.EOF Then 'We are at the last record
        rsp.AddNew
        rsp!vessel = vesselid
        rsp!Lat = -1 * avglat / avgctr
        rsp!long = avglong / avgctr
        rsp!pdate = firstdate
        rsp.Update
        avglat = 0
```

```
        avglong = 0
        avgctr = 0
    End If
Loop

End Function

Function FindHFPoll()
'This function finds the polls, which are less than 40 minutes apart: HF polls.

Dim db As Database
Dim rs As Recordset
Dim curpol As Date

Set db = CurrentDb()
Set rs = db.OpenRecordset("select * from VMS01_NightTrawlersHF order by vessel, pdate",
dbOpenDynaset)

DoCmd.RunSQL "update VMS01_NightTrawlersHF set HFPoll = false"

rs.MoveFirst
curpol = rs!pdate
Do Until rs.EOF
    rs.MoveNext
    If DateDiff("s", curpol, rs!pdate) < 2400 Then '< 40 minutes ( = 2400 seconds)
        rs.Edit
        rs!HFPoll = True
        rs.Update
    End If
    curpol = rs!pdate
Loop

End Function

Function VesselLinesNight()
'This function writes the vessel night tracks for further processing in the GIS

Dim db As Database
Dim rs As Recordset
Dim curdate As Date
Dim cl As Long
Dim xfirst As Boolean
Dim xtxt As String
Dim xnight As Date
Dim vesselid As String
Dim writedate As Date

Set db = CurrentDb()
Set rs = db.OpenRecordset("select * from _N_07UnionNightTables order by vessel, local_time",
dbOpenDynaset)
cl = 1
xfirst = True
```

```
Open "C:\Documents and Settings\projects\Surrogates\VMS\VMSVL01N.txt" For Output As #1
Open "C:\Documents and Settings\projects\Surrogates\VMS\VMSLI01N.txt" For Output As #2
xtxt = "Line_ID, Vessel_ID, Date"
Print #2, xtxt
xtxt = cl
Print #1, xtxt

If Format(rs!local_time, "hh:mm") < #12:00:00 PM# Then
   xtxt = cl & "," & rs!vessel & "," & DateAdd("d", -1, Format(rs!local_time, "dd/mm/yyyy"))
Else
   xtxt = cl & "," & rs!vessel & "," & Format(rs!local_time, "dd/mm/yyyy")
End If
Print #2, xtxt

cl = cl + 1

rs.MoveFirst
'Determine which night we are in
If Format(rs!local_time, "h") >= 17 And Format(rs!local_time, "h") <= 23 Then
   xnight = DateAdd("d", 1, Format(rs!local_time, "dd/mm/yyyy"))
Else
   xnight = Format(rs!local_time, "dd/mm/yyyy")
End If
vesselid = rs!vessel

Do Until rs.EOF

   If rs!local_time < DateAdd("h", -7, xnight) Or rs!local_time > DateAdd("h", 8, xnight) _
     Or vesselid <> rs!vessel Then
      'New night
      xtxt = "END"
      Print #1, xtxt
      xtxt = cl
      Print #1, xtxt

      If Format(rs!local_time, "hh:mm") < #12:00:00 PM# Then
         xtxt = cl & "," & rs!vessel & "," & DateAdd("d", -1, Format(rs!local_time, "dd/mm/yyyy"))
      Else
         xtxt = cl & "," & rs!vessel & "," & Format(rs!local_time, "dd/mm/yyyy")
      End If

      Print #2, xtxt
      cl = cl + 1
      vesselid = rs!vessel
      xtxt = rs!long & "," & rs!Lat
      Print #1, xtxt
   Else
      xtxt = rs!long & "," & rs!Lat
      Print #1, xtxt
      vesselid = rs!vessel
   End If
   If Format(rs!local_time, "h") >= 17 And Format(rs!local_time, "h") <= 23 Then
      xnight = DateAdd("d", 1, Format(rs!local_time, "dd/mm/yyyy"))
```

```
    Else
        xnight = Format(rs!local_time, "dd/mm/yyyy")
    End If
    rs.MoveNext
Loop
xtxt = "END"
Print #1, xtxt
Print #1, xtxt

Close #1
Close #2

End Function

Function VesselLinesDay()
'This function writes the vessel night tracks for further processing in the GIS

Dim db As Database
Dim rs As Recordset
Dim curdate As Date
Dim cl As Long
Dim xfirst As Boolean
Dim xtxt As String
Dim xnight As Date
Dim vesselid As String
Dim writedate As Date

Set db = CurrentDb()
Set rs = db.OpenRecordset("select * from _N_08UnionAllDayTables order by vessel, local_time",
dbOpenDynaset)
cl = 1
xfirst = True

Open "C:\Documents and Settings\projects\Surrogates\VMS\VMSVL01D.txt" For Output As #1
Open "C:\Documents and Settings\projects\Surrogates\VMS\VMSLI01D.txt" For Output As #2
xtxt = "Line_ID, Vessel_ID, Date"
Print #2, xtxt
xtxt = cl
Print #1, xtxt

xtxt = cl & "," & rs!vessel & "," & Format(rs!local_time, "dd/mm/yyyy")
Print #2, xtxt

cl = cl + 1

rs.MoveFirst
'Determine which night we are in
xnight = Format(rs!local_time, "dd/mm/yyyy")
vesselid = rs!vessel

Do Until rs.EOF

    If Format(rs!local_time, "dd/mm/yyyy") <> Format(xnight, "dd/mm/yyyy") _
```

```
  Or vesselid <> rs!vessel Then
    'New night
    xtxt = "END"
    Print #1, xtxt
    xtxt = cl
    Print #1, xtxt
    xtxt = cl & "," & rs!vessel & "," & Format(rs!local_time, "dd/mm/yyyy")

    Print #2, xtxt
    cl = cl + 1
    vesselid = rs!vessel
    xtxt = rs!long & "," & rs!Lat
    Print #1, xtxt
  Else
    xtxt = rs!long & "," & rs!Lat
    Print #1, xtxt
    vesselid = rs!vessel
  End If
  xnight = Format(rs!local_time, "dd/mm/yyyy")
  rs.MoveNext
Loop
xtxt = "END"
Print #1, xtxt
Print #1, xtxt

Close #1
Close #2

End Function

Function N1_HF_Poll(xtype As String)
'This function identifies each record as to day/night and 30/50 min poll.

Dim db As Database
Dim rs As Recordset
Dim firsttime As Date
Dim vessel As String
Dim xfile As String
Dim xmin As Integer
Dim xmax As Integer

Select Case xtype
  Case "D30"
    xfile = "_N1_30minDay"
    xmin = 1800
    xmax = 2700
  Case "D50"
    xfile = "_N1_50minDay"
    xmin = 3000
    xmax = 3900
  Case "N30"
    xfile = "_N1_30minNight"
    xmin = 1800
```

```
    xmax = 2700
  Case "N50"
    xfile = "_N1_50minNight"
    xmin = 3000
    xmax = 3900
End Select

DoCmd.RunSQL "update " & xfile & " set inhf = false"
Set db = CurrentDb()
Set rs = db.OpenRecordset("select * from " & xfile & " order by vessel, local_time", dbOpenDynaset)

rs.MoveFirst
firsttime = rs!local_time
vessel = rs!vessel

Do Until rs.EOF
  rs.MoveNext
  If rs.EOF Then Exit Do
  If vessel = rs!vessel Then
    If DateDiff("s", firsttime, rs!local_time) >= xmin And _
      DateDiff("s", firsttime, rs!local_time) <= xmax Then
      rs.MovePrevious
      rs.Edit
      rs!inhf = True
      rs.Update
      rs.MoveNext
      rs.Edit
      rs!inhf = True
      rs.Update
    End If
  End If
  firsttime = rs!local_time
  vessel = rs!vessel
Loop

End Function

Function N1_HF_Poll_WriteResult(xtype As String)
'This function identifies each record as to day/night and 30/50 min poll and exports the records in a text file for further processing in GIS

Dim db As Database
Dim rs As Recordset
Dim ctr As Integer
Dim xtxt As String
Dim xout As String
Dim xfile As String

Select Case xtype
  Case "D30"
    xfile = "_N1_30minDay"
    xout = "30D"
  Case "D50"
```

```
        xfile = "_N1_50minDay"
        xout = "50D"
    Case "N30"
        xfile = "_N1_30minNight"
        xout = "30N"
    Case "N50"
        xfile = "_N1_50minNight"
        xout = "50N"
End Select

Set db = CurrentDb()
Set rs = db.OpenRecordset("select * from " & xfile & " where inhf = true order by vessel,local_time",
dbOpenDynaset)
ctr = 1

Open "C:\Documents and Settings\projects\Surrogates\VMS\VMSHF" & xout & ".txt" For Output As
#1
xtxt = "Point, Long, Lat, Vessel, Date"
Print #1, xtxt

rs.MoveFirst
Do Until rs.EOF
    xtxt = ctr & "," & rs!long & "," & rs!Lat & "," & rs!vessel & "," & Format(rs!pdate, "dd/mm/yyyy
hh:mm:ss")
    Print #1, xtxt
    rs.MoveNext
    ctr = ctr + 1
Loop

Close #1

End Function
```

Methods used to extract dredge data

SS9003

```
/* This program (s03_dredge.sas) extracts the dredge invert & fish data and
        calculates the total number of each species caught

        NB All dredges from SS9003 were of 15 min duration */

libname gulfish oracle user=gulfish password=****
   path=forty2;
libname d 'c:\documents\surrogates\data\';

*Get the dates that the stations were sampled;
data ss03_dates1;
        set gulfish.all_dredge_log;
        station1=input(station,4.0);
        where cruise='SS0390';
        if station1 < 109;
```

```
        keep station1 the_date;
run;

data ss03_dates2;
        set ss03_dates1;
        station=station1;
        drop station1;
        run;

proc sort data=ss03_dates2;
        by station; run;

data dlog;
        set gulfish.dredge_log;
        slat1=-1*(slat+(slatmin/60));
        slon1=slon+(slonmin/60);
        elat1=-1*(elat+(elatmin/60));
        elon1=elon+(elonmin/60);
        drop slat slon elat elon slatmin slatsec slonmin slonsec elatmin elatsec elonmin elonsec;
        if gear="CHURCH" then gear="DREDGE";
        *Replace missing start times- these are educated guesses derived from looking at times of
adjacent stations;
        if station=22 then starttime=18000;
        if station=81 then starttime=63750;
        if station=97 then starttime=10;
        run;

proc sort data=  dlog;
        by station;
 run;

data dredge_log;
        merge dlog ss03_dates2;
        by station;
        run;
data d.dredge_log;
        set dredge_log;
        sdate=the_date+starttime;
        format sdate datetime20.;
        drop starttime endtime the_date;
        run;
*******************************************************************************;
*Don't do this bit- use the species code table which has NEWCODE & SPECIES_CODE
        (d.sur_sp_code)so it can be used with the
        later cruises;
        /*
data d.spcode;
        set ora.ascspp_senior;  *-- ascspp_senior is gbr_basetables.ascspp_new where synon='S' --;
        drop common_name recorder origin name newname group_variable oldname oldcode;
        run;
*/
**
*******************************************************************************;
```

```
        data d.dinvert;
        set gulfish.dredge_catch;
        drop quality_control up_date name load_sequence group_variable;
                if name in('FIS', 'FISH', 'FISHDR', 'TELEOST;FISH', 'TRASH',
'RUBBLE','RUBBLE SHELL') then do;
                put "Generic fish/trash deleted from the dataset " cruise station spcode name;
                delete;
        end;
                *these records are just flagging that there were fish or trash in the dredge -
                        the species data for the fish is in the dredge_catch_fish table;
        if newcode='M2020170' then newcode='M2020169';
        run;
data d.dfish;
                length spcode $9;
        set gulfish.dredge_catch_fish;
        format spcode $9.;
        informat spcode $9.;

        drop  quality_control up_date name load_sequence group_variable name notes ;

run;


data d.dred_all;
        set d.dinvert d.dfish;
        where newcode not in('000003', 'DSHELL','RUBBLE', 'TRA');
        if newcode='' then newcode=spcode;
        drop spcode;
                if newcode='Z0000000' then do;
                put "Generic trash deleted from the dataset " cruise

        station

        newcode;
                delete;
        end;
        if nos=. then do;
                put "NULL in numbers column - replaced with 1  " station newcode;
                nos=1;
        end;
                if newcode='' then do;
                put "Newcode was null- record deleted from the dataset (nos, wt)" newcode nos wt;
                delete;
        end;


        run;
proc sort data = d.dred_all;
        by station;
        run;
proc sort data=d.dredge_log;
        by station;
        run;
```

```
data f2;
	merge d.dredge_log d.dred_all;
	by station;
	if station=999 then delete;

	if t_field='T' then
do;
		nosph=(nos/dur)*60;
		wtph=(wt/dur)*60;
end;
	else if t_field='S' then
do;
		nosph=((nos*cgf)/dur)*60;
		wtph=((wt*cgf)/dur)*60;
end;

	*drop nos wt;
run;
*Get the species names for the unsummarised catch data;

proc sort data=d.all_species_codes;
	by newcode;
	run;
proc sort data=f2;
	by newcode;
	run;

data tmpdcatch;

	merge  f2 d.all_species_codes;
		by newcode;
		run;

libname splus v6 'c:\documents\surrogates\data\splus\';
data splus.ss0390d1;
	length gear $15.;
	format gear $15.;
	set tmpdcatch;

	where station ne .;
	if species ne '';
	drop speed restsam cgf notes sample totcatch elat1 elon1 slat1 slon1 t_catch t_field;
	if gear ='DREDGE' then gear='Benthic Dredge';
	lat=slat1;
	lon=slon1;
***************************************************************************;
*convert the date and start time to char so that SPlus can import them;
	ndate=datepart(sdate);

	informat nday $2. nmth $2. nyr $4. d1 $1. d2$1. m1 $1. m2 $1.;
		nday=day(ndate);
		nmth=month(ndate);
```

```
                    nyr=year(ndate);
*pad out the days & months with leading zeros;
                    d1=substr(nday,1,1);
                    d2=substr(nday,2,1);
                    if d1=' ' then d1='0';
                    nnday=(trim(d1)||trim(d2));

                    m1=substr(nmth,1,1);
                    m2=substr(nmth,2,1);
                    if m1=' ' then m1='0';
                    nnmth=(trim(m1)||trim(m2));

                    cdate=(trim(nnday)||trim(nnmth)||trim(nyr));

  drop nday nnday nmth nnmth nyr d1 d2 m1 m2 sdate ndate;
*turn the times into char vars as well;

          stime=timepart(sdate);
          informat nhr $2. nmin $2. h1 h2 mi1 mi2 $1. ntime $5.;
          nhr=hour(stime);
          nmin=minute(stime);

          h1=substr(nhr,1,1);
          h2=substr(nhr,2,1);
          if h1=' ' then h1='0';
          nnhr=(trim(h1)||trim(h2));

          mi1=substr(nmin,1,1);
          mi2=substr(nmin,2,1);
          if mi1=' ' then mi1='0';
          nnmin=(trim(mi1)||trim(mi2));

          ntime=(trim(nnhr)||":"||trim(nnmin));
          drop nhr nmin h1 h2 mi1 mi2 nnhr nnmin stime ;
          depth_m=depth;
          opno=station;
          nfam=family_no;
          spcode=species_code;

          xdate=cdate;
          drop depth station family_no species_code cdate;

run;

/*
*********************************************************************************;
*Calculate the total numbers and weights of each species caught over the entire cruise;
proc sort data=tmpdcatch;
          by newcode;
          run;
proc means noprint data=tmpdcatch;
          by newcode;
          var nos wt;
```

```
        output out=sumsp sum=totn totwt;
run;

proc sort data=d.sur_sp_code;
        by newcode;
        run;
*Get the species names for the summary catches;
data f3;
        length scientific_name $35.;
        merge sumsp d.sur_sp_code;
                by newcode;
                drop _type_ _freq_;
                format scientific_name $35.;
                noccur=_freq_;
                run;

data d.dr_sp;
        set f3;
        *where nos >=10;
        if scientific_name ne '';
                where totwt ne .;
        run;

proc sort;
by descending noccur;
run;

proc print split="*";
var scientific_name species_code noccur totn totwt;
        format totn 6. totwt 6.2;
        title 'SS0390 - Dredge Catches (107 stations) sorted by number of occurrences';
        label noccur='Number of*Occurrences'
                totn='Total Numbers'
                totwt='Total Weight';
run;

*/
/*
data d.species;
        set d.dr_sp;
        count +1;
        run;
*/
```

SS9702, SS9708 and SS9803

Imported the catch data for the sustainability cruises from \\Anchovy\File Shares\GoC surrogates\data\GOC dredge.mdb (3 queries: QSS9702_SelectDredgeCatch, QSS9708_SelectDredgeCatch, QSS9803_SelectDredgeCatch) into SAS and concatenated them to create: \\Anchovy\File Shares\GoC surrogates\data\susd.sas7bdat

Name	Type	Length	Format	Informat
CATCH_COUNT	Num	8	7.	7.
CATCH_WEIGHT	Num	8	10.4	10.4
CRUISE_ID	Char	6	$6.	$6.
DEPTH_M	Num	8	8.2	8.2
FAMILY_NO	Num	8	3.	3.
FRACTION_SAMPLED	Num	8	6.3	6.3
GEAR_CODE	Num	8	4.	4.
GEAR_NO	Num	8	3.	3.
OPERATION_NAME	Char	35	$35.	$35.
OPERATION_NO	Num	8	5.	5.
SCIENTIFIC_NAME	Char	35	$35.	$35.
SLAT1	Num	8	9.5	9.5
SLON	Num	8	10.5	10.5
SPECIES_CODE	Num	8	9.	9.
START_DATE	Num	8	DATETIME20.	DATETIME20.
SUBSAMPLE_FLAG	Char	1	$1.	$1.

Sus_import.sas – concatenates all sustainability dredge catches and estimates catch rates for all species. It generates a file sus_dge1.ssd

These files have the extra taxonomic classifications attached.

\\Anchovy\File Shares\GoC surrogates\data\splus\concat_all_dredges.sas joins the data from all 4 cruises (SS9003, SS9702, SS9708 & SS9803) these two files together to form a new file with all dredges from all cruises.

Sediment data

Sediment data for the NPF was collated from all available cuisse in the area from the early 1980s through to the late 1990s. As some of the data were only available as % dry weights rather than sieve weights all the data were converted to % dry weight by the following SAS program and reloaded back into ORACLE as OPS$HAY180.NPF_SEDIMENT

```
****************************************************************************
EXTRACT_NPF_SEDIMENT_DATA.SAS  - This job extracts sediment data from a number
of different ORACLE users and tables and combines them into a single dataset
ready for further analysis;
```

```
libname gulf oracle user = 'gulfish' path= '@forty2' password =*****;

*Get the SS0390 sediment data;
data ss0390sed;
        set gulf.sediment;
        where cruise='SS03';
        run;
proc sort data=ss0390sed;
        by station;
        run;
/*
proc means noprint data=ss0390sed;
        by station;
        var cobble pebble granule vcsnd csnd msnd fsnd vfsnd pelite totwt;
        id cruise prov yymm sedcolor;
        output out=ss0390sed1 mean=;
        run;
*/
data ss0390log;
        set gulf.grab_log;
        keep station lat lon rep;
        lat = -1*(slat+(slatmin/60));
        lon = slon+(slonmin/60);
        run;
proc sort data=ss0390log;
        by station;
        run;
proc means noprint data=ss0390log;
        by station;
        var rep;
        id lat lon;
        output out=ss0390l mean=;
run;

data ss0390s;
        merge ss0390l ss0390sed; *ss0390sed1;
        by station;
                *fill in the missing lats & lons using dredge position as an approximation;
        if station=1 then do;
                lat=-10.0533;
                lon=137.1867;
        end;
        if station=2 then do;
                lat=-10.502;
                lon=137.2005;
        end;
        if station=4 then do;
                lat=-11.545;
                lon=137.23;
        end;
        if station=6 then do;
                lat=-12.5233;
```

```
                lon=137.2;
        end;
        if station=7 then do;
                lat=-12.9783;
                lon=137.1967;
        end;
        if station=8 then do;
                lat=-12.955;
                lon=137.1967;
        end;
        if station=9 then do;
                lat=-13.495;
                lon=136.7;
        end;
        if station=10 then do;
                lat=-13.5617;
                lon=137.2067;
        end;
        if station=14 then do;
                lat=-14.4967;
                lon=136.3167;
        end;
        drop _type_ _freq_ rep count;

*Calculate the percentage composition of each fraction;
        array sed{9} cobble -- pelite;
                do count = 1 to 9;
                        sed{count}=(sed{count}/totwt)*100;
                end;
        stn=station;
        drop station;
        sand=sum(of vcsnd csnd msnd fsnd vfsnd);
        run;

*********************************************************;
        *Get the SS0591 sediment data;
data ss0591sed;
        set gulf.sediment;
        where cruise='ss05';
        if cruise='ss05' then cruise='SS0591';
                array sed1{10}cobble pebble granule vcsnd csnd msnd fsnd vfsnd pelite totwt;
                        do count = 1 to 10;
                        if sed1{count}=-9 then sed1{count}=0;
                        if sed1{count}<0 then sed1{count}=abs(sed1{count});
                end;

        run;
proc sort data=ss0591sed;
        by station;
        run;
/*
proc means noprint data=ss0591sed; *get the average of the replicates at each site;
        by station;
```

```
          var cobble pebble granule vcsnd csnd msnd fsnd vfsnd pelite totwt;
          id cruise prov yymm sedcolor;
          output out=ss0591sed1 mean=;
          run;
          */
data ss0591log;
          set gulf.ss05_catch;
          keep cruise station lat lon;
          lon=longt;
          lat=-1*latt;
          run;
proc sort data=ss0591log;
          by station;
          run;
proc means noprint data=ss0591log;
          by station;
          var lat lon;
          id cruise;
          output out=ss0591l max=;
          run;
data ss0591s1;
          merge ss0591l ss0591sed; *ss0591sed1;
          by cruise station;
          drop _freq_ _type_;

*Calculate the percentage composition of each fraction;
          array sed{9}cobble pebble granule vcsnd csnd msnd fsnd vfsnd pelite;
                    do count = 1 to 9;
                              sed{count}=(sed{count}/totwt)*100;
                    end;
run;
data ss0591s;
          set ss0591s1;
          where (cobble ne .);
          if lat ne .;
          drop yymm prov count station;
                    stn=station;
          sand=sum(of vcsnd csnd msnd fsnd vfsnd);

          run;


***************************************************************************;
*Extract the data from Brian Long's sediment tables;
libname dong oracle user = 'ops$lon084' password = ***** path='@forty2';
data longsed;
          set dong.sediment_grain_size;
          where prov in('WGC', 'GTE', 'EGC', 'JBG');

          *remove negative values except for those that flag missing data;
          array chk{10}cobble pebble granule vcsnd csnd msnd fsnd vfsnd pelite wetweight;
                              do count = 1 to 10;
                              if chk{count} <0 then chk{count}=0;
```

```
                    end;

        if (wetweight=0) or (cruise='WC08') then do;
                wetweight=sum(of cobble pebble granule vcsnd csnd msnd fsnd vfsnd pelite);
        end;

        *Calculate the percentage composition of each fraction;
        if wetweight >0 then do;
                array sed{9}cobble pebble granule vcsnd csnd msnd fsnd vfsnd pelite;
                    do count = 1 to 9;
                        sed{count}=(sed{count}/wetweight)*100;
                    end;
        end;

        if wetweight=0 then do;
                put "record deleted - no sediment data "  cruise loc site yymm wetweight;
        end;
        run;
proc sort data=longsed;
        by cruise prov reg loc site;
        run;
data longlog;
        set dong.seagrass_environmental_data;
        keep cruise prov reg loc site yymm lat lon;
        where prov in ('WGC', 'GTE', 'EGC', 'JBG');
        lat=-1*(latdeg+(latmin/60));
        lon=longdeg+(longmin/60);
        run;
proc sort data=longlog;
        by cruise prov reg loc site;
        run;
data longs1;
        merge longlog longsed;
        by cruise prov reg loc site;
        run;
data longs;
        set longs1;
        format site 12.;
        informat site 12.;
        where (lat ne .)and (cobble ne .);
        drop wetorganic dryorganic count site;
        if cruise='MX28' and loc='0039' and yymm='07MAR1985:00:00:00'dt then delete;
        stn=input(site,8.0);
        sand=sum(of vcsnd csnd msnd fsnd vfsnd);
        run;


************************************************************;

        *Get Ilona's sustainability sediment data;
libname ss9803 oracle user = 'ss9803' password = ***** path= '@forty2';
data sussed1;
        set ss9803.grab_sediment;
```

```
        pebble=pebble_4000um_seive;
        granule=granule_2000um_seive;
        vcsnd=vcsnd_1000um_seive;
        csnd=csnd_500um_seive;
        msnd=msnd_250um_seive;
        fsnd=fsnd_125um_seive;
        vfsnd=vfsnd_63um_seive;
        pelite=pelite_less_63um;
        cruise=cruise_id;
        stn=operation_no;

        wetweight=sum(of pebble granule vcsnd csnd msnd fsnd vfsnd pelite);
        *Calculate the percentage composition of each fraction;
        if wetweight >0 then do;
                array sed{8}pebble granule vcsnd csnd msnd fsnd vfsnd pelite;
                        do count = 1 to 8;
                                sed{count}=(sed{count}/wetweight)*100;
                        end;
        end;
        keep cruise stn pebble granule vcsnd csnd msnd fsnd vfsnd pelite;

        run;

proc sort data=sussed1;
        by cruise stn;
        run;

data suslog;
        set ss9803.operation_log;
        keep cruise stn lat lon;
        lat=operation_start_lat;
        lon=operation_start_lon;
        stn=operation_no;
        cruise=cruise_id;
        run;
proc sort data=suslog;
        by cruise stn;
        run;

data sussed2;
        merge suslog sussed1;
        by cruise stn;
        run;
data ss9803s;
        set sussed2;
        where pebble ne .;
        sand=sum(of vcsnd csnd msnd fsnd vfsnd);
        run;
*************************************************************;
        *Get the Somers' sediment data - NB it is all stored as %s in ORACLE;
libname somers oracle user='ops$som028' password=***** path='@forty2';
        data som1;
                set somers.sediments;
```

```
                    yymm=sdate;
                    stn=input(site, 8.0);
                    lat=-1*latitude;
                    lon=longitude;
                    cruise=source;
                    pelite=mud;
                    vcsnd=vcsand;
                    csnd=csand;
                    msnd=msand;
                    fsnd=fsand;
                    vfsnd=vfsand;
                    keep cruise yymm stn lat lon pebble granule sand pelite
                              vcsnd csnd msnd fsnd vfsnd;
run;
proc sort data=som1;
by stn;
run;
*Concatentate all the files into a single file;
data npfsedx;
          length cruise $20.;
          set ss0390s ss0591s longs ss9803s som1;
          where (cruise ne '');
          *if (cruise ne 'SS0591') and (stn ne 50);
          *gets rid of a couple of records having crappy data;
          drop pelite;

          mud=pelite;
          run;
data npf_sediment;
retain cruise reg prov loc yymm stn lat lon sedcol rep cobble pebble granule vcsnd
          csnd msnd fsnd vfsnd sand mud totwt;
          set npfsedx;
                    if totwt=. then totwt=wetweight;
          *where cobble ne .;
          drop wetweight replicate sedcolor;
          rep=replicate;
          sedcol=sedcolor;

                    format cobble pebble granule vcsnd
          csnd msnd fsnd vfsnd sand mud 5.2  lat lon 7.4 yymm datetime16.;
          informat yymm datetime16.;


run;
proc sort;
by yymm;
run;
proc contents data=npfsed;
run;

*Load the derived sediment data into ORACLE;
proc dbload dbms=oracle data=npf_sediment;
          user='ops$hay180'; password=*****;
```

```
                path="@forty2";
                table=npf_sediment;
                type cruise 'varchar2(6)'
                        reg 'varchar2(4)'
                        prov 'varchar2(4)'
                        loc 'varchar2(4)'
                        yymm 'date'
                        stn 'number(5,1)'
                        lat 'number(8,4)'
                        lon 'number(9,4)'
                        sedcol 'varchar2(20)'
                        rep 'number(3,0)'
                        cobble 'number(7,2)'
                        pebble 'number(7,2)'
                        granule 'number(7,2)'
                        vcsnd 'number(7,2)'
                        csnd 'number(7,2)'
                        msnd 'number(7,2)'
                        fsnd 'number(7,2)'
                        vfsnd 'number(7,2)'
                        mud 'number(7,2)'
                        sand 'number(7,2)'
                        totwt 'number(9,2)'
                        site 'varchar2(6)';
        list;
        load;
        run;


/*
*Export the data to Excel;

PROC EXPORT DATA= WORK.NPFSED
        OUTFILE= "C:\Documents\Surrogates\Data\NPF_sediments.xls"
        DBMS=EXCEL2000 REPLACE;
RUN;
*/
```

CARS Metadata

CARS SEASONAL CLIMATOLOGY DATA (BENTHIC)
==

ORIGINAL SOURCE FILE : CARS2_bot.asc
FILENAME : CARS2_bot.asc.txt
FORMAT : CSV
RESOLUTION : Point Data

NOTES RQ = maximum radius of data source region for each mapping,
large values indicating sparse data and consequent higher smoothing,
at that location and depth.

LONGITUDE	Longitude (deg)
LATITUDE	Latitude (deg)
T_MEAN	Mean Bottom Temperature (deg C)
T_SD	Locally Weighted Standard Deviation Bottom Temperature (deg C)
T_RQ	Maximum Radius of Temperature Data Source Region at Bottom
S_MEAN	Mean Bottom Salinity (psu)
S_SD	Locally Weighted Standard Deviation Bottom Salinity (psu)
S_RQ	Maximum Radius of Salinity Data Source Region at Bottom
O2_MEAN	Mean Bottom Oxygen (ml/l)
O2_SD	Locally Weighted Standard Deviation Bottom Oxygen (ml/l)
O2_RQ	Maximum Radius of Oxygen Data Source Region at Bottom
SI_MEAN	Mean Bottom Silicate (uM)
SI_SD	Locally Weighted Standard Deviation Bottom Silicate (deg C)
SI_RQ	Maximum Radius of Silicate Data Source Region at Bottom
PO4_MEAN	Mean Bottom Phosphate (uM)
PO4_SD	Locally Weighted Standard Deviation Bottom Phosphate (uM)
PO4_RQ	Maximum Radius of Phosphate Data Source Region at Bottom
NO3_MEAN	Mean Bottom Nitrate (uM)
NO3_SD	Locally Weighted Standard Deviation Bottom Nitrate (uM)
NO3_RQ	Maximum Radius of Nitrate Data Source Region at Bottom

read_cars.sas

```
filename outsp 'i:\anthias\hay180\mpa\cars\cars_sp.txt';
filename outatt 'i:\anthias\hay180\mpa\cars\cars_att.txt';
data cars;
        retain counter 0;
        infile 'c:\documents\eudora\attach\cars2_bot.asc' delimiter=' ';
        input lon lat t_mean t_sd t_rq s_mean s_sd s_rq o2_mean o2_sd o2_rq
        si_mean si_sd si_rq po4_mean po4_sd po4_rq no3_mean no3_sd no3_rq;
        counter +1;
        run;
/*
data ora.cars_npf;
        set cars;
        run;
        */
data cars_sp;
        set cars;
        file outsp;
        put counter 6. ", " lon 8.4 ", " lat 8.4;
        run;

data cars_att;
        set cars;
        file outatt;
        put counter 6. ", " t_mean 5.2 ", " t_sd 4.2 ", " t_rq 5. ", "
                                        s_mean 6.3 ", " s_sd 5.3 ", "  s_rq 5. ", "
                                        o2_mean 4.2 ", " o2_sd 4.2 ", " o2_rq 5. ", "
                                        si_mean 6.2 ", " si_sd 5.2 ", " si_rq 5. ", "
                                        po4_mean 4.2 ", " po4_sd 4.2 ", " po4_rq 5. ", "
                                        no3_mean 5.2 ", " no3_sd 4.2 ", " no3_rq 5. ;
                                run;
```

Current Stress Metadata

GoC_Current_Stress_MetaData.txt

LOW RES GoC WIDE CURRENT STRESS
================================

ORIGINAL SOURCE FILE : NPF_stress_stats.txt
FILENAME : NPF_Stress.dbf
FORMAT : dBASE File
RESOLUTION : Point Data

LON	Longitude (deg)
LAT	Latitude (deg)
MEAN	Mean Current Stress
MEDIAN	Median Current Stress
MAXIMUM	Maximum Current Stress
STD_DEV	Standard Deviation Current Stress

HIGH RES MILNER CURRENT STRESS
===============================

ORIGINAL SOURCE FILE : stress.zip
FILENAME : milner_stress_1.txt
FORMAT : CSV
RESOLUTION : Point Data

LON	Longitude (deg)
LAT	Latitude (deg)
MEAN	Mean Current Stress
MEDIAN	Median Current Stress
MAXIMUM	Maximum Current Stress
STD_DEV	Standard Deviation Current Stress

HIGH RES MORNINGTON CURRENT STRESS
===================================

ORIGINAL SOURCE FILE : stress.zip
FILENAME : mornington_stress_1.txt
FORMAT : CSV
RESOLUTION : Point Data

LON	Longitude (deg)
LAT	Latitude (deg)
MEAN	Mean Current Stress
MEDIAN	Median Current Stress
MAXIMUM	Maximum Current Stress
STD_DEV	Standard Deviation Current Stress

HIGH RES VANDERLINS CURRENT STRESS
===============================

ORIGINAL SOURCE FILE : stress.zip
FILENAME : vanderlins_stress_1.txt
FORMAT : CSV
RESOLUTION : Point Data

LON	Longitude (deg)
LAT	Latitude (deg)
MEAN	Mean Current Stress
MEDIAN	Median Current Stress
MAXIMUM	Maximum Current Stress
STD_DEV	Standard Deviation Current Stress

read_stress.sas

```
filename outsp 'i:\anthias\hay180\mpa\cars\stress_sp.txt';
filename outatt 'i:\anthias\hay180\mpa\cars\stress_att.txt';
data stress1;
        retain counter 0;
        infile 'c:\documents\surrogates\data\npf_stress_stats.txt' delimiter=' ' firstobs=9;
        input day lon lat str_mn str_med str_max str_sdev;
        counter +1;
        run;
/*
data ora.cars_npf;
        set cars;
        run;
        */
data stress_sp;
        set stress1;
        file outsp;
        put counter 8. ", " lon 8.4 ", " lat 8.4;
        run;

data str_att;
        set stress1;
        file outatt;
        put counter 6. ", " str_mn 9.5 ", " str_med 9.5  ", " str_max 9.5 ", " str_sdev 9.5;
        run;
```

Seawifs metadata

Chlorophyll-a concentration is in units of mg/m^3 (mean and standard deviation).

K490 is the diffuse attenuation coefficient at wavelength 490nm, in units of m-1 (mean and standard deviation). {ie Light decays with an e-folding depth of 1/K490. Calculated from Seawifs estimated water-leaving radiances at 443 and 550 nm, using an empirical regression, based almost all on Northern Hemisphere oceanic measurements. Reference Seawifs Technical report Vol 41, chapter 2, (1997)Case Studies for SeaWiFS Calibration and Validation, part 4.}

The sample and segment are indicators of how much data went into the mean calculation, but since we are looking at a three year averages, it is safe to assume that there is adequate data at every grid point and these columns can be ignored.

SeaWiFS may not be calibrated particularly well for the NPF, but this shouldn't be a major problem for use as surrogates.

Wave height metadata

Data for wave height is in the Surrogates area. The following is an excerpt of an email from Scott Condie about this data:

Attached are statistics from the surface wave modelling I have done for the NPF (mean, median, maximum (average of upper 10%) and standard deviation in wave height). While the main determinant of the wave field is the winds, the waves also include the influence of depth and sheltering (ie fetch dependence). They are also that part of the wind influence most likely to directly impact benthic habitat (through the high frequency sloshing back and forth generated by the passing waves crests).

SPlus jobs

Bill Venables has worked with a modified data file named dredges.modified.WNV.xls. The file is located in the Surrogates area.

AncillaryFunctions.ssc

```
# Ancillary functions and the depths data set used in building data sets.
# addDepths assumes that the S-PLUS spatial module is attached for functions
#                   quad.tree and find.neighbor
# addDepths also assumes that the data frame to which depths are being added
# contains two columns labelled [sic] "Longitude" and "Latitude" specifying the
# location of each station

"rsum"<- function(X)
as.vector(as.matrix(X) %*% rep(1, ncol(X)))
"csum"<- function(X)
as.vector(rep(1, nrow(X)) %*% as.matrix(X))

## buildTable constructs a Stations x Species matrix allowing for repeats
## of the same species within some stations (as often occurs)  The input
## is a data frame with columns "Row" identifying the Station, "Col"
## identifying the species and "Var" giving the result (Wt or No).

"buildTable"<-
function(dataFrame, Row, Col, Var, trace = F)
{
        Row <- deparse(substitute(Row))
        Col <- deparse(substitute(Col))
        Var <- deparse(substitute(Var))
        dataFrame <- dataFrame[, c(Row, Col, Var)]
        dataFrame[[Row]] <- as.factor(dataFrame[[Row]])
        dataFrame[[Col]] <- as.factor(dataFrame[[Col]])
```

```
        M <- table(dataFrame[[Row]], dataFrame[[Col]])
        M[] <- 0
        if(trace) cat(nrow(dataFrame), "\n")
        if(any(d <- is.na(dataFrame[[Var]]))) dataFrame <- dataFrame[!d, ]
        repeat {
                if(trace) cat(nrow(dataFrame), "\n")
                RowCol <- paste(as.character(dataFrame[[Row]]),
                                        as.character(dataFrame[[Col]]))
                d <- duplicated(RowCol)
                if(any(d)) {
                        dataFrame1 <- dataFrame[d,  ]
                        dataFrame <- dataFrame[!d, ]
                        stopFlag <- F
                } else stopFlag <- T
                m <- cbind(match(as.character(dataFrame[[Row]]), dimnames(M)[[1]]),
                                        match(as.character(dataFrame[[Col]]), dimnames(M)[[2]]))
                M[m] <- M[m] + dataFrame[[Var]]
                if(stopFlag) break else dataFrame <- dataFrame1
        }
        M[is.na(M)] <- 0
        data.frame(M)
}

"addDepths"<- function(data) {
        k <- match("Depth", names(data))
        if(!is.na(k))
                names(data)[k] <- "OriginalDepth"
        ind <- find.neighbor(cbind(data$Latitude, data$Longitude), quad.tree(
                cbind(depths$Lati, depths$Long)))
        data$Depth <- depths$Depth[ind[, 2]]
        data$Depthdist <- ind[, 3]
        data
}
"depths"<-
structure(.Data = list(Latitude = c( ...data follows
```

BuildBycatchDataFrames.ssc

```
# Construct data frames for Stations x Weights and Stations x predictors for the bycatch
# (prawn trawl) studies.  Uses local copies of surrogates study files.

# All* indicates "all available stations"
# Some* indicates "only stations in the GOC are included".  Stations outside the GOC are
# excluded usually because the predictor variables are not all available.

# Also assumes the S-PLUS spatial module is attached (for functions quad.tree and find.neighbor)

import.data(FileName = "D:\\Kuranda\\Surrogates\\Data\\Invertebrates\\invert_catches_wv.xls",
        FileType = "Excel",
        ColNames = "",
        Format = "",
        TargetStartCol = "1",
```

```
        DataFrame = "invert.catches.wv",
        NameRow = "",
        StartCol = "1",
        EndCol = "END",
        StartRow = "1",
        EndRow = "END",
        Delimiters = ", \\t",
        SeparateDelimiters = F,
        PageNumber = "1",
        RowNameCol = "",
        StringsAsFactors = "Auto",
        VLabelAsNumber = F,
        DatesAsDoubles = F,
        Filter = "",
        OdbcConnection = "",
        OdbcSqlQuery = "")

bycatch.WNV <- invert.catches.wv

bycatch.WNV$Case <- paste("SS", substring(bycatch.WNV$newopno, 1, 4), ".",
substring(bycatch.WNV$newopno, 5, 7), sep="")

ca <- sort(unique(bycatch.WNV$Case))
sp <- sort(unique(as.character(bycatch.WNV$taxon1a)))

m <- cbind(match(bycatch.WNV$Case, ca), match(bycatch.WNV$taxon1a, sp))

AllBycatchWT <- matrix(0, length(ca), length(sp), dimnames = list(ca, sp))
AllBycatchWT[m] <- bycatch.WNV$weighthr
AllBycatchWT <- data.frame(AllBycatchWT)

AllBycatchWT$Rock <- AllBycatchWT$Trash <- NULL

import.data(FileName = "D:\\Kuranda\\Surrogates\\Data\\Invertebrates\\All Prawn Trawls WNV.xls",
        FileType = "Excel",
        ColNames = "",
        Format = "",
        TargetStartCol = "1",
        DataFrame = "All.Prawn.Trawls.WNV",
        NameRow = "",
        StartCol = "1",
        EndCol = "END",
        StartRow = "1",
        EndRow = "END",
        Delimiters = ", \\t",
        SeparateDelimiters = F,
        PageNumber = "1",
        RowNameCol = "",
        StringsAsFactors = "Auto",
        VLabelAsNumber = F,
        DatesAsDoubles = F,
        Filter = "",
        OdbcConnection = "",
```

```
        OdbcSqlQuery = "")

AllBycatchX <- All.Prawn.Trawls.WNV[, c(1,4,5)]

st <- substring(AllBycatchX$newopno, 5, 7)
cr <- substring(AllBycatchX$newopno, 1, 4)
AllBycatchX$Station <- paste("SS", cr, ".", st, sep = "")
AllBycatchX$Cruise <- factor(paste("SS", cr, sep=""))

X <- cbind(AllBycatchX$Longitude, AllBycatchX$Latitude)

Qx <- quad.tree(cbind(CARS$Long, CARS$Lati))
ind <- find.neighbor(X, Qx)
AllBycatchCARS <- cbind(CARS[ind[,2], 3:14], CARSdist = ind[,3])

Qx <- quad.tree(cbind(WaveHt$Long, WaveHt$Lati))
ind <- find.neighbor(X, Qx)
AllBycatchWaveHt <- cbind(WaveHt[ind[,2], -(1:2)], WaveHtdist = ind[,3])

Qx <- quad.tree(cbind(SeaWiFS$Long, SeaWiFS$Lat))
ind <- find.neighbor(X, Qx)
AllBycatchSeaWiFS <- cbind(SeaWiFS[ind[,2], 3:6], SeaWiFSdist = ind[,3])

Qx <- quad.tree(cbind(AllStress$LON, AllStress$LAT))
ind <- find.neighbor(X, Qx)
AllBycatchStress <- cbind(AllStress[ind[,2], 3:6], Stressdist = ind[,3])

Qx <- quad.tree(cbind(GOCSediments$Long, GOCSediments$Lati))
ind <- find.neighbor(X, Qx)
AllBycatchSediments <- cbind(GOCSediments[ind[,2], 4:9], Sedimentsdist = ind[,3])

names(AllBycatchWaveHt)[1:4] <- c("WaveHeight", "WaveHeight.Median", "WaveHeight.Max",
"WaveHeight.SD")

names(AllBycatchSeaWiFS)[c(2,4)] <- c("Chlorophyll.SD", "K.490.SD")
names(AllBycatchStress)[1:4] <- c("Stress", "Stress.Median", "Stress.Max", "Stress.SD")


AllBycatchX <- cbind(AllBycatchX, AllBycatchSediments, AllBycatchCARS, AllBycatchSeaWiFS,
AllBycatchWaveHt, AllBycatchStress)

AllBycatchX <- addDepths(AllBycatchX)

row.names(AllBycatchX) <- as.character(AllBycatchX$Station)

keep <- intersect(row.names(AllBycatchX), row.names(AllBycatchWT))

SomeBycatchX <- AllBycatchX[keep, ]
SomeBycatchWT <- AllBycatchWT[keep, ]
SomeBycatchX$TotalBiomass <- rsum(SomeBycatchWT)
SomeBycatchX$NoSpecies <- rsum(Bmatrix(SomeBycatchWT))

keep <- SomeBycatchX$Longitude > 135 & SomeBycatchX$Longitude < 142.5
```

```
SomeBycatchX <- SomeBycatchX[keep, ]
SomeBycatchWT  <- SomeBycatchWT[keep, ]
```

BuildDredgeDataFrames.ssc

```
# Script to build Stations x Weights and Stations x Predictors data frames
# for dredge data.  Naming conventions for "All*" and "Some*" are the same as
# for Prawn Trawl (bycatch) data sets.  Spatial module is assumed to be attached
# also.

import.data(FileName = "D:\\Kuranda\\Surrogates\\Data\\Dredge\\dredges.modified.WNV.xls",
        FileType = "Excel",
        ColNames = "",
        Format = "",
        TargetStartCol = "1",
        DataFrame = "dredges.WNV",
        NameRow = "",
        StartCol = "1",
        EndCol = "END",
        StartRow = "1",
        EndRow = "END",
        Delimiters = ", \\t",
        SeparateDelimiters = F,
        PageNumber = "1",
        RowNameCol = "",
        StringsAsFactors = "Auto",
        VLabelAsNumber = F,
        DatesAsDoubles = F,
        Filter = "",
        OdbcConnection = "",
        OdbcSqlQuery = "")

dredges.WNV$COMMENTS <- NULL
dredges.WNV$Taxon1 <- factor(dredges.WNV$Taxon1)
dredges.WNV$Case <- paste(substring(dredges.WNV$Site, 1, 6),
substring(1000+dredges.WNV$Station, 2), sep=".")


AllDredgesWT <- buildTable(dredges.WNV, Case, Spcode, WtPH)
AllDredgesNO <- buildTable(dredges.WNV, Case, Spcode, NosPH)

AllDredgesX <- data.frame(Longitude = tapply(dredges.WNV$Long, dredges.WNV$Case, "[", 1),
Latitude = tapply(dredges.WNV$Lati, dredges.WNV$Case, "[", 1))
AllDredgesX$Cruise <- factor(substring(row.names(AllDredgesX), 1, 6))

X <- cbind(AllDredgesX$Long, AllDredgesX$Lati)

Qx <- quad.tree(cbind(CARS$Long, CARS$Lati))
ind <- find.neighbor(X, Qx)
AllDredgesCARS <- cbind(CARS[ind[,2], 3:14], CARSdist = ind[,3])

Qx <- quad.tree(cbind(WaveHt$Long, WaveHt$Lati))
```

```
ind <- find.neighbor(X, Qx)
AllDredgesWaveHt <- cbind(WaveHt[ind[,2], -(1:2)], WaveHtdist = ind[,3])

Qx <- quad.tree(cbind(SeaWiFS$Long, SeaWiFS$Lat))
ind <- find.neighbor(X, Qx)
AllDredgesSeaWiFS <- cbind(SeaWiFS[ind[,2], 3:6], SeaWiFSdist = ind[,3])

Qx <- quad.tree(cbind(AllStress$LON, AllStress$LAT))
ind <- find.neighbor(X, Qx)
AllDredgesStress <- cbind(AllStress[ind[,2], 3:6], Stressdist = ind[,3])

Qx <- quad.tree(cbind(GOCSediments$Long, GOCSediments$Lati))
ind <- find.neighbor(X, Qx)
AllDredgesSediments <- cbind(GOCSediments[ind[,2], 4:9], Sedimentsdist = ind[,3])

names(AllDredgesWaveHt)[1:4] <- c("WaveHeight", "WaveHeight.Median", "WaveHeight.Max",
"WaveHeight.SD")

names(AllDredgesSeaWiFS)[c(2,4)] <- c("Chlorophyll.SD", "K.490.SD")
names(AllDredgesStress)[1:4] <- c("Stress", "Stress.Median", "Stress.Max", "Stress.SD")


AllDredgesX <- cbind(AllDredgesX, AllDredgesSediments, AllDredgesCARS,  AllDredgesSeaWiFS,
AllDredgesWaveHt,AllDredgesStress)

AllDredgesX <- addDepths(AllDredgesX)

AllDredgesX$TotalBiomass <- rsum(AllDredgesWT)
AllDredgesX$NoSpecies <- rsum(Bmatrix(AllDredgesWT))


keep <- AllDredgesX$Long > 135 & AllDredgesX$Long < 142
SomeDredgesX <- AllDredgesX[keep, ]
SomeDredgesWT <- AllDredgesWT[keep, ]
SomeDredgesNO <- AllDredgesNO[keep, ]
```

BuildFishTrawlDataFrames.ssc

```
# Script to build Stations x Species and Stations x Predictors data frames
# for Fish Trawl data.  Same assumptions and protocols for Prawn Trawl and
# Dredge data generating scripts.


import.data(FileName = "D:\\Kuranda\\Surrogates\\Data\\Fish\\fishdata1.xls",
	FileType = "Excel",
	ColNames = "",
	Format = "",
	TargetStartCol = "1",
	DataFrame = "fishdata1",
	NameRow = "",
	StartCol = "1",
	EndCol = "END",
```

```
        StartRow = "1",
        EndRow = "END",
        Delimiters = ", \\t",
        SeparateDelimiters = F,
        PageNumber = "1",
        RowNameCol = "",
        StringsAsFactors = "Auto",
        VLabelAsNumber = F,
        DatesAsDoubles = F,
        Filter = "",
        OdbcConnection = "",
        OdbcSqlQuery = "")

guiClose("data.frame", "fishdata1")

fishdata1$Case <- paste(as.character(fishdata1$Cruise), substring(1000+fishdata1$Station, 2),
sep=".")

AllFishTrawlsWT <- buildTable(fishdata1, Case, Spcode, WtPH)
AllFishTrawlsNO <- buildTable(fishdata1, Case, Spcode, NosPH)

AllFishTrawlsX <- data.frame(Longitude = tapply(fishdata1$Long, fishdata1$Case, "[", 1), Latitude =
tapply(fishdata1$Lati, fishdata1$Case, "[", 1))

AllFishTrawlsX$Cruise <- factor(substring(row.names(AllFishTrawlsX), 1, 6))

X <- cbind(AllFishTrawlsX$Long, AllFishTrawlsX$Lati)

Qx <- quad.tree(cbind(CARS$Long, CARS$Lati))
ind <- find.neighbor(X, Qx)
AllFishTrawlsCARS <- cbind(CARS[ind[,2], 3:14], CARSdist = ind[,3])

Qx <- quad.tree(cbind(WaveHt$Long, WaveHt$Lati))
ind <- find.neighbor(X, Qx)
AllFishTrawlsWaveHt <- cbind(WaveHt[ind[,2], -(1:2)], WaveHtdist = ind[,3])

Qx <- quad.tree(cbind(SeaWiFS$Long, SeaWiFS$Lat))
ind <- find.neighbor(X, Qx)
AllFishTrawlsSeaWiFS <- cbind(SeaWiFS[ind[,2], 3:6], SeaWiFSdist = ind[,3])

Qx <- quad.tree(cbind(AllStress$LON, AllStress$LAT))
ind <- find.neighbor(X, Qx)
AllFishTrawlsStress <- cbind(AllStress[ind[,2], 3:6], Stressdist = ind[,3])

Qx <- quad.tree(cbind(GOCSediments$Long, GOCSediments$Lati))
ind <- find.neighbor(X, Qx)
AllFishTrawlsSediments <- cbind(GOCSediments[ind[,2], 4:9], Sedimentsdist = ind[,3])

names(AllFishTrawlsWaveHt)[1:4] <- c("WaveHeight", "WaveHeight.Median", "WaveHeight.Max",
"WaveHeight.SD")

names(AllFishTrawlsSeaWiFS)[c(2,4)] <- c("Chlorophyll.SD", "K.490.SD")
names(AllFishTrawlsStress)[1:4] <- c("Stress", "Stress.Median", "Stress.Max", "Stress.SD")
```

```
AllFishTrawlsX <- cbind(AllFishTrawlsX, AllFishTrawlsSediments, AllFishTrawlsCARS,
AllFishTrawlsSeaWiFS, AllFishTrawlsWaveHt, AllFishTrawlsStress)

AllFishTrawlsX <- addDepths(AllFishTrawlsX)

AllFishTrawlsX$TotalBiomass <- rsum(AllFishTrawlsWT)
AllFishTrawlsX$NoSpecies <- rsum(Bmatrix(AllFishTrawlsWT))

keep <- AllFishTrawlsX$Long > 135 & AllFishTrawlsX$Long < 142
SomeFishTrawlsX <- AllFishTrawlsX[keep, ]
SomeFishTrawlsWT <- AllFishTrawlsWT[keep, ]
SomeFishTrawlsNO <- AllFishTrawlsNO[keep, ]
```

BuildRoxAnDredges.ssc

```
import.data(FileName = "D:\\Kuranda\\Surrogates\\Data\\Dredge\\dredges_WNV.xls",
        FileType = "Excel",
        ColNames = "",
        Format = "",
        TargetStartCol = "1",
        DataFrame = "dredges.WNV",
        NameRow = "",
        StartCol = "1",
        EndCol = "END",
        StartRow = "1",
        EndRow = "END",
        Delimiters = ", \\t",
        SeparateDelimiters = F,
        PageNumber = "1",
        RowNameCol = "",
        StringsAsFactors = "Auto",
        VLabelAsNumber = F,
        DatesAsDoubles = F,
        Filter = "",
        OdbcConnection = "",
        OdbcSqlQuery = "")

dredges.WNV$COMMENTS <- NULL
dredges.WNV$Taxon1 <- factor(dredges.WNV$Taxon1)
dredges.WNV$Case <- paste(substring(dredges.WNV$Site, 1, 6),
substring(1000+dredges.WNV$Station, 2), sep=".")


AllDredges.WT <- tapply(dredges.WNV$WtPH, list(dredges.WNV$Case, dredges.WNV$Spcode),
sum, na.omit = T)
AllDredges.WT[is.na(AllDredges.WT)] <- 0
AllDredges.WT <- data.frame(AllDredges.WT)

AllDredges.NO <- tapply(dredges.WNV$NosPH, list(dredges.WNV$Case, dredges.WNV$Spcode),
sum, na.omit = T)
```

```
AllDredges.NO[is.na(AllDredges.NO)] <- 0
AllDredges.NO <- data.frame(AllDredges.NO)

wh <- intersect(row.names(RoxAnX), row.names(AllDredges.WT))
RoxAnDredges.WT <- AllDredges.WT[wh, ]
RoxAnDredges.NO <- AllDredges.NO[wh, ]
RoxAnDredges.X <- RoxAnX[wh, ]

wh <- which(RoxAnDredges.X$Longitude < 142 & RoxAnDredges.X$Longitude > 135 &
RoxAnDredges.X$SampleCount > 70)
RoxAnDredges.WT <- RoxAnDredges.WT[wh, ]
RoxAnDredges.NO <- RoxAnDredges.NO[wh, ]
RoxAnDredges.X <- RoxAnDredges.X[wh, ]

RoxAnDredges <- cbind(RoxAnDredges.X, NoSpecies = rsum(Bmatrix(RoxAnDredges.NO)),
TotalBiomass = rsum(RoxAnDredges.WT))
```

BuildRoxAnX.ssc

```
# Script to build RoxAnn Station x predictors matrices
# Same assumptions as in the Dredges, Bycatch and Fish Trawl scripts
# assumes that the data set rox.f (huge!) is in memory.  Other
# assumptions as for other data building scripts apply.

RoxAnStations <- rox.f[!is.na(rox.f$opno), ]
st <- substring(RoxAnStations$opno, 5, 7)
cr <- substring(RoxAnStations$cruise, 3, 6)
RoxAnStations$Station <- paste("SS", cr, ".", st, sep = "")

X <- cbind(RoxAnStations$lon, RoxAnStations$lat)

Qx <- quad.tree(cbind(CARS$Long, CARS$Lati))
ind <- find.neighbor(X, Qx)
RoxAnCARS <- cbind(CARS[ind[,2], 3:14], CARSdist = ind[,3])

Qx <- quad.tree(cbind(WaveHt$Long, WaveHt$Lati))
ind <- find.neighbor(X, Qx)
RoxAnWaveHt <- cbind(WaveHt[ind[,2], -(1:2)], WaveHtdist = ind[,3])

Qx <- quad.tree(cbind(SeaWiFS$Long, SeaWiFS$Lat))
ind <- find.neighbor(X, Qx)
RoxAnSeaWiFS <- cbind(SeaWiFS[ind[,2], 3:6], SeaWiFSdist = ind[,3])

Qx <- quad.tree(cbind(AllStress$LON, AllStress$LAT))
ind <- find.neighbor(X, Qx)
RoxAnStress <- cbind(AllStress[ind[,2], 3:6], Stressdist = ind[,3])

Qx <- quad.tree(cbind(GOCSediments$Long, GOCSediments$Lati))
ind <- find.neighbor(X, Qx)
RoxAnSediments <- cbind(GOCSediments[ind[,2], 4:9], Sedimentsdist = ind[,3])
```

```
names(RoxAnWaveHt)[1:4] <- c("WaveHeight", "WaveHeight.Median", "WaveHeight.Max",
"WaveHeight.SD")

names(RoxAnSeaWiFS)[c(2,4)] <- c("Chlorophyll.SD", "K.490.SD")
names(RoxAnStress)[1:4] <- c("Stress", "Stress.Median", "Stress.Max", "Stress.SD")

fixDF <- function(df) data.frame(lapply(df, function(x) tapply(as.vector(x), RoxAnStations$Station,
mean, na.rm = T)))

RoxAnSediments <- fixDF(RoxAnSediments)
RoxAnCARS      <- fixDF(RoxAnCARS)
RoxAnSeaWiFS   <- fixDF(RoxAnSeaWiFS)
RoxAnWaveHt    <- fixDF(RoxAnWaveHt)
RoxAnStress    <- fixDF(RoxAnStress)
RoxAnX <- cbind(RoxAnSediments, RoxAnCARS, RoxAnSeaWiFS, RoxAnWaveHt, RoxAnStress)
row.names(RoxAnX)

RoxAnX$SampleCount <- table(RoxAnStations$Station)

RoxAnX$Depth.TM <- tapply(RoxAnStations$depth, RoxAnStations$Station, mean, trim = 0.05)
RoxAnX$Depth.MAD <- tapply(RoxAnStations$depth, RoxAnStations$Station, mad)
RoxAnX$Depth.95 <- tapply(RoxAnStations$depth, RoxAnStations$Station, quantile, prob = 0.95)
RoxAnX$Rough.TM <- tapply(RoxAnStations$rough, RoxAnStations$Station, mean, trim = 0.05)
RoxAnX$Rough.MAD <- tapply(RoxAnStations$rough, RoxAnStations$Station, mad)
RoxAnX$Rough.95 <- tapply(RoxAnStations$rough, RoxAnStations$Station, quantile, prob = 0.95)
RoxAnX$Hard.TM <- tapply(RoxAnStations$hard, RoxAnStations$Station, mean, trim = 0.05)
RoxAnX$Hard.MAD <- tapply(RoxAnStations$hard, RoxAnStations$Station, mad)
RoxAnX$Hard.95 <- tapply(RoxAnStations$hard, RoxAnStations$Station, quantile, prob = 0.95)

RoxAnX$Longitude <- tapply(RoxAnStations$lon, RoxAnStations$Station, median)
RoxAnX$Latitude <- tapply(RoxAnStations$lat, RoxAnStations$Station, median)
```

Acoustics metadata

Filter_RoxAnn_&_Insert_Trawl_Dredge_Site_Info.ssc
S-plus script file that filters RoxAnn data, cross-references with Biological (trawl/dredge) Sample information. Creates the S-plus data frame used in further analysis.

```
t<-
data.frame(opno=trawl$opno,optype=rep("trawl",length(trawl$opno)),sdate=trawl$sdate,edate=trawl$
edate,loc=trawl$loc,dn=trawl$dn)
d<-
data.frame(opno=dredge$opno,optype=rep("dredge",length(dredge$opno)),sdate=dredge$sdate,edate
=dredge$edate,loc=dredge$loc,dn=dredge$dn)
sites<-rbind(t,d)
rm(d,t)
sites<-sites[order(sites$sdate),]

ss9702.f<-ss9702[ss9702$depth<70&ss9702$depth>5,]
for(i in 1:10)
{
```

```
        cat(i,"\n")
        ss9702.f<-ss9702.f[c(T,abs(diff(ss9702.f$depth))<1),]
}

ss9708.f<-ss9708[ss9708$depth<70&ss9708$depth>5,]
for(i in 1:15)
{
        cat(i,"\n")
        ss9708.f<-ss9708.f[c(T,abs(diff(ss9708.f$depth))<1),]
}

ss9803.f<-ss9803[ss9803$depth<60&ss9803$depth>10,]
for(i in 1:10)
{
        cat(i,"\n")
        ss9803.f<-ss9803.f[c(T,abs(diff(ss9803.f$depth))<1),]
}

rox.f<-rbind(ss9702.f,ss9708.f,ss9803.f)

rm(ss9702.f,ss9708.f,ss9803.f)

index <- matrix(0,ncol=2,nrow=0)
n <- 50000
st <- sites$sdate
end <- sites$edate
N <- length(st)
for (first.d in seq(1,nrow(rox.f),by=n)) {
d <- rox.f$date[(first.d-1+1):min(first.d-1+n,nrow(rox.f))]
first <- min((1:N)[st>=d[1]])
last <- max((1:N)[end<=d[length(d)]])
cat(first,last,first.d,"\n")
cmp.st <- outer(d,st[first:last],">")
cmp.end <- outer(d,end[first:last],"<")
cmp <- cmp.st & cmp.end
index <- rbind(index,cbind(first.d - 1 + (1:n)[row(cmp)[cmp]],col(cmp)[cmp]+first-1))
}
rm(n,st,end,N,d,first,last,cmp.st,cmp.end,cmp)

rox.f<-
data.frame(cruise=rox.f$cruise,loc=NA,opno=NA,optype=NA,dn=NA,file=rox.f$file,date=rox.f$date,
lon=rox.f$lon,lat=rox.f$lat,depth=rox.f$depth,rough=rox.f$rough,hard=rox.f$hard)
rox.f$loc[index[,1]]<-as.character(sites$loc[index[,2]])
rox.f$opno[index[,1]]<-sites$opno[index[,2]]
rox.f$optype[index[,1]]<-as.character(sites$optype[index[,2]])
rox.f$dn[index[,1]]<-sites$dn[index[,2]]

rm(index)
```

GoC_Surrogates_RoxAnn_Data.txt
Metadata on original data sources and what they contain.

ROXANN SOURCE DATAFILES SS9702
================================
ORIGINAL SOURCE : floppy disk & forty2-cv:/mnt/prawn/van099/....

ROXANN SOURCE DATAFILES SS9708
================================
ORIGINAL SOURCE : forty2-cv:~van099/roxann ss oct 97/ & forty2-cv:~del104/RoxAnn data & stuff/raw rox oct97/

ROXANN SOURCE DATAFILES SS9803
================================
ORIGINAL SOURCE : \\Argyrops\NT-Shares\Fish\Bycatch sustainability\SS9803\roxann\roxdon

ROXANN SS9702
=============

FILENAME : ~sto206/analysis/roxanne/*.* SS9702 RoxAnn Data Sets - SAS,Excel,CSV
FORMAT : DataBase File
RESOLUTION : ??

DATE Date
TIME Time
DEG_LAT Latitude (deg)
MIN_LAT Latitude (decimal minutes)
DEG_LON Longitude (deg)
MIN_LON Longitude (decimal minutes)
DEPTH Depth (m)
ROUGH Roughness (integer)
HARD Hardness (integer)

ORACLE DATABASES
================
SS9702, SS9708, SS9803 : UNDERWAY_DATA, OPERATION_LOG
SS9803 : ROXANN ROXANN_BYOPER, R_SUMM_STATS_BYOP

##

UNFILTERED SS9702 ROXANN ACOUSTIC DATA
==

ORIGINAL SOURCE FILES : RoxAnn\ss9702*.rox
FILENAME : ss9702.txt
FORMAT : Comma Delimited Text File
RESOLUTION : Point Data

NOTES : 23 raw data files, 12Mb, 236682 records

CRUISE	Source Cruise Name (text)
FILE	Source File (*.rox) Name (text)
DATE	Date/Time (CCYYMMDD.dddddd) (i.e. Time in decimal days)
LON	Longitude (deg)
LAT	Latitude (deg)
DEPTH	Sea Depth (m)
ROUGH	Acoustic Roughness () (dimensionless 0-4096)
HARD	Acoustic Hardness () (dimensionless 0-4096)

UNFILTERED SS9708 ROXANN ACOUSTIC DATA
=====================================

ORIGINAL SOURCE FILES : RoxAnn\ss9708*.rox
FILENAME : ss9708.txt
FORMAT : Comma Delimited Text File
RESOLUTION : Point Data

NOTES : 59 raw data files, 56Mb, 1060652 records

CRUISE	Source Cruise Name (text)
FILE	Source File (*.rox) Name (text)
DATE	Date/Time (CCYYMMDD.dddddd) (i.e. Time in decimal days)
LON	Longitude (deg)
LAT	Latitude (deg)
DEPTH	Sea Depth (m)
ROUGH	Acoustic Roughness () (dimensionless 0-4096)
HARD	Acoustic Hardness () (dimensionless 0-4096)

UNFILTERED SS9803 ROXANN ACOUSTIC DATA
=====================================

ORIGINAL SOURCE FILES : RoxAnn\ss9803*.rox
FILENAME : ss9803.txt
FORMAT : Comma Delimited Text File
RESOLUTION : Point Data

NOTES : 644 raw data files, 38Mb, 717982

CRUISE	Source Cruise Name (text)
FILE	Source File (*.rox) Name (text)
DATE	Date/Time (CCYYMMDD.dddddd) (i.e. Time in decimal days)
LON	Longitude (deg)
LAT	Latitude (deg)
DEPTH	Sea Depth (m)
ROUGH	Acoustic Roughness () (dimensionless 0-4096)
HARD	Acoustic Hardness () (dimensionless 0-4096)

Rox_F_DataFrame_Metadata.txt
Metadata for the final S-plus data frame used in analysis.

CRUISE	Source Cruise Name (factor). Levels - "ss9702","ss9708","ss9803"
LOC	Location of Operation (character/text). E.g. "Torres_Strait"
OPNO	Operation Number (integer). E.g. 9702007 Digits 1-4 Cruise Id; Digits 5-7 Operation Id. NA Values correspond to "Off Transect" Samples e.g. while transiting
OPTYPE	Operation Type (character/text). e.g. "dredge","trawl","NA" for "Off Transect"
DN	Day/Night Indicator (integer). 1=Day,2=Night,"NA"="Off Transect"
FILE	Original Source File (*.rox) Name (factor)
DATE	Date/Time (CCYYMMDD.dddddd) (i.e. Time in decimal days) (double)
LON	Longitude (deg) (double)
LAT	Latitude (deg) (double)
DEPTH	Sea Depth (m) (double)
ROUGH	Acoustic Roughness (dimensionless 0-4096) (integer)
HARD	Acoustic Hardness (dimensionless 0-4096) (integer)

ss9702_FileList1.txt
Matlab input file. Collates and formats original RoxAnn file data.

```
ss9702,ss297ts.rox
ss9702,ss297ts2.rox
ss9702,ss297ts3.rox
ss9702,ss297w1.rox
ss9702,ss297w2.rox
ss9702,ss297bo.rox
ss9702,ss297bo2.rox
ss9702,ss297mn1.rox
ss9702,ss297mn2.rox
ss9702,ss297mnm.rox
ss9702,ss297mn3.rox
ss9702,ss297va1.rox
ss9702,ss297va2.rox
ss9702,ss297va3.rox
ss9702,ss297sg.rox
ss9702,ss297gi1.rox
ss9702,ss297sg1.rox
ss9702,ss297ng1.rox
ss9702,ss297cb1.rox
ss9702,ss297nm1.rox
ss9702,ss297nm2.rox
ss9702,ss297nm3.rox
ss9702,ss297nm4.rox
```

ss9702_Load.m
Matlab script file. Collates and formats original RoxAnn file data.

```
%-----------------------------------------------------------------------------
% ss9702_Load - Loads & Formats RoxAnn Data
%
% USAGE :
%    ss9702_load;
%
% DESCRIPTION :
%    Loads & Formats RoxAnn Data
%
% INPUTS :
%
% OUTPUTS :
%
%
% EXAMPLE :
%    ss9702_load;
%
% SEE ALSO :
%
%
%-----------------------------------------------------------------------------

%-----------------------------------------------------------------------------
% SS9702_LOAD 1.0 20/06/01
% Copyright (C) 2001 CSIRO Australia - All rights reserved.
%-----------------------------------------------------------------------------
% AUTHOR: Scott R. Gordon
% CONTACT: scott.gordon@marine.csiro.au
% CREATED: 20/06/01
% REVISION : 1.0
% LAST MODIFICATION: 20/06/01
% MODIFICATION HISTORY:
%             20/06/01 - SRG : Original 1.0
%-----------------------------------------------------------------------------

%-----------------------------------------------------------------------------
% FILE : ss9702_Load.m
% CALLED BY : Matlab
% CALLS :
% LOCAL VARIABLES :
%    cruise = string array of cruise names
%    filename = string array of file names
%    data = RoxAnn data array
%-----------------------------------------------------------------------------

%-----------------------------------------------------------------------------
cd 'C:\Documents and Settings\gor142\My Documents\Projects\GoC_Surrogates\Analysis\RoxAnn'
[cruise,filename]=textread('./ss9702_filelist.txt','%s%s','delimiter',',','whitespace','\n');
```

```
fid=fopen('ss9702.txt','w');
fprintf(fid,'CRUISE,FILE,DATE,LON,LAT,DEPTH,ROUGH,HARD\n');
for i=1:size(cruise,1)
            i
            [d,t,lt,ltm,ln,lnm,dp,r,h]=textread(strcat('./',char(cruise(i)),'/',char(filename(i))),...
      '%6c,%6c,%u,%f,%*1c,%u,%f,%*4c,%f,%f,%f','whitespace','\n');
            data=[((str2num(strcat('19',cruise{i}(3:4),d(:,3:4),d(:,1:2))))+...
         ((str2num(t(:,1:2))+(str2num(t(:,3:4))+(str2num(t(:,5:6))/60))/60)/24)) ...
         (ln+lnm/60) -(lt+ltm/60) dp r h];
   eval(['fprintf(fid,''' cruise{i} ',' filename{i}(1:(size(filename{i},2)-4)) ...
         ',%8.6f,%2.4f,%2.4f,%0.3f,%u,%u\n'',data'');']);
end
fclose(fid);
clear
%-----------------------------------------------------------------------------
```

ss9708_FileList.txt
Matlab input file. Collates and formats original RoxAnn file data.

```
ss9708,031097.rox
ss9708,041097.rox
ss9708,051097a.rox
ss9708,051097b.rox
ss9708,061097a.rox
ss9708,061097b.rox
ss9708,071097a.rox
ss9708,071097b.rox
ss9708,081097a.rox
ss9708,081097b.rox
ss9708,091097a.rox
ss9708,091097b.rox
ss9708,101097a.rox
ss9708,101097b.rox
ss9708,111097a.rox
ss9708,ra111049.rox
ss9708,ra111047.rox
ss9708,111097b.rox
ss9708,121097a.rox
ss9708,121097b.rox
ss9708,131097a.rox
ss9708,131097b.rox
ss9708,141097a.rox
ss9708,141097b.rox
ss9708,151097a.rox
ss9708,151097b.rox
ss9708,161097a.rox
ss9708,161097b.rox
ss9708,171097a.rox
ss9708,171097b.rox
ss9708,181097a.rox
ss9708,181097b.rox
ss9708,191097a.rox
ss9708,191097.rox
ss9708,201097a.rox
ss9708,201097b.rox
ss9708,211097a.rox
ss9708,221097a.rox
ss9708,221097b.rox
ss9708,231097.rox
ss9708,231097b.rox
ss9708,241097a.rox
ss9708,241097b.rox
ss9708,251097a.rox
ss9708,251097b.rox
ss9708,261097a.rox
ss9708,261097b.rox
ss9708,271097b.rox
ss9708,281097a.rox
ss9708,281097b.rox
ss9708,291097a.rox
ss9708,301097a.rox
ss9708,301097b.rox
ss9708,311097a.rox
ss9708,311097b.rox
ss9708,011197a.rox
ss9708,011197b.rox
ss9708,021197a.rox
ss9708,021197b.rox
```

ss9708_Load.m
Matlab script file. Collates and formats original RoxAnn file data.

```
%-----------------------------------------------------------------------------
% ss9708_Load - Loads & Formats RoxAnn Data
%
% USAGE :
%    ss9708_load;
%
% DESCRIPTION :
%    Loads & Formats RoxAnn Data
%
% INPUTS :
%
% OUTPUTS :
%
%
% EXAMPLE :
%    ss9708_load;
```

```
%
% SEE ALSO :
%
%
%--------------------------------------------------------------------------

%--------------------------------------------------------------------------
% SS9708_LOAD 1.0 20/06/01
% Copyright (C) 2001 CSIRO Australia - All rights reserved.
%--------------------------------------------------------------------------
% AUTHOR: Scott R. Gordon
% CONTACT: scott.gordon@marine.csiro.au
% CREATED: 20/06/01
% REVISION : 1.0
% LAST MODIFICATION: 20/06/01
% MODIFICATION HISTORY:
%            20/06/01 - SRG : Original 1.0
%--------------------------------------------------------------------------

%--------------------------------------------------------------------------
% FILE : ss9708_Load.m
% CALLED BY : Matlab
% CALLS :
% LOCAL VARIABLES :
%    cruise = string array of cruise names
%    filename = string array of file names
%    data = RoxAnn data array
%--------------------------------------------------------------------------

%--------------------------------------------------------------------------
cd 'C:\Documents and Settings\gor142\My
Documents\Projects\GoC_Surrogates\Analysis\RoxAnn'
[cruise,filename]=textread('./ss9708_filelist.txt','%s%s','delimiter',',','whitespace','\n');
fid=fopen('ss9708.txt','w');
fprintf(fid,'CRUISE,FILE,DATE,LON,LAT,DEPTH,ROUGH,HARD\n');
for i=1:size(cruise,1)
            i
            [d,t,lt,ltm,ln,lnm,dp,r,h]=textread(strcat('./',char(cruise(i)),'/',char(filename(i))),...
     '%6c,%6c,%u,%f,%*1c,%u,%f,%*4c,%f,%f,%f','whitespace','\n');
            data=[((str2num(strcat('19',cruise{i}(3:4),d(:,3:4),d(:,1:2))))+...
        ((str2num(t(:,1:2))+(str2num(t(:,3:4))+(str2num(t(:,5:6))/60))/60)/24)) ...
        (ln+lnm/60) -(lt+ltm/60) dp r h];
   eval(['fprintf(fid,''' cruise{i} ',' filename{i}(1:(size(filename{i},2)-4)) ...
        ',%8.6f,%2.4f,%2.4f,%0.3f,%u,%u\n'',data'');']);
end
fclose(fid);
clear
%--------------------------------------------------------------------------
```

ss9803_FileList.txt
Matlab input file. Collates & formats original RoxAnn file data.

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ss9803_Load.m
Matlab scrip file. Collates & formats original RoxAnn file data.

```
%---------------------------------------------------------------------------
% ss9803_Load - Loads & Formats RoxAnn Data
%
% USAGE :
%    ss9803_load;
%
% DESCRIPTION :
%    Loads & Formats RoxAnn Data
%
% INPUTS :
%
% OUTPUTS :
%
%
% EXAMPLE :
%    ss9803_load;
%
% SEE ALSO :
%
%
%---------------------------------------------------------------------------

%---------------------------------------------------------------------------
% SS9803_LOAD 1.0 20/06/01
% Copyright (C) 2001 CSIRO Australia - All rights reserved.
%---------------------------------------------------------------------------
% AUTHOR: Scott R. Gordon
% CONTACT: scott.gordon@marine.csiro.au
% CREATED: 20/06/01
% REVISION : 1.0
% LAST MODIFICATION: 20/06/01
% MODIFICATION HISTORY:
%            20/06/01 - SRG : Original 1.0
%---------------------------------------------------------------------------

%---------------------------------------------------------------------------
% FILE : ss9803_Load.m
% CALLED BY : Matlab
% CALLS :
% LOCAL VARIABLES :
%    cruise = string array of cruise names
%    filename = string array of file names
%    data = RoxAnn data array
%---------------------------------------------------------------------------

%---------------------------------------------------------------------------
cd 'C:\Documents and Settings\gor142\My
Documents\Projects\GoC_Surrogates\Analysis\RoxAnn'
[cruise,filename]=textread('./ss9803_filelist.txt','%s%s','delimiter',',','whitespace','\n');
fid=fopen('ss9803.txt','w');
fprintf(fid,'CRUISE,FILE,DATE,LON,LAT,DEPTH,ROUGH,HARD\n');
for i=1:size(cruise,1)
            i
```

```
        [d,t,lt,ltm,ln,lnm,dp,r,h]=textread(strcat('./',char(cruise(i)),'/',char(filename(i))),...
    '%6c,%6c,%u,%f,%*1c,%u,%f,%*4c,%f,%f,%f','whitespace','\n');
        data=[((str2num(strcat('19',cruise{i}(3:4),d(:,3:4),d(:,1:2))))+...
      ((str2num(t(:,1:2))+(str2num(t(:,3:4))+(str2num(t(:,5:6))/60))/60)/24)) ...
      (ln+lnm/60) -(lt+ltm/60) dp r h];
  eval(['fprintf(fid,''' cruise{i} ',' filename{i}(1:(size(filename{i},2)-4)) ...
      ',%8.6f,%2.4f,%2.4f,%0.3f,%u,%u\n'',data'');']);
end
fclose(fid);
clear
%-----------------------------------------------------------------------------
```

Prawn trawl data

The following description is of the data processing required for the invertebrate data for bycatch cruise SS9708. A parallel process was carried out for the other two cruises, SS9702 and SS9803, and subsequently occurred for the fish data. All the data manipulation was carried out in SAS and data was stored as SAS data files.

Catch data was retrieved from the bycatch group’s Oracle database tables. Station detail data was retrieved to SAS file ss9708trawl.sas7bdat and catch data by species was retrieved to SAS file ss9708_ff.sas7bdat.

The SAS data files fish_catches.sas7bdat and invert_catches.sas7bdat are the main files that were used to perform further analyses.

The SAS jobs used to manipulate the data are as follows:

Invert_job_1.sas
Selects all invertebrate species codes (<37000000) from the catch file and all prawn trawls (net codes 121, 124) from the station details file. Some non-standard trawls were eliminated from the analysis at this stage.

```
libname surrogat 'k:surrogates/';
libname ss9708 'k:/surrogates/ss9708/';

*****************************************************
*     output from invert_job_1.sas
*****************************************************;
*****************************************************
*         selects all invertebrate species codes (< 37000000)
*         and prawn trawl net codes (121, 124) from the catch
*         file and the station details file
*****************************************************;


data ss9708.ss9708_invert;
set ss9708.ss9708_ff;

where species_code < 37000000 and gear_code in (121,124)
         and operation_no not in (35,36,37,87,127,
         128,310,353,354,355,390,391,433,477,478);

data ss9708.ss9708trawla;
set ss9708.ss9708trawl;
```

```
where gear in (121,124) and opno not in (35,36,37,87,127,
        128,310,353,354,355,390,391,433,477,478);

run;
```

Invert_job_2.sas

Corrects catches for any sub sampling so that the catches then represent the total catch from each trawl. The two prawn trawl gear codes (main net and cod end cover) were combined to give one record for each trawl operation. Catches were then standardized by the time trawled to give a catch per hour.

```
libname surrogat 'k:surrogates/';
libname ss9708 'k:/surrogates/ss9708/';

****************************************************
*    output from invert_job_2.sas
****************************************************;

data file1;
set ss9708.ss9708_invert;

**************************************************
*       corrects catches for fraction sampled
**************************************************;

data file2;
set file1;

where catch_weight > .;

ncount=catch_count;
nweight=catch_weight;

if subsample_flag="S" then do;
        ncount=catch_count/fraction_sampled;
        nweight=catch_weight/fraction_sampled;
end;

**************************************************
*       combines gear codes 121 and 124 into one record
*       per opno (trawl)
**************************************************;

proc sort data=file2;
by operation_no species_code family_no gear_code;

proc means noprint data=file2;
var ncount nweight;
by operation_no species_code family_no;
id;
output out=file3 sum=;
**************************************************
*       reads in data from ss9708trawla containing
*       dur_h, loc, daynight variables and standardise
```

```
*          catches by time trawled
*************************************************;

data file4;
set ss9708.ss9708trawla;

operation_no=opno;

proc sort data=file4;
by operation_no;

proc means data=file4 noprint;
by operation_no;
var gear;
id loc dur_h daynight;
output out=file4a min=;

data file5;
merge file3 file4a (drop=gear);
by operation_no;

data ss9708.catch (drop=_type_ _freq_ ncount nweight);
set file5;

counthr=ncount/dur_h;
weighthr=nweight/dur_h;

if operation_no=254 then counthr=0;
if operation_no=254 then weighthr=0;
if operation_no=254 then species_code=35000000;
if operation_no=254 then family_no=1;
if operation_no=267 then counthr=0;
if operation_no=267 then weighthr=0;
if operation_no=267 then species_code=35000000;
if operation_no=267 then family_no=1;
if operation_no=269 then counthr=0;
if operation_no=269 then weighthr=0;
if operation_no=269 then species_code=35000000;
if operation_no=269 then family_no=1;

run;
```

Invert_job_3.sas

Creates a new file that is a subset of the main station file, having one record for each prawn trawl made.

```
libname surrogat 'k:surrogates/';
libname ss9708 'k:/surrogates/ss9708/';

****************************************************
*      output from invert_job_3.sas
****************************************************;
****************************************************
*   creates a file which is a subset of the main
*          station file, having one record for each prawn
```

```
*          trawl made
**************************************************;

data file1;
set ss9708.ss9708trawla;

operation_no=opno;

proc sort data=file1;
by operation_no;

proc means data=file1 noprint;
by operation_no;
var gear;
id loc dur_h daynight;
output out=ss9708.no_trawls min=;

proc print data=ss9708.no_trawls;

run;
```

Invert_job_4.sas

Creates a new file from the catch file having one record for each species caught on the cruise.

```
libname surrogat 'k:surrogates/';
libname ss9708 'k:/surrogates/ss9708/';

**************************************************
*      output from invert_job_4.sas
**************************************************;
**************************************************
*   creates a new file from the catch file having
*          one record for each species caught on the cruise
**************************************************;

data file2;
set ss9708.ss9708_ff;

where species_code < 37000000;

proc sort data=file2;
by species_code family_no;

proc means data=file2 noprint;
by species_code family_no;
var catch_weight;
output out=ss9708.nspecies n=freq;

proc print data=ss9708.nspecies;
var species_code family_no freq;
run;
```

Invert_job_5.sas

Takes the results of the previous two jobs to create a new file that has a record for each trawl and each species caught on the cruise with catches for all species codes zero-filled.

```
libname surrogat 'k:surrogates/';
libname ss9708 'k:/surrogates/ss9708/';

**************************************************
*     output from invert_job_5.sas
**************************************************;
**************************************************
*  takes the results of invert_job_3 and invert_job_4
*         to create a new file that has a record for each
*         trawl and each species caught on the cruise with
*         catches for all species codes zero-filled
**************************************************;

data testop (keep=opno loc dn);
set ss9708.no_trawls;

opno=operation_no;
if daynight='day' then dn=1;
if daynight='dusk' then dn=2;
if daynight='night' then dn=2;

data testsp (keep=spec fam);
set ss9708.nspecies;

spec=species_code;
fam=family_no;

data ss9708.allspec (keep=opno dn loc spa);
set testsp end=last;

retain count 1 sp1-sp539;

array sp{539} sp1-sp539;

sp{count}=spec;
count+1;
*output file1;

if last then goto one;
return;

one: set testop end=last1;

do i=1 to count-1;
         spa=sp{i};
         output ss9708.allspec;
end;

goto one;

run;
```

Invert_job_6.sas

Takes the results of invert_job_2 and invert_job_5 to create a new file that has complete catch data for all species codes, including zeros, for all prawn trawl records (fcatch.sas7bdat).

```
libname surrogat 'k:surrogates/';
libname ss9708 'k:/surrogates/ss9708/';

**************************************************
*	output from invert_job_6.sas
**************************************************;
**************************************************
*  takes the results of invert_job_2 and invert_job_5
*	to create a new file that has complete catch data
*	for all species codes, including zeros, for all
*	prawn trawl records
**************************************************;

data file1 (keep=opno dn loc spa counthr weighthr);
set ss9708.catch;

opno=operation_no;
spa=species_code;

if daynight='day' then dn=1;
if daynight='dusk' then dn=2;
if daynight='night' then dn=2;

if counthr=. then counthr=99999;
if weighthr=. then weighthr=99999;

data file2;
set ss9708.allspec;

counthr=0;
weighthr=0;

data file3;
set file1 file2;

proc sort data=file3;
by opno spa;

proc means data=file3 noprint;
by opno spa;
var counthr;
id loc dn weighthr;
output out=ss9708.fcatch max=;

run;
```

Invert_job_7.sas

Takes the results of invert_job_6 and a file of new taxonomic levels for each species code created by MDEH, and merges the new taxonomic levels with the old species codes. It then calculates new catch rates for the new taxa for each trawl (cat_tax1.sas7bdat).

```
*libname surrogat 'k:surrogates/';
*libname ss9803 'k:surrogates/ss9803/';
libname ss9708 'k:surrogates/ss9708/';

**************************************************
*     output from invert_job_7.sas
**************************************************;
**************************************************
*  takes the results of invert_job_6 and a file
*        of new taxonomic levels for each species code
*        created by MDEH, and merges the new taxonomic levels
*        with the old species codes: it then calculates new
*        catch rates for the new taxa for each trawl
**************************************************;

data file1 (drop=_freq_ _type_);
set ss9708.fcatch;

if counthr=99999 then counthr=.;
if weighthr=99999 then weighthr=.;

proc sort data=file1;
by spa;

data file2 (drop=species_code species newcode taxon1
        taxon2 taxon3 taxon4 comments);
set ss9708.all_species_codes;

speciesa=substr(species,1,50);
*newcodea=substr(newcode,1,50);
taxon1a=substr(taxon1,1,50);
taxon2a=substr(taxon2,1,50);
taxon3a=substr(taxon3,1,50);
taxon4a=substr(taxon4,1,50);
commentsa=substr(comments,1,50);

spa=species_code;

proc sort data=file2;
by spa;

data file3;
merge file1 file2;
by spa;

data ss9708.fcatch_taxon;
set file3;

where weighthr ne .;

proc sort data=ss9708.fcatch_taxon;
by opno taxon1a;

proc means data=ss9708.fcatch_taxon noprint;
by opno taxon1a;
var weighthr counthr;
```

```
id dn loc;
output out=ss9708.cat_tax1 sum=;
run;
```

Invert_job_8.sas

Takes the results of the previous job for all three bycatch cruises and combines to one file (invert_catches) with a new operation number created as a unique station identifier, incorporating the cruise id and the old operation number.

```
libname surrogat 'k:surrogates/';
libname ss9702 'k:/surrogates/ss9702/';
libname ss9708 'k:/surrogates/ss9708/';
libname ss9803 'k:/surrogates/ss9803/';

**************************************************
*      output from invert_job_8.sas
**************************************************;

data file1 (drop=opno _type_ _freq_);
set ss9702.cat_tax1;

newopno=9702000 + opno;

if weighthr=0 then delete;

data file2 (drop=opno _type_ _freq_);
set ss9708.cat_tax1;

newopno=9708000 + opno;

if weighthr=0 then delete;

data file3 (drop=opno _type_ _freq_);
set ss9803.cat_tax1;

newopno=9803000 + opno;

if weighthr=0 then delete;

data surrogat.invert_catches;
set file1 file2 file3;

if dn=. then delete;

proc sort data=surrogat.invert_catches;
by newopno;

run;
```

CHAPTER 4

FINE SCALE DISTRIBUTION OF TRAWL EFFORT

Chapter Author:

Mick Haywood

Final Report on FRDC Project 2000/160: Surrogates I – Predictors, impacts, management and conservation of the benthic biodiversity of the Northern Prawn Fishery

CHAPTER 4

FINE SCALE DISTRIBUTION OF TRAWL EFFORT IN THE NPF

Mick Haywood

Summary

- VMS data was analysed for all NPF trawlers for the period 1 August 2000 to 31 October 2000
- Records for non-trawling periods and daytime were excluded and corrections were made for variations in polling interval
- The resulting polling distribution was integrated with 6 nm trawl effort data compiled from logbook records to produce 1 nm resolution maps of the distribution of fishing effort.
- The new effort maps represent a 36 times increase in resolution over the logbook information
- Distribution of fishing effort within the 6 nm grids squares is highly variable; in some areas it is relatively evenly spread across the grid, but in other areas effort is highly aggregated in small parts of the grid square
- In some parts of the fishery, trawl effort is very much focused around the edges of patches of untrawlable ground but in areas where the untrawlable ground is more fragmented there is no clear spatial relationship between the two
- The analysis has been highly successful and continuing analyses should be useful to managers and researchers in providing a more accurate picture of the actual effort distribution

Introduction

The Australian Fisheries Management Authority (AFMA) collects a daily record of each fisher's catch and position through the logbook program. The positional information is recorded at a resolution of 6 nautical miles. This is of limited use in describing the fine-scale patterns of trawling in the NPF. Since 1999 AFMA has administered a Vessel Monitoring System (VMS) throughout the NPF. All NPF-registered vessels are fitted with a transponder/GPS unit that transmits the vessel's position to AMFA in Canberra at intervals decided by AFMA. AFMA use this information principally for compliance, however, it also has a research function since it can be used for determining patterns of fishing effort at a finer scale than that provided by the daily logbook records. Our aim was to produce a map of fishing effort for the NPF at a resolution of 1 nautical mile in order both to develop a process and to examine the output.

Methods

AFMA made available to us all VMS data from the NPF for the period 01 Aug 2000 to 31 Oct 2000 for the analysis (Fig. 4.1). The dataset comprised 122, 505 records. We found that 5244 records were duplicates. In addition some of the data collected by the VMS system was redundant and so were excluded from our analyses. We excluded data for daytime polls from the GoC (Zones 3 & 4 in Fig 4.2) because there is a restriction on daytime trawling in the Gulf at this time of year. We also excluded polls from vessels that were travelling at speeds greater than trawling (speed > 3.5 knots) since the vessels would not be trawling.

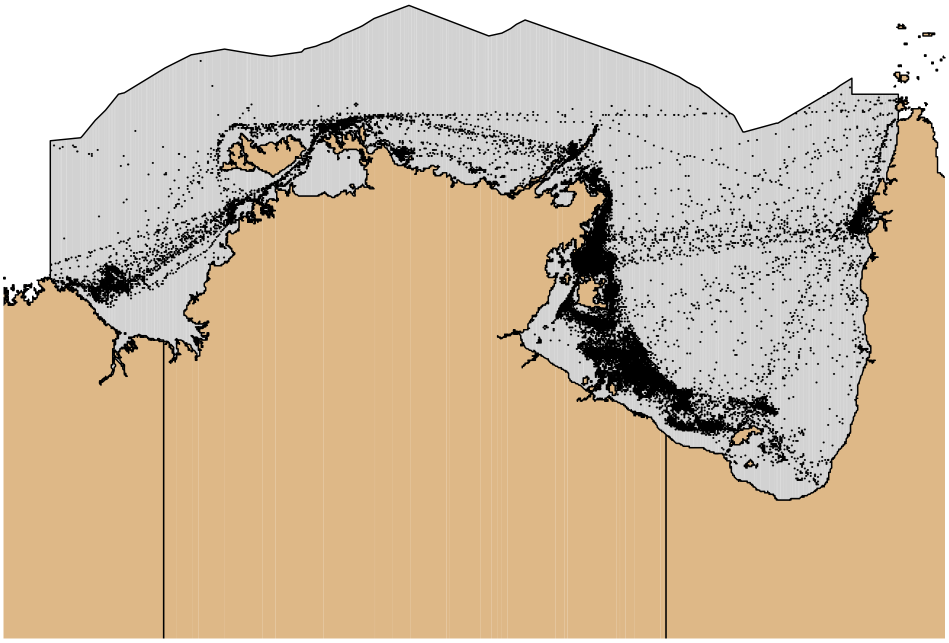

Figure 4.1 NPF Vessel Monitoring System data for all vessels; second season 2000. Polling points (black dots) include vessels that are trawling and steaming – a point therefore does not necessarily indicate a trawling site.

Identifying daytime polls in the GoC was complicated by the two time zones in the Gulf and the fact that there is a ban on daylight fishing in the GoC, but not in the areas of the fishery outside the GoC. The time zones differ by 30 minutes and change at the Queensland/Northern Territory border. To facilitate analysis we divided the NPF into 4 zones (Fig 4.2, Table 4.1).

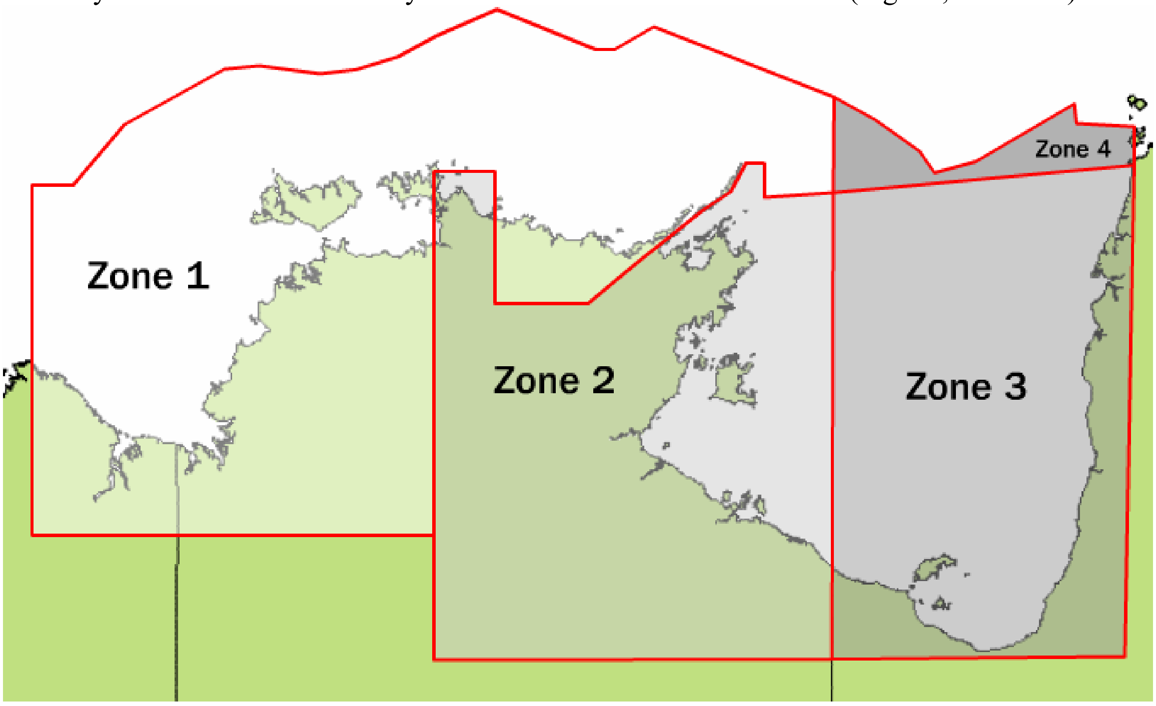

Figure 4.2 The four zones used in VMS data analysis

The daylight closure operated in zone 2 from 2230 to 0830 UTC (0830 to 1830 local time) and from 2200 to 0800 UTC (0800 to 1800 local time) in zone 3. Each poll record in the VMS dataset included a UTC timestamp and so we were able to restrict the records to those collected during the times that fishing was permitted.

Table 4.1 A description of the four zones used in the analysis of the VMS data.

Zone No.	Description	Daylight Fishing Permitted?	Time Zone
1	Western NT	Yes	UTC + 9.5 h
2	Goulburn Islands & Western GoC	No	UTC + 9.5h
3	Eastern GoC	No	UTC + 10 h
4	North-eastern AFZ	Yes	UTC + 10 h

Most of the poll records did not include information on vessel speed, so we could not use speed to determine whether a vessel was trawling or travelling. Instead we loaded all data into a GIS (Arc/Info) and converted the poll records (points) for each day (10 h in zones 1 & 4) and night (14h in all zones) and vessel into lines, such that for each day/night a particular vessel's track was represented by a separate line. We then excluded all lines that were longer than it would have been possible for a vessel to travel if it had been steaming at 3.5 knots (average trawling speed) during the 10/14 h period.

We had planned to produce a map of the fine-scale distribution of effort by creating a grid with a resolution of 1 nautical mile, the value of each cell in the grid being simply the count of the number of VMS poll points lying within its boundaries. This method required that the time interval between VMS polls be approximately equal, otherwise the measure of effort would be biased to areas where the poll interval was shorter.

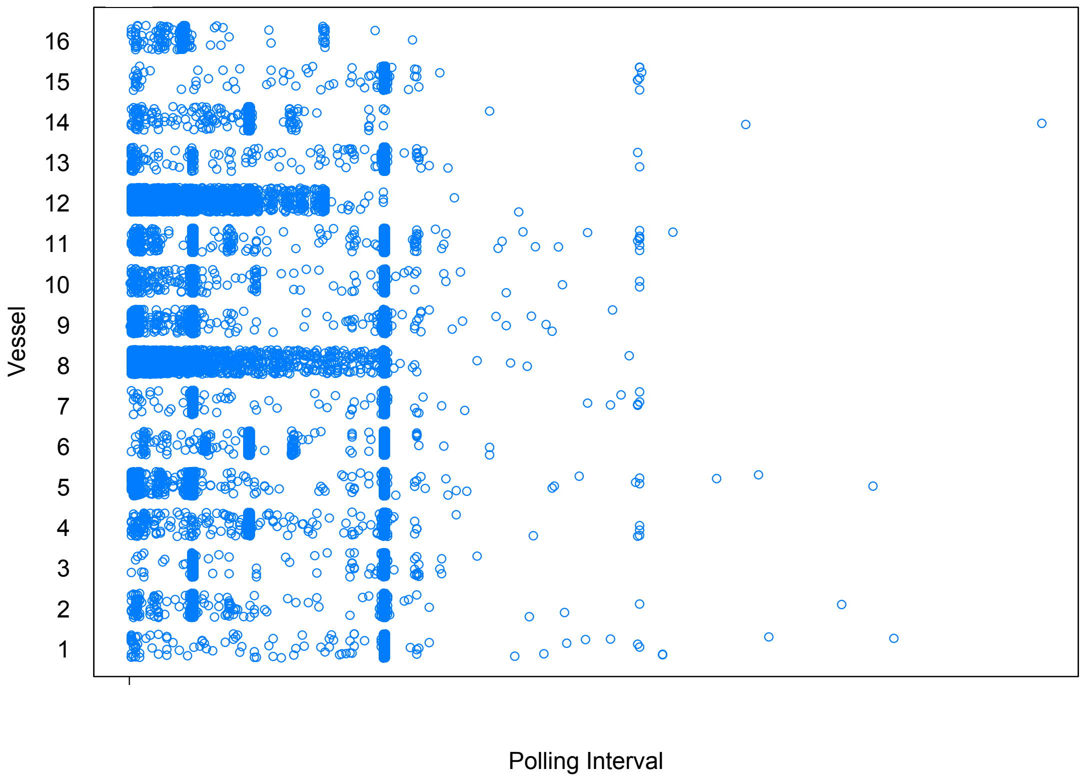

Figure 4.3 Polling intervals for a sample of 16 different NPF trawlers during August to October 2000. Actual polling intervals cannot be shown for reasons of confidentiality.

An initial analysis of the data indicated that the poll intervals varied from seconds to hours. There are two principal reasons for these variations. The first is that AFMA both automatically and manually alters polling frequencies for different areas of the fishery depending on events in the fishery such as the proximity to closures and other sensitive areas. The second relates to very frequent polls that may be the result of individual VMS unit malfunctions. An example of how polling intervals varied among vessels and for the same vessel at different times is shown for a sample of 16 vessels in Figure 4.3.

We partly overcame this problem by adding equally spaced nodes to the trawl track lines every 55.56 m. This particular spacing was chosen because it represented the distance travelled every 0.01 h at the average trawling speed of 3.5 knots. The nodes were converted to points in the GIS and a 1 nautical mile grid was created from the points (Fig. 4.4). The 1 nautical mile grid was developed such that it overlaid the AFMA 6 nautical mile grid upon which the logbook program is based. The value of each 1 nautical mile grid cell was the sum of the number of points within the cell, so the cell value/100 gives a rough estimate of the hours of trawling within each cell. This is generally an underestimate because we could only do a straight-line interpolation between individual vessel polls as we have no information on where the vessel is between polls; the true vessel course could have deviated from a straight line. This problem becomes more severe as the interval between polls increases. Contour maps of fishing effort were then created from the effort grid (Fig 4.4c).

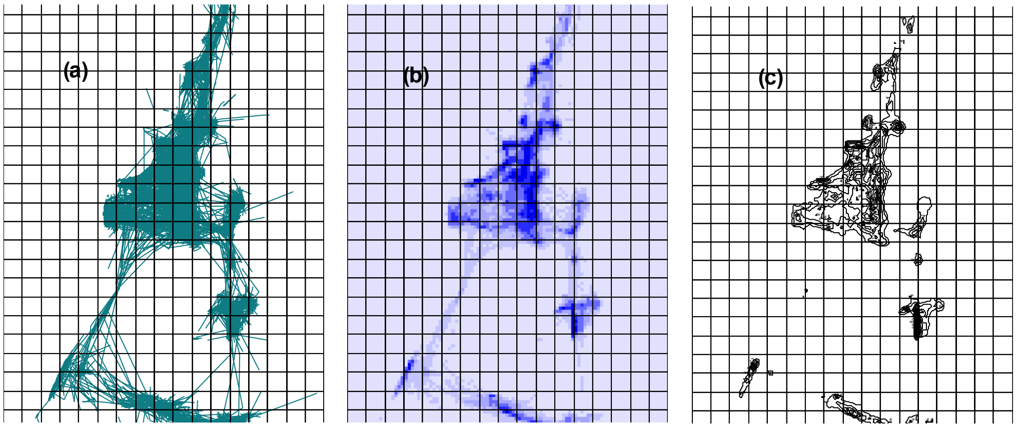

Figure 4.4 A series of maps illustrating the process of converting the raw VMS data into contour maps of effort. The VMS data was filtered to exclude tracks made by vessels that were not trawling and the poll points converted to lines (a). Points were then inserted at equal intervals along each line (55.56 m) and a 1 nautical mile grid was created from these points such that the value of each grid cell was equal to the number of points it enclosed (b). The grid was then converted to contours of fishing effort (c). The coarse-mesh grid in these figures represents the resolution at which the daily logbook data is collected (6 nautical miles)

The effort distribution created from the VMS data was highly correlated with that recorded in the AFMA log books (Pearson Correlation coefficient = 0.89; $p< 0.0001$) suggesting that logbook records are quite reliable at the 6 nautical mile level of resolution. However, the fine-scale effort patterns generated from the VMS data reveal that the distribution of fishing effort within the 6 nautical mile grids squares is highly variable; in some areas it is relatively evenly spread across the 6 nm grid, but in other areas effort is highly aggregated in small parts of the 6 nm grid square (Figures. 4.5, 4.6 and 4.7).

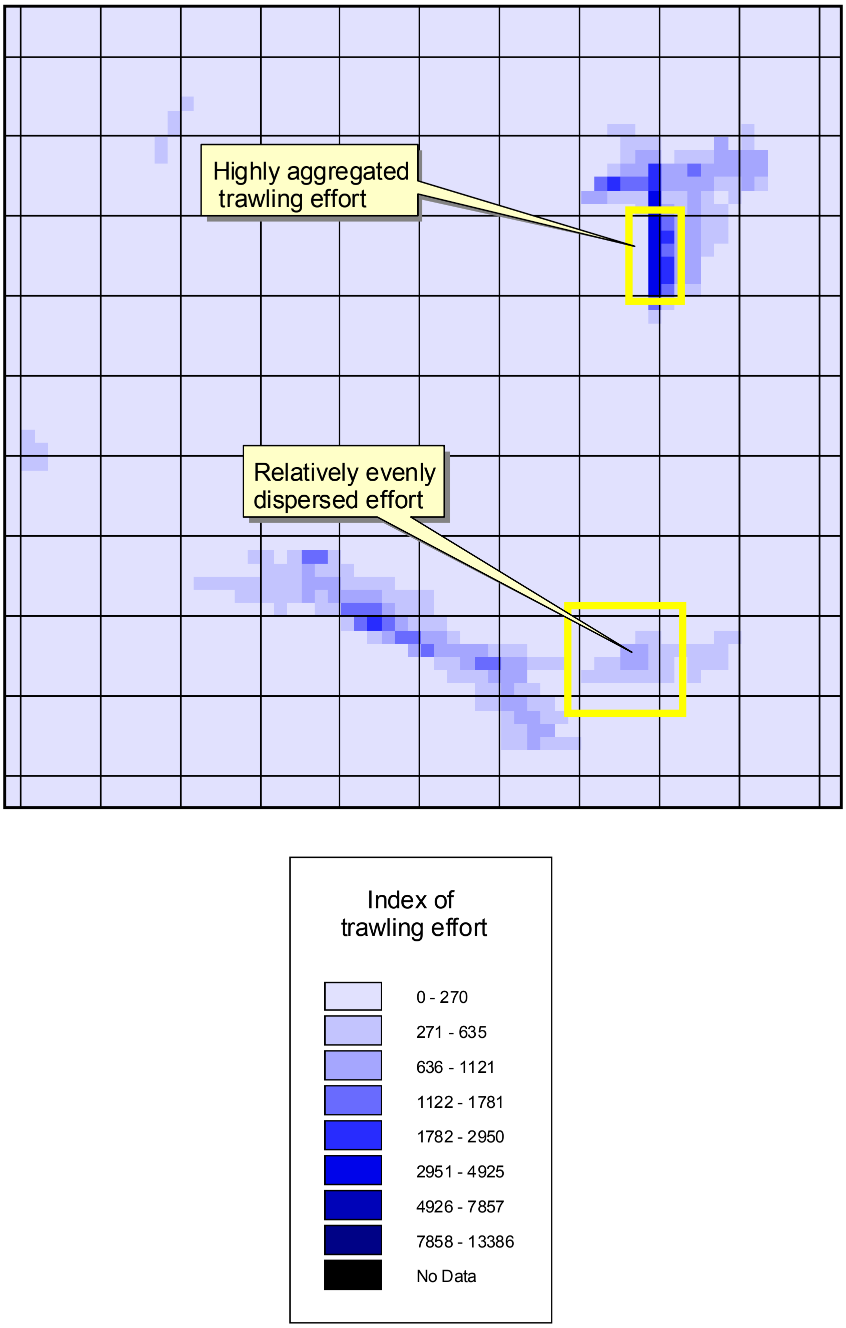

Figure 4.5 VMS-generated fine-scale map of trawling effort for a section of the trawl grounds showing areas of highly aggregated and relatively dispersed trawling effort.

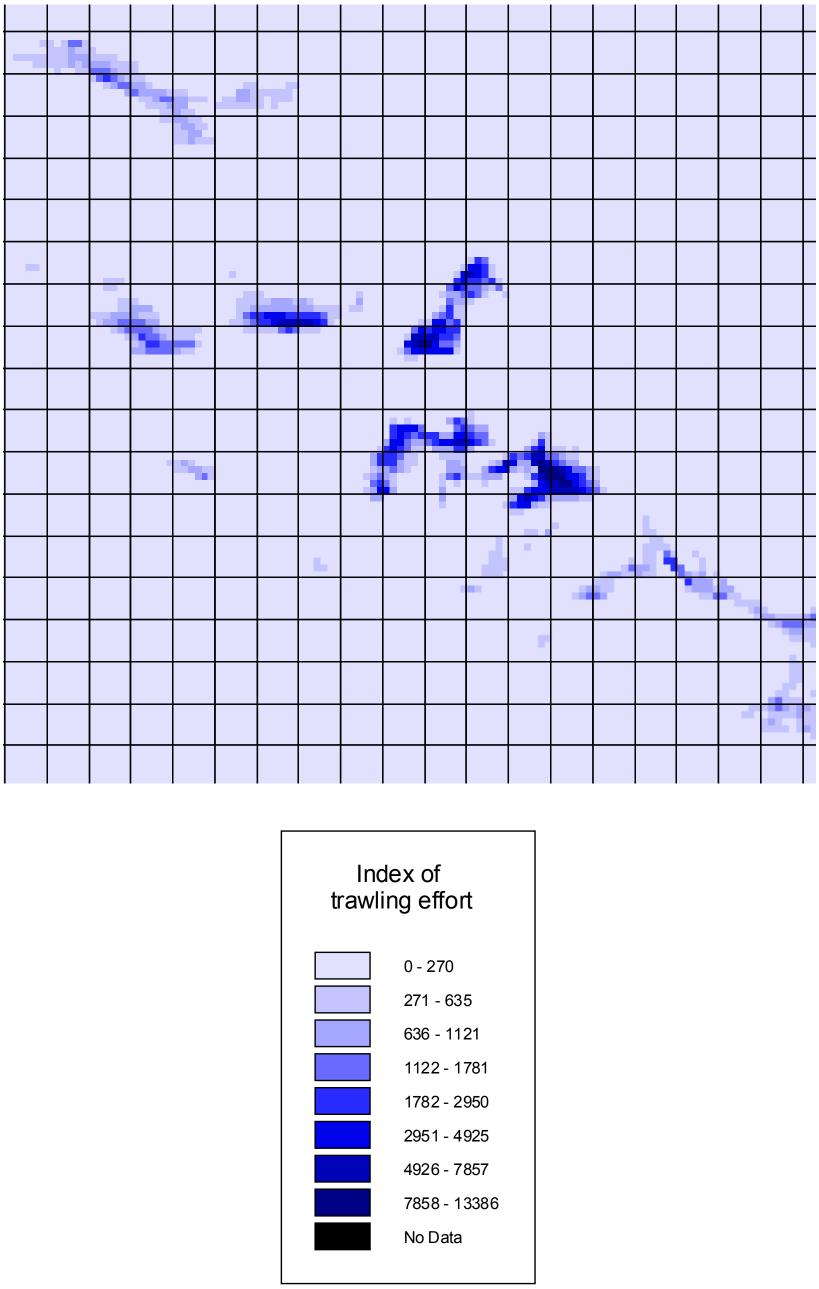

Figure 4.6 VMS-generated fine-scale map of trawling effort for a section of trawl grounds showing areas of highly aggregated trawling effort along a north-west to south-east axis.

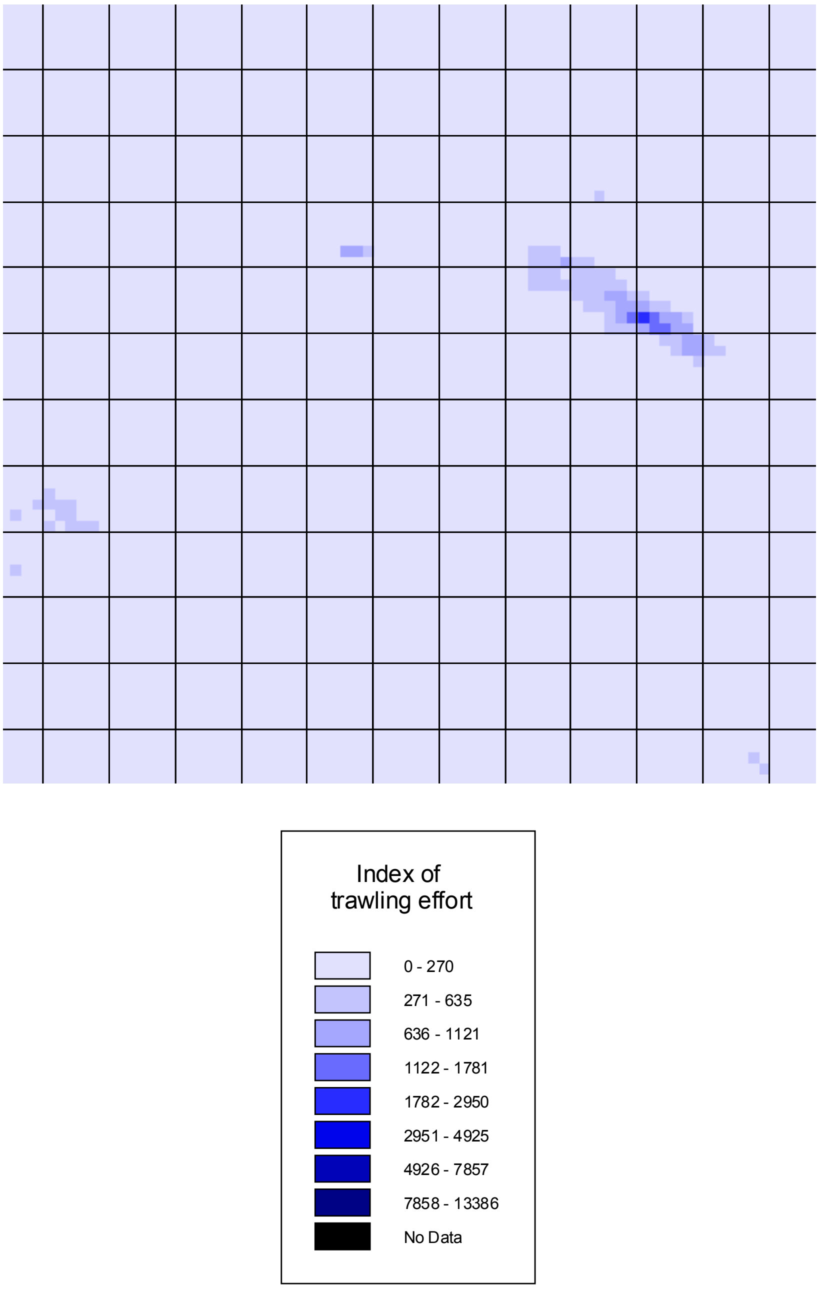

Figure 4.7 VMS-generated fine-scale map of trawling effort for an isolated trawl ground.

In an earlier study (FRDC 95/014) we collected GPS plotter data from 29 NPF fishers and in consultation with them, developed a map of the untrawlable grounds (reefs and rough ground where nets hook-up) throughout the fishing grounds of the NPF. When displayed in conjunction with the VMS-generated fine-scale effort patterns some interesting information

(a)

(b)

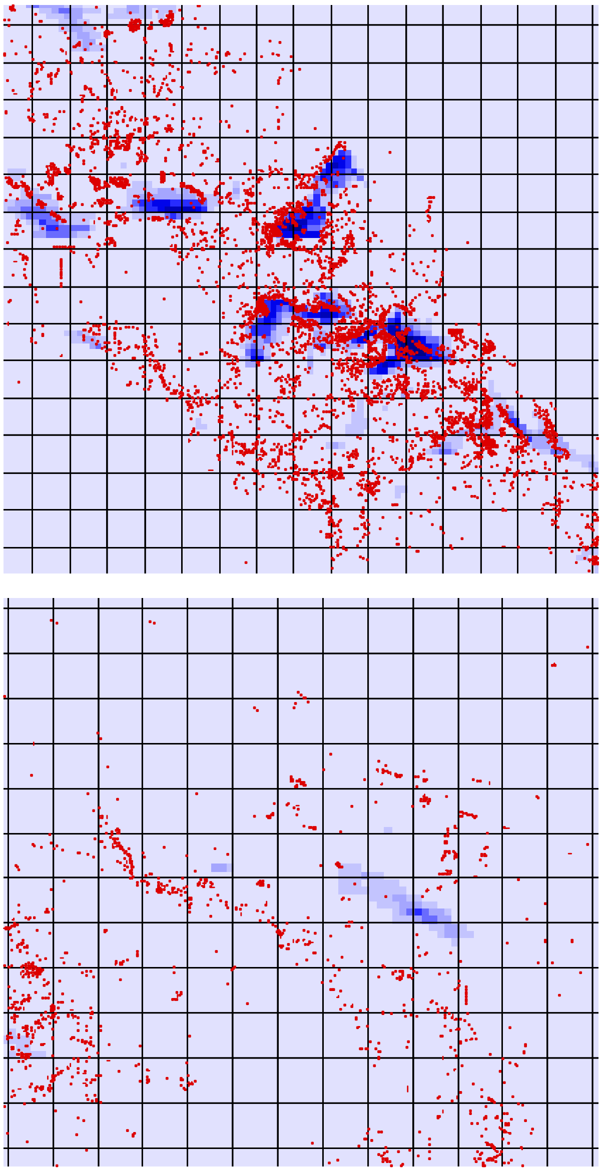

Figure 4.8 Untrawlable grounds (shown in red) from two different areas in the NPF overlaid with the VMS-generated fine-scale maps of trawling effort for the trawl grounds

emerges. In some parts of the fishery, trawl effort is very much focused around the edges of patches of untrawlable ground [Fig. 4.8(a)]. In contrast, in areas where the untrawlable ground is more fragmented [4.8 (b)] there is no clear spatial relationship between the two.

Discussion

The VMS analysis has permitted us to describe the spatial distribution of prawn trawl effort at a resolution of 1 nm. This is 36 times better than the current 6 nm commercial fishing grid records. The finer resolution shows that in many areas, fishing is highly aggregated. It also shows for the first time the trawling patterns around the reef structures identified in an earlier project (FRDC 95/014). These patterns of aggregated or targeted effort are being described in many fisheries as technology increases the capacity to track fishing. The high degree of aggregation is significant because it means that some areas are being fished more heavily than would be the case if fishing were equally distributed across the fishing grounds. It also means that extensive areas are either not being fished at all or are being fished at much lower intensities than would be predicted from a model that assumed equal distribution of effort. This is particularly important when seen against a background of declining effort and reduction in the area that is trawled in the NPF (See Chapter 10).

We have applied this high-resolution information in the modelling of the impacts of trawling on seabed fauna in Chapter 8. We see the information as being of particular value in future studies of the effects of trawling especially as the number of years of data builds up.

References

Indices of recruitment and effective spawning for tiger prawn stocks in the Northern Prawn Fishery. FRDC Project 95/014

CHAPTER 5

BIODIVERSITY, SURROGATES AND INDICATOR SPECIES OF THE FAUNA OF THE GULF OF CARPENTARIA

Mick Haywood
Bill Venables
Scott Gordon

Introduction

In this chapter we have investigated several features of the seabed fauna. These are

- biodiversity and its spatial distribution
- relationships between biological properties – in this case biodiversity and biomass – and a range of environmental variables in order to identify any surrogates
- occurrence of indicator species for biodiversity.

As pointed out in Chapter 3, we have biological data from the Gulf of Carpentaria collected by three different sampling gears – dredge (107 stations across the GoC and 44 additional samples from the trawl grounds), fish trawl (107 stations across the GoC) and prawn trawl (1085 samples). We also have a range of physical and chemical data as well as the results from our models of hydrodynamics and sediment as listed in Chapter 3. The adequacy of the biological data from the different gears is assessed in Chapter 5.1.

The techniques of analysis for these three different gears is similar and is described more fully for the dredge data (Chapter 5.2) and more briefly for the fish (Chapter 5.3) and prawn trawl (Chapter 5.4) data. We have given a single discussion of the results as well as a list of references in Chapter 5.5.

CHAPTER 5.1

ADEQUACY OF SAMPLING OF THE FAUNA OF THE GULF OF CARPENTARIA

Chapter author

Mick Haywood

CHAPTER 5.1

CHAPTER 5.1

ADEQUACY OF SAMPLING

OF THE

THE FAUNA OF THE GULF OF CARPENTARIA

Mick Haywood

Summary

- We compiled species accumulation curves using data from samples from different gears used in the Gulf of Carpentaria (GoC)
- The curve for fish caught in fish trawls does not appear to approach an asymptote suggesting fish have not been adequately sampled in the central GoC
- Benthic invertebrates and fish captured in the dredge have also not been adequately sampled across the central GoC
- Fish captured with prawn trawls have probably been adequately sampled overall on the commercial fishing grounds
- Invertebrate taxa from prawn trawls have been inadequately sampled but this conclusion needs to be treated with caution since the sampling may have been adequate if the samples had been identified to species level
- Analysis of sampling of invertebrates from prawn trawls on a regional basis shows that sampling is in equate for only two out of eight regions
- We also tested these samples using a criterion suggested by a reviewer that adequate sampling has been achieved when a doubling of samples results in an additional 10% or fewer species or taxa. The results confirmed our interpretation of the species accumulation curves
- We carried out a statistical analysis of the problem, this confirmed the earlier conclusions but showed that the species accumulation curves are not really asymptotic requiring an additional decay term
- We conclude that 'adequacy' depends on the aim of the sampling. The most abundant species are detected in relatively few samples, relative biodiversity can be detected without knowing all the species while nearly complete knowledge of the species or taxon composition requires a very large number of samples because of intrinsic properties of the marine fauna.

Introduction

We have data from three different sampling devices in the Gulf of Carpentaria – a fish trawl, a benthic dredge and a prawn trawl. The numbers of species or taxa in the samples collected by the three gears is given in Table 5.1.1.

Table 5.1.1 Number of species or taxa recorded in fish trawl, dredge and prawn trawl samples from the NPF

Fish trawl	Dredge	Prawn trawl bycatch
289 species	840 species of invertebrates	234 taxa of invertebrates 390 species of teleosts 43 species of elasmobranchs

As can be seen in Table 5.1.1, the total number of species or taxa collected by the three gears is very different. The number of species collected is a function of the number of samples up to some asymptotic level.

A species accumulation curve is a plot of the cumulative number of species identified in a given region as a function of some measure of effort used to find them. Plotting a species accumulation curve provides a useful method for quantifying species richness. It is also sometime used to assess the adequacy of sampling. In theory the curve will approach an asymptote once the total number of species in the area has been identified. Species accumulation curves can be used to compare species richness between different communities or between different treatments. An anonymous reviewer suggested a rule of thumb for assessing adequacy. This was that if the number of samples was doubled, the sampling was adequate if the number of species or taxa collected did not increase by 10%.

Methods

Species accumulation curves were generated using a freeware software product – Estimates (Colwell 2000). The software counts the number of species in each sample and generates a cumulative total as each sample is encountered. The process is repeated a number of times (in our case 50). During each iteration, the order in which the samples are chosen is randomised. Randomising the order and averaging the cumulative number of species over the randomisations reduces the effect of the sample order and produces a smooth curve.

Results

The shape of the curve generated for the number of species of fish caught in the fish trawls (Fig.5.1.1) indicates that after 107 samples the number of new species is still increasing. The increase in number of species from 50 stations to 100 stations is around 17% which is more than the suggested criterion of 10% (Table 5.1.2). Thus according to this criterion, the fish fauna for the central Gulf of Carpentaria has not been adequately sampled. The shape of the curve for the fish and invertebrates from the dredge-caught samples (Fig. 5.1.2) is similar but the slope in the latter parts is steeper. The increase in number of species from 50 stations to 100 is 30% (Table 5.1.2) suggesting the dredge fauna has also been inadequately sampled.

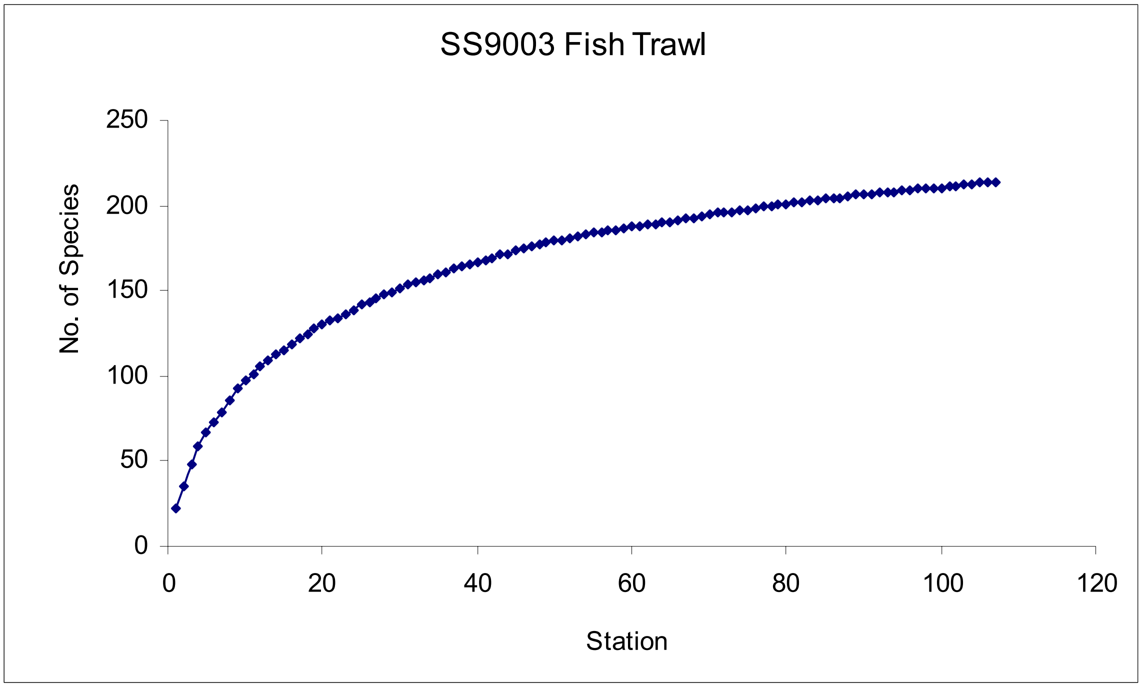

Figure 5.1.1. Species accumulation curve for the fish species caught in the fish trawl during the Gulf-wide survey (cruise SS9003).

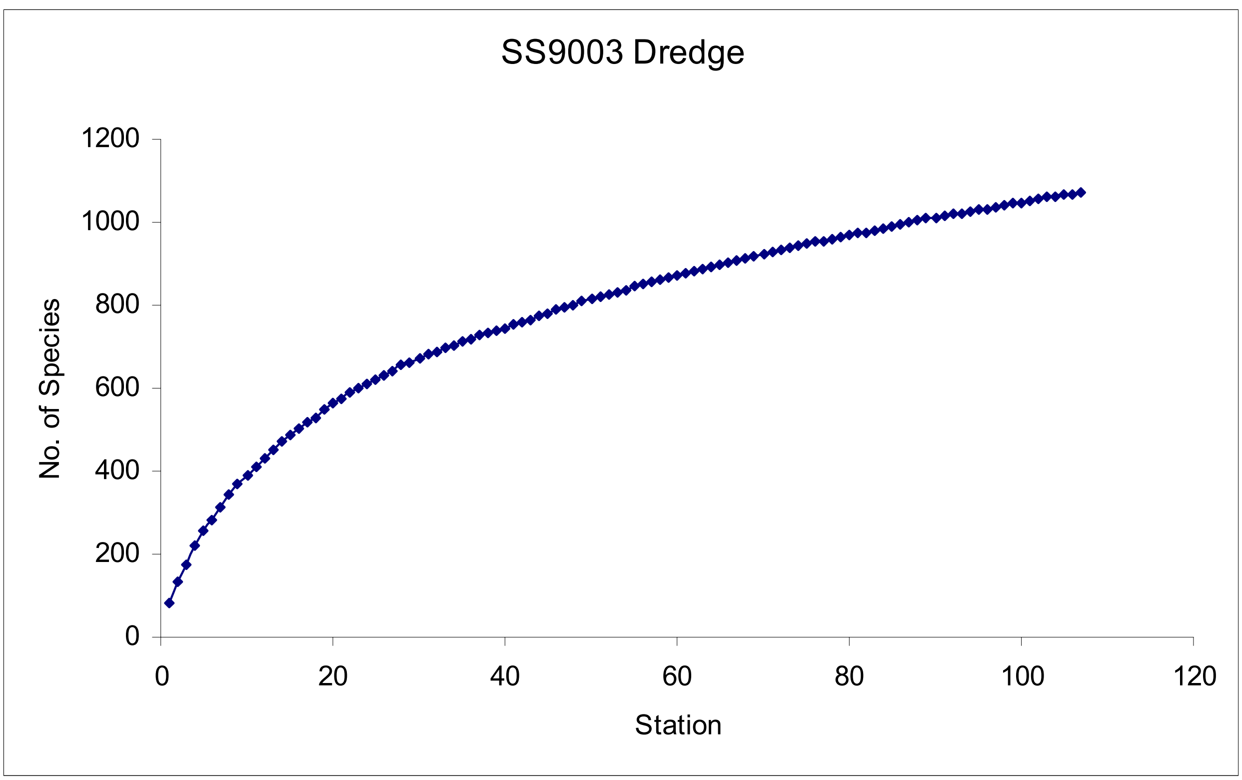

Figure 5.1.2 Species accumulation curve for fish and invertebrate taxa caught in the dredge during the Gulf-wide survey (SS9003).

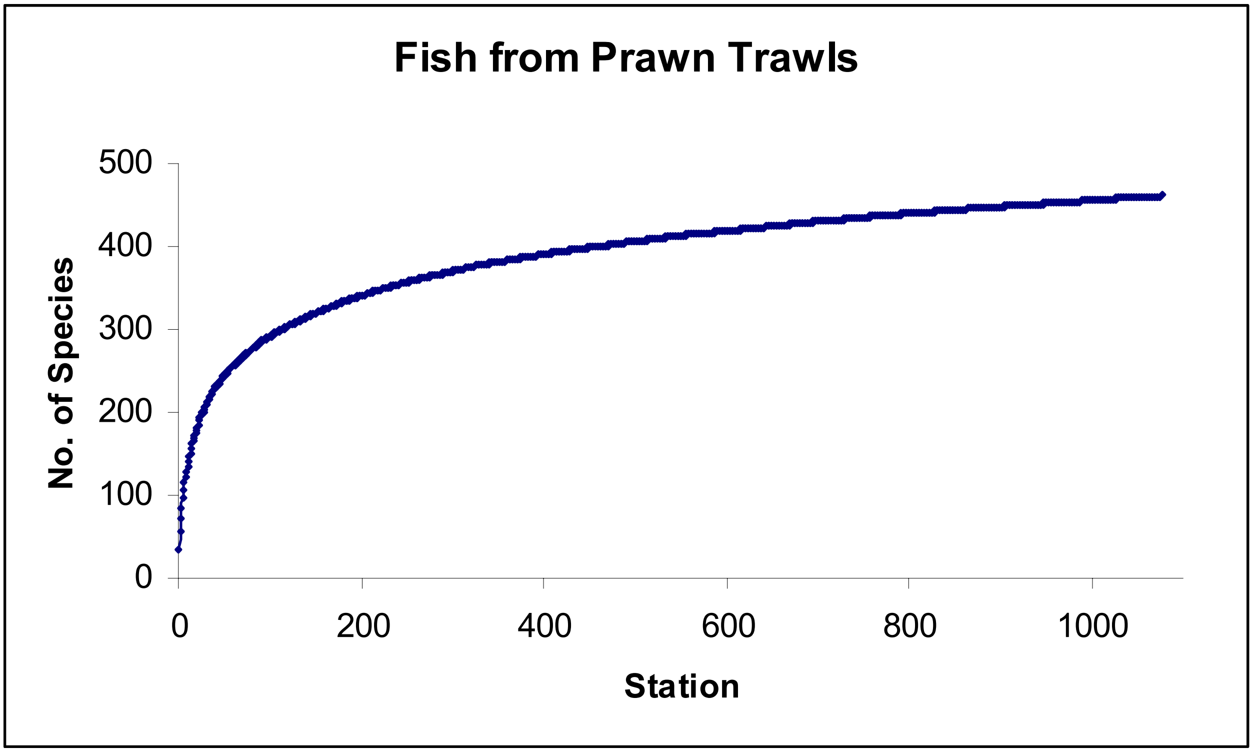

Figure 5.1.3 Species accumulation curve for fish species caught using prawn trawls during the prawn bycatch sustainability studies (cruises SS9702, SS9708 and SS98803)

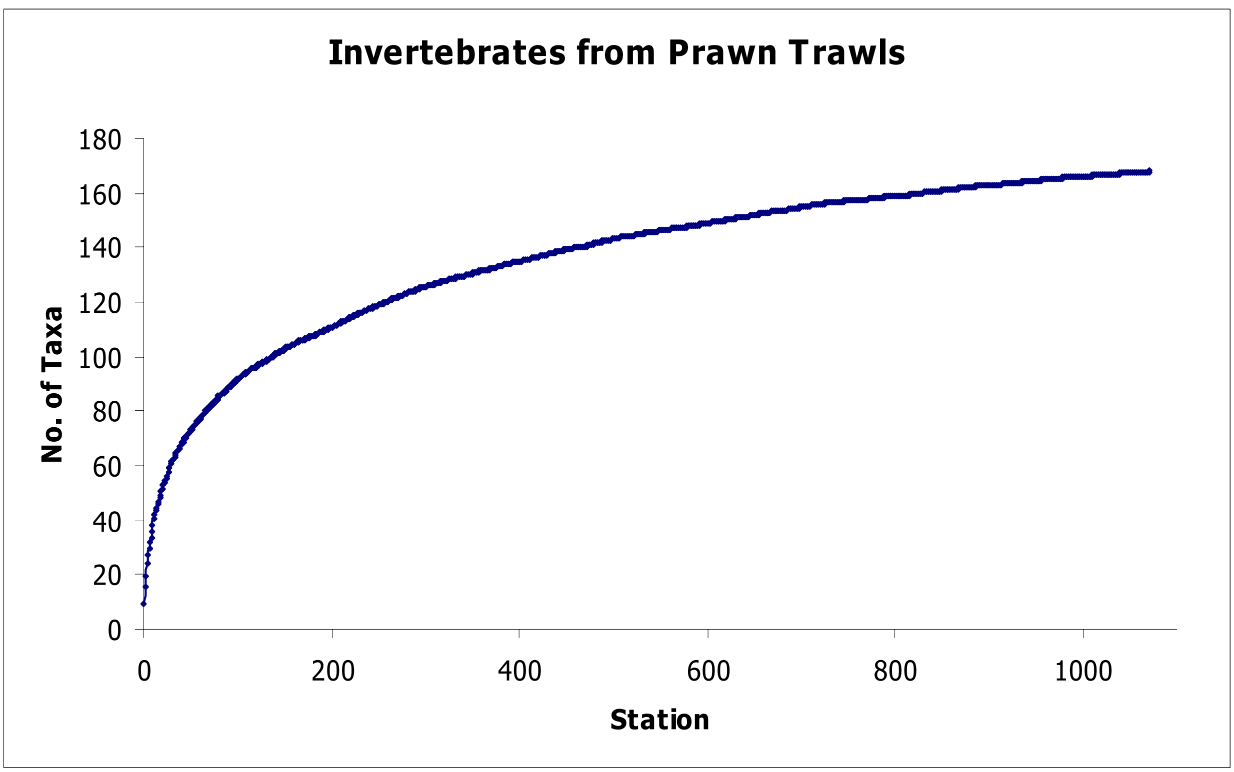

Figure 5.1.4 Species accumulation curve for invertebrate taxa caught using prawn trawls during the prawn bycatch sustainability studies (cruises SS9702, SS9708 and SS98803). Note that as many of the invertebrate taxa could not be identified to species this figure has used data based on identification to the Family level.

The species accumulation curves generated for the fish caught in prawn trawls (Fig. 5.1.3) shows an increase of 12% when sampling was doubled from 538 to 1076 stations suggesting that sampling for this group is approaching adequacy (Table 5.1.2). However the invertebrates from prawn trawls increased by 18% suggesting that this group has not been adequately sampled (Table 5.1.2). However we must be cautious about this interpretation since we were limited to dealing with taxa. It is possible that if the material had been identified to species, that we would have had considerably more species and that the sampling involving over 1000 stations might have been adequate. This illustrates one of the problems when dealing with samples that have not been identified to the species level. The slope of the species accumulation curves gradually becomes less steep as more samples are taken but it appears to be a long way from becoming asymptotic.

Table 5.1.2 The percentage increase in the number of species or taxa when the number of samples is doubled

	Double samples
Fish from fish trawls	18%
Fish from prawn trawls	12%
Invertebrates from prawn trawl:	16%
Fish and invertebrates from dre	29%

When dealing with accumulation curves derived from samples collected over a wide area, it is possible for under-sampling of one area to affect the curve for the total area. If we examine separate curves generated for prawn trawl invertebrates for the different regions within the fishery it is apparent that some areas were sampled less comprehensively than others (Fig. 5.1.5).

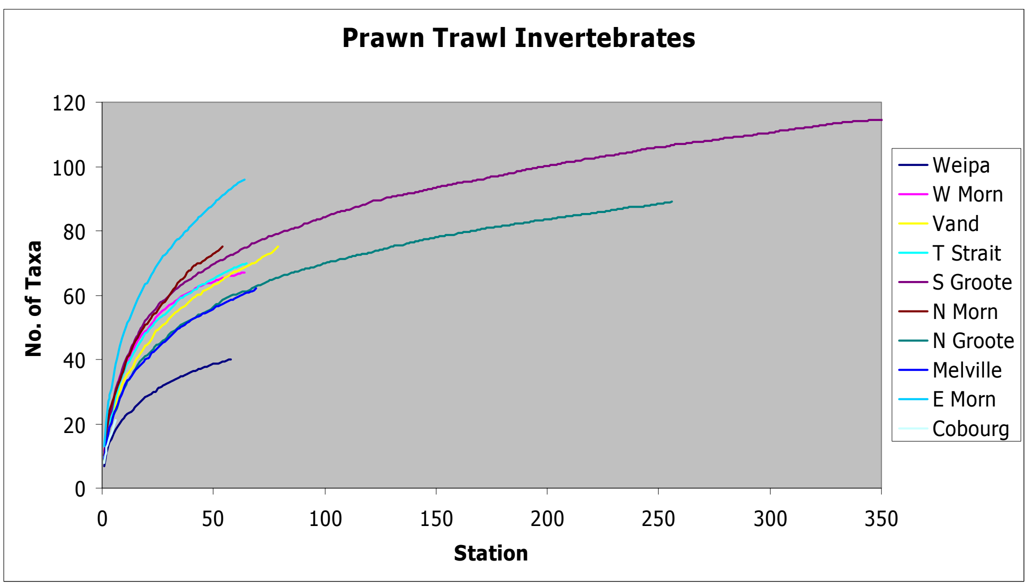

Figure 5.1.5 Species accumulation curves for invertebrate taxa caught using prawn trawls during the prawn bycatch sustainability studies (cruises SS9702, SS9708 and SS98803). Separate curves are presented for each region sampled in the Northern Prawn Fishery. The regions are abbreviated as follows: Weipa = Weipa; W Morn = West of Mornington Island; Vand = Vanderlin Island; T Strait = Torres Strait; S Groote = South of

Groote Eylandt; N Morn = North of Mornington Island; N Groote = North of Groote Eylandt; Melville = Melville Island; E Morn = east of Mornington Island; Cobourg = Cobourg Peninsula.

Notes on the cumulative number of species: Fish trawls

In order to gain some insight into the possible benefits of continued sampling, we estimated the cumulative number of species found as the number of samples (trawls) increases. The following diagram is generated by taking the observed trawls in repeated random sequences and averaging the incremental number of new species at each sample number. The curve may be shown in either cumulative or incremental form (Fig 5.1.6 and 5.1.7).

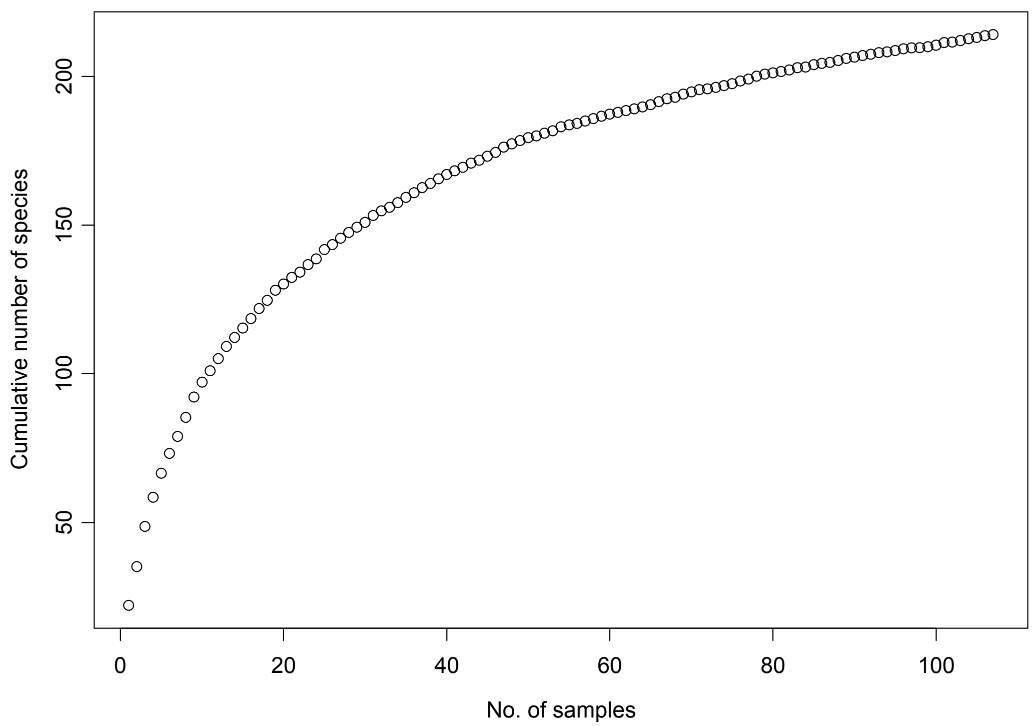

Figure 5.1.6 Cumulative number of species with increasing samples for Fish trawls.

The regularity shown in the cumulative diagram is partly artificial. The number of new species discovered at any sampling level must be non-negative so the cumulative number of species must be increasing.

An anonymous reviewer suggested that sampling is adequate if the number of species increased by 10% or less if the number of samples were doubled. Essentially, this is saying that when sampling is adequate, as we go from S_1 to $2S_1$, then N_1 goes to N_2 and that $N_2 = 1.1\ N_1$. It can be shown mathematically that in this case $N_2 = 0.9\ N_\infty$ i.e. that when sampling is adequate – doubling results in 10% more species - then 90% of all species have been collected. We developed a model-based estimate of this value when the following question was posed:

What percentage increase would there be in the number of species found if the number of samples were to be doubled?

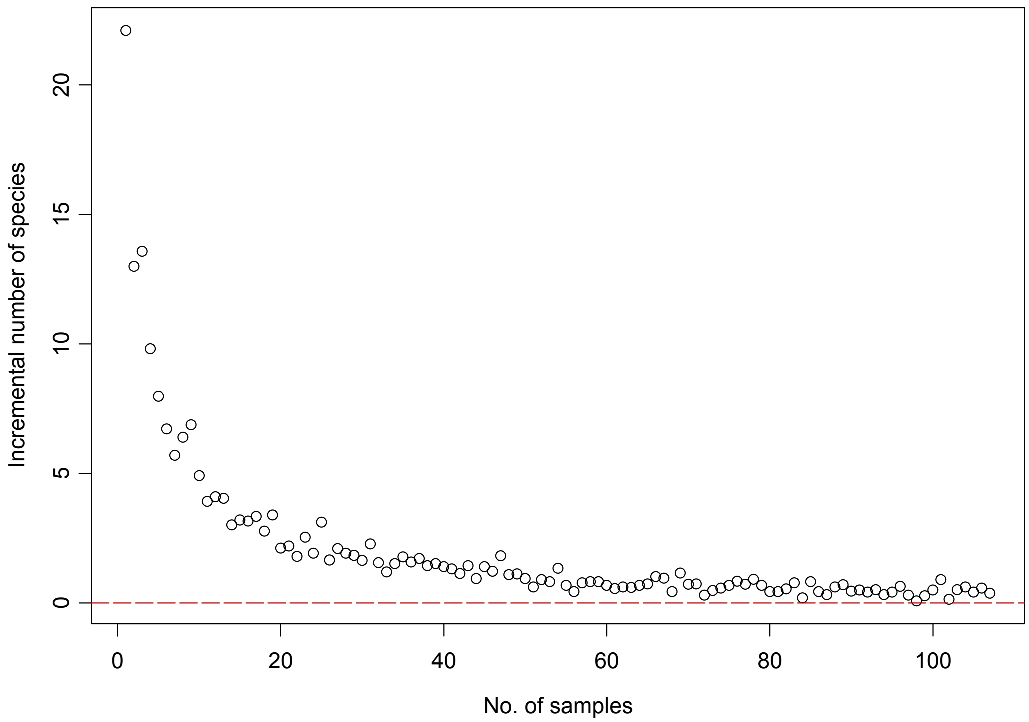

Figure 5.1.7 Average number of new species found as the number of samples increases for fish caught in fish trawls

Models

Let N_s be the number of species found after s samples. A simple model for this quantity is

$$\mathrm{E}[N_s] = A\{1 - \exp(-s/\theta)\}$$

leading to a model for the increments as

$$\mathrm{E}[N_{s+1} - N_s] = A\exp(-s/\theta)\{1 - \exp(-1/\theta)\}$$

Here A is the asymptote and θ governs the rate at which the asymptote is approached. These parameters may be estimated by non-linear regression, but as this requires an assumption of independence and equal variance in the observations, it is clearly more satisfactory to do this with the incremental data rather than the cumulative data directly.

Inspection of the fit of the model shows that this simple model is not quite adequate to describe the situation, as it seems to omit a second component that is decaying quite slowly. We therefore propose a slightly more complex model, namely

$$\mathrm{E}[N_{s+1} - N_s] = A_1\exp(-s/\theta_1) + A_2\exp(-s^{\alpha}/\theta_2) \tag{1.1}$$

The first term is mathematically equivalent to the previous model, but has a slightly simplified form for convenience. The second term contains a power parameter, α, which we anticipate will be much less than 1. In this case the parameters do not have a simple interpretation, but the model appears to capture the message in the data very well.

The parameter estimates for Figure 5.1.7 are as follows:

A_1	A_2	θ_1	θ_2	α
1.5263389	717.9975437	10.3567549	0.2807317	0.1566263

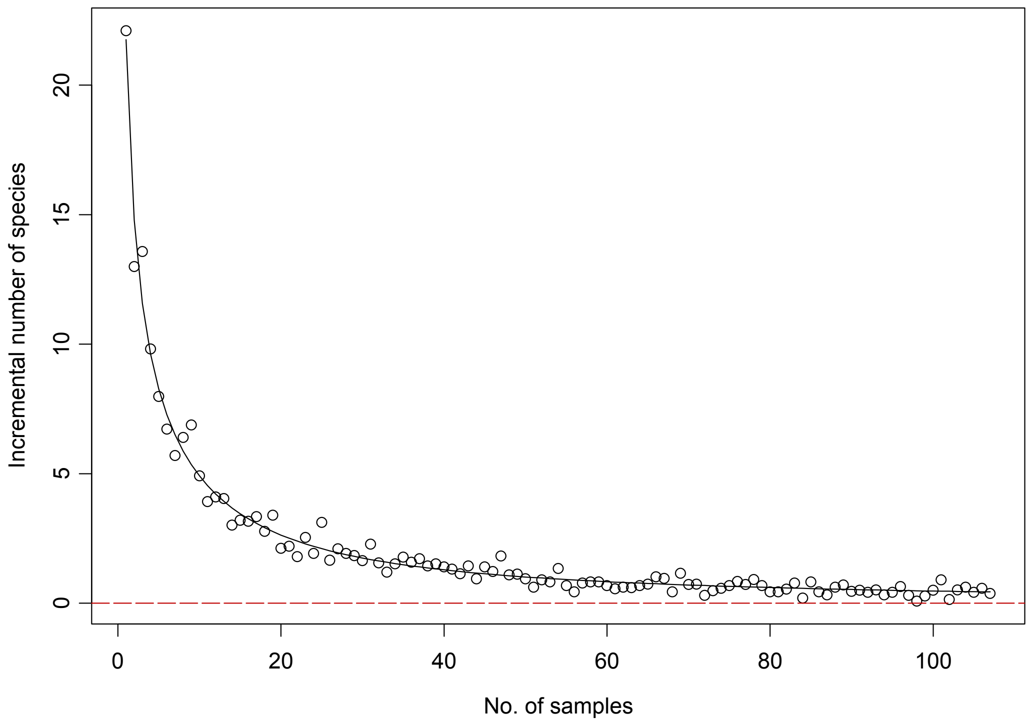

Figure 5.1.8 Species increments with a predictive parametric model fit for fish caught in fish trawls

Figure 5.1.8 shows quite a close fit with a credible error structure. The curve remains quite flat at a nearly constant gap above zero for a long section of the range. This indicates that the approach to a cumulative asymptote may be quite slow.
This impression is confirmed by Figure 5.1.9 which shows the cumulative number of species together with a cumulative version of the model fit, extrapolated to 220 samples. The model credibly suggests that a doubling of the sample numbers from 107 to 214 is expected to increase the number of species from 214.4 to 244.5, an increase of 14%. In this instance accurate standard errors are not easily available. We concede they would be wide, but not wide enough to suggest that this increment could be any lower than, say, 10%.

With this extended model the precise asymptote is not easy to derive mathematically, but further graphical exploration suggests it is approximately 300 species, although the information available to assess this is again very limited (Figure 5.1.10). Thus the total number of species of fish that might be expected in the offshore part of the Gulf of Carpentaria that could be captured in a fish trawl appears to be approximately 300 (Figure 5.1.10). Catching this number of species is achieved only by taking 2000 fish trawls – a very expensive exercise.

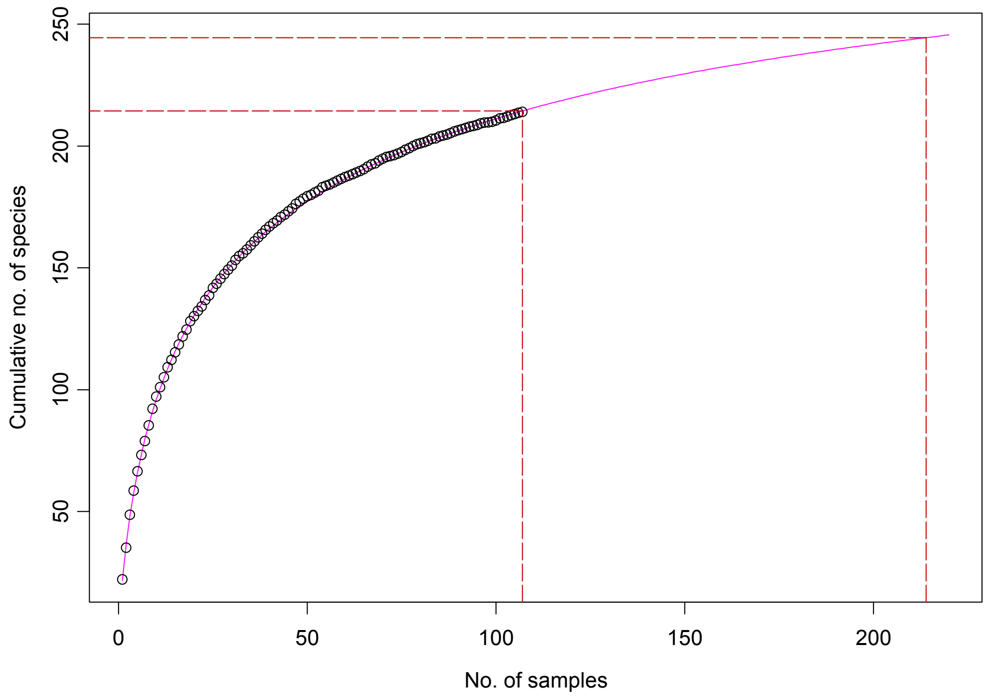

Figure 5.1.9: Cumulative number of species of fish caught with increasing numbers of samples (fish trawls).

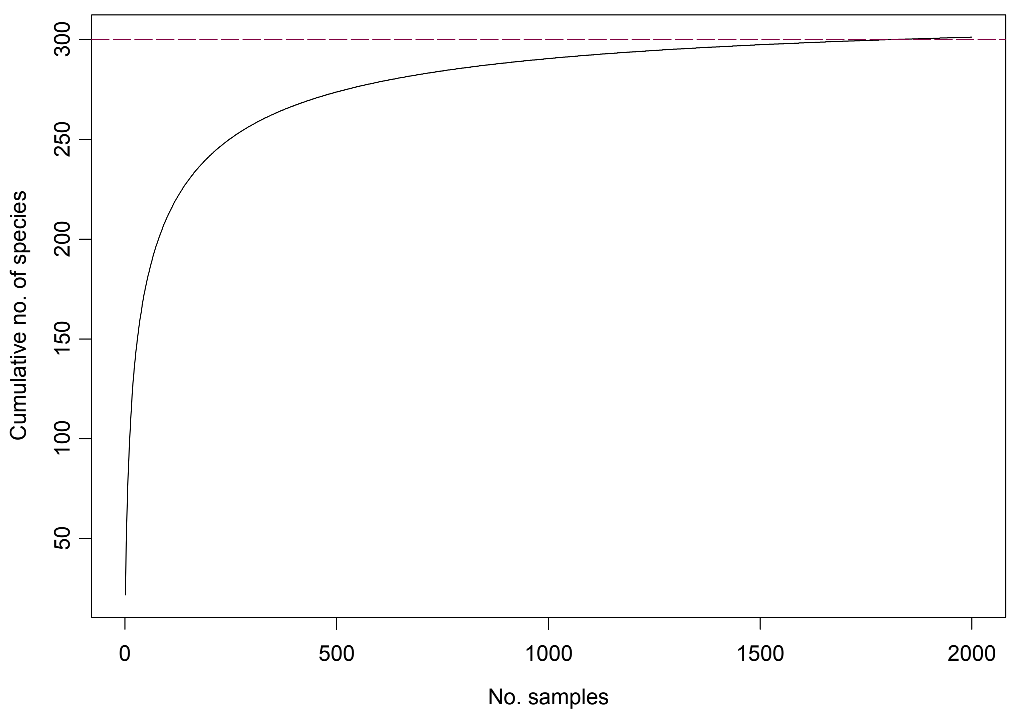

Figure 5.1.10 Predicted cumulative number of species of fish captured with increasing numbers of samples (fish trawls).

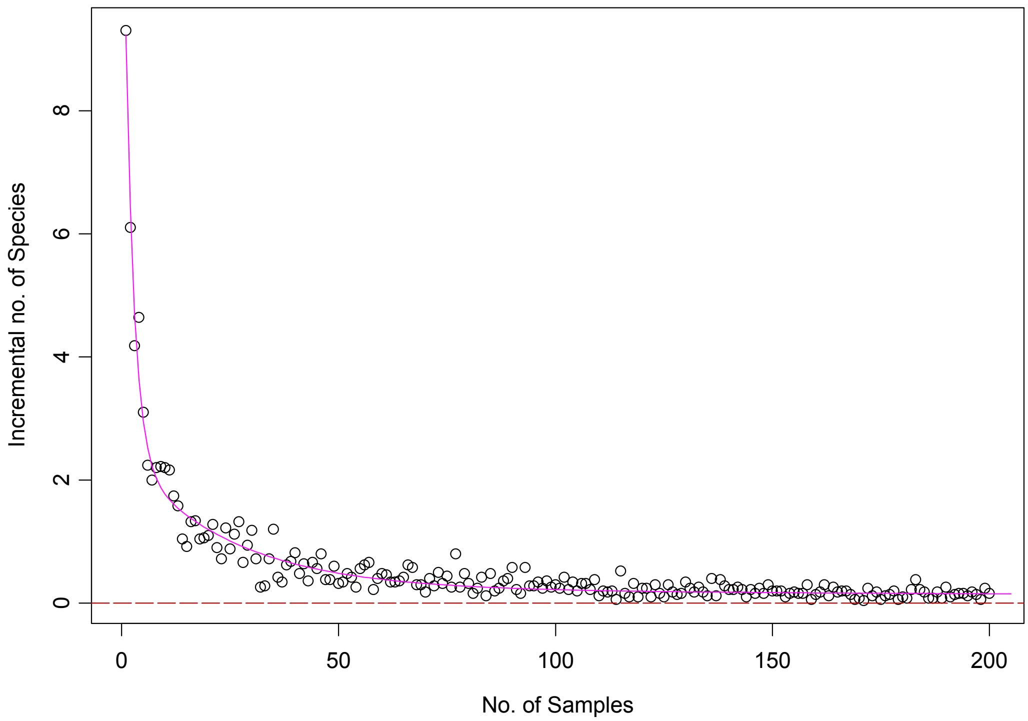

Figure 5.1.11 Species increments with a predictive parametric model fit for the invertebrate bycatch from prawn trawls – first 200 samples only

The parameter estimates for Figure 5.1.11 are as follows:

$$\mathrm{E}[N_{s+1} - N_s] = \alpha_1 \exp(-s/\theta_1) + \alpha_2 \exp(-s/\theta_2) + \alpha_3 \exp(-s/\theta_3)$$

	1	2	3
α	2.235002	11.371021	0.2217126
θ	24.285306	1.982076	531.5617237

In the following three figures we have repeated this analysis for the other groups and gears.

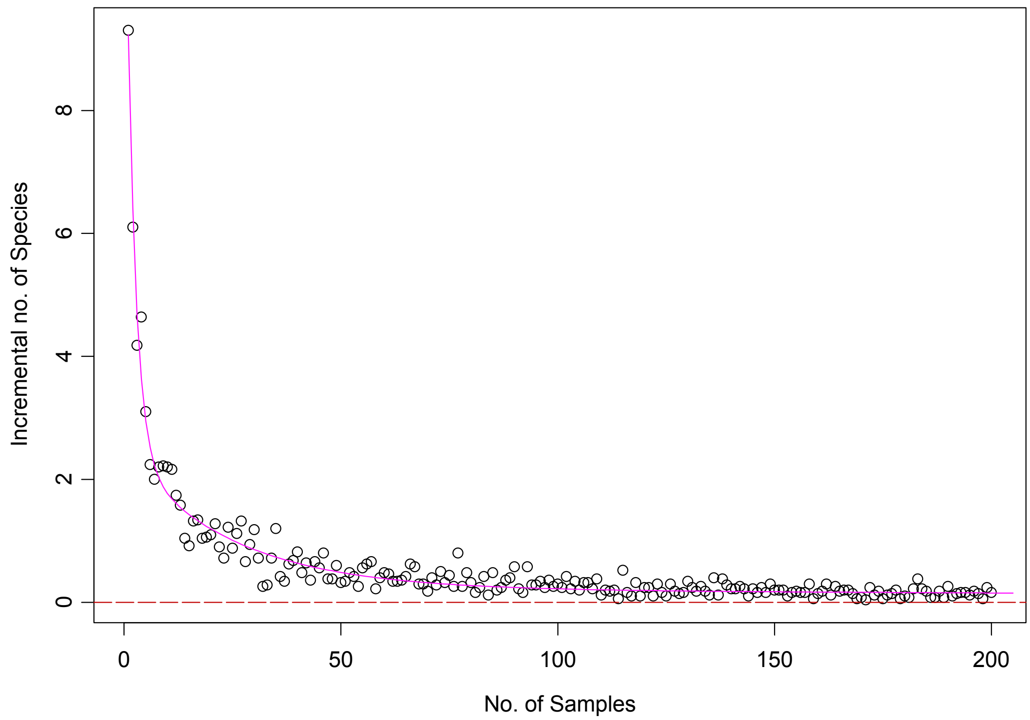

Figure 5.1.12 Species increments with a predictive parametric model fit for fish caught in prawn trawls, first 200 samples only.

The parameter estimates for Figure 5.1.12 are as follows:

$$E[N_{s+1} - N_s] = \alpha_1 \exp(-s/\theta_1) + \alpha_2 \exp(-s/\theta_2) + \alpha_3 \exp(-s/\theta_3)$$

	1	2	3
α	7.935727	39.820455	0.4902918
θ	22.999789	2.118264	516.7433596

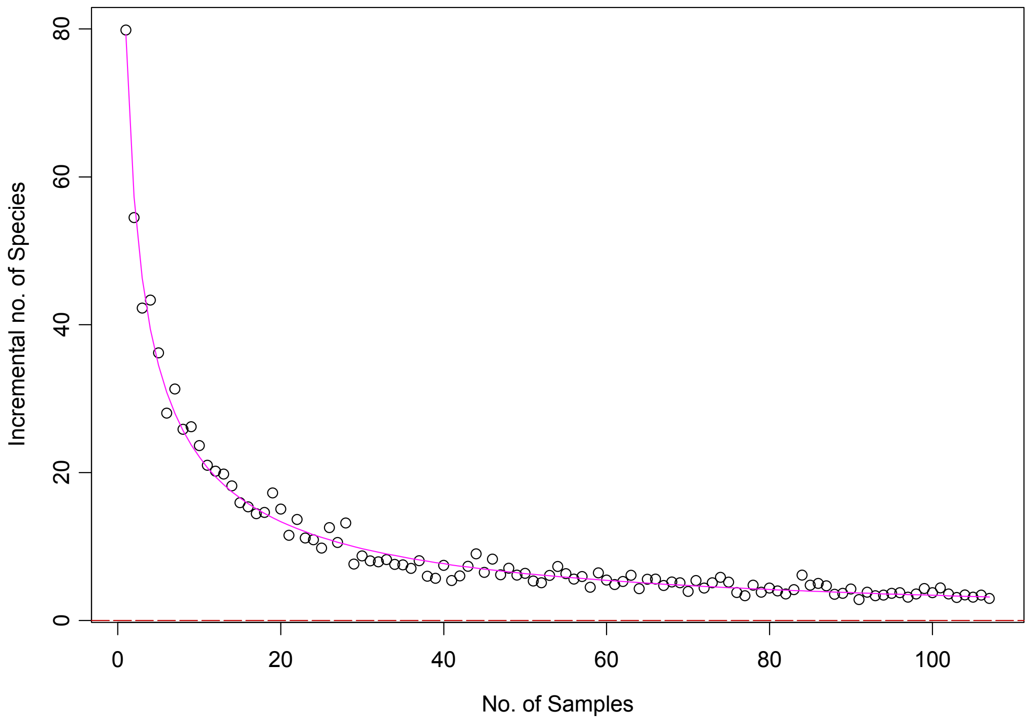

Figure 5.1.13 Species increments with a predictive parametric model fit to species caught in the dredge samples

The parameter estimates for Figure 5.1.13 are as follows:

$$E[N_{s+1} - N_s] = \alpha_1 \exp(-s/\theta_1) + \alpha_2 \exp(-s^{\delta}/\theta_2)$$

α_1	θ_1	α_2	θ_2	δ
1.970871	220.5578	576.2563	0.4977582	0.2221616

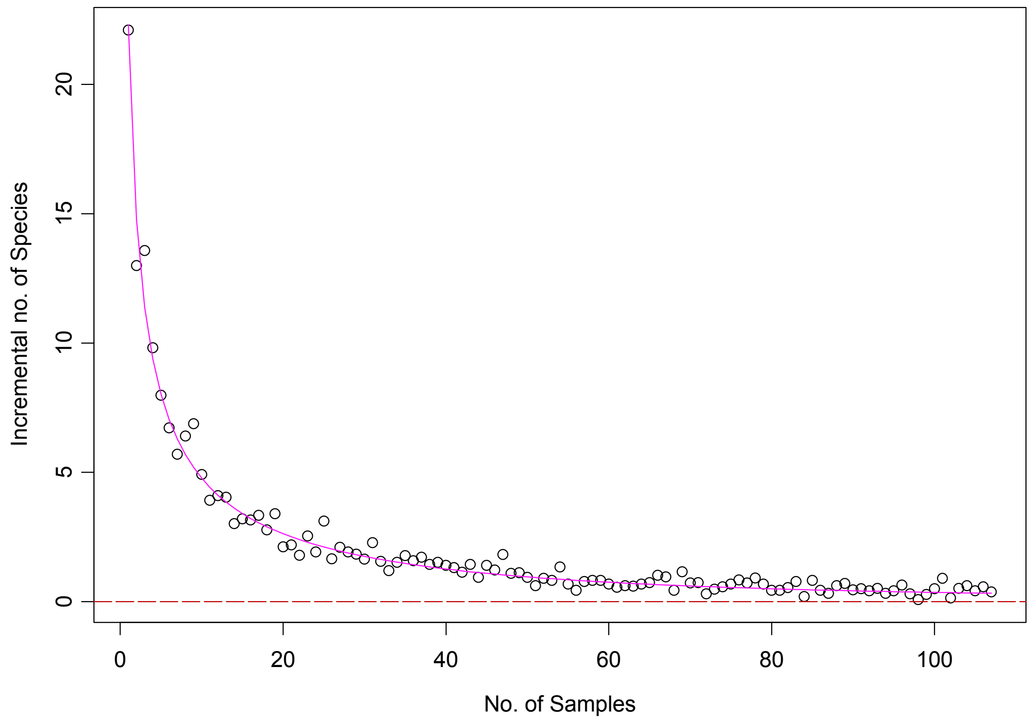

Figure 5.1.14 Species increments with a predictive parametric model fit to the data on fish caught in fish trawls.

The parameter estimates for Figure 5.1.14 are as follows:

$$E[N_{s+1} - N_s] = \alpha_1 \exp(-s/\theta_1) + \alpha_2 \exp(-s^{\delta}/\theta_2)$$

α_1	θ_1	α_2	θ_2	δ
1.136117	26.97166	657.4095	0.29123	0.1721742

Discussion

The really important question that needs to be asked when assessing adequacy is 'adequate for what'? A taxonomist or someone conducting an inventory of the fauna would want to collect as near to 100% of the species in an area as possible. As we have shown above this means collecting a very large number of samples because most species are rare and so this is expensive and time consuming. In the case of fish caught in fish trawls for example, it would take 2000 trawls to catch all 300 species that are estimated to be available to be captured in a fish trawl. As we have shown elsewhere (Wassenberg et al, 1997), a fish trawl does not catch all the species of fish in an area and so this major effort would still not ensure a complete inventory of all fish species. A second requirement could be to obtain a description of the major components of the fauna. Examination of Figures 5.11 to 5.14 shows that the number of new species or taxa per sample is relatively large in the first samples but that it gradually declines and in most cases only around two species or taxa are obtained from additional samples after the first approximately 50.

As we have shown elsewhere, (Chapter 10), a relatively small proportion of the species or taxa collected make up a large part of the weight of the animals that are captured. The implication here is that, at least in the NPF, around 50 samples would adequately describe the major components of the fauna. A third requirement is to assess the biodiversity of an area. Figure 5.1.5 shows the species accumulation curves for various regions of the NPF and Torres Straits. Even though most of these curves show significant under sampling, we can fairly confidently conclude that Torres Straits (upper curve) has a higher level of biodiversity than Weipa (lower curve). Within the remaining areas, it appears that somewhere between 50 and 100 samples will usually give a reasonable indication of the relative biodiversity. This 'rule of thumb' should not be applied indiscriminately to other regions where the total biodiversity may be much more or less.

An interesting property of the species accumulation curves in areas of high biodiversity is that they do not reach an asymptote despite a large number of samples. There always appear to be a few more species. There are several reasons for this, the most important are:

- Catchability is not 1 and so species may be missed in initial sampling. This is particularly important when we consider that use of different gear in the same area will result in different species compositions. For example, a fish trawl is not efficient at catching either pelagic fish or benthic fish such as soles.
- Additional sampling may include habitats not previously sampled. This is also evident in that larger areas tend to yield more species – see for example Frank and Shackell (2001)
- There is an inherent patchiness in marine fauna.
- Many marine species are really rare and so are collected only occasionally.

Together these factors combine to make it almost impractical to collect all the species in tropical marine systems unless the area is very limited. In the NPF where we are dealing with thousands of square kilometers of seabed and the cost of collecting samples is high, we have to be satisfied with considerably less than 100%.

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Frank T and Shackell NL (2001). Area dependent patterns of finfish diversity in a large marine ecosystem. Canadian Journal of Fisheries and Aquatic Sciences 58: 1703-1707

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CHAPTER 5.2

RELATIONSHIPS BETWEEN ENVIRONMENTAL VARIABLES AND THE DREDGE FAUNA

Chapter Authors:

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CHAPTER 5.2

RELATIONSHIPS BETWEEN ENVIRONMENTAL VARIABLES AND THE DREDGE FAUNA

Bill Venables
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Scott Gordon

Summary

Analysis of dredge data

- Biodiversity as indicated by number of species caught per station (α biodiversity) was higher in the eastern and northern GoC but there was a high level of variation.
- Rarely caught species (those caught in 3 or fewer trawls) were found mainly in the eastern and northern sections of the GoC. Oxygen and temperature were the most influential terms but the pebble fraction of sediments also contributed
- Total biomass caught at a station was used as another biological property. Although there is not a large spatial structure, there appears to be higher biomass in the NE, SE and SW regions with lower values offshore and in the NW
- A tree model showed oxygen is the most effective variable in determining log(total biomass) but the multiple linear regression coefficient is about 49% indicating a weak level of prediction
- A linear regression model yielded the terms oxygen, bottom current stress, K490 and chlorophyll

Surrogates

- We found only limited relationships between the seabed invertebrate fauna and the environmental variables available for analysis. We attribute this to the limited range of samples available – all from offshore in the Gulf of Carpentaria, and the limited type of environmental factors that could be tested
- We tested the relationship between biodiversity and a range of physical and chemical factors (depth, bottom current stress, chlorophyll, K490 absorption, NO_3, PO_4, salinity, O_2, temperature, Si, and the percentages of cobble, granules, mud, pebble and sand).
- The most significant generalized linear model contained two terms – oxygen and temperature. This probably results from thermocline formation in the GoC and the low range of other terms in the region

Indicator species

- A species of spider crab (*Micippa excavata*) had the highest number of associated species (128) and could be regarded as an indicator species for biodiversity of the fauna sampled by the dredge. The next highest indicator species was a small shrimp (*Sicyonia cristata= lancifer*) which was associated with 98 species

SURROGATES

Bill Venables

Introduction

In this section we have analysed the relationship between the benthic invertebrate fauna of the Gulf of Carpentaria and a range of environmental factors. We have used data from 107 dredge samples taken on CSIRO research cruise SS0390 in the GoC in 1990. Details on the collection of these samples is summarised in Table 3.1.1 in Chapter 3.1 (Sources of Data) more details are given in Long et al (1995).

α-biodiversity

One measure of biodiversity is simply the number of species caught, it is referred to as the α-biodiversity. For this data set the α-biodiversity is based on 8 to 163 separately identified species at each station. The data itself can be interpolated to show an indication of a spatial pattern in the Gulf of Carpentaria, as shown in Figure 5.2.1. Observation points are also given on this diagram

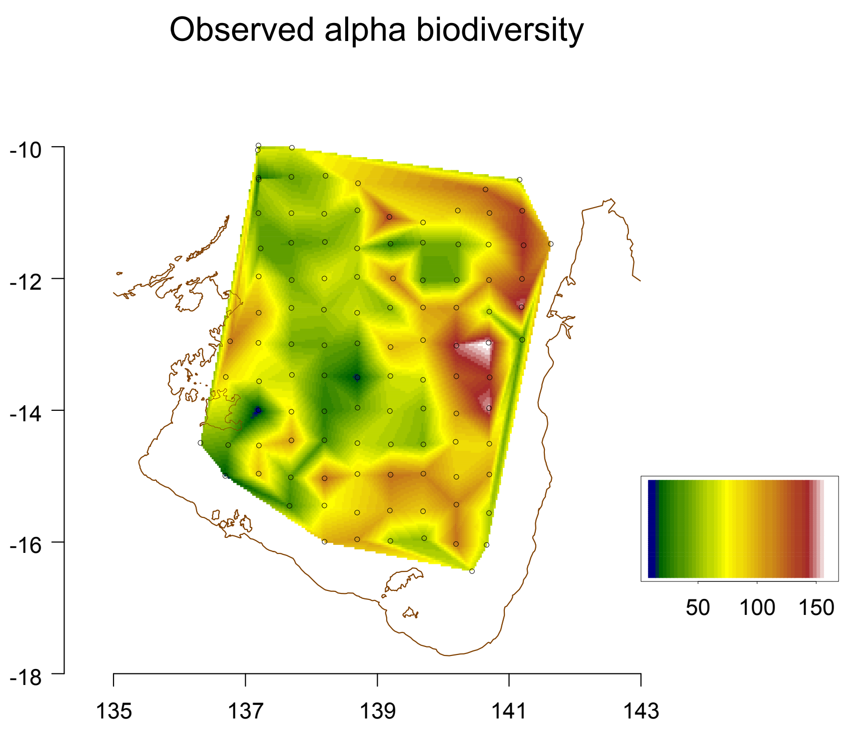

Figure 5.2.1 Interpolated α-biodiversity for the dredge data. The scaling refers to numbers of species captured.

The overall impression from this diagram is that the α-biodiversity is higher in the eastern and northern parts of the Gulf and lower in the southern and western parts. The level of variation is high however and the pattern shows a strong dependency on the observation points. To explain the pattern in terms of underlying predictor variables we considered a generalized linear model with α-biodiversity as the discrete response and possible predictors from Table 5.2.1.

Table 5.2.1 Possible predictor variables and their origins. K490 is the light attenuation coefficient at 490 nm

Physical	SeaWiFS	CARS	Sediment
Depth	*Chlorophyll*	*Nitrate*	*% Cobble*
Bottom Stress	*K.490*	*Phosphate*	*% Granule*
		Salinity	*% Mud*
		Oxygen	*% Pebble*
		Temperature	*% Sand*
		Silica	

The generalized linear model considered functions of these predictor variables, including spline terms in the major continuous predictors (*Depth, Bottom Stress, Chlorophyll, Salinity, Temperature, Oxygen, Silica)* and linear or polynomial terms in the remaining variables.
We considered several possible distributions for the response, but the most satisfactory (in the sense of producing the least surprising residual patterns) was a negative binomial model with a log-link (Venables and Ripley, 2002). Because of strong redundancy patterns in the predictor variables several possible models performed about equally well. The simplest effective model we could find contained just two terms, namely spline terms in *Temperature* and *Oxygen*, with 5 knots each located at the percentiles of the respective variables. Natural splines were chosen for convenience. The model may be expressed as

$$N \sim NB(\theta,\mu),\ \log(\mu) = \beta_0 + ns(Temperature, 5) + ns(Oxygen, 5$$

Here μ is the mean of the distribution and the variance is $\text{Var}[N] = \mu + \mu^2 / \theta$; as θ becomes large the distribution approaches Poisson form. The estimate of this parameter is

$$\hat{\theta} = 7.46, \quad \text{SE}[\hat{\theta}] = 1.14$$

The two spline-function components are shown in Figure 5.2.2. Both components have an optimal range and deviation from this maximum in either direction results in a fall in log-mean.
The dotted lines on either side of the function indicate point wise confidence intervals for the component and where these become very wide the precise form of the function becomes more doubtful. The fine vertical lines at the base of the plots indicate effectively where the variable is measured and hence give some idea of the local strength of information on which the estimate is based.

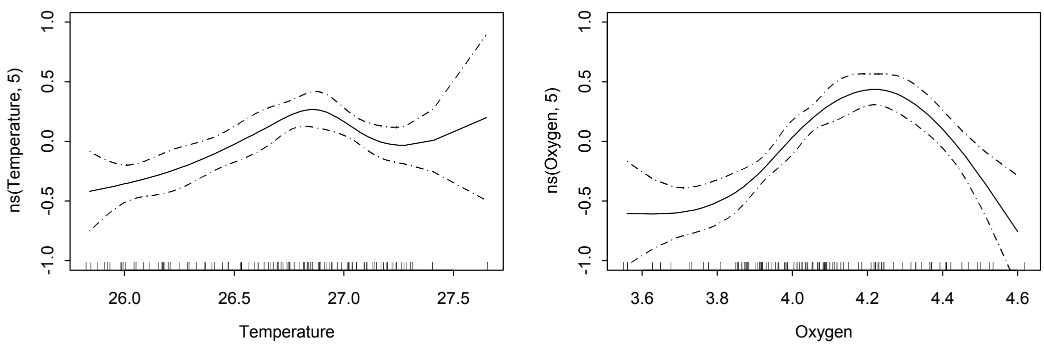

Figure 5.2.1 Spline function components of the negative binomial log-mean

The mean α-biodiversity pattern as implied by the model is shown in Figure 5.2.3. This is similar to the data-based estimate shown in Figure 5.2.1, suggesting that the model captures the mean pattern in the data reasonably well and acts as a justified smoothing mechanism.

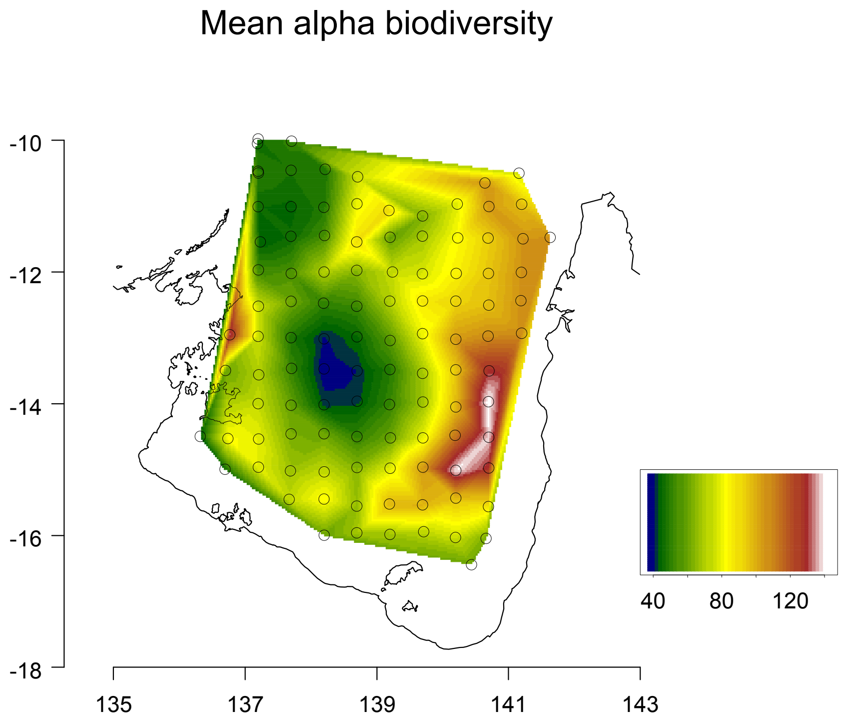

Figure 5.2.2 Model-based estimate of mean α-biodiversity for the dredge data

Since only two variables are involved in the model for the log-mean it is useful to look at the degree of smoothing through the pattern in predictor variable space.

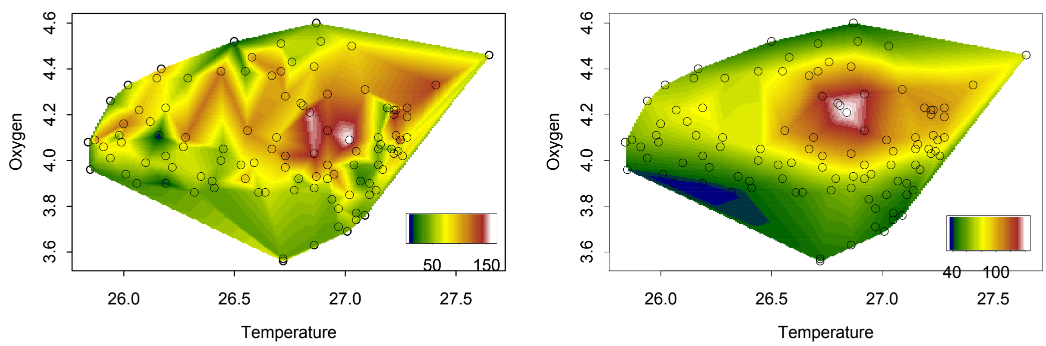

Figure 5.2.3 Observed and expected α-biodiversity patterns in predictor variable space

Sampling coverage of the predictor variables space is not nearly as uniform as it is of physical space, but it is reasonable. The model does exert a high degree of smoothing in this space, though.

Rarely caught species

The second biological property tested was the distribution of species rarely caught in the dredge. We defined a species to be "rarely caught" if it appeared in 3 or fewer stations out of the total of 107 that were sampled. The maximum number of rarely caught species appearing in any one station is 45 and the minimum 0. In Figure 5.2.5 the number of rarely caught species at each station is represented as a circle centred at the station with area proportional to the number caught at that station.

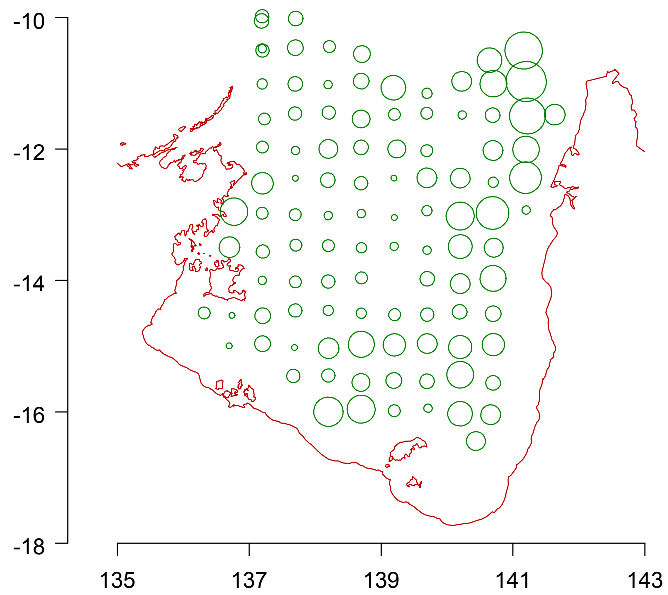

Figure 4.1.5 Numbers of species rarely caught in the dredge at each station

There is a clear tendency for more rarely caught species to be found in the eastern and northern sections of the region.

We may construct a similar negative binomial for this discrete measure. The same two-spline terms in *Temperature* and *Oxygen* are the most influential once again. There is also a linear term in the proportion of *Pebble* in the sediment sample that contributes in this case.

Another simple heuristic way to view the degree of 'exotic' character of the catch is to standardize the Presence/Absence matrix so that the column sums are unity and then to take the row sums as a simple 'index of rarity' associated with the catch. In these totals, species caught only once will contribute 1 to the sum, species caught twice will contribute ½, and so on. Hence large values of the index will indicate that the catch contained many relatively uncommonly caught species. A simple representation of the result is given in Figure 5.2.6, where the circles centred on each dredge station have radii proportional to this simple rarity index. Again the Eastern and Northeastern parts of the Gulf have a relatively higher index.

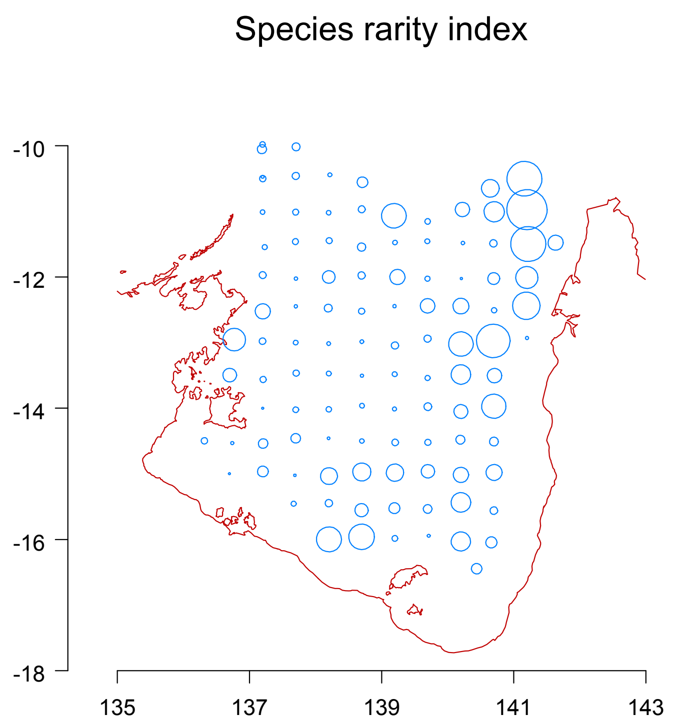

Figure 5.2.5 Simple index of the degree to which the species appearing at each station were rarely caught

The total biomass

The third biological property that we used is the total biomass caught in the dredge at each station, standardized to an hourly rate. As with α-biodiversity the composition of the biomass will vary greatly with the samples. Biomass and biodiversity are largely independent of one another.

If we look at the distribution of total biomass between dredge samples without considering possible driver variables it becomes clear that the distribution is very skew. This skewness is largely removed if we work in the log scale. This is shown in Figure 5.2.7, which gives the same simple kernel density estimate of this distribution on the natural and log scales. This in turn suggests that the external drivers to the system tend to induce proportional rather than additive changes to the total biomass, which seems heuristically reasonable, at least.

Most of the analyses in this section will focus on log (Total Biomass) from here on.

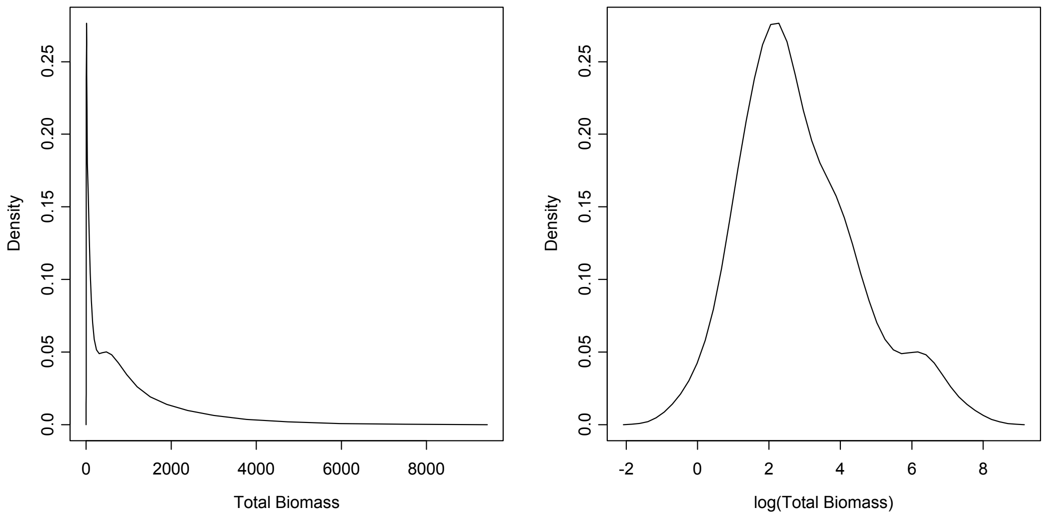

Figure 5.2.7 Density estimate of Total Biomass on the natural scale (left) and on the log scale (right)

The observed pattern of total biomass is shown in Figure 5.2.8, which shows the crude total biomass at each station with simple linear interpolation between stations. There is not a great deal of spatial structure although we may note that there seems to be some consistently higher total biomass inshore on the north-east, south-east and south-west sections of the GoC, with low total biomass (mostly) offshore and towards the north-west section.

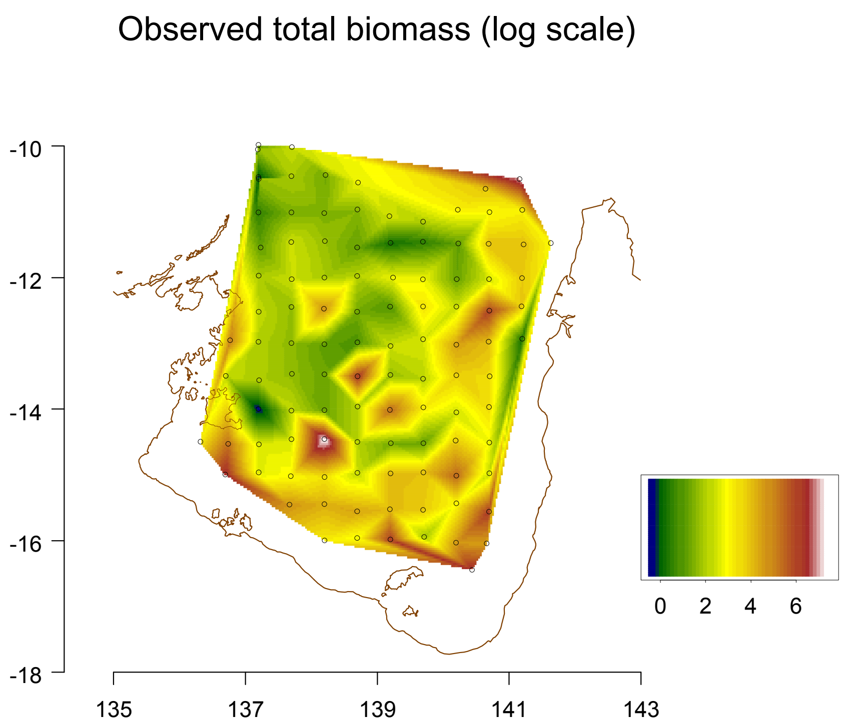

Figure 5.2.8 Observed total biomass with linear interpolation between stations

We considered two approaches to building predictor models for the total biomass (and hence implicitly uncovering effective surrogate variables), namely a tree model and an ordinary regression model.

A tree model for the total biomass

Tree models build predictors for the variable of interest, here log (total biomass), by constructing binary decision rules. At each stage the sample is split into two parts by taking respectively all observations to the left and to the right of a break point in a given variable. Variable and break point are chosen so that the greatest possible reduction in residual sum of squares is achieved at each stage. After any stage, the same procedure is applied independently to each part of the partition. The result is presented in a tree diagram, of which an example will be given shortly. There are subtle questions of just how complex a tree model is warranted by the data and the statistical method of cross validation is usually used to address this.

To apply the tree model for prediction the predictor variables for the new case are used to guide a way down the tree to a terminal node. At the terminal node the predictor is just the sample mean of those observations in the original sample that were allocated to that node.

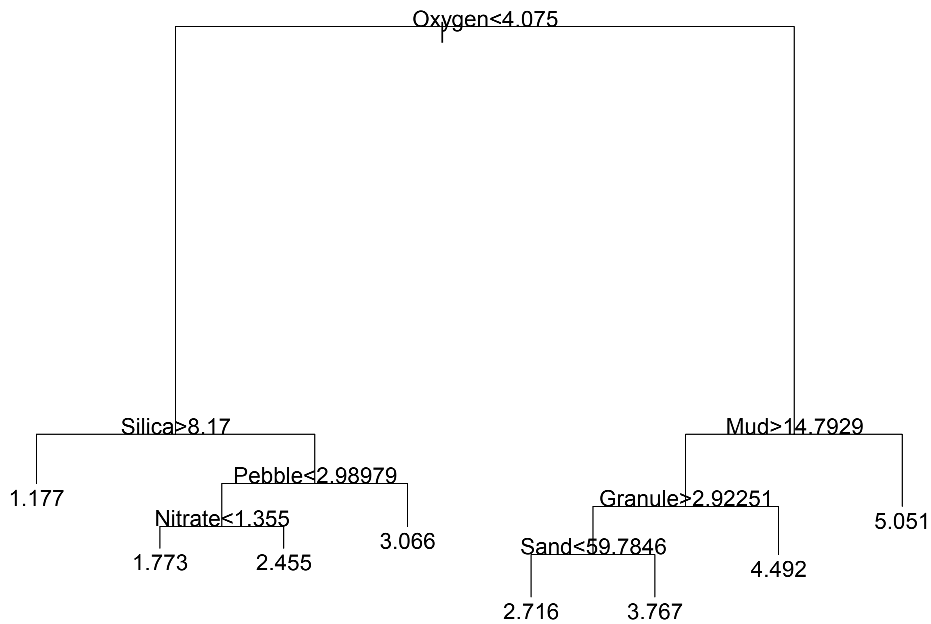

Figure 5.2.9 An initial tree model for the log (total biomass)

The initial tree model shown in Figure 5.2.9 indicates that the first split is made on Oxygen. If the value is less than 4.075 the left branch is selected, otherwise the right. The lengths of the vertical lines in the diagram are proportional to the reduction in sums of squares achieved by that split, and the values below the terminal nodes are the prediction values for that node. This indicates that Oxygen is the most effective variable in determining log (total biomass), but other variables may be able to achieve some slight gains as well. In this case, however, the standard rules suggest that a simple tree model that contains only the first split (on Oxygen) is warranted in this case.

Using the tree model for back casting on the current data gives a smoothing of the original data, possibly highlighting features made obscure by random variations in the original. This is shown in Figure 5.2.10, which shows the interpolated back cast data.

The analogue of the multiple regression coefficient for this data and tree model is only about 49%, indicating that only a fairly weak level of prediction is achievable.

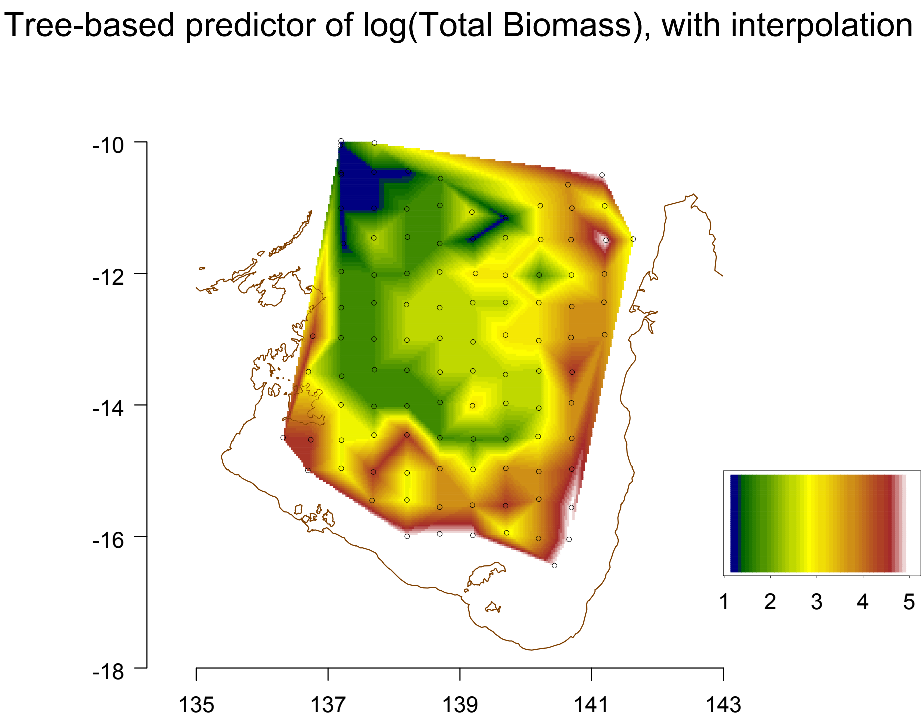

Figure 5.2.10 Tree model back casting of the original log (total biomass) data

A linear regression model

A more standard form of predictor for this continuous response variable is a linear model. This has the advantage of indicating continuous dependencies on continuous predictor variables instead of discontinuous relationships as in the tree models. These are familiar from elementary statistical practice and will not be further described here.

In building a regression model we considered all variables named in Table 5.2.1.

Since the sediment variables are percentages that add to 100, not all can be included at once in the same linear model, but if, for example, we transform them to the logistic scale,

$$t = \log \frac{x + \varepsilon}{100 - x + \varepsilon}$$

(where ε is a small constant used to avoid singularities) they are no longer linearly dependent in the same way and may all be included. There are other heuristic reasons to suggest that this transformation may be supported on other grounds as well. As the model building process proceeded we also found it useful to reduce Cobble to a binary factor recording simply whether Cobble was present or not.

Some regression variables were also considered in log-transformed forms but the only variable for which this was important, ultimately, was Oxygen.

As well as the primary variables and their transformations we considered polynomials in specified variables and two-term interactions between all terms. We adopted a model-building strategy initially guided automatically by minimizing the AIC but pruned at the later stages by stepwise elimination of least significant terms. In the end the model turned out to be very simple with terms in Oxygen (again the dominant contribution), Bottom stress, and K 490 Chlorophyll. The final model had the form

$$\log(\text{Total Biomass}) = \beta_0 + \beta_1 \log(\text{Oxygen}) + \beta_2 \text{Chlorophyll} + \beta_3 \text{K490} +$$
$$\beta_4 P_1(\text{Stress}) + \beta_5 P_2(\text{Stress}) + Error$$

where P_1 and P_2 are the first and second degree orthogonal polynomials. The coefficients and their standard errors and significance values are shown in Table 5.2.2.

Table 5.2.2 Coefficients and significance values for the regression model

Term	Beta	Std. Error	t-value	Signif. Prob.
(Intercept)	-13.05	4.57	-2.86	0.01
Log (Oxygen)	16.46	2.92	5.63	<0.00001
K 490	-181.50	80.38	-2.26	0.03
Chlorophyll	11.23	5.59	2.01	0.05
P_1(Stress)	2.24	1.42	1.58	0.12
P_2(Stress)	2.69	1.54	1.75	0.08

Neither coefficient for the polynomials in bottom stress is significant at the conventional 5% level but the two terms together are just 5% significant. The case for a term in bottom stress is not strong.
More insight on this model can be gained by looking at the profiles of each of these terms in the sense of the (relative) contribution each makes to the error. These are shown in Figure 5.2.11 along with point wise standard errors and the so-called partial residuals, which are the original response variable values but adjusted for the contributions of all other terms.

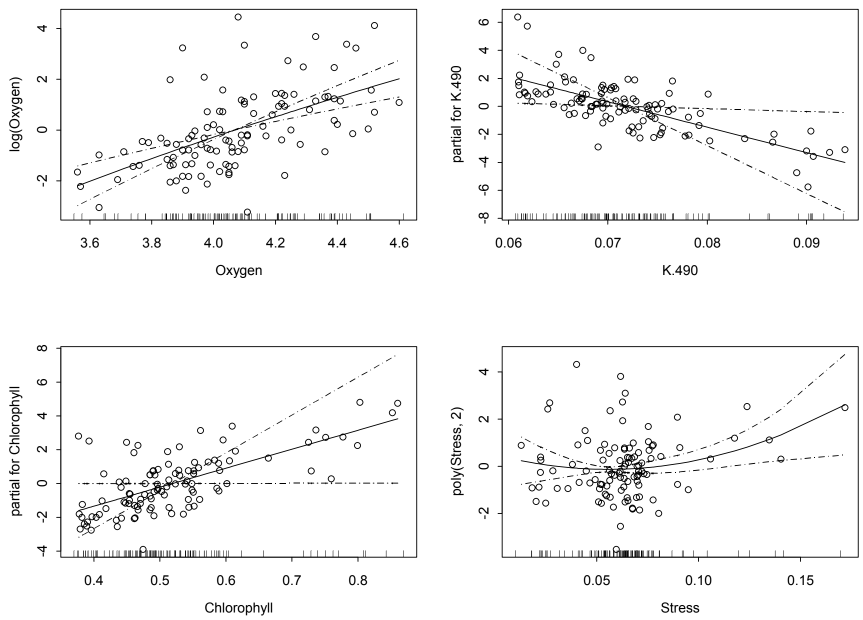

Figure 5.2.11 Partial contributions to linear model predictor, with standard error curves and partial residuals

The predictions from this model are spatially much smoother than the tree model. These are shown, again with linear interpolation between stations, in Figure 5.2.12. The features are now probably artificially crisp.

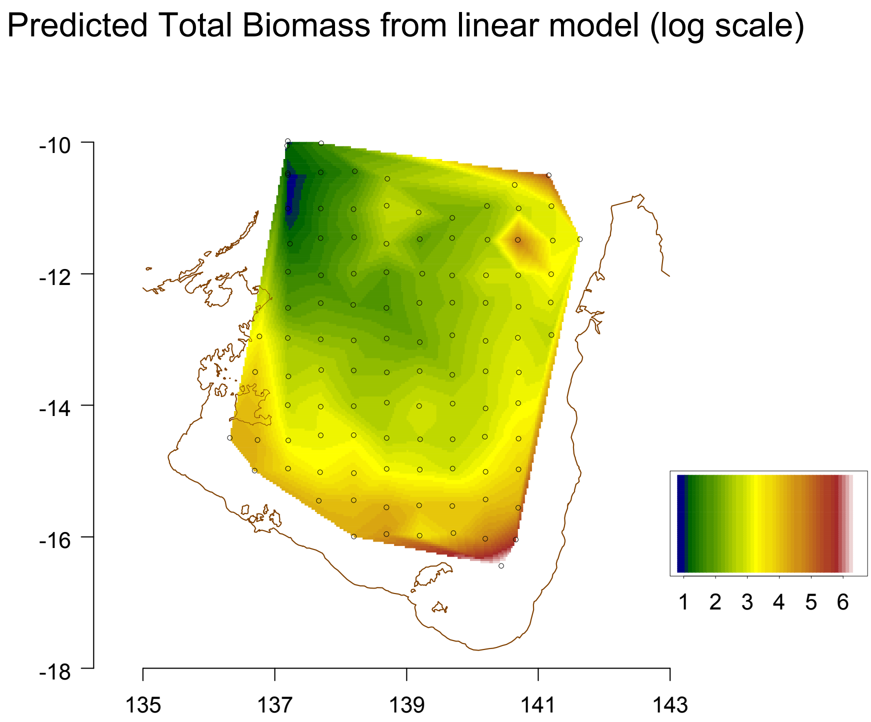

Figure 5.2.12 Predicted log (total biomass) from linear model, with linear interpolation

Surrogates derived from the dredge data

We used several different analyses in an attempt to identify environmental factors that might be used as surrogates for the seabed fauna collected by the dredge.

Canonical Correspondence Analysis

Canonical correspondence analysis (CCA) finds simultaneous ordinations of Stations and Species with a maximum correlation property. The ordination pairs are ordered, with the first pair being the most effective at maximising the correlation, the second pair the next most effective subject to the constraint that they be uncorrelated with the first, and so on. The technique uses a Stations × Species matrix to specify the strength of association of each species with each station separately. Several choices are possible, the simplest being presence/absence. An alternative is to use $\log(1+weight)$ rather than presence/absence to give more specificity to the association measure. The log-transform will both make the measure unit free and diminish the effect of outliers. Adding 1 to the weight leave zeros as zeros but otherwise has little effect.

The station ordinations form a natural coordinatisation for studying similarities and differences between stations determined by the biota and the species ordinations similarly form a natural coordinatisation of species to study or construct notional ‘assemblages’ of species that tend to occupy similar stations.

The technique is sensitive to outliers and to species that occur either too rarely or too frequently in a presence/absence framework. For this reason we examine several different protocols for choosing species to use in the analysis. It is also necessary to exclude stations with too few species occurring of the set of species chosen, but for our data sets this is rarely a problem. We begin with presence/absence representations of Station × Species association.

Dredge data, presence/absence

The sled data, when restricted to the Gulf of Carpentaria, has 1328 species observed at 146 stations. The frequency of stations within cruises is given in Table 5.2.3. We initialled considered the data from all cruises.

Table 5.2.3 Dredge stations in each of four cruises

Cruise:	SS9003	SS9702	SS9708	SS9803
No. Stations:	107	5	15	19

Choice of species

Rarely occurring species tend to inflate the canonical correlation by isolating a few stations at which only rarely occurring taxa occur. This may be a real effect but in most cases it is an artefact of the sampling. One way to assess a minimum occurrence requirement for a taxon to be included is to plot the change in canonical correlations as the criterion for inclusion (which we call the minimum occupancy requirement) is increased. Figure 5.2.13 shows the change for the first 5 correlations as the minimum occupancy requirement is raised from 1 to 30 (out of 146 stations). Initially the correlations decrease steadily but by about 20 they tend to remain stable for a while, and the first two correlations are considerably higher than the ones following. We chose a cut-off requirement that each taxon occurred in at least 20 stations and we only considered the first two canonical ordinations. This gave 146 stations with 131 taxa.

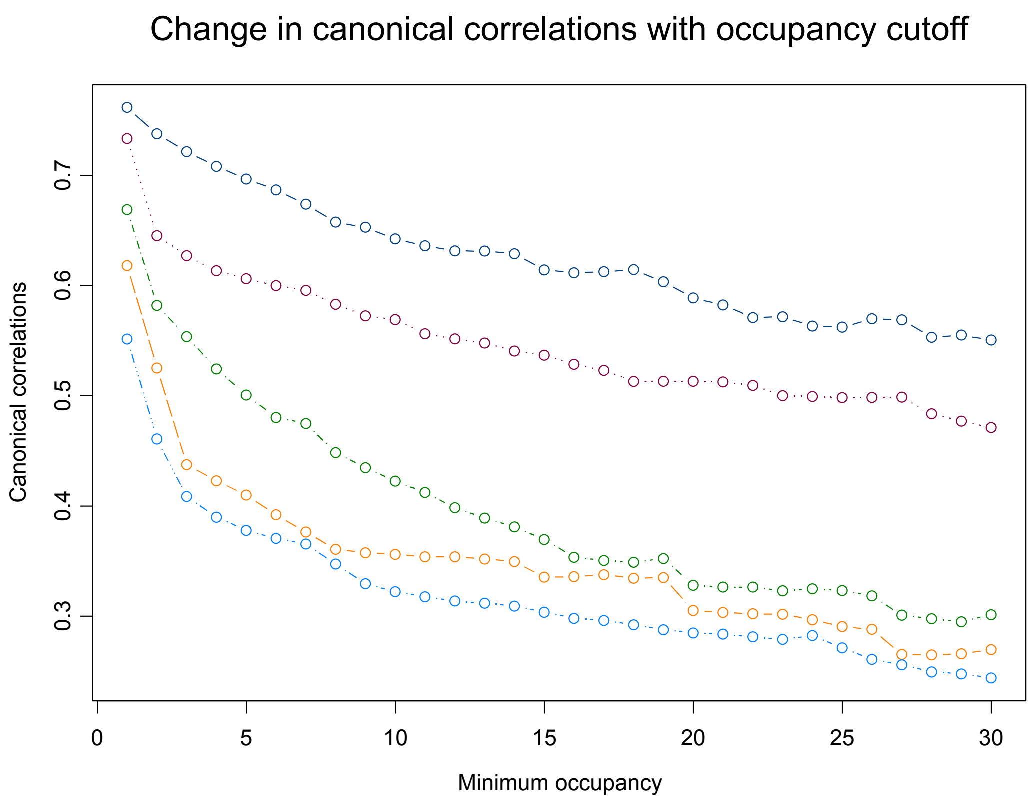

Figure 5.2.13 Change in canonical correlations with increasing minimum occupancy requirement for inclusion of taxa

The maximum correlations are 0.588 and 0.513. The plot in Figure 5.2.14 shows the first and second ordinations, but identified by the cruise in which the station was observed.
There are clearly very strong differences between cruises, which may be due to differences in time of sampling, time of year, subtly different sampling methods, very different focus of sampling in the geographic sense or a combination of all of these. In our view this suggests that the cruises should be considered separately, or at least the 1990 cruise should be considered on its own. In the remaining cruises there were relatively few dredge samplings anyway.

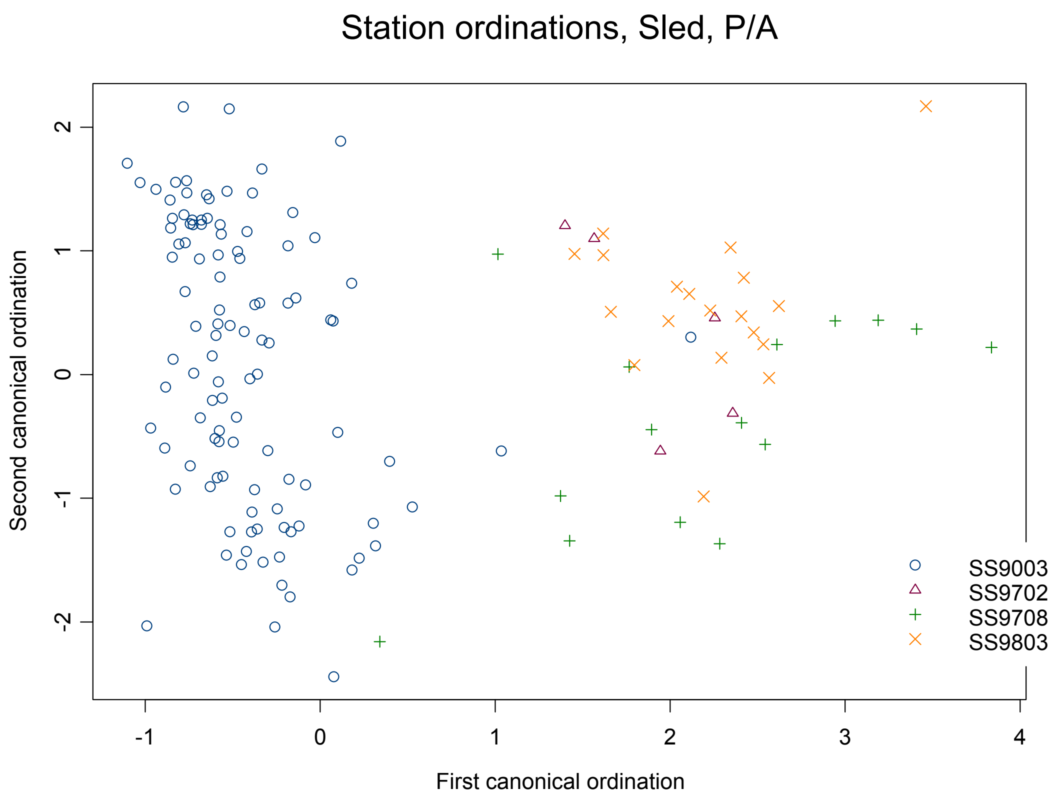

Figure 5.2.14 Plot of first and second canonical ordinations of stations, all cruises. For inclusion a taxon had to occur in at least 20 stations.

Restricting the data to the 1990 cruise gives 107 stations. We chose a proportionately lower minimum occupancy requirement of 15 and this gave a 107 × 144 Stations × Taxon matrix.
The first 5 canonical correlations were 0.5451327, 0.3295221, 0.3069144, 0.2932385 and 0.2769716, strongly suggesting that only the first ordination is probably useful.
Figure 5.2.15 shows a smoothed, interpolated version of this first canonical ordination. Areas with similar colour are suggested to have somewhat similar patterns of biodiversity.

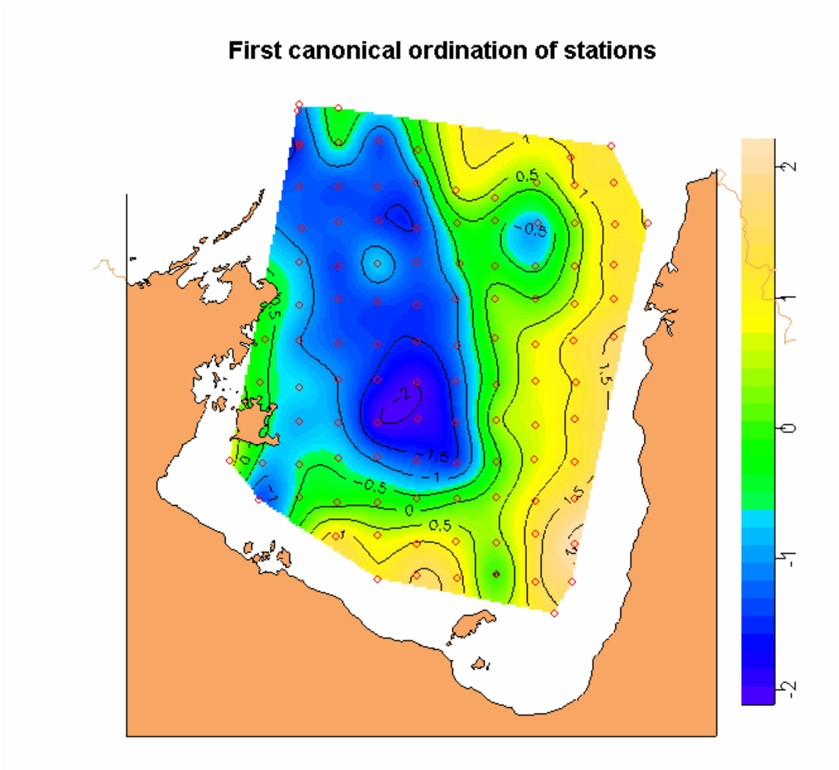

Figure 5.2.15 Smoothed and interpolated representation of the first canonical ordination of the 1990 cruise stations. Dredge data, presence/absence, with a minimum occupancy cut-off of 15. 107 stations × 144 taxa.

One way to investigate surrogates is to relate this ordination to the available predictor variables. A simple way to do this is to use tree-based methods to predict the observed canonical score (or ordination) from the available predictors. This is a slightly non-standard procedure but justified in the sense that the results are seen only as investigatory.

Figure 5.2.16 shows the usual representation of this regression tree. The height of the vertical lines is proportional to the effectiveness of the branch in reducing the residual sum of squares, that is, in improving the fit to that part of the data. Clearly sediment variables dominate, with Sand (or, almost equivalently, Mud) as the first branching variable.

The occurrence of *Nitrate SD* (local variability in Nitrate reading) and *Oxygen SD* (similarly) suggest that no clearly interpretable variable is available, but these have been selected by the fitting algorithm as the nearest to such an interpretable variable. Figure 5.2.17 shows a smoothed interpolated representation of the *%Sand* variable with the major cut point of the tree model indicated by a black contour line and minor cuts indicated by red contour lines. Cuts based on *Mud* are shown by a very near equivalent cut based on *Sand* and minor cuts based on non-sediment variables are not shown.

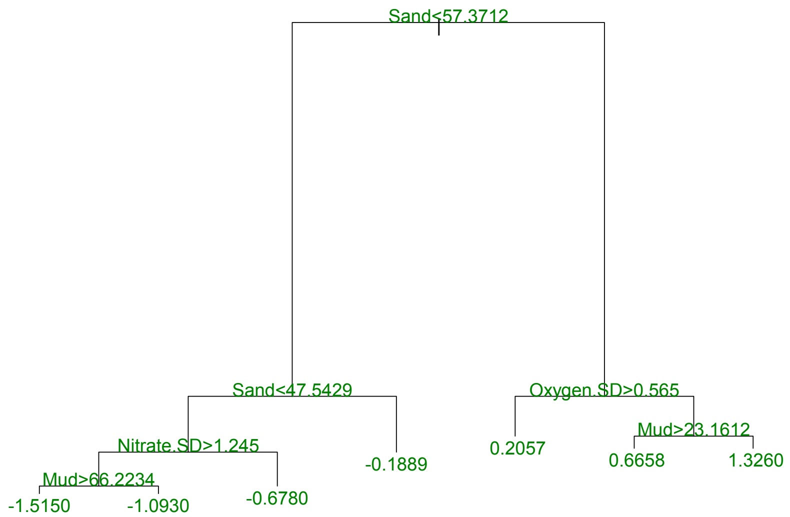

Figure 5.2.16 Regression tree for first canonical ordination of the dredge stations

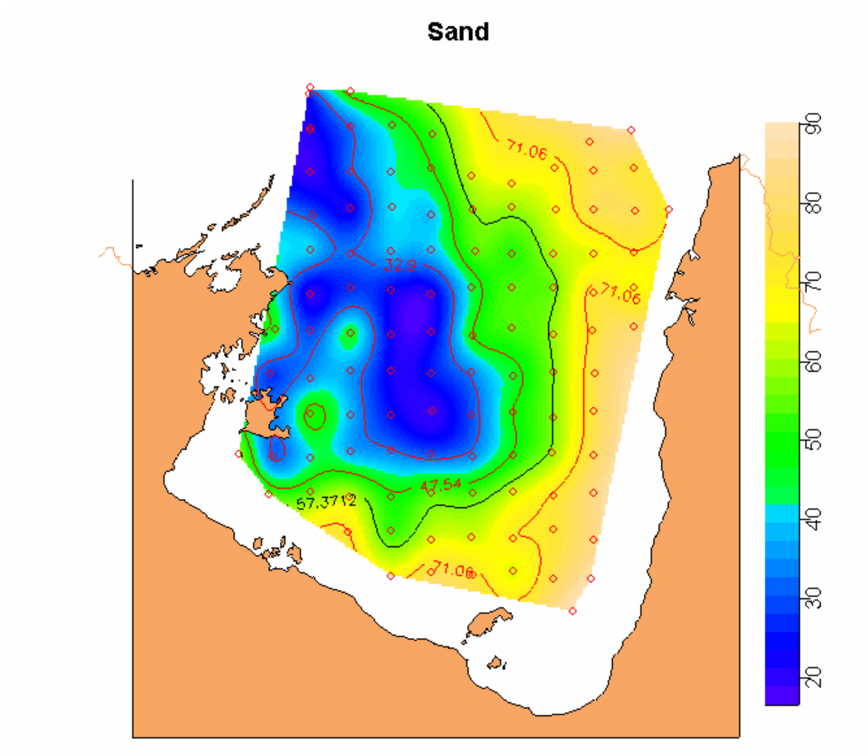

Figure 5.2.17 Major cut contours of the tree-based model for the first canonical ordination. Cuts based on Mud have been changed to near equivalent cuts based on Sand and cuts based on non-sediment variables are not shown.

Species ordinations

For ease of presentation we used the first two ordinations to show the species. Figure 5.2.18 shows such a plot where the points have been classified on the basis of the first two digits of their species code. There appears to be no discernable pattern, in other words no clear association even with high-level taxonomic classifications. The second canonical ordination appears to rely heavily on singling out one taxon, the crab *Portunus acerbiterminalis* (20241228), from the bulk of the others.

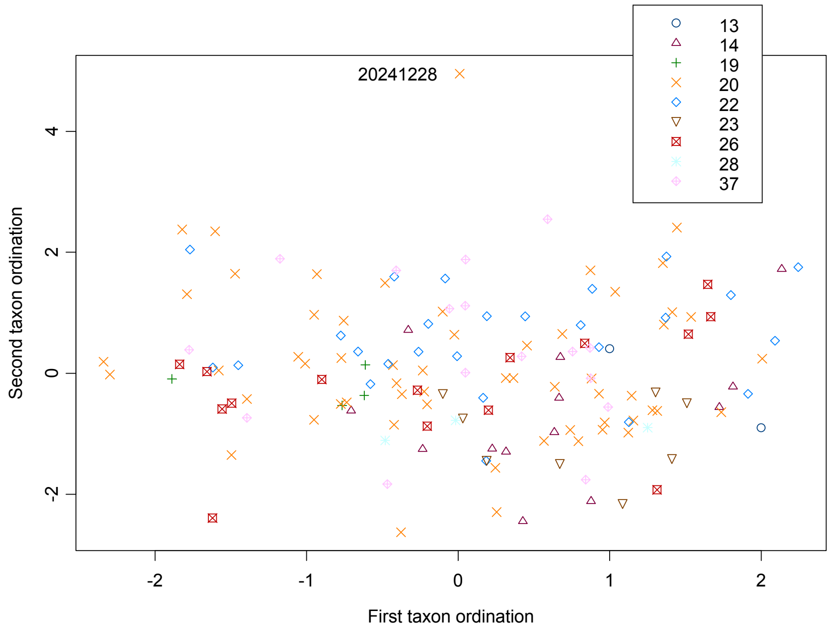

Figure 5.2.18 First two canonical ordinations of the taxa from the 1990 cruise dredge data. Species 20241228 = *Portunus acerbiterminalis*.

Predictors of individual taxa

We also looked at separate models for predicting the occurrence of each taxon and checked for any commonly occurring variables in these predictors. We selected tree-based models for this analysis because the predictors are likely to be highly non-linear, to contain numerous unpredictable interactions and to have some sharp discontinuous features.

Under this scheme, some taxa will admit of reasonably effective tree predictor models and other will not. Taxa in the former group have some demonstrable link with the predictor variables and the others, at least in this limited sense, do not. It is natural to consider consequent procedures limited to the former group. In summary the strategy is to:

1. Fit tree-based models to individual presence/absence of taxa and prune back according to the commonly recommended “one SE rule”.
2. Restrict the taxa to those that have a non-trivial tree model, that is the tree must have at least two nodes.
3. Look at the variables involved in the primary splits and find the most common ones. These will include the main variable as well as any “surrogate” split variables, that is variables identified as producing as nearly as effective a split as the main one.
4. Perform a correspondence analysis on the presence/absence data for the taxa that admit of a non-trivial tree.
5. Construct a matrix of predicted probabilities of occurrence for each taxon and perform a comparative correspondence analysis using this matrix in place of the binary presence/absence matrix.

The logic behind steps 4 and 5 above is that a comparison of the results of the correspondence analysis based on (a) the raw presence/absence data and on (b) the "smoothed" presence/absence matrix (i.e. replacing the binary entries by estimates of the corresponding probability of occurrence) may give some insight on the effect of false negatives, that is on stations where some taxa do occur but are not collected in the sample.

Presence/absence data, dredge, SS9003 cruise

For reasons outlined elsewhere we limited our consideration to the SS9003 cruise. With the dredge data there are 1389 taxa of which just 52 admitted a non-trivial, optimally pruned tree. The taxa involved are listed in Table 5.2.4. The split variables that were either the main split variable or a split surrogate of it are listed, sorted by frequency of occurrence, in Table 5.2.4.

Table 5.2.4 Taxa of the SS9003 dredge data admitting of a non-trivial tree model with given predictors

Taxa from dredge (invertebrates and teleosts)		
Hydroid 5	*Charybdis truncata*	*Sepia* sp. 1
Hydroid 6	*Portunus gracilimanus*	*Octopus* sp 1
Alcyonarian 5	*Portunus spinipes*	*Triphyllozoon* sp.
Sphenopus sp. 1	*Jonas luteanus*	*Retiflustia cornea*
Polychaeta	*Pagurus* sp. 2	Crinoid 1
Polychaete Tubes Empty	*Spiropagurus* sp. 3	*Astropecten* sp. 1
Oratosquilla perpensa	*Diogenes* sp. 1	*Metrodira subulata*
Solenocera pectinata	*Carcinoplax purpurea*	*Laganum* sp. 1
Sicyonia cristata (=lancifer)	*Ommatocarcinus macgillivrayi*	*Laganum* sp. 2
Dorippe quadridens	*Ceratoplax* sp. 1	Brittle Star 3
Leucosia ocellata	*Ceratoplax* sp. 2	*Uranoscopus cognatus*
Leucosia whitei	*Strombus vittatus*	*Brachypleura novaezeelandiae*
Arcania septemspinosa	*Chicoreus cervicornis*	*Pseudorhombus elevatus*
Myra mammilaris	*Bassina calophylla*	Cynoglossidae
Phalangipes australiensis	*Dosinia mira*	
Parthenope hoplonotus	*Cultellus cultellus*	

Table 5.2.5 Number of times each predictor variable occurs as a main split variable or as a split surrogate of the main split variable

Predictor variables					
Chlorophyll	1	Stress SD	4	Phosphorus SD	12
Chlorophyll SD	1	Stress max	5	Silica SD	12
Depth	2	Temperature	5	Oxygen SD	16
K.490	2	Wave Height median	6	Wave Height max	21
Salinity	2	Gravel	7	Oxygen	22
Temperature SD	2	Nitrate	7	Mud	24
K.490.SD	3	Salinity SD	7	Sand	31
Phosphorus	3	Stress	7	Wave Height SD	32
Silica	3	Wave Height	9		
Stress median	4	Nitrate SD	10		

It is also of interest to see how these variables occur together, that is the patterns of variables that tend to co-occur as surrogate variables for the same split. We can do this by looking at a clustering of variables with a similarity measure given by the proportion of all cases where the two variables in question occur as surrogates. This leads to a dendrogram with clearly defined clusters shown in Figure 5.2.18. The further down this diagram a variable occurs the more often it figures as a main split variable or a surrogate of it, and the groups of variables that occur together have the property not that they are necessarily highly correlated but that they tend to supply equivalent splits for tree models predicting presence or absence of taxa. In the case of *Mud* and *Sand* for example, the two variables are highly negatively correlated.

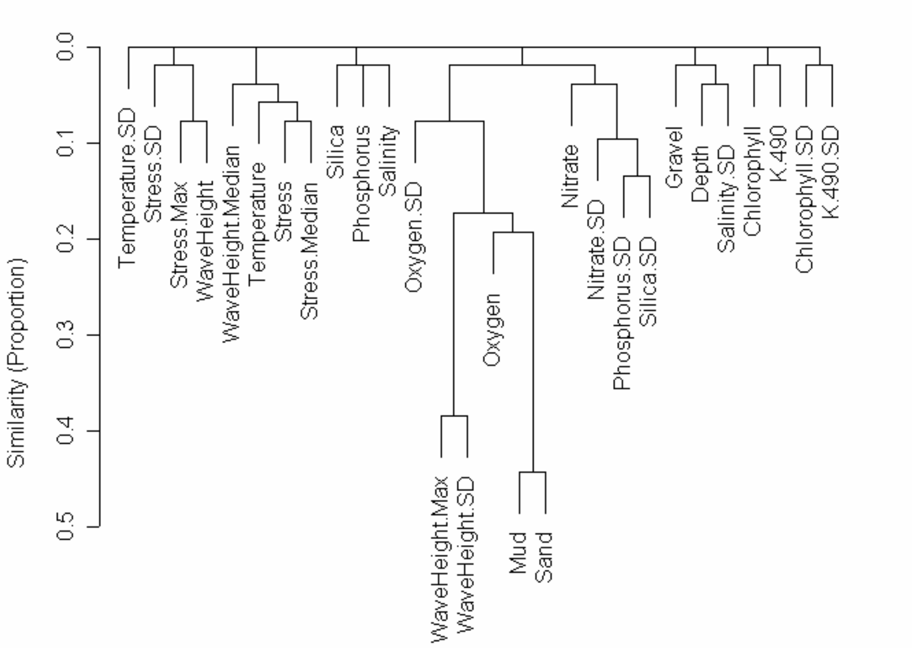

Figure 5.2.18 Clustering of split variables (or surrogates) based on proportions of all cases where the variables occur together

<u>Break points</u>

Figure 5.2.19 shows a histogram of the break points that were selected for the nine most frequently occurring variables. In some cases the splits favour a part of the range fairly strongly while for other variables they tend to be almost evenly distributed. The horizontal ranges of these histograms has been set to cover the range of the variables itself to give some perspective to the concentration of break points.

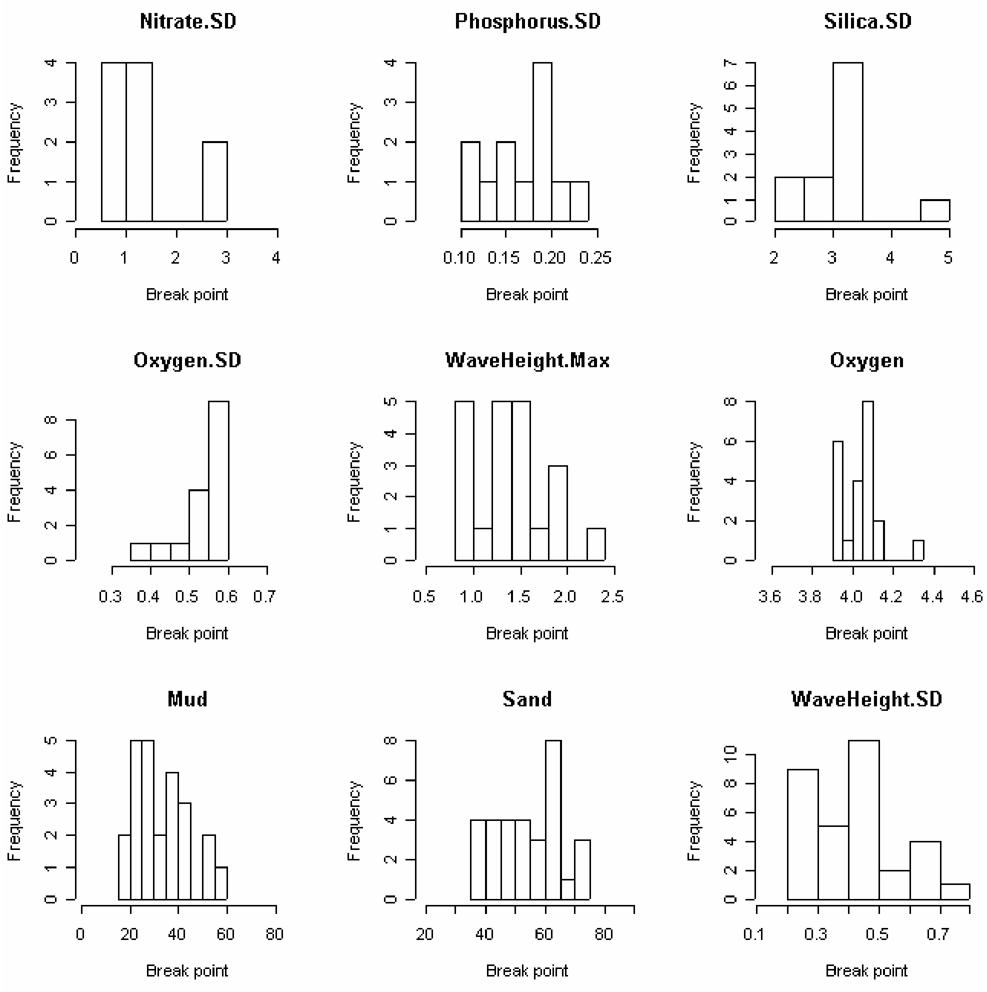

Figure 5.2.19 Histograms of the break points for the 9 most commonly occurring main split variables (or surrogates) ordered by increasing frequency. The histograms are placed on a horizontal axis that covers the range of the variable itself.

Correspondence analysis of tree-selected taxa

If we choose the presence/absence data of the 52 taxa selected by the tree method the resulting 107 × 52 station × taxon matrix has occupancies ranging from 7 to 75.

The first 5 canonical correlations are 0.5952467, 0.3175827, 0.2990480, 0.2705308 and 0.2598357, again suggesting that only the first ordination is likely to be useful. Figure 5.2.20 is a spatial representation of this ordination. The similarity with the previous ordination based merely on taxa that occur at least 15 times is clear.

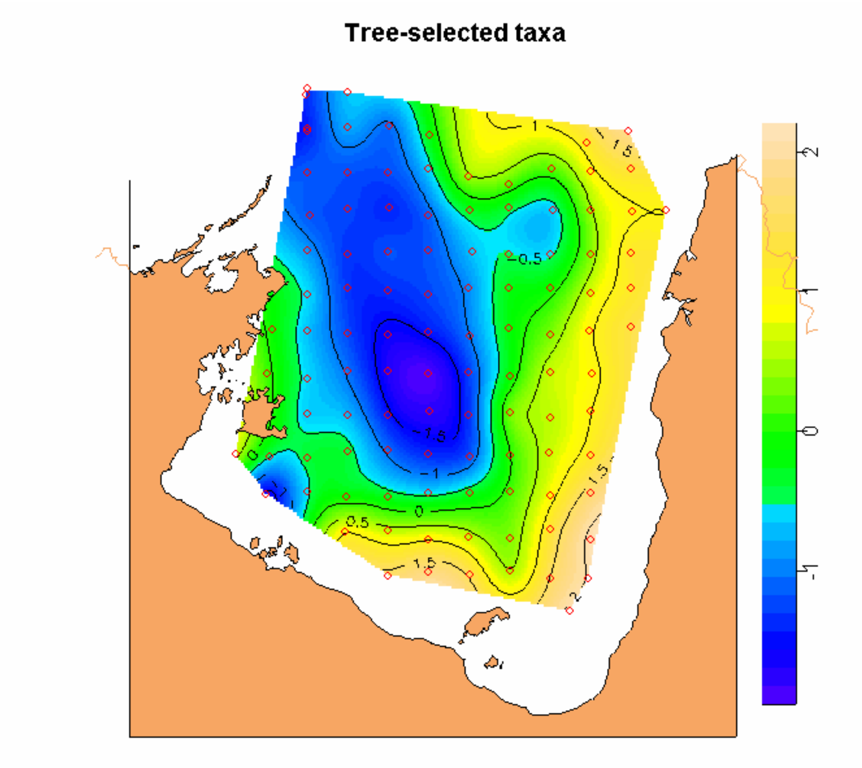

Figure 5.2.20 Smoothed, interpolated first canonical ordination of stations, based on tree-selected taxa and presence/absence data.

Smoothed presence/absence data

We also considered a correspondence analysis using the same 52 species but rather than using their binary presence/absence readings we use the predicted probabilities for occurrence of each taxon, using its tree-based predictor, at each station.

The correlations for this smoothed version of the PA matrix are suppressed relative to the previous case. They are now 0.4916563, 0.2766762, 0.2402649, 0.1936065 and 0.1734308. The first canonical ordination of stations is again the only useful one and Figure 5.2.21 shows the spatial pattern. The result is an even smoother version of the previous diagram, although the general features are very similar.

We conclude that false negatives are probably not strongly affecting the outcome, and neither is the precise suite of taxa selected.

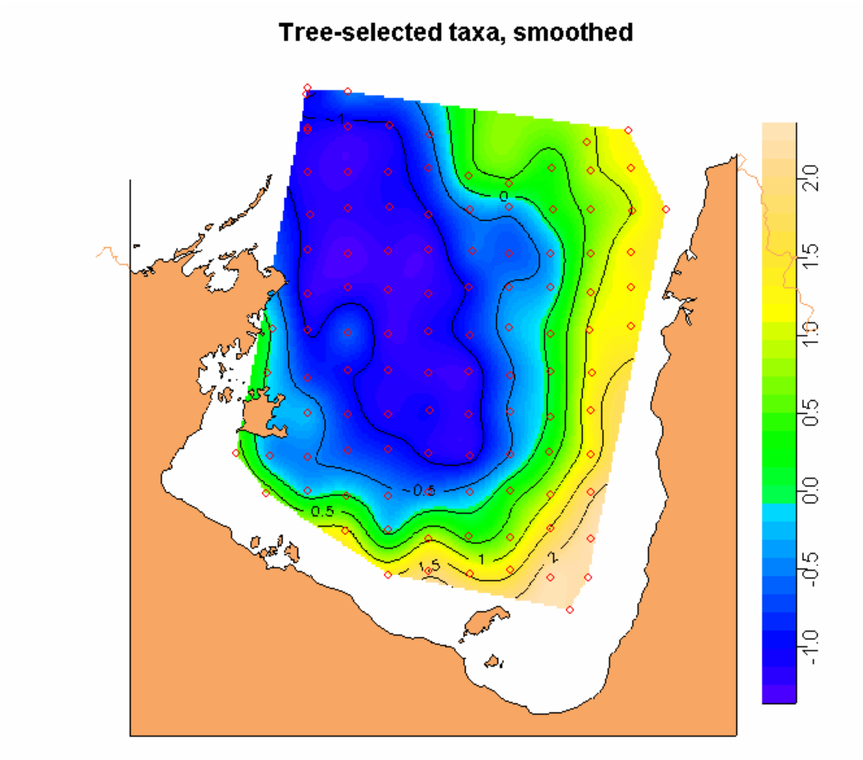

Figure 5.2.21 Smoothed, interpolated first canonical ordination of stations, based on tree-selected taxa and estimated presence probabilities rather than raw presence/absence data.

<u>Ordination of taxa</u>

We have plotted the first two canonical ordinations of taxa using the smoothed presence absence data. The second axis is not effective, but curiously the extreme taxon on the first axis is also the extreme on the second. The plot is shown in Figure 5.2.22. Other than several taxa that appear to be (perhaps informative) outliers, no clear groups emerge.

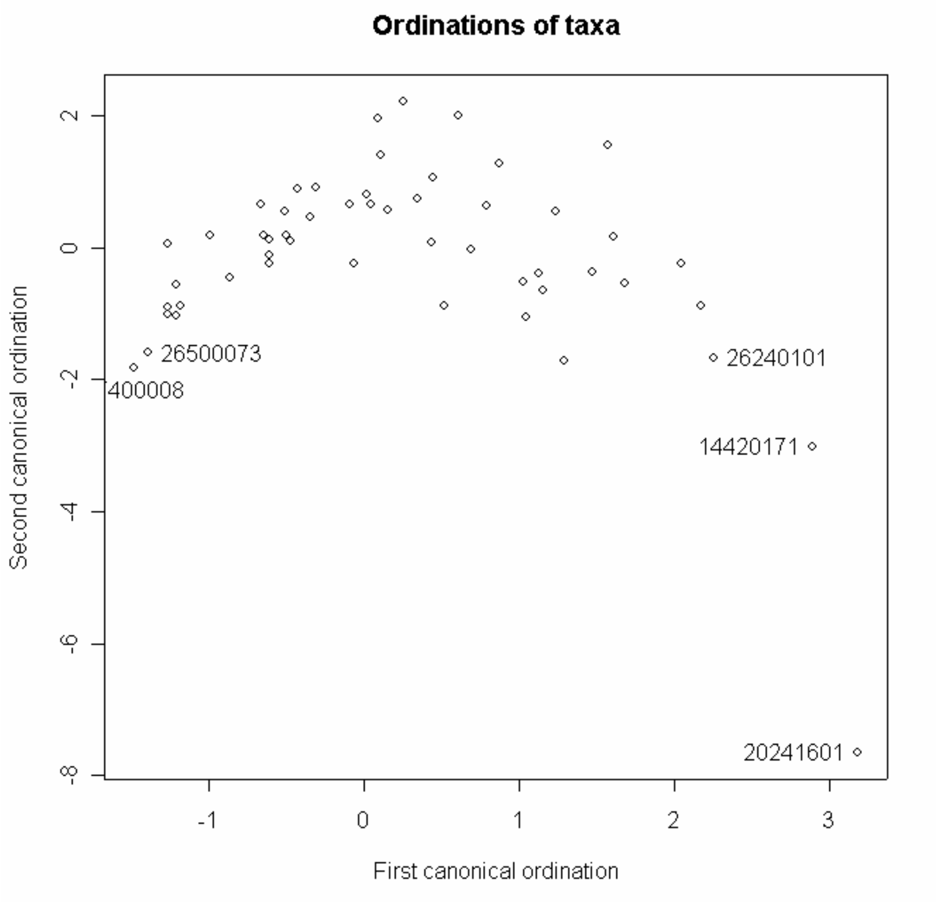

Figure 5.2.22 Ordinations of tree-selected taxa using smoothed presence/absence data. The highest three and lowest two taxa have been identified with their species codes (400008 = *Uranoscopus cognatus* (teleost), 26500073 = Brittle Star 3, 26240101 = *Metrodira subulata* (asteroid), 14420171 = *Sphenopus* sp. 1 (anthozoan), 20241601 = *Pagurus* sp. 2 (Pagurid)

INDICATOR SPECIES

Bill Venables

Introduction

Landres et al. (1988) defined ‘an indicator species as an organism whose characteristics (e.g. presence or absence, population density, dispersion, reproductive success) are used as an index of attributes too difficult, inconvenient, or expensive to measure for other species or environmental conditions of interest’. Indicator species are used for measuring environmental change as well as for identifying areas of high biodiversity, i.e. they are surrogates for some environmental or biological attribute. In this project we are interested in identifying indicator species (surrogates) that can be used for pinpointing areas of high or low biodiversity. Caro and O’Doherty (1998) set out criteria for measurement attributes of surrogate species. In the case of biodiversity indicators the criteria are that it should represent other species, should be a guild of species, have well known biology and should be easily sampled or observed. The latter criterion cannot easily be met in the case of species living on the seabed that have to be sampled by gear such as dredge or trawl but for the foreseeable future we see this as the only practical sampling for much of the seabed fauna. Indicator species for high α-biodiversity can be found by using the presence/absence indicators for individual species as predictors for the total number of species observed at a site.

One easily appreciated way to find possible indicator species is to construct a tree model. If we do this for the SS9003 cruise benthic dredge data we have 1036 species that occur at least once in the data and the α-biodiversity at a station ranges from 8 to 156. The fact that the species itself is part of the total number is a minor complication only, since the total number of species is generally at least 20 and we will be considering only a very small number of possible indicator species. A regression tree model produces the tree shown in Figure 5.2.23.

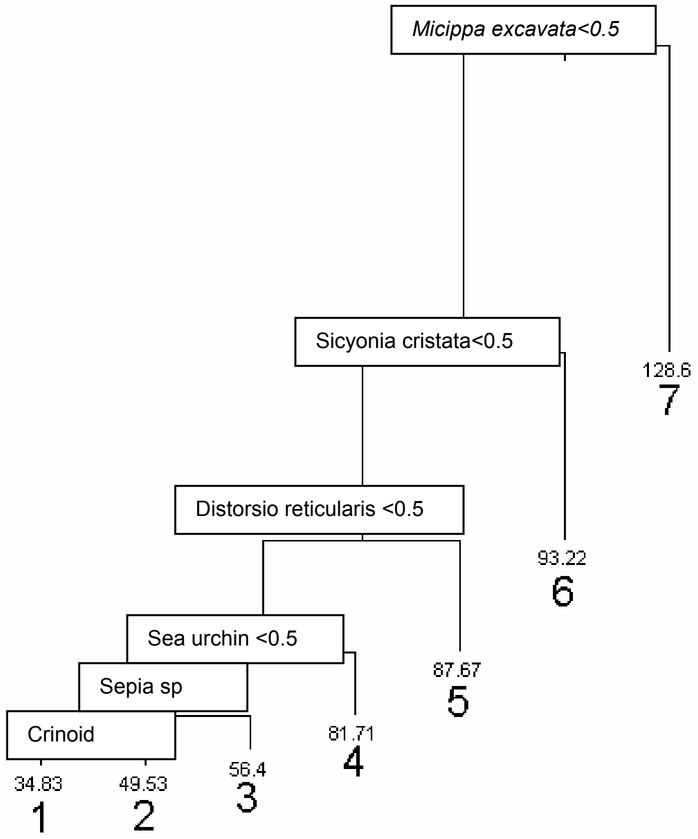

Figure 5.2.23 A regression tree for the α-biodiversity using presence/absence of individual species as possible predictors. The smaller type numbers below each node are the average numbers of species observed at such stations and the larger type numbers are a labeling of the node used in later graphical presentations.

This tree model diagram should be read as follows, starting from the top of the diagram. If species 20241001 (*Micippa excavata*) is present in the sample go to the right (Node 7) and the mean number of species is 128.6 otherwise go to the left. In this latter case if species 20240501 (*Sicyonia cristata = lancifer*) is present go to node 6 and the mean number of species is 93.22 otherwise go to the left, and so on. Each step to the left leads to a set of stations (or node) with a lower mean number of species, although this is not guaranteed to happen by the tree construction algorithm.
Table 5.2.5. shows the numbers of stations at each node as well as the mean α-biodiversity at each of the seven nodes

Table 5.2.5: Numbers of stations and mean numbers of species at each node of the indicator species tree.

.

Node label:	1	2	3	4	5	6	7
No. Stations:	24	15	15	7	12	23	11
Mean No. Species	34.8	49.5	56.4	81.7	87.7	93.2	128.6

To give some idea of the variation in species numbers for each node class of stations we used box plots as shown in Figure 5.2.24.

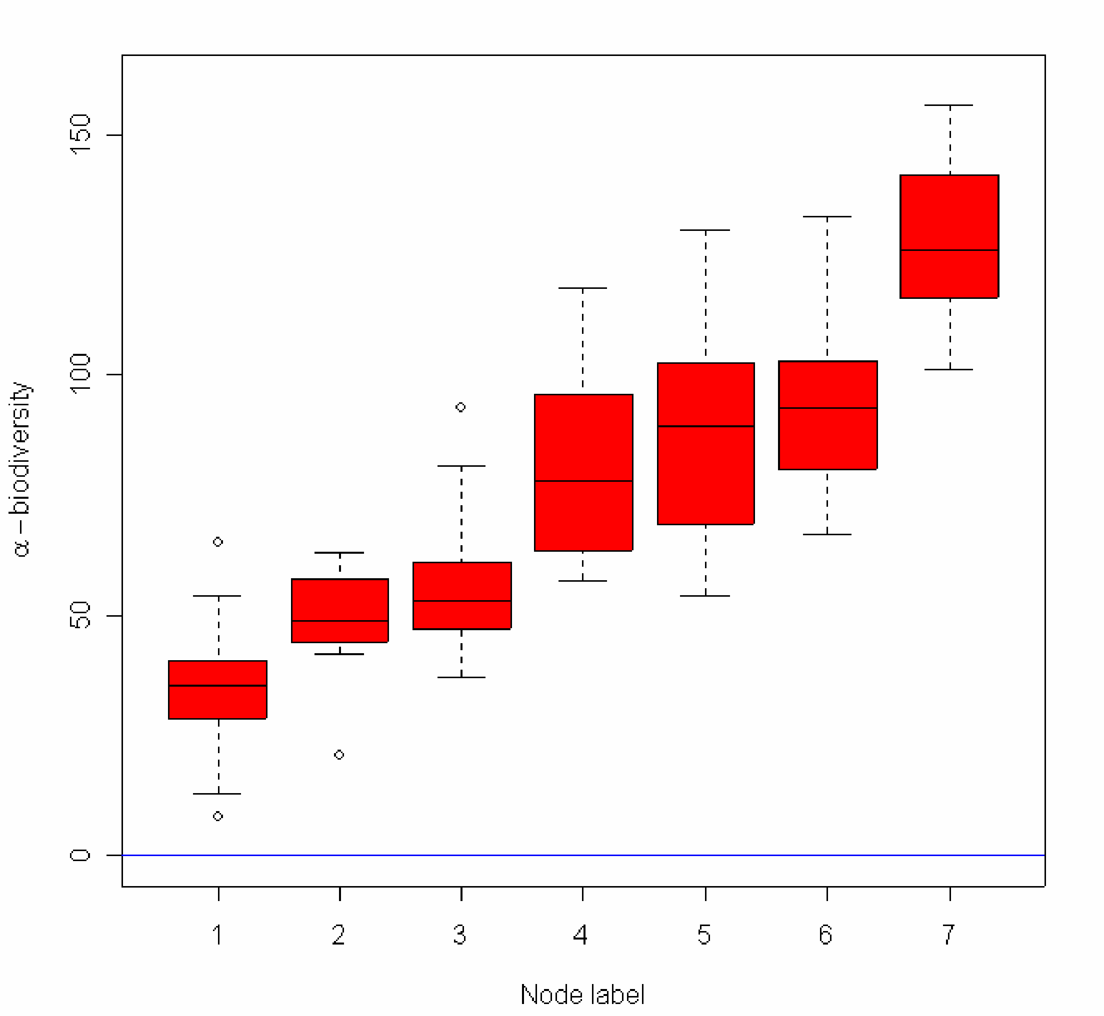

Figure 5.2.24 Box plots of α-biodiversity for the 7 nodes (groups of stations).

The spatial location of the tree node groups is shown in Figure 5.2.25.

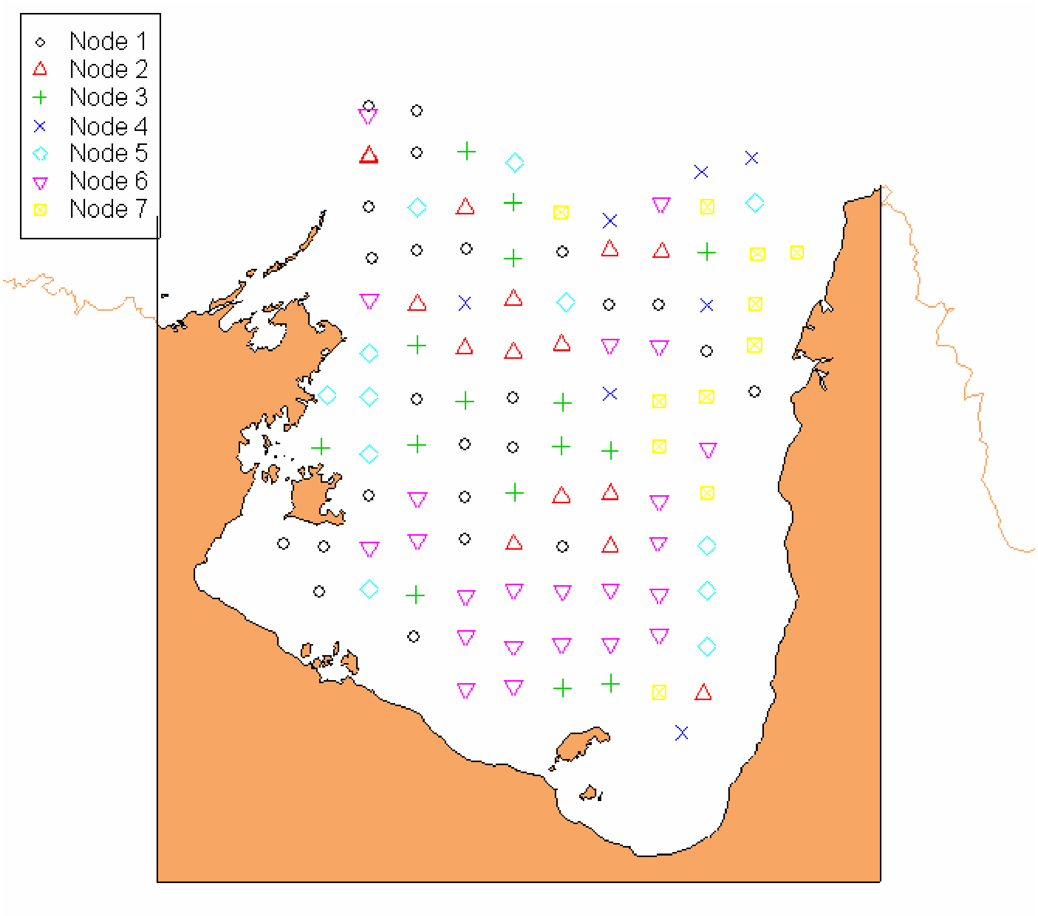

Figure 5.2.25 Spatial location of the 7 tree node groups.

An alternative approach to the α-biodiversity indicator species problem

The problem of finding indicator species for regions of high biodiversity is not completely well defined, as it requires a trade-off between rarity of occurrence and the coincidence of occurrence with stations of high biodiversity. Clearly very commonly sampled species are not useful as indicators as they will, by definition, tend to occur everywhere while very rarely sampled species will also tend to occur at stations where the number of species sampled is very large. Nevertheless a species that is only sampled once or twice in the record can hardly be seen a useful indicator of anything. An alternative, more directed method of finding possible indicator species to the tree-based model approach is the following.

1. Classify the α-biodiversity values into groups corresponding to increasingly high α-biodiversity. Since we are interested in high biodiversity the groups should become smaller as the values increase.
2. For each candidate species cross tabulate its presence/absence with the biodiversity groups defined above.
3. Choose those species where (formally at least) the association between species presence/absence and biodiversity groups is strong. Since there are a large number of candidate species we should choose a very high significance level to allow for selection effects.
4. Inspect the nature of the strong association and if it is positive with increasing biodiversity, tentatively accept the species as an indicator.
5. Check the reasonableness of each possible indicator species from biological as well as statistical considerations.

The particular grouping of α-biodiversity values chosen here and the numbers of stations falling into each group are shown in the following table.

Table 5.2.6 The number in brackets is the grouping – or range – of α-biodiversity values chosen. The notation used is that square brackets indicates the range is ≥ or ≤ than the adjacent number, round brackets indicate the number is > or < than the adjacent number.

α-biodiversity range	[7,63]	(63,97]	(97,109]	(109,126]	(126,156]	Total
Number of stations:	54	26	10	10	7	107

The first group contains roughly half the stations, the next a further quarter and the top three approximately one-third of the remainder each. Table 5.2.7 shows the 20 species with P-value less than 10^{-6}.

Table 5.2.7 Surrogate species or taxa. Notation as for Table 5.2.6. The four surrogate split variables for the main tree split also occur here and are shown on the table as (tree model) panels. Absent indicates the species was absent from that range of stations, present indicates it was present in the range.

Species	Range	[7,63]	(63,97]	(97,109]	(109,126]	(126,156]	Total
Sicyonia cristata (lancifer) (Shrimp)	Absent	54	14	3	6	3	80
	Present	0	12	7	4	4	27
Minichlamys scabricostata (Bivalve) (Tree model)	Absent	53	16	5	2	3	79
	Present	1	10	5	8	4	28
Dorippe quadridens (Crab)	Absent	44	9	2	0	1	56
	Present	10	17	8	10	6	51
Laganum sp. 3 (Echinoid)	Absent	54	26	5	10	2	97
	Present	0	0	5	0	5	10
Micippa excavata (Spider crab) (Tree model)	Absent	54	26	9	5	2	96
	Present	0	0	1	5	5	11
Spiropagurus sp. 3 (Hermit crab)	Absent	47	17	1	4	0	69
	Present	7	9	9	6	7	38
Lupocyclus rotundatus (Portunid crab)	Absent	50	18	3	5	0	76
	Present	4	8	7	5	7	31
Alcyonarian 11	Absent	53	25	6	7	1	92
	Present	1	1	4	3	6	15
Heart Urchin 7 (Spatangoid)	Absent	54	26	10	7	2	99
	Present	0	0	0	3	5	8
Bursa rana (Gastropod)	Absent	49	13	4	2	2	70
	Present	5	13	6	8	5	37
Trachypenaeus granulosus (Penaeid crustacean) (Tree model)	Absent	48	19	4	3	0	74
	Present	6	7	6	7	7	33
Majidae sp. 1 (Spider crab)	Absent	52	21	6	4	1	84
	Present	2	5	4	6	6	23

Ficus subintermedius (Gastropod) (Tree model)	Absent	52	23	7	4	1	87
	Present	2	3	3	6	6	20
Leucosia whitei (Leucosid crab) (Tree model)	Absent	50	16	5	2	2	75
	Present	4	10	5	8	5	32
Distorsio reticularis (Gastropod)	Absent	52	15	7	4	2	80
	Present	2	11	3	6	5	27
Myra mammilaris (Leucosid crab)	Absent	51	19	5	4	1	80
	Present	3	7	5	6	6	27
Sea urchin 3	Absent	51	22	6	4	1	84
	Present	3	4	4	6	6	23
Parthenope longispinus (Parthenopid crab)	Absent	48	18	5	1	2	74
	Present	6	8	5	9	5	33
Dardanus hessii (hermit crab)	Absent	46	15	3	2	1	67
	Present	8	11	7	8	6	40
Brittle Star 1	Absent	51	25	10	6	1	93
	Present	3	1	0	4	6	14
Common totals		54	26	10	10	7	107

INVERTEBRATE ASSEMBLAGES

Mick Haywood

We have used the data collected on three cruises (SS9003, SS9702, SS9708 and SS9803) for mapping the spatial distribution of benthic invertebrates The same epibenthic dredge was used to obtain all of these samples. There were 107 dredge samples taken in 1990 across the GoC during SS9003, however most of these were in waters offshore from the prawn trawling grounds (Fig 5.2.26). The samples from the remaining cruises were collected on trawl grounds during 1997 and 1998, although there were fewer samples (7 in SS9702 and 18 in both SS9708 and SS9803).

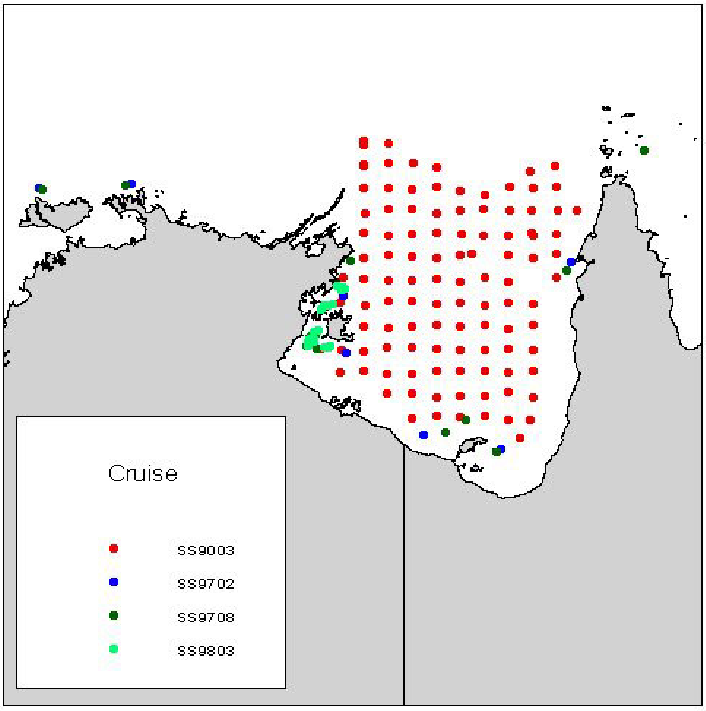

Figure 5.2.26. Map showing the stations where dredge samples were taken during cruises SS9003, SS9702, SS9708 and SS9803.

Not all the animals caught were identified to species, many could only be identified to Family level and many of the sponges could only be identified as “Sponge”. In total there were 1174 invertebrate taxa caught in the four cruises. Echinoderms (mostly spatangoids [heart urchins]) and sponges dominated the catches in terms of biomass (Table 5.2.8).

Table 5.2.8 Catch rates by weight (kg h^{-1}) and numbers per hour for the various broad classes of benthos collected by the dredge

Class	Weight	Numbers
Echinodermata	5168.5	720434.1
Porifera	2302.3	95171.0
Anthozoa	356.4	890812.1
Coelenterata	326.6	69206.5
Malacostraca	217.6	52818.9
Bivalvia	200.4	27540.6
Bryozoa	119.4	41570.1
Urochordata	115.1	6656.9
Gastropoda	45.1	16619.0
Annelida	34.9	20833.1
Cephalopoda	26.5	1666.0
Chordata	17.5	2875.0
Mollusca	8.7	732.2
Echiura	2.6	128.0
Sipuncula	0.4	71.5
Gorgonacea	0.3	50.1
Crustacea (non-Malacostraca)	0.2	38.4
Nemertea	0.1	24.0
Platyhelminthes	0.1	4.0
Cirrepedia	0.1	80.0
Ctenophora	<<0.1	0.1

Only five taxa were found at 50% or more of the 150 stations. These were the decapod crustaceans: *Myra biconica* (Fig 5.2.27), *Parthenope longimanus* (Fig 5.2.27) and *Arcania novemspinosa* and the bivalves: *Amusium pleuronectes* (Fig. 5.2.27) and *Bassina calophylla*. Most taxa were not widespread with 946 taxa being found at ≤10 stations and 389 taxa found at only a single station. Nevertheless some taxa were locally abundant e.g. a species of flabellid solitary coral was the single most abundant taxon with 123, 429 individuals all caught at a single station. Catches of unidentified spatangoids and the spatangoid *Maretia planulata* were very high at a few stations, but they were not caught at the majority of stations (Fig 5.2.27).

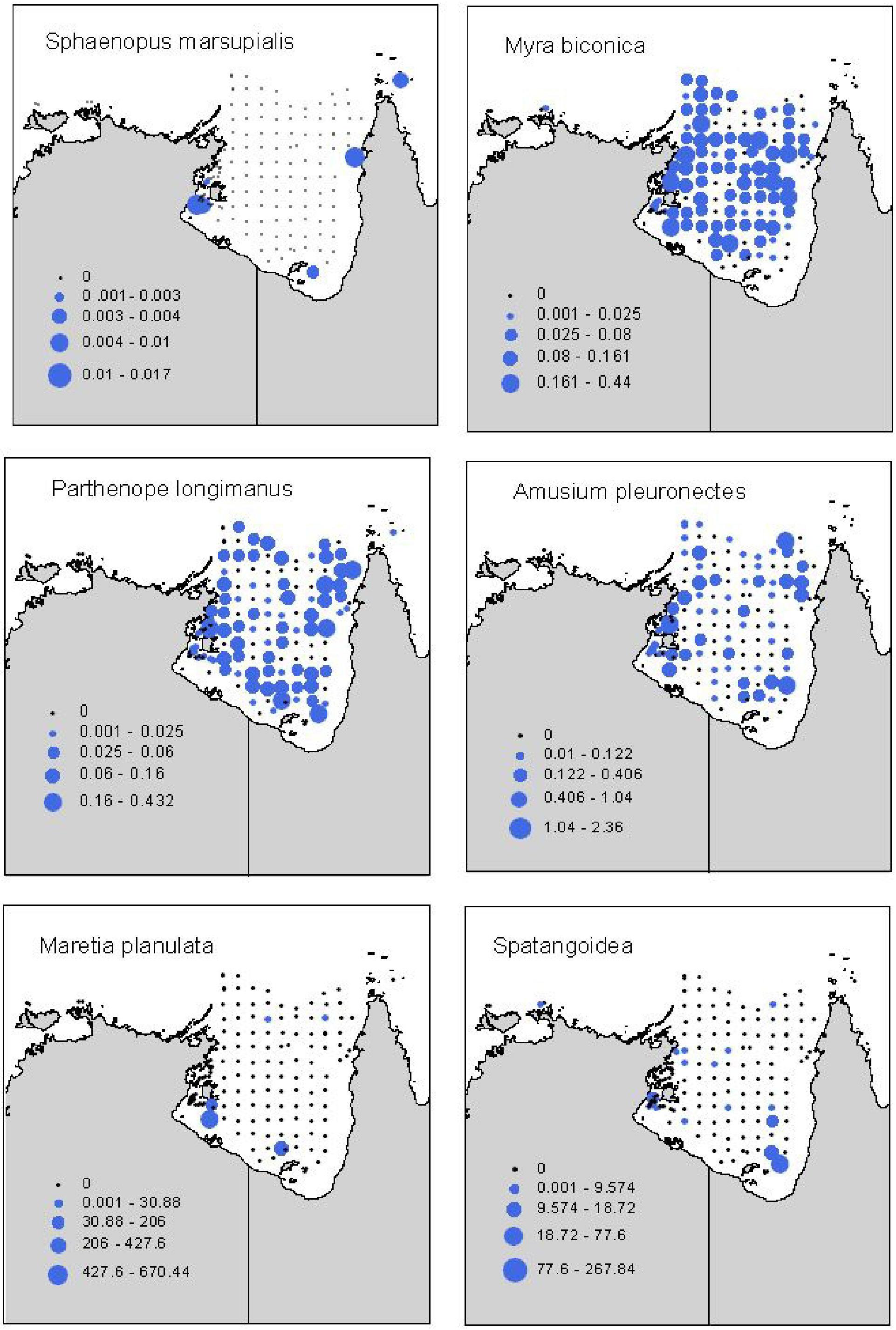

Figure 5.2.27 Distribution and catch rates (kg/h) of 6 taxa of benthic invertebrates collected in the Northern Prawn Fishery during the cruises SS9003, SS9702, SS9708 and SS9803.

The dredge stations were clustered based on their Bray-Curtis similarities in terms of catch rates and species composition. Hourly catch rates for each taxon were 4th root transformed and clustered using group-average linking (Fig. 5.2.28). At a similarity of 15% the stations form 12 groups.

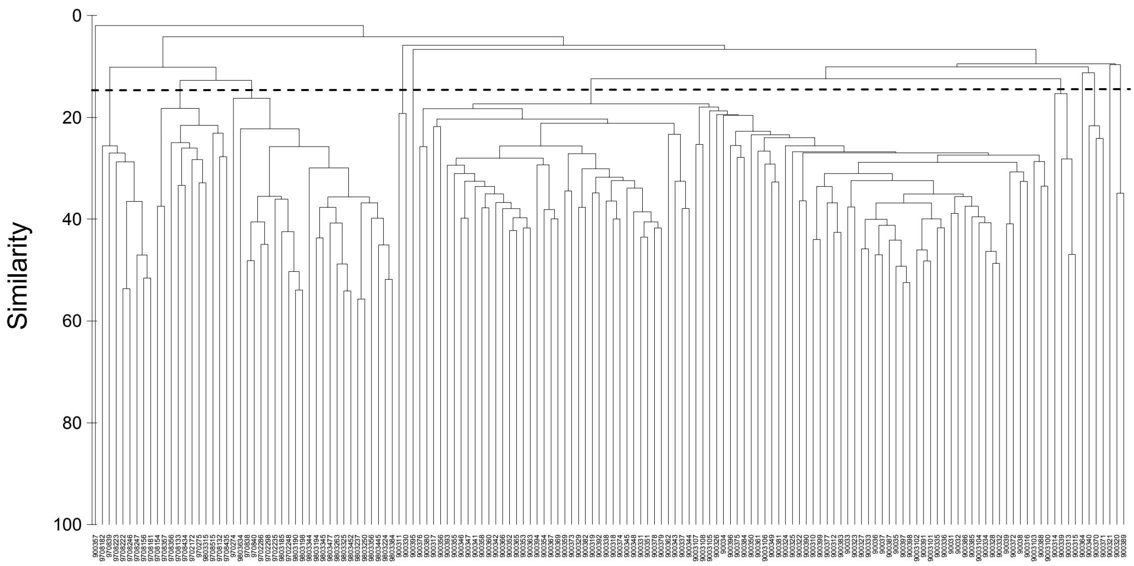

Figure 5.2.28. Dendrogram derived from Bray-Curtis similarities of the stations sampled for invertebrates using the benthic dredge on cruises: SS9003, SS9702, SS9708 and SS980. The dashed line is drawn at a similarity of 15% where the stations separate into 12 groups.

The data were also plotted as an MDS ordination with the stations labelled according to their group membership as determined by the cluster analysis (Fig. 5.2.29[a]) and as to whether the station was within or outside the prawn trawling grounds (Fig. 5.2.29[b]). The prawn trawling grounds were defined as all the 6–minute grids that were reported as having being fished between 1996 and 2000 in the AFMA logbooks.

Cluster group membership was reflected quite well in the MDS plot (Fig. 5.2.29(a)). The cluster analysis identified one large group of stations (group 7; 92 stations) that consisted of most of the dredge stations that were located outside of the commercial fishing grounds in the deeper waters of the GoC (Fig. 5.2.29, Fig 5.2.30 (a)). Analysis using the SIMPER package (described in the preceding section) indicated that this was a diverse group with 105 species accounting for 90% of the average similarity within the group. The five taxa that contributed the most to the similarity of the stations within group 7 were Alcyonarian sp.4, *Metapenaeus palmensis*, *Bassina calophylla, Myra biconica* and *Amusium pleuronectes*

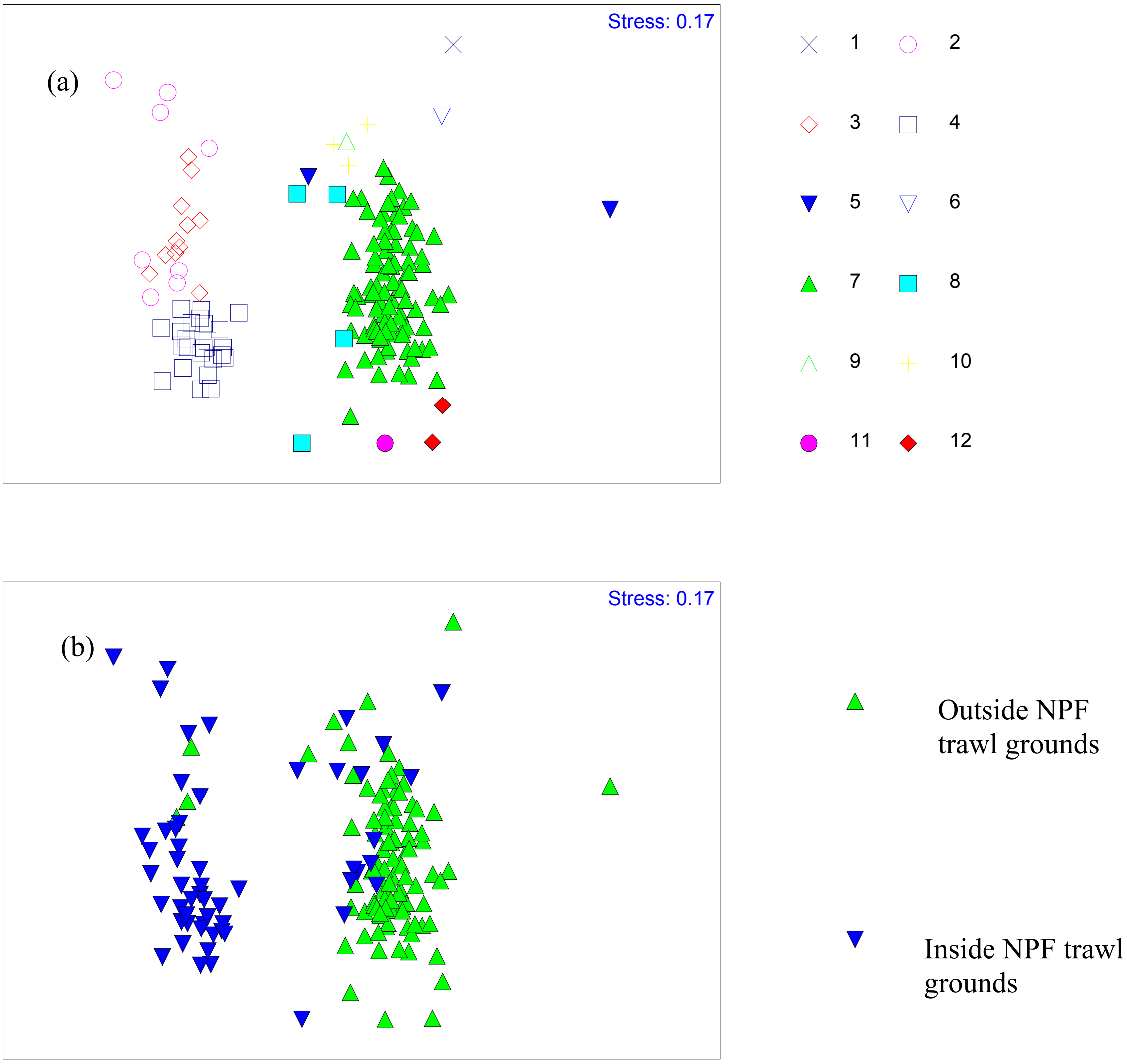

Figure 5.2.29. Multi-Dimensional Scaling ordination of Bray-Curtis similarities of benthic invertebrate taxa collected with a benthic dredge on three cruises (SS9003, SS9702, SS9708 and SS9803) in the NPF. The coloured symbols represent the group membership of individual stations as determined at a similarity level of 15% in (a) the cluster analysis and (b) whether or not the station was located in or outside the prawn trawling grounds (b).

Group 4 (24 stations) was comprised of inshore stations around Groote Eylandt, Mellville Island and a single station near Weipa (Fig. 5.2.30). Group 3 (11 stations) also included mainly inshore stations to the south of Groote Eylandt, Weipa, Torres Strait and around Mornington Island (Fig. 5.2.30). These two groups are relatively close together in the MDS ordination (Fig. 5.2.28 (a)), however they are distinguished principally by their catches of Loveniidae (heart urchins), two unidentified species of *Ircinia* (sponges), unidentified species of *Poterion* (cup sponge), *Pentaceraster* (starfish) and *Amusium pleuronectes* (scallop).

Group 2 was a small (8 stations) group of inshore stations southwest of Groote Eylandt and a single station north of Cobourg Peninsular that was comprised largely of spatangoid urchins. Group 8 consisted of 3 stations to the south of Groote Eylandt and a single station north of

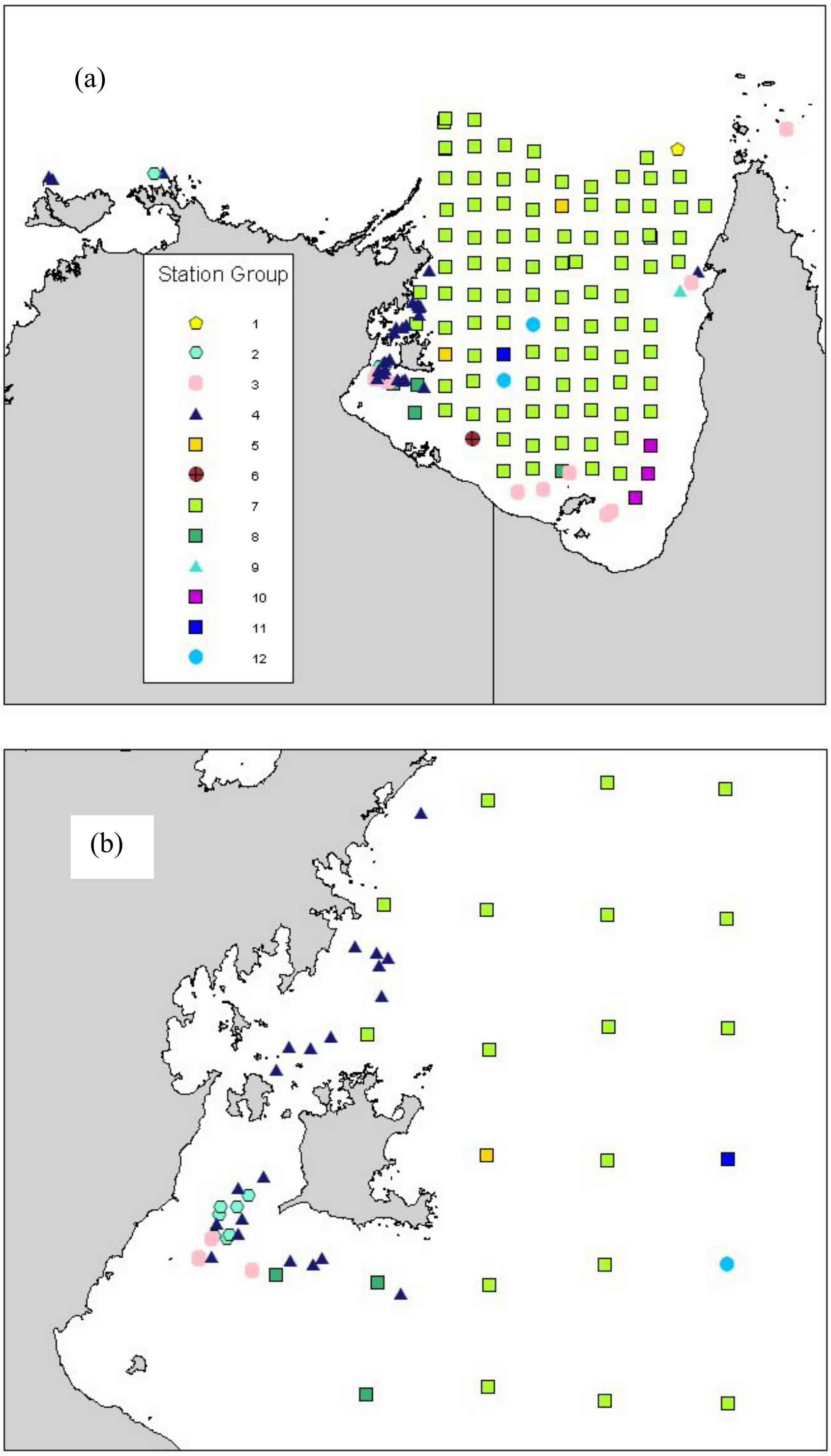

Figure 5.2.30 Stations sampled using the benthic dredge throughout the NPF (a) and around Groote Eylandt (b); the colours identify station group membership as determined by cluster analysis.

Mornington Island. This group was characterised by very high catches of the spatangoid urchin *Maretia planulata* (Fig. 5.2.27, Fig 5.2.30). Group 10 (3 stations) were all located in the south-eastern GoC and all had high catches of an unidentified zooanthid (*Sphenopus* sp.)

and an unidentified species of asteroid. The remaining station groups consisted of only one or two stations each that were singled out because of unusually high catches of one or two taxa. For example group one which was the first group to separate out from all other stations in the cluster analysis (Fig. 5.2.28) consisted of a single station where there was a very high catch rate of the oyster *Pinctada sugillata*.

CHAPTER 5.3

FISH FAUNA FROM FISH TRAWLS

Chapter Authors

Mick Haywood, Bill Venables

Final Report on FRDC Project 2000/160: Surrogates I – Predictors, impacts, management and conservation of the benthic biodiversity of the Northern Prawn Fishery

CHAPTER 5.3

THE FISH FAUNA

FROM FISH TRAWLS

Bill Venables

Mick Haywood

Summary

Demersal fish assemblages

- Analyses of fish trawl samples from 107 stations across the GoC yielded a total of 289 species
- Ten species were common occurring at 70% of more of the stations but most of the rest were rare
- We identified 7 major fish assemblages
- The fish assemblage with the widest distribution across the Gulf of Carpentaria was made up of species associated with reefs suggesting that reef structures may be widespread across the GoC
- This assemblage may be useful as a form of indicator species for reef ecosystems
- The distribution of fish biodiversity of the Gulf of Carpentaria is fairly uniform over much of the central area with a different grouping more inshore

Surrogates

- α-biodiversity of the fish fauna is much less, and much less variable, than for the dredge data reported in Chapter 5.1.
- We tested a total of 28 variables: Temperature, Chlorophyll, K.490, phosphorus, silica, salinity, nitrate, seabed current stress, sediment, wave height, mud, oxygen, depth together with derivatives of some of these (maximum and standard deviation)
- The connection between the fish fauna and available environmental variable information is relatively weak. A tree analysis showed that wave height (mean, standard deviation and maximum) are the most important factors in clustering of the stations from which fish were collected
- A tree analysis of the species indicated that salinity SD, nitrate SD and oxygen were the split variables with the highest frequency of occurrence. These water quality properties are probably linked to thermocline formation in summer in the Gulf of Carpentaria and the associated water quality changes are probably key drivers in determining the distribution of mobile species such as most teleosts.

Indicator species

- The highest level of biodiversity was found at eight stations, these had a mean of 53.8 species. These stations all had the three species *Pseudorhombus diplospilus*, *Lagocephalus scleratus* and *Gerres macracanthus.*
- The area with the highest biodiversity of teleosts is in the north east of the Gulf of Carpentaria

Comparison between fish and benthic invertebrate biodiversity

- Our analysis shows that biodiversity as measured by two different gears – fish trawl and dredge – is not the same. A comparison of the number of species and of the biomass shows a weak statistical correlation

Introduction

The data on the distribution of demersal fish assemblages in the NPF is restricted to the Gulf of Carpentaria. There are two relevant datasets that contain fish data for this region. Firstly, there is the Gulf-wide survey (Cruise SS9003) conducted in November and December 1990 using a Frank and Bryce Fish trawl. The second dataset comprises the fish bycatch data from a series of prawn trawls made during 3 cruises which focussed on key prawn trawling regions throughout the NPF (Stobutzki et al., 2000). In mapping and analysing the distribution of demersal fish we have used only the data from the Gulf-wide cruise (SS9003), because of the wide spatial distribution of the sampling sites. We also have not combined the two datasets because the fishing gears were very different and because as shown by Wassenberg et al (1997), fish catches from fish and prawn trawls are not comparable. Fish captured in fish trawls are dealt with in this chapter, fish from prawn trawls are covered in Chapter 5.4. All fish captured were identified to species.

FISH ASSEMBLAGES

Mick Haywood

Methods

We used cluster analysis to characterise the similarities in fish biomass between stations. Catch rates were transformed ($\log_e$+1) to reduce the dominant effects of large catches of small species and individuals of very large species. A Bray-Curtis similarity matrix was generated and the data clustered using group-average linking. The stations were also plotted as a Multi-Dimensional Scaling (MDS) ordination with the sites labelled according to their group membership as indicated in the cluster analysis.

The data were then analysed to determine which species were typical of each of the seven groups identified from the cluster analysis. This was done using the SIMPER routine from the software package PRIMER 5 (PRIMER-E 2001). SIMPER decomposes the similarities of all within group comparisons into their contributions from each species. These species are often also good discriminators between groups, but not necessarily as they may be typical of more than one group.

Results

Data was available from a total of 107 stations that had been sampled on an approximately 30 nm grid across the Gulf of Carpentaria. Approximately 412,100 fish weighing 15,900 kg including 289 species were caught. Ten species could be described as widespread, occurring in 70% or more of the stations across the GoC (e.g. *Priacanthus tayenus* and *Pentaprion longimanus*, Table 5.3.1; Fig.5.3.1). Most other species were rarely caught; although sometimes in very high numbers e.g. *Secutor insidiator* (Fig. 5.3.1). Sixty-three species were caught at only a single station.

Table 5.3.1. Species of fish caught at ≥70% of the stations sampled during cruise SS9003.

Species	Number of stations
Priacanthus tayenus	102
Pentaprion longimanus	94
Leiognathus bindus	93
Nemipterus hexodon	91
Saurida micropectoralis	90
Nemipterus nematopus	88
Fistularia petimba	85
Upeneus sulphureus	81
Carangoides malabaricus	77
Paramonacanthus filicauda	74

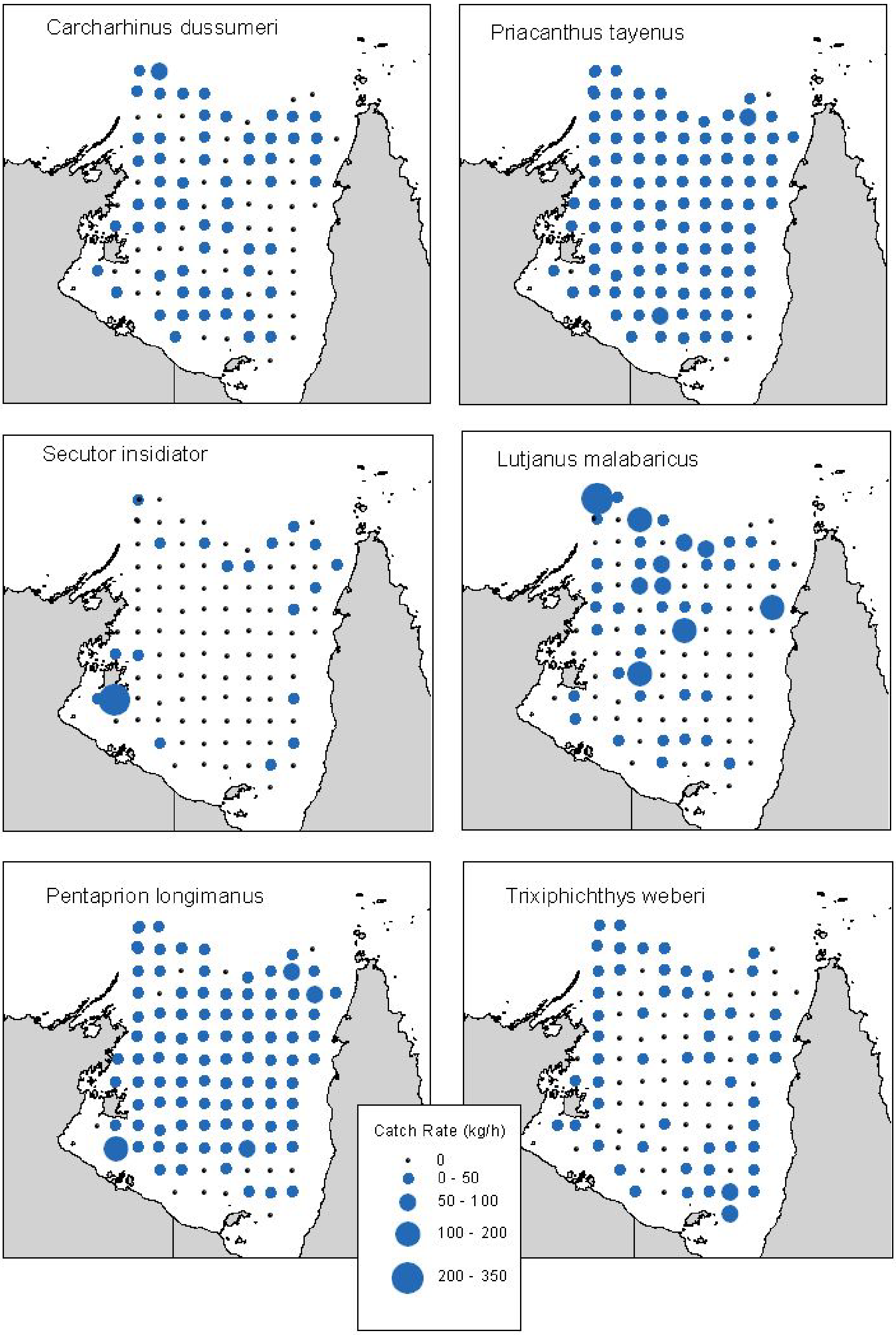

Figure 5.3.1. Distribution and catch rates (kg/h) of 6 species of demersal fish captured in the GoC during SS9003 (November-December 1990)

The results of the Bray-Curtis similarity matrix are shown in Fig 5.3.2. The stations were separated into seven groups at a similarity level of 26.3. Below this level there were many groups that were difficult to interpret and above this level too much information was lost.

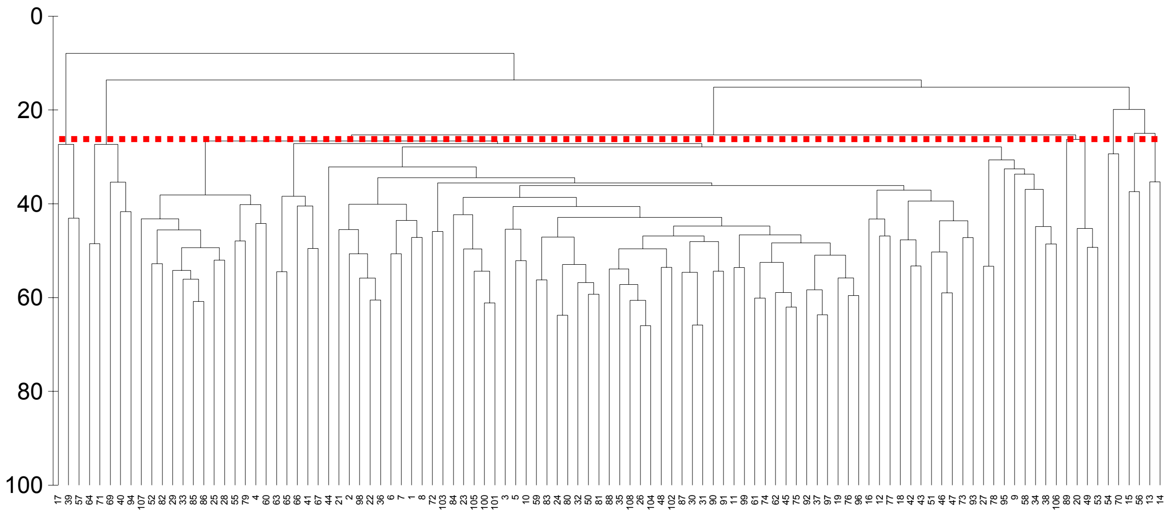

Figure 5.3.2. Dendrogram of fish caught in the GoC on SS9003. The dotted red line is drawn at a similarity level of 26.3%; there are 7 groups at this level

Figure 5.3.3 shows the MDS separation of the various groups. Although we do not have a very marked overall separation, there is a clear tendency for certain areas to do so. Examples include Group 2, Group 7, Group 1 and Group 3. Group 5 by contrast is widely dispersed. There is little separation between the various groups with the notable exception of fish group 2.

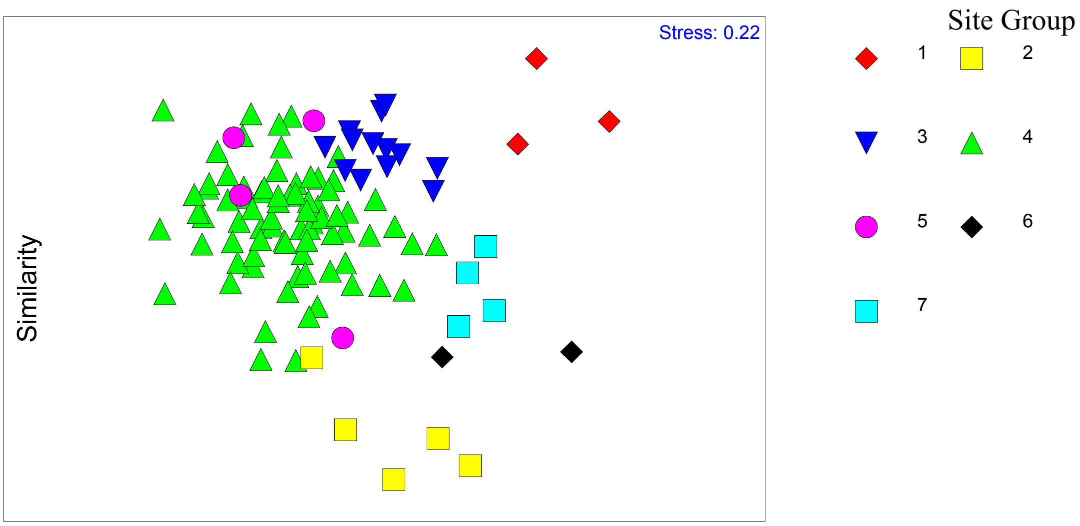

Figure 5.3.3 Multi-Dimensional Scaling plot of Bray-Curtis similarities of the fish species and their catch rates from the fish trawls conducted throughout the GoC on SS9003. The coloured symbols represent the seven groups identified at a similarity level of 26.3 in the cluster analysis

The largest site group (Group 4) consists of 75 sites that were mainly in the offshore regions of the Gulf (Fig. 5.3.4). Group 4 included *Priacanthus tayenus* a species associated with coral reef and rocky bottoms, the two nemipterids, *Nemipterus hexodon* and *N. nematopus* and

Saurida micropectoralis which inhabit muddy bottoms and trawling grounds and *Pentaprion longimanus* which is generally found over sandy bottoms.

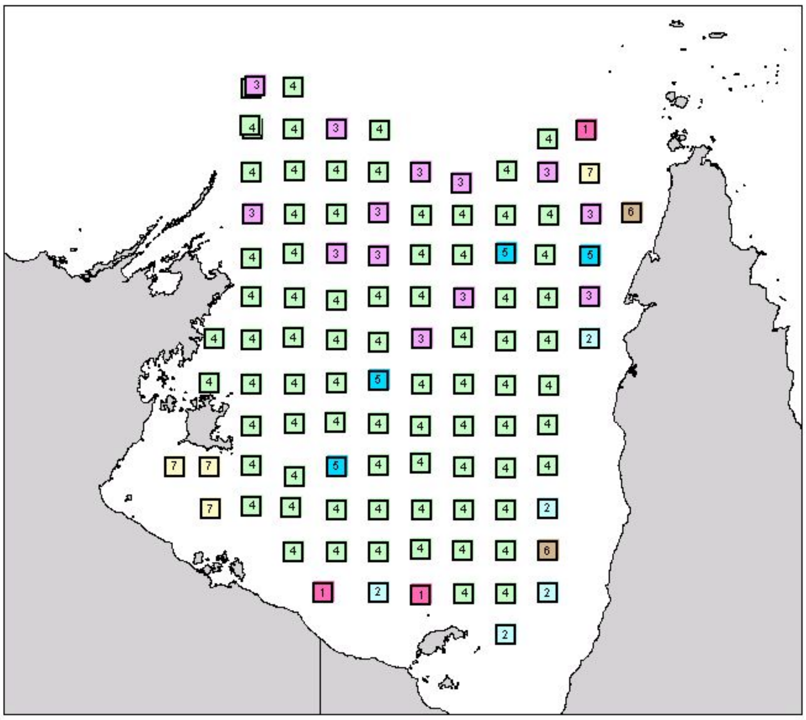

Figure 5.3.4 Gulf of Carpentaria; SS9003 fish trawl sample sites with showing site similarity based on Bray-Curtis similarity measures derived from fish species occurrences and catch rates.

The second largest group (3) is fairly widespread over the northern part of the GoC occurring both inshore and in the central Gulf (Fig. 5.3.4). This group includes *Lutjanus malabaricus* which is found on reefs and trawl grounds, *Diagramma pictum* and *Lethrinus lentjan* which inhabit sandy areas close to coral reefs and *Lutjanus sebae* and *L. vittus* which are generally found in the vicinity of coral reefs and rocky outcrops (Table 5.3.2).

Group 2 is a number of stations in the prawn trawling grounds of the southern GoC and west of Weipa in the north-eastern GoC. This group is dominated by three species common to trawling grounds (*Nemipterus furcosus, N. peroni* and *Trixiphichthys weberi*) and two species that are found in inshore and offshore waters around reefs (*Echeneis naucrates* and *Stegosoma fasciatum*).

Group 1 is a small group of three sites, two in the southern and one in the north-eastern GoC. It mainly includes species found on sandy areas close to coral reefs, but also by a single species commonly found on trawl grounds (*Nemipterus furcosus*).

Table 5.3.2. The average catch rate and percent contribution of the five most important taxa to the similarity of each group of demersal fish.

Group	Number of Sites	Average Similarity	Species	Average Abundance (kg/h)	Contrib %	Cum %
1	3	35.3	*Lethrinus nebulosus*	162.7	19.6	19.6
			Diagramma pictum	28.5	14.4	33.9
			Abalistes stellaris	41.5	8.9	42.8
			Nemipterus furcosus	7.5	8.2	51.0
			Chaetodontoplus duboulayi	5.1	6.5	57.4
2	5	32.3	*Nemipterus furcosus*	36.5	31.1	31.1
			Nemipterus peroni	3.4	9.9	41.0
			Trixiphichthys weberi	12.4	8.4	49.4
			Echeneis naucrates	3.0	6.8	56.2
			Stegostoma fasciatum	27.9	5.6	61.8
	13	44.9	*Lutjanus malabaricus*	90.2	14.5	14.5
			Diagramma pictum	32.5	9.0	23.5
			Lethrinus lenjan	27.1	7.2	30.8
			Lutjanus sebae	11.9	6.1	36.8
			Lutjanus vitta	5.9	5.4	42.2
4	75	33.9	*Priacanthus tayenus*	7.2	10.4	10.4
			Nemipterus hexodon	9.5	9.7	20.1
			Nemipterus nematopus	7.6	9.0	29.1
			Saurida micropectoralis	5.5	8.1	37.2
			Pentaprion longimanus	7.4	7.8	45.0
5	4	37.5	*Dasyatidae*	122.5	21.7	21.7
			Carcharhinus dussumieri	16.4	20.3	42.0
			Nemipterus hexodon	6.4	10.7	52.6
			Pentaprion longimanus	3.0	10.1	62.7
			Priacanthus tayenus	1.5	6.4	69.2
6	2	27.7	*Pomadasys maculatum*	2259.4	15.1	15.1
			Caranx bucculentus	252.3	11.9	27.0
			Terapon theraps	102.2	11.9	38.9
			Johnius bornensis	16.6	10.4	49.3
			Polydactylus multiradiatus	44.3	9.3	58.6
7	4	28.2	*Leiognathus bindus*	77.6	15.3	15.3
			Carangoides humerosus	12.5	13.2	28.5
			Leiognathus leuciscus	48.2	11.5	40.0
			Selaroides leptolepis	12.6	7.2	47.1
			Carcharhinus dussumieri	9.2	7.1	54.2

Group 5 is a disparate group of sites – in both the central and north-eastern GoC. Important species in this group are a mixture of species common over trawl grounds (*Nemipterus hexodon*), reefs (*Priacanthus tayenus*) and coastal species (*Carcharhinus dussumerei* and *Pentaprion longimanus*).

Group 6 consists of two inshore sites in the southeastern and northeastern Gulf. They are categorized by coastal species and dominated by high catches of *Pomadasys maculatum.*

Characteristic species of group 7 are four coastal schooling species (*Leiognathus bindus*, *L. leuciscus, Carangoides humerosus* and *Selaroides leptolepis*). This group of sites is mainly to the south of Groote Eylandt with one station to the west of Torres Strait (Fig. 5.3.4).

Discussion

This data has been analysed previously by Blaber et al. (1994), however we felt it was worth re-analysis because Blaber et al. (1994) used principal-coordinates analysis to examine the structure of the fish communities and their relationship with abiotic factors. One of the inherent weaknesses of principal co-ordinates analysis is that distances between samples may be distorted when projected onto a 2-dimensional ordination. We chose to use non-metric multidimensional scaling because it is generally recognised that non-metric multi-dimensional scaling is better at maintaining the rank order of dissimilarity between samples in two dimensions than principal co-ordinates analysis. Nevertheless the results from the two different analyses have many aspects in common. Both techniques identified a large group of stations that were mainly located in the central Gulf, a small group to the south of Groote Eylandt, and a group widely dispersed across the north. The main difference in the results was that the earlier analysis identified a single fairly homogenous group of stations extending along the eastern and southern edge of the Gulf, whereas our analysis classified the fish in this region into several groups.

An interesting finding was the widespread occurrence of species of teleosts that are associated with reefs – especially Group 4. This suggests that reef structures are wide spread in the Gulf of Carpentaria. We presently have indications of possible reefs only from the prawn trawl grounds where they are classified as 'untrawlable grounds'. An example of these grounds is given in Figure 4.8 in Chapter 4. Group included species that are not associated with reefs for example *Saurida micropectoralis* which inhabit muddy bottoms and *Pentaprion longimanus* which is found over sandy seabed. This apparent discrepancy is almost certainly a result of the samples being collected by a trawl that is towed over a distance of nearly 3 km. We would expect that over such long distances, the trawls covers different types of seabed and so yields fish from different habitats.

SURROGATES

Bill Venables

Choice of species

In Chapter 5.2, we pointed out that very rarely, or very commonly occurring species tend to inflate the canonical correlation by isolating a few stations at which rarely occurring taxa only occur (or at which very commonly occurring taxa do not occur). This may be a real effect but in most cases it is an artefact of the sampling. As in the case of the analysis of dredge samples , we have assessed a minimum occurrence/non-occurrence requirement for a taxon to be included by plotting the change in canonical correlations as the criterion for inclusion (minimum occupancy requirement) is increased. Figure 5.3.5 shows the change for the first 5 correlations as minimum occupancy requirement is raised from 1 to 30 stations (out of 128 stations). Initially the correlations decrease steadily but by about 20 stations they tend to level out – although some decrease further with more station occupancy. It is clear that the first three correlations are considerably higher than the ones following. We chose a cut-off requirement that each taxon occur in at least 20 stations (and must *not* occur in at least 20 stations). This gave 128 stations with 71 taxa.

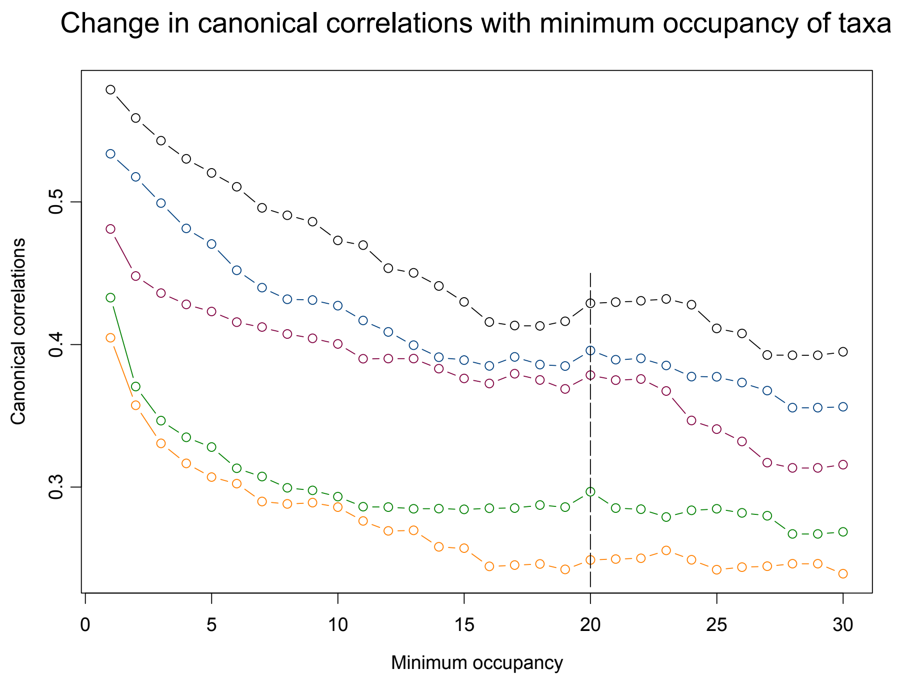

Figure 5.3.5 Change in canonical correlations with increasing minimum occupancy requirement for inclusion of taxa

The five largest correlations are 0.4288889, 0.3957227, 0.3785597, 0.2966954 and 0.2488924. None of these is very large. We concentrated on the first of these but also considered the first three for some analyses. The initial impression is that the connection between fish fauna and stations is relatively weak.

Figure 5.3.6 shows a smoothed, interpolated version of this first canonical ordination. Areas with similar colour are suggested to have similar patterns of biodiversity.

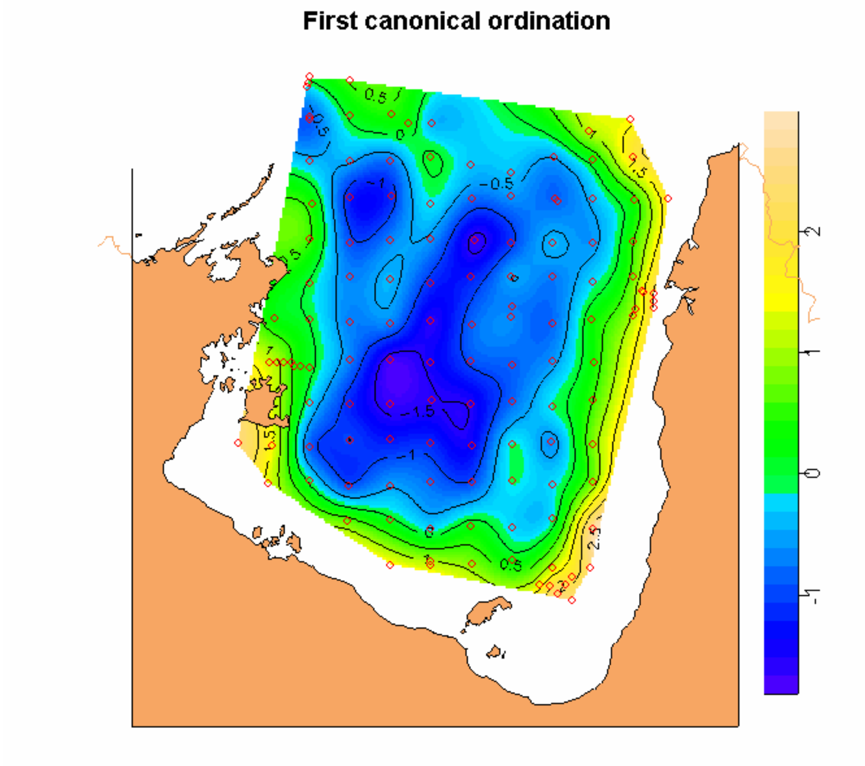

Figure 5.3.6 Smoothed and interpolated representation of the first canonical ordination of the 1990 fish trawl cruise stations. Fish trawl data, presence/absence, with a minimum occupancy cut-off of 20. Based on 128 stations × 71 taxa

Showing the spatial patterns in the first three canonical ordinations is more difficult, but one way to do so is to use the three ordinations of stations to define a number of discrete clusters in the data and then to represent the clusters by colouring the station points. Using the station scores, a divisive clustering of the stations using the *diana* procedure of Kaufman and Rousseeuw (1990) gives the following dendrogram (Figure 5.3.7). For specificity we summarise the patterns so defined with 7 groups and these then have occupancies:

Group:	1	2	3	4	5	6	7
Frequency:	46	16	16	33	5	1	11

Group 6 consists of one station in the extreme south-eastern corner of the Gulf.

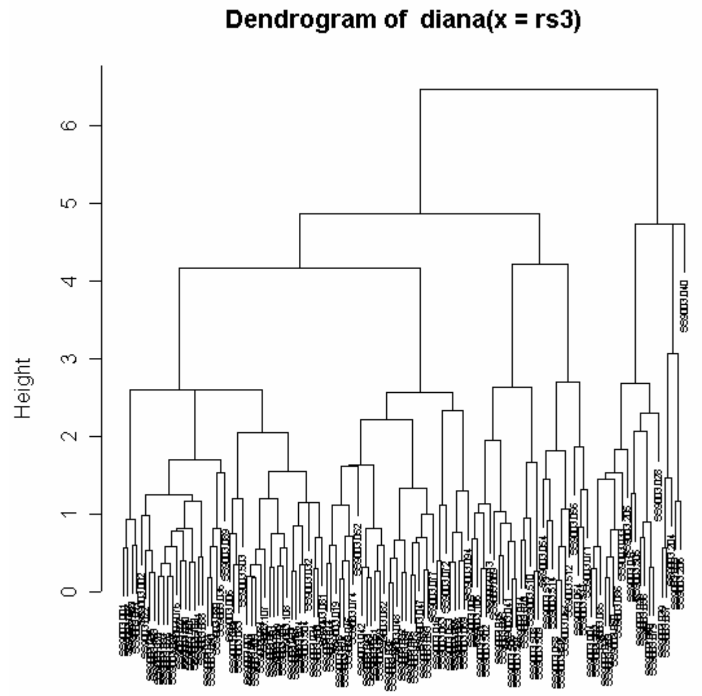

Figure 5.3.7 Divisive classification of Fish Trawl stations based on first three canonical ordinations.

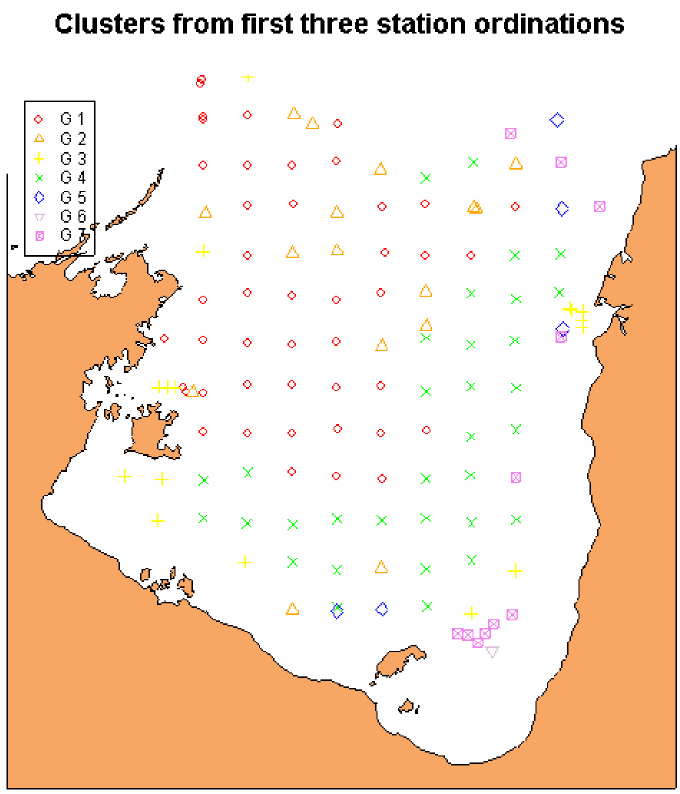

Figure 5.3.8 Divisive clustering of Fish Trawl stations based on first three canonical ordinations

The distribution of the groups is shown in Fig 5.3.8. Despite the relatively weak correlations, the clustering appears to show some topographical cogency.

The next step in identifying possible surrogates is to relate these clusters to the available predictor variables. We used tree-based methods to predict the observed cluster from the available predictors. This is a slightly non-standard procedure but justified in the sense that the results are seen only as investigatory.

Figure 5.3.9 shows the usual representation of this classification tree. The height of the vertical lines is proportional to the effectiveness of the branch in reducing the impurity measure of the nodes, that is, in improving the fit to that part of the data.

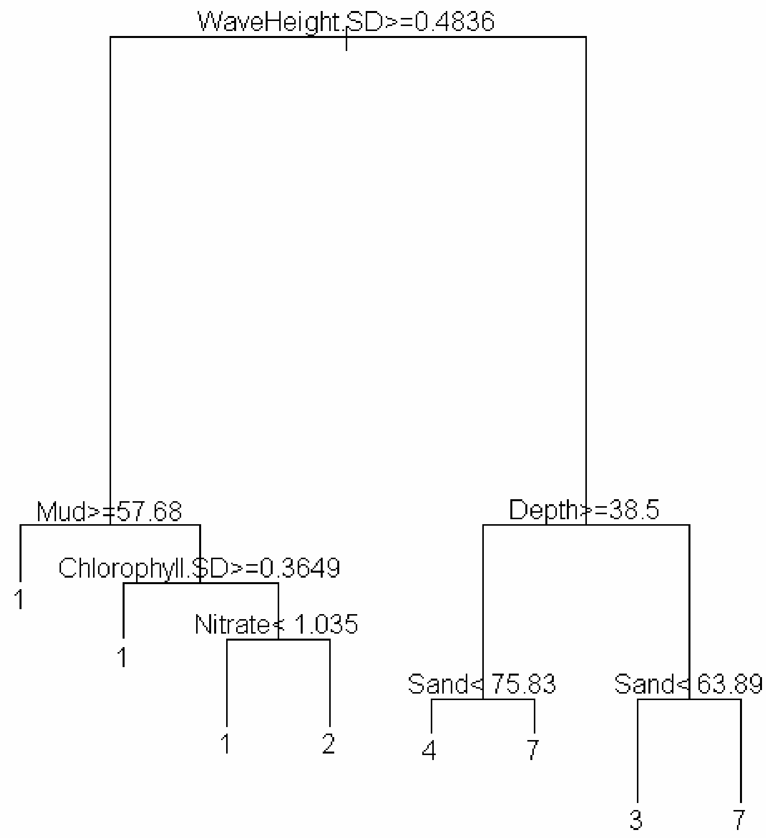

Figure 5.3.9 Classification tree for the 7 canonical clusters of the fish trawl stations

Surrogate split variables for the first node are WaveHeight.SD, WaveHeight.Max, WaveHeight (mean), Sand and Oxygen, which all belong to one of the variable groups shown for the dredge data (see Chapter 5.1).

Species ordinations

Figure 5.3.10 shows a 'pairs plot' of each of the three-taxon ordinations against the others. (Note that the panels above the diagonal are mirror images of those below.) There appears to be no discernable pattern although the dendrogram coming from these scores (Figure 5.3.11) suggests there may be 3 major groups.

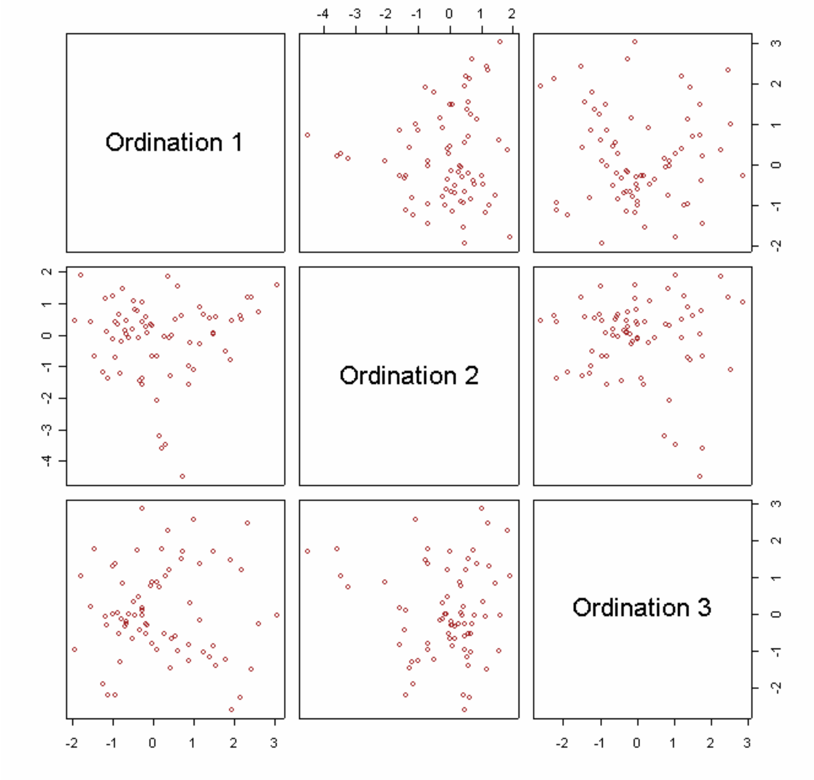

Figure 5.3.10 Pairs plot of the first three canonical ordinations of the taxa from the 1990 cruise fish trawl data.

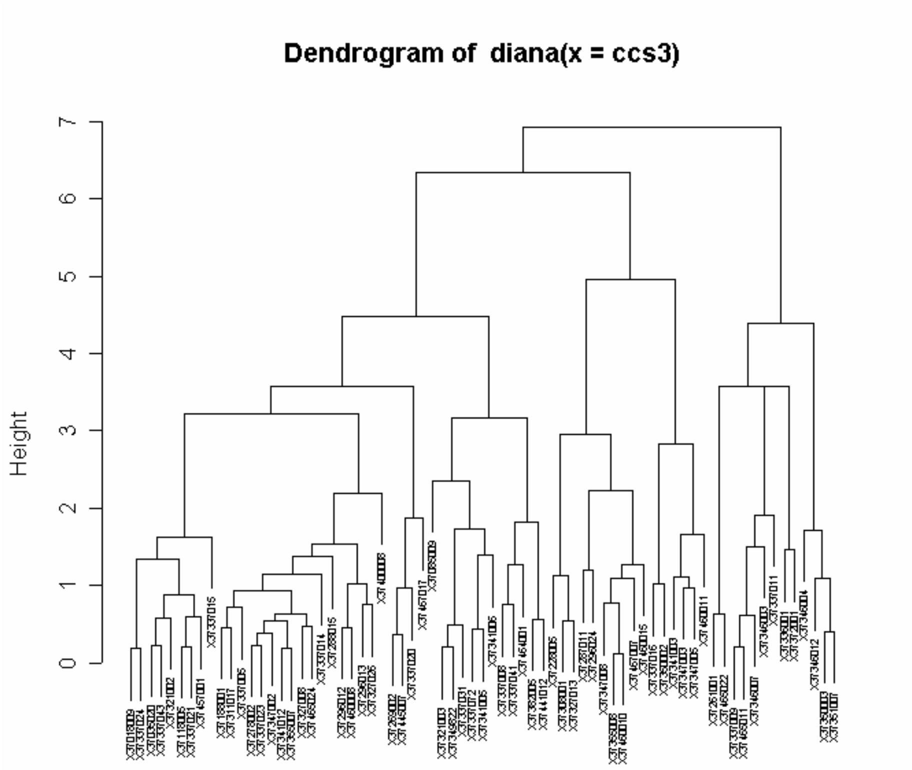

Figure 5.3.11 Dendrogram of divisive clustering of Fish Trawl taxa

Predictors of individual taxa

We investigated possible surrogates by looking at separate models for predicting the occurrence of each taxon and checking for any commonly occurring variables in these predictors. Since the predictors are likely to be highly non-linear, to contain numerous unpredictable interactions and to have some sharp discontinuous features, tree-based models are an appropriate method of analysis.

Under this scheme, some taxa will admit of reasonably effective tree predictor models and other will not. Taxa in the former group then have some demonstrable link with the predictor variables and the others, at least in this limited sense, do not. It is then natural to consider consequent procedures limited to the former group. In summary the strategy is:

1. Fit tree-based models to individual presence/absence of taxa and prune back according to the commonly recommended "one SE rule".
2. Restrict the taxa to those that have a non-trivial tree model, that is the tree must have at least two nodes.
3. Look at the variables involved in the primary splits and find the most common ones. These will include the main variable as well as any "surrogate" split variables; that is variables identified as producing as nearly as effective a split as the main one.
4. Perform a correspondence analysis on the presence/absence data for the taxa that admit of a non-trivial tree.
5. Construct a matrix of predicted probabilities of occurrence for each taxon and perform a comparative correspondence analysis using this matrix in place of the binary presence/absence matrix.

The logic behind steps 4 and 5 is that a comparison of the results of the correspondence analysis based on (a) the raw presence/absence data and on (b) the "smoothed" presence/absence matrix (i.e. replacing the binary entries by estimates of the corresponding probability of occurrence) may give some insight on the effect of false negatives, that is on stations where some taxa do occur but were not collected in the sample.

Presence/absence data, fish trawls, SS9003 cruise

For reasons outlined elsewhere we initially limited our consideration to the SS9003 cruise. With the fish trawl data there 305 taxa of which just 41 admitted a non-trivial, optimally pruned tree. The taxa involved are given in Table 5.3.3.

Table 5.3.3 Species in the SS9003 fish trawl data admitting of a non-trivial tree model with given predictors

Abalistes stellaris	*Leiognathus moretoniensis*	*Psettodes erumei*
Apogon fasciatus	*Lepidotrigla sp. 2*	*Pseudorhombus argus*
Argyrops spinifer	*Lutjanus malabaricus*	*Pseudorhombus elevatus*
Carangoides humerosus	*Nemipterus furcosus*	*Scolopsis taeniopterus*
Carangoides malabaricus	*Nemipterus nematopus*	*Selaroides leptolepis*
Caranx bucculentus	*Nemipterus peronii*	*Seriolina nigrofasciata*
Carcharhinus dussumieri	*Nemipterus virgatus*	*Sillago ciliata*
Decapterus russellii	*Netuma thalassinus*	*Sphyraena forsteri*
Elates ransonetii	*Paramonacanthus filicauda*	*Suggrundus macracanthus*
Fistularia petimba	*Pellona ditchela*	*Trixiphichthys weberi*
Gazza minuta	*Pentapodus paradiseus*	*Upeneus sp. 1*
Grammatobothus polyophthalmus	*Pomadasys maculatus*	*Upeneus sulphureus*
Lagocephalus scleratus	*Priacanthus tayenus*	*Uranoscopus cognatus*
Leiognathus leuciscus	*Pristotis jerdoni*	

The split variables that were either the main split variable or a split surrogate of it are listed, sorted by frequency of occurrence, in Table 5.3.4.

Table 5.3.4 Number of times each predictor variable occurs as a main split variable or as a split surrogate of the main split variable

Predictor Variable and frequency

Temperature.SD	1	Stress.Median	5	WaveHeight.SD	10
Chlorophyll.SD	2	Gravel	6	Mud	11
K.490.SD	2	Stress.SD	6	Oxygen.SD	11
Phosphorus	2	WaveHeight.Median	6	Sand	11
Silica	2	Chlorophyll	7	Depth	13
Salinity	3	K.490	7	Oxygen	14
Temperature	3	WaveHeight	8	Nitrate.SD	15
Nitrate	4	Silica.SD	9	Salinity.SD	17
Stress	5	Phosphorus.SD	10		
Stress.Max	5	WaveHeight.Max	10		

Some of these variables occur together, that is the patterns of variables tend to co-occur as surrogate variables for the same split. We can address this by looking at a clustering of variable with a similarity measure given by the proportion of all cases where the two variables in question occur as surrogates. This leads to a dendrogram with clearly defined clusters as shown in Figure 5.3.12. The further down this diagram a variable occurs the more often it figures as a main split variable or a surrogate of it, and the groups of variables that occur together have the property not that they are necessarily highly correlated but that they tend to supply equivalent splits for tree models predicting presence or absence of taxa. In the case of Mud and Sand for example, the two variables are highly negatively correlated.

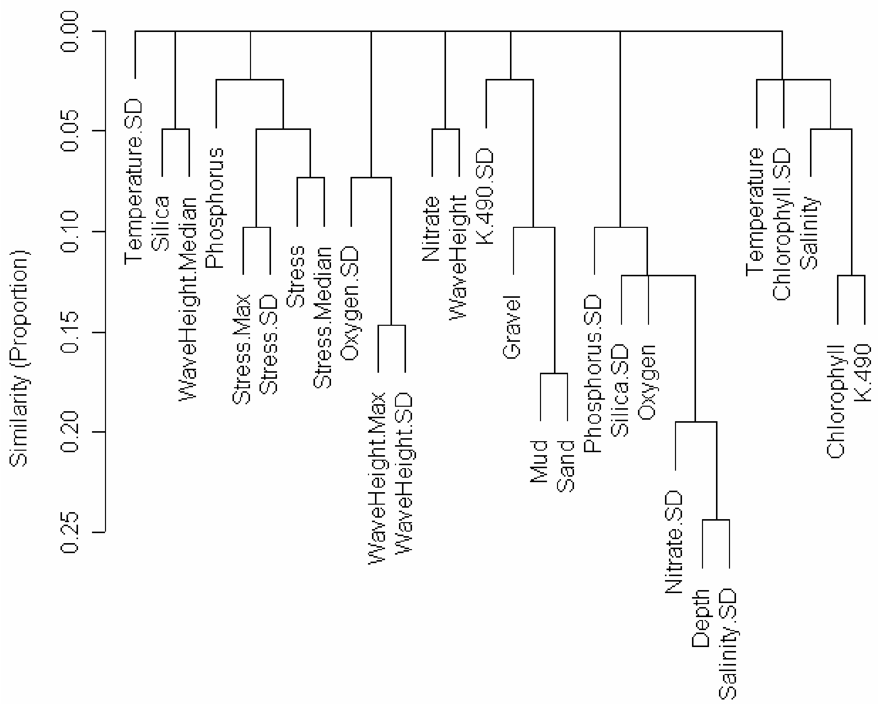

Figure 5.3.12 Clustering of split variables (or surrogates) based on proportions of all cases where the variables occur together.

Break points

Figure 5.3.13 shows a histogram of the break points that were selected for the 12 most frequently occurring variables. In some cases the splits favour a part of the range fairly strongly while for other variables they tend to be almost evenly distributed. The horizontal ranges of these histograms have been set to cover the range of the variables itself to give some perspective to the concentration of break points (or otherwise).

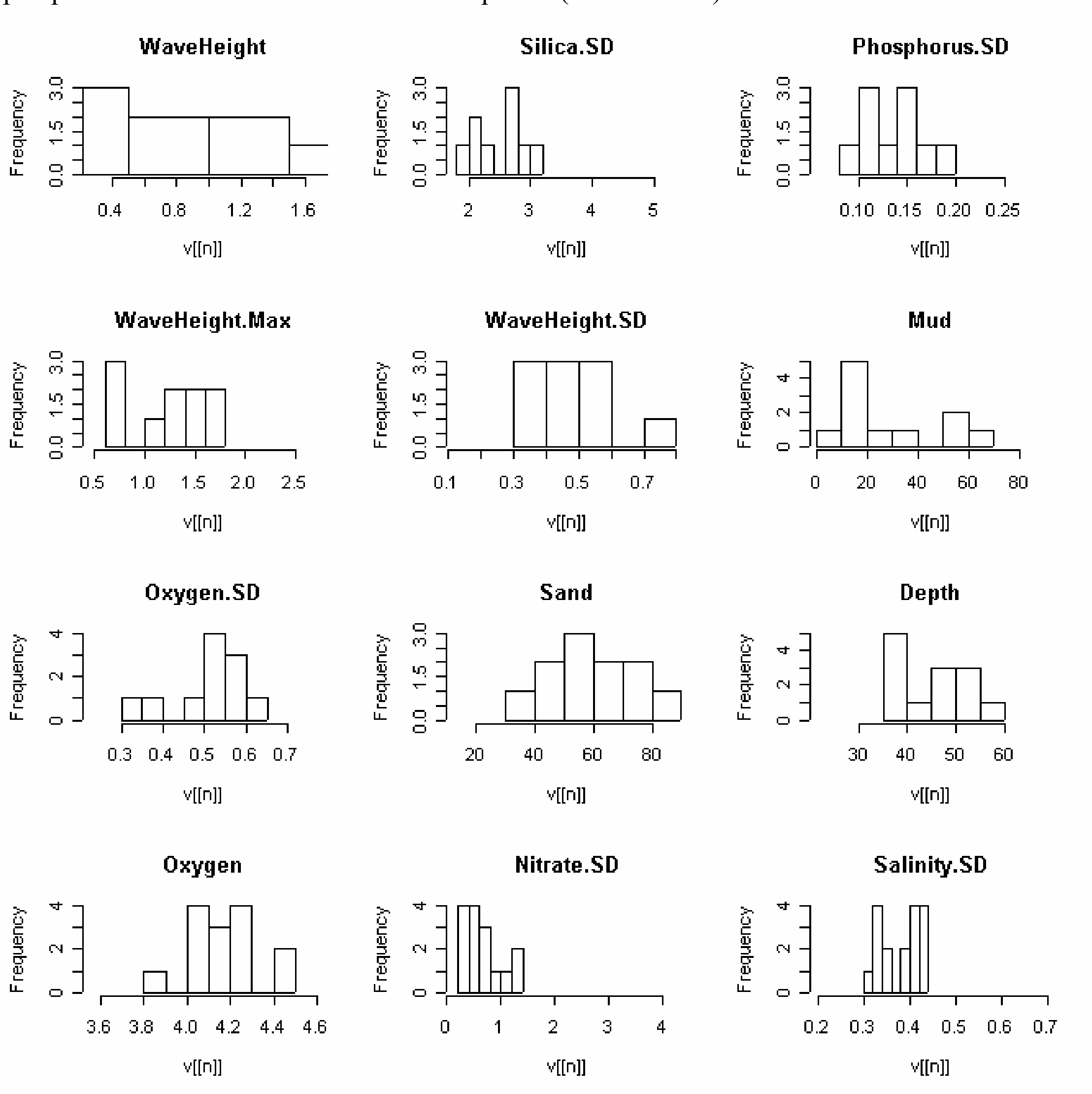

Figure 5.3.13 Histograms of the break points for the 12 most commonly occurring main split variables (or surrogates) ordered by increasing frequency. The histograms are placed on a horizontal axis that covers the range of the variable itself.

Correspondence analysis of tree-selected taxa

If we choose the presence/absence data of the 41 taxa selected by the tree method the resulting 128 × 41 station × taxon matrix has occupancies ranging from 9 to 120, and row totals from 5 to 27.

The first 5 canonical correlations are 0.5040964, 0.3895732, 0.3135284, 0.2686576 and 0.2531685, suggesting that only the first ordination is likely to be useful. Figure 5.3.14 shows a geographical display of this ordination. The similarity with the previous ordination based merely on taxa that occur at least 20 times is fairly clear. In this figure, areas with similar colours have similar species groupings. Thus the central blue area has a different composition to the adjacent green area.

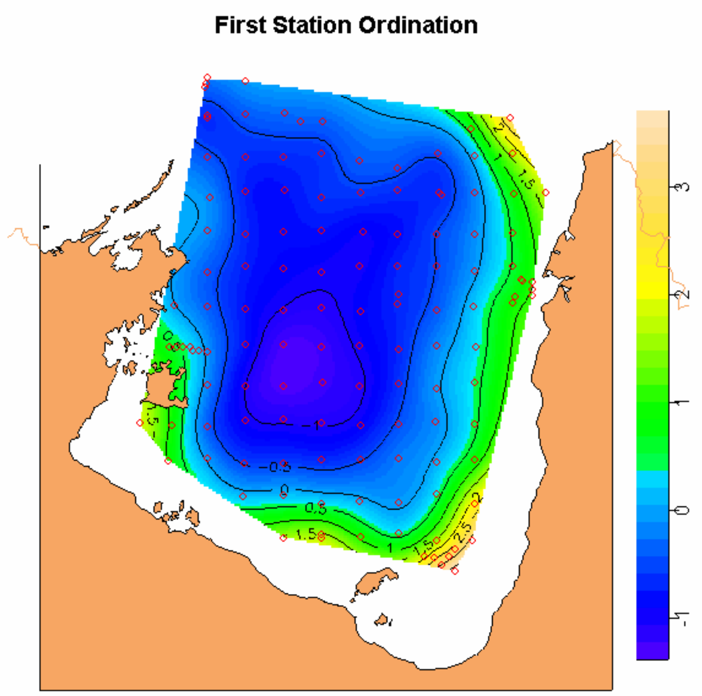

Figure 5.3.14 Smoothed, interpolated first canonical ordination of stations, based on tree-selected taxa and presence/absence data.

Smoothed presence/absence data

We carried out a correspondence analysis using the same 41 species but rather than using their binary presence/absence readings we used the predicted probabilities for occurrence of each taxon, using its tree-based predictor, at each station.

The correlations for this smoothed version of the PA matrix are suppressed relative to the previous case. They are now 0.4391464, 0.2624159, 0.2103234, 0.1801868 and 0.1629778. The first canonical ordination of stations is again the only useful one and this yields the following geographical representation. Figure 5.3.15 gives the corresponding geographical representation. The result is an even smoother version of the previous diagram, although the general features are very similar.

We conclude that false negatives are likely not strongly affecting the outcome, and nor is the precise suite of taxa selected.

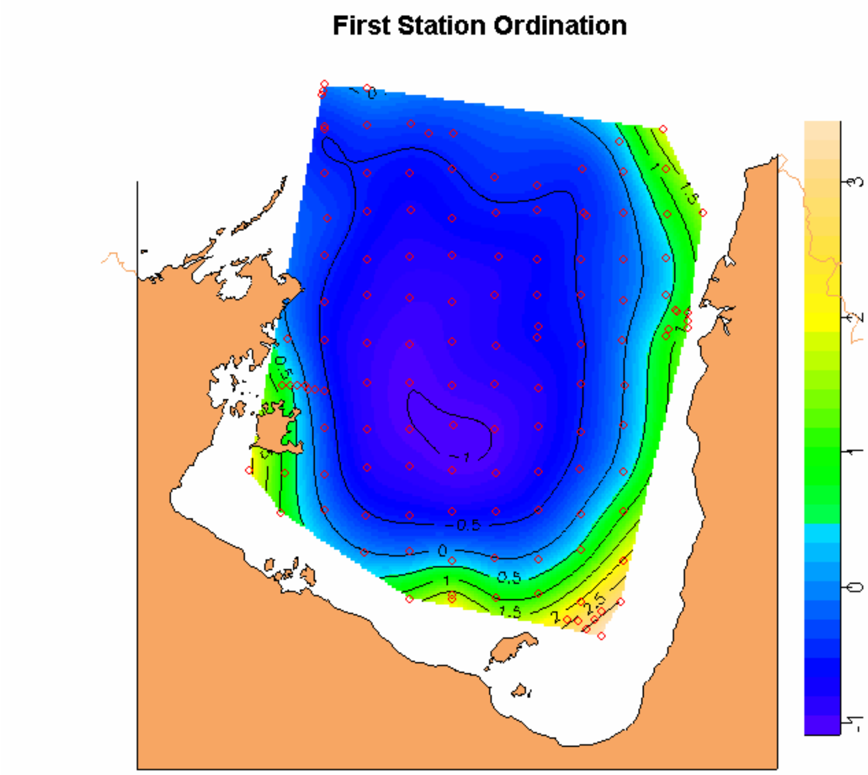

Figure 5.3.15 Smoothed, interpolated first canonical ordination of stations, based on tree-selected taxa and estimated presence probabilities rather than raw presence/absence data.

Ordination of taxa

We plotted the first two canonical ordinations of taxa using the smoothed presence absence data. The second axis is not effective, but curiously the extreme taxon on the first axis is also the extreme on the second. The plot is shown in Figure 5.3.16. Other than several taxa that appear to be (perhaps informative) outliers, no clear groups emerge.

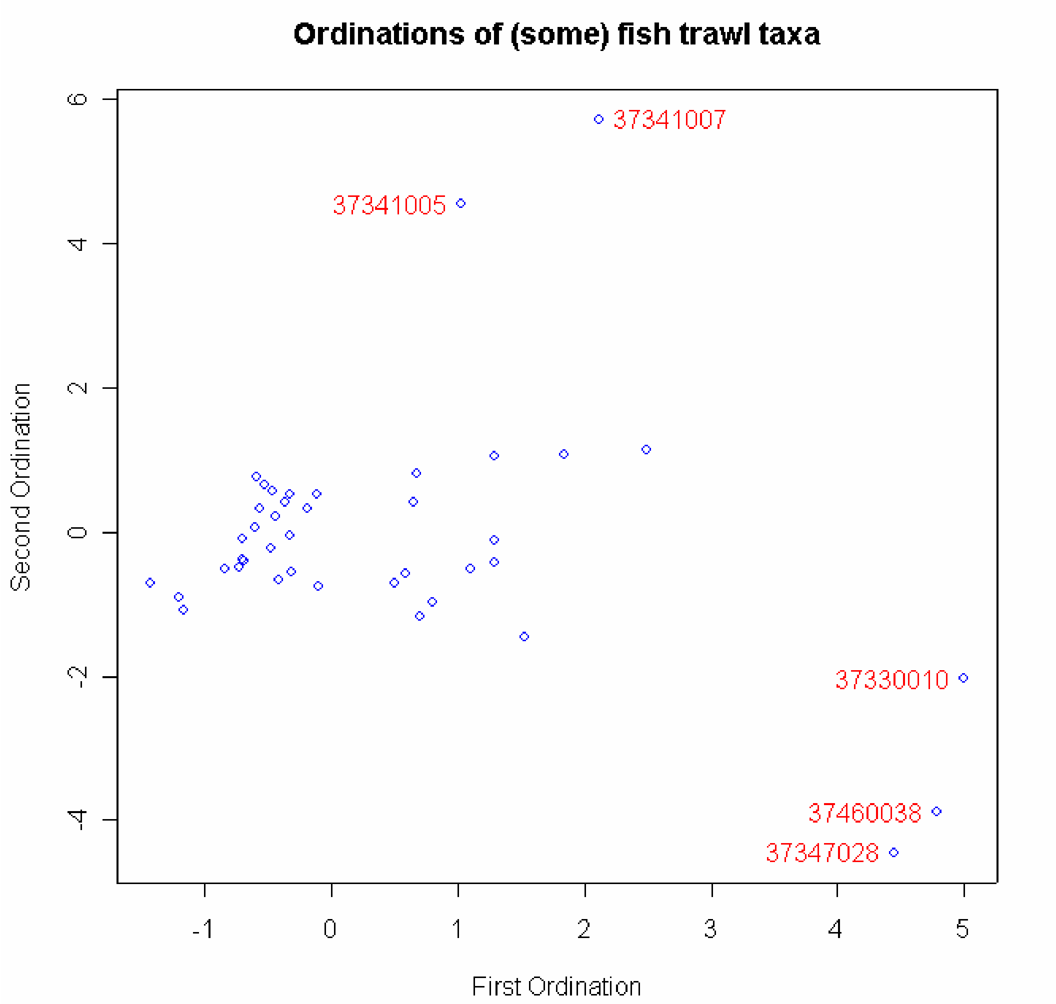

Figure 5.3.16 Ordinations of tree-selected taxa using smoothed presence/absence data. The highest three and lowest two taxa have been identified with their species codes: 37341007 = *Gazza minuta*, 37341005 = *Leiognathus leuciscus*, 37330010 = *Sillago ciliata*, 37460038 = *Pseudorhombus argus*, 37347028 = *Pentapodus paradiseus*.

Discussion

Analysis of the fish trawl samples from 107 stations across the Gulf of Carpentaria showed that α-biodiversity of the fish fauna is much less, and much less variable, than for the dredge data reported in Chapter 5.2. We tested a total of 28 variables: Temperature, Chlorophyll, K.490, phosphorus, silica, salinity, nitrate, seabed current stress, sediment, wave height, mud, oxygen, depth together with derivatives of some of these (maximum and standard deviation). The connection between the fish fauna and available environmental variable information is relatively weak. A tree analysis showed that wave height (mean, standard deviation and maximum) is the most important factor in clustering of the stations from which fish were collected.

A tree analysis of the species indicated that salinity SD, nitrate SD and oxygen were the split variables with the highest frequency of occurrence. These water quality properties are probably linked to thermocline formation in summer in the Gulf of Carpentaria (Somers et al 1987) and the associated water quality changes are probably key drivers in determining the distribution of mobile species such as most teleosts. The analysis indicates that the distribution of fish biodiversity of the Gulf of Carpentaria is fairly uniform over much of the central area with a different grouping more inshore.

INDICATOR SPECIES

Bill Venables

We wished to know whether there were species of teleosts that were characteristic of high biodiversity. We used data collected on Cruise SS9003 in which fish trawls were carried out at 107 stations in the Gulf of Carpentaria. The samples included a total of 289 species and the number of species per station ranged from 20 to 67. We used the same approach in analysing the fish trawl data as for the dredge data (see Chapter 5.1).

The indicator species tree has 9 nodes and an increase in α-biodiversity is now indicated sometimes by the presence of a species and sometimes by the absence (Fig 5.3.17). Key indicator species of high biodiversity are *Pseudorhombus diplospilus* (a sole), *Gerres macracanthus* (a purse mouth) and *Lagocephalus scleratus* (a puffer fish). The highest group is indicated by the presence of three species (rightmost node)

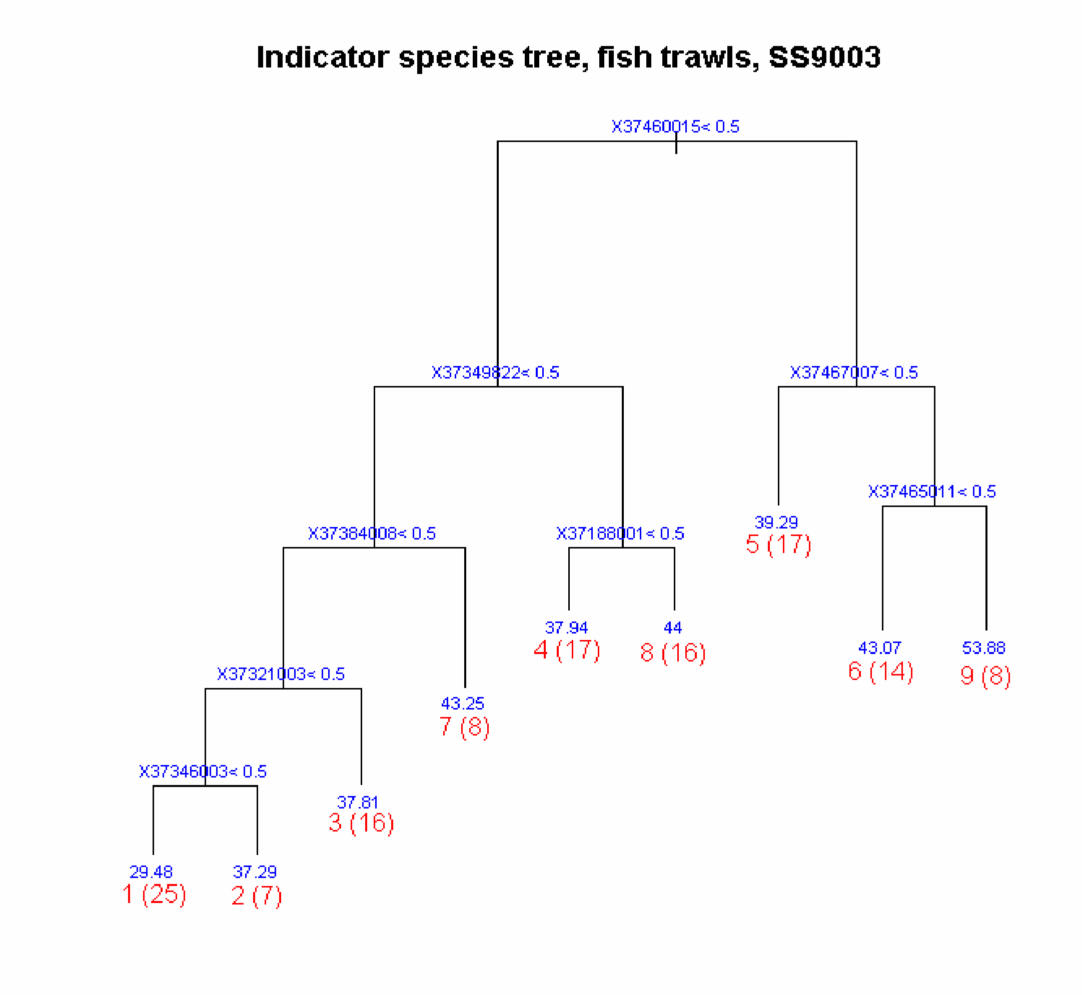

Figure 5.3.17 Indicator species tree for the fish trawl data. The larger type numbers in red below each node give a node label and a number of stations at that node (in parentheses). The nodes are labelled from 1 to 9 so that the mean α-biodiversity is increasing – with 1 the lowest and 9 the highest. The small blue numbers below each node are the mean number of species found at such station. Species codes are as follows: 37460015 = Pseudorhombus *diplospilus*; 37349822 = *Gerres macracanthus*; 37467007 = *Lagocephalus scleratus*; 37384008 = *Choerodon monostigma*; 37188001 = *Netuma thalassinus*; 37465011 = *Abalistes stellaris*; 37321003 = *Terapon theraps*; 37346003 = *Lutjanus vitta*

As is the case with the analysis of dredge data, the tree model diagram for teleosts should be read as follows, starting from the top of the diagram. If species 37460015 (*Pseudorhombus diplospilus*) is present in the sample go to the right. If species 37467007 = *Lagocephalus scleratus* is absent go left (node 5), there are 17 stations with this combination and they have an average of 39.29 species (Table 5.3.5). If species 37467007 = *Lagocephalus scleratus* is present, go right, the mean number of species is 128.6 with this combination. Otherwise go to the left. In this latter case if species 37465011 = *Abalistes stellaris* is present go to the right (node 9). There are 8 stations with this combination and they have a mean of 53.88 species. If *Abalistes stellaris* is not present, go the left (node 6) and there are 14 stations with this combination with a mean of 43.07 species.

The highest level of biodiversity (number 9 in Figures 5.3.17 and 5.3.18) was found at eight stations with a mean of 53.88 species. Following the tree, these stations all had the three species *Pseudorhombus diplospilus*, *Lagocephalus scleratus* and *Abalistes stellaris.*

Table 5.3.5: Numbers of stations and mean numbers of species at each node of the indicator species tree

Node label	1	2	3	4	5	6	7	8	9
No stations	25	7	16	17	17	14	8	16	8
Mean no species	29.48	37.29	37.81	37.94	39.29	43.07	43.25	44	53.88

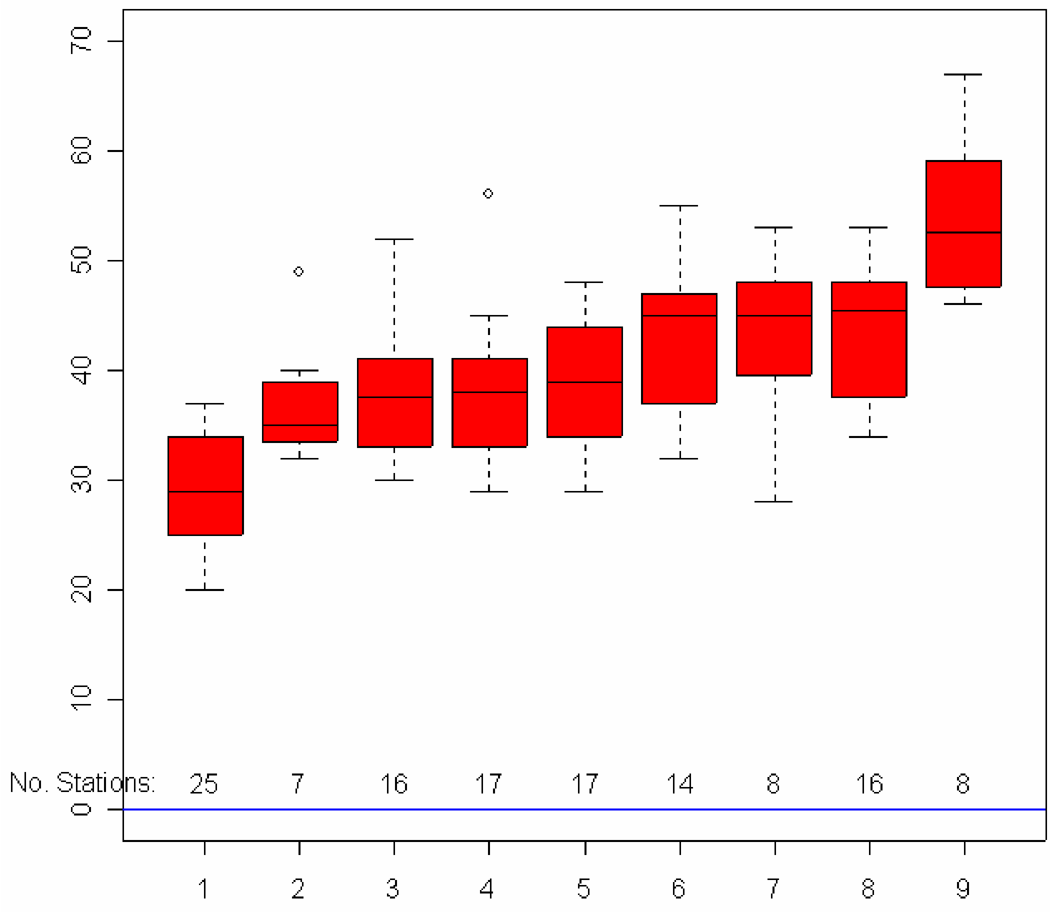

Figure 5.3.18 Box plots of α-biodiversity for the nine fish-trawls nodes. The station numbers are shown. The nodes are labelled so that the means are increasing

Box plots have been used to indicate the variation in species numbers for each node class of station (Figure 5.1.18) and the spatial locations of the nodes is given in Figure 5.3.19.

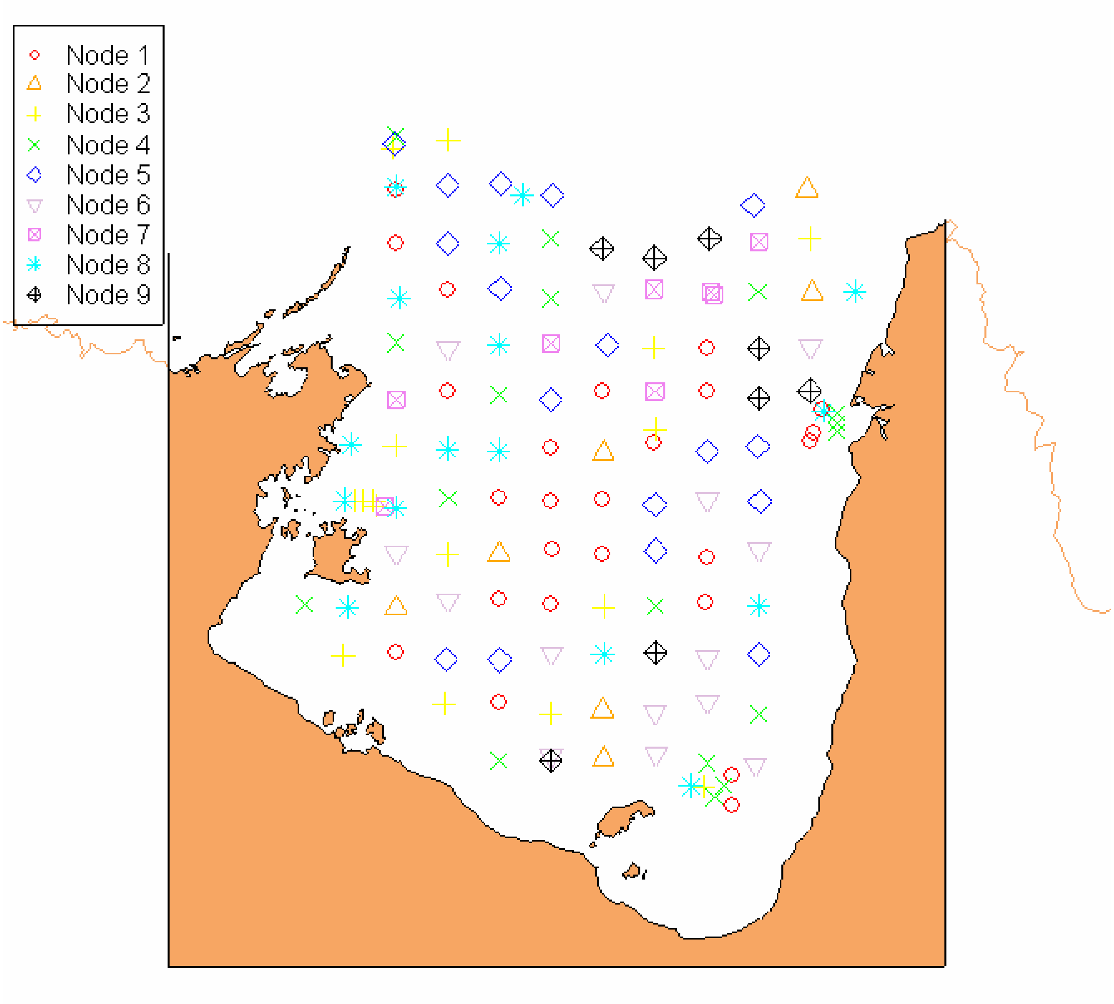

Figure 5.3.19 Location of 9 node groups of stations determined by indicator species for fish trawl stations, SS9003.

As can be seen in Figure 5.3.19, the areas with the highest biodiversity of teleosts (node 9) are mostly in the north east. The stations with second highest value node (8) are more scattered but the majority are in the north west. There is no clear pattern to the spatial distribution of the remaining nodes.

Discussion

The area with the highest biodiversity of teleosts is in the north east of the Gulf of Carpentaria. The highest level of biodiversity was found at eight stations with a mean of 53.9 species. These stations all had the three species *Pseudorhombus diplospilus*, *Lagocephalus scleratus* and *Abalistes stellaris*. We suggest that these species might be used as indicator species of fish biodiversity but we have some reservations. Despite their association with high biodiversity, none of these species featured in the seven main groupings of fish assemblages. This may indicate that the data set is not large enough to identify robust relationships.

COMPARISON OF BIODIVERSITY ESTIMATES FROM FISH TRAWLS AND DREDGE

Bill Venables

A natural question is the extent to which the assessment of biodiversity or biological activity at a station depends on the sampling device. The SS9003 cruise covered a very wide area of the Gulf of Carpentaria and for 107 stations we have paired samples from dredges and fish trawsl. The question then is the extent to which the α-biodiversity or total biomass measures at the same station are correlated.

Figure 5.3.20 shows the plot of the total number of species for Fish Trawl and Dredge samples. The correlation, 0.4097 is highly significant in the statistical sense, but from a practical point of view the connection is insufficient to allow accurate prediction in either direction.

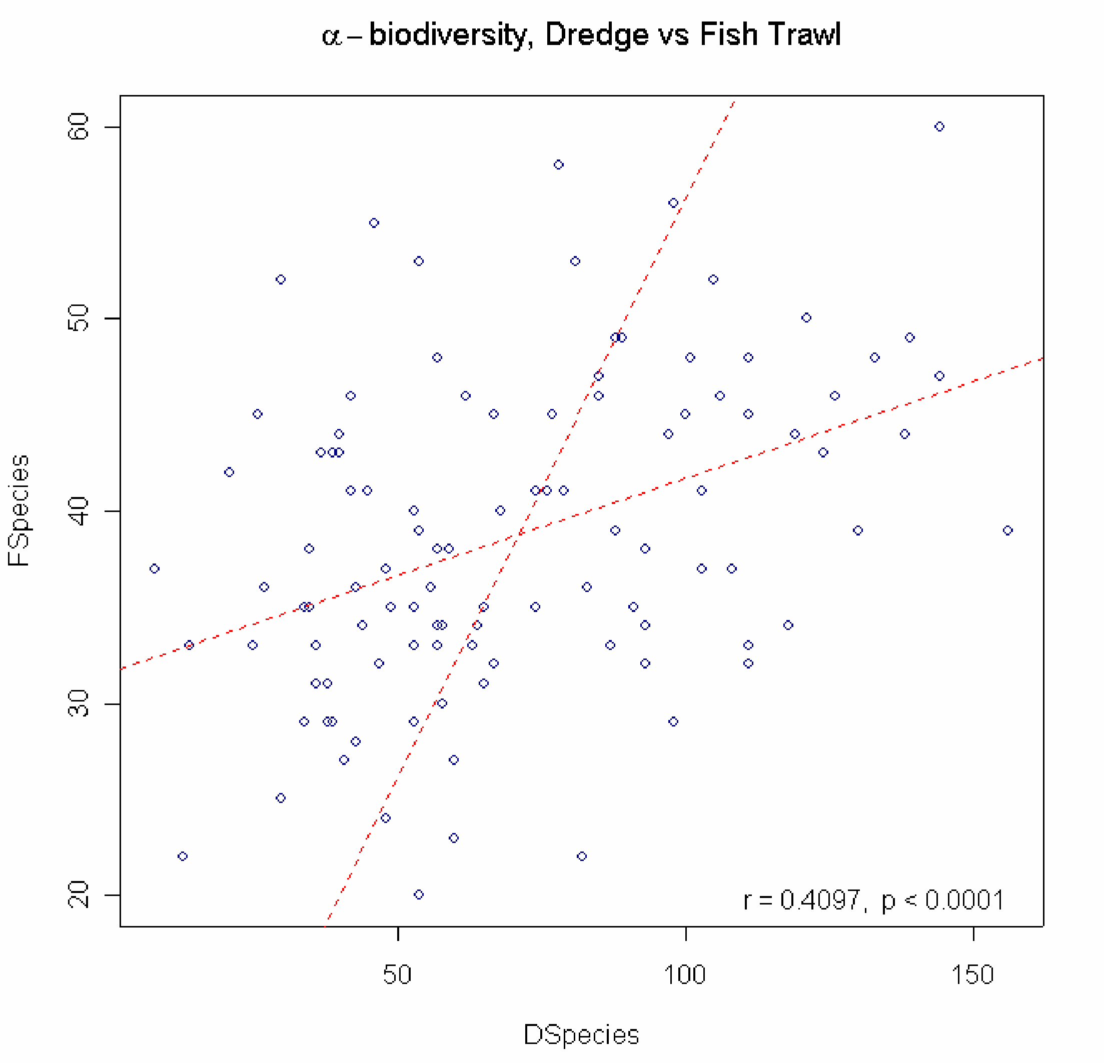

Figure 5.3.20 Correlation between α-biodiversity measures from Fish Trawl and Dredge samples

Figure 5.3.21 shows a plot of log(Biomass) for Dredge and Fish Trawls at the 107 stations from SS9003 where both are available. The plot also gives the regression lines in both directions. The log transformation has been used to correct substantial skewness in the Biomass. In practical terms the degree of association is slight, but more formally the Pearson correlation is only 0.209 which has a significance level $p = 0.0307$ which is just significant at the 5% level.

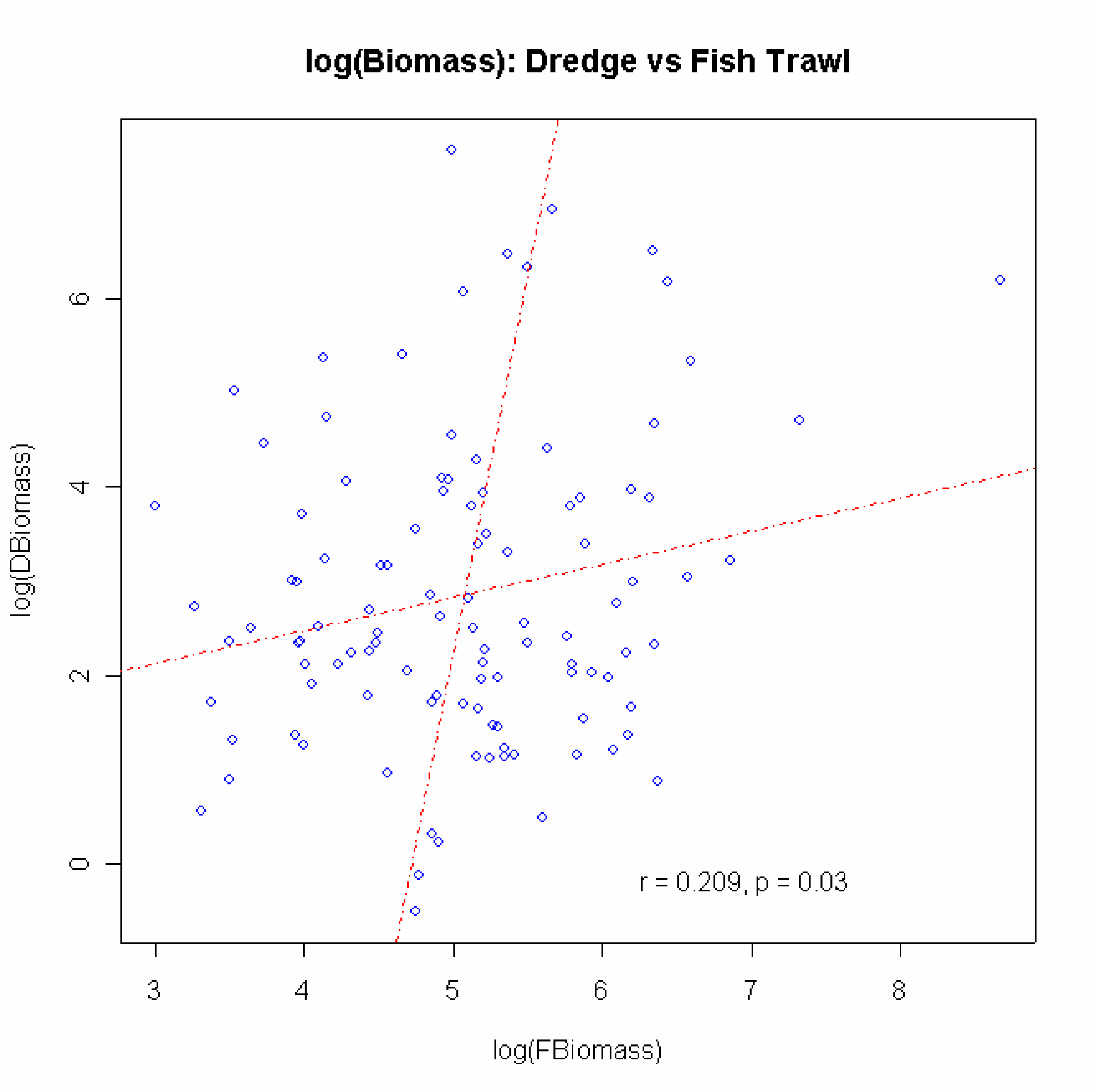

Figure 5.3.21 Correlation between log(Biomass) for Dredge and Fish Trawl samples.

Discussion

Areas with a high biomass are sometimes regarded as being biologically rich. The analyses presented here however shows that biomass and biodiversity are not interchangeable measures. Areas of high biomass may have large numbers of a few species and areas of low biomass may have many species but these may be present in low numbers.

CHAPTER 5.4

FISH FROM PRAWN TRAWLS

Chapter Authors:

Bill Venables, Mick Haywood, Scott Gordon

CHAPTER 5.4

FISH FROM PRAWN TRAWLS

Bill Venables
Scott Gordon
Mick Haywood

Summary

We analysed prawn trawl bycatch data collected from 920 sampling stations

Biodiversity
- Biodiversity of fish was similar off Weipa and north of Groote Eylandt but the analysis is restricted to the inshore regions since trawl samples were collected only from this area

Surrogates
- Depth, Oxygen.SD, Nitrate, and Oxygen are the most important surrogate environmental factors that group the stations that were sampled for the first node
- These factors were also important in grouping the fish trawl stations indicating a commonality between the shallow (20-40 m depth) stations and those of the more offshore stations (mostly >40 m) sampled with the fish trawl.
- The trawl biomass surrogates analysis showed that for all cruises salinity and temperature are significant surrogates. Sediment characteristics provided no potential surrogate information consistently across all cruises.
- A similar result to the biomass surrogates analysis shows temperature and salinity to be important surrogates for biodiversity but less so than for biomass
- Individual cruises gave different results:
  - Chlorophyll and K490 parameters are significant for the SS9702 and SS9708 cruises
  - Sediment covariates (sand, mud, pebble, and granule) were important as were acoustic parameter variations (roughness standard deviation and hardness standard deviation) for the SS9702 cruise
  - Acoustic information (roughness and hardness standard deviation) is important as well as sediment (mud see Figure 5.4.12), bottom water column attributes (silica, nitrate) and depth for the SS9708 cruise
  - Temperature and salinity almost completely describe the biomass variation and are highly statistically significant for the SS9803 cruise

Indicators of biodiversity
- Three species of teleost taken together were associated with high biodiversity. These were *Nemipterus peronii*, *Lethrinus genivittatus* and *Echeneis naucrates*. Although they were found together at only a few stations, these stations had a mean species count of 78.4

Introduction

We used data on prawn trawl bycatch samples collected on three research cruises using the 66m stern trawler RV Southern Surveyor in the main prawn fishing grounds of the NPF. The results of 1076 catch samples were available for analysis. Details of the sampling are given by Stobutzki et al., (2000) and a summary is given in Chapter 3.1 (see Table 3.1.1). The approach in analysing this data is similar to that used for samples from the fish trawl and benthic dredge (Chapters 5.1 and 5.2).

FISH BIODIVERSITY

Physical Surrogates (including Acoustics) for Trawl Biological Parameters

The analysis of the physical covariates to establish surrogates for biological parameters from prawn trawl data used similar techniques described in the dredge analysis (Chapter 5.2). That is we have attempted to explain the pattern in terms of underlying physical predictor variables.

For the analysis we considered a generalized linear model with total biomass for a trawl and biodiversity (in terms of the number of distinct taxonomic families) as the discrete response variables. Possible predictor variables included acoustic information (depth, roughness, hardness means and standard deviations); CARS modeled seabed water properties (nitrate, phosphate, salinity, oxygen, temperature, silica); SeaWiFS remote sensed data (chlorophyll, K.490), seabed current stress information, data on untrawlable grounds, trawl effort information and sediment properties (% cobble, % granule, % mud, % pebble, % sand). At this stage we have not included the modeled. Initially we included all available physical covariates in the model and automatically selected the simplest model by eliminating terms to minimize the Akaike Information Criterion. The resulting simple model results are presented here. While initially the cruise was included as a term in the model in order to establish if it was significant; further analysis treating each cruise discretely provided extra insight into the development and interpretation of surrogates. In this chapter we deal with the fish captured in prawn trawls. This material was identified to species level. Fish made up 73% of the bycatch by weight (Stobutzki el al., 2000).

Prawn trawl data, presence/absence

The Prawn trawl data comes from the "Florida Flyer" gear and was collected on cruises SS9702, SS9708, SS9803. Details are provided in Chapter 3.1 (Table 3.3.1). There were 381 species observed at 920 stations (Table 5.4.1).

Table 5.4.1 Number of stations sampled on each of three research cruises

Cruise:	SS9702	SS9708	SS9803
No. stations:	163	391	366

The distribution of the sampling is shown in Figure 5.4.1. The three research trawl cruises were concentrated in regions of high commercial trawling intensity. The final cruise was restricted to a small region north and south of Groote Eylandt (Figure 5.4.1).

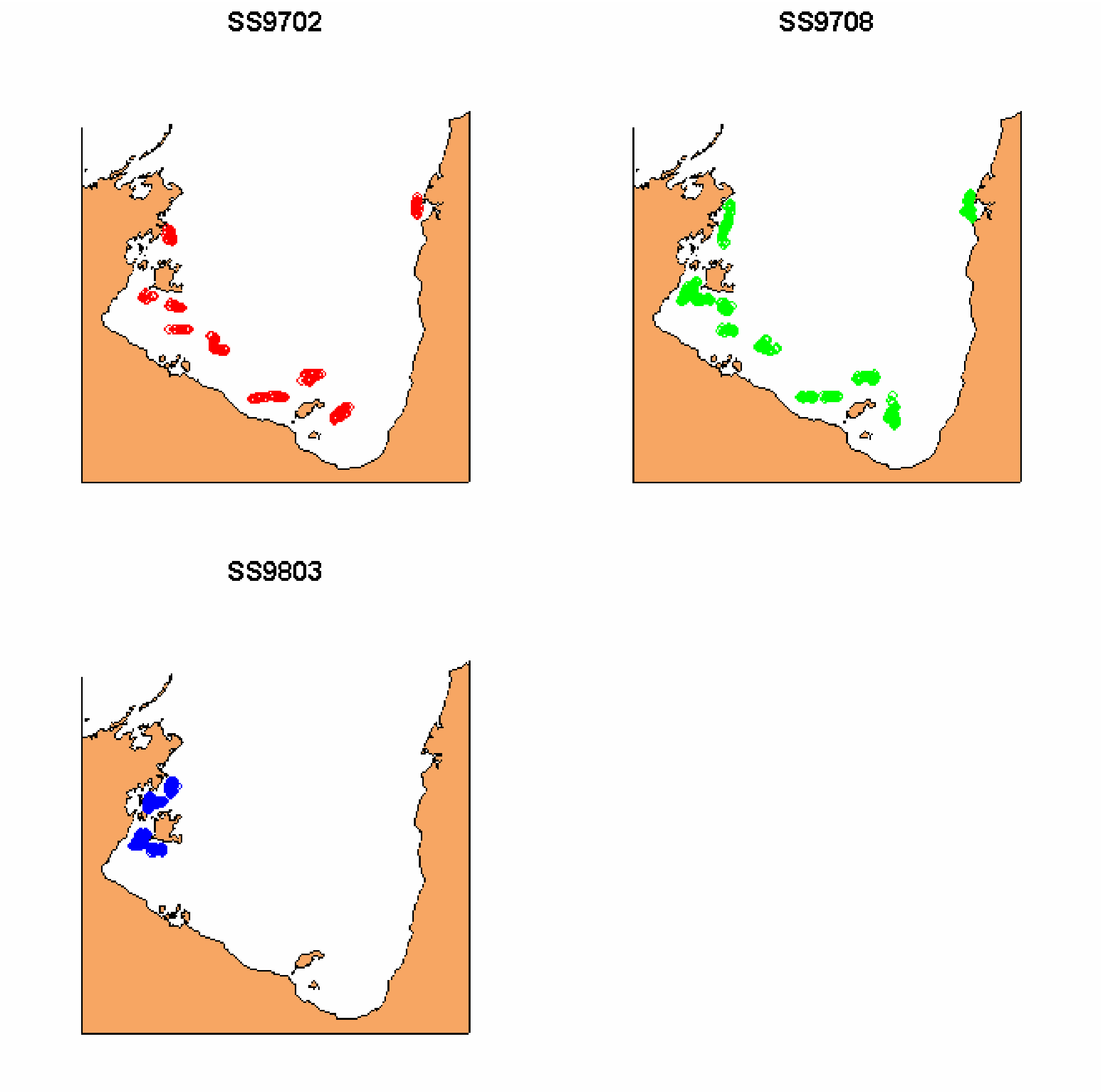

Figure 5.4.1 Station positions for the prawn trawl bycatch data classified by cruise.

Choice of species

As pointed out in the analysis of fish trawl and dredge data, very rarely, or very commonly occurring species tend to inflate the canonical correlation by isolating a few stations at which rarely occurring taxa only occur (or at which very commonly occurring taxa do not occur). This may be a real effect but in most cases it is an artefact of the sampling. One way to assess a minimum occurrence/non-occurrence requirement for a taxon to be included is to plot the change in canonical correlations as the criterion for inclusion (which we call the minimum occupancy requirement) is increased. Figure 5.4.2 shows the change for the first 6 correlations as minimum occupancy requirement is raised from 1 to 40 (out of 920 stations). The correlations are very stable, even at low occupancy requirements. We chose a cut-off requirement that each taxon occur in at least 30 stations (and must *not* occur in at least 30 stations, though this condition does not exclude any taxa). This gave 920 stations with 152 taxa.

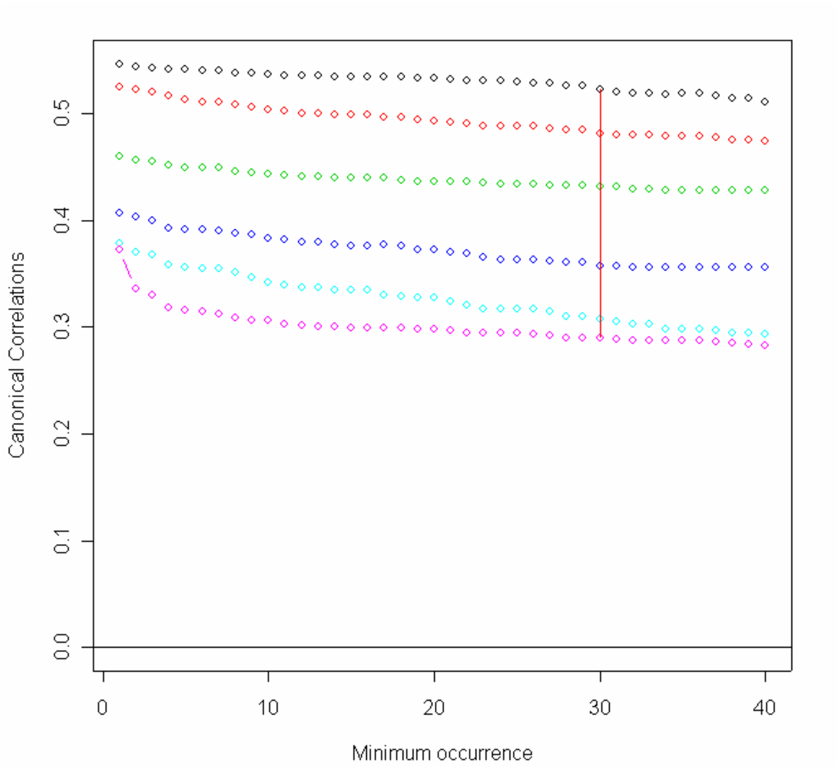

Figure 5.4.2 Change in canonical correlations with an increasing minimum occupancy requirement for inclusion of taxa

The six highest value correlations are 0.5232, 0.4812, 0.4319, 0.3574, 0.3074 and 0.2893. None of these can be considered very large. We concentrate on the first of these but also consider the first three for some analyses. The initial impression is that the connection between biota and stations is relatively weak.

Homogeneity over cruises

Figure 5.4.3 shows plots of the first three canonical station ordinations against each other, separated by cruise. Although there are some differences as might be expected, on the whole there is no serious systematic difference that might cause us to examine the three cruises separately, (as was the case with the benthic sled data, for example – see Chapter 5.2). No large or obvious systematic differences emerge, though subtle ones are present

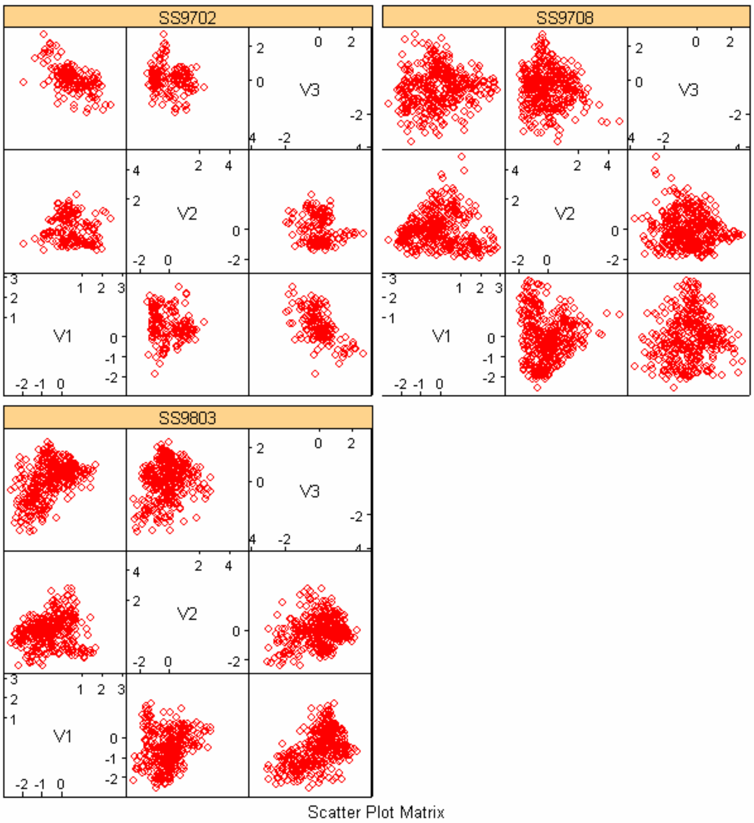

Figure 5.4.3 Graphical checks for systematic differences in ordinations between cruises. Pairwise scatter plots of the first three canonical station ordinations classified by cruise.

Figure 5.4.4 shows a representation of this first canonical ordination, but only at the station locations. Areas with similar colour are suggested to have similar patterns of biodiversity. The cruises are separated, but combined in the final diagram. The fine lines across the top of the diagram are a key showing the relationship between colour and relative ordination score. Because of the differences in locations in SS9803, except for the area around Groote Eylandt, we have only two comparisons for Weipa in the north eastern GoC and the Mornington and Sir Edward Pellew group across the southern GoC. The summary figure showing the combined data, suggests a similarity in biodiversity between Weipa (really Albatross Bay and offshore) and the waters to the north of Groote Eylandt. The fauna around the islands in the southern GoC also shows similarities in biodiversity.

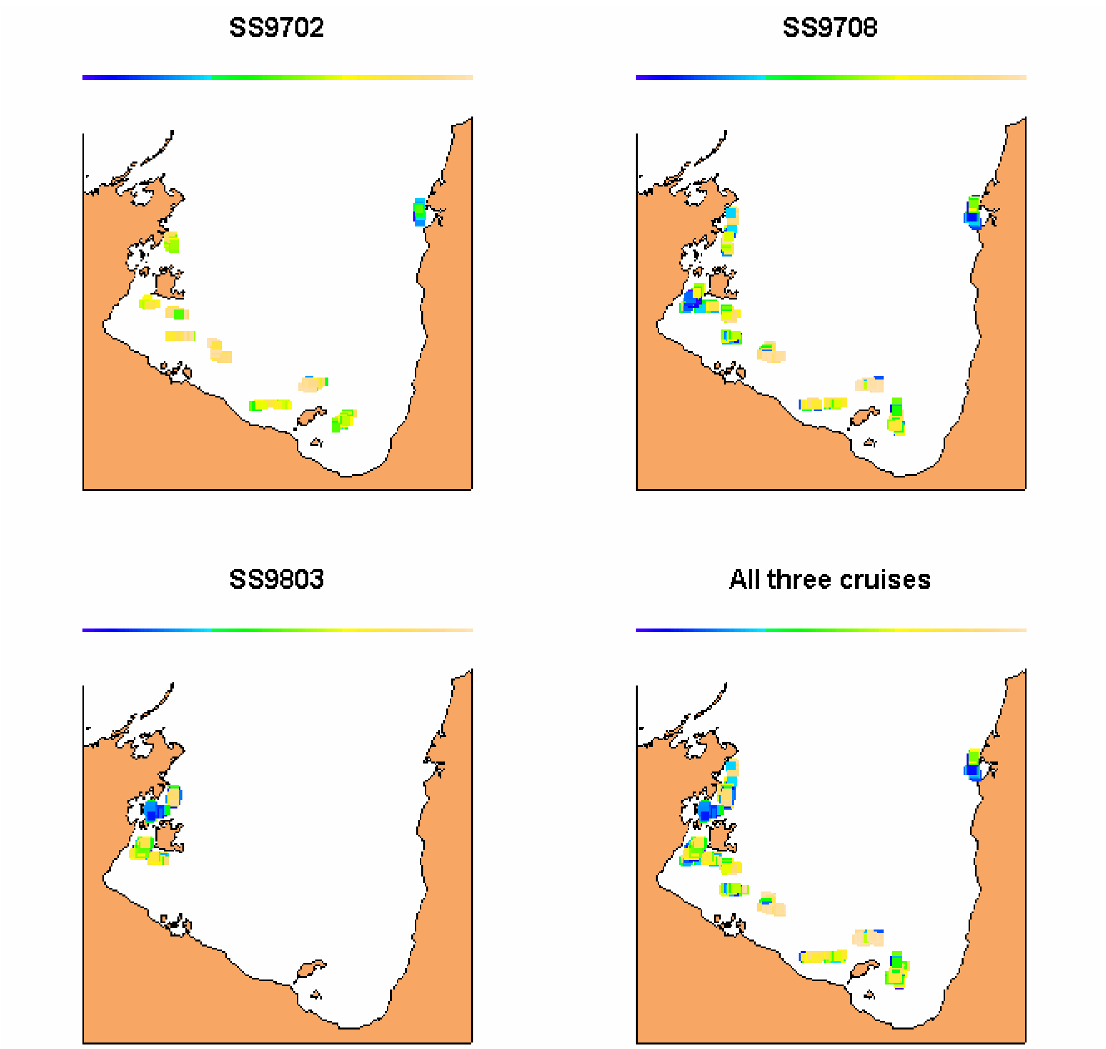

Figure 5.4.4 A representation of the first canonical ordination of the Prawn Trawl stations.

Showing the spatial patterns in the first three canonical ordinations is more difficult, but one way to do so is to use the three ordinations of stations to define a number of discrete clusters in the data and then to represent the clusters by colouring the station points. Using the station scores a divisive clustering of the stations using the *diana* procedure of Kaufman and Rousseeuw[1] gives the dendrogram shown in Figure 5.4.5. For specificity we summarise the patterns so defined with 5 groups and these then have occupancies:

Group:	1	2	3	4	5
Frequency:	140	231	287	86	176

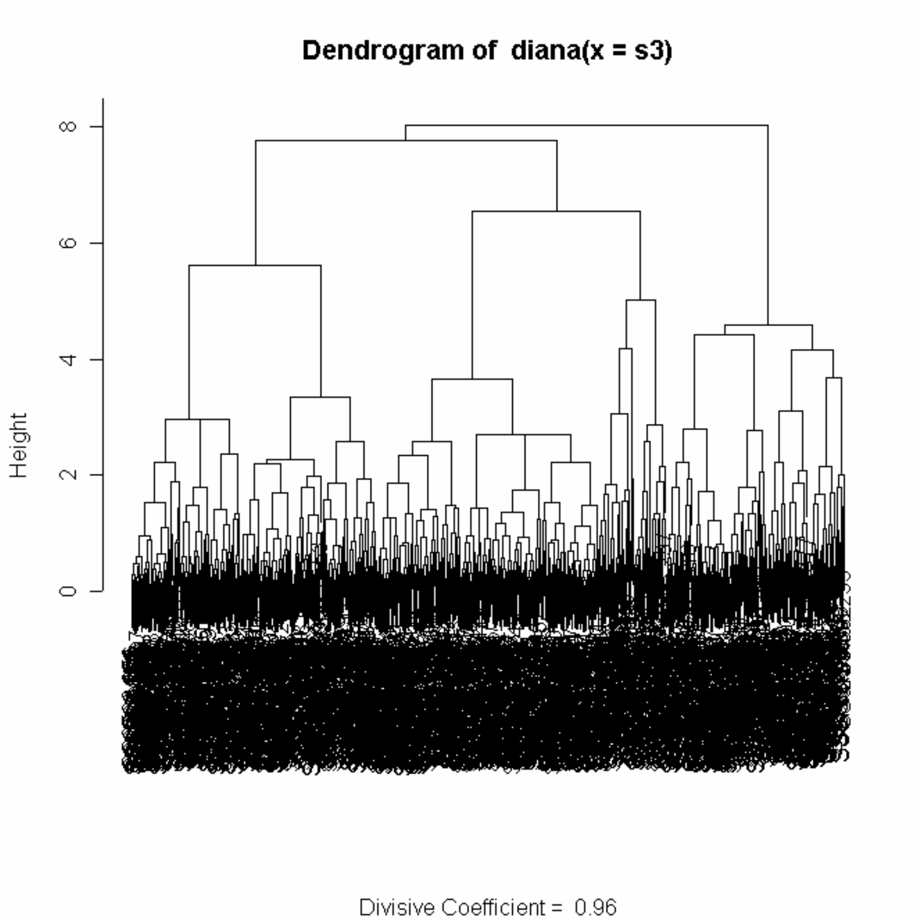

Figure 5.4.5 Divisive classification of Prawn Trawl stations based on first three canonical ordinations.

The groups are shown in Figure 5.4.6. Despite the relatively weak correlations involved, the clustering appears to show some topographical cogency with the region around Groote Eylandt and Weipa showing the highest values.

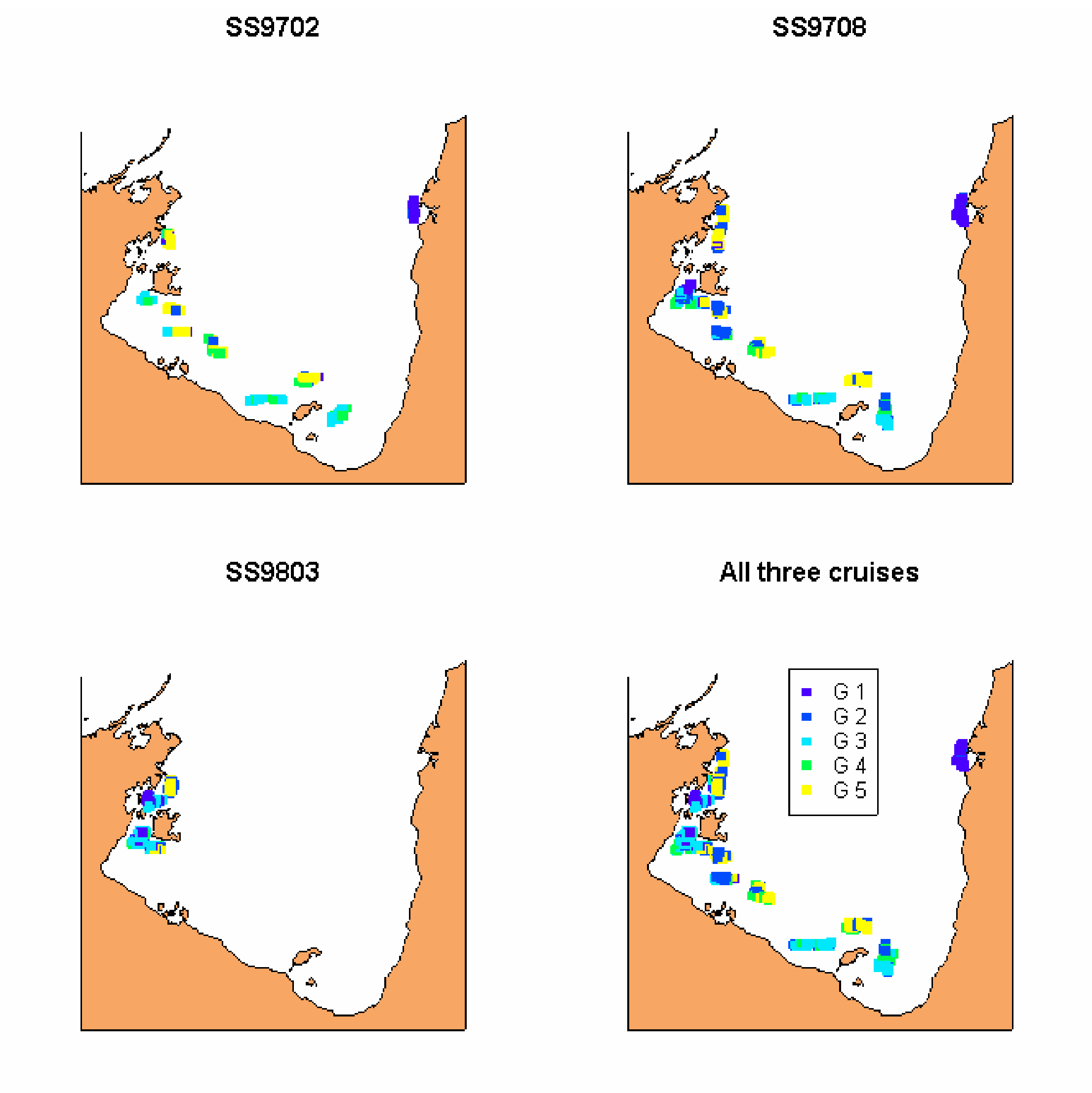

Figure 5.4.6 Divisive clustering of Prawn Trawl stations based on first three canonical ordinations

One way to investigate surrogates is to relate these clusters to the available predictor variables. A simple way to do this is to use tree-based methods to predict the observed cluster from the available predictors. This is a slightly non-standard procedure but justified in the sense that the results are only seen as investigatory.

Figure 5.4.7 shows the usual representation of this classification tree. The height of the vertical lines is proportional to the effectiveness of the branch in reducing the impurity measure of the nodes, that is, in improving the fit to that part of the data.

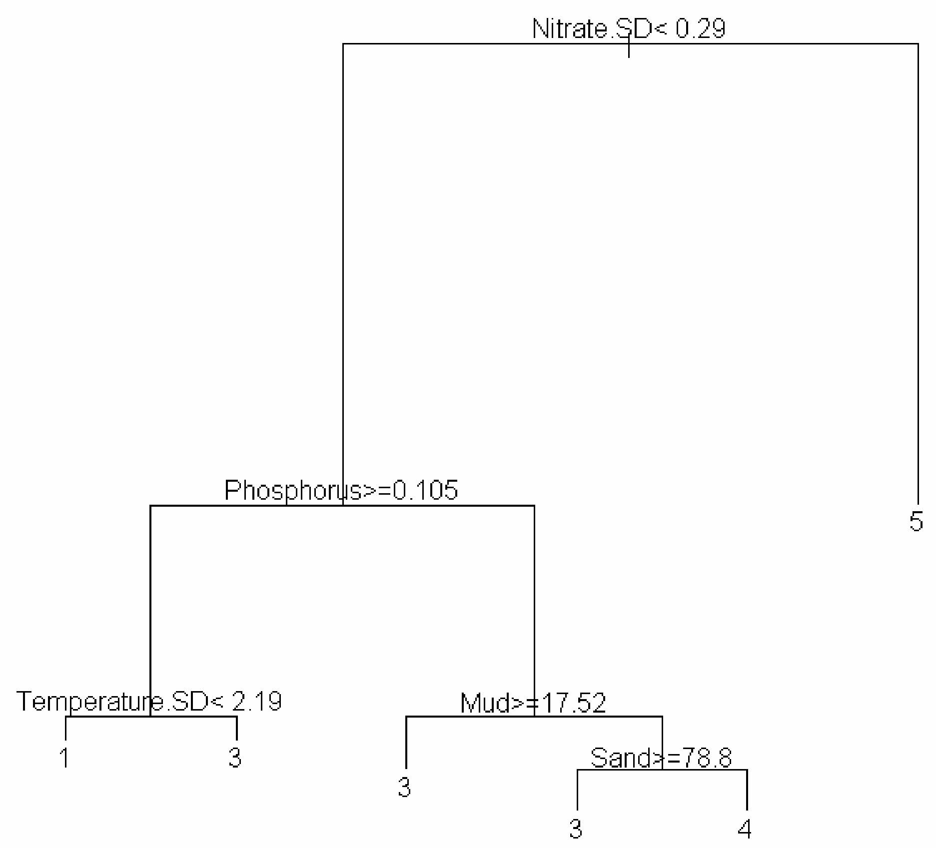

Figure 5.4.7 Classification tree for the 7 canonical clusters of the Prawn trawl stations

Surrogate split variables for the first node are *Depth*, *Oxygen.SD*, *Nitrate*, and *Oxygen.*

Species ordinations

An example of a 'pairs plot' of each of the three taxon ordinations against the others is shown in Figure 5.4.8. (Note that the panels above the diagonal are mirror images of those below.) There appears to be no discernable pattern although the dendrogram coming from these scores shown in Figure 5.4.9 suggests there are two or possibly four major groups.

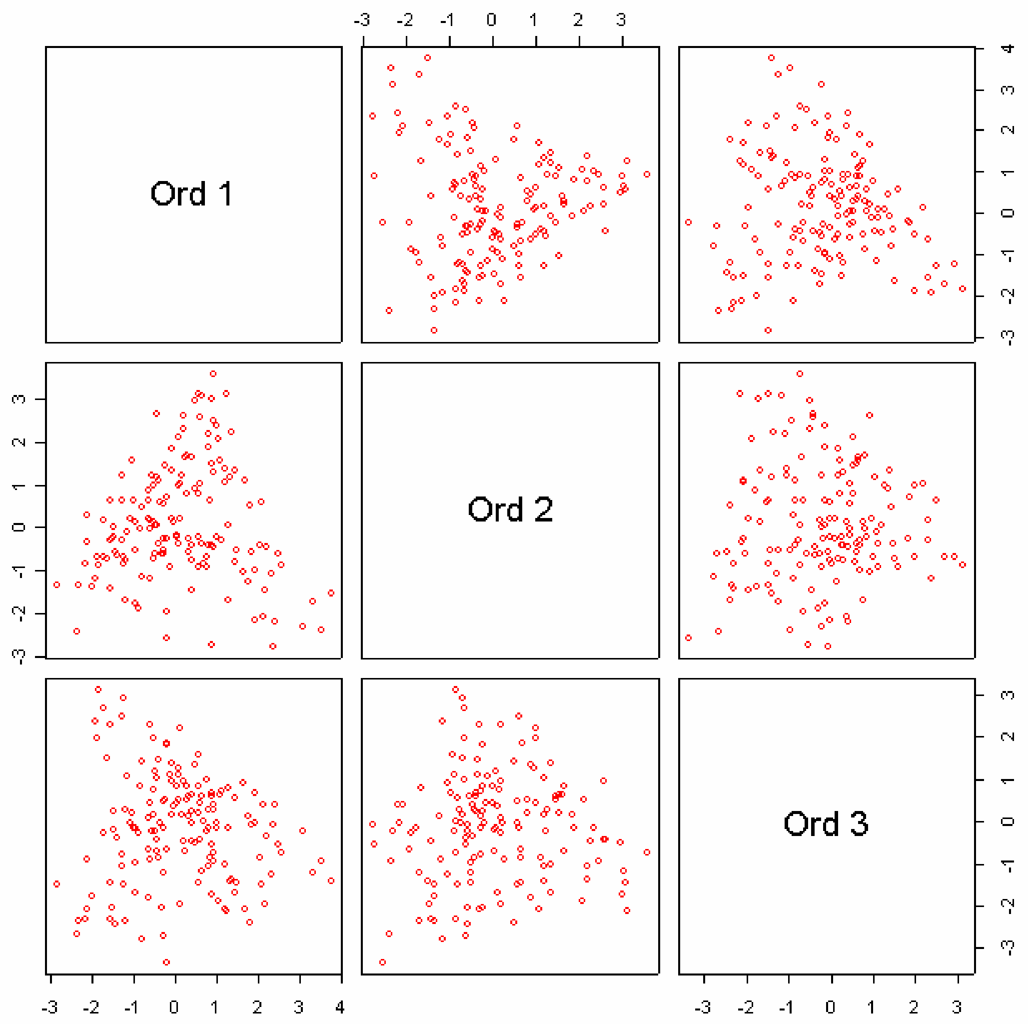

Figure 5.4.8 Pairs plot of the first three canonical ordinations of the taxa from the prawn trawl data

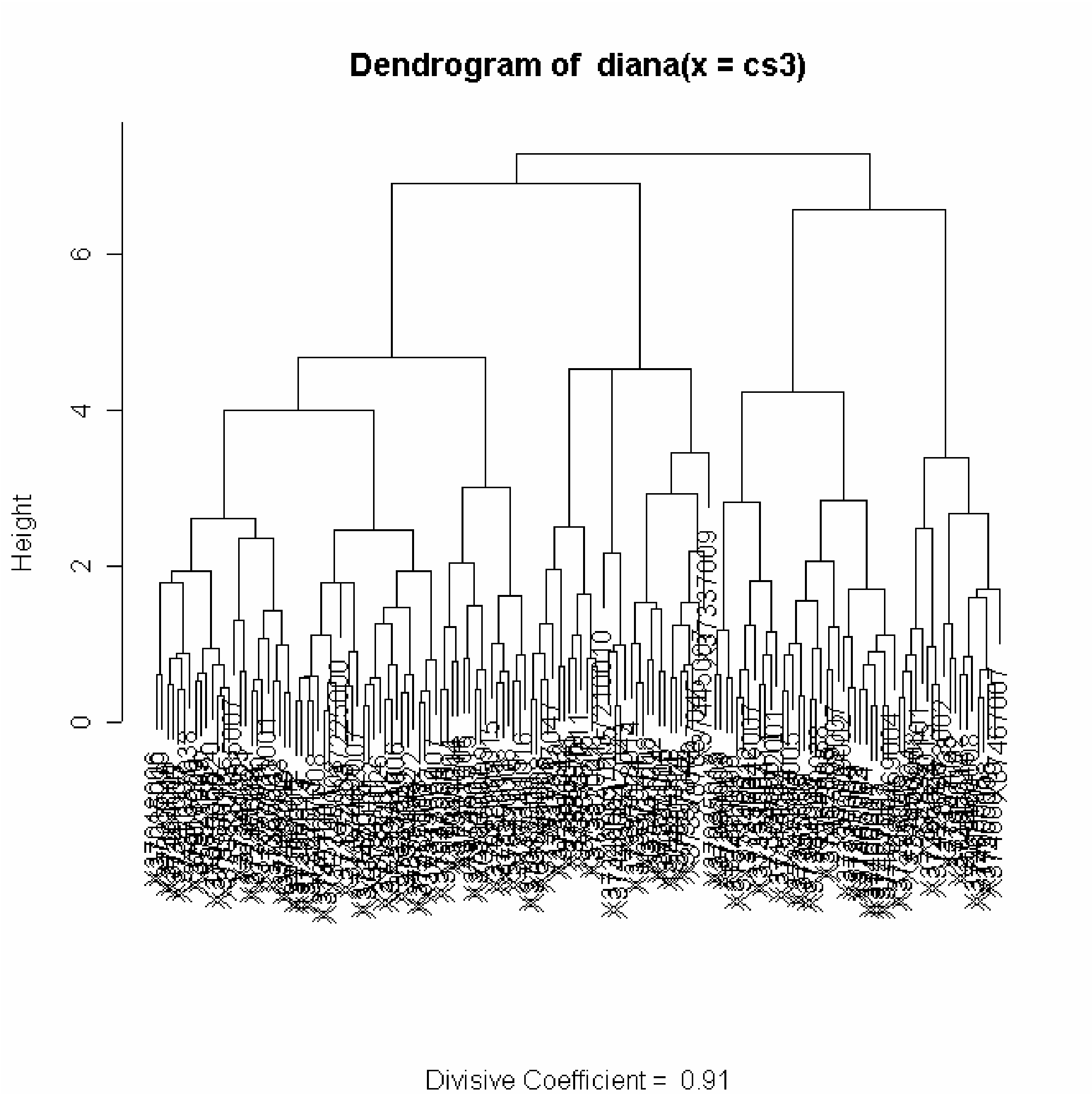

Figure 5.4.9 Dendrogram of divisive clustering of Prawn Trawl taxa

PREDICTORS OF INDIVIDUAL TAXA

We investigated possible surrogates by means of separate models for predicting the occurrence of each taxon and checking for any commonly occurring variables in these predictors. We used tree-based models since the predictors are likely to be highly non-linear, to contain numerous unpredictable interactions and to have some sharp discontinuous features. Under this scheme, some taxa will admit of reasonably effective tree predictor models and other will not. Taxa in the former group then have some demonstrable link with the predictor variables and the others, at least in this limited sense, do not. It is then natural to consider consequent procedures limited to the former group. In summary the strategy is then:

1. Fit tree-based models to individual presence/absence of taxa and prune back according to the commonly recommended "one SE rule".
2. Restrict the taxa to those that have a non-trivial tree model, that is the tree must have at least two nodes.
3. Look at the variables involved in the primary splits and find the most common ones. These will include the main variable as well as any "surrogate" split variables, that is variables identified as producing a split as nearly as effective as the main one.

4. Perform a correspondence analysis on the presence/absence data for the taxa that admit of a non-trivial tree.
5. Construct a matrix of predicted probabilities of occurrence for each taxon and perform a comparative correspondence analysis using this matrix in place of the binary presence/absence matrix.

The logic behind steps 4. and 5 above is that a comparison of the results of the correspondence analysis based on (a) the raw presence/absence data and on (b) the "smoothed" presence/absence matrix (i.e. replacing the binary entries by estimates of the corresponding probability of occurrence) may give an insight into the effect of false negatives, that is on stations where some taxa do occur but are not collected in the sample.

Presence/absence data, prawn trawls

With the Prawn trawl data there 381 fish species of which just 70 admitted a non-trivial, optimally pruned tree. The taxa involved are shown in Table 5.4.2.

Table 5.4.2 Fish species in the prawn trawl data admitting of a non-trivial tree model with given predictors.

Carcharhinus dussumieri	*Carangoides talamparoides*	*Upeneus sundaicus*
Fistularia petimba	*Leiognathus moretoniensis*	*Lagocephalus sceleratus*
'Dactyloptena papilio	*Nemipterus peronii*	*Saurida micropectoralis*
Sillago ingenuua	*Gerres macrosoma*	*Rogadius asper*
Ulua aurochs	*Upeneus sp. 1*	*Apogon ellioti*
Gazza minuta	*Grammatobothus polyophthalmus*	*Atule mate*
Lutjanus russelli	*Anodontostoma chacunda*	*Leiognathus leuciscus*
Pentaprion longimanus	*Suggrundus macracanthus*	*Leiognathus decorus*
Lethrinus lentjan	*Priacanthus tayenus*	*Nemipterus hexodon*
Callionymus grossi	*Caranx bucculentus*	*Diagramma pictum*
Pellona ditchela	*Leiognathus bindus*	*Upeneus sp. 2*
Centriscus scutatus	*Leiognathus equulus*	*Lagocephalus lunaris*
Pelates quadrilineatus	*Nemipterus furcosus*	*Netuma thalassinus*
Carangoides malabaricus	*Gerres macracanthus*	*Inegocia japonica*
Carangoides hedlandensis	*Upeneus asymmetricus*	*Apogon poecilopterus*
Leiognathus splendens	*Trixiphichthys weberi*	*Carangoides humerosus*
Nemipterus nematopus	Engraulididae	*Secutor insidiator*
Gerres subfasciatus	*Elates ransonetii*	*Lutjanus vitta*
Upeneus sulphureus	*Apogon fasciatus*	*Pentapodus paradiseus*
Scomberomorus queenslandicus	*Carangoides caeruleopinnatus*	*Pomadasys trifasciatus*
Sardinella gibbosa	*Leiognathus sp*	*Polydactylus multiradiatus*
Apistus carinatus	*Leiognathus ruconius*	*Torquigener whitleyi*
Terapon theraps	*Scolopsis taeniopterus*	
Selar crumenophthalmus	*Pomadasys maculatus*	

The split variables that were either the main split variable or a split surrogate of it are listed, sorted by frequency of occurrence, in Table 5.4.3.

Table 5.4.3 Number of times each predictor variable occurs as a main split variable or as a split surrogate of the main split variable

K.490.SD	2	Sand.SE	7	Gravel	9	Mud	16
WaveHeight.SD	4	Silica.SD	7	Stress.Med	9	Oxygen	16
Mud.SE	5	Stress.SD	7	Nitrate	13	Sand	16
Chlorophyll.SD	6	WaveHeight	7	Oxygen.SD	14	Nitrate.SD	18
Salinity	6	Cruise	8	Chlorophyll	15	Salinity.SD	18
WaveHeight.Max	6	Phosphorus.SD	8	K.490	15	Depth	19
WaveHeight.Med	6	Stress	8	Phosphorus	15	Silica	20
Gravel.SE	7	Stress.Max	8	Temperature.SD	15	Temperature	20

We examined how these variables occur together, that is the patterns of variables that tend to co-occur as surrogate variables for the same split by looking at a clustering of variable with a similarity measure given by the proportion of all cases where the two variables in question occur as surrogates. This leads to a dendrogram with clearly defined clusters (Fig 5.4.10). The further down this diagram a variable occurs the more often it figures as a main split variable. Groups of co-occurring variables have the property not that they are necessarily highly correlated but tend to supply equivalent splits for tree models predicting presence or absence of taxa. In the case of *Mud* and *Sand*, for example, the two variables are highly negatively correlated. The variables oxygen, salinity SD, depth and nitrate SD form a group.

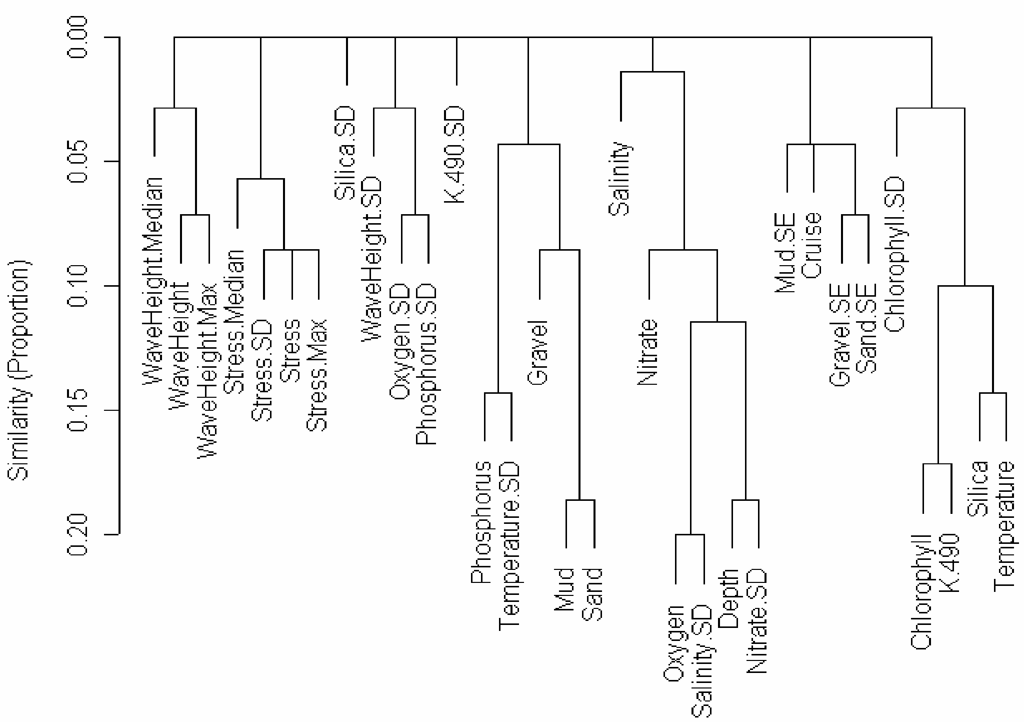

Figure 5.4.10 Clustering of split variables (or surrogates) based on proportions of all cases where the variables occur together

Correspondence analysis of tree-selected taxa

If we choose the presence/absence data of the 70 taxa selected by the tree method the resulting 920 × 70 station × taxon matrix has occupancies ranging from 17 to 636, and row totals from 2 to 52.

The first six canonical correlations are 0.4991431, 0.4513735, 0.4107750, 0.3402060, 0.2997024 and 0.2768773 suggesting that certainly no more than the first three ordinations are likely to be useful. Figure 5.4.11 shows a combined pairs scatter plot of the three ordinations found previously with the occupancy restricted species list and the three ordinations based on the tree-selected species. The colours separate cruises but the result is not very clear, partly because the cruises are not very different and partly because we are dealing with 920 stations. The important panels are those showing the plots between the corresponding ordinations of each type. Clearly these are very highly correlated. (The fact that the correlation between the two third ordinations is negative is a computational artefact)

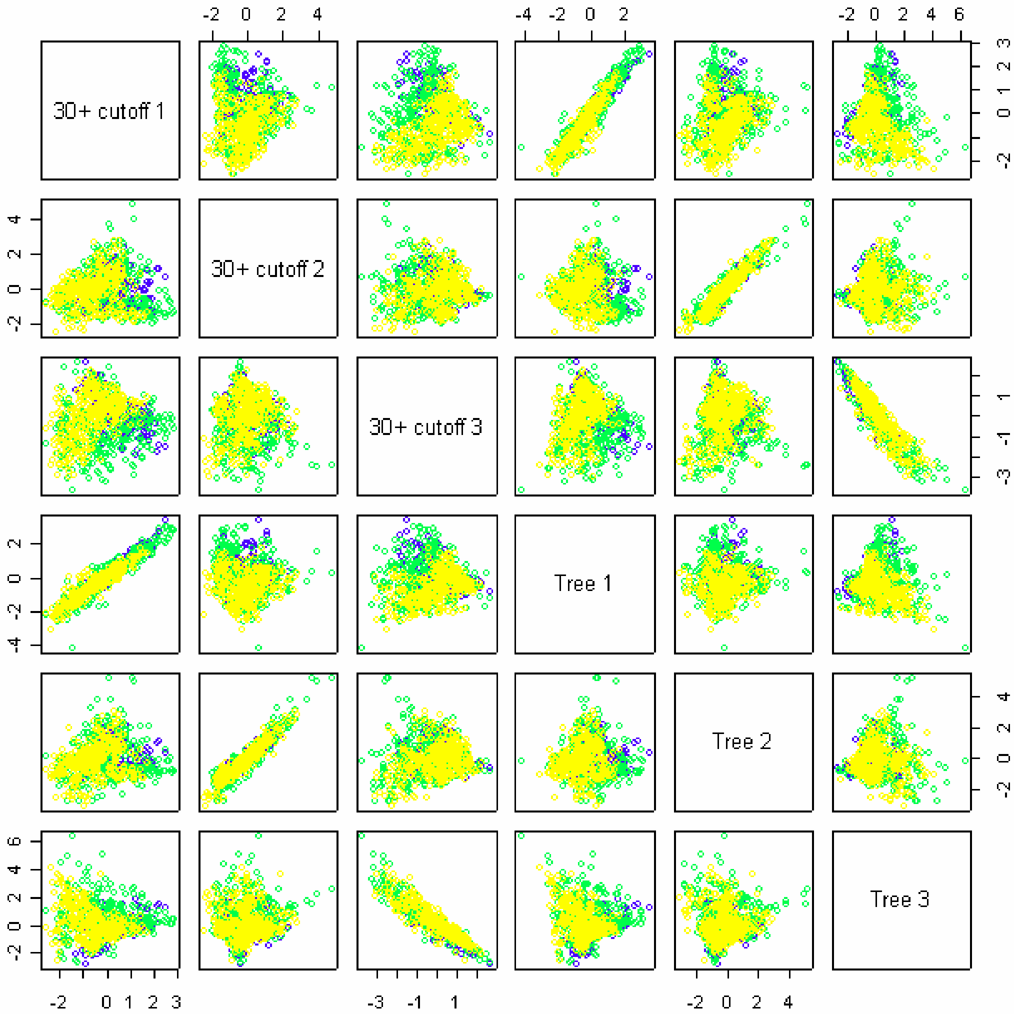

Figure 5.4.11 Pairs plots of scores for the first three ordinations obtained by selecting variables by two methods.

We can conclude that the station ordination is relatively insensitive to the choice of species used to construct it, provided some reasonable method is used.

Trawl Biomass Surrogates

Results of the trawl biomass surrogates analysis showed that for all cruises salinity and temperature are significant surrogates. It was surprising that sediment characteristics provided no potential surrogate information consistently across all cruises. In the case of the Gulf of Carpentaria wide cruises (both SS9702 and SS9708), chlorophyll and K490 parameters are significant (possibly as there is a significant range in values across this area). For the SS9702 cruise, sediment covariates (sand, mud, pebble, and granule) become important as do acoustic parameter variations (roughness standard deviation and hardness standard deviation). For the SS9708 cruise acoustic information (roughness and hardness standard deviation) is important as well as sediment (mud see Figure 5.4.12), bottom water column attributes (silica, nitrate) and depth. For the SS9803 cruise temperature and salinity almost completely describe the biomass variation and are highly statistically significant. Phosphate is also included as a potential surrogate

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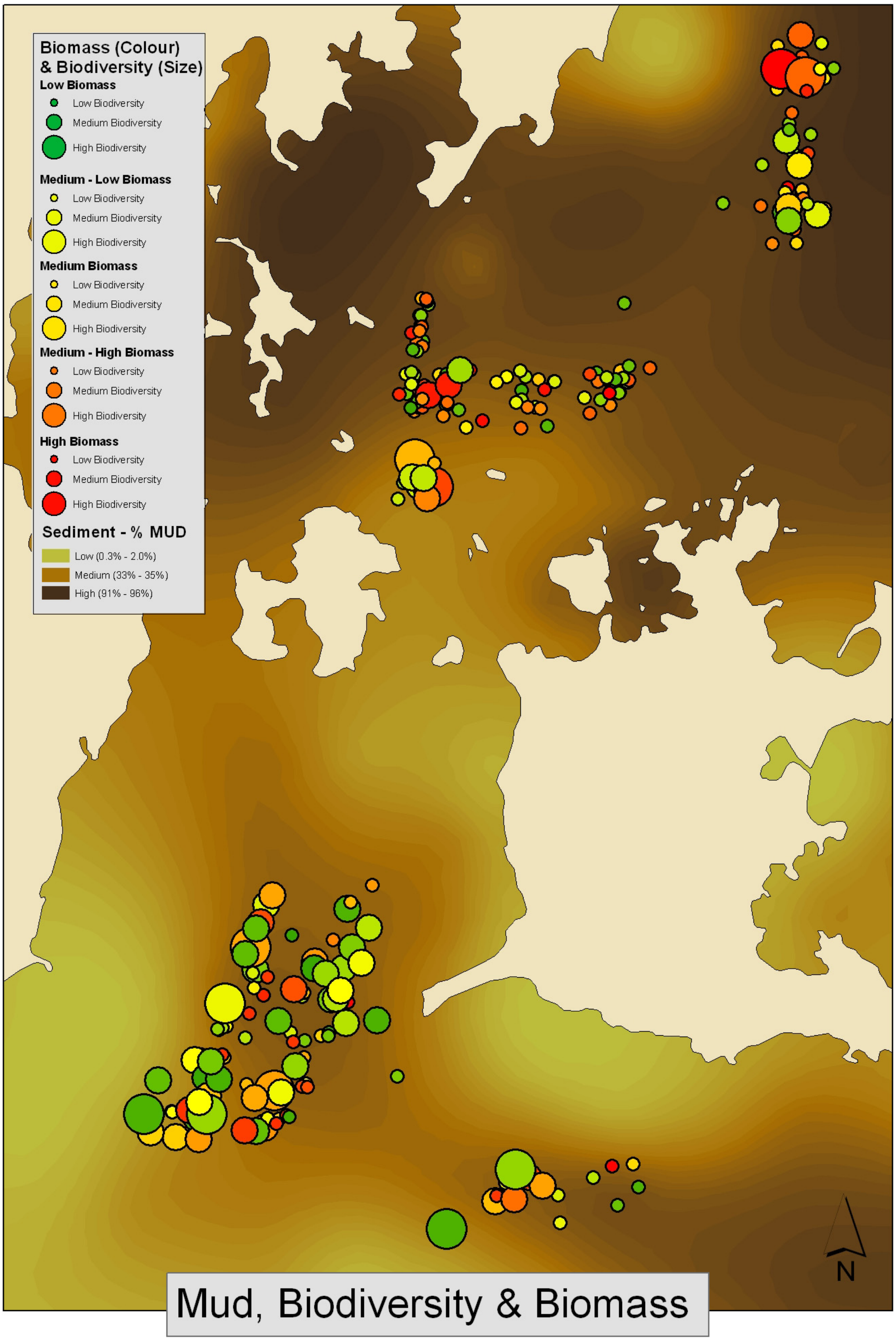

Figure 5.4.12 Variation of the measured biological parameters (biodiversity and biomass) with the modelled physical surrogate percent mud sediment property in the Groote Eylant area.

Trawl Biodiversity Surrogates

Results of the trawl biomass surrogates analysis showed significant differences between cruises, making a discrete by-cruise analysis necessary. The % mud sediment parameter is an important surrogate providing the most information and being statistically significant across all cruises. Areas of higher mud content have less biodiversity (Fig 5.4.13). Temperature and salinity are important surrogates for biodiversity but less so than for biomass. Acoustic parameters especially hardness and hardness standard deviation are important across all cruises, but surprisingly depth is not an important surrogate for biodiversity

Analysis for the SS9702 cruise shows that it may be wholly described by sediment characteristics of mud and granules as surrogates, however there were processing errors with this analysis and this result should be treated with caution. In contrast to the biomass surrogates analysis, chlorophyll and K.490 parameter for the Gulf-wide cruises (SS9702 and SS9708) do not seem to be important as a surrogate for biodiversity. Results for the SS9708 cruise show water parameters especially oxygen are important. For the SS9803 cruise temperature, salinity and phosphate best describe the biodiversity, as they did for the biomass.

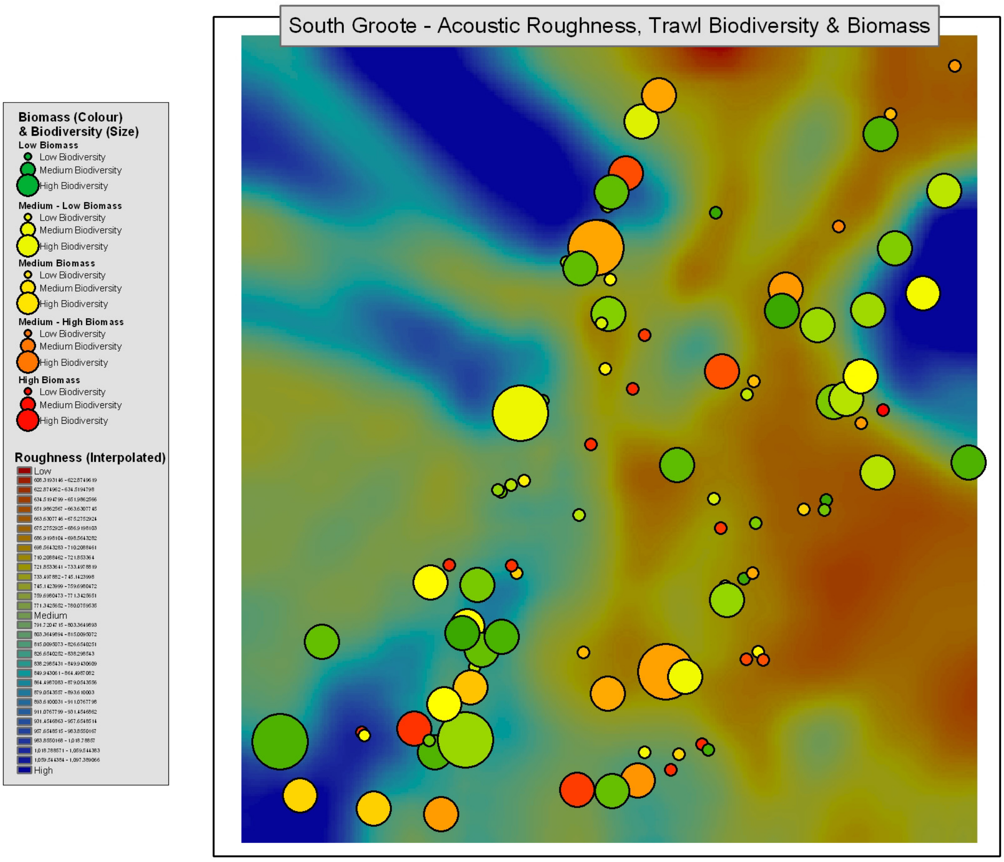

Figure 5.4.13 Variation of the measured biological parameters (biodiversity and biomass) with the modelled physical surrogate acoustic roughness surface in the area south of Groote Eylant.

This preliminary analysis showed somewhat surprising results. Quite often the variation (in terms of standard deviation) of the roughness / hardness is a more important predictor for total biomass, total number of species and even for presence / absence of individual species. There is good evidence that acoustic measurements can play an important role as surrogates. There is a relationship between biodiversity and acoustic parameters (Fig 5.4.13). Low acoustic roughness (red areas) and low biodiversity (small circles) are related.

Biodiversity and biomass are not necessarily related biological properties. An area may have a large biomass of a few species and hence low biodiversity compared to another where the benthos may be fairly sparse but made up of a large number of species. In the case of the

NPF, this can be seen in Figs 5.4.14 and 5.4.15.

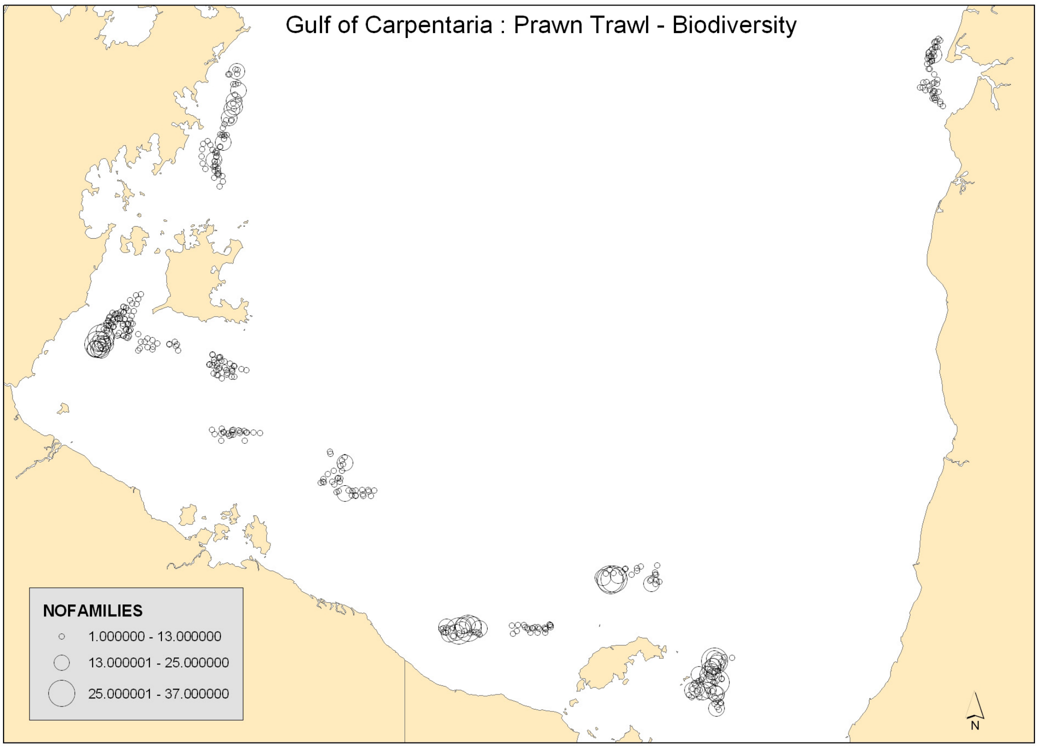

Figure 5.4.14. The distribution of biodiversity as reflected by the number of taxa in prawn trawl bycatch samples in the NPF.

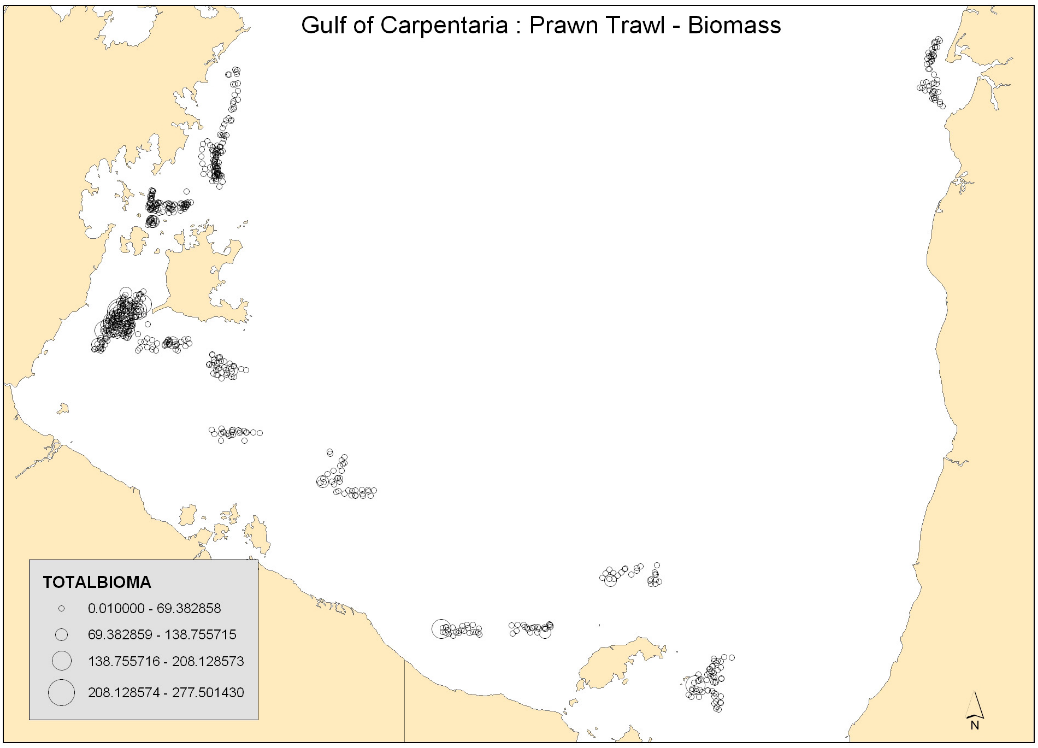

Figure 5.4.15. The relative biomass of prawn trawl bycatch samples from the NPF.

INDICATOR SPECIES FOR HIGH α-BIODIVERSITY

Prawn trawl data

Indicator species for high α-biodiversity can be found by using the presence/absence indicators for individual species as predictors for the total number of species observed at a site[2]. One easily appreciated way to find possible indicator species is to construct a tree model. If we do this for the prawn trawl data we have 381 species that occur at least once in the data and the α-biodiversity at a station ranges from 2 to 109.
A regression tree model produces the tree shown in Figure 5.4.16.

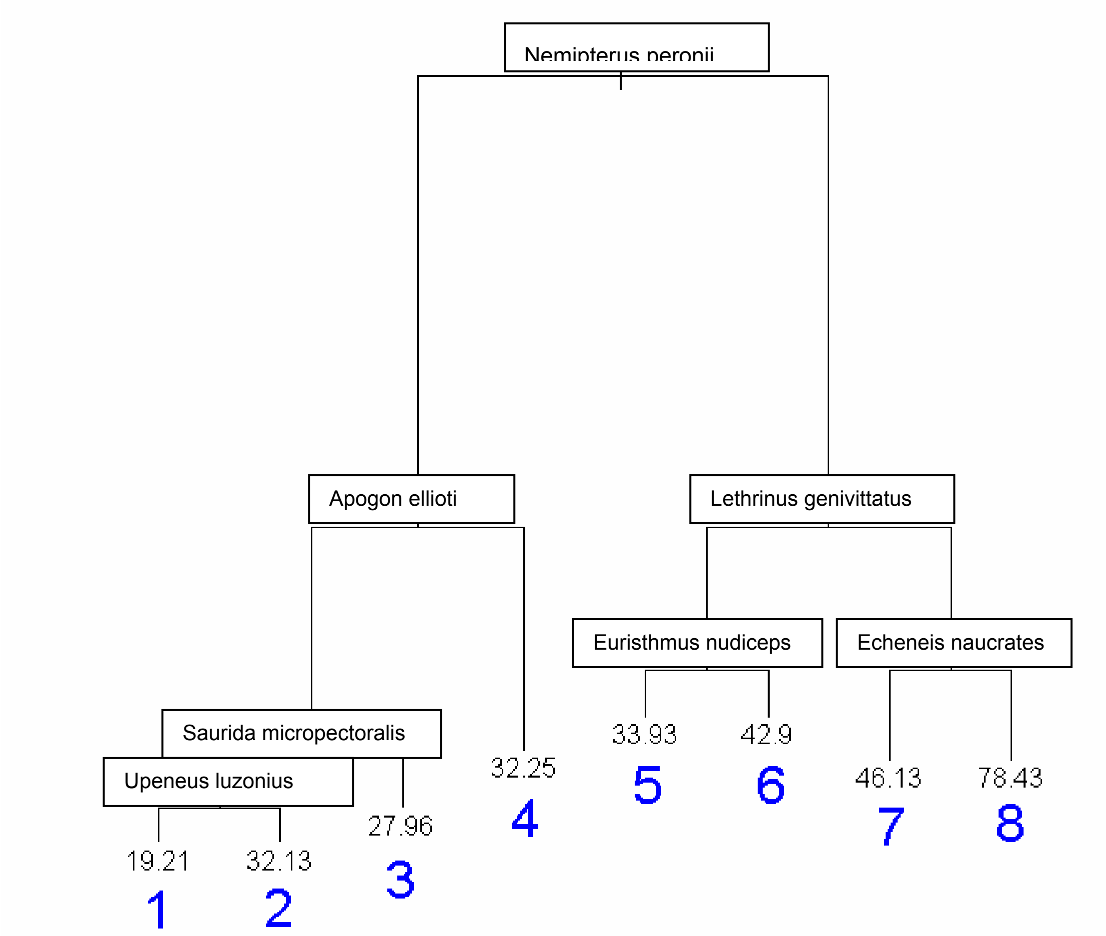

Figure 5.4.16 A regression tree for the α-biodiversity using presence/absence of individual species as possible predictors. The smaller type numbers below each node are the average numbers of species observed at such stations and the larger type blue numbers are a labelling of the node used in later graphical presentations

This tree model diagram shows a more complex picture than in any of the other cases, with the highest biodiversity level, for example, associated with three species (*Nemipterus peronii, Lethrinus genivittatus, Echeneis naucrates*) being present simultaneously, but the group of stations where this occurs is very small.

[2] The fact that the species itself is part of the total number is a minor complication only, since the total number of species is generally at least 20 and we will be considering only a very small number of possible indicator species.

Table 5.4.4 shows the numbers of stations at each node as well as the mean α-biodiversity at each of the eight nodes, separated into cruises.

Table 5.4.4 Numbers of stations and mean numbers of species at each node of the indicator species tree, classified by cruise

	Frequencies			Mean no. species		
Group	SS9702	SS9708	SS9803	SS9702	SS9708	SS9803
1	21	131	121	22.71	18.81	19.02
2	4	8	3	34.00	29.25	37.33
3	19	40	15	28.84	26.65	30.33
4	46	83	81	33.24	32.36	31.57
5	46	101	108	35.11	31.81	35.40
6	2	9	37	41.00	45.89	42.27
7	21	16	1	46.81	44.69	55.00
8	4	3	0	82.00	73.67	-

Note that there is reasonably good agreement between cruises. We have used box plots to indicate the variation in species numbers for each node class of stations (Figure 5.4.17).

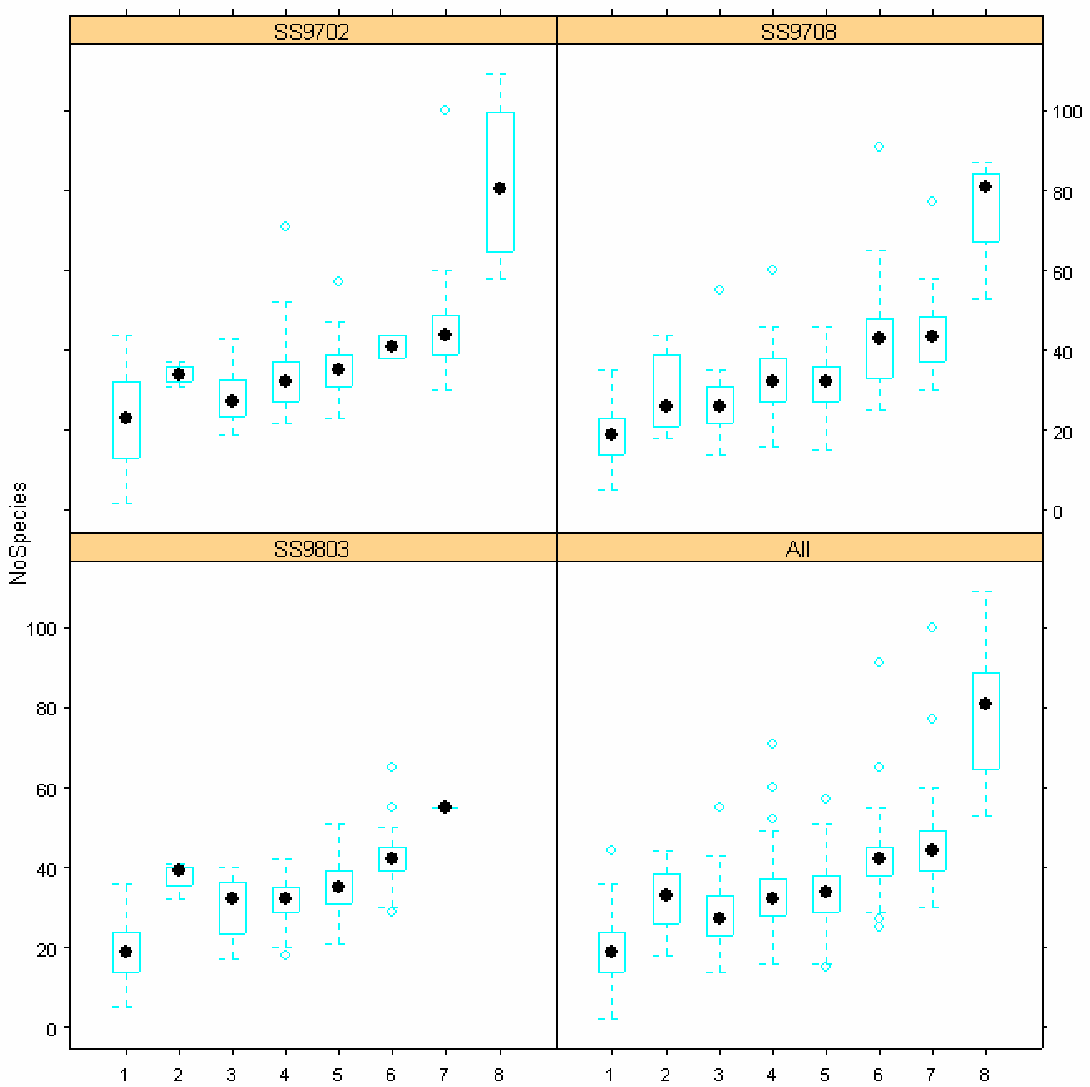

Figure 5.4.17 Boxplots of α-biodiversity for the 8 nodes (groups of stations)

Finally we show the spatial location of the tree node groups (Fig 5.4.18). No clear spatial pattern is evident.

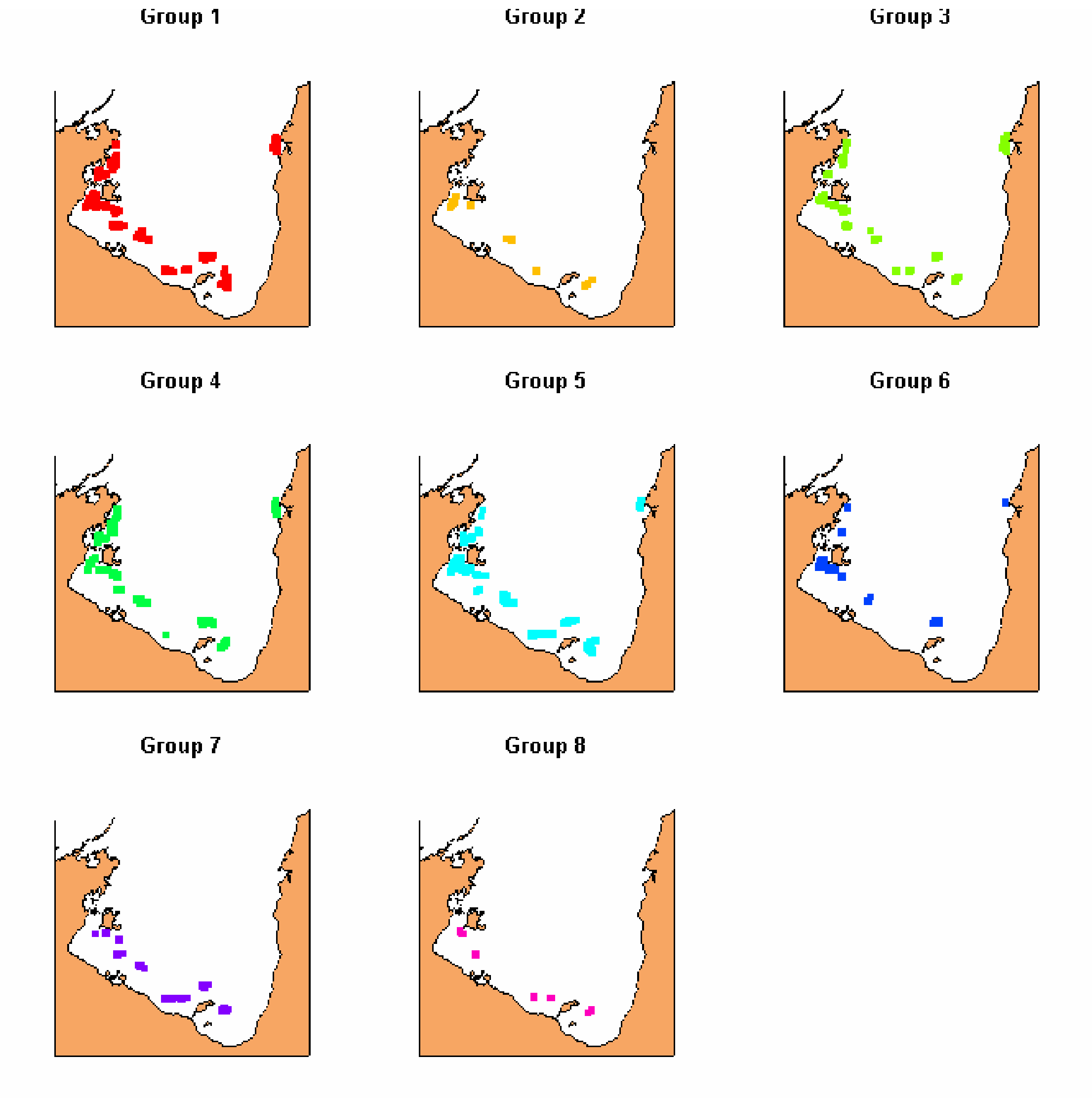

Figure 5.4.18 Spatial location of the 8 tree node groups.

CHAPTER 5.5

INVERTEBRATES FROM PRAWN TRAWL BYCATCH

Chapter Authors:

Bill Venables, Scott Gordon, Mick Haywood

CHAPTER 5.5

INVERTEBRATES

FROM PRAWN TRAWL

BYCATCH

Bill Venables

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Scott Gordon

Summary

We analysed prawn trawl bycatch data collected from 920 sampling stations. The invertebrates were identified to various taxonomic levels

Surrogates

- The predictive capacity of environmental variables for stations is not particularly good implying that they are not strongly linked to the benthic variables.
- Environmental variables associated with the seabed – mud SE, sand SE, acoustic roughness and hardness - appear to be important in determining the distribution of some species of invertebrates captured by prawn trawls and might be useful as surrogates

Indicator species

The highest biodiversity level is associated with the occurrence of two species of crabs - *Portunus gracilimanus* and *Dorippe quadridens* but the group of stations where this occurs is very small.

Introduction

As explained above (Chapter 5.3) we analysed the invertebrate data from prawn trawls separately from the fish data. We used data on prawn trawl bycatch samples collected on three research cruises using the 66m stern trawler RV Southern Surveyor in the main prawn fishing grounds of the NPF. The results of 920 catch samples of the 1076 taken were used for analysis. Details of the sampling are given by Stobutzki et al., (2000) and a summary is given in Table 3.1.1 in Chapter 3.1. The approach in analysing this data is similar to that used for samples from the fish trawl and benthic dredge (Chapters 5.2 and 5.3).

Methods

The first step was to determine whether we could identify surrogates to predict station clustering from the available environmental variables. We had data from 920 stations including 589 taxa. As pointed out previously, very rarely or very commonly occurring species tend to inflate the canonical correlation by isolating a few stations. If the minimum occupancy is raised, that is the minimum number of times a species must occur before it is included in the correspondence analysis, the canonical correlations change. We plotted the change in the first six canonical correlations as the criterion for inclusion is increased (Fig

5.5.1). We chose 20 as the minimum occupancy required for inclusion of a species since if the bar is raised any higher one station drops out through losing all species. There is a sudden reduction in correlation 4 as the minimum occupancy is increased from 21 to 22, but the others are fairly stable.

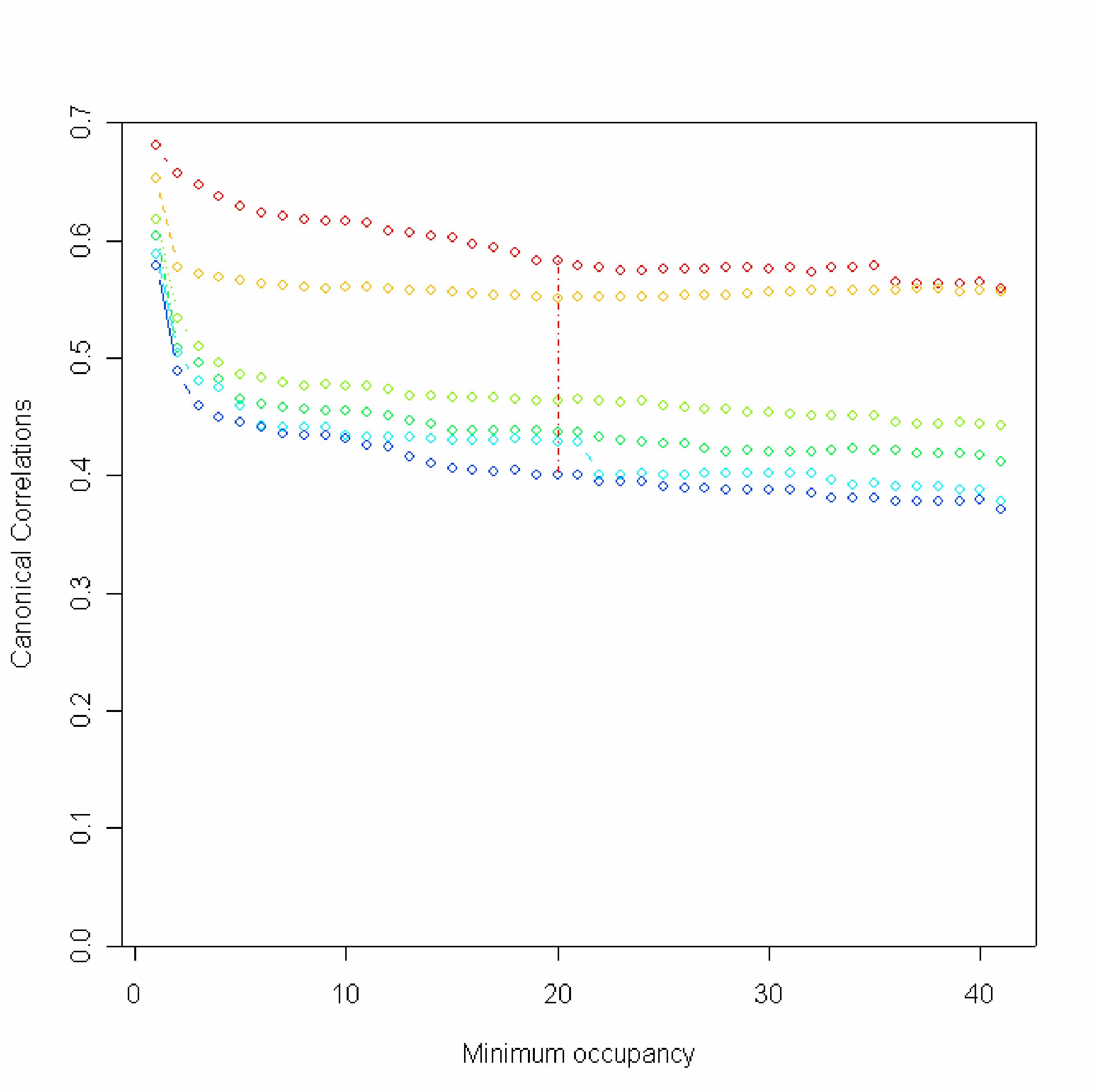

Figure 5.5.1 Changes in canonical correlations with increasing minimum occupancy

With a minimum occupancy of 20 we have 920 stations and 102 taxa. The first two canonical correlations (using presence/absence data) are 0.5830827 0.5507059 (not very high) and the third is much lower. The first two, at most, seem to be useful.

Plotting the second ordination against the first, separately by cruise, gives the relationship shown in Fig 5.5.2.

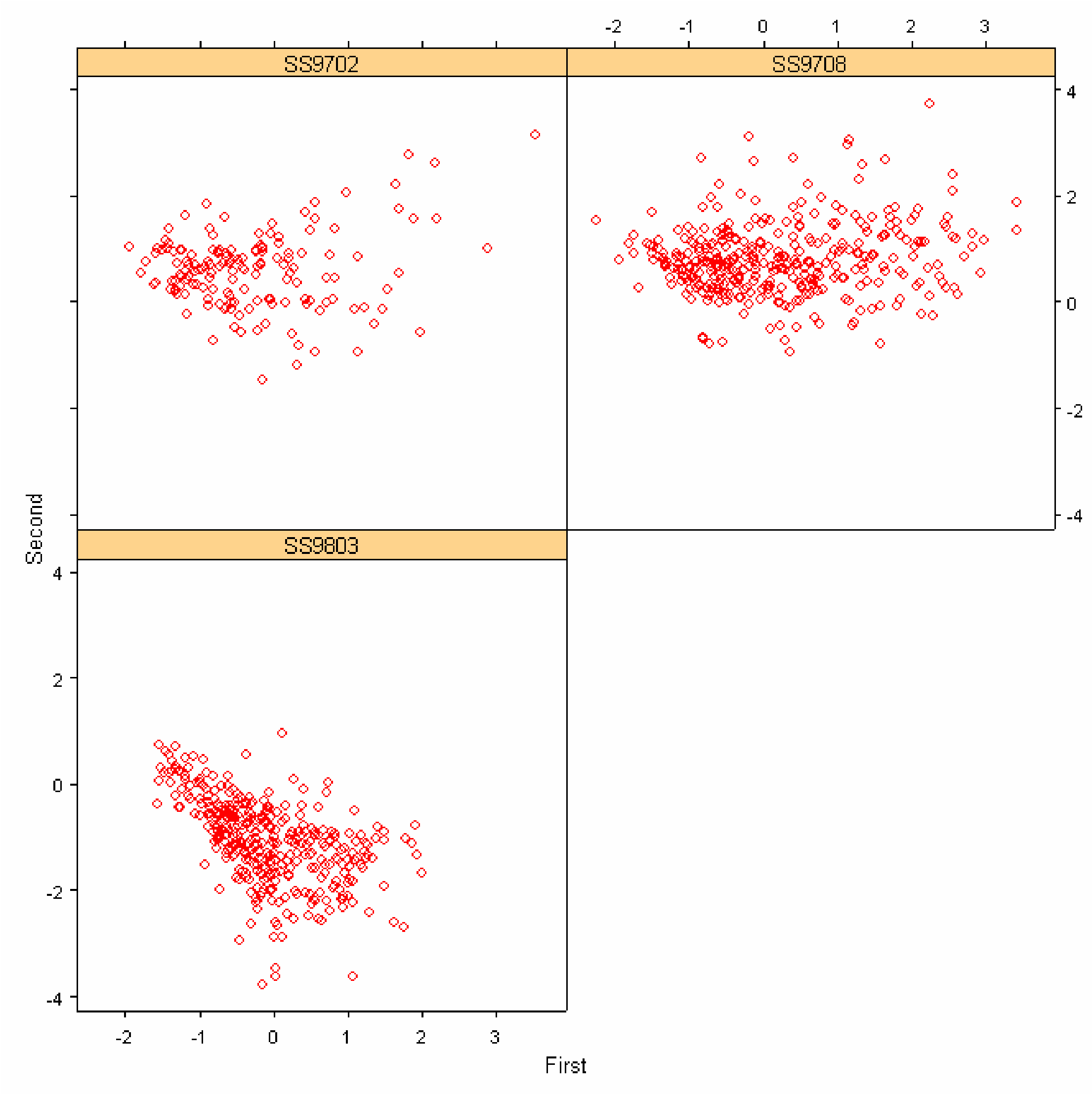

Figure 5.5.2 Graphical comparison of plots of the first and second ordinations for the three cruises

This figure possibly indicates a difference between the first two cruises (above) and the third cruise (below). The third cruise was largely confined to the north and south of Groote Eylandt whereas the other two were more widespread. No obvious groups stand out. This is confirmed by Fig 5.5.3 which is the same plot, but with all three cruises superimposed.

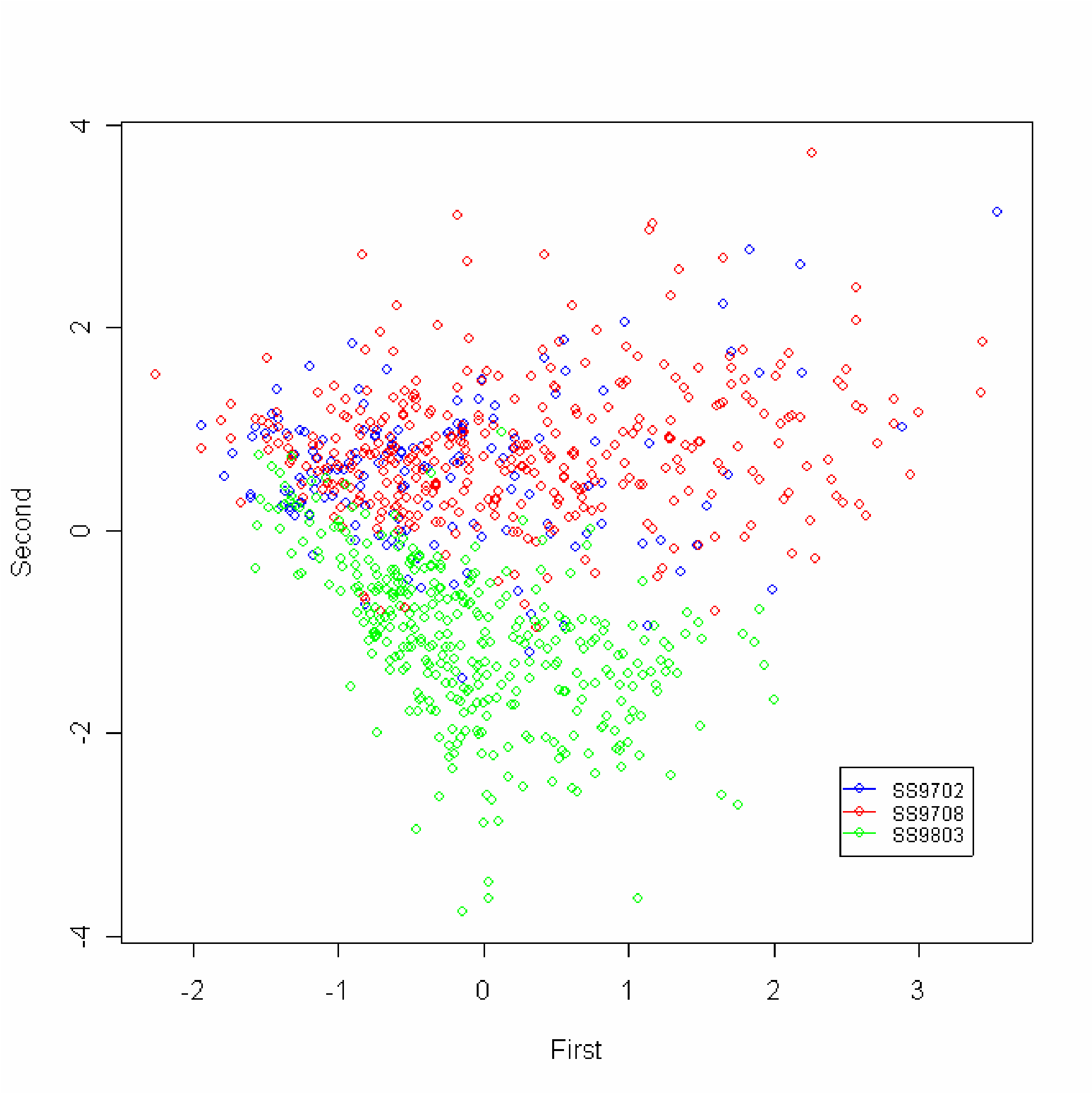

Figure 5.5.3 Superimposition of plots of the first and second ordinations for the three cruises

Note that it is mainly the second ordination that separates the 1998 cruise from the two in 1997. We do not know the reason for this.

The ordinations were used to define a number of groups in the stations in order to see which benthic variables best describe the groups. We chose 10 clusters (fairly arbitrarily), they are shown in Figure 5.5.4. The clustering method was the ***diana*** procedure of the Kaufmann and Rousseeau suite of methods previously cited, using a Euclidean distance measure.

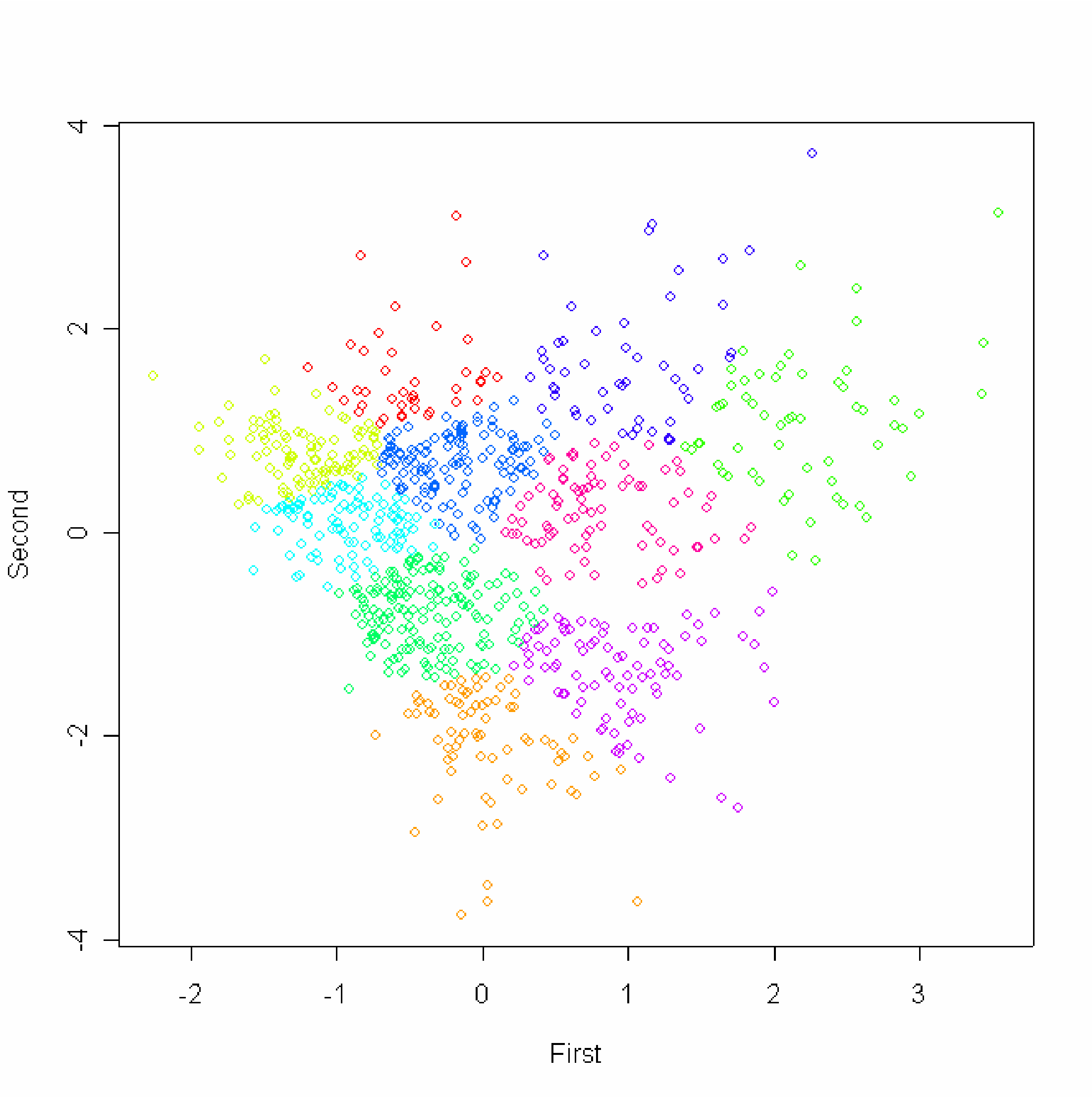

Figure 5.5.4 Result of clustering the first and second ordinations into 10 groups

Geographically these groups have no clear pattern.

We use these groups as a kind of discrete approximation to the joint ordination provided by the first two canonical scores. In exploring the connections between the potential surrogate variables and the canonical ordination, it seems natural to consider classification tree models as these provide a simple way of appreciating how group membership can be described in terms of the predictors. We are aware, however, that tree models are unstable in the sense that an almost equally effective classifier can often be achieved in a variety of ways using cut-points on different key variables. Nevertheless the particular variables, and combinations of these, used for the cut points in the optimal tree model would seem to be a natural thing to consider for our purposes. The result of this tree model is shown in Figure 5.5.5. The numbers appearing below the terminal nodes are the group labels of the most likely group at each.

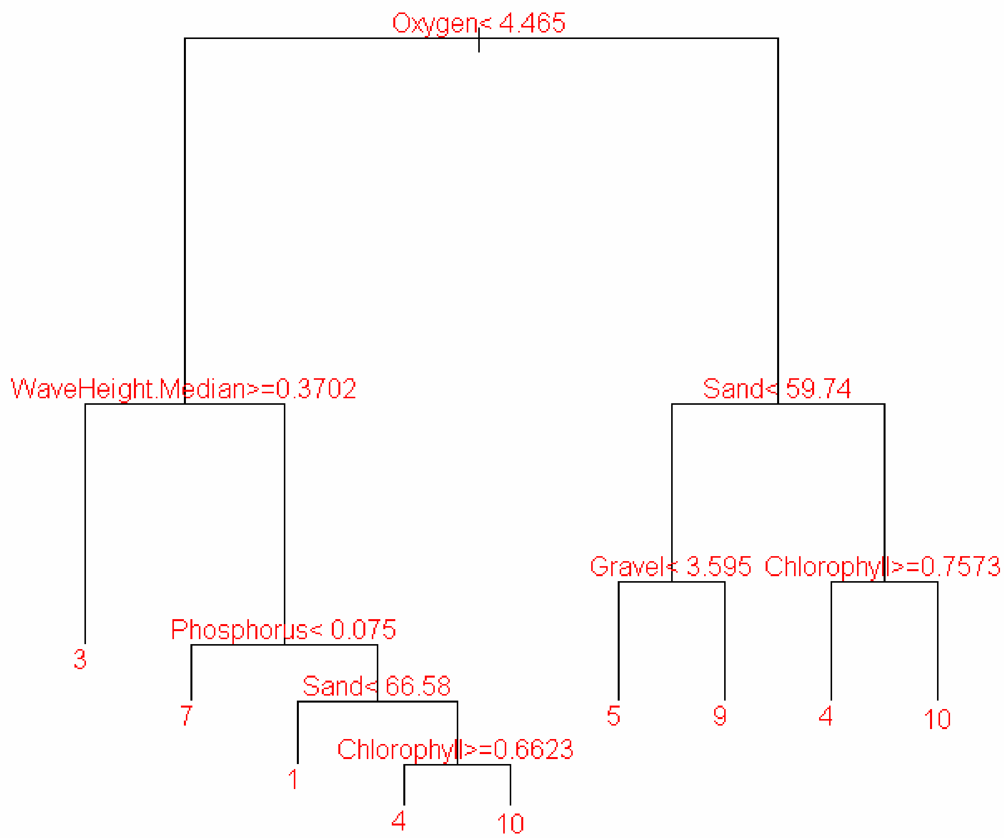

Figure 5.5.5 Classification tree for the 10 canonical clusters of the prawn trawl stations

The predictive capacity is not particularly good. The error rate is 57%, that is, if you use this tree to predict the class for a station, even with the ones on which the tree was built the predictions are between ½ and 2/3 wrong. The implication is that the ordination of stations based on the biota present is not strongly linked to the benthic variables. Nevertheless the tree does give some indication of the variables on which reasonably effective splits might be made.

Individual Species ordinations

The number of species admitting a non-trivial tree model predictor, out of the original 589, is just 28. These are given in Table 5.5.1.

Table 5.5.1 Species associated with a non-trivial predictor

Species or taxon	
Alcyonacea	*Photololigo* sp 2
Amusium pleuronectes	*Portunus acerbiterminalis*
Brittle Star 5	*Portunus gracilimanus*
Chaetodiadema granulatum	*Portunus rubromarginatus*
Charybdis truncata	Scyphozoa
Ctenophora	Sepioidae
Gorgonian 13	*Sicyonia cristata*
Loveniidae	*Solenocera australiana*
Metapenaeopsis spp	*Sphenopus marsupialis*
Metapenaeus endeavouri	Sponge Porifera
Metapenaeus ensis	Teuthoidea
Oratosquilla inornata	*Thenus indicus*
Penaeus esculentus	*Thenus orientalis*
Penaeus semisulcatus	*Trachypenaeus* sp

The environmental variables involved in the main splits, including the best 5 stand-in variables, are shown in Table 5.5.2 together with their frequency of occurrence.

Table 5.5.2 The environmental variables involved in the main splits together with their frequency of occurrence.

Environmental variables and frequency			
Stress Max	1	Nitrate	5
Chlorophyll SD	2	Oxygen SD	5
K.490.SD	2	Phosphorus SD	5
Salinity	2	WaveHeight Median	5
Stress	2	Gravel SE	6
Stress Median	2	Mud	6
Stress SD	2	Temperature SD	6
Chlorophyll	3	Oxygen	7
Depth	3	Salinity SD	7
K.490	3	Sand SE	7
Nitrate SD	3	Silica	7
WaveHeight Max	3	Wave height	7
Gravel	4	Sand	8
Temperature	4	Phosphorus	9
WaveHeight SD	4	Mud SE	10

One aspect of this table that was slightly surprising is that the variable VMS index, a local estimator of fishing pressure from the Northern Prawn Fishery, does not appear. The fine scale distribution of fishing for tiger prawns has changed over the past few years and it is possible that this may partly explain the lack of a relationship between the invertebrate species and fishing effort. Our VMS data was collected during a single fishing season (1

August - 31 October 2000) and the prawn trawl bycatch data was collected between 2 to 3 years prior to this.

We then examined how these variables occur together, that is the patterns of variables that tend to co-occur as stand-in variables for the same major split. We did this by looking at a clustering of variable with a similarity measure given by the proportion of all cases where the two variables in question occur as stand-ins for each other. This leads to a dendrogram with clearly defined clusters shown in Figure 5.5.6. The further down this diagram a variable occurs the more often it figures as a main split variable or a surrogate of it, and the groups of variables that occur together have the property not that they are necessarily highly correlated but that they tend to supply equivalent splits for tree models predicting presence or absence of taxa. One explanation of this could of course be that they are indeed highly correlated, of course. The variables mud SE, sand SE and gravel SE form a group indicating that substrate is an important surrogate for invertebrate taxa.

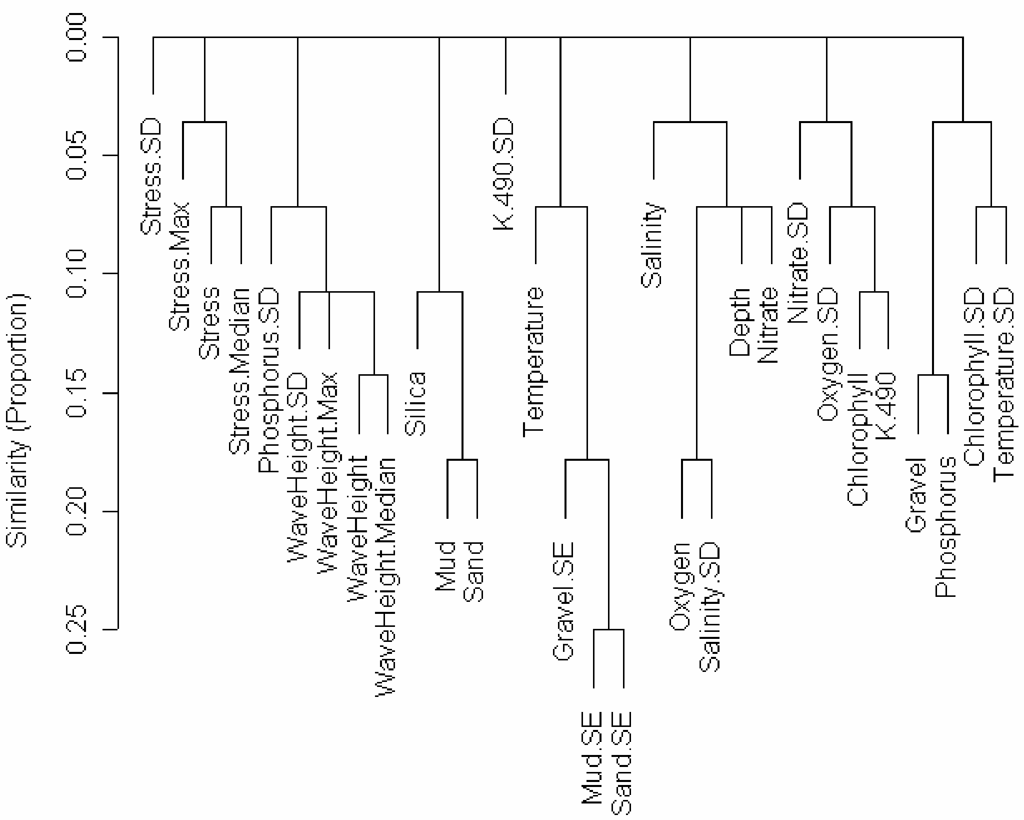

Figure 5.5.6 Clustering of split variables – or surrogates – based on proportions of all cases where the variables occur together

The species were clustered using the diana procedure of Kaufman and Rousseeau (1990). This is a divisive clustering and 6 groups were chosen by cutting the dendrogram (Fig 5.5.7) at a height between 2 and 3. The species selected were those that occurred in at least 20 trawls, of which there were 102.

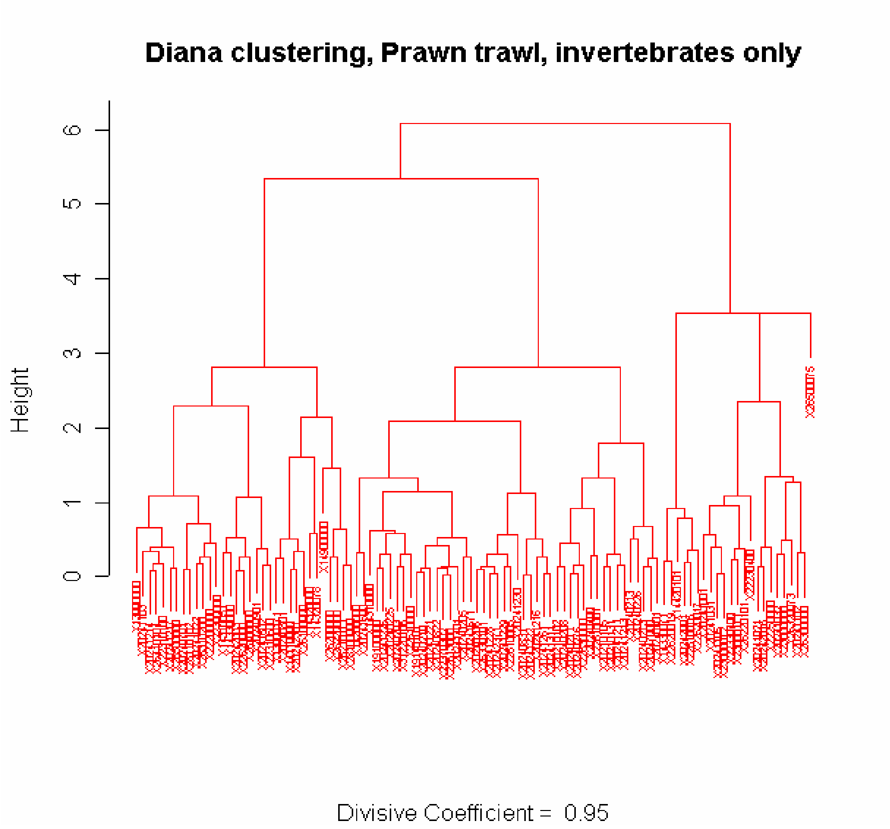

Figure 5.5.7 Dendrogram of divisive clustering of invertebrates from prawn trawls

A plot based on the first two canonical ordinations of species is shown in Fig 5.5.8.

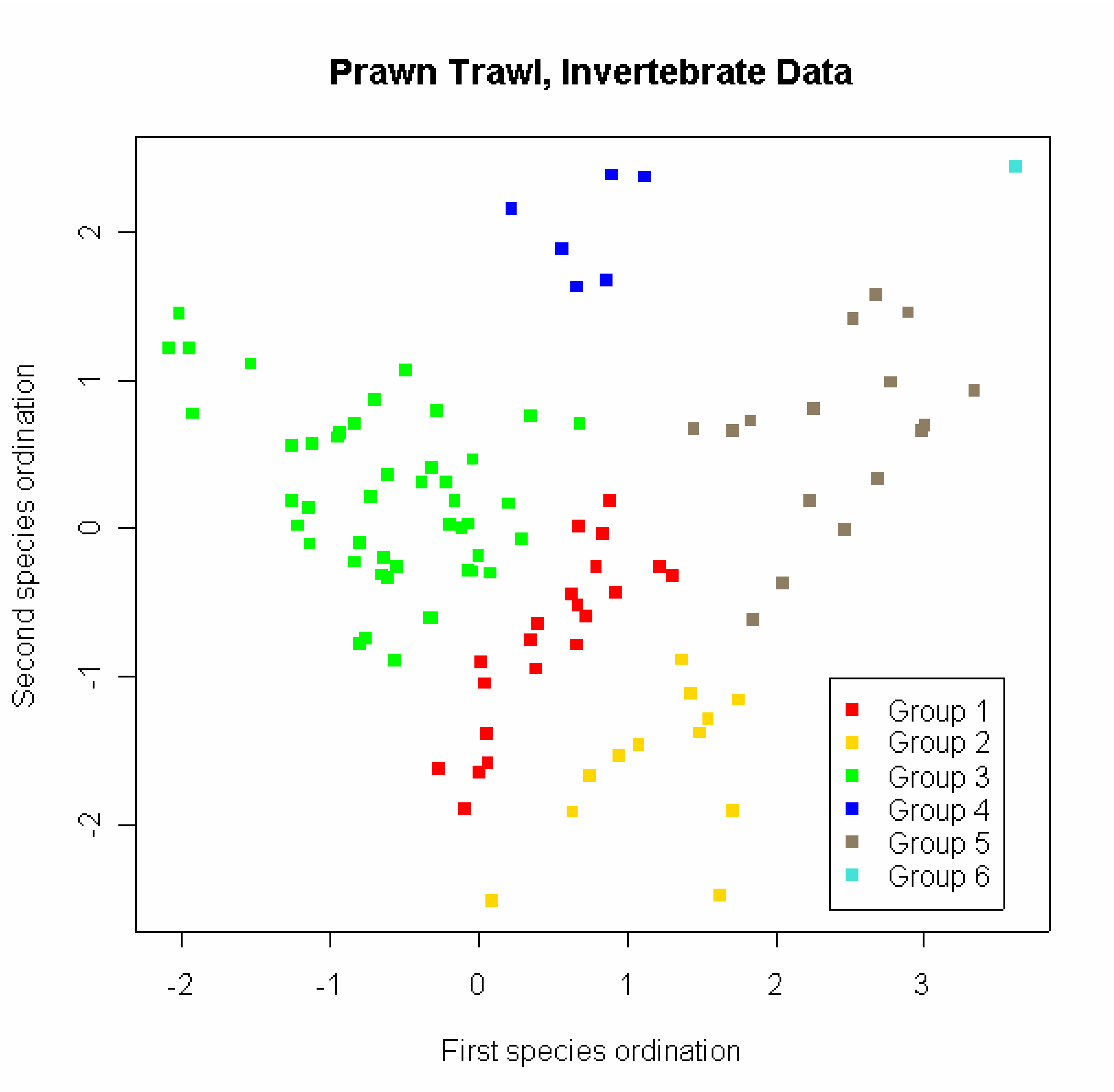

Figure 5.5.8 Plot based on the first two canonical ordinations of species

The composition of the six groups shown in Fig 5.5.7 is given in Table 5.5.3.

Table 5.5.3 Composition of the six groups admitting of a non-trivial tree model.

Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
Porifera	*Ircinia* sp	Scyphozoa	Alcyonarian 1	*Micippa excavata*	Brittle Star 5
Virgularia sp	Hydroid	Pennatulacea	*Sphenopus marsupialis*	*Phalangipes australiensis*	
Alcyonacea	Hydrozoa	Polychaeta	*Thenus orientalis*	*Hyastenus cambelli*	
Dorippe quadridens	Gorgonacea	*Chloeia flava*	*Sepia smithi*	*Hyastenus sp 1*	
Calappa terraereginae	Gorgonian 13	*Oratosquilla woodmasoni*	*Photololigo sp 2*	*Parthenope hoplonotus*	
Phalangipes longipes	Ctenophora	*Oratosquilla inornata*	*Photololigo* sp 4	*Parthenope longispinus*	
Parthenope longimanus	*Leucosia ocellata*	*Dictyosquilla foveolata*	Alcyonarian 1	*Scyllarus demani*	
Charybdis jaubertensis	*Bathypilumnus pugilator*	*Penaeus longistylus*		Muricidae	
Charybdis yaldwin	Crinoidea	*Penaeus latisulcatus*		Nudibranchia	
Dardanus hessii	Stelleroidea	*Penaeus merguiensis*		Pectinidae	
Thenus indicus	Asteroidea	*Penaeus semisulcatus*		Bryozoa	
Veneridae	*Pentaceraster* sp 1	*Penaeus esculentus*		Bryozoan 3	
Cardiidae	Clypeasteroida	*Metapenaeopsis palmensis*		*Triphyllozoon* sp	
Teuthoidea,	Ascidiacea	*Metapenaeus endeavouri*		*Luidia maculata*	
Loveniidae		*Metapenaeus ensis*		Echinoidea	
Holothuroidea		*Metapenaeopsis spp*		Sea urchin 3	
Thyone spp		*Atypopenaeus*			
Stelleroidea		*Trachypenaeus sp*			
Ophiuroidea		*Solenoceridae*			
Rhopalaea crassa		*Solenocera australiana*			
		Arcania novemspinosa			
		Myra biconica			
		Charybdis truncata			
		Charybdis feriatus			
		Charybdis callianassa			
		Portunus rubromarginatus			
		Portunus gracilimanus			
		Portunus tenuipes			
		Portunus acerbiterminalis			
		Portunus sanguinolentus			
		Portunus pelagicus			
		Podopthalmus vigil			
		Liagore rubromaculata			
		Jonas luteanus			
		Paguridae			
		Spiropagurus sp 1			
		Ceratoplax sp 1			
		Caridea			
		Amusium pleuronectes			
		Sepiidae			
		Sepioidae			
		Sepia elliptica			
		Sepiolidae			
		Octopoda			
		Chaetodiadema granulatum			

Indicator species for high α-biodiversity

Indicator species for high α-biodiversity can be found by using the presence/absence indicators for individual species as predictors for the total number of species observed at a site[1]. One easily appreciated way to find possible indicator species is to construct a tree model. If we do this for the prawn trawl data we have 589 invertebrate species that occur at least once in the data and the α-biodiversity at a station ranges from 1 to 62.

A regression tree model produces the tree shown in Fig 5.5.9. *Portunus gracilimanus* and *Dorippe quadridens* are crabs, *Metapenaeopsis* spp are penaeid prawns, *Luidia maculate* is an asteroid and *Triphyllozoon* is a bryozoan.

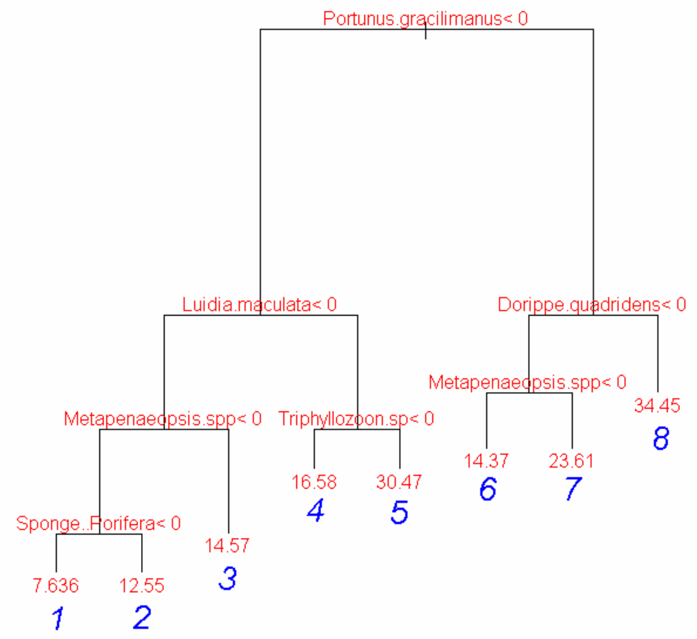

Figure 5.5.9 A regression tree for α-biodiversity using presence/absence of individual species as possible predictors. The smaller type numbers below each node are the average numbers of species observed at such stations and the larger type blue numbers are a labelling of the node used in later graphical presentations.

This tree model diagram shows a more complex picture than in any of the other cases, with the highest biodiversity level, for example, associated with two species being present simultaneously, but the group of stations where this occurs is very small.

Table 5.5.4 shows the numbers of stations at each node as well as the mean α-biodiversity at each of the eight nodes, separated into cruises.

[1] The fact that the species itself is part of the total number is a minor complication only, since the total number of species is generally at least 20 and we will be considering only a very small number of possible indicator species.

Table 5.5.4 Numbers of stations and mean numbers of species at each node of the indicator species tree, classified by cruise

	Frequencies			Mean no. species		
Group	SS9702	SS9708	SS9803	SS9702	SS9708	SS9803
1	106	150	151	8.97	6.71	7.62
2	4	35	61	11.75	13.03	12.33
3	35	121	45	12.09	15.30	14.56
4	1	24	1	6.00	16.96	18.00
5	0	17	0	-	30.47	-
6	7	11	39	14.71	14.82	14.18
7	1	19	54	10.00	24.95	23.39
8	2	5	13	27.00	35.60	35.15

There is reasonably good agreement between cruises.

The variation in species numbers for each node class of stations is shown in the boxplots in Fig 5.5.10.

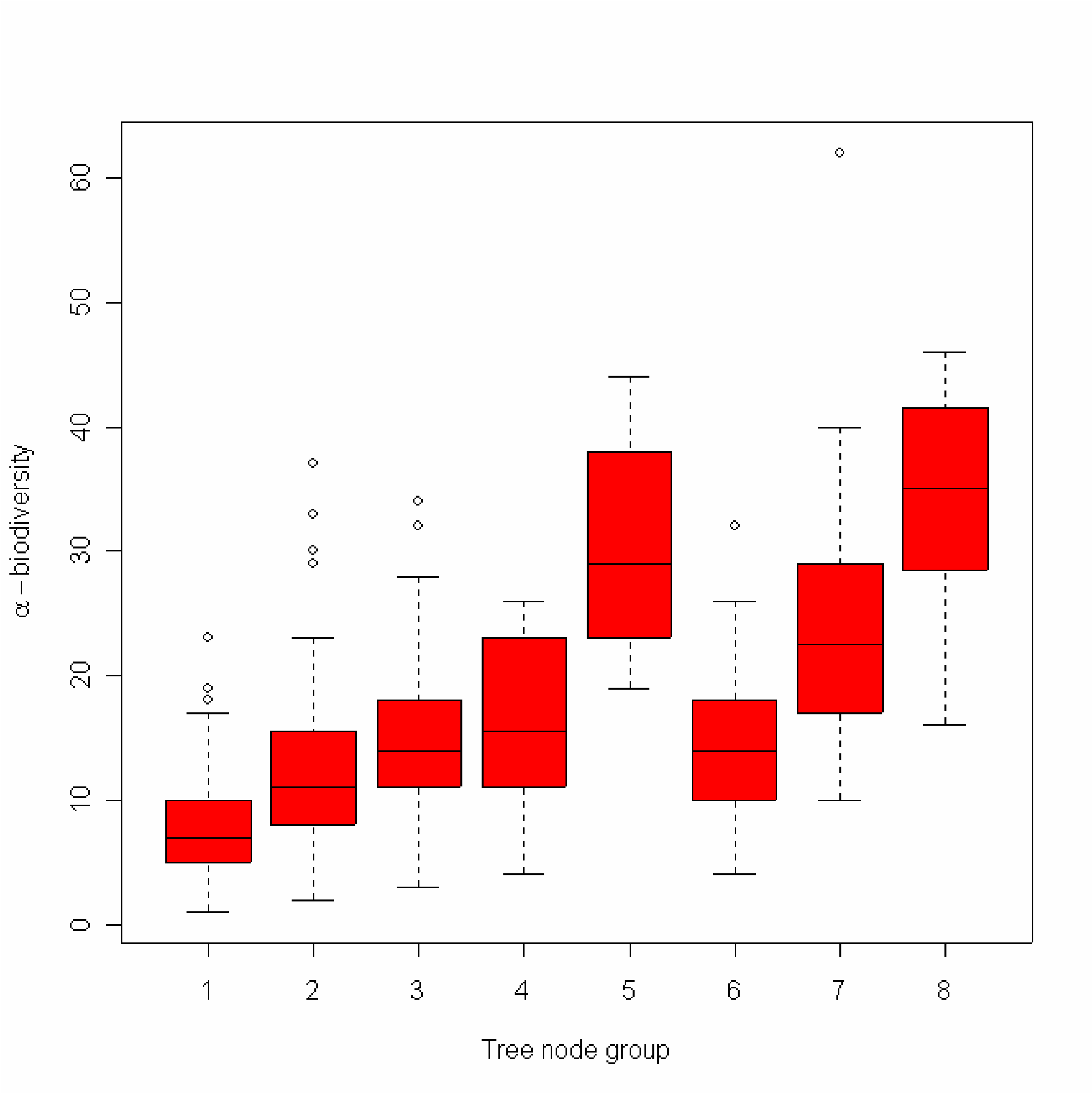

Figure 5.5.10 Boxplots of α-biodiversity for the 8 nodes (groups of stations).

The spatial location of the tree node groups is given in Fig 5.5.11. No clear spatial pattern emerges.

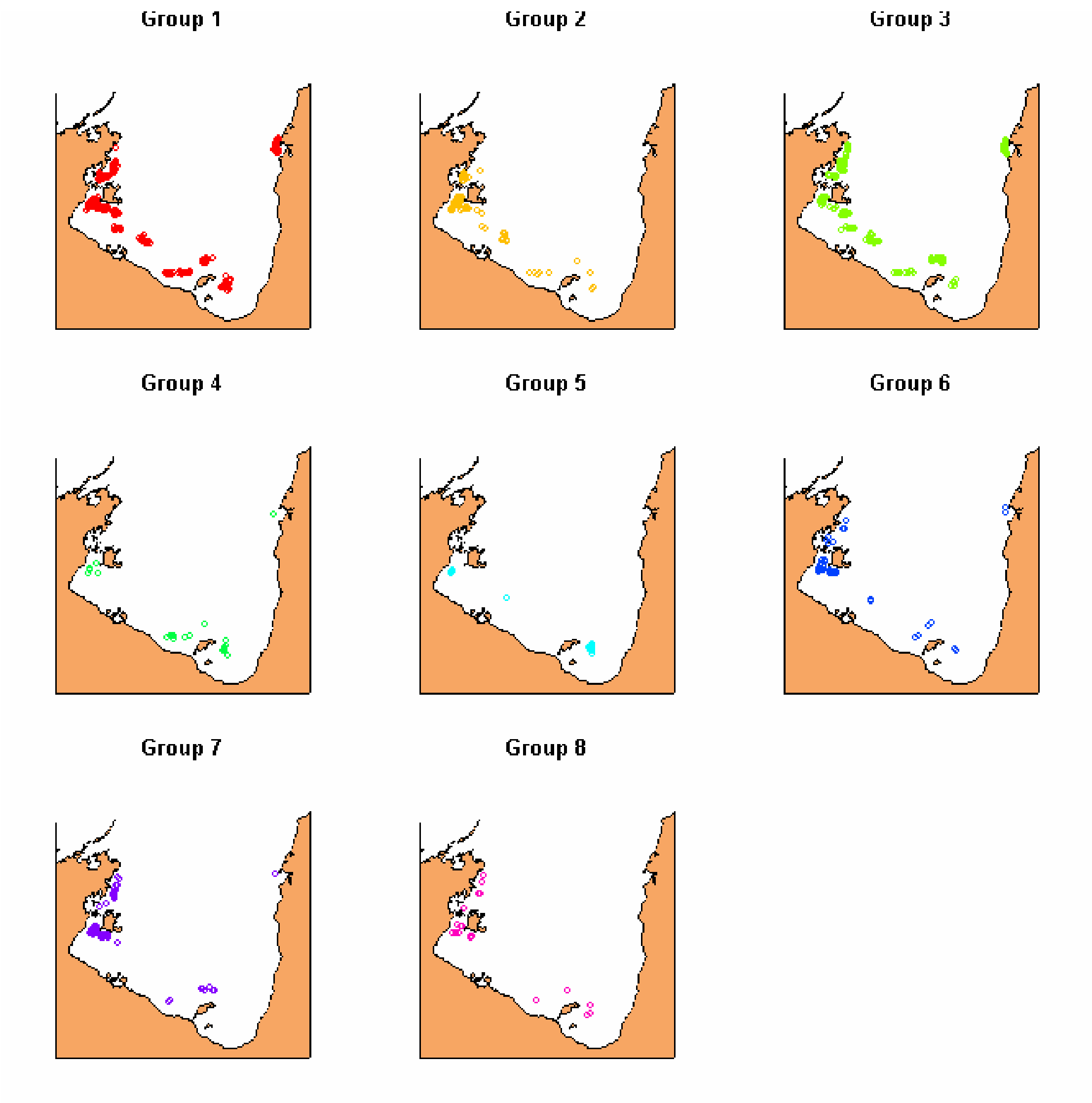

Figure 5.5.11 Spatial location of the 8 tree node groups.

Acoustic data

data is available from a continuous acoustic sampling of the seabed for a subset of the trawls from the sustainability cruises. Details of the acoustic information used may be found in Chapter 3.4. To match the acoustic sampling record with the biological and other properties, four derived quantities were used, namely Hard, Rough, HardSD and RoughSD, that is, the mean Hardness and Roughness and their standard deviations throughout the trawl. Other summary measures could clearly be used but these were seen as possibly the most likely to be generally useful, and in some ways the most convenient. We also have a continuous record of depth along the trawl, from which a mean and standard deviation can be calculated. We labelled these variables Depth2 and DepthSD respectively. The ordinary depth estimate is retained as Depth; this provides a smoothed and less local assessment of depth and so differs in principle from Depth2.

Not all stations had acceptable acoustic records. Removing those where either the acoustic sampling was not taken or where the record was inadequate, usually due to equipment failure, led to the following numbers of stations (Table 5.5.5).

Table 5.5.5 Numbers of stations with a usable acoustic sampling record for each of the three sustainability cruises.

SS9702	SS9708	SS9803
94	325	160

Tree model predictors for single species

The reduced numbers of stations with acoustic data available reduced further the number of species that occurred at these stations at least once to 589. Individual classification tree models were fitted to these species and pruned in accordance with the usual recommendation of the "one standard error" rule (Breiman *et al,* 1984). Most were left with a single node tree, indicating that the species was not predictable using such a tree model and the available predictor variables, except trivially. There were, however, 30 species of invertebrates that admitted of a non-trivial tree-model predictor. Table 5.5.6 shows these species, together with their main split variables and four potential stand-in split variables for the main split. The table has been sorted by the main split variable and its first stand-in. Clearly the acoustic variables are useful for some species.

Code	Species	Main split variable	First stand-in	Second stand-in	Third stand-in	Fourth stand-in
20241226	*Portunus tenuipes*	Depth2	Silica	Temperature	Mud	Salinity.SD
13000000	Sponge: Porifera	Gravel	Sand	Temperature	Phosphorus	Mud
26310200	Loveniidae	Gravel	Stress.SD	Temperature.SD	Phosphorus	Nitrate.SD
20242001	*Thenus orientalis*	Hard	HardSD	Mud	Mud.SE	Sand.SE
22620017	*Photololigo sp 2*	Hard	K.490.SD	Rough	Chlorophyll.SD	Temperature.SD
14330000	Alcyonacea	Hard	Mud.SE	Sand.SE	Gravel.SE	HardSD
14310051	*Virgularia sp*	Hard	Rough	Temperature	Sand.SE	Mud.SE
23000072	Bryozoan 3	Hard	Rough	Stress	Stress.Median	Stress.SD
23000171	*Triphyllozoon sp*	Hard	Rough	Mud.SE	Mud	Sand
14900000	Ctenophora	Hard	RoughSD	Mud.SE	Sand.SE	Gravel.SE
20242003	*Thenus indicus*	Hard	RoughSD	Mud.SE	Rough	Sand.SE
22620000	Teuthoidea	Hard	Sand.SE	Gravel.SE	Rough	Mud.SE
20240208	*Penaeus semisulcatus*	Nitrate	Nitrate.SD	Oxygen	Salinity.SD	Sand
20240226	*Metapenaeus ensis*	Nitrate	Phosphorus	Temperature.SD	Sand	Salinity.SD
20240271	*Metapenaeopsis spp*	Oxygen	Nitrate.SD	Depth2	Nitrate	Depth
20240276	*Trachypenaeus sp.*	Oxygen	Temperature.SD	Nitrate	Phosphorus	Nitrate.SD
20240205	*Penaeus latisulcatus*	Oxygen.SD	Phosphorus.SD	Depth2	Depth	Nitrate.SD
20240210	*Penaeus esculentus*	Phosphorus	Temperature.SD	Sand	Gravel	DepthSD
20241230	*Portunus pelagicus*	Phosphorus	Temperature.SD	Silica.SD	K.490.SD	Chlorophyll.SD
20240225	*Metapenaeus endeavouri*	RoughSD	Nitrate.SD	Depth2	Salinity.SD	Chlorophyll
14320078	Gorgonian 13	Salinity	RoughSD	Salinity.SD	Oxygen	Depth2
26330101	*Chaetodiadema granulatum*	Silica	K.490	Chlorophyll	Rough	Depth2
20240400	Solenoceridae	Silica	Phosphorus	Temperature	Depth2	Mud
26500075	Brittle Star 5	Stress.Median	Stress	Stress.Max	Stress.SD	Sand.SE
14420101	*Sphenopus marsupialis*	Temperature.SD	Oxygen.SD	Silica	Chlorophyll	K.490
14200000	Scyphozoa	WaveHeight	WaveHeight.Median	WaveHeight.Max	WaveHeight.SD	Stress
20210105	*Oratosquilla inornata*	WaveHeight	WaveHeight.Median	WaveHeight.Max	WaveHeight.SD	Nitrate
20241211	*Charybdis truncata*	WaveHeight.Max	Phosphorus.SD	WaveHeight	WaveHeight.SD	Nitrate.SD
22370302	*Amusium pleuronectes*	WaveHeight.Median	Oxygen.SD	Silica	Phosphorus.SD	WaveHeight
20240401	*Solenocera australiana*	WaveHeight.Median	WaveHeight.SD	WaveHeight.Max	WaveHeight	Phosphorus.SD

Table 5.5.6. The species, together with their main split variables and four potential stand-in split variables for the main split

We can summarise the connections between these split variables in the same way as in previous sections. This leads to the following diagram showing these relationships in the form of a dendrogram (Fig 5.5.12).

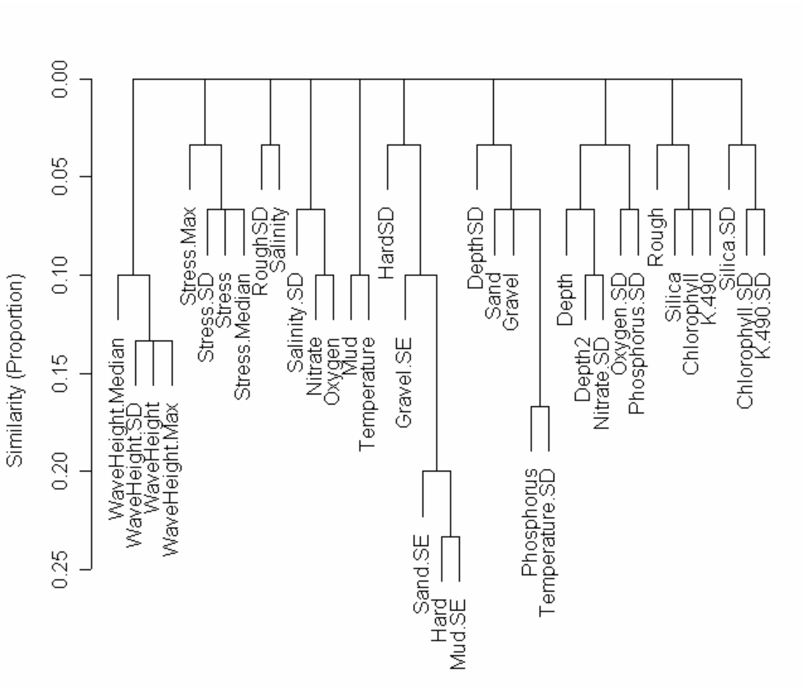

Fig 5.5.12 Clustering of split variables based on proportions of all cases where the variables occur together

Total biomass

If we fit a tree model to predict log(TotalBiomass) again the acoustic variables (including DepthSD) are used for the main splits. The pruned tree is shown in Fig 5.5.13.

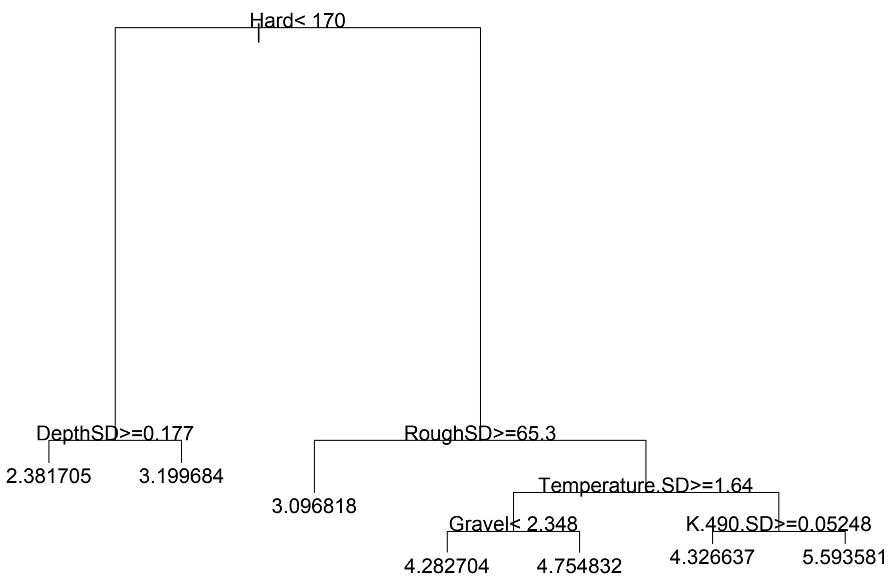

Figure 5.5.13 Tree model including acoustic variables for the main splits.

This tree accounts for about 49% of the variation in log(TotalBiomass), that is it has an effective multiple correlation of 0.49. This is not impressive, and would be inadequate for accurate prediction, but it does clearly show a signal is present that can be captured by a tree model using mainly the acoustic variables.

We contrast this with an ordinary multiple regression model with the same variables. If we perform a stepwise regression using the BIC criterion to penalize over-fitting, this leads to the following variables:

Table 5.5.7 Variables selected using multiple regression mode

	Coefficient	Std. Error	t-value	P-value
(Intercept)	67.870000	13.0200000	5.212	2.621e-007
Salinity	-1.987000	0.3714000	-5.352	1.264e-007
Salinity.SD	-4.379000	0.4625000	-9.469	0.000e+000
Hard.SD	0.004007	0.0007342	5.457	7.221e-008
Rough.SD	-0.010100	0.0015930	-6.337	4.754e-010
Gravel	0.132500	0.0276200	4.798	2.053e-006
Silica	0.530300	0.0933300	5.682	2.121e-008
K.490	-20.970000	4.2890000	-4.890	1.315e-006
Gravel.SE	3.406000	0.8341000	4.083	5.072e-005

Some acoustic variables are selected. However this regression has a multiple correlation of only 0.36 and hence does considerably worse than the tree model.

Note on the use of tree models

Tree models are attractive for this study for two main reasons:

- They seek cut-points in the predictors, hence automatically detecting, if possible, any critical values. If the surrogate variables are ultimately used for selecting MPAs this may have useful consequences.
- They automatically find important variables (in the sense of having useful cut-points) and automatically uncover complex interrelationships between variables, again in this sense. Where there are very many variables to consider, as here, this is a considerable advantage.

There are, of course, disadvantages as well. These include

- Although they produce stable predictors, tree models themselves are typically unstable in the sense that the same analysis may nearly be done by cuts on variables other than the main ones selected.
- They find (near) discontinuous changes in the response fairly easily, but if the change is gradual and nearly linear they can become rather inefficient compared to some more conventional linear models.

There is always a danger in placing too much emphasis on main split variables in tree models. We need to take some note of main split variables here, but we always consider the so-called "stand-in" (or, confusingly for us, "surrogate") split variables as well. Another precaution we take to avoid over-interpreting the results is to prune the trees according to the "one standard error" rule of Breiman et al. 1984. This results in many trees failing in the sense that no predictor model at all is claimed, other than the trivial one. We need to keep in mind that the variables in question are for tree models only important for the splits they can provide. This is quite different from the case in linear regression where, with other variables remaining constant, the change in the response is proportional to any change in the predictor.

References

Breiman, L., Friedman, R.A., Olshan, R.A. and Stone, C.J. (1984). Classification and regression trees. Wadsworth.

CHAPTER 5.6

DISCUSSION AND REFERENCES

Chapter authors

Mick Haywood, Bill Venables, Scott Gordon, Burke Hill

CHAPTER 5.6

DISCUSSION AND REFERENCES

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Bill Venables

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Summary

Adequacy of sampling

- In addition to the inadequate biological sampling in the NPF outside of the Gulf of Carpentaria, our analysis of adequacy of sampling shows that benthic invertebrates have not been adequately sampled across the Gulf. Prawn bycatch has been adequately sampled in only two out of eight regions in the Gulf. The only group that has been adequately sampled in the Gulf is fish by fish trawls
- We have recommended minimal levels of sampling to meet two criteria – identifying the major components of the fauna, and obtaining a relative estimate of biodiversity

Biodiversity and biomass

- Biodiversity of invertebrates captured by the dredge was highest in the eastern and northern Gulf of Carpentaria. Biomass was highest in the north-east, south-east and south-west regions. The highest biodiversity of teleosts was found in the north-east of the Gulf of Carpentaria. There is a clear separation of fish into deeper and a shallower water components

Surrogates

- Biodiversity of the dredge fauna was most affected by oxygen and temperature – probably the results of thermocline formation in summer but we were not able to identify any useful surrogates for the dredge fauna from the available range of environmental variables The trawl biomass surrogates analysis showed that for all cruises salinity and temperature are significant surrogates
- Surrogate environmental variables were only weakly correlated with fish biodiversity and distribution but salinity and temperature were correlated with fish biomass
- Substrate properties were an important surrogate for invertebrates captured by prawn trawls.

Indicator species

- A majiid crab (*Micippa excavata*) and a shrimp (*Sicyonia cristata*)appeared to be indicators of high biodiversity of invertebrates captured by the dredge
- The performance of indicator fish species caught in fish trawls for biodiversity is poor, largely because the variation in α-biodiversity is very small in the first place. Three fish species taken together were associated with high biodiversity - *Pseudorhombus diplospilus* (sole), *Lagocephalus scleratus* (puffer) and *Abalistes stellaris* (trigger fish).
- The analysis for indicator species in the case of invertebrates captured in prawn trawls shows a more complex picture than in any of the other groups. The highest biodiversity level is associated with the occurrence of two species of crabs - *Portunus gracilimanus* and *Dorippe quadridens*

Adequacy of sampling

In Chapter 5.1, we used species accumulation curves to assess the thoroughness of survey effort. The curves indicated that fish caught in fish trawls have been well sampled in the central Gulf of Carpentaria. By contrast, benthic invertebrates collected by dredge have not been well sampled and more sampling would be needed to adequately describe the biodiversity. Grouped analysis of fish and invertebrates captured in prawn trawls indicated they had both been well sampled on the commercial prawn fishing grounds. However when we carried out the analysis by region it appeared that only two out of the eight regions had been adequately sampled. We have also presented an analysis of the criterion suggested by a reviewer namely that adequate sampling is reached when a doubling of sample numbers results in a 10% or less increase in the number of species or taxa. We have also made recommendations on minimum sampling strategies for identifying the major components of the fauna and for obtaining a relative indication of biodiversity. These can probably be achieved by sampling levels well below these needed to meet the criterion suggested by the reviewer. This criterion is however of importance in making comprehensive inventories or in describing in full the fauna of a region.

Dredge fauna

There were two main benthic macrofauna communities in the Gulf: a community located in predominantly sandy sediments along the eastern and south-eastern margins of the Gulf comprised mainly of sessile suspension-feeding sponges, zoantharians, pennatulaceans, bivalve molluscs and ascidians. The second community is located in the muddier sediments in the central and western Gulf and comprimises mainly deposit-feeding spatangoids and sand dollars. Sessile suspension-feeders were found in the central Gulf wherever suitable substrata were present.

Biodiversity as indicated by number of species caught per station (α biodiversity) was higher in the eastern and northern GoC but there was a high level of variation. We tested the relationship between biodiversity and a range of physical and chemical factors (depth, bottom current stress, chlorophyll, K490 absorption, NO_3, PO_4, salinity, O_2, temperature, Si, and the percentages of cobble, granules, mud, pebble and sand). The most significant generalized linear model contained two terms – oxygen and temperature. This probably results from thermocline formation in the GoC and the low range of other terms in the region.

The nature of the benthic fauna is to have a large number of species but the majority are present in low numbers. Long et al., (1995) for example found that spatangoid echinoids made up 60% of the biomass of the 107 dredge samples taken across the Gulf of Carpentaria and that five taxa accounted for 87% of the biomass. The remaining 841 taxa accounted for only 13% of the biomass. Rarely caught species - those captured in 3 or fewer trawls - were found mainly in the eastern and northern sections of the GoC. The most important environmental factors associated with these rare species were oxygen and temperature.

The distribution of total biomass does not show a domination of any areas but there is a generally higher biomass in the north-east, south-east and south-west regions. The biomass is lower in the central and north-west GoC. Biomass was only weakly correlated with environmental variables with oxygen providing the highest linear regression correlation coefficient. As is the case for biodiversity, we suspect this may be due to the effects of thermocline formation in summer in the deeper waters of the GoC. If the samples had extended into the more coastal parts of the GoC we might have detected other correlations.

We were not able to identify any useful surrogates for the dredge fauna from the available range of environmental variables. The wave height SD as well as sand and mud were the strongest indicators. Sand and mud are negatively correlated so in effect are the same. We suspect that one factor in the lack of clear surrogates is the limited area from which samples were taken – it excluded the inshore regions. In addition the GoC has a relatively narrow range for many of the variables – for example we know that the seabed currents outside of the GoC are higher than inside it (Chapter 3.2, Hydrodynamic models).

The analysis indicates that there are a few key indicator species amongst the dredge fauna. The species with the highest indication of biodiversity is a majiid crab *Micippa excavata* (Fig 5.6.1). It was found at 11 stations and these stations had a high biodiversity of 128 species. Majiid spider crabs are found in a variety of habitats; some are found on gravely or shelly seabed but many are associated with sessile animals such as sponges or gorgonians. In the Gulf of Carpentaria, they were found mainly in the east (Node 7 in Fig 5.2.25, Chapter 5.2). The next highest level indicator is another decapod crustacean - *Sicyonia cristata (=lancifer)* (Fig 5.6.2). This is a small shrimp that occurs throughout the Indo-Pacific. They were found at 23 stations and in this case the associated biodiversity was 93 species. In the Gulf of Carpentaria it is found mainly in the southern half but also at a few sites in the west.

Fig 5.6.1 *Micippa excavata*. Photo CSIRO Marine Research

The crab *Micippa excavata* was also identified by the tree model as were three other species (the penaeid *Trachypenaeus granulosus*, the gastropod *Ficus subintermedius* and the crab *Leucosia whitei*). This correspondence is encouraging.

Twenty species or taxa identified in Table 5.27 (Chapter 5.2), of these 55% (11) are crustaceans. According to Long et al, (1995), 26% of the taxa collected were crustaceans. This means that crustaceans have a high probability of being surrogate species. By contrast only 15% (3) of the list are echinoids and they made up 17% of the dredge fauna. Generally the crustaceans are far more mobile than the echinoids and are probably better able to move into 'preferred areas'. We do not know however why they should also be associated with areas of high biodiversity. We do know that some species of echinoids are found in exceptionally high densities. Long et al. (1995) found that spatangoid echinoids were the dominant taxa in the GoC in terms of biomass – they accounted for 60% of the total biomass collected in dredge samples. It is possible that these high densities may exclude or inhibit other species leading to lower biodiversity

Figure 5.6.2 *Sicyonia cristata (=lancifer).*Photo CSIRO Marine Research

Fish captured in fish trawls

The areas with the highest biodiversity of teleosts are mostly in the north-east. The stations with a lower biodiversity are more scattered but the majority are in the north-west. There is no clear pattern to the spatial distribution of the remaining fish fauna.

The initial impression is that the connection between the fish fauna and stations is relatively weak. The analysis indicates that the distribution fish biodiversity of the Gulf of Carpentaria is fairly uniform over much of the central area. Towards the margins it is different but again there is a large degree of uniformity around the Gulf. Unfortunately we do not have fish trawl data for the inshore regions. Surrogate split variables for the first node are WaveHeight.SD, WaveHeight.Max, WaveHeight (mean), Sand and Oxygen, which all belong to one of the variable groups shown for the dredge data.

Depth and salinity are the highest split variables. Mud and sand and wave parameters are also fairly high. However, even the highest of these variables is lower than that found for dredged invertebrates (Chapter 5.2). This might reflect the greater mobility of fish relative to most invertebrates allowing them to be less tightly tied to environmental variables.

By contrast a tree analysis of the species, indicated that salinity SD, nitrate SD and oxygen were the split variables with the highest frequency of occurrence. Depth, sand and mud were also important but at a lower level. This suggests that water quality parameters are important in deciding fish distributions in the Gulf of Carpentaria and substrate properties are secondary to these. A thermocline forms in summer in the Gulf of Carpentaria (Somers et al 1987) and the associated water quality changes are probably key drivers in determining the distribution of mobile species such as most teleosts. There is a clear separation of the fish into a deeper water group with separate groupings occurring into shallower water.

In contrast to the dredge samples, the performance of indicator fish species is very mediocre, largely because the variation in α-biodiversity is very small in the first place. As can be seen in Figure 5.2.19 (Chapter 5.2), the areas with the highest biodiversity of teleosts (node 9) are mostly in the north east. The stations with second highest value node (8) are more scattered but the majority are in the north west. There is no clear pattern to the spatial distribution of the remaining nodes. The highest level of biodiversity was found at eight stations with a mean of 53.88 species. These stations all had the three species *Pseudorhombus diplospilus* (sole), *Lagocephalus scleratus* (puffer) and *Abalistes stellaris* (trigger fish).

The biological information available for the three indicator species identified here does not give any indication of why these species should be either associated with each other or with high biodiversity. According to Fishbase, these species are all found in similar habitats.

Pseudorhombus diplospilus (Figure 5.6.3) is found in shallow water (10 m) on mud and sand bottoms of coastal zones.

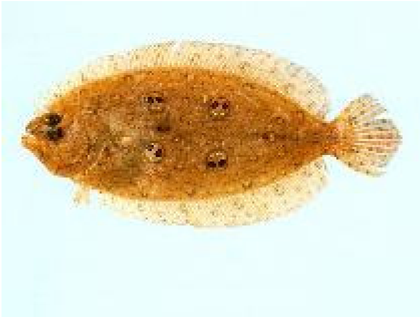

Figure 5.6.3 *Pseudorhombus diplospilus* (Photo CSIRO)

Abalistes stellaris (Fig 5.6.4) inhabits coastal areas, it is usually found over muddy and sandy bottoms, also around reefs, together with the sponges and algae.

Figure 5.6.4 *Abalistes stellaris* (Photo CSIRO)

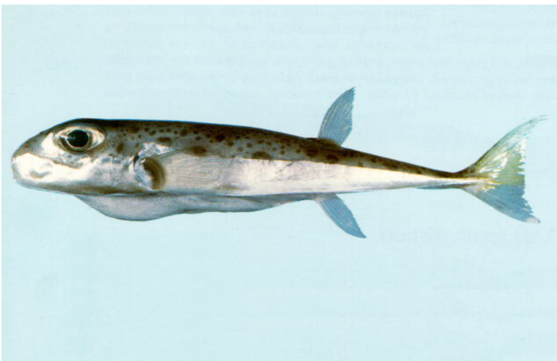

Figure 5.6.5 *Lagocephalus scleratus* (Photo CSIRO)

Lagocephalus scleratus (Figure 5.6.5) Inhabits offshore reefs, also occurs on benthic sandy and muddy bottoms to 40 m. It is difficult to generalise with such sparse information but it appears that we are dealing with three species typically found on sandy and muddy seabed but two of the species are also associated with reef or megafauna structure.

Fish caught in prawn trawls

Although we are dealing with a large number of trawl bycatch samples from three different cruises, the geographical spread of the samples is limited to the commercial prawn fishing grounds. This means that we are dealing with a relatively narrow range of physical and chemical environmental factors.

There appears to be a similar biodiversity between Weipa (really Albatross Bay and offshore) and the waters to the north of Groote Eylandt. The fauna around the islands in the southern GoC also shows similarities in biodiversity. This data is of interest because the fish and dredge samples reported in Chapters 5.2 and 5.3 did not extend to these inshore regions.

The most important surrogate environmental factors that group the stations are *Depth*, *Oxygen.SD*, *Nitrate*, and *Oxygen.* These factors were also important in grouping the fish trawl stations (See Chapter 5.3). This indicates a commonality between the shallow (20-40 m depth) stations and those of the more offshore stations (mostly >40 m sampled with the fish trawl.

The trawl biomass surrogates analysis showed that for all cruises salinity and temperature are significant surrogates. Sediment characteristics provided no potential surrogate information consistently across all cruises. We found differences between cruises, for example in SS9702 and SS9708 cruises chlorophyll and K490 parameters are significant. For the SS9702 cruise sediment covariates (sand, mud, pebble, and granule) were important as are acoustic parameter variations (roughness standard deviation and hardness standard deviation). In the case of SS9708 cruise acoustic information (roughness and hardness standard deviation) is important as well as sediment (mud see Figure 5.3.12, Chapter 5.3), bottom water column attributes (silica, nitrate) and depth. For the SS9803 cruise temperature and salinity almost completely describe the biomass variation and are highly statistically significant.

Three species taken together were associated with high biodiversity. These were *Nemipterus peronii*, *Lethrinus genivittatus* and *Echeneis naucrates*. Although they were found together at only a few stations, these stations had a mean species count of 78.4.

There was no clear spatial pattern to prawn trawl fish biodiversity.

Our analysis shows that biodiversity as measured by two different gears – fish trawl and dredge – is not the same. A comparison of the number of species and of the biomass shows a weak statistical correlation. We do not however consider that the relationship is sufficiently strong to be used to predict either biodiversity or biomass. In other words, given the results of our analysis, it is not possible to say that high biodiversity of teleosts in an area means that we also have high benthic faunal biodiversity.

Invertebrates caught in prawn trawls

The predictive capacity of environmental variables for stations is not particularly good. The error rate is high and most predictions based on the tree analysis would be wrong. The implication is that the groups are not strongly linked to the benthic variables. By contrast environmental variables associated with the seabed –mud SE, sand SE and gravel SE - form a group indicating that substrate is an important surrogate for invertebrates captured by prawn trawls.

The analysis for indicator species shows a more complex picture than in any of the other groups. The highest biodiversity level is associated with the occurrence of two species of crabs - *Portunus gracilimanus* and *Dorippe quadridens*. These have to be present simultaneously, but the group of stations where this occurs is very small.

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CHAPTER 6

SUSTAINABILITY OF ANIMALS CAPTURED IN PRAWN TRAWLS

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CHAPTER 6.

SUSTAINABILITY OF ANIMALS CAPTURED IN PRAWN TRAWLS AND THEIR DISTRIBUTION

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Summary

We assessed the sustainability of 115 taxa of invertebrates with respect to trawling

This assessment is for populations found on trawl grounds although the existence of part of the population off the trawl grounds was regarded as positive because it would allow recruitment from individuals not directly affected by trawling

Only two of the taxa were found predominantly off the trawl grounds – Corystidae and Goneplacidae - both are brachyuran crustaceans. The rest were found either predominantly on trawl grounds or equally on and off trawl grounds

Sustainability of seabed invertebrates was assessed on two axes, the Susceptibility of the fauna to trawl impacts and the ability of the fauna to Recover from a trawl impact.

<u>Susceptibility</u>: Six factors were used in assessing susceptibility:

- Ability to avoid the trawl net or catchability
- Survival from trawling
- Day/night distribution – animals on the seabed at night were assumed to be more vulnerable than those that buried at night
- Preferred habitat – the relative distribution on and off the trawl grounds
- Regional analyses – the relative abundance on grounds with different levels of commercial trawl effort

<u>Recovery</u>: Four factors were used in the assessment:

- Fragility with respect to trawl damage
- Ability to regenerate following damage
- Reproductive pattern – whether or not there is a larval dispersal phase
- Effect of trawl damage on reproduction – especially the vulnerability of eggs to trawl damage

Analysis showed correlation between the Preferred Habitat and Regional Analyses although these were based on different data sets. We included both criteria but weighted them to compensate

The following twelve taxa were identified as the most sustainable:

- Pectinids (bivalve), venerids (bivalve), xenophorids (gastropod), holothuroids, mactrids (bivalve), corystids (crab), goneplacids (crab), cardiids (bivalve), pagurids (hermit crab), portunids (crab), scyllarids (bug), asteroids

The twelve taxa identified as being the least sustainable were:

- Soft corals, bryozoans, echinoids, octopods, olivids (gastropod), palinurids (lobster), parthenopids (pea crab), pennatulids (sea pen), sepiolids (cephalopod), solemyids (bivalve), solenids (bivalve) and teuthoids (squid)

The overall conclusion is that:

- The echinoids appear to have low overall sustainability as they have both low susceptibility scores and a low ability to recover
- The asteroids and holothuroids appear to be the most sustainable groups as they have a high recovery and a moderate susceptibility score.
- The more delicate families of Crustacea such as crangonids, carids and parthenopid crabs have low sustainability. The most robust Crustacea are the hermit crabs, portunid crabs and the bugs (scyllarids)
- Of the 12 least sustainable invertebrate taxa, the following are relatively widely distributed

across the GoC: Alcyonacea, Bryozoa and Parthenopidae and to a lesser extent the Echinoidea, Octopodidae and Pennatulacea. The remaining taxa were collected from only a few sites.

- The distribution of the least sustainable invertebrates shows a similar pattern to that previously reported for teleosts. About half the species are widely distributed but five fall into the rarely caught category.

Introduction

The traditional focus on target species by fisheries management is being broadened by questions about the sustainability of all species affected by fishing. This is a massive task especially in tropical fisheries with hundreds of species for most of which there is little information. Traditional fisheries approaches using historical catch per unit effort, growth and mortality rates, fecundity and catchability cannot be done because of the absence of the data. Collecting this data is not feasible given the large number of species and the cost and time that this would involve. Powles et al. (2000) have pointed out that factors associated with known extinctions and near extinctions include specific life-history characteristics such as low fecundity, high age at maturity, low mobility, habitat degradation, high value and high susceptibility to harvesting as well as ecological specialization. Pope et al., (2000) proposed that for non-target species, models founded on basic knowledge of life history parameters, and on generally established relationships between these parameters, may offer the only practical approach for gauging fishing mortality. Stobutzki et al. (2001) used this approach to estimate the sustainability of teleosts and elasmobranchs relative to shrimp trawling in Australia's far northern waters in the region known as the Northern Prawn Fishery (NPF). They collected over 800 trawl bycatch samples from the fishing grounds to characterise the fish fauna. The Sustainability model developed by Stobutzki et al. (2001) incorporated two attributes or axes: The first axis was the susceptibility of capture and mortality due to a prawn trawl (Susceptibility). The second axis dealt with the capacity of a species to recover once the population is depleted (Recovery). We decided to follow this path to assess the sustainability of invertebrates found on trawl grounds. We assumed that trawl impacts would vary between species. For example, animals such as soft corals or large sponges that are highly fragile are more likely to be damaged than those that are robust – for example heavy shelled gastropods or bivalves. Numerous experiments on trawl impacts confirm this differential susceptibility. Van Dolah et al. (1987) for example found different levels of damage from experimental trawls between species of sponges, soft corals and hard corals. Freese et al. (1999) similarly found differential damage to sponges by fish trawls – vase sponges were especially vulnerable whereas finger sponges were not significantly reduced. Damage by trawls is only one aspect of sustainability; another important aspect is the ability to recover from an impact. White and Pickett (1995) point out that in general short-lived, highly mobile or dispersed species with high reproductive rates will recover from disturbance faster than long-lived, sessile, low dispersing species.

The analysis carried out by Stobutzki et al. (2001) was based on by catch samples collected in the NPF region. They limited their analysis to fish (teleosts and elasmobranch). The invertebrates – which make up around 20% of their bycatch - were not analysed. The present paper analyses this invertebrate collection using biological knowledge from the literature and from other studies in the region.

We assessed Susceptibility using a series of criteria. For example, we assumed that animals found only on trawl grounds are more susceptible than those that also occur off the grounds. Similarly animals that can avoid a trawl by burying or swimming are assumed to be less susceptible than those that cannot – for example attached animals. In the case of Recovery, populations of animals that produce planktonic larvae are assumed to be better able to recover from trawl impacts because of a greater ability to repopulate areas. We did not have a free choice of criteria. In Recovery for example, we would expect that factors such as growth rates, age at first reproduction and fecundity would all be important. Unfortunately this biological information was not available for most taxa and so we had to use a more restricted set of criteria.

Assessment of sustainability is complicated by having animals living both on and off the trawl grounds. We could assume that species or taxa that are found predominantly off the grounds are probably not threatened directly by trawling. We found only two taxa in this category – a corystid crab and a goneplacid crab. The small number is probably because most of our samples come from trawl grounds, we would not claim to have a comprehensive off-trawl ground sampling. Because of this we are not attempting to describe the sustainability of the seabed fauna across the entire NPF, this assessment is really of animals found on the trawl grounds and the sustainability of this subset of the population with respect to trawling. Because only around 25% of the NPF is trawled, this is a conservative assessment.

As stated in Chapter 3.1, for the purposes of this study, we had prawn trawl bycatch samples taken from cruises in the Gulf of Carpentaria by Stobutzki et al. (2000, 2001) and dredge samples collected by Long et al. (1995). Although our approach is similar to that used by Stobutzki et al. (2000), because of differences in the amount of information available for most invertebrates compared to fish, we have introduced several changes.

Methods

All samples used in this study were collected from the 66 m research stern trawler Southern Surveyor. Two sets of data on invertebrates were available for analysis. Firstly prawn trawl bycatch samples from 401 night time trawls made in 1997 and 363 trawls (207 at night and 156 in the day) made in 1998 on or adjacent to the fishing grounds in the Gulf of Carpentaria (Fig 1). Trawl samples were taken from trawls of approximately 30 minutes duration using a single 26.5 m head rope length Florida Flyer prawn trawl net made of 57 mm stretched mesh with a 150 x 150 mesh cod end of 45 mm stretched mesh. The net was rigged with 100 m bridles and No 9 Bison trawl boards (490 kg) and towed at an average speed of 3.2 knots. Net height and spread were monitored by SCANMAR. More information on the sample sites is given in Chapter 3.1 and in Stobutzki et al. (2001). Because the trawl samples were made largely on fishing grounds, we could not use these data for determining whether animals were also found off the fishing grounds. For that analysis we used the second set of data which was derived from dredge samples. In 1990, dredge samples were taken in a grid pattern of stations across the Gulf of Carpentaria, with 93 dredges taken off the trawl grounds and 14 dredges taken on the trawl grounds. In the 1998 sampling, an additional 44 dredge samples were taken on the trawl grounds. The dredge samples were taken with a 3.0 m wide by 1.2 m high beam trawl or Church dredge rigged with a 30 mm stretch mesh bag towed for 15 minutes at 6 km h^{-1}. The ship was working continuously and so about half the dredge samples were taken at night and half in the day. Because of the nature of the fauna sampled by the dredge this was not regarded as a problem. More information about the sampling is given in Long et al. (1995). Trawl and dredge material was sorted and identified at sea.

Unfortunately most invertebrate taxa collected in the prawn trawls were not identified to species level. We have species information for Crustacea but for most other groups the material was identified only to family because more detailed information was not required in the original study. After examination of the data, we decided to use the Family taxon level; this gave 115 taxa for the analysis. Each of the 115 taxa was scored against every criterion. Scores for each criterion are on a scale of 1 to 3 with a score of 1 being for the worst case and a score of 3 the best case. If only two conditions were identified, only the top and bottom scores were allocated. Where there was insufficient information to categorise the taxon a default score of 1 was given. The scores for each taxon were averaged to determine the overall Susceptibility and ability to Recover of that taxon. Some of the criteria were scored on the basis of analysis of the available data, for example day – night catch rates, distribution on and off the fishing grounds. Other information was derived from the literature. The main sources of this information were: Beesley and Ross (1998) for molluscs, Fabricius and Alderslade (2001) for soft corals and sea fans, Hooper and Wiedenmayer (1994) for sponges and Rowe and Gates (1995) for echinoderms. At the time when our samples were collected, the Octocorals (formerly Alcyonaria) were divided into Penatulacea, Gorgonacea (gorgonians) and Alcyonacea (soft corals). The latter two taxa are now regarded as one group, the Alcyonacea, because morphological intermediates exist (Fabricius and Alderslade, 2001). For convenience we have retained the separation into gorgonians and soft corals as typifying the distinctive types of Octocorals found as bycatch in trawls.

Sustainability

Sustainability was assessed on two axes: the Susceptibility of the fauna to trawl impacts and the ability of the fauna to Recover from a trawl impact.

Susceptibility

We identified five criteria that we considered were important in determining susceptibility and which could be measured:

Avoidance or catchability

This measures the susceptibility to capture of animals that are sessile and cannot avoid a trawl compared to those that may be able to avoid a trawl for example by being able to bury rapidly or by living buried. We obtained the information to score this criterion from the biological literature.

Survival from trawling

Robust animals such as many bivalves and gastropods can survive being trawled, exposed to air and being discarded. These are less vulnerable than those that are killed by the trawl. Scoring was based on published data on survival of discards

Day/night distribution

Animals that bury into the substrate at night or can swim up into the water column at night – such as squid - were presumed to be less vulnerable to being caught by nighttime trawls. Data from two Southern Surveyor cruises (October/November 1997 and March 1998) were used for this analysis. On each cruise, trawls of approximately 30 minutes duration were made on trawl grounds during the day and night using a Florida Flyer prawn trawl net. In October/November 1997, trawls were made in each of eight regions but in 1998, trawls were made in only two regions – North and South of Groote Eylandt. We had data from 468 trawls made in October/November 1997, and 378 trawls made in 1998.

The weight of each taxon caught in each trawl was standardized by the duration of the trawl and so the catch in weight hour $^{-1}$ was used in further analyses. Catches were transformed (logx +1) because the distributions of catches for most taxa were not normal. A 2-way ANOVA was carried out on the data from each cruise separately using day-night and region as the two independent variables. Taxa that had significantly higher catches at night in at least one cruise or were not significantly different between day and night were scored as 1. Taxa that were caught significantly more during the day were scored as 3.

Preferred habitat

We assumed that animals found only on trawl grounds are more susceptible than those also found off the grounds. Data for this analysis came from four Southern Surveyor cruises – the Gulf-wide cruise in 1990, and the subsequent trawl-ground cruises in February/March 1997, October/November 1997 and March 1998. Samples were taken with a Church Dredge towed for approximately 10 – 15 minutes at each location. Samples were defined as being on or off the trawl grounds based on the mean distribution of fishing effort in the Gulf of Carpentaria between 1996 and 2000.

In 1990, the grid pattern of research sampling covered most of the Gulf of Carpentaria, with 93 dredges taken off the trawl grounds and 14 dredges taken on the trawl grounds. In the other three cruises, a total of 44 dredges were taken, all on the trawl grounds in various fishing regions of the NPF. Data from all four cruises was combined for the analysis.

For each taxon, the score in the preferred habitat category was determined by the relative log-odds, namely:

$$R = \log\left(\frac{n_T + \frac{1}{2}}{m_T + \frac{1}{2}} \Big/ \frac{n_O + \frac{1}{2}}{m_O + \frac{1}{2}} \right)$$

where

n_r = the number of times the taxon was caught in dredges on regular trawl grounds,
m_r = the number of dredges on regular trawl grounds in which the taxon was NOT caught,
n_o = the number of times the taxon was caught in dredges not on regular trawl grounds
m_o = the number of dredges off regular trawl grounds in which the taxon was NOT caught.

We added 0.5 to all values to overcome problems associated with zero values.

The taxa were then ordered by increasing score and plotted out against score. The distribution of scores was mostly linear with a relatively distinct tail at each end of the distribution. Taxa in the tail at the lower end of the scores (those caught in substantially higher numbers off the trawl grounds) were given a susceptibility score of 3, while taxa in the tail at the higher end of the scores (those caught in substantially higher numbers on the trawl grounds) were given a susceptibility score of 1. All other taxa were scored as 2.

Regional analyses

We measured the fishing intensity on trawl grounds where the taxon is found and assumed that animals living in areas of low fishing effort would be less vulnerable than those on grounds that are heavily fished. Two data sets were used for this analysis.

(a) Fishing effort data from fisher's logbooks for the commercial tiger prawn (*Penaeus esculentus* and *P. semisulcatus*) fishery in the NPF were used to calculate an index that reflects the relative intensity of fishing effort in different fishing regions of the NPF.
(b) Survey data from CSIRO research cruises were used to determine the distribution of each taxon throughout fishing regions of the NPF.

The two data sets were combined to calculate an index of susceptibility for each taxon based on its distribution throughout fished regions of the NPF.

Commercial fishing effort

The number of boat days of tiger prawn fishing effort for each 6-nm fishing grid for each year from 1995 to 1999 in the NPF was available for analysis. The fishery was divided into 8 regions based on relatively discrete fishing areas sampled by Southern Surveyor cruises in 1997. The area potentially available to be trawled in each region (A) was calculated by summing the area of all 6-nm grids that were fished at all over the 5-year period. An estimate of the actual area of seabed trawled each year in each region (T) was then calculated using the following formula:

T = (B * H * SA * SP)/5

where:

B = number of boat days of fishing effort for each year
H = 12 (the approximate number of hours fished each night)
SA = 40 (the average swept area of trawl nets used in the NPF in m)
SP = 5556 (the approximate trawling speed of vessels in the NPF in m hr^{-1})

Each region was then rated from 1 to 10 based on the percentage of the potential area actually trawled, such that 1-10 % = 10; 11-20 % = 9……..91-100 % = 1.

Table 6.1 Characteristics of the fishing regions in the NPF and the area rating used in the analyses. Actual area refers to the area of the grids that were fished.

Region	No of grids	Potential area (km^2)	Boat-days	Actual area (km^2)	% of potential area	Area rating
Weipa	58	6617.2	1710.4	4561.3	68.9	4
Karumba	99	11215.3	1378.2	3675.4	32.8	7
North Mornington	112	13264.6	2175.8	5802.6	43.7	6
West Mornington	123	14500.2	2246.4	5990.8	41.3	6
Vanderlins	180	20992.9	3042.9	8115.0	38.7	7
South Groote	88	9880.4	1787.0	4765.7	48.2	6
North Groote	88	9804.0	3294.3	8785.4	89.6	2
Melville	47	5650.0	303.0	808.0	14.3	9
Totals	795	91924.6	15938	42504.2		47

Survey data

Data from two Southern Surveyor cruises (February/March 1997 and October/November 1997) were used for this analysis. On each cruise, trawls of approximately 30 minutes duration were made on trawl grounds in each of the eight regions described above using a Florida Flyer prawn trawl net. In February/March 1997, trawls were only made at night but in October/November 1997, trawls were made during day and nighttime.

The occurrence of each taxon was registered simply as presence or absence in each region, irrespective of the relative abundance of the taxon. Each taxon then received a score for each region that was zero if the taxon did not occur in the region or the "area rating" (see table) if the taxon was caught in that region. The total score for each taxon was then calculated as the sum of the scores for all regions for each taxon. The maximum total score if a taxon was caught in all regions was 47 (see table).

The range of possible total scores for each taxon (0-47) was divided into 3 equal groups, i.e. 0-16, 17-32, 33-47 and the susceptibility score for each taxon was calculated as 1, 2 or 3 according to the following table:

Total score	Susceptibility score
0-16	1
17-32	2
33-47	3

Recovery

We identified four criteria that could be used for measuring the relative ability of an animal to recover from a trawl impact. As pointed out above, other criteria such as growth rate could not be used because of a lack of information.

Fragility with respect to trawl impacts

Animals such as large sponges, soft corals and nudibranchs are likely to be seriously damaged by impacts with prawn trawls. Others, such as many bivalves and gastropods, are sufficiently robust that damage by a trawl is minimal. Information was derived from the general literature and our observations on trawlers.

Regeneration

The ability to repair trawl damage. Some animals such as echinoids can deal with only minor wounds and are killed by trawl damage. Many other invertebrates have well developed regeneration abilities. Studies of post-cyclone or hurricane effects have also shown that many animals can regenerate from fragments, and so have a well developed ability to regenerate or even reproduce asexually following severe damage. Information was derived from the general literature.

Reproductive Pattern

Populations of species that have planktonic larval stages are presumed to be better able to recover from trawl impacts than those without this distributive phase because recruitment can occur from outside the impacted area. Gaines and Lafferty (1995) have however pointed out that species that have planktonic larvae may have no local reproduction because larvae are dispersed. This suggests that in the case of a severe depletion, planktonic larvae would be a negative characteristic. Nevertheless we consider that the possession of larvae is an asset for a species that is trawled. Wray (1995) for example state that wider dispersal offers potential increases in geographic range and population size while larval feeding enables larger brood sizes and exploitation of different food resources early in the life cycle. The overwhelming majority of marine invertebrates have planktonic larvae but there are some important exceptions including a species of solitary coral that was found in the highest numbers of any species in the bycatch. Information on the possession of larval stages was derived from general literature.

Effects of trawl damage on Reproduction

Some forms of reproduction expose eggs to a high risk of trawl damage. We have identified two behaviours that appear to be important here. The first deals with trawl damage to eggs. Certain species of gastropods, lay their eggs on the substrate where trawls may damage them and we regarded this as a negative characteristic. Females of many decapod crustaceans carry their eggs and, even if the adults survive trawling, the eggs may suffer some damage and so we also regarded this as a negative characteristic. The second behaviour is found in species that are free spawners. Free-swimming sperm generally live at most an hour or two and their life is shorter when they are in low densities (Levitan, 1995). In these species it is important for spawners to live in close proximity. If trawling reduces population density of adults it could impact on spawning success. Information was derived from general literature.

The criteria and scoring used are summarised in Table 6.2.

Table 6.2 Criteria and scoring used in determining the Susceptibility to trawling and the ability to Recover for each taxon in the invertebrate bycatch.

Susceptibility to trawling

Criterion	Scoring
Avoidance	1 = attached or sessile, cannot avoid a trawl 2 = mobile but with limited ability to avoid a trawl. Could move away from disturbed area or bend under trawl 3 = Mobile, can probably avoid a trawl, or are able to bury rapidly or are mostly buried
Survival from trawling	1 = <33% survive 2 = between 33 and 66% survive 3 = >66% survive
Day night catchability	1 = Significantly higher catch rate at night 2 = No significant diff between day and night or no data 3 = Significantly higher catch rate in day
Preferred habitat	1 = Caught in substantially higher numbers on the trawl grounds 2 = Intermediate 3 = Caught in substantially higher numbers off the trawl grounds
Regional analyses	1 = Sum of area rating (fishing intensity on grounds where found) is between 0 and 16 (see methods) 2 = Sum of area rating between 17 and 32 3 = Sum or area rating 33 or more (maximum 47)

Recovery

Criterion	Scoring
Fragility with respect to trawl	1 = Very fragile 2 = Damage from trawls is probably not lethal 3 = Very robust
Ability to regenerate	1 = Regeneration limited to minor wound repair, likely to be killed by trawl impact 2 = Can replace appendages but not recover from major damage 3 = Well developed regeneration ability
Reproductive pattern	1 = No or short-lived larval dispersal stage 3 = Pelagic larval stage
Effect of trawl damage on reproduction	1 = Eggs vulnerable to trawl damage or are broadcast spawners 3 = Trawl damage limited to juvenile or adult stage

Independence of Sustainability Criteria

Before combining susceptibility or recovery scores into any single overall Susceptibility or Recovery index we tested the independence of the characters. Since only linear operations are envisaged (for example adding or weighted averaging) the most important kind of independence to check is linear independence. We did this by treating the 115 benthic taxa for which scores are available as a pseudo-random sample and then examining the variance matrix. We tested the two axes – Susceptibility and Recovery - separately.

Susceptibility

The basic summary statistics of the five Susceptibility criteria are outlined in Table 6.2.

Table 6.2 Means, standard deviations and correlations for Susceptibility characters using 115 benthic taxa

	Avoidance	*Day/night catchability*	*Survival from trawl*	*Preferred habitat*	*Fishing intensity on grounds where captured*
Means	1.7130	1.0174	2.0087	2.2043	2.7391
Standard Deviations	0.6979	0.1865	0.7433	0.8027	1.3944
Correlations:					
Avoidance	1.0000				
Day/night catchability	0.1735	1.0000			
Survival from trawl	-0.1304	-0.1276	1.0000		
Preferred habitat	0.1526	-0.0825	0.1440	1.0000	
Fishing intensity on grounds where captured	0.1252	0.1188	0.0149	0.6593	1.0000

Table 6.2 shows that -

- The standard deviation (SD) for each character increases as the mean for each character increases.
- Day/night catchability has a very much lower (SD) than other characters, this is a result of 114 taxa being scored as 1 and one taxon (Teuthoidea*)*, being scored as 3.
- Four character scores are allowed to take on only three equally spaced values, while one character, *Fishing intensity on grounds where captured*, can take on eight. This influences the relative amount of variability as expressed by the SD.
- Correlations are low except between *Preferred Habitat* and *Fishing intensity on grounds where captured* (0.6593). The strong positive correlation in this case suggests only one of these characters should be included.

The eigen-analysis of the variance matrix (i.e. the principal component variances and loadings) is shown in Table 6.3. One of the normalised linear functions of the Susceptibility characters has a relatively low variance (0.0311), suggesting there is appreciable linear dependence (or co-linearity). Consequently some characters may be removed without affecting the information content, specifically *Fishing intensity on grounds where captured* and Preferred *habitat* (as also seen in the correlations in Table 6.2.

Table 6.3 Eigen-analysis of the variance matrix of the Susceptibility scores

Eigenvalues:	2.2911	0.6041	0.4553	0.2815	0.0311
Eigenvectors:					
Avoidance	0.0800	0.4542	-0.8541	0.2353	0.0497
Day/night catchability	0.0108	0.0519	-0.0057	0.0857	-0.9949
Survival from trawl	0.0252	-0.8718	-0.3762	0.3122	-0.0161
Preferred habitat	0.4120	-0.1657	-0.2869	-0.8455	-0.0754
Fishing intensity on grounds where captured	0.9073	0.0588	0.2161	0.3535	0.04211

Although the day/night catchability criterion separated out only one taxon, we decided to include it in the Susceptibility calculation. Exclusion of this criterion would have meant ignoring the markedly different behaviour of squid that makes them less available at night compared to all of the other taxa tested. The analysis presented here also indicates that either Preferred habitat or Fishing Intensity could be removed without a loss of information. This was initially surprising given that the data used for each criterion is completely different and independent of each other (dredge samples versus trawl samples). However in essence each is testing whether the taxa are found on areas that are either not or only lightly fished. Because we did not wish to exclude one of these criteria arbitrarily we included both. Because this could bias the result, we weighted these criteria by 0.5 to make their combined weight equivalent to the other criteria.

Recovery

The basic summary statistics of the four criteria are given in Table 6.4.

Table 6.4 Means, standard deviations and correlations for Recovery characters using 115 benthic taxa

	Reproductive pattern	*Fragility*	*Trawl effect*	*Regeneration*
Means	1.6522	1.9391	2.1304	1.9739
Standard deviations	0.9276	0.7409	0.9958	0.8529
Correlations:				
Reproductive pattern	1			
Fragility	0.0327	1		
Trawl effect	-0.5392	-0.1199	1	
Regeneration	-0.1779	-0.0858	0.3449	1

With scores allowed to take on only three equally spaced values the potential for outliers is effectively eliminated. There are no real surprises in this table other than the mildly high negative correlation between the two characters *Reproductive pattern* and *Effect of trawling on reproduction.*

The eigen-analysis of the variance matrix (i.e. the principal component variances and loadings) is shown in Table 6.5. We note that any normalised linear function of the characters has a variance of at least 0.39, and hence there is no appreciable linear dependence (or co-linearity). Hence all four characters are informative and none may be removed without affecting the information content.

Table 6.5 Eigen-analysis of the variance matrix of the recovery scores

Eigenvalues	1.5579	0.6493	0.5346	0.3865
Eigenvectors:				
Reproductive pattern	-0.5884	0.5099	-0.0231	0.6272
Fragility	-0.0954	-0.2989	0.9397	0.1879
Trawl effect	0.7181	-0.0252	-0.0741	0.6915
Regeneration	0.3592	0.8062	0.3574	-0.3053

The two characters (Reproductive pattern) and (Effect of trawling on reproduction) were negatively correlated, which in hindsight is clearly what should happen. Also the first principal component is not something like an "average recovery score" that would rank families from "good recoverers" to "poor recoverers". Rather it is a contrast between "Recovery pattern" and "Regeneration", which again in hindsight is not unexpected since we would expect all animals to have some form of recovery pattern but not necessarily the same one.

Results

Because of the number of taxa, the resulting spreadsheet is large. We have presented here results for only the 12 least and 12 most sustainable taxa, in the form of a table (Table 6.6) and figures (Fig 6.1 – 6.6). The full list is given in Appendix A at the end of the Chapter.

Table 6.6. Scores for each criterion in the Susceptibility and Recovery matrix for the 12 taxa with the highest and lowest sustainability. Criteria are explained in text.

	Susceptibility					Recovery			
	Avoid	Day Night	Survival	Prefer habitat	Fishing intensity	Repro pattern	Fragility	Effect of trawling on repro	Regen-eration
Most sustainable									
Pectinids	2	1	3	2	2	1	3	3	1
Venerids	2	1	3	2	2	1	3	3	1
Xenophorids	2	1	3	2	2	3	3	1	1
Holothuroids	2	1	3	2	2	1	2	3	2
Mactrids	3	1	3	1	1	3	3	3	1
Corystids	2	1	2	3	3	3	2	1	2
Goneplacids	2	1	2	3	3	3	2	1	2
Cardiids	3	1	3	2	2	1	3	3	1
Pagurids	2	1	3	2	2	3	3	1	2
Portunids	2	1	3	2	2	3	3	1	2
Scyllarids	2	1	3	2	2	3	3	1	2
Asteroids	2	1	3	2	2	1	3	3	3
Least sustainable									
Soft corals	1	1	1	1	1	1	1	3	1
Bryozoams	1	1	1	2	2	1	1	1	3
Echinoids	1	1	1	2	2	1	1	3	1
Octopods	3	1	1	1	1	3	2	1	1
Olivids	2	1	3	1	1	1	3	1	1
Palinurids	2	1	1	1	1	3	2	1	2
Parthenopids	2	1	2	1	1	3	1	1	2
Pennatulids	2	1	1	2	2	1	1	3	1
Sepiolids	3	1	1	1	1	3	1	1	1
Solemyids	3	1	1	1	1	1	1	3	1
Solenids	3	1	2	1	1	1	1	3	1
Teuthoids (squid)	3	3	1	1	1	3	1	1	1

The scores for each taxon were averaged to give a single score for each of the attributes – Susceptibility and Recovery. In the following six figures we have presented a graphical form of the result estimates of Sustainability. These are either taxonomically or functionally based. Each figure is divided for convenience of interpretation into quadrants, these quadrants are not meant to have any statistical value. The lower left quadrant includes the least sustainable groups – those having low scores for both Susceptibility and Recovery. The top right quadrant represents the most sustainable groups – those having high scores for Susceptibility and Recovery. The other two quadrants represent the remaining combinations.

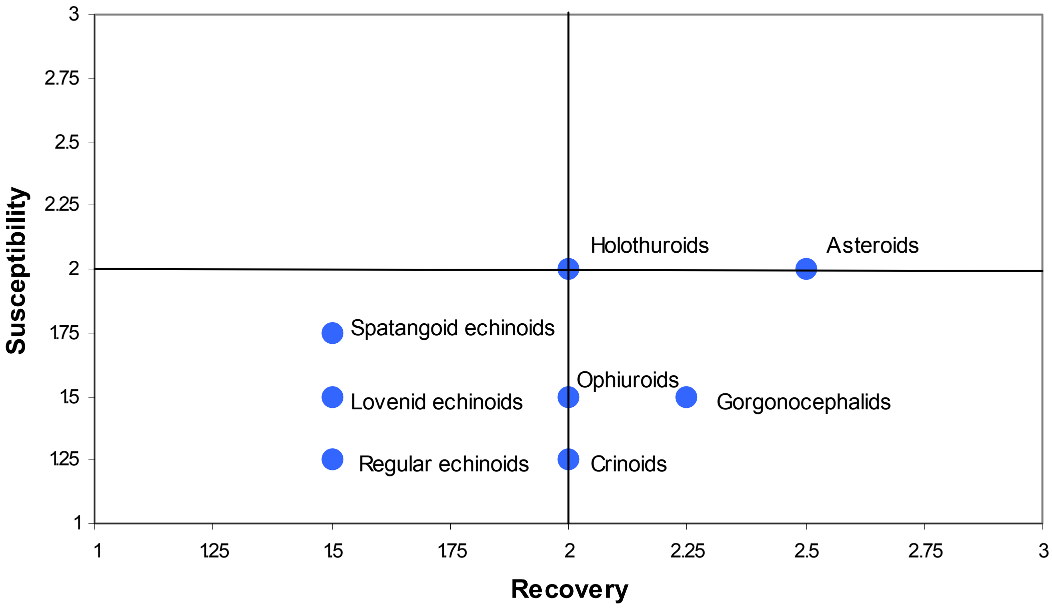

Figure 6.1 Sustainability of echinoderms with respect to prawn trawling

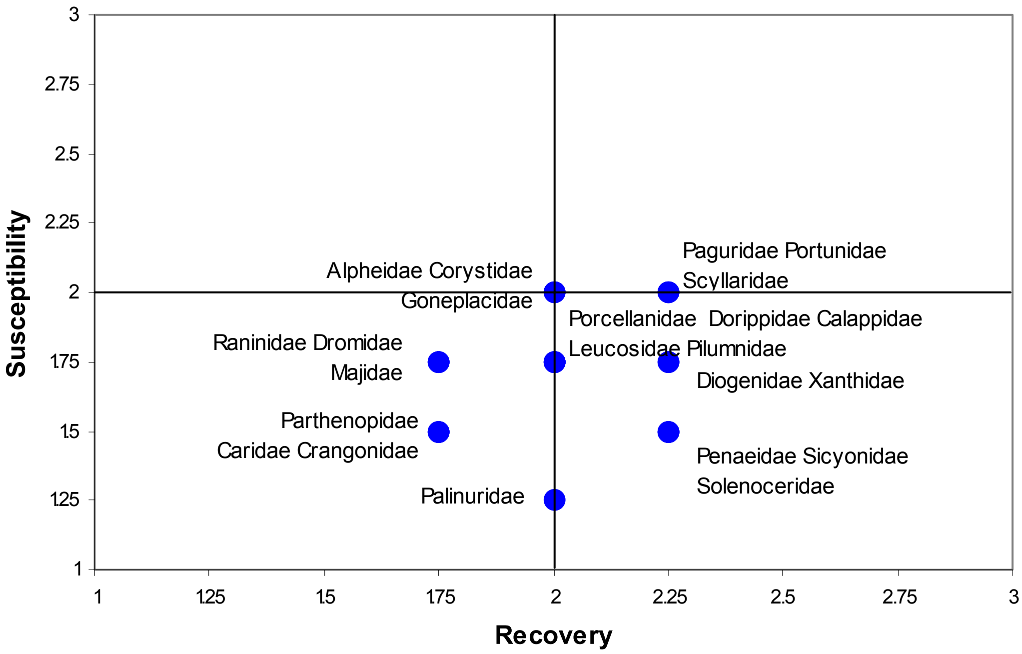

Figure 6.2 Sustainability of crustaceans with respect to prawn trawling

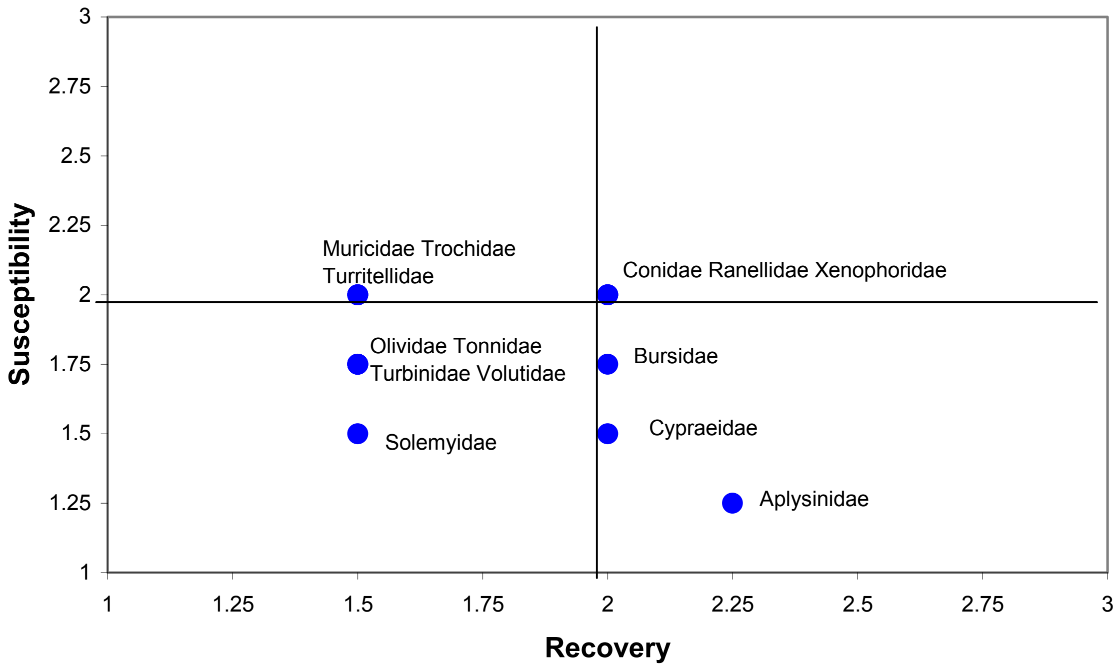

Figure 6.3 Sustainability of gastropods with respect to prawn trawling

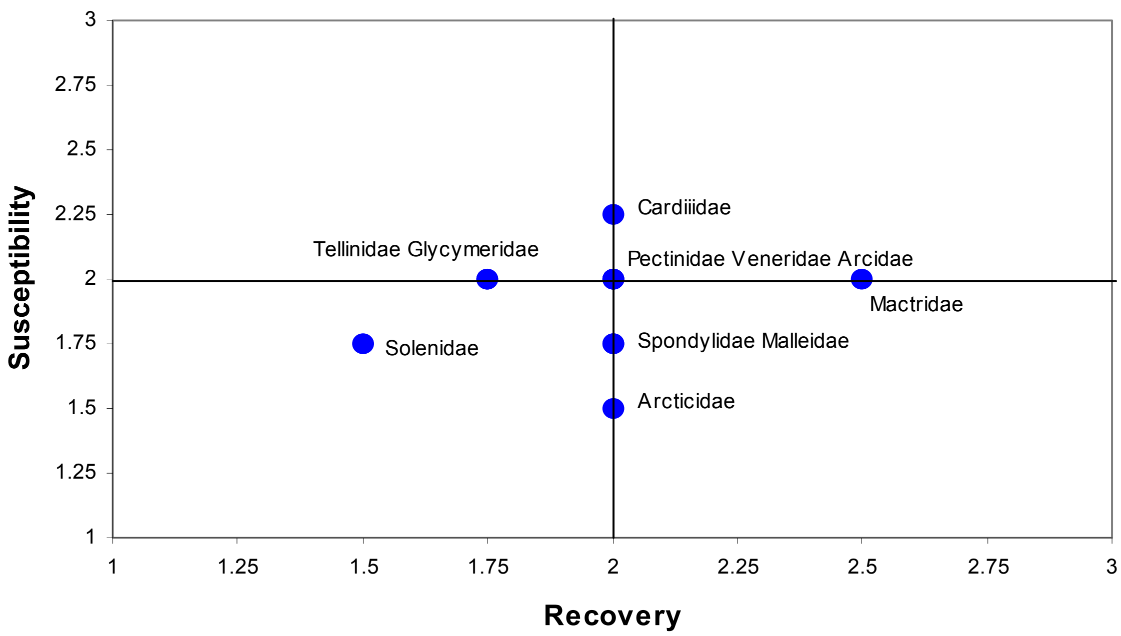

Figure 6.4 Sustainability of bivalves with respect to trawling

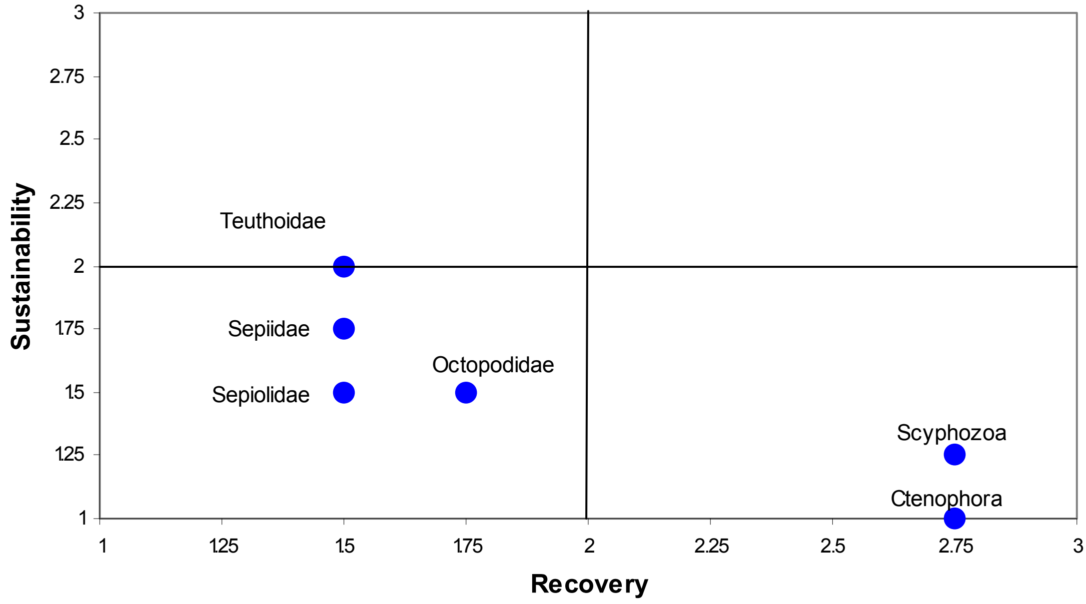

Figure 6.5 Sustainability of swimming or highly mobile invertebrates with respect to prawn trawling

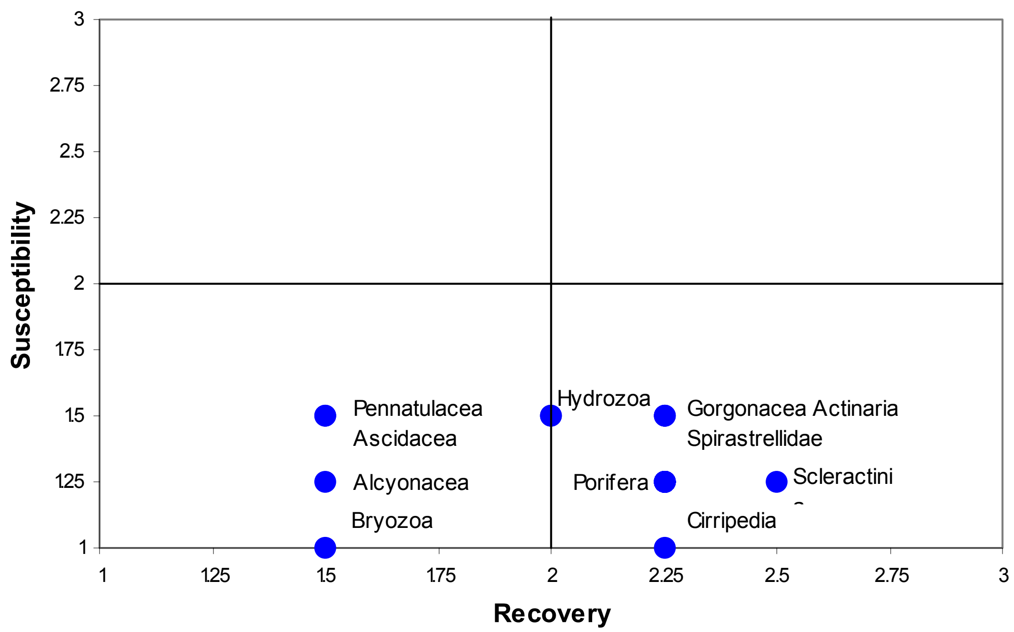

Figure 6.6 Sustainability of attached invertebrates with respect to trawling.

DISTRIBUTION OF THE LEAST SUSTAINABLE SPECIES

Mick Haywood
Burke Hill

We plotted the distribution of the least sustainable species that we had identified to see whether they were evenly spread or whether certain areas had a high concentration. This information could be useful in future decisions on establishment of marine protected areas. The data sets encompass only the Gulf of Carpentaria and so the maps are limited to this region. The least sustainable taxa of invertebrates were based on those that are collected as bycatch in prawn trawls but we used distribution information from dredges and fish trawls to supplement this information. Stobutzki et al. (2000) identified the least sustainable teleosts and elasmobranchs. We did not map the elasmobranchs because the catch numbers were extremely low and do not provide an accurate record of their distribution.

Invertebrates

The 12 least sustainable invertebrate taxa are listed in Table 6.7.

Table 6.7 List of the 12 least sustainable invertebrate taxa

Taxon
Alcyonacea (Cnidaria)
Bryozoa
Echinoidea (Echinodermata)
Octopodidae (Cephalopoda, Mollusca)
Olividae (Mollusca, Gastropoda)
Palinuridae (Crustacea)
Parthenopidae (Brachyura, Crustacea)
Pennatulacea (Cnidaria)
Sepiolidae (Cephalopoda, Mollusca)
Solemyidae (Bivalvia, Mollusca)
Solenidae (Bivalvia, Mollusca)
Teuthoidea (Cephalopoda, Mollusca)

Figure 6.7 shows the distribution of sampling sites and those at which each of the twelve least sustainable invertebrate taxa was recorded (black points) and the sites that were sampled but the taxa were not found in samples (grey dots). There appear to be two different distribution patterns. The Alcyonacea (in the older taxonomy ≡ soft corals), Bryozoa and Parthenopidae and to a lesser extent the Echinoidea, Octopodidae and Pennatulacea have wide distributions and are found at a high proportion of the sites. The remaining taxa by contrast were collected from few sites. The area north of Groote Eylandt stands out as one in which a high proportion of these least sustainable taxa were found.

Teleosts

The 12 least sustainable species of teleosts found in the NPF region according to Stobutzki et al., (2000) are listed in Table 6.8.

Table 6.8 The 12 least sustainable species of teleosts. Data from Stobutzki et al., (2000)

Species
Saurida undosquamis
Antennarius hispidus
Lumiconger Arafura
Siphamia roseigaster
Saurida micropectoralis
Engyprosopon grandisquamum
Grammatobothus polyophthalmus
Branchypleura novaezealandiae
Arius bilineatus
Arius proximus
Arius nella
Paramonacanthus japonicus

The distribution of the least sustainable teleosts shows a similar pattern to that of the invertebrates (Fig 6.8). About half the species are widely distributed but five fall into the rarely caught category. Again the area north of Groote Eylandt has a high incidence of these least sustainable species.

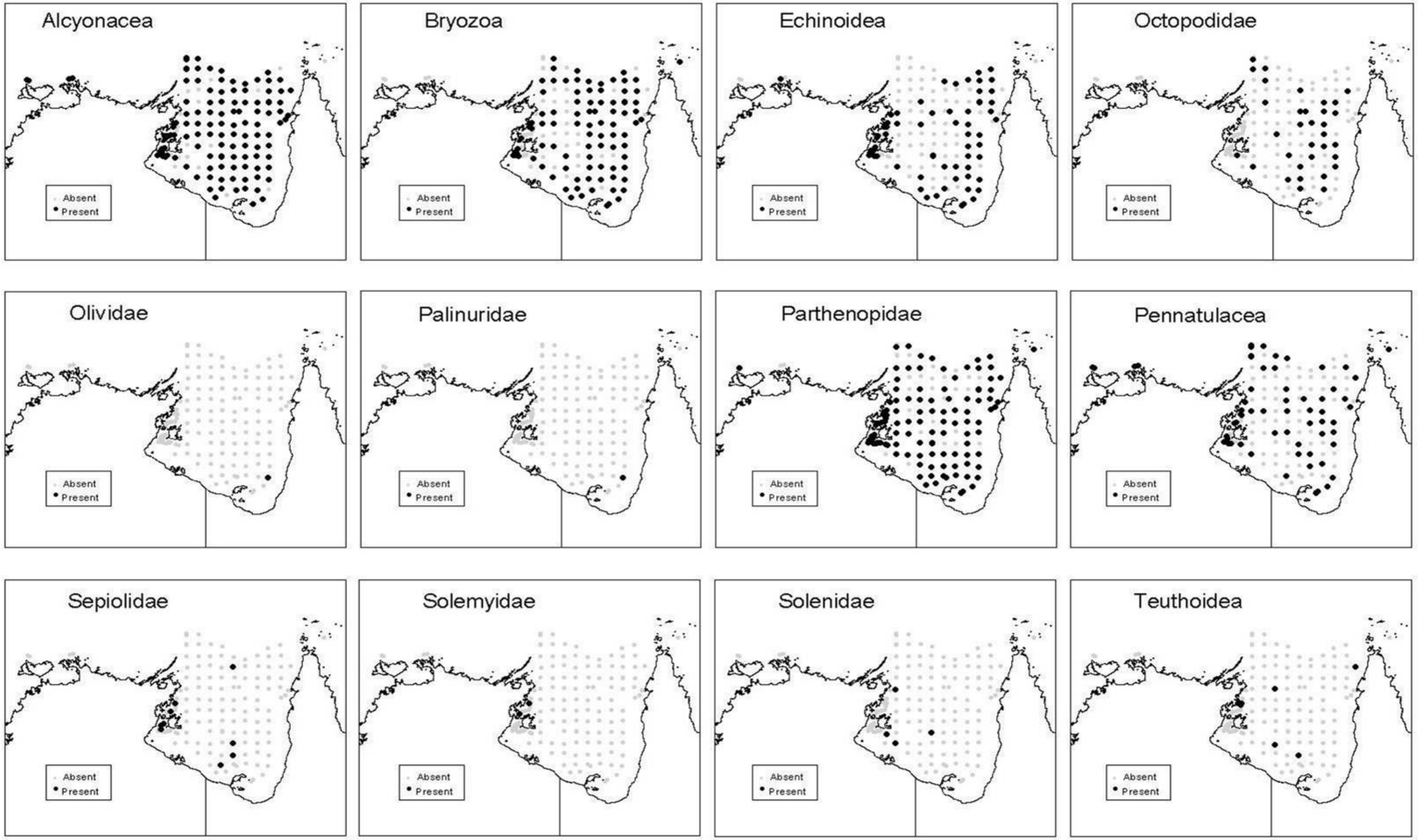

Fig 6.7 Distribution of the 12 least sustainable invertebrate taxa in the NPF.

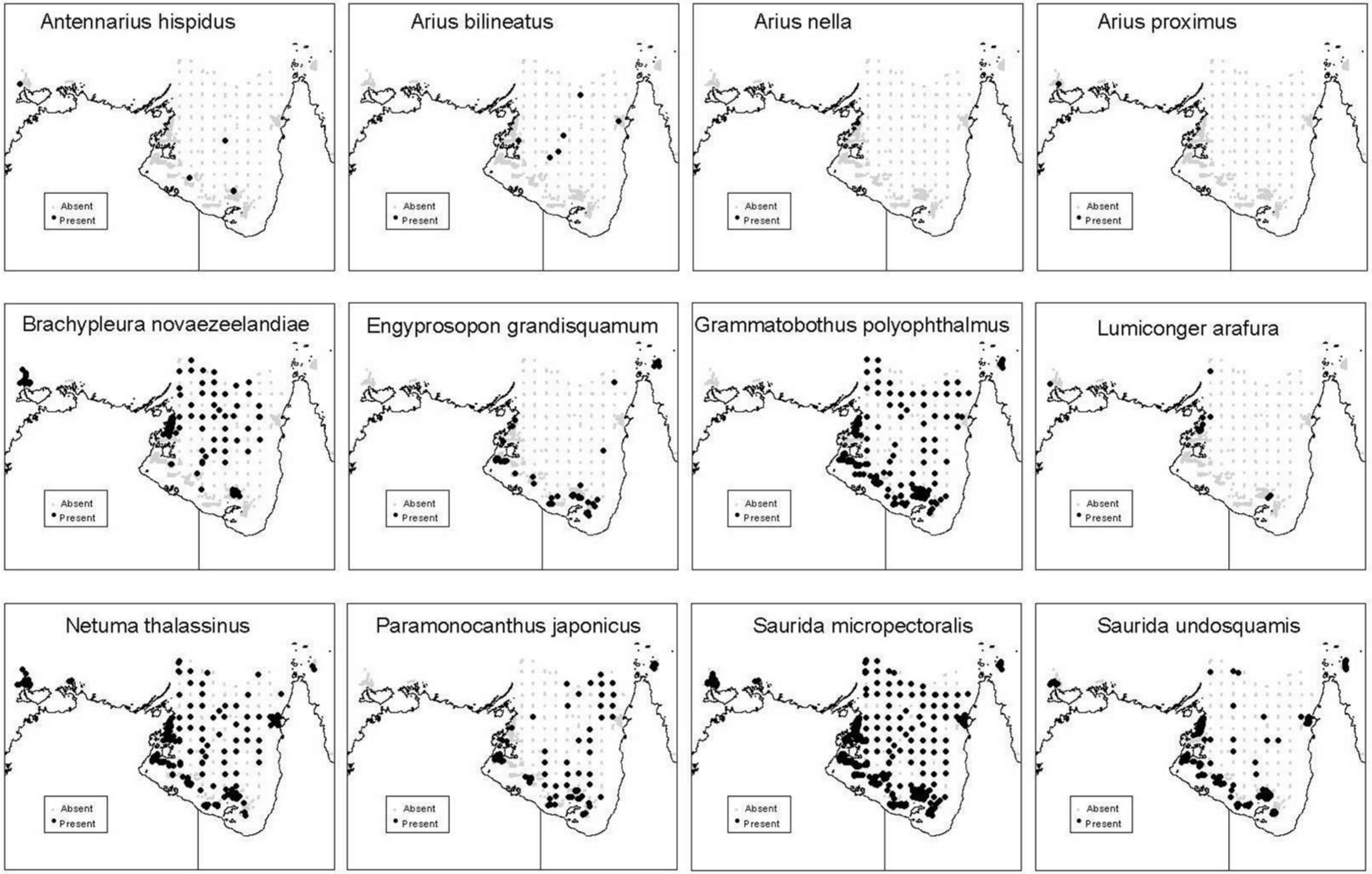

Figure 6.8 Distribution of the 12 least sustainable teleost species in the NPF.

Discussion

All of the invertebrates that we have evaluated have a relatively low susceptibility score indicating they are all vulnerable to trawling. This is not surprising since we are dealing with bycatch of prawn trawls and so the animals must be able to be captured in a trawl. There are however quite large differences in the degree of susceptibility.

The echinoids (Fig 6.1) appear to have low overall sustainability as they have both low susceptibility scores and a low ability to recover. The asteroids and holothuroids appear to be the most sustainable groups as they have a high recovery and a susceptibility score of 2. Crustacea (Fig 6.2) are more tightly grouped. The more delicate families such as crangonids, carids and parthenopid crabs have low sustainability. The most robust groups are the hermit crabs, portunid crabs and the bugs (Scyllarids). The position of the penaeids is of interest. They are scored as being quite vulnerable which is not surprising given that they occur almost exclusively on the trawl grounds, they have a high catchability and the there is a high mortality when captured in a prawn trawl. However they also have a high recovery score which is influenced by their having planktonic larvae as well having juvenile stages that live off the trawl grounds unlike most invertebrates. The Bivalves (Fig 6.3) and Gastropods (Fig 6.4) both show low recovery although many score well on Susceptibility.

Fig 6.5 shows that the cephalopods have low sustainability with respect to trawling. The high recovery scores for scyphozoans and ctenophores reflect the well developed ability of these groups to regenerate as well as their reproductive pattern. It is interesting to note that in some years, trawling cannot be carried out on some grounds in the NPF because of high scyphozoan numbers. The attached invertebrates (Fig 6.6) scored low on Susceptibility but many of them have a high recoverability partially as a consequence of their ability to grow from fragments.

In summary, few invertebrate groups have representatives in the highly sustainable quadrant. Nevertheless, trawlers are still able to catch quite large quantities of invertebrates as bycatch indicating that recovery strategies are effective in these animals. However it is highly likely that populations of many or even most species are below their original levels. This aspect is dealt with in Chapter 8 (Modelling the Impacts of Prawn Trawls on Seabed Fauna).

The question now is to what extent the sustainability analysis reflects the true situation with respect to the status of the seabed fauna. The current status is determined by at least three factors: the original condition, the rate at which it has been fished down, and the rate at which it recovers. There is an additional factor that is very difficult to estimate, this is the movement of mobile seabed fauna between the fished and the unfished areas. The sustainability is probably a reasonable approximation for animals that live only on trawl grounds. If there are also populations off the trawl ground then these are probably a source of repopulation of fished area. As has been shown in Chapter 4 (Fine Scale Distribution of Effort) the fishery is targeted and fished areas are surrounded by unfished ones and so for most species, there is a source of recruits unaffected by trawling. This movement may however be a negative factor for some mobile species with a low sustainability. Stobutzki et al., (2000, 2001) for example identified sawfish as having these properties. Because they move around, the whole population is vulnerable to being trawled and because they have low sustainability they cannot resist heavy fishing pressure. In this case their off-trawl ground distribution does not ensure their survival. This situation is completely different to that of sessile animals such as sponges. The individuals that live off the trawl grounds are totally protected from trawl impacts and they can also provide larval recruits to fished areas. Thus although sponges on trawl grounds may have low sustainability, their distribution and habit ensures that they are unlikely to be threatened by trawling.

The maps of the distribution of the least sustainable taxa suggest that some species or taxa that appear to have a low sustainability to prawn trawling, are in fact very widely distributed in the

Gulf and are probably not seriously threatened by trawling. Secondly, the area north of Groote has an unusually high incidence of these least sustainable species or taxa. There is no other region in the Gulf of Carpentaria that shows this effect, for example none of the least sustainable species were recorded around Weipa or Mornington. This outcome might be a result of the high level of sampling north of Groote, but as can be seen from the maps, the areas south of Groote and around Mornington were also intensively sampled. We suspect then that this is a real condition that we cannot explain at present.

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Appendix A Scores for each criterion in the Susceptibility and Recovry Matrix for all taxa. Criteria are explained in the text. Note that the scores shown for Preferred Habitat and Fishing Intensity were subsequently weighted by 0.5 in the analysis

	Susceptibility					Recovery			
	Avoid	Day night	Survival	Prefer habitat	Fishing intensity	Fragility	Regenerate	Repro pattern	Trawl effect on repro
PORIFERA									
unidentified Porifera	1	1	2	2	3	1	3	1	3
Irciniidae	1	1	2	1	1	2	3	1	3
Phloeodictyidae	1	1	2	1	1	2	3	1	3
Spongiidae	1	1	2	1	1	2	3	1	3
Desmoxyidae	1	1	2	1	1	2	3	1	3
Suberitidae	1	1	2	1	1	2	3	1	3
Coelosphaeridae	1	1	2	1	1	2	3	1	3
Mycalidae	1	1	2	1	1	2	3	1	3
Niphatidae	1	1	2	1	1	2	3	1	3
Raspailiidae	1	1	2	1	2	2	3	1	3
Petrosiidae	1	1	2	1	1	2	3	1	3
Microcionidae	1	1	2	1	1	2	3	1	3
Myxillidae	1	1	2	1	1	2	3	1	3
Aplysinidae	1	1	2	1	1	2	3	1	3
Axinellidae	1	1	2	1	1	2	3	1	3
Callyspongiidae	1	1	2	1	1	2	3	1	3
Dysideidae	1	1	2	1	1	2	3	1	3
Desmacellidae	1	1	2	1	1	2	3	1	3
Spirastrellidae	2	1	2	1	1	2	3	1	3
Halichondriidae	1	1	2	1	1	2	3	1	3
Darwinellidae	1	1	2	1	1	2	3	1	3
Geodiidae	1	1	2	1	1	2	3	1	3
Tetillidae	1	1	2	1	1	2	3	1	3
Phoriospongiidae	1	1	2	1	1	2	3	1	3
Druinelliidae	1	1	2	1	1	2	3	1	3
Ancorinidae	1	1	2	1	1	2	3	1	3
Ianthellidae	1	1	2	1	1	2	3	1	3
CNIDARIA									
Gorgonacea	2	1	2	1	3	2	3	1	3
Alcyonacea	1	1	1	2	3	1	1	1	3
Pennatulacea	2	1	1	2	3	1	1	1	3
Hydrozoa	1	1	2	2	3	1	3	1	3
Alcyonaria	1	1	1	1	1	1	1	1	3
Actiniaria	1	1	3	1	2	2	3	1	3
Scleractinia	1	1	2	1	2	3	3	1	3
Scyphozoa	2	1	1	1	3	2	3	3	3
unidentified Cnidaria	1	1	1	1	1	1	1	3	3
CTENOPHORA	1	1	1	1	1	2	3	3	3
POLYCHAETA	2	1	1	2	3	1	3	1	3
ECHIURA	1	1	2	1	1	2	1	1	1
SIPUNCULA	1	1	2	1	1	2	3	1	1
CRUSTACEA									

	Susceptibility					Recovery			
	Avoid	Day night	Survival	Prefer habitat	Fishing intensity	Fragility	Regenerate	Repro pattern	Trawl effect on repro
Penaeidae	2	1	1	2	3	1	2	3	3
Sicyoniidae	2	1	1	2	1	1	2	3	3
Solenoceridae	2	1	1	2	3	1	2	3	3
Diogenidae	1	1	3	2	3	3	2	3	1
Paguridae	2	1	3	2	3	3	2	3	1
Porcellanidae	2	1	2	2	1	2	2	3	1
Thalassinidae	3	1	1	1	1	1	2	2	1
Upogiibidae	3	1	1	1	1	1	2	2	1
Corystidae	2	1	2	3	3	2	2	3	1
Dorippidae	2	1	2	2	3	2	2	3	1
Dromiidae	2	1	2	2	2	2	2	2	1
Calappidae	2	1	2	2	3	2	2	3	1
Leucosiidae	2	1	2	2	3	2	2	3	1
Majidae	2	1	2	2	3	1	2	3	1
Parthenopidae	2	1	2	1	3	1	2	3	1
Portunidae	2	1	3	2	3	3	2	3	1
Raninidae	3	1	2	1	1	1	2	3	1
Xanthidae	2	1	2	2	3	3	2	3	1
Gonoplacidae	2	1	2	3	3	2	2	3	1
Pilumnidae	2	1	2	2	2	2	2	3	1
Alpheidae	3	1	2	2	3	2	2	3	1
Crangonidae	2	1	1	2	1	1	2	3	1
Caridea	2	1	1	2	3	1	2	3	1
Palinuridae	2	1	1	1	1	2	2	3	1
Scyllaridae	2	1	3	2	3	3	2	3	1
Stenopodidae	2	1	1	1	1	1	2	1	1
Eurysquillidae	2	1	2	1	1	2	2	1	1
Odontodactylidae	2	1	2	1	1	2	2	1	1
Harpiosquillidae	2	1	2	1	1	2	2	1	1
Squillidae	2	1	2	1	1	2	2	1	1
Cirripedia	1	1	1	1	1	3	2	3	1
MOLLUSCA									
Bivalves									
Amussiidae	2	1	3	2	3	3	1	1	3
Arcidae	2	1	3	2	1	3	1	1	3
Arcticidae	1	1	3	1	1	3	1	1	3
Bivalvia	1	1	3	1	3	1	1	1	3
Cardiidae	3	1	3	2	2	3	1	1	3
Glycymerididae	2	1	3	2	1	2	1	1	3
Mactridae	3	1	3	1	1	3	1	3	3
Malleidae	1	1	3	2	2	3	1	1	3
Pectinidae	2	1	3	2	3	3	1	1	3
Solemyidae	3	1	1	1	1	1	1	1	3
Solenidae	3	1	2	1	1	1	1	1	3
Spondylidae	1	1	3	2	2	3	1	1	3
Tellinidae	2	1	3	2	1	2	1	1	3
Veneridae	2	1	3	2	3	3	1	1	3

	Susceptibility					Recovery			
	Avoid	Day night	Survival	Prefer habitat	Fishing intensity	Fragility	Regenerate	Repro pattern	Trawl effect on repro
Gastropods									
Bursidae	1	1	3	2	3	3	1	3	1
Conidae	2	1	3	2	1	3	1	3	1
Cypraeidae	1	1	3	1	1	3	1	3	1
Gastropoda	1	1	3	2	3	1	1	1	1
Muricidae	2	1	3	2	3	3	1	1	1
Nudibranchia	2	1	1	2	3	1	1	1	1
Olividae	2	1	3	1	1	3	1	1	1
Opisthobranchia	2	1	1	1	2	1	1	1	1
Ranellidae	3	1	3	1	2	3	1	3	1
Tonnidae	2	1	3	1	1	1	1	1	3
Trochidae	2	1	3	2	2	3	1	1	1
Turbinidae	2	1	3	1	1	3	1	1	1
Turritellidae	2	1	3	2	1	3	1	1	1
Volutidae	2	1	3	1	1	3	1	1	1
Xenophoridae	2	1	3	2	2	3	1	3	1
Cephalopods									
Octopoda	3	1	1	1	1	2	1	3	1
Sepiidae	3	1	1	2	3	1	1	3	1
Sepiolidae	3	1	1	1	3	1	1	3	1
Teuthoidea	3	3	1	1	3	1	1	3	1
ECTOPROCTA									
Bryozoa ??	1	1	1	2	3	1	3	1	1
ECHINODERMATA								3	
Loveniidae	3	1	1	1	1	1	1	1	3
Spatangoida	3	1	1	2	1	1	1	1	3
Holothuroidea	2	1	3	2	3	2	2	1	3
Echinoidea	1	1	1	2	3	1	1	1	3
Asteroidea	2	1	3	2	3	3	3	1	3
Gorgonocephalidae	1	1	2	2	2	2	3	1	3
Crinoidea	1	1	1	2	3	1	3	1	3
Clypeasteroida	3	1	1	1	1	1	1	1	3
Ophiuroidea	2	1	1	2	3	1	3	1	3
CHORDATA									
Ascidiacea	1	1	2	2	3	2	1	1	2

CHAPTER 7

THREATS TO THE SEABED FAUNA

OF

THE NPF MANAGED AREA

Chapter Authors:

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CHAPTER 7

THREATS TO THE SEABED FAUNA OF THE NPF MANAGED AREA

Burke Hill
Mick Haywood

Summary

In the first section of this chapter we describe a range of possible threats to the seabed fauna of the NPF namely:

- Fishing (Prawn trawling, line fishing, net fishing, fish trawling, recreational fishing and traditional fishing
- Mining (Mining of bauxite, lead and zinc, manganese, gas, oil, seismic exploration, port facilities for export, siltation from mining)
- Shipping (Introduction of marine pests, antifouling paint, oil pollution, chemical pollution, shipping accidents)
- Agriculture (Land clearing, water diversion, acid sulphate soils, pesticide and herbicide runoff)
- Aquaculture (Introduction of diseases, pollution and habitat destruction)
- Global warming - increasing sea temperature, rise in sea level, changes in rainfall and increased frequency of cyclones

In the second section, we have carried out an evaluation of the threats using a Risk Assessment method developed as part of the National ESD Reporting Framework for Australian Fisheries.

- Two threats were scored as having a risk greater than 19 and are classified as Extreme Risk – these are the introduction of a serious marine pest, and changes in rainfall (Table 7.8).
- Five threats were scored as High risk (scores 13-18.9). These included three climate change effects (rise in sea level, rise in sea temperature and increased frequency of cyclones), changes in water flows in estuaries and the direct impacts on the benthos from prawn trawling
- We recommend that a further scoring be carried out by a broader group of stakeholders when the modified version of the ESD Reporting Framework is available.

Introduction

Because seabed faunas are largely out of sight, changes resulting from human activities can easily go undetected unless they happen in highly visible areas and they are sufficiently dramatic. This is especially true of remote regions such as the NPF. Despite its remoteness, the NPF is the focus of several activities that could conceivably impact on the seabed fauna and the processes that sustain it. While we can identify many of these threats, it is not feasible at this time to quantify them. The ESD Reporting Framework for Australian Fisheries presents a model in which the initial step is to make a qualitative assessment of various processes that may affect a fishery. Processes identified as posing a serious risk should then be pursued in greater detail in an attempt to quantify the risk and to examine ways of ameliorating it. We have adopted this approach in this Chapter. We describe activities that might threaten the seabed fauna of the NPF and have attempted to provide sufficient information for the reader to undertake the assessment of the risk associated with each threat. This assessment makes up the second section of the Chapter.

The area of the Northern Prawn Fishery encompasses the seas over most of the northern part of the Australian EEZ – an area of about 800,000km^2. It extends from the northern tip of Cape York in Queensland to Cape Londonderry in Western Australia (Fig 7.1).

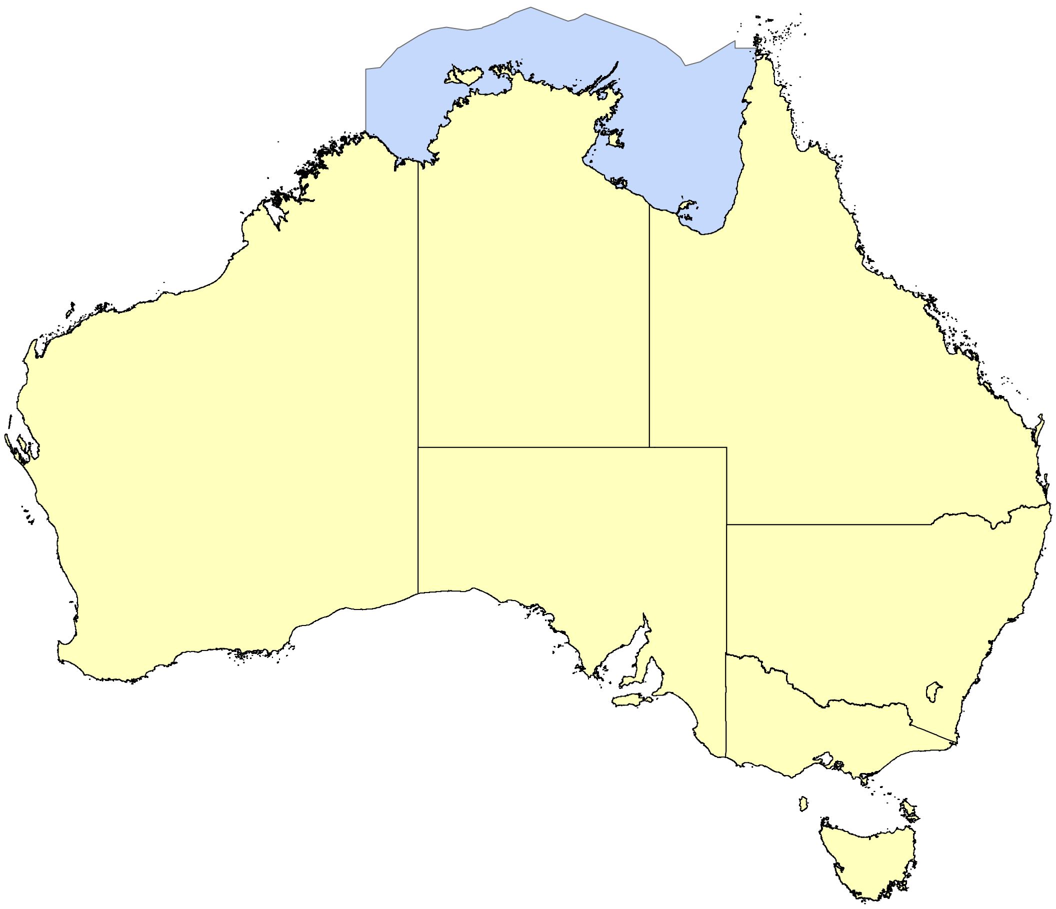

Figure 7.1. Map showing the extent of the Managed Area (pale blue) of the Northern Prawn Fishery

Much of the region is remote and difficult to access; there is only one major city, Darwin. It might be assumed therefore that the benthic fauna should be safe from environmental impacts. There are however several activities that might pose threats to the marine environment and the benthic fauna. One of these is the prawn trawl fishery because it impacts directly on the seabed faunas. Other possible sources of threats include mining, agriculture and shipping. There is a substantial amount of mining in northern Australia and especially around the Gulf of Carpentaria. Although the mines are on land, they use the sea for exporting their products and importing fuel oil and chemicals. Projects for exploitation of gas are being developed in the Timor Sea and these may also impact on the NPF region. Shipping associated with mining, fishing and general trade poses threats through associated dredging and port development as well as from the introduction of marine pests and discharge of waste or oil. The most widespread activity on land in the north is agriculture and this has the potential to modify freshwater inflows to the sea. Two mechanisms for this are changes in water flow and chemical runoff. Because of the highly seasonal rainfall pattern, agriculture in northern Australia blocked creeks and rivers to form ponded pastures for feeding cattle and constructed dams to provide water for irrigation. This restricts spawning movements for some animals such as barramundi. Agricultural crops in the tropics are especially vulnerable to insect pests and so large amounts of insecticides are commonly used; these together with fertilizers can pollute runoff from agricultural land. In addition to prawn trawling, other forms of fishing such as commercial line and net fishing as well as a growing recreational fishery need to be evaluated as possible threats.

Thus despite its remoteness and apparently near pristine condition, this vast region potentially faces many of the environmental problems associated with the more settled parts of Australia. In this chapter we have identified possible sources of threats and the measures that are being taken to minimise them. Finally we have assessed the risk of each threat using a matrix approach in which one axis is the Consequence of the threat and the second is the Likelihood of the threat occurring.

SECTION 1 – DESCRIPTION OF POSSIBLE THREATS

Fishing

Prawn trawling

Trawling is widely regarded as having a larger impact than other industrial forms of fishing because of the large area that is impacted, the possibility of modifications to the seabed habitat and because of the killing of non-target species. Recent developments of accurate navigational aids have enabled trawlers to operate in previously inaccessible areas such as close to reefs, this has extended the area of impact. It has proved difficult to quantify these effects. Experiments in which previously untrawled grounds are experimentally trawled and then compared to untrawled controls are generally regarded as the best approach but are often not achievable because of the absence of suitable untrawled areas. In addition these experiments have to be replicated and so are expensive. No such study has been carried out in the NPF. A major study was done in the northern Great Barrier Reef (GBR)[(102)] but differences in fauna and seabed structure make comparisons tenuous. Generally however it appears that infauna is not highly vulnerable to trawling [(e.g. 73)] whereas attached animals living on the seabed are at considerable risk of being damaged or destroyed. These attached animals feed in the water column and are responsible for filtering vast amounts of water. Large-scale removal of suspension feeders has been suggested to be the main reason for population explosions of microbes responsible for increasing eutrophication, diseases of marine species and toxic blooms (Jackson et al., 2001 [(56)]). Bacteria now dominate some major regions such as the Baltic and the Adriatic. While the NPF is clearly in far better condition than these bodies of water, it is likely that large-scale removal of sponges from trawl grounds occurred in the past and this may have changed the environment.

Trawling for prawns started in the NPF region in the early 1960s. At that time the fishery was targeted at a single species – banana prawns (*Penaeus (Fenneropenaeus) merguiensis*). In the 1980s the fishery expanded to include brown (*P. esculentus*) and grooved (*P. semisulcatus*) tiger prawns. The fishery for banana prawns concentrated on searching for schools, when a school was found it was fished with short duration trawls. Tiger prawns are more dispersed and the fishing method uses long duration trawls – around three hours – in areas of high yield and so this fishery is regarded as potentially having a greater impact on the seabed fauna than the banana prawn fishery. Although most of the prawn catch is taken in the Gulf of Carpentaria, the fishery has spread across the whole of northern Australia with significant catches coming from Mellville-Essington and Joseph Bonaparte Gulf (Fig 7.2). Originally around 250 trawlers operated in the fishery but management measures to reduce effort resulted by 2002 in a reduction to around 100 modern steel hulled vessels (Fig 7.3). Restrictions to protect the stocks have reduced fishing time considerably in recent years. In 2002 only 133 days were available (1 April to 13 May and September to 1 December). The amount of trawl gear that can be towed is controlled and in addition, all seagrass areas are closed to trawling to protect prawn nursery grounds. Extensive areas are also closed to reduce the catch of small tiger prawns in order to enhance the value of the catch.

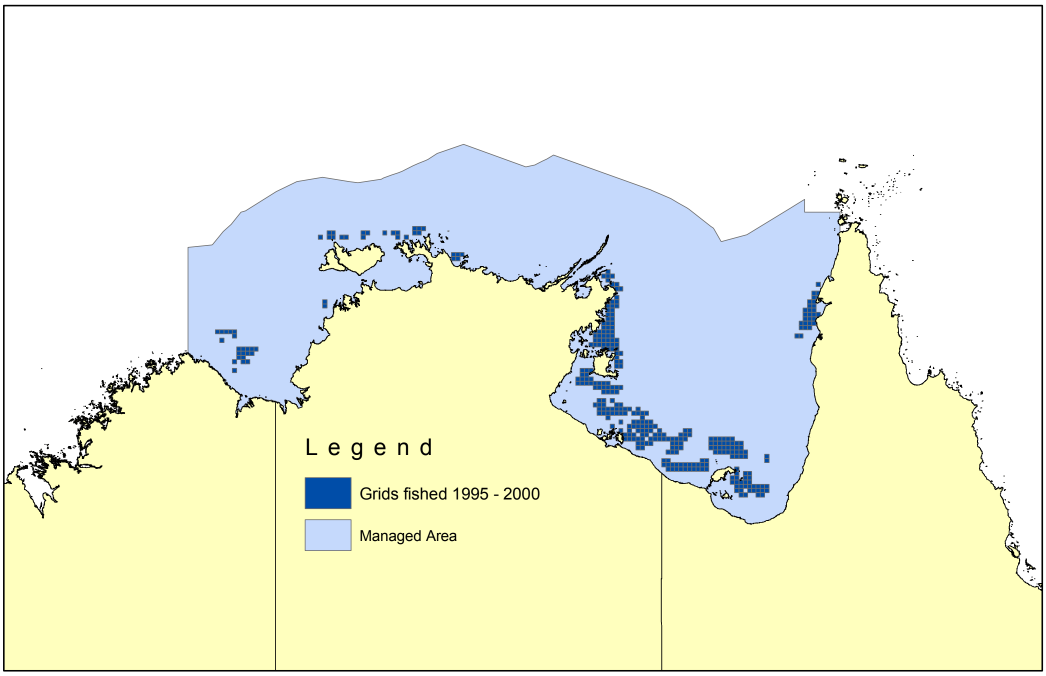

Figure 7.2: Extent of trawl grounds (shaded squares) within the NPF area. For confidentiality reasons the number of grid cells displayed has been restricted to those with at least 10 days of effort or to those that were fished by at least 5 boats between 1996 and 2000 inclusive.

Figure 7.3. A typical Northern Prawn Fishery trawler

Prawns are not spread evenly over the trawl grounds and skippers search for the areas with the highest yield (Fig 7.4).

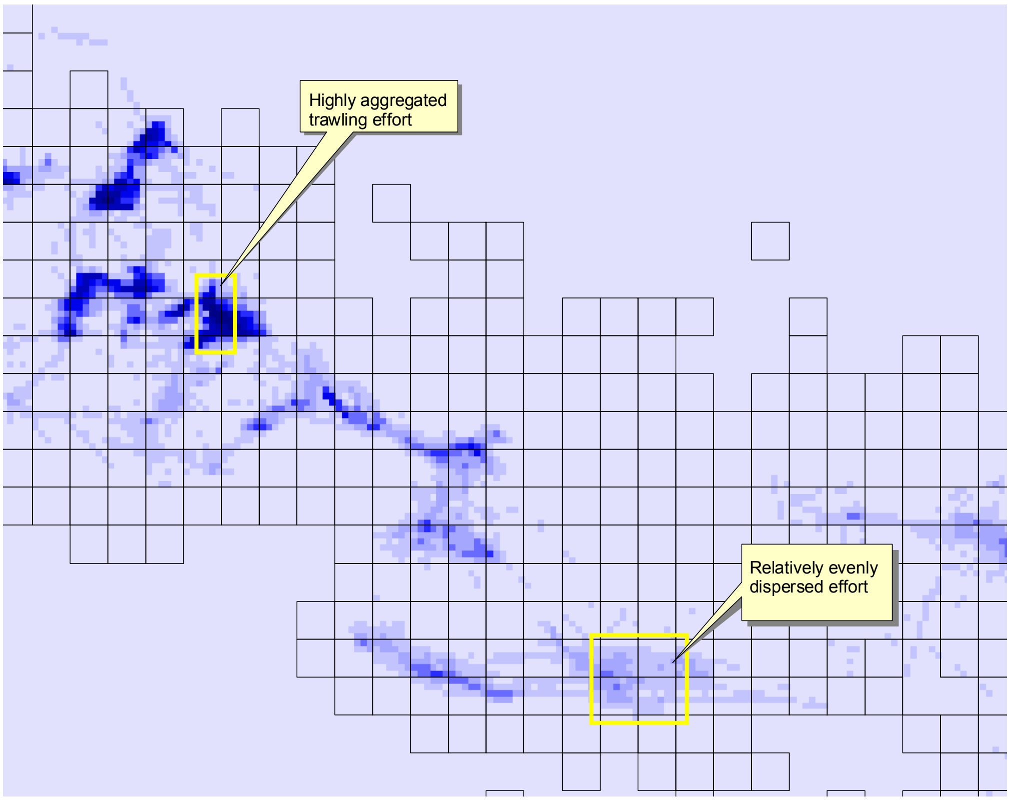

Figure 7.4. VMS-generated fine-scale map (1 nm resolution) of trawling effort for a section of the trawl grounds showing areas of highly aggregated and relatively dispersed trawling effort. Relative effort is shown by shading – dark squares show areas of high effort; light squares show areas of low effort. The coarse grid is the 6 nm resolution used in logbook records. Figure modified from Chapter 4 which also has the key to effort.

Substantial parts of the NPF seabed have areas of low reef that prevent trawling. In some areas, trawling takes place close up to the reefs whereas in others it is more dispersed (Fig 7.5). The result is that some areas of the seabed are trawled very intensively while others are not trawled at all.

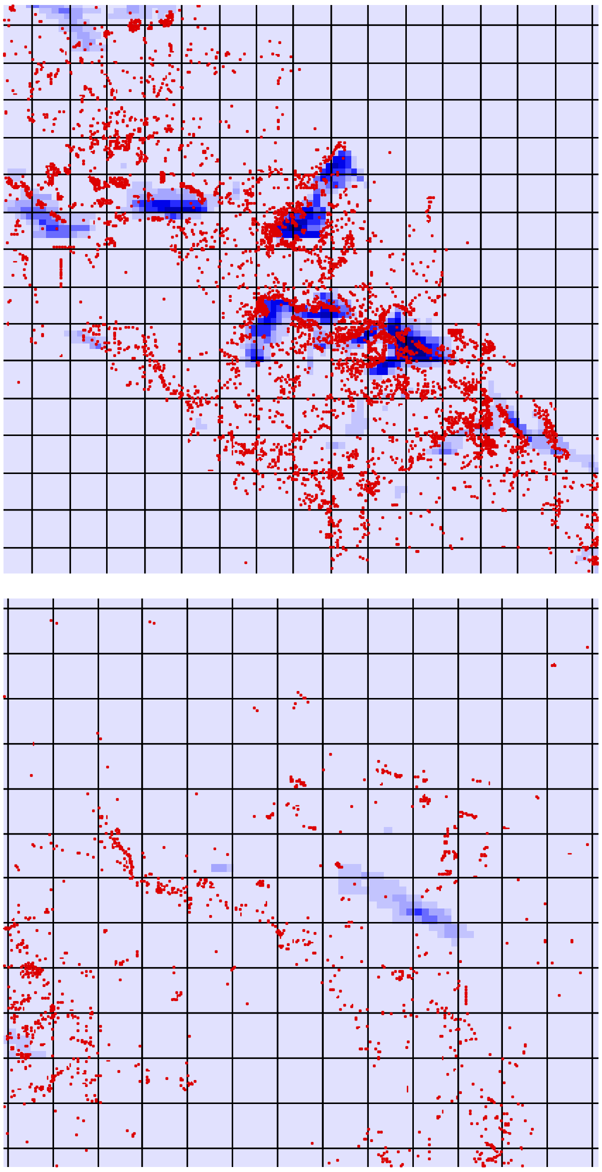

Figure 7.5. Untrawlable grounds (shown in red) from two different areas in the NPF overlaid with the VMS-generated fine-scale maps of trawling effort for the trawl grounds (blue). Original figure from Chapter 4.

In the NPF, trawling for tiger prawns is seen as potentially having a greater impact on the seabed fauna than trawling for banana prawns for two reasons. Firstly the banana prawn fishery is now of very short duration – a few weeks each year, whereas tiger prawn fishing continues through the whole season. Secondly the nets used for tiger prawns are on the bottom for around 10 to 12 hours each night whereas those used for banana prawns are mainly deployed on schools and are usually in the water for less than an hour for each shot. Most of the time in the banana prawn fishery is spent searching for these schools. The tiger prawn trawl nets catch a large amount of bycatch – considerably more than the prawns. A recent study of the NPF tiger prawn fishery has shown that prawns make up only around 10% of the catch of commercial trawls [41]. Teleosts made up 63%, elasmobranchs 4% and invertebrates around 20%. With around 3 000 tonnes of tiger prawns being caught annually, this means that about 6 000 tonnes of benthic invertebrates are caught and retained in the trawls. Some of the more robust species in the bycatch such as many molluscs can survive being trawled but nearly all the teleosts, an unknown proportion of elasmobranchs and large numbers of invertebrates are killed [42, 43, 44]. Studies in the GBR have shown that a large number of invertebrates are disturbed by trawling but are not captured in the trawls ([102]).

Sustainability

In Chapter 6 of this report, we have analysed the sustainability of invertebrates with respect to the trawl fishery taking into account their vulnerability to being trawled and their ability to recover from trawling. The analysis shows considerable variation between groups. The least sustainable include representatives from most phyla. Echinoids for example have low sustainability whereas asteroids have high sustainability. Amongst the crustaceans, delicate animals such as crangonids and carids have low sustainability in contrast to robust taxa such as hermit crabs, portunid crabs and bugs. Amongst the molluscs, most bivalves and some gastropods have high sustainability whereas cephalopods have low sustainability. Attached invertebrates were shown to be vulnerable to trawls but many of them have a well developed ability to recover from trawl damage. A spatial analysis of the distribution of the least sustainable invertebrates, and teleosts showed that the area north of Groote Eylandt had the highest concentration although they could be found over the whole Gulf of Carpentaria, (Chapter 6).

Our analysis of trawl impacts (Chapter 8) showed that under current levels of trawling, many benthic groups will continue to decline in trawl areas. If effort is reduced, a gradual recovery can be expected to occur. Fig 7.6, which is reproduced from Chapter 8, shows the modelled biomass of echinoids in the Groote Eylandt region. Echinoids were identified as a taxon with low sustainability. In 2002, NPF fishing effort was reduced by around 25% through a combination of a reduction in the amount of trawl gear that can be towed and additional time closures. Fig 7.6 indicates that this effort reduction is likely to result in a gradual increase in biomass of echinoids with a new steady state being reached in around 20 years. This steady state will be considerably above the level that would have resulted if present effort had continued. As explained in Chapter 8, animals with a higher sustainability are also expected to benefit from the reduction in trawl effort.

Discarding of nets and other rubbish

Prawn trawlers may impact on marine animals in ways other than direct impacts on seabed fauna. These include the dumping of rubbish and used oil at sea as well as the discarding of damaged sections of trawl nets. There has been a substantial improvement in managing these activities and trawlers now store used oil and non-biodegradable rubbish on board for discharge in port.

A major cleanup of nets on Groote Eylandt funded by NPF industry in 1997/98 revealed large quantities of net debris on the beaches [68]. A total of 812 fragments of netting, weighing nearly 56 tonnes was collected from 137 km of beach. The level of net pollution is very high (1313 kg km^{-1}) compared to less than 50 kg km^{-1} reported in surveys from other parts of Australia. Netting from the NPF prawn trawl fishery accounted for only 7% of the debris by weight. Most netting came from foreign fish trawlers (59% by weight) and gill netters (25% by weight) probably operating in the Arafura and Timor seas. In addition to causing resentment from locals whose beaches are despoiled by netting, nets can also ghost fish. Sea turtles, scale fish, sharks and seabirds were recorded as trapped in debris although the numbers were not large. It is however difficult to assess the extent of ghost fishing since modern net materials may last for many years or even decades whereas animals trapped in the nets may soon be scavenged and their remains disappear.

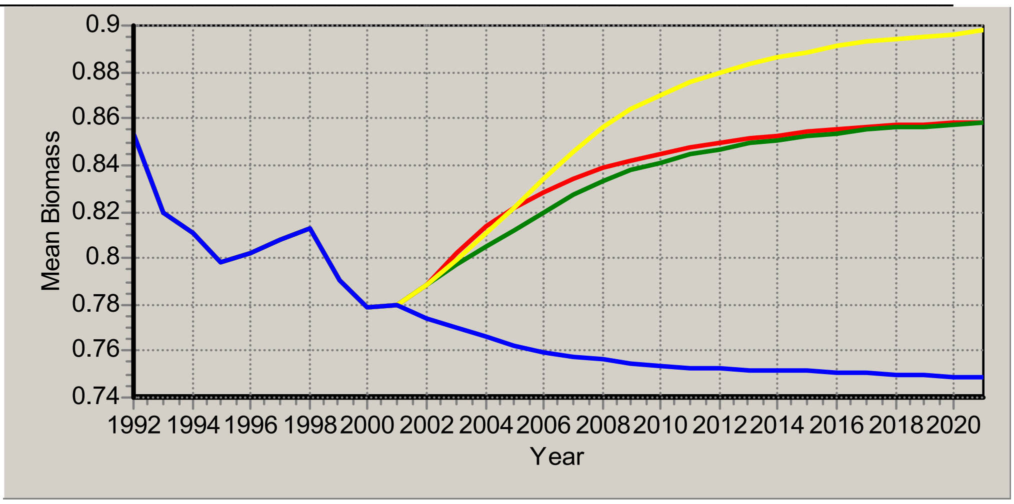

Figure 7.6. Estimated biomass of echinoids in the Groote Eylandt region under four different levels of trawl effort. Blue is no change in effort; red is 25% reduction of effort from 2002 (this is the actual situation); green is a 25% reduction phased in over five years (2002-2006) and yellow is a 50% reduction over five years. Original from Chapter 8.

Area trawled in the NPF

We calculated the proportion of the NPF that is fished by summing the number of 6-minute grids fished during the years 1996 - 2000. In this period, 1,563 grids were reported as being fished - an area of 188,960 km^2. If accept the figure as approximately correct and knowing that the area of the whole NPF is about 800,000 km^2, we estimate that the fishery trawls at most 24% of the NPF. This percentage figure is not accurate since trawlers do not trawl the whole of a grid. This was clearly shown in Chapter 4 – see Figs 4.5, 4.6 and 4.7. In addition, the figure is not constant and the number of grids that were fished has varied over time (Fig 7.7).

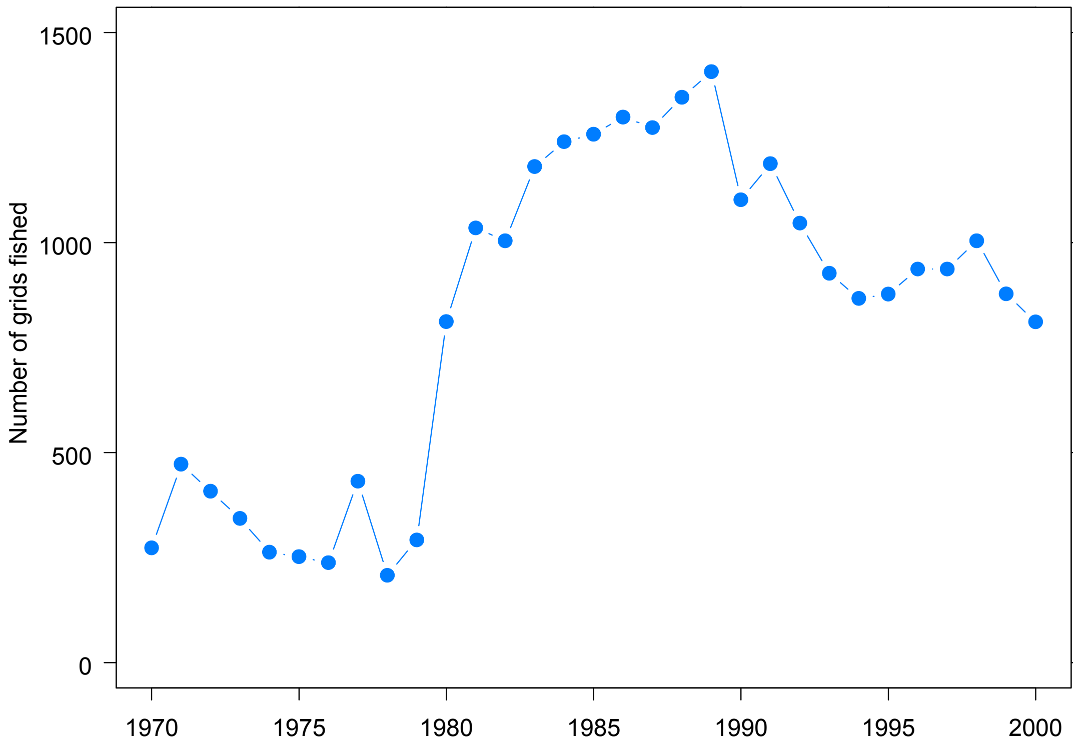

Figure 7.7 The number of 6 nm grids fished for prawns in the NPF over time.

It is generally accepted that there was a high degree of under reporting during the 1970's and early 1980's, consequently the figures for this period in Fig 7.7are probably underestimated. The recent decrease in the area fished is the result of reductions in the number of trawlers allowed to operate in the NPF – from 250 in the 1980s to around 100 by 2002 and the increasing restriction in the amount of fishing time. The result is that NPF trawlers presently fish a much smaller area than they did prior to 1990. In assessing the impacts of prawn trawling we therefore need to balance the direct impact of trawls on the seabed with the continually reducing proportion of the NPF that is trawled.

In Chapter 5, we showed that in the Gulf of Carpentaria, the benthic invertebrate fauna sampled by dredge on the trawl grounds was different to that off the trawl grounds (Fig 7.8). Thus although only a fraction of the total NPF is trawled, the fishery may be trawling a special subset of the total seabed fauna and in this way might be having a greater impact than if we simply estimated the trawl area as a percentage of the total NPF.

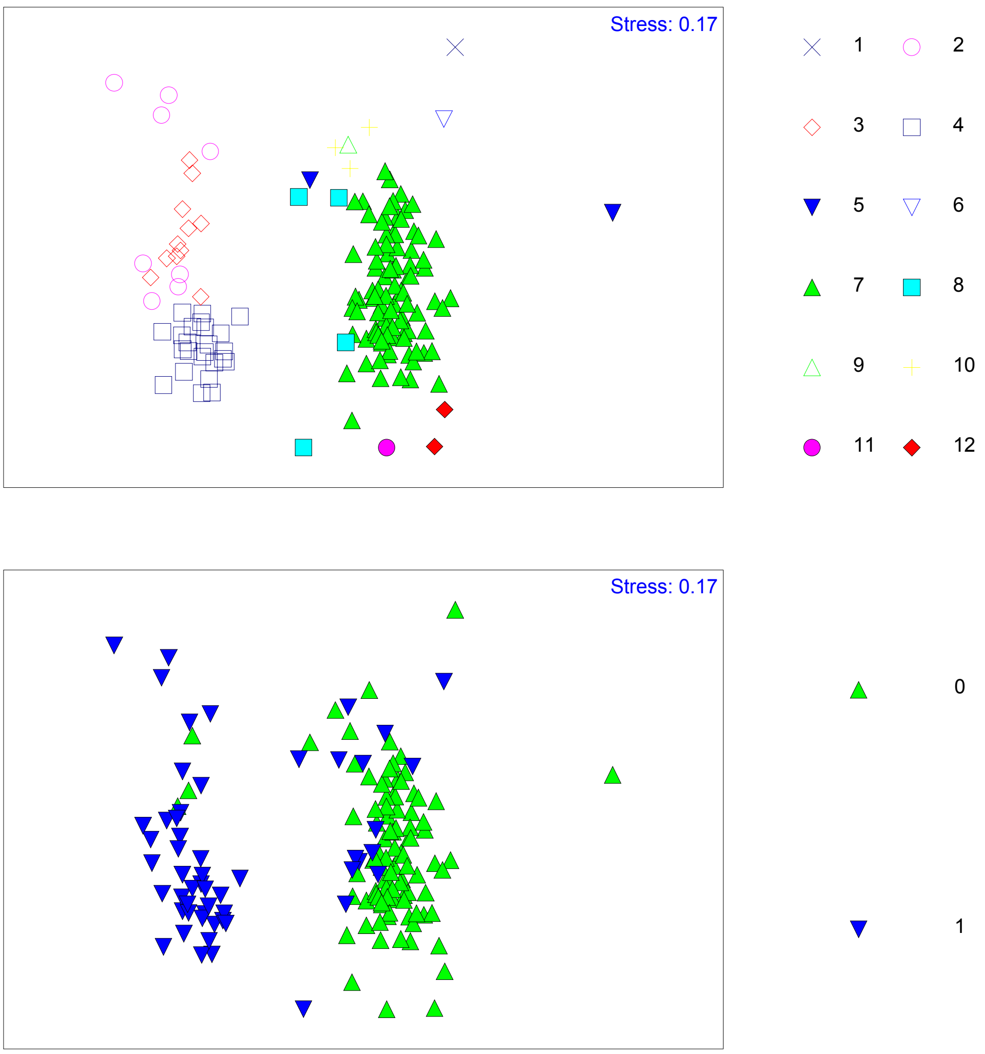

Figure 7.8 Multi-Dimensional Scaling ordination of Bray-Curtis similarities of benthic invertebrate taxa collected with a benthic dredge on three cruises (SS9003, SS9702, SS9708 and SS9803) in the NPF. The coloured symbols represent the group membership of individual stations as determined at a similarity level of 15% in (a) the cluster analysis and (b) whether or not the station was located inside (blue triangles) or outside (green triangles) the prawn trawling grounds (Figure from Chapter 5, explanation of the groups is also given in Chapter 5)

Line and net fishing

There are significant line and net fisheries in inshore waters of the NPF in Queensland and the Northern Territory (NT). Catch data for the major commercial species are given in Tables 7.2 and 7.3. Landings of some species have changed in recent years, for example landings of grey mackerel in Queensland have increased substantially. The reasons for changes in landings of this and other species are complex relating not only to stock size but also to rainfall patterns and changes in effort. Not all of the fished species are likely to affect the seabed fauna of the NPF. Some such as barramundi and the threadfins are found in estuaries or close inshore while grey mackerel are pelagic feeders. A possible impact could come from the offshore shark fishery in Queensland waters. Sharks were formerly taken as part of the inshore gill net barramundi fishery but in recent years an offshore (7 to 25 nm from the coast) gill net fishery specialising in shark and grey mackerel has developed. This fishery also catches benthic feeders such as stingrays. The latter were shown by Stobutzki et al. (2000) as being the least sustainable elasmobranchs with respect to prawn trawling because of their low ability to recover from fishing pressure and factors such as high mortality when captured.

A restocking project initiated by commercial fishermen in the southern Gulf of Carpentaria has developed into a community-based activity. The Gulf Barramundi Restocking Association (GBRA) has been breeding and releasing about 100,000 barramundi fingerlings each year into southern Gulf of Carpentaria rivers since 1993. The program is being extended to include grunter fingerlings. No assessment has been made at this stage of the effectiveness of the restocking but if there is good survival of fingerlings, the project could go some way to offsetting fishing mortalities. The program is of course directed at target species and so does not benefit bycatch species or any elasmobranchs.

Table 7.2 Commercial catch records (tonnes) for the period 1995 to 2000 for the major commercial finfish species taken in Queensland waters of the Gulf of Carpentaria (84)

	1995	1996	1997	1998	1999	2000
Barramundi	419	506	423	544	689	597
Grey mackerel	155	294	467	437	377	526
Shark	298	213	204	219	243	247
Threadfin - king	169	194	169	230	289	226
Threadfin - blue	58	67	41	53	92	36
Grunter	20	22	16	13	26	17

Table 7.3. Catch Figures (tonnes) for the Northern Territory by Fishery per year (55)

Fishery	1995	1996	1997	1998
Barramundi	759	761	834	970
Shark	916	1028	775	682
Timor Reef	155	317	311	482
Spanish Mackerel	192	236	232	216
Coastal & Bait Net	37	63	33	29
Coastal Line	116	115	82	63
Others	118	88	99	293

Catches in the Northern Shark Fishery have been very low since foreign fishing ceased in 1986. Traditional Indonesian fishers are permitted to fish in a strictly limited area. No estimate of the catch taken by these vessels is available, but it may be considerable. Marketing problems have hindered expansion of the domestic fishery. However, a growing demand for fins is changing the characteristics of the fishery. The principal species are the black tip shark (*Carcharhinus tilstoni*) and the spot-tail (*C. sorrah*) shark. Increasing demand for shark products especially fins in the 1990s led to significant price rises and the Australian fishery grew to meet demand. There is no accurate stock assessment available for these northern shark populations but there is concern about the level of effort. Retention of sharks or parts of sharks by NPF trawlers was banned in 2000 following an industry initiative.

Queensland and NT commercial line and net fisheries in NPF waters target fish such as barramundi and salmon inshore and sharks offshore. In addition, bycatch from Queensland offshore nets includes rays and sawfish as well as the target of sharks. There are also unofficial reports of catches of turtles and dolphins in the offshore nets. We cannot quantify any impact on seabed animals of the removal of these large animals but it is important to bear in mind that many or most fisheries based on elasmobranchs worldwide have collapsed. Elasmobranchs such as large rays, mantas and sawfish do not have the biological characteristics that enable them to withstand high rates of mortality. They are generally slow growing and have few young. The scientific literature is beginning to document the negative ecological consequences of removal of large consumer species including elasmobranchs [(56)]. These consequences include negative and unforseen impacts on benthic organisms.

Fish trawling

Only around 5 to 10% of the large demersal fish resource in the Arafura Sea is considered commercially important to Australian fishers [(40)]. Foreign fishing vessels were phased out in 1990 and domestic trawl licences issued. However by 1997 only one trawler remained. This is not considered to be a threat because of the small scale of the fishery. There is however a substantial fish trawl fishery operating in Indonesian waters. This is estimated at around 700 vessels (CSIRO data). Their gear is basically a fish trawl but the cod end mesh is around 45 mm which is far smaller than permitted for Australian fish trawls, thus they are able to take small as well as large animals. The red snapper (*Lutjanus malabaricus*) resource appears to be severely overfished with catch rates declining since around 1992. Preliminary genetic analysis suggests that stocks of several important species including *Pristipomoides multidens, Lutjanus malabaricus and L. erythropterus,* overlap with those in Australian waters and so overfishing on the Indonesian side will impact here (CSIRO unpublished information).

Illegal fishing by foreign flagged vessels is a continuing problem in the north. In some cases the illegal fishing is carried out by a group of vessels. In 2001 six Chinese-owned Indonesian flagged trawlers were apprehended while fishing off the northeast tip of the Northern Territory. In January 2002, eight Indonesian fishing boats were apprehended in the eastern Gulf of Carpentaria. As stocks decline in Indonesian waters, these illegal incursions can be expected to increase. In addition these vessels pose a threat through the introduction of marine pests because of the condition of their hulls.

Squid fishing

A preliminary study has indicated that there may be a significant squid resource in northern Australian waters [(54)]. The species involved would be caught using jigs and so there is unlikely to be any direct benthic impact although indirect impacts might occur. Prawn trawlers target squid concentrations at certain times of the year but the impacts of the gear would be the same as prawn trawling and are not dealt with separately.

Beche de mer fishery

Fishing for beche de mer around Mornington Island is planned to start in 2002. At this stage it is only a limited operation. The animals are to be collected by hand by divers so there will be minimum impact on the seabed. However, beche de mer are benthic substrate feeders that process large amounts of seabed sediment daily. We do not know what impact their removal has on the general ecology of seabed assemblages but provided the fishery remains small the effect is likely to be minimal.

Recreational Fishing

In recent years there has been an increase in the number of recreational anglers visiting parts of northern Australia. The growing ownership of four-wheel drive vehicles, the establishment of fishing guiding operations at major centres and the general spread of detailed information on fishing have facilitated this. For example, one fishing book offers maps, extracts of nautical charts and aerial photographs of fishing spots for the coast from Cairns in Queensland to Broome in Western Australia. In the NPF region it covers the west coast of Cape York to Burketown and the top end within a day's sailing of Darwin. It supplies GPS positions for reefs, wrecks, river rock bars and good fishing holes [(45)]. Internet sites offer information on recreational fishing in other areas such as the Sir Edward Pellew Islands and Arnhem Land [(46, 47)]. It is possible that in the longer term, increased activity may result in local depletion of fish stocks. Apart from the impact on the recreational fishery itself, there are concerns emerging in the scientific literature of the ecological effects of the large-scale removal of predators from marine systems.

Some forms of angling use live bait, commonly juveniles of various estuarine species. Juveniles of introduced species of tilapia (*Oreochromis mossambicus* and *Tilapia mariae* sp) are also used in some parts of the coast in the north of Queensland. These species form dense schools in the shallows and are easily captured. They are hardy and can be transported over long distances. Unverified reports indicate that tilapia have been introduced into rivers on the west of the dividing range. If this is correct, they are likely to spread downstream. Tilapia can survive in salt water and they may compete with native fish and possibly prey on juvenile prawns. While this is an undesirable outcome, it is probably not a serious threat to the benthic fauna of the NPF.

Traditional fishing

Most of the NT coastline and some of the Queensland coast is controlled by Aborigines. Traditional fishing is largely carried out using small dinghies with spears for turtle and dugong and lines and nets for fish. In addition invertebrates are harvested from intertidal and shallow tidal areas. Because the fishing is carried out largely for local consumption and not for commerce, fishing pressures are relatively light. Nevertheless overfishing can develop especially when the resource is also targeted by other groups. In 2002 the Inhinoo Land Trust imposed a ban on the taking of black jewfish because of their belief that aggregations are being overfished. The nature of traditional fishing is such however that there appears to be little threat to benthic faunas from this source in the north.

Mining

Mining is a major industry in the NPF region. The mines most closely associated with the sea are those for minerals around the Gulf of Carpentaria but there is also increasing oil and gas production in the Timor Sea near the boundary of the NPF. The positions of ports associated with mining are shown in Fig 7.9.

The main minerals that are exploited are bauxite, manganese, lead and zinc. Proposals for mining alluvial gold offshore from the mouths of some of the Gulf of Carpentaria rivers appear to have disappeared with the decline in the price of gold and are not described here although, unfortunately, they may reappear if the price of gold rises significantly in the future. We have also not dealt with the environmentally destructive offshore dredging for diamonds that was proposed off the Kimberley coast and Cambridge Gulf in southern Joseph Bonaparte Gulf. This proposal fortunately also appears to be in abeyance with exploration shifting to the land.

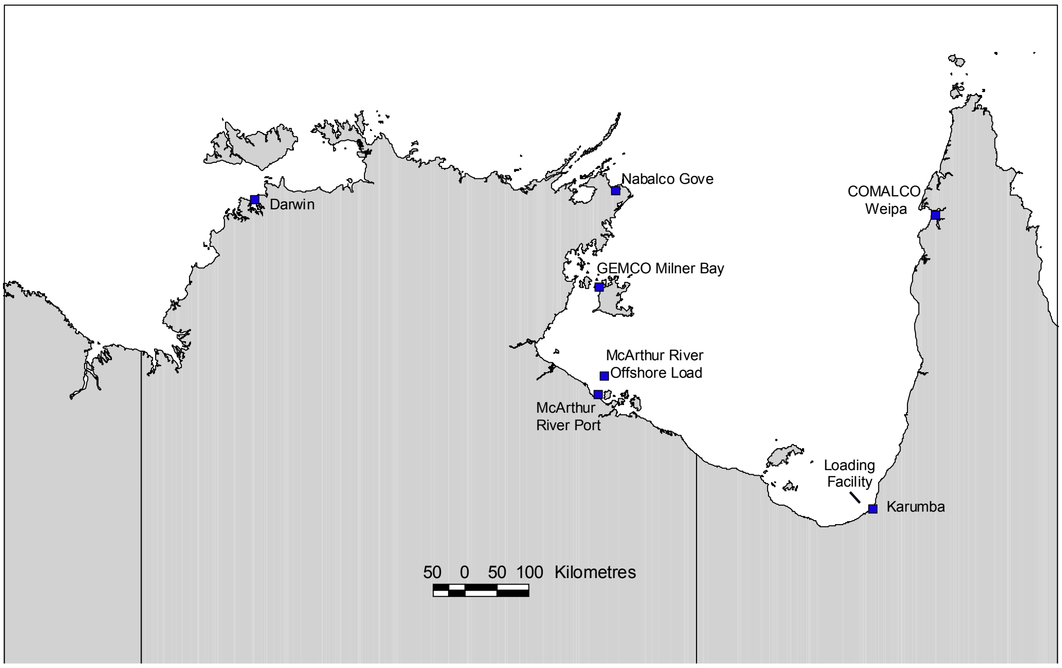

Figure 7.9. Map showing ports serving mines in the NPF region.

Bauxite

Bauxite is the source of aluminium. In the NPF region it is mined at Weipa and Gove using open cut methods. The mining involves removal of topsoil and overburden by bulldozers and scrapers. Front-end loaders, power shovels, or hydraulic excavators mine the underlying bauxite, broken by explosives if necessary. This results in substantial disturbance of topsoil and loss of ground cover over large areas (see Fig 7.10). Subsequent treatment of the ore differs at the two mines. Weipa produces about 11 million tonnes of bauxite annually and this is exported by sea [(2,3)]. The Weipa mine also produces about 150,000 tonnes of calcined bauxite for use as an industrial abrasive. The Gove bauxite mine processes bauxite to produce 2 million tonnes of beneficiated bauxite and 1.8 million tonnes of alumina (aluminium oxide Al_2O_3) per annum [(1,4)].

Alumina is produced from bauxite using the Bayer Process. This is a continuous chemical process in which finely ground bauxite is mixed with caustic soda to produce alumina. The alumina is separated from impurities, precipitated and dried. The waste material, known as red mud, has a high iron content. It is washed to remove caustic soda but remains highly alkaline and is stored in ponds to protect the environment. At Gove it is stored in bunded areas, covered with residue sand and rehabilitated. The alumina is stored in concrete silos until it is conveyed to bulk carriers [(1)].

Lead and Zinc

Lead and zinc are recovered from two mines. One is the open cut operation at the Century Zinc mine south of the Gulf of Carpentaria. Each year, 500,000 tonnes of zinc in a high-grade concentrate and 40,000 tonnes of lead in concentrate are pumped as slurry at very high pressure (3,000 psi or 18 mega pascals) through a 300 km long underground pipeline to Karumba at the mouth of the Norman River. Here the concentrates are dewatered and stockpiled in an 80,000 tonne capacity covered shed. Approximately 1,600 mega litres of filtrate water sourced from an aquifer at the mine site are treated at Karumba annually and used in a ponded pasture system supporting the local cattle industry [(7)]. Century Zinc began exporting zinc concentrate in 2000 and planned to export 40 000 t per month by the end of 2001 [(5)].

The second lead and zinc mine is the McArthur River underground mine. This is also south of the Gulf of Carpentaria. It is exploiting one of the world's largest zinc deposits [(8)]. In 1998/99, the mine produced over 345,000 tonnes of zinc/lead concentrate. The ore is concentrated at the mine and the mixed lead-zinc-silver concentrate is transported by road to a port facility at Bing Bong [(8)]. At both mines the lead-zinc concentrate is transported by self-unloading barges from the port facilities to offshore roadstead areas in the Gulf of Carpentaria and transferred to ships for export.

These two lead and zinc mines have relatively short lives, McArthur River only to 2015 [(5)] and Century Zinc to around 2020[(7)]. However there are other minable deposits in the richly mineralised area to the south of the Gulf of Carpentaria. For example another ore lode appears to exist 100 km north of Century at Elizabeth Creek. Consequently we can expect lead and zinc mining to carry on long after the present mines have ceased operating.

Manganese

Manganese is mined in open cut operations on Groote Eylandt in the western Gulf of Carpentaria. The mine produces over 2 million tonnes of manganese each year - more than 15% of the world's high-grade manganese ore production. The ore is extracted using open-cut, strip mining methods from an 84 km^2 mining lease on the western side of the island. After the ore has been mined from the cut, the area is backfilled with overburden, topsoil is added and environmental rehabilitation takes place with native grasses and trees. After treatment, ore is discharged into a hopper system and transported to Milner Bay where it is stockpiled using a travelling stacker. Ore is reclaimed by conveyors and transported to ore carriers for export [(8)].

Offshore Gas

The seabed under the Timor Sea has large reserves of natural gas. Increases in the world price of liquefied natural gas (LNG) have raised interest in exploitation of these reserves. Contracts were signed in 2002 for the annual supply of 4.8 million tonnes of LNG from the Timor Sea 500 km northwest of Darwin. Two possibilities were considered for processing. The first is to use a floating processing plant and export the liquefied product to overseas markets by sea. The alternative is to pipe the gas to Darwin along a pipe buried in the seabed. After processing on land, some gas would be piped to users in Australia and some exported by sea. In late 2002 the Darwin processing option was rejected. However, there is more than one prospective gas site in the Timor Sea and even if the initial exploitation is via a floating platform, there remains a possibility that in the long term a processing plant will be constructed at Darwin and be fed by a gas pipeline.

If a gas pipeline were constructed from the Timor gas fields to Darwin, it would be buried in a trench on the seafloor. In general, direct environmental impacts associated with pipeline installation are limited to displacement or destruction of benthos in the immediate vicinity of the pipeline and turbidity created by the digging. It is thought that a pipeline would not have any environmental impact once it is installed. Nevertheless it does have the potential to impact on commercial fisheries through restrictions on access to the pipeline corridor and possible gear interactions. Fishing effort is however low in the pipeline area and the concrete casing used for weighing down the pipeline is claimed to provide adequate protection in the event of impact from trawling in the pipeline corridor [(11)].

In the event of rupture, a considerable volume of gas could be released from a pipeline 500 km long and 660 mm in diameter. The impacts of such an event could include freezing of seawater in the vicinity of the rupture, impacts on animals caught in the bubble upwelling zone and impacts on surface animals and birds (natural gas is lighter than air) in the immediate vicinity. In the EIS for the construction of the pipeline, it was stated that the raw gas to be transported would contain less than 1% condensate. This condensate would also be released into the marine environment in the event of a major rupture. The buoyancy of the gas would preclude any impacts on the seabed from condensate, except in the immediate vicinity of the leak. Turbulent mixing within the water column, and rapid evaporation (6-12 hours) at the sea surface would, it is claimed, minimise impacts on local fauna [(11)].

Port facilities associated with mines

Three of the Gulf of Carpentaria mines can load their product directly onto ore carriers from shore through the availability of a deep-water port. At Weipa this was achieved by extensive dredging works in the Embley estuary and the adjacent Albatross Bay (Fig 7.10). A deep-water harbour is available at Gove [(4)] and at Milner Bay on Groote Eylandt. These facilities can accommodate large ore carriers - up to 230m in length [(8)].

Figure 7.10 Port of Weipa in Embly estuary. Areas cleared for bauxite extraction are clearly visible. (Photo by Ports Corporation of Queensland)

Deepwater ports for the export of ore from the two lead and zinc mines are not available on the southern coast of the Gulf of Carpentaria because of the shallow water. Barges are used to transport the ore from land to ore carriers offshore. This requires additional handling of ore including transhipping at sea increasing the risk of spillage. At Karumba, ore is loaded onto a 5,000 DWT self unloading vessel which takes it to export ships anchored a designated roadstead area some 50 km offshore At McArthur river, concentrate is also loaded onto a self unloading barge for transhipment to ships at another roadstead offshore in deeper water

Siltation from mining

Open cut mining can result in erosion of the mine area as well as erosion of stockpiled soils with consequent siltation of estuaries and coastal seagrass beds. High rainfall in the monsoon period exacerbates this problem. At Weipa and at Gove, topsoil is required to be stockpiled and used for rehabilitation. Both mines also operate a replanting program. It appears that these prevention methods have been effective and siltation has not been reported to be a serious problem.

Dredging and disposal of spoil

The port at Weipa is in the Embley River. It was necessary to dredge the river to accommodate large ore carriers (Panamax class) and to dredge a 10 km long approach channel in Albatross Bay. Periodic maintenance dredging is needed to counteract silting. Spoil is dumped on a spoil ground in Albatross Bay and formerly also in a deep hole off Hey

Point. Environmental monitoring by Ports Corporation of Queensland indicates that the benthos was altered by the dumped spoil, but has recovered on a disused dump ground (4 years without dumping). It is difficult to assess whether the tests used would have sufficient power to detect anything but the severest of changes in the benthic communities. Ports Corporation is also monitoring seagrass beds in the estuaries and has not detected changes. However, this is not to say the seagrass has not been altered from its pre-mining condition since monitoring has been relatively recent.

Even though Century Zinc and McArthur River use shallow draft barges for transhipment of ore to offshore ore carriers moored in deep water, dredging was necessary to create channels for the passage of barges. In both areas, this channel cut across an area of seagrass beds. McArthur River Mining contracted a study to provide information on the effect on the environment of dredging a swing basin (200 m diameter 5 m deep) and an access channel (3.8 km long, 60 m wide, 5 m deep) ([28]). Dredge spoil was pumped to a bunded area. Seagrass and associated algae as well as penaeid prawns were sampled before construction and at three intervals (0, 1 and 2 years) after completion. The study found little impact on seagrass away from the dredged area compared to control areas. This contrasts with findings on the impacts of dredging in other areas outside of the NPF [(29,30)]. The authors suggest the low impact at McArthur River was related to the on-land disposal of dredge spoil and that this minimised problems due to turbidity.

Dredge spoil from the channel at Karumba was dumped on a spoil ground about 10 km offshore from the low tide level. Dredging and dumping generated large turbidity plumes but dumping of spoil was timed to minimise impact on adjacent seagrass beds. Monitoring of the benthic fauna on the spoil ground and an adjacent control site six months after dredging showed no substantial impact on the resident benthic communities. Changes were less than those associated with normal seasonal changes in sediment composition [(48)].

It is important to bear in mind in assessing these results that we are dealing with very shallow environments dominated by fine sediments in areas exposed to occasional strong wave action. The Gulf of Carpentaria also has a high incidence of cyclones. Accordingly we could expect the shallow water fauna to be adapted to coping with disturbance of the type associated with dredging and disposal.

Pollution by spillage of ore

The red mud produced from processing bauxite is very fine and can cause siltation, smothering of benthic species and increases in turbidity if dispersed into the sea. It is also caustic – pH 12. It is difficult to rehabilitate by covering and revegetating because of the upward movement of caustic pore water ([99]). At some mines overseas, there have been environmental impacts on surrounding swamps as a result of red mud ponds overflowing in periods of heavy rainfall [(37)]. Although spillage of red mud has occurred at mines in the NPF we did not trace any reports of environmental impacts.

Lead and zinc ores from the Century Zinc and McArthur River mines are ground to very small sizes - below 10µm - as part of the process of reducing silica content. These fine ores are difficult to contain and can be blown around as dust in air and distributed by currents in water. In the sea, the small particle size makes them liable to be taken up by deposit-feeding animals and so to enter the food chain. Biomethylation of lead by benthic microorganisms can lead to its mobilization and introduction into the aqueous environment [(10)]. Lead is highly toxic and so it is essential to prevent spillage of these fine-grained ores.

At both mines, steps have been taken to prevent loss of ore. In the case of the McArthur River mine, the concentrate storage facility at Bing Bong has been constructed to withstand the effects of cyclones and flooding. All conveyors transferring product, including those on the bulk carrier, are fully enclosed. The cargo hold on the barge used for transhipping ore from the McArthur River mine is fully enclosed to reduce ore dust loss and the ship has a compartmentalised double hull to provide added protection. Although an emergency remote controlled spill recovery system is permanently available, its effectiveness has not been proven.

The effects of spillage of manganese ores are not clear. It is toxic under conditions of altered pH. Experimentally it has been shown that manganese is less toxic to larvae of *Penaeus pencillatus* than is cadmium but it is more toxic than zinc[(38)]. Although manganese nodules occur naturally in the sea, a precautionary approach would be to prevent spillage of manganese ore as far as possible. Fortunately, the high value of the ores makes it likely that the mining companies would attempt to recover any major spillages. Low-level chronic spills are thus of greater concern.

Because of concerns by the fishing industry of adverse impacts on markets of the presence of heavy metals in prawns, NORMAC and Pasminco instigated a joint monitoring program at the offshore loading site for the Century Zinc mine. This is based on analysis of prawns collected in the area but there have been problems with obtaining samples. Monitoring of Crustacea for heavy metals requires knowledge of the responses of the species being monitored. For example, a study of intertidal crabs showed that the level of accumulation varied with sex and size of the animals [(36)]. Monitoring of prawns in the Gulf of Carpentaria was introduced because there is no exact loading point for ore, only an offshore roadstead and vessels do not necessarily anchor at the same site on each visit. If a spillage occurred it would be difficult to locate.

Spillage of chemicals used in processing of ores

Alumina (hydrated aluminium hydroxide) is produced at Gove. The process requires large amounts of caustic soda. In 1999 a tank of caustic soda collapsed at Gove closing down alumina production [(12)]. We have not traced any report on the environmental impact of this spill. National arrangements for responding to chemical spills in the marine environment are currently being developed through the draft Chemplan, the National Maritime Chemical Spill Contingency Plan [(31)].

Oil exploration

The Commonwealth government controls oil exploration in Australian waters. Offshore oil and gas exploitation involves several phases including exploration, drilling, producing and transporting the product and finally closing down an oil-drilling platform. Environmental impacts can occur at all phases [(58)]. As can be seen in Fig 7.11, there is oil and gas production in areas of the Timor Sea adjacent to the NPF but no or little oil or gas production within the NPF region at present although two potential producer sites exist in the Joseph Bonaparte Gulf. Potential oil or gas basins exist within the same general area. Recent exploration has included areas in the south of the Joseph Bonaparte Gulf.

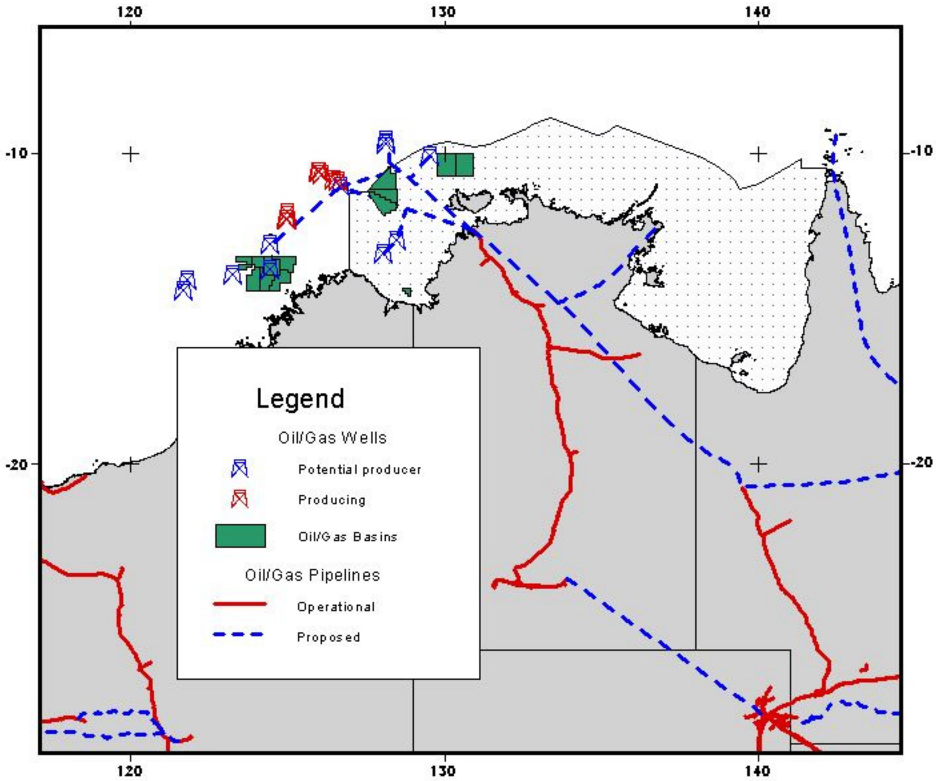

Figure 7.11 Oil and gas activities in northern Australia. Source: Commonwealth Department of Industry, Science and Resources

Exploration for offshore oil and gas is mostly done using seismic techniques in which the speed of sound waves is measured as they travel through different layers of the rock beneath the seabed. Reflected and refracted sound waves are analysed. The data can be used to describe the rock structure and identify potential oil and gas reservoirs. A variety of mechanisms are used to produce sound waves generally in the range 50 Hz to 4 kHz. Most sound sources rely on high-pressure air but electrical sparks and broadband sources are also used. The most commonly used system for oil and gas exploration is an airgun. This is a pneumatic source that produces high-pressure bubbles typically at operating pressures of 10-15 mega-Pascals generating sound levels of 250 decibels. The guns are towed behind a survey vessel that also tows an array of hydrophones for receiving the sound (Fig 7.12). Opinions vary on the impact of the explosions on marine organisms. Environmental groups claim impacts mainly on cetaceans as well as other animals whereas the oil and gas industry claims that impacts are not serious. According to APPEA (Australian Petroleum Production and Exploration Association), a recent environmental report on the oil and gas industry by an Independent Scientific Review Committee stated with respect to seismic surveys that:

> *Except for plankton and larvae at close range, few animals or organisms are likely to be killed outright. Effects on fish eggs and larvae are very small compared with the size of the larval population in the survey area.*
> *Experiments indicate that shellfish and crustaceans are relatively immune to the sound of air-operated devices. Evidence suggests that most invertebrates would only be able to 'hear' seismic survey sounds at very close range - perhaps less than 20 metres. Other experiments have shown that fish can be exposed directly to the sound of seismic survey without lethal effects. There is a wide range of susceptibility among fish. However, those with a swim bladder will be more susceptible than those without this organ.*

The impression given by the review is of an impact confined to a 20 m radius. In practice seismic surveys are a major undertaking and the impact covers a substantial area. Many sound sources may be used simultaneously, these may be towed in line or spread in a fan that can may be 100 m wide. The guns are fired at 6 to 60 second intervals. Thus the impact really occurs along a path wider than 20 m and hundreds or thousands of kilometres in length. The immediate impact is however of short duration since the ship is travelling and each track line is covered only once and so it is not known whether there is a serious impact on seabed fauna.

Figure 7.12. Seismic profiling at sea. Picture reproduced with the permission of the Cetacean Research & Rescue Unit (CRRU) (www.crru.org.uk).

Oil sources are tapped by drilling and accidents in this phase can lead to oil spills. According to Patin [59] two major categories of drilling accidents should be distinguished. One of them covers catastrophic situations involving intense and prolonged hydrocarbon gushing as a result of abnormally high pressure encountered during exploratory drilling in new fields. The probability of such extreme situations is relatively low. The other group of accidental situations includes regular, routine episodes of hydrocarbon spills and blowouts during drilling operations. These accidents can be controlled effectively (in several hours or days) by shutting in the well with the help of blow out preventers and by changing the density of the drilling fluid. There has been no accident of this kind in Australia. During the drilling process, fluids are used to carry the drill cuttings to the surface, to lubricate the drill bit and to maintain hydrostatic pressure in the well. Drilling fluids used in Australia are water based (mainly seawater) with mainly inert or non-toxic additives being used to provide the necessary viscosity and lubrication. Water-based drilling fluids are non-toxic and approved for discharge into the sea [92]. To further reduce friction, particularly in deep or deviated wells, non-water based (low toxicity synthetic and oil based) fluids are occasionally used. These specialised fluids are costly and are generally recovered during the drilling process for subsequent re-use; they are seldom used in Australian waters [92].

Oil pollution by mines

Mines are a major user of oil in the NPF region; their supplies are imported by sea. There are thus two potential pathways for oil pollution, firstly spillage at sea and secondly spillage on land. There appears to have been no significant spill of oil at sea in the NPF region and generally tanker accidents are rare. Unfortunately when they happen very large amounts of oil are released into the environment. According to the State of the Marine Environment Report [17], far more oil enters the sea from land in Australia than through marine oil spills. There have been significant oil spills associated with mines on land in the NPF region. In 1995 Gemco admitted that diesel oil had been leaking into the ground from its Milner Bay fuel handling facilities on Groote Eylandt, possibly for several years. A total of around 3.8 million litres of diesel had accumulated underground. Corrective action involved the use of 86 bores and pumps to recover the free phase fuel. More than 1.1 million litres had been recovered by 1997 and was disposed of by blending for use in the company power station. Fuel handling facilities have been upgraded to prevent a repetition of the incident [13]. Gemco was fined $A45,000 for the spill. Other reported spills at mine sites are relatively minor. For example, in 2000, Comalco reported minor hydrocarbon spills at their Power Station, at their Ship Loader and at a service bay [66].

Pollution from mining discharges

The best-documented case of pollution from mining on land adjoining the NPF is the Rum Jungle Mine in the Northern Territory. The former uranium mine is on the headwaters of the Finiss River that drains into Fog Bay in Joseph Bonaparte Gulf. Major mining operations started around 1952 and continued until 1971.
'Rum Jungle treated 863,000 tonnes of 0.28-0.41% U_3O_8 ore to produce 3,530 tonnes of U_3O_8, according to the most authoritative accounts, (along with 20,000 tonnes of copper concentrate from other ore). Extremely large amounts of tailings and wastewater were discharged from the mine. The tailings were discharged as 55 % (by weight) solids slurry to the various disposal areas. The liquid effluents were discharged at about 1,000,000 litres per day, with a pH of about 1.5 (corresponding to a sulphuric acid concentration of 0.032 N H_2SO_4). From the start of processing operations in 1954, the discharge of tailings was unconstrained and the solids settled out, while the acidic supernatant liquors drained into "Old Tailings Creek" and thence to the East Branch of the Finniss River, 0.8 km to the west.' [67].

A Report by a Senate Select Committee on Water Pollution contained the following statement: 'One of the major pollution problems in the Northern Territory is that caused by copper and uranium mining at Rum Jungle. The strongly acidic effluent from the treatment plant flows via the East Finniss River into the Finniss River, making the water unsuitable for either stock or human consumption for a distance of 20 river miles. Vegetation on the river banks has been destroyed and it will be many years before this area can sustain growth.' There is no report on the effects of these pollutants on the seabed fauna of the neighbouring sea.

According to the AAEC (Australian Atomic Energy Authority - AAEA; later the AAEC) the variable course of the Finniss in its lower reaches makes it *'difficult to predict just where the released metals may have gone'*: About a hundred square kilometres of floodplain were affected by the discharges, and average concentrations of copper, manganese and zinc were 1,500 per cent, 1,400 per cent and 33 per cent above natural levels. Whilst only a few per cent of the amount released is contained in the surface soil of the area, the whereabouts of the remainder is not known. As the AAEC said, rather vaguely, it *'has been removed elsewhere, has migrated through the soil profile or, less probably, has yet to reach the plain'*.

The Commonwealth government has spent nearly $24 million on rehabilitation work at the former mine site.

Rum Jungle was a major environmental disaster and it is hoped that modern technology and government regulation can prevent this happening again in Northern Australia. Unfortunately, major spills from mines of highly toxic chemicals especially cyanide as well as contaminated sludge from failure of settling or holding ponds as well as discharges continue to occur worldwide [74, 75, 76].

Shipping

In the NPF region, there is a considerable amount of shipping both between ports in the region and to ports in other parts of Australia and overseas. The Port of Darwin handled 1600 international ship visits in the period 1997 to 1999. The number of bulk ship visits to Darwin is likely to increase considerably in the next 5 to 10 years because of the completion of the new container port, the construction of the Darwin – Alice springs rail link which is scheduled to be completed by 2004 and the proposed LNG plant – if this proceeds. Other ports receiving significant international shipping are those associated with the mines in the Gulf of Carpentaria. The mines export product in bulk carriers that operate to ports around the world. Prawn trawlers operate within the NPF region but nearly all are based either in Western Australia or on the East coast of Queensland. Some operate in PNG or Indonesian waters when the NPF is closed to trawling. Northern Australia is also a popular area for recreational yachts most of which have spent time in overseas ports. The overall situation is that there is a complex pattern of coming and going by ships ranging from yachts to bulk carriers and that many of these have spent time in foreign waters. In addition there is a large number of internal shipping movements between ports in the NPF and the rest of Australia.

Introduced Marine Pests

Surveys around Australia in recent years have revealed a high level of exotic marine pests especially in southern waters. In Port Phillip Bay in 1998, over 35% of all seabed dwelling animals (50% by weight) were exotics [(72)]. A dramatic decline in scallops in the Bay despite a ban on dredging has been attributed to these exotics although the link is not clear and there also appears to have been overfishing of the resource. The two major mechanisms for introduction of marine pests via shipping are on hulls or in ballast water. Clearly hull pests can come from any form of shipping although in general antifouling paints will limit this source on the major ore carriers. The ballast water route is more likely to be associated with large ore carriers such as those servicing mines in the Gulf of Carpentaria. The ships arrive in ballast and so discharge large quantities of ballast water before loading. Although few carriers presently visit Darwin, this will change if a LNG industry is established [(18)].

Figure 7.13 Fouling under a yacht. Source: NIWA ([100]).

The small marine snail *Maoricolpus roseus* that has invaded the seabed off southeast Australia offers some idea of the impact of a vigorous benthic alien. This species is now so abundant in some areas that the benthic habitat has been altered from one of fine sand or mud to one with a dense cover of live and dead shells (Fig 7.14). Mucus produced by *M. roseus* appears to consolidate the sediments and also leads to an increase in the bacterial load. This may impact on larval settlement and post settlement survival of a variety of benthic organisms [(21)]. Pests that spread into the marine environment are beyond control. Thus introduced marine pests may pose a serious, irreversible, long-term threat to the benthic fauna of northern Australia.

Figure 7.14 Population of the small marine snail *Maoricolpus roseus* on the seabed east of Tasmania. Source: CSIRO Marine Research

Three species of alien marine organisms have been recorded as being established in the NPF [20].

Crustacea: *Megabalanus tintinnabulum* (barnacle)
Mollusca: *Aeolidiella indica* (nudibranch)
Marine plants: *Caulerpa taxifolia* (green algae).

During a survey of the Port of Darwin in late March 1999, divers from CSIRO's Centre for Research on Introduced Marine Pests (CRIMP) detected a new and potentially serious marine pest — the black-striped mussel, *Mytilopsis* sp (fig 7.15). This fingernail-sized bivalve is closely related to the zebra mussel that has caused massive economic and ecological impacts since it was introduced into the North American Great Lakes system in the mid 1980s. A major response by the NT government costing several million dollars involved treating port waters with sodium hypochlorite and copper sulphate as well as at sea inspections of vessels that had recently visited Darwin harbour. The eradication appears to have been successful. This marine mussel is believed to have been introduced into Northern Territory waters on the hulls of commercial or recreational vessels sometime after September 1998. This is the first known incursion into tropical Australian waters of a marine species that warrants classification as a potentially serious pest. *Mytilopsis* sp. is a native of tropical and subtropical eastern Pacific waters, extending from the Gulf of Mexico to Columbia. The same mussel is believed to have invaded Fiji (prior to 1900), India (Visakhaptnam Harbour, ca. 1967), Japan, Taiwan (1970s) and Hong Kong (early 1980s) [19].

Figure 7.15 Black striped mussel, *Mytilopsis* sp (Photograph CSIRO DMR).

A Caribbean serpulid tubeworm *(Hydroides sanctaecrucis*) was discovered in Trinity Inlet at Cairns in 2001[57]. It was found on vessels that had been moored for a long time as well as on pontoons and pilings where it builds large calcareous colonies. This species settles readily on surfaces containing low concentrations of copper such as slow release antifouling and underwater fittings containing copper for example brass and cupronickel. This shortens the effective life of antifouling, fouls propellers and blocks inlets and outlets on ships [83]. *Hydroides sanctaecrucis* is a tropical species capable of colonising the warm waters of northern Australia. Given the large amount of local shipping between Cairns and the Gulf of Carpentaria as well as the long periods for which some NPF trawlers spend in Cairns between seasons, there is a distinct possibility that this species could enter the NPF in the future. At this stage it is thought that the main impact will be on increased costs for shipping rather than on the marine environment where it appears to compete mainly with other fouling organisms.

The NT government has established an Aquatic Pest Management Unit for the purpose of protection of biological diversity in aquatic ecosystems, reducing the likelihood of the introduction of aquatic pest species and to increase awareness of the potential damage pest species can inflict on aquaculture, fisheries, tourism, defence and the economy.

Internationally, the Marine Environmental Protection Committee of the International Maritime Organisation (IMO) is developing a convention on the management and control of ballast water to be applied from 2003. The Australian Quarantine Service has recently introduced new mandatory arrangements for managing ballast water. Amongst other requirements, vessels now need to exchange ballast water in mid-ocean.

Anti-fouling Paint

A variety of substances are used to prevent fouling of the hulls of vessels by sessile invertebrates. The basic formulation is a biocide that is held in a base such as resin or chlorinated rubber. The base allows the biocide to leach into the water. The dilemma with antifouling paints is that while they provide an important barrier against the importation and spreading of marine pests spread on vessels hulls, they are toxic and can have severe localised environmental impacts.

Copper sheathing or copper based paints (copper oxide or copper thiocyanate) were traditionally used for prevention of hull fouling until the development of tributyl tin (TBT). TBT is a very effective antifouling substance but is regarded as the most toxic substance ever developed for release into the marine environment. Studies in many areas have shown that it causes malformations in marine invertebrates. In 1991, Australia banned its use on all vessels smaller than 25 m and it is now restricted to low leaching forms on larger vessels. These regulations presently do not apply to vessels registered outside of Australia. Most of the bulk carriers used to export ore from the Gulf of Carpentaria fall into this category. Australia was committed to ban the use of TBT on ships that are repainted in Australian docks by January 2006. However, the International Maritime Organisation (IMO) has introduced a total ban on the application of TBT-based antifouling paint by January 2003 and the Australian government supports this ban.

A major source of pollution by TBT is through cleaning of the hulls of vessels that have been painted with antifouling. In 1999 restrictions on hull cleaning in coastal waters were introduced into all ports managed by the Ports Corporation of Queensland – including Weipa and Karumba (26). Nevertheless the possibility of TBT pollution remains since the sediments in many ports contain old residues and these are periodically washed into the sea during floods or may be disturbed during dredging. In Queensland, dredge spoil contaminated by heavy metals or TBT has to be disposed of on land. A code of practice has been developed for use of antifouling paint and for cleaning and maintenance of hulls (39).

. The ban on TBT has resulted in a shift back to antifouling paints incorporating copper, zinc pyrithione or proprietary substances such as diurin. Copper rapidly is highly toxic but it binds to organic substances and sediments and so disappears from the water. It can be re-mobilised if the sediments are disturbed and so continues to be a source of toxicity. Although Zinc pyrithione is very toxic to marine animals, it breaks down into less toxic substances in water. The s-triazine herbicide Irgarol© 1051 is used in some antifouling paints but it is not registered for use as a biocide in antifouling paints in Australia. Nevertheless, high concentrations have been found in seagrass samples from the east coast of Queensland and are thought to have originated in antifouling paint (35). This toxic substance is likely to have long-term effects on marine herbivores and on endosymbiotic algae. We have no information on the occurrence of this herbicide in waters of the NPF but if it is being used in antifouling paint, then it probably is present.

Research is underway to provide alternate ways of preventing fouling, for example by use of silicone and fluorinated coatings such as Teflon© that make it difficult for animals to attach to the surface (34). These methods rely on high water speeds (>10 knots) to dislodge biota that attach to the hull and so are not suitable for relatively slow moving vessels such as trawlers or those that are moored for long periods. Another approach is to use ‘natural’ antifouling substances such as zosteric acid which is produced by the seagrass *Zostera marina,* and capsaicin, the active ingredient in chili pepper.

Oil Pollution from shipping

Large quantities of fuel oil and diesel are transported by sea through the NPF to meet the needs of mines, the fishing industry and the general economy. Significant facilities managed by major oil companies are found at Weipa, Karumba, Gove, Groote Island and Darwin. Some major industries maintain their own fuel facilities. In addition a number of anchored barges provide refuelling and other services to trawlers of the NPF fleet.

Records published by the Australian Maritime Safety Authority include around 300 oil discharge sightings and oil spills from ships in Australian waters annually. The number and sources of discharges over a five-year period are shown in Fig 7.16. The majority of oil discharges are from tugs, barges and ferries but fishing vessels are the second largest single sources of oil discharges.

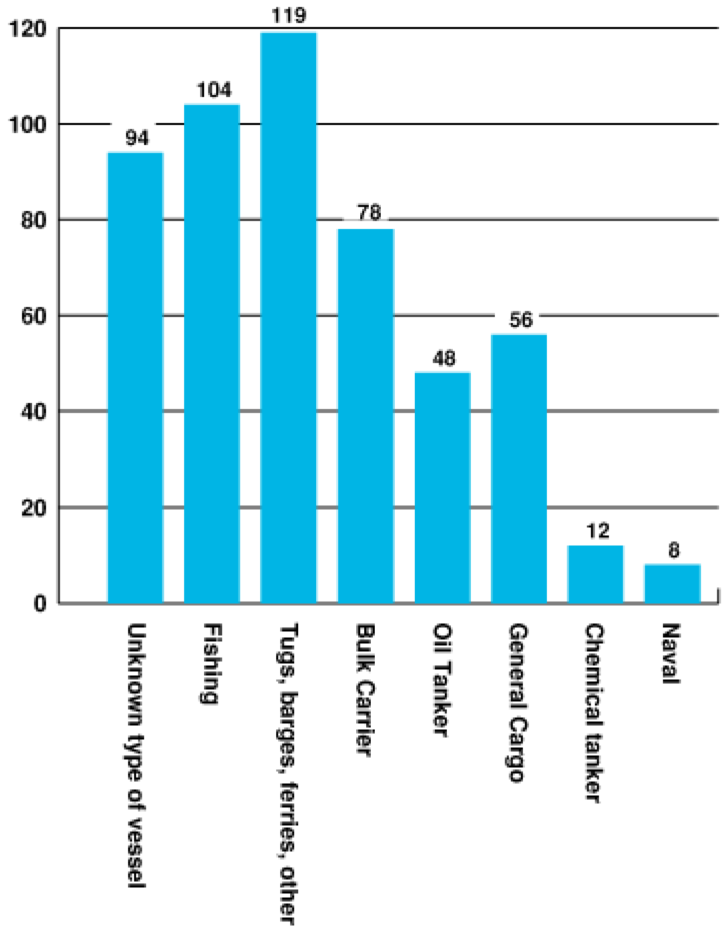

Figure 7.16 The number of incidents of oil discharges in Australian waters by vessel class in the five-year period from the 1992/1993 to 1996/1997. Source: Australian Maritime Safety Authority

Oil industries in Australia operate the Australian Marine Oil Spill Plan. This is a cooperative arrangement to respond to oil spills. Under the plan, industries collaborate in training of personnel, sharing of information and the maintenance of a stockpile of equipment to use in dealing with oil spills. This stockpile supplements equipment held by individual companies and governments [15, 16].

The Australian Maritime Safety Authority (AMSA) is responsible for the National Plan to Combat Pollution of the Sea by Oil and other Noxious and Hazardous Substances and oversights oil spill Contingency plans for all states and the NT. Information on spillage events in the previous year is published by AMSA [77]. AMSA is also responsible for oversighting other international conventions such as

- International Convention for the Prevention of Pollution from Ships 1973/78 (MARPOL 73/78)
- International Convention on Oil Pollution Preparedness, Response and Co-operation 1990 (OPRC 90)
- The Convention relating to Intervention on the High Seas in Cases of Oil Pollution Casualties 1992 (the Intervention Convention)
- International Convention on Civil Liability for Oil Pollution Damage 1992 (the Civil Liability Convention) which applies to tankers and the International Convention on Civil liability for Bunker Oil Pollution Damage 2001 which covers bulk ships and container ships. Under these conventions, the owner of the vessel that spills the oil is liable for the clean up costs regardless of whether or not he or she was at fault.

- International Convention on the Establishment of an International Fund for Compensation for Oil Pollution Damage 1992

The Northern Territory *NT Marine Pollution Act* covers disposal and pollution by oil, noxious liquid substances, packaged substances, sewage and garbage.

Chemical pollution

We have not traced any recent reports of chemical pollution from vessels in the NPF region but the potential is illustrated by the case of the tanker MV *Explorer LT*. On 9 November 1995, the MV *Explorer LT*, carrying a cargo of bulk caustic soda liquid, 400 tonnes of heavy bunker oil and 200 tonnes of diesel fuel, reported engine failure during its passage through the Torres Strait while bound for Gove. The vessel subsequently regained engine power and successfully landed its cargo at Gove.

Shipping accidents

A summary of serious shipping accidents in the NPF region in recent years (reports released up to December 2002) according to the Australian Transport Safety Bureau (ATSB) is given in Table 7.1. In addition to the formal ATSB reports, there are mentions in the complete record of the grounding of the MV *Fitzroy* River of twelve other bulk carrier groundings at Weipa between 1967 and 1980. These vessels were leaving the port fully laden at maximum draft and were usually refloated within 24 hours. The exception is the MV *Gold Star* which had to be lightered and was floated off only after 11 days.

Table 7.1. Serious shipping accidents in the NPF region since 1990. Source: Reports from the Australian Transport Safety Bureau [78].

Date	Vessel	Incident	Outcome	Reference
November 1998	Livestock carrier Norvantes	Grounded on the edge of the dredged channel at Karumba while leaving port under pilotage	Refloated without damage	60
August 1998	Bulk carrier Fitzroy River	Grounded in the navigation channel while departing the port of Weipa under control of the Master	Refloated without damage	61
January 1996	Livestock carrier Carabao 1	Struck Old Man Rock in the East Arm of the Darwin harbour while leaving port under pilotage	Inspection of the hull showed no serious damage	62
May 1993	Fully laden 81,248 tonnes deadweight bulk carrier Oppama Spirit	Grounded in port at Gove following a power failure caused through blockage of cooling system by mud, sand and shells churned up from the sea bed	No damage was sustained by the ship and no oil pollution occurred	64
April 1993	Fully laden 34,752 tonnes deadweight bulk carrier Malinska	Grounded while leaving Groote Eylandt under control of the Master	No pollution resulted from the grounding but partial unloading was needed to refloat the vessel.	65
February 1990	Bulk carrier Gold Star	Grounded on edge of channel while departing port of Weipa in gale force winds	Refloated without damage after 11 days following unloading	61 (complete report)

All serious shipping accidents reported by ATSB in the NPF region in recent years have involved groundings (Table 7.1). Three of these were bulk carriers and two were livestock carriers. Groundings can lead to local oil pollution incidents if oil tanks are ruptured. Fortunately this did not occur. A key feature of the incidents is that they all took place while the vessels were travelling at low speed in sheltered waters and in most cases the grounding took place on relatively soft bottom. These factors are probably the main reason for the absence of serious hull damage that could have led to oil spills. Nevertheless it does illustrate that accidents involving large ships do occur in the NPF region. The ATSB estimates that based on available figures, the rate of groundings at Weipa is one in every 300 movements. These have the potential to cause pollution and consequent impact on marine fauna and flora. Although trawlers carry far smaller quantities of fuel, the fuel barges that service the fleet represent a larger source of potential oil spillage. However, these vessels carry diesel rather than bunker or fuel oil and this, although toxic to marine animals, would evaporate fairly rapidly at tropical temperatures because of its lighter nature and would cause less damage than a spillage of bunker oil from a large ship.

Agriculture

Land Clearing

A considerable amount of clearing of native vegetation is taking place in northern Australia. At present around 2% of the area of the NT has been cleared but this figure is expected to increase in the future. In Queensland, most clearing takes place in the central region but the lands bordering the southern Gulf of Carpentaria are also being cleared [(90)]. Land clearing can facilitate the spread of weeds and damage significant vegetation communities; it can also affect runoff and erosion and thus alter water quality with impacts on inshore benthic communities. Land clearing is also thought to be a factor in some fish kills (Figure 7.17). The NT government provides guidelines for land clearing [(88)] and new procedures are being implemented in Queensland. There is however considerable disagreement between landholders and other stakeholders especially the conservation movement, on the extent of land clearing that should be allowed.

Fig 7.17 Fish kill in northern Australia possibly caused by land clearing. Photo by CM Finlayson [(89)]

Water diversion

The mean annual discharge of rivers draining into the Gulf of Carpentaria account for more than 20% of Australia's annual surface water run-off [106]. The runoff is very seasonal. Large irrigation dams are designed to interfere with river flows, usually to capture water in the wet season and supply it in the dry season. The largest water diversion in the NPF region is on the Ord River. This drains into Cambridge Gulf in the Western Australian part of Joseph Bonaparte Gulf. A dam was constructed on the river in the 1970s. The water is used for irrigation and more recently also for electricity generation. The initial stage involved irrigating 13 000 ha of agricultural land.

The Ord River dam has resulted in considerably altered flows of water in the Ord River because water flow now occurs throughout the year and not only in the wet season as previously [33]. This leads to salinities remaining low in the upper reaches year round instead of rising as previously. Studies by CSIRO show that the salinity changes have altered the prawn population in the Ord River Estuary [104]. A stage 2 development proposal to increase the area under irrigation by about 50 000 ha has been deferred.

In Queensland, feasibility studies have begun for the construction of a dam 17 kilometres downstream from the township of Richmond on the Flinders River that drains into the eastern Gulf of Carpentaria. The proposed dam will have a 600 000 mega litre capacity with an expected yield of 120 000 mega litres per annum. This will give an irrigation capacity of 12 000 ha on extensive arable black soil plains Cotton genetically manipulated for resistance to insect pests may be used for the development of a sustainable cotton industry in this region. The use of insect-resistant cotton has the potential to reduce the use of chemical pesticides on cotton crops. The first cotton using water from the Flinders River was harvested in 2000 from a 200 ha (400 acre) experimental commercial crop [22, 23].

Ponded pastures are a method of using shallow stored water to overcome the feed constraints of the seasonally dry tropics. In this system the drainage of water from low-lying areas is controlled by levee banks. Forage grasses may be planted in the pasture to enhance production. Ponded pastures impact on estuaries because they decrease freshwater runoff with negative effects on fauna and flora in those parts of the river system below the ponding [24, 25]. At this stage these impoundments are not common in the land adjoining the NPF except for the Darwin – Kakadu region where the NT government is encouraging their use [49]. Until recently, the Queensland government actively promoted the development of ponded pastures but a change in policy has led to restrictions on their development. Ponded pastures may no longer be established in areas below high tide, adjacent to wetlands or in areas of high conservation or fish habitat value. Planting of species of grasses that were introduced for dry-season cattle fodder and have become weeds will be discouraged.

Acid Sulphate soils

Acid sulphate soils are former marine sediments with a high iron sulphide content (mostly from inundation by seawater when sea levels rose around 10,000 years ago). When exposed to air – mostly through agriculture, the sulphide oxidises to sulphuric acid that can mobilise other elements – mainly metals. The sulphuric acid lowers the pH of the water and can directly damage plants and animals. In addition mobilisation of toxic metals such as aluminium can harm biota. Large sections of the coast of the NPF are underlain by acid sulphate soils. Figure 7.18 illustrates the distribution of these soils in Queensland and shows that almost the entire Queensland Gulf coast potentially could give acid runoff problems if disturbed.

The present level of agriculture development in the coastal lands of the NPF does not pose a large-scale threat from acid runoff. Nevertheless, parts of the NT especially in the vicinity of Darwin are undergoing increasing development – supported by government – and potentially this could give rise to problems in the future.

Figure 7.18 Distribution of acid sulphate soils in Queensland. Source of information: Department of Natural Resources, Queensland.

Pesticide and herbicide runoff

Crop production in tropical areas is often difficult because of high levels of pest infestation. This requires more frequent application of pesticides. Cotton has a history of severe pest attack because it has a long growing season, the pests can disperse over long distances, they are polyphagous and most have a high insecticide resistance. In the case of the Ord River, cotton growing was phased out in 1973 after pesticide treatment costs had tripled in the previous five seasons. Over that period, the number of sprays applied had more than doubled [(52)]. During high rainfall periods, pesticides are washed into waterways and eventually the sea. Genetically modified cotton chosen for the Flinders River cotton project should require fewer insecticides than unmodified types.

Agriculture makes extensive use of herbicides for weed control. On the Queensland East coast, two herbicides Ametryn© and Diuron© have been found in high concentrations in mangrove sediments around dead and dying mangrove trees in the Mackay region [(103)]. Canegrowers and the Queensland DPI have rejected calls for the banning of these herbicides because it is claimed there is no conclusive evidence that they are the cause of mangrove dieback. Given the relatively small area of mangroves in the NPF region and their importance as a habitat for young banana prawns and fish including barramundi, great caution is needed in the use of agricultural herbicides in the NPF.

Siltation from agriculture

Despite many claims that agriculture on the Queensland East Coast has been responsible for significant siltation of inshore areas through increasing runoff rates and soil erosion, the issue is still the subject of considerable disagreement [(50)]. The very small amount of agriculture on most of the coast of the NPF suggest that this is presently not a threat but as irrigation farming spreads it could become a local problem. There is already strong evidence of a major siltation impact from the Ord River scheme. According to Wolanski et al., (2000)[(53)], the East arm has silted measurably over the last 30 years and the stream cross-sectional area has decreased by about 50%. Field and numerical studies suggest that this is due to the dam-induced suppression of large river floods and by the tidal pumping of sediment into the Ord River estuary from Cambridge Gulf. The Ord River estuary appears to be geomorphologically unstable and to have been destabilised by human activities. Numerical studies suggest it may take as little as 100 years for the Ord River to reach a new equilibrium. This equilibrium may be characterised by a salinity intrusion length half that before damming, a channel width and depth reduced by 70%, and a much stronger tidal asymmetry characterised by an increasing size of the tidal bore.

Burning of bush land

Large-scale and widespread burning of the ground cover takes place across northern Australia each year (Fig 7.19). This produces a considerable amount of ash and also exposes the soil to erosion. There must be some runoff of nutrients and soil if rain follows the burning but the impact of this process – which has been going on for thousands of years – on the neighbouring marine environment is not known.

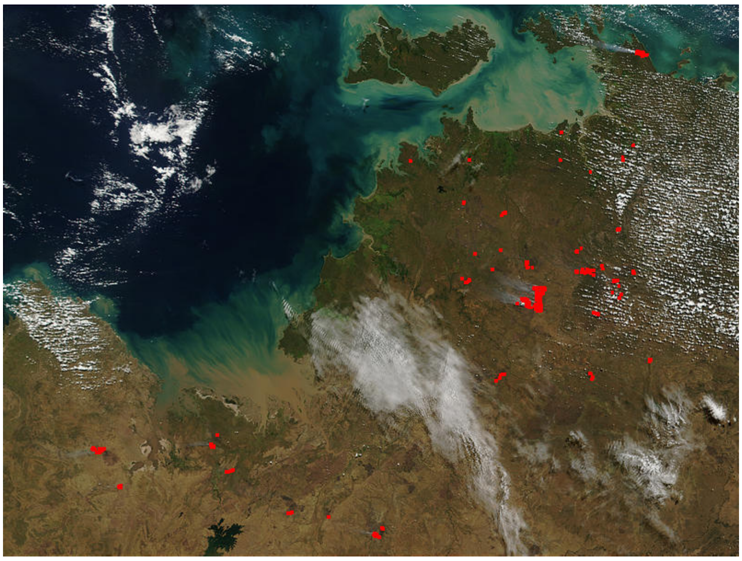

Figure 7.19 Burning in northern Australia, January 2002. The area shown is from the south-eastern section of Joseph Bonaparte Gulf to western Arnhem Land. Source of figure: MODIS Land Rapid Response Site at University of Maryland ([96]).

There have been and are numerous proposals for development of aquaculture on the land bordering the NPF. The main proposals are for cultivation of prawns and fish. The Northern Territory government has actively encouraged the development of aquaculture through the Draft Aquaculture Development Plan for the Northern Territory 1999-2004. The Western Australian Department of Fisheries and the Kimberley Development Commission have prepared a detailed Aquaculture Development Plan and established a regional Aquaculture Development Group to promote aquaculture in the Kimberley region. There is also a proposal for a 1000 ha prawn aquaculture farm in the Ord River scheme. Several large-scale aquaculture projects have failed in the NT in the past leaving areas with a degraded coastal environment of cleared land and abandoned ponds.

Pearl oyster aquaculture is the most valuable sector of the aquaculture industry in the Northern Territory. Limits on production imposed by West Australia and Northern Territory restrict the annual production of pearls from both wild and hatchery sourced pearl oysters. Prawn and barramundi farming is carried out in the Northern Territory but the scale is still relatively small and unlikely to have any significant impact. Prawn farming is an emerging industry sector with significant latent potential and it is anticipated that investment in prawn farming will grow significantly in the next few years. The lack of a reliable local supply of brood stock and/or post larval prawns has been the most significant technical factors limiting the performance of this sector in recent years. All brood stock and larvae are imported from Queensland.

Mud crab aquaculture is the subject of considerable research but it is not clear whether commercialisation will occur in the near future.

Barramundi is the only species of fish (excepting aquarium fish species) currently being farmed in the Territory. The largest barramundi farm in Australia is located on Port Hurd on Bathurst Island. In 2001 it had around 250 000 barramundi in sea cages. The market for plate-sized barramundi has been found to be relatively small in Australia and so farmers are now growing more fish to a larger size (around 3 kg) for fillets, a much larger market in Australia. A farm is being established to cultivate S*pirulina*, a micro alga, for the health food market.
Aquaculture has been growing rapidly in Queensland; - value of production has doubled over last seven years and is now worth about a third of the wild fishery (72). This expansion has taken place on the East Coast with no major aquaculture projects being developed on the Gulf of Carpentaria. The higher costs of operating in the Gulf together with a lack of suitable sites and infrastructure is likely to continue to limit aquaculture development in this region.

Introduction of disease

The major threat from aquaculture to the NPF is the introduction of diseases to the wild prawn population via prawn farms. Although several viral diseases occur naturally in wild prawn populations, the incidence can increase rapidly in the crowded conditions in aquaculture ponds. Accidental release of diseased prawns into the wild might lead to the spreading of viral diseases. Concerns about the introduction of White Spot Syndrome Virus (WSSV) into Australian waters have been raised recently and have led to tighter controls on imports of uncooked prawns. The virus was detected at research facilities in Darwin in 2000. Investigations to date have not shown WSSV to be present in Darwin Harbour. Under Australia's quarantine rules, prawns can be imported only for human consumption and not for bait or aquaculture feed. It is, however, difficult to prevent diversion of imported prawns into bait. A code of practice has been drawn up for importers and domestic producers of prawns in the handling of waste. Mandatory certification from exporting countries and inspection of all consignments of whole green shrimp is already in place.

Pollution and Habitat destruction

Prawn ponds produce high nutrient effluents that can cause pollution problems if discharged into the marine environment. Research is underway in Australia to deal with effluents in an ecological sustainable manner.

The development of aquaculture in many overseas tropical countries led to the devastation of vast areas of mangrove swamps. The practice of cutting mangroves in order to clear land for aquaculture ponds is not allowed in Australia.

Climate Change

It is now generally accepted that an increase in greenhouse gases in the atmosphere is leading to a gradual rise in temperature. The main – but not only – impacts of climate change that follow from global warming are an increase in sea water temperature; a rise in sea level due to thermal expansion of the water as well as melting of polar ice and changes in precipitation patterns with some areas receiving less rainfall and others receiving more. A greater frequency of severe storm events including cyclones is also predicted. All of these changes can affect marine faunas but there is extremely little information on the quantitative effects on marine benthic faunas

Temperature rise

The increase in temperature in the 20th century appears to have been largest of any century during the last 1000 years. It is also likely that in the Northern Hemisphere, the 1990s was the warmest decade and 1998 the warmest year [(80)]. Temperature rise is continuing and in 2002 the total increase was conservatively estimated by the USA Environmental Authority (EPA) to be between 2.5 and 4^{o}C in the 21st century [(93)].

The most dramatic impact in the sea has been the highly visible global distribution of coral bleaching. It is possible that less noticeable impacts are occurring on a similar scale. Many tropical marine organisms live very close to their upper thermal limits and so cannot tolerate even moderate temperature rises. Continued high temperatures may affect reproduction because in most species this is limited to a narrower temperature range than is survival. Minimum temperatures are increasing at twice the rate of maximum temperatures resulting in a narrower temperature range [(82)]. This may have unknown ecological effects since many plants and animals use temperature rise in spring as a trigger for reproduction. Temperature rises are not expected to be even around the world, some places will change slowly whereas others are likely to heat up rapidly. Between 1961 and 1976, mean temperatures of the land to the south of the Gulf of Carpentaria rose faster than the average suggesting this region may continue to heat up more rapidly which could affect water temperatures given the shallow nature of the Gulf of Carpentaria [(82)].

Sea level rise

The 3.2 $\pm$ 0.2_millimetre average annual global mean sea level rise observed by the Topex/Poseidon satellite over 1993-98 is fully explained by thermal expansion of the oceans as a result of warming [(69)]. Melting of glaciers, ice shelves and ice caps will increase the sea level rise. Latest calculations that take into account the potential contribution from North American glaciers, estimate that sea level will rise by up to 0.8 m over the century [(79)]. In the southern Gulf of Carpentaria, sea level rises will cause the shoreline to retreat considerably, effectively shortening the length of estuaries. This will reduce the area of mangroves with possibly effects on animals such as banana prawns that use these areas as juveniles. Seagrass beds along the south western and western coasts of the Gulf of Carpentaria, are likely to move up as the sea level rises and the shoreline moves landward and so may be less affected than mangroves. Generally it is thought that areas having a high tidal range are likely to be less affected by sea level rise than those with a low tidal range [(70)].

Rainfall

Rainfall patterns are expected to change with many areas receiving less rain than at present but others receiving more. In the NPF region the main change is expected to be an increase in precipitation over Arnhem Land [(82)]. Areas of increased rainfall can expect more flooding than in the past. This in turn will result in lowered salinities in estuaries affecting both the estuarine fauna and those species that spend part of their life cycle in inshore waters.

Change in the frequency of cyclones

Since 1945, there has been an average of 1.8 cyclones a year for the area south of 0^{o} and between 125^{o}E and 137^{0}E. The number of cyclones per annum varies considerably – from none to 6 (Fig 20) but the frequency is expected to increase as a result of global warming.

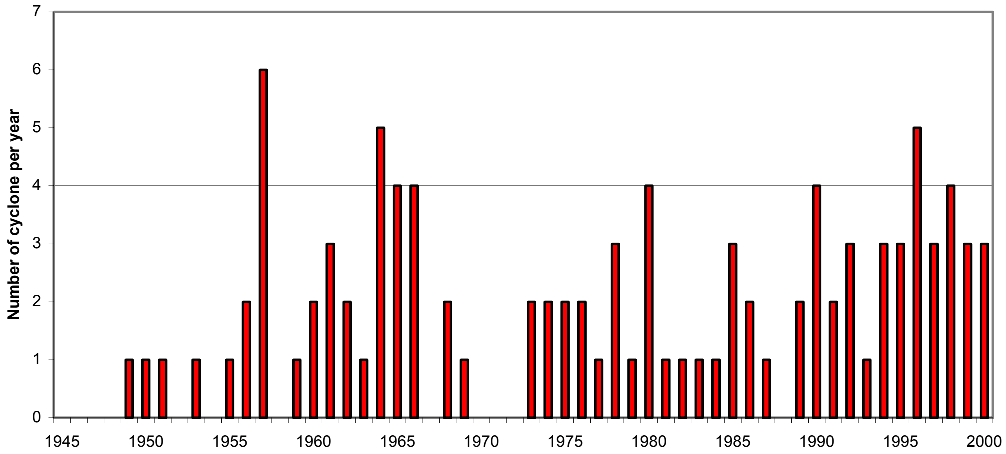

Figure 7.20 Number of cyclone by year in northern Australia from 1945 to 2000. Data from Hurricane Alley ([95]).

Most cyclones occur from December to April with very few recorded outside of these months (Fig 7.21).

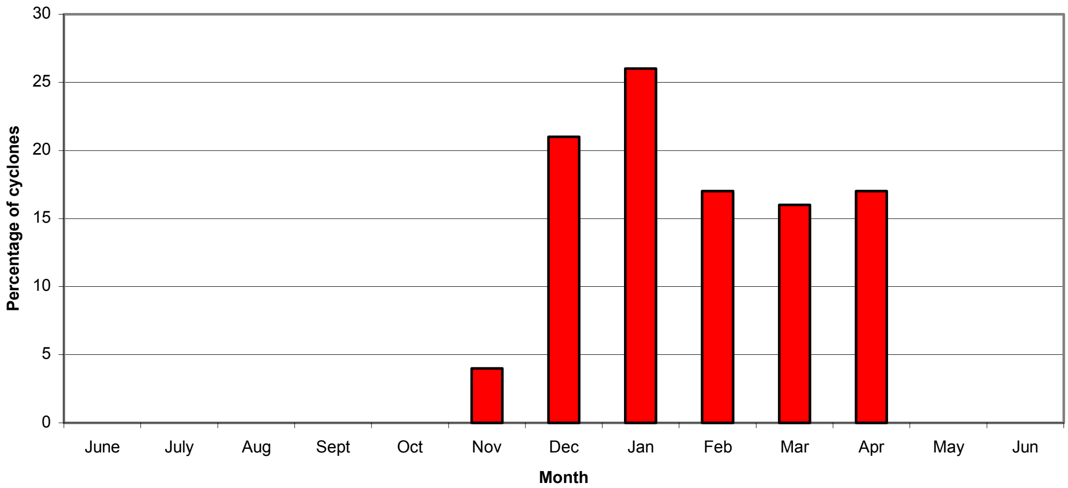

Figure 7.21 The monthly distribution of cyclones (n=101) recorded in northern Australian between 1945 and 2000. Data from Hurricane Alley ([95]).

The high winds associated with cyclones can cause considerable destruction of seabed habitat when cyclones are in shallow water. This is happens mainly when cyclones are adjacent to the coast as is the case with the cyclone shown in Fig 7.22 (Cyclone Steve). There is no noticeable relationship between the strength of a cyclone and the impact on seagrass [(101)]. An analysis on the effects of four cyclones on previously mapped seagrass in the western Gulf of Carpentaria found that only one – Cyclone Sandy had a major impact. The main difference was that instead of crossing the coast at approximately right angles as happens with most cyclones, Cyclone Sandy ran parallel to the coast for about 100 km. The 220 km $^{h-1}$ winds produced huge seas (12 m swell) as well as a significant storm surge. It was estimated that

183 km^2 of seagrass was removed by this cyclone [98]. This represented a 20% reduction of the entire Gulf of Carpentaria seagrass beds [101]. A series of follow-up surveys showed no apparent recolonisation for the first two years but by 1994, the seagrasses had recovered back to pre-cyclonic conditions. Thus this cyclone caused a major impact and it took nearly 10 years for the seagrasses to recover. Although we have no information on the fauna associated with the seagrass we can safely presume there must have been an impact on it. We do know that commercial catches of penaeid prawns declined significantly in the areas offshore of the destroyed seagrass beds. We have no information on the impacts of cyclones on the deeper seabed fauna in the NPF but information from other parts of the world suggests it is highly likely that there are significant effects. In 1992, Hurricane Andrew passed in close proximity to eight natural reef biological monitoring stations and eleven artificial reef sites offshore of Florida [104]. Visual surveys and quantitative photogrammetric surveys were used to estimate the impact of the hurricane on the natural reefs. The fore reef slope of the offshore (5 km offshore) reef, between 17 and 29 m depth was most heavily affected. The algal community consistently showed the greatest loss (40 to >90%) of benthic cover. The sponge community was slightly (0-25%) to heavily (50-75%) impacted, showing the greatest loss on the offshore reef and least on the inshore reef. Soft corals showed a similar trend with 25-50% loss and 0-25% on the offshore and inshore reef, respectively. An additional effect of cyclones is to cause flooding from the heavy rainfall. This flooding occurs in the tropical wet season (Fig 7.21) and so it is unclear whether there is a major impact from the additional flows to the sea.

Cyclones are damaging to the seabed fauna and flora and although they have been part of the natural climate of the region, increased frequency will result in greater impacts in the future.

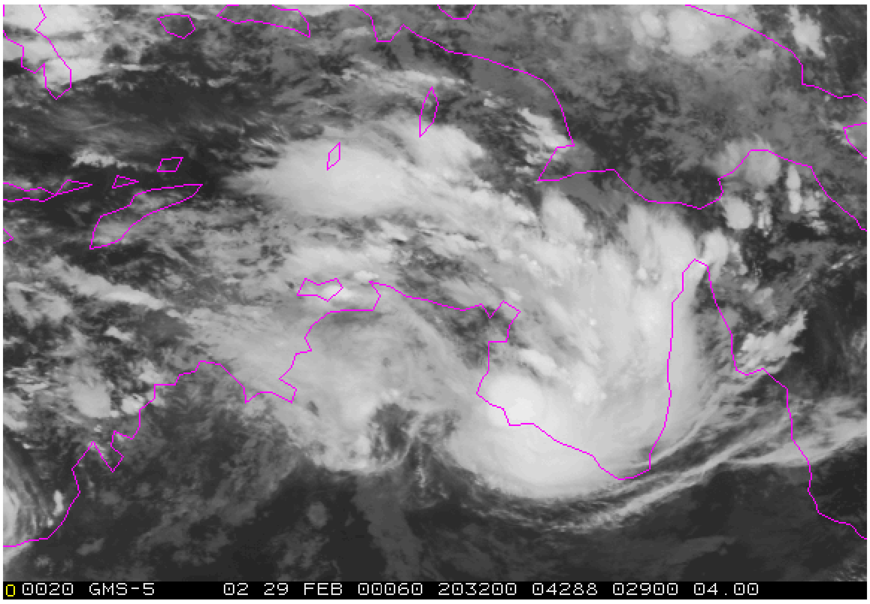

Figure 7.22 Cyclone Steve in the southern Gulf of Carpentaria, March 2000. Photo from Bureau of Meteorology, Australia ([97]).

Coastal development

The most concentrated coastal development in the NPF region is around Darwin. In 2000, the Northern Territory Minister for Lands Planning and Environment announced a proposal to provide additional space for the city of Darwin. This involves building a tidal weir on the Elizabeth River to flood around 800 ha of mangroves that would be removed [107]. Land clearing is allowed in both Queensland and the NT although conditions under which this can be done are gradually tightening. For example in the Litchfield Shire in the NT, owners of land zoned for Rural Living are allowed to clear 50% of the land with no environmental assessment process. The environmental impact of this gradual loss of vegetation – including mangroves – is extremely difficult to assess but overall we can expect it to lead to processes such as increased silt loads in rivers with sedimentation of shallow inshore waters.

SECTION 2 – RISK ASSESSMENT OF THREATS

Methods

The national ESD reporting framework described a method to assess ecological risk for fisheries [91]. The major objective of carrying out the risk assessment is to separate minor acceptable risks from major unacceptable risks so that attention can be focused on the latter. Two factors are estimated – the probable **consequence** of a particular activity and the **likelihood** that this consequence will occur. The product of these factors is termed a risk factor.

The Ecological Risk Assessment (ERA) model uses three levels of assessment:

Level 1 – qualitative risk assessment
Level 2 – semi-quantitative risk assessment
Level 3 – full quantitative risk assessment

The process starts with the Level 1 assessment. Activities that are identified as having a high Level 1 Risk would move into a Level 2 assessment. In turn, activities identified by the Level 2 assessment as high risk would ideally move into a Level 3 risk assessment. The assessment presented here on seabed fauna, is at Level 1 since this is regarded as the initial stage of identifying risks or threats to the seabed fauna and there is little quantifiable data present.

A set of consequence and likelihood tables to assist in this process are given in Tables 7.4 and 7.5.

Table 7.4. General consequence scores. Source: Modified from reference 91

Level	Score	Description
Negligible	0	Very insignificant impacts. Unlikely even to be measurable against natural background levels
Minor	1	Possibly detectable, but minimal impact
Moderate	2	Maximum appropriate/acceptable level of impact
Severe	3	This level will result in wider and longer term impacts occurring
Major	4	Very serious impacts now occurring with relatively long time frame likely to be needed to restore to an acceptable level.
Catastrophic	5	Widespread and permanent/irreversible damage or loss will occur - unlikely to ever be fixed

Table 7.5. Likelihood scores. Source: Modified from reference 91

Level	Score	Description
Remote	1	Unheard of, but not impossible
Rare	2	May occur in exceptional circumstances
Unlikely	3	Uncommon, but reported elsewhere
Possible	4	Some evidence to suggest it is possible here
Occasional	5	May occur
Likely	6	Expected to occur

We have some concern about allocating a score of 0 in the Consequence table since the description of this category is ‘Negligible’. This is not zero and so a score of 1 might be more appropriate. We have maintained the 0 score in this exercise since we are really more interested in the higher level scores but we recommend that further development of this approach should address this point.

After each threat has been allocated a consequence and likelihood scores, these are plotted in a matrix to calculate a Risk Value for each activity as the product of the consequence and likelihood scores. The cells of the matrix are grouped into five "Risk Ranking" categories from Negligible Risk to Extreme Risk (Table 7.6). Risks having values of 7 or greater should trigger a Level 2 assessment (semi-quantitative).

Table 7.6 Risk Matrix. The numbers in the cells are the product of Likelihood and Consequence and indicate risk value. **Blue** - negligible risk (Value 0); **Green** – low risk (Value 1-6.9); **Yellow** - moderate risk (Value 7-12.9 **Pink** - high (Value 13-18.9); **Red** – extreme (Value >19). Source: Modified from reference 91

		Consequence					
		Negligible	Minor	Moderate	Severe	Major	Catastrophic
Likelihood		0	1	2	3	4	5
Remote	1	**0**	**1**	**2**	**3**	**4**	**5**
Rare	2	**0**	**2**	**4**	**6**	**8**	**10**
Unlikely	3	**0**	**3**	**6**	**9**	**12**	**15**
Possible	4	**0**	**4**	**8**	**12**	**16**	**20**
Occasional	5	**0**	**5**	**10**	**15**	**20**	**25**
Likely	6	**0**	**6**	**12**	**18**	**24**	**30**

Results

The various activities that might pose a threat to the seabed fauna of the NPF are categorised in Table 7.8. Nine participants in the project – all scientists - read the chapter and then independently scored Likelihood and Consequence. In the table we have presented the mean scores for each category as well as the Risk Value derived as the product of Likelihood and Consequence. The categories have been ranked by risk.

Table 7.7 Mean scores for Consequences and Likelihood from 9 participants and the calculated Risk score. Risk Values are ranked and colour coded in accord with the scheme used in Table 7.6

	Mean Consequences	Mean Likelihood	Risk
Introduction of a serious marine pest	4.2	4.8	20.2
Change in rainfall with some areas experiencing more and some less rain	3.8	5.1	19.2
Rise in sea temperature	3.7	5.1	18.7
Direct impact on benthos (prawn trawling)	3.4	5.3	18.4
Altered water flows and salinity changes in estuaries	3.2	5.1	16.5
Rise in sea level	3.3	4.9	16.3
Increased frequency of cyclones	2.9	5.4	15.7
Introduction of disease (aquaculture)	3.5	3.6	12.6
Pesticide and herbicide runoff	2.9	4.3	12.5
Removal of predator species causing changes down food chain	2.8	4.3	12.0
Siltation	2.8	4.2	11.7
Removal of predator species causing changes down food chain	2.8	4.1	11.4
Conversion of coastal wetlands	3.0	3.8	11.3
Dredging and disposal of spoil which in some cases is contaminated by heavy metals	2.3	4.7	10.9
Oil Pollution	2.8	3.8	10.5
Burning of bush land	1.8	5.7	10.4
Pollution from mining discharge	3.8	2.8	10.3
Spillage of chemicals used in processing of ores	2.7	3.8	10.1
Discarding of nets causing ghost fishing and pollution of beaches	2.2	4.4	9.9
Pollution by spillage of ore	2.4	4.0	9.8
Dredging for diamonds or gold	3.2	3.0	9.7
Introduction of exotic live bait species	2.8	3.5	9.6
Dumping of rubbish especially plastics	1.9	5.1	9.6
Acid sulphate soils	2.3	4.1	9.6
Possible reduction in numbers of top predators	2.7	3.6	9.5
Siltation	2.2	4.0	8.9
Disposal of rubbish including nets	1.8	4.6	8.1
Poisoning by Anti-fouling Paint	2.3	3.4	8.0
Beche de mer fishery	1.9	4.1	7.7
Oil pollution by mines	2.2	3.4	7.7
Chemical pollution	2.4	3.0	7.2
Pollution and habitat destruction	2.6	2.8	7.2
Shipping accidents	2.0	3.5	7.0
Discarding of trawl nets leading to ghost fishing and pollution of beaches	1.7	4.0	6.7
Impacts on target species	1.9	3.0	5.7
Release of gas from pipelines	1.8	2.3	4.1

Discussion

We have attempted to cover all possible threats to the seabed biota of the NPF Managed area. Clearly some of these are more important than others and the threat analysis is a first attempt to rank the threats. Scientists involved in the Surrogates Project carried out the ranking presented here and so it is not representative of the full range of stakeholders. There was a wide divergence in opinion especially in Consequence scores where the mean score per participant ranged from 1.7 to 5 as compared to a range of only 3.6 to 4.6 for the Likelihood scores. The scoring in this exercise was directed at consequences for the seabed biota as whole but it appears that some participants tended to take a narrower viewpoint and give high scores in cases where the consequences although serious, are probably likely to be limited spatially. We were concerned about the nature of the scoring in the National ESD Framework, especially with regard to having a score of 0 as one of the categories in Consequences. A committee set up by AFMA which is interested in using the scoring to assess all Commonwealth Fisheries is presently reviewing the process and we expect changes to be made to the framework. These changes include a possible broadening of the Consequences axis in the matrix to take into account factors such as frequency, intensity and spatial scale of the threat.

Two threats were scored as having a risk greater than 19 and are classified as Extreme Risk – these are the introduction of a serious marine pest, and changes in rainfall (Table 7.8). Five threats were scored as High risk (scores 13-18.9). These included three climate change effects (rise in sea level, rise in sea temperature and increased frequency of cyclones), altered water flows in estuaries and the direct impacts on the benthos from prawn trawling. Only three threats were classified as Low and none were classified as Negligible.

The high scoring of threats associated with climate change perhaps reflects the scientific interest of the people who did the scoring but climate change does represent an overarching threat that applies to the entire marine fauna. Unfortunately we know little about the consequences of climate change and managers of a fishery are not in a position to reverse it. It is important however to recognise that it is occurring and to take it into account in assessing the fishery.

One of the main intentions of the ESD Framework Risk assessment is to identify those activities or threats that pose a high risk. This serves to focus attention on the important issues that can then be reviewed more thoroughly – and hopefully more quantitatively – than is possible in a general account as presented here. We recommend that the next step in the case of the NPF would be to have a broader more representative group undertake a scoring using the modified version developed by AFMA when this is available.

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CHAPTER 8

MODELLING THE IMPACTS OF PRAWN TRAWLS

ON

THE SEABED FAUNA

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CHAPTER 8

MODELLING OF THE IMPACTS OF PRAWN TRAWLS ON THE SEABED FAUNA OF THE NPF MANAGED AREA

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Summary

The trawl impact model developed for the Queensland East Coast trawl fishery has been applied to the NPF using the following inputs.

- Trawl depletion data based on experiments carried out on the Queensland East Coast
- Recovery data derived from the Sustainability analysis carried out for the Surrogates Project (see Chapter 6)
- Trawl impacts based on effort data at a 1 nm resolution derived by partitioning of 6 nm NPF logbook data using 2001 VMS data (see Chapter 4)

Results

- We demonstrated the value of the model by testing various management options involving different strategies for reduction in effort
- An instantaneous reduction in effort by 25% (the management measure applied in 2002) had similar outcomes to phasing in the reduction over 5 years
- As expected, a 50% reduction over 5 years resulted in greater relative biomass of benthos, more grids exceeded 20% of initial biomass and there was a higher median biomass
- Groups that were impacted the most were gastropods and echinoids. Asteroids were impacted the least
- Medium effort grids showed the greatest responses to changes in effort

Note

An analysis showed that the community structure of the invertebrate and fish benthos of the GBR Green Zone is very different to that of the NPF. We recommend that NPF data be obtained before management decisions are taken in the NPF on the basis of the model

Introduction

The condition of the seabed biota in a trawled area is the result of several factors. These include the original or pre-trawling condition, the rate at which the benthos is removed by trawling and the rate at which the benthos recovers from trawling. Because depletion and recovery are dynamic processes, the condition is a variable that can be altered by changes in either of the two rate processes. If we know the rates for these processes, we can estimate the impacts of trawling and, more importantly, we can assess the effects of management-induced changes in fishing effort. The trawl impact model developed by CSIRO for the Queensland East Coast trawl fishery estimates the impact of repeated trawling on marine epibenthos expressed in terms of percentage removed biomass per vulnerability class on a 6 x 6 nautical mile grid given the level of trawl effort in that grid (Ellis, Pantus and Pitcher, in prep). It does this by integrating information on the amount of benthos removed by a trawl as it runs across the seabed, the rate of recovery of benthos from trawl impact and the number of times a trawl passes over the seabed. The model has been used to test the effect on benthos of management options such as increasing or decreasing effort over various time periods. In this Chapter, we describe the application of this model to the NPF.

Methods

The structure of the trawl impact model is shown in Figure 8.1.

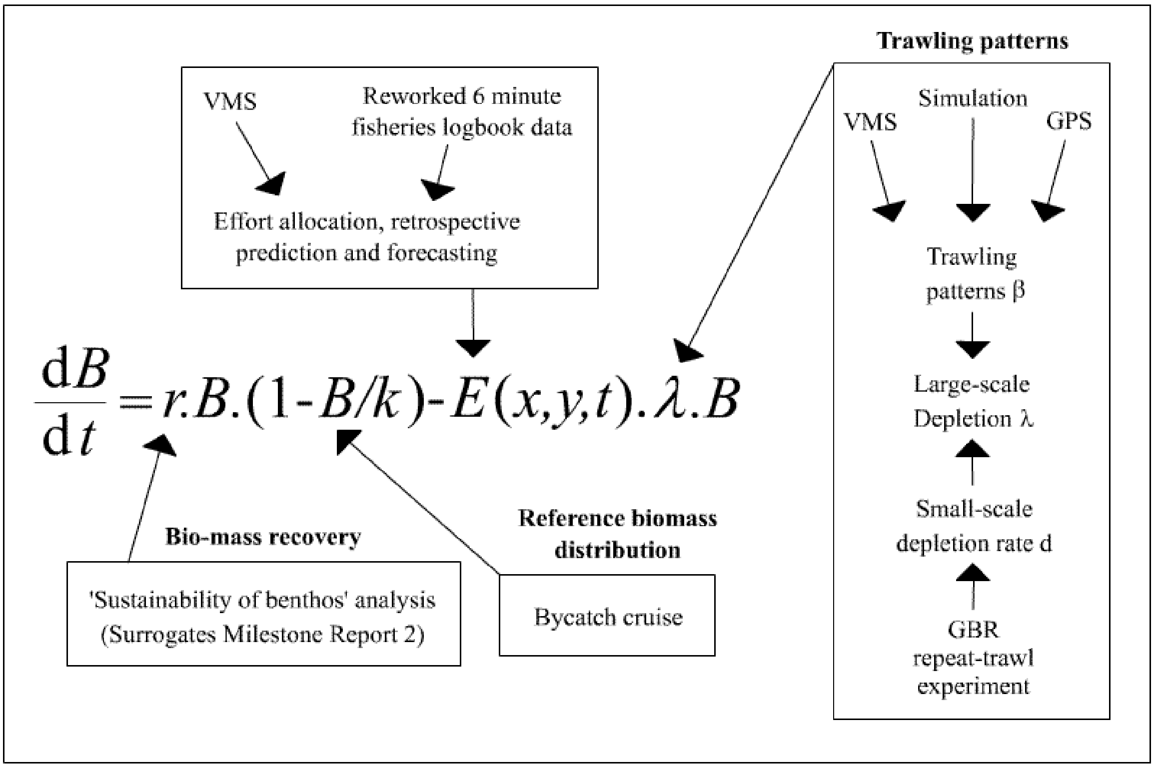

Figure 8.1 Operational model for the scenario modelling

The four main input parameters of depletion rate, recovery rate, level of trawl aggregation and the total effort expended are critical. The following section describes the source of the data and the way we have used the information in applying the East Coast model to the NPF.

Depletion rate

As a trawl runs over the seabed, it affects a proportion of the benthos in its path. We have no information on depletion rates for NPF benthos but there is data from the northern GBR. This was collected by Poiner et al (1998) who carried out a repeat-trawl experiment in an area closed to trawling in the far northern Great Barrier Reef Marine Park. They made 13 successive tows using a 22 m head rope net over the same – or nearly the same – track. Information on the methods and the level of accuracy is given in Poiner et al (1998) and in Burridge et al (2002).

The depletion rates for the most commonly caught benthic organisms were estimated from the change in benthic bycatch over the 13 trawls. The rates are shown in Table 8.1. Although the mean rate of depletion is about 10%, there were quite significant differences between various taxa. Examples of the effect of different depletion rates with repeated trawls are shown in Figure 8.2.

The two plots show the estimated biomass remaining along a particular track after 0 to 13 tows. Although the depletion rates are different, both groups show an exponential decline in biomass indicating that repeated trawling does not alter the rate of depletion.

Table 8.1 Mean depletion rates (%) for various benthic taxonomic groups from a single pass of a prawn trawl. Data from Burridge et al (2002).

Taxonomic group	Mean depletion rate	Taxonomic group	Mean depletion rate
Algae	4	Crustaceans	13
Sponges	12	Bivalves	9
Hydrozoans	8	Gastropods	20
Gorgonians	15	Asteroids	10
Nephtheid soft corals	9	Crinoids	8
Zoantharians	11	Echinoids	14
Bryozoans	9	Holothuroids	11
Ascidians	11	Ophiuroids	9

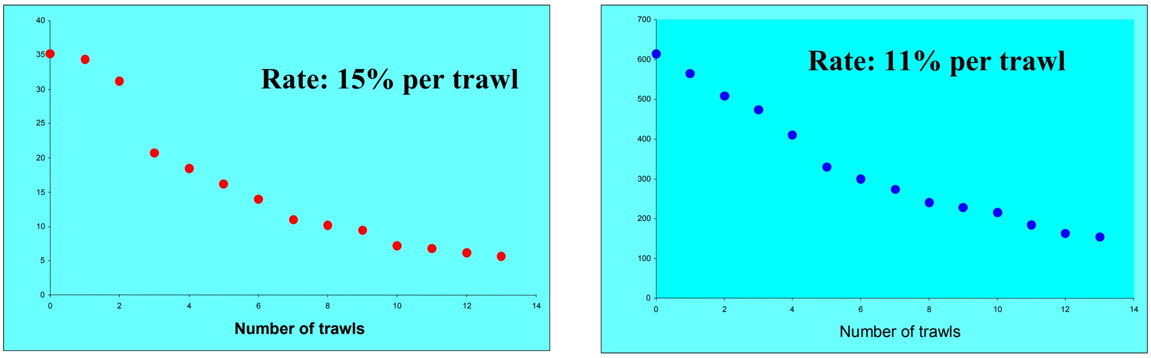

Figure 8.2 Estimated biomass during a series of trawls for two species, one with 15% depletion per tow, the other with 11% depletion per tow.

Comparison between GBR and NPF benthos

As we have used depletion rates from the GBR in applying the impact model to the NPF, we considered it important to compare the prawn trawl bycatch composition from the Great Barrier Reef study with that collected in the NPF.

A small subset of the data collected by Poiner et al. (1998) from the northern Great Barrier Reef was suitable for comparison with data from the NPF. Trawls in the GBR were made using the QDPI Research Vessel Gwendoline May in May 1992. Data from the NPF was collected using the CSIRO Research Vessel Southern Surveyor in February/March and October/November 1997 and in March 1998. All data used in the comparison were collected with prawn trawl nets towed at night. Most fish were identified to species level whereas many of the invertebrates could be identified only to higher taxonomic levels. Fish and invertebrates have therefore been treated separately in the analyses reported here. Because of the difficulty in identifying many of the invertebrates and the variability in levels of identification, the invertebrates were combined into 17 taxonomic groups. Only fish species that occurred in at least 5% of the samples for each major region (GBR and NPF) were included in the analyses, resulting in 188 fish species being used. The weight of each species or taxon was standardized by the duration of the trawl, and catch in weight hour^{-1} was used in further analyses.

Multi-dimensional scaling analyses were carried out on the two data sets using the PRIMER analysis package. The data was square root transformed and species similarity matrices were constructed using the Bray-Curtis similarity coefficient. MDS plots for invertebrates (Figure 8.3) and fish (Figure 8.4). Both showed substantial differences in the species distribution between the GBR trawls and the NPF trawls. These differences were tested using the ANOSIM test in PRIMER and were found to be highly significant (0.1%). Because of the relatively small amount of data available for comparison, the interpretation of these results needs to be treated with some caution.

There is a large separation evident in the two MDS plots indicating that invertebrate and fish communities of the GBR are different from those of the Torres Strait and the NPF. There are also some differences with respect to the invertebrates within the NPF and – to a lesser extent also in the fish – the Melville community appears to be different to the rest of the NPF.

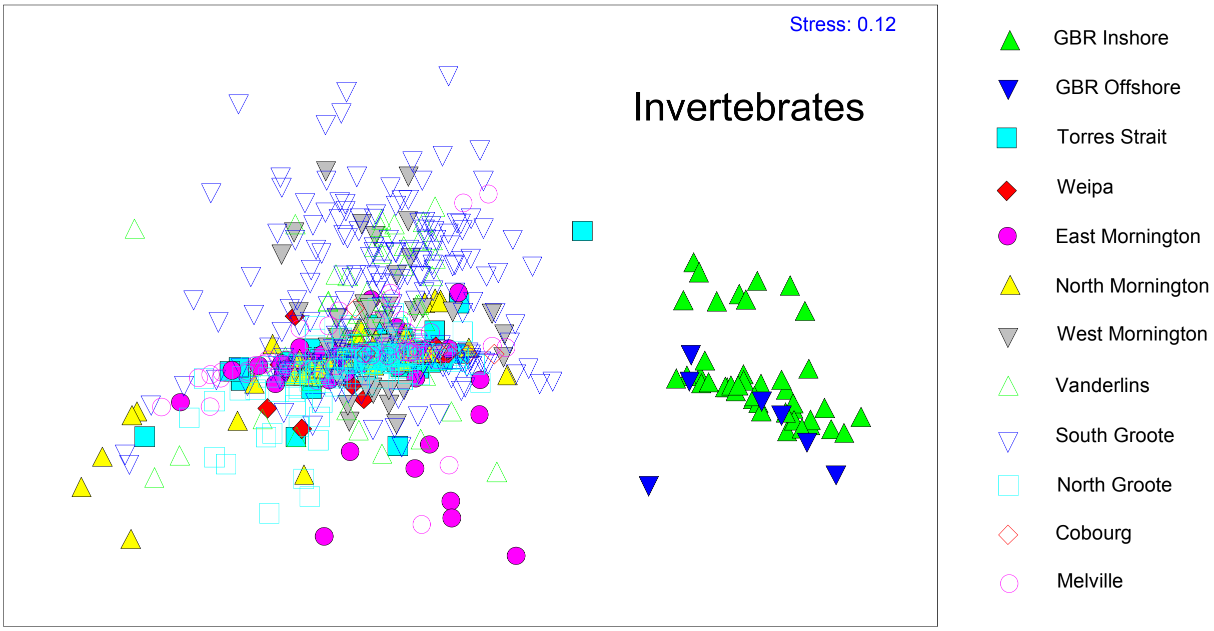

Figure 8.3 MDS plot of the species similarity matrix produced using 17 invertebrate taxonomic groups for trawls in 12 regions of the northern Great Barrier Reef (GBR), Torres Strait, and the Northern Prawn Fishery.

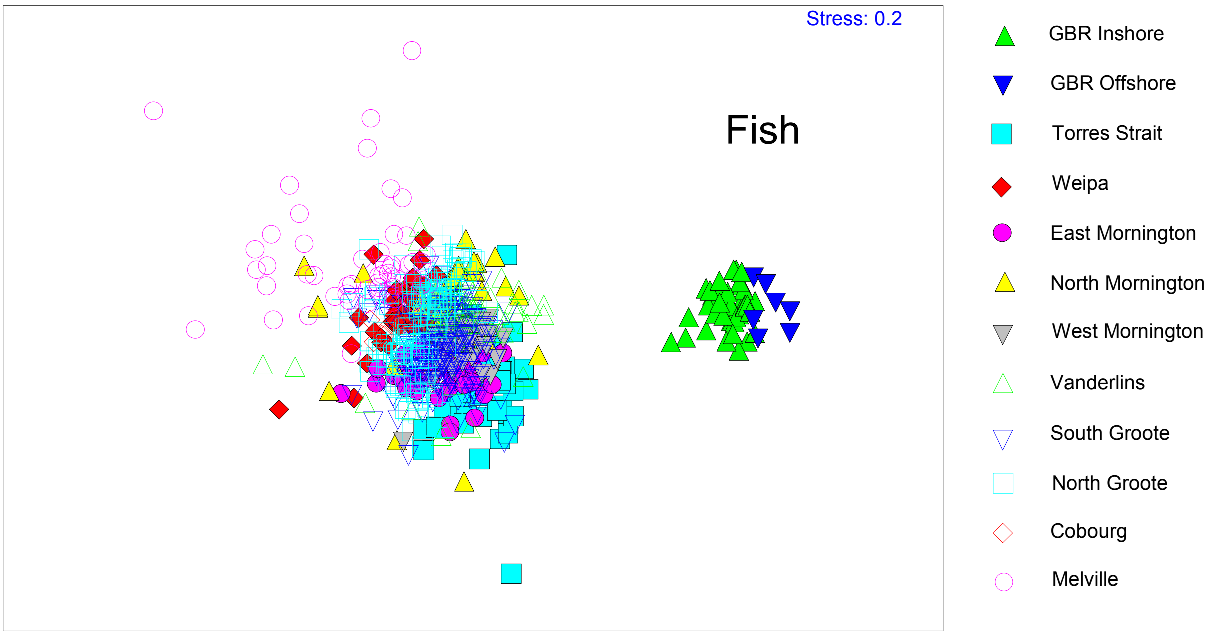

Figure 8.4. MDS plot of the species similarity matrix produced using fish species for trawls in 12 regions of the northern Great Barrier Reef (GBR), Torres Strait, and the Northern Prawn Fishery.

In Table 8.2 we present the percentage composition by weight of the invertebrate taxonomic groups for the various regions that were analysed. The table shows that the benthos is dominated by crustaceans. In many areas sponges also make up a major proportion of the benthic biomass. The only other groups to make a major contribution in some areas are the echinoids– in the Vanderlins and South Groote they make up over 40% of the biomass. The most striking difference between the Green Zone and the NPF is the very high contribution by asteroids in the offshore Green Zone (21%) compared to only 2.5% in any other area. Apart from this difference, the range in composition for the various invertebrates between the inshore and offshore parts of the Green Zone nearly covers the range in the NPF.

These analyses show differences in the composition of the benthic fish and invertebrate communities between the GBR and NPF. These differences make it questionable whether we should use depletion rates derived from the GBR in the NPF model. In the absence of any depletion rates for the NPF, we have used the GBR rates here, but we do have reservations about doing so. We recommend that depletion rates for the NPF benthos should be measured before any management decisions are based on the trawl impact model.

Recovery Rate

Although several studies have examined the rate at which benthos is removed by trawling, there is little information on the rate at which benthos recovers. No measurements of the rate of recovery by benthos from trawling are available for the NPF. This represents a major gap in our knowledge on the impact of trawling on benthic organisms. There is some information resulting from monitoring of the depleted tracks in the GBR experiment. Monitoring was carried out at intervals for five years using video to minimize further impacts (Pitcher et al, in preparation). This monitoring has only recently been completed and the data is not yet available. At this stage we can draw only general conclusions about the rate at which the benthos recovers, namely, that the process of recovery to a population structure comparable to the unfished condition appears to be very slow. Only sessile animals were monitored in the GBR study and so we have no information on recovery of the many mobile species. We suspect that in the case of mobile animals, immigration into trawled areas may be an important mechanism in maintaining populations in the area, but we have no data on this. Continuing high levels of bycatch in trawled areas supports the existence of a dynamic process of immigration into trawled areas. After one year, the GBR monitoring showed a large scale colonization by soft corals in both trawled and control areas. After four years, gorgonians, whips and some

Table 8.2. Percentage contribution of various taxonomic groups to the bycatch in regions of the northern GBR (Green Zone inshore and offshore), Torres Strait and the NPF.

	Algae	Ascidians	Asteroids	Bivalves	Bryozoans	Cephalopods	Crinoids	Crustacea	Echinoids	Gastropods	Gorgonians	Holothuroids	Hydrozoans	Ophiuroids	Soft Coral	Sponges	Zoantharians
Green Zone Inshore	0.02	0.05	2.12	9.46	0.08	5.25	0.38	39.91	0.81	0.01	2.51	0.61	0.49	0.06	0.60	37.60	0.04
Green Zone Offshore		0.23	20.96	0.13	1.39	8.31	0.63	65.74			0.44		0.12	0.68	1.23	0.09	0.05
Torres Strait	0.01	1.58	1.21	0.85	0.03	4.11	0.83	54.47	0.31	0.10	2.51	1.29	0.41	0.01	0.18	32.05	0.05
Weipa			0.05	5.46		4.37		84.58		0.03		1.11	0.05	0.01	1.83	0.70	1.81
East Mornington	0.02	0.20	2.55	1.91	0.15	3.31	0.37	26.75	1.36	0.11	25.45	0.96	0.01	0.38	0.25	36.04	0.19
North Mornington		1.84	2.48	8.72	0.35	10.67		59.31	8.46	0.17		1.39	0.01	0.01	0.50	5.97	0.13
West Mornington		0.02	1.08	5.42	0.36	6.23	0.00	43.78	31.82	5.03	0.37	2.25	0.05	0.00	0.16	3.29	0.16
Vanderlins		0.11	0.87	1.50	0.03	3.43	0.02	28.73	41.06	0.28	0.49	0.21	0.01	0.23	0.03	22.98	0.04
South Groote	0.00	0.52	1.75	7.93	0.10	2.21	0.03	22.32	47.89	0.92	3.23	1.62	0.05	0.02	0.11	10.44	0.87
North Groote		0.18	0.26	12.29	0.01	12.47		69.02	1.40	0.26	0.28	2.84	0.04	0.10	0.53	0.23	0.08
Cobourg				0.49		0.33		93.19	0.04	0.07	0.06	5.07			0.44		0.30
Melville			1.52	2.80		2.15	0.03	42.75	15.28	0.13	0.66	33.91		0.02	0.24	0.14	0.39

sponges were also present, but all were small. Hard corals showed little sign of recovery. Using this preliminary information, we have divided the benthos into three broad classes on the basis of recruitment. Firstly animals such as soft corals, which can recruit rapidly and within a year were present in large numbers in the depleted and control areas although the individuals were small. Secondly gorgonians and sponges that appear to be capable of recruiting within 5 years although again they have not grown to full size. Thirdly a group that after 5 years had undergone only limited recruitment and which we suspect take longer to recover. These rates are low which is surprising given that this shallow water fauna is exposed to periodic natural damage from storms and especially cyclones.

As reported in Chapter 6 we have carried out an evaluation of the vulnerability and recovery of the NPF benthos to trawling as part of the estimation of the sustainability of the benthos. In that evaluation, we scored the sustainability of each benthic group on a scale of 1 to 3 on the basis of a number of biological attributes. The attributes used for recovery are repeated here in Table 8.3.

A score of 3 for an attribute indicated a high recovery rate with respect to that attribute. The scores were averaged to give an index of recoverability for each group. In the absence of any direct measures of recovery for the NPF benthos, we have used these scores but converted them into a scale of recovery time τ; this is the time taken for a group of organisms to recover from 50% biomass to 95% biomass. We assigned a recovery time of 1 year for animals with a recovery index of 3, 5 years for a recovery index of 2 and 10 years for a recovery index of 1, but note that this may be a major underestimate for some species. Actual conversions were made using the relationship,

$$\tau = 14.33 - 4.5\, i,$$

where i is the mean recovery index and τ is in years.

The trawl depletion model assumes that, in the absence of depletion, the biomass of an organism will follow the sigmoidal curve,

$$B(t) = B_{\max}\exp(r_s t)/(1+\exp(r_s t)),$$

with recovery rate parameter r_s. The conversion from recovery time to recovery rate is:

$$r_s = 3/\tau$$

Table 8.4 shows the combined values of depletion and recovery rates that are used in the scenario modelling.

Table 8.3: Recovery attributes used in assessing sustainability of benthic taxa in the NPF. Source: Chapter 6

Criterion	Scoring
Fragility with respect to trawl	1 = very fragile 2 = damage from trawls is probably not lethal 3 = very robust
Ability to regenerate	1 = Regeneration limited to minor wound repair, likely to be killed by trawl impact 2 = Can replace appendages but not recover from major damage 3 = Well developed regeneration ability
Reproductive strategy	1 = No or short-lived larval dispersal stage 3 = Pelagic larval stage
Effect of trawl damage on reproduction	1 = eggs vulnerable to trawl damage or are broadcast spawners 3 = trawl damage limited to juvenile or adult stage

Table 8.4 Recovery and depletion values for the 12 taxa for which trawl management scenarios were run

Taxon	recovery rate r_s (year^{-1})	depletion rate per tow d
Ascidians	0.40	0.11
Asteroids	0.97	0.10
Bivalves	0.52	0.09
Bryozoans	0.40	0.09
Crinoids	0.56	0.08
Crustaceans	0.52	0.13
Echinoids	0.40	0.14
Gastropods	0.41	0.20
Gorgonians	0.71	0.15
Holothuroids	0.56	0.11
Hydrozoans	0.56	0.08
Ophiuroids	0.63	0.09
Soft corals	0.40	0.09
Sponges	0.71	0.12

Trawl effort and aggregation

The prawn fishery can be divided into two on the basis of the species targeted – banana prawns (*Penaeus merguiensis*) and tiger prawns (*P. esculentus* and *P. semisulcatus*). Trawling for banana prawns lasts for up to a month each year. During this period, most time is spent searching for schools. When a school is found, the nets are in the water only for the period while the trawler steams across the school. A high opening net is used and it spends little time on the seabed. Following the banana prawn fishery, the trawlers fish for tiger prawns for the remaining 5 to 6 months for which the fishery is open. In fishing for tiger prawns, the net is almost continuously on the bottom, trawl shots are around 3 hours in length and turn-around time between shots is short. The net is trawled on the seabed. Because of these differences, we have assumed that trawling for tiger prawns has a larger impact on the benthos than does trawling for banana prawns

Skippers of NPF trawlers are required to record in their fishing logs in which 6 nautical mile grid square they did most of their fishing each night. Trawling does not occur at random across a 6 × 6 nm grid because skippers target areas with the highest catch rates of prawns. Thus trawling is aggregated to some extent.

In the East Coast version of our model we modelled within-grid aggregation by means of a statistical distribution of point coverage. This statistical model was motivated by examination of real tracks of trawlers from on-board plotter data and by simulation of trawler behaviour to generate virtual trawl tracks *in silico*. We found that the degree of aggregation could be adequately controlled by a single parameter β.

In the current study, we have used a different approach to quantify aggregation than that used in the East Coast study; the approach here is based on VMS data, which has been aggregated at a fine scale of 1 nm grids. We partitioned the log book effort, which is at 6 nm resolution, into 1 nm grids by allocating effort to each grid according to the relative degree of effort as measured by the VMS method described below and in more detail in Chapte 4. We then ran the trawl depletion model on the 1 nm grid.

The aggregation parameter β is still a free parameter in our model. This determines the degree of aggregation occurring at scales *finer* than the grid on which effort is measured. We could specify further aggregation at the sub-1nm grid level, by setting a positive value of β. However, in the absence of more detailed information, we have assumed random trawling within each 1nm grid, implying β=0. This means that the aggregation is fully accounted for at the 1 nm level.

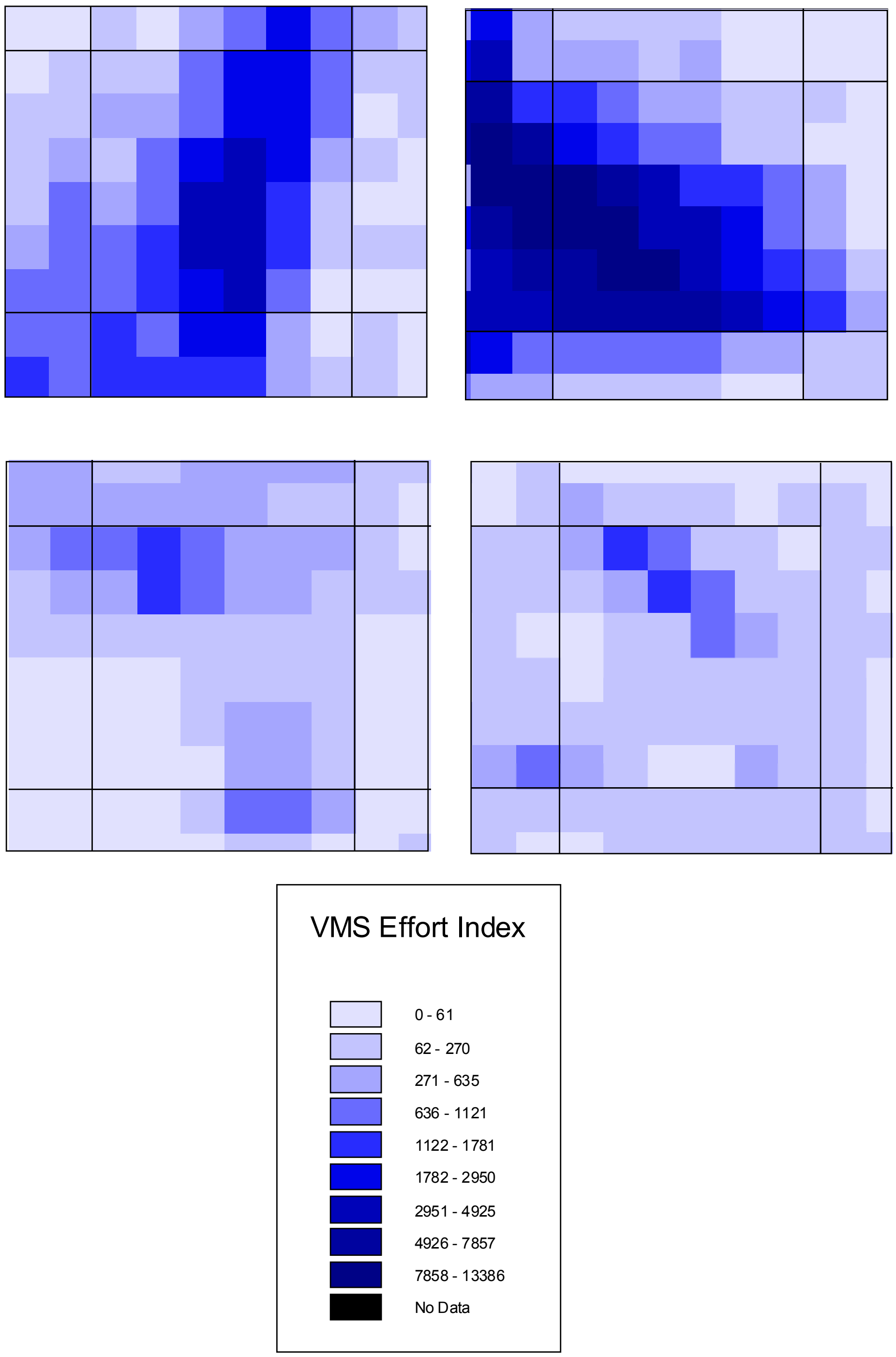

Figure 8.5 Four examples of fishing effort generated from VMS data collected throughout the NPF during the period 1 August 2000 to 31 October 2000. The large squares are the 6 x 6 minute grids representing the scale at which AFMA collected daily catch records from the fishers. The coloured squares show the fishing effort partitioned on a 1 x 1 minute scale using the distribution of VMS data. Top left (a high effort grid) is based on 317 nights of effort (two vessels on the same night is counted as two nights of effort) by 44 vessels. Top left (a high effort grid) is based on 425 nights of effort by 60 vessels. Bottom left (a low effort grid) is based on 71 nights of effort by 9 vessels. Bottom right (a low effort grid) is based on 30 nights of effort by 11 vessels.

Since the start of the 1999 season, all trawlers in the NPF have been required to carry a VMS (Vessel Monitoring System) that enables the manager (AFMA) to poll the vessel and establish its position. AFMA made available to us a subset of the VMS data covering August, September and October 2000 which is the peak of the tiger prawn fishing. We have used this subset to partition the effort. The method used is described in detail in Chapter 4. We present here effort for four grids in the NPF (Figure 8.5). In each case the 6 nm grid is shown as the larger outline. The pixels show the result of allocation of the effort reported for the 6 nm grid to 1 nm squares using VMS data for the partition. Each example shows that effort is not spread uniformly across the 6 nm grid but tends to be aggregated. In order to protect confid-entiality of logbook information, we have not identified here the position of these four 6 nm grids within the NPF.

Depletion with recovery

As the benthos is being depleted, it is also recovering at some rate. The condition of the benthos at any particular point in the fishery is the result of these two simultaneous processes. We have shown elsewhere (Ellis, Pantus and Pitcher, *in prep*; Ellis and Pantus, 2001), that the biomass $B(t)$ is governed by the following differential equation

$$\frac{dB}{dt} = rB(t)(1 - B(t)/K) - \lambda e(t)B(t),$$

where K is the carrying capacity, λ is the large-scale depletion rate and r is the large-scale recovery rate. These large-scale quantities are defined in terms of the depletion rate per tow d and the (small-scale) recovery rate r_s thus:

$$\lambda = \log(1 + \beta d)/\beta \text{ and } r = r_s \log(1+\beta d)\big/\left[-\beta \log(1-d)\right],$$

where β is the aggregation parameter. We assume here that trawling is random within 1-minute grids so that $\beta = 0$. In this case we find

$$\lambda = d \text{ and } r = r_s d\big/\left[-\log(1-d)\right].$$

Most outputs of the simulations are in terms of the *relative biomass* $b(t) = B(t)/K$, which is the biomass as a fraction of its carrying capacity. We make the assumption that the biomass was at carrying capacity before the trawl fishery began, so that the pristine relative biomass was 1.

Management Intervention Options

We ran the model with constraints that mimic management intervention. These were:

1. Status quo: no management intervention.
2. Instantaneous reduction in effort of 25%.
3. Reduction in effort by 25% over a five year period.
4. Reduction in effort by 50% over a five year period.

This second case simulates the 25% reduction in total head rope length that came into force at the start of the 2002 season. Option (3) is considered in order to contrast the instantaneous introduction of a reduction with a gradual introduction. We will see that in the long term these two options are practically identical. Option (4) is a more severe reduction to be contrasted with option (3). It is important to include option (1) as a benchmark against which all the other options are compared. This is nominally the status quo situation which arises as a result of no management intervention. However, we should note that it does not take into account changes that arise independently of management intervention, such as effort creep – the gradual increase in effort brought about by improvements in technology.

Area of the model

Although we can run the model for any part of the NPF, we present here the results for two areas, North and South Groote since these are the areas for which we have the best data on benthos. These areas represent a major section of the tiger prawn fishery.

Effort allocation for future times

As a result of analyses carried out in this project (see Chapter 4) we have 1-minute effort data based on combined logbook and VMS information for the years 1991–2000. Our scenarios run from 2001 to 2020 and so we need a way to allocate effort to the grid over these years. We used a two stage approach: First we assigned a nominal effort to a grid by randomly selecting from one of the years 1996–2000; we did this for all grids. Second, we rescaled the effort uniformly over all grids so that the total effort equaled the desired effort cap for the scenario in question. The effort cap is relative to the reference year 1999 chosen because the overall effort in 1999 was close to the average effort over 1991–2000 in the Groote region. The random allocation in the first step above is the same for all 4 scenarios in order to make the scenarios comparable. Note that our scenarios do not include closures; if closures are incorporated, it is necessary also to consider displacement of effort from closed grids.

Results

The results come in various levels of detail. At a very high level is the *decision table*. This summarizes the overall effect of the 3 alternative management scenarios relative to the status quo scenario, for 3 different performance indicators (see Figure 8.6). The summaries, in this case means and standard deviations as represented by the error bars, are taken over all 12 taxa. The performance indicators are chosen so that higher values correlate with higher benthic abundance. The general impression of this decision table is that: all scenarios lead to greater conservation of the benthic fauna than the status quo (because the percentage change is positive); the 50% reduction scenario has the greatest effect; and the two 25% reduction scenarios have very similar effects.

If we wish to investigate the results in more detail we can look at an expanded decision table showing the effects on the individual taxa (Table 8.5). The taxa are ranked according to percentage change. One obvious feature is that this ranking is totally consistent over all scenarios and indicators. This means that the taxa can be ranked according to vulnerability with gastropods and echinoids the most vulnerable and asteroids the least. Looking back at the recovery and depletion values in Table 8.4, we see that gastropods and echinoids are vulnerable because they have relatively high depletion rates and low recovery rates. In comparison sponges and gorgonians, which also have high depletion rates, are less vulnerable because of their relatively high recovery rates.

The decision table shows that there is very little difference between the two 25% reduction scenarios, at least in 2020. We could investigate why this is so by looking at the time histories of the indicator, in particular in the transitional period 2002–2006. We restricted attention to echinoids; the results are qualitatively similar for the other taxa. Time histories are shown in Figure 8.7 for the mean relative biomass indicator and two other indicators: first quartile of relative biomass and proportion of grids exceeding 70% initial biomass. The graphs are qualitatively similar. Prior to the introduction of the management action the curves are

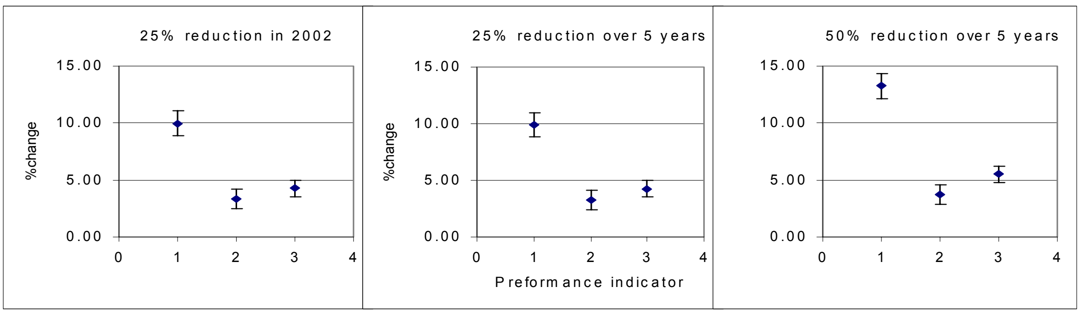

Figure 8.6 Decision table for 3 performance indicators. The indicators are 1) mean relative biomass, 2) proportion of grids exceeding 20% initial biomass, and 3) median relative biomass, all measured in 2020. The vertical scale is the percentage change of the performance indicator under the 3 alternative scenarios relative to the status quo scenario. The error bars show the mean and standard deviation of the percentage change over the 12 taxa.

identical. There is a sharp change in the gradient of the indicators at 2002 and initially the ‘25% reduction in 2002’ scenario has the greatest conservative affect. However, the 50% reduction scenario soon emerges as the most conservative case. The ‘25% reduction over 2002–2006’ scenario, lags behind the other 25% reduction scenario but eventually catches up with it and they become virtually indistinguishable beyond about 2015. Another important thing to note is that the status quo scenario has not reached a steady state by 2000 and the biomass declines further in this case. That is, keeping the effort at today’s levels does not

Percentage change of indicator relative to status quo in 2020		Management Action		
Indicator	Taxon	25% reduction in 2002	25% reduction over 2002-2006	50% reduction over 2002-2006
Mean relative biomass	Gastropods	18.2	18.1	25.0
	Echinoids	14.7	14.6	19.9
	Ascideans	12.1	12.1	16.2
	Crustaceans	11.5	11.4	15.2
	Bryozoans, Soft corals	10.1	10.1	13.4
	Gorgonians	10.0	10.0	13.2
	Holothuroids	9.1	9.1	12.0
	Bivalves	7.9	7.9	10.5
	Sponges	7.9	7.9	10.4
	Ophiuroids	6.6	6.6	8.6
	Crinoids, Hydrozoans	6.5	6.5	8.6
	Asteroids	4.7	4.7	6.1
Proportion of grids exceeding 20% initial biomass	Gastropods	10.6	10.5	12.3
	Echinoids	6.9	6.7	7.9
	Ascideans	4.7	4.6	5.2
	Crustaceans	4.0	3.9	4.4
	Gorgonians	2.8	2.8	3.2
	Bryozoans, Soft corals	2.8	2.7	3.1
	Holothuroids	2.2	2.2	2.5
	Bivalves	1.6	1.6	1.8
	Sponges	1.6	1.6	1.7
	Ophiuroids	1.1	1.1	1.1
	Crinoids, Hydrozoans	1.1	1.1	1.1
	Asteroids	0.4	0.4	0.4
Median relative biomass	Gastropods	10.7	10.7	13.9
	Echinoids	7.0	7.0	9.0
	Ascideans	5.1	5.1	6.7
	Crustaceans	4.7	4.7	6.0
	Bryozoans, Soft corals	4.1	4.1	5.3
	Gorgonians	3.8	3.8	4.9
	Holothuroids	3.5	3.5	4.5
	Bivalves	3.0	3.0	3.9
	Sponges	2.9	2.9	3.7
	Crinoids, Hydrozoans	2.4	2.4	3.1
	Ophiuroids	2.4	2.4	3.1
	Asteroids	1.6	1.6	2.1

Table 8.5: Decision table for 3 performance indicators. The indicators are 1) mean relative biomass, 2) proportion of grids exceeding 20% initial biomass, and 3) median relative biomass, all measured in 2020. The value shown is the percentage change of the performance indicator relative to the status quo scenario. The taxa are sorted in decreasing order of percentage change for the 50% reduction scenario.

keep the benthos at today's levels.

All the indicators are statistics (such as means or quantiles) on the relative biomass distribution over the spatial area of interest, which is a rectangular region centred on Groote Eylandt. We can get more detailed information by looking at the distribution itself by means of histograms. In Figure 8.8 we see the histograms of relative biomass for gastropods, gorgonians and asteroids. For asteroids, practically all the 1-minute grids have a relative biomass close to 1. However, for gastropods (and to a lesser extent for echinoids) a small number of grids have been almost totally depleted (relative biomass < 0.1), although this number is fewer for the 50% reduction scenario compared to the others.

Having identified that there are grids with a high level of depletion, we can identify where they are on a map. Figure 8.9 shows a related quantity, that is, the difference in relative

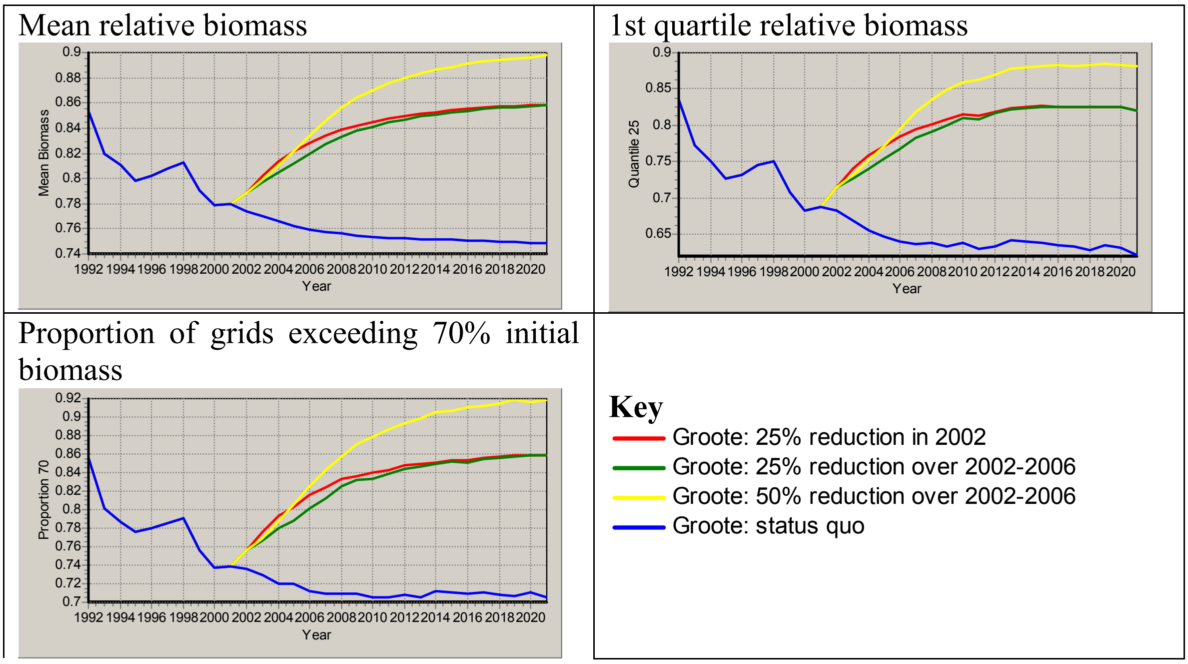

Figure 8.7 Time histories of various indicators for echinoids over period 1991–2020

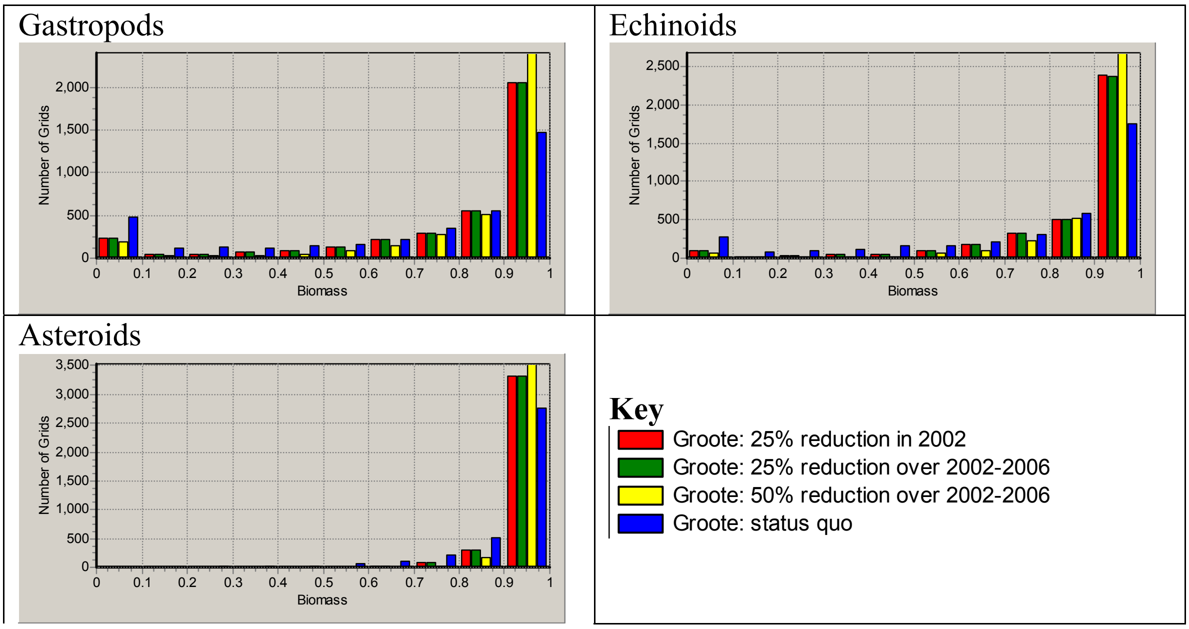

Figure 8.8 Histograms for relative biomass in 2020 for 3 taxa

biomass between the 50% reduction scenario and the status quo. This is everywhere greater than zero because the 50% reduction scenario is more conservative than the status quo. The difference is naturally largest in areas where the effort is greatest. The relative spatial pattern is similar for the various taxa.

It is important to be aware that these maps are based on *relative* biomass. One can think of relative biomass as the biomass that would be present if the pristine (i.e. pre-fishing) biomass in each grid cell were everywhere equal to 1. We can also produce maps of *absolute* biomass providing we have a reference map of absolute biomass from survey data for some particular year. If B_r is the reference absolute biomass, b_r is the modelled relative biomass for that reference year and b_t is the modelled relative biomass for some other year t, then the modelled absolute biomass for year t is simply given by

$B_t = B_r\,(b_t/b_r)$.

We have used raw survey data from 1998 to obtain a map of echinoid density off the south-west corner of Groote Eylandt. The raw data consist of catch per hour of echinoids at various

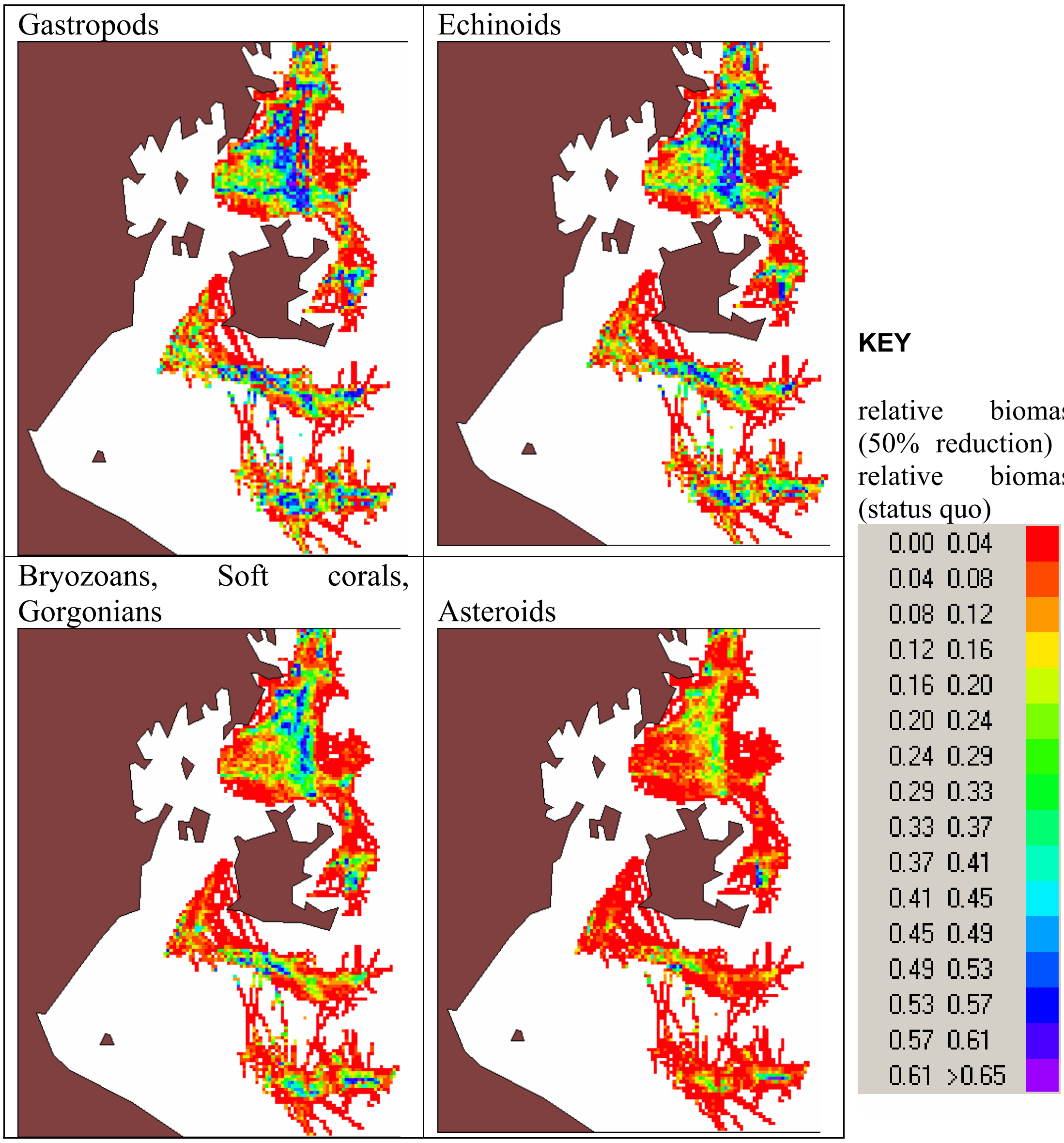

Figure 8.9 Maps of the *difference* in relative biomass between the 50% reduction scenario and the status quo scenario for the year 2020. All maps are drawn on the same scale ranging from 0 (red) to 0.65 (purple).

stations. We chose to analyse echinoids in this region because they occurred at most of the stations. Other taxa were either very sparsely sampled or not highly impacted by trawling. We used a simple local regression smoothing procedure to generate the maps (Figure 8.10). The density is in units of g m^{-2}. This has been converted from the raw hourly catch rates by dividing the area trawled per hour and by the depletion rate per tow.

We show the density measured in 1998 and the modelled density in 2020 for the status quo and 50% reduction scenarios. Echinoids were observed in greatest abundance in the green V-shaped region in the west, south-west and centre at a density of about 0.5 g m^{-2}. (The apparently high density to the north of the region is probably an artefact caused by extrapolation outside the convex hull of the stations.) The areas of high effort are in the centre, west, south-west and south-east. Therefore the highest impact occurs when both effort and density are high, that is, in the west and centre. We can see that the 50% reduction scenario has higher density in these areas. In the other areas, there is little difference in the scenarios, either because the density is low (in the south-east) or because the effort is low (in the north).

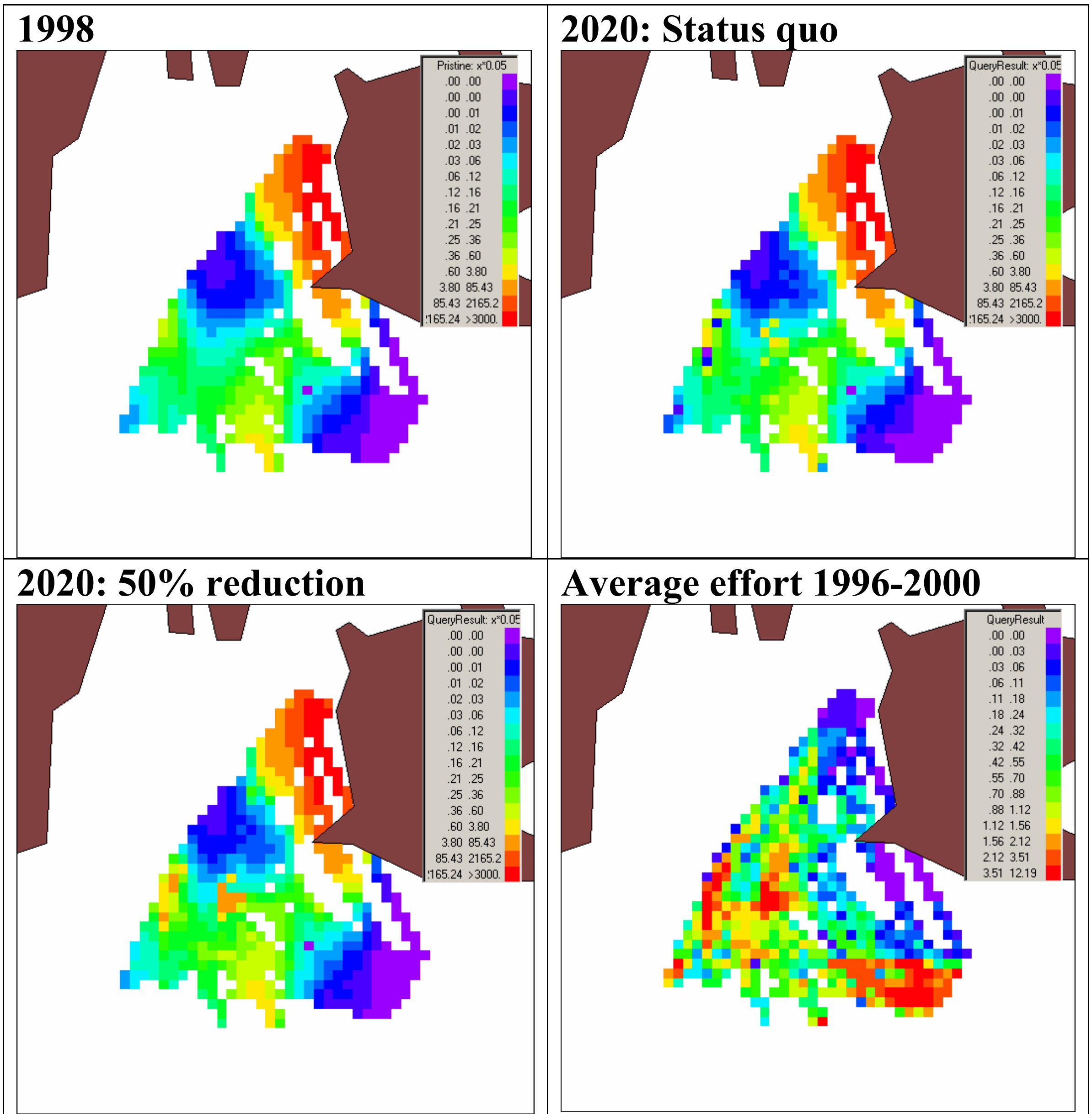

Figure 8.10 Modelled echinoid density (g m^{-2}) in the survey year (1998) and after the status quo and 50% reduction scenarios in 2020. Also shown is the average effort in 1996–2000, which is the period from which effort is reallocated for future years. The density maps are all on the same scale.

Low effort grid:
0.2 boat days
20th percentile

Medium effort grid:
2.3 boat days
80th percentile

High effort grid:
10.8 boat days
99th percentile

Key:

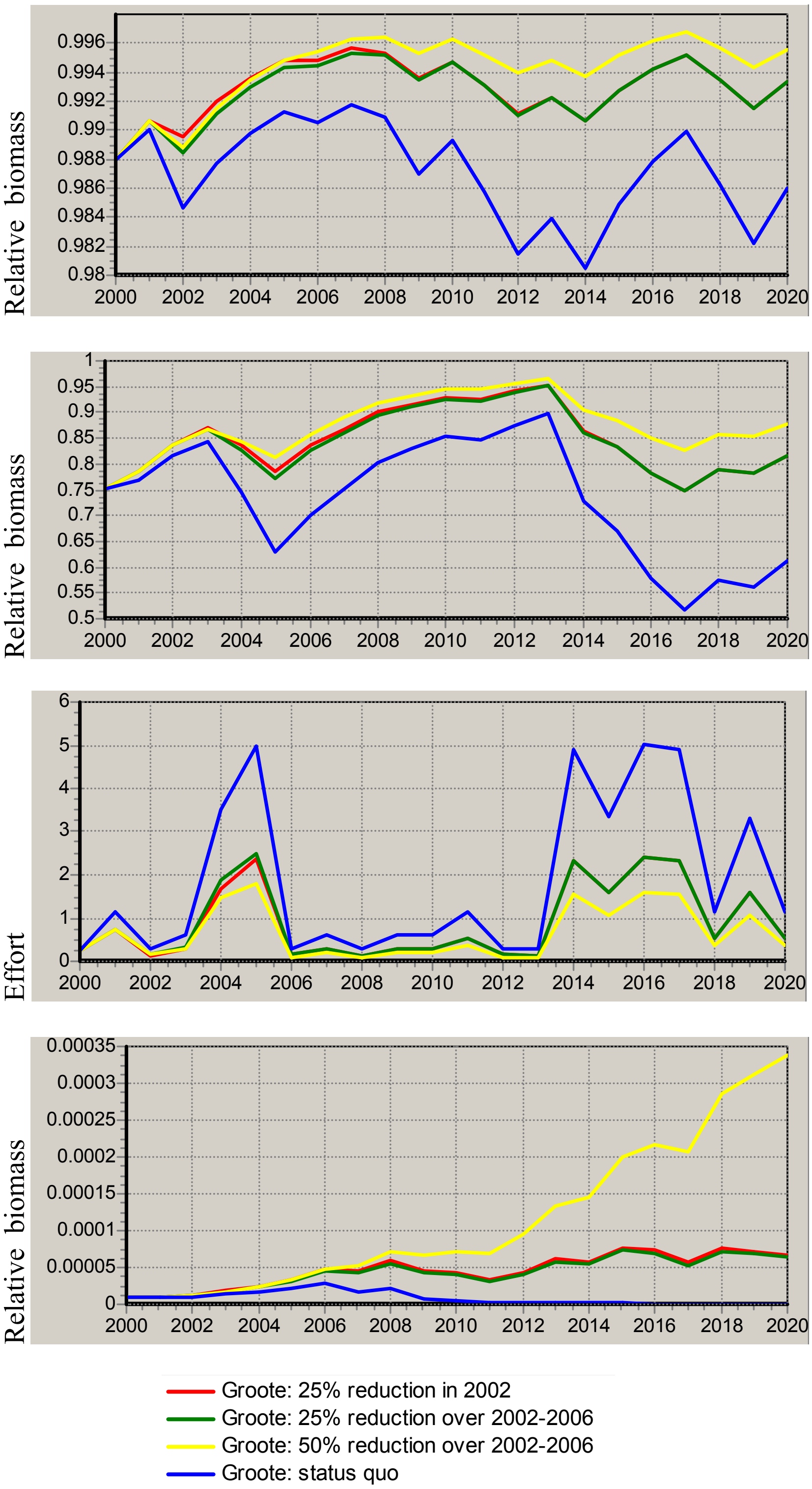

Figure 8.11 Time histories of relative biomass of echinoids over 2000–2020 for individual grids having (*top*) low, (*middle*) medium and (*bottom*) high effort. The 3 grids are on different scales. For the medium effort grid the effort history is also shown.

There are some grids near the centre where the density under the status quo scenario is actually higher than it was in 1998. This can happen if the randomly selected effort in that grid is lower than the average effort in 1991–2000, and it is more noticeable for high-effort grids.

We can investigate the results of scenario modelling at the level of individual grids by plotting time histories. For instance, Figure 8.11 shows how the relative biomass changes over time for 3 grids, one with low effort, one with medium and one with high. Note that the 3 graphs are on very different scales. Both the low effort and high effort grids result in rather small changes in relative biomass over the 20 years of the simulation (less than 0.02 and 3.5×10^{-4}, respectively). This is because, for the low effort grid, the effort has little impact in any case, and, for the high effort grid, biomass is so depleted that population growth rates are very low. Nevertheless, for this particular high effort grid, the status quo scenario leads to extinction, whereas the 50% reduction scenario would lead to eventual recovery to some fraction of the pristine level.

The most dramatic changes are for the medium effort grid, where the relative biomass varies by as much a 0.5 over the different scenarios. The large changes occur because the population growth rates are near their maximum, which occurs when relative biomass = 0.5. It is for these intermediate grids that the management actions have a significant effect.

The curves for each scenario within a grid have similar shapes because the same random allocation was used for each scenario. The only difference in the scenarios is the scale. This is illustrated for the medium effort grid in the Figure. It can be seen that depletion occurs during high effort and recovery during low effort.

Figure 8.12 Burrowing echinoid

Conclusions

We have shown how to apply the trawl impact model, originally developed for the Queensland East Coast trawl fishery, to the NPF. We have drawn on the following sources: depletion data based on experiments carried out on the Queensland East Coast; recovery data derived from the Sustainability analysis carried out for the Surrogates Project (Chapter 6); and effort data based on a novel combination of 6 nm NPF logbook data with year-2000 VMS data processed to 1 nm resolution (Chapter 4).

We have reservations about the validity of the depletion data, because our analysis has shown that the community structure of the invertebrate and fish benthos of the GBR Green Zone is very different to that of the NPF. We recommend that NPF data be obtained before management decisions are taken in the NPF on the basis of the model. This data will be obtained in the new Effects of Trawling Project (FRDC 2002/102) that commenced in the NPF in 2003.

The analysis of recovery is based on qualitative information from the Sustainability analysis. We believe the ranking of recovery rates for the various fauna to be reasonably reliable. However, the absolute recovery rates may be seriously in error. One way to obtain more reliable estimates of recovery rates is to monitor the growth and recruitment of fauna at impacted sites. This is an objective of the Recovery Dynamics project (Pitcher et al, *in prep*) and a 2003 and will also be obtained in the new Effects of Trawling Project.

The derivation of the fine-scale effort pattern is probably one of the more reliable aspects of the model. However, it is based on an assumption that the fine-scale trawling pattern in 2000 is representative of the pattern for all years 1991–2020. There are also some issues as to the accuracy of trawl tracks with long polling intervals (Chapter 4).

We have demonstrated the model under four simple management scenarios. We have shown that: an instantaneous reduction in effort by 25% (the management measure applied in 2002) had similar outcomes to a reduction over 5 years starting from 2002; a 50% reduction resulted in greater relative biomass of benthos over all grids. Gastropods and echinoids were the most highly impacted groups with asteroids impacted the least. An interesting result was that, in the short to medium term, management interventions are locally most apparent in medium effort grids, that is, grids in which the fauna biomass is roughly 50% of carrying capacity. Note that the definition of 'medium effort' depends on the vulnerability of the fauna: a more vulnerable fauna, would reach 50% relative biomass at a lower level of effort.

We have also shown how different scenarios can be evaluated using a top-down approach starting at the decision table. This high-level information provides a rapid assessment of the comparative effects of the different scenarios. It is then possible to drill down to finer levels of detail in order to further understand the results. Examples of further exploration are time histories of individual grids or indicators, histograms of relative biomass and maps of relative of absolute biomass at various times or of time-averaged quantities such as effort.

Another important assumption of the trawl impact model is that carrying capacity is constant and unaffected by trawling; this implies that a population that had been depleted to almost nothing could recover completely to its pre-trawling abundance once trawling was completely removed by a closure. Future development, based perhaps on the Sustainability analysis, could remove this assumption and allow for trawling to reduce or change carrying capacity.

A novel aspect of the work presented here is the mapping of *absolute* abundance of benthic fauna, in this case, echinoids. We have not attempted a serious mapping of echinoid abundance based on surrogate information. Rather, we have obtained a rough mapping from raw catch rates based on a crude spatial smoothing, in order to demonstrate the concept of modelling the abundance distribution in response to trawling impacts under different management regimes. One limitation to bear in mind is that errors in the initial abundance are *amplified* under management regimes that *reduce* the effort, especially when the initial relative biomass is small. It may be possible to ameliorate this instability by introducing spatial interdependence between grids to allow some kind of smoothing. The prospect of obtaining high-quality abundance information from surrogates will challenge the capabilities of the impact model and prompt further improvements to it.

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CHAPTER 9

IDENTIFICATION OF MARINE PROTECTED AREAS WITHIN THE NPF MANAGED AREA

Drew Tyre, Burke Hill , Rodrigo Bustamante , Mick Haywood

Final Report on FRDC Project 2000/160: Surrogates I – Predictors, impacts, management and conservation of the benthic biodiversity of the Northern Prawn Fishery

CHAPTER 9

IDENTIFICATION OF MARINE PROTECTED AREAS WITHIN THE NPF MANAGED AREA

Drew Tyre
Burke Hill
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Summary

- The primary objective of the Commonwealth system of Marine Protected Areas (MPAs) is protection of biodiversity, following the principles of comprehensiveness, adequacy, and representativeness
- This Chapter sets out a framework for the identification of potential MPAs. It does not identify MPAs
- A flow chart for the process is presented.
- The starting point of the process is seen as adequate stakeholder consultation; a list of possible stakeholders is provided
- Stakeholders should be asked to identify objectives and values to be used in the process
- There are serious shortcomings in the data presently available for the NPF managed area. It has high biodiversity with 15 IMCRA bioregions identified but most of these have not been surveyed
- There is a lack of economic data apart from for the prawn trawl fishery
- Summaries are provided of presently available state of the art computer software for identification of MPAs

Introduction

The Commonwealth Government is committed to creating a National Representative System of Marine Protected Areas (NRSMPA) throughout Australia's entire marine environment. The definition of a Marine Protected Areas (MPAs) is given in the box:

Marine Protected Area

An area of intertidal or subtidal terrain together with its overlying water and associated fauna, flora, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment (Kelleher and Kenchington, 1991).

MPAs are designed to protect representative areas of all major ecological regions and the animal and plant communities found in them (IMCRA 1998). Representative systems will be assessed on the basis of ecosystems and the biodiversity they support.

The primary goal of the NRSMPA is to conserve marine biodiversity (ANZECC Task Force on Marine Protected Areas 1998). However, this requires extensive information on species distributions and abundance; information which in many marine ecosystems is incomplete. Gaps in information on species distributions have often been addressed by predictive techniques that use other more readily available biological or physical information (surrogates). This assumes a quantifiable link between each of these surrogate measurements and the species of interest. To be effective in reserve planning. surrogate variables should be clearly defined and available over the entire area of interest. The bulk of this Final Report is based on analysing existing data sets in order to provide some background on the scientific information that is needed as part of the process of establishing MPAs. We have set out the status of knowledge of the marine environment of the NPF in Chapter 3 and specifically identified gaps in this knowledge base (Chapter 3.5). In Chapter 3.6, we made recommendations on filling these gaps. We have also attempted to identify surrogates using data sets collected from the NPF by means of a dredge (Chapter 5.1), fish trawl (Chapter 5.2) and prawn trawl (Chapter 5.3). In Chapter 6 we have estimated the sustainability of the seabed fauna with respect to prawn trawling while in Chapter 7 we have described the activities most likely to threaten the seabed fauna and flora of the NPF. Finally in Chapter 8 we have modelled the impacts of prawn trawls on seabed biota. Together this represents a substantial advance in our knowledge and understanding of processes important in reserve planning.

It was not intended that the Surrogates project should actually identify marine reserves in the NPF. We have rather given a description of the process that needs to be followed in identifying marine reserves in the NPF and recommend a state of the art software technique that could be used for dealing with the complex computations. As pointed out in Chapter 3.5, there are important gaps in the presently available information. Some of these gaps are so large that they will need to be addressed before decisions can be made on MPAs in a large part of the NPF.

Steps in identifying marine protected areas

The Commonwealth government intends that the declaration of marine reserves should involve three key steps:

- Bioregionalisation of the marine environment
- Establishment of nationally agreed principles and guidelines
- Development of techniques for the identification and selection of MPAs.

This general process is however also subject to the particular needs and properties of individual reserves given the many variables such as: uses of the area, commercial value of the area, intrinsic biological properties such as biodiversity and habitats and threats as well as the existing management regimes governing the area.

A bioregionalisation of the seas around Australia has been completed (Interim Marine and Coastal Regionalisation for Australia Technical Group, 1998). The diversity of habitats in the managed area of the NPF is demonstrated by the identification of 16 bioregions in this region (Fig 1).

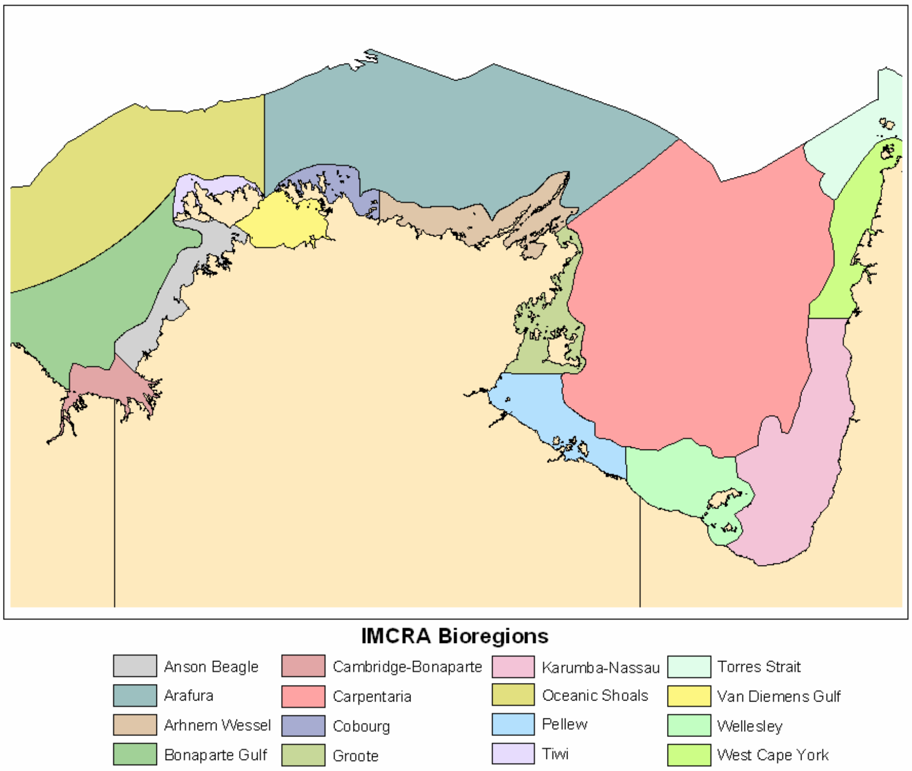

Figure 9.1 Marine bioregions of Northern Australia. Source: (Interim Marine and Coastal Regionalisation for Australia Technical Group 1998).

These bioregions were identified from information on climate, oceanography, geology, geomorphology, biota and estuaries, collected by marine management and research agencies within the Australian States and Territories, and the Australian Commonwealth. The quality and quantity of data varied greatly between subjects and organisations and does not include the more recent CSIRO studies in the region (e.g. see related projects FRDC 95/14, FRDC 96/257, FRDC 98/109). Because of its tropical location and isolation, the managed area of the NPF is likely to contain areas with very high biodiversity. The region also lies close to the global centre of marine biodiversity in the South East Asian region. Current information indicates that the marine fauna of northern Australia remains pristine by world standards.

The process must also conform to the principles outlined for the National Representative System of Marine Protected Areas in the recent Strategic Plan (ANZECC TFMPA 1999) with respect to Comprehensiveness, Adequacy, and Representativeness. The principle of **comprehensiveness** requires an MPA system to sample the full range of ecosystems in the marine environment. At a regional scale, this would mean that every IMCRA bioregion should be included in the reserve system. At present this is not the case. In particular, four of the five bioregions in the Gulf of Carpentaria have no coverage in the NRSMPA, while the Karumba-Nassau bioregion has less than 1% coverage (ANZECC TFMPA 1999). Note that these figures include only areas designated primarily for biodiversity conservation, and that protected areas for fisheries production purposes do exist. The present interim bioregionalisation is still too coarse to achieve this principle, as each IMCRA bioregion contains many ecosystems.

The principle of **adequacy** requires those areas included in an MPA system to be sufficient to ensure the integrity and viability of populations, species, and communities. The precise relationship between the area of an ecosystem reserved and the viability of communities inside it is largely unknown. Generally, the more area is protected, the higher the probability of long term survival for a species. This will vary from species to species, between ecosystems and bioregions, and depend on the levels of external threats to each ecosystem. A general rule of thumb from biogeography is that a loss of 95% of the area corresponds to a loss of 50% of the species pool (see Box 1). In the context of marine protected areas this implies that protecting 5% of the area will only capture 50% of the species in a region.

The principle of **representativeness** requires an MPA system to include the full diversity of elements present within an ecosystem. This ensures that a reserve system includes rare species that may not be found everywhere within an ecosystem, but are not generally found anywhere else either.

The basis of the process for developing an MPA system is a map of "planning units" - spatial blocks that can be either included or excluded from the MPA system. Each planning unit will have a number of conservation features, that describe the ecological, cultural, or geological characteristics of a planning unit that are to be conserved by an MPA system. Each planning unit also has an opportunity cost, which is an absolute or relative index of the economic losses for placing that planning unit into the MPA system. The overall process outlined in this document uses these costs to ensure that the conservation goals established by stakeholders are met as efficiently as possible, i.e. at a minimum cost to stakeholders in the region.

Two concepts directly relevant to the selection of planning units for MPAs are **irreplaceability** and **complementarity**. Two planning units are completely "complementary" if their conservation features do not overlap at all. The more conservation features they share, the less complementary they are. Consider an artificial set of 21 "planning units" with 17 conservation features (Table 9.1), randomly selected from the 107 fish trawl samples taken by SS9003. Out of the first three planning units, 52 is more complementary to 60 than 82 is, because unit 52 has three species not found in unit 60, whereas 82 has only one species not found in unit 60. When attempting to construct an efficient reserve system, sites that are highly complementary with each other are desirable. Although the idea is straightforward with a simple problem, with more sites and species it rapidly increases in complexity.

Box 9.1 Modelling adequacy using species-area curves

A common biogeographical result from data on oceanic islands as well as nested areas within continuous regions is that the number of species found increases with area following a power law:

$$S = cA^{z}$$

Where *c* and *z* are constants estimated from data. *z* usually has a value of 0.25 for habitat islands, and 0.15 for continuous regions of similar habitat (Rosenzweig 1995). The proportion of species found in a subset of an area is S_1 / S_0:

$$\frac{S_1}{S_0} = \left(\frac{A_1}{A_0}\right)^{0.25}$$

which eliminates the need to know *c*. Thus an area that is 5% of a larger area will contain $0.05^{0.25} = 0.47$ as many species as the larger area on islands, and conserving 20% of the area will preserve 0.67 of the species. In continuous areas of similar habitats the same figures are 63% of species in 5% of area, and 78% of species in 20% of the area.

Table 9.1 Artificial planning unit by conservation feature matrix derived by randomly sampling the fish trawl data from SS9003. Units 52, 51 and 73 (red) are considered irreplaceable – see text.

	Planning Units																					
Conservation Features	52	60	82	67	33	84	51	104	100	73	105	99	92	103	102	31	106	71	69	78	22	Abundance
Fistularia petimba	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**21**
Priacanthus tayenus	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	**20**
Carangoides talamparoides	1	1	0	1	1	1	0	1	1	1	1	1	0	0	1	1	1	0	0	0	0	**13**
Scolopsis taeniopterus	1	1	1	1	1	0	1	0	0	1	0	0	0	0	0	0	0	1	0	0	0	**8**
Uranoscopus cognatus	0	0	0	0	0	1	0	0	1	0	0	1	1	1	1	1	0	0	0	0	1	**8**
Lethrinus lentjan	1	1	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**5**
Lagocephalus lunaris	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	**5**
Rastrelliger kanagurta	0	1	0	1	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	**4**
Velifer hypselopterus	0	0	0	0	0	0	0	1	1	0	0	1	0	1	0	0	0	0	0	0	0	**4**
Choerodon monostigma	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	**3**
Carcharhinus macloti	0	0	0	0	0	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	**3**
Scolopsis monogramma	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**2**
Aetomylaeus nichofii	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**2**
Coradion chrysozonus	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**2**
Leiognathus leuciscus	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**1**
Pseudochromis quinquedentatus	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	**1**
Dipterygonotus balteatus	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**1**
Species Richness	**8**	**8**	**7**	**6**	**6**	**6**	**5**	**5**	**5**	**5**	**5**	**5**	**4**	**4**	**4**	**4**	**4**	**3**	**3**	**3**	**3**	

Planning units with unique conservation features are "irreplaceable", because conservation targets cannot be achieved without including those sites. In this example, planning units 52, 51, and 73 are irreplaceable, because they each contain a unique conservation feature. Planning units without unique species may be relatively irreplaceable, because they have high levels of complementarity with other planning units. The theoretical irreplaceability of a planning unit is the proportion of all possible optimal reserve systems that meet the conservation targets that include the planning unit (Ferrier et al 2000). It is effectively impossible to calculate because of the huge number of potential reserve systems involved, but it can be estimated and used as the basis for reserve design decisions. We outline these methods in the section on existing software.

Throughout the remainder of this chapter we will frequently refer to reserve system designs that are "efficient". By this we mean that the system meets its conservation targets at a relatively low social or economic opportunity cost (Pressey and Nicholls 1989). A system that meets conservation targets at a lower cost than an alternative is more "efficient".

In the rest of this chapter we outline a process that could be used to identify a system of marine protected areas for the NPF region. We then review and recommend available software tools for identifying systems of marine protected areas. Finally, we estimate the required efficiencies these tools must achieve to justify expenditure on further biological survey work in the NPF region.

Outline of the Process

A wide variety of processes have been used to identify reserve systems around the world, varying considerably in their specific content. For example, the Great Barrier Reef process includes extensive stakeholder consultation (GBRMPA 2002), while the process used by The Nature Conservancy (TNC; Groves et al 2002) concentrates exclusively on identifying regional systems that meet biodiversity targets. These particular differences reflect the nature of the organisations involved. On the one hand, GBRMPA is a public body charged with the management of a public resource. On the other hand, TNC is a private organisation seeking to achieve biodiversity conservation on private land. Given that the NPF region is largely a public resource managed by the Commonwealth, the process should look more like that used by GBRMPA than TNC. Parts of the process will be similar to the work carried out by TNC. Margules and Pressey (2000) give another detailed review of processes for selecting reserve systems, although they too give little consideration to consultation with stakeholders.

There is another key difference between the processes outlined by Margules and Pressey (2000) and the TNC (Groves et al 2002) and what we are proposing. We will not assess the conservation features found in existing closures and protected areas, as suggested by these authors. The reason for this is that existing protected areas have generally not been selected with regional conservation targets in mind, and locking these areas in at the beginning of the process can seriously degrade the efficiency with which conservation targets are met (Stewart and Possingham, unpublished manuscript). We recommend that potential efficient reserve systems should be calculated without reference to existing closures to maximise the efficiency with which they meet conservation targets. Once a series of proposed systems are available, one factor against which they could be assessed is the degree of overlap with existing reserves. This could mean that areas currently closed might be reopened.

Identification of and agreement on the objectives of the reserve by stakeholders

There appears to be some confusion in Australia on whether the role of MPAs is for biodiversity conservation or fisheries management (Baelde et al 2001). This is one of the issues that generate most difficulties in MPA debates between conservation agencies, the commercial fishing industry and the community. Manson and Die (2001) point out that in the United States the National Marine Sanctuaries Program is driven by fisheries management agencies and closely follows the boundaries of fisheries management zones whereas in Australia the development of a system of representative MPAs is led by conservation management agencies. However, given the history of declaration of MPAs, it is clear that the fishing industry is a major stakeholder whose interests have to be considered although not to the exclusion of others. The National Representative System of Marine Protected Areas is explicitly targeted at biodiversity conservation (ANZECC TFMPA 1999), so the extent to which a process for the NPF region conforms to that strategic plan will resolve whether the goal of the process is for biodiversity, fisheries management, or both.

We recommend that the process should start with stakeholder consultation. Inattention to this essential step has caused major problems with introduction of MPAs. Public protests about potential fishery closures off the coast of the state of California (US) led State officials to scrap a two-year process to plan a network of marine reserves, and start over. State officials agreed with recreational fishermen, commercial fishermen, and other groups that stakeholders had insufficient input into the planning process. A new process will involve representatives from an array of stakeholder groups in the study of potential closures (Fletcher et al, 2002).

In 2001, the Victorian government postponed the introduction of an extended MPA system following protests from fishers about inadequate compensation for the losses following proposals to phase out all extractive industries including commercial and recreational fishing in the proposed parks and sanctuaries. New proposals have recently been developed in consultation with the fishing industry. Under the revised plan, financial assistance will be available to eligible fishery license holders to cover increased fishing operating costs and reduced catches directly resulting from the MPAs.

The West Australian government used an extensive consultation process following concerns from the fishing industry about proposals first developed in the 1980s for MPAs which did not cater for fishing – or education and research. In 1994 the government produced a revised planning process (Baelde et al 2001). The policy was updated in 1998 and now includes a Marine Parks and Reserves Authority that oversees the planning and management of marine reserves. CALM has also developed participation procedures for non-statutory stakeholders. According to Baelde et al (2001), this initiative has greatly improved MPA negotiations.

These examples reinforce the need for adequate stakeholder consultation. In a large complex area such as the NPF there are numerous bodies likely to have an interest in the declaration of MPAs. These include the following but there are probably others:

- Commonwealth, Queensland and NT governments
- NPF trawling industry
- NORMAC
- Commonwealth agencies: AFMA, AFFA, EA, NOO
- Queensland and NT government agencies for fisheries
- Commonwealth, Queensland and NT government agencies for conservation, transport, agriculture and mining
- Local authorities
- Mining companies with interests in the region – including oil and gas companies
- Agricultural bodies with interests in the region
- Shipping companies with interests in the region
- Authorities for ports in the region
- Aboriginal groups
- Conservation NGOs
- Fishers from other fisheries in the region
- Recreational fishers
- Tourist industry

The stakeholders, as representatives of the community, need to decide on the objectives of setting aside Marine Protected Areas and which economic, social and conservation values should be considered in the process.

It is important that stakeholders know what information is already available for inputs and what information is not available. Economic data dealing with the Northern Prawn Fishery is available from the ABARE surveys but we have not identified other economic information relevant to the region. We also have not dealt with social information since this is beyond the scope of the project although it is also relevant to the identification and declaration of MPAs.

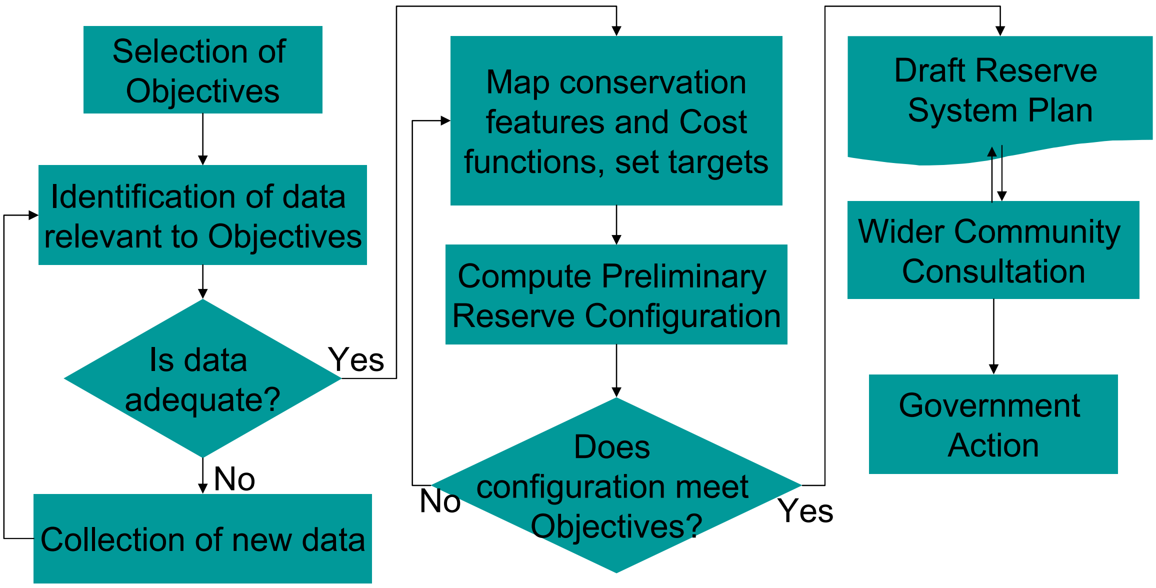

Figure 9.2 Diagram of the recommended overall process for identifying marine protected areas in the NPF.

There is a range of possible objectives that can be taken into account when identifying reserves. These may be quite general or specific. The objectives of the Western Australian marine reserve system are very general:

- To preserve representative as well as special ecosystems in the marine environment; and
- To put a formal management framework in place to ensure the various uses of marine conservation reserves are managed in an equitable, integrated and sustainable manner.
- The primary role of MPAs is biodiversity conservation

Such a general set of objectives provides little guidance in identifying reserves. More tightly defined objectives or constraints are usually required especially where the aim is to optimise the reserve configuration with respect to one or more features such as biodiversity or cost to a stakeholder group. General objectives also give no guidance on optimal size of reserves. All of these issues must be dealt with at the level of choosing conservation features, setting representation targets, and identifying costs.

Identification of data relevant to objectives

The data requirements are influenced by the objectives for declaration of the MPA. For example an MPA that is meant to improve fisheries requires information about the fisheries. An MPA that excluded fishing and was aimed at preservation of biodiversity would require only marginal fishery information – largely the impacts of shifting fishing effort to areas outside the MPA, and the economic costs of losing access to particular areas. Manson and Die (2001) trialled two surrogate classification systems for ecosystems within the NPF, the first used bioregions and depth strata, the second used trawl fishery data. They were able to identify the extent of fishing grounds that would have to be surrendered to meet various criteria for defining the size of protected areas. They also found that the way fisheries data are used for the surrogate classification is crucial and factors such as changes in spatial distribution of the fishery and the intensity of fishing need to be taken into account.

The first key step in declaration of marine reserves by the Commonwealth is bioregionalisation. Under the Interim Marine and Coastal Regionalisation for Australia (IMCRA), there are 15 bioregions in the NPF managed area. The validity of this bioregionalisation has not been tested but needs to be done in order to appropriately locate MPAs. While the overall bioregionalisation has provided a useful first overview, IMCRA boundaries have been questioned in some areas. Initial results from a project to accurately map marine habitats in Tasmania have shown that the IMCRA boundaries in the Bruny bioregion were incorrect. GBRMPA has undertaken its own bioregionalisation for the Great Barrier Reef Marine Park and come up with a much finer resolution version that has 70 bioregions. Work by CSIRO Marine Research in the Twofold Shelf bioregion has identified significant meso-scale habitat variability within the bioregion (Bax and Williams 2001, Williams and Bax 2001).

Because biological surveys require expensive ship time costing many thousands of dollars a day, they are expensive and in the past have focussed on fishing rather than measuring biodiversity. The very large area of the NPF - approximately 770,000 km^2 - has exacerbated this. In Chapter 3, we have identified gaps in the data for assessing biodiversity in the NPF. A major problem with the present data is that it deals almost exclusively with the Gulf of Carpentaria. We have very little biological information from the area north of Arnhem Land. In the case of Joseph Bonaparte Gulf there is no biological data of the seabed invertebrate fauna. The extent of trawl grounds in these poorly studied areas is quite small and studies of untrawled areas are difficult to justify and finance. However, surveys of these areas may reveal seabed with properties that meet the objectives of the reserve system allowing greater options in identifying MPAs, for example on untrawled grounds. Balmford and Gaston (1999) demonstrated that targeted biodiversity surveys needed to yield only a small gain in efficiency of meeting conservation targets (~0.4%) in order to justify the costs of carrying out the surveys. Their conservative estimate of the efficiency gain from making full use of detailed biological data was 5% and often far higher. Obviously the opportunity and survey costs differ for the marine environment, and carrying out this exercise for the NPF region would be a fruitful future piece of work.

Selection of spatial scale, conservation features, targets, and cost functions

Spatial Scale

There are two components to the spatial scale of an MPA system, the “extent” and the “grain”. The extent is the entire region over which the planning exercise is conducted. While it may seem obvious what extent is, it must be a conscious choice for any given planning exercise because areas outside the extent will not contribute to planning targets within the present exercise, even if the conservation features are substantially the same. The obvious extent is the entire northern Australian regional marine planning area. However, the planning exercise could also be conducted separately for each IMCRA bioregion. The extent used does affect the ultimate outcome. Erasmus et al. (1999) compared the efficiency of reserve designs for the mammalian fauna of northern South Africa at the regional scale and separately for provinces nested inside that region. They found that the larger extent was more efficient, in that fewer sites were required to reach conservation targets. Moreover, the spatial overlap between reserves at the two scales was <14%, so the particular areas that were included were markedly different.

The grain of the system is the size of the individual planning units that are used to construct the system, it need not be constant. For terrestrial reserve design exercises, the cadastral parcels into which land ownership is divided often dictate the size and shape of planning units. For a MPA system, and especially one located primarily in Commonwealth waters, "ownership" of a planning unit is unlikely to be an issue. Therefore the size and shape of planning units can be set to a scale that makes sense for both management and biological considerations. A constant planning unit size and shape across the Gulf is the most straightforward to implement.

The finest grain for which data on conservation features and opportunity costs is available sets the lower size limit of planning units. Trawl effort data from the Northern Prawn Fishery is probably the primary opportunity cost in much of the Gulf, and this is available on a six nautical mile square grid. The available biological data is on a much coarser grain. However, biophysical surrogates have been calculated for the six nautical mile square grid. A finer grain size is possible, but all planning units within a single six nm grid cell would have identical conservation features and opportunity costs, and so a finer grid increases the difficulty of the problem without adding appreciably to the value of the resulting system.

Planning units larger than the finest grain possible may be of value for two reasons. First, from a pure computational point of view the larger the planning units, the fewer of them are required to cover the region, and this will reduce the computational burden of solving the problem. Whether this is required or not can only be determined from test runs of the problem using the optimisation software. From a biological point of view, the size of a single planning unit is the smallest size of a single protected area. If a single planning unit is too small to support self-sustaining populations, then it is possible that some protected areas would fail to meet the principle of adequacy. Having planning units that are individually large enough to support flora and fauna populations will ensure that the resulting reserve system is adequate. However, this is not the only way to ensure adequacy, and larger planning units reduce the flexibility of the system to respond to other constraints.

Therefore, we recommend the planning units in the Gulf be based on the trawl effort grid, and possibly larger to reduce computational loads if necessary.

Quantification of the conservation features of the area

The choice of which conservation features to include in the reserve design process closely reflects the intentions held by stakeholders for the MPA system. Conservation features that have been used in other reserve design exercises include at least three different types:

1. Ecological communities
2. Threatened species
3. Special features (other than biological)

Ecological communities and threatened species are most closely related to the outputs of the Surrogates project, but all three are relevant to an MPA system for the Gulf of Carpentaria. Almost anything can be used as a conservation feature, but the key feature is that it must be unambiguously quantified for every planning unit in the region.

Ecological communities are mostly based on habitat or vegetation classifications. This step is usually taken because there is insufficient data on the distributions of individual species to clearly say which planning units are utilised by all species in the region (Roff and Taylor 2000). The assumption is that if each habitat type is represented in the reserve system, then species utilising that habitat type will also be represented. This is a large leap of faith. McNally et al. (2002) tested this assumption by comparing how well vegetation classifications in Box Ironbark forests in Victoria represented biodiversity from several different taxa (plants, birds, insects etc.). They found that while vegetation classifications generally performed well in representing differences in bird, mammal and tree communities,

they failed to represent reptiles and invertebrates. They recommended that ecological communities not be used alone in identifying representative reserve systems. Ward et al., (1999) evaluated the use of habitats and species assemblages as surrogates for biodiversity for a specific marine ecosystem. They found that the performance of the surrogates was related to the level of representation that was set, the higher the level of representation the more taxa were included. Habitat and plant assemblages generally performed poorly whereas fish and invertebrate assemblages performed well even at levels of representation as low as 10%.
For the NPF there is an additional problem in that the information that we have on communities is strongly affected by the way in which sampling was carried out. In Chapter 5 we have shown that biodiversity as reflected by the number of taxa, is different when measured by a dredge, a prawn trawl or a fish trawl. Importantly, this information is available for few areas and various surrogates have been investigated as alternatives.

It is worth noting that the predicted species richness or biomass across the Gulf could be used as a conservation feature. However, it is difficult to see how it can contribute to identifying a MPA system that is comprehensive and representative. While it is possible to conserve planning units with more than a certain expected number of species, there is no guarantee that the species in those units will represent the full range of biodiversity in the region. For example, if there are species that only occur in relatively species poor habitats, these will not be represented in a system that is based on species richness. The idea of using species richness to identify priority areas for conservation was originally known as the “Biodiversity Hotspots” idea (Myers 1988, 1990), and was intended to elicit investment in conservation by international agencies in underdeveloped and tropical regions. It was never intended to be relevant to developed nations, where development is more likely to be restrained by government regulation, and a more planned approach to conservation is feasible (Myers 1998).

Rare and threatened species, where sufficient information on their spatial distribution is available, can be another useful conservation feature. As described in the introduction, the principle of representativeness requires a reserve system to include rare species that are components of the ecosystem. In many cases the preservation of threatened species is an objective of the reserve system, so including their distributions as conservation features directly contributes to this. The primary difficulty is having sufficient data to adequately describe the distributions. For example, many of the rare by-catch species in the NPF are known from one or a few samples at most. Do these samples represent widely distributed, but difficult to sample species, or locally abundant species with restricted distributions? For the Gulf, much of the required distribution data has been generated for other projects such as by-catch risk assessment. In Chapter 6 we have categorised the sustainability of the seabed fauna of the Gulf of Carpentaria and presented spatial information on their distribution. This shows that taxa having a low sustainability are not evenly spread across the Gulf and thus different values for this attribute apply spatially.

Finally, special features other than biological ones can be included as conservation features. This would include cultural, geological and geographic features such as those described in the planned conservation assessments for Environment Australia. Note that some of these features may span more than one planning unit, which will require careful specification of targets if it is desired to represent the entire feature in the MPA system, rather than only a portion of it. We have no data at present on these features for the NPF.

For the NPF MPA process, the information collated by the Surrogates project could be used to create habitat classifications as the most comprehensive baseline conservation features. However, in general the available information does not have sufficient geographic coverage to do a good job of this. Where distribution information exists for threatened species or special features, these should also be included. The data assembled by the Surrogates project could be used to design a highly targeted biodiversity survey of the region to efficiently fill in the gaps and ensure that the distribution of unique ecosystems have been identified.

Set targets for each conservation feature

The conservation features are chosen to meet the principles of comprehensiveness and representativeness. The principle of adequacy is incorporated into the choice of targets for the incorporation of each feature into the reserve system. The simplest possible target is to represent each ecosystem in the reserve system at least once. However, this clearly will not ensure that the reserve system will ensure sustainability of the populations inside it. In addition, the type and levels of threats experienced by the seabed fauna should influence the targets, as ecosystems under greater threats require larger areas to ensure they remain sustainable in the long term.

In Chapter 7 we have considered the various threats to the seabed fauna of the NPF Managed area. A process developed as part of the National ESD reporting framework for Australian fisheries (Fletcher et al. 2002) was used to assess the risk from the various threats. Risk was calculated as the product of the consequences of the threat and the likelihood of the threat occurring. In Chapter 7 we have listed the outcomes of this exercise when carried out by the members of the Surrogates research project. The results for extreme and high risk threats was:

Extreme Risk

- Introduction of a serious marine pest
- Changes in rainfall patterns

High Risk

- Rise in sea level
- Increased sea temperature
- Increased frequency of cyclones
- Changes in water flows in estuaries
- Direct impacts of prawn trawling

We recommend that stakeholders should carry out an independent risk evaluation because this would bring in a wider range of values. Fletcher et al. (2002) give likely reporting requirements for different levels of risk. In Chapter 7, we have suggested alternative responses but, if stakeholders undertake a risk analysis, they need to consider what responses are appropriate bearing in mind that Marine Protected Areas are one form of response but in themselves will not address most of the highest risk threats such as climate change effects or the introduction of a marine pest.

One commonly used target is to conserve some agreed percentage of all bioregions or habitat types. If this approach is adopted then stakeholders need to agree on the percentage. The decision does need to be informed by ecological theory (e.g. Box 1) in order to ensure adequacy. It is not necessary that every habitat type or conservation feature have the same target under this system. GBRMPA has set percentage representation targets of between 20 and 30% for each of its bioregions (GBRMPA 2002). This approach reflects the experience on land where it has been realised that we should be attempting to identify and conserve representative spaces or landscapes rather than preserve individual species (Roff and Taylor, 2000).

A problem with this approach is that it implies that we can quantify the distribution of biodiversity in some way. Species level information is not available for most marine areas and certainly not for most taxa in the NPF. The absence of species level data for most of the marine environment and the high cost of collecting this information has lead to the use of higher taxonomic level data. Vanderklift et al (1999) have shown that genus and family level data provides nearly as much information for fish and invertebrates as species level data. In the Surrogates project, we used species level information for fish but family level for invertebrates because the available invertebrate data was not to species.

A second type of target is to include *n* different examples of a particular conservation feature, possibly accompanied by specifications of the minimum size of each example, and a minimum distance that must separate them. This kind of target is useful to protect the contents of a reserve system from the effects of catastrophes such as cyclones. Sea grass communities, although they eventually recover from such natural disturbances, can be locally eliminated by cyclone effects. It is possible to calculate how far apart examples of such ecosystems should be to protect against catastrophes (Allison et al in press).

The often arbitrary nature of targets used in many previous processes reflects another key research gap. In general, the best ecological theory has been able to do to date is to say that larger areas are more likely to allow fauna populations to persist. However, in the highly connected marine environment, what takes place outside an MPA has a large influence on the sustainability of populations and ecosystems inside the MPA.

Identification of cost function components

As pointed out in the introduction, the goal of the process is to identify reserve systems that are “efficient” (*sensu* Pressey and Nicholls 1989), that is, they achieve conservation targets at a minimum economic cost. Therefore we must calculate the opportunity cost of excluding activity from each planning unit, that is the present value of future income from that planning unit. These opportunity costs mapped for each planning unit form the “cost function” of the reserve design process.

Several of the stakeholders in the NPF region have a monetary interest in the area. The most obvious is the fishing industry but mining, shipping, local authorities and the tourist industry also have significant interests. The best economic information for the NPF is for the trawling industry. ABARE undertakes detailed economic surveys of this industry every two years. These economic data on the costs of fishing can be combined with catch and effort data available on a 6 x 6 nm grid over the whole of the trawled area to produce a cost function for the reserve design process. A problem with the data is that it is not applicable to the whole of the NPF because the fishery operates in only around 25% of the NPF managed area. Consequently we do not have a cost function for most of the region. One approach is to assume there is no cost with respect to declaration of MPAs outside of trawl grounds. This is not accurate because there are other users of the NPF who do operate outside of the trawl grounds – for example recreational fishers, inshore gill netters and offshore fish trawling. It may not be feasible to obtain accurate data on the monetary value of benefits and costs of all stakeholders but it may be possible to estimate them to obtain some relative information. Stakeholders will need to decide what additional economic information is needed.

There are two complications with using the spatial distribution of catch and effort to calculate the opportunity cost of a reserve system to the NPF, and both depend heavily on the movement patterns of both the target species, and the fishing fleet. First, excluding trawling from a planning unit may not mean that the expected catch from that planning unit is lost to the fishery, because at least some of the prawns may move out of the closed area. The fishery may find that catches outside protected areas increase as prawns move through protected areas. Note that this is distinct from arguing that protected areas will increase prawn catches overall; it seems that such a benefit is unlikely. This effect could only be assessed by modelling the movement of prawn stocks in some detail.

The second complication is the effect of displacement of fishing effort. If fishing effort that was expended inside a new MPA is displaced to regions outside the MPA, there is a potential for a decrease in the overall production of the fishery, or greater environmental impacts, as open areas are fished more intensively. As with the first complication, the exact response will depend on the movement of the target species. The behavioural response of the fishing fleet to the closure of previously fished areas is also relevant. The option of exploring new areas no longer exists in this mature fishery, all grounds that potentially yield prawns have been explored already. There is the likelihood that lower yielding grounds might be exploited but this would affect the economics of the fishery as well as introducing trawl effort into areas that are now untrawled. The issue of compensation needs to be addressed since one way of dealing with potential displaced effort is for it to be bought out and effectively reduce effort overall. As the closures have a clear public benefit, the matter of whether the government pays the cost of buying out effort would need to be addressed.

The complex and dynamic nature of these responses to the declaration of an MPA make them difficult to include directly in the calculation of efficient reserve designs. Therefore, we recommend that assessments of this cost be carried out by careful modelling after the preliminary design phase has generated a range of options, and the results of this modelling used to evaluate the effects of the reserve on fishing as part of the assessment of the preliminary reserve configuration. To some extent, the problem can be minimised by ensuring that fishing effort is incorporated into the opportunity costs of planning units, as this will minimise the amount of fishing effort displaced by the declaration of an MPA. The trawl effects model developed in Chapter 8, combined with additional work on modelling fleet movements, would be able to assess the environmental effects of displaced fishing effort.

Computation of preliminary reserve system configuration(s)

Once the conservation features, targets for those features, and opportunity costs have been determined for each planning unit, the next step is to apply computational tools to identify potential reserve systems. There are a range of toolkits and software that have been developed to aid in meeting conservation targets at minimum social and economic costs, and we review some of these below. Uncertainties about the best structure of the conservation features, targets, and opportunity costs should be incorporated by rerunning any selection algorithms for a range of scenarios. For example, the calculation of economic costs of a planning unit will involve an economic "discount rate" which represents the decrease in value of income earned in the future (or alternatively of costs paid in the future). The higher the discount rate, the less future income or costs will count towards the opportunity cost of a planning unit. Discount rates tend to vary between groups of people or individuals, and so it would be worth examining a range of scenarios that differ in the discount rate used to calculate opportunity costs of planning units to see what effect this has on the calculated configurations of sites.

Whatever tools are chosen, they must be able to account for the spatially explicit nature of the reserve design problem, which generally rules out most linear optimisation methods.

Assessment of preliminary configuration(s) against objectives

In this step, the range of reserve designs produced is assessed against the objectives in consultation with stakeholders. This may include modelling indirect effects of MPAs on areas outside the MPA through the displacement of fishing effort, for example, using the trawl impacts model described in Chapter 8. A key research gap is the absence of a model that is able to predict how mobile target species such as prawns will respond to the declaration of MPAs in the Gulf. If a reserve design can be developed that meets all objectives and is satisfactory to the stakeholders involved in the consultation, then a draft reserve system plan can be produced for wider community consultation.

Consultation with wider community

Once a draft reserve system plan has been produced, the wider community beyond the immediate group of stakeholders needs to be consulted. This is the stage the Great Barrier Reef Marine Park Authority is currently engaged in. Once the public have provided comments, it may be necessary to return to one of the previous steps to address concerns. Just how far back the process should go at this stage is a matter for debate. If the group of stakeholders invited to participate in the entire process is truly representative of the wider community, and their concerns have been faithfully addressed, this stage should not produce surprises.

Review of reserve system design software

At the core of the reserve design problem is the goal of minimizing the area encompassed in the reserve network while still meeting an ecological bottom-line (Pressey et al. 1993, Possingham et al. 2000). This has been described by Kirkpatrick (1983) as the minimum representation problem and is derived from the idea that, while biodiversity conservation objectives may wish to maximise the area within the reserve system, they must compete against social, economic and management constraints (Possingham, 2000).

MARXAN (v1.8.3) – a tool for Marine Reserve Design, was designed by Ian Ball and Hugh Possingham (Ball 2000) and based on terrestrial reserve design software by the same authors. The designers of the software recognised the need for a single framework, which unifies the central aims of conservation whilst also serving other socio-economic demands. This software is used internationally in current marine and terrestrial reserve design exercises. In Australia, early versions of the software were used to formulate plans for the Reserve Forest Agreements process in New South Wales, and in designing "Green Zones" for the Great Barrier Reef Marine Park. The current MPA process in South Australia will probably use MARXAN to identify sites.

MARXAN employs simulated annealing to select sites that satisfy a set of ecological, social and economic criteria. This is achieved by selecting a set of conservation features meeting the targets for each criterion for a minimum social and economic cost. A solution is then returned as a configuration of planning units. With many possible combinations of planning units, each solution is scored against an objective function, according to how well it meets targets. The implicit objective is to minimize area, costs and boundary length, whilst ensuring that the specified level of representation for each conservation feature is met. This forms the standard mathematical programming problem:

Minimize the objective function: (1)

$$\sum_{i=1}^{M} c_i x_i + BLM(\sum_{i=1}^{M} x_i l_i - 0.5\sum_{i=1}^{M} x_i \sum_{k=1}^{M} x_k b_{ik})$$

subject to the constraints: (2)

$$\sum_{i=1}^{M} a_{ij} x_i > t_j \sum_{i=1}^{M} a_{ij} \quad \text{for all } j = 1.. N,$$

$$x_i \in \{0,1\} \quad \text{for all } i = 1..M,$$

where x_i are the control variables such that if x_i=1 then site i is selected for the reserve system and if x_i=0 then site i is not in the reserve system, c_i is the "cost" of site i, l_i is the perimeter or boundary length of site i, b_{ik} is the common boundary length of sites i and k, and BLM is a Boundary Length Modifier that converts the reserve system area and its boundary length into a common currency. The constraints ensure the target for each conservation feature is conserved where a_{ij} is the abundance of the feature type j in site i and t_j sets the target fraction for each feature type. A feasible solution is one that selects a set of sites (using the control variables x_i) such that all the constraints are met. All of the types of conservation features and targets described earlier can be incorporated into the model.

Information on adjacent land type uses can be used to apportion cost to each planning unit. One example might be concerned with those instances where a potential MPA abuts a terrestrial reserve and so minimises management costs by having contiguous parks. Another way of controlling spatial arrangement is by locking in a sub-set of sites, for example if the MPA is to be built around an existing reserve (eg. the seagrass closures in the Gulf of Carpentaria or the extensive areas that are closed to trawling to protect juvenile prawns). The reserve system solution is mapped using a geographical information system (GIS) interface, to enable the planner to view alternative MPA configurations.

There are at least two other Australian developed packages that can be used in conjunction with MARXAN, TRADER (G. De'ath, unpublished work) and C-PLAN (Pressey et al 1995). Both packages have a GIS based "front end" for viewing reserve system plans, and use heuristic rules to find solutions to the minimum representation problem. In the case of C-PLAN, the rule is based on selecting sites with a high "irreplaceability", using a statistical estimator of that theoretical quantity (Ferrier et al 2000). TRADER uses a three-part rule that grows MPA systems around sites that must be included until all targets are met. In both cases, the primary advantage is that the systems can be (and have been in the case of C-PLAN) used directly in consultation with stakeholder representatives, because as areas are added and deleted from the system the effect on biodiversity targets can be directly visualised. The main disadvantage of using these systems is that they do not perform as well as full optimisation algorithms in identifying areas that meet biodiversity targets at a minimum cost (Ball 2000).

Conclusions and Recommendations

- A process for selecting MPAs in the NPF region must have broad stakeholder consultation to be successful
- The objectives of the process should be to comprehensively and adequately represent marine biodiversity at a minimum social and economic cost
- Existing data on the NPF is probably insufficient to characterise habitat and ecosystem variation at the scale of tens of kilometres that would be required
- The output of the present Surrogates project could be used to target a biodiversity survey that would efficiently fill in the gaps
- Research is required to understand the notion of adequacy for marine ecosystems: how much area is enough, where should it be, and how should we monitor it?
- Research is also required to understand the interrelationship between MPAs and highly mobile species, both target species such as prawns and by-catch species
- MARXAN, an existing reserve selection tool, can be employed together with GIS to map biodiversity, efficiently identify representative areas, and assess the biodiversity benefits of existing closures. TRADER or C-PLAN may be used during stakeholder consultation to highlight how changing the boundaries of MPA systems influences the distribution of biodiversity.

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CHAPTER 10

DISCUSSION

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CHAPTER 10

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Seabed fauna of the Northern Prawn Fishery Managed Area

Geographical coverage

We reviewed 16 research cruises in the NPF but found that the biological coverage was largely limited to the Gulf of Carpentaria. After completion of the project we became aware of a series of fish trawl research cruises undertaken in 1980-81 that included other parts of the NPF (Okera and Gunn, 1986). This data should be used in future analysis of the biota of the region. There appears to be no dredge or prawn trawl samples of benthic fauna at all for Joseph Bonaparte Gulf and very limited data for the top end region between the two Gulfs. Data on the composition and distribution of the fauna was available from three different sampling devices – fish trawls, prawn trawls and a benthic dredge. These devices sample different components of the biota and a description of the biota/biodiversity needs to have data from all three. Unfortunately our data sets do not overlap – we have fish and dredge samples from the central Gulf of Carpentaria and prawn trawl bycatch samples from the more inshore regions (Figure 10.1).

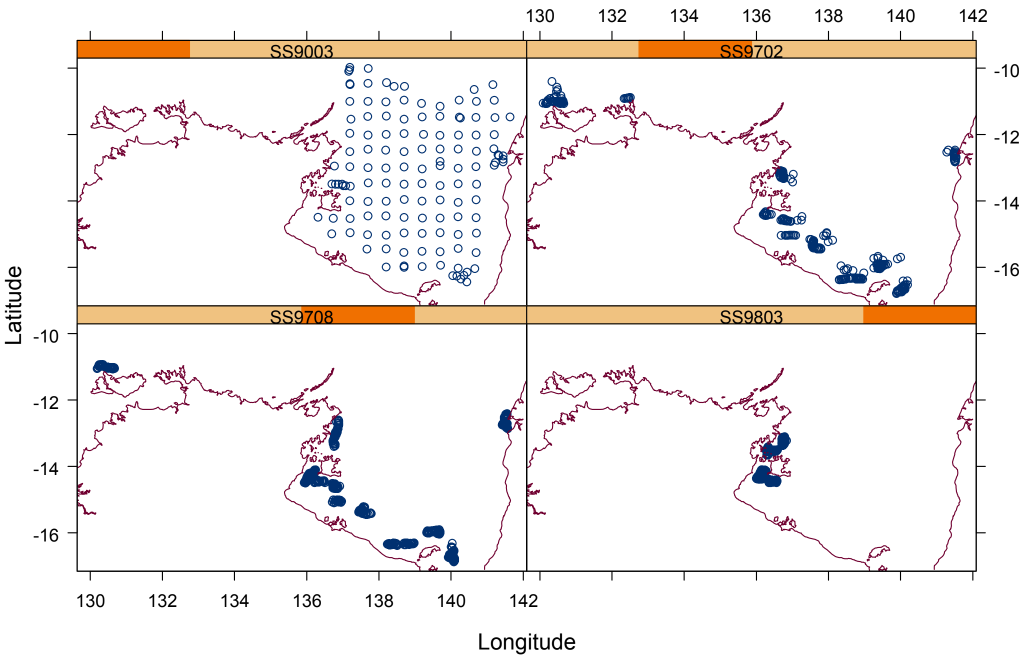

Figure 10.1 Location of sampling stations used in the study. The top left figure shows the sample stations used for collection of fish trawl and dredge samples (Cruise SS9003). The remaining three figures show the location of prawn trawl samples (Cruises SS9702, SS9708 and SS9803).

This is a serious drawback. This is illustrated by our coverage of the bioregions. There are 15 bioregions in the NPF, for four of these we have no prawn trawl, fish trawl or dredge samples at all. Many of the others are inadequately sampled, for example 10 bioregions have less than 10 dredge samples, and this is insufficient for a description of the benthic biota.

Although our study has been restricted to the Gulf of Carpentaria, it is important not to categorise the entire NPF on the basis of this one area. Data on sponges for example, shows that the area to the west of the Gulf of Carpentaria is far richer in species than the Gulf (Table 10.1). In Chapter 3.6 we have recommended that additional sampling be carried out to cover the regions outside of the Gulf of Carpentaria – an essential step in assessing where marine protected areas be established.

Table 10.1 Sponge fauna in the NPF region. Table modified from Hooper et al (2002).

Region	Localities sampled	Number of species
East Gulf of Carpentaria	52	93
South Gulf of Carpentaria	36	48
West Gulf of Carpentaria	37	52
Gove Region	17	39
Wessel Islands	133	315
Darwin and Cobourg Peninsula regions	87	274
Joseph Bonaparte Gulf	14	19

Description of the seabed fauna

Although the Gulf of Carpentaria (GoC) appears a relatively uniform body of shallow water, there are some marked spatial variations in physical conditions and these are important in determining the distribution of the fauna. The Gulf has an area of around 3.7 x 10^5 km^2. Despite the large area it is shallow – mostly less than 70 m deep. The coastline is generally sandy or muddy in the east and south but more rocky in the west. To the north it opens to the deeper Arafura Sea. Currents in the Gulf are driven by tides and wind and are generally low (Chapter 3.2). The only areas with significant bottom current stress are where islands alter the flow – most notably to the west of Groote Eylandt and east of Mornington. Reflecting the predominant south-easterly winds and the long fetch, the north west coast is subjected to the greatest wave actions with maximum waves reaching 2 m (Chapter 3.2). As would be expected in a low current region, seabed sediments are generally fine and mud dominates. Sediments in the east tend to be coarser than those in the west (Chapter 3.3).

There are two published accounts of the seabed fauna, one deals with the megabenthos and one with the fish. Long et al. (1995), described two main communities of megabenthos in the Gulf: a community located in predominantly sandy sediments along the eastern and south-eastern margins of the Gulf that comprised mainly sessile suspension-feeding sponges, zoantharians, pennatulaceans, bivalve molluscs and ascidians; and a community located in the muddier sediments in the central and western Gulf compromised mainly of deposit-feeding spatangoids and sand dollars. However, sessile suspension-feeders were also found in the central Gulf wherever suitable substrata were present. Our analysis of Long et al.'s data showed biodiversity as indicated by number of species caught per station (α biodiversity) was higher in the eastern and northern GoC but there was a high level of variation. Oxygen and temperature were found to be important drivers of this biodiversity. We suspect this may be the result of thermocline formation in the summer. The lack of dredge samples from the more inshore regions of the GoC probably explains why we did not find significant effects of factors such as depth or seabed current stress.

The distribution of total biomass of dredge fauna does not show a domination of any areas but there is a generally higher biomass in the north-east, south-east and south-west regions. The biomass is lower in the central and north-west GoC. Biomass was only weakly correlated with environmental variables with oxygen providing the highest linear regression correlation coefficient. As is the case for biodiversity, we suspect this may be due to the effects of thermocline formation in summer in the deeper waters of the GoC. If the samples had extended into the more coastal parts of the GoC we might have detected other correlations.

Blaber et al (1994) surveyed the fish fauna of the Gulf of Carpentaria. The catch rates were similar to those of other tropical shallow-water demersal fish communities. They found indications that the fish fauna on prawn trawl grounds might be modified by intensive trawling. Statistical analysis did not reveal any correlation between biological attributes and environmental parameters except for depth. We have confirmed that depth is an important factor in the distribution of fish biodiversity in the GoC. Sampling stations in the deeper central waters of the Gulf have similar biodiversity that is different to that of the more shallow margins.

Composition of the fauna

The most striking attribute of the fauna of the NPF is that despite a high diversity – hundreds of taxa - it is dominated by a relatively few taxa; most are rare or at least rarely caught. Table 10.2 showing the composition of prawn trawl invertebrate bycatch illustrates this.

Table 10.2 Composition by weight of the major species accounting for 90% of the invertebrate bycatch from prawn trawls in NPF. Note the different levels of taxonomic resolution. Table from Chapter 3.1

	Taxon	Abundance % by weight	Accumulated % wt
1	Unidentified Porifera	17.8%	18%
2	Loveniidae (heart urchins)	11.9%	30%
3	Spatangoida (heart urchins)	6.3%	36%
4	*Portunus pelagicus* (crab)	5.8%	42%
5	*Portunus rubromarginatus* (crab)	5.3%	47%
6	*Amusium pleuronectes* (crab)	4.9%	52%
7	*Thenus* sp. nov. (bug)	4.8%	57%
8	Sepiidae (cuttlefish)	4.8%	62%
9	*Metapenaeopsis* spp (prawn)	4.7%	66%
10	*Charybdis truncata* (crab)	3.3%	70%
11	Ctenophora (comb jellies)	3.3%	73%
12	Holothuroidea (sea cucumbers)	3.2%	76%
13	*Chaetodiadema granulatum* (urchin)	2.7%	79%
14	*Trachypenaeus* spp (prawn)	2.7%	82%
15	Teuthoidea (squid)	2.5%	84%
16	Gorgonacea (gorgonians)	2.4%	87%
17	*Portunus gracilimanus* (crab)	1.2%	88%
18	*Oratosquilla inornata* (stomatopod)	1.0%	89%
19	*Portunus sanguinolentus* (crab)	1.0%	90%

As can be seen from Table 10.2, a very few taxa made up most of the prawn trawl invertebrate bycatch. Half of the bycatch consisted of only six taxa of which two were echinoids and three were crabs. Crustaceans were the largest single group in the invertebrate bycatch making up 20% by weight, echinoderms made up 14% by weight and Porifera 12%. Most (94%) of the Crustacea were decapods and 76% of these were crabs and 24% non-commercial penaeid prawns. Portunid crabs made up 77% of the weight of crabs. This dominance by a few groups is even more evident in the fauna sampled by the dredge. Long et al. (1995) found that spatangoid echinoids made up 60% of the biomass of the 107 dredge samples taken across the Gulf of Carpentaria. The most abundant species was a solitary coral (*Flabellum* sp); 123,428 individuals were collected but these all came from a single station, it was not recorded on any other station.

The fish fauna of the Gulf of Carpentaria is similarly dominated by a small number of species. Blaber et al., (1994) found that 25 of the 300 species made up 75% of the biomass of the day trawl catches and 70% of the night trawl catches. One family alone, the Haemulidae, made up 29% of the catch during the day.

This dominance of the fauna by a few species is a widespread phenomenon in marine ecosystems. The corollary is that there are a large number of species or taxa that are rarely caught. Long et al (1995) reported that amongst the 846 species of invertebrates captured in the dredge, 411 were represented by less than 10 individuals and 143 by only a single individual. Most species were also very patchily distributed: 410 species were collected at only one or two stations. This property makes the measurement of biodiversity very dependent on the number of samples taken and so comparisons between areas requires comparable sampling effort. Unfortunately this is not the case in the NPF region where the sampling is highly skewed towards the Gulf of Carpentaria to the exclusion of the rest. We have for example, no dredge or prawn trawl samples from the Joseph Bonaparte Gulf. As pointed out in Chapter 3.5, there are 15 bioregions in the NPF, for four of these we have no prawn trawl or dredge samples at all. Many of the others are inadequately sampled, for example 10 bioregions have less than 10 dredge samples.

Taxonomy

Biodiversity is one of the key pieces of information used in describing fauna and it is an important factor used in establishment of marine reserves. Three categories are recognised:

- *alpha diversity:* the number of species found at a site
- *beta diversity*: the change in species composition from place to place, or along environmental gradients – thus if neighbouring areas have high alpha diversity but the species in them are much the same, the beta diversity is low. If on the other hand there is a large change in species composition between neighbouring areas, then beta diversity is high
- *gamma diversity:* the diversity of a region or landscape – i.e. the total diversity

An important point is that these categories depend on knowledge of the fauna at a species level. Identification of animals from tropical seas presents major problems because of the high number of undescribed species and the dwindling number of taxonomy specialists. The extent of the problem varies across taxa. The problem is well illustrated by the sponges. Hooper et al., (2002) carried out a major study of the biodiversity of sponges of tropical Australia. Although this study was carried out by expert sponge taxonomists, most species (>70%) could not be assigned to a known taxon and they established a knowledge base of around 4000 'morphospecies' for their study.

Attempts to overcome this problem by using higher taxonomic levels – which are easier to establish – have had mixed success on land. Vanderklift et al., (1998) investigated this approach in identifying reserve configurations in a large marine embayment. They found that species, genus and family levels gave varying results and that a key factor was the frequency of assemblage occurrences that were reserved. The higher the frequency the greater the correspondence. At high levels there was little difference between species, genus and family level for fish and invertebrates. Information at the class level performed poorly. Vanderklift et al, (1998) advocate caution in using lower taxonomic resolution survey data for reserve selection. Unfortunately for the foreseeable future given that action on marine reserves is likely to move more rapidly than resolution of taxonomic issues, we will have to rely on family level information in northern Australia.

The distribution of total biomass of benthic invertebrates does not show a domination of any areas but there is a generally higher biomass in the north-east, south-east and south-west parts of the GoC. The biomass is lower in the central and north-west Gulf. Biomass was only weakly correlated with environmental variables. Oxygen provided the highest linear regression correlation coefficient. As is the case for biodiversity, we suspect this may be due to the effects of thermocline formation in summer in the deeper waters of the GoC. If the samples had extended into the more coastal parts of the GoC we might have detected other correlations.

Surrogates

MacNally et al., (2002) point out that surrogates based on single or small numbers of species have limited usefulness and they recommend using more general ecological categorizations – usually ecosystems. Classification of the marine environment into ecosystems has lagged behind the land. Ward et al., (1999) identified habitats in a shallow embayment and used these and species assemblages as surrogates for marine biological diversity. Unfortunately the level of information they used is not widely available. The IMCRA bioregions are a form of marine ecosystem classification but they are too broad – and generally too poorly described – to be useful as surrogates at this time. Consequently we are constrained in our choice of information that can be used for identifying surrogates. In the present study we have related physical and chemical attributes such as sediment type or water quality to a biological attribute – in this case alpha biodiversity.

We found some physical attributes that do appear to act as significant surrogates. For example oxygen and temperature are important to the fish in the Gulf of Carpentaria. This is probably linked to the formation in the GoC of a thermocline in summer (Somers et al., 1987). Mobile species such as teleosts are able to migrate out of low oxygen areas. In Table 10.3 we have listed the physical and chemical factors that we have found to be the most important drivers of biota.

Table 10.3. Main split variables for each of the three faunal groups analysed. The variables are listed in their order of significance. SD = Standard Deviation, SE = Standard Error

Factor ranking	Dredge fauna	Prawn trawl bycatch - invertebrates (no acoustics)	Prawn trawl bycatch – invertebrates (with acoustics)	Prawn trawl bycatch - fish	Fish trawl Fish
1	Wave height SD	Mud SE	Hardness	Temperature	Salinity SD
2	Sand	Phosphorus	Temperature SD	Silica	Nitrate SD
3	Mud	Sand	Sand SE	Depth	Oxygen
4	Oxygen	Wave height	Roughness	Salinity SD	Depth
5	Wave height max	Silica	Phosphorous	Nitrate SD	Sand
6	Oxygen SD	Sand SE	Nitrate SD	Sand	Oxygen SD
7	Silica SD	Salinity SD	Mud SE	Oxygen	Mud
8	Phosphorus SD	Oxygen	Depth	Mud	Wave height SD
9	Nitrate SD	Temperature SD	Wave height	Temperature SD	Wave height max
10			Silica	Temperature SD	Phosphorus SD

At first sight the data presented in Table 10.3 suggests that the most important environmental factors are not the same for each faunal group. For example wave height SD is the most significant for factor for the dredge fauna but it is only in 8th rank for fish from fish trawls. Salinity SD, the most important factor for fish does not even feature for the dredge fauna. However, when we consider that 28 different environmental factors were tested, there is a degree of commonality in the highest scoring 9 or 10. Factors relating to the nature of the seabed substrate such as sand and mud appear in all cases as does oxygen. Aspects of water chemistry such as silica, phosphorus, nitrate and salinity each appear in at least three of the four faunal samples. In the set of prawn trawls for which we had acoustic data, acoustic hardness and roughness of the seabed were both important. We suggest that these factors should be investigated further as surrogates for the marine fauna.

We are hesitant of using only physical data for classifying the marine environment as suggested by Day and Roff (2000). A marine classification based solely on physical attributes would certainly serve as a good basis for marine reserves for physical features but we consider that the biological interactions that occur in nature are such that physical features alone cannot account for an adequate description of the distribution of the biota. The major gap is in the extent to which biological interactions affect the composition of the marine fauna. Predator prey relationships and competition are major drivers in determining the distribution of fauna, they cannot be ignored. The distribution of the fauna on rocky shores is a good example of the interplay between physical and biological forces. Unfortunately at present we do not know much about these relationships for benthic faunas although Long et al. (1995) did divide the benthic invertebrates into feeding guilds and there have been some feeding studies of teleosts in the Gulf of Carpentaria. This information may eventually provide the additional understanding needed to provide a broader base to classification of the seabed fauna of the NPF.

Indicator species

We found two possible indicator species for biodiversity amongst the dredge fauna. The species with the highest indication of biodiversity in the benthic invertebrates is a majiid crab *Micippa excavata* (Fig 5.1.26). It was found at 11 stations, mainly in the east. These stations had a high biodiversity of 128 species. Majiid spider crabs occur in a variety of habitats. Some are found on gravely or shelly bottoms but many are associated with sessile animals such as sponges or gorgonians. The next highest-level indicator is another decapod crustacean - *Sicyonia cristata (=lancifer)*. This is a small shrimp that occurs throughout the Indo-Pacific. They were found at 23 stations and in this case the associated biodiversity was 93 species. In the Gulf of Carpentaria it is found mainly in the southern half but also at a few sites in the west.

We had two sets of fish samples; one derived from prawn trawls and the other from fish trawls. Biodiversity indicator species from these two different sources were not the same. In the case of fish trawls, three species, *Pseudorhombus diplospilus*, *Lagocephalus scleratus* and *Gerres macracanthus* were associated with high biodiversity. The most significant indicator species for biodiversity of teleosts in the prawn trawl bycatch were a different three species: *Nemipterus peronii*, *Lethrinus genivittatus* and *Echeneis naucrates*. This lack of correspondence in fish indicators is probably attributable to the differences in composition of the catch of prawn and fish trawls. The fish assemblage with the widest distribution across the Gulf of Carpentaria was made up of species associated with reefs suggesting that reef structures may be widespread across the GoC. This assemblage might be useful as a form of indicator species for reef ecosystems (Chapter 5.2).

Sustainability

Given the practical problems of assessing the sustainability of fish captured in prawn trawl bycatch, Stobutzki et al (2001) developed a method that uses biological attributes to estimate the susceptibility and ability to recover of the various bycatch species. Scores for these two attributes were used to derive an overall sustainability index. We followed a similar process for the prawn trawl invertebrates (Chapter 6). All of the invertebrates that we evaluated have a relatively low susceptibility score indicating they are all vulnerable to trawling. This is not surprising since we are dealing with bycatch of prawn trawls and so the animals must be able to be captured in a trawl. There are however quite large differences in the degree of susceptibility.

We found examples of taxa with either high or low sustainability scores in nearly all phyla. Echinoids have a low sustainability whereas asteroids and holothuroids have high sustainability. Delicate Crustacea such as crangonids, carids and parthenopid crabs have low sustainability while hermit crabs, portunid crabs and the bugs (Scyllarids) have high sustainability. Amongst the molluscs, bivalves have high sustainability while cephalopods have low sustainability. These results show that we cannot generalise about the impact of trawling on the various groups. They also suggest that one of the impacts of trawling will be to shift the species composition of the benthic fauna towards the 'weedy species' that have high sustainability. Consequently we can expect the seabed fauna of trawl grounds to be different from the original condition.

In applying the results of our sustainability estimates, consideration has to be given to the distribution of taxa on and off trawl grounds. In essence we have estimated the sustainability of animals that occur on trawl grounds. Individuals that live off the trawl grounds are not exposed directly to trawling and they can also provide larval recruits to fished areas. Thus although sponges on trawl grounds may have low sustainability, their wide spread distribution in the NPF ensures that they are unlikely to be threatened by trawling over the whole area.

Fine scale patterns of trawl effort

We analysed data for the period 1 August 2000 to 31 October 2000 from the satellite-based Vessel Monitoring System (VMS) that covers the NPF. All trawlers in the NPF carry this system and are polled at irregular intervals. The system serves both for surveillance and for research. After corrections for factors such as non-trawling periods, time of day or night and variations in polling interval we developed a polling distribution for the area of the fishery. The resulting polling distribution was integrated with 6 nm trawl effort data compiled from logbook records to produce 1 nm resolution maps of the distribution of fishing effort. These effort maps represent a 36 times increase in resolution over the existing logbook information. We cannot use this data to back project fishing effort because fishing patterns change from year to year. VMS data is being continuously collected however and so it will be possible to identify high resolution fishing effort patterns in the future.

The high resolution maps of effort showed that the distribution of fishing effort within the 6 nm grids squares is highly variable; in some areas it is relatively evenly spread across the grid, but in other areas effort is highly aggregated in small parts of the grid square.

A feature of the NPF trawl grounds is the presence of areas that are untrawlable. The fleet has identified these as areas where they are liable to hook up trawl nets. We do not know exactly what the untrawlable grounds are but we suspect they are reefs. In some parts of the fishery, trawl effort is concentrated around the edges of patches of untrawlable ground but in areas where the untrawlable ground is more fragmented there is no clear spatial relationship between the two.

Threats to the seabed fauna

We identified a range of threats to the seabed fauna of the NPF. These included fishing, mining, shipping, agriculture, aquaculture, aquaculture and global warming. We have also evaluated the risks using a Risk Assessment method developed as part of the National ESD Reporting Framework for Australian Fisheries. Scoring was carried out on two axes – Consequences of a threat occurring and the Likelihood of it happening. Scores were then multiplied together to obtain a Risk measure. The outcomes of scoring by the scientists involved in the Surrogate project identified two threats as having an Extreme Risk – these were the introduction of a serious marine pest, and changes in rainfall. Five threats were scored as High risk. These included three climate change effects (rise in sea level, rise in sea temperature and increased frequency of cyclones) as well as altered water flows in rivers and estuaries as a result of water abstraction by agriculture and the direct impacts on the benthos from prawn trawling.

The scoring system is being reviewed by AFMA and it will probably change to reflect concerns about aspects such as having a zero score on one of the axes. We were also concerned about the weighting that should be given to risks. Consequences for example, have strong spatial and temporal dimensions that are not reflected in the present system. We recommend that a further scoring be carried out by a broader group of stakeholders when the modified version of the ESD Framework is available.

If we accept the results of the Risk analysis at this stage, the managers of the fishery can do little about global warming effects and these account for four of the six high or extreme risk threats. Governments are gradually acknowledging the ecological problems associated with water abstraction and the Queensland government for example has stopped promoting the use of ponded pastures. The remaining two risks – introduction of a serious marine pest and the direct impact of trawling are nearer home. These are covered in the next two sections

Marine Pests

Antifouling paints use a biocide in a resin base. The resin determines the rate at which the biocide leaches. The most potent biocide is organotins. A new IMO Convention prohibited the use of organotins in anti-fouling paints from January 2003. The phasing out of the most potent antifouling paints is a welcome development in banning of toxic chemicals from the marine environment but it also removes a highly effective weapon in the fight against hull-borne pests. Although there are several alternatives biocides including copper and a range of new types under development, it is likely that methods that involve leaching of biocides into the marine environment will gradually be phased out. Alternative methods being tested include non-stick coatings based on silicones, self-polishing coatings that remain slippery underwater and fibre coatings (Waterman et al. 2001). The latter consist of high density (200 fibres/mm^2) coatings of fibres that are oriented at right angles to the hull forming a spiny surface that is unattractive to larvae. The NPF fishing industry should actively support measures to prevent the introduction of marine pests. Silicone and self-polishing coatings are more successful in vessels that travel at high speeds and spend little time in port. They rely on settled animals being unable to maintain a hold when subject to water pressure.

The present management regime of the NPF is resulting in some of the fleet being tied up in port for long periods – a factor that increases the probability of hull fouling. The low operating speed of NPF trawlers additionally reduces the effectiveness of the modern alternatives to leaching biocides – they are most effective at speeds of 15 knots or greater which is well beyond the capabilities of trawlers. In view of the high risk to the seabed fauna posed by a serious marine pest, the NPF industry needs to consider its role in preventing introduction of marine pests.

Trawl impacts on the fauna

Trawl fishing was identified in Chapter 7 as a high-risk activity to the seabed fauna. There is a rapidly growing international literature on the negative impacts of trawling on seabed faunas. Much of this is factual but there is also an emotional component that cannot be ignored. The real situation is more complex than claimed by many of those who are opposed to trawling. Poiner et al (1998) have shown that trawl impacts are selective with some species or taxa being impacted more than others. They also showed that the impacts are cumulative and that in the northern GBR region around 7 trawls over the same area would result in depletion or removal of around 50% of the seabed fauna. The matter of cumulative impacts has focussed attention on the patterns of trawling. Until recently this information was not generally available and the general public assumed that trawling patterns were comparable to a farmer harvesting a wheat field. The introduction of satellite-based monitoring systems has changed our understanding of what really happens.

Trawler skippers operating in the Northern Prawn Fishery are required to record their fishing operations in a logbook. Position is reported in relation to a 6 nm grid square. When trawling commenced in the Gulf of Carpentaria in the 1960s, this was a high level of accuracy but the availability of satellite based navigation systems has allowed far more accurate position fixing. The fleet routinely uses GPS-based position monitoring to improve their efficiency in targeting concentrations of prawns. In 2000, AFMA made the use of a satellite-based Vessel Monitoring system compulsory in the NPF. The system was introduced with two main aims, firstly to improve and reduce the cost of surveillance of closures and secondly to assist research and fisheries monitoring. In the Surrogates project we have used a subset of the VMS data to partition trawl effort at a resolution of 1 nm. This represents a 36 times improvement in resolution of the logbooks (Chapter 6). The resulting maps show a high degree of patchiness in trawl activity with effort being concentrated in relatively small areas. This is an important finding and the information can be used to improve estimates of prawn mortality in the fishery. Piet et al (2000) for example, found that improving the spatial resolution of fishing effort from the standard ICES rectangles to 1 x 2 nm squares resulted in a systematic reduction of the estimated population mortality of benthic fauna by a factor of 0.7 due to the patchy effort distribution.

Assessment of impacts of trawling should be greatly assisted by accurate mapping of where trawling has occurred and at what intensity. Patches of untrawled ground in close proximity to trawled areas provide refuges for animals that are impacted by trawling. This of course is part of the thinking behind the creation of marine protected areas namely that establishment of areas without trawl or other impacts will result in populations that can ensure the survival of the species or community.

Deng et al. (submitted) have pointed out the problems involved in analysis of VMS data including the fact that trawlers do not necessarily travel in straight lines between polling points. Despite the difficulties, we see VMS-derived effort distribution as providing considerable benefits to researchers, managers and ultimately the industry.

One of the clear trends in trawl effort in the NPF is the steady reduction that has taken place in the last 20 years. The number of boat days is now significantly less than in the early 1980s (see Fig 7.7 in Chapter 7). The result has been a contraction in the area fished as trawlers concentrate on the areas with the highest catch rates and do not fish low yield areas.

While prawn trawling may presently be the only significant anthropogenic impact on the seabed fauna of the NPF, its spatial distribution needs to be taken into account. The decreasing area that is fished and the shortening of the fishing season must be reducing the extent of the impact.

Modelling the impacts of trawling on seabed fauna

CSIRO has developed a trawl impact model for the Queensland East Coast trawl fishery. This model uses trawl depletion and recovery data for the various taxa generated by experiments carried out on the Queensland East Coast. The impact model was applied to the NPF using the GBR depletion data from the GBR and recovery data derived from the Sustainability analysis carried out for the Surrogates Project (Chapter 6). The model generated trawl impacts using effort data at a 1 nm resolution derived by partitioning of 6 nm NPF logbook data using 2001 VMS data (Chapter 4).

The value of the resulting model was demonstrated by testing various management options involving different strategies for reduction in effort. In 2002, the fishery underwent an instantaneous reduction in effort by 25% as a result of a series of management interventions. We modelled the effect of this effort reduction on the seabed fauna and showed that there would be significant recovery of the fauna as a result of lessening effort. The modelling showed that the groups that are impacted the most by trawling are gastropods and echinoids. Asteroids were impacted the least.

The main weakness of the model at this stage is that we are using inputs from the Great Barrier Reef region. A new research project commencing in 2003 is designed to fill this gap by measuring depletion and recovery rates for the benthic fauna of the NPF.

Marine Protected Areas

The establishment of marine protected areas (MPAs) has become fashionable worldwide. Numerous studies have shown changes in areas protected from fishing. These generally are a greater abundance of some species as well as an increase in size of many of the formerly targeted species. Benefits have been claimed to extend to fishers through the migration of target species out of MPAs into adjacent areas open to fishing. While these changes and benefits are most commonly described for reef related species, there is evidence for similar changes to invertebrate faunas previously exposed to trawling (e.g. Piet et al., 1998). Baelde et al. (2001) have shown that the benefits of MPAs are not always obvious because the objectives of the reserves are not explained to stakeholders who also often have little input in defining them.

Despite the apparent benefits of the establishment of MPAs, in many areas they have become controversial. The key to this problem is the exclusion of fishers – in some cases recreational as well as commercial – from traditional fishing grounds. This exclusion often occurs without adequate consultation or offers of compensation. The problem of displaced effort resulting in increased effort in the areas remaining open is also seldom addressed. The very basis of the selection of an area as an MPA is also often not clear. In Chapter 10 we have set out the need for adequate data as well as consultation with stakeholders before MPAs are identified in the NPF. We have identified gaps in our data – both biological and economic - that must be filled before the process can proceed. As we have pointed out, once the data is available it is not a trivial process to draw boundaries around an area of sea. Ideally MPAs should set out to protect some attributes of the fauna. Although biodiversity is often selected, it is not the only biological attribute that should be considered. The drawing of boundaries should be an optimisation process in which biological attributes are maximised while economic costs are minimised. There are software packages to deal with the often complex computation of solutions but once more, adequate stakeholder consultation is recommended to obtain a broader base of information and to prevent a domination of the process by scientists.

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APPENDICES

APPENDIX A

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APPENDIX B

RELATED RESEARCH

Ecological Sustainability of bycatch and biodiversity in prawn trawl fisheries

FRDC Project 96/257
Project Leader: Dr Ilona Stobutzki – CSIRO Marine Research
Timing: 1997 – 1999
Date of Final Report: 2000

This major study was carried out in the NPF. Over 600 prawn trawl bycatch samples were collected on or adjacent to trawl grounds. The report analysed the teleosts and elasmobranchs but not the invertebrates. This invertebrate data set has been a major input to the Surrogates study. The study also broke new ground with an original approach to measuring sustainability of bycatch teleosts and elasmobranchs using biological characteristics of each species. In the Surrogates project we have followed a similar approach to estimating sustainability of invertebrates in prawn trawl bycatch. We have also used the data on teleosts and elasmobranchs from the Sustainability Project to produce maps of the distribution of the 12 least sustainable species from each group.

Design, trial and implementation of an integrated long-term bycatch monitoring program, road tested in the NPF

FRDC Project Proposal
Project Leader: Dr Ilona Stobutzki – CSIRO Marine Research
Collaborator: AFMA
Timing: Commence 2003

The proposed project will design, trial and implement a bycatch monitoring program for the NPF as part of the introduction of a long-term integrated monitoring program. This research capitalises on the FRDC's and the NPF's past investments in bycatch research by providing a mechanism for the NPF to measure its ongoing impact on the bycatch taken by the fishery, and its intention to ensure ecological sustainability of these species. The outputs will include evaluations of different long-term monitoring approaches, cost-benefits of each and how to combine approaches and procedures to ensure effective, integrated, long-term monitoring in Australian fisheries.

The project will also take the vital first step towards understanding the bycatch issues of the Joseph Bonaparte Gulf (JBG). This is a section of the fishery about which very little is known. The JBG represents about 17% ($10-20 million/y) of the total NPF banana prawn catch and 20% of the total banana prawn effort (taken from data for 1996-2000). The project will provide the first description of the bycatch from the Joseph Bonaparte Gulf.

The absence of any biological information from the Joseph Bonaparte Gulf was identified in the Surrogates I project as a major gap in our knowledge of the benthic fauna of the NPF region.

Designing, implementing and assessing an integrated monitoring program for the NPF

FRDC Project Proposal
Project Leader: Dr Cathy Dichmont – CSIRO Marine Research
Collaborator: AFMA
Timing: Commence 2003

The 2001 stock assessment indicated that the tiger prawn resource is overexploited and, in particular, the brown tiger stock levels are critically low. The recent external review of the tiger prawn stock assessment for the NPF has supported this conclusion and has also drawn attention to the high level of uncertainty in the assessment. An external consultant recommended that the logbook data be augmented by fishery-independent survey data. The survey should be designed both to supply an independent index of abundance for each tiger prawn species and to capture fishing power changes. In light of the finding of the assessment that both species are overexploited, the addition of survey data to the assessment is particularly urgent. Fishery-independent surveys are now regarded as being indispensable in many of the well-managed fisheries of the world.

A well-designed independent survey may also be able to perform other urgently needed tasks in the fishery without compromising its primary function. Examples are bycatch monitoring, as required by the Bycatch Action Plan, byproduct monitoring and some benthic studies to assess the state of the ecosystem itself.

The spatial contraction of the prawn fishery, which has been highlighted in this study, and changes in fishing power cannot be investigated through a January survey alone, when the prawns are not being fished commercially. The project therefore designed a further survey at the start of the second fishing season (September) with the main aim of developing a fishery-independent index of biomass that will help managers, researchers and industry interpret trends in tiger prawn catches in the fishery. It will also attempt to estimate the biomass of prawns in areas that used to be fished and are no longer fished (in some areas a large number of grids). If fewer prawns are found in those grids that are no longer fished, then, the overall prawn abundance has actually declined more than the stock assessments suggest.

Bycatch samples will also be collected during these surveys.

Comment

The bycatch samples that will be collected in this project could be of value to future surrogates research. Although there will be considerable spatial overlap with the existing bycatch data set, the new information will be useful in providing information on temporal changes in bycatch composition.

Is the inshore area a spatial refuge for commercial prawns in the NPF? At-sea research to develop a new method of evaluating catch rates of banana and tiger prawns.

FRDC Project Proposal
Project Leader: Dr Cathy Dichmont – CSIRO Marine Research
Collaborator: AFMA
Timing: Commence 2003

In recent years, industry, researchers and managers have been concerned about the status of the tiger prawn stocks in the Northern Prawn Fishery and declines in catches of banana prawns. This led to an AFMA Research Fund project to investigate the interaction between the environment and banana prawn catch in the NPF. In some areas, rainfall still best explains the annual variation in catch. Although banana prawn catches improved in some regions in 2001, the extreme catches in the NPF in 2001 have highlighted that we still do not clearly understand all the factors that determine banana prawn catches - particularly at Weipa, where unexplained record-low catches have occurred for three of the last four years. The first stock assessment model for banana prawns was constructed during this project and used to investigate whether the prawn fishery is governed by an underlying stock-recruitment function, or whether recruitment is largely driven by random environmental influences. The model indicates that there is a stock-recruitment relationship in some areas, but the relationship is not consistent between regions. This is a major change in thinking on banana prawns.

The results of recently completed research suggest that much of the effective spawning of tiger prawns (and possibly banana prawns) in the Gulf of Carpentaria probably occurs in relatively shallow water (Condie et al. 1999, Die et al. 2001, Vance and Pendrey 2001). All these recent studies have highlighted that we know very little of the inshore distribution (i.e. inshore of where the prawns are fished) of banana and tiger prawns, particularly whether there is significant inshore spawning. The presence of significant inshore spawning is likely to confound the assessment of prawn stocks.

Comment

Because this project is focused on prawns, it is unlikely to provide information that would be of much value to future surrogates research.

Quantifying the effects of trawling on the seabed fauna in the Northern Prawn Fishery

FRDC Project 2002/102
Project Leader: Dr Burke Hill – CSIRO Marine Research
Timing: Commence 2003

Australian fisheries are being required to demonstrate their environmental sustainability through an AFMA and EA assessment processes. This requirement is being driven by new legislation such as the EPBC Act and by industry through the need for meeting standards for certification. To date there has been no study of the sustainability of the seabed communities in the NPF. A CSIRO-QDPI study of the impacts of trawling on inter-reef seabed communities in the northern GBR (Poiner et al 1998) showed that in inter-reefal areas, trawling caused an overall epibiota depletion of between 5 and 20% for each trawl and the effect was cumulative. This inter-reef seabed is not typical of most NPF prawn trawl grounds, which are muddier and have a different biota. The CSIRO-QDPI study recommended that a future study should quantify the response of soft-sediment fauna and vegetation to trawl disturbance. This proposal aims to do this and addresses the NPF High Priority Research Areas: Effects of fishing ("improved efficiency in fishing gear and techniques in order to reduce bycatch and discarding and environmental impacts on the benthos"). The major outputs will be a fine scale mapping of NPF-wide trawl effort, the measurement of the rates of depletion of seabed biota from trawling, and short term measurements of the rates of recovery of the affected biota following trawling. A longer term measurement of recovery would depend on the extent of recovery after two years. If it was thought that there was information to be gained by longer term monitoring, a new proposal to do this would be developed.

Comment

The outputs from this Project would be used as inputs to the CMR Trawl Scenario Model, which can evaluate a range of management scenarios and contrast environmental benefits with implications for the fishery.

APPENDIX C

INTELLECTUAL PROPERTY

No commercial intellectual property arose from this work.

APPENDIX D

STAFF

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APPENDIX E

REFEREE REPORT

The following is from an anonymous reviewer of this Final Report

Hill et l.: Surrogates I – predictors, impacts, management and conservation of the benthic biodiversity of the Northern Prawn Fishery.

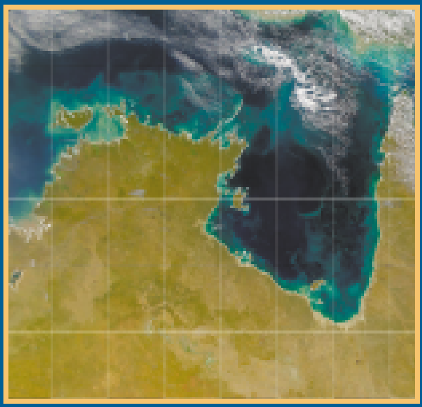
This is an important document, which constitutes a comprehensive baseline that facilitates the understanding and management of the complex ecology of NT waters. I perceive the report as highly interesting reading. It sets the stage of the NPF and the present knowledge of the environment where fishing occurs and the marine region as a whole. The report furthermore highlights the need for biological baselines in order to evaluate environmental impacts and particularly the ecological sustainability of the NPF. My review of this large work is due to time constraints at best superficial but I nevertheless have the following comments:

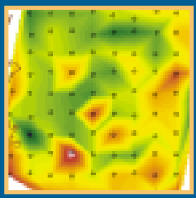
The authors argue a case of more broader geographical coverage. This in addition to an ecological impact evaluation of the NPF also to aid in the development of marine protected areas and parks. I will suggest to separate these two objectives simply because biological investigations for the purpose of defining marine protected areas and parks have a much longer time-scale than required to meet the immediate needs to assess the ecological impacts of a dynamic NPF. To compare fished ecosystems with non-fished ecosystems in this context is likely to be unproductive. The only practical (and economical) way to collect baseline data at such a large scale as the NPF is by the prawn trawlers themselves with added appropriate controls.

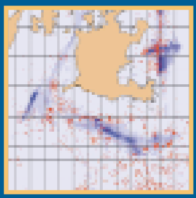
The report more than adequately meets the objectives – it is a large and difficult undertaking and the report constitutes a massive piece of scientific work. The analyses are highly sophisticated although the data is most cases only allows for speculations. The authors call for more surveys to fill the missing gaps of marine biological parameters (Chapter 2 etc.). An in depth study of the biogeography of the region may be important for classification purposes but I think this requires a bit more thinking. The GoC region is likely to be highly dynamic and surveys only reflect a moment in time. To implement ESD and ecosystem-based management there is a need to develop dynamic research programs in step with the NPF and others that impact on the marine environment.

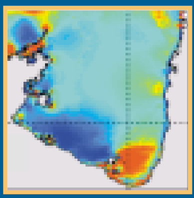
The surrogate indicator pursue appears at this stage to have failed because of scale and lack of baseline data. However, I believe that these will not easily be found in highly diverse assemblages because in less diverse assemblages at closer scrutiny they always appear to be illusions. I don’t think that my criticism is new to the authors because the conclusion in Chapter 9 clearly summarised this: “Research is required to understand the notion of adequacy for marine ecosystems: how much area is enough, where should it be, and how should we monitor it?”

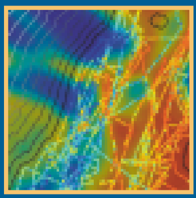
END











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