# Long-term recovery of trawled marine communities 25 years after the world's largest adaptive management experiment

Final Report for project 2017-038 for the Fisheries Research and Development Corporation

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CSIRO Oceans and Atmosphere Research

19 December 2021

Australia's National
Science Agency

**ISBN 978-1-925994-25-4 (PDF Digital on-line)**

Long term recovery of trawled marine communities 25 years after the world's largest adaptive management experiment [FRDC 2017-038]

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Keesing, J.K., Althaus, F., Alvarez, B., Bryce, M., Lozano-Montes, H., Miller, M., Mortimer, N., Orr, M., Pitcher, C.R., Pogonoski, J., Rochester, W., Sainsbury, K.J., Wakeford, J., Westlake, E. and Williams, A. (2021). Long term recovery of trawled marine communities 25 years after the world's largest adaptive management experiment. Final Report for project 2017-038 for the Fisheries Research and Development Corporation. CSIRO, Australia.

Individual chapters maybe cited, for example: Lozano-Montes, H. (2021). North West Shelf Ecosystem Trophodynamics Model. Chapter 7 in Keesing, J.K., Althaus, F., Alvarez, B., Bryce, M., Lozano-Montes, H., Miller, M., Mortimer, N., Orr, M., Pitcher, C.R., Pogonoski, J., Rochester, W., Sainsbury, K.J., Wakeford, J., Westlake, E. and Williams, A. (2021). Long term recovery of trawled marine communities 25 years after the world's largest adaptive management experiment. Final Report for project 2017-038 for the Fisheries Research and Development Corporation. CSIRO, Australia.

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# List of acronyms

AFZ – Australian Fishing Zone

AHD – Australian Height Datum

ARA – Angular Range Analysis

Chl-*a* – Chlorophyll-*a*

CPUE – Catch per unit of effort

CSIRO – Commonwealth Scientific and Industrial Research Organisation

CTD – Conductivity, temperature and depth

DO – Dissolved oxygen

DOM – Dissolved organic matter

DPIRD – Department of Primary Industries and Regional Development

EE – Ecotrophic Efficiency

EwE – Ecopath with Ecosim

FA – Fishing area

IMG – Image

IMCRA – Integrated Marine and Coastal Regionalisation of Australia

INV2017_05 – Surveys conducted in 2017 onboard the RV *Investigator*

KSi – Keystone species index

MP – Marine Park

MTI – Mixed Trophic Impacts

NWS – North West Shelf

PAR – Photosynthetically active radiation

P/B – Production / Biomass ratio

PFTF – Pilbara Fish Trawl Fishery

PMCP – Pilbara Marine Conservation Partnership

Q/B – Consumption / Biomass ratio

RTI – Relative total impact

SBP – Sub-bottom profiler

SPM – Suspended particulate matter

TWT – Two-way time

VME – Vulnerable marine ecosystem

# Acknowledgments

This research was carried out aboard the RV *Investigator* (voyage INV2017_05) with funding and logistical support provided by Australia's Marine National Facility, the Fisheries Research and Development Corporation, Parks Australia and CSIRO. Particular thanks to the crew of the RV *Investigator*; Voyage Manager, Max McGuire; and the support staff of the Marine National Facility. Drs Beth Fulton and Cathy Bulman provided guidance on development of modeling scenarios. All samples were taken in accordance with CSIRO Wildlife and Large Animal - Animal Ethics Committee approval 2017_17, the Australian Fisheries Management Authority scientific permit 1003509, Australian Department of National Parks permits E2017-0134 and AU-COM2017-378 and the Western Australian Department of Biodiversity, Conservation and Attractions permit number 08-0011252-1.

# Executive summary

## Background

Australia's North West Shelf (NWS) was extensively fished, mainly by the Taiwanese pair trawlers (Liu et al. 1978) in international waters and for a few years after the NWS came under Australian management jurisdiction in 1979, and then by Australian fishers (Newman et al. 2018). Research was conducted by CSIRO and others between from 1982 to 1997 (Sainsbury 1987; 1988; 1991, Sainsbury et al. 1997) that included fish species composition, the distribution of seabed habitats and an adaptive fishery management regime. Analysis of the planned adaptive management experiment, conducted between 1986 and 1991, indicated improvements both in terms of recovery of seabed habitats and rebuilding fish stocks (Sainsbury et al. 1997). The extent to which trawled seabed habitats have recovered to their untrawled state since international fleets ceased trawling has remained a topic of interest, but the initial analysis could not determine the longer-term effects.

The aims of this project are (i) to determine the extent to which habitat-forming benthic invertebrate and demersal fish assemblages of the North West Shelf (NWS) have recovered from high levels of foreign trawling effort between the early 1970s and the mid-1980s, and (ii) to compare these with areas that have been closed to trawling since 1998 and areas that continued to be fished with lower levels of effort since 1990 within the area under management of the Pilbara Fish Trawl Fishery (PFTF).

The effects of trawling on the seabed are a major issue worldwide and the results of this project are both significant in an international context and relevant to the management of trawl fisheries around Australia. The results have significant potential for uptake into and impact on fisheries and marine ecosystem management.

A survey to re-sample the study area to assess recovery was undertaken in 2017 aboard the Marine National Facility RV *Investigator*. The study also draws on data collected on the NWS between 1982 and 1997 by CSIRO as part of the adaptive management regime, as well as other available data.

## Objectives

By contrasting the diversity, abundance, and biomass of the demersal fish community and epibenthic, habitat forming invertebrates across gradients of historical and recent trawl-effort intensity, and by comparing these data with that collected in the 1980s and 1990s using the same methods, conclusions about the recovery of trawled communities and the sustainability of trawling may be inferred.

Consistent with the earlier development of the adaptive management regime, it is hypothesised that areas where trawling effort has ceased or has been dramatically reduced since the comparative surveys in the 1980s and 1990s will be characterised by (1) re-establishment of benthic habitats with greater coverage, biomass and complexity of larger habitat-forming filter-feeder communities, and (2) higher biomass of key habitat-associated demersal fish species (e.g. families Lethrinidae and Lutjanidae).

### Structure of this report

Chapter 1 sets out the background to the study, provides context to the earlier research on the NWS and summarises how the work was designed and carried out on the 2017 voyage. A detailed description of all the methods employed in the study, including field operations and laboratory analyses, is provided in Appendix A.

Chapter 2 provides a physical and biological characterisation of benthic habitats using acoustic and image analysis methods. Habitat information was collected by mapping depths, sub-bottom profiling to determine seabed structure and multibeam acoustic swathing (bathymetry and backscatter [seabed hardness/softness]). Each of the sites surveyed have about 7 km of seabed swathed. Although depths are shallow, multiple passes at most sites mean the swath width is about 500–1000 m. The seabed imagery covers transects of about 3 km at each site. The analyses describe and compare the substrate type, topography and the benthic biota at sites grouped spatially into the Pilbara Fish Trawl Fishery areas, Marine Parks, and other relevant practical spatial classifications.

Chapter 3 describes the diversity and assemblage structure of habitat forming filter feeder communities (sponges and soft corals) and fish assemblages. A list of species caught is provided for sponges, softcorals and fishes with a discussion of notable taxa, especially those of important conservation significance.

Chapter 4 sets out the analysis of historical fishing effort and environmental and biological datasets that were available pre-voyage and how these were used to design the sampling strategy for the project.

Chapter 5 analyses the extent of recovery of the trawled sessile benthos communities 25 years after the period of Taiwanese pair-trawling ceased on the NWS. The basis of the assessment was the 2017 sampling survey that sampled areas previously subjected to high levels of pair-trawling but were then closed and remained untrawled. Data from the earlier surveys in the 1980s and 1990s were also re-assessed using similar approaches. In addition, the assessments also accounted for environmental gradients that may influence benthos distributions and abundance and potentially confound comparisons of trawl impact effects if not considered.

Chapter 6 present a spatial and temporal analysis of the demersal fish community from survey sampling during the 1980s through to the 2017 NWS voyage and examines trends in abundance over that period in each of the spatial constructs of interest to the area.

Lastly, chapter 7 presents an ecosystem model (Ecopath with Ecosim energy balance model) for the NWS, using data acquired during this study. These models have been widely applied to inform ecosystem-based management; climate change impacts, fishing impacts, spatial closures and impacts of artificial reefs since their development in the late 1980s. The model used a range of fishing scenarios to evaluate impacts of trawling.

## Sampling design and methods

Survey sampling occurred aboard the RV *Investigator* between 12 October and 6 November 2017 between 30 and 125 km offshore between Port Hedland and the Montebello Islands on the Pilbara section of the NWS, WA, in water depths of 25 m to 100 m. Much of the area surveyed was within the PFTF which is divided into 6 management zones (called “Areas”). Some of these are referred to below.

The study also draws on data collected on the NWS using similar methods between 1982 and 1997 by CSIRO as part of an adaptive management experiment (Sainsbury 1987; 1991; Sainsbury et al. 1997). A random-stratified sampling design was implemented in 1982 and maintained consistently through to the 1997 survey.  The design was based on 19 strata representing: three spatial areas, each with different management arrangements (see Figure 1); depth (shallow, middle, deep); and substratum type (shelly sand, sand, silty sand, undefined). These surveys conducted trawl sampling, using a McKenna trawl on two RV Southern Surveyor voyages (SS199508: 108 stations; SS199707: 106 stations), and Frank & Bryce trawls on 11 FRV Soela voyages (SO198205 to SO198805: 1096 stations) and two RV Southern Surveyor voyages (SS199002: 133 stations; SS199104: 101 stations). Identification and quantification of these trawl samples focussed primarily on fishes, with some identification of invertebrates at species or higher taxonomic levels. Sponges were quantified at the phylum level only on the two McKenna trawl voyages. On most voyages (10 of 15), a 35 mm still film camera was fitted to the headline of many trawls and provided images of sessile benthos on the seabed ahead of the trawl net. Photos were available for 583 stations (of a total of 1544 trawls) and typically about 80 photos were available for each, although this ranged widely. The imagery of the 10 voyages were analysed to assess abundance of seabed benthos and were used in analyses presented by Sainsbury (1991) and Sainsbury et al. (1997).

The principal limitation for the current study was that the field work needed to be conducted on just one voyage with about 25 days of operations available. It was envisaged that we would be able to sample about 100 sites in this time. The stratification needed by the 2017 survey required that the biological space (which is continuous) be sampled representatively to ensure that the influence of environmental gradients on demersal habitats and fish assemblages could be accounted for in analyses of trawl impacts and recovery.

The study area was constrained in comparison to the 1980s/90s surveys (Figure 1) and was first stratified by the trawl-effort contrasts reflecting combinations of contrasting historical (1979–1985) and recent (2005-2016) trawl effort (Figure 3). The trawling effort level contrasts for both historical and recent trawl effort included zero/low, low/medium, medium/high and high (see Figure 4). There were 16 possible combinations, although only 13 of the possible combinations existed (i.e. there were no cases of low/zero historical effort and medium, high or very high recent effort, Figure 4). Areas in the higher trawl effort categories were also relatively rare, particularly for the recent effort and especially the high-historical and high-recent combination, but all contrasts were allocated at least a minimum number of stations. Each combination was further stratified by important environmental gradients and clustered into a number of groups corresponding to the required number of stations for each contrast. Stations were then selected from each cluster group, prioritising locations previously sampled by earlier surveys that had recorded catches of benthos, otherwise the most central cell for each cluster was selected. In some cases, buffer zones around submarine cables, gas pipelines and other oil and gas infrastructure had an impact on where actual sampling could be undertaken. In total 100 stations were selected. To enable as close a comparison as possible with the earlier work, a McKenna trawl net was employed using the same time/distance for each shot and a trawl headline camera was used to capture images of the seabed to assess abundance of seabed benthos ahead of the net as had been done previously. Habitat and environmental data were also collected at each site using acoustic swath mapping and sub-bottom profiling. CTD profiles and Niskin water sampling were undertaken at some sites. A full description of the design methodology is provided in Chapter 4 and the methods are given in detail in Appendix A.

## Summary of Results

### Benthic habitat characterisation

One hundred sites across the NWS were surveyed in 2017. Each site was grouped among the four relevant PFTF Areas (1, 2, 3 or 4) or were allocated to a grouping inshore of the fishery (including sites in the Dampier Marine Park) or west of the fishery (including sites in the Montebello Marine Park. Characteristics of each of these 6 areas were compared with similar data from sites sampled in the same areas between 1982 and 1997. Data on seabed habitat characteristics from each site were assessed from images taken by the trawl headline camera and included substrate type and topography and the proportion of different biota types. For 2017, seabed type was available from the sub-bottom profiler and sediment grain size and some water column parameters were also measured.

Sites inshore of the commercial trawl fishery ranged in depth from 30 to 57 m with predominantly flat bottom of fine sand or fine sand overlaying hard substrate. The sub-bottom profiler revealed a high proportion of sites (13/23) exhibiting >50% hard bottom and 16/23 exhibiting 100% hard and/or thin sediment over hard bottom. Consequently, it was this inner-shelf area that the highest levels of filter-feeder habitat with 15/23 (65%) sites having sponges comprising >10% of the benthic biota visible in seabed imagery. This was similar to that for historical data (103/179 sites, 57%).

Sites west of the commercial trawl fishery ranged in depth from 55 to 84 m with predominantly flat bottom of fine sand. The sub-bottom profiler showed the seabed was predominantly thick or thin sand with only 2/13 sites having >10% hard bottom. These two sites (W14 and W49) were also the ones with the highest density of filter feeding habitat, predominantly soft corals. No sites had seabed biota comprising >10% sponges. In contrast, 12/20 of the historical sites, while having similar sediment features, had > 10% sponge cover and 6/20 had >20% sponges. These differences between the recent and historical data may explain the change in fish biomass over time (see below) but the reason for the change in biota is not clear.

Sites in PFTF Area 1 ranged in depth from 56 to 82 m (only 2 sites >80 m) and were of two types; 11/28 sites were >60% thick or thin sediment over bedrock and 15/28 were hard bottom. The seabed was largely flat with a fine sand on the surface; 9/15 (60%) of the hard substrate sites had >20% of seabed biota such as sponges. For the historical samples this was lower (20/48 sites or 42%).

Sites in PFTF Area 2 were very similar to those in PFTF Area 1. They ranged in depth from 57 m to 91 m (only one site >82 m) and were of two types; 8/21 sites were >60% thick or thin sediment over bedrock and 13/21 were hard bottom and or rocky outcrops. The seabed was largely flat with a fine sand on the surface; 11/21 (52 %) of the hard substrate sites had >10% of seabed biota being sponges (4/21 or 19% had >20% sponges). For the historical samples this was higher with 41/62 sites or 66% having >10% of seabed biota being sponges and 22/62 sites or 35% have >20% sponges.

Sites in PFTF Area 3 ranged in depth from 60 to 76 m and were of two types; 5/8 sites were 100% thick or thin sediment over bedrock and 2/8 were 100% hard bottom. The seabed was largely flat with a fine sand on the surface. Only 1 site (12 %) had >5% of seabed biota being sponges. For the historical samples this was much higher, 12/22 sites or 54% had > 10% biota being sponges. The other difference between the 2017 and historical sites was that 7/22 of the historical sites had >40% coarse sand compared to all of the 2017 having >95% fine sand.

Sites in PFTF Area 4 were mostly deep, ranging in depth from 73 to 91 m. These were also of two types, 3/7 sites had >70% hard bottom while 2/7 had >70 % thin sediment. All sites had fine surface sand and were flat in terms of topography. None of the 2017 sites had >5% sponge biota which was in contrast to the historical sites which had 11/22 (50%) of sites with >10% benthic biota being sponges.

In summary the 2017 spatial groupings fell into 3 categories, the shallow largely hardbottom and dense filter feeder habitats inshore of the commercial trawl fishery, a mix of hard and soft bottom types with dense filter feeder habitats in some areas (PFTF 1 and 2) and mostly soft bottom habitats with sparse filter feeder habitat (PFTF3, PFTF 4 and the area west of the commercial trawl fishery).

### Fish, sponge and softcoral diversity

Approximately 373 fish taxa from 89 families were identified from the 2017 NWS voyage. The following families had the highest number of identified taxa: Carangidae (19 species), Apogonidae (17), Serranidae and Labridae (16 species), Lutjanidae, Monacanthidae, Nemipteridae and Scorpaenidae (12), Dasyatidae, Synodontidae and Platycephalidae (11) and Lethrinidae (10). Other diverse families included Gobiidae, Bothidae and Tetraodontidae (9), Chaetodontidae and Paralichthyidae (8), Mullidae, Muraenidae and Ostraciidae (7 each), and Syngnathidae (6 each). All other families had five or less species and 41 families were represented by a single species.

One hundred and thirty-three "soft coral" species (133) within the subclass Octocorallia, Order Alcyonacea were identified. All five suborders within the Alcyonacea were present, representing 14 families and 44 genera. The five suborders comprised 2 Stolonifera octocoral species, 32 Alcyoniina, 12 Scleraxonia, 73 Holaxonia, and 14 Calcaxonia. The following families had the highest number of identified taxa: Plexauridae (58), Nephtheidae (13), Acanthogorgiidae (13), Ellisellidae (12) and Nidaliidae (10).  All other families were represented by only a few species (1–9).

For this study, a full sponge species catch composition could only be achieved for the 11 stations that fell within the Dampier and Montebello MPs. This was made possible by additional project funds being provided by Parks Australia for post voyage taxonomy of some invertebrate groups. A total of 153 species from 12 orders, 38 families and 87 genera were found. Only 73 of those could be assigned to previously described species. The 153 species belong to a diverse number of families. The families with the greatest number of species were Raspailiidae, followed by the Callyspongiidae and Axinellidae. The most common species in these families were *Echinodictyum mesenterinum, Arenosclera WAM sp. 1 cf.* and *Axinella aruensis* (variety II) respectively. Most species found (78%) were singletons suggesting the area has high levels of endemism.

New species and/or new records for Australia or Western Australia were found among the fish, sponge and soft coral samples collected indicating that the fauna of the NWS is still poorly known despite relatively intensive previous sampling.

### Patterns of distribution and recovery of benthos from trawling

A key aim of this study was to assess the extent of recovery of the trawled seabed communities 25 years after the cessation of foreign pair-trawling and closure of large areas to all trawling.

To achieve this, multiple lines of evidence were considered, including: (1) simple temporal comparisons of the sampled biomass of sponges; (2) temporal comparisons of depletion trends in observed benthos on the gradient of pair-trawling intensity; and (3) simulation modelling of trawl impacts for the entire history of trawling in the region, to date. In summary: (1) The temporal comparisons of trawl-sampled sponge biomass suggested that sponge densities in 2017 were similar to those sampled in neighbouring locations in 1963, whereas those sampled in 1995-97 were less than both 1963 and 2017. (2) The analyses of trawl-gradient trends showed primarily negative trends indicative of benthos depletion during and shortly after the period of pair-trawling; however, analyses of the 2017 survey data showed zero (or even positive) trends indicative of recovery. (3) The trawl simulation modelling of the annual distribution and intensity of all trawling in the region from 1959 to 2016 suggested that following the peak of foreign pair-trawling regional benthos populations may have been depleted by 5%–35%, depending on the benthos type and uncertainty scenario, but subsequently recovered gradually after pair-trawling ceased and with progressive reductions in domestic trawl effort. Multiple lines of evidence indicated that the regional benthos populations had largely recovered to within a few percent of the estimated pre-trawl levels by 2017. Further, and more optimistic scenarios are plausible, indicating strong recovery of benthic communities. Recent trawling activities has some negative trends for some benthic morpho-types but this are highly localised and may have limited regional-scale population impacts of less than ~1%–2% of benthic cover.

### Spatial and temporal trends in fish assemblages

An analysis of continental shelf fish assemblages of the NWS used a data set from eight historical research surveys (1986–1997) with standard sampling characteristics. Fish assemblages were strongly structured by depth, and there was no evidence of longitudinal pattern in the surveyed area. Two inner/mid-shelf assemblages in ~25–100 m depths were prominent, and strongly differentiated by species-habitat associations—either to structured benthic habitat (genera *Lethrinus* and *Lutjanus*) or unstructured habitat (genera *Nemipterus* and *Saurida,* and *Abalistes stellatus*). These assemblages had no broad spatial sub-structure, but were highly mixed at the scale of individual trawl samples, indicating association with a mosaic of habitats existing at fine spatial scales. Two other assemblages were associated with a prominent steep rocky paleocoastline at ~100 m depth, and a single stable deep-shelf assemblage occurred beyond the paleocoastline in ~100-150 m. In greater depths (> ~150 m), two less-stable assemblages were classified within relatively few samples from the steep and narrow continental shelf edge.

A time-series (by year) analysis of biomass change in inner/mid-shelf fish assemblages was made for the smaller area of the NWS surveyed in 2017 survey. This analysis used data from two additional years (1982 and 1983) when foreign trawl activity was recent, intense and widespread in the region. The study area was segmented into five fishery management areas of the PFTF and six areas characterised by a variety of contrasts between historical and recent trawl effort (Chapter 4). Widespread significant increases in fish biomass were consistent with an overall reduction in fishing mortality, but the prominence of species with associations to structured benthic habitat provided support for the hypothesis that biomass increases were a positive response to benthos recovery. This was corroborated by a general increase in the abundance of large benthos consistent with a decreased impact from bottom trawling as the intensity and spatial extent of trawl effort declined over the period of analysis (1983 to 2017) (and see Chapter 5). This result reinforces the findings of Sainsbury et al. (1997) which showed and increase in the benthos even after a relative short post-trawling period of the adaptive management experiment.

Several within-area changes in fish biomass did not, however, correspond to expectations of trend based on trawling history — these included a significant biomass increase in the core fishery PFTF

Area 1 where trawling effort remains relatively high, and, conversely, no significant increase in the PFTF Area 3 trawl closure. Areas where changes in fish biomass were inconsistent with expectations also corresponded to areas where there were unforeseen changes in abundance of large benthos — with co-located large increases in fish and benthos apparently reflecting areas with a higher pre-fishery carrying capacity and greater than expected recovery potential. A notable example was the aggregated sub-areas of PFTF Area 1 where high trawling effort had been consistently located throughout the duration of the fishery (trawl contrast area TC 3C in chapter 6). These aggregated areas appear to be the locations of the region's best trawling grounds, and therefore our data suggest they are characterised by habitats with elements of hard seabed structure, and that their relatively high potential for benthos recovery supported a greater than predicted increase in the biomass of fishes associated with structured habitats.

In contrast, the low biomass of habitat-associated fishes and lack of significant increase of fish biomass in the PFTF Area 3 closure correlate with a low carrying capacity (low benthos abundance and low potential for recovery), perhaps indicating the trawl closure was located where there was relatively little value for the fishery. Our findings differ somewhat from those of Langlois et al. (2021) whose 2010 study using baited remote underwater video found evidence of higher biomass and/or abundance of some target fish species including *Lutjanus sebae* and *Epinephelus multinotatus* in PFTF Area 3 as compared to other PFTF areas. The reasons for these differences warrant further examination of fish habitat dynamics in PFTF Area 3 but are most likely to reflect differences in time frames, methodology, scale of observations and how habitat varied at the sites were selected for sampling in the two studies. Langlois et al. (2021) compare biomass/abundance *between* areas at one point in time (2010). Our study examines trends *within* areas over a much longer period (1983 to 2017). The significant decline in biomass in all fish groups (with the exception of *Saurida*) in the Barrow area — the only area showing decline — is unexplained. It may be linked to limited recovery of benthos, (although there is limited evidence that this was ever an area of very high benthic filter feeder abundance) despite having a 'high to low' trawl contrast and being largely within the Montebello Marine Park which has been closed since 1993. There appears to be a local and unmeasured driver of change that has not affected adjacent areas to the east.

### Ecological modelling

The structure and functioning of one of the most biodiverse ecosystems in Australia, the North West Shelf (NWS) in Western Australia was elucidated in this study using an ecosystem model developed with Ecopath with Ecosim software (www.Ecopath.org). The model was assembled using biological information for 73 functional groups sampled at 100 sites across gradients of historical and recent fishing effort, using a demersal fish trawl and epibenthic sleds during 2017 in the model region. Biomass of 59 of the 73 functional groups in the model were estimated directly from data collected during this biological survey. Model outputs from the network analysis suggest that the NWS is a system with medium to high maturity, stability and disturbance resistance. Keystone groups were identified (e.g. lizardfish, squids, sharks), which have an important role in the structuring of this food web from top down forces associated with predation. The effect of fishing was explored using a set of scenarios. For example, results from scenario "Business as Usual" showed a mean increment of 19% in the biomass of commercial exploited groups after 20 years of fishing at 2016/17 fishing rates. The simulation of closing all fisheries over 20 years resulted in an increase of 64% in the relative biomass of target species. The mean trophic level of the catch (MTLc) of the fisheries that access areas which form the NWS region was 3.61, markedly higher than the average estimate of the trophic level catch for global coast and reef systems worldwide of 2.54 (Pauly et al., 1998). Analysis of commercial catches in the NWS reveals two contrasting periods of the MTLc. First, a fishing down effect is observed from 1973 to 1991, where the MTLc declined from 3.6 to 2.7 (indicating potential problems with overfishing), followed by a recovery from 1992 to 2018 with high trophic level fishes dominating the landings and increasing the MTLc in 2018 to 3.61 (estimated by the model) and to 3.58 (estimated from the catch data). The recovery in the MTLc most probably is explained by the introduction of continuous management actions since 1992, such as areas closures, gear restrictions, removing foreign fleets, and the use of input controls. The upward trend of the MTLc since the middle 1990s is an indication of the presence of effective governance to achieve sustainability and reflect the success of management regulations established since 1992. The model developed in this study integrates the data available in the region and it provides a summary of our current knowledge of the biomass, consumption, production, and trophic flows across the NWS.

## Implications for stakeholders

Comparisons of this study with the results of the earlier adaptive management experiment (Sainsbury 1991) and the current long-term study are consistent. The intentions of the adaptive management experiment (Sainsbury 1991) were to examine the recovery of the seabed habitats and rebuild fish stocks. The short-term review of the experiment confirmed both these improvements (Sainsbury et al. 1997) but could not determine the longer-term effects. The 2017 survey and the results of this study have confirmed and refined the extent of the seabed recovery and stock rebuilding.

The results suggest that the region has largely recovered from the effects of heavy/intense historical foreign trawling and that existing levels of trawl effort are not impacting habitat-forming filter-feeder benthic habitats or fish stocks to a level which threatens the health of either. That is, the overall aims of the adaptive management experiment in the 1980s and 1990s, plus the following fishery management arrangements through the PFTF, were achieved. In general, the premise that filter-feeder habitat supports—or is at least associated with—a higher biomass and diversity of demersal fish species was supported. In most cases examined, there was evidence that fish biomass of target groups such as lethrinids and lutjanids had increased in association with recovery of filter feeder biomass and, in cases where comparisons were made, between historically high levels of trawl effort to lower levels. In some cases, results did not follow our expectations. Firstly, the area west of PFTF Area 1, much of which now comprises the Montebello Marine Park showed a reduction in fish biomass and an apparent decline in seabed habitat complexity. The reasons for this are unclear but warrant further investigation. Secondly, fish biomass did not increase to the extent anticipated in Area 3 which had been closed to trawling since 1998. Langlois et al. (2021) used baited remote underwater video in their 2010 study and found evidence of higher biomass and/or abundance of some target fish species in Area 3 relative to other PFTF areas. Our findings are interpreted as an indication that this area did not have historically high levels of benthic filter feeder habitat relative to other areas and despite the closure, and thus, its capacity to recover from trawling was not as great as other areas. Langlois et al. (2021) found only subtle differences in benthic filter feeder benthos and given the differences in methodology (our 2 km x 20 m trawl swath camera survey and trawl fish catch versus their fixed site, baited remote camera survey seven years earlier), the conclusions/interpretations about seabed benthos between the two studies can be regarded as being largely consistent.

## Recommendations

The results of the study suggests that habitat recovery has occurred on the NWS since cessation of the high level of pair trawling effort in the 1970s and 1980s, and that there is little evidence that fishing effort since ~2005 has prevented continued recovery of filter feeder habitats. It is recommended that further exploration be undertaken of the reasons for the apparent decline in both seabed habitat complexity and fish biomass in the area west of the commercial trawl fishery.

## Keywords

North West Shelf, NWS, Effects of Fishing, Vulnerable Marine Ecosystems, VMEs, ecological interactions, trawling, conservation, Marine Parks, biodiversity, fishes, sponges, soft corals filter-feeders

# 1 Introduction

John Keesing (CSIRO Oceans and Atmosphere Research)

Australia's North West Shelf (NWS) was extensively fished, mainly by the Taiwanese pair trawlers (Liu et al. 1978) in international waters and for a few years after the NWS came under Australian management jurisdiction in 1979, and then by Australian fishers (Newman et al. 2018). Research was conducted by CSIRO and others between from 1982 to 1997 as part of an adaptive management experiment conducted between 1986 and 1991 (Sainsbury 1991, Sainsbury et al. 1997). The adaptive management experiment was to test several hypotheses about the role of the seabed seabed habitats in determining fish community composition and the rates of their recovery from fishing. The adaptive management regime introduced sequential spatial management in the fishery. The Pilbara Fish Trawl Fishery (PFTF) was developed for the Australian fishing industry in 1990. The PFTF introduced spatial management arrangements in the late 1990s that were very similar to the adaptive management design, though there were some differences, and the domestic fishing effort was minor compared to the previous Taiwanese fishing. The adaptive management experiment was analysed in 1997, after the intended period of the experiment (Sainsbury et al. 1997). This found some increase in both habitat forming organisms and the associated fish community, confirming one of the tested hypotheses, but the extent of full recovery could not be determined from the short time series available then. As a result, the current project was conducted some 25 years after the original adaptive management experiment.

The aim of this project is to determine the extent to which habitat forming benthic invertebrate and demersal fish assemblages of the North West Shelf (NWS) have recovered from high levels of foreign trawling effort between the 1960s and the late 1980s and to compare these with areas which have been continuously fished with lower levels of effort or completely protected from trawling within the area under management of the Pilbara Fish Trawl Fishery (PFTF) since 1990.

Firm conclusions about the rates of recovery of trawled communities and the sustainability of trawling may be made by contrasting the diversity, abundance, biomass and size/age composition of the demersal fish community and epibenthic, habitat forming invertebrates across these gradients of historical and recent fishing effort, and by comparing these data with that collected in the 1980s using the same methods. It is hypothesised that areas where trawling effort has ceased or has been dramatically reduced will be characterised by re-establishment of benthic habitats with greater coverage, biomass and complexity of larger habitat-forming filter-feeder communities, and of higher production of key demersal fish species (families: Lethrinidae, Lutjanidae) since comparative surveys in the 1980s.

The results obtained and samples collected on the trip will enable an evaluation of the recovery of benthic habitats and demersal fish assemblages 30+ years after very significant reductions in trawl effort and enable a comparison with areas which have been trawled continuously over that period. The ability to do this with access to comparative data collected in the 1980s is unprecedented as a result of this voyage. This will result in significant improvements in what is understood about the ability of trawl-impacted systems to recover in the long term and whether management responses have been effective in both protecting and enabling recovery of impacted ecosystems.

The effects of trawling on the seabed are a major issue worldwide and these results will be both significant in an international context and relevant to the management of trawl fisheries in Australia and overseas. The results are likely to have significant potential for uptake into and impact on fisheries and marine ecosystem management.

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## 1.1 Survey design and research methods

Research surveys and sampling were undertaken in October and November 2017 aboard the RV *Investigator.* The study also draws on data collected on the North West Shelf between 1982 and 1997 by CSIRO as part of an adaptive management experiment (Sainsbury 1987; 1991; Sainsbury et al. 1997). A random-stratified sampling design was implemented in 1982 and maintained consistently through to the 1997 survey.  The design was based on 19 strata representing: three spatial areas (Legendre, Hedland, Barrow, each with different management arrangements, see Figure 1); depth (shallow, middle, deep); and substratum type (shelly sand, sand, silty sand, undefined). These surveys conducted trawl sampling, using a McKenna trawl on two RV Southern Surveyor voyages (SS199508: 108 stations; SS199707: 106 stations), and Frank & Bryce trawls on 11 FRV Soela voyages (SO198205 to SO198805: 1096 stations) and two RV Southern Surveyor voyages (SS199002: 133 stations; SS199104: 101 stations). Identification and quantification of these trawl samples focussed primarily on fishes, with some identification of discrete invertebrates at high taxonomic levels. Sponges were quantified at the phylum level only on the two McKenna trawl voyages. On most voyages (10 of 15), a 35 mm still film camera was fitted to the headline of many trawls and provided images of sessile benthos on the seabed ahead of the trawl net. Photos were available for 583 stations (of a total of 1544 trawls) and typically about 80 photos were available for each, although this ranged widely. The imagery of the 10 voyages was annotated in a series of annotation efforts over the years using protocols outlined in an internal report by Troje & Campbell (1989), and early annotation data were used in analyses presented by Sainsbury (1991) and Sainsbury et al (1997).

The principal limitation for the current study was that the field work needed to be conducted on just one voyage with about 25 days of operations available. It was envisaged that we would be able to sample about 100 sites in this time. The stratification needed by the 2017 survey required that the biological space (which is continuous) be sampled representatively to ensure that the influence of environmental gradients on demersal habitats and fish assemblages could be accounted for in analyses of trawl impacts and recovery.

The study area was constrained in comparison to the 1980s/90s surveys (Figure 1) and was first stratified by the trawl-effort contrasts reflecting combinations of contrasting historical [1979–1985] and recent [2005-2016] trawl effort (Figure 3). The trawling effort level contrasts for both historical and recent trawl effort included zero/low, low/medium, medium/high and high (see Figure 4). There were 16 possible combinations, although only 13 of the possible combinations existed (i.e. there were no cases of low/zero historical effort and medium, high or very high recent effort, Figure 4). Areas in the higher trawl effort categories were also relatively rare, particularly for the recent effort and especially the high-historical and high-recent combination, but all contrasts were allocated at least a minimum number of stations. Each combination was further stratified by important environmental gradients and clustered into a number of groups corresponding to the required number of stations for each contrast. Stations were then selected from each cluster group, prioritising locations previously sampled by earlier surveys that had recorded catches of benthos, otherwise the most central cell for each cluster was selected. In some cases, buffer zones around submarine cables, gas pipelines and other oil and gas infrastructure had an impact on where actual sampling could be undertaken. In total 100 stations were selected. To enable as close a comparison as possible with the earlier work, a McKenna trawl net was employed using the same time/distance for each shot and a trawl headline camera was used to capture images of the seabed as had been done previously. A full description of the design methodology is provided in Chapter 4 and the methods are given in detail in Appendix A.

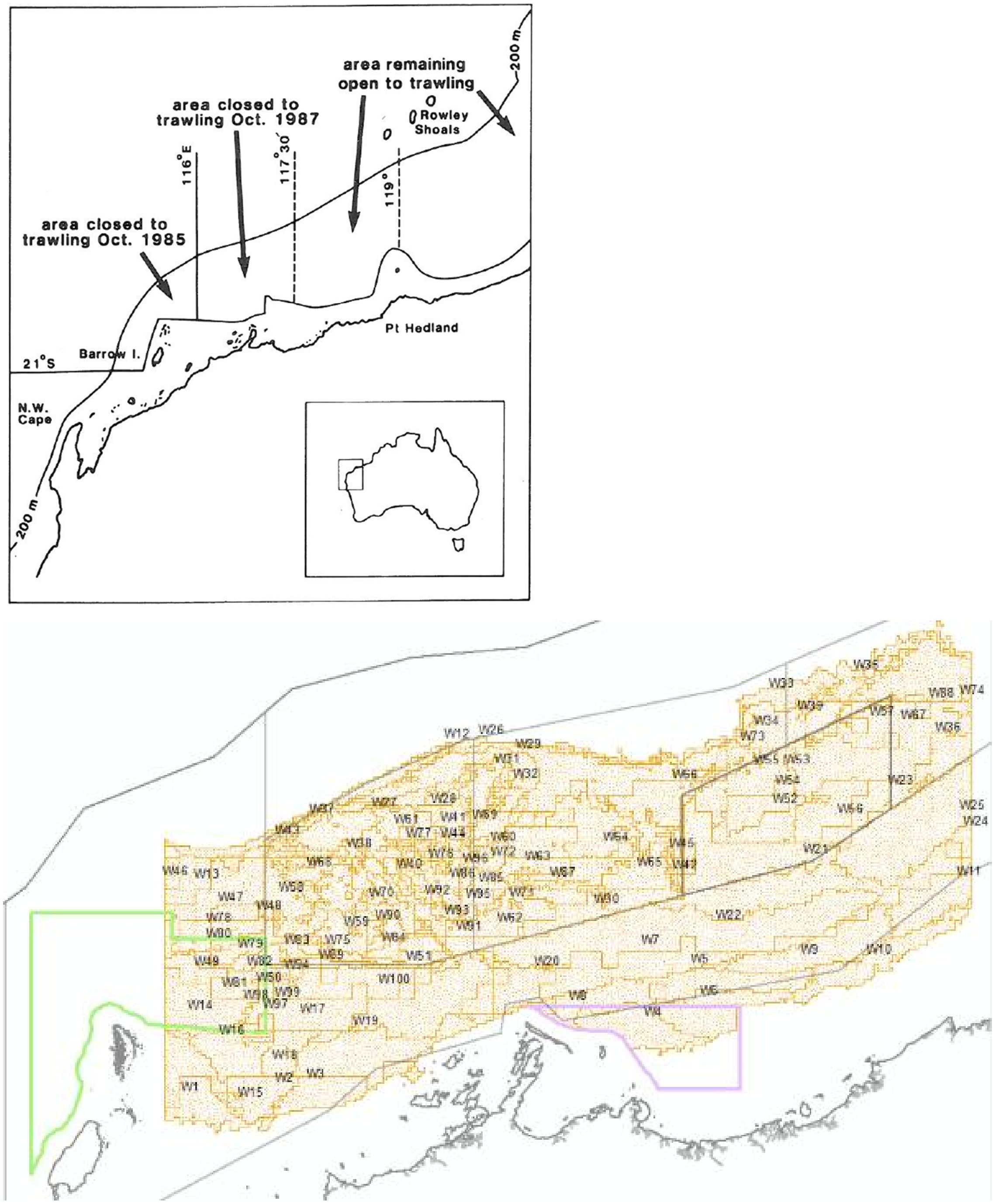


Figure 1. Upper panel shows the spatial strata used in the 1982 to 1997 voyages (from Sainsbury 1991). The three areas indicated by the bolded arrows reflect the zoning areas for the experimental adaptive management experiment conducted between 1986 and 1991 (see Sainsbury et al. 1997). In this current study we have referred to these three areas from west to east as the Barrow, Legendre and Hedland subregions. Lower panel shows 100 sites sampled in the 2017 study. Each site sits within the environmental stratification described in detail in Chapter 4. The location of the zoning boundaries within the PFTF and Montebello and Dampier MPs are also shown. Greater spatial detail of the strata is shown in Chapter 4 and of the location of sample sites in Chapter 2.

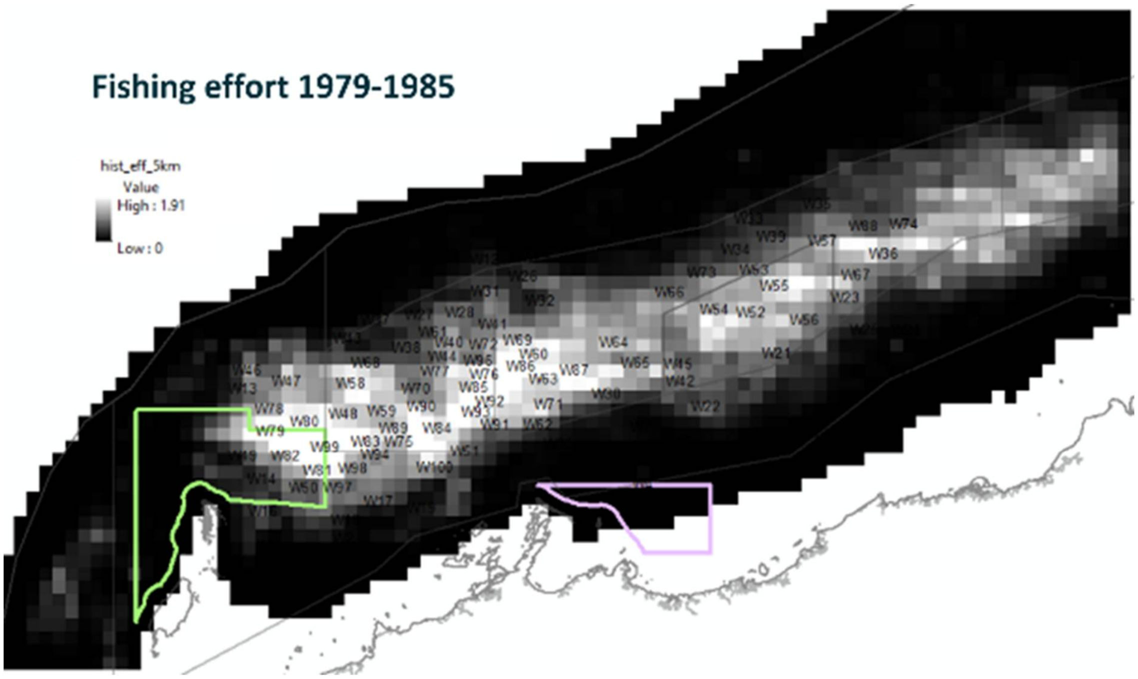


Figure 2. Historical trawl fishing effort in the NWS study region from 1979 to 1985. Area trawled = 191% per annum (hist_eff: 1.91).

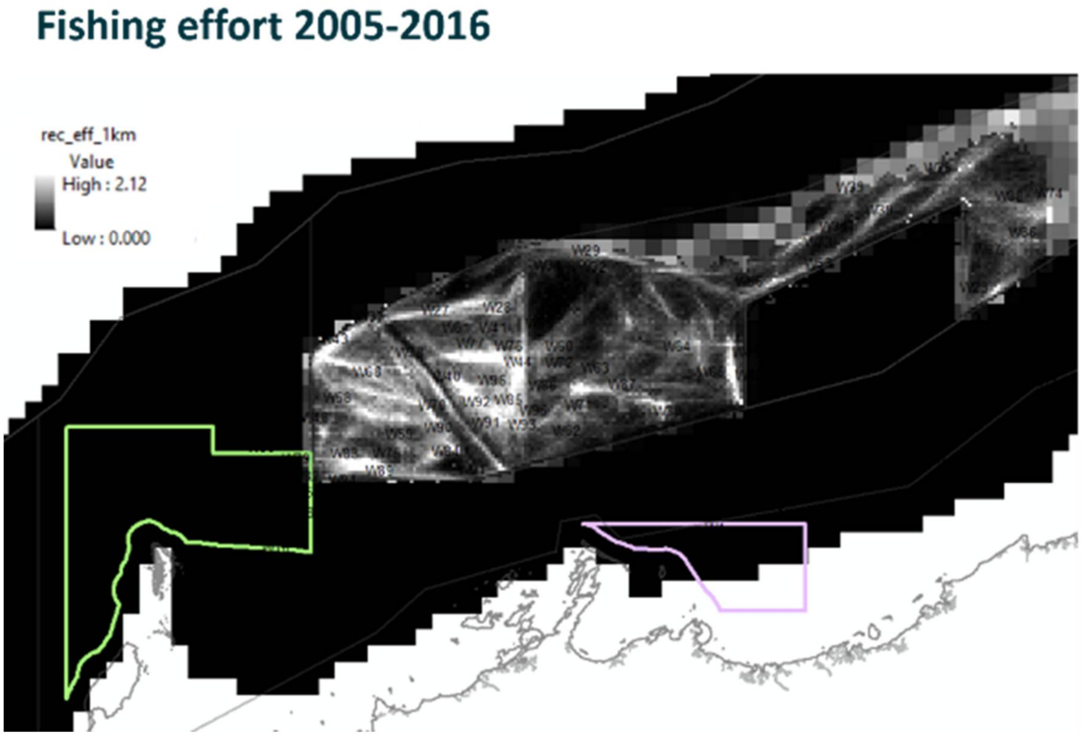


Figure 3. Recent trawl fishing effort in the NWS study region from 2005 to 2016. Area trawled = 212% per annum (rec_eff: 2.12).

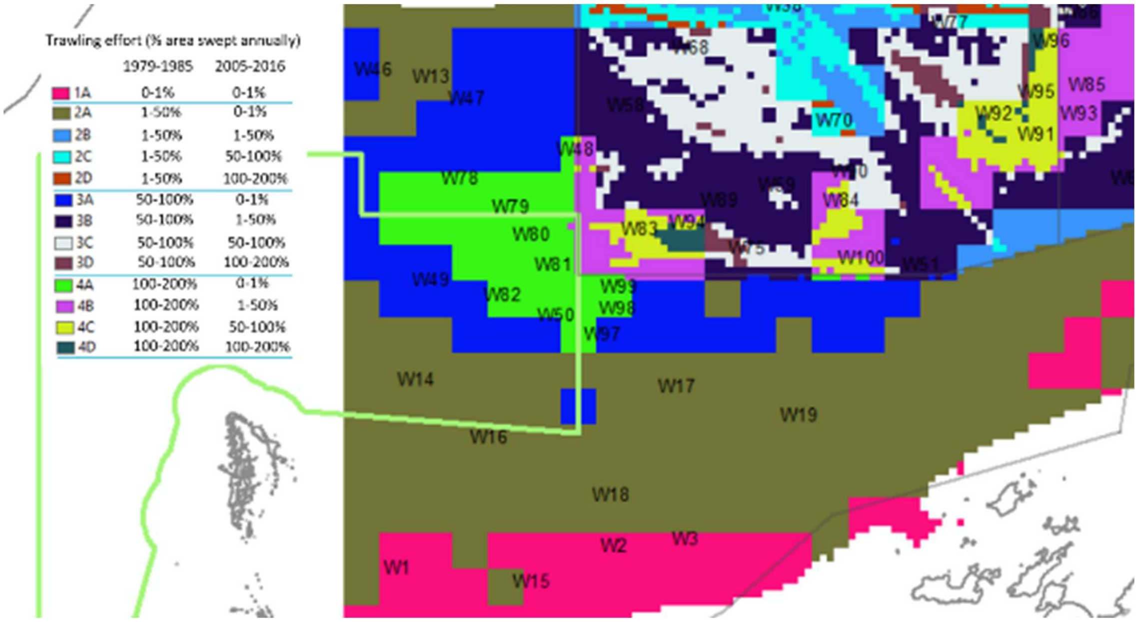


**Figure 4. Example of groupings of categories of historical and recent fishing effort in the western part of the NWS study region. Categories 1 – 4 reflect zero/low, low/medium, medium/high and high levels of historical (1979–1985) trawl effort respectively and categories A – D reflect zero/low, low/medium, medium/high and high levels of recent (2005–2016) trawl effort respectively. Effort levels reflect the percentage of the seabed swept by trawl shots annually. See Chapter 4 for more detail.**

**Table 1. Spatial stratification of the 100 sites surveyed. See Chapter 4 and Appendix A for explanation of the source of fishing effort data and how the strata of historical and recent effort were established. See Figure 5 for location of sites. Colours representing the different combinations of historical and recent effort correspond to those shown in Figure 4.**

| Site | Current Fishing or Conservation Zone | Historical effort (%) swept area per year | Recent effort (%) swept area per year | Site | Current Fishing or Conservation Zone | Historical effort (%) swept area per year | Recent effort (%) swept area per year |
|---|---|---|---|---|---|---|---|
| W1 | inshore of commercial trawl fishery | 0-1 % | 0-1 % | W51 | inshore of commercial trawl fishery | 50-100% | 0-1% |
| W2 | inshore of commercial trawl fishery | 0-1 % | 0-1 % | W52 | PFTF Closed Area 3 | 50-100% | 0-1% |
| W3 | inshore of commercial trawl fishery | 0-1 % | 0-1 % | W53 | PFTF Closed Area 3 | 50-100% | 0-1% |
| W4 | Dampier MP | 0-1 % | 0-1 % | W54 | PFTF Closed Area 3 | 50-100% | 0-1% |
| W5 | inshore of commercial trawl fishery | 0-1 % | 0-1 % | W55 | PFTF Closed Area 3 | 50-100% | 0-1% |
| W6 | Dampier MP | 0-1 % | 0-1 % | W56 | PFTF Closed Area 3 | 50-100% | 0-1% |
| W7 | inshore of commercial trawl fishery | 0-1 % | 0-1 % | W57 | PFTF Closed Area 3 | 50-100% | 0-1% |
| W8 | Dampier MP | 0-1 % | 0-1 % | W58 | PFTF Area 1 | 50-100% | 1-50% |
| W9 | inshore of commercial trawl fishery | 0-1 % | 0-1 % | W59 | PFTF Area 1 | 50-100% | 1-50% |
| W10 | inshore of commercial trawl fishery | 0-1 % | 0-1 % | W60 | PFTF Area 2 | 50-100% | 1-50% |
| W11 | inshore of commercial trawl fishery | 0-1 % | 0-1 % | W61 | PFTF Area 1 | 50-100% | 1-50% |
| W12 | PFTF Area 6 | 1-50% | 0-1 % | W62 | PFTF Area 2 | 50-100% | 1-50% |
| W13 | west of commercial trawl fishery | 1-50% | 0-1 % | W63 | PFTF Area 2 | 50-100% | 1-50% |
| W14 | Montebello MP | 1-50% | 0-1 % | W64 | PFTF Area 2 | 50-100% | 1-50% |
| W15 | inshore of commercial trawl fishery | 1-50% | 0-1 % | W65 | PFTF Area 2 | 50-100% | 1-50% |
| W16 | inshore of commercial trawl fishery | 1-50% | 0-1 % | W66 | PFTF Area 2 | 50-100% | 1-50% |
| W17 | inshore of commercial trawl fishery | 1-50% | 0-1 % | W67 | PFTF Area 4 | 50-100% | 1-50% |
| W18 | inshore of commercial trawl fishery | 1-50% | 0-1 % | W68 | PFTF Area 1 | 50-100% | 50-100% |
| W19 | inshore of commercial trawl fishery | 1-50% | 0-1 % | W69 | PFTF Area 1 | 50-100% | 50-100% |
| W20 | inshore of commercial trawl fishery | 1-50% | 0-1 % | W70 | PFTF Area 1 | 50-100% | 50-100% |
| W21 | PFTF Closed Area 3 | 1-50% | 0-1 % | W71 | PFTF Area 2 | 50-100% | 50-100% |
| W22 | inshore of commercial trawl fishery | 1-50% | 0-1 % | W72 | PFTF Area 2 | 50-100% | 50-100% |
| W23 | PFTF Closed Area 3 | 1-50% | 0-1 % | W73 | PFTF Area 2 | 50-100% | 50-100% |
| W24 | inshore of commercial trawl fishery | 1-50% | 0-1 % | W74 | PFTF Area 4 | 50-100% | 50-100% |
| W25 | inshore of commercial trawl fishery | 1-50% | 0-1 % | W75 | PFTF Area 1 | 50-100% | 100-213% |
| W26 | PFTF Area 2 | 1-50% | 1-50% | W76 | PFTF Area 1 | 50-100% | 100-213% |
| W27 | PFTF Area 1 | 1-50% | 1-50% | W77 | PFTF Area 1 | 50-100% | 100-213% |
| W28 | PFTF Area 1 | 1-50% | 1-50% | W78 | west of commercial trawl fishery | 100-192% | 0-1% |
| W29 | PFTF Area 2 | 1-50% | 1-50% | W79 | Montebello MP | 100-192% | 0-1% |
| W30 | PFTF Area 2 | 1-50% | 1-50% | W80 | Montebello MP | 100-192% | 0-1% |
| W31 | PFTF Area 2 | 1-50% | 1-50% | W81 | Montebello MP | 100-192% | 0-1% |
| W32 | PFTF Area 2 | 1-50% | 1-50% | W82 | Montebello MP | 100-192% | 0-1% |
| W33 | PFTF Area 2 | 1-50% | 1-50% | W83 | PFTF Area 1 | 100-192% | 1-50% |
| W34 | PFTF Area 2 | 1-50% | 1-50% | W84 | PFTF Area 1 | 100-192% | 1-50% |
| W35 | PFTF Area 4 | 1-50% | 1-50% | W85 | PFTF Area 2 | 100-192% | 1-50% |
| W36 | PFTF Area 4 | 1-50% | 1-50% | W86 | PFTF Area 2 | 100-192% | 1-50% |
| W37 | PFTF Area 1 | 1-50% | 50-100% | W87 | PFTF Area 2 | 100-192% | 1-50% |
| W38 | PFTF Area 1 | 1-50% | 50-100% | W88 | PFTF Area 4 | 100-192% | 1-50% |
| W39 | PFTF Area 4 | 1-50% | 50-100% | W89 | PFTF Area 1 | 100-192% | 50-100% |
| W40 | PFTF Area 1 | 1-50% | 50-100% | W90 | PFTF Area 1 | 100-192% | 50-100% |
| W41 | PFTF Area 1 | 1-50% | 50-100% | W91 | PFTF Area 1 | 100-192% | 50-100% |
| W42 | PFTF Area 2 | 1-50% | 50-100% | W92 | PFTF Area 1 | 100-192% | 50-100% |
| W43 | PFTF Area 1 | 1-50% | 100-213% | W93 | PFTF Area 1 | 100-192% | 50-100% |
| W44 | PFTF Area 1 | 1-50% | 100-213% | W94 | PFTF Area 1 | 100-192% | 100-213% |
| W45 | PFTF Area 2 | 1-50% | 100-213% | W95 | PFTF Area 1 | 100-192% | 100-213% |
| W46 | west of commercial trawl fishery | 50-100% | 0-1% | W96 | PFTF Area 1 | 100-192% | 100-213% |
| W47 | west of commercial trawl fishery | 50-100% | 0-1% | W97 | Montebello MP | 100-192% | 0-1% |
| W48 | west of commercial trawl fishery | 50-100% | 0-1% | W98 | inshore of commercial trawl fishery | 100-192% | 0-1% |
| W49 | Montebello MP | 50-100% | 0-1% | W99 | inshore of commercial trawl fishery | 100-192% | 0-1% |
| W50 | Montebello MP | 50-100% | 0-1% | W100 | inshore of commercial trawl fishery | 100-192% | 0-1% |

## 1.2 Voyage summary and operations undertaken

The voyage took place between 11 October 2017, following the departure of the RV *Investigator* from Broome, and 10 November 2017 when the ship berthed in Henderson, near Fremantle. Active sampling occurred between 12 October and 6 November between 30 and 125 km offshore between Port Hedland and the Montebello Islands on the Pilbara section of the NWS, WA, (Figure 5), in water depths of 25 to 93 m.

In total, 100 sites were sampled over 584 operations. Table 2 summarises the operations undertaken at each site and shows that the full set of planned operations were undertaken at most sites. Appendix B provides a full description of all operations undertaken at each site.

Sampling for biodiversity was undertaken at each site using a commercial scale (McKenna) demersal trawl net and epibenthic sled. The trawl net covered a large area (~ 3 km by 20 m width) and effectively sampled demersal fish and representatively sampled large benthic invertebrates. The epibenthic sled covered a smaller area (400 m by 1.5 m width) effectively sampling benthic invertebrates from 50 cm down to ~ 20 mm. Habitat and environmental data were collected at each site using acoustic swath mapping, sub-bottom profiling and a still camera attached to the trawl net headline, which captured an image every 3 seconds or every ~ 4 m. CTD profiles and Niskin water sampling were undertaken at some sites.

Although not reported in this study, sediment grab, turbulence probe and plankton net sampling were also undertaken at most sites. Tow video was not part of the original survey plan, however, in the latter part of the voyage time allowed for video to be collected at five sites as part of efforts to quantify the efficiency of trawl net sampling. A detailed description of the sampling methods and equipment used is given in Appendix A.

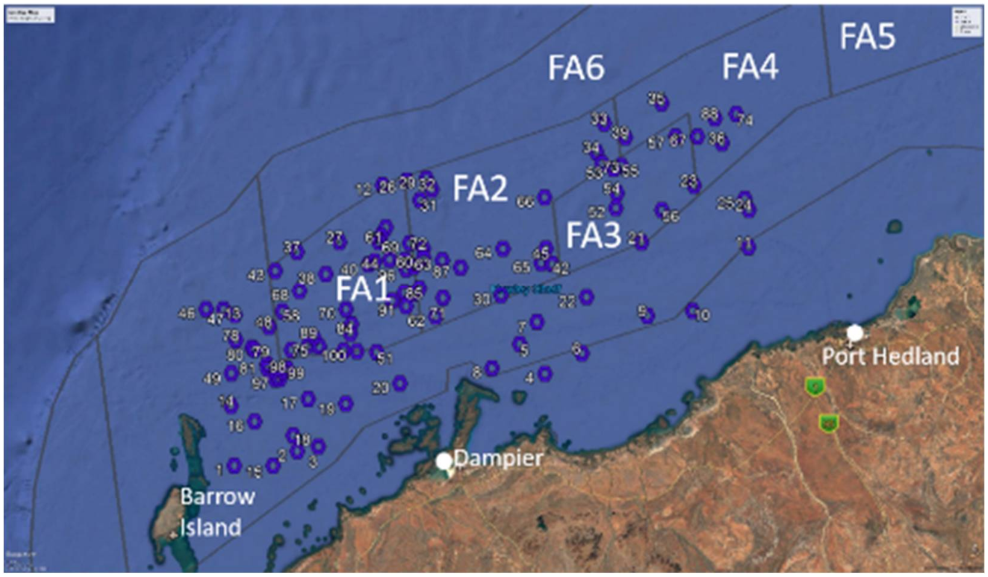


**Figure 5. Map of survey area showing survey sites and location of the six fishing areas (FA) zoned within the PFTF.**

**Table 2. Summary of site locations, depth and sampling operations undertaken for each site on the October-November INV2017_05 RV *Investigator* voyage. SBP = Sub-bottom profiler. *not reported on in this study due to gear failure and net damage at site W29.**

| Summary of operations undertaken at each site | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site | Depth (m) | Long ºE | Lat ºS | Swath/ SBP | Trawl | Trawl Camera | Tow Video | Sled | Grab | CTD | Plankton Tow | Turb. probe |
| W1 | 36 | 115.73 | -20.6 | Yes | Yes | Yes | | Yes | Yes | | | |
| W2 | 36 | 116.03 | -20.57 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W3 | 37 | 116.13 | -20.56 | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| W4 | 34 | 117.21 | -20.36 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W5 | 37 | 117.36 | -20.19 | Yes | Yes | Yes | | Yes | Yes | | Yes | |
| W6 | 30 | 117.39 | -20.29 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W7 | 44 | 117.2 | -20.13 | Yes | Yes | No | | Yes | Yes | Yes | Yes | Yes |
| W8 | 31 | 116.97 | -20.31 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W9 | 39 | 117.71 | -20.16 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W10 | 33 | 117.92 | -20.16 | Yes | Yes | Yes | | Yes | Yes | | Yes | |
| W11 | 38 | 118.21 | -19.91 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W12 | 82 | 116.57 | -19.47 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W13 | 80 | 115.77 | -19.92 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W14 | 41 | 115.75 | -20.34 | Yes | Yes | Yes | Yes | Yes | Yes | | Yes | |
| W15 | 33 | 115.91 | -20.62 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W16 | 37 | 115.85 | -20.42 | Yes | Yes | Yes | Yes | Yes | Yes | | Yes | |
| W17 | 45 | 116.11 | -20.35 | Yes | Yes | Yes | Yes | Yes | Yes | | Yes | |
| W18 | 42 | 116.02 | -20.5 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W19 | 40 | 116.28 | -20.39 | Yes | Yes | Yes | | Yes | Yes | | Yes | |
| W20 | 46 | 116.86 | -20.2 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W21 | 60 | 117.72 | -19.84 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W22 | 50 | 117.44 | -20.05 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W23 | 63 | 117.99 | -19.62 | Yes | Yes | Yes | | | | | | |
| W24 | 37 | 118.23 | -19.75 | Yes | Yes | Yes | | Yes | Yes | | Yes | |
| W25 | 52 | 118.22 | -19.7 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W26 | 82 | 116.68 | -19.46 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W27 | 57 | 116.34 | -19.69 | Yes | Yes | Yes | | Yes | Yes | | Yes | Yes |
| W28 | 64 | 116.53 | -19.68 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W29 | 81 | 116.77 | -19.46 | Yes | Yes* | Yes | | Yes | Yes | Yes | Yes | Yes |
| W30 | 57 | 117.05 | -20 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W31 | 57 | 116.73 | -19.55 | Yes | Yes | Yes | | Yes | Yes | | | |
| W32 | 70 | 116.79 | -19.51 | Yes | Yes | Yes | | Yes | Yes | | Yes | Yes |
| W33 | 95 | 117.61 | -19.31 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W34 | 89 | 117.56 | -19.43 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | |
| W35 | 91 | 117.88 | -19.25 | Yes | Yes | Yes | | Yes | Yes | | Yes | |
| W36 | 73 | 118.14 | -19.45 | Yes | Yes | Yes | | Yes | Yes | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| W37 | 80 | 116.14 | -19.71 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W38 | 74 | 116.26 | -19.82 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W39 | 86 | 117.7 | -19.38 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W40 | 65 | 116.46 | -19.8 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W41 | 63 | 116.56 | -19.65 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W42 | 62 | 117.3 | -19.89 | Yes | Yes | Yes | | Yes | Yes | | Yes | |
| W43 | 79 | 116.03 | -19.78 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W44 | 64 | 116.56 | -19.79 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W45 | 61 | 117.29 | -19.82 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W46 | 84 | 115.69 | -19.91 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W47 | 78 | 115.82 | -19.95 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W48 | 73 | 115.97 | -20.02 | Yes | Yes | Yes | | Yes | Yes | | Yes | |
| W49 | 61 | 115.77 | -20.2 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W50 | 55 | 115.97 | -20.25 | Yes | Yes | Yes | Yes | Yes | Yes | | Yes | |
| W51 | 51 | 116.45 | -20.18 | Yes | Yes | Yes | | Yes | Yes | | Yes | |
| W52 | 67 | 117.62 | -19.68 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W53 | 75 | 117.63 | -19.51 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W54 | 70 | 117.63 | -19.62 | Yes | Yes | Yes | | Yes | Yes | | Yes | |
| W55 | 70 | 117.67 | -19.5 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W56 | 60 | 117.83 | -19.71 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W57 | 76 | 117.93 | -19.4 | Yes | Yes | Yes | | Yes | Yes | Yes | | Yes |
| W58 | 74 | 116.04 | -19.96 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W59 | 60 | 116.25 | -20.07 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W60 | 65 | 116.72 | -19.8 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W61 | 64 | 116.52 | -19.71 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W62 | 59 | 116.74 | -20.06 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W63 | 73 | 116.8 | -19.82 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W64 | 70 | 117.08 | -19.8 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W65 | 61 | 117.25 | -19.88 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W66 | 75 | 117.3 | -19.6 | Yes | Yes | Yes | | Yes | Yes | | Yes | |
| W67 | 74 | 118.03 | -19.41 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W68 | 74 | 116.13 | -19.88 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W69 | 58 | 116.66 | -19.73 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W70 | 56 | 116.33 | -19.98 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W71 | 71 | 116.78 | -19.98 | Yes | Yes | Yes | | Yes | Yes | | Yes | |
| W72 | 58 | 116.72 | -19.76 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W73 | 79 | 117.58 | -19.48 | Yes | Yes | Yes | | Yes | Yes | | Yes | |
| W74 | 80 | 118.22 | -19.33 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W75 | 60 | 116.19 | -20.13 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W76 | 62 | 116.63 | -19.8 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W77 | 66 | 116.49 | -19.79 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W78 | 72 | 115.81 | -20.06 | Yes | Yes | Yes | | Yes | Yes | | Yes | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| W79 | 70 | 115.88 | -20.1 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W80 | 68 | 115.89 | -20.11 | Yes | Yes | Yes | | Yes | Yes | | Yes | Yes |
| W81 | 66 | 115.94 | -20.18 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W82 | 60 | 115.94 | -20.2 | Yes | Yes | Yes | | Yes | Yes | | Yes | Yes |
| W83 | 62 | 116.06 | -20.13 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W84 | 56 | 116.34 | -20.09 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W85 | 64 | 116.68 | -19.93 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W86 | 67 | 116.67 | -19.83 | Yes | Yes | Yes | | Yes | Yes | | Yes | Yes |
| W87 | 71 | 116.88 | -19.86 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | |
| W88 | 80 | 118.12 | -19.34 | Yes | Yes | Yes | | Yes | Yes | | | |
| W89 | 62 | 116.17 | -20.09 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W90 | 57 | 116.35 | -20.05 | Yes | Yes | Yes | Yes | Yes | Yes | | Yes | |
| W91 | 63 | 116.61 | -20 | Yes | Yes | Yes | Yes | Yes | Yes | | Yes | Yes |
| W92 | 62 | 116.55 | -19.97 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W93 | 66 | 116.65 | -19.95 | Yes | Yes | Yes | | Yes | Yes | | Yes | Yes |
| W94 | 61 | 116.14 | -20.12 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W95 | 61 | 116.61 | -19.94 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W96 | 62 | 116.63 | -19.87 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W97 | 56 | 115.99 | -20.25 | Yes | Yes | Yes | | Yes | Yes | | Yes | |
| W98 | 56 | 116.01 | -20.22 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| W99 | 54 | 116.03 | -20.21 | Yes | Yes | Yes | | Yes | Yes | | Yes | |
| W100 | 57 | 116.36 | -20.17 | Yes | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |

# 2 Characterisation of marine habitats across the North West Shelf

Emma Westlake, John Keesing and Margaret Miller (CSIRO Oceans and Atmosphere Research)

## 2.1 Introduction

Information on physical and biological attributes of marine habitats were collected across 100 sites on the NWS in order to understand the distribution of fishes and habitat-forming filter feeders, and to assess the status and extent of recovery of communities impacted by trawling.

Seabed information was collected by swathing depths, sub-bottom profiling to determine seabed structure, and multibeam acoustic swathing (bathymetry and backscatter [seabed hardness/softness]). Bathymetry and backscatter data were primarily used in planning the trawl survey operations in real time and to aid the interpretation of the sub-bottom profiling data.

Water column information was collected by CTD profiling to measure chlorophyll-*a* (chl-*a*), salinity, temperature, dissolved oxygen and photosynthetically active radiation (PAR). Water sampling was undertaken to measure nutrients.

Information on benthic substrata and biota were derived from still camera images obtained from the trawl headline camera which captured images ahead of the demersal trawl net every 3–4 seconds.

A detailed description of the methods used to collect seabed and water column data and to score and analyse the images is given in Appendix A.

## 2.2 Structure of this chapter and the analyses

The results of the survey and analyses of historicial data is presented in spatial subsets (Table 1) as follows

- Sites inshore of the commercial trawl fishery (including the Dampier MP)
- Sites west of the commercial trawl fishery (including the Montebello MP)
- Sites within the commercial fishery, PFTF Areas 1, 2, 3 (curently closed to fishing) and 4.

## 2.3 Data sources and methodology

This chapter of the report makes use of data collected on the 2017 RV *Investigator* voyage (INV2017_05) and the 1982–1997 CSIRO North West Shelf (NWS) Effects of Trawling project (Sainsbury 1988; 1991), hereafter called the CSIRO 1982–1997 surveys.

### 2.3.1 Bathymetry and acoustic backscatter

Depths were recorded continuously during the voyage using the Kongsberg EM710 multibeam echo-sounder used on the RV *Investigator*. The instrument also collected acoustic backscatter data in addition to bathymetry. This provided a measure of the reflectivity off the seabed which can be interpreted as the relative ‘hardness’ or ‘softness’ of the seabed (hard surfaces are more reflective) and ‘roughness’ by using the measured angle of incidence as sound is reflected from the seabed (Angular Range Analysis). These data were used to help interpret the sub-bottom profiling data when characterising the seabed but are not presented in detail in this report.

### 2.3.2 Sub-bottom profiling

#### Categorisation of bottom types from the sub-bottom profiler

The Kongsberg SBP120 sub-bottom profiler (SBP) used on the RV *Investigator* used acoustic signals to produce a 2-dimensional stratigraphy of the seabed. It is a ‘chirp’ system: a wide-band frequency modulated SBP that produces very high resolution (0.3 milliseconds/~ 0.25 m) profiles in soft sediments. The thickness of sediment layers cannot be measured accurately but can be approximated from the time it takes the sound signal to return (this is called ‘two-way time’, TWT).

These high frequency systems give very detailed information for near-surface features making them suitable for the interpretation of the recent geomorphology of the seabed (for example, rippled surfaces and reefs) and tracking of thin (decimetre scale) sub-surface layers. The extent of layers of consolidated and unconsolidated material like coarse sediment, compacted sand and rock outcrops, were interpreted with the aid of acoustic backscatter data.

The following bottom type categories were used in this project:

1. Rock outcrop
2. Flat Hard Surface
3. Thin sediment (< 3 milliseconds, < ~ 2.5 m over rock)
4. Thick sediment (> 3 milliseconds, > ~ 2.5 m over rock)
5. Dunes

Examples of each of these are shown in Figure 6, Figure 7 and Figure 8. These interpretations were then applied to each of the sub-bottom profile lines which corresponded to the trawl lines (e.g. Figure 9).

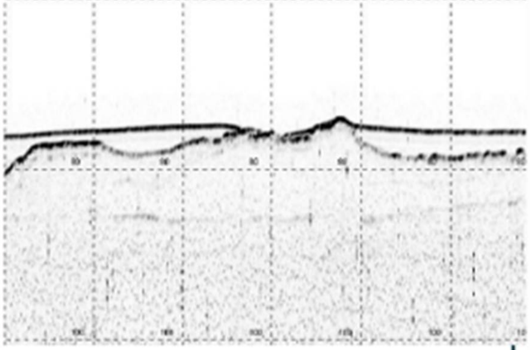
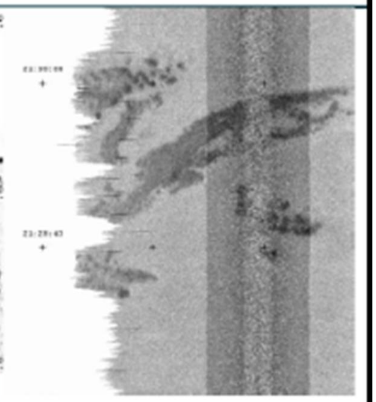
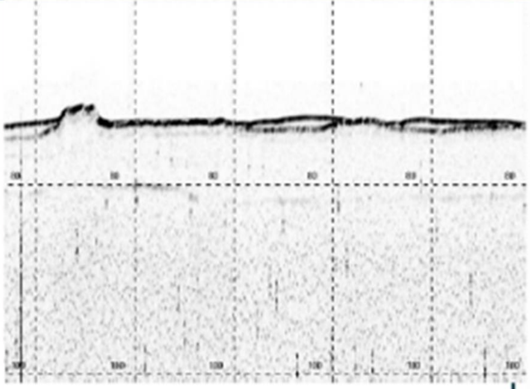
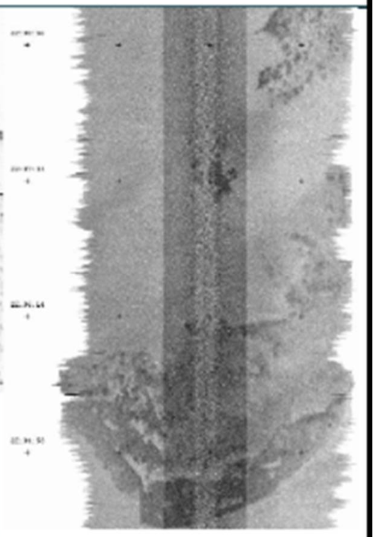
| Classification | Sub-bottom Profiler | Seafloor Backscatter |
|---|---|---|
| **1 – Outcrop**<br>**4 - Thick Sediment**<br>UTC 20.10.2017<br>Time: 21:28<br>Before Trawl W71<br>(no photo)<br>SBP Line019_001<br>MB 0544 |  |  |
| **1 – Outcrop**<br>**3 - Thin Sediment**<br>UTC 20.10.2017<br>Time: 22:10<br>Trawl W71<br>Op#<br>SBP Line019_001<br>MB 0544 |  |  |

**Figure 6. Examples of reef outcrop from thick (upper panel) and thin (lower panel) overlying sediment showing interpretation using SBP and acoustic backscatter data.**

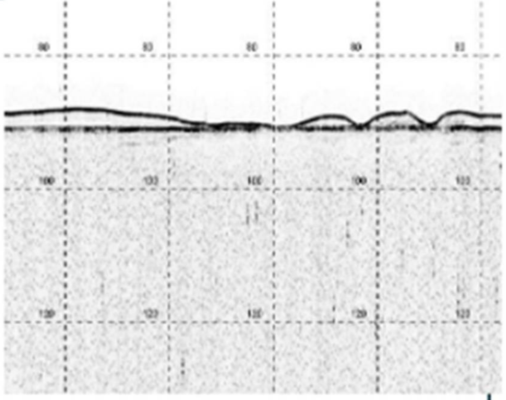
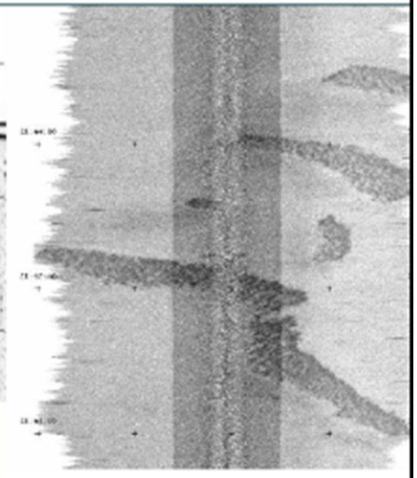
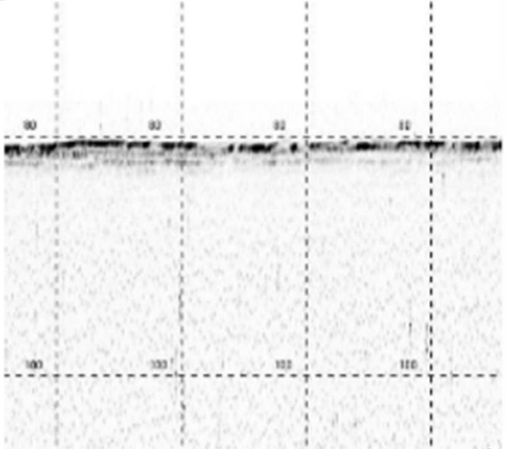
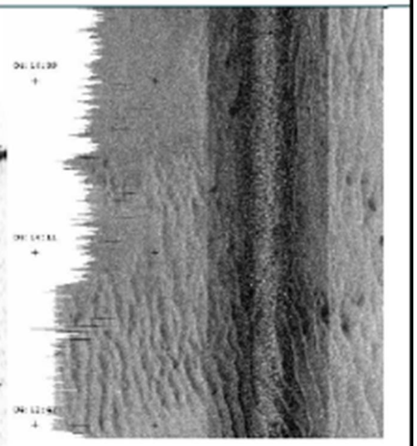
| Classification | Sub-bottom Profiler | Seafloor Backscatter |
|---|---|---|
| **5 - Dunes**<br>**Reef/Pockmarks**<br>W30? |  |  |
| **5 – Ripples**<br>UTC 15.10.2017<br>Time 04:15 |  |  |

Figure 7. Examples of sand dunes overlying reef (upper panel) and sand ripples (lower panel) showing interpretation using SBP and acoustic backscatter data.

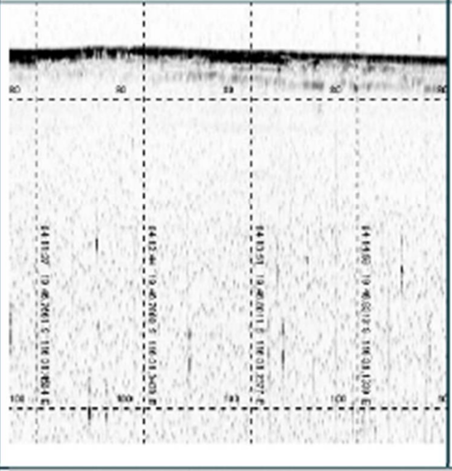
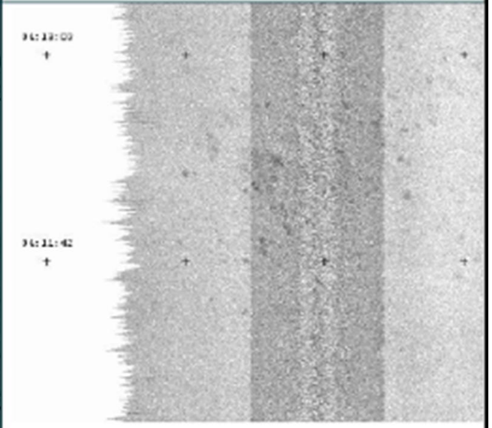
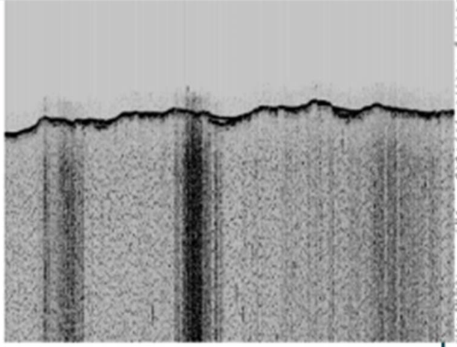
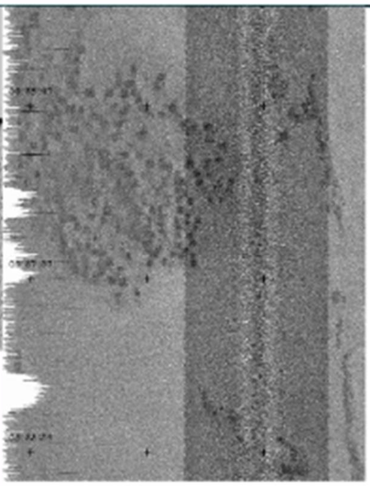
| Classification | Sub-bottom Profiler | Seafloor Backscatter |
|---|---|---|
| **2 – Reef**<br>**Flat Hard**<br>W77 Trawl<br>Net not yet down<br>SBP Line050<br>MB 676 |  |  |
| 6 – **Reef/pockmark**<br>SBP Line008_005 |  |  |

**Figure 8. Examples of flat hard (reef) bottom (upper panel) and pockmarked reef (lower panel) showing interpretation using SBP and acoustic backscatter data.**

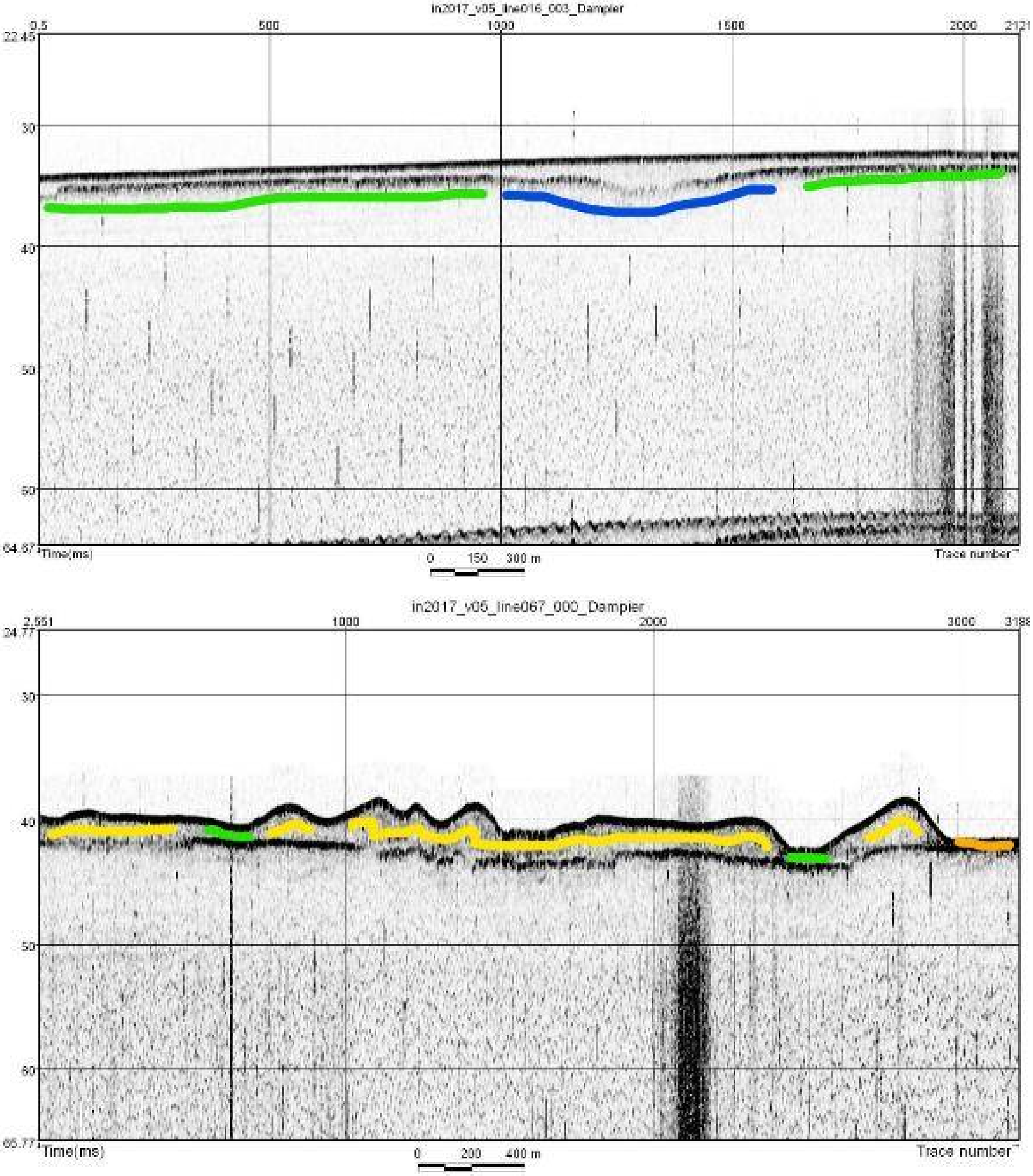


**Figure 9. Examples of scoring of categories along sub-bottom profile tracks. Numbers on y-axis in milliseconds. Green is thin sediment, blue is thick sediment, yellow is sand dunes and orange is flat hard bottom.**

### 2.3.3 Water column sampling

#### Nutrients

Water samples were collected using a 24 x 10 L Niskin bottle rosette. Replicate 10 mL water samples of unfiltered seawater from each depth were analysed for dissolved inorganic nutrients (nitrate + nitrite [hereafter nitrate], ammonia, phosphate and silicate) by flow injection analysis (Lachat QuickChem 8000), with detection by absorbance at specific wavelengths for silicate [QuikChem Method 31-114-27-1-D], nitrate [QuikChem Method 31-107-04-1-A] and phosphate [QuikChem Method 31-115-01-1-G]), and by fluorescence for ammonia (Watson et al. 2005). Detection limits were 0.02 µM for all inorganic nutrient species, with a standard error of < 0.7%.

#### Pigments

In addition to nutrients, samples for chl-*a* were collected with 1 L of seawater from each depth vacuum-filtered onto a Whatman 25 mm diameter glass fibre filter (GF/F) (nominal pore size of 0.7 µm). The filters were stored in at -80°C until analysis (24–48 hours post-collection). Pigments were extracted in 90% acetone overnight and analysed for chl-*a* and phaeopigment (represents the total chl-*a* fraction) using a calibrated Turner Designs model 10AU fluorometer and the acidification technique of Parsons et al. (1989).

#### Physical measurements

Water column profiles of conductivity (as a proxy for salinity) and temperature (Seabird SBE 9/11 dual-sensor unit), photosynthetically active radiation (PAR 400–700 nm; Biospherical Instruments QCP-2300), fluorescence (Chelsea Instruments Aquatracka™ fluorometer), and dissolved oxygen (DO; Anderra 3975 series optode) were determined concurrently via a CTD rosette deployed from the starboard side of the ship.

### 2.3.4 Benthic substrate and topography

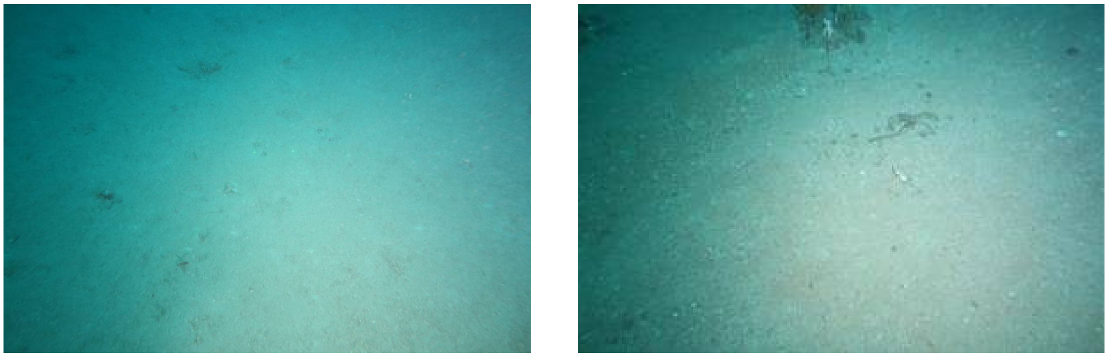
#### Classification of categories of substrate and topography

**Substrate types**

Five main substrate types were recognised from the INV2017_05 camera images; silt, fine sand, coarse sand, rock and rubble, and various combinations of these substrate types. These are illustrated in Figure 10 and Figure 11. Similar categories were used when scoring the trawl headline camera images from the earlier CSIRO 1982–1997 surveys.

Silt (Fine Sand/Silt)

Fine Sand

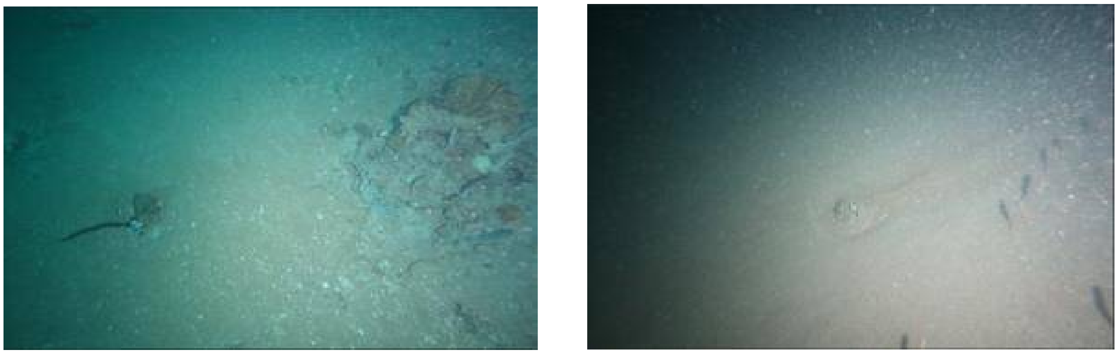


Fine Sand/Coarse Sand

Fine Sand/Coarse Sand/Rubble

Fine Sand/Coarse Sand/Rock

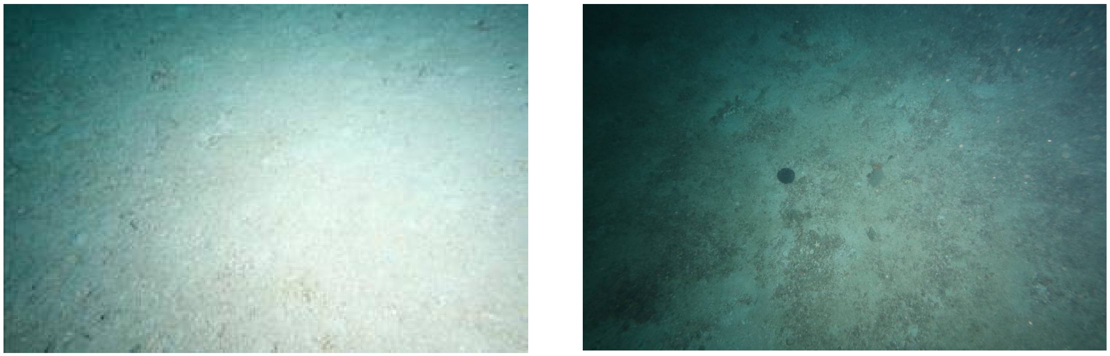
Fine Sand/Rubble



Fine Sand/Rubble/Rock

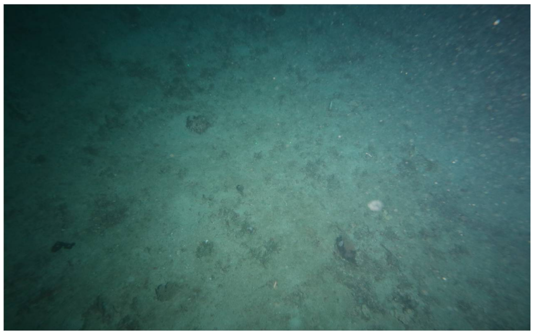
Fine Sand/Rock

**Figure 10. Examples of the different substrate categories used to score INV2017_05 still images. Similar categories were used for CSIRO 1982-1997 images.**



Coarse Sand

Coarse Sand/Rubble

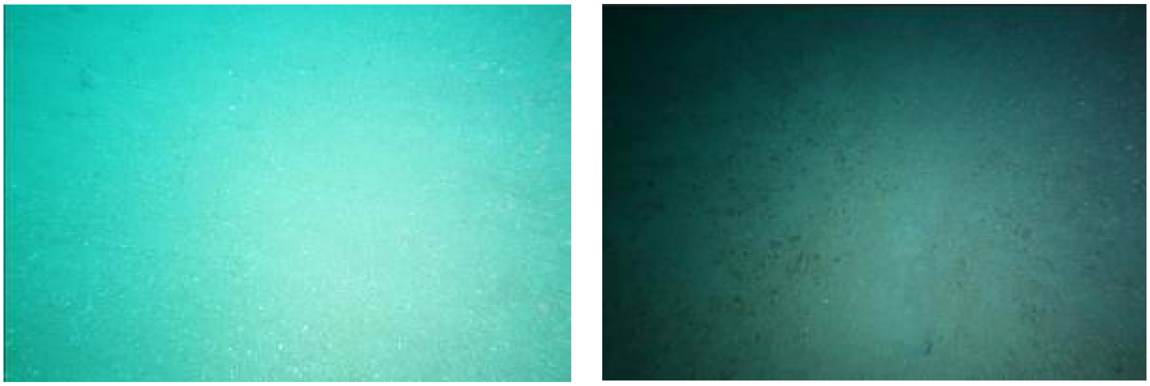


Coarse Sand/Rock

**Figure 11. Examples of the different substrate categories used to score INV2017_05 still images. Similar categories were used for CSIRO 1982-1997 images.**

## Soft bottom topography types

Four main types of soft-bottom topography were identified from the INV2017_05 camera images of soft bottom habitats; flat bottom, fine sand ripples, bioturbation, and furrows, and various combinations of these topographic types. Examples of these are illustrated in Figure 12.

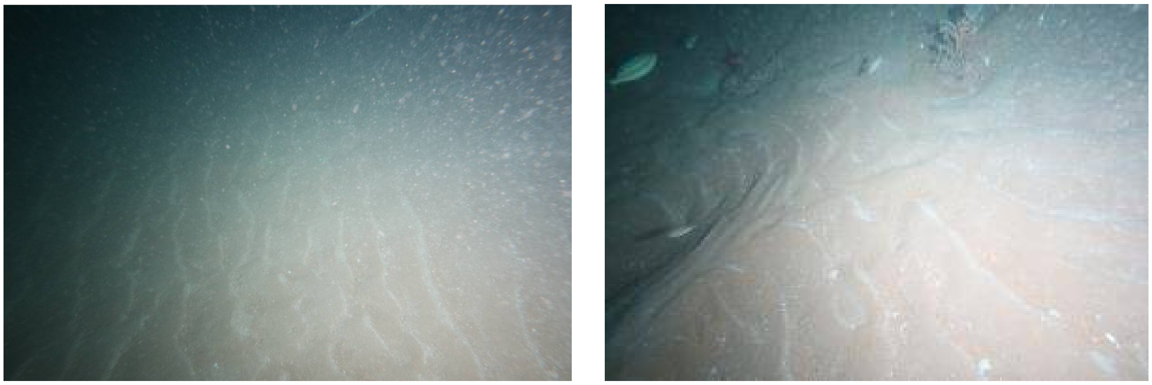


Flat Bottom

Flat Bottom/Bioturbated

Flat Bottom/Fine Ripple

Flat Bottom/Fine Ripple/Bioturbated



Fine Ripple

Fine Ripple/Furrow

Figure 12. Examples of the different bottom topography categories used to score INV2017_05 still images.

### 2.3.5 Benthic biota and biohabitats

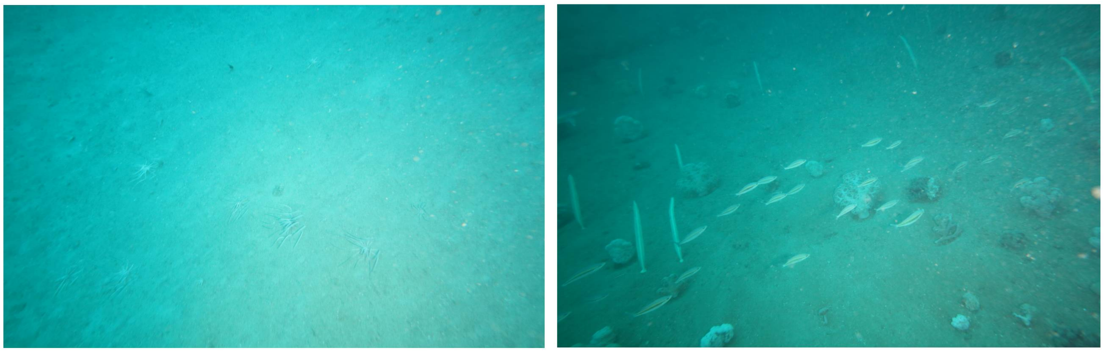
Data used to describe benthic biota were principally derived from still camera images taken from the trawl headline camera. This applied to both INV2017_05 and historical CSIRO 1982–1997 surveys. Benthic biota were classified into eight main categories: sponge; hydroid; whip; seapen; gorgonian; crinoid; soft coral; and 'other' (Figure 13). 'Other' comprised all benthic biota species not identified by the main categories and, during historical surveys, included hydroids. Images containing no biota were also identified. A detailed description of the methods used to collect, score and analyse the images is given in Appendix A.

Sponge (multiple morphologies)

Hydroid

Whip

Seapen



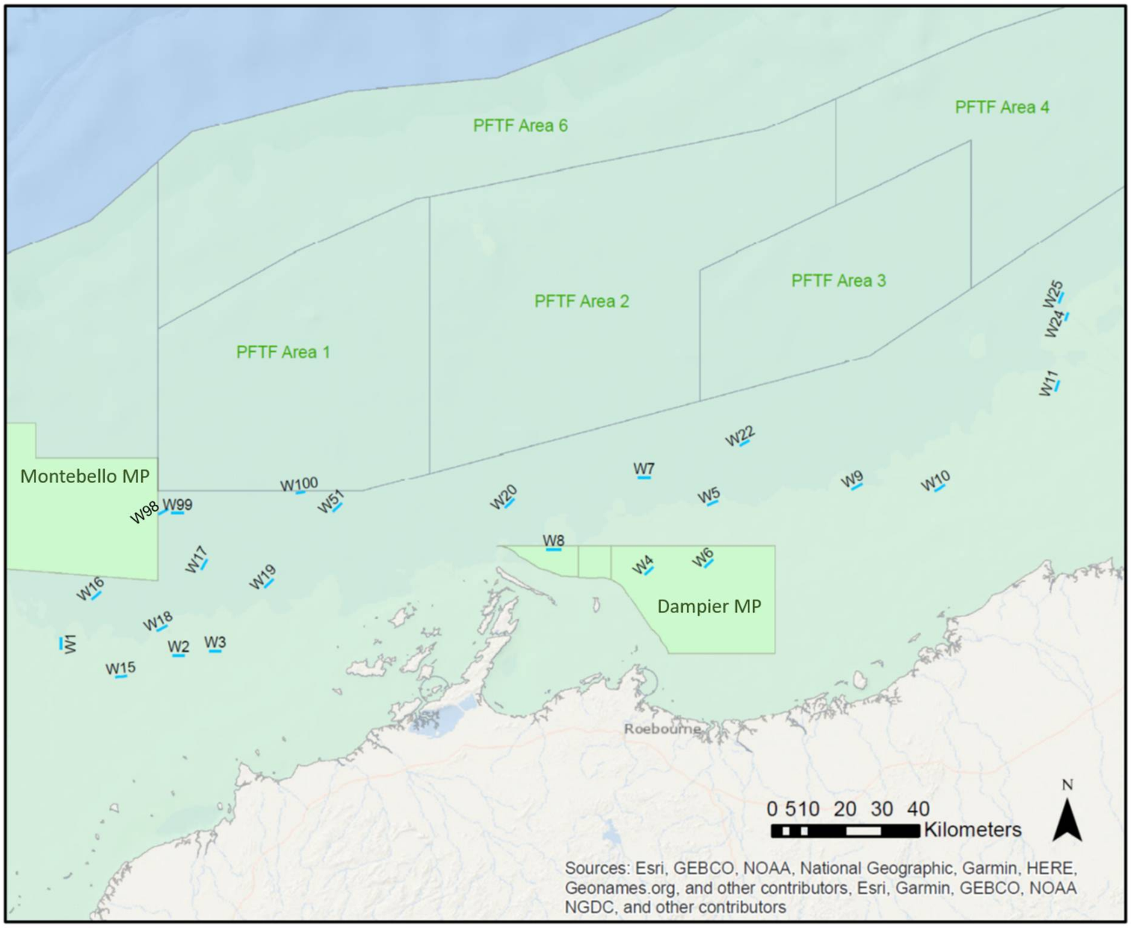
Crinoid

Soft coral (seapens also visible)

Figure 13. Examples of the different benthic biota categories used to score INV2017_05 still images.

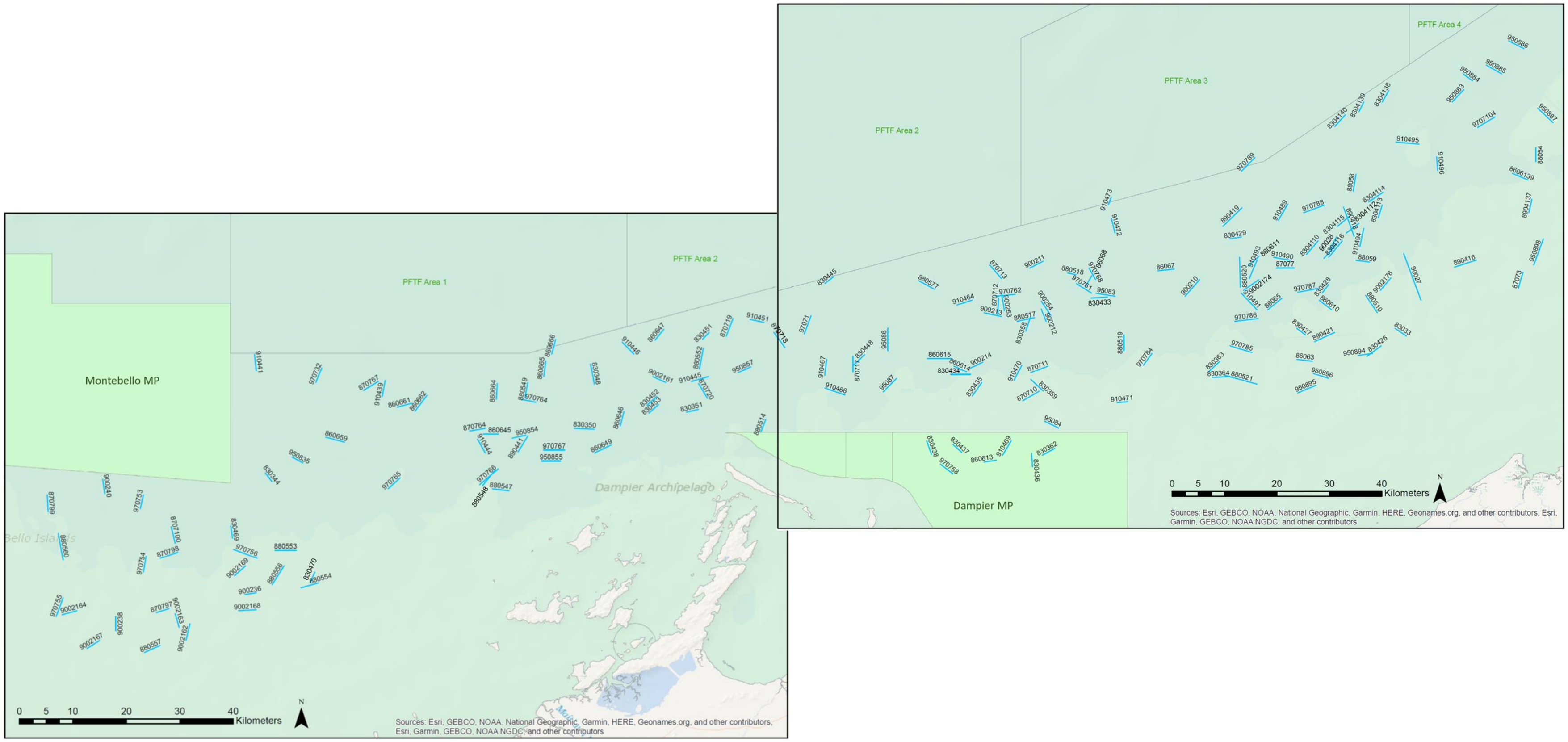
## 2.4 Results from sites inshore of the commercial trawl fishery (including the Dampier Marine Park)

During the INV2017_05 voyage, 24 sites were surveyed within the area inshore of the commercial trawl fishery (Figure 14). This included three sites located within Dampier MP. The location of historical trawls conducted within this area between 1982–1997 for which habitat data were collected, including within the since-formed Dampier MP, are shown in Figure 15.



Sources: Esri, GEBCO, NOAA, National Geographic, Garmin, HERE, Geonames.org, and other contributors, Esri, Garmin, GEBCO, NOAA NGDC, and other contributors

**Figure 14. Location of INV2017_05 sites for which habitat data were collected inshore of the commercial trawl fishery, including Dampier MP. Table showing the start/end latitude and longitude for each trawl transect is given in Appendix D.**



Sources: Esri, GEBCO, NOAA, National Geographic, Garmin, HERE, Geonames.org, and other contributors, Esri, Garmin, GEBCO, NOAA NGDC, and other contributors

Sources: Esri, GEBCO, NOAA, National Geographic, Garmin, HERE, Geonames.org, and other contributors, Esri, Garmin, GEBCO, NOAA NGDC, and other contributors

**Figure 15. Location of historical trawls from CSIRO 1982–1997 for which habitat data were collected within the southern (left) and northern (right) extent of the area inshore of the commercial trawl fishery, including within the since-formed Dampier MP. Table showing the start/end latitude and longitude for each trawl transect is given in Appendix E. Trawl number = year, voyage and site number (e.g. 970758 was site 58 on the seventh voyage in 1997).**

### 2.4.1 Water column analyses

CTD profiles were obtained for 15 sites within the area inshore of the commercial trawl fishery, including three sites within Dampier MP (Figure 16–Figure 19). Salinity varied little across inshore sites (< 1 psu), ranging from 34.9–35.8 psu. Salinity remained constant for most sites, with most of these sites showing either very slight increases or decreases in salinity with depth. Sites W7, W20 and W25 which all showed a layer of mixing between 10–20 m depth.

Temperature ranged from 24.4–26.3°C across sites. Thermoclines were evident at sites W2, W3 and W25, highlighted by a decrease in temperature of roughly 0.5°C generally between 15–20 m depth. A larger decrease in temperature (almost 1°C) was observed at site W18, again within the 15–20 m depth range. A small thermocline forming between 8–12 m was observed at site W8 within Dampier MP, corresponding with a reduction in temperature of roughly 0.5°C. These temperature changes and subsequent formations of thermoclines generally coincided with an increase in chl-*a*.

Dissolved oxygen (DO) ranged from 205–219 mg/L with reductions in DO levels recorded at 20 m. Sites within Dampier MP showed mixed waters, with no discernible or consistent pattern evident. Inshore sites showed a more rapid reduction in DO levels than other sites. Many sites showed a subsurface maximum, generally associated with a thermocline. However, some sites (sites W9, W15 and W22) exhibited a constant DO profile. Site W100 was the only site to show a DO maximum near the surface that then decreased with depth.

PAR profiles across the inshore sites generally diminished with depth. A steady decline in PAR was recorded across all sites, except for an anomalous surface signal at site W6, likely caused by ship shadow. Site W25 showed a constant PAR of 0 (zero PAR profile) across all depths, but this was due to the survey at this site being conducted after 1800 h. PAR profiles showed light reached the seabed reduced by 22% from surface values at site W6 while at sites W4 and W8 the percent surface irradiance decreased to 10% or lower at the bottom (Figure 16).

Chlorophyll-*a* ranged from 13–34 mg.m$^{-2}$ and generally increased with depth to maxima between 20–30 m, except site W8 within Dampier MP which showed a more constant chl-*a* profile. Chlorophyll-*a* maxima were reached at shallower depths for inshore sites compared to those offshore.

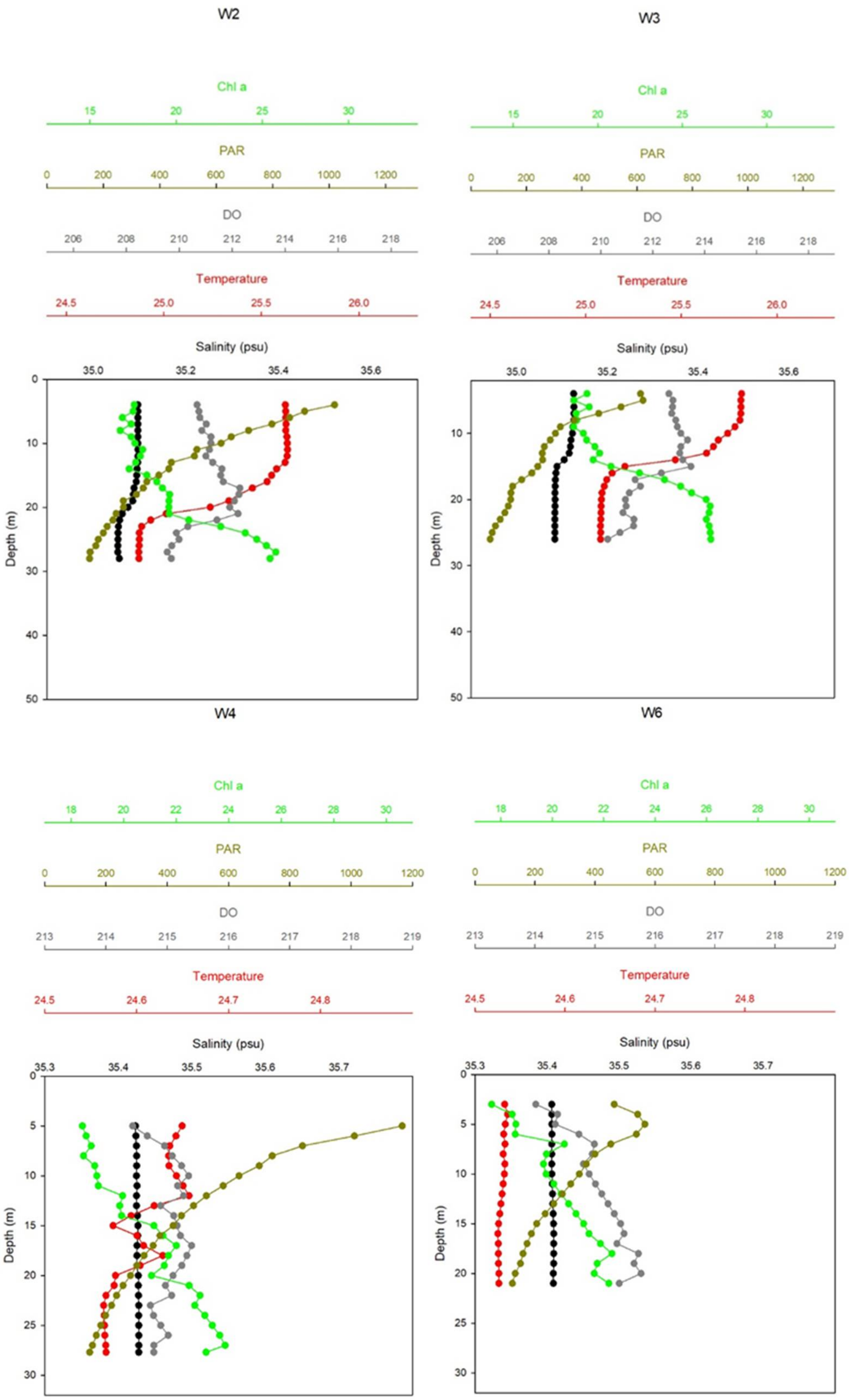


**Figure 16. CTD profiles of water column parameters from sites W2, W3, W4* and W6* inshore of the commercial fishery. * denotes sites within Dampier MP.**

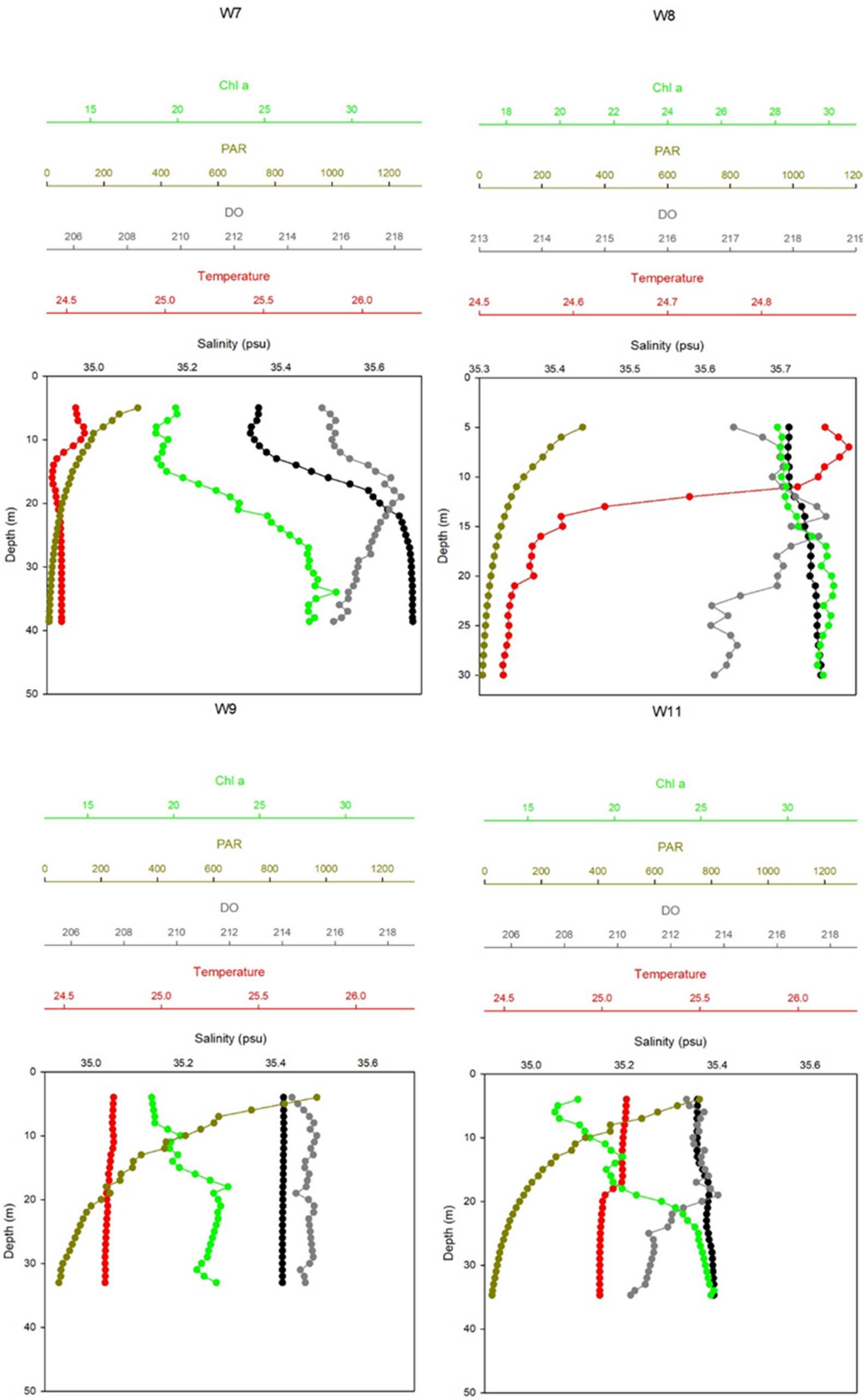


**Figure 17. CTD profiles of water column parameters from sites W7, W8*, W9 and W11 inshore of the commercial fishery. * denotes sites within Dampier MP.**

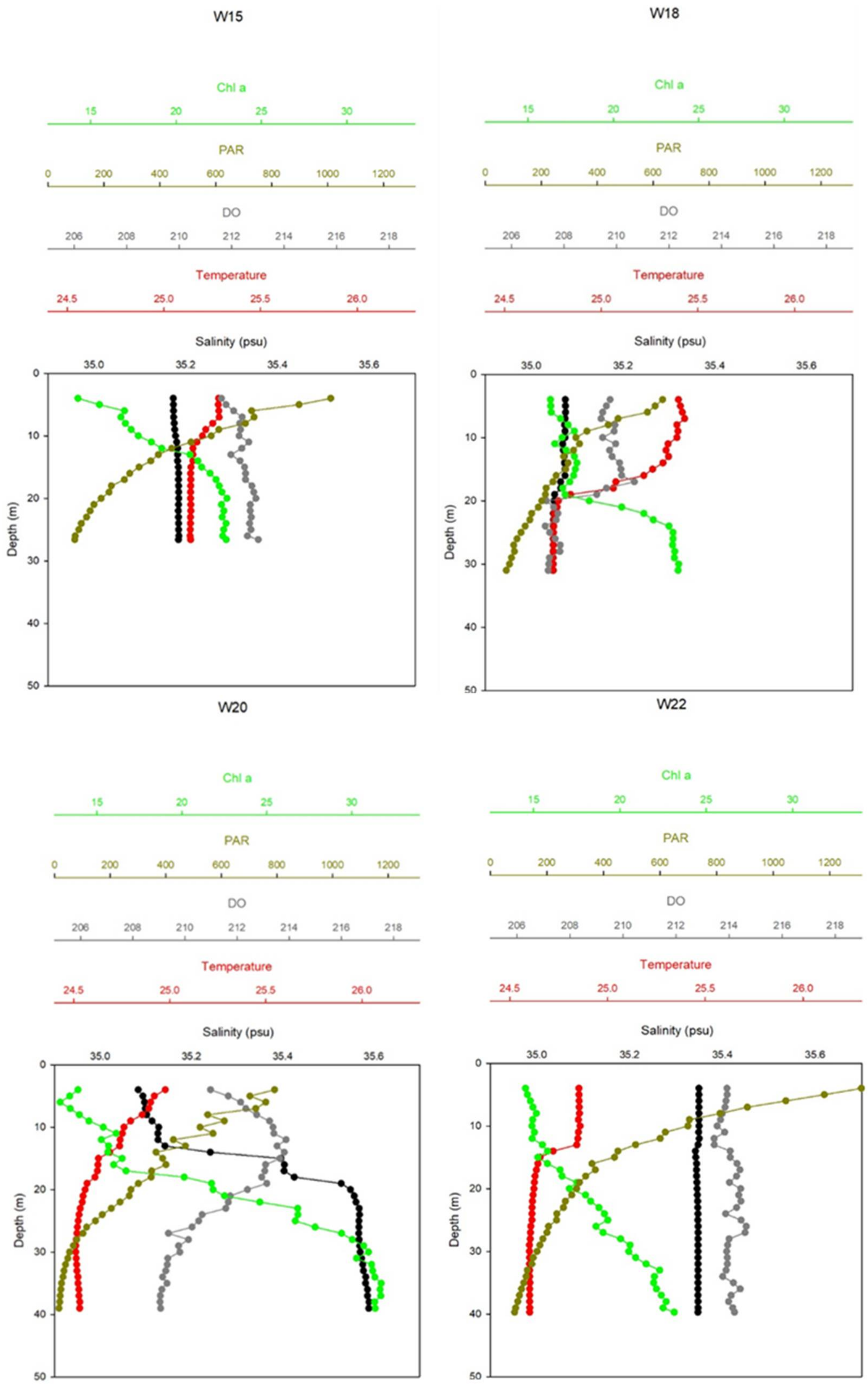


**Figure 18. CTD profiles of water column parameters from sites W15, W18, W20 and W22 inshore of the commercial fishery.**

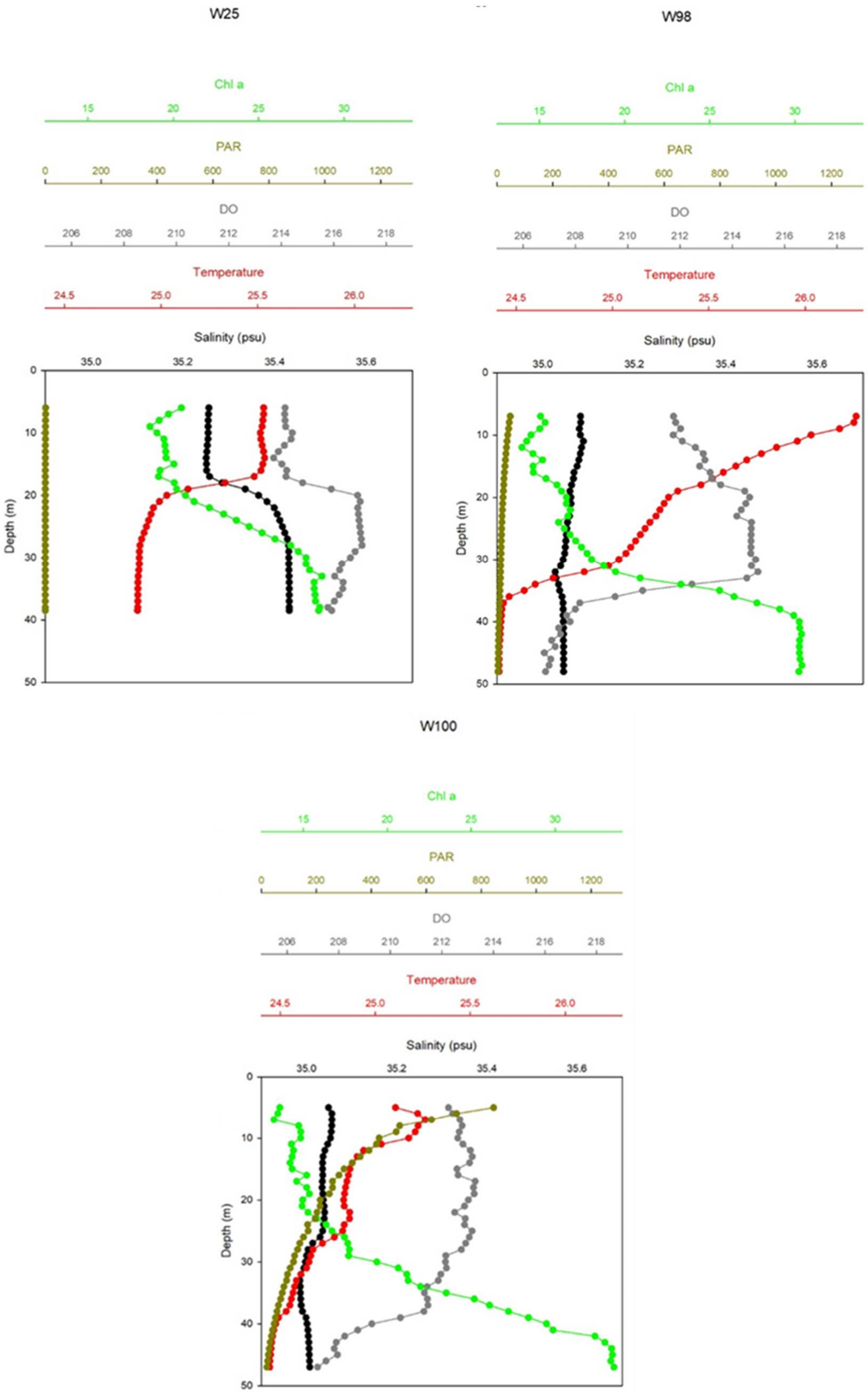


**Figure 19. CTD profiles of water column parameters from sites W25, W98 and W100 inshore of the commercial fishery.**

Depth-averaged nutrient values were obtained at 15 sites within the area inshore of the commercial trawl fishery, including the three sites within Dampier MP (Table 3, Figure 20). Mean total chl-*a* ranged from 0.16 to 0.48 mg $m^{-2}$ across sites, with the lowest value recorded at site W18 and lowest at site W8 within Dampier MP (Figure 20, top). Nitrate concentrations ranged from 0.010 mmol $m^{-2}$ (site W4 within Dampier MP) to 0.040 mmol $m^{-2}$ (site W100). Mean ammonia ranged from 0.005–0.024 mmol $m^{-2}$ while silica ranged from 1.471–6.177 mmol $^{-2}$. Both minimums were recorded at site W8 within Dampier MP, while both maximums were recorded at site W2 inshore of Montebello MP. Phosphate concentrations ranged from 0.110 mmol $m^{-2}$ again at site W8, to 0.154 mmol $m^{-2}$ at site W22, offshore of Dampier MP.

**Table 3. Nutrients (depth averaged values) for sites surveyed inshore of the commercial trawl fishery. * denotes sites within Dampier MP. nd denotes no data.**

| Site | Mean total Chl-*a* (mg $m^{-2}$) | Mean $NO_x$ (mmol $m^{-2}$) | Mean $NH_4$ (mmol $m^{-2}$) | Mean $PO_4$ (mmol $m^{-2}$) | Mean Si (mmol $m^{-2}$) |
|---|---|---|---|---|---|
| W2 | 0.26 | 0.015 | 0.008 | 0.134 | 6.177 |
| W3 | 0.31 | 0.018 | 0.024 | 0.138 | 5.893 |
| W4* | 0.30 | 0.010 | 0.011 | 0.140 | 3.905 |
| W6* | 0.27 | 0.013 | 0.014 | 0.132 | 3.513 |
| W7 | 0.30 | 0.016 | 0 | 0.132 | 2.749 |
| W8* | 0.48 | 0.017 | 0.009 | 0.110 | 1.471 |
| W9 | 0.26 | 0.022 | nd | 0.141 | 3.701 |
| W11 | 0.30 | 0.023 | 0.005 | 0.149 | 4.171 |
| W15 | 0.24 | 0.018 | 0.008 | 0.127 | 4.555 |
| W18 | 0.16 | 0.020 | 0.023 | 0.151 | 5.373 |
| W20 | 0.31 | 0.027 | 0.009 | 0.129 | 3.052 |
| W22 | 0.21 | 0.016 | nd | 0.154 | 4.778 |
| W25 | 0.34 | 0.029 | nd | 0.131 | 3.765 |
| W98 | 0.16 | 0.024 | 0.01 | 0.118 | 4.234 |
| W100 | 0.28 | 0.040 | 0.022 | 0.127 | 4.282 |

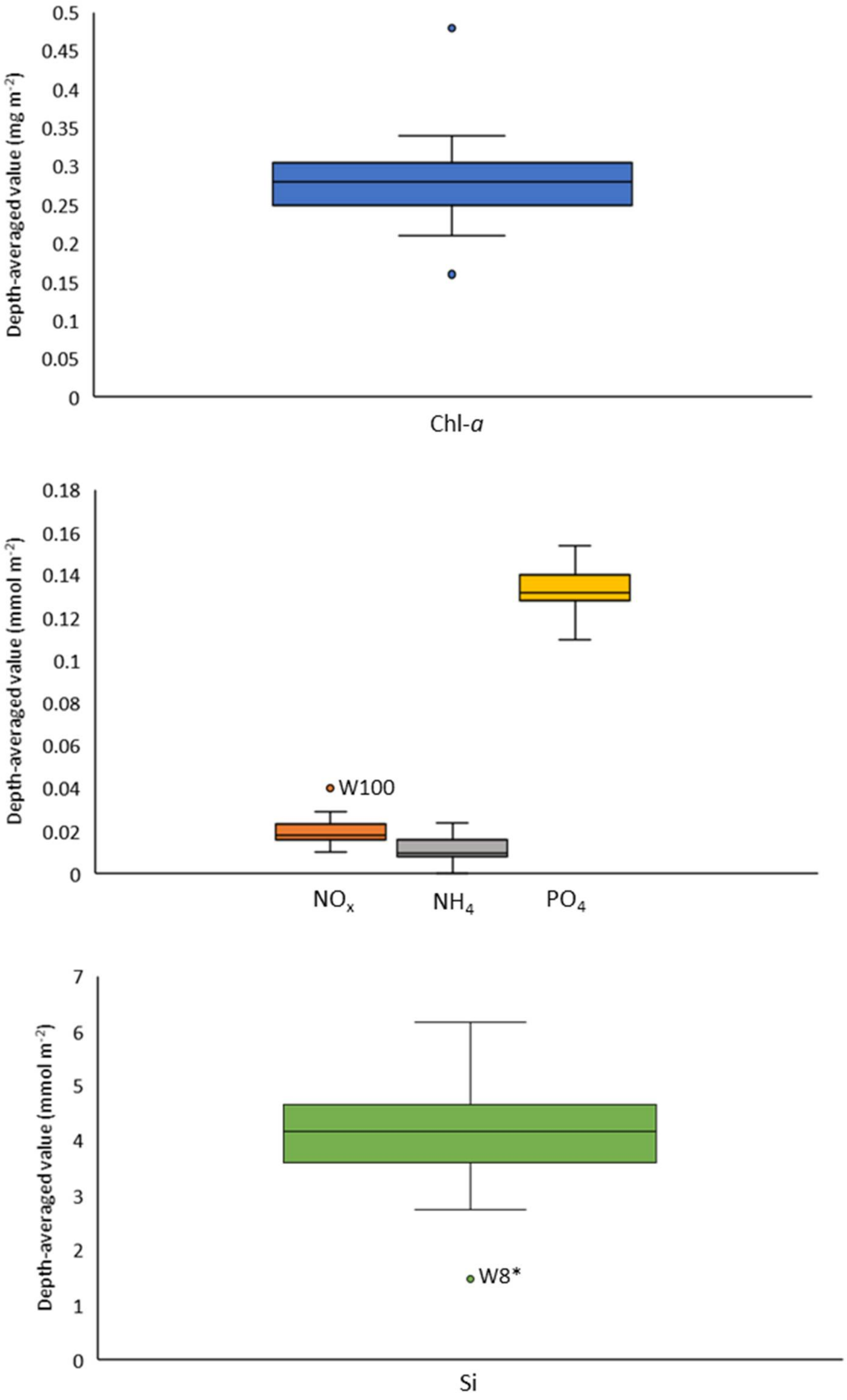


**Figure 20. Depth-averaged nutrient values for sites surveyed inshore of the commercial trawl fishery. Box plots show the median, 25th and 75th percentiles and outliers falling outside the 10th and 90th percentiles. * denotes sites within Dampier MP.**

### 2.4.2 Sub bottom profiling INV2017_05 sites

Sub-bottom profiling of sites inshore of the commerical trawl fishery showed varying bottom types (Figure 21. Note: no SBP data available for site W7). Bottom type was generally hard or a combination of hard bottom and either dune or thin sediment over rock. Sites W2 and W15 both exhibited a combination of dune and thick sediment on rock bottom, while site W18 was categorised solely as thick sediment. Site W24 was a combination of thick and thin sediment over rock, while a small proportion of outcrop was detected at site W19.

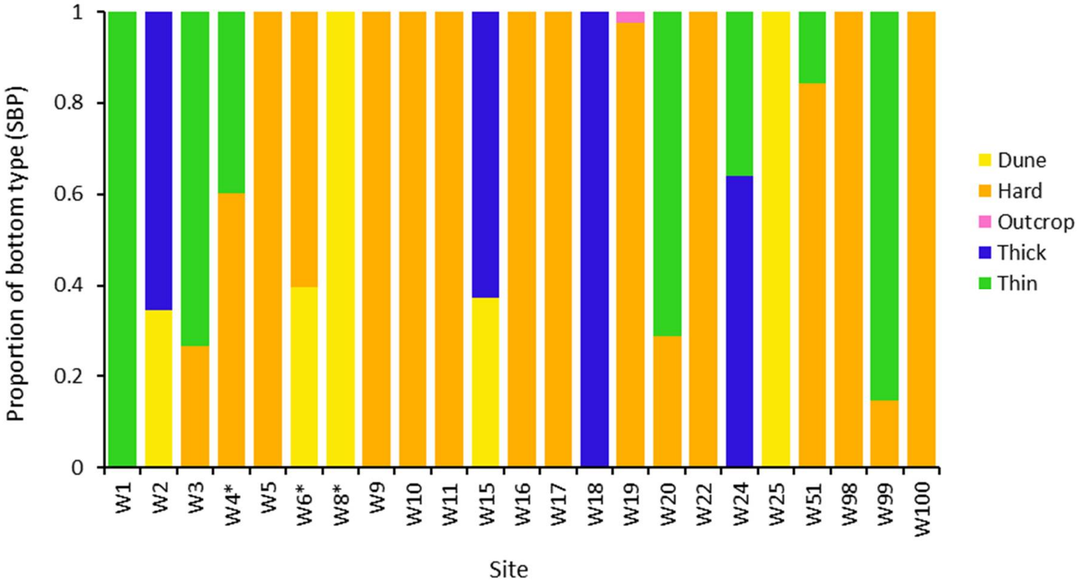


Figure 21. Proportion of bottom types determined using SBP for INV2017_05 sites inshore of the commercial trawl fishery. * denotes sites within Dampier MP.

### 2.4.3 Substrate and topography

#### INV2017_05 survey sites

In 2017, the trawl headline camera images revealed that fine sandy flat bottom substrates dominated sites inshore of the commercial fishery (Figure 22. Note: no substrate or topography data available for site W7). Coarse sand and rock were also identified at some sites. Shepard's plots of sediment classification for all sites inshore of the commercial trawl fishery (Figure 23) and those within Dampier MP (Figure 24) confirmed sediment composition as predominantly sand. Fine ripple topography was present at sites W1, W24, and W4, W6 and W8 within Dampier MP, while bioturbations were seen at site W100.

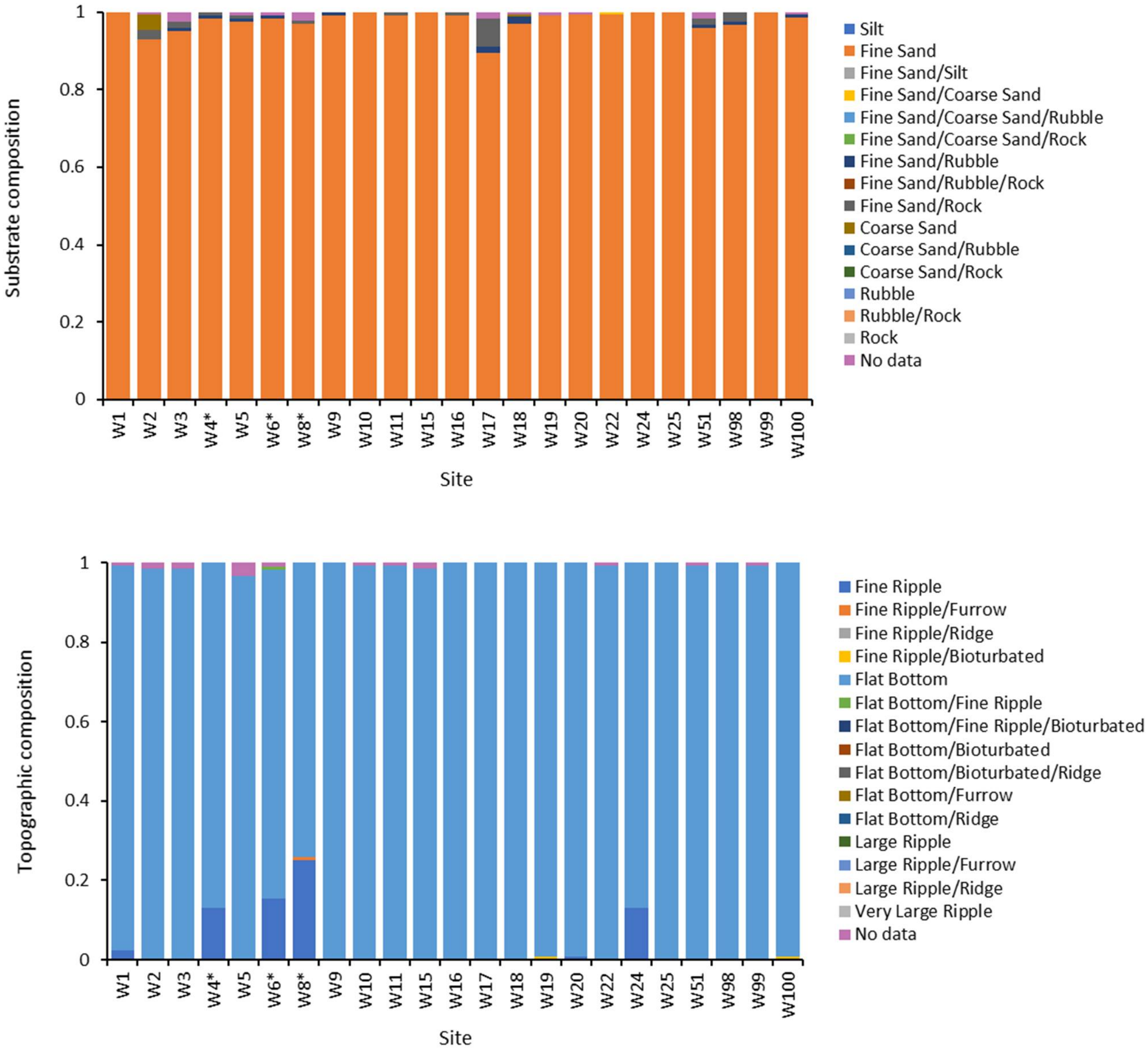


**Figure 22. Proportion of substrate (top) and topography (bottom) types in seabed images along trawl lines for INV2017_05 survey sites inshore of the commercial trawl fishery. * denotes sites within Dampier MP.**

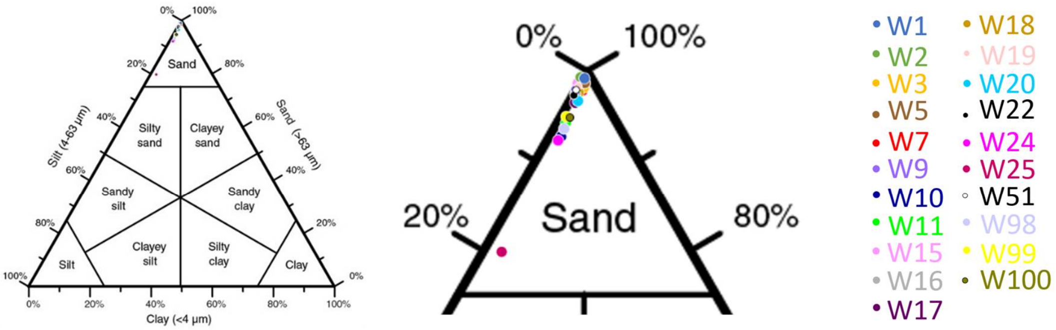


Figure 23. Shepard's plot of sediment classification for INV2017_05 survey sites inshore of the commercial trawl fishery (excluding Dampier MP).

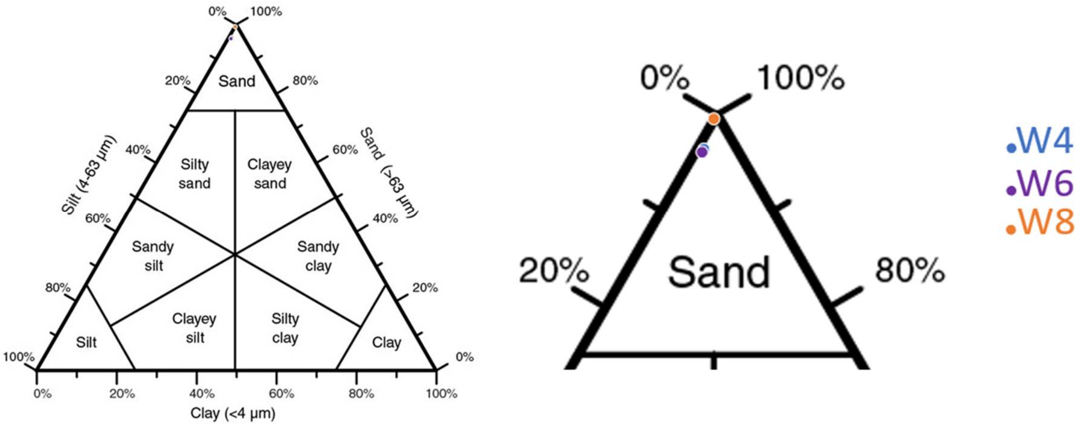


Figure 24. Shepard's plot of sediment classification for INV2017_05 survey sites within Dampier MP (inshore of the commercial trawl fishery).

## CSIRO 1982–1997 surveys

Sites were dominated by fine and coarse sandy substrates during historical CSIRO 1982–1997 surveys (Figure 25 and Figure 26). A small proportion of rubble was identified at some sites including sites 830453 and 830470, while rock was also seen in very small proportions including at site 830362 in the since-formed Dampier MP.

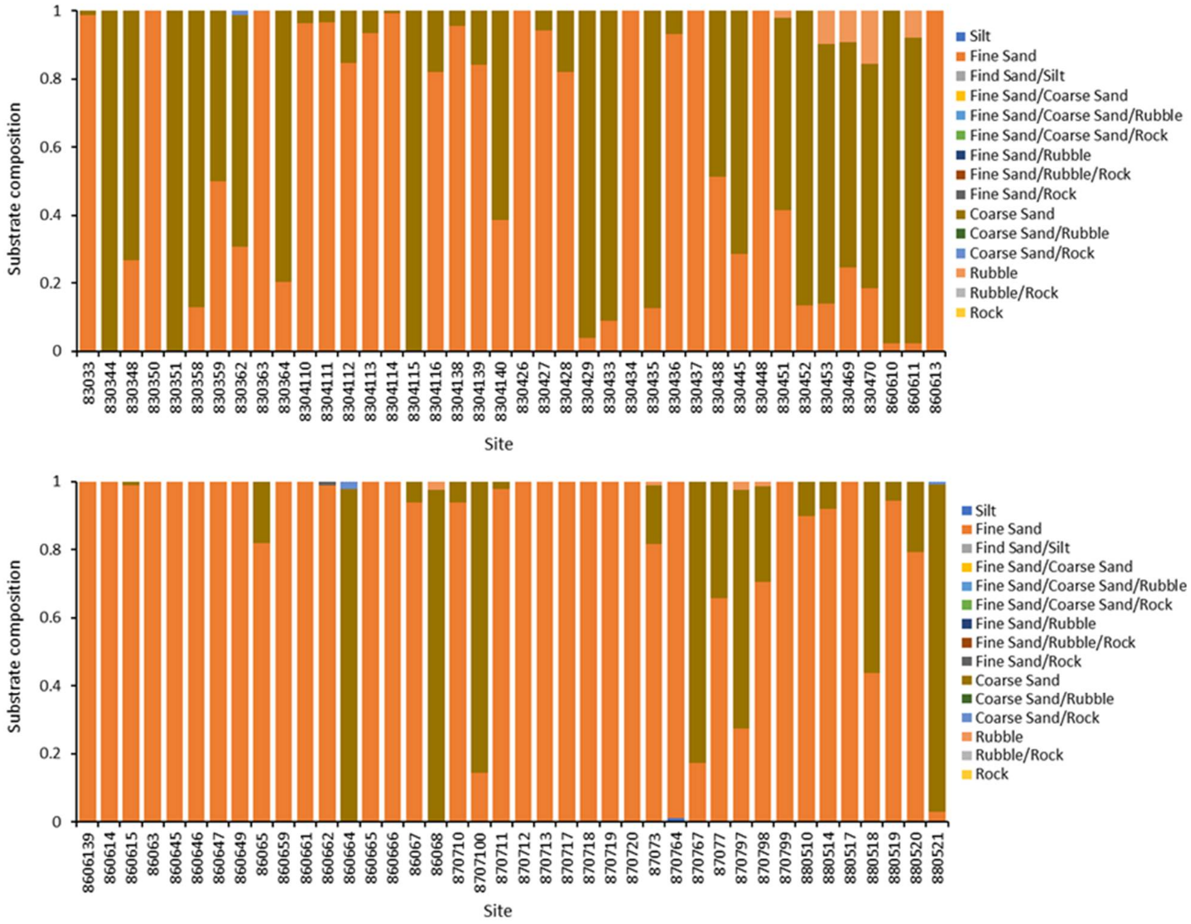


**Figure 25. Proportion of substrate types in seabed images along trawl lines for historical CSIRO (1982–1997) survey sites inshore of the commercial trawl fishery. * denotes sites within the since-formed Dampier MP.**

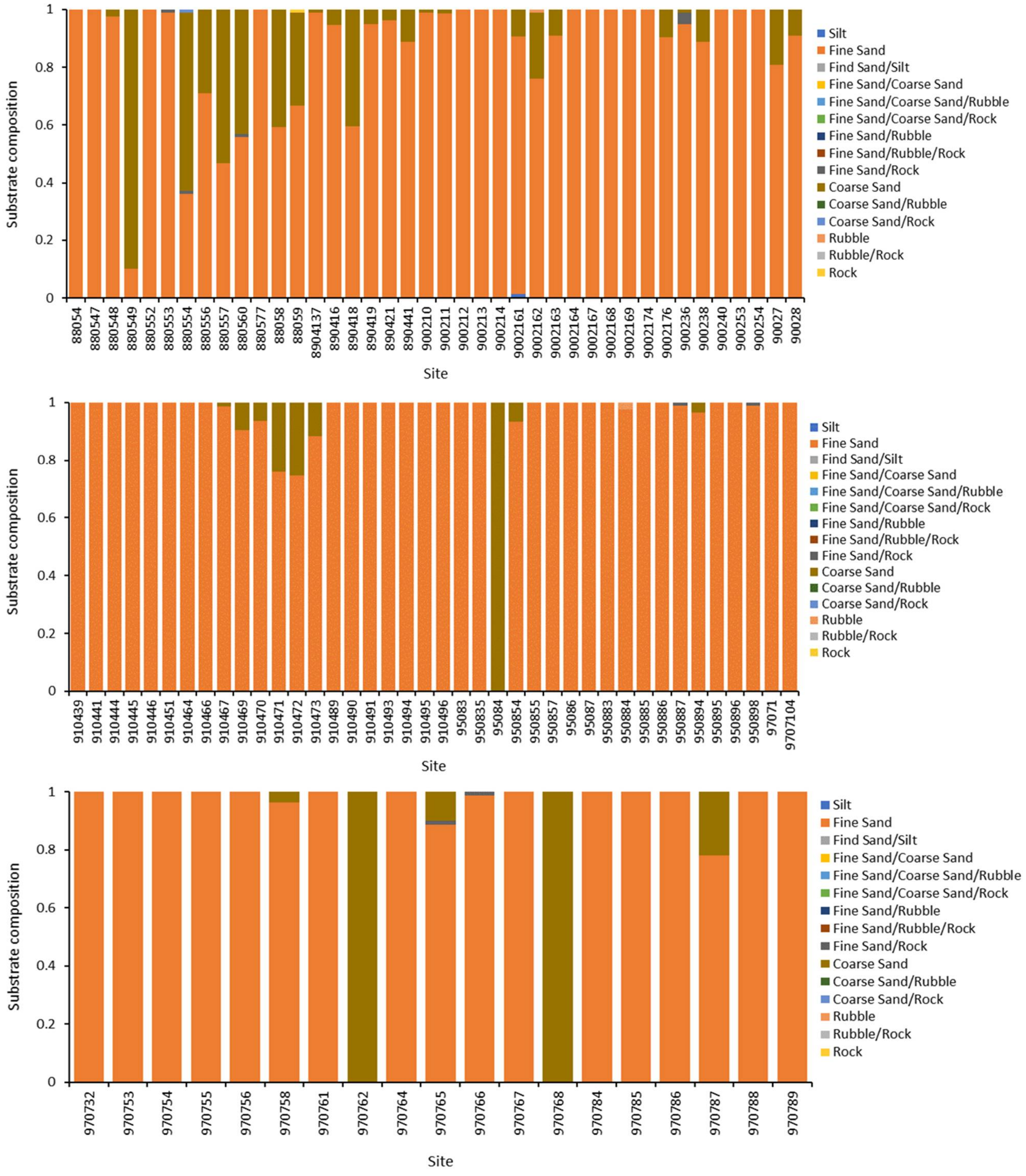


**Figure 26. Proportion of substrate types in seabed images along trawl lines for historical CSIRO (1982–1997) survey sites inshore of the commercial trawl fishery. * denotes sites within the since-formed Dampier MP.**

Topographic composition during CSIRO 1982–1997 surveys was predominantly flat or fine rippled bottom. Some large ripples and ridges were present (Figure 27 and Figure 28), most notably at site 90027 and 890441, respectively. Bioturbations were also identified at some sites, with the largest proportion evident at sites 880552 and 970767.

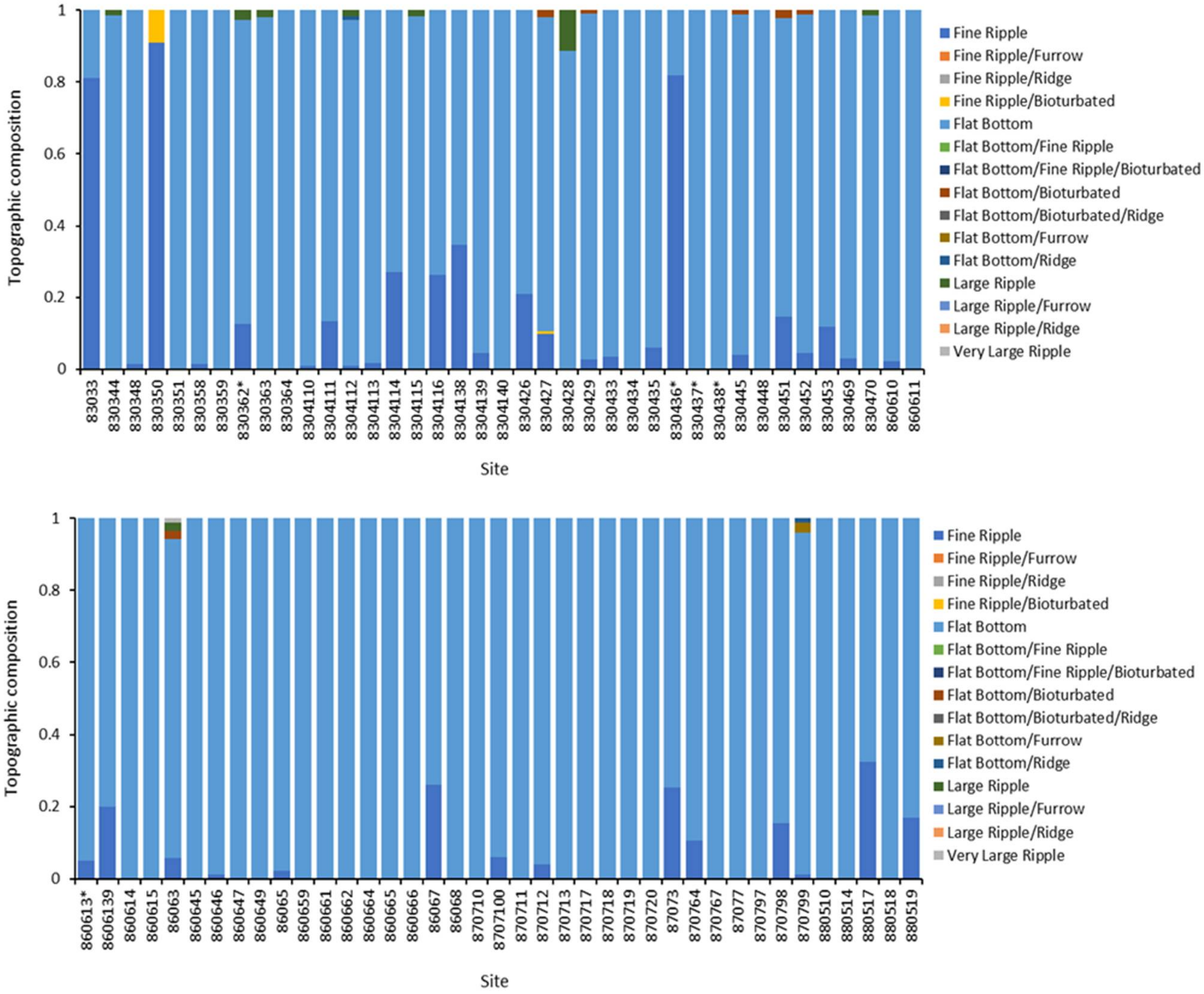


**Figure 27. Proportion of topographic types in seabed images along trawl lines for historical CSIRO (1982–1997) survey sites inshore of the commercial trawl fishery. * denotes sites within the since-formed Dampier MP.**

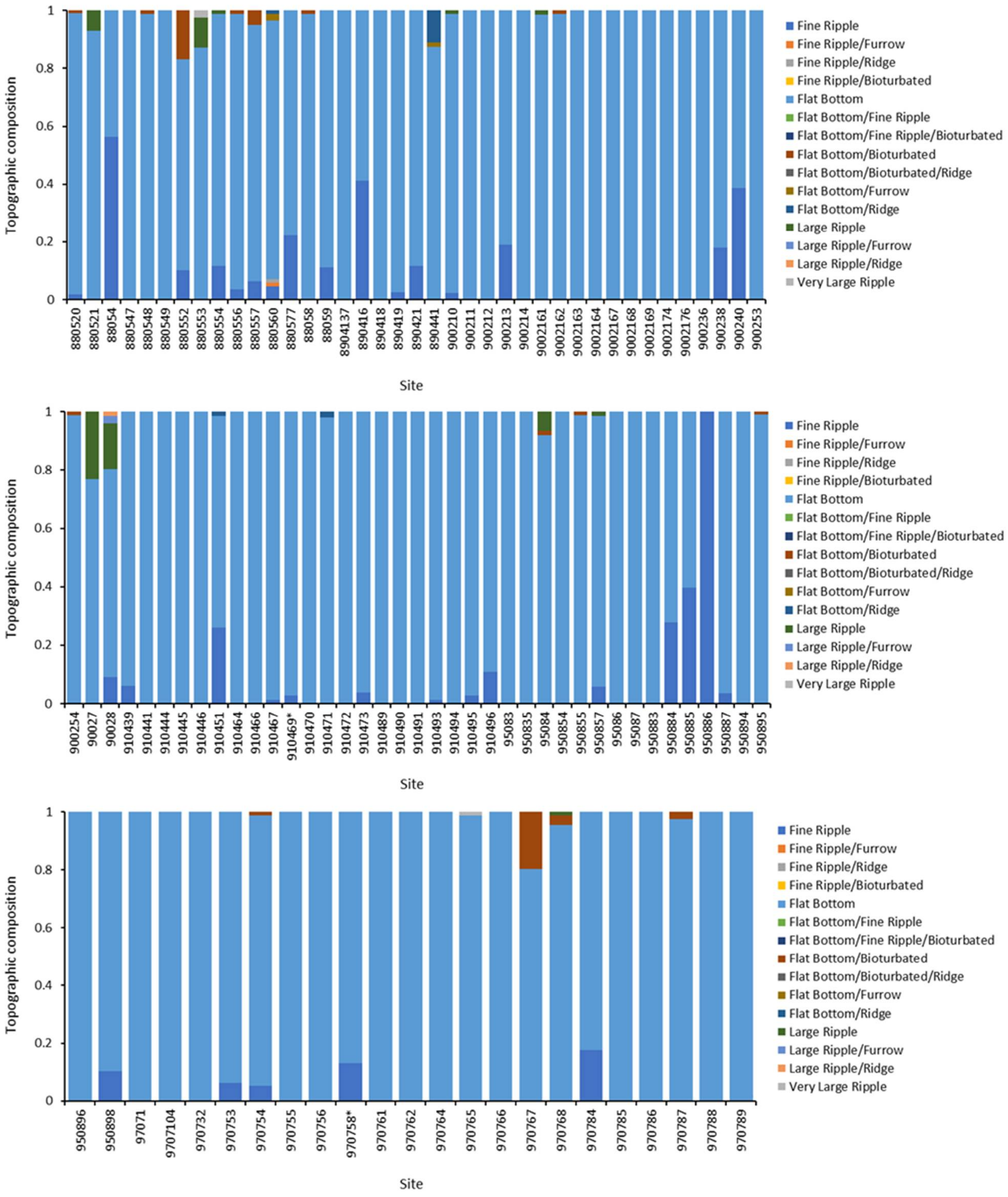


**Figure 28. Proportion of topographic types in seabed images along trawl lines for historical CSIRO (1982–1997) survey sites inshore of the commercial trawl fishery. * denotes sites within the since-formed Dampier MP.**

### 2.4.4 Benthic biota

#### INV2017_05 survey sites

Benthic biota composition was determined for 23 sites during INV2017_05 surveys (Figure 29, also see representative images of each site in Appendix C. Note: no biota data available for site W7). Except for sites W20, W22 and W24 where the absence of biota was observed in large proportions, benthic filter feeders were abundant and diverse. Sponges were greatest at sites W3, W4, W17 and W51, while hydroids dominated sites W19, W51 and W100. Seapens were predominant at site W25, comprising over 60% of benthic biota. Similarly, crinoids had the greatest contribution to biota composition at site W99. Both whips and soft corals were most evident at sites W2 to W18. Within Dampier MP, sponges and whips such as *Junceella fragilis* (Figure 30) formed more than 70% of biota at W4. Site W4 also had a high biomass of very large erect and massive form sponges (Figure 31–Figure 33), while site W6 had large numbers of fans and site W8 had high numbers and biomass of *Dendronephthya* soft corals (Figure 34).

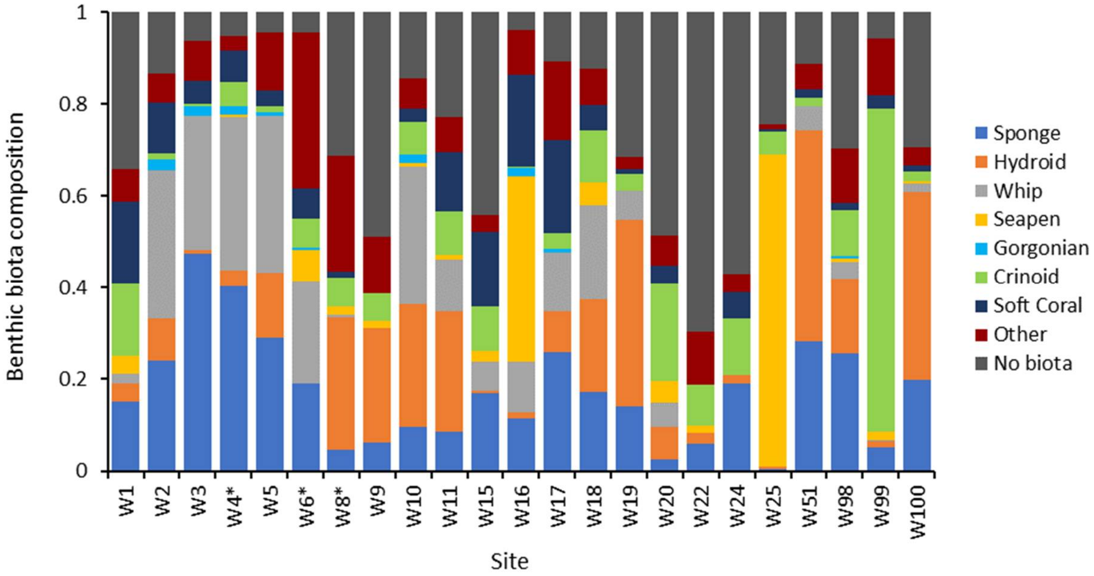


Figure 29. Proportion of biota types in seabed images for INV2017_05 survey sites inshore of the commercial trawl fishery. * denotes sites within Dampier MP. Dark grey = no biota present in images. 'Other' includes either filter feeders which could not be accurately allocated to a specific group because of image quality or other organsims.

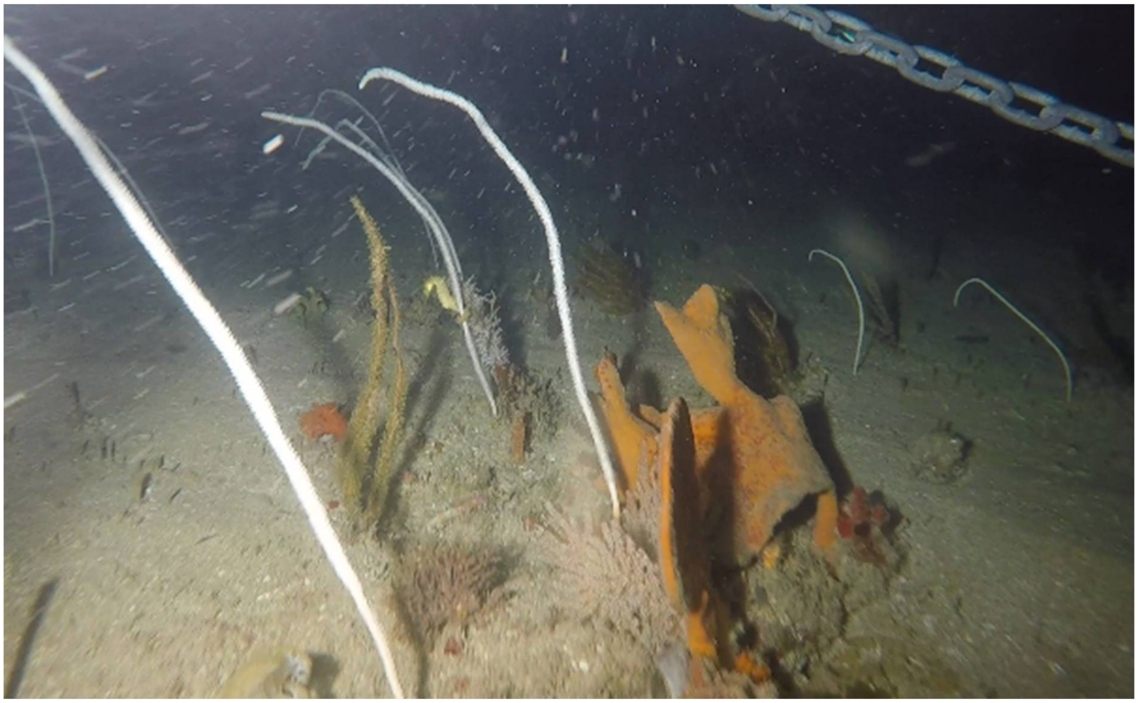


**Figure 30. Sea whips *Junceella fragilis* provide an anchorage point for a sea horse at site W4 within the area inshore of the commercial fishery.**

**Figure 31. Example of sponge community at site W4 within the area inshore of the commercial fishery.**

**Figure 32.** Large *Ianthella flabelliformis*, an example of erect sponge from within the area inshore of the commercial fishery.

**Figure 33.** Massive form sponge common at site W4 within the the area inshore of the commercial fishery.

**Figure 34. Large pink *Dendronephthea* sp. soft coral at sites including W8 inshore of the commercial fishery.**

## CSIRO 1982–1997 survey sites

As with INV2017_05 surveyed sites, the biota observed during CSIRO 1982–1997 surveys were variable across sites, both in diversity and abundance (Figure 35 and Figure 36). Large absences of biota were observed at many sites including sites 830348, 830351,830451, 830452, 860645, 860647, 860659 and 860661 where less than 20% benthic biota were identified. Sponges, whips, crinoids, seapens and 'other' biota including hydroids were common across sites. Proportions of seapens were notably high at sites 830448, 860615, 870712, 830351, 830434, 880517, 910464, 910427 and 950855, while only very small proportions of gorgonians were present across all sites (comprising less than 5% at each site). Only a limited number (approximately 15% of all sites) had extremely high proportions of biota identified (greater than 90%).

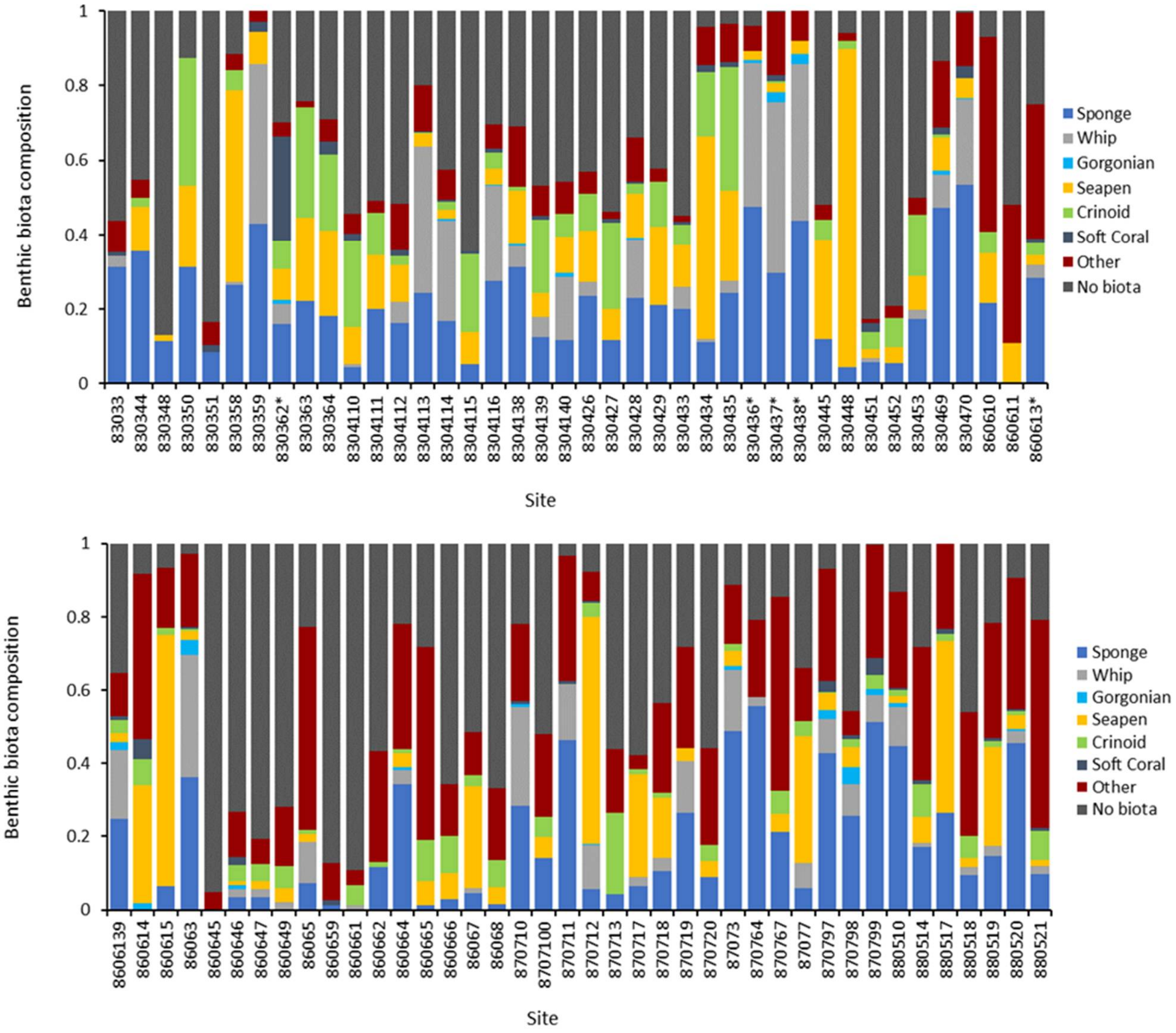


**Figure 35. Proportion of biota types in seabed images for historical CSIRO (1982–1997) survey sites inshore of the commercial trawl fishery. * denotes sites within the since-formed Dampier MP. Maroon = no biota present in the images, 'Other' includes hydroids, filter feeders which could not be accurately allocated to a specific group because of image quality and other benthic organisms not otherwise listed.**

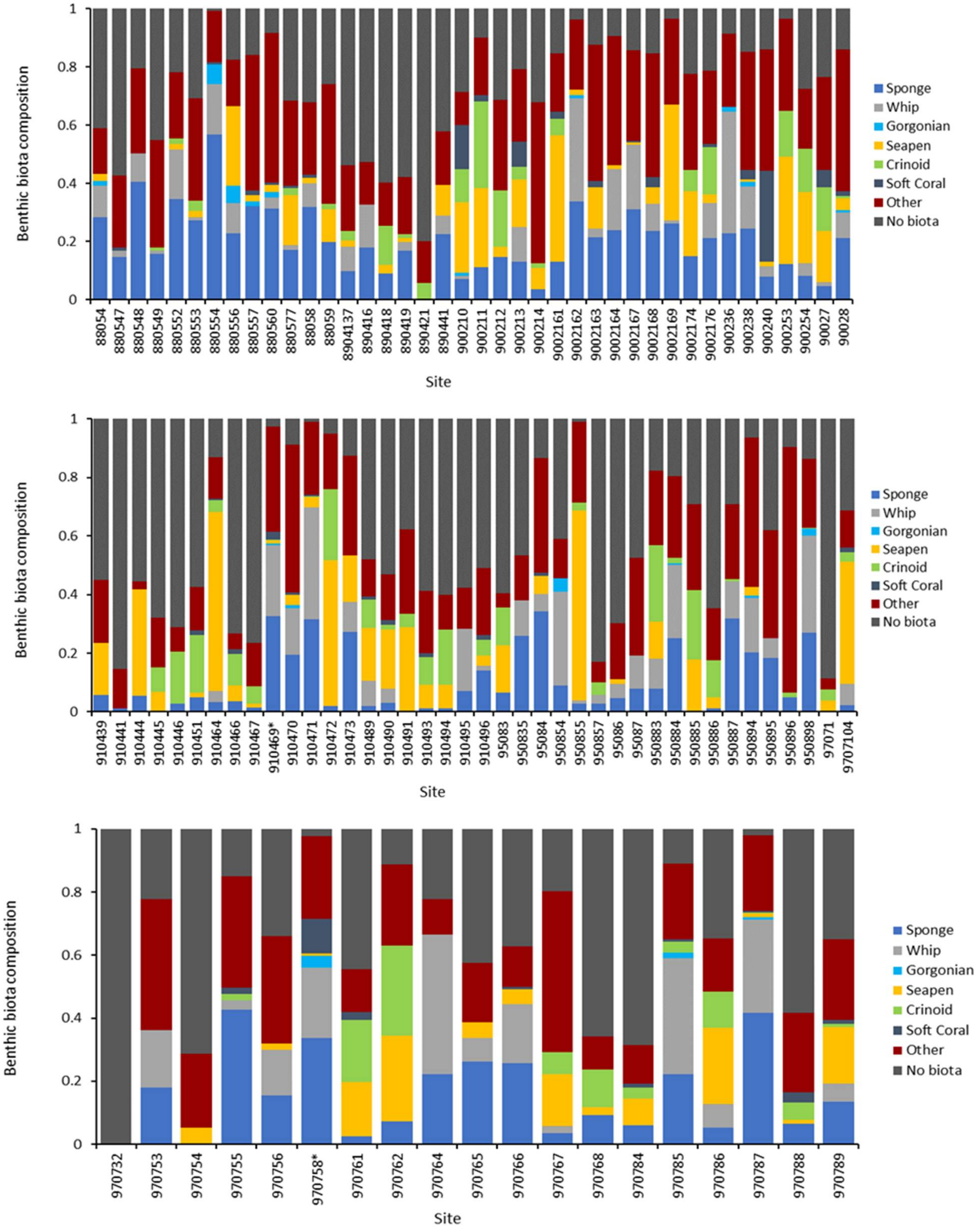


**Figure 36. Proportion of biota types in seabed images for historical CSIRO 1982–1997 survey sites inshore of the commercial trawl fishery. * denotes sites within the since-formed Dampier MP. Maroon = no biota present in the images, 'Other' includes hydroids, filter feeders which could not be accurately allocated to a specific group because of image quality and other benthic organisms not otherwise listed.**

## 2.5 Results from sites west of the commercial trawl fishery (including the Montebello Marine Park)

During the INV2017_05 voyage, 13 sites were surveyed within the area west of the commercial trawl fishery (Figure 37). This included eight sites located within Montebello MP. The location of historical trawls conducted within this area between 1982–1997 for which habitat data were collected, including within the since-formed Montebello MP, are shown in Figure 38.

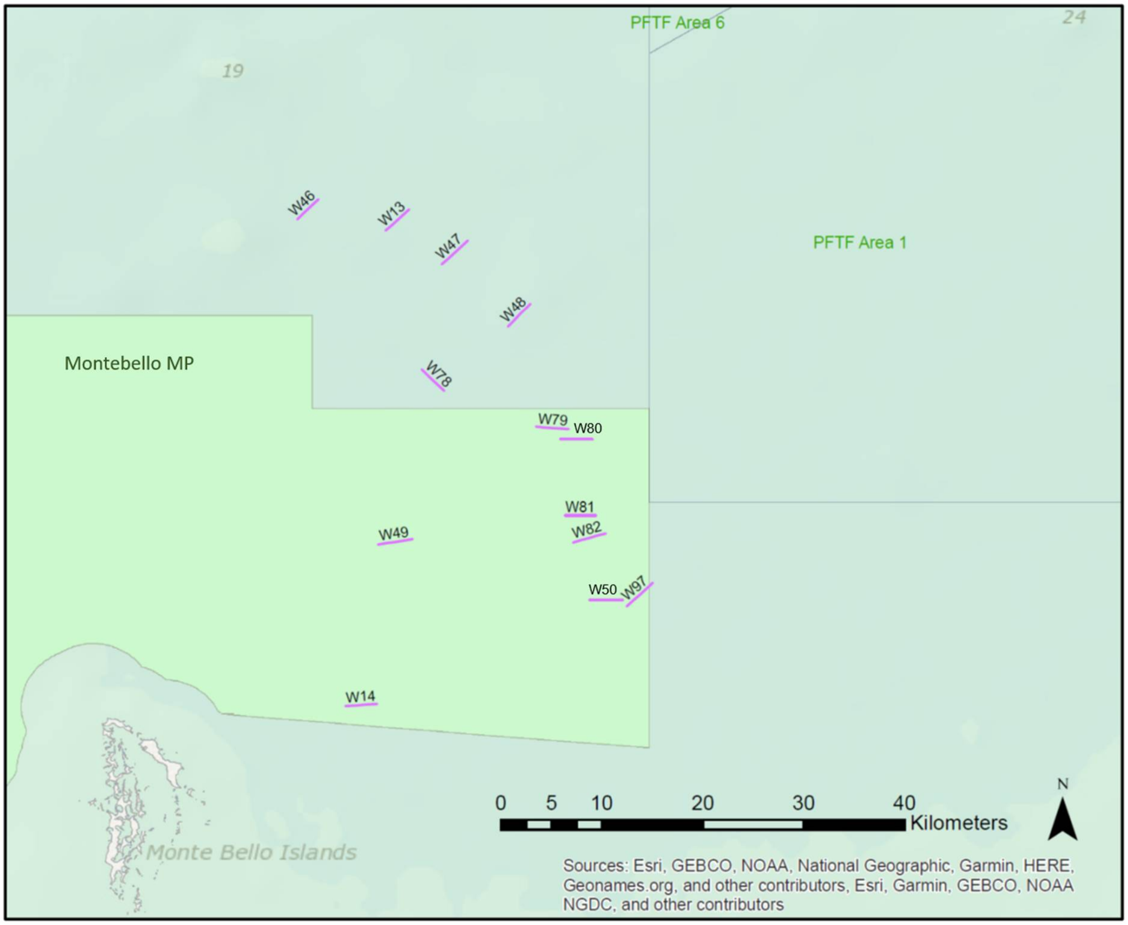


**Figure 37. Location of INV2017_05 sites within the area west of the commercial trawl fishery, including Montebllo MP. Table showing start/end latitude and longitude for each trawl transect is given in Appendix D.**

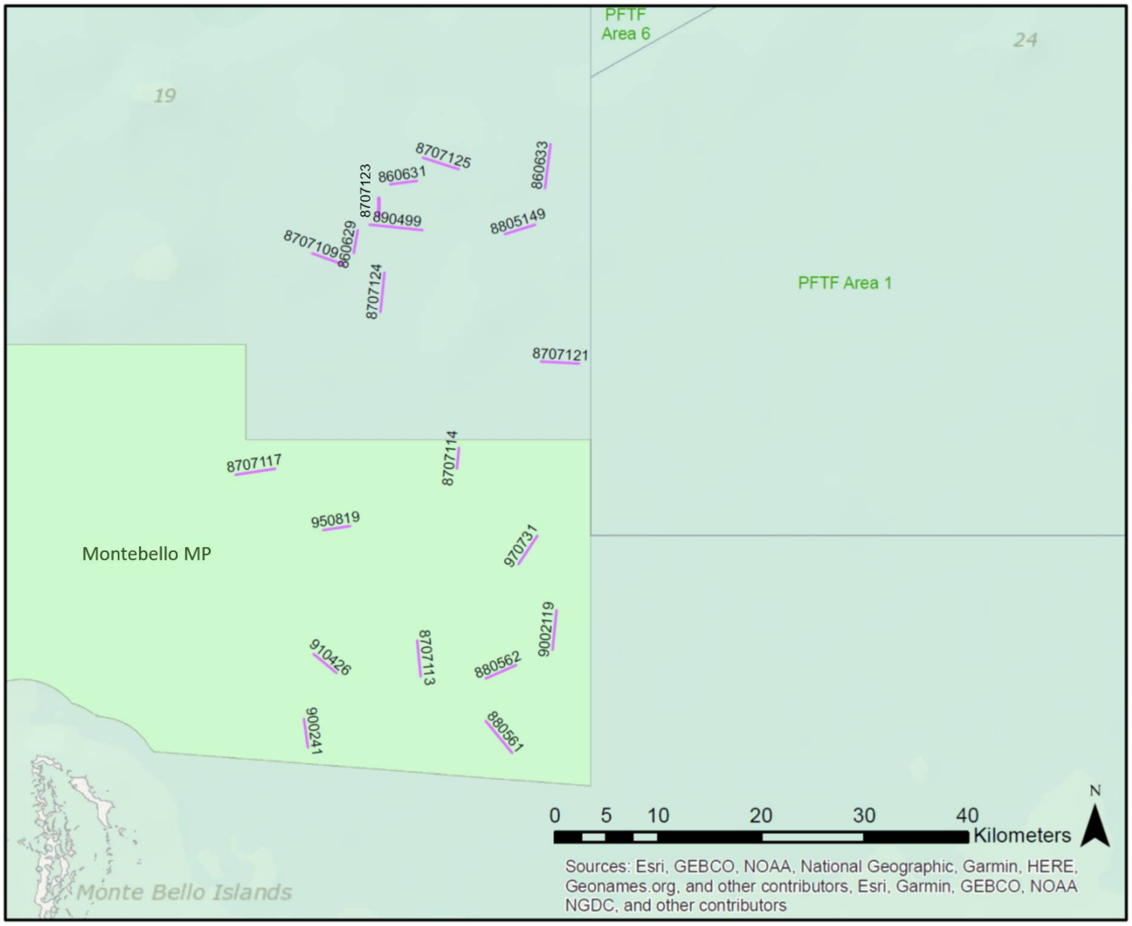


**Figure 38. Location of historical CSIRO 1987–1997 trawls for which habitat data were collected within the area west of the commercial trawl fishery, including within the since-formed Montebllo MP. Table showing start/end latitude and longitude for each trawl transect is given in Appendix E. Trawl number = year, voyage and site number (e.g. 970758 was site 58 on the seventh voyage in 1997).**

## 2.5.1 Water column analyses

CTD profiles were obtained at six sites within the area west of the commercial fishery, including three sites within Montebello MP (Figure 39 and Figure 40). Salinity differed slightly across sites and depth, ranging from 34.8–35.7 psu. Pycnoclines were recorded at sites W49, W79 and W81 around 25–40 m and were associated with the thermoclines at these sites. The salinity profile at site W79 had an anomalous signal near the surface before the trace changed to a profile similar to the two other sites within Montebello MP.

Temperature ranged from 23.9–26.5°C across all sites, with the highest value recorded within Montebello MP. Thermoclines were evident at sites W46, and W49, W79 and W81 within Montebello MP. Those within Montebello MP were deeper, characterised by a temperature change of between 1–2°C at a depth of 25–30 m (site W49), and a more subtle ~ 0.5°C at 35 m and 40 m (site W81 and W79 respectively). These temperature decreases and subsequent formations of thermoclines generally coincided with an increase in chl-*a*.

Dissolved oxygen concentrations generally decreased with depth following a maximum. Dissolved oxygen ranged from 184–215 mg/L with reductions in DO levels recorded at depths of 50–60 m for sites west of the commercial fishery, while occurring higher in the water column at depths of 40 m at sites within Montebello MP. At these sites, DO followed a similar pattern to salinity, with a DO minimum associated closely with the pycnocline at sites W79 and W81. Conversely, at site W49, the DO maximum rather than the minimum was associated with the pycnocline.

PAR profiles across the sites west of the commercial fishery generally diminished with depth with a steady decline in PAR across most sites. Site W47 was characterised by a relatively constant low to zero PAR profile, due to it being a late afternoon station. The depth range of light extinction for sites was > 65 m and 50–55 m for sites within Montebello MP, with approximately 1% light levels reaching the bottom depth at sites W79 and W81. Site W49 was profiled early in the morning with low surface PAR levels resulting in inaccurate calculation of the light dissipation at depth.

Chlorophyll-*a* ranged from 8–35 mg.m$^{-2}$ and increased with depth across all sites, with maximums reached within 60–80 m depth and 35–45 m for sites within Montebello MP.

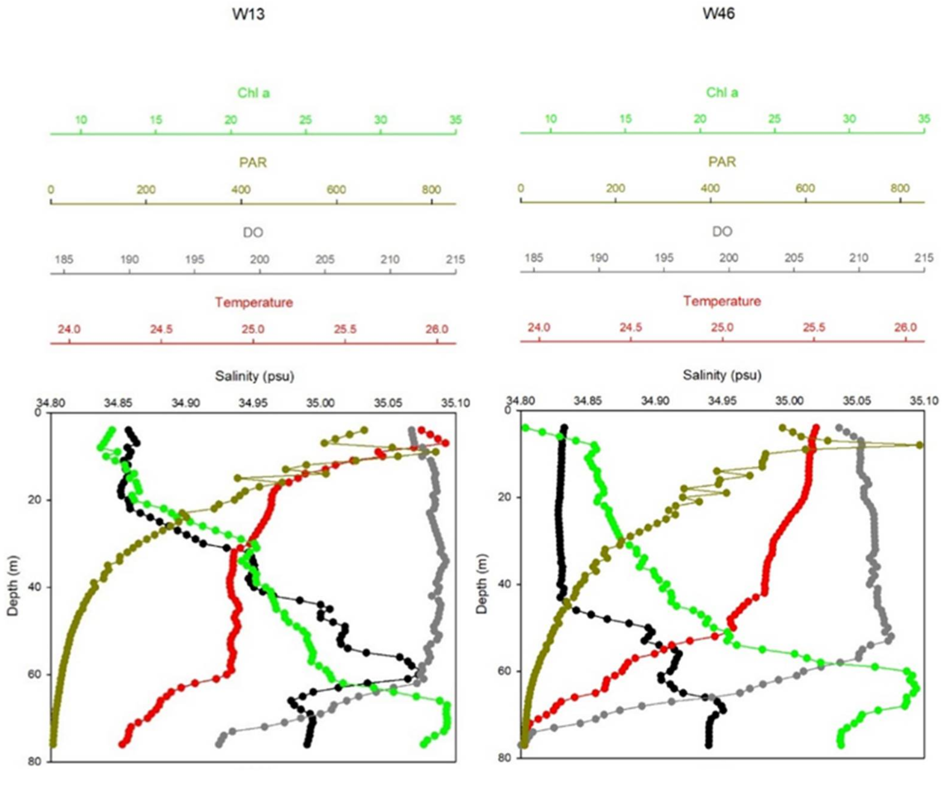


**Figure 39. CTD profiles of water column parameters from sites W13 and W46 within the area west of the commercial fishery.**

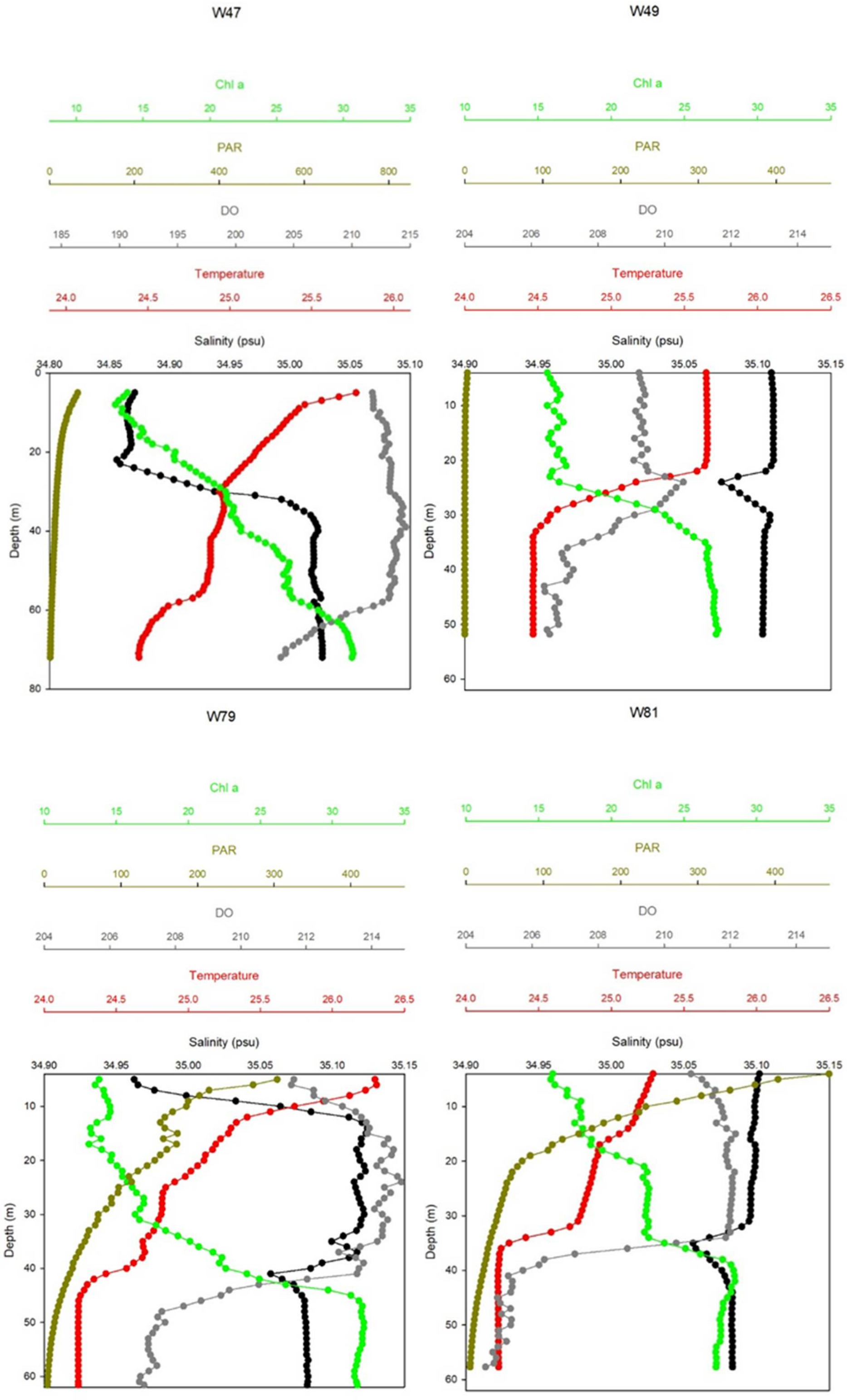


**Figure 40. CTD profiles of water column parameters from sites W47, W49*, W79* and W81* within the area west of the commercial fishery. * denotes sites within Montebello MP.**

Depth-averaged nutrient values were obtained at six sites within the area west of the commercial trawl fishery, including three sites within Montebello MP (Table 4, Figure 41. Depth-averaged nutrient values for sites surveyed west of the commercial trawl fishery (including sites within Montebello MP). Box plots show the median, 25th and 75th percentiles and outliers falling outside the 10th and 90th percentiles. Figure 41Table 3). Mean total chl-*a* ranged from 0.27 to 0.38 mg $m^{-2}$ across sites, with the highest value recorded at site W13 (Figure 41, top). Nitrate concentrations ranged from 0.043 mmol $m^{-2}$ (site W81 within Montebello MP) to 0.769 mmol $m^{-2}$ (site W46). Mean ammonia ranged from 0.003–0.083 mmol $m^{-2}$ while silica was relatively consistent across sites, ranging from 3.928–4.838 mmol $^{-2}$. Both minimums were recorded at site W47, while site W49 within Montebello MP had the highest mean silica and second highest $NH_4$ values. Site W79, also within Montebello MP had the highest mean $NH_4$. Phosphate concentrations ranged from 0.116 mmol $m^{-2}$ at site W47, to 0.156 mmol $m^{-2}$ at site W46.

**Table 4. Nutrients (depth averaged values) for sites surveyed west of the commercial trawl fishery. * denotes site within Montebello MP.**

| Site | Mean total chl-*a* (mg $m^{-2}$) | Mean $NO_x$ (mmol $m^{-2}$) | Mean $NH_4$ (mmol $m^{-2}$) | Mean $PO_4$ (mmol $m^{-2}$) | Mean Si (mmol $m^{-2}$) |
|---|---|---|---|---|---|
| W13 | 0.38 | 0.450 | 0.008 | 0.137 | 4.059 |
| W46 | 0.29 | 0.769 | 0.016 | 0.156 | 4.067 |
| W47 | 0.31 | 0.176 | 0.003 | 0.116 | 3.928 |
| W49* | 0.27 | 0.046 | 0.057 | 0.137 | 4.838 |
| W79* | 0.28 | 0.049 | 0.083 | 0.118 | 4.236 |
| W81* | 0.27 | 0.043 | 0.015 | 0.124 | 4.455 |

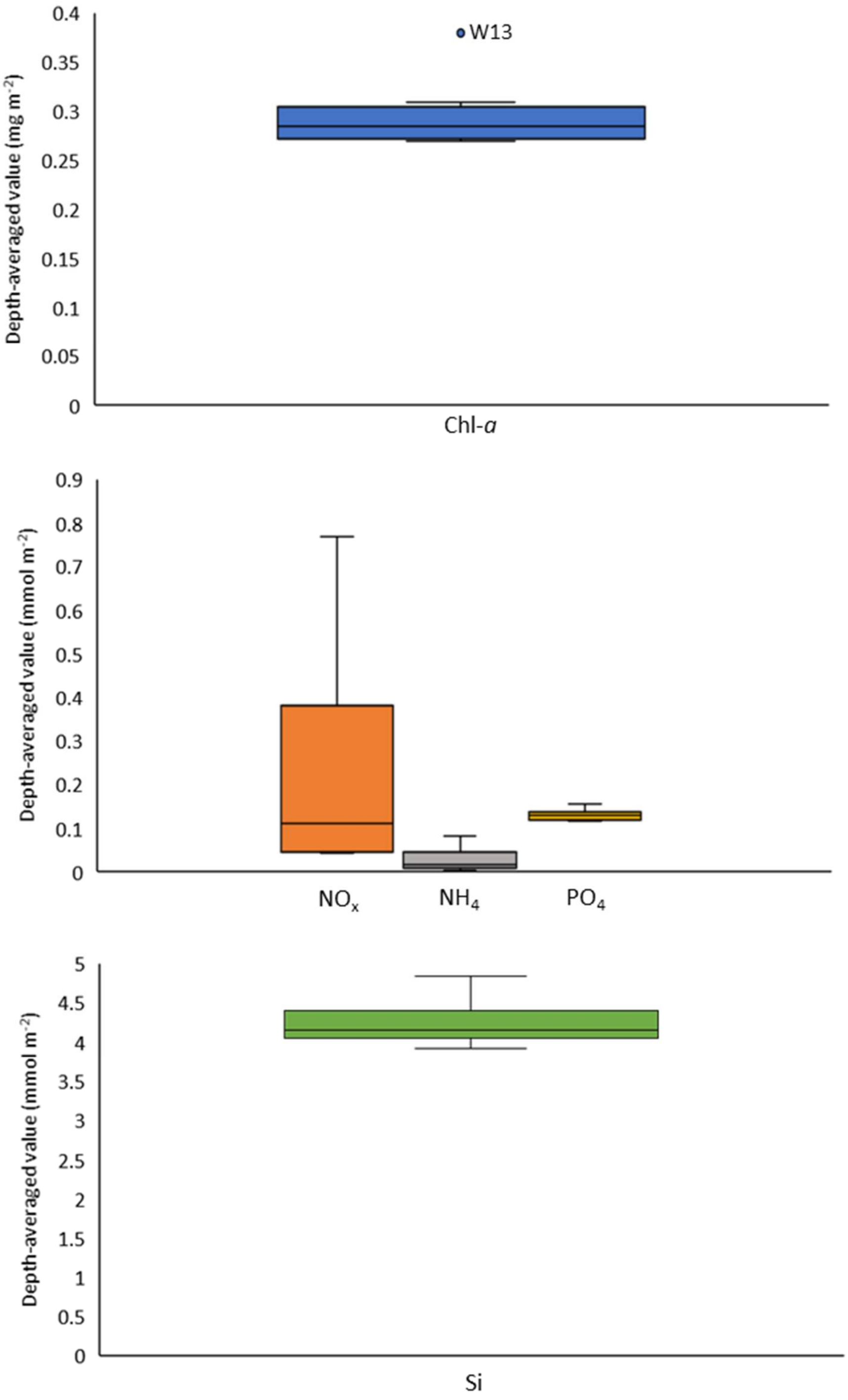


**Figure 41. Depth-averaged nutrient values for sites surveyed west of the commercial trawl fishery (including sites within Montebello MP). Box plots show the median, 25th and 75th percentiles and outliers falling outside the 10th and 90th percentiles.**

### 2.5.2 Sub bottom profiling INV2017_05 sites

Sub-bottom profiling of sites west of the commerical trawl fishery showed predominantly thin sediment over rock bottom (Figure 42). Sites W79 and W80 within Montebello MP were characteristed by a combination of thick and thin sediment over rock, while site W49, also within Montebello MP, was a mixture of thick sediment and hard bottom. Sites W14, W48, W81 and W97 were all characterised as predominantly thin sediment over rock with a small proportion of hard bottom.

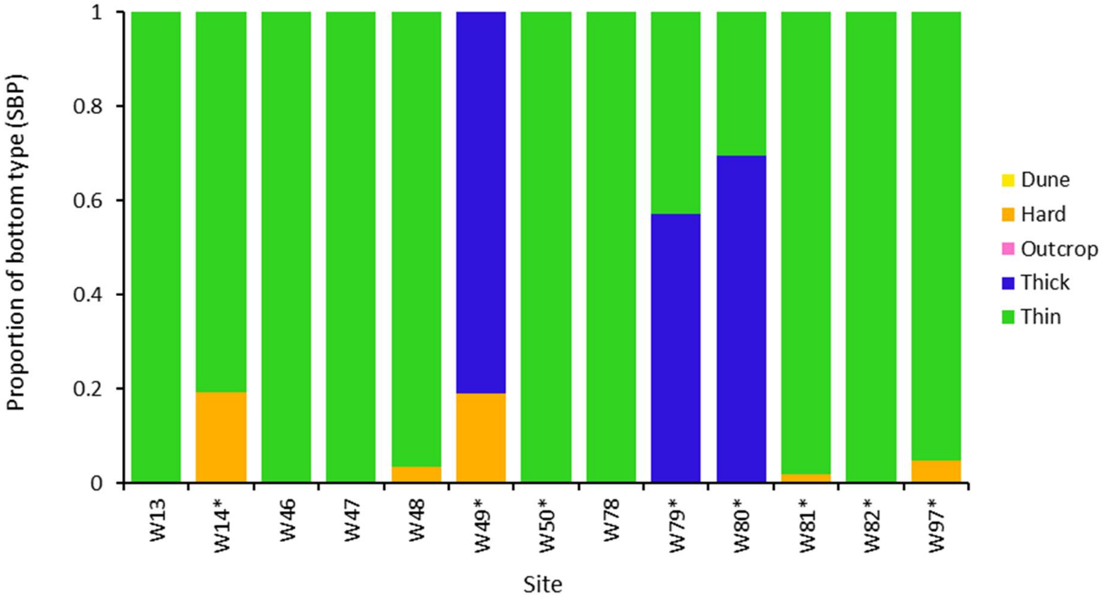


Figure 42. Proportion of bottom types determined using SBP for INV2017_05 sites within the area west of the commercial trawl fishery. * denotes sites within Montebello MP.

### 2.5.3 Substrate and topography

#### INV2017_05 survey sites

Fine sandy substrates dominated sites west of the commercial fishery during INV2017_05 surveys (Figure 43, top). Site W81, within Montebello MP, was the exception dominated by coarse sand. Shallower sites W14 and W49, also within Montebello MP, showed a small proportion (approximately 20% and 30% respectively) of a combination of fine sand, coarse sand and rubble, and rock (W14 only). Shepard's plots also confirmed sediment classification as sand across sites (Figure 44) including those within Montebello MP (Figure 45).

Flat bottom topography was ubiquitous across all sites (Figure 43, bottom). Bioturbations were evident at five sites, however, comprised a very small proportion of topographic composition.

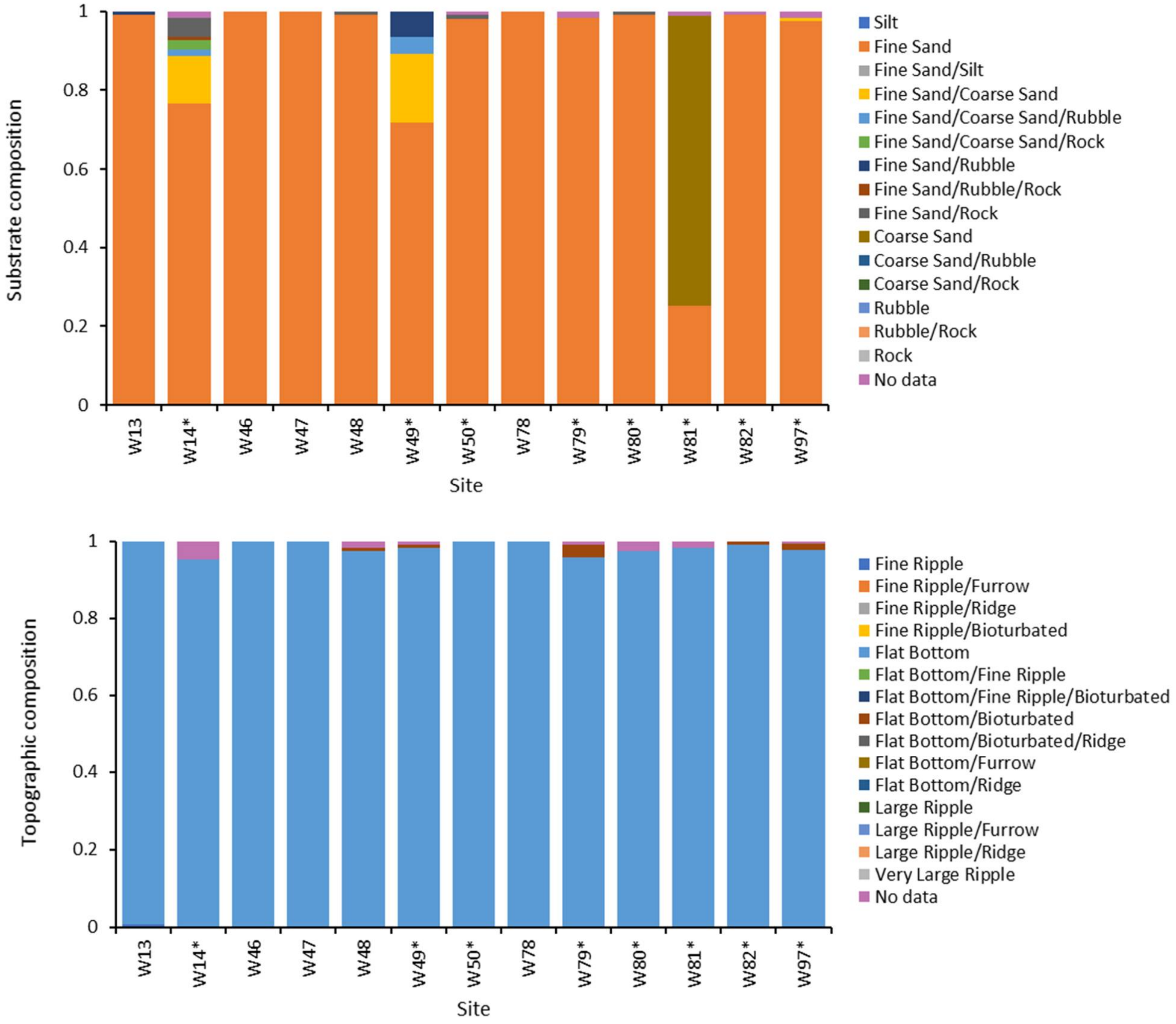


**Figure 43. Proportion of substrate (top) and topography (bottom) types in seabed images along trawl lines for INV2017_05 survey sites west of the commercial trawl fishery. * denotes sites within Montebello MP.**

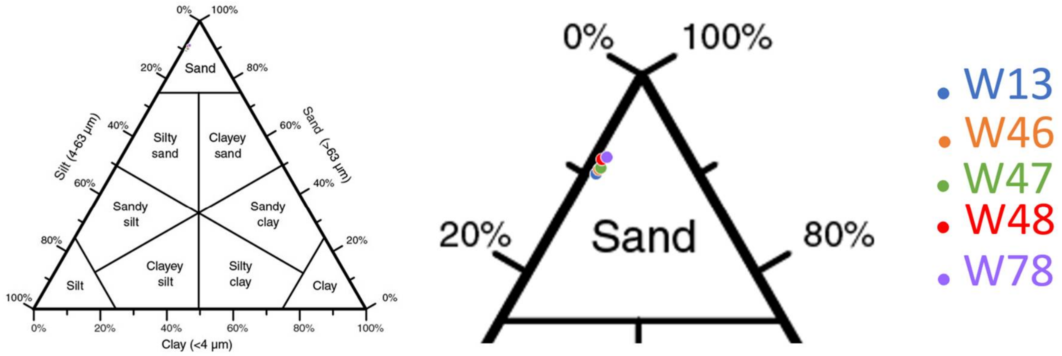


Figure 44. Shepard's plot of sediment classifications for INV2017_05 survey sites west of the commercial trawl fishery (excluding Montebello MP).

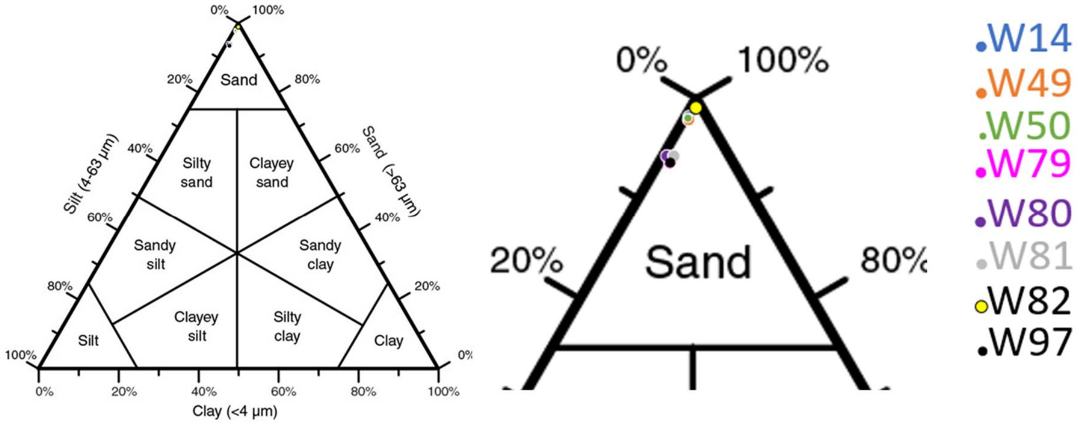


Figure 45. Shepard's plot of sediment classifications for INV2017_05 survey sites within Montebello MP (west of the commercial trawl fishery).

## CSIRO 1982–1997 survey sites

Substrate type at CSIRO 1982–1997 historical sites west of the commercial fishery were predominantly fine sand or a mix of fine and coarse sand substrate (Figure 46, top). Site 8707117 was dominated by coarse sand, comprising over 95% of substrate composition. Topography was mostly flat bottom or flat bottom with ripples (Figure 46, bottom). Bioturbations were only present at site 860633. Sites 8707121 and 890499 had the largest proportion of fine ripples with these comprising greater than 60% and 80%, respectively.

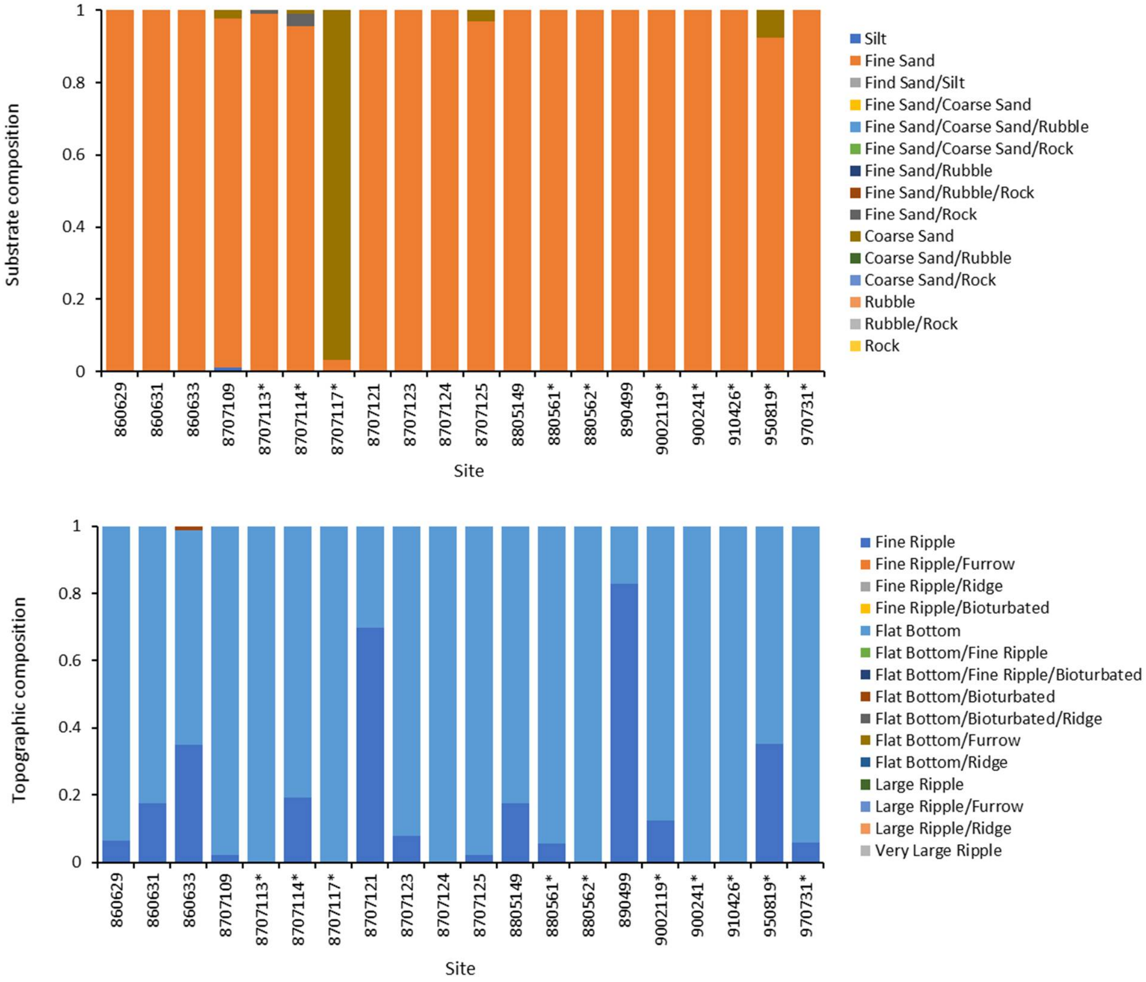


**Figure 46. Proportion of substrate (top) and topography (bottom) types in seabed images along trawl lines for historical CSIRO 1982–1997 survey sites west of the commercial trawl fishery. * denotes sites within the since-formed Montebello MP.**

### 2.5.4 Benthic biota INV2017_05 survey sites

A clear distinction was evident between the benthic biota composition across sites west of the commercial trawl fishery (Figure 47, also see representative images in Appendix C ). Those outside of Montebello MP were predominantly lacking in benthic biota, with site W48 showing the greatest proportion (30%) and diversity of benthic biota. Sponges, crinoids and 'other' biota were present at all sites. Both seapens and 'other' biota were present in the greatest proportions at site W47, while sponges and crinoids were greatest at sites W48 and W78, respectively. Gorgonians were only present at site W48.

Conversely, sites within Montebello MP had high proportions of benthic biota present. With the exception of the most inshore and shallowest of these (site W14, Figure 48), sites surveyed during INV2017_05 in the eastern section of Montebello MP had low numbers of soft corals. Sponges, whips and gorgonians were also minimal, and as a result, complex benthic filter feeder communities were largely absent (e.g. see representative imagesin Appendix C in Appx Figure 24–Appx Figure 36). Instead, the dominant filter feeders were crinoids, hydroids and seapens. The most commonly recorded cronoid was *Comatula rotalaria* (Figure 49) which is free living on sand rather than associated with other filter feeders like gorgonians. Site W49 was notable for the large number of seapens present (Figure 50).

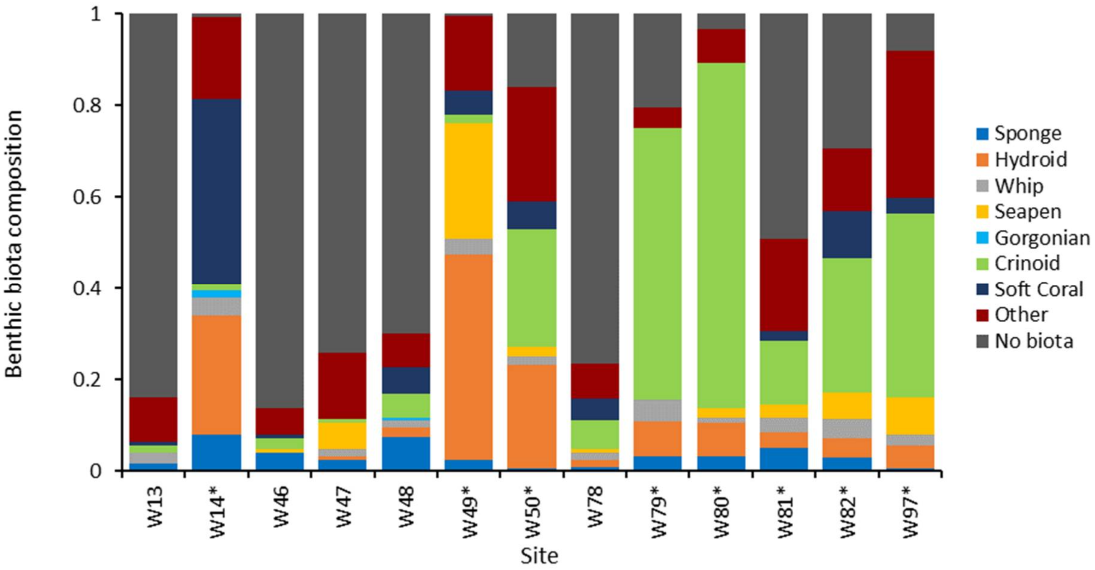


**Figure 47. Proportion of biota types in seabed images along trawl lines for INV2017_05 survey sites west of the commercial trawl fishery. * denotes sites within the since-formed Montebello MP. Dark grey = no biota present in the images, 'Other' includes both filter feeders which could not be accurately allocated to a specific group because of image quality and other benthic organisms not otherwise listed.**

**Figure 48.** ***Dendronephthea*** **spp. soft corals at site W14 within the area west of the commercial trawl fishery.**

**Figure 49. Free-living crinoid** ***Comatula rotalaria*** **very common at sites W79, W80 and W97 within the area west of the commercial trawl fishery. The crinoid pictured was ~ 20 cm in diameter.**

**Figure 50. Two of the common seapen species at site W49 within the area west of the commercial trawl fishery. Left panel: very common *Scytalium* sp., right panel: *Pteroeides* sp.**

## CSIRO 1982–1997 survey sites

Similar to INV2017_05 surveys, sites within the since-formed Montebello MP showed a greater proportion of benthic biota than sites outside this area during CSIRO 1982–1997 surveys (Figure 51). With the exception of these sites within Montebello MP, the presence of benthic biota was generally greater during historical surveys than at INV2017_05 sites west of the commercial fishery (7–85% and 14–30%, respectively). Biota was dominated by sponges and 'other' biota including hydroids. Site 880561, within the since-formed Montebello MP, had the greatest proportion of biota, including seapens and 'other' benthic biota. Sponges were greatest at sites 880562 and 8707125, while crinoids made up a vastly greater proportion of biota at site 8707121 than at any other site. Seapens were abundant at sites 880561, 910426 and 8805149. Soft corals were greatest at site 9002119, making up almost 45% of benthic biota at this site.

The biota recorded at the historical CSIRO 1982–1997 sites varied markedly from that during the INV2017_05 surveys, in particular the large proportion of sponges and small proportion of crinoids seen at historical sites. However, two historical sites (950819 and 970731) located in the eastern part of the MP where the 2017 samples were taken, also had a large proportion of images with no biota.

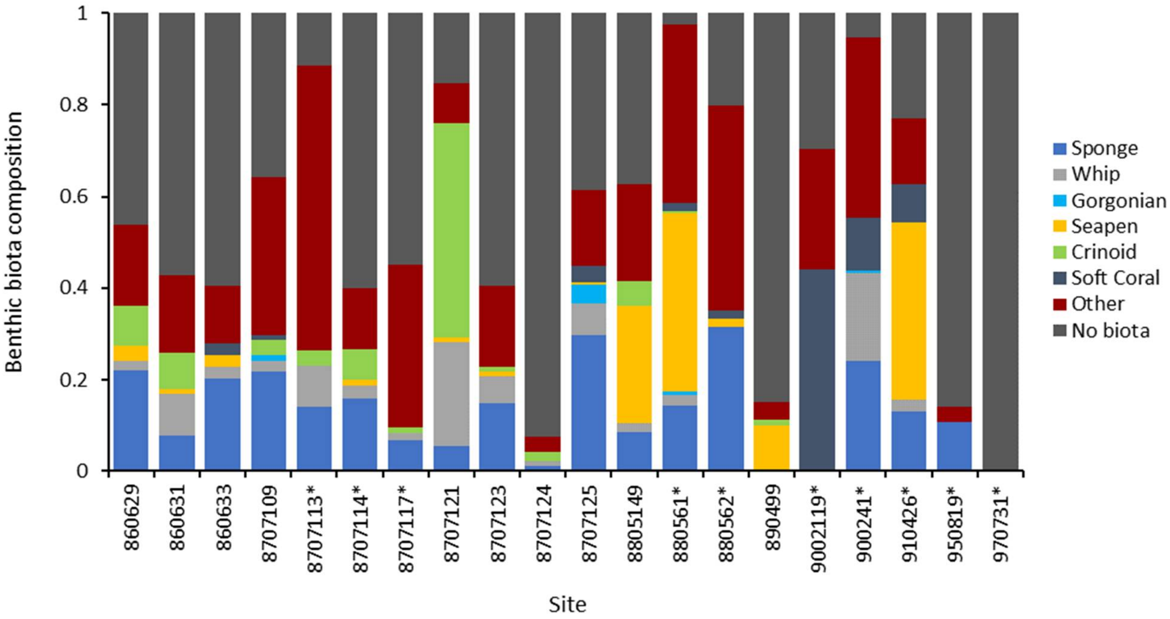
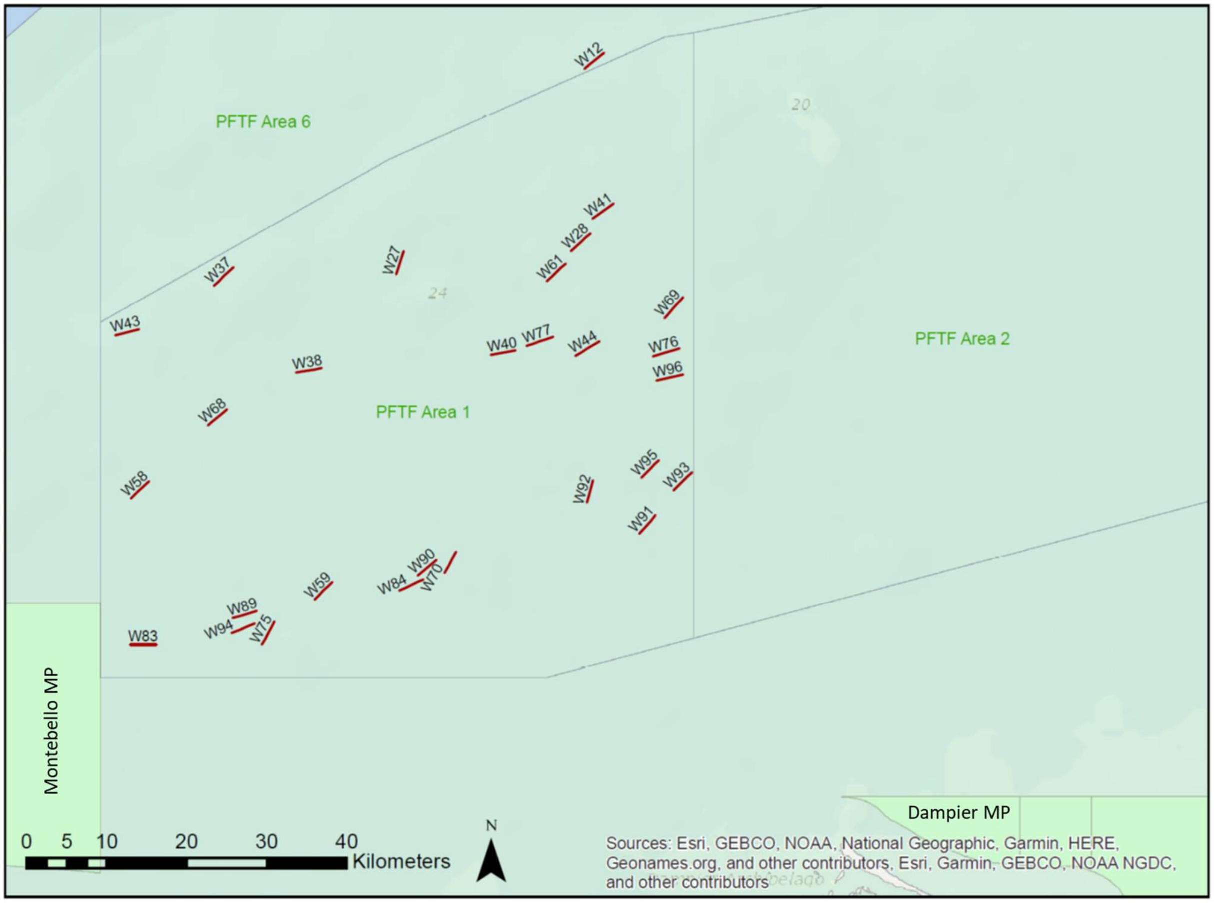


**Figure 51. Proportion of biota types in seabed images along trawl lines for historical CSIRO 1982–1997 survey sites west of the commercial trawl fishery. * denotes sites within the since-formed Montebello MP. 'Other' includes hydroids, filter feeders which could not be accurately allocated to a specific group because of image quality and other benthic organisms not otherwise listed.**

## 2.6 Results from sites in Pilbara Fish Trawl Fishery Area 1

During the INV2017_05 voyage, 26 sites were surveyed within PFTF Area 1 (Figure 52). An additional site, W12 within PFTF Area 6, was also surveyed and included in the analysis of PFTF Area 1 due to its close proximity to this area. The location of historical trawls conducted within this area between 1982–1997 for which habitat data were collected are shown in Figure 53.



Sources: Esri, GEBCO, NOAA, National Geographic, Garmin, HERE, Geonames.org, and other contributors, Esri, Garmin, GEBCO, NOAA NGDC, and other contributors

**Figure 52. Location of INV2017_05 sites within PFTF Area 1, including Area 6. Table showing start/end latitude and longitude for each trawl transect is given in Appendix D.**

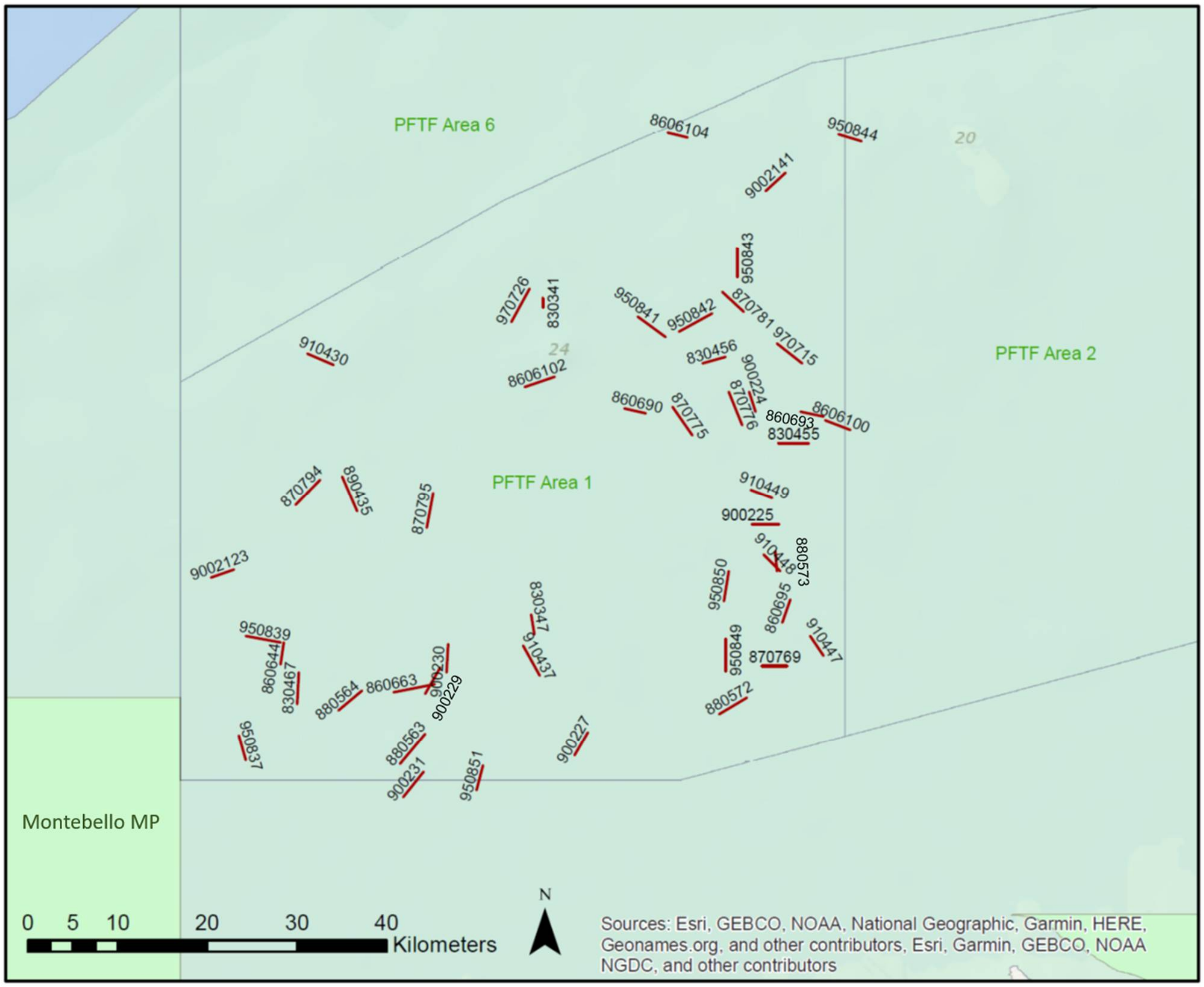


**Figure 53. Location of historical CSIRO 1987–1997 trawls for which habitat data were collected within PFTF Area 1, including Area 6. Table showing start/end latitude and longitude for each trawl transect is given in Appendix E. Trawl number = year, voyage and site number (e.g. 970758 was site 58 on the seventh voyage in 1997).**

### 2.6.1 Water column analyses

CTD profiles were obtained at 21 sites within PFTF Area 1, including site W12 within PFTF Area 6 (Figure 54–Figure 59). Salinity varied little across sites within PFTF Areas 1 and 6, ranging from 34.8–35.05 psu. Salinity remained constant for most sites, showing either very slight increases or decreases with depth. Pycnoclines were recorded at sites W44, W69 and W95 at 20–30 m depth. The salinity profile at site W61 had an anomalous signal near the surface before the trace changed to a profile similar to the other sites within PFTF Area 1.

Temperature ranged from 23.5–26.5°C across sites, with both maximum and minimum values recorded at site W12 within Area 6. Obvious thermoclines were present at sites W38, W83 and W89, characterised by a decrease in temperature of roughly 0.5°C generally between 35–40 m depth. A larger reduction in temperature (roughly 1°C) was observed at site W40, with this shallower than other sites sitting at 20 m depth. Again, these temperature declines and subsequent formations of thermoclines generally coincided with an increase in chl-*a*. Site W43 showed a very subtle decrease in temperature from the surface to around 60 m depth, decreasing roughly 0.5°C over this depth range.

Dissolved oxygen ranged from 180–226 mg/L with decreases in DO levels generally recorded at 40 m. Sites W37 and W44 showed decreases in DO much shallower at 20 m depth, while changes at site W12 within PFTF Area 6, and sites W43 and W58 were deeper at around 60 m. This deeper decrease in DO at site W43 was also associated with a deep chl-*a* maximum and temperature change.

As with the areas inshore and west of the commercial trawl fishery, PAR profiles across sites within PFTF Areas 1 and 6 generally progressively diminished with depth. Six sites were characterised by near zero/zero PAR profiles (sites W37, W43, W69, W70, W84, W95 were all done in the ealy morning or late evening). Site W58 showed a steep reduction of PAR at 10 m depth. Light extinction ranged from 40–50 m, while at site W12 within PFTF Area 6 this was much deeper, at 65 m indicative of greater water clarity.

Chlorophyll-*a* ranged from 12.5–37.7 mg.m$^{-2}$ with maximum values generally reached at depths of 40–60 m. Sites W44 and W59 had chl-*a* maxima at 30–35 m, while site W43 had a deeper chl-*a* maximum at around 70 m – typical for this area. Like salinity, the chl-*a* profile at site W61 had an anomalous signal near the surface before the trace changed to a profile similar to the other sites within PFTF Area 1.

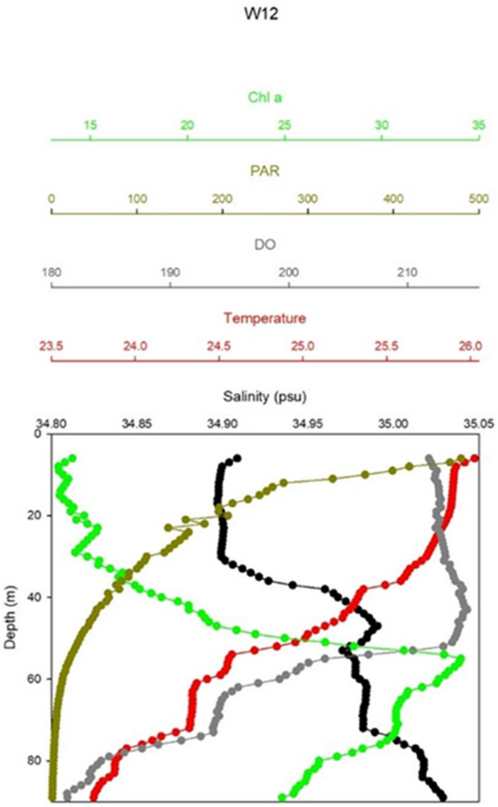


Figure 54. CTD profiles of water column parameters from site W12 within PFTF Area 6, combined with PFTF Area 1.

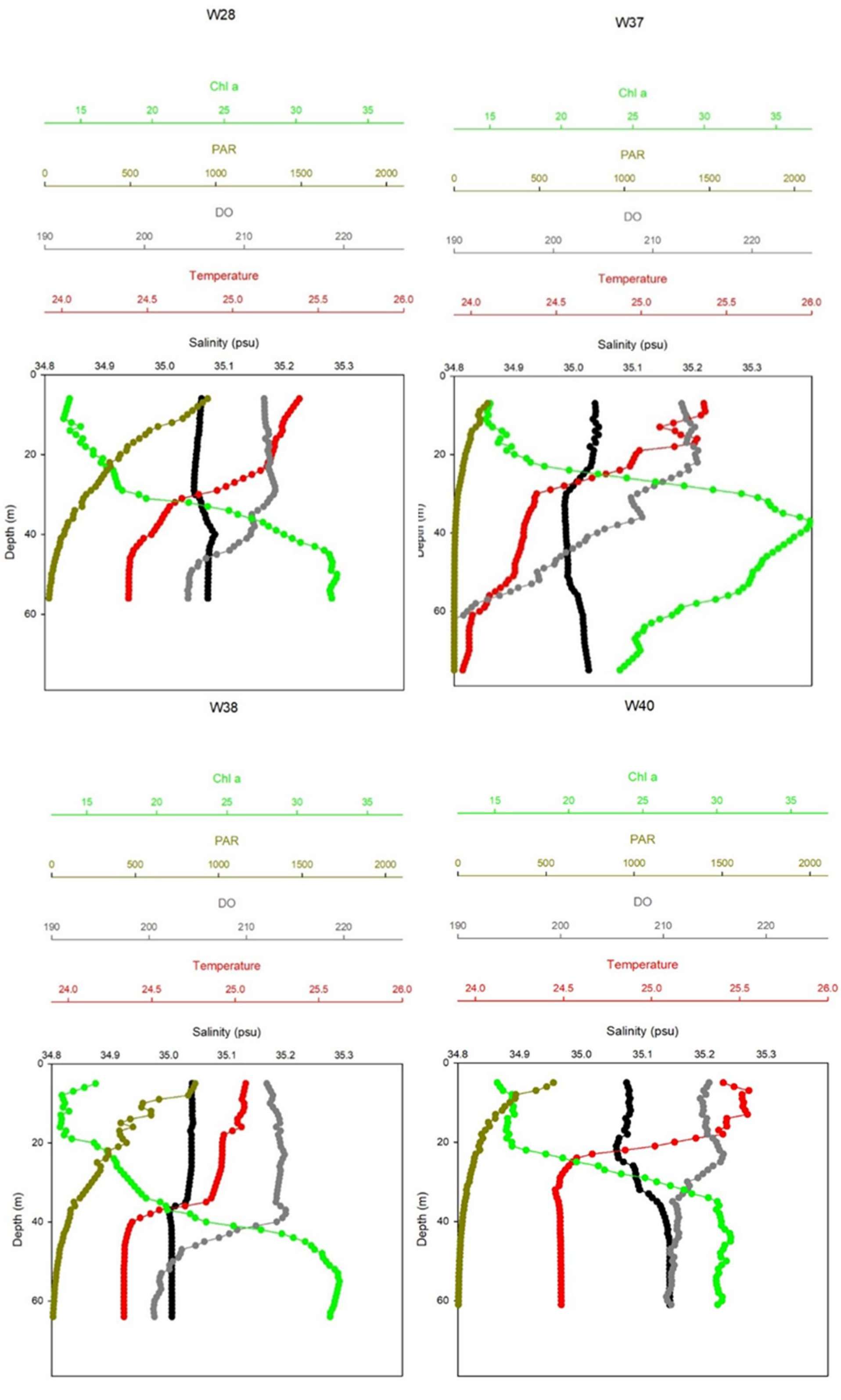


Figure 55. CTD profiles of water column parameters from sites W28, W37, W38 and W40 within PFTF Area 1.

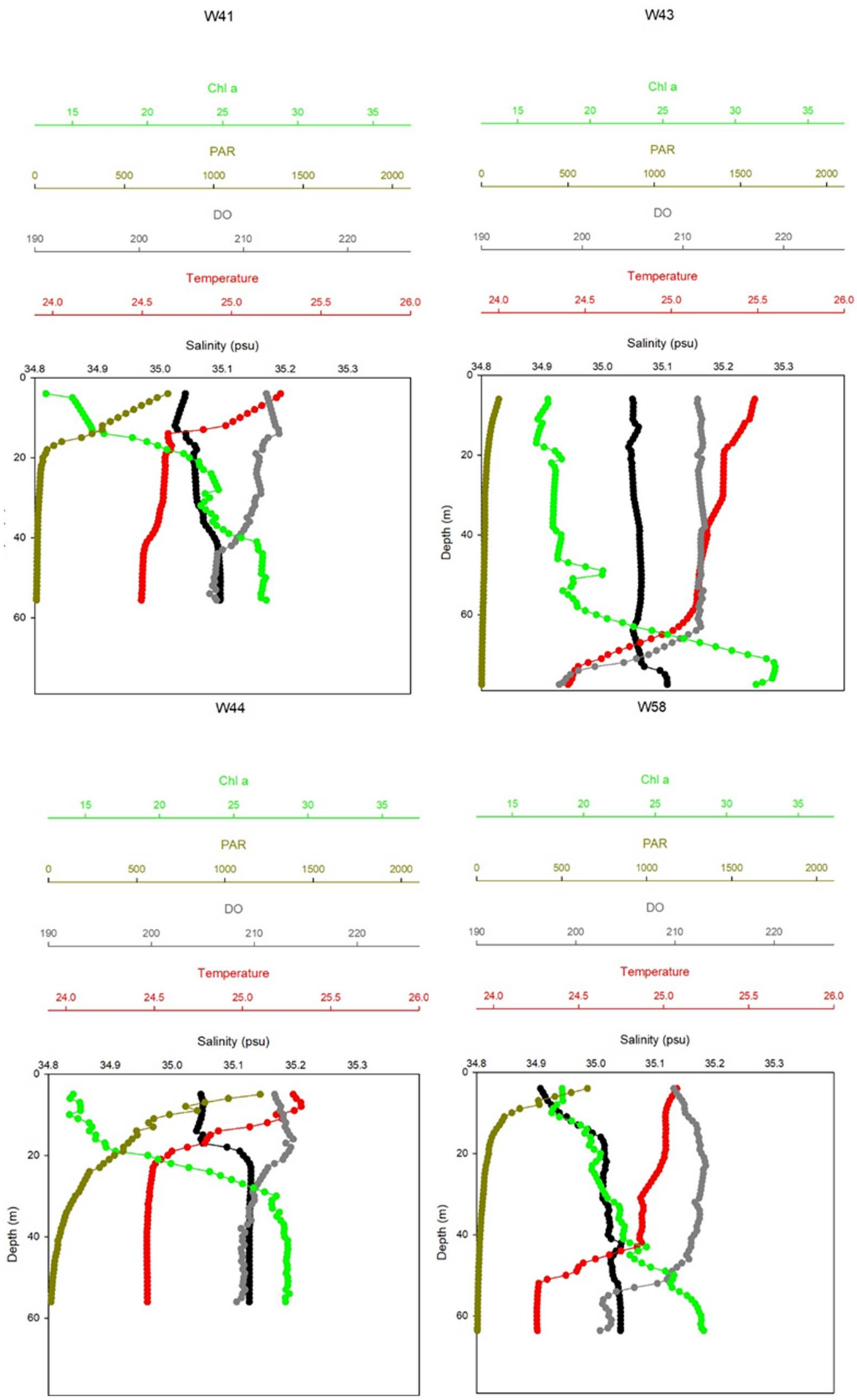


Figure 56. CTD profiles of water column parameters from sites W41, W43, W44 and W58 within PFTF Area 1.

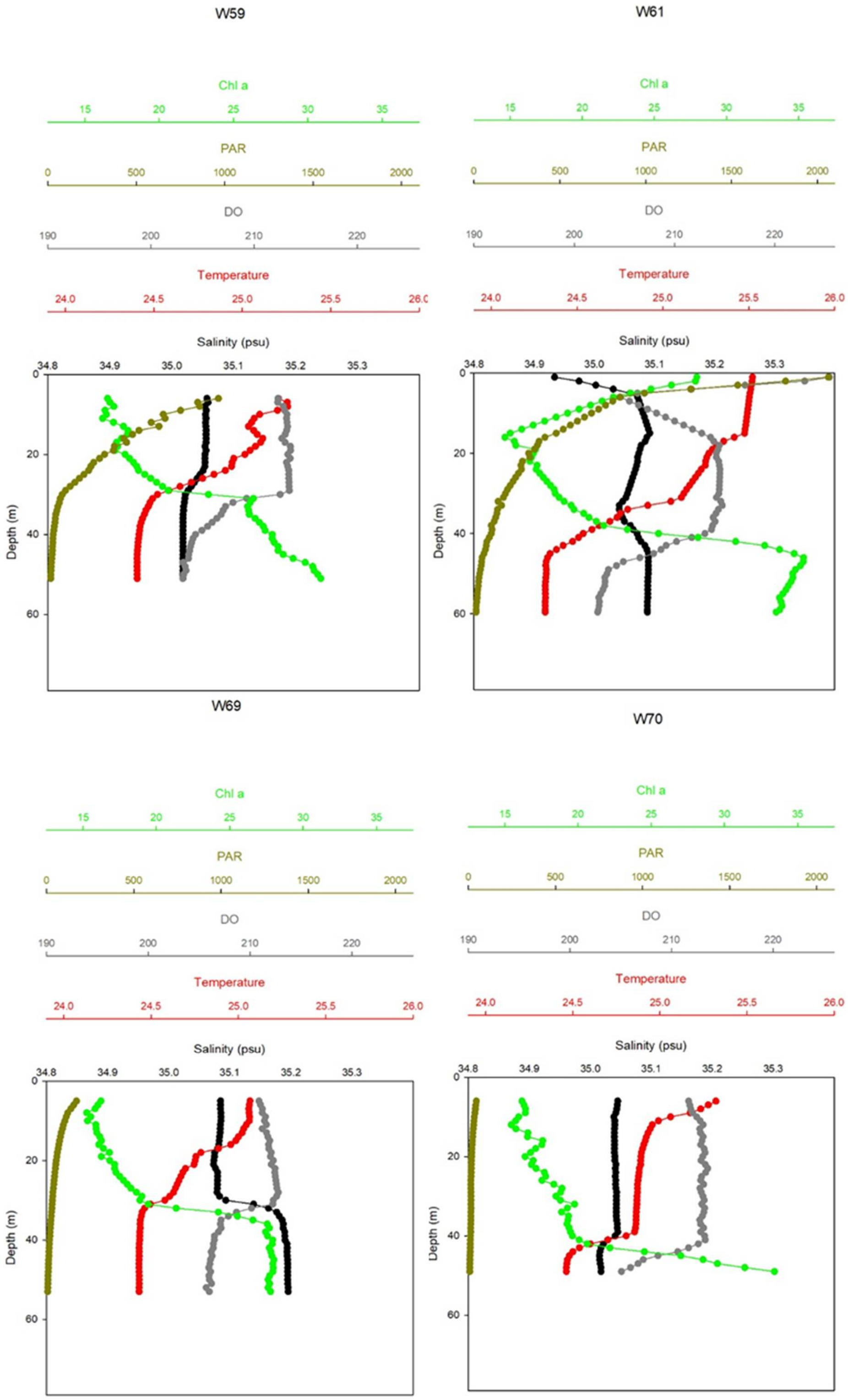


Figure 57. CTD profiles of water column parameters from sites W59, W61, W69 and W70 within PFTF Area 1.

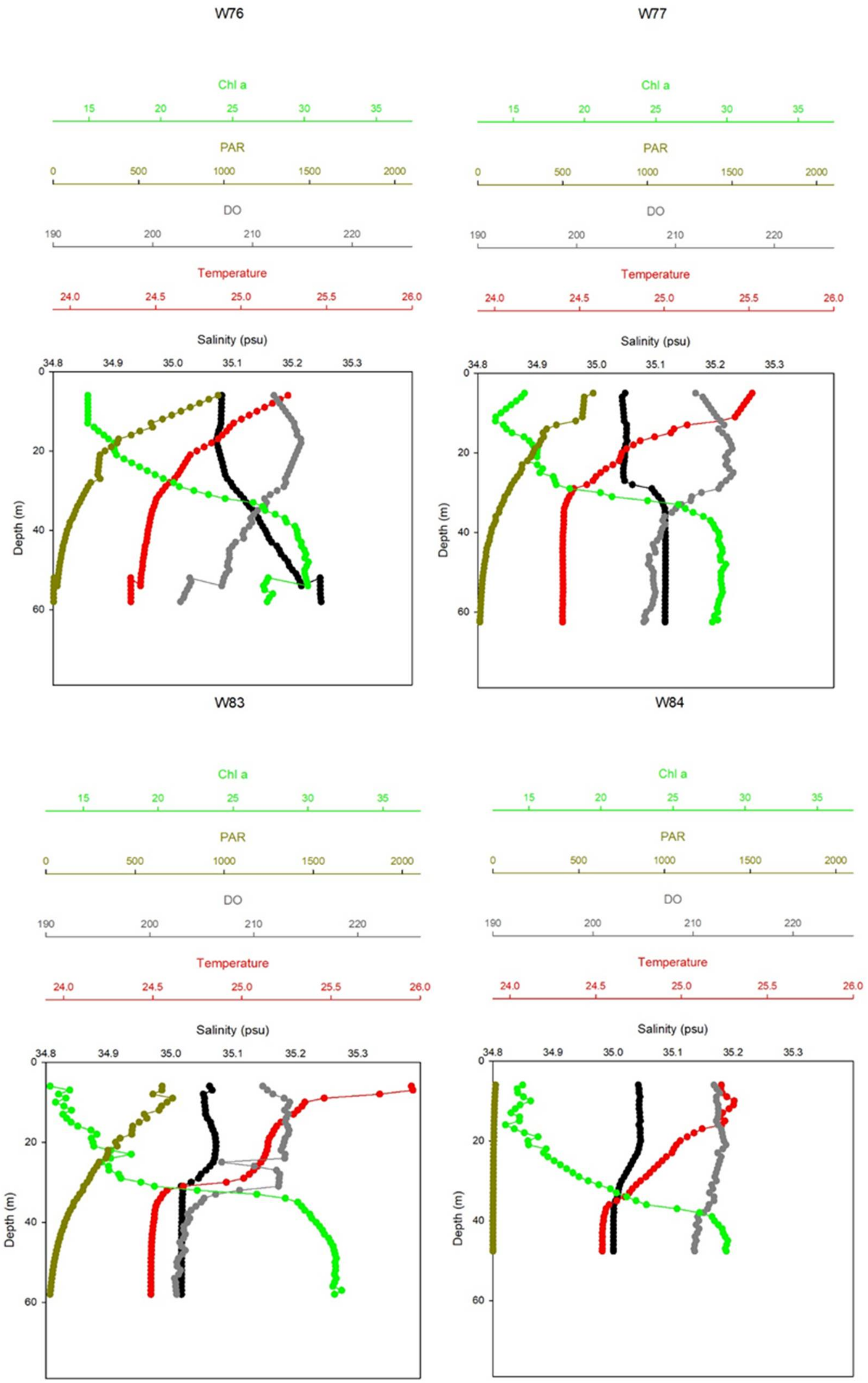


Figure 58. CTD profiles of water column parameters from sites W76, W77, W83 and W84 within PFTF Area 1.

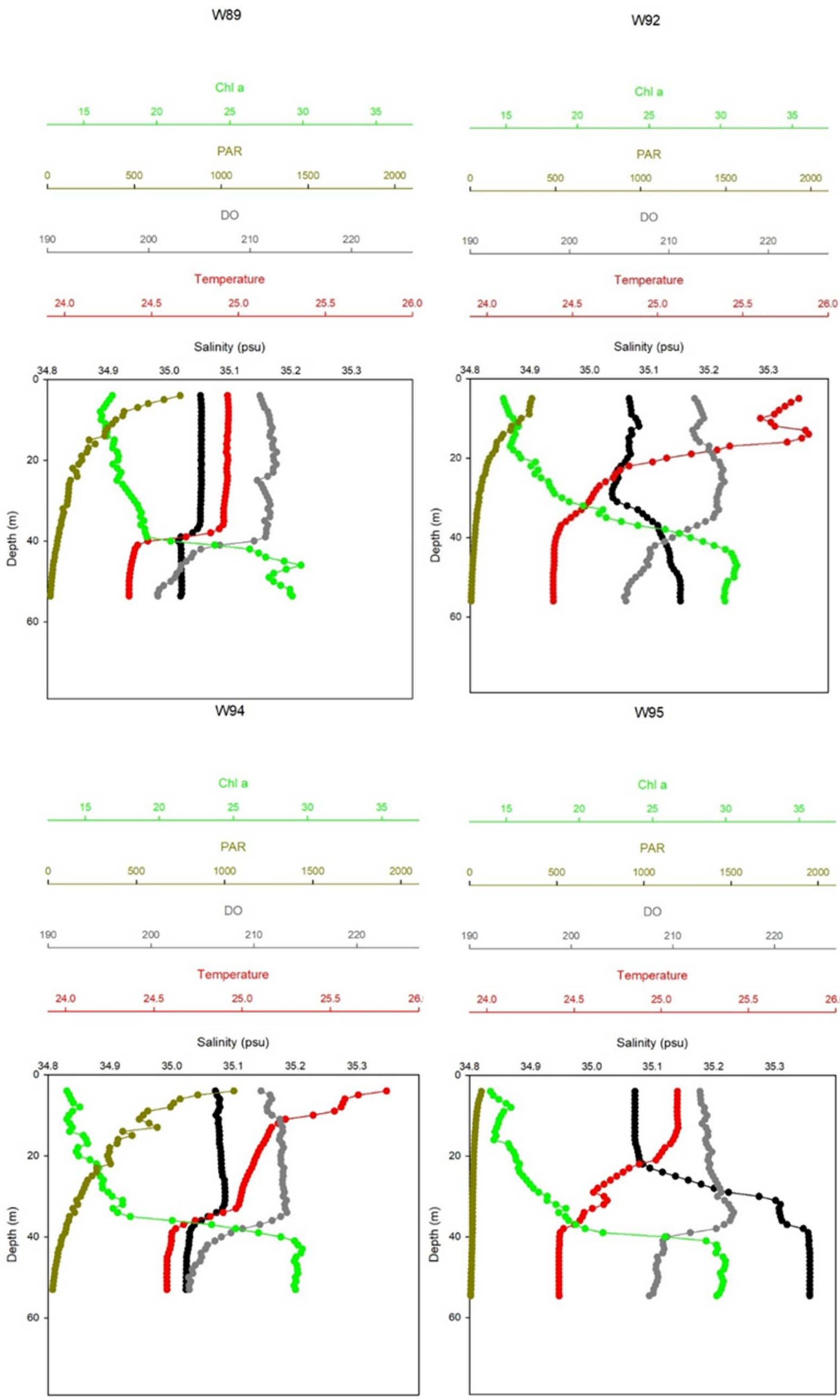


**Figure 59. CTD profiles of water column parameters from sites W89, W92, W94 and W95 within PFTF Area 1.**

Depth-averaged nutrient values were obtained at 19 sites within PFTF Area 1 and one site within PFTF Area 6 (Table 5, Figure 60). This site, site W12, was included in PFTF Area 1 as no other sites within PFTF Area 6 were surveyed. Total chl-*a* ranged from 0.20 to 0.41 mg $m^{-2}$ across sites, with the highest value recorded at sites W38 and W51. Nitrate concentrations ranged from 0.026 mmol $m^{-2}$ (site W44) to 1.462 mmol $m^{-2}$ (site W12 within PFTF Area 6). This value was far higher than all other sites, with the next highest value of 0.911 mmol $m^{-2}$ obtained at site W37. Mean ammonia ranged from 0.013–0.130 mmol $m^{-2}$ (sites W59 and W58, respectively) while silica was relatively consistent across sites, ranging from 3.821 (site W28) to 4.848 mmol $^{-2}$ (site W70). Phosphate concentrations ranged from 0.120 mmol $m^{-2}$ at site W84, to 0.167 mmol $m^{-2}$ at site W39. Site W12, within PFTF Area 6, recorded a slightly higher $PO_4$ value than sites within PTFT Area 1 of 203 mmol $m^{-2}$.

**Table 5. Nutrients (depth averaged values) for sites surveyed within PTFT Area 1. * denotes site within PFTF Area 6. Nd denotes no data.**

| Site | Mean total chl-*a* (mg $m^{-2}$) | Mean $NO_x$ (mmol $m^{-2}$) | Mean $NH_4$ (mmol $m^{-2}$) | Mean $PO_4$ (mmol $m^{-2}$) | Mean Si (mmol $m^{-2}$) |
|---|---|---|---|---|---|
| W12* | 0.23 | 1.462 | nd | 0.203 | 4.753 |
| W28 | 0.28 | 0.203 | 0.038 | 0.141 | 3.821 |
| W37 | 0.37 | 0.911 | nd | 0.167 | 4.645 |
| W38 | 0.41 | 0.408 | nd | 0.134 | 4.508 |
| W40 | 0.30 | 0.041 | 0.038 | 0.123 | 3.923 |
| W41 | 0.26 | 0.118 | 0.042 | 0.151 | 3.823 |
| W43 | 0.27 | 0.482 | nd | 0.143 | 4.182 |
| W44 | 0.28 | 0.026 | 0.032 | 0.149 | 3.934 |
| W58 | 0.41 | 0.117 | 0.130 | 0.162 | 4.141 |
| W59 | 0.28 | 0.138 | 0.013 | 0.137 | 4.325 |
| W61 | 0.32 | 0.312 | 0.019 | 0.137 | 4.065 |
| W69 | 0.25 | 0.080 | 0.058 | 0.151 | 3.934 |
| W70 | 0.29 | 0.156 | 0.019 | 0.143 | 4.848 |
| W76 | 0.29 | 0.097 | 0.056 | 0.134 | 3.932 |
| W77 | 0.26 | 0.063 | 0.115 | 0.151 | 4.081 |
| W83 | 0.31 | 0.177 | 0.021 | 0.129 | 4.759 |
| W84 | 0.20 | 0.030 | 0.011 | 0.120 | 4.175 |
| W89 | 0.29 | 0.281 | 0.031 | 0.150 | 4.478 |
| W92 | 0.23 | 0.125 | 0.038 | 0.127 | 3.896 |
| W94 | 0.22 | 0.148 | 0.052 | 0.127 | 4.829 |
| W95 | 0.26 | 0.061 | 0.053 | 0.121 | 3.969 |

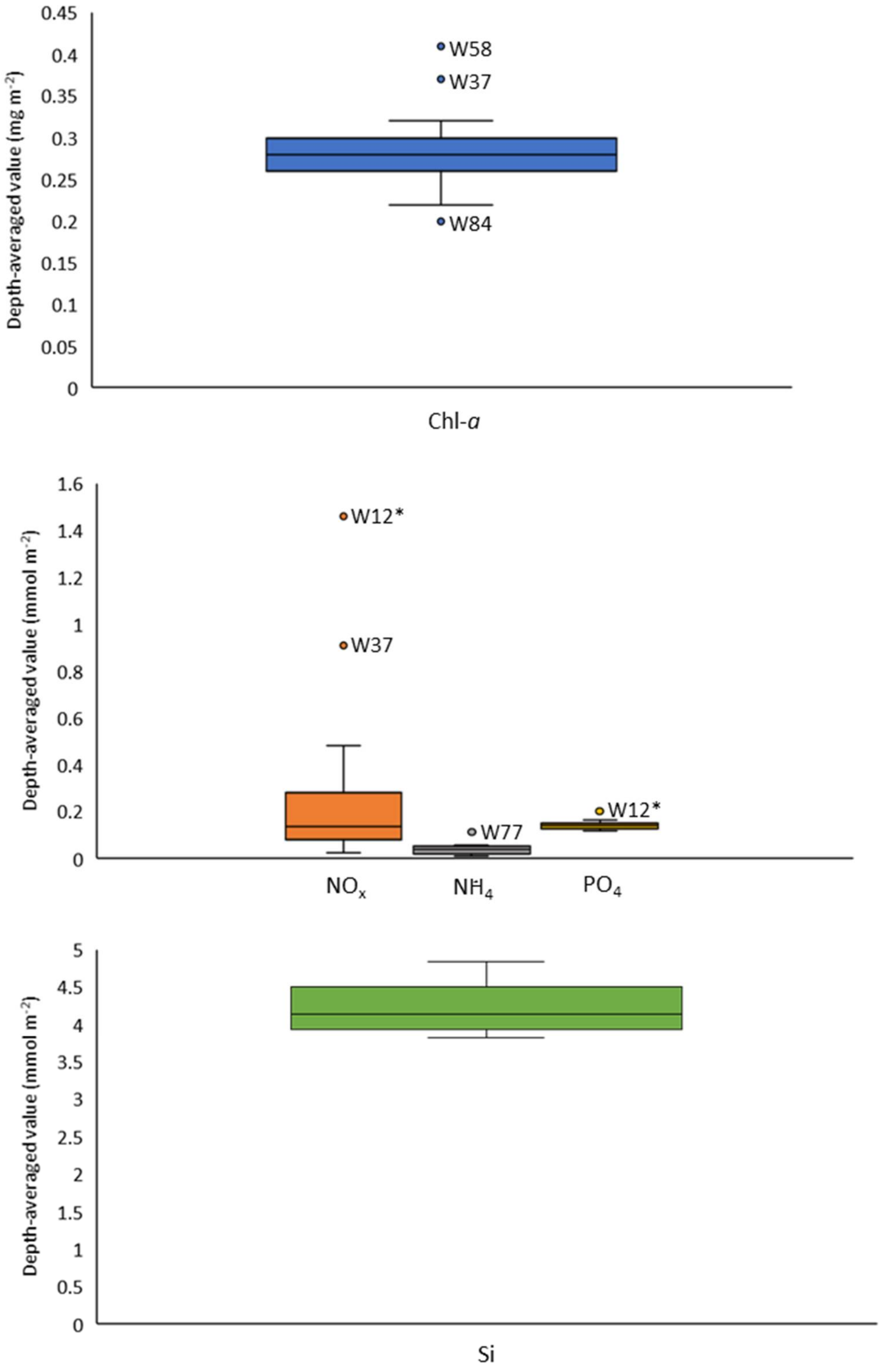


**Figure 60. Depth-averaged nutrient values for sites surveyed within PFTF Area 1 and W12 which fell within PFTF Area 6. Box plots show the median, 25th and 75th percentiles and outliers falling outside the 10th and 90th percentiles. * denotes site within PFTF Area 6.**

### 2.6.2 Sub bottom profiling INV2017_05 sites

Sub-bottom profiling of sites within PFTF Area 1 showed predominantly hard bottom or thin sediment over rock (Figure 61). Sites W58 and W89 were characterised by thick sediment over rock, while sites W37 and W94 showed a combination of thin sediment and hard bottom. Site W41 was a mixture of thin sediment and hard bottom with areas of rocky outcrop, while site W75 was a combination of hard bottom and thick sediment. Site W12, within PTFT Area 6, was characterised by a mix of thin and thick sediments over rock and hard bottom.

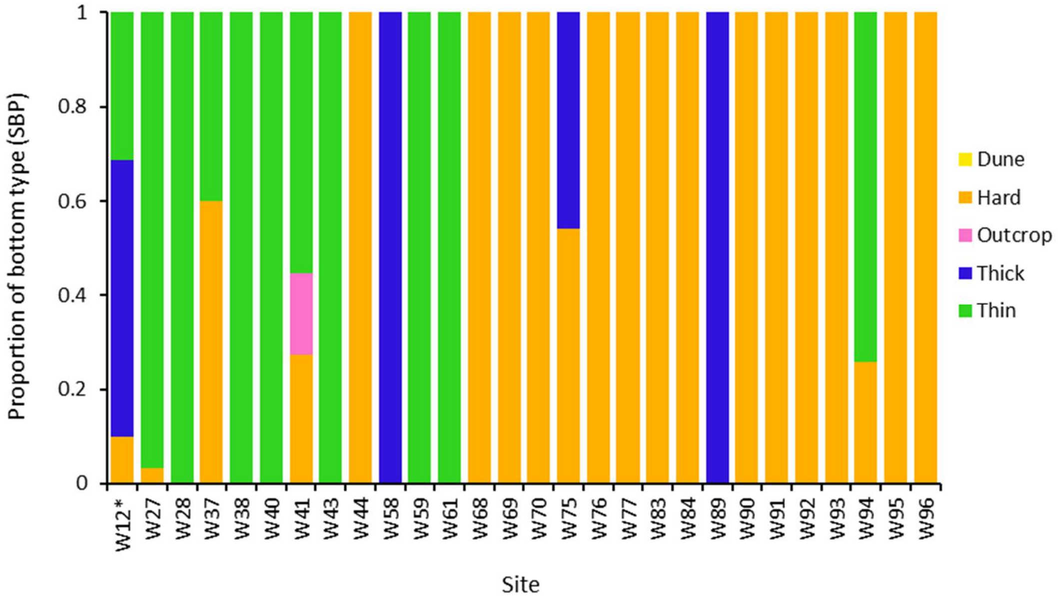


**Figure 61. Proportion of bottom types determined using SBP for INV2017_05 sites within PFTF Area 1. * denotes site within PFTF Area 6.**

### 2.6.3 Substrate and topography

#### INV2017_05 survey sites

Substrate type was dominated by fine sand across all sites within the PFTF Area 1 (Figure 62, top). Site W76 showed the greatest proportion of coarse sand across all sites, making up approximately 25% of substrate composition. Shepard's plots of sediment classification confirmed substrate as predominantly sand (Figure 63). Substrate identified from images as fine sand at site W12, located farther north within PFTF Area 6 and slightly deeper, was classified by Shepard's plots as silty sand (Figure 64). Bottom topographic composition was dominated by flat bottom, while areas of fine ripples were also identified across some sites, most notably at site W41 (Figure 62, bottom). Site W12 was the only site where bioturbations were observed.

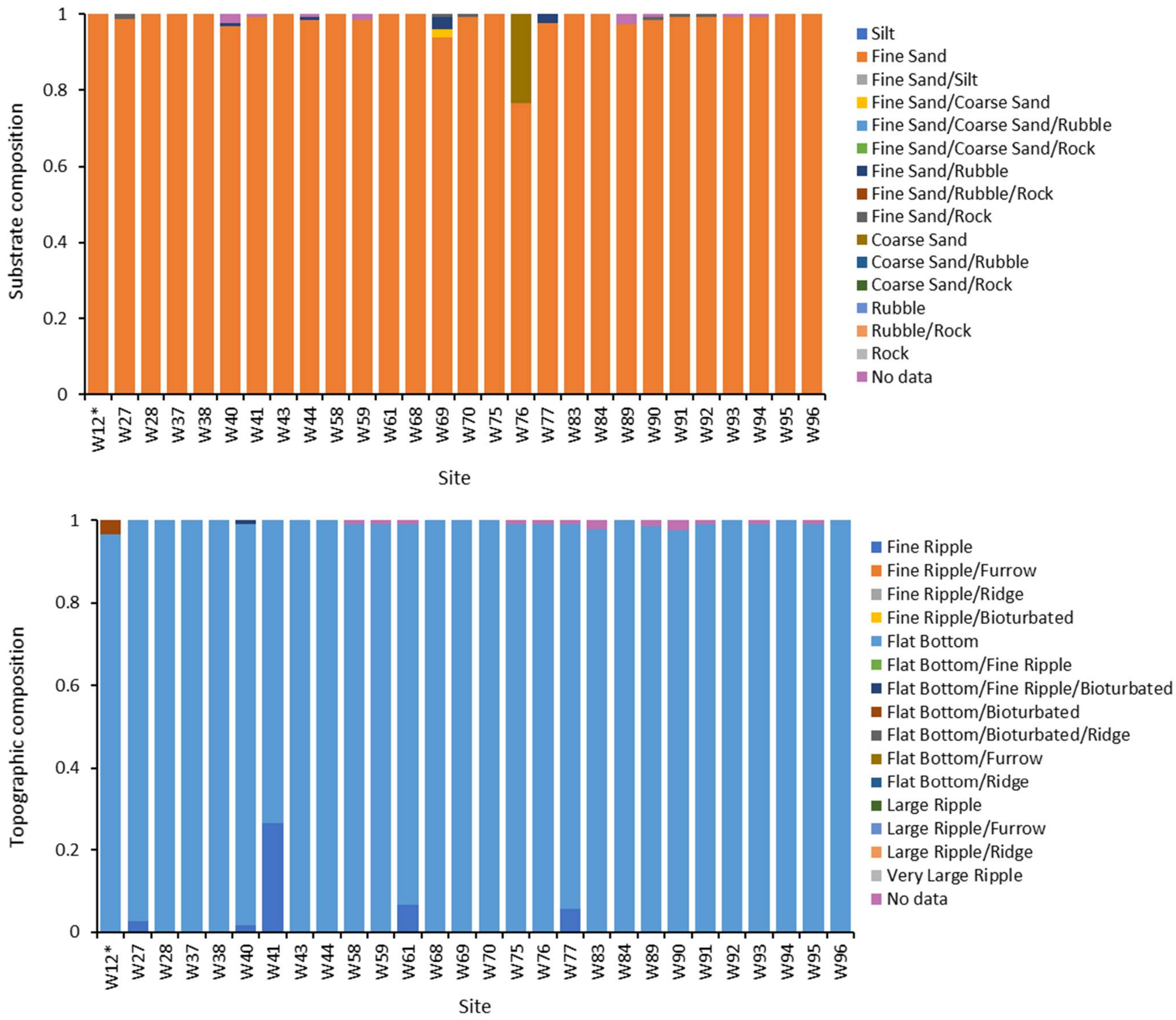


**Figure 62. Proportion of substrate (top) and topography (bottom) types in seabed images along trawl lines for INV2017_05 survey sites within PFTF Area 1. * denotes site within PFTF Area 6.**

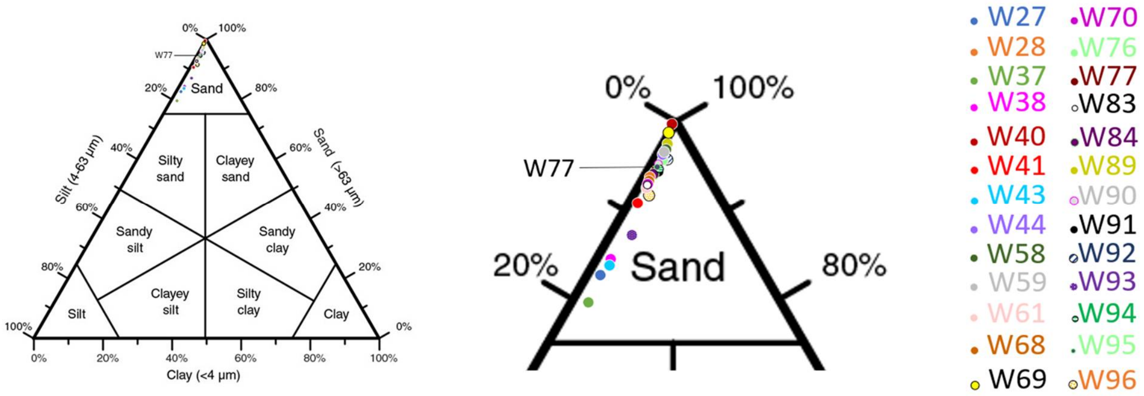


**Figure 63. Shepard's plot of sediment classifications for INV2017_05 survey sites within PFTF Area 1 (excluding W12).**

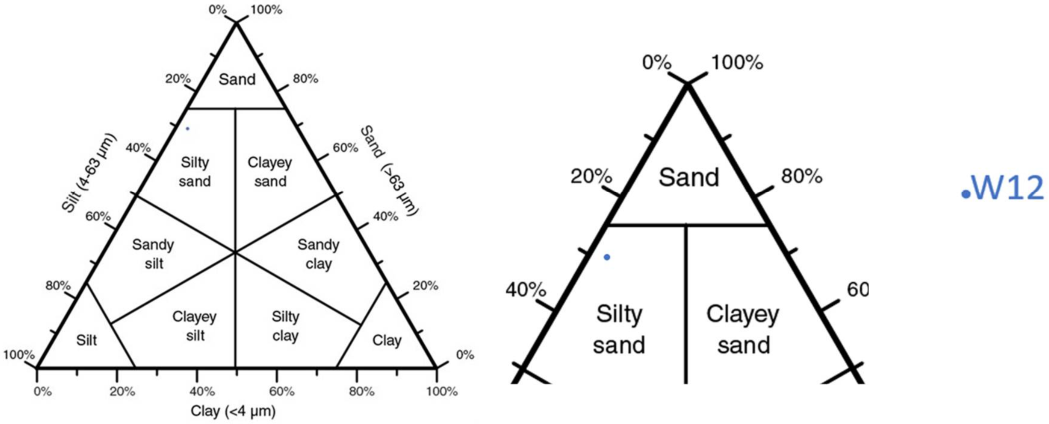


**Figure 64. Shepard's plot of sediment classifications for INV2017_05 survey site W12 within PFTF Area 6.**

## CSIRO 1982–1997 survey sites

Historical surveys showed predominantly fine sandy substrates with some sites having combinations of fine sand, coarse sand and rubble (Figure 65, top). Rubble made up approximately 60% of substrate composition at site 830455. A greater proportion of coarse sand was identified across sites during historical surveys compared to those conducted during INV2017_05 surveys. Flat bottom and fine ripples dominated topographic composition (Figure 65, bottom). Large ripples were identified at eight sites, including sites 900225, 900227 and 950841, while bioturbated areas were also evident at some sites including site 880563.

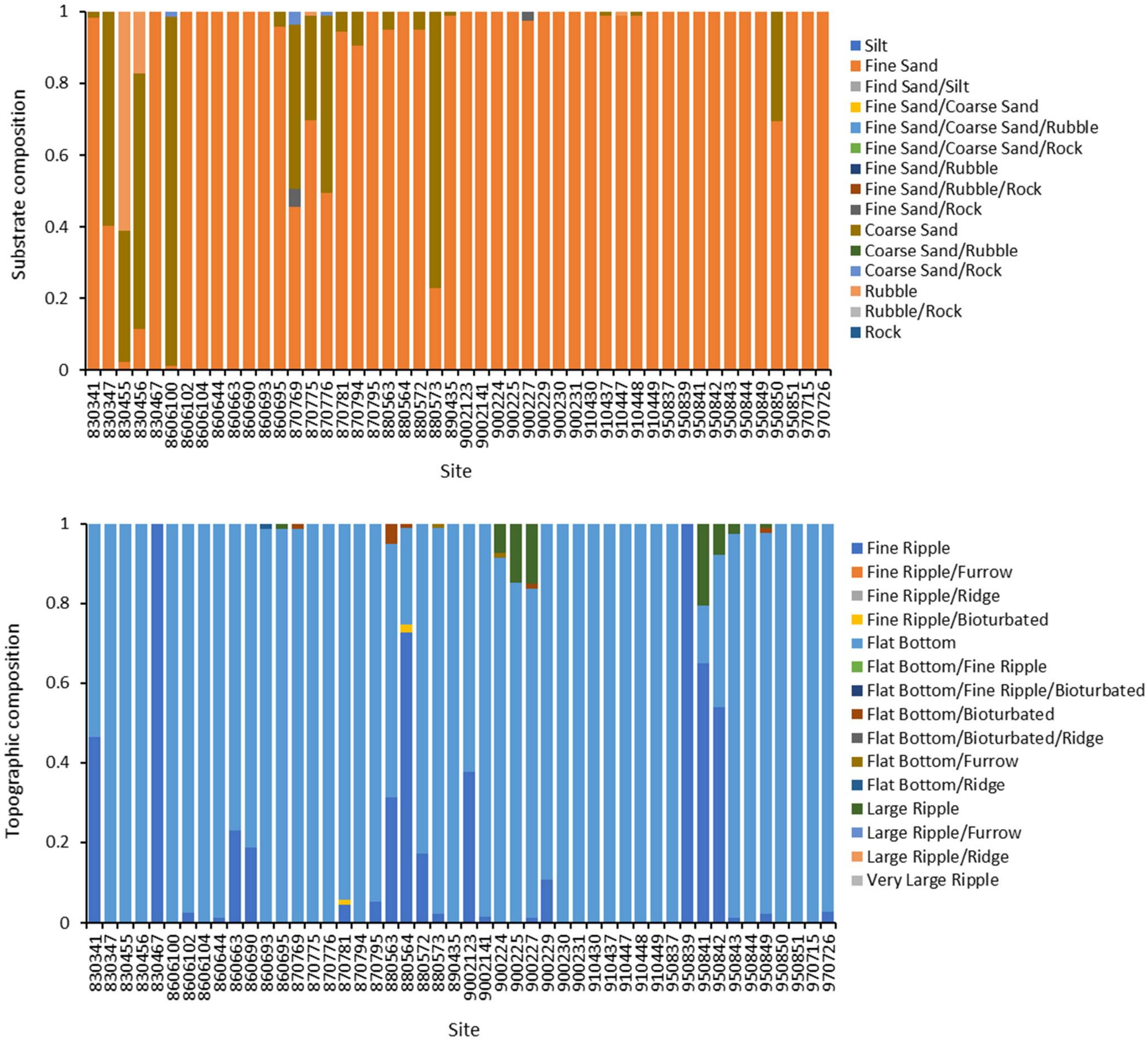


**Figure 65. Proportion of substrate (top) and topography (bottom) types in seabed images along trawl lines for historical CSIRO 1982–1997 survey sites within PFTF Area 1.**

### 2.6.4 Benthic biota

#### INV2017_05 survey sites

Biota varied considerably across sites within PFTF Area 1 (Figure 66, also see representative images in Appx Figure 37–Appx Figure 64. Note: no images available for site W85). Almost half of all sites recorded an absence of biota in more than 50% of images scored. High numbers of crinoids were evident at sites W28, W41, W59, W75, W89 and W94, while sponges were greatest at sites W70 and W90. Hydroids and whips were also abundant across sites and most notable at sites W76 and W84, and W93 and W96 respectively. Site W12, located within PFTF Area 6, showed very little benthic biota, with over 80% of images absent of biota.

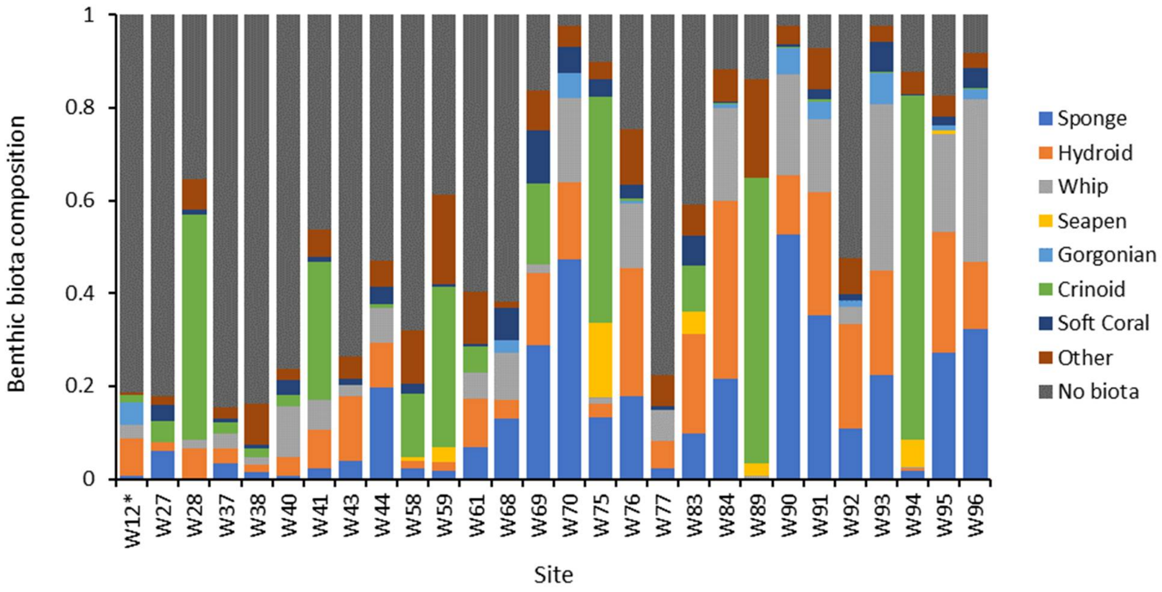


Figure 66. Proportion of biota types in seabed images along trawl lines for INV2017_05 survey sites within PFTF Area 1. * denotes site within PFTF Area 6. 'Other' includes both filter feeders which could not be accurately allocated to a specific group because of image quality and other benthic organisms not otherwise listed.

## CSIRO 1982–1997 survey sites

As with INV2017_05 surveys, biota type varied considerably across sites within PFTF Area 1 (Figure 67). Sponges, whips, seapens and ‘other’ benthic biota including hydroids were the dominant biota types identified. Few soft corals and gorgonians were present. Approximately one third of sites had an absence of biota greater than 50%. While crinoids were less abundant during historical surveys (greatest contribution to biota composition at site 950839), a far greater proportion of seapens was identified across sites during historical surveys than in INV2017_05 surveys. ‘Other’ biota also comprised a larger proportion of benthic biota composition during historical surveys. Sponges were most dominant at site 830347.

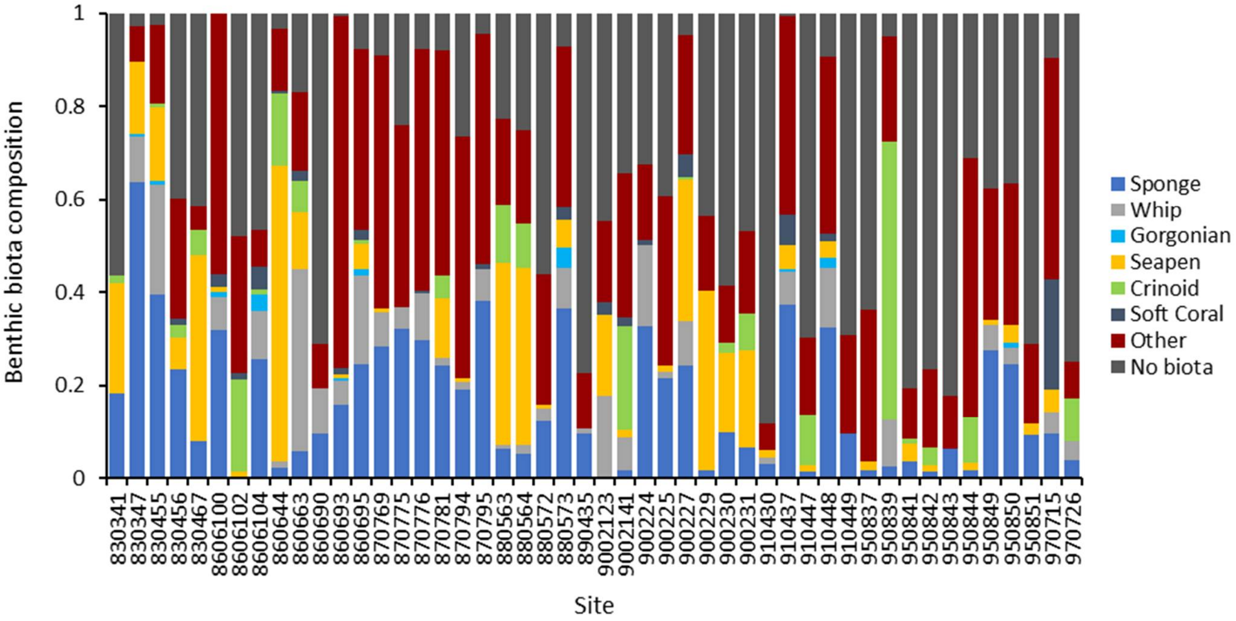
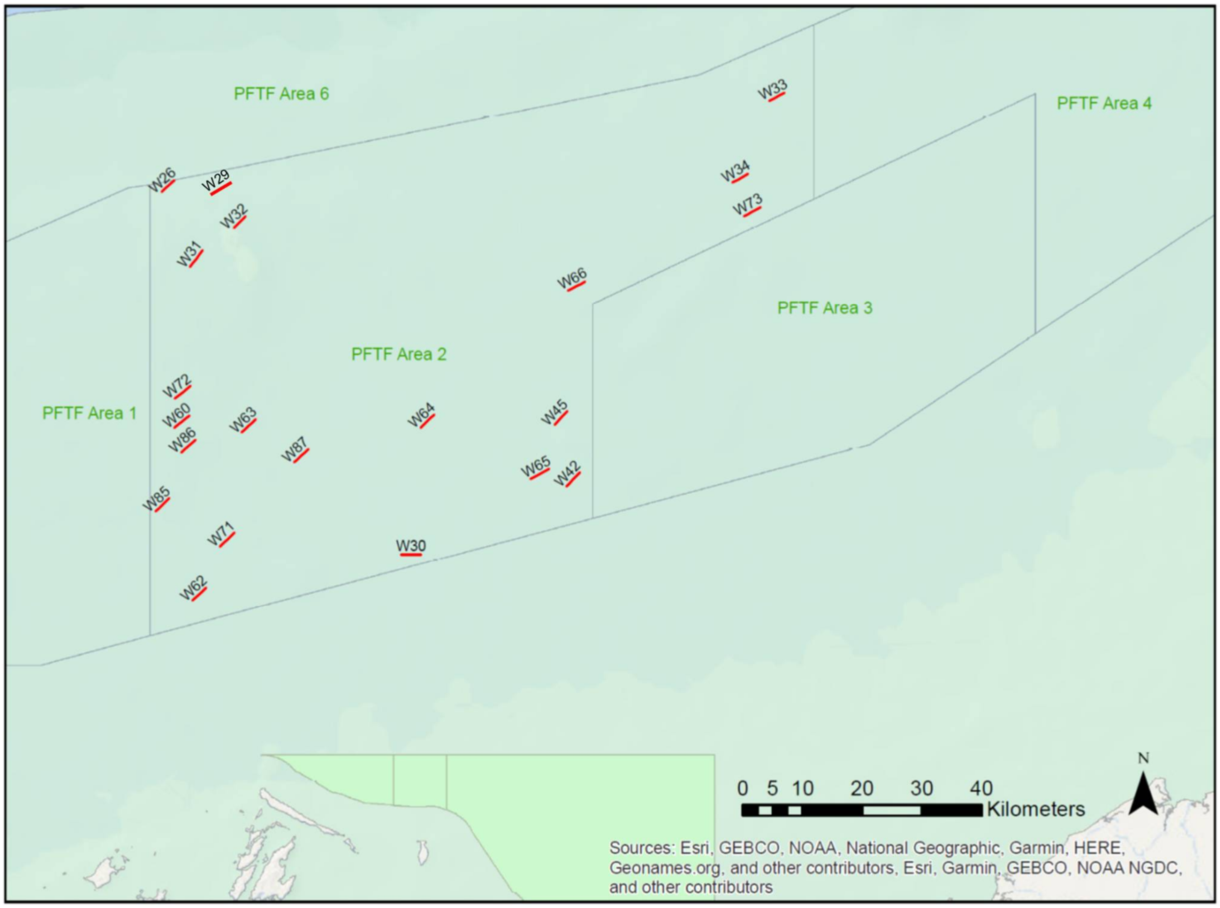


**Figure 67. Proportion of biota types in seabed images along trawl lines for historical CSIRO 1982–1997 survey sites within PFTF Area 1. ‘Other’ includes hydroids, filter feeders which could not be accurately allocated to a specific group because of image quality and other benthic organisms not otherwise listed.**

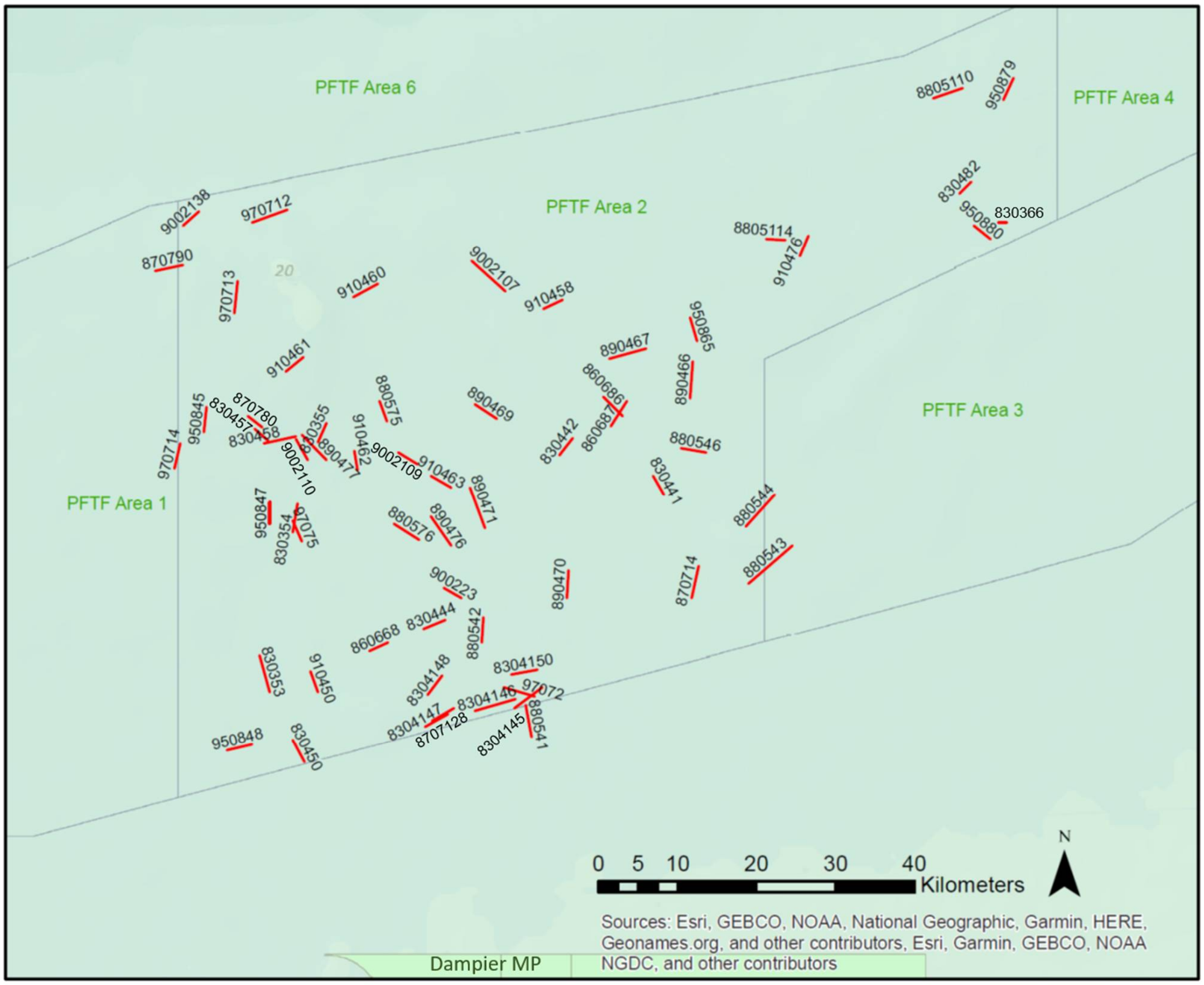
## 2.7 Results from sites in Pilbara Fish Trawl Fishery Area 2

During the INV2017_05 voyage, 22 sites were surveyed within PFTF Area 2 (Figure 68). The location of historical trawls conducted within this area between 1982–1997 for which habitat data were collected are shown in Figure 69.



Sources: Esri, GEBCO, NOAA, National Geographic, Garmin, HERE, Geonames.org, and other contributors, Esri, Garmin, GEBCO, NOAA NGDC, and other contributors

**Figure 68. Location of INV2017_05 sites within PFTF Area 2. Table showing start/end latitude and longitude for each trawl transect is given in Appendix D.**



Sources: Esri, GEBCO, NOAA, National Geographic, Garmin, HERE, Geonames.org, and other contributors, Esri, Garmin, GEBCO, NOAA NGDC, and other contributors

**Figure 69. Location of historical CSIRO 1987–1997 trawls for which habitat data were collected within PFTF Area 2. Table showing start/end latitude and longitude for each trawl transect is given in Appendix E. Trawl number = year, voyage and site number (e.g. 970758 was site 58 on the seventh voyage in 1997).**

### 2.7.1 Water column analyses

CTD profiles were obtained for 13 sites within PFTF Area 2 (Figure 70–Figure 73). Again, salinity varied little across sites within PFTF Area 2 (< 1 psu), ranging from 34.8–35.5 psu. Salinity remained relatively constant for many sites with all sites showing an increase in salinity with depth. This increase was slight at most sites, except sites W62 and W63 which recorded the largest salinity variation, increasing 0.3 psu throughout the water column. Slight haloclines were recorded at sites W62 and W85 corresponding with depths of around 40 m. Layers of stratification were seen at some sites, again around 40 m depth. Site W29 and W33 showed this deeper at around 60 m while at site W72 this was closer to 20 m depth. Interestingly, site W87 showed stratification at two depths, evident at 20 m and 50 m.

Temperature ranged from 23.7–26.0°C across sites. Thermoclines were recorded at three sites (W29, W60 and W85). These were characterised at sites W60 and W85 by a decrease in temperature of 0.5–1°C at 20 m depth, while site W29 was much deeper, highlighted by a 1°C change at 60 m. Of note, temperature at site W26 remained steady throughout the water column before decreasing roughly 2°C between 40–70 m depth. Site W80 also showed a substantial decline of 1°C at a much shallower depth, between 10–20m. Again, temperature reductions and subsequent formations of thermoclines generally coincided with an increase in chl-*a*. This was not the case for sites W60 and W80 where temperature decreases were at shallower depths than chl-*a* increases.

Dissolved oxygen ranged from 185–217 mg/L with decreases in DO levels recorded at around 40 m for most sites. Sites W29 and W63 were the exception, with decreases in DO levels commencing a little deeper, at 60 m and 50 m, respectively. Most sites showed a subsurface maximum, generally at around 40 m, before progressively decreasing with depth. Sites W65 and W87 exhibited a more constant DO profile throughout the water column.

PAR profiles obtained within PFTF Area 2 generally showed a progressive diminishing with depth, with a steady decline recorded at most sites. Sites W29 and W60 recorded near zero PAR profiles with PAR dropping to zero at about 20 m depth, while site W65 was the only site to show a constant PAR of zero across all depths, due to this site being surveyed after 1800 h. PAR was generally reduced to zero at around 40–60 m depth while at four sites this occurred deeper at around 60–80 m.

Chlorophyll-*a* ranged from 10–37 mg.m$^{-2}$ and increased with depth until a maximum between 40–60 m before decreasing with depth. Site W65 was the only site to record a more constant chl-*a* rate within the water column.

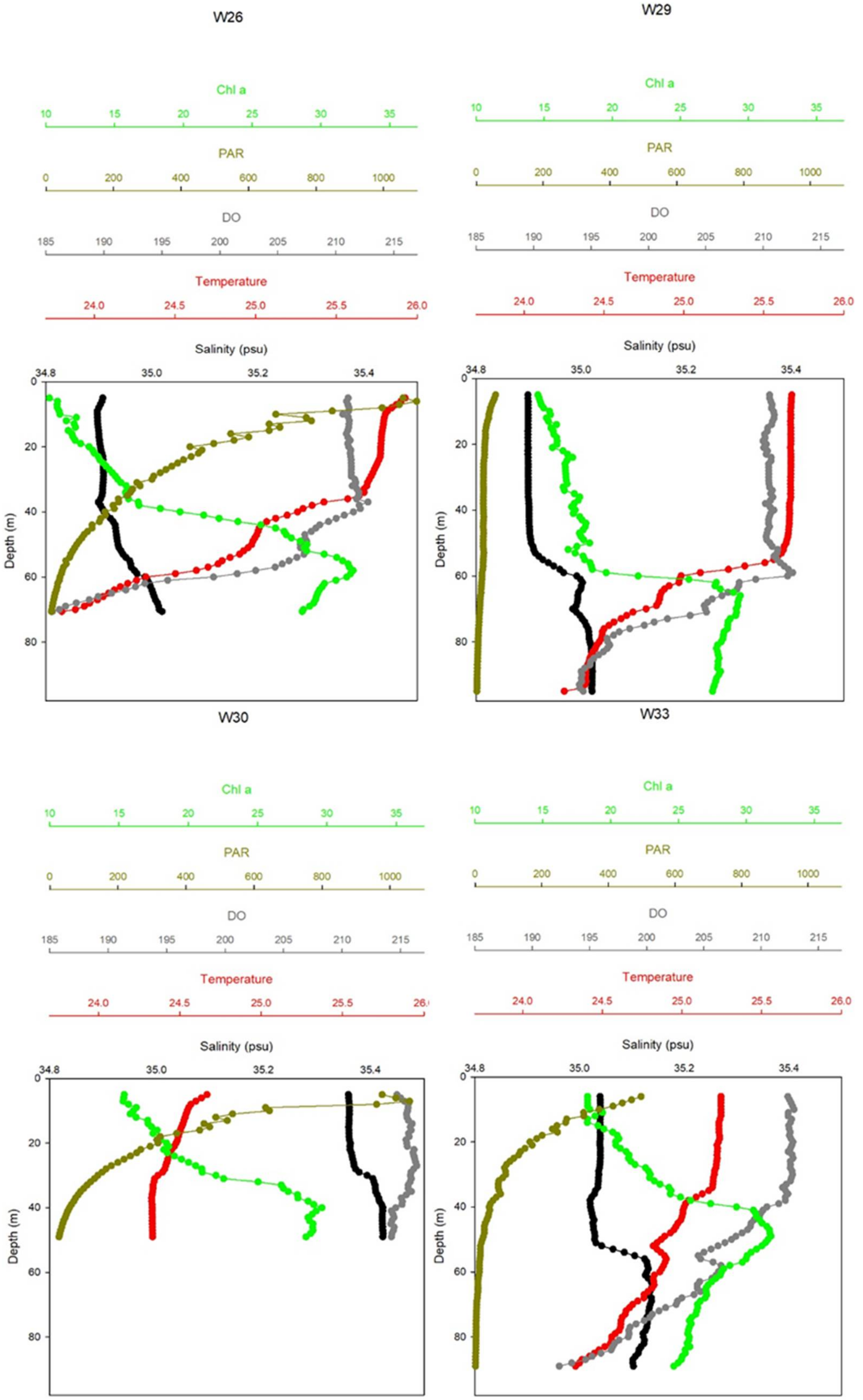


Figure 70. CTD profiles of water column parameters from sites W26, W29, W30 and W33 within PFTF Area 2.

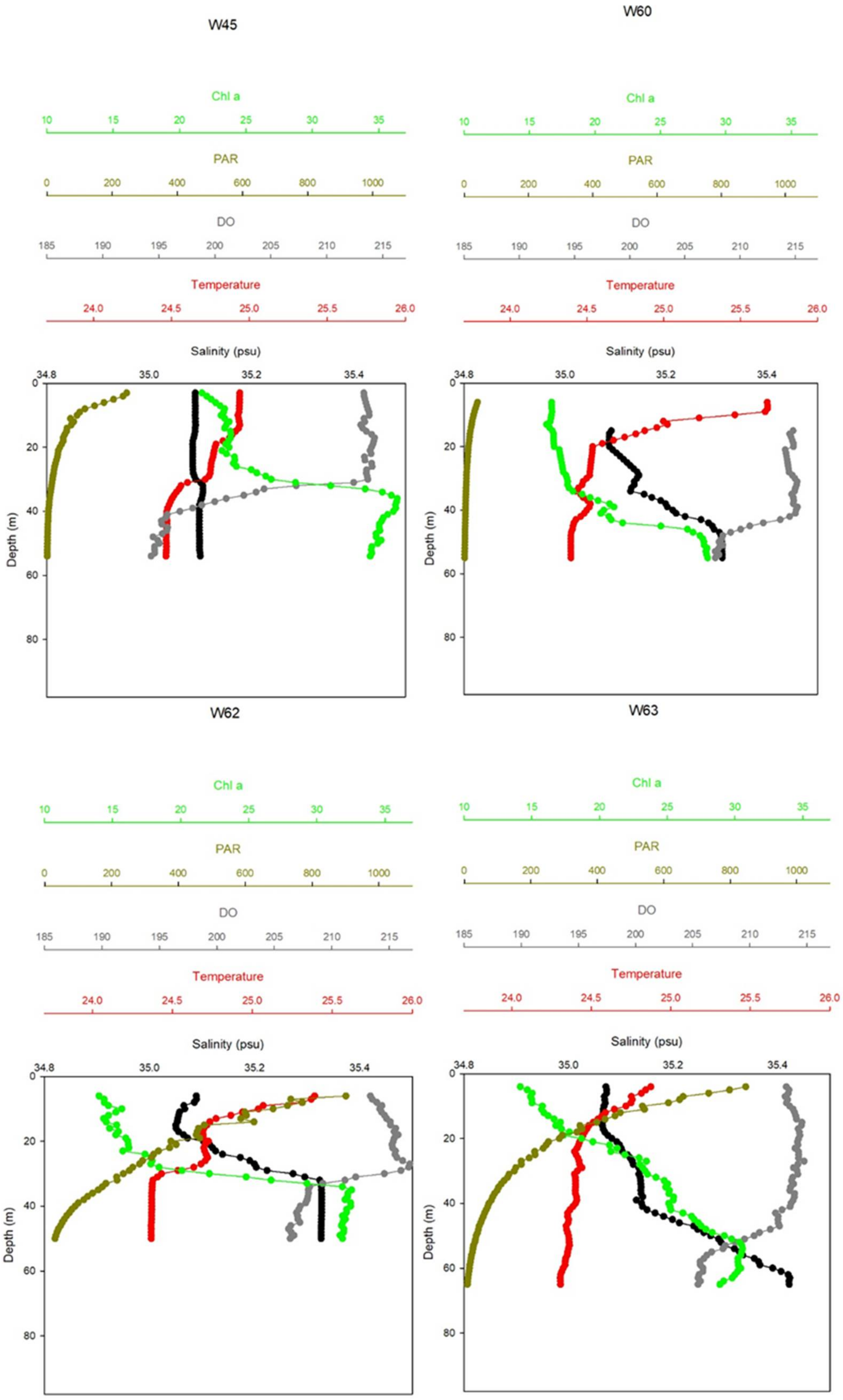


Figure 71. CTD profiles of water column parameters from sites W45, W60, W62 and W63 within PFTF Area 2.

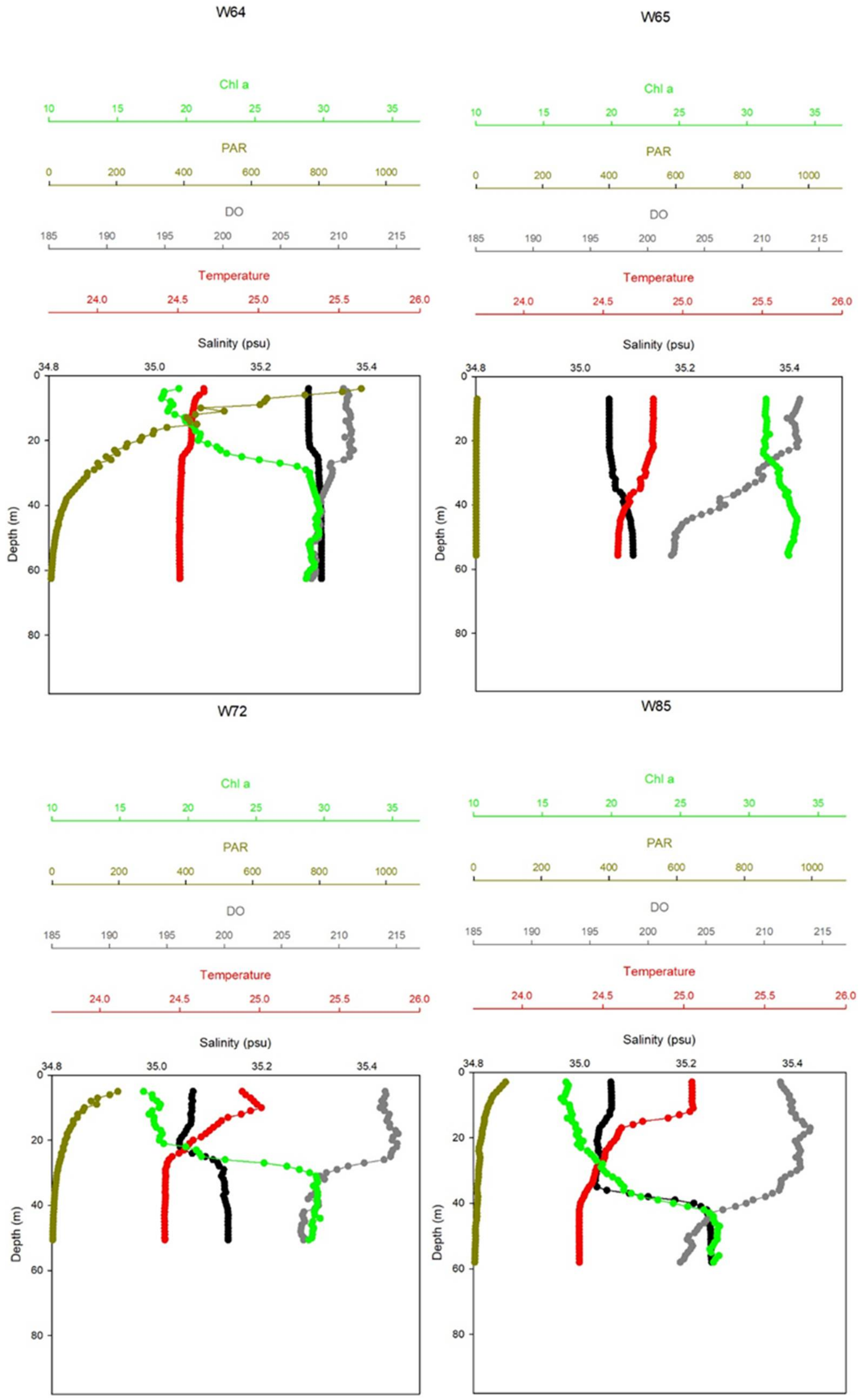


Figure 72. CTD profiles of water column parameters from sites W64, W65, W72 and W85 within PFTF Area 2.

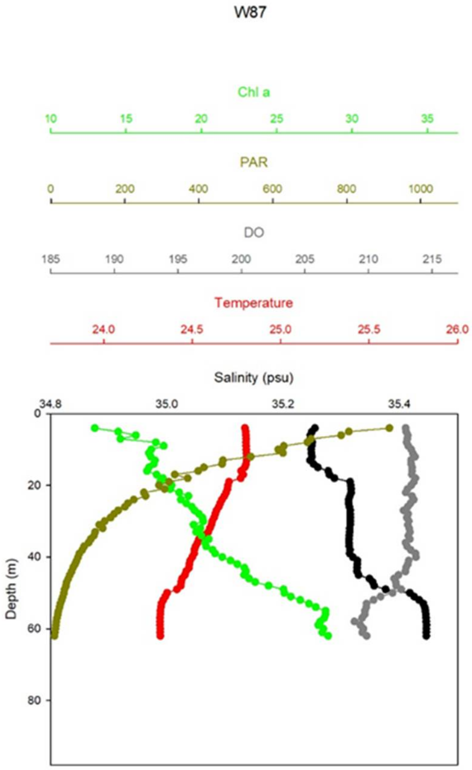


Figure 73. CTD profiles of water column parameters from sites W87 within PFTF Area 2.

Depth-averaged nutrient values were obtained at 13 sites within PFTF Area 2 (Table 6, Figure 74). Total chl-*a* ranged from 0.18 to 0.61 mg $m^{-2}$ across sites, with the highest value recorded at site W65 and lowest at W26. Nitrate concentrations ranged from 0.019 mmol $m^{-2}$ (site W30) to 1.266 mmol $m^{-2}$ (site W26). Mean ammonia ranged from 0.001–0.110 mmol $m^{-2}$ (sites W26 and W87, respectively) while silica ranged from 3.677 (site W30) to 4.864 mmol $^{-2}$ (site W26). Phosphate concentrations ranged from 0.116 mmol $m^{-2}$ at site W72, to 0.197 mmol $m^{-2}$ at site W45. Site W26 recorded the highest nutrient values for $NO_x$ and silica and lowest values for total chl-*a* and $NH_4$.

**Table 6. Nutrients (depth averaged values) for sites surveyed within PFTF Area 2. Nd denotes no data.**

| Site | Mean total chl-*a* (mg $m^{-2}$) | Mean $NO_x$ (mmol $m^{-2}$) | Mean $NH_4$ (mmol $m^{-2}$) | Mean $PO_4$ (mmol $m^{-2}$) | Mean Si (mmol $m^{-2}$) |
|---|---|---|---|---|---|
| W26 | 0.18 | 1.266 | 0.001 | 0.186 | 4.864 |
| W29 | 0.23 | 0.626 | 0.007 | 0.147 | 3.874 |
| W30 | 0.29 | 0.019 | 0.034 | 0.145 | 3.677 |
| W33 | 0.31 | 0.798 | 0 | 0.169 | 4.338 |
| W45 | 0.54 | 0.586 | nd | 0.197 | 4.723 |
| W60 | 0.26 | 0.084 | 0.056 | 0.136 | 4.054 |
| W62 | 0.36 | 0.066 | 0.043 | 0.140 | 4.174 |
| W63 | 0.32 | 0.124 | 0.281 | 0.122 | 3.865 |
| W64 | 0.36 | 0.076 | 0.022 | 0.172 | 4.677 |
| W65 | 0.61 | 0.275 | 0.005 | 0.155 | 4.053 |
| W72 | 0.28 | 0.116 | 0.075 | 0.116 | 3.925 |
| W85 | 0.23 | 0.132 | 0.101 | 0.140 | 3.991 |
| W87 | 0.31 | 0.054 | 0.110 | 0.138 | 4.104 |

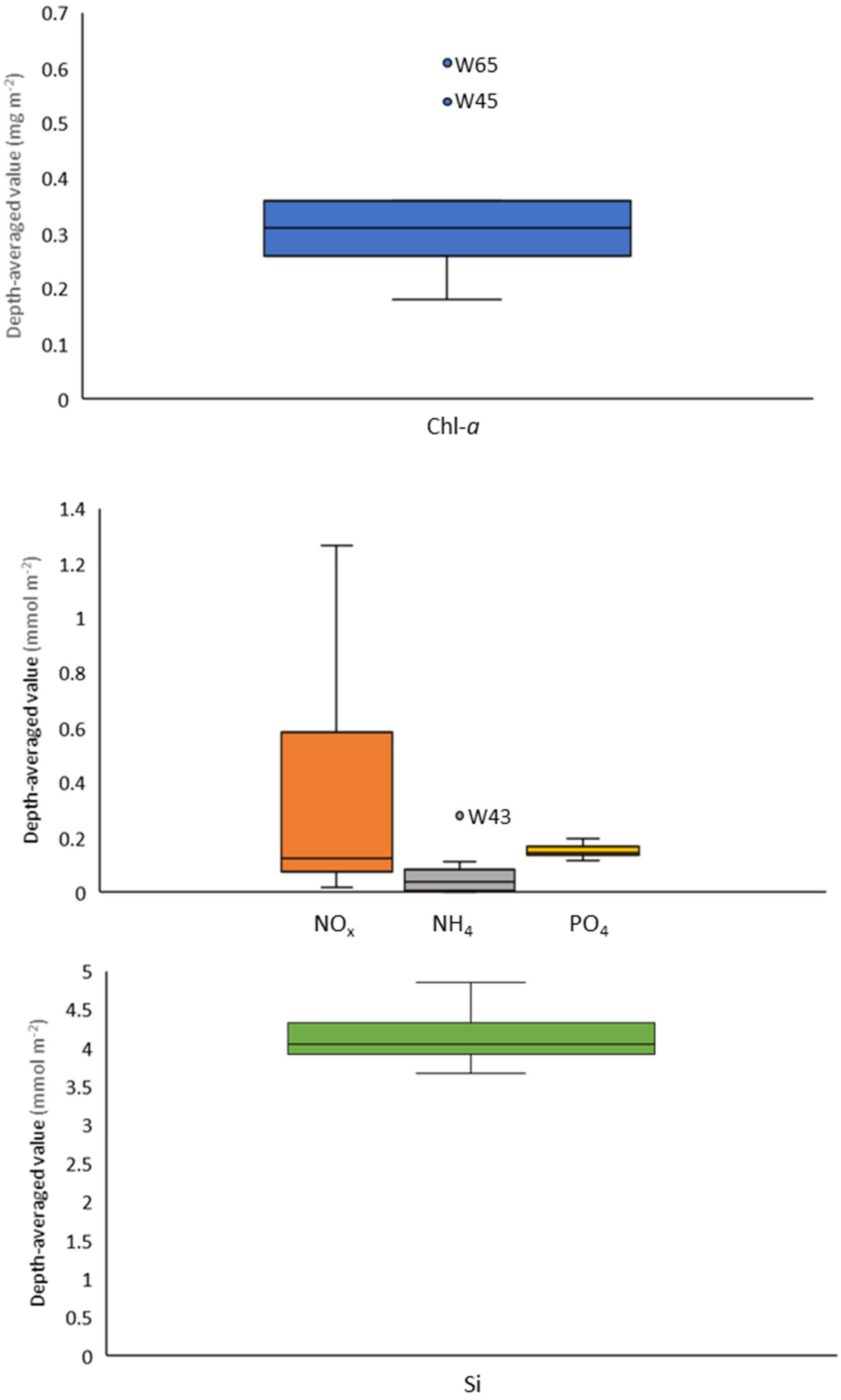


**Figure 74. Depth-averaged nutrient values for sites surveyed within PFTF Area 2. Box plots show the median, 25th and 75th percentiles and outliers falling outside the 10th and 90th percentiles.**

### 2.7.2 Sub-bottom profiling – INV2017_05

Sub-bottom profiling of sites within PFTF Area 2 varied across sites (Figure 75). Most sites were classified as either hard bottom or thin sediment over rock, or a combination of hard bottom and thick (site W26) or thin sediment (W30, W42 W63 and W65). Site W64 was classified as thick sediment over rock, while W87 was thin sediment only. Sites W32 and W66 were characterised by a combination of hard bottom and rocky outcrop.

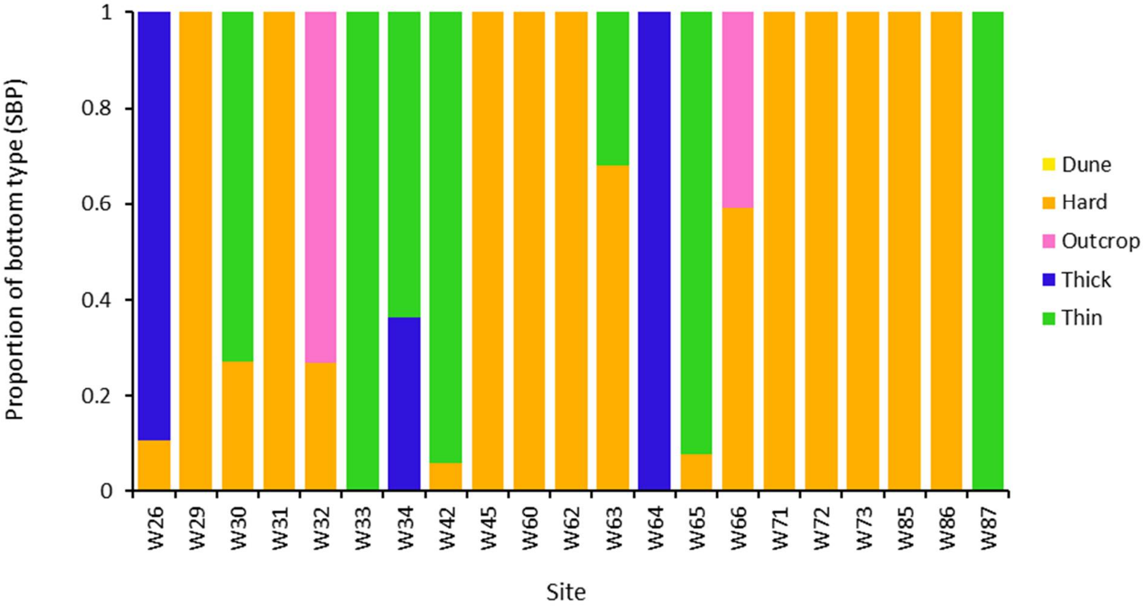


Figure 75. Proportion of bottom types determined using SBP for INV2017_05 sites within PFTF Area 2.

### 2.7.3 Substrate and topography

#### INV2017_05 survey sites

Similar to PTFT Area 1, substrate type in PFTF Area 2 was dominated by fine sand (Figure 76, top). Coarse sand was notably high at site W72. Shepard's plots of sediment classification confirmed sediment type as sand (Figure 77). Topography was predominantly flat bottom across all sites except site W34 which showed a large proportion of fine ripples (Figure 76, bottom). Bioturbations were evident at sites W66 and W73.

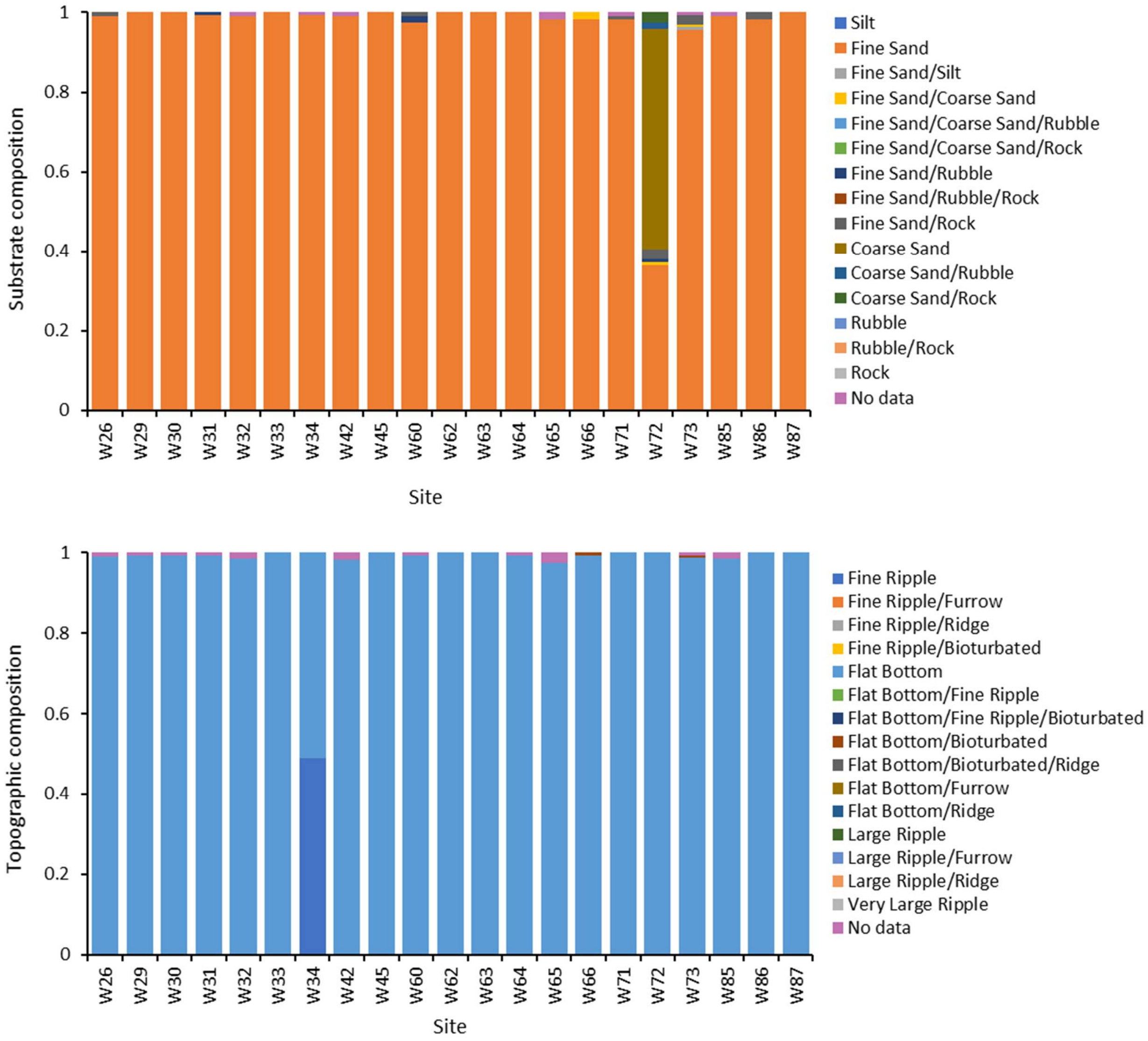


**Figure 76. Proportion of substrate (top) and topography (bottom) types in seabed images along trawl lines for INV2017_05 survey sites within PFTF Area 2.**

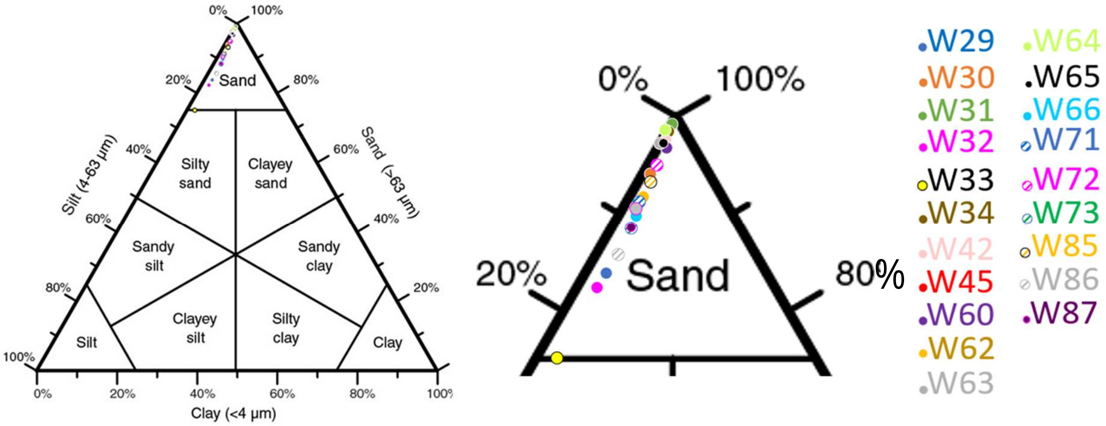


Figure 77. Shepard's plot of sediment classifications for INV2017_05 survey sites within PFTF Area 2.

## CSIRO 1982–1997 survey sites

Fine and coarse sand substrates dominated historical survey sites in PFTF Area 2 (Figure 78, top). Rubble was evident at some sites, notably sites 830458 and 830457, while silty sediment was observed at site 8805110. Flat bottom and fine ripples were the most common topographic types across all sites (Figure 78, bottom). Very large ripples were evident at site 97072, while bioturbations were also identified at some sites including 830442, 830444 and 8805110.

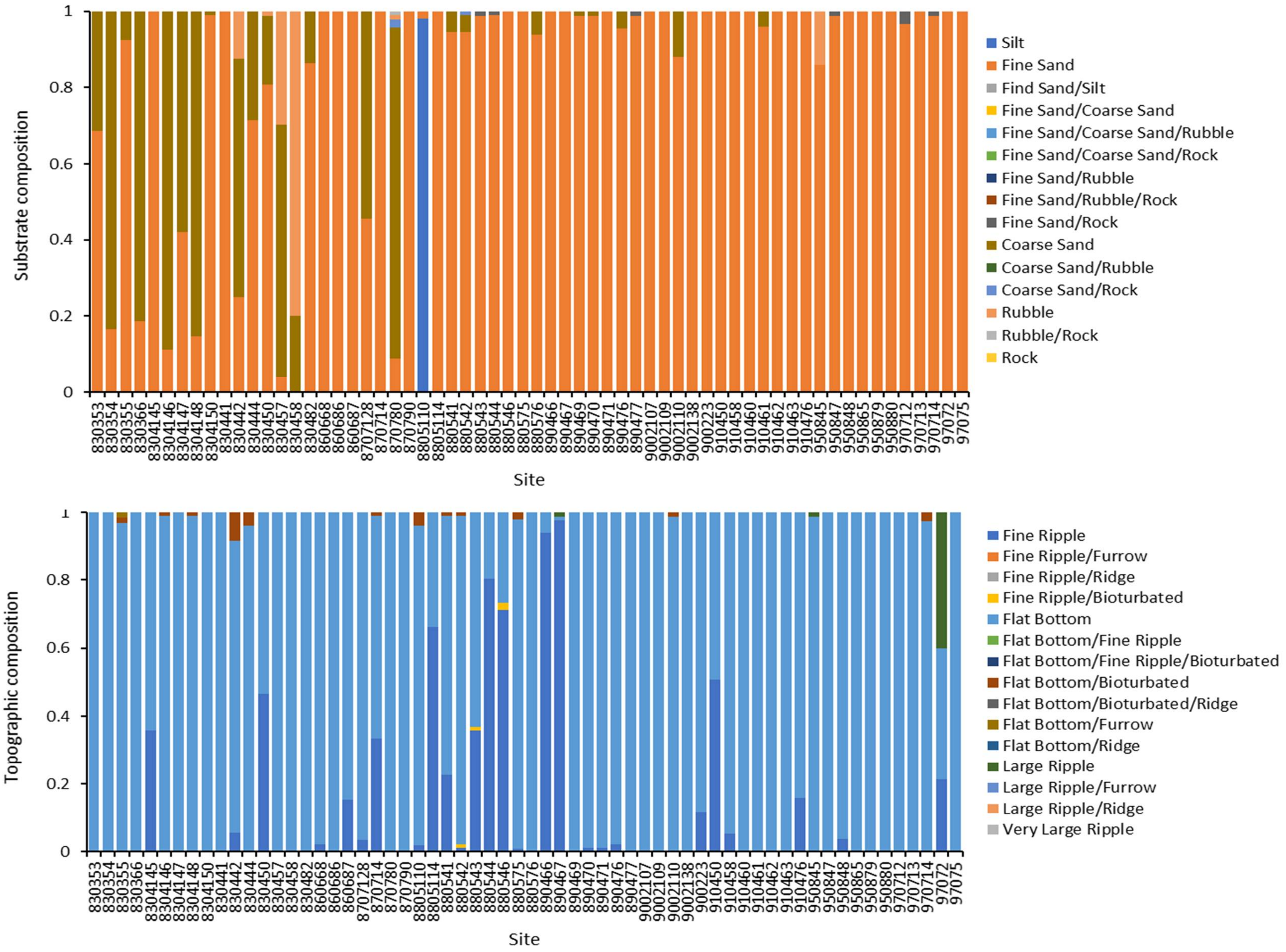


**Figure 78. Proportion of substrate (top) and topography (bottom) types in seabed images along trawl lines for historical CSIRO 1982–1997 survey sites within PFTF Area 2.**

### 2.7.4 Benthic biota

#### INV2017_05 survey sites

Similar to PFTF Area 1, biota abundance and diversity varied between sites within PFTF Area 2 (Figure 79, also see representative images in Appx Figure 65–Appx Figure 84**Error! Reference source not found.**). While site W26 was dominated by gorgonians, crinoids were greatest at sites W30, W42 and W65. Whips were greatest at sites W60, W72 and W85, and sponges were identified mainly at sites W60 and W86. Seapens were evident at eight sites in PFTF Area 2. Ten sites showed a low proportion of benthic biota, notably at sites W33, W34, W64 and W87.

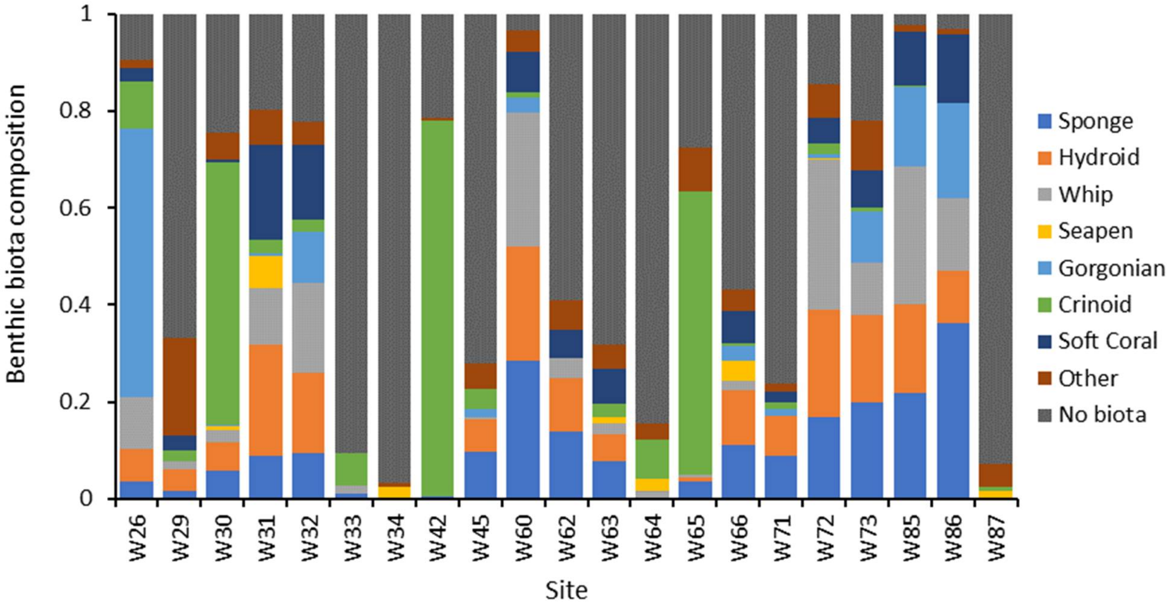


Figure 79. Proportion of biota types in seabed images along trawl lines for INV2017_05 survey sites within PFTF Area 2. 'Other' includes both filter feeders which could not be accurately allocated to a specific group because of image quality and other benthic organisms not otherwise listed.

## CSIRO 1982–1997 survey sites

Biota types were variable across sites in PFTF Area 2 during CSIRO 1982–1997 surveys, with higher proportions of sponges, seapens and ‘other’ biota (including hydroids) present at most sites than during INV2017_05 surveys (Figure 80). Seapens and sponges were present at most sites, with sponges most notable at sites 830355, 830457 and 910461. Sites 830355, 950845, 870780, 830457 and 910461 showed the greatest proportion of biota in general (98–100%), compared to all other sites. Crinoids were greatest at sites 880544, 970713 and 880546, while the highest proportion of whips was at site 830355. Although diverse and abundant at many sites, benthic biota was identified in less than 50% of images for almost half of all sites (29 of 62 sites). Biota at these sites were very limited, with two of these – sites 97075 and 870790, having biota present in only 5% and 6% of images, respectively.

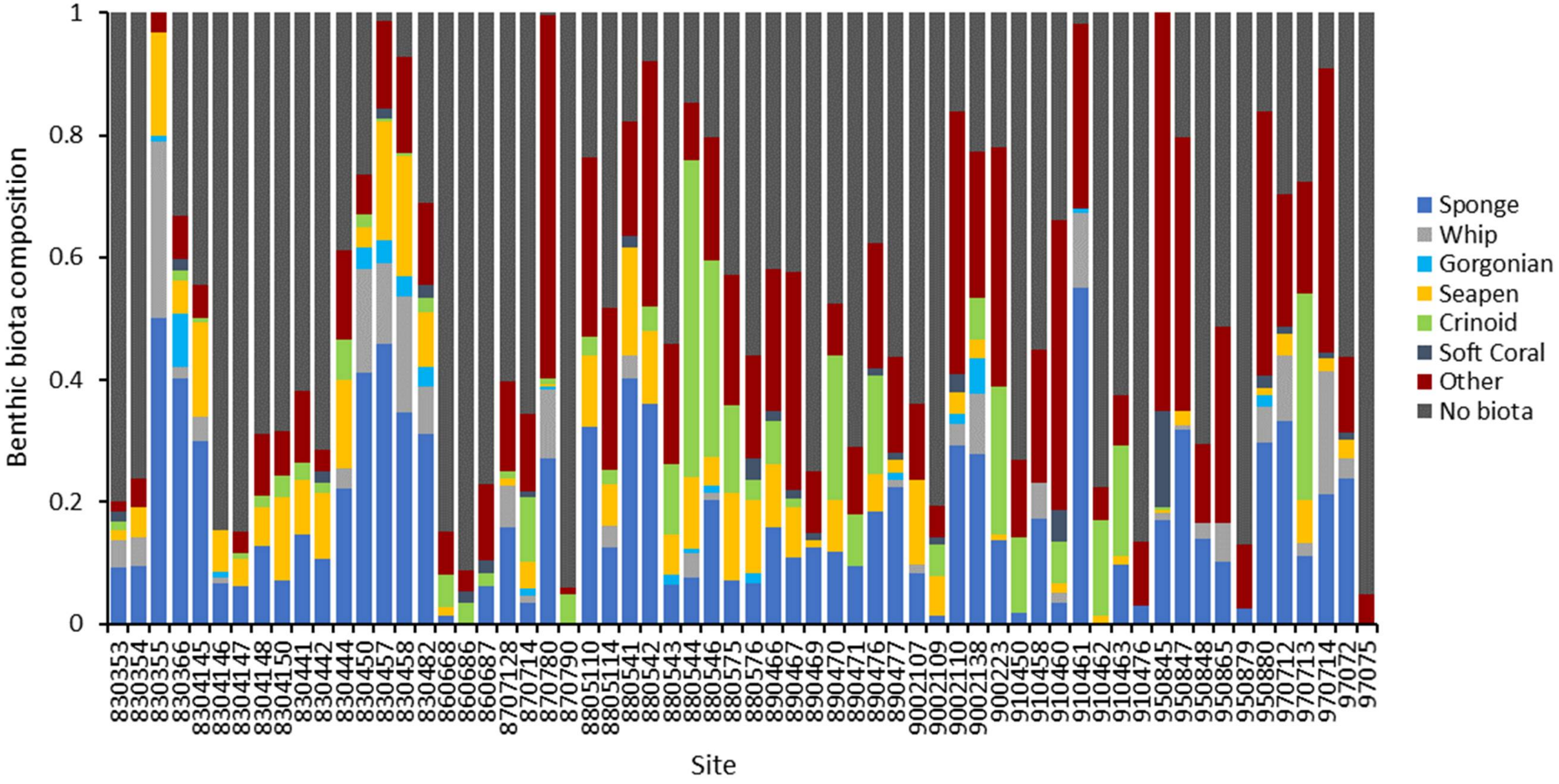
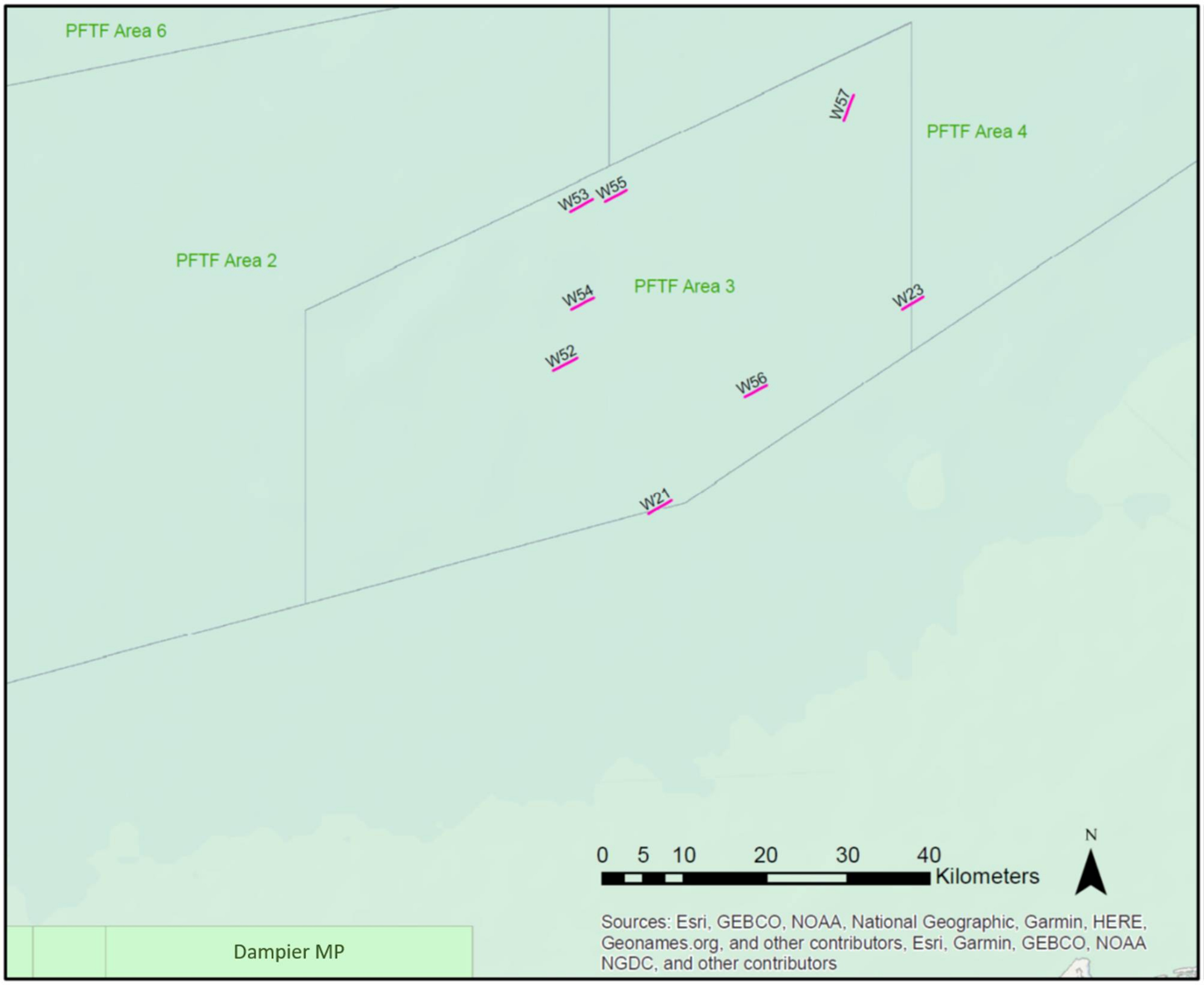


**Figure 80. Proportion of biota types in seabed images along trawl lines for historical CSIRO 1982–1997 survey sites within PFTF Area 2. ‘Other’ includes hydroids, filter feeders which could not be accurately allocated to a specific group because of image quality and other benthic organisms not otherwise listed.**

## 2.8 Results from sites in Pilbara Fish Trawl Fishery Area 3

During the INV2017_05 voyage, eight sites were surveyed within PFTF Area 3 (Figure 81). The location of historical trawls conducted within this area between 1982–1997 for which habitat data were collected are shown in Figure 82.



Sources: Esri, GEBCO, NOAA, National Geographic, Garmin, HERE, Geonames.org, and other contributors, Esri, Garmin, GEBCO, NOAA NGDC, and other contributors

**Figure 81. Location of INV2017_05 sites within PFTF Area 3. Table showing start/end latitude and longitude for each trawl transect is given in Appendix D.**

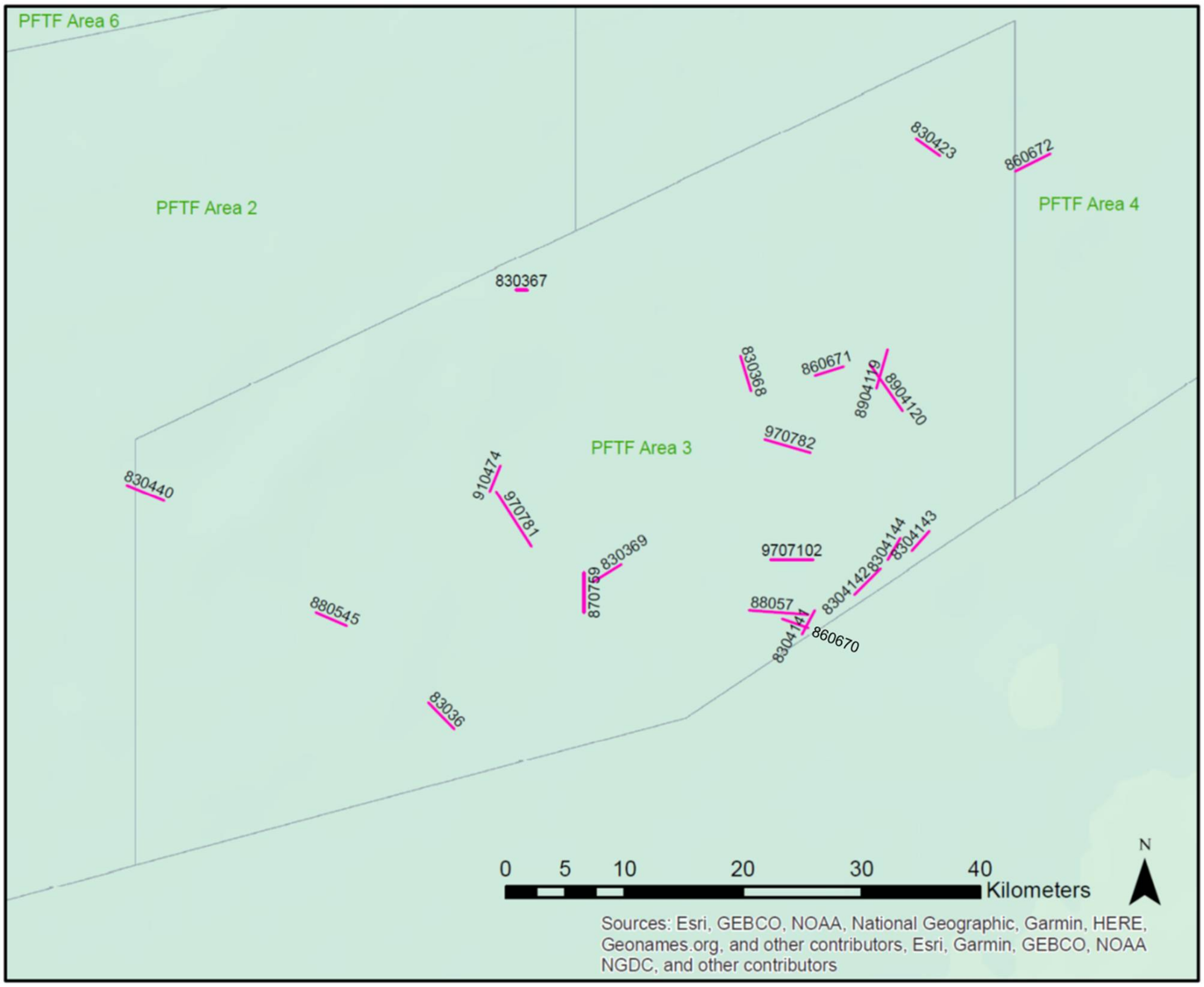


**Figure 82. Location of historical CSIRO 1987–1997 trawls for which habitat data were collected within PFTF Area 3. Table showing start/end latitude and longitude for each trawl transect is given in Appendix E. Trawl number = year, voyage and site number (e.g. 970758 was site 58 on the seventh voyage in 1997).**

### 2.8.1 Water column analyses

CTD profiles were obtained at six sites within PFTF Area 3 (Figure 83 and Figure 84). Salinity again varied little across sites, ranging from 34.9–35.35 psu. Profiles remained relatively constant throughout the water column, with slight increases with depth observed at all sites except site W52 which showed a decrease with depth following a halocline at around 25 m.

Sites surveyed within PFTF Area 3 showed the smallest variation in temperature of all sites (1°C), ranging from 24.5–25.5°C. All sites recorded a decrease in temperature with depth, except site W52 which showed an increase in temperature at 25–30 m depth coinciding with a halocline, before once again decreasing. No thermoclines were recorded at these sites.

Dissolved oxygen ranged from 200–216 mg/L with decreases in DO levels recorded at depths of 40–50 m, except site W56 where this reduction occurred slightly shallower at around 35 m. Site W55 recorded an increase in DO at 60–70 m depth. Little discernible patterns in DO were evident at sites W21, W52 and W57.

Once again, PAR profiles for most sites within PFTF Area 3 showed a progressive decrease with depth declining to zero at 40–60 m. Site W56 was the exception, recording a constant zero PAR throughout the water column due to the CTD cast being carried out in the evening.

Chlorophyll-*a* ranged from 10–35 $mg.m^{-2}$ with maximums reached at 50–60 m depth, except site W57 which recorded a slightly shallower chl-*a* maxima (~ 40 m). The chl-*a* profile at site W21 had an anomalous signal near the surface before the trace changed to a profile similar to the other sites within PFTF Area 3.

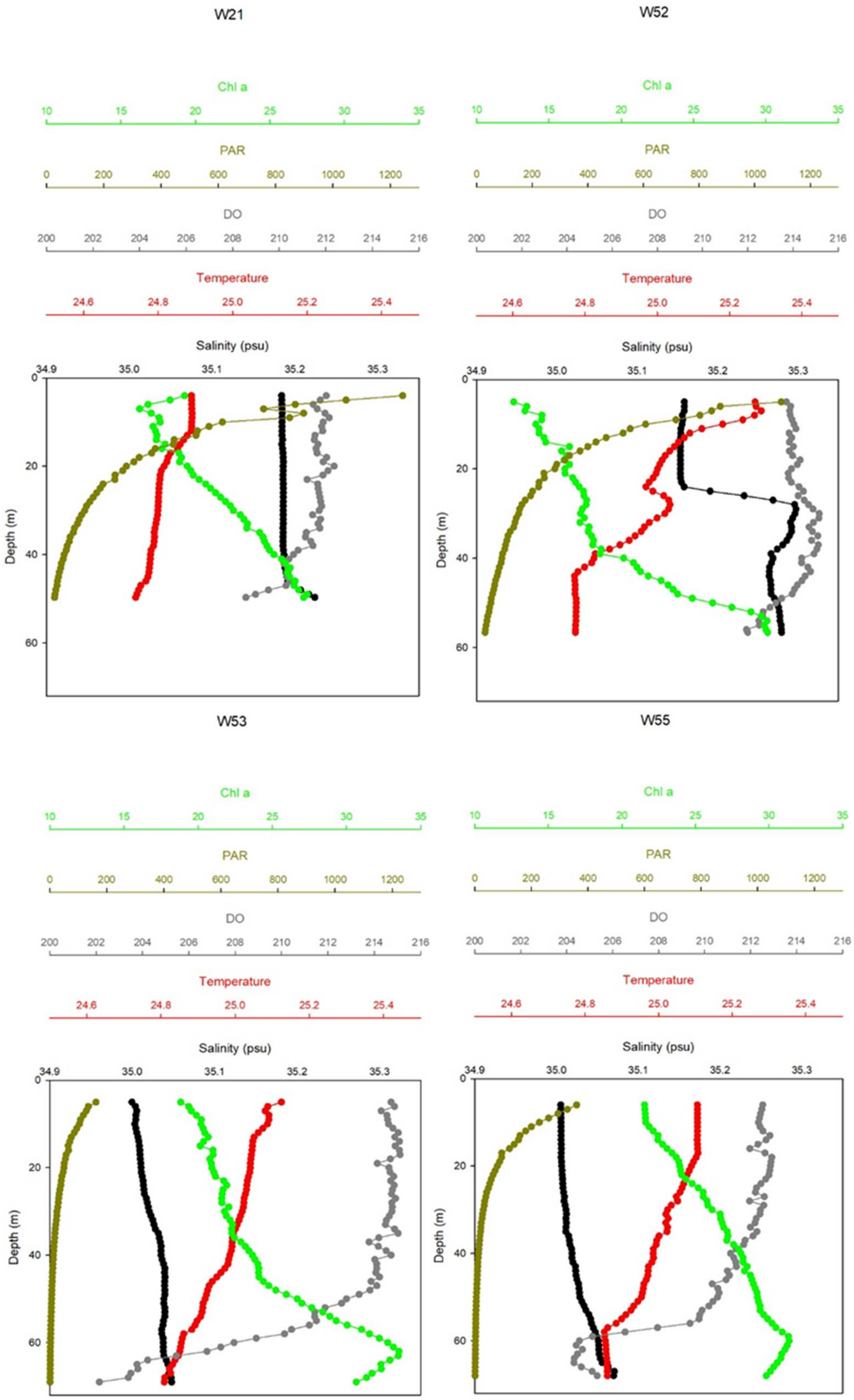


**Figure 83. CTD profiles of water column parameters from sites W21, W52, W53 and W55 within PFTF Area 3 (currently closed to fishing).**

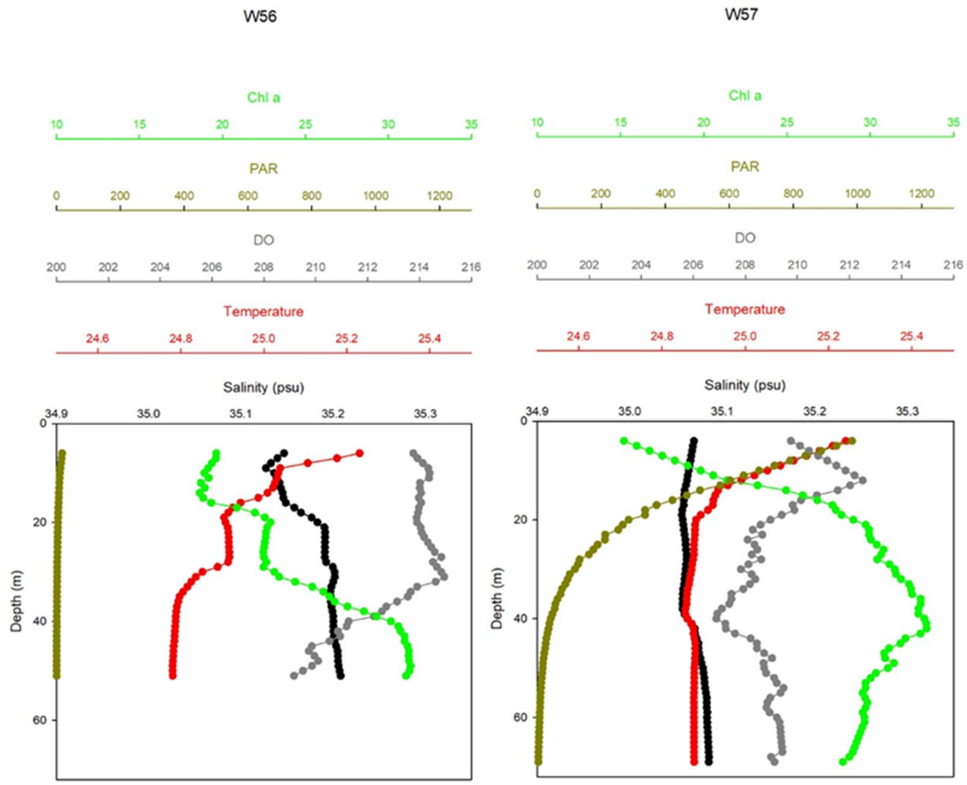


**Figure 84. CTD profiles of water column parameters from sites W56 and W57 within PFTF Area 3 (currently closed to fishing)**

Depth-averaged nutrient values were obtained at six sites within PFTF Area 3 (Table 7, Figure 85). Total chl-*a* was relatively consistent across sites, ranging from 0.24 mg $m^{-2}$ at site W52 to 0.43 mg $m^{-2}$ W57. Nitrate concentrations ranged from 0.018 mmol $m^{-2}$ (again at site 52) to 0.172 mmol $m^{-2}$ (site W55). Mean ammonia ranged from 0.005–0.06 mmol $m^{-2}$ (sites W53 and W56, respectively). Like chl-*a*, silica was consistent across sites, ranging from 3.187–3.614 mmol $^{-2}$. Phosphate concentrations ranged from 0.135 mmol $m^{-2}$ at site W55, to 0.178 mmol $m^{-2}$ at site W21.

**Table 7. Nutrients (depth averaged values) for sites surveyed within PTFT Area 3 (currently closed to fishing).**

| Site | Mean total chl-*a* (mg $m^{-2}$) | Mean $NO_x$ (mmol $m^{-2}$) | Mean $NH_4$ (mmol $m^{-2}$) | Mean $PO_4$ (mmol $m^{-2}$) | Mean Si (mmol $m^{-2}$) |
|---|---|---|---|---|---|
| W21 | 0.29 | 0.029 | 0.045 | 0.178 | 3.510 |
| W52 | 0.24 | 0.018 | 0.008 | 0.161 | 3.614 |
| W53 | 0.33 | 0.177 | 0.005 | 0.142 | 3.187 |
| W55 | 0.37 | 0.172 | 0.036 | 0.135 | 3.557 |
| W56 | 0.29 | 0.034 | 0.06 | 0.141 | 3.564 |
| W57 | 0.43 | 0.113 | 0.054 | 0.143 | 3.557 |

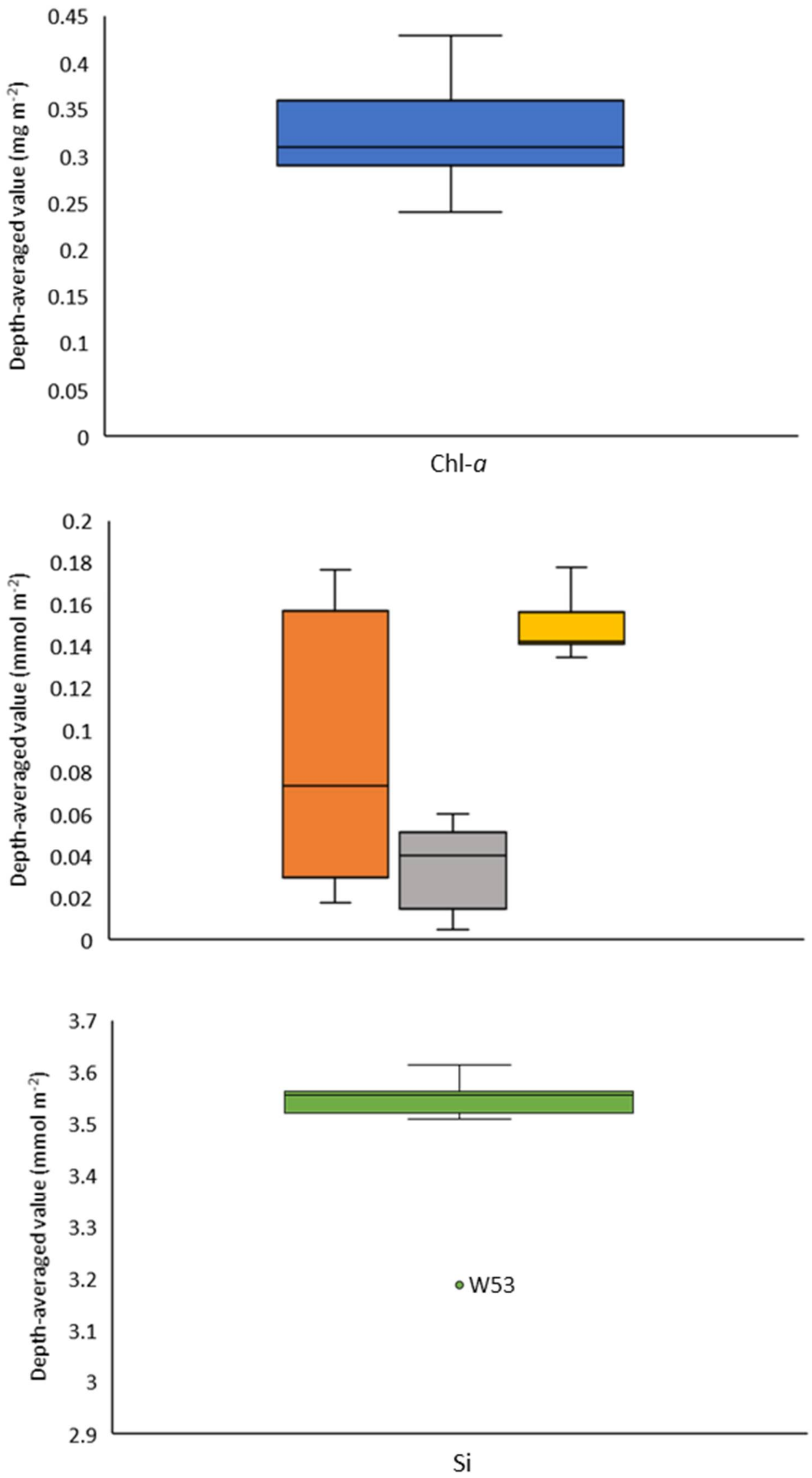


**Figure 85. Depth-averaged nutrient values for sites surveyed within PFTF Area 3 (currently closed to fishing). Box plots show the median, 25th and 75th percentiles and outliers falling outside the 10th and 90th percentiles.**

### 2.8.2 Sub-bottom profiling – INV2017_05

Sub-bottom profiling of sites within PFTF Area 3 varied across sites (Figure 86). Again, most sites were classified as either hard bottom or thin sediment over rock. Site W21 was classified as predominantly thin sediment over rock with hard bottom making up around 20% of bottom type at this site. Site 54 was characterised by thick sediment over rock only, while site W87 was a combination of thick and thin sediment types.

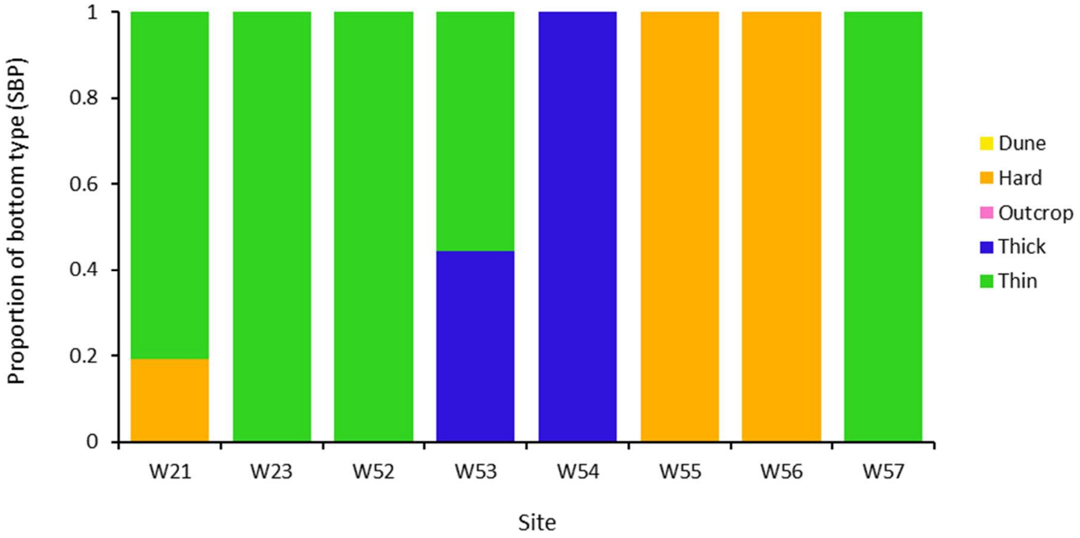


**Figure 86. Proportion of bottom types determined using SBP for INV2017_05 sites within PFTF Area 3, currently closed to fishing.**

### 2.8.3 Substrate and soft-bottom topography

#### INV2017_05 survey sites

Substrate type within PFTF Area 3 was vastly dominated by fine sand (Figure 87, top). A very small proportion of rock was identified at site W56. Shepard's plots confirmed these identifications, classifying sediment at all sites as sand (Figure 88). Topography was once again dominated by flat bottom, while fine ripples were identified at sites W54 and W57 (Figure 87, bottom).

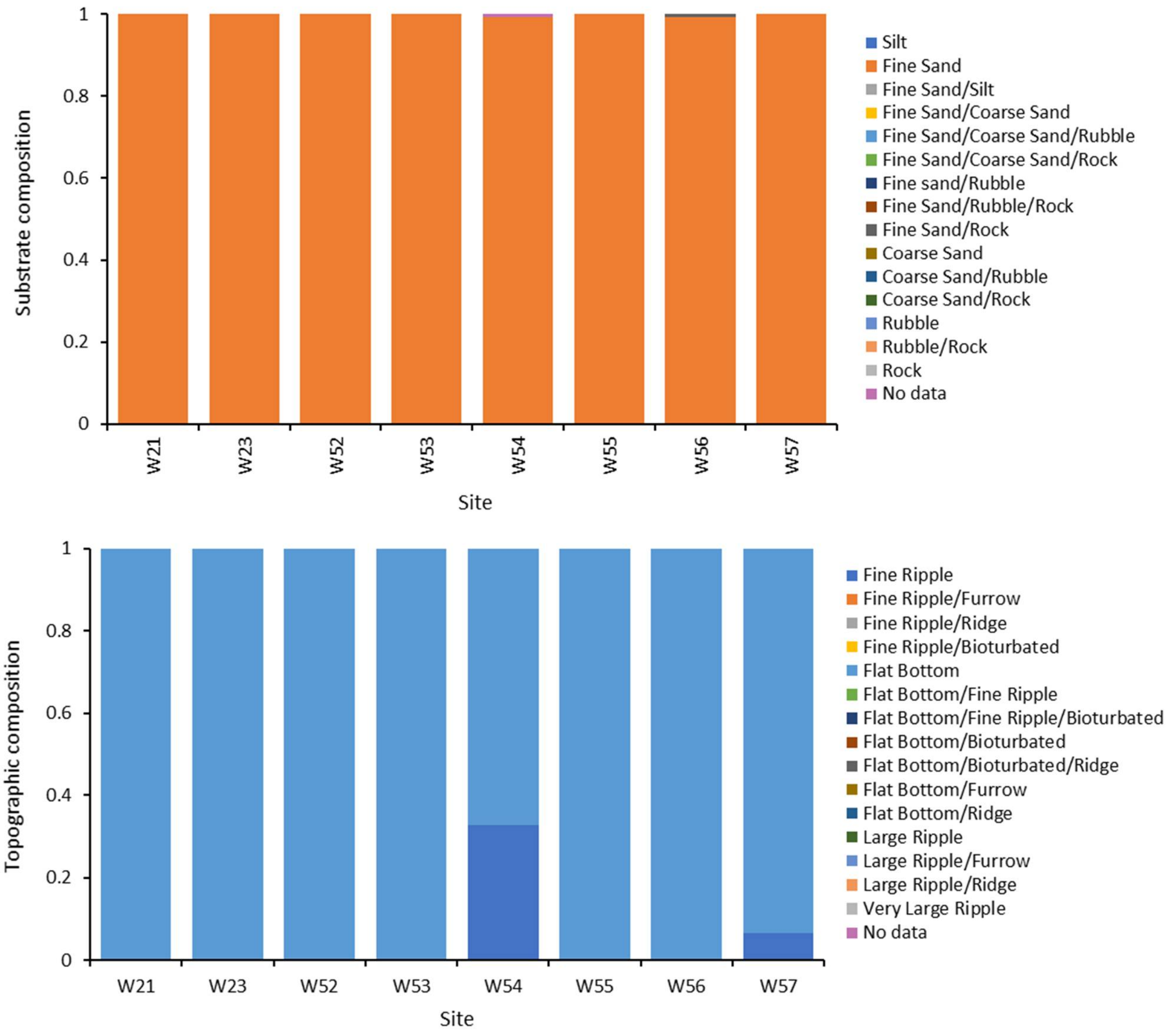


**Figure 87. Proportion of substrate (top) and topography (bottom) types in seabed images along trawl lines for INV2017_05 survey sites within PFTF Area 3 (currently closed to fishing).**

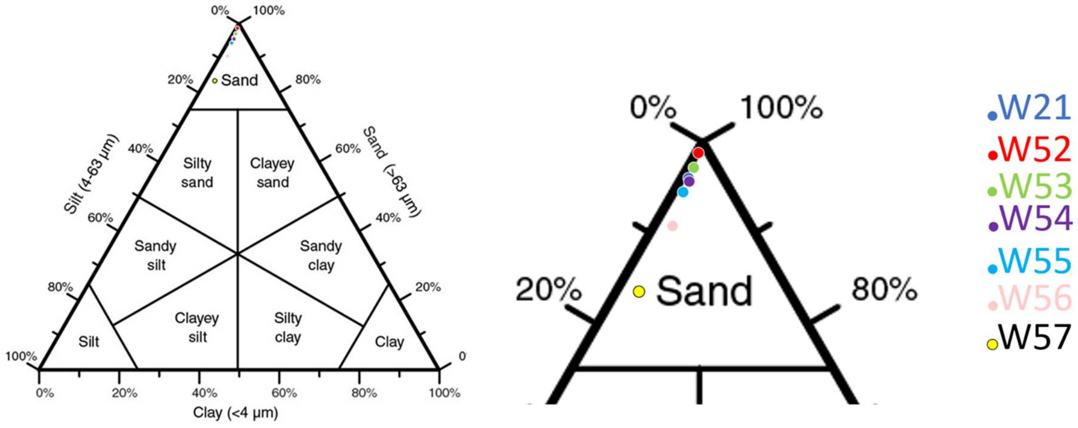


**Figure 88. Shepard's plot of sediment classifications for INV2017_05 survey sites within PFTF Area 3 (currently closed to fishing).**

## CSIRO 1982–1997 survey sites

Historical surveys indentified fine and coarse sandy substrates within PFTF Area 3 (Figure 89, top). Sites 83036 and 830369 were vastly dominated by coarse sand, with this making up 100% of the sediment composition at site 9707102. Rubble was only identified at site 8304141. Flat bottom and fine ripples dominated topographic composition across sites (Figure 89, bottom). A very small proportion of ridge topography was identified at site 8304142.

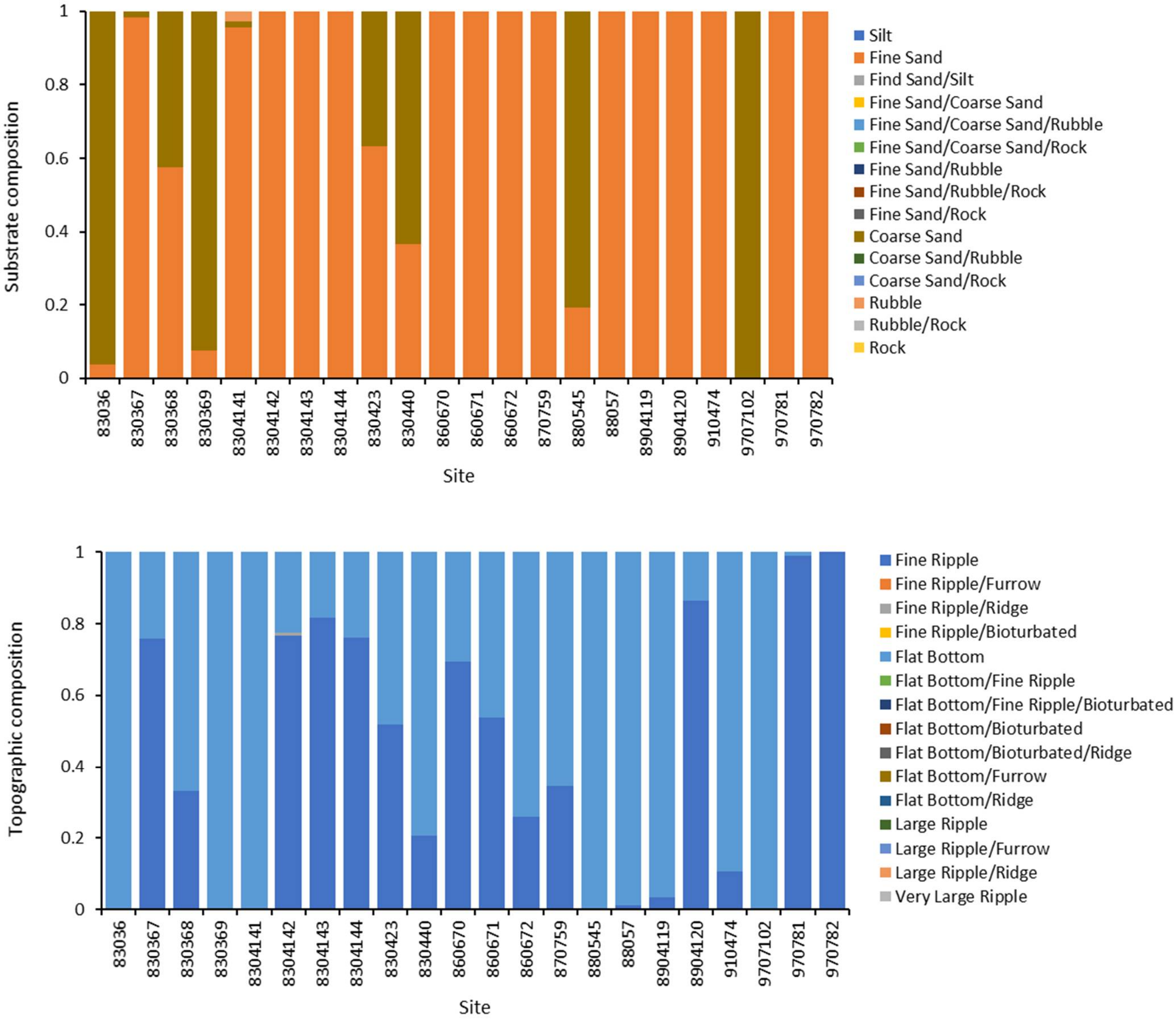


**Figure 89. Proportion of substrate (top) and topography (bottom) types in seabed images along trawl lines for historical CSIRO 1982–1997 survey sites within PFTF Area 3 (currently closed to fishing).**

### 2.8.4 Benthic biota

#### INV2017_05 survey sites

Interestingly, sites within PFTF Area 3 – which is currently closed to fishing – showed little biota across all eight sites (Figure 90, also see representative images in Appx Figure 85–Appx Figure 92). Of the biota present, hydroids, crinoids and whips made up the greatest proportion. Site W56 showed the greatest proportion of biota in PFTF Area 3 (approximately 40%). This site also had the highest proportion of sponges and whips, while hydroids were greatest at site W57.

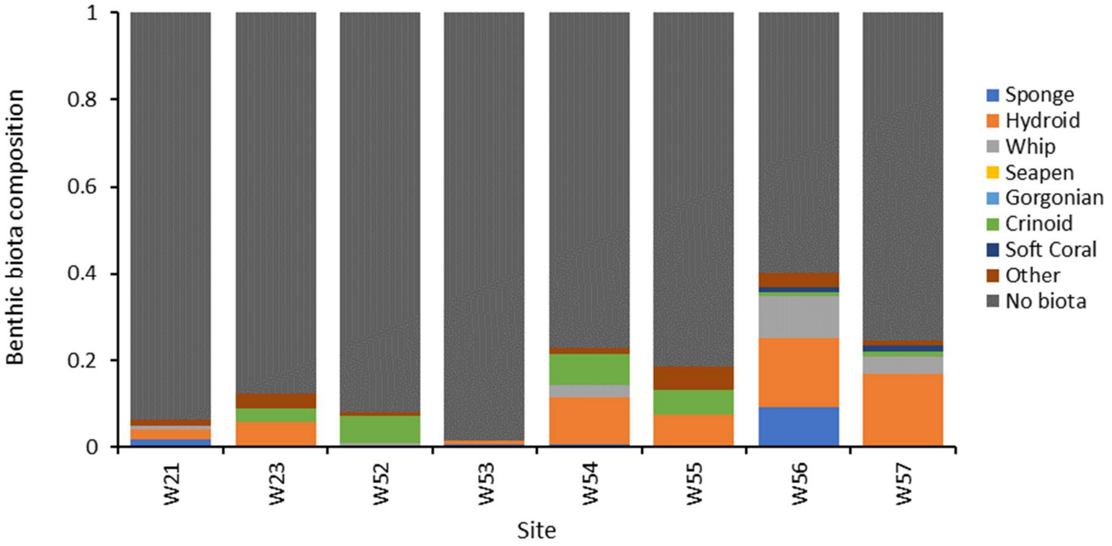


Figure 90. Proportion of biota types in seabed images along trawl lines for INV2017_05 survey sites within PFTF Area 3 (currently closed to fishing). 'Other' includes both filter feeders which could not be accurately allocated to a specific group because of image quality and other benthic organisms not otherwise listed.

## CSIRO 1982–1997 survey sites

Although currently closed to fishing operations, greater proportions of biota were identified across all sites in PFTF Area 3 during historical surveys (Figure 91, also see representative images in Appx Figure 93–Appx Figure 98) than during INV2017_05 surveys. Approximately half of sites had a proportion of benthic biota greater than 40%, compared to all sites having less than this during INV2017_05 surveys. Site 970782 was predominantly void of biota, while site 8304143 did not have any biota identified from images. Sponges, seapens and 'other' biota including hydroids contributed largely across PFTF Area 3. Notably, the highest proportion of biota was evident at site 870759 (92%). Both seapens and crinoids contributed the greatest to benthic biota composition at site 830440, while the proportion of sponges was greatest at sites 8904119 and 8304142.

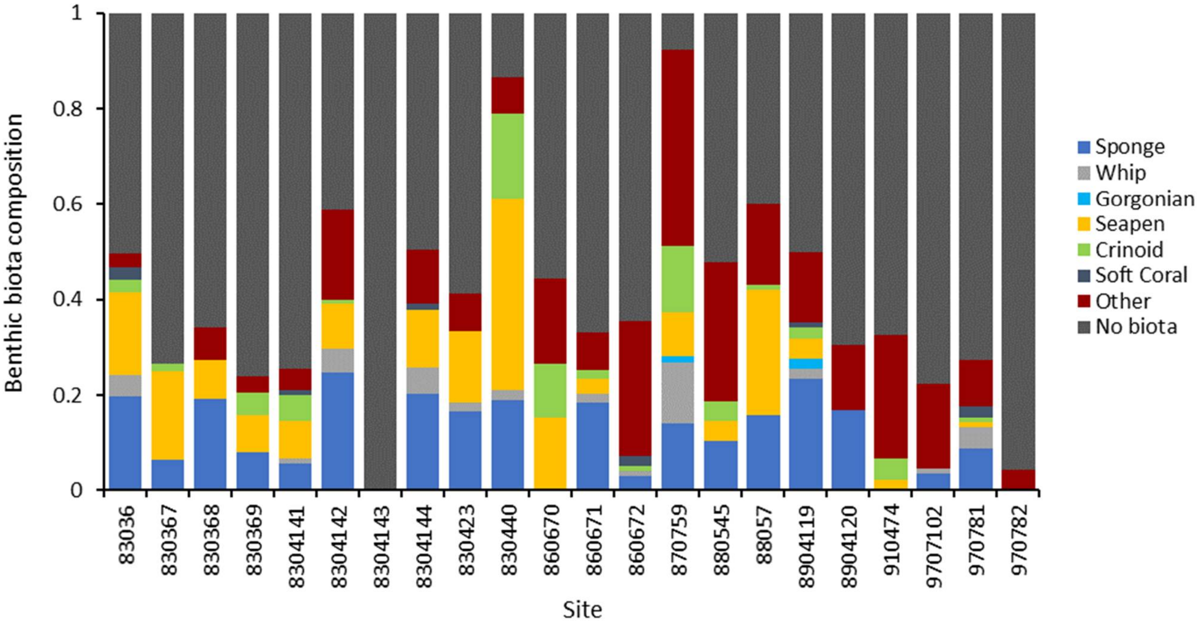
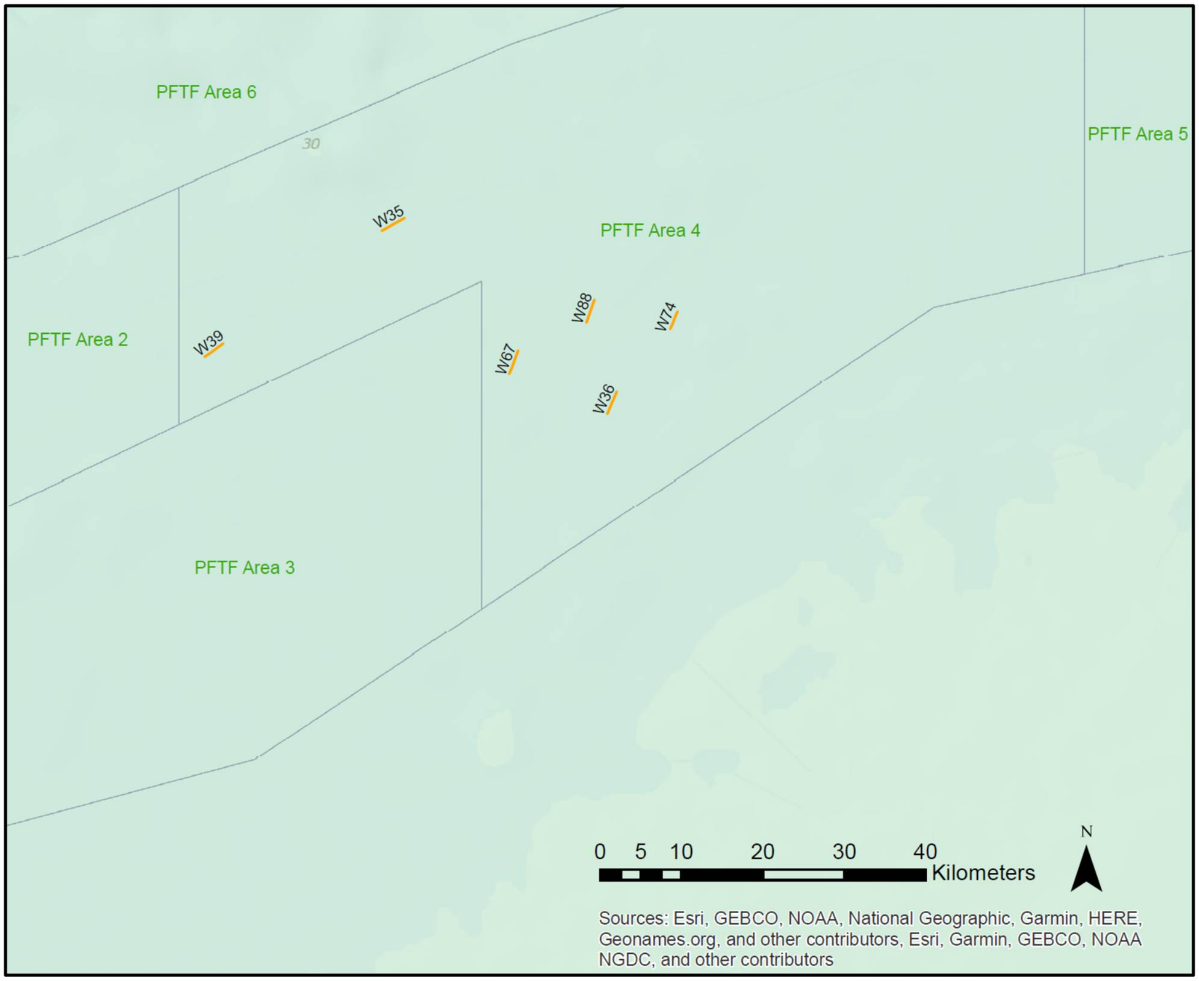


**Figure 91. Proportion of biota types in seabed images along trawl lines for historical CSIRO 1982–1997 survey sites within PFTF Area 3 (currently closed to fishing). 'Other' includes hydroids, filter feeders which could not be accurately allocated to a specific group because of image quality and other benthic organisms not otherwise listed.**

## 2.9 Results from sites in Pilbara Fish Trawl Fishery Area 4

During the INV2017_05 voyage, six sites were surveyed within PFTF Area 4 (Figure 92). The location of historical trawls conducted within this area between 1982–1997 for which habitat data were collected are shown in Figure 93.



Sources: Esri, GEBCO, NOAA, National Geographic, Garmin, HERE, Geonames.org, and other contributors, Esri, Garmin, GEBCO, NOAA NGDC, and other contributors

**Figure 92. Location of INV2017_05 sites within PFTF Area 4. Table showing start/end latitude and longitude for each trawl transect is given in Appendix D.**

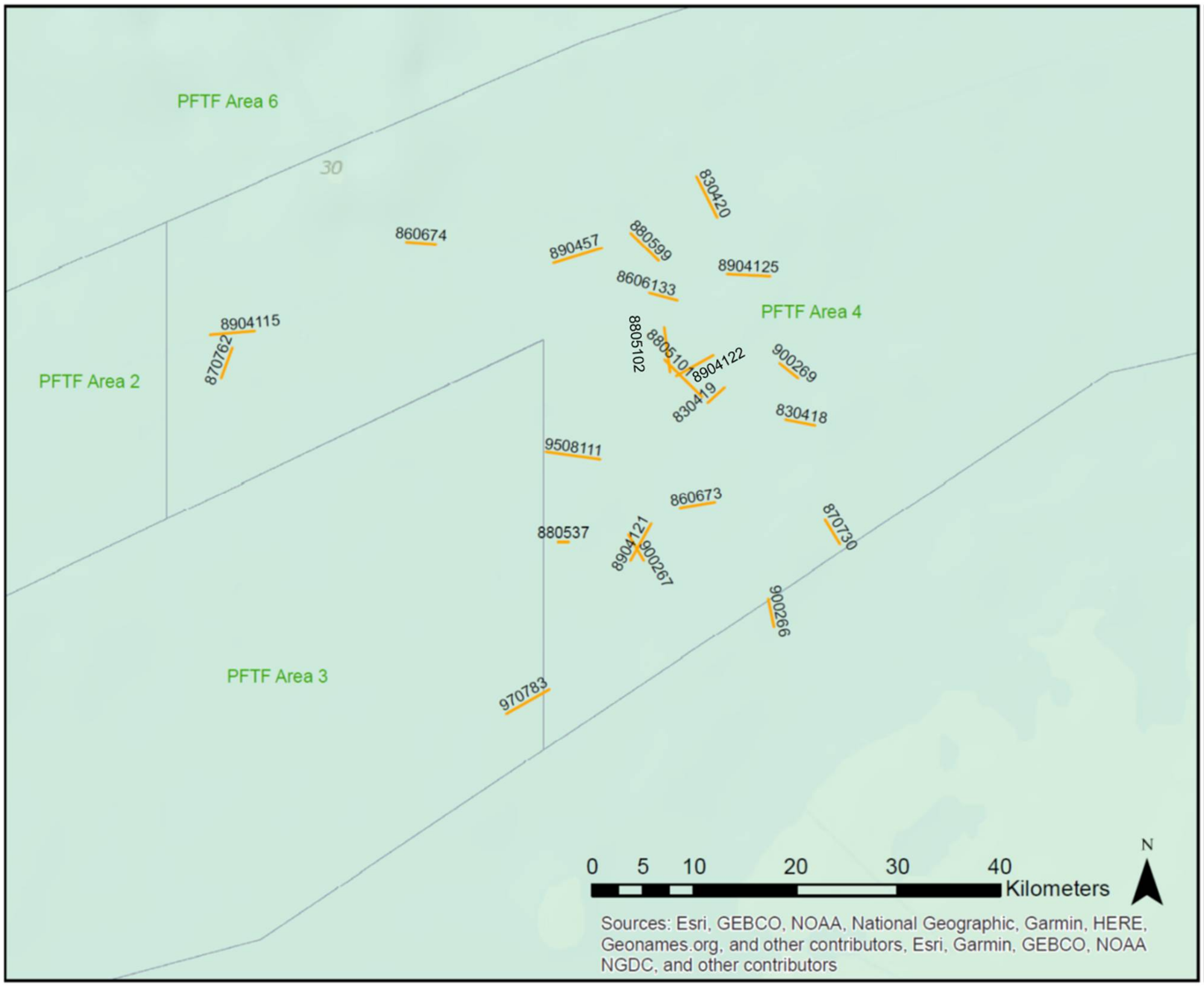


**Figure 93. Location of historical CSIRO 1987–1997 trawls for which habitat data were collected within PFTF Area 4. Table showing start/end latitude and longitude for each trawl transect is given in Appendix E. Trawl number = year, voyage and site number (e.g. 970758 was site 58 on the seventh voyage in 1997).**

### 2.9.1 Water column analyses

CTD profiles were obtained for three sites within PFTF Area 4 (Figure 94). Salinity again varied very little across sites (< 0.5 psu) within PFTF Area 4, ranging from 35.0–35.4 psu. Salinity remained constant for sites W39 and W67, while site W74 differed from these two profiles, continuously increasing with depth.

Temperature ranged from 24.6–25.7°C. All sites were characterised by a decrease in temperature with depth to 40 m before becoming well-mixed. No thermoclines were recorded, however, a decrease in temperature of around 0.3°C between 10–15 m depth was observed at site W74 before, like the other two sites, becoming well-mixed at 40 m.

Dissolved oxygen ranged from 200–215 mg/L with reductions in DO levels evident at 40 m depth. Sites W39 and W67 showed a DO maximum near the surface and an area of well-mixed water below with concentrations decreasing with depth below 40 m. Site W74, however, recorded a subsurface maximum, with DO increasing to 30 m before decreasing below this depth.

While all sites recorded a diminishment in PAR with depth, the PAR profiles of these sites varied somewhat. Site W39 recorded a large decrease in PAR (the largest decrease of the three sites) within the top 20 m of the water column. Site W74 showed a similar shaped profile, although PAR levels and subsequent diminishment were less dramatic, while site W67 recorded an almost constant PAR of zero below 25 m.

Chlorophyll-*a* ranged from 12.5–33.5 $mg.m^{-2}$ and increased with depth to a maximum between 40–60 m at all sites. A spike in chl-*a* was recorded at roughly 55 m depth at site W67 before once again decreasing at 60 m.

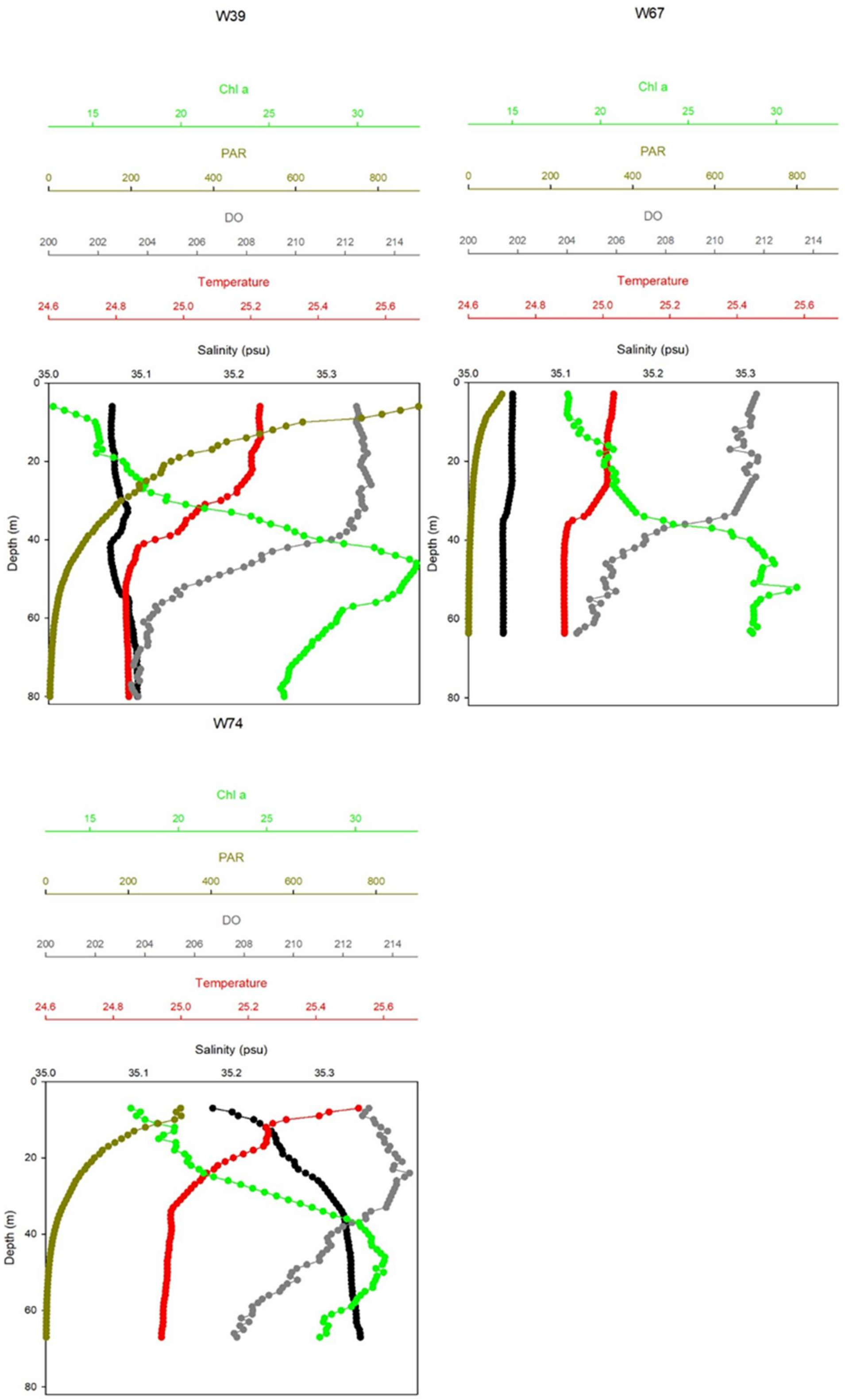


Figure 94. CTD profiles of water column parameters from sites W39, W67 and W74 within PFTF Area 4.

Depth-averaged nutrient values were obtained at three sites within PFTF Area 4 (Table 8, Figure 95). Total chl-*a* was consistent across sites, ranging from 0.30 mg $m^{-2}$ at site W39 to 0.32 mg $m^{-2}$ at both sites W67 and W74. Nitrate concentrations ranged from 0.085 mmol $m^{-2}$ (site W74) to 0.192 mmol $m^{-2}$ (site W39). Mean ammonia ranged from 0.021–0.085 mmol $m^{-2}$ (sites W67 and W39, respectively). Silica ranged from 3.471–4.124 mmol $^{-2}$ (sites W39 and W67, respectively) Phosphate concentrations ranged from 0.139 mmol $m^{-2}$ to 0.157 mmol $m^{-2}$ at site W74. Minimum nutrient values for silica and phosphate were both recorded at site W39.

**Table 8. Nutrients (depth averaged values) for sites surveyed within PTFT Area 4.**

| Site | Mean total chl-*a* (mg $m^{-2}$) | Mean $NO_x$ (mmol $m^{-2}$) | Mean $NH_4$ (mmol $m^{-2}$) | Mean $PO_4$ (mmol $m^{-2}$) | Mean Si (mmol $m^{-2}$) |
|---|---|---|---|---|---|
| W35 | No sample | No sample | No sample | No sample | No sample |
| W36 | No sample | No sample | No sample | No sample | No sample |
| W39 | 0.30 | 0.192 | 0.085 | 0.139 | 3.471 |
| W67 | 0.32 | 0.164 | 0.021 | 0.146 | 4.124 |
| W74 | 0.32 | 0.085 | 0.068 | 0.157 | 4.069 |
| W88 | No sample | No sample | No sample | No sample | No sample |

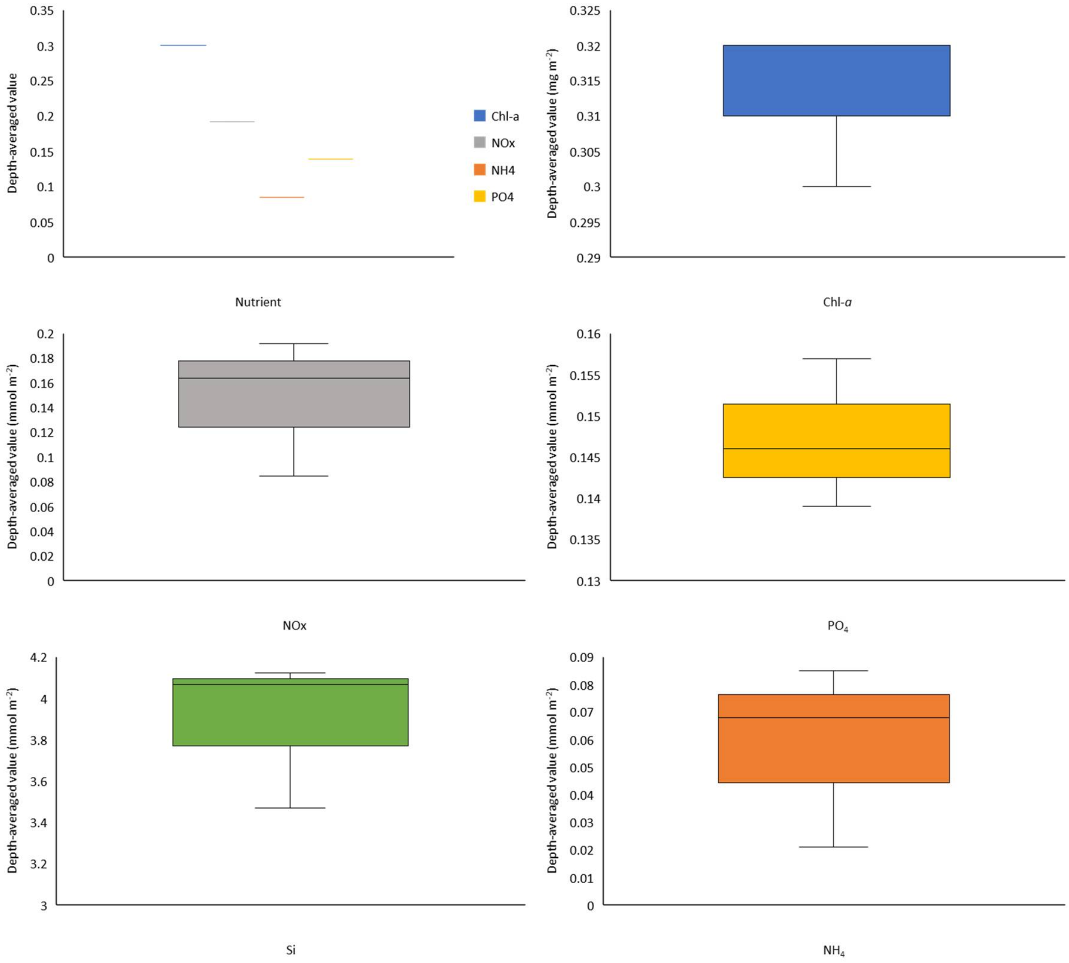


**Figure 95. Depth-averaged nutrient values for sites surveyed within PFTF Area 4. Box plots show the median, 25th and 75th percentiles and outliers falling outside the 10th and 90th percentiles. Note: different scales used.**

### 2.9.2 Sub-bottom profiling – INV2017_05

Sub-bottom profiling of sites within PFTF Area 4 were predominantly characterised as hard bottom or a combination of hard bottom and thin sediment over rock (Figure 96). Two sites, W35 and W67, also showed sand dune formations, while a small proportion of outcrop was evident at site W39.

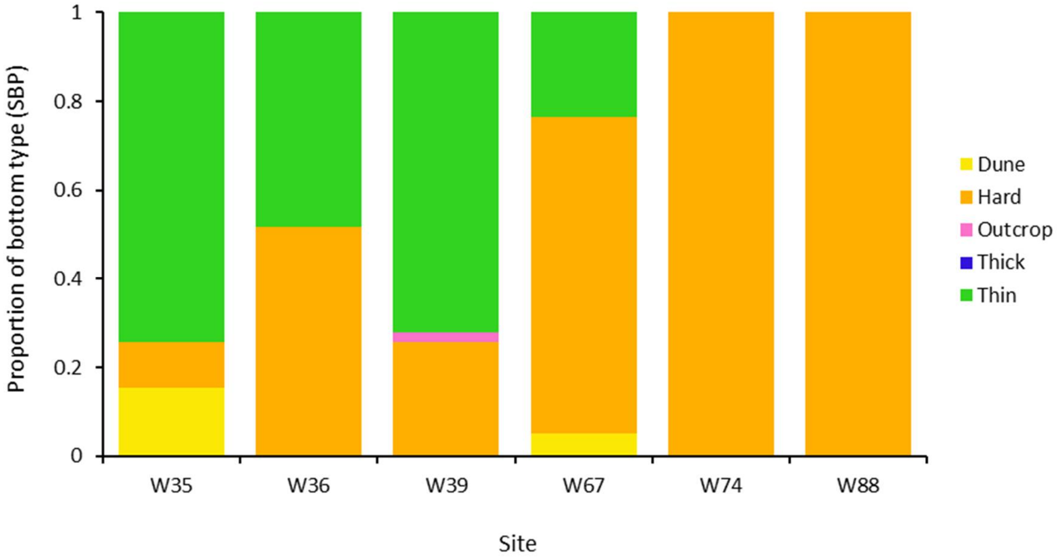


Figure 96. Proportion of bottom types determined using SBP for INV2017_05 sites within PFTF Area 4.

### 2.9.3 Substrate and topography

#### INV2017_05 survey sites

Fine sandy substrate dominated across all sites within PFTF Area 4 (Figure 97, top), confirmed using Shepard's plots of sediment classification (Figure 98). Flat bottom was evident at all sites (Figure 97, bottom), while fine ripples were identified at site W39 only.

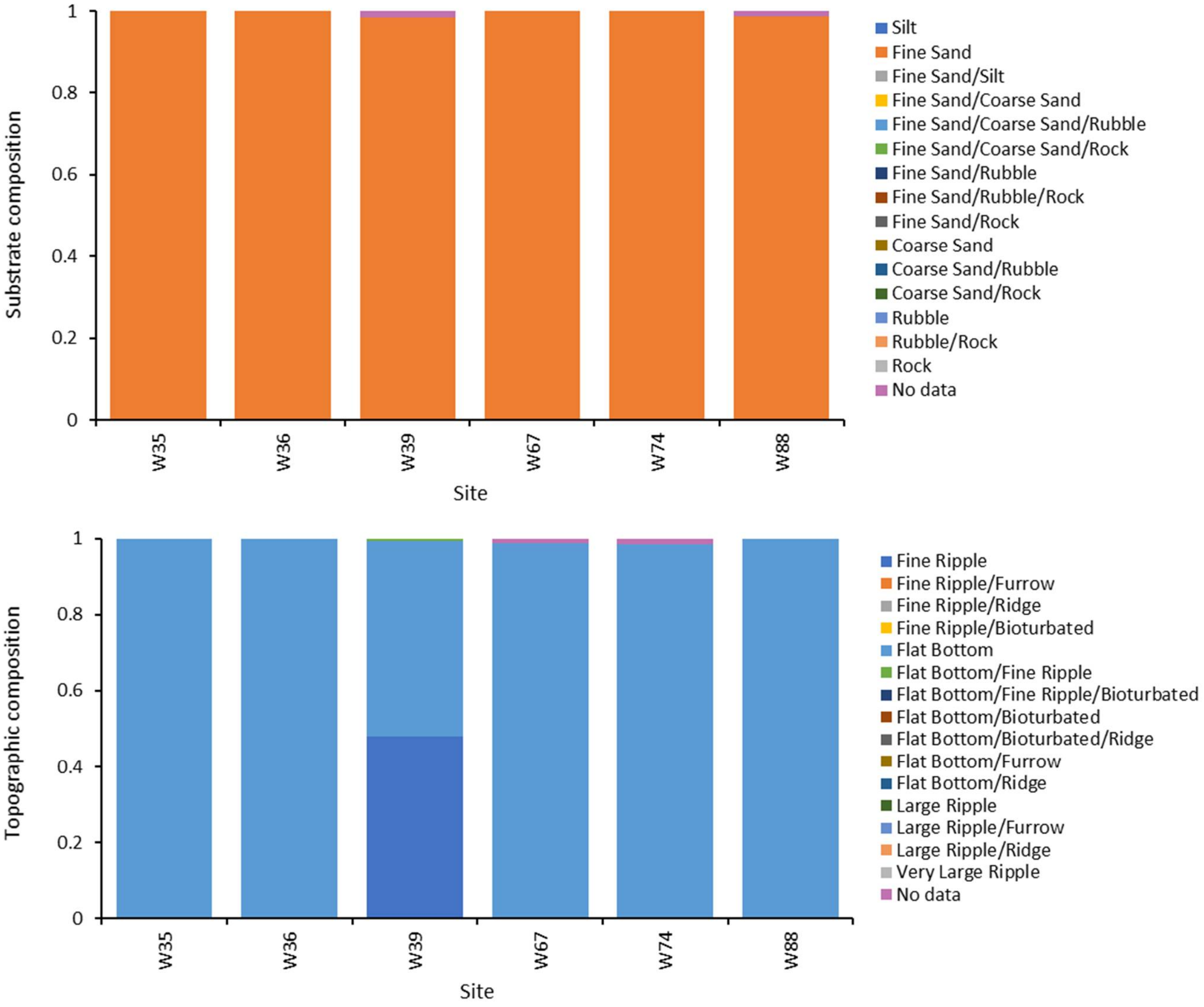


**Figure 97. Proportion of substrate (top) and topography (bottom) types in seabed images along trawl lines for INV2017_05 survey sites within PFTF Area 4.**

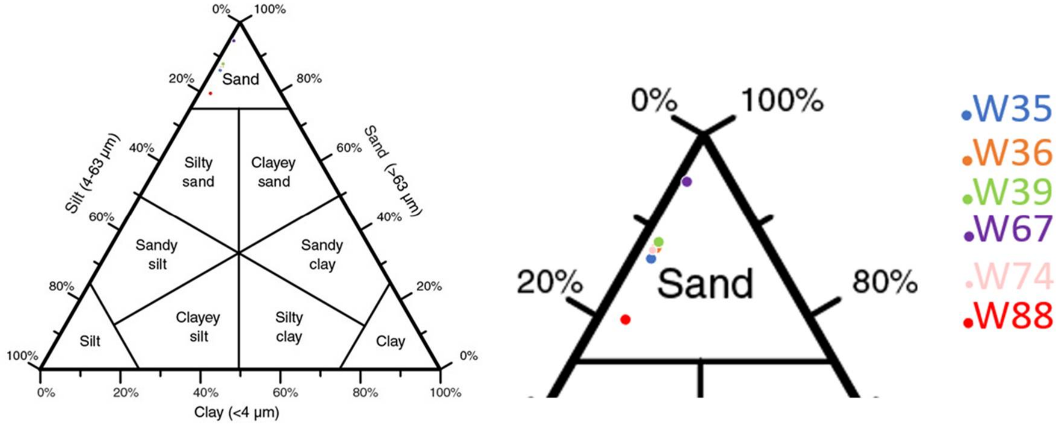


**Figure 98. Shepard's plot of sediment classifications for INV2017_05 survey sites within PFTF Area 4.**

## CSIRO 1982–1997 survey sites

Fine sand and a combination of fine and coarse sandy substrates were observed at all sites in PFTF Area 4 during historical surveys (Figure 99, top). Silt was identified at four sites (8606133, 870730, 870762 and 8904122). Very small proportions of rubble and rock were also identified at sites 870762 and 8805102. Topographic composition was once again dominated by flat bottom and fine ripples (Figure 99, bottom). Large ripples and ridges made up small proportions of topographic composition at sites 970783, and 900266 and 8904125, respectively. Bioturbations were present at sites 900267 and 8805102.

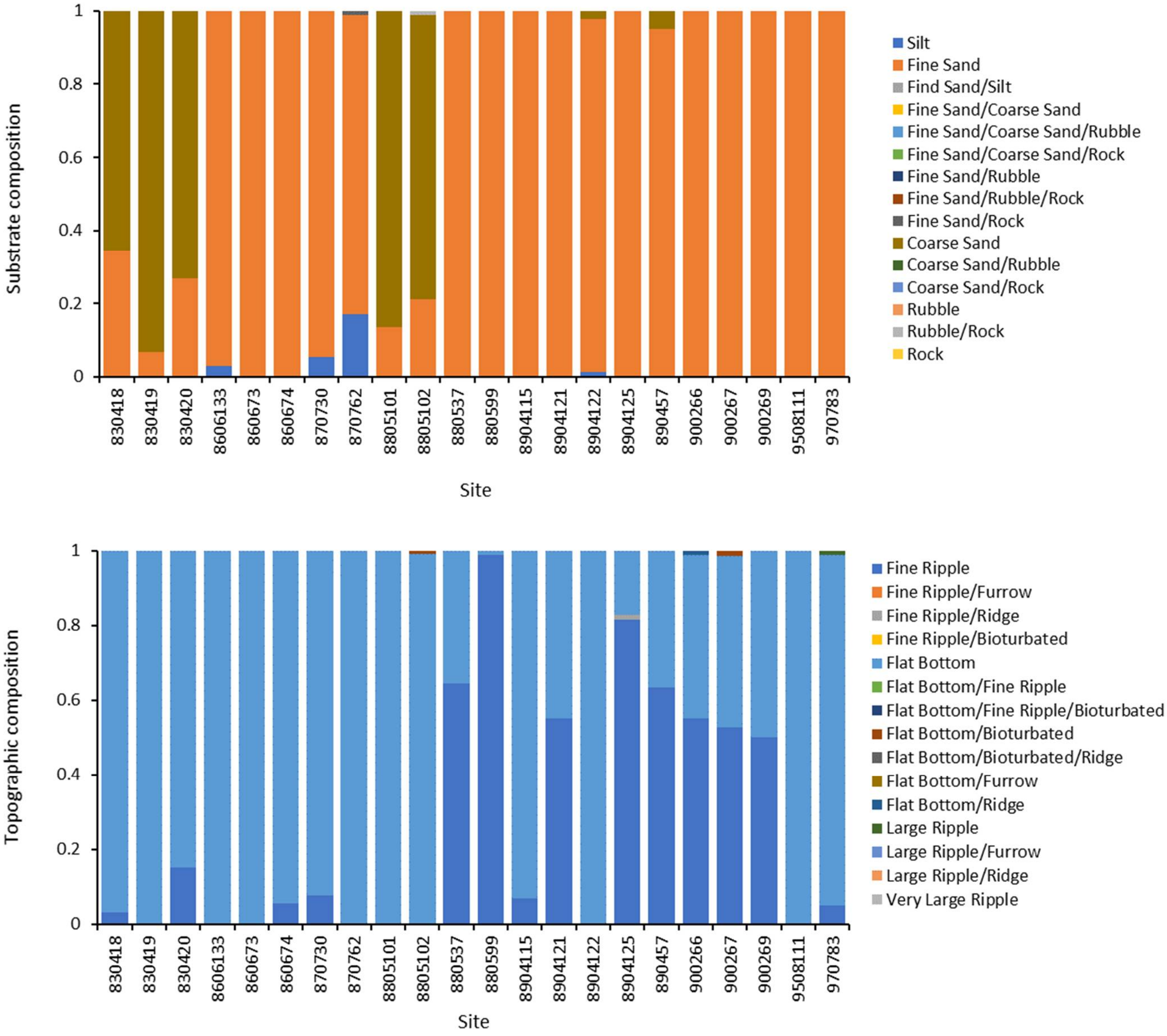


**Figure 99. Proportion of substrate (top) and topography (bottom) types in seabed images along trawl lines for historical CSIRO 1982–1997 survey sites within PFTF Area 4.**

### 2.9.4 Benthic biota

#### INV2017_05 survey sites

As with INV2017_05 surveys of PFTF Area 3, all sites within PFTF Area 4 had small proportions of biota present (Figure 100, also see representative images in Appx Figure 93–Appx Figure 98Appendix C ). Of the biota types present, hydroids and 'other' biota made up the greatest proportion. Sites W67, W74 and W88 showed the highest proportions of benthic biota, with all three dominated by hydroids. Soft corals were also identified at all sites except site W35.

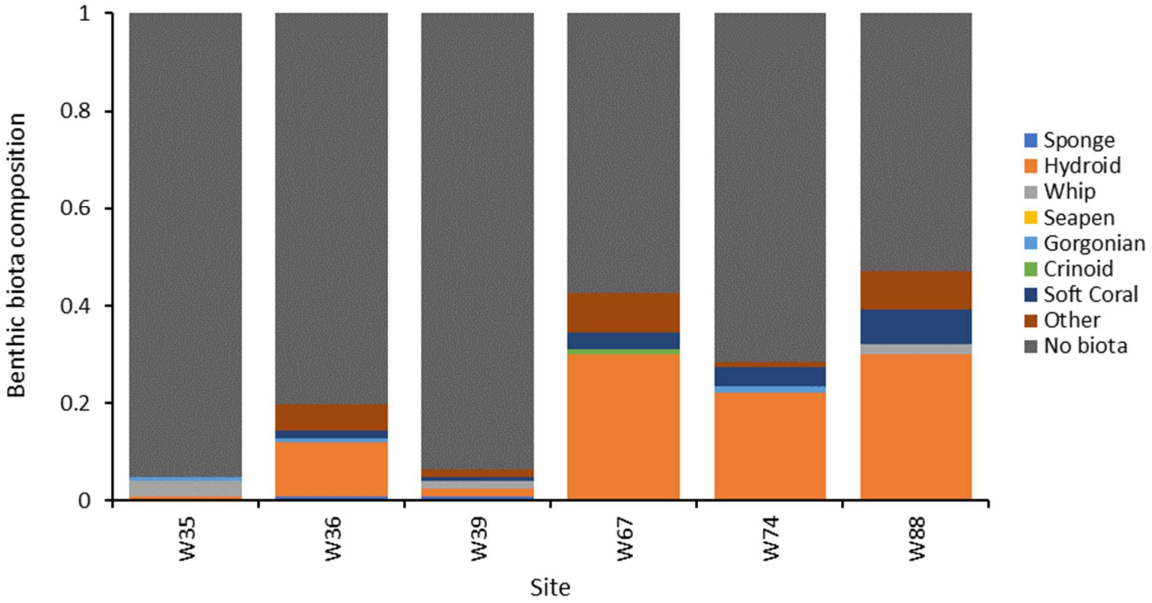


**Figure 100. Proportion of biota types in seabed images along trawl lines for INV2017_05 survey sites within PFTF Area 4. 'Other' includes both filter feeders which could not be accurately allocated to a specific group because of image quality and other benthic organisms not otherwise listed.**

## CSIRO 1982–1997 survey sites

Greater proportions of biota were identified within PFTF Area 4 during historical surveys (Figure 101) than during INV2017_05 surveys. While only two INV2017_05 sites showed proportions of biota greater than 40% (42% at site W67 and 47% at site W88), approximately half of all historical sites exceeded this, with some sites showing proportions of greater than 80% (sites 870762, 8805102 and 880599) and up to 93% (site 880537). Sponges and 'other' biota including hydroids dominated benthic biota types. Crinoids were greatest at site 880537, while seapens were the dominant biota type at site 880599. 'Other' biota were identified at all sites, making up the largest proportions at sites 8805101, 860673 and 870730.

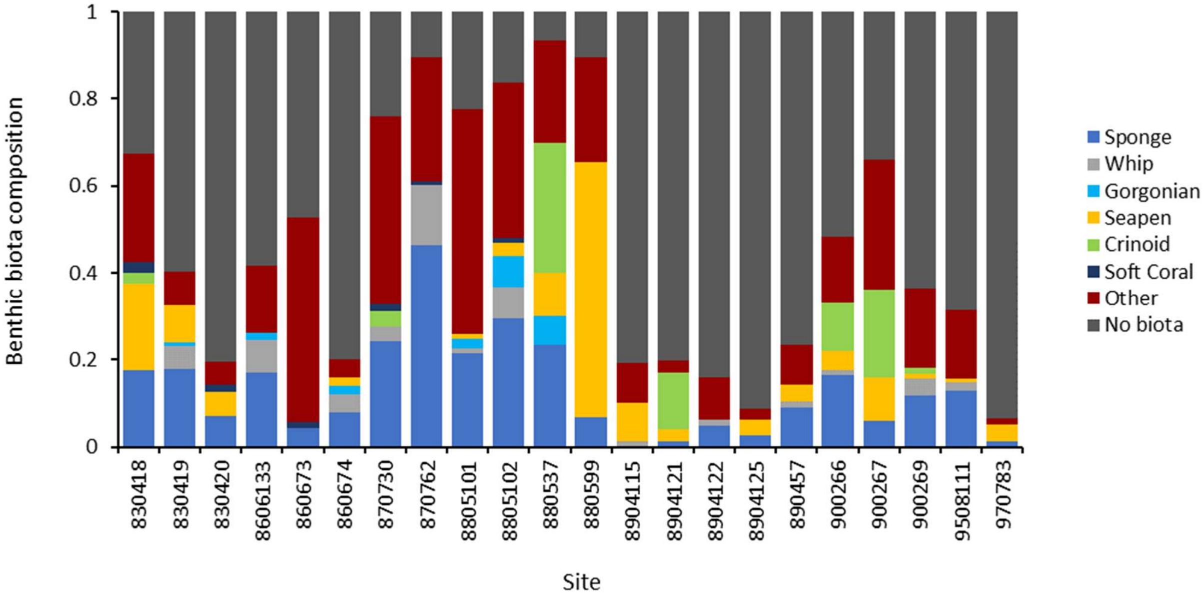


**Figure 101. Proportion of biota types in seabed images along trawl lines for historical CSIRO 1982–1997 survey sites within PFTF Area 4. 'Other' includes hydroids, filter feeders which could not be accurately allocated to a specific group because of image quality and other benthic organisms not otherwise listed.**

# 3 Characterisation of fish and benthic filter feeder fauna assemblages

John Pogonoski, Monika Bryce and Belinda Alvarez (CSIRO Oceans and Atmosphere)

## 3.1 Overview

A key focus for this study was the association and dependencies of demersal fish assemblages on benthic habitat forming filter feeders, principally sponges and soft corals, which are disturbed and/or damaged by trawling. This chapter describes the species assemblages of fishes, sponges and soft corals sampled on the 2017 voyage. The work on identification of the fish is complete and is advanced for the sponges and soft corals. While the full diversity of sampled fishes will be presented in the final report, it was not possible to identify all sponges and soft corals captured at all stations. However, all soft corals that were vouchered from each station haven been identified as has a large proportion of the sponges. For the benthic filter feeders a greater emphasis was placed on a complete analysis of catch numbers and biomass of the different growth forms at each station rather than on an exhaustive taxonomic effort.

## 3.2 Fishes

### 3.2.1 Taxonomic and Collection Scope

Fishes were collected using a CSIRO Semi V Wing trawl net (McKenna trawl net) or an epibenthic sled (Pitcher et al. 2016) at 103 stations including 100 stations within the study area during the RV Investigator Voyage (INV2017_05).

Fishes were sorted onboard into species or operational taxonomic units (OTUs), depending on level of difficulty, given time constraints to clear the catch. Voucher specimens were photographed, sampled for genetics and either preserved onboard in 10% formaldehyde or frozen for later fixation. Counts and weights of each taxon were recorded and databased. In almost all cases, large sharks and rays were photographed, measured, fin-clipped for genetic analyses and released alive. A reference collection of the vast majority of species (excluding most large elasmobranchs) has been registered and deposited into the CSIRO Australian National Fish Collection (ANFC), Hobart.

To maintain consistency with taxonomic identifications, most fishes were identified onboard by John Pogonoski, with assistance from Alastair Graham (both CSIRO ANFC). Keith Sainsbury identified all specimens of *Saurida* spp. (Synodontidae), Carangidae and Mullidae onboard to maintain stability of identifications with those groups, although some needed to be revisited post voyage. For uniformity of data recording, all onboard fish data were entered by Margaret Miller (CSIRO). During and post-voyage, expert taxonomists were contacted to assist with the identification of various fish groups via the transfer of images, data and occasionally by the loan of preserved specimens. Experts who assisted (in taxonomic order) included William White and Peter

Last (elasmobranchs; some identifications confirmed remotely during voyage), Yusuke Hibino (Ophichthidae), Barry Russell (Synodontidae and Nemipteridae), Keita Koeda (Carapidae - genus *Onuxodon*), Rudie Kuiter (Solenostomidae), Glenn Moore (Syngnathidae and miscellaneous groups), Hiroyuki Motomura (Scorpaenidae and miscellaneous groups), Mizuki Matsunuma (Scorpaenidae: Pteroinae, Synanceiidae), Martin Gomon (Triglidae and Uranoscopidae), Jeff Johnson (Aploactinidae, Haemulidae, Pinguipedidae and Acanthuridae), Hisashi Imamura (Platycephalidae), Anthony Gill (Serranidae and Pseudochromidae), Tom Fraser (Apogonidae), Chris Dowling (Sillaginidae), Bill Smith-Vaniz (Carangidae), Seishi Kimura (Leiognathidae), Yukio Iwaksuki (Sparidae), Satoshi Morishita (Sphyraenidae), Ofer Gon (Champsodontidae and Apogonidae: *Jaydia*), Ron Fricke (Callionymidae), Doug Hoese and Helen Larson (Gobiidae), Keichii Matsuura (Tetraodontidae) and Gerry Allen (Pomacentridae and miscellaneous groups).

Approximately 373 fish taxa from 89 families were identified from the breadth of the NWS voyage from 103 sites sampled in late 2017 (Appendix C). For the voyage as whole, the following families had the highest number of identified taxa: Carangidae (19), Apogonidae (18), Labridae (17), Serranidae (16 species), Lutjanidae, Monacanthidae, Nemipteridae and Scorpaenidae (12), Dasyatidae and Platycephalidae (11) and Synodontidae and Lethrinidae (10). Other diverse families included Gobiidae, Bothidae and Tetraodontidae (9), Chaetodontidae and Paralichthyidae (8), Mullidae, Muraenidae and Ostraciidae (7 each), and Syngnathidae (6). All other families had five or less species and 41 families were represented by a single species.

Most species could be identified to species level, but a few taxa remain unresolved due to some groups being in need of or currently in the process of taxonomic revision, including leptocephalus eel larvae (unidentified species of multiple Anguilliformes families), *Ariosoma* spp. (family Congridae), *Pterois* spp (family Scorpaenidae), *Bregmaceros* sp. (family Bregmacerotidae), *Ophidion* sp. (family Ophidiidae), *Onigocia* sp. (family Platycephalidae), *Gymnapogon* spp. and *Ostorhinchus* spp. (family Apogonidae), family Gobiidae, especially *Bathygobius* spp., *Larsonella* spp. and *Sueviota* spp., some flatfishes (order Pleuronectiformes) and *Paramonacanthus* spp. (family Monacanthidae). Some other taxa of uncertain status have a ‘cf’ included in their name to highlight that their identity is uncertain and although the species name listed is possibly the closest species, they may not be that species. Most of these unresolved taxa made up a very small component of the catches.

### 3.2.2 COI barcoding

To aid the morphological identification of fish specimens, muscle samples (~ 0.5 g) were removed from all fish taxa for analysis of the Cytochrome Oxidase mitochondrial DNA barcode gene (COI). DNA was extracted and bi-directionally sequenced using the FishF1, FishF2 and FishR2 primers of Ward et al. (2005); sequencing was undertaken at the Ramaciotti Centre for Genomics, University of New South Wales - http://www.ramaciotti.unsw.edu.au/ and at the CSIRO Marine Laboratories on 3730xl and 3130xl DNA Analyzers, Thermo Fisher Scientific, USA, respectively, for at least one specimen from each taxon that had been sampled (300 taxa or 87% of all species recorded). Forward and reverse sequences were trimmed, de novo assembled, checked by eye and then converted into consensus sequences using Geneious (Biomatters Ltd, New Zealand) vers R8.1.4. Consensus sequences for each sample were compared using the Barcode of Life Data Systems v4 (BOLD) identification system (http://www.boldsystems.org/index.php/IDS_OpenIdEngine) and

GenBank BLASTn (via an internal application in Geneious) to check the similarity of sample sequences against existing database sequences. Species identification was usually based on a percentage of sequence identity, with homology of ≥99% as the criterion used here for species confirmation. On some occasions the COI sequence was not obtainable or the result did not concur with morphological data. In these cases, the identification listed in Appendix C is the closest possible match to a known taxon. Sequences from this survey are available in Barcode of Life Data (BOLD) Systems, http://www.boldsystems.org/.

### 3.2.3 Discussion of species detection methods used

Accurate and thorough documentation of marine biodiversity for any given area is ideally required for effective marine management, especially in the designation, zoning and ongoing monitoring of Marine Parks or areas closed to fishing. A suite of methods are available for species detection, but no single method has been reliably proven to be the ultimate answer. Although non-destructive techniques (e.g. towed video, BRUV, environmental DNA) are often favoured due to their low level of interference with the marine environment, destructive sampling is also required in areas that are poorly studied and to assist with ground-truthing of data collected by non-destructive techniques. For example, a combination of towed video or Baited Remote Underwater Videos (BRUVS) and trawl sampling would allow for greater accuracy of data extrapolation from the towed video or BRUVS alone. Voucher specimens and associated fresh colour images from the trawling allows more accurate identification of towed video or BRUV images as the trawl samples allow for consideration of spatial (distributional) and temporal (seasonal) confirmation. Environmental DNA relies on reference sequences from sampled and known specimens being available in public sequence databases.

Numerous species collected during this NWS survey could not have been reliably detected without destructive sampling. For example, the fish trawl takes advantage of the behavioural aspect of fish schooling allowing a herding effect that is not possible using a smaller beam trawl or sled, where large and/or fast-swimming fishes could easily escape. Only one of 27 sharks and rays was collected by the benthic sled, whereas all 27 species were collected by fish trawl.

BRUVS have their place for detection of large, mobile species that can outswim a trawl net (e.g. tunas, mackerels in the pelagic environment) or when species-specific/fishery-specific questions need to be answered relating to a low number of easily detectable and identifiable species.

However, BRUVS have minimal benefit for species that cannot be reliably identified from images or external appearance (many fishes can only reliably be identified from scale counts, gill raker counts or other internal features) or for cryptic and/or shy species that are not attracted to baits.

The benthic sled collected some rarely recorded (rusty perchlet, *Plectranthias ferrugineus* new species; Dampierian threadtail anthias, *Tosana dampieriensis* and highfin cardinalfish, *Gymnapogon velum* new species), cryptic (e.g. the snake eels *Apterichthus* cf *nariculus* and *Scolecenchelys gymnota*) and nocturnal species (e.g. spinyeye cardinalfish, *Pristiapogon fraenatus*) not collected by the trawl.

### 3.2.4 Novelty

Although the vast majority of fishes collected from the present surveys have been encountered previously in WA, at least three new species were discovered and others are the first records of their species in Australia or Western Australia.

#### New species

Eight specimens of a new perchlet species (rusty perchlet, *Plectranthias ferrugineus* Gill et al. 2021a)) were collected in a sled at operation 358 (site W26), one specimen of a new anthias (Dampierian threadtail anthias, *Tosana dampieriensis* Gill et al. 2021b) was collected in a sled at operation 310 (site W93) and two new species of cardinalfishes of the genus *Gymnapogon* have recently (*Gymnapogon velum* Fraser 2019) or are currently in the process of being described (Fraser, in preparation) after specimens were collected in sled (Operation 310, site W93) and trawl samples (operations 278, 296, 297; sites W92, W51 and W19, respectively). Additional undescribed taxa are possible within the following genera, but await further investigation: *Apogonichthyoides*, *Ariosoma*, *Chromileptes, Lepidotrigla, Ostorhinchus, Solegnathus* and *Velifer.* Undescribed species that were previously known from the survey area include one species each of *Pterois* (Matsunuma, in preparation) and *Bathygobius* (Hoese, in preparation). One specimen of a newly described wrasse (Opaline Razorfish, *Iniistius opalus* Fukui 2018), was trawled (operation 581, site W3) and a single specimen of another known, but undescribed species of *Iniistius* (Fukui, in preparation) was taken in a sled (operation 411, site W59). Several specimens of the newly described Western Queen scorpionfish, *Scorpaena sororreginae* Wibowo & Motomura 2021 were collected by sled and trawl from operations 126 (W10), 169 (W5), 533 (W3), 571 (W14).

#### New Australian records

The Moluccan moray *Gymnothorax moluccensis*, previously known from Indonesia and a few other Indo-Pacific localities, has now been confirmed from Australian waters from two specimens, one each from trawl operations 109 (site W34) and 557 (site W15). The snake eel *Apterichtus nariculus* cf. (sled operation 435, site W58) is also a new record for Australia. The only other known specimens are from Indonesia (McCosker & Hibino, 2015). Several other species are likely to be new Australian records when more fully investigated.

#### New Western Australian records

Taylor's pygmy leatherjacket, *Brachaluteres taylori* was confirmed for the first time from Western Australia from a single specimen collected at trawl operation 539 (site W17).

#### Interesting findings – catsharks associated with sponges

On 20th October 2017 at site W6 (op 174, 32–33 m depth), a large *Ircinia* sponge (family Irciniidae) was trawled that had many holes and tunnels where animals could live. Upon closer investigation, some shark tails were seen protruding from the sponge holes. A total of 30 banded catsharks, *Atelomycterus fasciatus* were discovered living inside this single sponge (Figure 102, Figure 103), revealing an important habitat association not previously documented for this shark. Five individuals (1 juvenile male, 1 juvenile female, 2 late adolescent to mature males and 1 likely mature female) were retained for the CSIRO ANFC and the remaining 25 (9 juvenile males, 11 females and 5 late adolescent to mature males) were released alive. The fact that both adults and juveniles of both sexes were present suggests a possible small home range for this species. No egg cases were found in the sponge, so it is unknown if it is also used as an egg-laying substrate. This catshark is a north-western WA endemic, occurring from Exmouth northwards to Eighty Mile Beach in 25–125 m depth (Last & Stevens, 2009).

**Figure 102. Image showing 30 banded catsharks (*Atelomycterus fasciatus*) removed from a large sponge, *Ircinia* sp. at Site W6.**

**Figure 103. One of the banded catsharks *Atelomycterus fasciatus* collected from Dampier MP (Site W6) retained for the CSIRO ANFC (mature male 38 cm total length).**

## Interesting Findings – smalleye stingray

On 2nd November 2017 at site W81 (op 497, 63 m depth), a mature female smalleye stingray, *Megatrygon microps* (204 cm disc width, 230 cm total length) was captured in the trawl net

(Figure 104, Figure 105). This was the second individual captured during the voyage – the other (female 218 cm disc width) being a week earlier in 68 m depth about 70 km to the north-east. This massive and distinctive semi-pelagic stingray that gives birth to a single pup is a new record for the Western Australian fish fauna. It is known from patchy records across the breadth of the Indian Ocean and western Pacific, but Australian records were previously limited to a few sightings further north and east in the Arafura Sea, Gulf of Carpentaria (Northern Territory) and north-eastern Queensland. The individuals collected on this voyage were photographed and fin-clipped for genetic analysis and released alive; the Montebello MP individual was observed actively swimming after release. Recent molecular research suggests that this species may belong in its own family, separate to the true stingrays of the family Dasyatidae (Last et al. 2016).

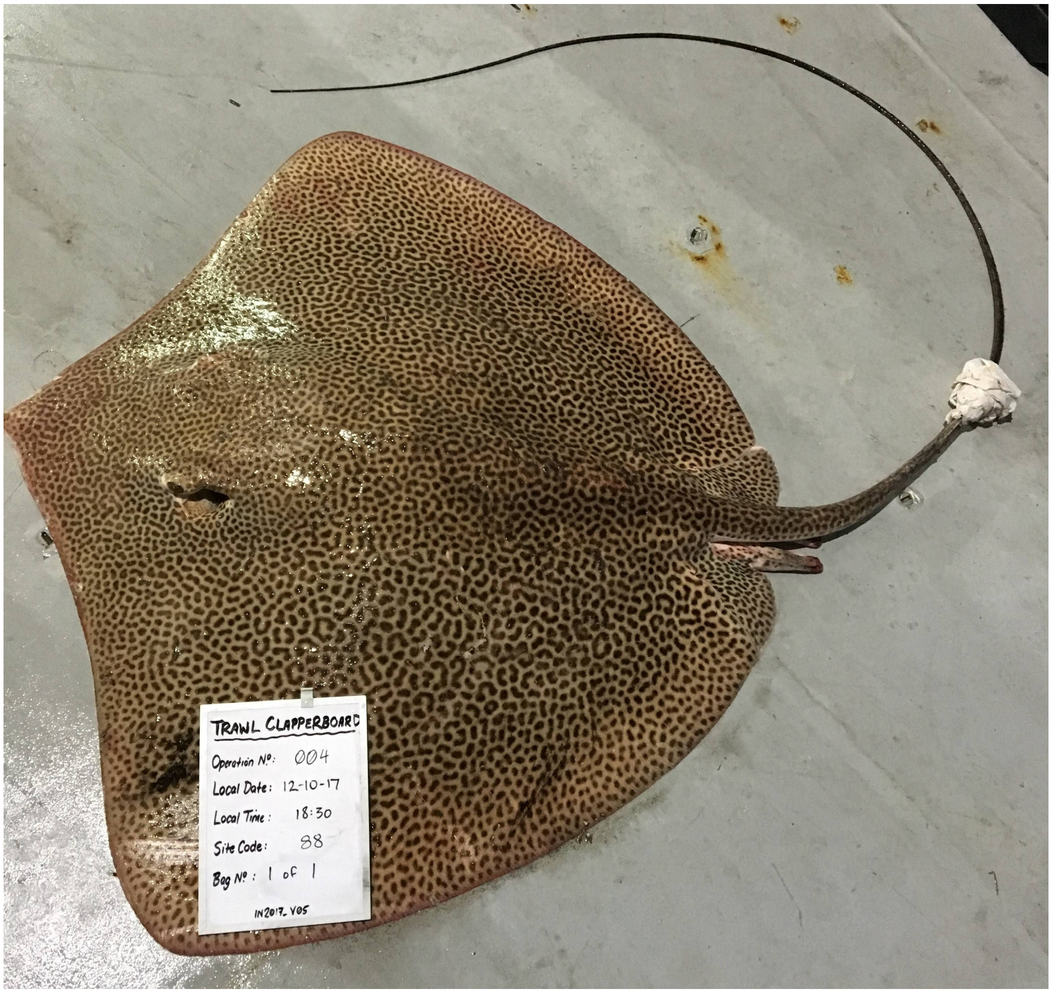
**Figure 104. Smalleye stingray, *Megatrygon microps* captured in the Montebello MP. The hose is being used to maintain water flow over the gills before measurement, DNA sampling and release**

**Figure 105. Smalleye stingray, *Megatrygon microps* captured in the Montebello MP being measured. The hose is being used to maintain water flow over the gills before DNA sampling and release**

### 3.2.5 Elasmobranchs

Twenty seven (27) species of elasmobranchs (sharks and rays) were recorded from the NWS survey, consisting of nine shark species and 18 batoid species (11 stingrays, two guitarfishes, three shovelnose rays, one eagle ray and one butterfly ray). All species were collected with the trawl net and a juvenile of one species (banded catshark, Atelomycterus fasciatus) was collected with the benthic sled. Eight elasmobranchs were recorded from the Montebello MP and five from the Dampier MP. Two species (banded catshark Atelomycterus fasciatus and whitespotted guitarfish, Rhynchobatus australiae) were recorded from both MP's. The small-eye stingray, Megatrygon microps (new record for Western Australia) and the pink whipray, Pateobatis fai had not previously been recorded from the Montebello MP (ALA spatial tool).

Some of the elasmobranch species collected were at maximum or near maximum known sizes of their species. These species included a number of stingrays (family Dasyatidae), e.g. reticulate whipray Himantura australis (Figure 106), 143 cm disc width (DW) and 480 cm total length (TL) (previously recorded to 113 cm DW and 350 cm TL by Last et al. 2016), leopard whipray, Himantura leoparda 183 cm DW and 360 cm TL (previously known to 140 cm DW and 410 cm TL, Last et al. 2016), blackspotted whipray, Maculabatis astra, 92 cm DW and 213 cm TL (previously documented to 80 cm DW and 180 cm TL by Last et al. 2016) and blotched fantail ray, Taeniurops meyeni, 190 cm DW, 260 cm TL (previously known to 180 cm DW and 330 cm TL, Last et al. 2016), the ornate eagle ray, Aetomylaeus vespertilio (family Myliobatidae), 301 cm DW and 365 cm TL (documented to at least 300 cm DW, possibly 350 cm DW and 600 cm TL by Last et al. 2016) and the whitespotted guitarfish, Rhynchobatus australiae (family Rhinidae, Figure 107), 287 cm TL (recorded to 300 cm TL by Last et al. 2016). The large sizes of elasmobranchs from some sites, including mature males and/or females suggests there are important feeding and/or mating areas for these species in the survey area. Very few juvenile elasmobranchs were collected which suggests that the species encountered may be giving birth in shallower, inshore waters.



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Local Date: 12-10-17
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IN2017_V05

Figure 106. Reticulate whipray *Himantura australis* (mature male, 143 cm disc width, 4.8 m TL). The white cloth was used as a safety measure to cover the tail spine while measurements, photos and a fin-clip for genetic analysis was taken and removed before being released alive.

Figure 107. Whitespotted guitarfish, *Rhynchobatus australiae*. Female 287 cm TL released alive after measurement, photo and genetic fin-clip.

### 3.2.6 Syngnathidae (seahorses, pipefishes, etc.)

Four species of Syngnathidae were collected during the survey – all were landed dead or discovered dead late in the sorting process due to their small size and/or camouflage within invertebrate debris.

A single specimen of the zebra seahorse, *Hippocampus zebra* (Figure 108) was collected during the survey (Dampier MP site W6, op 174, 32–33 m depth). This species has previously been recorded from the Dampier MP.

Four specimens of Queensland seahorse, *Hippocampus spinosissimus* (Figure 109) were collected in 54–62 m depth – two outside the MPs (sites W76, W99) and two inside the Montebello MP (site W49 – Op 573 and Op 578). This species has previously been recorded from the Montebello MP.

Five specimens of western spiny seahorse, *Hippocampus angustus* (Figure 110) were collected in 34–63 m depth – all outside the MPs (one each at sites W3, W18 and W95, and two at site W91). This species has a wide distribution in northern Australian from Shark Bay, WA (25°57`S) to east of Agnes Water (24° 11'S), Qld.

All *Hippocampus* specimens were loaned to Dr Glenn Moore (Western Australian Museum), who is undertaking taxonomic and molecular investigations into the genus with international collaborators.

Two specimens of western pipehorse, *Solegnathus* sp. 2 [of Kuiter, 2009] (Figure 111) were collected in 73–97 m depth, both outside the MPs (sites W12, W68). This species is possibly undescribed and has also been referred to as *Solegnathus hardwickii*. Its taxonomic status and distribution needs further research. The voucher specimens and associated genetic material collected from this survey will aid resolving its identity.

**Figure 108. Zebra seahorse, *Hippocampus zebra* (juvenile male, 32 mm height)**

**Figure 109. Queensland seahorse, *Hippocampus spinosissimus* (male, 80 mm height)**

**Figure 110. Western spiny seahorse, *Hippocampus angustus* (female, 60 mm height)**

**Figure 111. Western pipehorse, *Solegnathus* sp. 2 [of Kuiter, 2009] (450 mm standard length)**

## 3.3 Soft Corals (Octocorallia, Hexacorallia, Ceriantipatharia)

### 3.3.1 Introduction

Soft corals and sea fans are a major component of coral reef communities and marine benthos, and among the most important contributors to the total biomass of Indo-Pacific coral reef systems (Tursch and Tursch 1982; Fabricius and Alderslade 2001). Soft corals and sea fans occur worldwide in all benthic habitats from the intertidal to abyssal depths. In the tropical Indo-Pacific they are represented by over 90 genera (Fabricius and Alderslade 2001). Octocorals perform important functions in tropical environments as they provide substrata for primary production, habitats for other invertebrates and fishes, increase the topographic complexity of the seabed, and influence physical seabed processes. Despite their ecological importance, the diversity of octocorals remains poorly known and new species, genera and families are still discovered and described (e.g. Breedy et al. 2012; McFadden and van Ofwegen, 2013; Bryce et al. 2015; Bryce & Wilson 2018). Surveys into octocoral diversity are fundamental to assessing the biodiversity of ecosystems with respect to ecosystem function (food web-dynamics and conductivity), assessing the long term changes in benthic community structure and understanding and monitoring the outcomes of habitat recovery after disturbance (Williams 1992, Fabricius et al. 2007, Chanmethakul et al. 2010, Benayahu et al. 2012, Shackleton and Rees 2016). The aim of this part of the study was the assessment of marine biodiversity of the soft coral and gorgonian fauna on the NWS off the coast of WA over a wide range of habitats and locations as part of determining long-term recovery of trawled communities, and to comment on diversity trends, community composition and spatial patterns of this faunal group.

### 3.3.2 Methods

#### Taxonomic and collection scope

Cnidarian vouchers were collected using a CSIRO Semi V Wing trawl net (McKenna trawl net) or an epibenthic sled (Pitcher et al. 2016) at 100 stations during the RV *Investigator* Voyage (INV2017_05). All soft corals and sea fans (Alcyonacea) were sorted into morphotypes (massive, /whips, fans, *Dendronephthya*) and all cnidarian into size categories (<25 cm, 25–50 cm, 50–100 cm, >100 cm). Counts and weights of each morphotype and size category combination were recorded and databased. Cnidarian vouchers were collected at each station for further taxonomic determinations to species level utilising either the binomial species or OTU concepts. Species within the genus *Dendronephthya* (Alcyonacea, Nephtheidae) and the genus *Pteroeides* (Pennatulacea, Pennatulidae) were identified to genus level only due to high taxonomic uncertainty resulting from high level of intracolony and intraspecies variability (McFadden et al. 2009, Williams 1995). The concept of morphospecies assumes that each OTU represents a single species, which has not been identified using the Linnaean binomial system; they have differences in morphological characters from published descriptions and/or are preliminary identifications. Subsequent research will determine if they represent an undescribed species or have been previously described in historic taxonomic literature. A reference collection of all species has been registered and deposited in the Western Australian Museum, Perth.

### Morphological identification

Vouchers were photographed, counted and weighed on deck and then preserved in 100% ethanol until transferred into 75% ethanol at the CSIRO laboratory. Soft coral and sea fan sclerites were prepared for microscopy by cutting small subsamples from the voucher from five different regions (polyps, surface of the polyp region, surface of the base, interior of the polyp region and interior of the base), which were put into dissolved sodium hypochlorite (13% available chlorine). After the organic material had dissolved, the sclerites were rinsed with distilled water and dried on a glass microscope slide for further investigation. *Durcupan ACM*(™) was used as a mounting medium for permanent slides (Fabricius and Alderslade 2001). Sea pen sclerites were examined by dissolving small subsamples from the voucher from the polyps, surface of the polyp region, surface of the base, and interior of the base, on a microscope slide (sodium hypochlorite, 13% available chlorine). Hard corals were bleached in sodium hypochlorite (13% available chlorine) until all organic matter was dissolved and then rinsed in water.

## 3.3.3 Species composition and assemblages of higher Alcyonacean octocoral taxa

One hundred and thirty three species (133) within the subclass Octocorallia, Order Alcyonacea were identified. All five suborders within the Alcyonacea were present, representing 14 families and 44 genera (Bayer 1981) (Table 9). The five suborders comprised 2 Stolonifera octocoral species, 32 Alcyoniina, 12 Scleraxonia, 73 Holaxonia, and 14 Calcaxonia (Figure 112). Species belonging to *Dendronephthya* (Nephtheidae) were identified to genus only due to high taxonomic uncertainty as a result of a high level of intracolony and intraspecies variability (McFadden et al. 2009). Nevertheless, the high variability in colony shape and colour, and the extreme high biomass at many locations suggests a high diversity within this genus. The following families had the highest number of identified taxa: Plexauridae (58), Nephtheidae (13), Acanthogorgiidae (13), Ellisellidae (12) and Nidaliidae (10) (Figure 112). All other families were represented by only a few species (1–9).

Within the suborder Stolonifera, only two species within the family Clavulariidae were present in the survey area (Table 1). *Telesto arborea* Wright & Studer, 1889 was common in the turbid coastal areas. *Paratelesto* Utinomi, 1958 (Coelogorgiidae) was a new Australian geographical record from this survey.

The suborder Alcyoniina was presented with the families Alcyoniidae (4 genera), Nephtheidae (4), Viguieriotidae (1), and Nidaliidae (3) (Table 9). The family Alcyoniidae showed extremely low biodiversity with only four species found in the survey area. One new species, *Eleutherobia sumbawaensis* Verseveldt & Bayer, 1988 was collected at close proximity at station 57 (PFTP Area 3) and station 88 (PFTP Area 4) from a depth of approximately 80 meters. This small digitate species was first described from Indonesia in 1988 and seems to present a new Australian geographical record from this survey.

The suborder Alcyoniina was strongly represented by the family Nephtheidae with the genera *Dendronephthya*, *Chromonephthea*, *Scleronephthya*, and *Umbellulifera* respectively. Species within the genus *Dendronephthya* (Nephtheidae) were not identified to species level due to high taxonomic uncertainty, and have been treated in this report as ‘one species’ (McFadden et al. 2009). Nevertheless, the high variability in colony shape and colour suggests a high diversity within this genus. The family Nidaliidae included eight species of *Chironephthya*, one species of

*Siphonogorgia*, and *Nephthyigorgia kükenthali* Broch, 1916. *N. kükenthali* was common in the inshore area. This species was first described from Cape Jaubert, south of Broome and thought rare, but can now be considered very abundant from sandy environments of the Pilbara region (Keesing et al. 2011; Pitcher et al. 2016; Bryce et al. 2018). The same seems to hold true for the rarely reported species *Studeriotes crassa* Kükenthal, 1910 (Viguieriotidae). No specimens from the family Xeniidae were collected in the survey area.

Within the Scleraxonia the sea fans *Annella reticulata* (Ellis & Solander, 1786), *Subergorgia suberosa* (Pallas, 1766), *Melithaea* spp., and *Parisis australis* Wright & Studer, 1889 were abundant, as well as *Solenocaulon tortuosum* and *Iciligorgia mjoebergi* within the family Anthothelidae. The high abundance of *S. tortuosum* was remarkable. It is known to have a wide Indo-Pacific distribution in turbid, silty environments with strong currents, but was thought to be uncommon in Australia. *P. australis* was considered to be rare in shallow waters, but was collected from 30-103 metres in the survey area.

Within the suborders Holoxonia the family Plexauridae was extremely abundant and speciose with all genera represented. Several genera were thought to be uncommon (*Euplexaura, Bebryce, Echinomuricea, Trimuricea, Paracis, Paraplexaura*), but can now be considered very abundant from sandy environments of the Pilbara region (Keesing et al. 2011; Pitcher et al. 2016; Bryce et al. 2018). This has been confirmed by this survey.

Within the suborder Calcaxonia the family Ellisellidae was very diverse with sea whip and sea fan species, *Ctenocella pectinata*, *Dichotella gemmacea*, *Junceella fragilis* and *J. juncea*, *Ellisella*, *Verrucella*, and *Viminella* being very common. The family Primnoidae was the only other family represented within the Calcaxonia. *Plumarella penna* was collected from a depth range between 33-65 metres. This delicate, feather-like, soft coral has rarely been recorded from shallow waters (< 60 m). Only a few specimens within the genus *Callogorgia* were so far collected from the West coast of Australia and are held in WAM. At this stage it can be considered extremely rare. We collected *Callogorgia* at three offshore sites in close proximity (PFTF Area 1 – station 26, 29, 32) from a depth range between 64-111 metres.

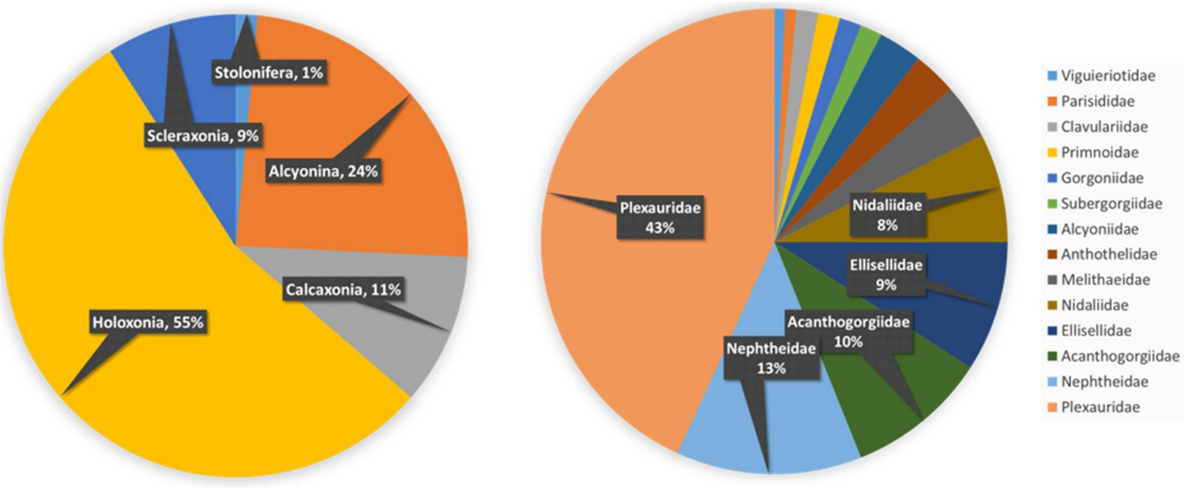

**Figure 112**. **Composition of octocoral taxa. Left chart shows Orders and right chart shows Families**

## Table 9. Species of Octocorallia (Alcyonacea) recorded from the Kimberley North West Shelf (NWS) survey area (RV INV_05 2017)

| **Taxa** |
|---|
| **STOLONIFERA** |
| CLAVULARIIDAE |
| *Telesto arborea* Wright & Studer, 1889 |
| *Paratelesto* sp. 1 |
| **ALCYONIINA** |
| ALCYONIIDAE |
| *Cladiella* sp. 1 |
| *Klyxum* sp. 1 |
| *Eleutherobia sumbawaensis* Verseveldt & Bayer, 1988 |
| *Sinularia* sp. 7 |
| NEPHTHEIDAE |
| *Chromonephthea aldersladei* van Ofwegen, 2005 |
| *Chromonephthea benayahui* van Ofwegen, 2005 |
| *Chromonephthea cf. rubra* (Kükenthal, 1910) |
| *Chromonephthea complanata* (Kükenthal, 1910) |
| *Chromonephthea dampierensis* (Verseveldt, 1977) |
| *Chromonephtea* spp. |
| *Dendronephthya* spp. |
| *Scleronephthya* sp. 1-5 |
| *Umbellulifera* sp. 1-6 |
| NIDALIIDAE |
| *Chironephthya* sp. 1-8 |
| *Nephthyigorgia kükenthali* Broch, 1916 |
| *Siphonogorgia* sp. 1 |
| VIGUIERIOTIDAE |
| *Studeriotes crassa* Kükenthal, 1910 |
| **SCLERAXONIA** |
| ANTHOTHELIDAE |
| *Alertigorgia mjöbergi* Broch, 1916 |
| *Iciligorgia brunnea* (Nutting, 1911) |
| *Iciligorgia* sp. 1 |
| *Solenocaulon tortuosum Gray, 1862* |
| SUBERGORGIIDAE |
| *Annella reticulata* (Ellis & Solander, 1786) |
| *Subergorgia suberosa* (Pallas, 1766) |
| MELITHAEIDAE |
| *Melithaea* spp. |
| PARASIDIDAE |
| *Parisis australis* Wright & Studer, 1889 |
| **HOLOXONIA** |

| |
|---|
| ACANTHOGORGIIDAE |
| *Acanthogorgia* (sp. 1-7) |
| *Anthogorgia* (sp. 1-3) |
| *Muricella* (sp. 2-4) |
| PLEXAURIDAE |
| *Astrogorgia* sp. 2-12 |
| *Bebryce studeri* Whitelegge, 1897 |
| *Bebryce* sp. 1-3 |
| *Echinogorgia* sp. 1-3 |
| *Echinogorgia* sp. 22-26 |
| *Echinomuricea* sp. 1-2 |
| *Echinomuricea* sp. 3-5 |
| *Euplexaura* sp. 1 |
| *Euplexaura* sp. 5-12 |
| *Menella* sp. 2 |
| *Menella* sp. 6-7 |
| *Menella* sp. 8-9 |
| *Paracis* sp. 1 |
| *Paraplexaura* sp. 6-11 |
| *Trimuricea* sp. 1-2 |
| *Villogorgia* sp. 1-2 |
| GORGONIIDAE |
| *Pseudopterogorgia australiensis* (Ridley, 1884) |
| *Guaiagorgia anas* Grasshoff & Alderslade, 1997 |
| **CALCAXONIA** |
| ELLISELLIDAE |
| *Ctenocella pectinata* (Pallas, 1766) |
| *Dichotella gemmacea* (Milne Edwards & Haime, 1857) |
| *Ellisella* sp. 1. |
| *Ellisella* sp. 3 |
| *Junceella fragilis* (Ridley, 1884) |
| *Junceella juncea* (Pallas, 1766) |
| *Verrucella* sp. 1 |
| *Verrucella* sp. 3 |
| *Verrucella* sp. 5 |
| *Viminella* sp. 1 |
| *Viminella* sp. 2 |
| *Viminella* sp. 3 |
| PRIMNOIDAE |
| *Plumarella penna* (Lamarck, 1815) |
| *Callogorgia* sp. 1 |

## 3.4 Sponges

### 3.4.1 Introduction

Sponges (Phylum Porifera) are filter feeders and the oldest metazoan group on Earth. They have been found in all aquatic habitats including freshwater, from intertidal to deep water marine habitats. Sponge species grow in very distinct shapes, from encrusting to massive or large cups or barrels. They have very different colours and smells and an important source of natural chemicals for products like pharmaceuticals. Their body organisation is simple and supported by a siliceous and/or spongin skeleton which is the main characteristic used for their classification and taxonomic identification.

Sponges are one of the most abundant and diverse group of invertebrates inhabiting the NWS. The area is reported as a sponge biodiversity hotspot with approximately 344 species and a 37% of 'apparent endemics' (species counts include OTUs) one of the highest reported for Australia (Hooper et al. 2002).

Although prior to this study, limited sampling had been carried out within many parts of the NWS, the sponge diversity of Dampier Archipelago is reasonably well known. Dampier Archipelago has been surveyed previously, and sponge collections made by SCUBA and limited to shallow waters are available. Those studies (Fromont 2004; 2006) reported a range of 150 sponge species, based in quantitative survey to 275 from non-quantitative surveys. Quantitative surveys captured only 56–80% of the sponge diversity and indicated that 48% were 'apparent endemics' supporting conclusions of Hooper et al. (2002). Despite nearly half of the sponge fauna potentially being endemic, the area remains poorly known in terms of sponge biodiversity and only three species and one new genus have been named so far: *Anthotethya fromontae* Sara &Sara, 2002; *Laxotethya dampierensis* Sara & Sara, 2002, *Tetrapocilon bergquistae* Fromont, Alvarez, Gomez & Roberts, 2010. A survey of the southern Pilbara by CSIRO in 2013 (PMCP study, Pitcher et al. 2016) overlapped in the southern part of our study area (near Barrow Island) and showed the area holds a high diversity of sponges. Approximately 114 different species were found in that survey. At least one new species, *Ceratopsion montebelloensis* Hooper, 1993 has been described from this area.

### 3.4.2 Collections made and species identification

Sponge specimens were collected using a CSIRO Semi V Wing trawl net (McKenna trawl net) or an epibenthic sled (Pitcher et al. 2016) in the surveyed stations between 30 and 70 m. Once on deck they were sorted in morphotypes (i.e. Massive, Erect, Cups, see Figure 113) following the classification system developed by Christine Schoenberg (Australian Institute of Marine Sciences) and Jane Fromont (Western Australian Museum, WAM), and those into size categories (<25 cm, 25–50 cm, 50–100 cm, >100 cm) giving a total of 12 sorting categories. Fragments of specimens that could not be unambiguously assigned to any of the categories were separated in a different category. Individual counts and weights were recorded for each category. One representative specimen of each morphospecies (i.e. species that look different based on external morphology) included in the sorted categories was separated and photographed. A subsample was preserved in 100% ethanol or frozen for taxonomic identification. Selected entire specimens were preserved frozen for exhibition display or for future genetic studies. Some specimens were also selected for fluorescence studies by Dr. Peter Karuso (Macquarie University, NSW).

A thick section and spicule slide was prepared from each sponge voucher using standard methods (Rützler, 1978), identified to genus following Hooper & van Soest (2002), and assigned to valid species as listed in the current version of the World Porifera database (van Soest et al., 2018) using available taxonomic literature. Specimens that did not fully agree with all the characters described for the species were denoted with 'cf.' A unique code or OTU was assigned to unknown or undescribed species and matched to existing ones deposited at WAM. We used the WAM OTU code if matches were found, to facilitate future comparisons of species composition and richness in the area. A few specimens lacked characters for recognition beyond the genus level and were denoted with '?'.

Sponge collections of the WAM, Queensland Museum and Northern Territory Museum and, records from scientific literature have been published in the Atlas of Living Australia (ALA) (https://www.ala.org.au/) allowing us to find which species have been previously recorded for the area. Using the spatial search tool of that platform we listed species recorded in a demarcated area in the Pilbara bio-region and within the surveyed MPs and compared it to the species recorded in this study. We also interrogated the WAM database and extracted registered specimens that have been previously found in the surveyed area for further comparisons of the sponge biodiversity.

### 3.4.3 Taxa sampled

For this study, a full sponge species catch composition could only be achieved for the 11 stations that fell within the Dampier and Montebello MPs. This was made possible by additional project funds being provided by Parks Australia for post voyage taxonomy of some invertebrate groups. A total of 365 sponge vouchers were examined and identified to species/OTU level. Table 10 shows the list of taxa identified for the surveyed stations. Only one specimen from the Class Calcarea was represented in the collection. All the rest belonged into the class Demospongiae. A total of 153 species from 12 orders, 38 families and 87 genera were found. Only 73 of those could be assigned to previously described species.

Eighty species were assigned to OTUs (Table 10) as they could not be assigned to known species. Approximately 60% of those matched OTUs from the WA Museum (WAM) collections which suggest they have been found in the Western Australian waters previously. OTUs labelled with the prefix '0BA' in Table 10 could not be match to existing OTUs and are likely to be either new species or new records for the area. The 153 species belong to a diverse number of families (Figure 114). The families with the greatest number of species were Raspailiidae, followed by the Callyspongiidae and Axinellidae (Figure 114). The most common species in these families were *Echinodictyum mesenterinum, Arenosclera WAM sp. 1 cf.* and *Axinella aruensis* (variety II) respectively (Figure 115). Most species found (78%) were singletons suggesting the area has high levels of endemism.

Full taxonomic documentation and even genetic studies are necessary to fine-tune the sponge diversity knowledge of what appear to be a highly diverse area as reported by previous studies. The standardisation of sponge identifications done by different taxonomists is an essential step to achieve this. However, there is no doubt that the area supports one of the highest sponge diversities recorded for Australian waters.

**Figure 113. Examples of some of the sponge morphotypes sorted by size categories during the 2017 survey**

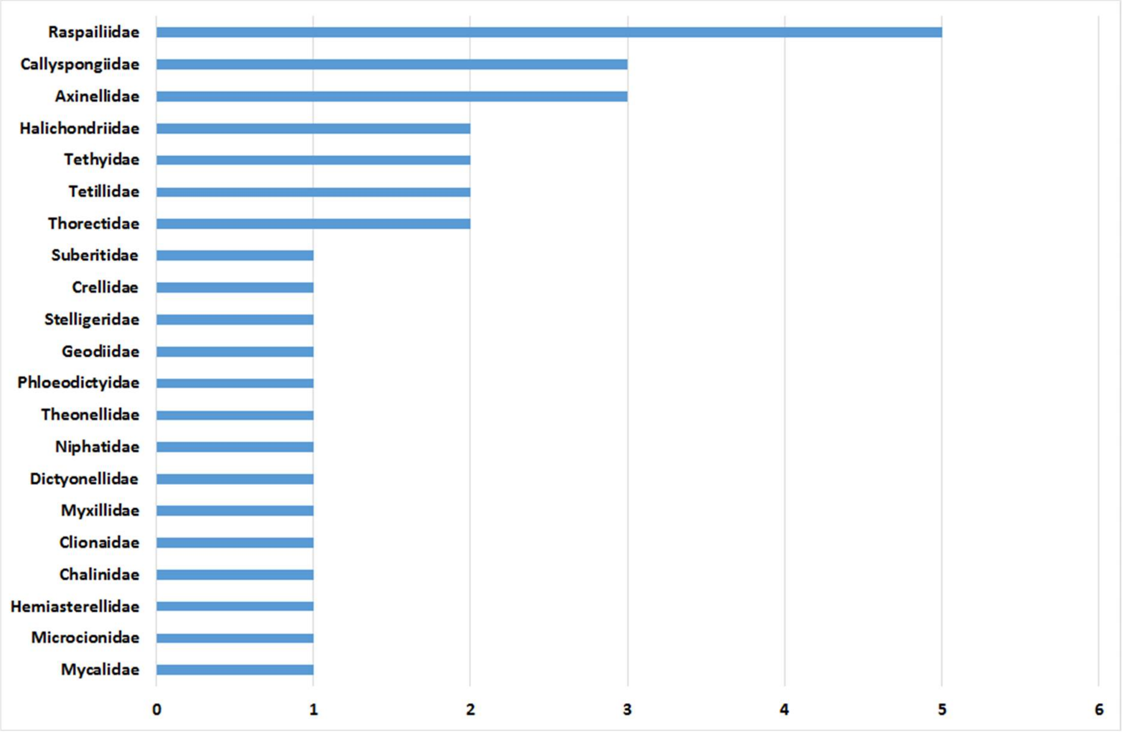

Figure 114. Sponge families found in Dampier and Montebello MPs sorted by number of occurrences.

Figure 115. Common sponge species found in Dampier and Montebello MPs. A–B *Echinodictyum mesenterinum,* B, *Arenosclera WAM sp. 1 cf.* D-E *Axinella aruensis* varieties.

**Table 10. List of sponge species and their higher taxonomic classification found in the Dampier and Montebello MP stations (W4, W6, W8, W14, W49, W50, W79, W80, W81, W82, W97). 'cf.': specimens that lack some of the diagnostic characteristics of the species. '?': specimens that could not be identified beyond the level of genus**

| CLASS | ORDER | FAMILY | GENUS | SPECIES/OTUs |
|---|---|---|---|---|
| Calcarea | Clathrinida | Leucetiidae | *Leucetta* | ? |
| Demospongiae | Axinellida | Axinellidae | *Axinella* | *aruensis* I |
| Demospongiae | Axinellida | Axinellidae | *Axinella* | ? |
| Demospongiae | Axinellida | Axinellidae | *Axinella* | *aruensis* |
| Demospongiae | Axinellida | Axinellidae | *Axinella* | WAM sp. Ng3 cf. |
| Demospongiae | Axinellida | Axinellidae | *Axinella* | *sinoxea* cf. |
| Demospongiae | Axinellida | Axinellidae | *Axinella* | *aruensis* II |
| Demospongiae | Axinellida | Axinellidae | *Dragmacidon* | 0BA1 |
| Demospongiae | Axinellida | Axinellidae | *Phakellia* | *tropicalis* cf. |
| Demospongiae | Axinellida | Axinellidae | *Phycopsis* | *pesgalli* |
| Demospongiae | Axinellida | Axinellidae | *Pipestela* | *occidentalis* |
| Demospongiae | Axinellida | Axinellidae | *Ptilocaulis* | *spiculifer* cf. |
| Demospongiae | Axinellida | Axinellidae | *Reniochalina* | WAM0006 |
| Demospongiae | Axinellida | Axinellidae | *Reniochalina* | *stalagmitis* |
| Demospongiae | Axinellida | Heteroxyidae | *Myrmekioderma* | *granulata* |
| Demospongiae | Axinellida | Raspailiidae | *Ceratopsion* | 0BA1 |
| Demospongiae | Axinellida | Raspailiidae | *Ceratopsion* | *montebelloensis* |
| Demospongiae | Axinellida | Raspailiidae | *Ceratopsion* | *palmatum* |
| Demospongiae | Axinellida | Raspailiidae | *Echinodictyum* | *clathrioides* |
| Demospongiae | Axinellida | Raspailiidae | *Echinodictyum* | *conulosum* |
| Demospongiae | Axinellida | Raspailiidae | *Echinodictyum* | *cancellatum* cf. |
| Demospongiae | Axinellida | Raspailiidae | *Echinodictyum* | *cancellatum* |
| Demospongiae | Axinellida | Raspailiidae | *Echinodictyum* | *mesenterinum* |
| Demospongiae | Axinellida | Raspailiidae | *Ectyoplasia* | *vannus* |
| Demospongiae | Axinellida | Raspailiidae | *Ectyoplasia* | *tabula* |
| Demospongiae | Axinellida | Raspailiidae | *Raspailia* | *compressa* |
| Demospongiae | Axinellida | Raspailiidae | *Raspailia* | 0BA1 |
| Demospongiae | Axinellida | Raspailiidae | *Raspailia* | *vestigifera* |
| Demospongiae | Axinellida | Raspailiidae | *Raspailia (Clathriodendron)* | *keriontria* |
| Demospongiae | Axinellida | Raspailiidae | *Sollasella* | WAM n sp. |
| Demospongiae | Axinellida | Raspailiidae | *Thrinacophora* | *cervicornis* |
| Demospongiae | Axinellida | Raspailiidae | *Trikentrion* | *flabelliforme* |
| Demospongiae | Axinellida | Stelligeridae | *Higginsia* | *mixta* |
| Demospongiae | Bubarida | Dictyonellidae | *Acanthella* | *pulcherrima* |
| Demospongiae | Bubarida | Dictyonellidae | *Acanthella* | *cavernosa* cf. |
| Demospongiae | Bubarida | Dictyonellidae | *Acanthella* | *pulcherrima* cf. |
| Demospongiae | Bubarida | Dictyonellidae | *Phakettia* | *virgultosa* |
| Demospongiae | Bubarida | Dictyonellidae | *Phakettia* | *euctimena* |
| Demospongiae | Bubarida | Dictyonellidae | *Stylissa* | *carteri* |
| Demospongiae | Bubarida | Dictyonellidae | *Stylissa* | *carteri* cf. |
| Demospongiae | Clionaida | Clionaidae | *Spheciospongia* | *congenera* |
| Demospongiae | Clionaida | Clionaidae | *Spheciospongia* | *vagabunda* |

| | | | | |
|---|---|---|---|---|
| Demospongiae | Clionaida | Placospongiidae | *Placospongia* | *melobesioides* cf. |
| Demospongiae | Dendroceratida | Darwinellidae | Darwinellidae_unknown genus | ? |
| Demospongiae | Dendroceratida | Darwinellidae | *Dendrilla* | *lacunosa* |
| Demospongiae | Dendroceratida | Dictyodendrillidae | *Dictyodendrilla* | 0BA1 |
| Demospongiae | Dictyoceratida | Dysideidae | *Dysidea* | 0BA1 |
| Demospongiae | Dictyoceratida | Dysideidae | *Dysidea* | 0BA2 |
| Demospongiae | Dictyoceratida | Dysideidae | *Euryspongia* | 0BA1 |
| Demospongiae | Dictyoceratida | Irciniidae | *Ircinia* | 0BA4 |
| Demospongiae | Dictyoceratida | Irciniidae | *Ircinia* | 0BA1 |
| Demospongiae | Dictyoceratida | Irciniidae | *Ircinia* | 0BA2 |
| Demospongiae | Dictyoceratida | Irciniidae | *Ircinia* | 0BA3 |
| Demospongiae | Dictyoceratida | Irciniidae | *Ircinia* | *irregularis* cf. |
| Demospongiae | Dictyoceratida | Irciniidae | *Ircinia* | *pinna* cf. |
| Demospongiae | Dictyoceratida | Irciniidae | *Ircinia* | NTM sp. 0089/WAMSI Ircinia sp. 1 |
| Demospongiae | Dictyoceratida | Irciniidae | *Ircinia* | *irregularis* |
| Demospongiae | Dictyoceratida | Irciniidae | *Sarcotragus* | WAM sp. PB1 |
| Demospongiae | Dictyoceratida | Spongiidae | *Coscinoderma* | 0BA1 |
| Demospongiae | Dictyoceratida | Spongiidae | *Hippospongia* | 0BA1 |
| Demospongiae | Dictyoceratida | Spongiidae | *Hippospongia* | 0BA2 |
| Demospongiae | Dictyoceratida | Spongiidae | *Hyattella* | *intestinalis* cf. |
| Demospongiae | Dictyoceratida | Spongiidae | *Hyattella* | WAM sp. 1 cf. |
| Demospongiae | Dictyoceratida | Spongiidae | *Hyattella* | ? |
| Demospongiae | Dictyoceratida | Spongiidae | *Hyattella* | WAM sp.1 cf. |
| Demospongiae | Dictyoceratida | Spongiidae | *Spongia* | 0BA1 |
| Demospongiae | Dictyoceratida | Thorectidae | *Aplysinopsis* | NTM sp. 017 |
| Demospongiae | Dictyoceratida | Thorectidae | *Dactylospongia* | 0BA1 |
| Demospongiae | Dictyoceratida | Thorectidae | *Fascaplysinopsis* | 0BA1 |
| Demospongiae | Dictyoceratida | Thorectidae | *Hyrtios* | 0BA1 |
| Demospongiae | Dictyoceratida | Thorectidae | *Strepsichordaia* | 0BA1 |
| Demospongiae | Dictyoceratida | Thorectidae | *Thorectandra* | *excavatus* |
| Demospongiae | Dictyoceratida | Thorectidae | Thorectidae unknown genus_1 | 0BA1 |
| Demospongiae | Dictyoceratida | Thorectidae | Thorectidae unknown genus_2 | 0BA1 |
| Demospongiae | Haplosclerida | Callyspongiidae | *Arenosclera* | WAM sp. EG1 |
| Demospongiae | Haplosclerida | Callyspongiidae | *Arenosclera* | WAM sp. 1 |
| Demospongiae | Haplosclerida | Callyspongiidae | *Arenosclera* | WAM sp. 1 cf. |
| Demospongiae | Haplosclerida | Callyspongiidae | *Callyspongia* | WAM sp. 2 |
| Demospongiae | Haplosclerida | Callyspongiidae | *Callyspongia (Callyspongia)* | WAM sp. K1 |
| Demospongiae | Haplosclerida | Callyspongiidae | *Callyspongia (Callyspongia)* | WAM sp. SS1 cf. |
| Demospongiae | Haplosclerida | Callyspongiidae | *Callyspongia (Cladochalina)* | *aerizuza* cf. |
| Demospongiae | Haplosclerida | Callyspongiidae | *Callyspongia (Toxochalina)* | WAM sp.1 cf. |
| Demospongiae | Haplosclerida | Callyspongiidae | *Callyspongia (Toxochalina)* | WAM sp. 2 |
| Demospongiae | Haplosclerida | Callyspongiidae | *Callyspongia (Toxochalina)* | WAM sp. 1 |
| Demospongiae | Haplosclerida | Chalinidae | *Chalinula* | 0BA1 |

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|---|---|---|---|---|
| Demospongiae | Haplosclerida | Chalinidae | *Haliclona (Gellius)* | NTM sp. 146 |
| Demospongiae | Haplosclerida | Chalinidae | *Haliclona (Haliclona)* | 0BA1 |
| Demospongiae | Haplosclerida | Chalinidae | *Haliclona (Haliclona)* | 0BA2 |
| Demospongiae | Haplosclerida | Chalinidae | *Haliclona (Reniera)* | 0BA1 |
| Demospongiae | Haplosclerida | Niphatidae | *Amphimedon* | WAM sp.3 cf. |
| Demospongiae | Haplosclerida | Niphatidae | *Amphimedon* | *paraviridis* cf. |
| Demospongiae | Haplosclerida | Niphatidae | *Cribrochalina* | 0BA1 |
| Demospongiae | Haplosclerida | Niphatidae | *Gelliodes* | WAM sp. KMB1 cf. |
| Demospongiae | Haplosclerida | Niphatidae | *Gelliodes* | WAM sp. KMB1 |
| Demospongiae | Haplosclerida | Niphatidae | *Niphates* | 0BA1 |
| Demospongiae | Haplosclerida | Petrosiidae | *Acanthostrongylophora* | *ashmorica* |
| Demospongiae | Haplosclerida | Petrosiidae | *Petrosia* | ? |
| Demospongiae | Haplosclerida | Phloeodictyidae | *Oceanapia* | *ramsayi* cf. |
| Demospongiae | Haplosclerida | Phloeodictyidae | *Oceanapia* | *macrotoxa* |
| Demospongiae | Haplosclerida | Phloeodictyidae | *Oceanapia* | WAM sp. SS3 |
| Demospongiae | Haplosclerida | Phloeodictyidae | Phloeodictyidae unknown genus_1 | 0BA1 |
| Demospongiae | Haplosclerida | Phloeodictyidae | *Siphonodictyon* | WAM sp. KB1 |
| Demospongiae | Poecilosclerida | Crellidae | *Crella (Yvesia)* | WAM sp. SS1 |
| Demospongiae | Poecilosclerida | Desmacididae | *Desmacidon* | WAM sp. SS1 cf. |
| Demospongiae | Poecilosclerida | Hymedesmiidae | *Hymedesmia* | dichela ? |
| Demospongiae | Poecilosclerida | Hymedesmiidae | *Phorbas* | WAM CERF sp. 1 cf. |
| Demospongiae | Poecilosclerida | Iotrochotidae | *Iotrochota* | *baculifera* cf. |
| Demospongiae | Poecilosclerida | Iotrochotidae | *Iotrochota* | *baculifera* |
| Demospongiae | Poecilosclerida | Iotrochotidae | *Iotrochota* | NTM sp. 0233 |
| Demospongiae | Poecilosclerida | Microcionidae | *Clathria (Thalysias)* | *reinwardti* |
| Demospongiae | Poecilosclerida | Microcionidae | *Clathria (Thalysias)* | *abietina* cf. |
| Demospongiae | Poecilosclerida | Microcionidae | *Clathria (Thalysias)* | *erecta* |
| Demospongiae | Poecilosclerida | Microcionidae | *Clathria (Thalysias)* | WAM sp. Ng1 |
| Demospongiae | Poecilosclerida | Microcionidae | *Clathria (Thalysias)* | *abietina* |
| Demospongiae | Poecilosclerida | Microcionidae | *Clathria (Thalysias)* | *vulpina* |
| Demospongiae | Poecilosclerida | Mycalidae | *Mycale (Aegogropila)* | WAM sp. 2 |
| Demospongiae | Poecilosclerida | Mycalidae | *Mycale (Aegogropila)* | WAM sp.1 |
| Demospongiae | Poecilosclerida | Myxillidae | *Psammochela* | *tutiae* cf. |
| Demospongiae | Poecilosclerida | Myxillidae | *Psammochela* | *tutiae* |
| Demospongiae | Poecilosclerida | Podospongiidae | *Diacarnus* | WAM sp. SS1 |
| Demospongiae | Poecilosclerida | Tedaniidae | *Tedania* | WAM sp. EG1 |
| Demospongiae | Suberitida | Halichondriidae | *Amorphinopsis* | *excavans* |
| Demospongiae | Suberitida | Halichondriidae | *Axinyssa* | *berquistae* cf. |
| Demospongiae | Suberitida | Halichondriidae | *Ciocalypta* | *stalagmitis* |
| Demospongiae | Suberitida | Halichondriidae | *Halichondria* | *phakellioides* |
| Demospongiae | Suberitida | Halichondriidae | *Hymeniacidon* | WAM sp. SS4 cf. |
| Demospongiae | Suberitida | Halichondriidae | *Hymeniacidon* | WAM sp. SS4 cf. |
| Demospongiae | Suberitida | Suberitidae | *Aaptos* | 0BA1 |
| Demospongiae | Suberitida | Suberitidae | *Caulospongia* | *biflabellata* |
| Demospongiae | Suberitida | Suberitidae | *Caulospongia* | *amplexa* |
| Demospongiae | Tethyida | Hemiasterellidae | *Axos* | *flabelliformis* |
| Demospongiae | Tethyida | Tethyidae | *Tethya* | *ingalli* cf. |

| | | | | |
|---|---|---|---|---|
| Demospongiae | Tethyida | Tethyidae | *Tethya* | *robusta* cf. |
| Demospongiae | Tethyida | Tethyidae | *Xenospongia* | *patelliformis* |
| Demospongiae | Tetractinellida | Ancorinidae | *Asteropus* | ? |
| Demospongiae | Tetractinellida | Ancorinidae | *Jaspis* | WAM sp. SS2? |
| Demospongiae | Tetractinellida | Ancorinidae | *Psammastra* | WAM sp. SS1 cf. |
| Demospongiae | Tetractinellida | Ancorinidae | *Rhabdastrella* | *globostellata* |
| Demospongiae | Tetractinellida | Ancorinidae | *Stelletta* | *clavosa* cf. |
| Demospongiae | Tetractinellida | Ancorinidae | *Stelletta* | WAM sp.CERF 2 |
| Demospongiae | Tetractinellida | Geodiidae | *Geodia* | WAM sp. CERF3 |
| Demospongiae | Tetractinellida | Tetillidae | *Cinachyrella* | NTM sp. 259 |
| Demospongiae | Tetractinellida | Tetillidae | *Cinachyrella* | WAM sp. SS2? |
| Demospongiae | Tetractinellida | Tetillidae | *Cinachyrella* | WAM sp. Ng1 |
| Demospongiae | Tetractinellida | Tetillidae | *Cinachyrella* | *australiensis* |
| Demospongiae | Tetractinellida | Tetillidae | *Tetilla* | WAM sp. SS1 |
| Demospongiae | Tetractinellida | Theonellidae | *Theonella* | *levior* cf. |
| Demospongiae | Trachycladida | Trachycladidae | *Trachycladus* | *laevispirulifer* |
| Demospongiae | Verongiida | Aplysinellidae | Aplysinidae unknown genus_1 | ? |
| Demospongiae | Verongiida | Ianthellidae | *Ianthella* | ? |
| Demospongiae | Verongiida | Ianthellidae | *Ianthella* | *flabelliformis* |
| Demospongiae | Verongiida | Pseudoceratinidae | *Pseudoceratina* | 0BA1 |
| Demospongiae | Verongiida | Pseudoceratinidae | *Pseudoceratina* | 0BA2 |

# 4 2017 North West Shelf survey design

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## 4.1 Introduction

The North West Shelf (NWS) area has a long history of commercial demersal trawling. Prior to the mid-late 1980s, foreign fishing fleets applied most of the trawl effort — particularly Taiwanese pair-trawlers from the early 1970s to the mid-late 1980s. From the mid-late 1980s, a domestic otter-trawl fishery developed, with effort peaking in the mid-1990s and subsequently tapering downwards following new management arrangements. A range of spatial management, where areas were closed to trawling, was introduced in the 1980s due to concerns about impacts of trawling on the seabed and on fish stocks—and to provide opportunities for domestic trap fishing. Further spatial management was introduced through the 1990s.

Associated with these changes were a series of research voyages and sampling surveys undertaken in the years 1982–1983, 1986–1991, 1995 and 1997—as part of a large-scale adaptive management experiment that aimed to assess the effects of spatial closures and different fishing methods (primarily trawling and trapping) on benthic habitat dynamics and overall productivity of the NWS fish stocks (Sainsbury et al. 1987;1988; 1991). This research highlighted trawl impacts on large sessile epi-benthos, such as various sponges and gorgonians, as an important contributing factor to the decline in stocks and change in catch compositions.

A key aim of this study, to be informed by a regional survey in 2017, was to assess the extent of recovery of the trawled seabed communities 25 years after the cessation of foreign pair-trawling and closure of large areas to all trawling. To address this, a key feature of the 2017 survey strategy was to re-sample areas that had been subject to high levels of pair-trawling but then closed and remained untrawled—in addition, other trawl contrasts were also of interest. Further, it was also important to account for environmental gradients that may influence benthos distribution and abundance and potentially confound comparisons of trawl impact effects if not considered.

To implement these features, a period of historical Taiwanese pair-trawl effort was quantified and mapped, as was a recent period of domestic otter-trawl fishery effort—and analyses were conducted to quantify the influence of multiple environmental gradients on the abundance composition of the biotic communities.

## 4.2 Characterising commercial trawling

### 4.2.1 Historical Taiwanese pair-trawling

Taiwanese pair-trawlers fished on the NWS between 1971 and 1989. Fishery logbook data available for the years 1973 to 1981 comprised total catch and effort, as number of hauls, recorded in half-degree square blocks. Later, 'shot-by-shot' fishing data were provided to the

Australian authorities, allowing higher-resolution mapping of the trawl effort for years 1979 to 1989 inclusive, although in 1979 at least these data substantially underestimated annual effort. The trawl start and end positions (latitude & longitude) of these individual shot data were recorded approximately (pre-GPS) and the finest resolution that these data could be reliably gridded to was ~0.05 degree. The annual average grid-cell effort (hours) for the period 1979 to 1985 was used to characterise the distribution and intensity of effort for the "Historical Taiwanese pair-trawling" period (Figure 116).

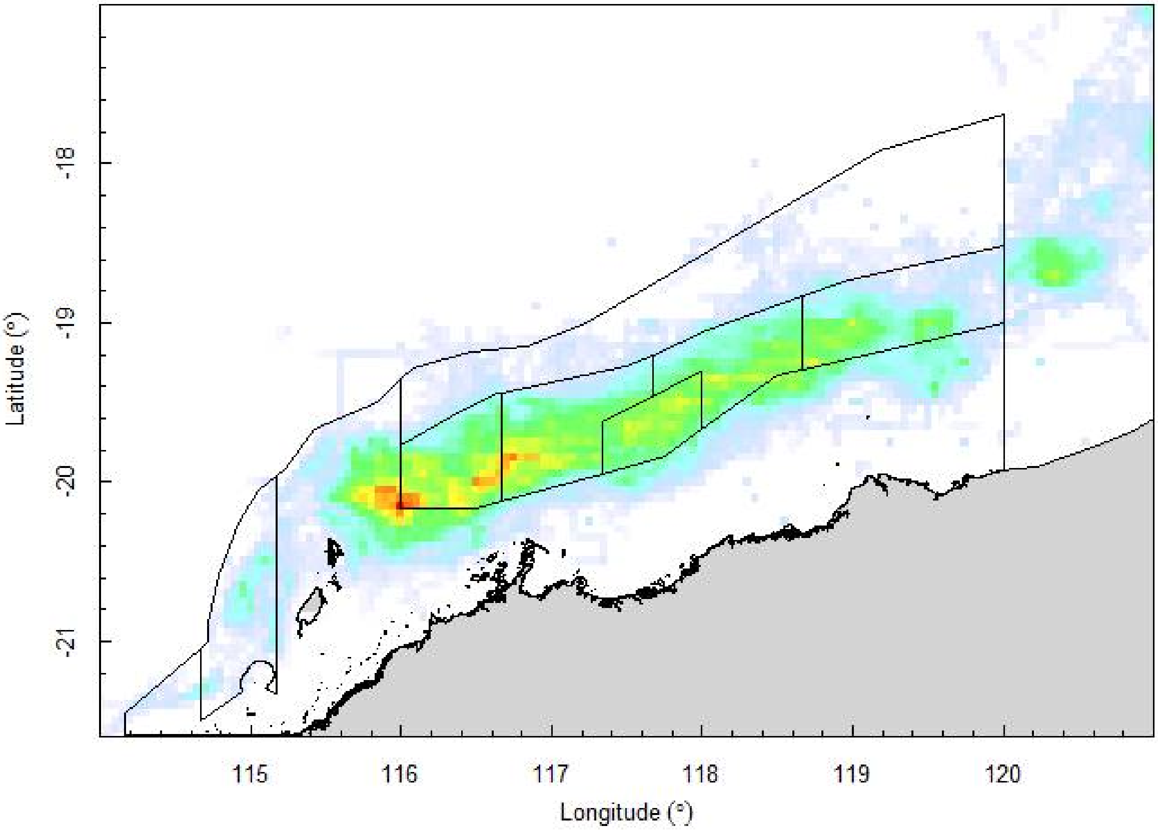


**Figure 116 Map of the NWS region showing the distribution and relative intensity of trawl effort (red=high, blue=low) for the "Historical Taiwanese pair-trawling" period 1979 to 1985. Black polygons outline current Western Australian management areas for their domestic trawl fishery [see Chapter 1].**

For the purpose of seabed impact analyses, trawl effort (e.g. in hours of trawling, per grid cell) needs to be converted to the area of seabed swept (contacted) by the trawl gear, per grid cell. The area swept by each trawl is a function of the bottom-contact width of the gear, the towing speed and the tow duration (hours). Tow durations were provided in the data, and towing speeds were about 3.5 knots based on reports by Shindo (1972), Liu et al. (1978) and Edwards (1983). Bottom-contact widths are difficult to quantify because pair-trawls do not use trawl doors. Initially, an estimate of 100m was used to calculate total swept area, which was sufficient to characterise the relative intensity of historical effort for the sampling design analyses. The total area swept by trawls divided by the area of each grid is the swept-area ratio (SAR) of trawling for each grid. SAR forms a key input to the trawl impact assessment; hence, later a more specific estimate was desired. Schematic diagrams, based on contemporary descriptions of the pair-trawl gear, were indicative of a spread at the head of the sweeps of about 120-125m (Addenda 4.4.1). Subsequent analyses of data from demersal pair-trawling trials conducted in Scotland provided predicted gear ground-contact widths of about 100–130m (mean: ~112m, ±SD 14.1m) (Addenda 4.4.2).

### 4.2.2 Recent domestic otter-trawling

Australian domestic trawling was recorded in commercial logbooks from 1987, but trawl effort remained low until 1989. The early domestic fishery logbook data recorded effort as boat-days in one-degree square blocks. From 1993 onwards, 'shot-by-shot' fishing data recorded in logbooks managed by Western Australian authorities, enabled higher-resolution mapping of the trawl effort for subsequent years. The trawl start and end positions (latitude & longitude) of these individual shot data were recorded more accurately with advent of GPS, and these data could be reliably gridded to 0.01 degree. The annual average grid-cell effort for the period 2005 to 2016 was used to characterise the distribution and intensity of effort for the “Recent domestic otter-trawling” period (Figure 117).

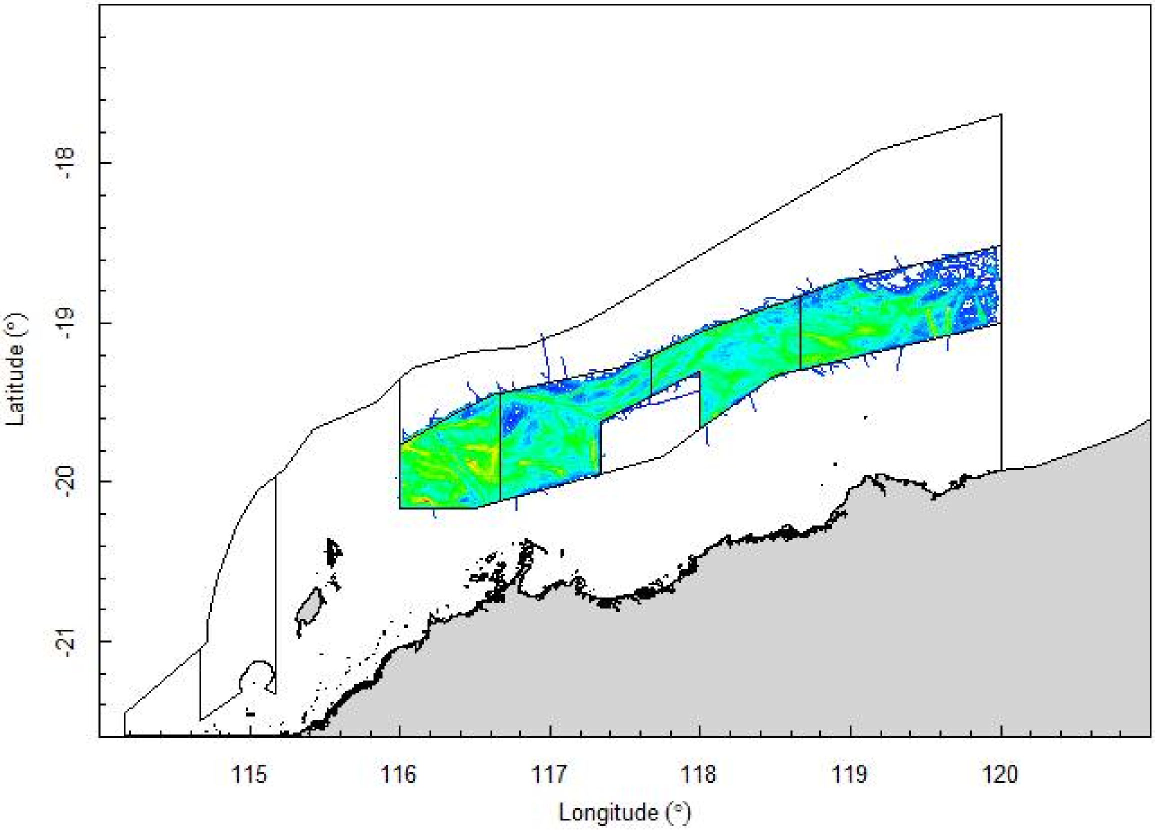


**Figure 117 Map of the NWS region showing the distribution and relative intensity of trawl effort for the “Recent domestic otter-trawling” period 2005 to 2016 (red=high, blue=low). Black polygons outline current Western Australian management areas for their domestic trawl fishery [see Chapter 1].**

The swept area of domestic otter trawling was estimated from tow durations (hours) recorded in logbooks for each trawl, towing speeds of 3.25kn and nominal bottom-contact widths of 100m as commonly used for Australian fish-trawls. This initial estimate was sufficient to characterise the relative intensity of recent effort for the sampling design analyses. Later, for the purpose of seabed impact analyses, an alternative estimate based on logbook data for total sweeps + bridles ≈ 110m, with the door-spread model from Ramm (1995), suggests mean contact width of about 80m.

### 4.2.3 Historical vs Recent trawl contrasts

To establish the suite of trawl contrasts to be sampled, both the historical and recent trawl effort (as SAR) were categorised as zero/low [0,0.01]; low/medium (0.01,0.5]; medium/high (0.5,1]; and high (1,~2]. The entire study area for the survey comprised 24,371 grid cells at 0.01° resolution. The categorised grid cells were mapped (Figure 118) and tabulated (Table 11). Grid cells in the higher trawl effort categories were relatively rare (Table 11), particularly for the recent effort and especially the high historical and high recent combination, but nevertheless required a minimum number of sampling stations to be allocated (at least 3).

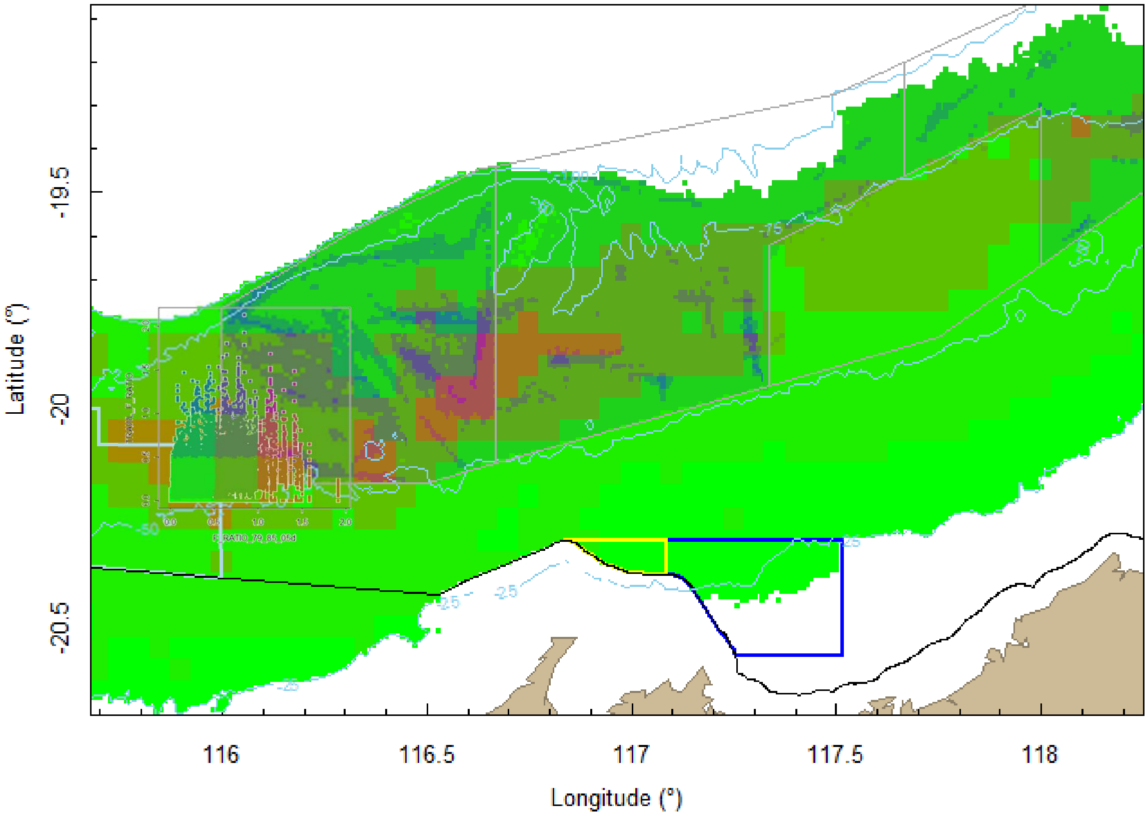


**Figure 118 Map of the NWS region showing the combinations of historical and recent trawl effort categories in the study area. The inset scatter-plot of the category combinations provides a category legend.**

**Table 11 number of grid cells in the study area categorised at different intensities of historical and recent trawl effort.**

| | HISTORICAL_CAT | | | |
|---|---|---|---|---|
| RECENT_CAT | [0,0.01] | (0.01,0.5] | (0.5,1] | (1,1.92] |
| [0,0.01] | 3915 | 7321 | 2740 | 502 |
| (0.01,0.5] | 0 | 4142 | 3219 | 562 |
| (0.5,1] | 0 | 628 | 826 | 273 |
| (1,2.13] | 0 | 95 | 110 | 38 |

To ensure adequate sampling of all historical and recent trawl effort combinations, the number of stations in each combination was pre-set prior to the bio-physical stratification of each category described in the next section. Sampling was biased towards the rare combinations by down-weighting the common combinations by a power of one-third, and then also adding some extra stations to the rarest or most important combinations (such as high historical and low recent trawl effort) to provide a total of 100 stations (Table 12).

**Table 12 number of sampling stations to be selected in different category combinations of historical and recent trawl effort intensities.**

| | HISTORICAL_CAT | | | |
|---|---|---|---|---|
| RECENT_CAT | [0,0.01] | (0.01,0.5] | (0.5,1] | (1,1.92] |
| [0,0.01] | 11 | 14 | 10+2 | 6+3 |
| (0.01,0.5] | 0 | 11 | 10 | 6 |
| (0.5,1] | 0 | 6 | 7 | 5 |
| (1,2.13] | 0 | 3 | 3 | 2+1 |

## 4.3 Characterising environmental gradients

To enable stratification of the 2017 sampling to account for environmental gradients that may influence benthos distributions and potentially confound comparisons of trawl impact effects, analyses were conducted using R package *gradientForest* (Ellis et al. 2012) to quantify the influence of multiple environmental variables on the abundance composition of the biotic communities. The demersal community sampling data were from the research voyages undertaken in 1982-1983, 1986-1991, 1995 and 1997 as part of the historical Sainsbury et al. (1987; 1988; 1991) NWS effects of trawling experiment. The sampling data included biomass of primarily fish species caught by two types of fish-trawls, and densities of sessile benthos morpho-types from trawl head-line camera photos. The environmental data were used from a comprehensive database of up to 41 variables (Table 13), gridded at 0.01° resolution for the Australian EEZ (Pitcher et al. 2018: FRDC 2016-039). The multiple biological survey datasets were analysed using *gradientForest* with the environmental layers to quantify the magnitude of change in demersal species composition along the environmental gradients (as predictors). This information was then used to predict and map the distribution of demersal assemblages on the 0.01° grid. Statistical details of *gradientForest* Forest, a regression-tree based modelling method, are described in Ellis et al. (2012), and example ecological applications are described in Pitcher et al. (2010, 2012), and Pitcher et al. 2018 (FRDC 2016-039) which produced biodiversity and bioregional maps around Australia. Further information is available at http://r-forge.r-project.org/projects/gradientforest/.

Other data required for the survey design included spatial data for offshore oil and gas infrastructure such as production platforms and pipelines, which have navigation exclusion zones around them that prohibit seabed sampling. These areas had to be excluded from possible selection as sampling stations.

**Table 13. Environmental variables mapped to the Australian EEZ, available to the project**

| # | Variable | Description |
|---|---|---|
| 1 | GA_BATHY | Bathymetry (depth) from Geoscience Australia digital elevation model (DEM) – metres |
| 2 | GA_SLOPE | Slope derived from Geoscience Australia bathymetry DEM – degrees |
| 3 | GA_ASPECT | Aspect of slope derived from Geoscience Australia bathymetry DEM – degrees T |
| 4 | GA_MUD | Sediment % mud grainsize fraction, (Ø < 63 µm) from Geoscience Australia |
| 5 | GA_SAND | Sediment % sand grainsize fraction, (63 µm < Ø < 2 mm) from Geoscience Australia |
| 6 | GA_GRAVEL | Sediment % gravel grainsize fraction, (Ø > 2 mm) from Geoscience Australia |
| 7 | GA_CRBNT | Sediment % carbonate ($CaCO_3$) composition, from Geoscience Australia |
| 8 | RBN_BSTRESS | Seabed current stress, RMS mean from CSIRO ‘ribbon’ model – $Nm^{-2}$ |
| 9 | RBN_BSTRESS_SR | Seabed current stress, Seasonal Range |
| 10 | CRS_NO3_AV | Nitrate bottom water annual average NO3 from CARS – µM |
| 11 | CRS_NO3_SR | Nitrate Seasonal Range |
| 12 | CRS_PO4_AV | Phosphate bottom water annual average PO4 from CARS – µM |
| 13 | CRS_PO4_SR | Phosphate Seasonal Range |
| 14 | CRS_O2_AV | Oxygen bottom water annual average O2 from CARS – ml $L^{-1}$ |
| 15 | CRS_O2_SR | Oxygen Seasonal Range |
| 16 | CRS_S_AV | Salinity bottom water annual average S from CARS – ‰ (ppt) |
| 17 | CRS_S_SR | Salinity Seasonal Range |
| 18 | CRS_T_AV | Temperature bottom water annual average T from CARS – °C |
| 19 | CRS_T_SR | Temperature Seasonal Range |
| 20 | CRS_SI_AV | Silicate bottom water annual average Si from CARS – µM |
| 21 | CRS_SI_SR | Silicate Seasonal Range |
| 22 | SW_CHLA_AV | Chlorophyll annual average from SeaWiFS – mg $m^{-3}$ |
| 23 | SW_CHLA_SR | Chlorophyll Seasonal Range |
| 24 | SW_K490_AV | Attenuation coefficient at wavelength 490nm annual average from SeaWiFS – $m^{-1}$ |
| 25 | SW_K490_SR | Attenuation coefficient Seasonal Range |
| 26 | MT_SST_AV | Sea Surface Temperature annual average from Modis – °C |
| 27 | MT_SST_SR | Sea Surface Temperature Seasonal Range |
| 28 | NPP_AV | Net Primary Production annual average from SeaWiFS – mg C $m^{-2}$ $d^{-1}$ |
| 29 | NPP_SR | Net Primary Production seasonal range |
| 30 | PAR_AV | Photosynthetically Active Radiation (PAR) from MODIS – Einsteins m-2day-1 |
| 31 | PAR_SR | Photosynthetically Active Radiation seasonal range |
| 32 | BIR_AV | Benthic Irradiance annual average, BIR = PAR × exp(-K490 * Depth) |
| 33 | BIR_SR | Benthic Irradiance Seasonal Range |
| 34 | EPOC_AV | Exported Particulate Organic Carbon flux annual average from SeaWiFS – mg C $m^{-2}$ $d^{-1}$ |
| 35 | EPOC_SR | Exported Particulate Organic Carbon seasonal range |
| 36 | TERAN_CHAN | Terrain channel, probability of membership of topographic shape "channel" (Lucieer, 2007) |
| 37 | TERAN_PASS | Terrain pass, probability of membership of topographic shape "pass" (Lucieer, 2007) |
| 38 | TERAN_PEAK | Terrain peak, probability of membership of topographic shape "peak" (Lucieer, 2007) |
| 39 | TERAN_PIT | Terrain pit, probability of membership of topographic shape "pit" (Lucieer, 2007) |
| 40 | TERAN_PLAN | Terrain plane, probability of membership of topographic shape "plane" (Lucieer, 2007) |
| 41 | TERAN_RIDG | Terrain ridge, probability of membership of topographic shape "ridge" (Lucieer, 2007) |

### 4.3.1 Results for historical photo-benthos data

The head-line camera photo-benthos dataset comprised densities of 14 morpho-types averaged over about 80 photos for each of 583 trawl stations collected between 1982 and 1997 (Figure 119). The *gradientForest* results for this dataset are provided in some detail; analogous results from analyses of the two fish-trawl datasets were subsequently combined.

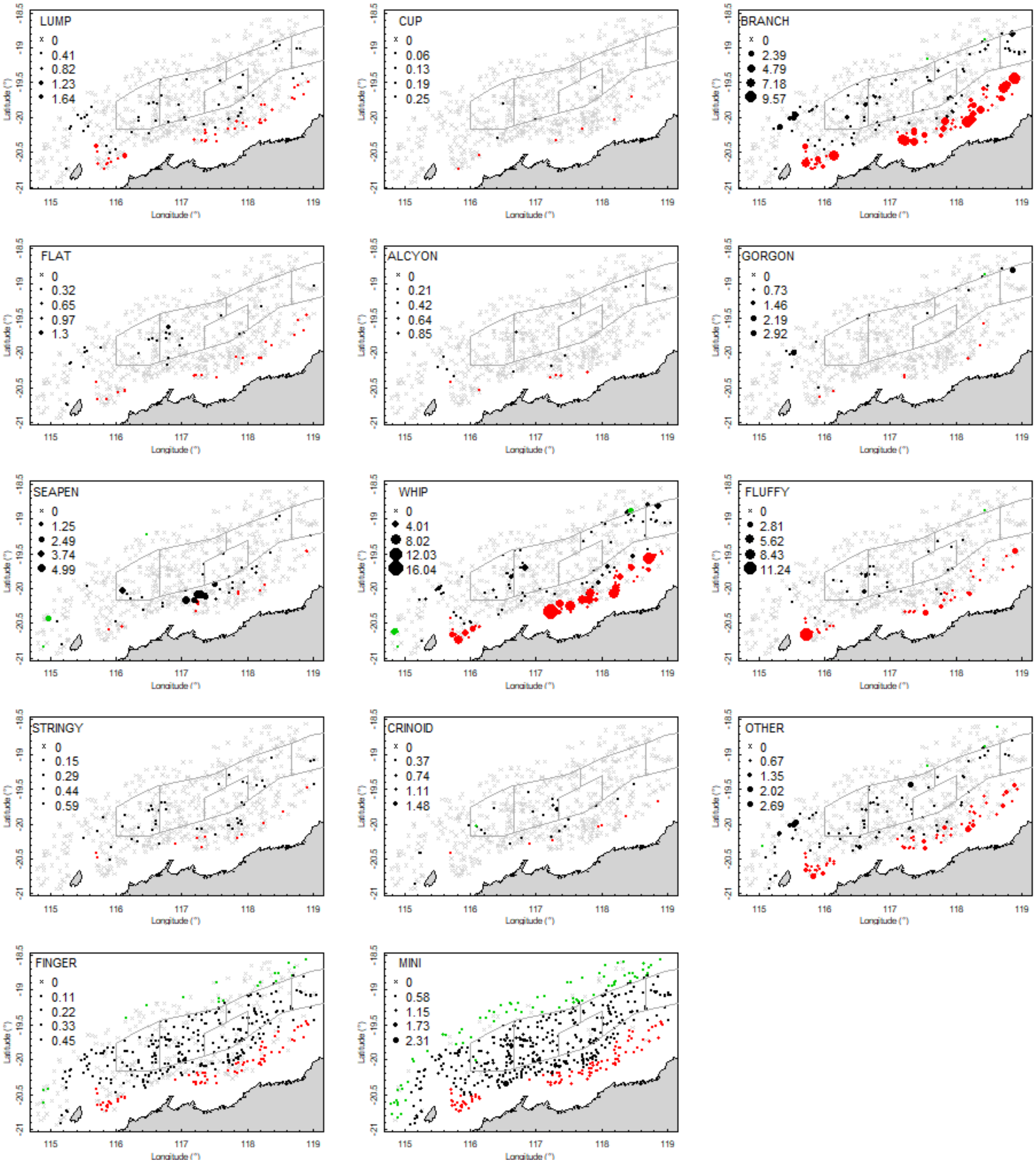


**Figure 119 Maps of the observed density distributions of 14 sessile benthos morpho-types (Sponges: Lump, Cup, Branched, Flat, Finger; Alcyonarian soft-corals; Gorgonians; Sea-pens; Sea-whips; 'fluffy' or 'stringy' hydroids or similar; Crinoids; other or small 'mini' benthos) scored from trawl head-line camera photos at historical sampling stations in the NWS study area. Symbol size indicates mean density per photo frame; symbol colours indicate each of three main assemblage compositions of benthos morpho-types, as determined by multi-variate regression tree analysis of these data.**

The most important environmental predictors associated with differences in patterns of abundance and composition of the 14 photo-benthos morpho-types included: seabed current stress, sediment gravel content, net primary productivity and seasonal range in bottom-water oxygen levels among others (Figure 120). The least important predictors included: photo-synthetically active radiation, sediment carbonate and mud content, annual average sea-surface temperature and recent trawl-effort intensity among others. The rate of change of benthos composition along each environmental gradient is not constant (Figure 121), typically there are peaks of change with intervals of little change. Different benthos morpho-types may change to different total extents along each environmental gradient (Figure 122). Sometimes, several benthos types may change at the same location on a gradient; other times different types may change most at different locations. The cumulative change in overall composition of the benthos community is typically non-linear (Figure 123); there may be abrupt step-changes in composition indicating sharp boundaries between assemblages at one or more locations on gradients interspersing areas of little compositional change. The environmental variables had different levels of predictive capacity for different benthos types (Figure 124); best performance was for branched sponges and sea whips, poorest was for sea pens and crinoids.

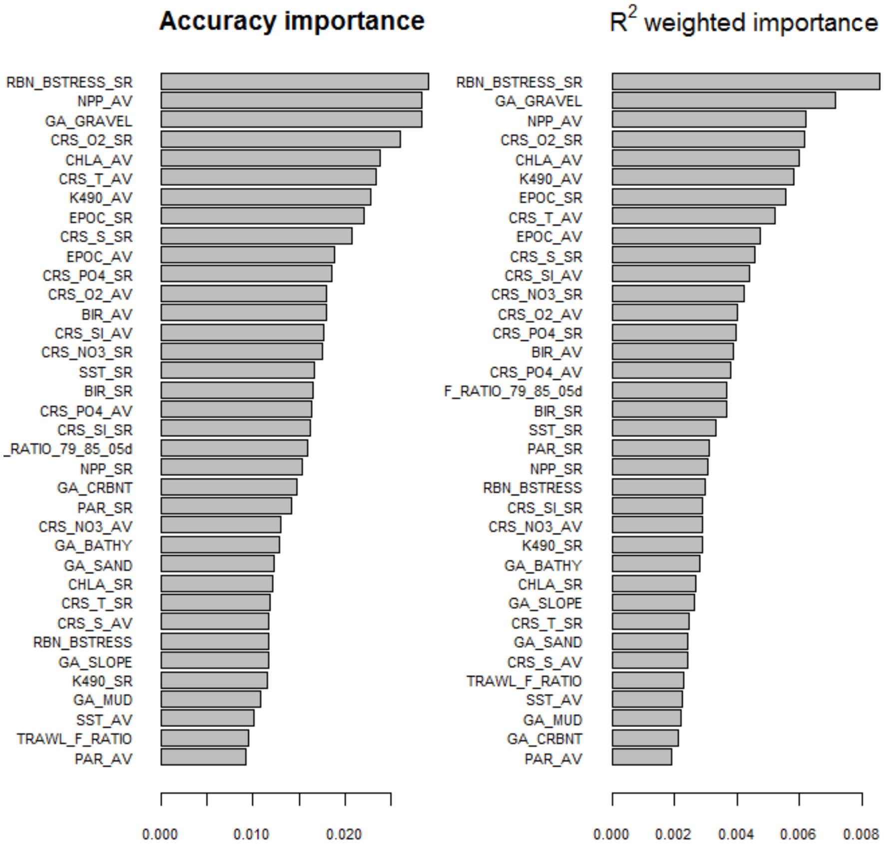


**Figure 120 Average importance of environmental predictors associated with differences in abundance and composition of 14 photo-benthos morpho-types at sampled stations in the NWS study area (see Table 13 for variable definitions). Accuracy importance is the average predictor importance on the in-bag (training) data; R² weighted importance is the average predictor importance on the out-of-bag (held-out test) data, weighted by the R² of prediction performance on the out-of-bag data.**

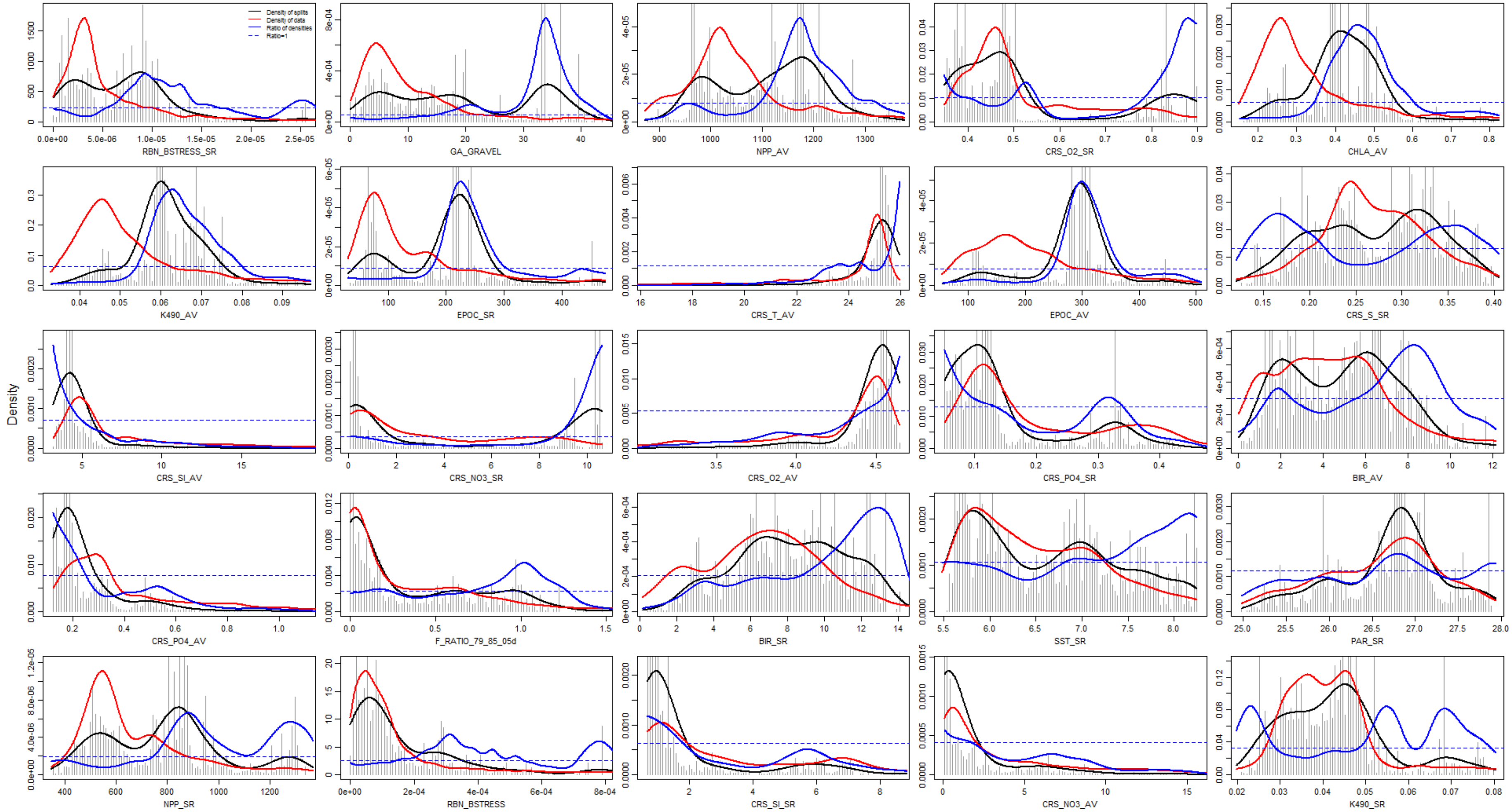


Figure 121 Splits-density plots for 14 sessile benthos morpho-types, showing tree-split importance and location on each environmental gradient (grey spikes), kernel density of splits (black lines), of observations (red lines) and of splits standardised by observations density (blue lines). Each distribution integrates to predictor importance. These plots indicate where important changes in the abundance of multiple species occur along each gradient; showing the rate of composition change.

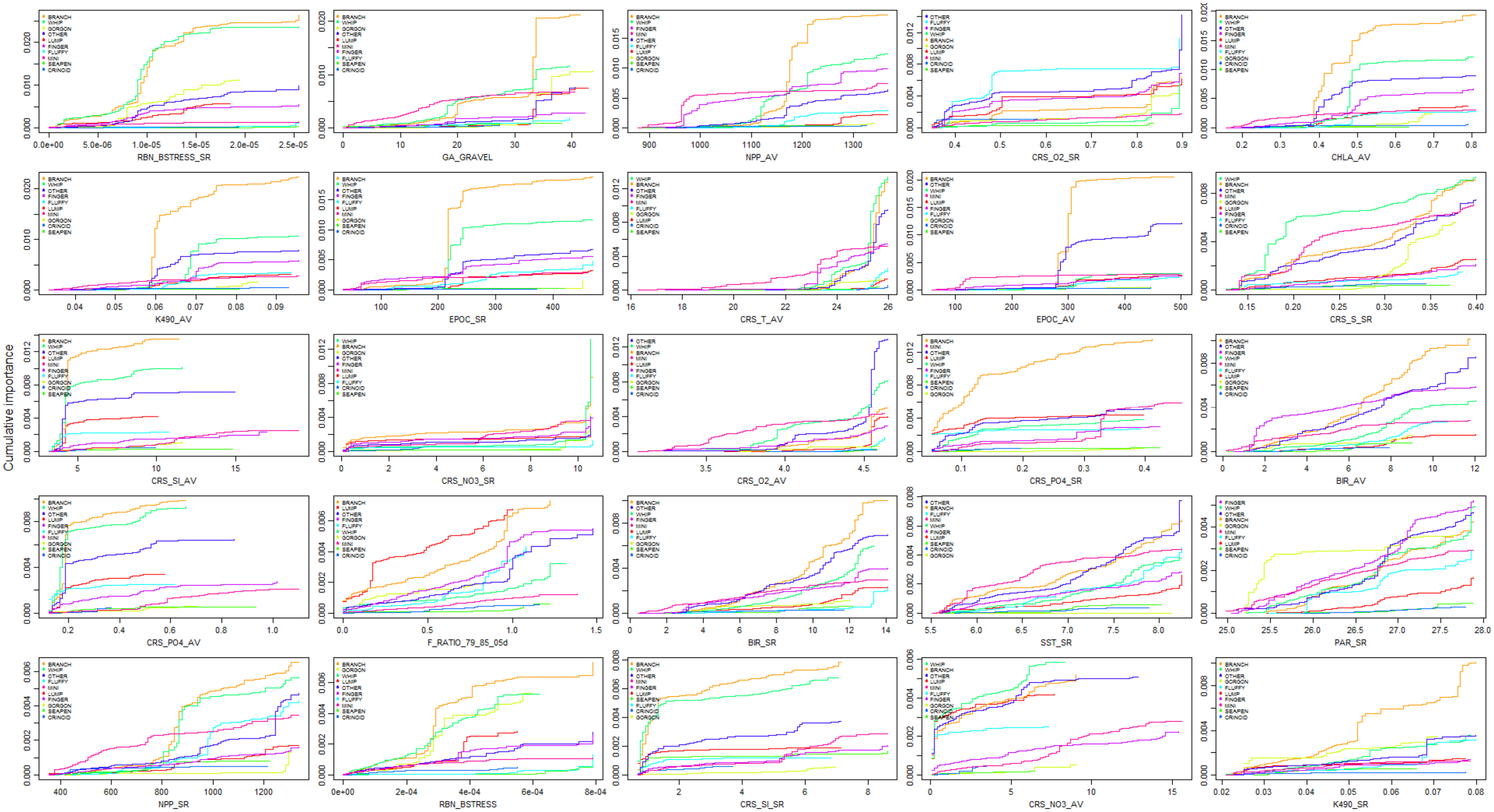


**Figure 122 Species cumulative plots for 14 sessile benthos morpho-types, showing cumulative importance distributions of tree-splits improvement scaled by R² weighted importance, and standardised by density of observations. These show cumulative change in abundance of individual morpho-types, where changes occur on the gradient, and the morpho-types changing most on each gradient.**

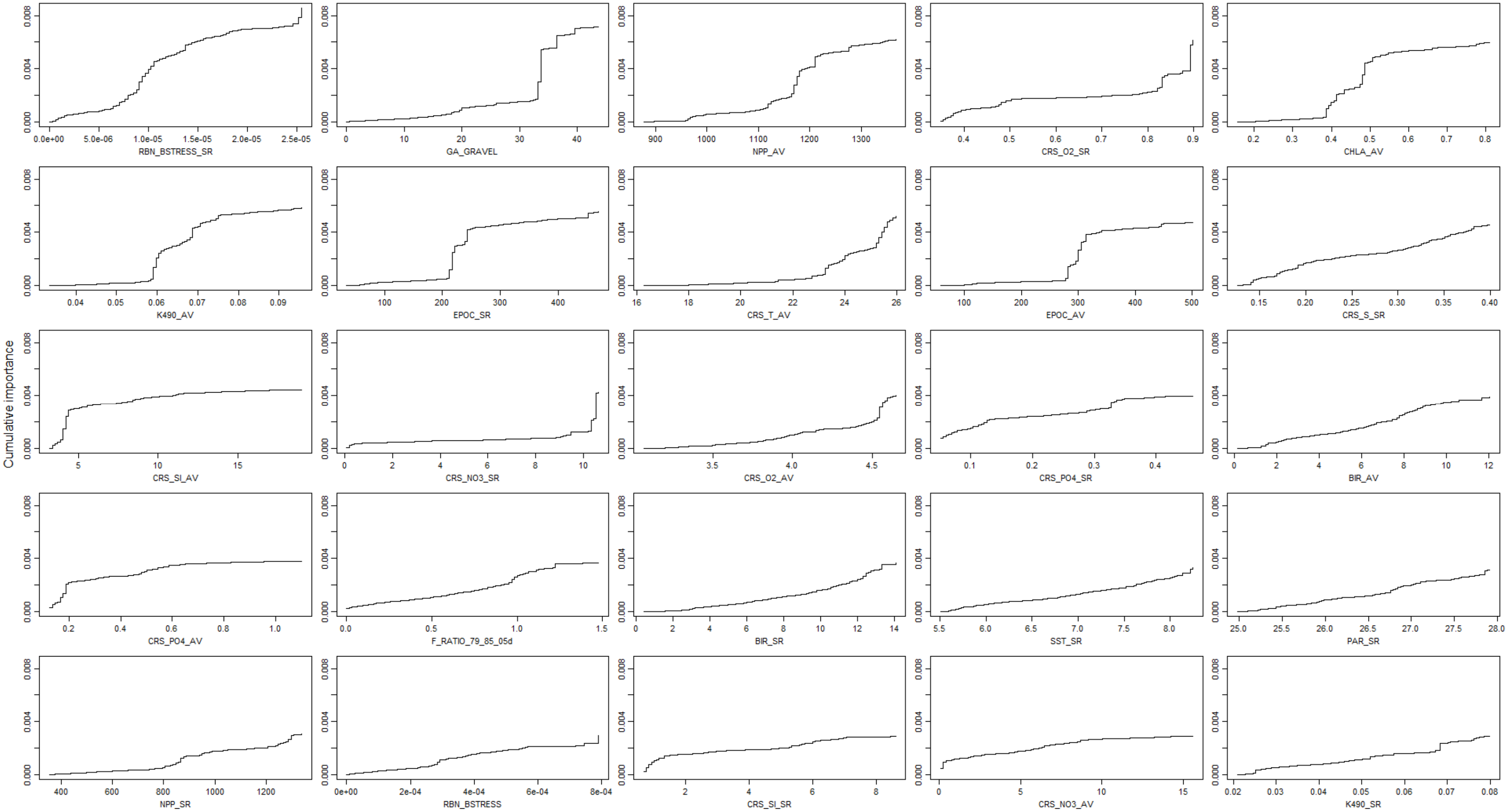


**Figure 123 Predictor cumulative plots, showing cumulative importance distributions of tree-splits improvement scaled by R² weighted importance, and standardised by density of observations, averaged over all 14 sessile benthos morpho-types. These show cumulative change in overall composition of the community, and where changes occur on the gradient.**

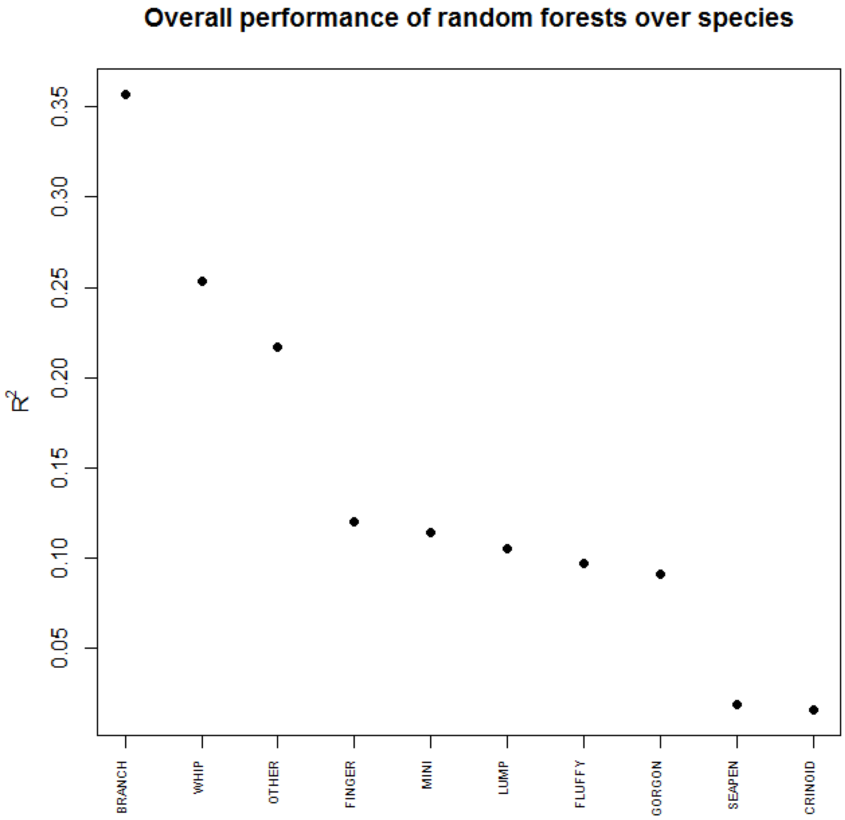


**Figure 124 R² Performance of the model predictions on the out-of-bag data for each of 14 photo-benthos morpho-types sampled at stations in the NWS study area.**

### 4.3.2 Combining results for photo-benthos and trawl datasets

The cumulative importance curves resulting from the analysis of the sessile benthos morpho-types dataset were combined with analogous curves output from analyses of the two fish-trawl datasets (Figure 125). The combined cumulative importance curves are not just simple averages across the three datasets, but also account for the information content and strength of evidence from each, including number of species, number of sites, model performance ($R^2$), and density of observations along each environmental gradient. The combined cumulative importance curves provide empirical transformation functions for each environmental gradient (measured on many disparate scales) to a common scale that represents gradients in biological composition associated with the environment. Variables with greater influence are associated with larger changes in composition. These functions were used to transform all gridded environmental variables across the entire study area and to predict the demersal compositional patterns in the region. After transforming, principal components analysis provided a multi-dimensional biological space (Figure 126) that represents predicted composition associated with the environment. Points close together in this space have similar composition (and colours) that differs from locations more distant in this space. Vectors indicate the direction and magnitude of influence of the major environmental variables. The biological space mapped into geographic space (Figure 127) represents the spatial distribution of these continuous changes in biological composition.

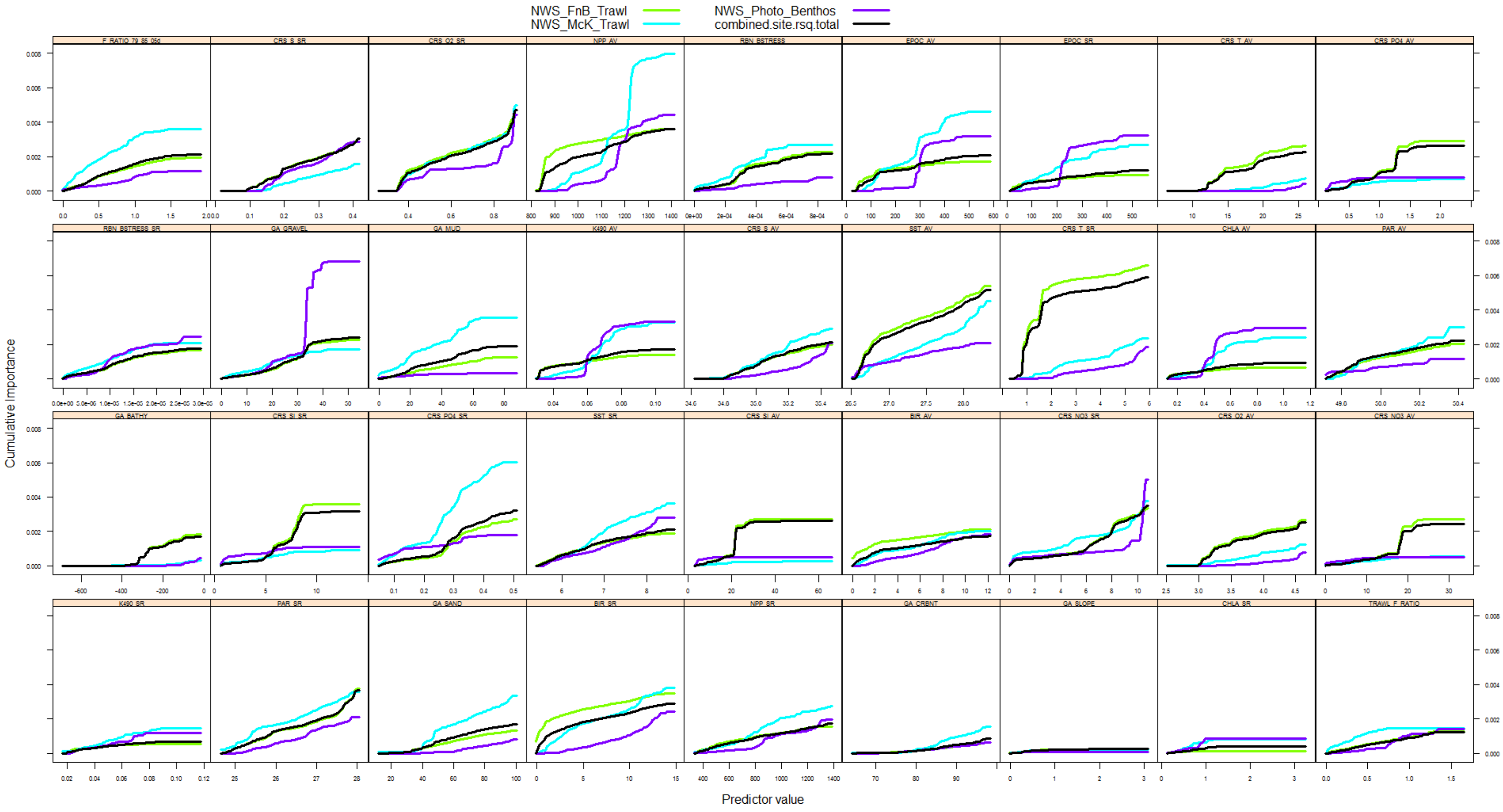


Figure 125 Combined predictor cumulative plots, showing cumulative importance distributions for the three biological datasets: NWS photo benthos, NWS Frank and Brice trawls samples and McKenna trawl samples. The combined cumulative importance distributions across all three datasets provide transformation functions for each environmental gradient to cumulative biological importance, used for predicting compositional change across the study area grid.

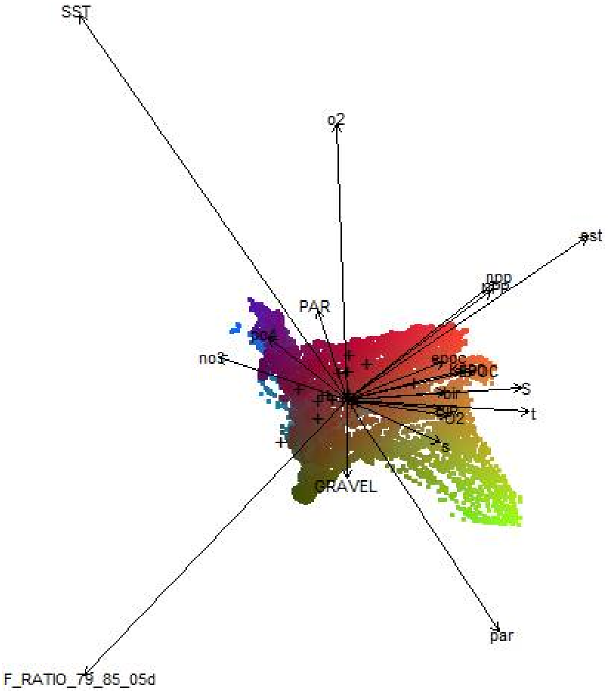


Figure 126 PCA plot, showing the first 2 dimensions of the multi-variate bio-physical space following transformation of each environmental gradient to cumulative biological importance, representing a prediction of compositional change throughout the entire study area.

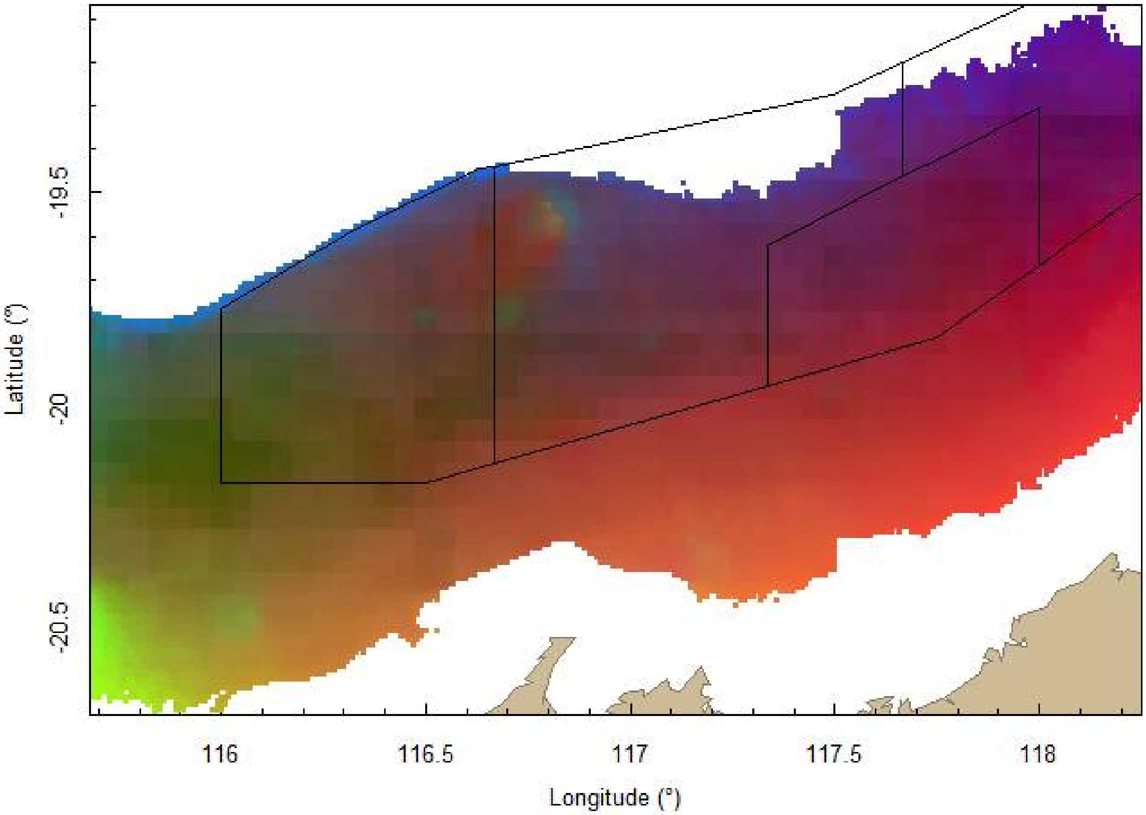


Figure 127 Map of transformed environmental gradients to cumulative biological importance, representing a prediction of continuous compositional change patterns across the study area grid.

### 4.3.3 Stratification for survey sampling

The stratification needed by the 2017 survey required that the continuous biological space (Figure 126) be sampled representatively to ensure that the influence of environmental gradient on demersal compositions could be accounted for in analyses of trawl impacts and recovery. A first-order stratification could be achieved by clustering the multi-dimensional biological space (Figure 126) into the same number of groups as the expected number of sampling sites (100). The medoid (most central) grid-cell in each group would be a suitable first-order choice for a representative sampling station (Figure 128). However, even though the historical trawl effort for 1979-85 was strongly represented in the biological space (Figure 126), the first-order clustering did not provide the minimum numbers of stations in the rarer historical–recent trawl effort combinations (Table 12) — even if the weighting of the trawl effort combinations was increased in the clustering. Consequently, the study area was first stratified by the trawl effort combinations (Figure 118), then biological space for each combination was clustered into the number groups corresponding to the required number of stations (Table 12); the medoid cell for each group provided an initial station selection.

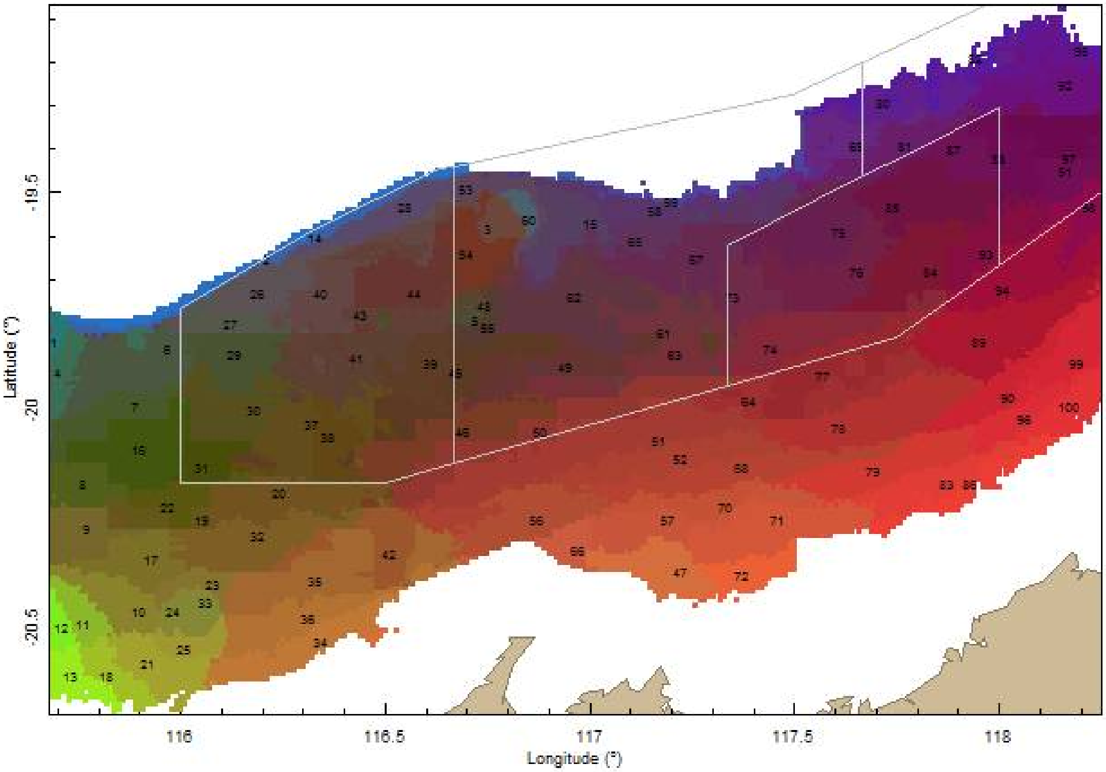


**Figure 128 Map of initial clustering of the transformed biological space, representing a first-order stratification — number 1-100 indicates medoid grid-cells, which could provide sampling stations representative of the environmental gradients.**

### 4.3.4 Selection of sampling stations

Grid-cells falling within navigation exclusion zones around offshore infrastructure were excluded from possible selection as sampling stations. Stations were then selected from each cluster group within each historical–recent trawl effort combination according to the following preference where possible: (1) Locations corresponding to stations sampled during the Japanese survey by the vessel Oshoro Maru in 1963, which recorded biomass of sampled sponges. (2) Locations corresponding to stations sampled during the CSIRO surveys on the RV Southern Surveyor in 1995 and 1997, which also recorded biomass of sampled sponges. (3) Nearest to medoid locations corresponding to stations sampled during other CSIRO surveys between 1982 and 1991. (4) The medoid cell if not in an exclusion zone, otherwise the nearest cell outside exclusion zones.

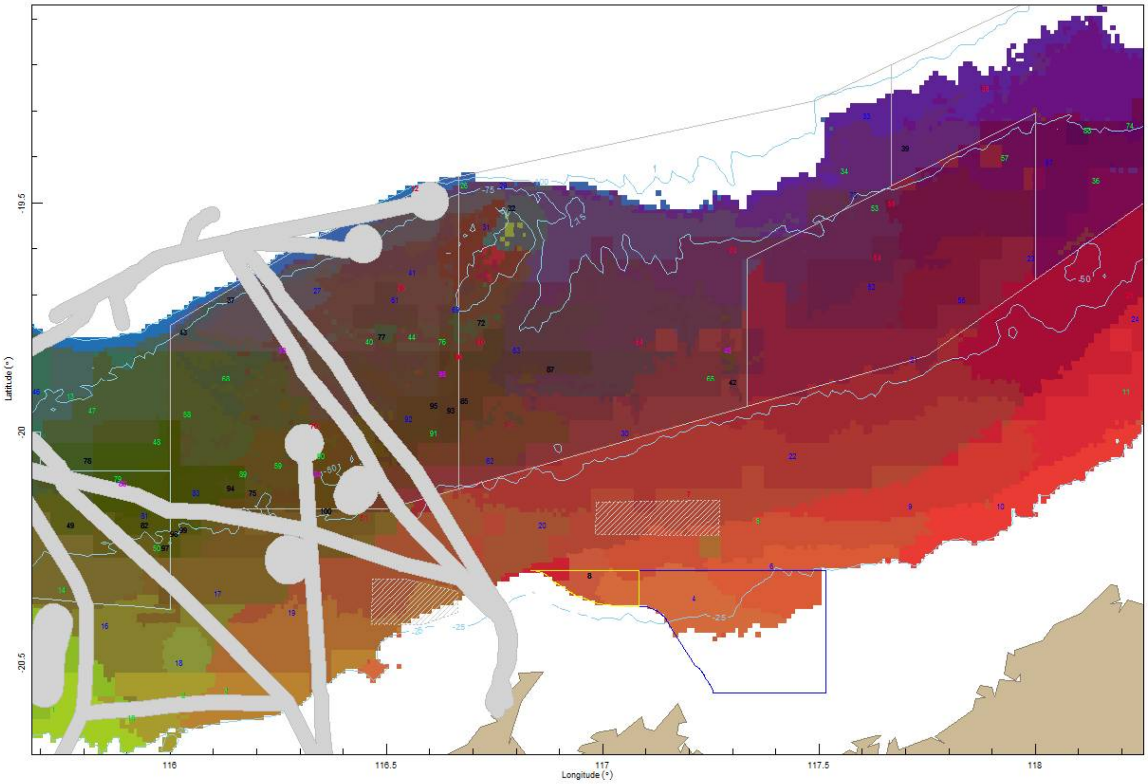


**Figure 129 Map of final effort-contrast stratification and biophysical clustering, with final sites numbered 1-100, selected from locations sampled by the Japanese vessel Oshoro Maru in 1963 (red), the CSIRO vessel Southern Surveyor in 1995 or 1997 (blue); other CSIRO surveys between 1982 and 1991 (green), or medoid cells (black) or cell nearest to medoid (magenta).**

## 4.4 Addenda

### 4.4.1 Schematics of pair-trawls

An outline description of the Taiwanese pair-trawl gear, contributing towards an estimate of their swept width is as follows. Trawl footrope length was reported as 75 m, with a spread factor of 0.67, giving a width of 50 m (Shindo 1972; Liu et al. 1978; Edwards 1983). However, this excludes any contact made by bridles, which average 5 m length, and by the sweep wires, which may be about 120 m in length but are in sections and some may be removed where sponges and corals were abundant Edwards (~1982). The sweep wires were bound with poly-rope and were called “combination ropes”; these were joined to tow warps of up to 500 m in length, but vary with water depth and the type of seabed (Edwards ~1982). The overall trawl swept width varies with these factors as well as the distance separating the paired trawlers. Edwards (~1982) visually estimated this distance as 400 to 500 m — but recollections by other fishery observers contacted personally ranged widely, from about 200 to 400 m. The UK Seafish Manual (Montgomerie & Forbes 2015) suggests vessel separation for pair-trawlers should be half the tow-warp length (implying a maximum of ~250m on the NWS). The FAO Fisherman's Workbook provides a formula for pair-trawl vessel separation of ⅖ of total gear length (i.e. ~625m max), which is also ~250m. While none of this information provides a confirmed estimate of bottom-contact width, nevertheless a schematic of these descriptions is indicative of a spread at the head of the sweeps of about 120-125m (Figure 130).

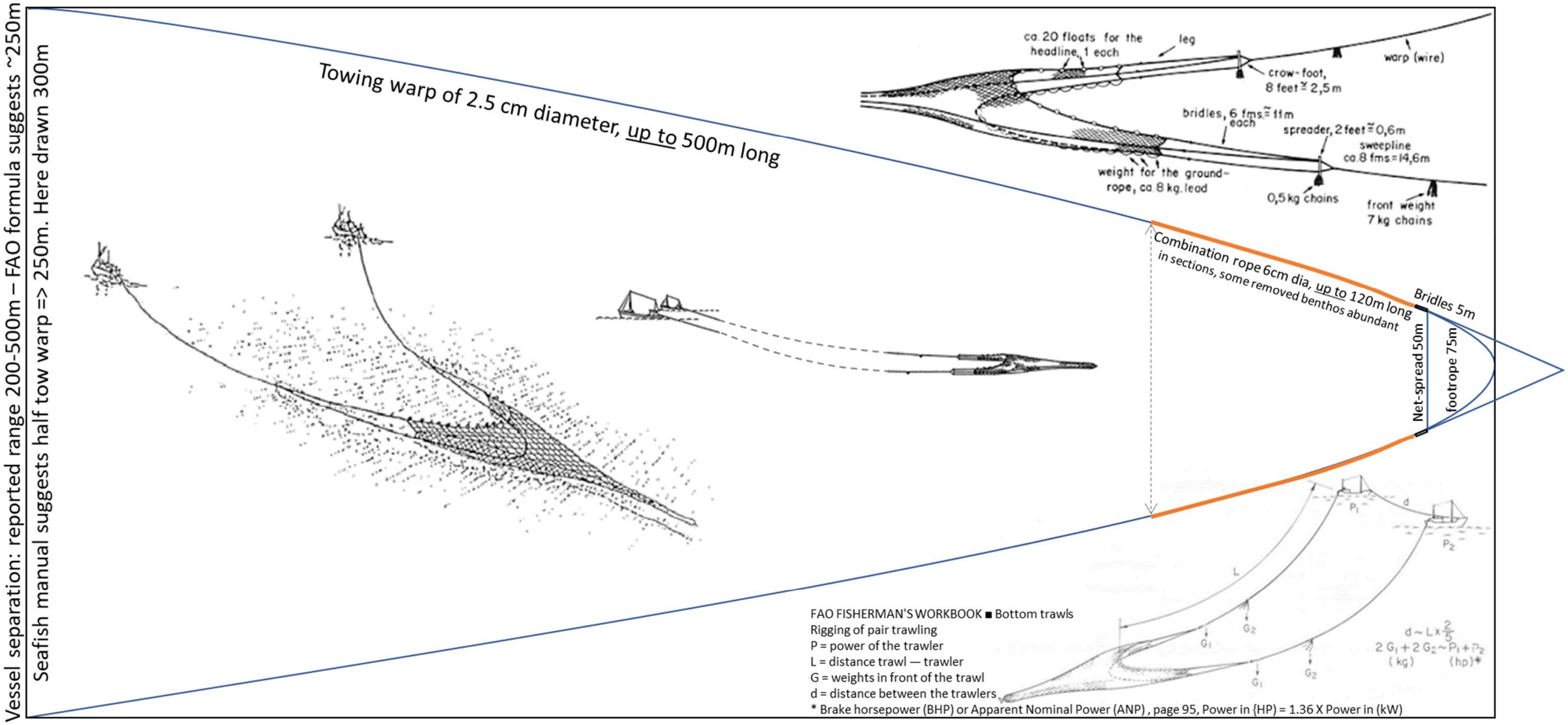


**Figure 130** Schematic of pair-trawl description and dimensions provided by Edwards (~1982), with additional drawings from the FAO Fisherman's Workbook. Given this unconfirmed layout, the spread at the head of the sweeps ("Combination rope") is about 120-125m (grey dotted line). Edwards reported that the bridles were spread by a "Dan Leno" bar, but did not report use of any weights attached to bridles or sweeps.

### 4.4.2 Analysis of Scottish pair-trawling trials data

Galbraith (1984) conducted demersal pair-trawling trials in Scotland, with the purpose of estimating bottom contact-widths of the gear, and provides comprehensive data for the gear performance. Their results showed that ground-contact spread decreases with speed, as the wires lift off, and increases with vessel separation — and they concluded that 'the lengths of wire in ground contact were much less than previously supposed'. Analyses of these data (converted to a suite of ratios among gear and operational components, so they would be more applicable to other depths and warp-lengths etc) provided predictions of spread-ratio (ground-contact spread / vessel separation distance) as a function of tow-speed, scope-ratio (warp length / depth) and vessel distance-ratio (vessel separation distance / warp length) (Figure 131).

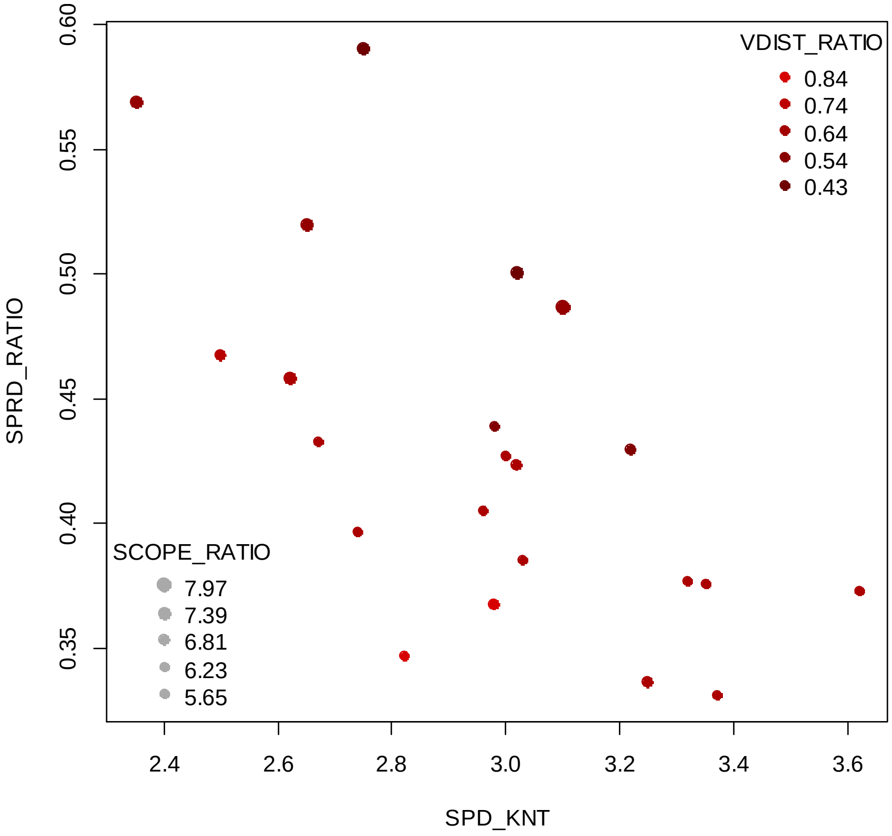


**Figure 131 Results of analysis of data from demersal pair-trawling trials conducted in Scotland (Galbraith 1984), showing relationships between gear spread-ratio (ground contact spread / vessel separation distance) as a function of tow-speed, scope-ratio (warp length / depth) and distance-ratio (vessel separation distance / warp length).**

Using the model from this analysis, and given the depths (~65m; 50–90) and tow-speeds (3.5kn) on the NWS, the expected scope-ratios are 6–8, warp lengths 350–550m, vessel separation distances 200–400m, and the predicted gear ground contact widths were 100–130m (mean: ~112m, ±SD 14.1m) (Figure 132).

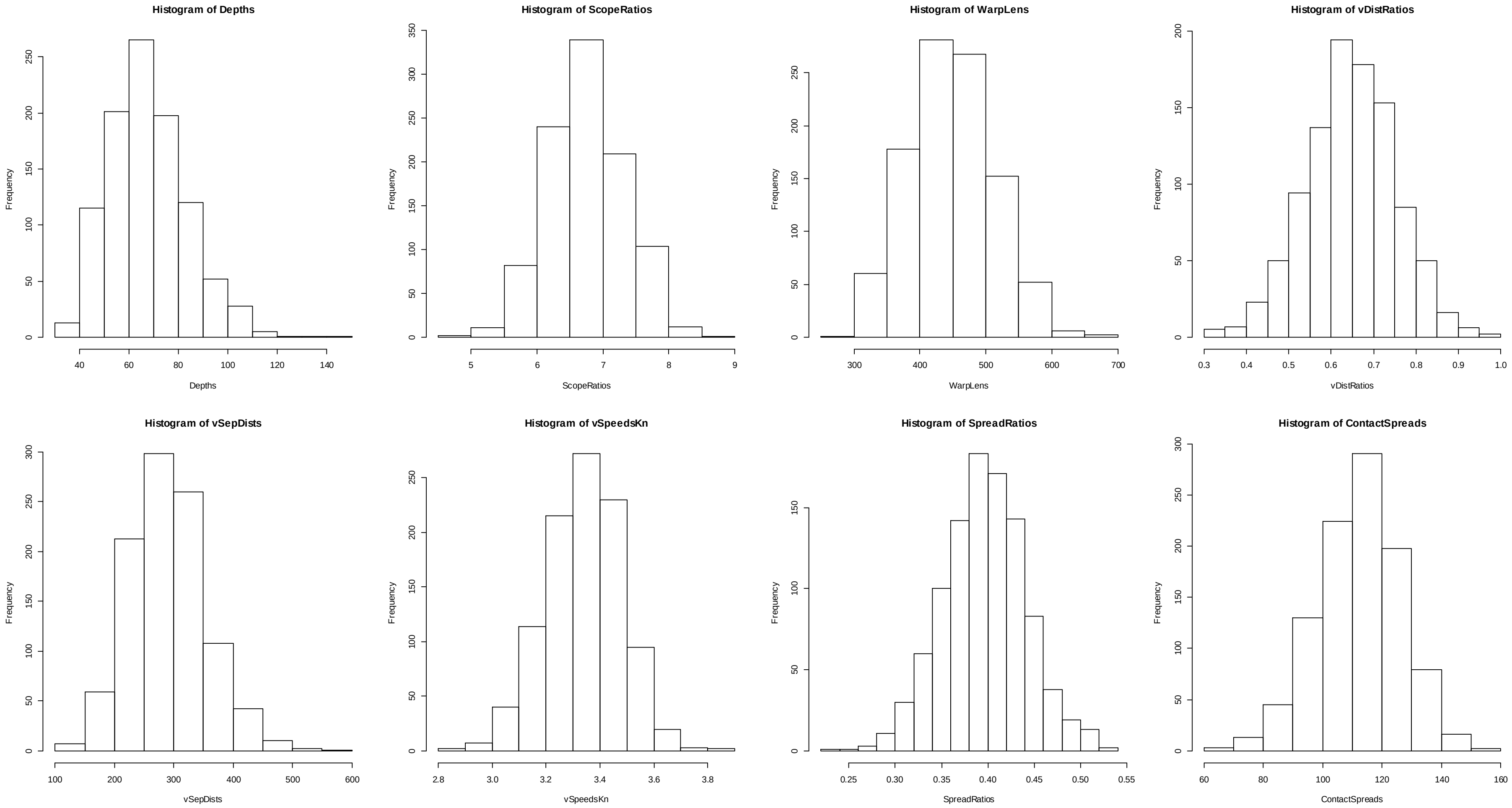


Figure 132 Results from prediction of pair-trawling trial relationships (Figure 131) to the NWS.

# 5 2017 North West Shelf survey benthos analyses

Roland Pitcher and Wayne Rochester (CSIRO Oceans and Atmosphere Research)

## 5.1 Introduction

The key aim of this part of the study was to assess the extent of recovery of the trawled sessile benthos communities 25 years after a period of Taiwanese pair-trawling ceased on the NWS. The basis of the assessment was the 2017 sampling survey that sampled areas previously subjected to high levels of pair-trawling but were then closed and remained untrawled. Data from the earlier surveys in the 1980s and 1990s were also re-assessed using similar approaches. In addition, the assessments also accounted for environmental gradients that may influence benthos distributions and abundance and potentially confound comparisons of trawl impact effects if not considered.

Multiple lines of evidence were considered to assess recovery, including: (1) simple temporal comparisons of the biomass of sponges sampled by trawls; (2) temporal comparisons of the trends in benthos depletion along the gradient of pair-trawling intensity, based on counts of morphotypes from images; and (3) simulation modelling of trawl impacts for the entire history of trawling in the region, to the current day.

(1) The temporal comparisons of trawl-sampled sponge biomass used data from a Japanese survey in 1963, CSIRO surveys in 1995 and 1997, and the MNF survey in 2017. All these samples could be standardised to kg / Ha, allowing direct comparisons between each time period.

(2) The image counts of sessile benthos morphotypes could not be standardised to densities because the counted area of images was not known for any survey. Thus, comparisons between time periods required an indirect approach whereby the coefficient of the trawl-gradient trend for each morphotype in each period were first estimated, then subsequently compared. Depletion of benthos by pair-trawling would be indicated by negative coefficients, whereas recovery would be indicated by zero (or possibly positive) coefficients.

(3) The trawl modelling involved simulation of the annual distribution and intensity of all trawling in the region from 1959 to 2016. The model simulated trawl impacts and recovery based on rates previously estimated for the same or similar benthos in the GBR. Starting distributions and abundances of benthos were predicted from regional grid-mappings of multiple environmental variables, based on fitted models of survey benthos abundances (adjusted trawl-gradient coefficients where appropriate) against the same environmental variables.

Additional trawl-gradient analyses were also conducted for sponge biomass from (1) the Japanese 1963 survey against Japanese trawl effort 1959-1963; (2) the CSIRO 1995 and 1997 surveys against Taiwanese pair-trawl effort; and (3) the MNF 2017 survey against Taiwanese pair-trawl effort. Further, MNF 2017 survey also acquired data for the distance (range) between the imaging camera and the seabed, and for seabed substratum classes from an acoustic sub-bottom profiler (SBP). Thus, the importance of image range standardisation and SBP class was also investigated, including their effects on analyses of the 2017 trawl-gradients. Finally, we examined the MNF 2017 survey data to provide some information on the relative catchability of sessile benthos into trawl nets.

## 5.2 Comparisons of trawl sponge-catch biomass with 'pre-trawl' biomass

Initial assessment of benthos recovery in the NWS was made by comparing the earliest known available sampling data for sponge biomass with that of subsequent CSIRO trawl surveys, and with the 2017 MNF survey trawl sponge biomass.

The earliest sponge sample biomass data were from a survey by the Japanese vessel Oshoro Maru, which sampled 20 trawl stations on the NWS in Dec 1963 – Feb 1964, and recorded catch weights of fish taxa and total sponge (Addenda 5.7.1, Figure 153). These samples do not represent true 'pristine' sponge biomass as Japanese commercial trawlers fished the region from Nov 1959 to Mar 1963 (Figure 153). Nevertheless, the Japanese trawling effort was relatively light compared with subsequent effort; they recorded 7616 trawls over 41 months, which at 1.95 hrs per haul (Robins 1969) corresponds to ~4,347 hrs/yr for 3.4 years. In comparison, heavily regulated current trawl effort in the region, using similar trawl gear is about 6000 hrs/yr — and except for 1987–89 is the lowest effort since the Taiwanese started fishing in 1972. Effort during the main period of the Taiwanese pair-trawl fishery averaged ~46,000 hrs/yr for 13 years.

The Oshoro Maru 1963 survey (OM1963) sponge catches were standardised to kg/Ha based on gear head-rope (38.2m), tow speeds (3.5kn) and tow durations (1–1.5hr) recorded in the voyage report. These densities were compared with standardised sponge densities sampled by CSIRO Southern Surveyor surveys on the NWS in 1995 and 1997 — and with total sponge densities from the 2017 MNF survey. For these comparisons, the SS1995-97 and MNF2017 stations were subsetted to those that fell within the same latitude, longitude and depth range as the OM1963 stations — plus a 0.05° and 10m depth buffer.

Visually, the simple mapped comparisons appear to indicate that SS1995-97 sponge densities were less than OM1963 in neighbouring locations (Figure 133), and that MNF2017 sponge densities were typically similar to or perhaps greater than OM1963 in neighbouring locations (Figure 134). Quantitatively, the mean OM1963 station density of sponges was 34.2 kg/Ha (range 3.98–144.4) compared with 13.5 kg/Ha for SS1995-97 (range 0.00–144.9), and 48.9 kg/Ha for MNF2017 (range 0.198–355.1), corroborating the visual interpretation. Nevertheless, raw densities are unlikely to be normally distributed and their means may be influenced be a few large values, hence means of log(x+1) transformed data were also compared. In this case, the log mean for OM1963 sponges was 3.14, compared with 1.94 for SS1995-97, and 3.15 for MNF2017 — suggesting that sponge densities in 2017 were similar to those in 1963, and greater than in 1995-97, for the same general area, and appears to indicate that total sponge biomass has now recovered.

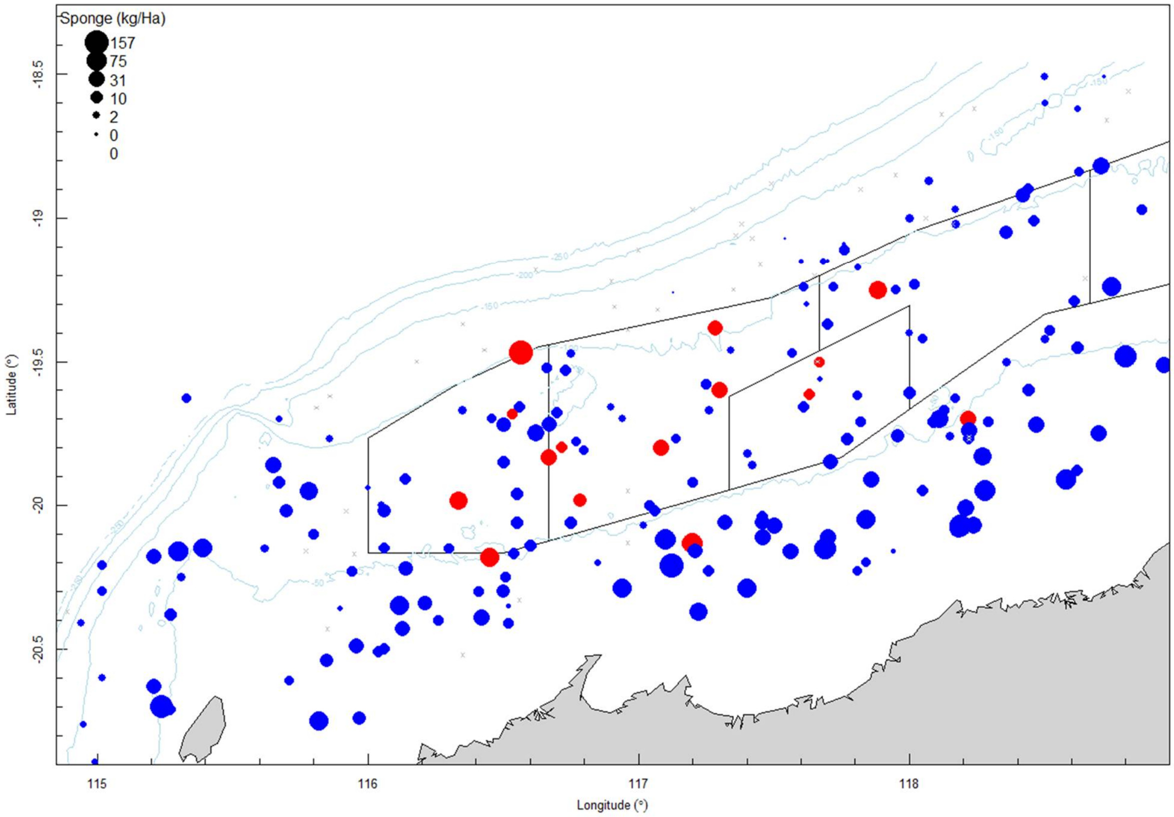


Figure 133 Map of the sampled density of total sponges at survey stations in the greater NWS study area. Symbol size indicates sponge density kg/Ha. Symbol colour indicates survey: red=OM1963; blue= SS1995-97. Black polygons outline current Western Australian management areas for their domestic trawl fishery. Depth contours are 50m intervals.

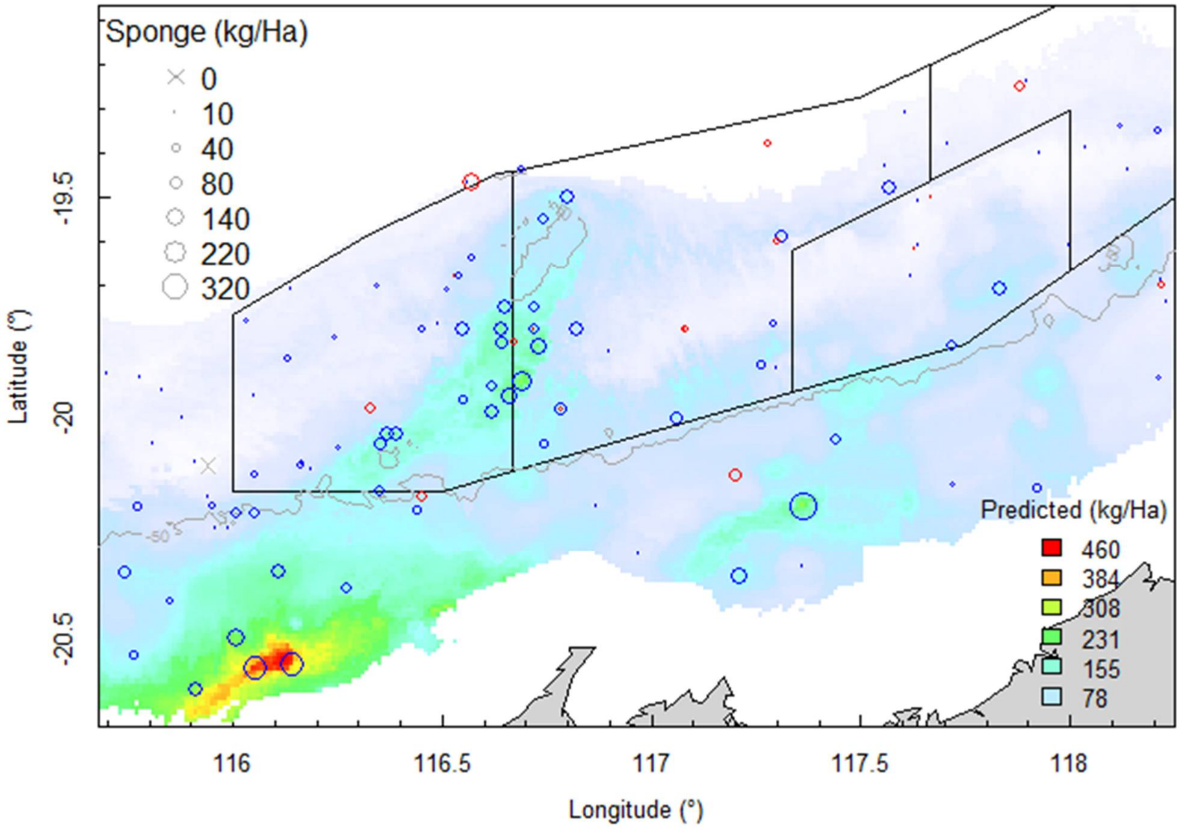


**Figure 134 Map of the sampled density of total sponges at survey stations in the NWS study area. Symbol size indicates sponge density kg/Ha. Symbol colour indicates survey: red=OM1963; blue=MNF2017. Hollow symbols are used because MNF2017 aimed to re-sample OM1963 stations where possible, hence some locations overlap. Background indicates the distribution and abundance of predicted 'pristine' total sponge biomass (see Section 5.5).**

## 5.3 Estimation of historical trawl gradient coefficient

The goal of this analysis was to estimate the impact effect on sessile benthos of the historical Taiwanese pair-trawling effort. The distribution and intensity of Taiwanese effort varied across the study area (Figure 116), hence there was a gradient of effort intensity among stations that had been sampled for sessile benthos, so more specifically the objective was to estimate the coefficient of the slope of benthos density along this gradient. Further, the distribution and abundance of sessile benthos was also likely to be determined by environmental and habitat factors (see section 4.3) independently of impacts due to trawling, thus it is important to attempt to disentangle these influences.

The method used to estimate the trawl gradient coefficient while accounting for the environmental influences can affect the interpretation of the results. For example, multiple regression ANOVA assumes the response is linearly related to the predictor variables. If the shape of benthos abundance response to a predictor variable (e.g. depth) is known a priori then perhaps a transformation of the environmental variable is possible before analysis; however, such shapes are rarely if ever known in advance and were not known in this case. Hence, multiple regression ANOVA methods were considered unsuitable for estimating the environmental influences. On the other hand, there is reason to expect that benthos abundance decreases exponentially with increasing trawl impact (i.e. a constant proportional decrease per unit of trawl effort, e.g. see Burridge et al. 2003; Pitcher et al. 2000, 2016, 2017; Ellis et al. 2014) — this is a log-linear response and can be estimated using regression ANOVA with log-transformation of the response. Because of these differences, we used a relatively experimental hybrid analysis approach (Chen et al. 2007; Venables 2011; Mazor et al. 2017) where the trawl coefficient is estimated by using a linear-regression method iteratively with a regression-tree method that accounts for the environmental influences flexibly, where successive iterations of each model are fit to the residuals of the previous until convergence, and the overall estimate of the trawl coefficient is the cumulative sum of the iterated estimates. In our application, we used the R function *lm*(), package base stats, to estimate the trawl gradient coefficient, and R function *randomForest*(), package *randomForest* (Liaw & Wiener 2002, based on Breiman 2001), to estimate the environmental influences flexibly.

### 5.3.1 CSIRO photo-benthos dataset vs historical Taiwanese effort

First, we analysed the photo-benthos dataset, comprising densities of 14 morpho-types, from the historical Sainsbury et al. NWS research voyages (1982 to 1997), as described in Sections 4.3 and 4.3.1 — along with the historical Taiwanese pair-trawling effort (Section 4.2.1) and the suite of mapped environmental variables (Section 4.3). Initially, we used an aggregation of large (>15cm high) and small (<15cm) benthos for each type, where counts of small types were scaled down by the estimated weight difference between small and large types before summing as a single measure per type. At the outset, we examined whether there was a bias in the estimate of the trawl gradient coefficient depending on whether the *lm* was executed before the *randomForest* in the iteration or vice-versa. This test demonstrated (Figure 135) that the *lm* first approach initially estimated very large negative trawl coefficients, which changed rapidly with each iteration and eventually drifted towards an asymptote. In contrast, the *randomForest* first approach initially estimated very small/zero trawl coefficients, which changed slowly with each iteration and eventually drifted towards the ~same cumulative estimate as the *lm* first approach. The *randomForest* first approach converged with fewer iterations, and given both approaches converged to the ~same estimate of the trawl coefficients, we proceeded to use the *randomForest* first approach in all subsequent analyses. The finding that the *randomForest* first approach converged more quickly and with less change in magnitude, compared with the *lm* first approach, suggests that the environmental influences on the regional distribution and abundance of these benthos are larger than the trawl effects.

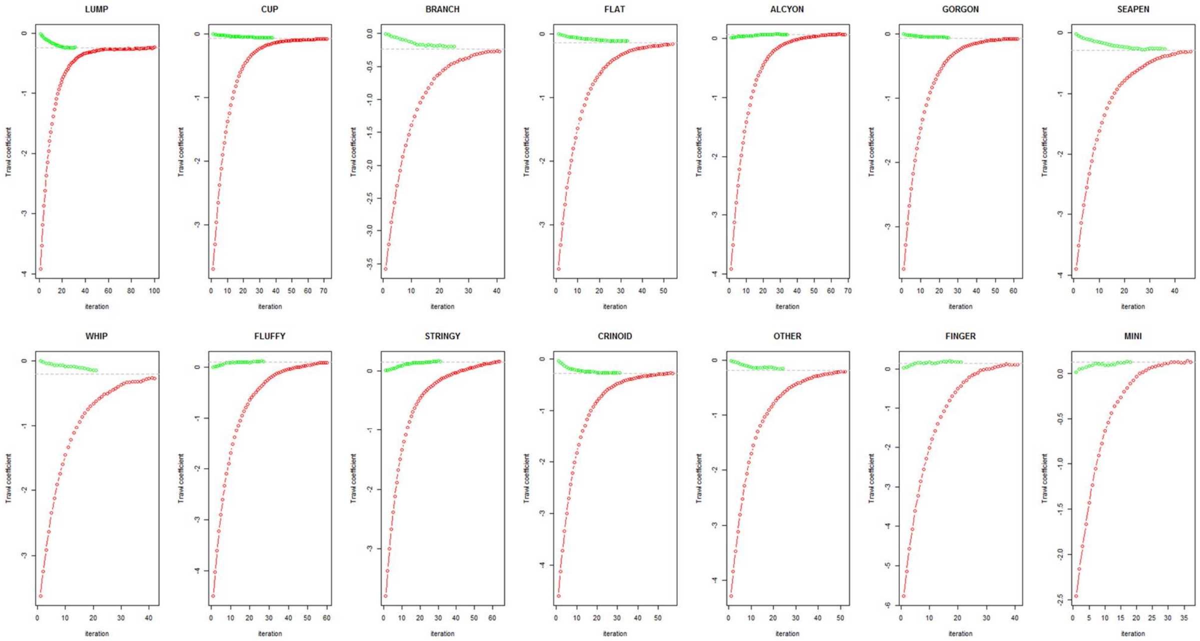


**Figure 135 Iterative estimation of the historical trawl gradient coefficient for 14 sessile benthos morpho-types (Sponges: Lump, Cup, Branched, Flat, Finger; Alcyonarian soft-corals; Gorgonians; Sea-pens; Sea-whips; 'fluffy' or 'stringy' hydroids or similar; Crinoids; other or small 'mini' benthos). Dots with lines show the progressive cumulative estimate of the trawl coefficient, red indicates the *lm*() first approach, green indicates the *randomForest*() first approach.**

The results of the *randomForest*() first approach are shown in Figure 136, and suggest that the major structure-forming benthos types (Sponges: Lump, Cup, Branched, Flat; Gorgonians; Sea-whips) all have negative responses along the historical trawl gradient, indicative of impacts. Some of the smaller benthos types, considered not to be important for forming habitat structure, do not show negative responses — possibly due to being more resilient and/or having faster recovery. These coefficients are quantified in Table 14 along with conversions to the corresponding percentage depletion per unit of swept-area-ratio (i.e. 100-exp(trawl_coef)*100), and an estimate of the approximate significance level. The latter is estimated by subtracting the estimated trawl-effect from the raw data (see blue crosses in Figure 136), fitting a single *randomForest*() model to these adjusted data to estimate the environmental influences, then calculating the difference between the *randomForest*() model predictions and the original unadjusted data, and finally fitting an *lm*() to these differenced data to re-estimate the trawl coefficient after removing the estimated environmental influences — the p-value from this final *lm*() model provides an approximate estimate of significant level. This indirect procedure means that formal statistical inference is difficult; the method is primarily exploratory and useful for indicating patterns and dependencies in the data.

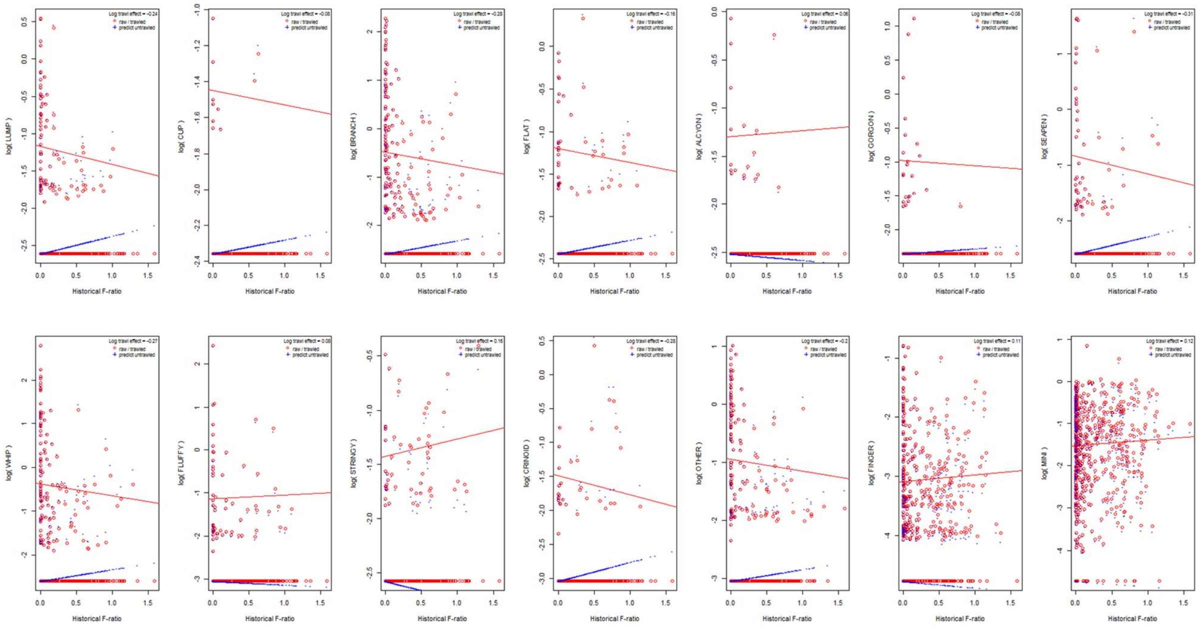


**Figure 136 Plots of log benthos counts (mean of each station, red circles) against average annual swept-area ratio (see section 4.2.1) of historical Taiwanese trawling for 14 sessile benthos morpho-types. Note that these are essentially scatterplots of the raw data and include all the variation due to environmental influences, they do not show the just the trawl effect in isolation. The red line indicates the final cumulative estimate of the trawl coefficient, following the *randomForest*() first iterative approach. The blue crosses indicate the expected pre-trawl response after adjusting for the trawl coefficient.**

**Table 14 cumulative estimates of the historical trawl gradient coefficient for 14 sessile benthos morpho-types, with corresponding conversion to percentage depletion per unit of swept-area-ratio, and *approximate* significance level (see text). Major structure-forming benthos types are highlighted.**

| **Morpho-type** | **Trawl Coef** | **depletion rate** | **Approx significance** |
|---|---:|---:|---:|
| LUMP | -0.239 | 21.2 | <0.001 |
| CUP | -0.079 | 7.6 | <0.001 |
| BRANCH | -0.277 | 24.2 | 0.03 |
| FLAT | -0.164 | 15.1 | 0.006 |
| ALCYON | 0.064 | -6.6 | 0.01 |
| GORGON | -0.079 | 7.6 | 0.06 |
| SEAPEN | -0.312 | 26.8 | <0.001 |
| WHIP | -0.270 | 23.7 | 0.13 |
| FLUFFY | 0.080 | -8.3 | 0.11 |
| STRINGY | 0.160 | -17.4 | <0.001 |
| CRINOID | -0.279 | 24.4 | <0.001 |
| OTHER | -0.204 | 18.5 | 0.09 |
| FINGER | 0.109 | -11.5 | 0.12 |
| MINI | 0.123 | -13.1 | 0.22 |

NOTE: “Flat” sponges are erect, fan-shaped – not prostrate.

As a second step, we analysed the photo-benthos dataset without aggregating large and small benthos for each type, and estimated the historical trawl coefficient separately for each of these sizes groups (Figure 137). In this case, the large size category for a number of the more major structure-forming benthos types tended to have more negative coefficients than the small size category, which might indicate that small sizes may be less affected by trawling and/or that benthos can recover to small sizes more quickly.

As a third step, given that some other datasets (e.g. trawl biomass from OM1963 and SS1995-97) only have highly aggregated data, we also analysed the photo-benthos dataset after aggregating all sponge types (Lump, Cup, Branched, Flat) and all gorgonian types (Gorgonians, Sea-whips), and estimated the historical trawl coefficient separately for each of these. In this case, both the all-sponges and all-gorgonians benthos types showed negative coefficients (Figure 138) somewhat intermediate to the corresponding dis-aggregated types shown in Table 14.

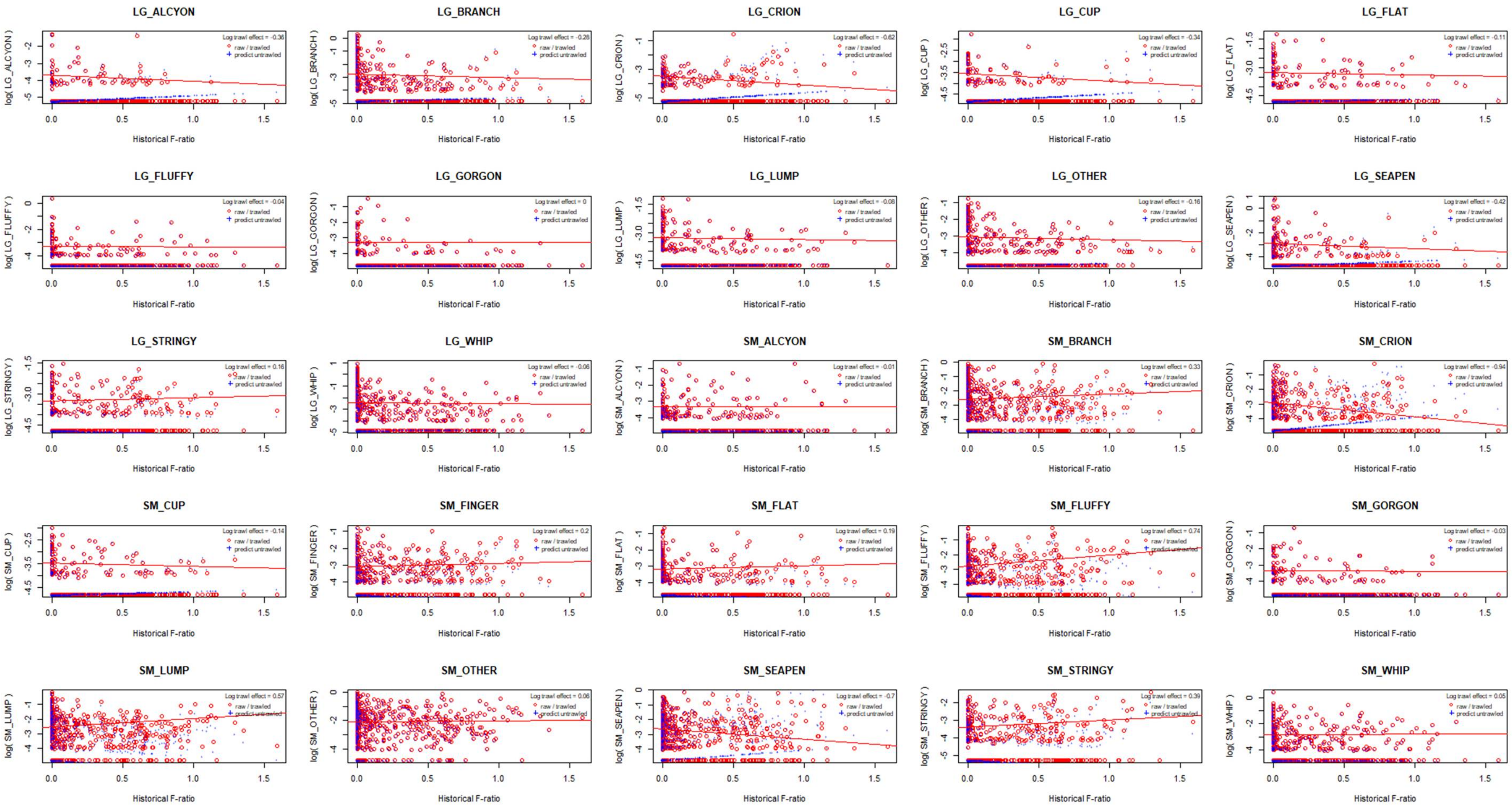


Figure 137 Plots of log benthos counts (mean of each station, red circles) against average annual swept-area ratio (see section 4.2.1) of historical Taiwanese trawling for large and small size categories of 14 sessile benthos morpho-types. See Figure 136 caption for further details.

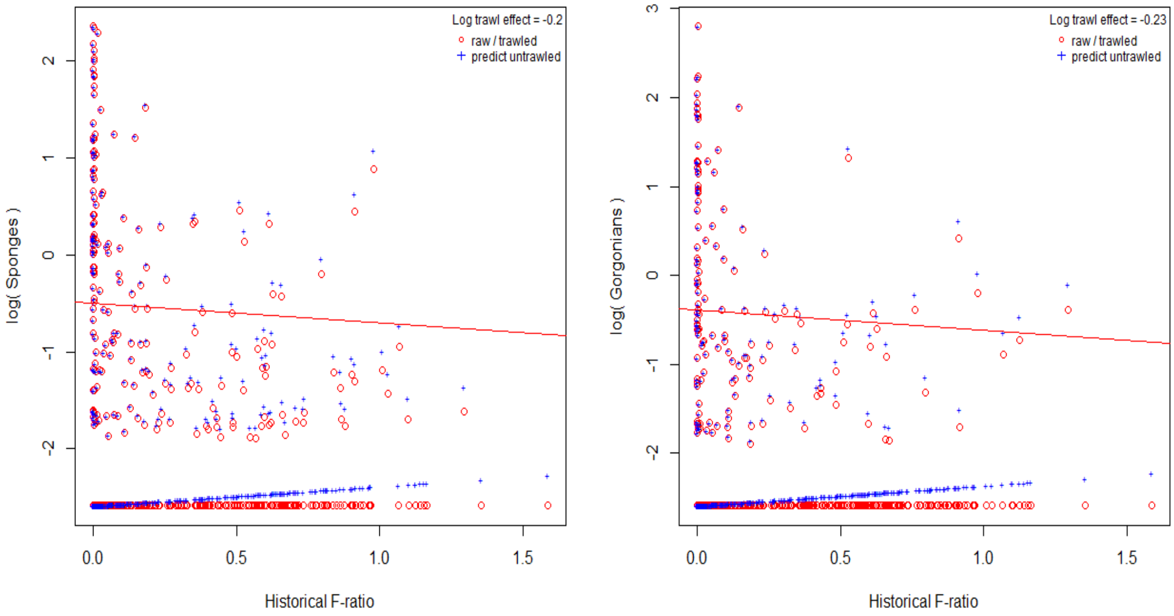


**Figure 138 Plots of log benthos counts (mean of each station, red circles) against average annual swept-area ratio (see section 4.2.1) of historical Taiwanese trawling for aggregated all sponge types (Lump, Cup, Branched, Flat) and all gorgonian types (Gorgonians, Sea-whips),. See Figure 136 caption for further details.**

## 5.3.2 CSIRO trawl survey sponge dataset vs historical Taiwanese effort

The standardised densities of total sponge biomass sampled by the CSIRO Southern Surveyor surveys on the NWS in 1995 and 1997 (Section 5.2, Figure 133) were analysed to estimate the effect of the historical Taiwanese pair-trawling effort (Section 4.2.1), using the same iterative method as described in the preceding section, which also aims to account for the environmental variables (Section 4.3). Again, the total sponge biomass showed a negative coefficient (Figure 139) consistent with (possibly more negative than) those shown by various aggregations of sponges from the photo-benthos dataset shown in the preceding section.

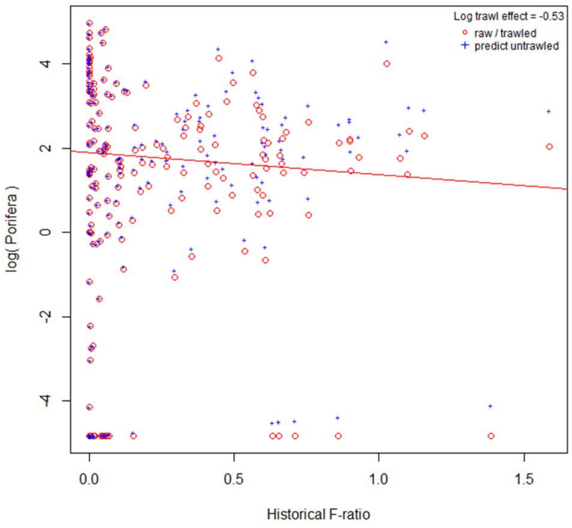


**Figure 139 Plot of log total sponge biomass (kg/Ha) for each SS95-97 station (red circles) against average annual swept-area ratio (see section 4.2.1) of historical Taiwanese trawling. See Figure 136 caption for further details.**

### 5.3.3 Japanese Oshoro Maru trawl survey sponge data vs historical Japanese effort

The earliest sponge sample biomass data, surveyed by the Japanese vessel Oshoro Maru at 20 trawl stations on the NWS in Dec 1963 – Feb 1964 (Section 5.2, Addenda 5.7.1, Figure 153), were also analysed to estimate the effect of the historical Japanese commercial otter-trawling effort in the region from Nov 1959 to Mar 1963 (Figure 153). The Oshoro Maru 1963 (OM1963) sponge catches were standardised to kg/Ha (Section 5.2, Figure 133), and the same iterative method was used as described in the preceding sections, which also aims to account for the environmental variables (Section 4.3). Note that this analysis is uncertain due to being compromised by the small number of stations (n<20) and the very coarse 0.5° mapping of Japanese effort (Figure 153). Nevertheless, the Oshoro Maru total sponge biomass also showed a negative coefficient against the Japanese trawl gradient (Figure 140).

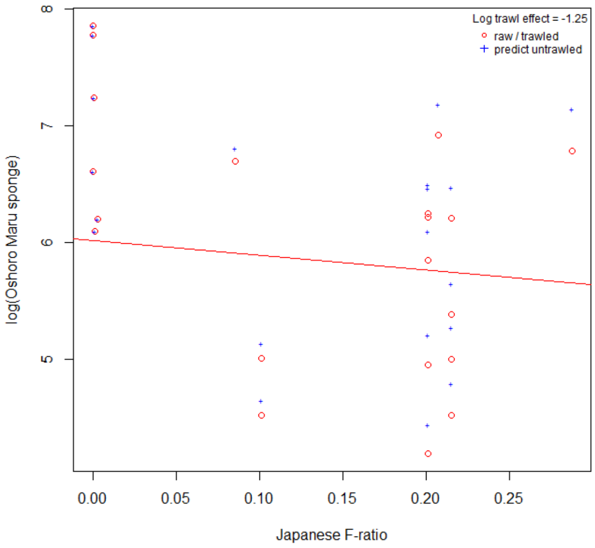


**Figure 140 Plot of log total sponge biomass (kg/Ha) for each Oshoro Maru station (red circles) against average annual swept-area ratio (see Figure 153) of historical Japanese trawling. See Figure 136 caption for further details.**

## 5.4 Analyses of MNF2017 benthos data

In 2017, the MNF Investigator voyage was able to acquire a range of additional data, to supplement the biological sampling data, which were not possible in earlier voyages. Among other things, the MNF2017 used a digital headline camera with a ~5 second image rate and also used scaling lasers, which enabled estimate of distance (range, m) from the camera to the point where the lasers reflected from the seabed for each image — estimates of image area *per se* however could not be known with certainty because the angle of the headline camera relative to the seabed could vary as the trawl net moved or slope of the seabed changed. Earlier voyages used a 35mm film camera with a ~20 second image rate and had no lasers, so range estimates were not possible. The MNF2017 also acquired sub-bottom profile (SBP) data, which enabled classification of seabed substratum and sediment cover into the following seabed types: "DUNE", "HARD", "OUTCROP", "THICK", "THIN" — one of these categories was attached to each image for which classified SBP data were available. Such classifications were not possible for any earlier voyages. Prior to estimating the historical trawl gradient coefficient for the 2017 MNF survey, the importance of the camera range data and SBP categories were examined relative to environmental and trawling intensity, at the scale of individual images within trawl stations, and subsequently at the scale of trawl stations (i.e. averages for within trawls).

### 5.4.1 Effect of image range standardisation and SBP class data at the image level

Ultimately, there were 89 stations with image range data, 101 with SBP data, and 89 with both — these data were attached to each image and merged with the individual image morpho-type counts data. For stations and images that have both range and SBP data, we used *randomForest* analyses at the image level to evaluate whether these data add value.

First, raw image-count data for each morpho-type – without range standardisation nor SBP variables – were modelled against the environmental variables and trawl effort as predictors. The Rsq performance of each morpho-type model and the *randomForest* importance measures for each predictor were extracted and stored. Second, the modelling was repeated after first dividing the raw image-count data by the square of the range (as a surrogate for image area), and again the Rsq performance and importance measures were stored. Third, the range-standardized image-count data were modelling again, with the SBP classification also included as a factor predictor. Again the Rsq performance and importance measures were stored.

Following these analyses, the Rsq performances of the unstandardised image models were compared with the range-standardized models — and the performances of the range-standardised models were compared with the range-standardized plus SBP factor models — by plotting the Rsq's against each other (Figure 141). These results suggest that standardising morpho-type counts by image range doesn't improve Rsq of model fits substantively (Figure 141, left). Nevertheless, range standardisation "de-quantises" counts from integers per image to continuous numbers per image depending on the varying range, and consequently there is a greater diversity of response values. Thus, the number of morpho-types that have >5 unique response values across all stations increases from 16 of 28 types that can be analysed to all 28 types. Including the SBP factor predictor (to range standardised data) appears to improve the Rsq performance of most models (Figure 141, right), with an average improvement in Rsq of almost 10% (regression coefficient = 1.097×).

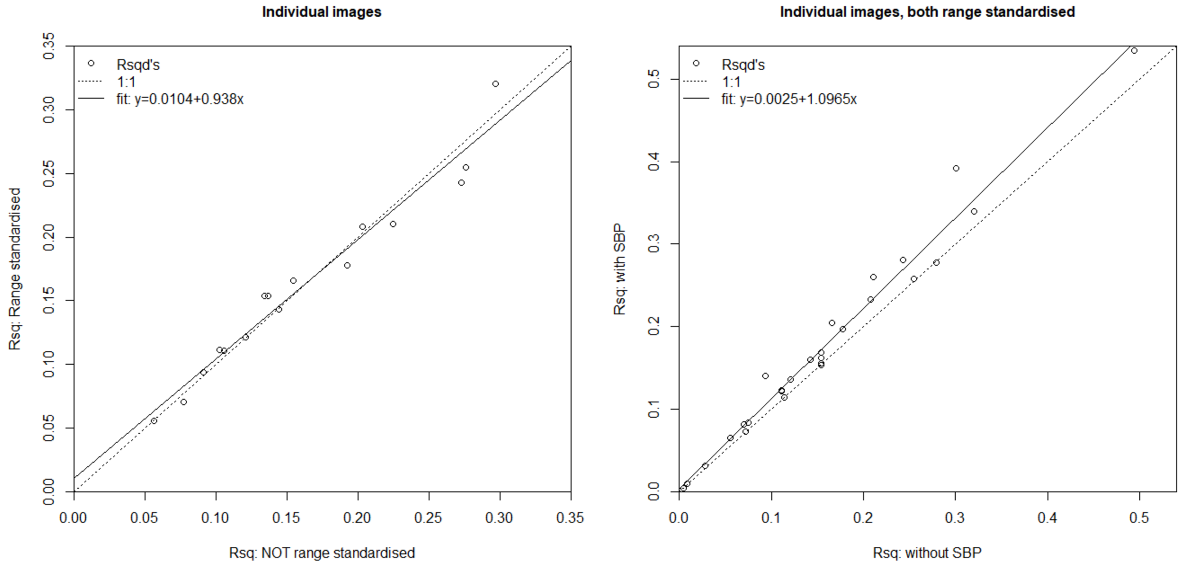


**Figure 141 Plots comparing Rsq performance of *randomForest* models of benthos morpho-type image counts with environmental predictors for (left) raw unstandardised counts vs range-standardised counts, and (right) range-standardised counts vs range-standardised counts with SBP classification as a factor predictor. Circles: paired results for each morpho-type; dotted line: the 1:1 comparison (no difference); solid line: linear regression fit.**

Plots of the Rsq-standardised predictor importance for the three sets of models (Figure 142) appears to indicate that range standardising the data increases variability in importance among morpho-type models (Figure 142, left cf. middle, wider boxes & whiskers, more outliers), although this could be due to an additional 12 morpho-types being included among the range standardised models. The overall order of most predictor importances are not greatly altered; for example historical trawl effort (F_Ratio_79_85) remains at high importance, but an obvious exception is recent effort (Trawl_F_Ratio) which drops from first to 12th in overall average importance. When the SBP factor predictor is included in models (Figure 142, right), it appears to be clearly most important in most morpho-type models — historical trawl effort again remains at high importance, but recent effort drops further to 28th in overall average importance.

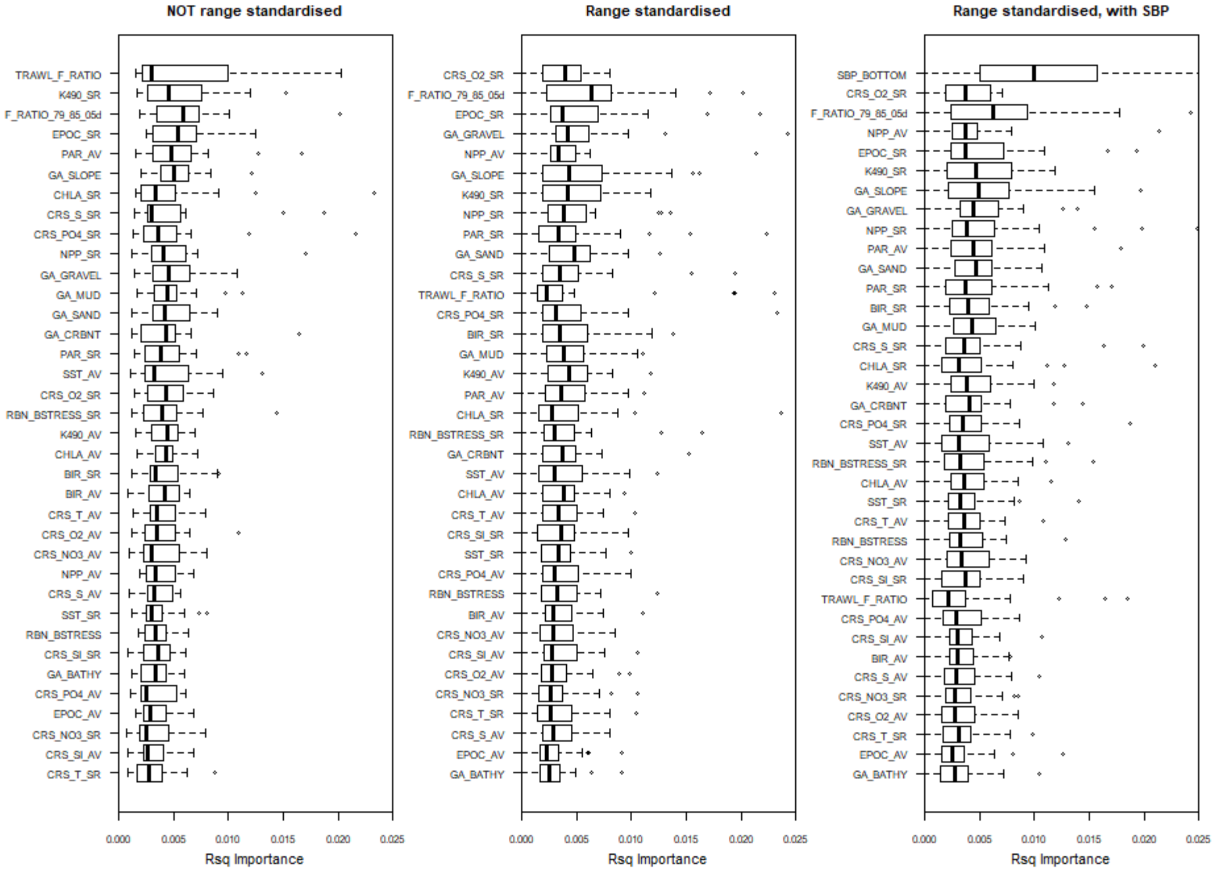


**Figure 142 Box-plots of Rsq-standardised predictor importance (ordered by mean importance, from the top) in *randomForest* models of benthos morpho-type image counts with environmental predictors for (left) raw unstandardised counts, (middle) range-standardised counts, and (right) range-standardised counts with SBP classification as a factor predictor.**

Given the stand-out importance of the SBP factor predictor at the image level, the response of benthos morpho-types to the SBP classification was examined further using *randomForest* marginal response plots (Figure 143). These plots show the mean response of each morpho-type to each of the SBP classes relative to their overall mean response at the average value of all other

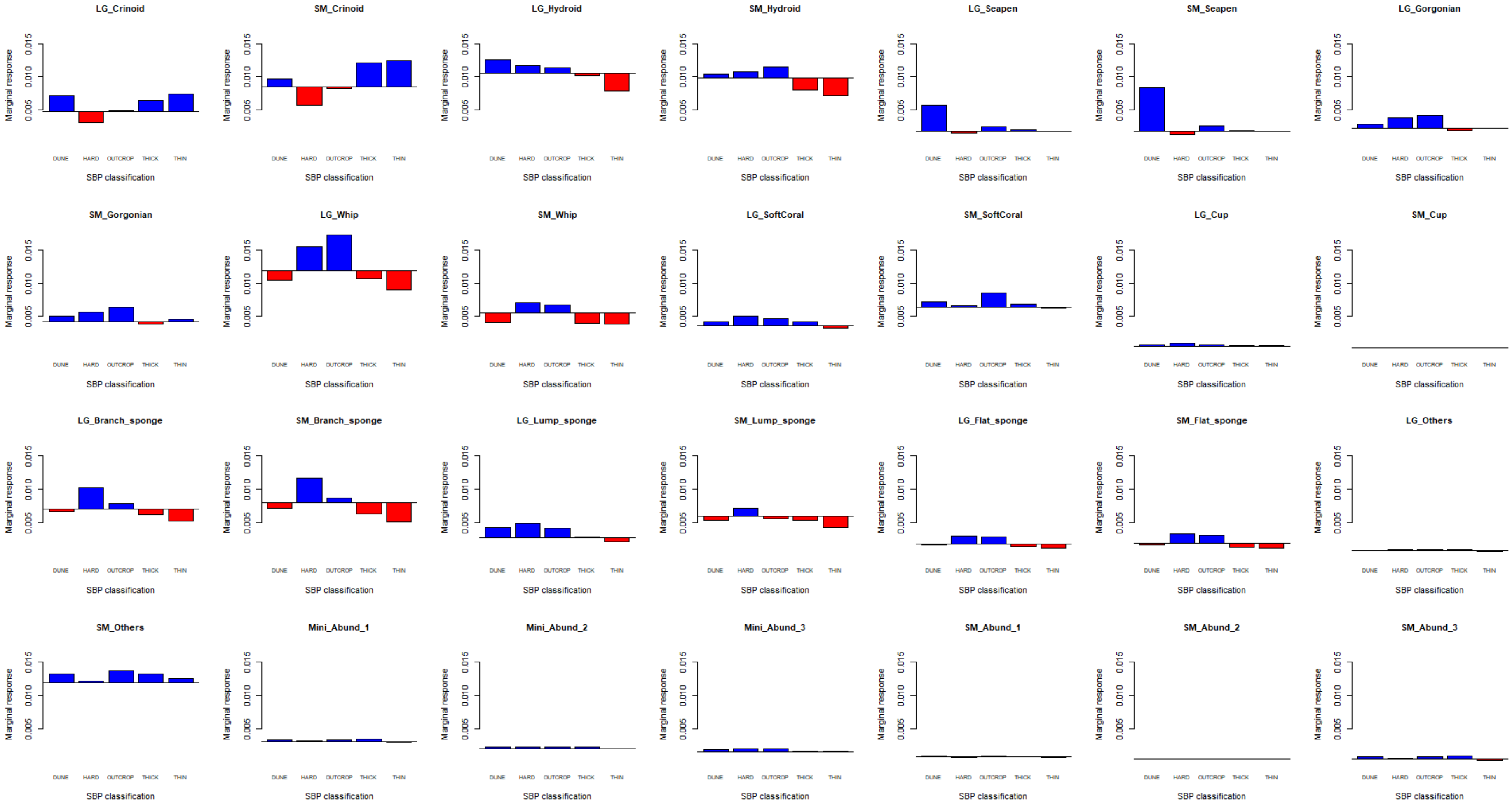


**Figure 143 Marginal response plots of the benthos morpho-types to each SBP class in *randomForest* models at the individual image level; all plots have the same Y-axis scale indicating the different degree of response of different morpho-types to each bottom type. Blue bars indicate positive responses, red bars indicate negative responses, relative to the mean response for each morpho-type.**

predictors; the Y-axis scaling is the same for all plots highlighting the contrasting responses different morpho-types to each bottom type. For example, crinoids are more abundant on sediments whereas most structure-forming attached benthos (gorgonians & whips, sponges) are more abundant on hard substrates and outcrop. These results are as expected given the known habitat requirements of such taxa.

Taken together, these results (Figure 141, Figure 142, Figure 143) suggest that morpho-type counts at image level should be range standardised and that the SBP classification should be included in subsequent modelling to estimate the trawl gradient coefficient. However, the analyses discussed in this sub-section were of the morpho-type data at the individual image level, whereas subsequent analyses would be at the trawl station level so would use the mean of image counts within trawls (which would be range standardised first), and SBP data would be summarised at the station level as a proportion of each of the 5 SBP class types occurring over the length of the trawl (i.e. 5 continuous variables rather than 1 factor variable).

### 5.4.2 Effect of SBP class proportions at trawl transect level

Before proceeding to estimate any residual effect of the historical Taiwanese trawl effort gradient on benthos morpho-types in 2017, as sampled by the MNF survey, the importance of the SBP bottom classification was further examined at the scale of trawl stations, relative to the importance of environmental variables and trawling intensity.

For analyses at the scale of trawl stations, the image-level counts of the benthos morpho-types were range standardised and the average count for each type was calculated for each trawl as the response variable, and the frequency of each SBP substratum type within each trawl was calculated as a proportion and provided 5 continuous predictor variables for each SBP class. These data were modelled with the station-level environmental variables and trawl effort as predictors, again using *randomForest* and extracting the predictor importance measures. The results indicated that the overall proportion of the HARD SBP class among the images within trawls often appears to be important for many benthos morpho-types (Figure 154, Addenda 5.7.2), and marginal response plots for HARD indicate that most benthos types (except Crinoids) have relatively higher mean abundance along trawls over seabed with higher proportions of HARD-classed seabed (Figure 155, Addenda 5.7.2). Like the image-level analyses, these trawl-station level results also indicate that the SBP classification should be included in modelling to estimate the trawl gradient coefficient.

### 5.4.3 Estimation of the residual historical trawl gradient effect in 2017

The historical Taiwanese trawl gradient coefficient for the 2017 MNF survey was estimated using the same iterative *randomForest*/*lm* approach as described in Section 5.3, where the *randomForest* fits the environmental variables and the *lm* fits the historical trawl effort gradient. Sections 5.4.1 and 5.4.2 provide evidence that benthos morpho-type image count data should be range standardised and that the analysis should include the SBP substratum type as predictors. Nevertheless, for completeness and understanding of the influence of this extra information on estimation of the historical trawl effect, three sets of analyses were run, using: 1. unstandardised benthos counts, averaged for each trawl; 2. benthos counts standardised by range², averaged for each trawl; 3. range standardised benthos counts, with SBP class proportions for each trawl as extra predictors.

The first results (unstandardised) suggest that, in 2017, all habitat-forming sessile benthos and most other types have positive responses along the historical trawl gradient (Figure 144), the exceptions being non-structure forming crinoids and seapens. The second results (range-standardised) are qualitatively the same (Figure 145), with minor differences in magnitude of the estimated trawl coefficient. The third results (range-standardised with SBP class proportions) are qualitatively similar with reduced absolute magnitude (both positive or negative) for most benthos types (Figure 146); however, the coefficient of small crinoids becomes positive on the trawl gradient, that of large and small Lump sponges become somewhat negative as do 'mini' benthos_1. Hence, it is possible that after accounting for trawl-scale substratum differences, there may still be some evidence of a small residual historical trawl effect on Lump sponges.

Further, we repeated the analysis, using range-standardised data with SBP class predictors, after aggregating the large (>15cm high) and small (<15cm) sizes for each benthos type, to (1) compare with the initial analysis of the historical photo-benthos dataset from the Sainsbury et al. NWS research voyages (1982–97, see Section 5.3.1, Figure 136), and (2) because subsequent simulation modelling of the entire temporal history of trawl-fishery impacts (Section 5.6) does not include the complexity of benthos size classes. The aggregation involved scaling up counts of large size classes of each benthos type by the ratio of average weight difference between large and small individuals of each type, based on the weights and counts of benthos sizes classes sampled by the trawls in MNF2017 (sponges: Cup=5.4, Branched & Flat=3.9, Lump=3.2, Gorgonians=3.5, Seapen=4.7, Soft Coral=2.3, Whips=23.3), before summing as a single index of abundance for each type. The aggregated analysis was completed for nine of the more major of the benthos morpho-types. The aggregated results suggest that all major habitat-forming sessile benthos and most other types have positive responses along the historical Taiwanese trawl effort gradient (Figure 147), the exceptions being non-structure forming sea-pens.

The final analysis for the 2017 MNF survey data against the historical Taiwanese trawl gradient coefficient was for the aggregation of the total biomass of all trawl-sampled sponges, to compare with the analysis results for the SS95-97 total sponge biomass (Section 5.3.2, Figure 139) — and with results for the Oshoro Maru survey total sponge biomass against the Japanese trawl gradient (Section 5.3.3, Figure 140). In this final case, total sponge biomass in 2017 showed a very slight positive coefficient (effectively zero, Figure 148), providing evidence of no residual reduced abundance of sponges ~30 years after the cessation of the historical Taiwanese pair trawling.

Taken overall, the results of these analyses of the MNF2017 data against the historical Taiwanese trawl gradient, when compared with the primarily negative coefficients of SS1995-97, suggest that most of the major habitat-forming sessile benthos morpho-types had recovered by 2017. There is some uncertainty for Lump sponges, as not all analyses were consistently positive. It is also unclear why crinoids and sea-pens would be consistently negative, as neither are known to be particularly sensitive to trawling in terms of high impact rates or slow recovery. It is possible that this reflects some unknown compensatory effect.

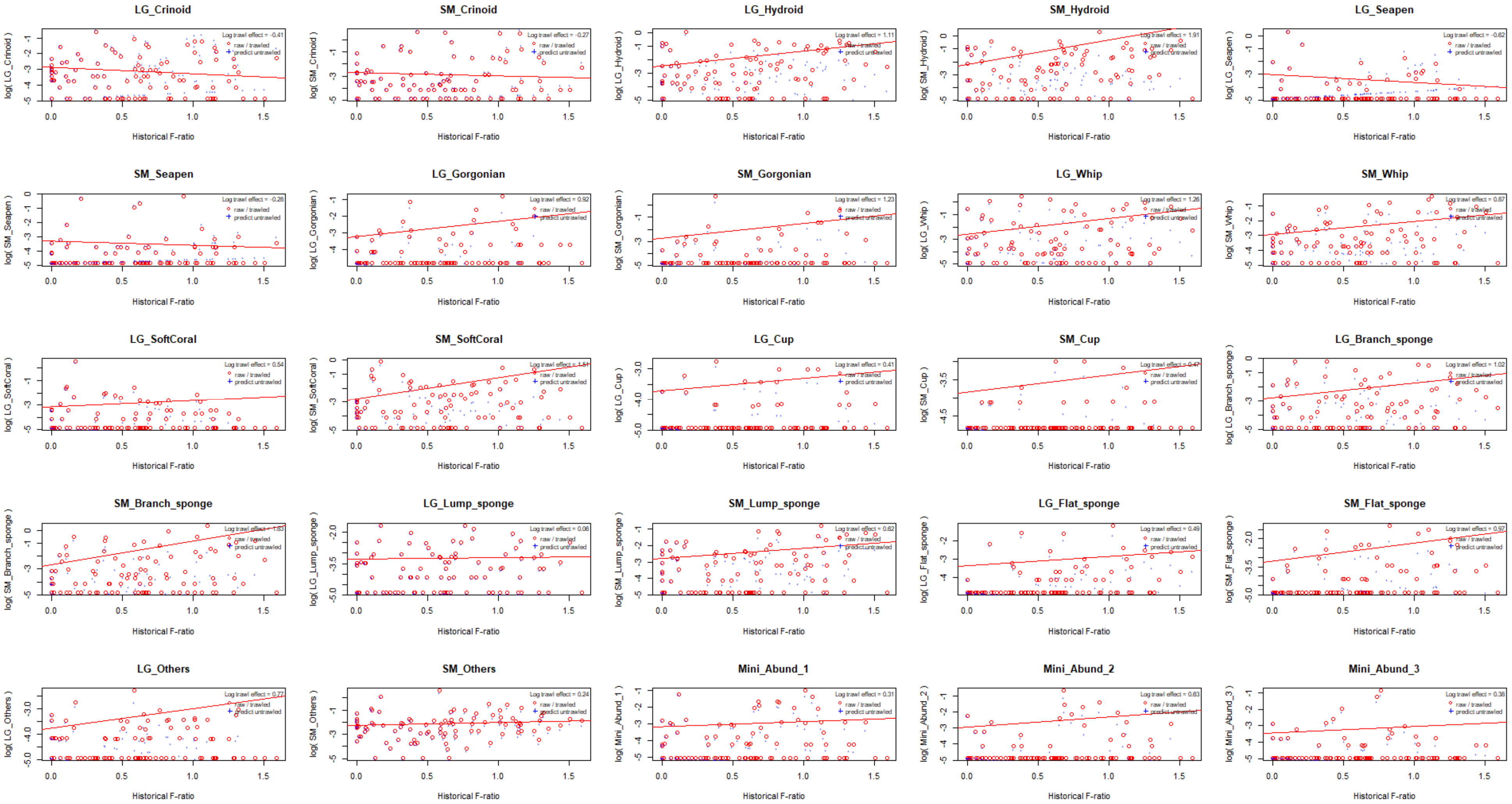


Figure 144 Plots of log benthos counts (unstandardised mean of each station, red circles) against average annual swept-area ratio (see section 4.2.1) of historical Taiwanese trawling for large and small size categories of 14 sessile benthos morpho-types. See Figure 136 caption for further details.

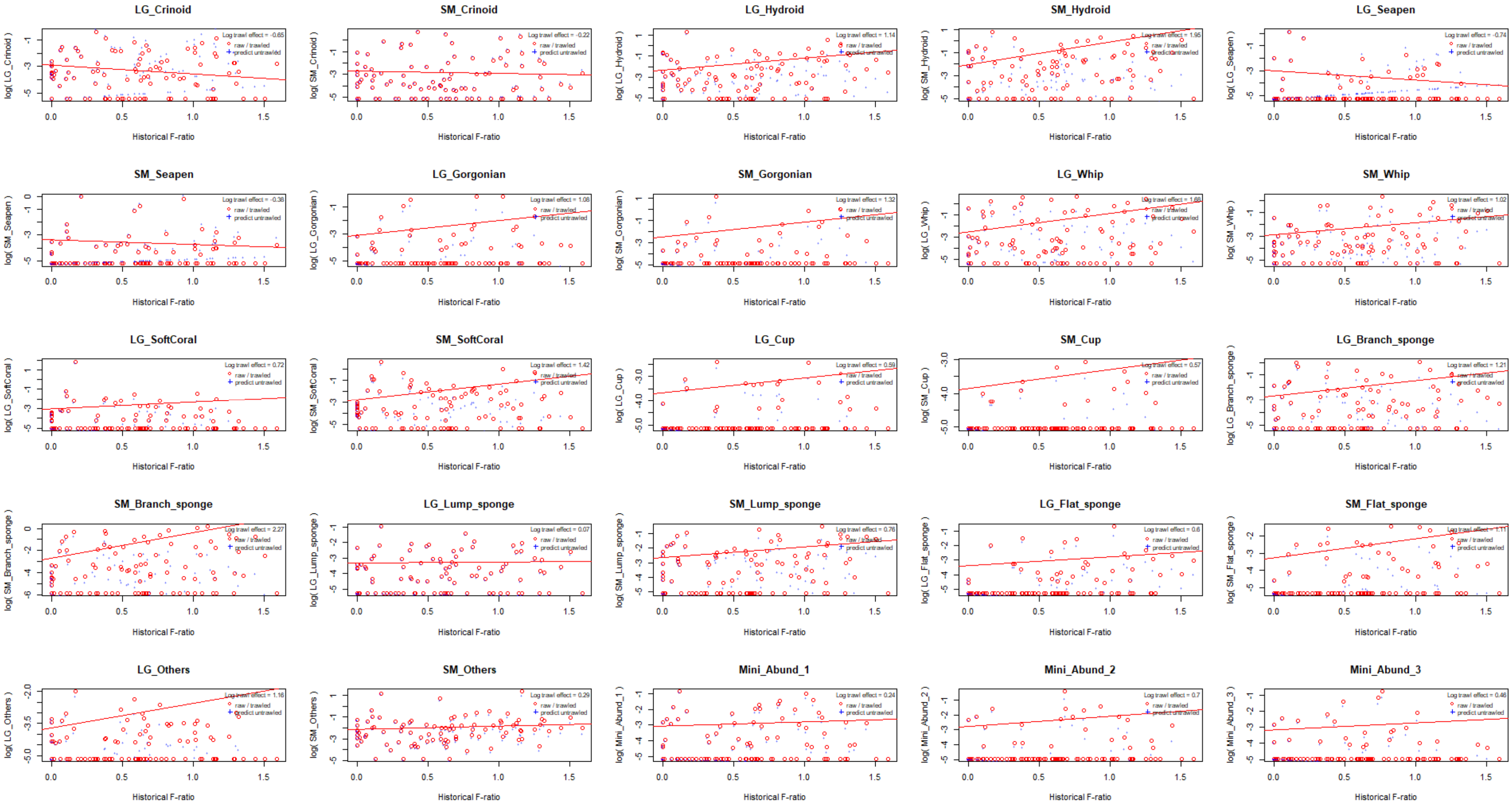


Figure 145 Plots of log benthos counts (range-standardised mean of each station, red circles) against average annual swept-area ratio (see section 4.2.1) of historical Taiwanese trawling for large and small size categories of 14 sessile benthos morpho-types. See Figure 136 caption for further details.

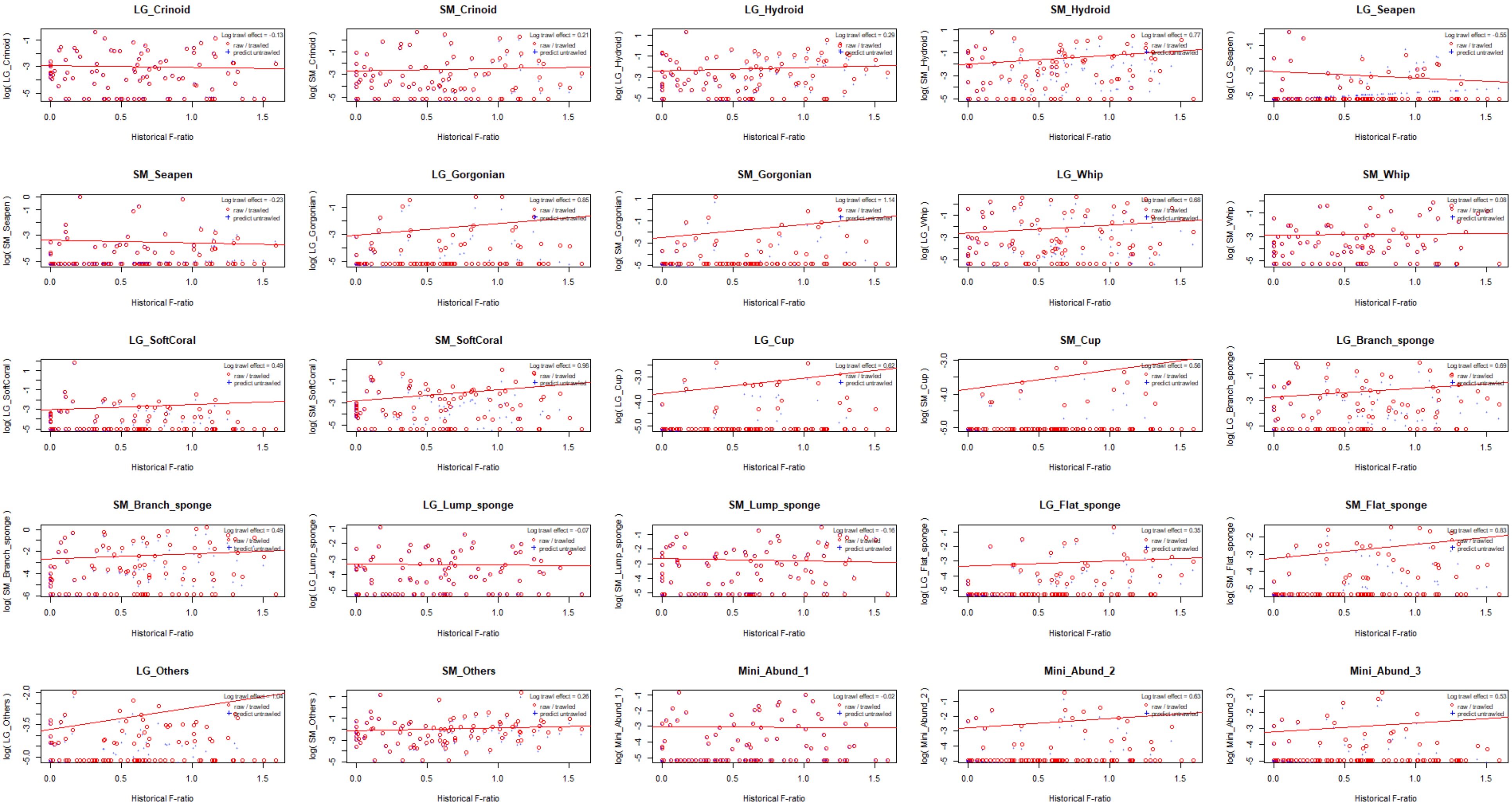


Figure 146 Plots of log benthos counts (range-standardised mean of each station, red circles) against average annual swept-area ratio (see section 4.2.1) of historical Taiwanese trawling for large and small size categories of 14 sessile benthos morpho-types, accounting for SBP substratum class proportions. See Figure 136 caption for further details.

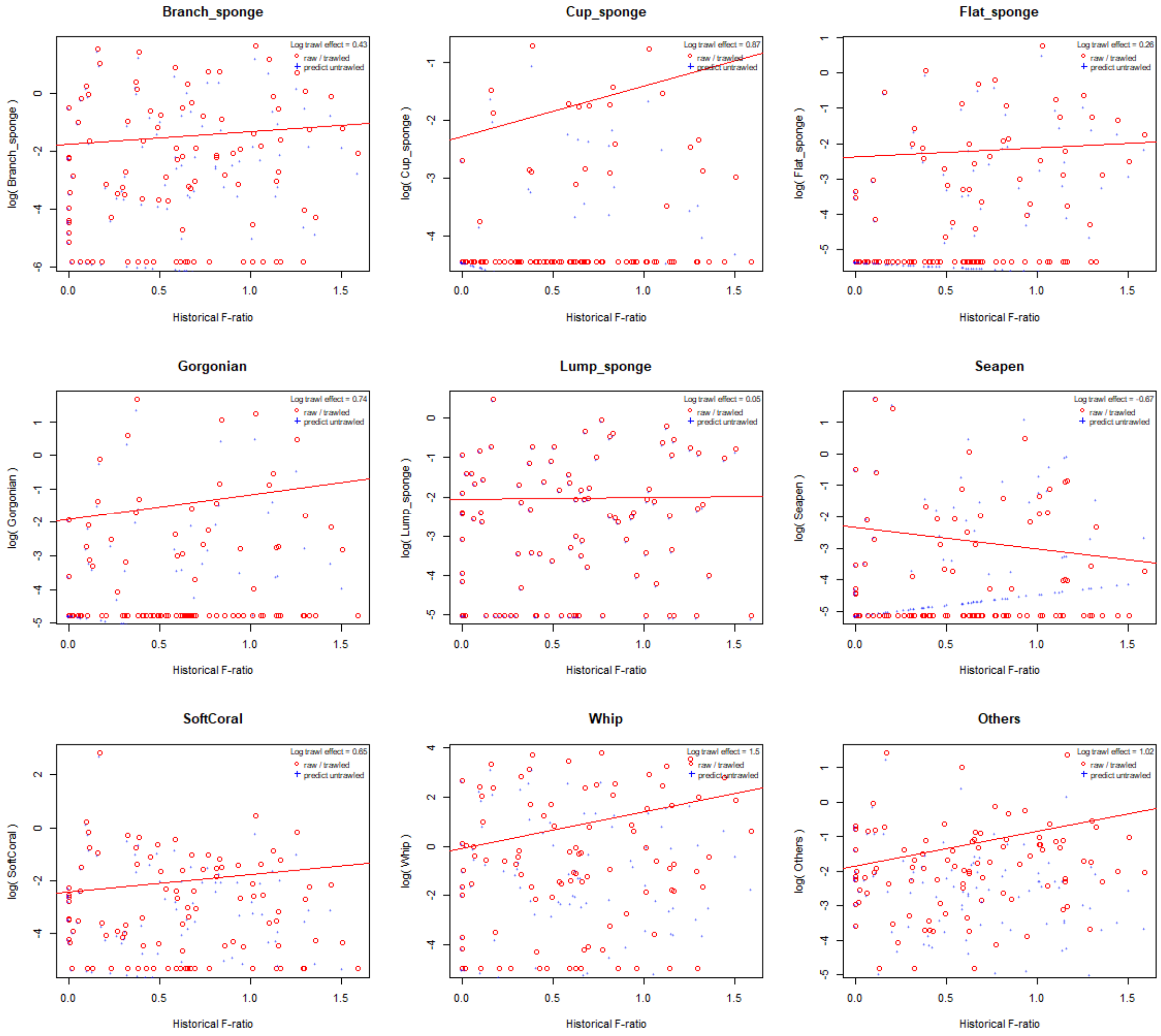


Figure 147 Plots of log aggregated large and small benthos morpho-types (range-standardised mean of each station, red circles) against average annual swept-area ratio (see section 4.2.1) of historical Taiwanese trawling for large and small size categories of 14 sessile benthos morpho-types, accounting for SBP substratum class proportions. See Figure 136 caption for further details.

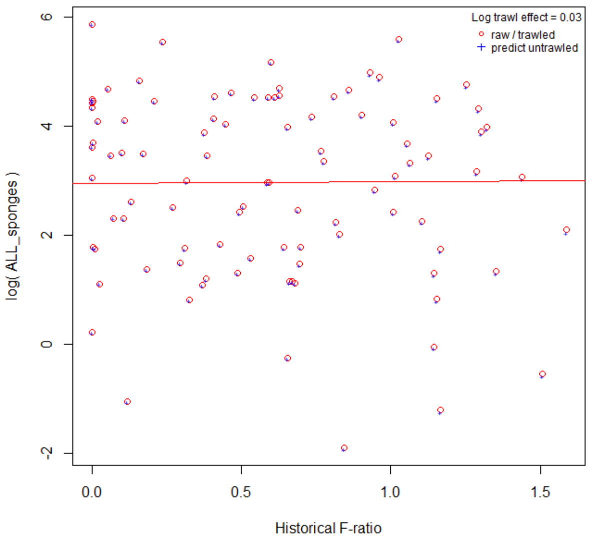


**Figure 148 Plot of log total sponge biomass (kg/Ha) for each MNF2017 station (red circles) against average annual swept-area ratio (see section 4.2.1) of historical Taiwanese trawling. See Figure 136 caption for further details.**

### 5.4.4 Catchability of sessile benthos morpho-types in trawl nets

With an aim of obtaining some understanding of catchability of sessile benthos morpho-types into trawl nets, we compared counts of each benthos type caught in trawl samples with counts of the same benthos types recorded from scoring the trawl head-line camera images. Trawl counts could be standardized by hectare, but unfortunately the camera image area is not known with sufficient certainty at this time, so image counts cannot be converted to density for a fully quantitative comparison with trawl catch counts (although they were standardized for range). In most cases, the trawl caught benthos types were recorded in more detail than possible from the images, so trawl caught benthos were aggregated to the same morpho-types and size-groups (small: <25cm, large: >25cm) as recorded for images — the main exception was that the Flat and Branched type sponges recorded from images were both recorded as Erect type sponges in trawl catches, hence image counts for Flat and Branched had to be aggregated to Erect type sponges. The count data from trawls and images were plotted against each other in log-log scale plots, for each benthos type and size-group (Figure 149). In most cases, there are reasonable relationships between benthos types and size observed in cameras and those caught in trawls. Further, while the coefficients of the relationships cannot directly quantify catchability (without image area estimates needed for standardization), there are clear differences in the relationships for large and small sizes of the same types showing relatively higher catch rates for large sizes and strongly indicating that large benthos have higher catchability than small benthos (as would be expected). Sainsbury et al. (1997) also found differences in selectivity of the trawl to different sizes of benthos.

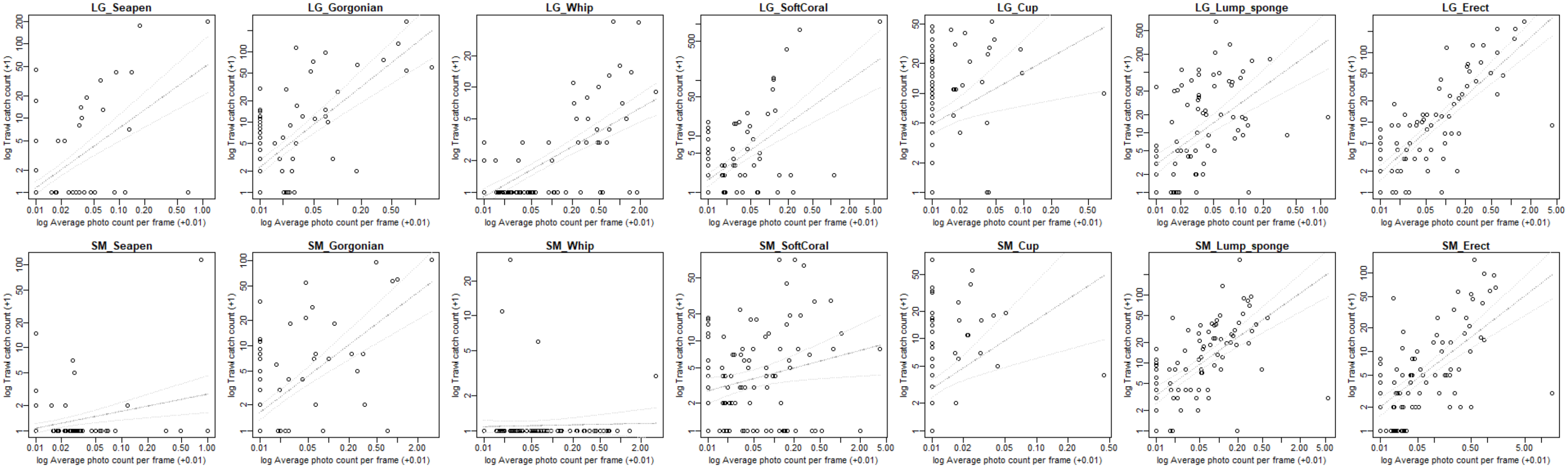


**Figure 149 Log-Log plots of counts of large and small benthos morpho-types recorded from trawl samples and head-line camera images. Note that axes have different scales.**

## 5.5 Prediction of pre-trawling sessile benthos distributions

Following estimation of benthos responses along the Taiwanese trawl gradient, the results for the (negative) trawl coefficient can be subtracted from the data and used to predict an estimate of the pre-trawl distribution from the environmental predictors using *randomForest*. The predicted initial distributions can then be used as a starting point in simulation modelling of the entire temporal history of trawl-fishery impacts (Section 5.6). There are constraints on the level of complexity of the trawl modelling that influenced the approach to predicting the pre-trawl distributions. In addition to abundance distributions, the trawl simulation modelling requires estimates of trawl impact rates and recovery rates. Estimates of these parameters for a number of sessile taxa are available from the GBR effects of trawling work (e.g. Pitcher et al 2007; Ellis et al 2014; Pitcher et al 2016), and many of the NWS benthos morphotypes can be directly or closely matched to the GBR taxa, but not all. The GBR work showed some trends in size depletion effects (higher depletion for larger benthos) but the effect was not significant, and there is only a single impact estimate for each taxon, and only one recovery rate estimate, regardless of size. Further, the simulation modelling treats each morphotype as a population, without separate size-classes (to do so would require too many unknown parameters). For these reasons, pre-trawl distributions were estimated for the aggregate of small and large sizes for each of the six most important habitat-forming benthos morphotypes (Sponges: Branched, Cup, Flat, Lump; Gorgonians and Whips).

For the MNF2017 image data, LG & SM sizes for each major morphotype were aggregated after first scaling counts based on the ratio of mean weights of large and small from the MNF2017 catch data (see Section 5.4.3). The aggregated image data were not further adjusted for the Taiwanese trawl gradient coefficient since there was no evidence of a negative trawl effect in the aggregated MNF2017 data (Figure 147). Then *randomForest* models were fitted to log(X+minX) transformed data with the environmental variables as predictors. Following fitting, the models were used with the full grid of environmental variables to make predictions of each morphotype on the log scale, which were back-transformed using the standard 'bias-correction' procedure ($e^{(\bar{y}+\sigma^2/2)}$). Standard deviations of the grid predictions (on the log scale) were calculated from the forest of individual tree predictions (*n*=500) for each benthos type.

For the historical photo-benthos dataset from the Sainsbury et al. NWS research voyages (1982–97, see Section 5.3.1), there was evidence that most large sizes had a negative coefficient for the historical Taiwanese trawl gradient effect (Figure 137). Hence, data for large and small sizes of each morphotype were adjusted for any negative Taiwanese trawl effects, before fitting *randomForest* models to log(X+minX) transformed data with the environmental variables as predictors. Again, grid predictions of benthos distributions from these models were back-transformed using bias-correction, and SDs were calculated. The separate back-transformed predictions for large and small sizes were added after first re-scaling to account for the mean weight differences between large and small benthos, as described above. The cell variances of the grid predictions on the log scale for large and small benthos, were pooled after taking into account the weight-scaling. The back-transformed predictions of pre-trawl distributions on the natural scale, from the historical period and from 2017, were ensembled for each morphotype. The ensembling involved weighted averaging, so that more uncertain predictions had lower weights,

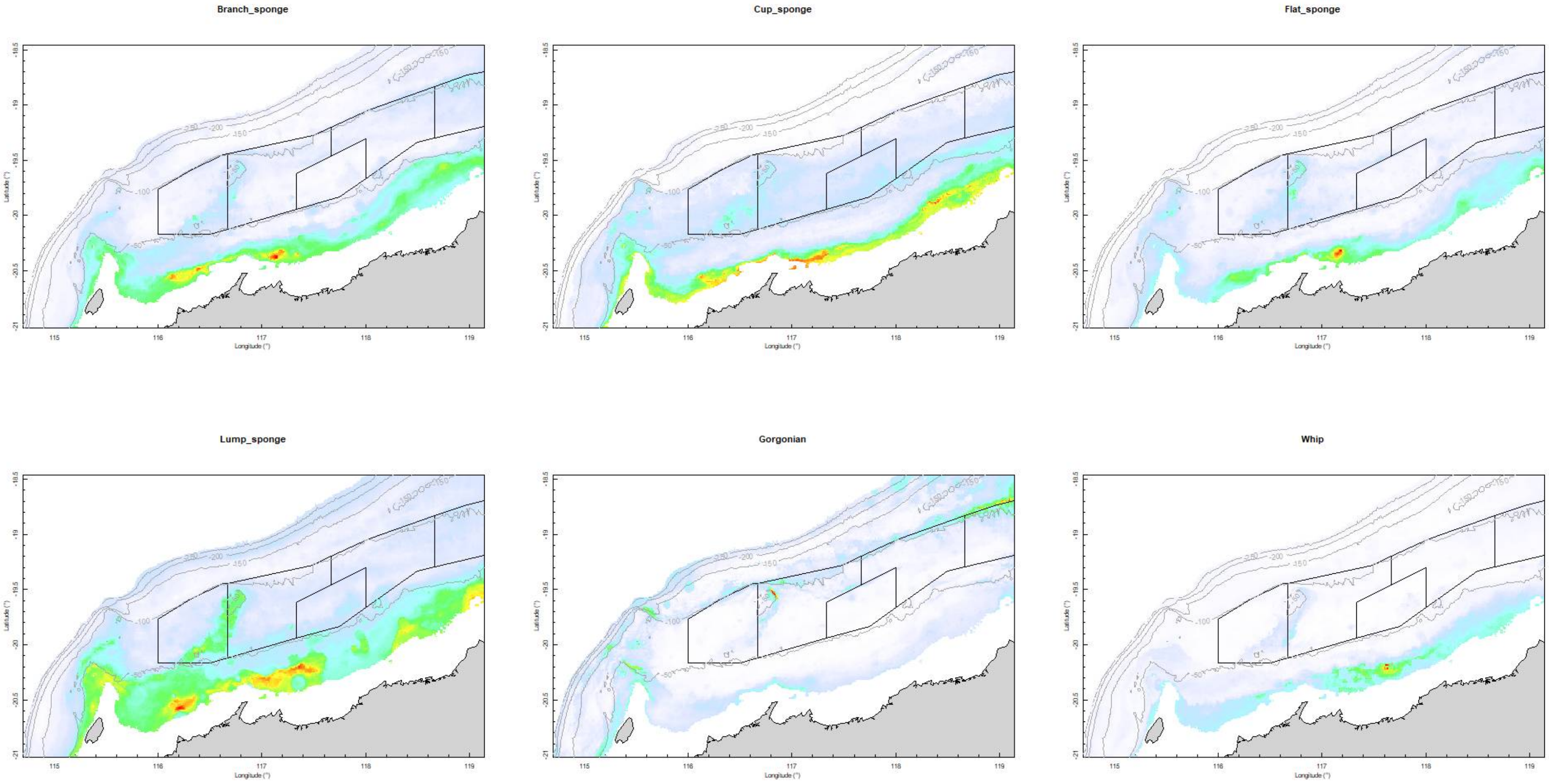
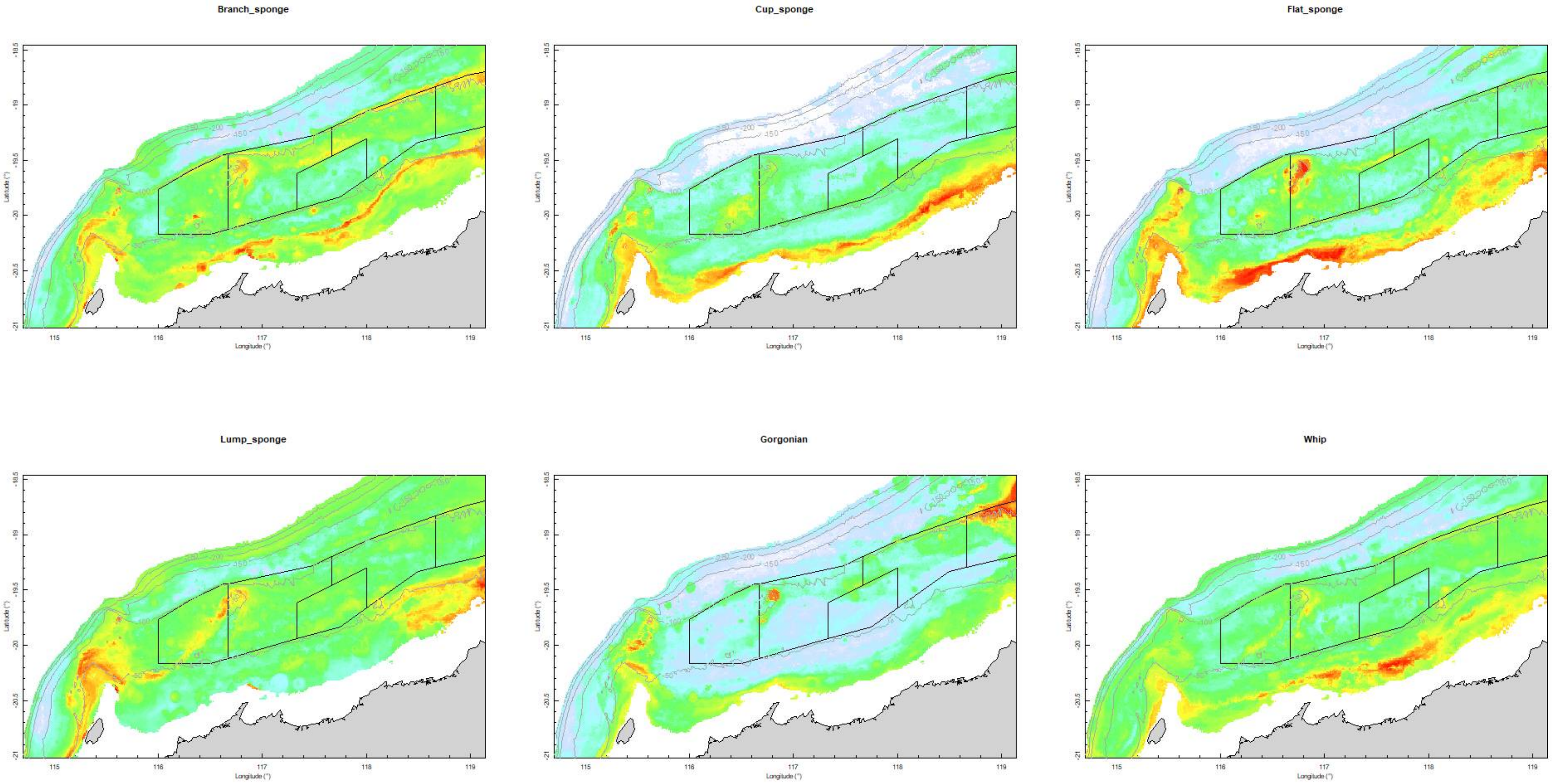

Branch_sponge
Cup_sponge
Flat_sponge
Lump_sponge
Gorgonian
Whip

Figure 150 Maps of ensemble predicted distributions of the relative abundance (red=high, blue/grey=low) of six major benthos morpho-types for the greater NWS study area. Black polygons outline current Western Australian management areas for their domestic trawl fishery. Depth contours are 50m intervals.


Branch_sponge

Cup_sponge

Flat_sponge

Lump_sponge

Gorgonian

Whip

Figure 151 Maps of uncertainty (pooled SDs on log scale; red=high, blue/grey=low) in ensemble predicted distributions of six major benthos morpho-types for the greater NWS study area. Black polygons outline current Western Australian management areas for their domestic trawl fishery. Depth contours are 50m intervals.

using minimum-variance-unbiased-estimator (MVUE) to calculate the weightings at the level of each grid-cell (based on inverse grid-cell SDs) as well as at the overall level (based on model Rsqd's). An estimate of the ensembled SDs for each grid-cell (on the log scale) was calculated using the same weighting procedure.

The ensembled mean grid-cell predictions on the natural scale were mapped (Figure 150), as were the estimated combined grid-cell SDs on the log scale (Figure 151). Given the image counts were re-scaled by the ratio of mean weights for large and small size-classes, the predictions may be considered to represent the estimated relative 'amount' of each benthos type. These were divided by totals to provide normalised distribution profiles that sum to 1, which were used as the starting distributions in the trawl impact simulation modelling.

## 5.6 Trawl impact simulation modelling

A spatial dynamic modelling framework (originally developed in 1999 for the GBR Marine Park area, see Ellis and Pantus 2001, and Ellis et al. 2014 for model details) was used to estimate the regional impact of trawling on sessile benthos types, in terms of removal of relative abundance, by implementing a simulation of the spatial and temporal pattern of all past trawling effort on the greater NWS study area, including the Japanese otter trawling, Taiwanese pair-trawling, and subsequent domestic otter trawling (to 2016). The model estimates a time-series of benthos relative abundance for each spatial grid-cell that depends on the sequence and intensity of trawl effort, and estimates of per-trawl depletion rates and post-trawl recovery rates. The model has been used to compare trawl management scenarios in the GBR (Pitcher et al 2007 and 2016) and in the Southeast Region (Pitcher et al 2015).

The trawl simulation model is based on a Schaefer (1954) equation, widely used in fisheries assessments, with the fishing removal term modified to describe benthic impacts of trawling:

$$\delta B/\delta t = rB(1-B/K) - dFB$$

where $\delta B/\delta t$ is the rate of change in abundance $B$ in time $t$, $r$ is the recovery rate, $K$ is carrying capacity, $d$ is the trawl depletion rate and $F$ is trawling effort as swept-area ratio. Each cell was assumed independent from neighbouring cells — a reasonable simplification for immobile sessile taxa that have short-range propagules. Estimates of $d$ and $r$ for a number of sessile taxa are available from the GBR effects of trawling work (see Pitcher et al. 2007); these were aggregated by morphotype to provide mean estimates for comparable morphotypes of the NWS benthos (Table 15), some of which are the same taxa (e.g. Flat sponge = *Ianthella* sp.s).

**Table 15 Estimates of trawl depletion rate *d* and logistic recovery rate *r*, with estimated uncertainty, aggregated to NWS benthos morhotypes, from analysis of the GBR effects of trawling work.**

| Benthos morho-type | *d*_value | low_d | high_d | *r*_value | low_r | high_r |
|---|---|---|---|---|---|---|
| Lump sponge | 0.38 | 0.29 | 0.46 | 0.45 | 0.33 | 0.56 |
| Cup sponge | 0.37 | 0.29 | 0.45 | 0.75 | 0.56 | 0.94 |
| Branch sponge | 0.36 | 0.28 | 0.44 | 0.48 | 0.36 | 0.60 |
| Flat sponge | 0.32 | 0.25 | 0.39 | 0.25 | 0.19 | 0.31 |
| Gorgonian | 0.41 | 0.32 | 0.50 | 1.15 | 0.86 | 1.44 |
| Whip | 0.08 | 0.06 | 0.10 | 0.64 | 0.48 | 0.80 |

Estimates of carrying capacity *K* were provided by the predictions of pre-trawl distributions (Section 5.5, Figure 150). Nevertheless, the model was run with a starting value of *K*=1 in all cells, thus model predictions are initially of relative benthos status (0–1) for each cell, which are subsequently multiplied by the predicted pre-trawl distribution for each cell, to provide an estimated time-series of ‘absolute’ status.

The annual trawl effort time series was provided by existing data and/or from fishery logbook databases. Japanese otter trawling effort for 1959 to 1963 was sourced from Robins (1969) on a 0.5° grid (see Section 5.2, Addenda 5.7.1). Taiwanese pair-trawling effort for 1972 to 1989 was originally sourced from Taiwanese fishery logbook data on a 0.5° grid for the years 1972 to 1981 (Althaus et al. 2006), and for years 1979 to 1989, 'shot-by-shot' trawl data were sourced from AFMA and were gridded at 0.05° resolution (see Section 4.2.1). Domestic otter trawling effort for 1987 to 1992 on a 1° grid was sourced from Fisheries WA catch and effort statistics (CAES, see in Althaus et al. 2006), and for years 1993 to 2016, 'shot-by-shot' trawl data were provided by WA DPIRD (updated in 2017 and 2020) and were gridded at 0.01° resolution (see Section 4.2.2). Trawl effort in number of tows and/or hours was converted to swept-area ratio *F* based on gear swept-widths and tow-speeds as described in Sections 4.2.1, 4.2.2, 5.2).

We also incorporated uncertainty around the parameters into the simulation, in addition to the mean estimates, to propagate uncertainty through the trawl model, so that the outputs would provide a distribution of potential outcomes. Uncertainty in depletion *d* and recovery rates *r* was provided by an analysis of the mean absolute deviations (MADs) of the estimates for the GBR taxa. Since benthos sensitivity to trawling is the ratio *d*/*r*, we characterised uncertainty by using ±half the MAD relative to the mean for each morphotype, which leads to a range of sensitivities comparable to the inter-quartile range of the total spread of sensitivity. This corresponds to about ±22.5% for *d* and about ±25% for *r* — thus, high sensitivity was *d*+22.5% with *r*-25%, and low sensitivity was *d*-22.5% with *r*+25% (see Table 15). For uncertainty in trawl swept-area ratio (SAR), we used mean and high estimates for the swept-width of trawl gear, where mean pair-trawl width was 112m and high (+1SD) was 126m (Section 4.2.1) and mean otter trawl door-to-door width was 80m and high was 100m (Section 4.2.2). Uncertainty in predicted distributions was represented by mean ± SD for each morphotype (see Section 5.5) — thus, low range distribution was exp(log(x)-SD), and high range distribution was exp(log(x)+SD) for each grid cell.

The trawl simulation model predicted that the regional status of the six sessile benthos morpho-types declined when trawl effort increased and recovered when trawl effort reduced (Figure 152).

Lowest status occurred around 1980, towards the end of the period of highest Taiwanese effort. Depending on the uncertainty scenario and morpho-type, the lowest status reached ranged between about 65% to 98% of pre-trawling abundances. There were indications of a secondary dip in status for some morpho-types in the mid-late 1990s as domestic trawl effort increased and peaked in 1996. The uncertainty range is wide for most morpho-types; greatest uncertainty appears to be with the benthos sensitivity to trawling, followed by mean vs high SAR, then distributions (where alternatives are likely to be correlated). Sponges (Branched, Cup, Flat, Lump) are most sensitive, Whips are least sensitive, and Gorgonians have intermediate sensitivity. The shapes of the status time-series varied among morpho-types; for example, compared with other morpho-types, the Cup Sponges (and also Flat Sponges) continued to be depressed by ongoing Taiwanese effort through the 1980s. These patterns are likely to be due to differing distributions; i.e. as spatial patterns of fishing changed over time, areas where cup sponges (and flat sponges) were distributed continued to be relatively more exposed to trawling than areas where the other benthos types occurred.

The status of the benthos morpho-types at the end of the time-series in 2016 varies with the uncertainty scenario, but is at the highest levels since Taiwanese trawling started in 1972. Further, given analyses of the MNF2017 data suggest little or no residual Taiwanese trawl effect remains in 2017 (Section 5.4.3) — and analogous empirical analyses of the MNF2017 data on the recent trawl gradient (while showing negative effects for some morpho-types) suggest regional-scale depletion of current status is less than ~1%-2% — thus, it is perhaps more likely that the more optimistic uncertainty scenarios are a more plausible reflection of the history of impacts.

Estimates of unfished benthos in this recent analysis are less than in the original analysis of the adaptive management experiment. This can be largely attributed to the Improved availability of environmental data for the recent analysis and because the impact of Taiwanese and other foreign trawling was estimated to be higher in the past analyses than is considered to be the case now.

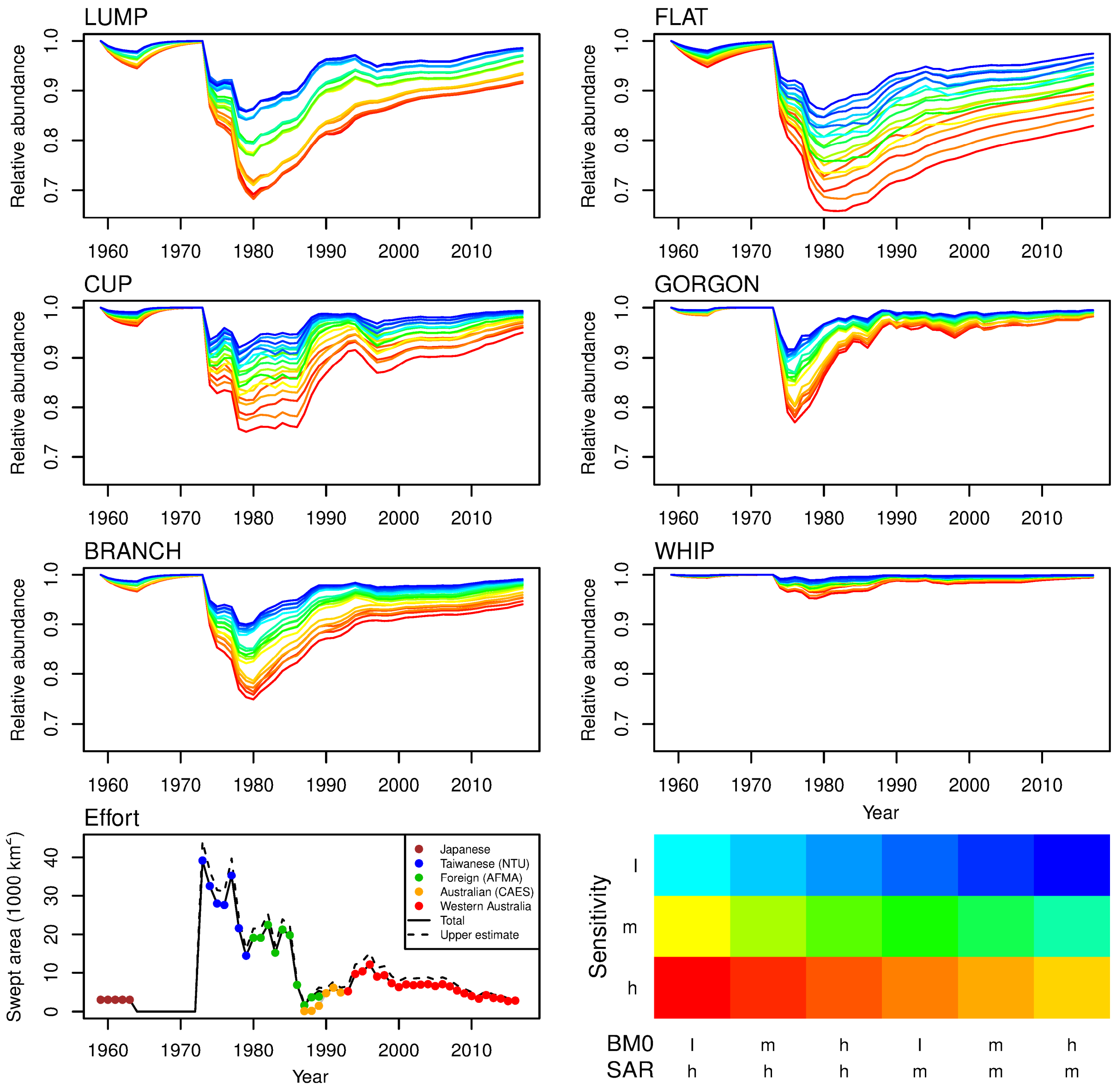


**Figure 152 Plots of trawl-impact simulation model results for predicted time-series of absolute status of 6 major benthos morpho-types (relative to pre-trawl abundance) in the greater NWS study area. Uncertainty is represented by 18 time-series lines for each morpho-type: for sensitivity to trawling, pre-trawling abundance, and swept-width of trawl gears. The time-series of trawling total annual swept-area is shown for each fishery.**

## 5.7 Addenda

### 5.7.1 Japanese commercial trawl effort and survey stations

Japanese commercial trawlers fished the NWS, using otter-trawl gear, from Nov 1959 to Mar 1963, and recorded 7616 trawls over 41 months (Robins 1969, Figure 153). The Japanese vessel Oshoro Maru sampled 20 trawl stations on the NWS in Dec 1963 – Feb 1964 (Figure 153). Two stations were well east of subsequent study areas, and 4 stations were at the same location in the middle of the current study area. The survey recorded the catches of 16 taxa of fishes, and total sponges.

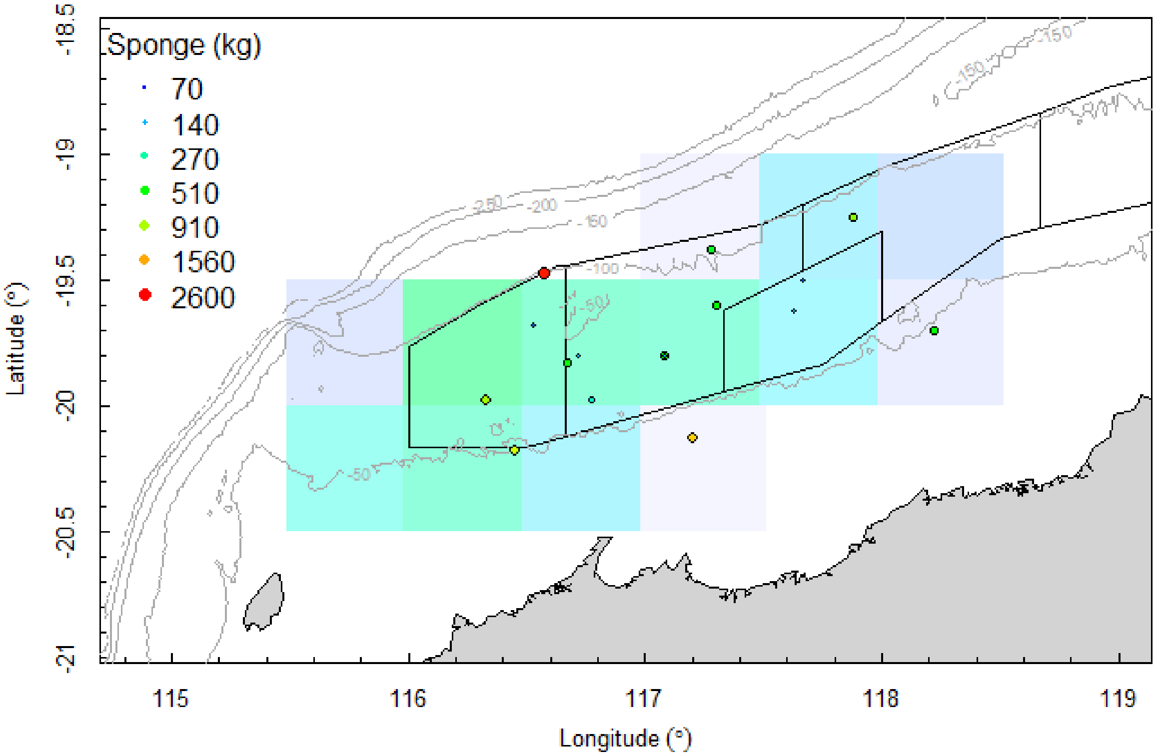


**Figure 153 Map of the NWS region showing the distribution and relative intensity of trawl effort (number of trawls per 0.5° grid-cell) for historical Japanese otter-trawling. Circles indicate trawl stations surveyed by the Japanese vessel Oshoro Maru, with circle size and colour indicating raw sponge catch weights. Black polygons outline current Western Australian management areas for the current domestic trawl fishery.**

### 5.7.2 *randomForest* results at the scale of trawl stations

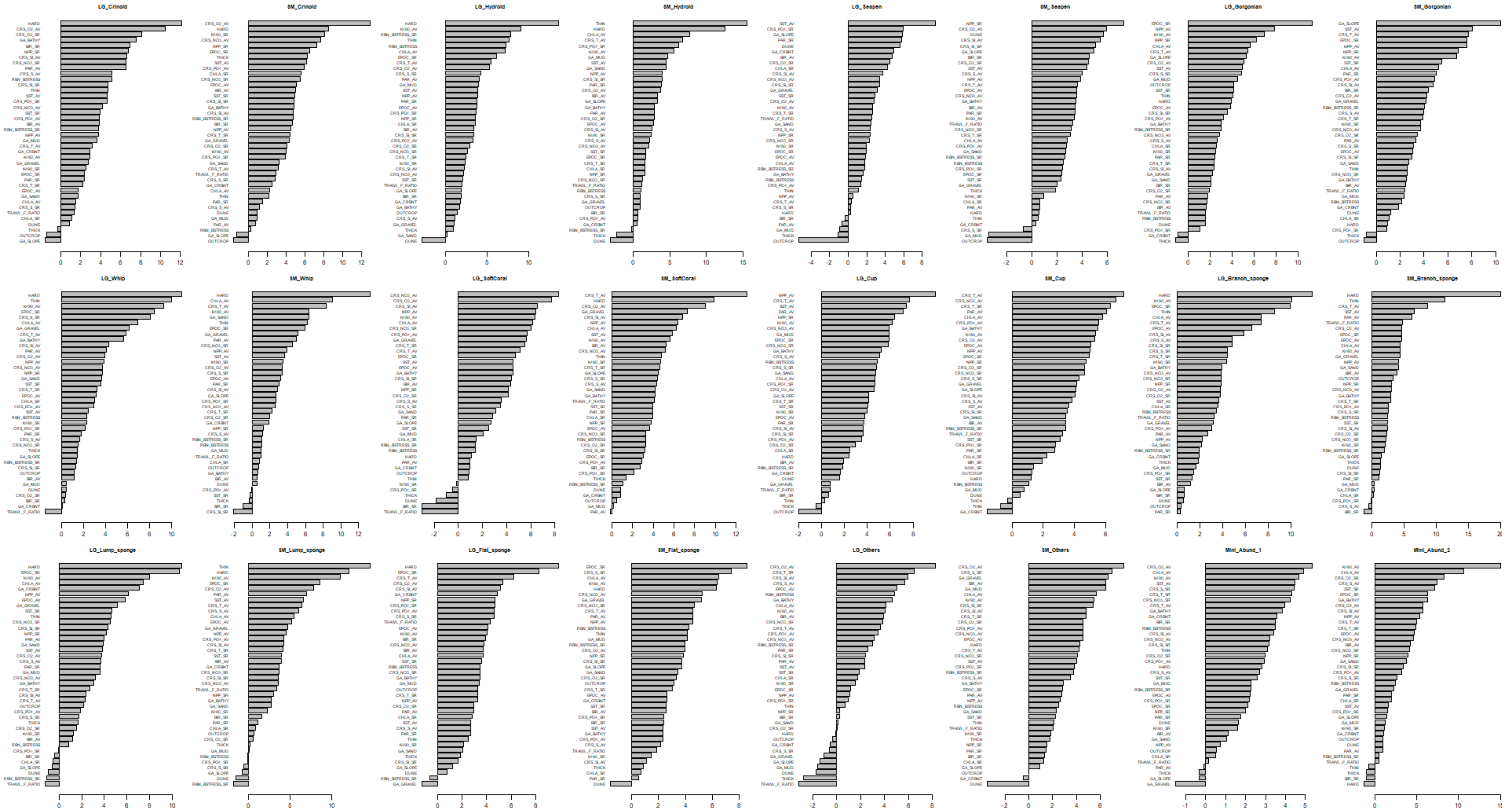


**Figure 154 Predictor importance in *randomForest* models of mean range-standardised benthos morpho-type counts at trawl station level, with environmental variables and proportion of SBP substratum classes as predictors.**

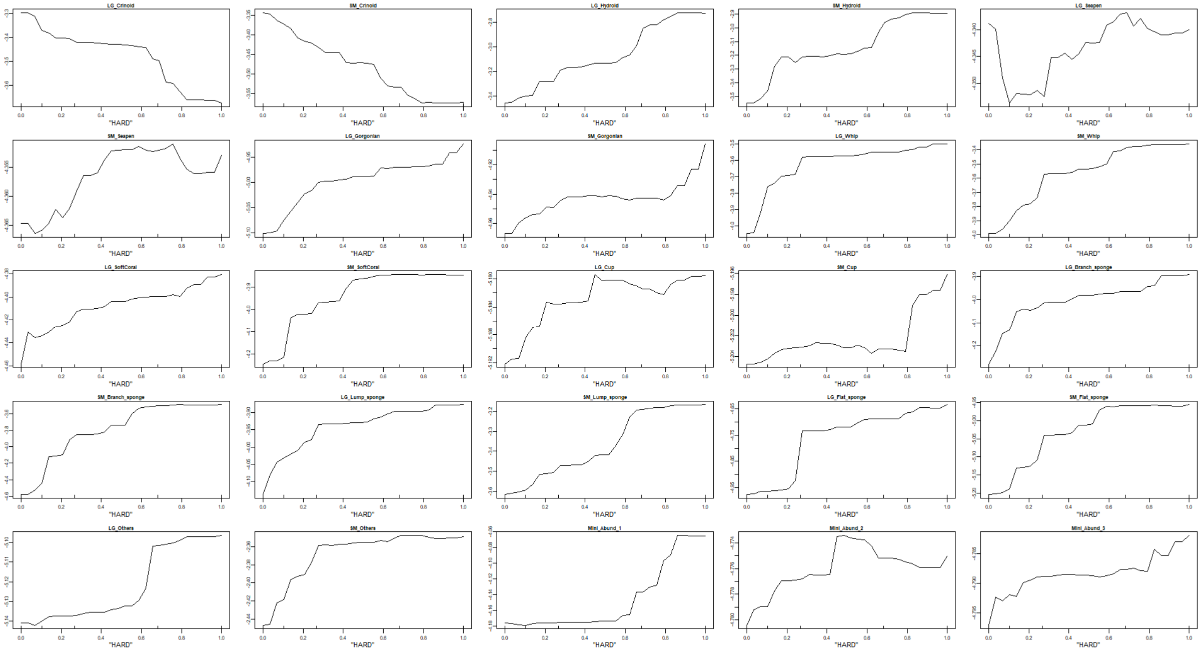


**Figure 155 Marginal response plots of the average counts of benthos morpho-types to the proportion of SBP HARD substratum class in *randomForest* models at the trawl transect level; plots have different Y-axis scale (log) indicating the trend of response of different morpho-types to hard bottom type.**

# 6 Structure and temporal changes in fish assemblages on the NWS

Alan Williams and Franzis Althaus (CSIRO Marine and Atmosphere Research)

## 6.1 Introduction

### 6.1.1 Trawling in the NSW region

The North West Shelf (NWS) area has a long history of commercial demersal trawling for scalefish (Section 7.2.1) and, relative to any other area in the Australian Marine Jurisdiction, a long history of research trawling for fishes. Research voyages include 16 large and statistically-designed surveys undertaken between 1982 and 2017 — a concentration of research effort linked to a large-scale adaptive management experiment (AME) (Sainsbury et al. 1991) that aimed to measure the effects of spatial closures and different fishing methods (primarily trawling and trapping) on the seabed habitats and overall productivity of the NSW scalefish fishery.

### 6.1.2 This chapter

In the context of evaluating the long-term recovery of trawled marine communities of the NWS, this chapter examines, firstly, regional-scale spatial structure (species composition and distribution) in NWS demersal fish assemblages and, secondly, temporal changes in assemblage structure and the abundances and size spectra of informative species for the period 1982 to 2017 within the study area. Data were available from 16 research surveys of the continental shelf area roughly between Dampier and Port Hedland in depths between ~20 and 200 m (Figure 119).

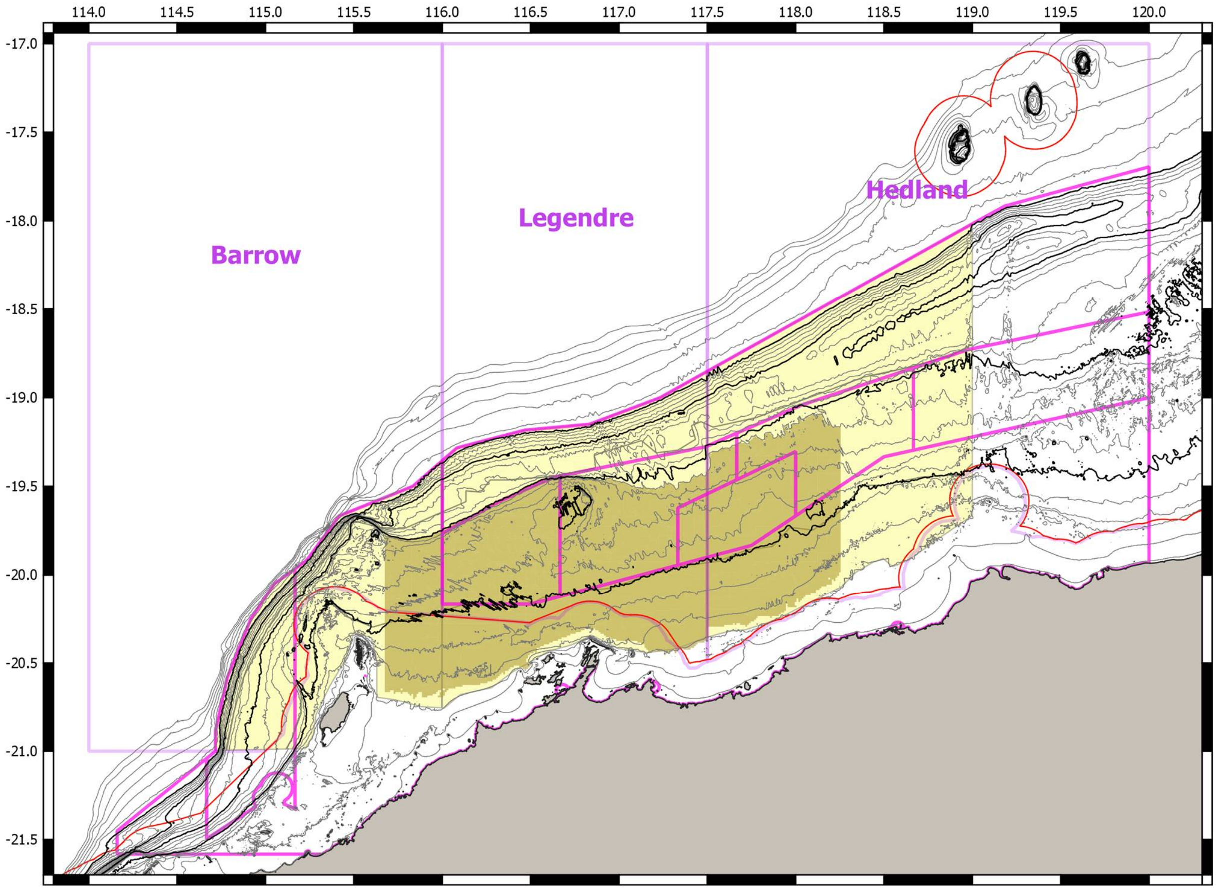


Figure 156 Map of the NWS region showing the regional study area (yellow) and the 2017 study area (brown). The Barrow, Legendre and Hedland subregions are strata used to randomise research trawls in the Adaptive Management Experiment (AME); boundaries of relevant Pilbara Fish Trawl Fishery management areas and zones are shown (pink lines) and explained in Section 7.2.1. Isobaths are 10 m depth intervals, with 50, 100, 150 and 200 m bolded. Red outline shows Australia's 12 n.m. territorial waters boundary.

This chapter's two primary objectives are to:

Objective 1) Determine regional-scale patterns in fish assemblage structure in the entire survey area (the "regional" analysis which captures the full area of previous surveys conducted between 1982 and 1997).

This analysis uses data from a sub-set of eight historical research surveys that have standardised sampling characteristics: the same regional extent (Figure 156), a consistent random-stratified statistical design, and complete records of catch weight for all species in every trawl sample. Six of these surveys occurred during a relative lull in trawling effort between 1986 and 1991 when the extent and intensity of foreign trawling rapidly declined and then concluded, and as the domestic trawl fishery commenced and its footprint expanded. The other two research surveys occurred in 1995 and 1997 when the domestic trawl footprint had stabilised but before fishery spatial management zoning was introduced in the Pilbara Fish Trawl Fishery (Wakefield et al. 2014). This analysis of data collected over a 12-year period (1986 to 1997) therefore smoothes the temporal effects of annually variable trawl effort intensity and distribution, and environment variation, to provide a "time-integrated" regional-scale description of the continental shelf fish assemblages. It excludes earlier survey data collected during the period of intense foreign trawling (7 surveys in 1982-1983), and data from the single survey undertaken a decade later (2017). These surveys were excluded either to avoid the period of intense foreign trawling and/or because they did not share all of the standard sampling characteristics – notably the reduced spatial extent of the 2017 survey.

Objective 2) Identify changes in fish assemblage structure in the sub-regional study area surveyed in 2017 based on a time-series analysis of historical survey data (the “time-series analysis”).

This analysis uses data from four additional surveys (two from 1982 (combined), one each from 1983, and 2017), but is limited to the sub-regional study area surveyed in 2017 (Figure 156). The surveys in 1982 and 1983 occurred prior to the AME when foreign trawl activity was intense and widespread in the region but concentrated in the sub-regional study area. This analysis examined changes in the composition and distribution of fish assemblages through a time-series (by year) analysis of historical survey data, including to use the ‘time-integrated’ regional analysis for context.

## 6.2 Materials and methods

### 6.2.1 History of commercial and research trawling

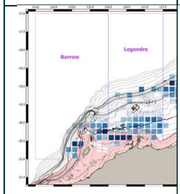
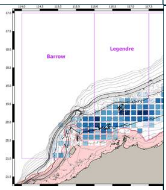
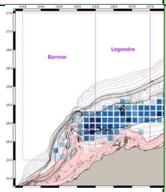
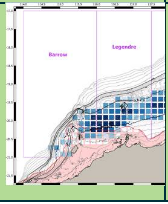
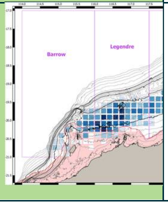
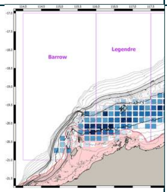
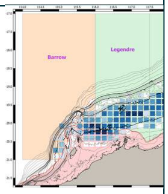
A key element of our analyses was to examine the complex spatial and temporal patterns of historical trawling effort and fishery closures so that the timing of scientific surveys could be interpreted in relation to historical trawl effort. This informed the selection of individual surveys best suited to addressing our objectives — not all surveys were used for each analysis.

#### Commercial trawling

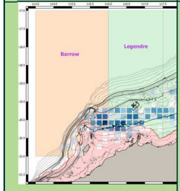
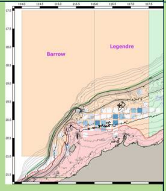
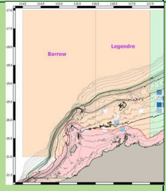
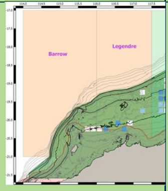
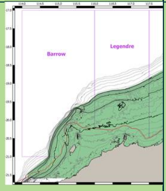
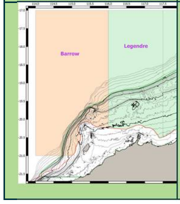
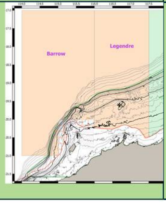
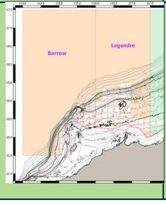
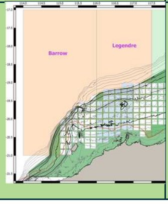
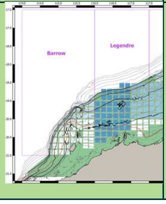
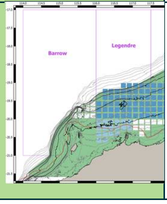
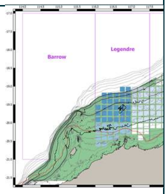
Demeral trawling on the NWS began with a Japanese experimental fishing program in 1935 (Sainsbury, 1987) but commercial fishing did not begin until 1958. This was initially by foreign fleets: Japanese trawlers operated between 1958 and 1963, followed by Taiwanese pair-trawlers between 1971 and 1989. Foreign trawling effort peaked around 1974 when there were > 100 pair trawlers active (Sainsbury, 1987); annual effort in the mid- to late 1970s varied between ~20,000 and 55,000 hours (NWSJEMS 2007). Most of the fishing on the NWS was in the High Seas until the Australian 200 nautical mile management zone was declared in 1979. A transition from foreign to domestic fishing occurred between 1987 and 1989: the most productive fishing area was closed to foreign trawling in 1987 and all foreign fishing concluded in 1989. Domestic trawling was recorded in commercial logbooks in 1987 but there was no appreciable effort until 1989; domestic trawl effort peaked in 1991 (around 15,000 hours), then declined by 1993 to a level of <10,000 hours annually.

## Distribution of commercial trawling through time

The spatial and temporal distribution of commercial trawling (annual gridded trawl effort data for foreign and domestic fleets overlaid on spatial fishery closures (**T1 — Foreign fishery only (yellow highlight: survey years)**

| 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 |
|---|---|---|---|---|---|---|
|  |  |  |  |  |  |  |

**T2 — OVERLAP of foreign (top row) and domestic (bottom row) fishery (yellow highlight: T2 survey years)**

| 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 |
|---|---|---|---|---|---|---|
|  |  |  |  |  | | |
|  |  |  |  |  |  |  |

**T3 — Domestic fishery only (yellow highlight: T3 survey years)**

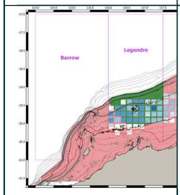
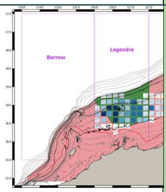
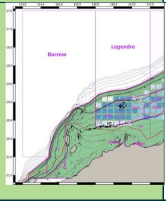
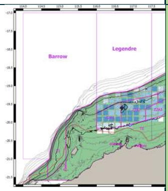
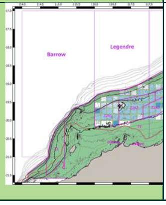
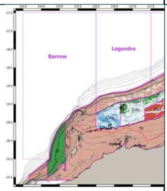
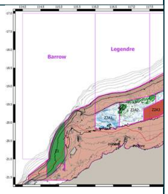
| 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|
|  |  |  |  |  |  |  |

Figure 157) show that:

- Historial foreign trawling occurred mainly between 50 and 100 m depths (hereby referred as the 'core' depth range).
- In the core depth range, annual historial trawling in relation to closures and the AME can be summarised as:
    - Prior to 1985: the overall distribution of foreign trawling was annually consistent, being spread across the Barrow, Legendre and Hedland subregions, but with a concentration at the Barrow-Legendre boundary.
    - 1985: there was little change in effort distribution recorded in this calender year despite the Barrow area being closed as the AME commenced (noting that the precise time of the AME closure in 1985 is not known).

  - 1986: foreign effort declined dramatically overall, but, remained relatively high in the Barrow-Legendre boundary area; there was no domestic effort.
  - 1987: the Legendre area is closed as the AME develops; foreign effort reduces further but remains widespread, including in the Barrow and Legendre areas; domestic effort commences at a very low level in Barrow.
  - 1988: foreign effort is largely restricted to the Hedland area; low-level domestic effort expands into Legendre (including either side of the ‘core’ foreign fishery depth range).
  - 1989: domestic effort extends further westwards into the Hedland area and intensifies in Legendre (coinciding with the transition to management of the NWS fishery by WA Fisheries).
  - 1990: foreign trawling has ceased; domestic trawling occupies the full regional area and is focussed in the Legendre area; the AME concludes.
  - 1991: domestic effort peaks and is largely focussed in the Legendre and western Hedland areas.
  - 1992: trawl effort distribution is similar to 1991, but there is no trawling in the Barrow area (perhaps closed?)
  - 1993-1994: trawling is restricted to the Legendre area in depths > 50 m by WA Fisheries
  - 1995: spatial zoning plan introduced by WA Fisheries but not implemented; trap areas were established, and trawling excluded (the Barrow area and all other areas in < 50 m depth).
  - 1996 onwards: WA Fisheries zoning implemented; trawling mostly in the Legendre area, but widespread and mostly low in Hedland. Some trawling continues in deep waters.
  - 1998: trawl closure (Z2A3) implemented (Wakefield et al. 2014). Trawl effort concentrated in Z2A1. Still some trawling in deep waters.
  - 1999: full implementation of zoning; trawl effort concentrated in Z2A1. No effort in deep waters.
- In depths shallower than ‘core’ (< 50 m) there is foreign effort where the Territorial Waters (TW) 12 n.m. boundary bulges seawards around the Dampier Peninsula and Barrow Island. Foreign fishing continues here into the AME period, including being strong in 1985. Many research samples were taken within TW, but only in the west where foreign fishing occurred – meaning there is no east-west bias in the distribution of research samples in relation to commercial trawl effort distibution. Elsewhere, there is very little historical effort inside TW. These patterns indicate the locations of research and foreign fishing was driven by depth, not by the TW boundary; research trawls were conducted landwards to 20 m depth, while commercial fishing extended in to only ~30-40 m depth.
- In depths greater than ‘core’ (> 100 m) there was an early period of Taiwanese trawling (during the 1970’s until 1979) but the real spatial extent of this effort is uncertain because data are coarsely mapped. Since 1980, there has been low effort in depths > 100 m; this

included virtually no foreign fishing, but low-level domestic effort since its early development (1988) until WA Fisheries zoning excluded deep trawling in 1998.

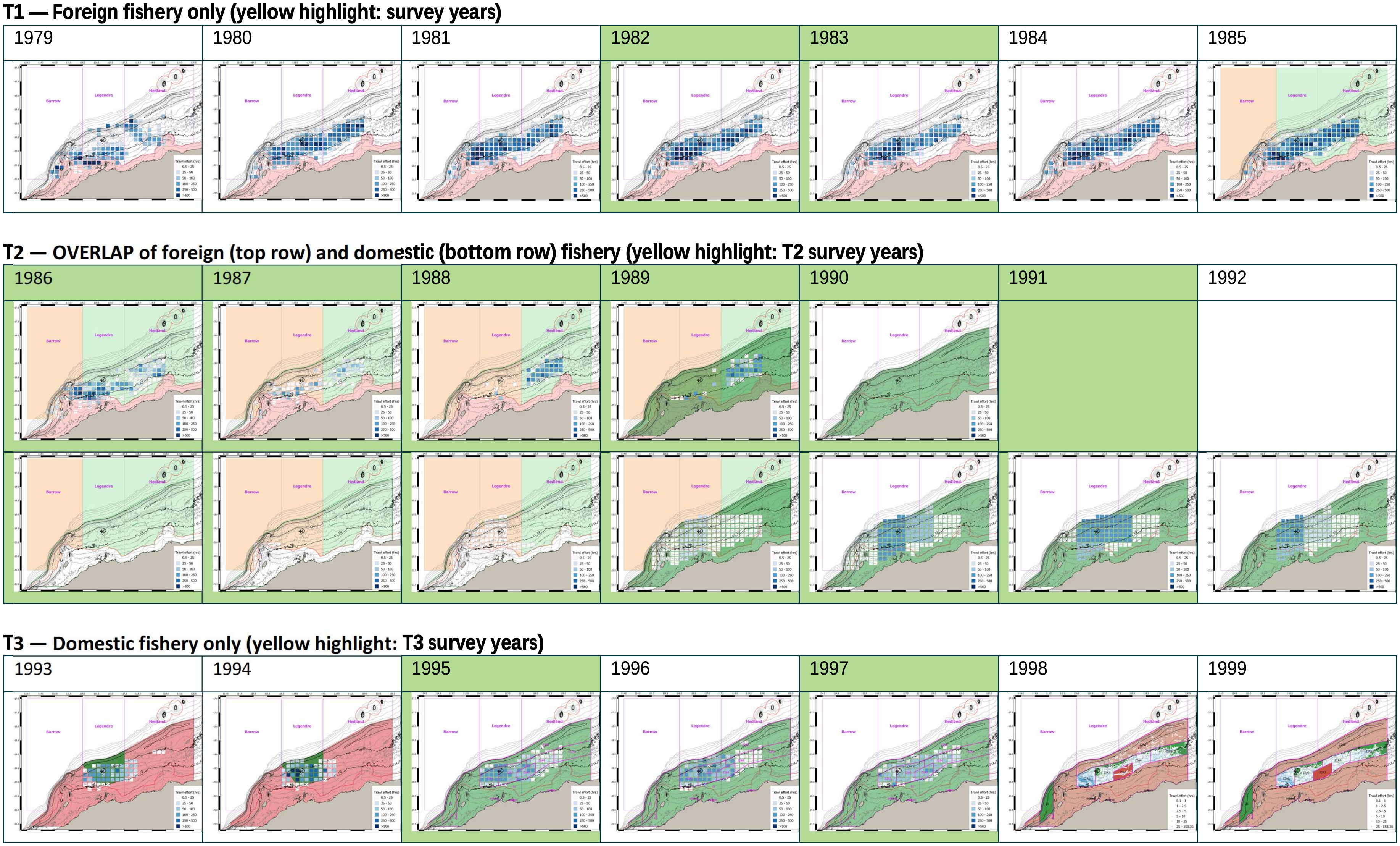


**Figure 157 Annual distribution of foreign (mostly Taiwanese) and domestic fish trawl effort across the North West Shelf. Fishery management zones are identified in Figure 1. Years in which scientific surveys were undertaken are highlighted in green.**

## History of research surveys (design and implementation)

Research trawl sampling commenced with a survey by a Japanese vessel in 1963 and was followed by a series of 16 surveys undertaken between 1982 and 2017, variously on Australian commercial and research vessels (Table 16; Figure 158). Thirteen of the 17 surveys were linked to the AME. Data from many of the 17 research surveys are used in the analyses presented here. (Some additional earlier research trawling was undertaken by the vessel Courageous, but those data were not used in our analyses.)

Table 16 Summary details of research surveys on Australia's North West Shelf

| Year | Vessel | Survey ID | Month | No. fish trawl samples | Random stratified trawl samples |
|---|---|---|---|---|---|
| 1963 | RV Osho Maru | OM196301 | Dec-Jan | 17 | |
| 1982 | RV Solela | SO198205 | Sept-Oct | 125 | 52 |
| 1982 | | SO198606 | Nov-Dec | 53 | 53 |
| 1983 | | SO198301 | Jan | 99 | 53 |
| 1983 | | SO198302 | April | 43 | 43 |
| 1983 | | SO198303 | June | 51 | 51 |
| 1983 | | SO198304 | August | 121 | 61 |
| 1983 | | SO198305 | Oct | 129 | 55 |
| 1986 | | SO198606 | Oct | 106 | 102 |
| 1987 | | SO198707 | Sept | 97 | 97 |
| 1988 | | SO198805 | Sept | 100 | 100 |
| 1989 | FV Pride of Eden | PE198904 | Sept | 108 | 104 |
| 1990 | RV Southern Surveyor | SS199002 | Sept | 130 | 130 |
| 1991 | | SS199104 | Sept | 96 | 96 |
| 1995 | | SS199508 | Aug-Sept | 102 | 96 |
| 1997 | | SS199707 | Aug | 102 | 102 |
| 2017 | RV Investigator | IN2017_V05 | Oct | 104 | 100 |

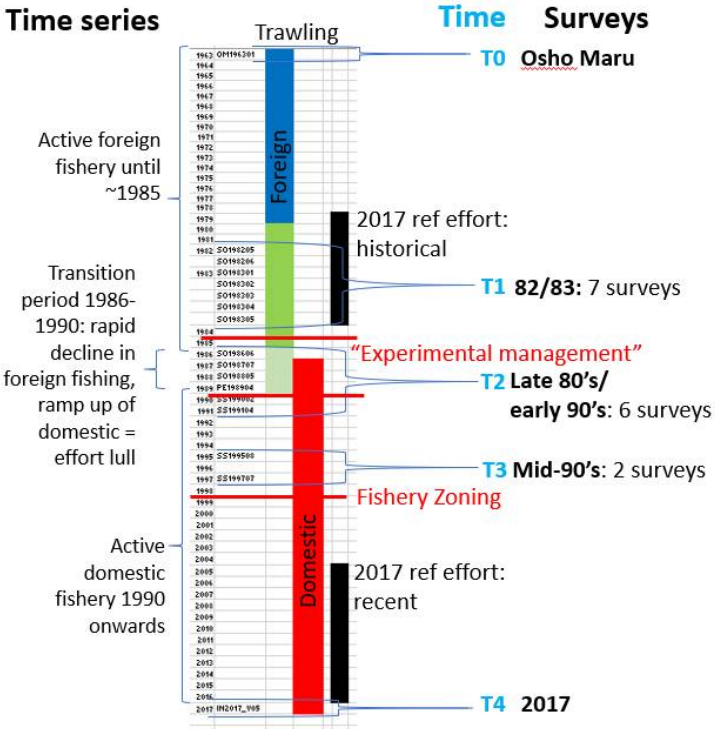
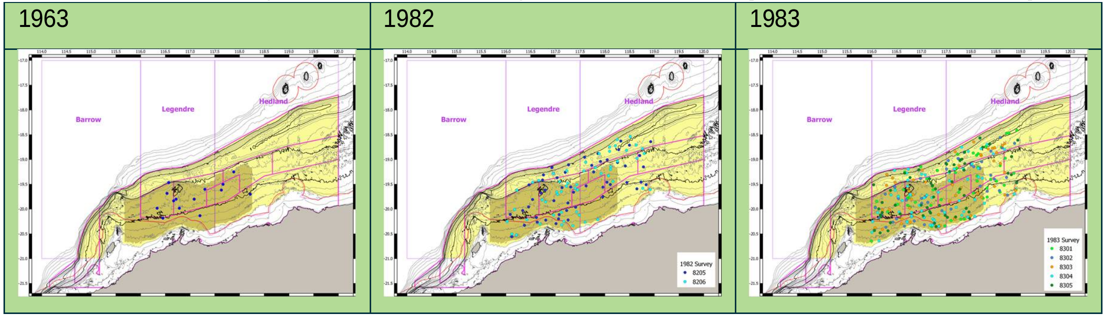


**Figure 158 Summary timeline of trawling activities, survey events, and management interventions relevant to this study showing the time periods identified for aggregating data in this analysis.**

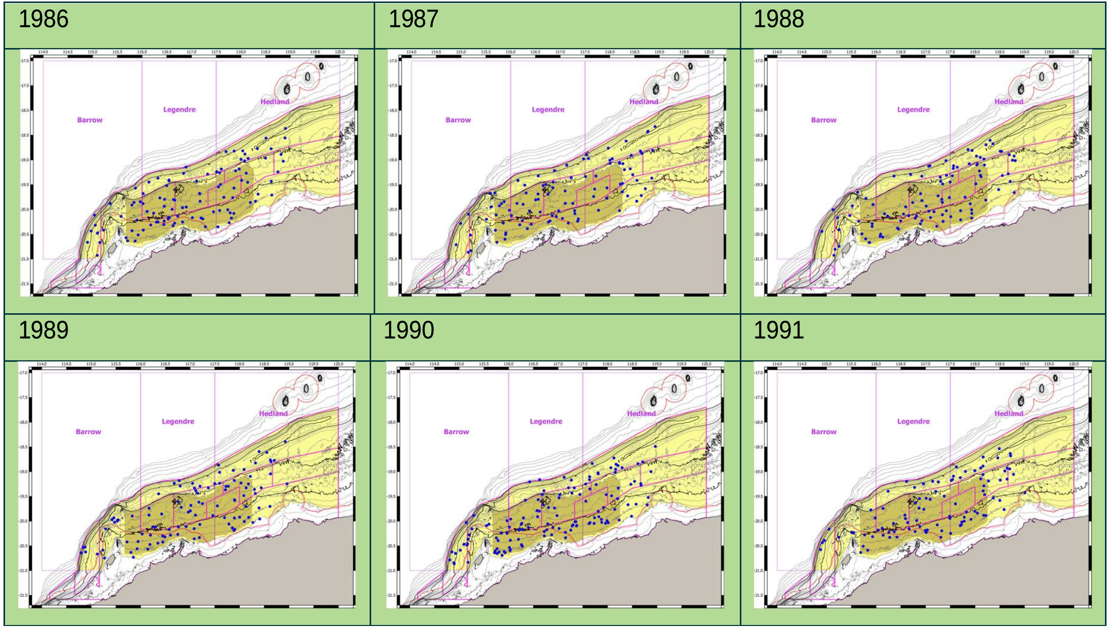
## Stratified random design vs other objectives

A random-stratified sampling design was implemented for the first Australian survey in 1982 and maintained consistently through to the 1997 survey. The design was based on 19 strata representing: subregion (Legendre, Hedland, Barrow); depth (shallow, middle, deep); and substratum type (shelly sand, sand, silty sand, undefined). Additional trawl samples were taken on some of the surveys, particularly in 1982, but these were not used in our analyses which were restricted to the randomised subset (Table 16). The random sampling in 1982 and 1983 was restricted to the Legendre and Hedland regions – strata 1-16 (Figure 159). In 2017, the sampling area was restricted to the central zone of the NWS and new strata were defined (see Chapter 4).

**T0 — Osho Maru survey** **T1 NWS study stratified random (restricted: 116$^{oE}$ – 119$^{o}$E)**



**T2 — NWS study stratified random (full study area - yellow)**



**T3 — NWS study stratified random (full study area)** **T4 — 2017 follow-up survey (restricted study area brown)**

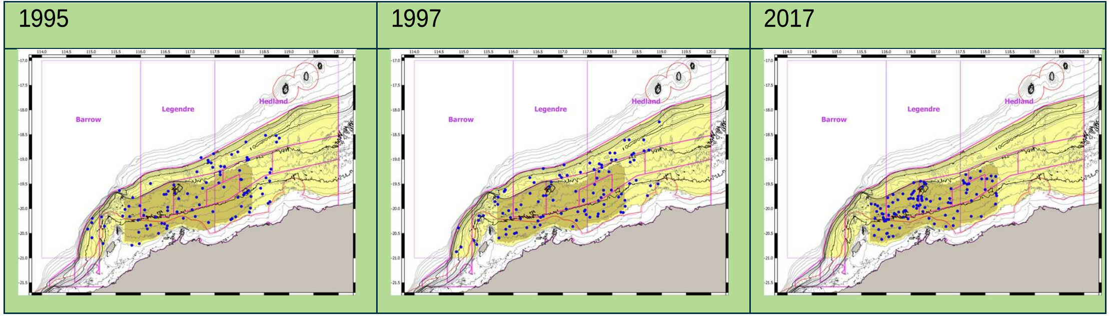


Figure 159 Spatial distribution of the random stratified survey samples from the North West Shelf, shown in relation to the Barrow, Legendre and Hedland subregions, the regional study area (yellow) and the 2017 study area (brown).

### 6.2.2 Description of data holdings

The database compiled for the NWS JEMS project (NWSJEMS 2007) was used to extract trawl sample and fish catch composition data.

### 6.2.3 Data selection

#### Trawl samples

Only geolocated trawl samples from the ramdomised sampling design with full catch composition data (all species accompanied by catch weights) were used for analysis (Figure 159). Trawls were geolocated using either trawl mid-point where start and end position were reported or by the single start or end point when only that was reported.

Mapping of trawl operations into the 19 strata subregion x depth x substratum strata showed that all were sampled by surveys between 1986 and 1997 (Table 17), but strata 17-19 in the western-most sub-region (Barrow) were not sampled prior to 1986 (Figure 159).

The 2017 (and Osho Maru) samples extended across only part of the regional study area and none were located in several strata, e.g. western Barrow, eastern Hedland and deep depths) (Figure 159).

**Table 17 Distribution of the research trawl samples by survey across the 19 NWS study strata; non-randomised trawls tallied separately**

| | NWS study strata | | | | | | | | | | | | | | | | Other | Non- |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Survey** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **12** | **13** | **14** | **17** | **18** | **19** | **strategy** | **random** |
| OM196301 | | | | | | | | | | | | | | | | | 17 | |
| SO198205 | 4 | | 7 | 3 | 3 | 2 | 6 | 7 | 5 | 4 | 4 | 4 | 3 | | | | | 73 |
| SO198606 | 5 | 1 | 7 | 3 | 2 | 3 | 6 | 5 | 8 | 2 | 6 | 1 | 4 | | | | | |
| SO198301 | | 3 | 3 | 5 | 3 | 4 | 7 | 7 | 7 | 2 | 7 | 2 | 2 | 1 | | | | 46 |
| SO198302 | 3 | | 5 | 4 | 3 | 2 | 5 | 5 | 5 | 2 | 5 | | 4 | | | | | |
| SO198303 | 4 | 2 | 5 | 5 | 5 | 1 | 3 | 8 | 4 | 1 | 7 | 4 | 2 | | | | | |
| SO198304 | 7 | 4 | 7 | 4 | 5 | 4 | 10 | 3 | 4 | 3 | 4 | 4 | 2 | | | | | 60 |
| SO198305 | 4 | 3 | 5 | 3 | 3 | 3 | 7 | 5 | 7 | 1 | 4 | 5 | 5 | | | | | 74 |
| SO198606 | 7 | 5 | 10 | 6 | 3 | 4 | 9 | 11 | 6 | 5 | 5 | 6 | 5 | 5 | 13 | 2 | | 4 |
| SO198707 | 8 | 1 | 6 | 6 | 4 | 5 | 9 | 11 | 7 | 6 | 4 | 5 | 4 | 6 | 11 | 4 | | |
| SO198805 | 8 | 6 | 8 | 5 | 3 | 4 | 11 | 10 | 6 | 5 | 5 | 5 | 5 | 7 | 9 | 3 | | |
| PE198904 | 9 | 6 | 8 | 8 | 3 | 3 | 9 | 10 | 8 | 5 | 7 | 5 | 4 | 6 | 10 | 3 | | 4 |
| SS199002 | 12 | 7 | 10 | 10 | 7 | 5 | 8 | 11 | 10 | 6 | 4 | 6 | 4 | 10 | 17 | 3 | | |
| SS199104 | 6 | 7 | 7 | 7 | 5 | 5 | 10 | 9 | 6 | 2 | 6 | 5 | 7 | 4 | 7 | 3 | | |
| SS199508 | 6 | 5 | 7 | 7 | 3 | 4 | 10 | 10 | 7 | 7 | 5 | 6 | 2 | 6 | 8 | 3 | | 6 |
| SS199707 | 6 | 5 | 9 | 8 | 4 | 6 | 8 | 12 | 7 | 5 | 4 | 3 | 5 | 5 | 11 | 4 | | |
| IN2017_V05 | | | | | | | | | | | | | | | | | 104 | |

### Taxonomic entities

Fish identifications recorded in catch composition data were linked to a numeric species-level identifier in a database that provides an authorative national standard for taxonomic nomenclature — Codes for Australian Aquatic Biota (CAAB) (Yearsley et al. 1997; Rees et al 1999; CAAB 2021). This 8-digit 'CAAB code' enables identifications, including revisions and synonymies, to be tracked, upgraded and standardised through time, and manipulated as checklists.

The data for the analyses presented here, as extracted from the digital database compiled during the NWSJEMS project, contained a total of 841 CAAB codes for fishes (37 000000). Of these, 693 were species-level identifications, 47 to genus, 71 to family, 27 to family groups and 3 codes referred to 'undifferentiated fishes'.

In addition 46 invertebrate CAAB codes — 6 sponge (10 000000), 8 cnidaria (11 000000), 1 bryozoa (20 000000), 4 cephalopods (23 000000), 1 bivalve (24 000000), 9 echinoderms (25 000000), 15 malacostracan crustacea (28 000000), and 2 ascidians (35 000000) — and 18 reptiles (39 000000) were also recorded in the database, but were excluded from analyses here.

## 6.2.4 Taxa included and excluded from analyses

We paid considerable attention to the provenance of taxonomic identifications because survey data were collected over a period of 35 years during which the taxonomic knowledge of Indo-West Pacific fishes advanced considerably. High quality identications were made on board by ichthyologists, and specimens of poorly known species were collected for laboratory examination. Continuity of identifications through time was underpinned by research on large numbers of specimens curated in museum collections, particularly the Australian National Fish Collection (ANFC) at CSIRO, and by using the CAAB system to systematically review the consistency of identifications in the data analysed here.

The review included three steps: (1) a complete species checklist was examined by ichthyologists to identify misidentifications, i.e. species that could be immediately recognised as spurious, those based on outdated nomenclature, and those outside their known distributional ranges; (2) the total numbers of fish species (CAAB codes), and species checklists with abundance (biomass) summed across all relevant trawl samples were generated for each survey. This enabled species presences and abundances to be compared across surveys to identify inconsistencies or trends through time, e.g. patterns of recording in known species-complexes, abrupt changes in the abundance of congeners or similar species at certain points in time, and the presence of species in only the most recent surveys; (3) the taxonomic histories and catch records of all species identified at steps 1 and 2 as being uncertain were examined in detail to determine if species-level identifications could be reconciled; this step included comparing CAAB codes and collection specimen lists.

When species-level identification could not be reconciled, decision rules were used to either aggregate taxa at genus or family level (inclusions), or to remove the data from our 'species-level' analyses (exclusions). The decision to exclude species was applied in a number of different circumstances; decisions were coded in the original database before making the data extracts used in our analyses:

Inclusions in species level analyses:

- s: species level identifications that are correct and consistent across surveys
- ss: species complexes recognised in later surveys but cannot be disentangled in early data
- g: genus level identification for inconsistently identified congeners, but where only few species were involved

Exclusions from species level analyses:

- d: delete mis-identified species that are spurious, or which cannot be reconciled
- df: family level identification only
- dg: genus level identification involving many species
- e: species recognised in later surveys (mostly only in 2017)

In summary, 97% of the 615 taxa included in analyses were true species; 172 taxa were excluded (Table 18). An electronic file of full list of recorded fishes and the translations/ rules applied in the reconciliation process described above is available the MarLIN metadata record of this project (MarLIN, 2021).

**Table 18 Summary of decisions made when reconciling taxonmic identifications of 787 CAAB taxa listed in the database showing rationale for including and excluding taxa in analyses**

| **Description of the taxonomic identification after reconciliation** | **Species-level Analyses** | **Number of final CAAB** |
|---|---|---|
| Species level identifications: correct and consistent across surveys | include | 597 |
| Species complexes | include | 6 |
| Genus level identification: two or few congeners | include | 12 |
| **TOTAL taxa included in species-level analyses referred to as ‘species’** | | **615** |
| | | |
| Species recognised in later surveys (mostly only 2017) | exclude | 42 |
| Species: spurious or unreconcilable | exclude | 2 |
| Genus level identification involving many species | exclude | 29 |
| Family level identification | exclude | 99 |
| **TOTAL taxa excluded** | | **172** |

### 6.2.5 Final data set

#### Data summary

The final data set comprised 1,195 fish trawl samples and 615 fish taxa. Except for three surveys with incomplete catch composition (Table 19, bolded), the relative contributions of the retained taxa to the final data set were mostly very large (>97.5% of total survey catch weight) (Table 19).

**Table 19 By survey summary of the catch data included in the present study, showing the number of samples, the total catch weight, weight per operatinand, number of species-level fishes, the total weight they comntribute. Also shown are the number identifications that were excluded from analyses and the relative weight they constitute. (data from Osho Maru 1963 not included)**

| Survey | Number of samples | Total sample weight (kg) | Weight per sample (kg) | Number of species (analyses) | Total weight (analyses) | Weight per sample (analyses) | Number of CAAB excluded | Percent of excluded taxa | Tot weight excluded | Percent weight of excluded taxa |
|---|---|---|---|---|---|---|---|---|---|---|
| SO198205 | 52 | 4567 | 88 | 73 | 4501 | 87 | 7 | 8.8 | 66 | 1.4 |
| SO198206 | 53 | 5077 | 96 | 76 | 5023 | 95 | 7 | 8.4 | 54 | 1.1 |
| SO198301 | 53 | 8455 | 160 | 326 | 8406 | 159 | 33 | 9.2 | 49 | 0.6 |
| **SO198302** | 43 | 6394 | 149 | 50 | 3966 | 92 | 1 | 2.0 | 2428 | **38.0** |
| **SO198303** | 51 | 5778 | 113 | 58 | 3225 | 63 | 5 | 7.9 | 2553 | **44.2** |
| SO198304 | 61 | 7988 | 131 | 290 | 7787 | 128 | 35 | 10.8 | 200 | 2.5 |
| **SO198305** | 55 | 9397 | 171 | 71 | 6083 | 111 | 7 | 9.0 | 3314 | **35.3** |
| SO198606 | 102 | 14644 | 144 | 350 | 14533 | 142 | 48 | 12.1 | 112 | 0.8 |
| SO198707 | 97 | 15014 | 155 | 350 | 14961 | 154 | 36 | 9.3 | 53 | 0.4 |
| SO198805 | 100 | 13292 | 133 | 351 | 12982 | 130 | 39 | 10.0 | 310 | 2.3 |
| PE198904 | 104 | 16012 | 154 | 327 | 15482 | 149 | 28 | 7.9 | 530 | 3.3 |
| SS199002 | 130 | 19186 | 148 | 331 | 18126 | 139 | 39 | 10.5 | 1061 | 5.5 |
| SS199104 | 96 | 8376 | 87 | 291 | 8339 | 87 | 23 | 7.3 | 37 | 0.4 |
| SS199508 | 96 | 15956 | 166 | 312 | 15849 | 165 | 38 | 10.9 | 107 | 0.7 |
| SS199707 | 102 | 17302 | 170 | 337 | 17288 | 169 | 17 | 4.8 | 14 | 0.1 |
| IN2017_V05 | 103 | 15816 | 154 | 293 | 15796 | 153 | 62 | 17.5 | 20 | 0.1 |

Not all species were fully recorded in the T1 (1982 and 1983) surveys, except for SO198301 and SO198304. Thus, for the initial regional assemblage analyses we limited analysis to data from six T2 surveys (1986 to 1991) and two T3 surveys (1995 & 1997). Characteristics of this series of surveys included: (1) the number of samples was high, between 96 and 130; (2) the regional strata were sampled relatively evenly; and (3) the number of species recorded in each was comparable (between 291 and 350). Excluded species (see above) made minor contributions to the total catches, i.e. collectively contributing < 3% of the total catch weight in every survey between 1986 and 1997 — except in 1990 where the excluded weight was 5.5%. In 2017, 17% of the recorded taxa (mostly ‘new’ species-level identifications) were excluded but these contributed only 1% of the total catch weight.

Cumulative catch weight in individual surveys from 1982 to 2017, based on all species ranked by total catch, showed that most biomass was represented by a restricted species pool – all curves tended to asymptote at <100 species (Figure 160). Two distinct groups of surveys were also revealed: group 1 — six individual 1982 and 1983 surveys plus the 1991 survey have relatively low total catches (<8,000 kg), and group 2 — the eight individual 1986-1997 surveys (except 1991) have total catches above 12,500 kg (Figure 160). Low catches in most 1982 and 1983 surveys are clearly explained by fewer contributing species (stemming from incomplete catch composition recording, Table 19). Low total catches in the two 1983 surveys with full catch composition recording (8301 & 8304) occured because, respectively, only 53 and 61 random-stratified trawls were conducted; catch rates per sample were comparable to the other surveys. The relatively low total catch in 1991 was based on 96 stratified random trawl samples and could neither be explained by other factors including unrecognised sub-sampling, changes in data recording or excluded species.

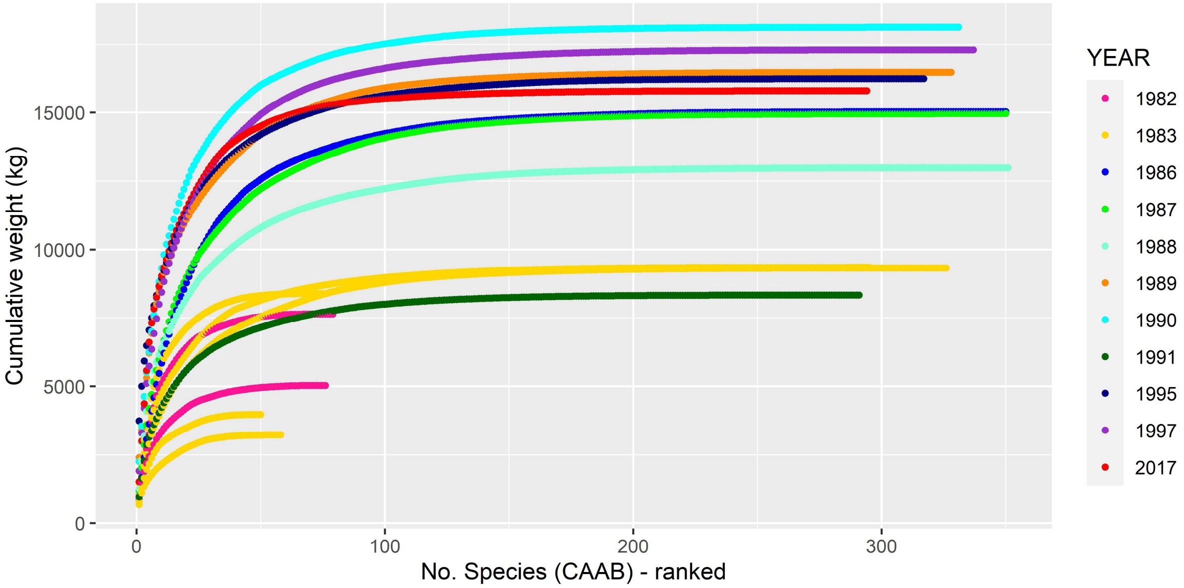


Figure 160 Cumulative catch weight by species for (a) all individual surveys labelled by survey year

The reason appeared to be an absence of large individual sample catches (> 250 kg) in 1991 (survey ID 9104) which were consistently taken in relatively low numbers in all other survey years (Figure 161a). The median and variance of total catch weight by sample across surveys showed, however, that the 1991 catches, though low, were within the ranges of the other surveys (Figure 161 b).

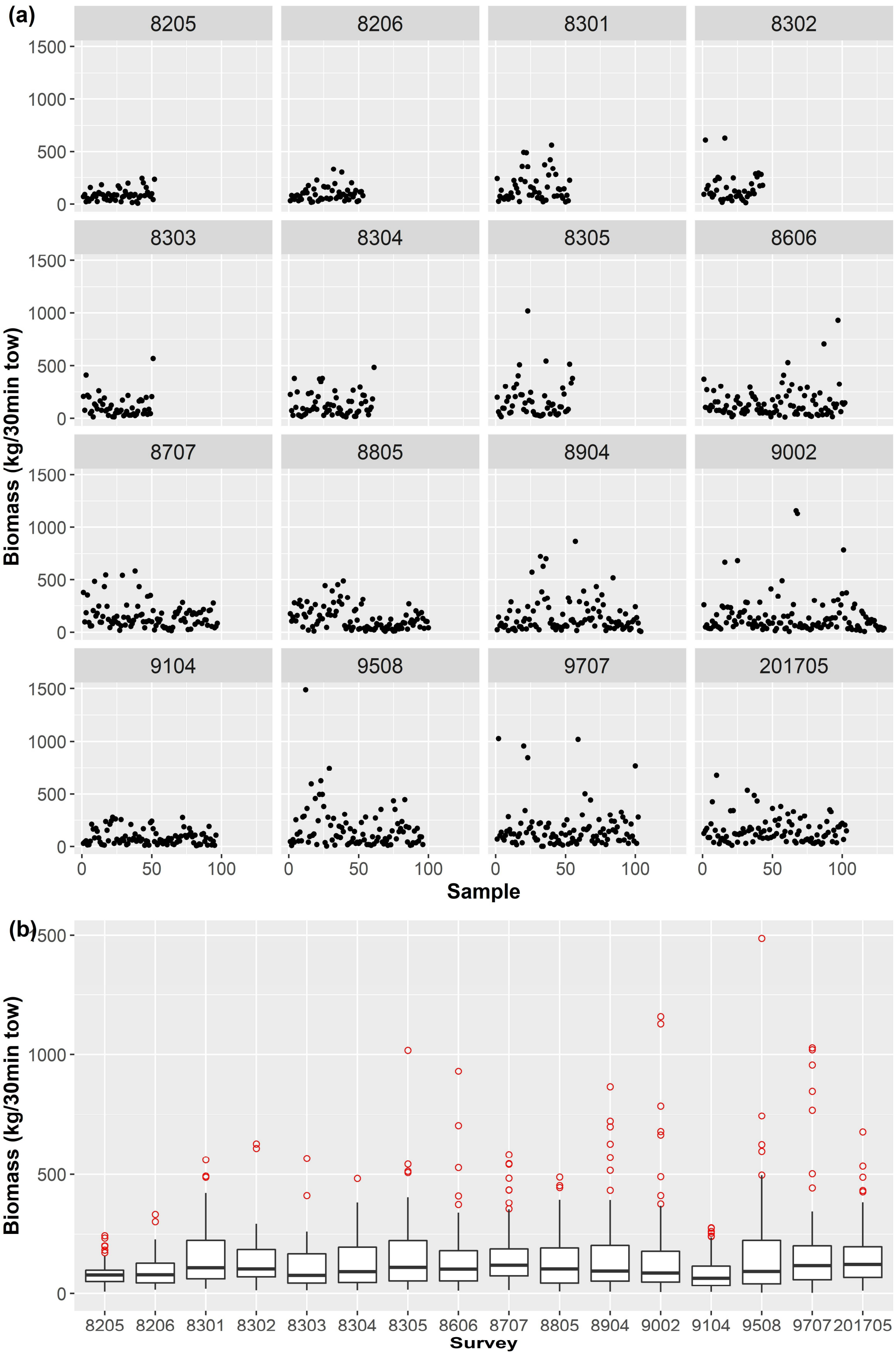


Figure 161 Catch weights (shown as rate) of individual trawl samples across all surveys

### Survey time periods

Five temporal groups of surveys (T0 to T4) (Figure 158) were identified in relation to phases of (1) bottom trawling and (2) spatial adaptive management of trawling effort in the NWS region:

- **T0**: a single Japanese survey (1963) that predated the commerical fishery.
- **T1**: a series of seven surveys spanning two years (1982-1983) that occurred during the concluding phase of trawling by foreign vessels, but shortly after peak trawling effort.
- **T2**: a series of six surveys spanning six years (1986-1991) that occurred during the transition from foreign to domestic trawling when total effort was relatively low, and, corresponding to the AME.
- **T3**: a pair of surveys (1995 and 1997) that followed the AME but preceeded the implementation of spatial management zones for the domestic fishery.
- **T4**: a single survey (2017) that followed 20 years of regulated trawling under the zoning plan

### Species reduction

A noteworthy feature of the fish fauna of this tropical shelf is its high species richness. The total of 787 ‘taxa’ in the combined data from the 16 surveys signalled the presence of many uncommonly caught species. We reduced this species pool to enhance the signal to noise ratio in the data by eliminating minor species that would not contribute informatively to single-species or assemblage-level patterns of ecological similarity. Our species reduction strategy variously included removal of (1) singleton species (on a per survey basis consistent with the need to treat individual surveys separately in time series analysis); (2) species contributing low abundance on a per survey basis (based on biomass rather than count to reflect relevance to fishery productivity — and because counts were not available for many surveys); and (3) species occurring in few surveys (recognising that scarce large-bodied species, and schooling species caught occasionally in large quantities, are retained by a reduction strategy based on rank-biomass but may not be informative).

## 6.2.6 Regional analysis (combined T2/T3 surveys)

Species reduction of the T2/T3 samples (533 of the 615 reconciled species) involved firstly removing singletons— defined as species occurring in only one sample in any individual survey — and then using ranked biomass per survey to screen out rarely occurring species. The potential positive inclusion bias towards large-bodied species and schooling species caught occasionally in large quantities was explored by further reducing species based on their frequency of occurence across surveys (1 to 8 surveys) in the combined T2/T3 data set.

Fish assemblages within the regional assemblage pool were identified using group-averaged clustering with a ‘similarity profile’ (SIMPROF) permuatation test to identify clusters or groups, and non-metric multidimntional scaling in PRIMER-e v7 (Clarke & Gorley2015).

Assemblage groups were visualised spatially by mapping trawl sample sites in a GIS (QGIS 2020). The final groups were identified at the similarity level where all resultant clusters differed from each other at 5% significance, based on 999 permutations in the SIMPROF analysis (here termed the 'threshold similarity'). Comparisions used MDS plots to visualise each analysis, and metrics for MDS stress, ecological similarity at the threshold similarity, number of groups identified at SIMPROF split, the number of groups with > 4 samples, and the number of outlier groups identified in cluster analyses. The effect of increasing the severity of data transformation to de-emphasise the influence of the most abundant species was examined for the base case T2/T3 species pool. Outputs from group-averaged clustering and MDS with 2nd, 4th and 8th root transforms were compared to raw abundance, also using MDS plots to visualise each analysis, and the metrics described above. Species with the largest influence on defining assemblage structure were identified using SIMPER analysis (Clarke & Gorley2015) that uses the average abundance in transformed data across samples within cluster groups to identify 'typifying' species (making the largest contributions to similarity within cluster groups) and 'distinguishing' species (making the largest contributions to dissimilarity between cluster groups). Because this analysis is based on transformed and averaged data, it has the potential to considerably de-emphasise the contribution of highly abundant species if the transform is strong.

Benthos observed in imagery collected by the trawl headline camera during the T2/T3 surveys was used to determine if there was a correlation between fish assemblages and benthos abundance. The unit of analysis for benthos was the frequency of occurrence of large (>25 cm), small (>5 cm but <25 cm) and mini benthos (<5 cm) (presence in an image) averaged over all images in an operation. Details of the image data collection and annotation methods are described in Appendix A. Failures of the camera and other circumstances meant that not each trawl operation had annotated imagery, so analysis was limited to only the operations where image data were available.

### 6.2.7 Time series analysis

#### Conceptual model for time-series analyses

Responses by the inner/ mid-shelf fish assemblage to a decline in trawl effort through time were expected to be mediated by recovering benthos, but also by unmeasurable or unknown effects. These included:

- an assemblage-level biomass increase due to reduced trawling fishing mortality (F);
- changes in trawl-induced F due to changes in fishing patterns and fishery regulations as the fishery evolved;
- selective removals by other fishing sectors, such as Trap;
- interspecific interactions such as predation or competition;
- environmental changes;
- other possible anthropogenic disturbance such as oil/gas industry activities;
- and combined effects.

Despite the complexity of these unmeasurable or unknown effects, we expected all areas analysed to show a general positive response (increased fish biomass) to reduced trawl-F, independent of benthos recovery and habitat association. We did not expect to observe significant declines in fish biomass but, if detected, they would be assumed to be attributable to effects such inter-species predation that were unknown aspects of species' ecology. Thus, any 'signal' of benthos-mediated change would be superimposed on 'noise' related mainly to reduced trawl-induced F.

Further, we expected to detect trends of biomass change (mostly increases) irrespective of between-area variation in the pre-fishery distribution and abundance of benthos ('carrying capacity') because (1) all areas analysed had been trawled in large part for several years (since at least 1980) and therefore there was potential for benthos recovery in every area, and (2) each was defined by a quantitative contrast in trawl effort (based either on fishery regulation or by analysis of trawl effort distribution and intensity).

Our expectation was therefore that the magnitude of biomass change would be stronger for those species with strong association to structured benthic habitat, and less predictable for those without habitat-association. We considered that the magnitude of change in fish biomass could also be influenced by between-area variation in pre-fishery benthos carrying capacity meaning that some areas had greater potential for benthos recovery than others, but this relationship was not known *a priori*. Notwithstanding, we were confident of detecting trends (catch rate) for the fishes analysed because most were highly abundant and frequently occurring across the time-series data, and/or were informative species — less abundant but strongly typifying either the habitat-associated or non-associated inner/mid-shelf assemblage. Attributing a response to benthos recovery was, however, less certain for some species (notably *S. undosquamis*, *N. furcosus* and *A. stellatus*) that were ubiquitously abundant in all habitats.

Based on this conceptual model we hypothesised, *a priori*, that:

(1) A widespread increase (recovery) of benthos would occur because mortality/removals by bottom trawling had declined.

(2) A widespread increase in fish biomass would occur as bottom trawling declined, principally due to the combined effect of reduced trawl-induced fishing mortality (F) and reduced trawling impacts on benthos.

(3) Relatively strong signals of biomass increase for fishes with marked association to structured benthic habitat would establish cause from the effect of reduced trawling impacts on benthos (as opposed to reduced F).

(4) The trend of the signals would correlate with the contrast in historical and recent bottom trawl effort, with strongest trends of increase where the decline in trawl effort was greatest, and weakest trend of increase where trawling continues.

(5) The magnitude of the signals — increased fish biomass and recovery of benthos — may be influenced by the pre-fishery benthos carrying capacity, i.e. greater increases may occur in areas with higher potential to recover and where trawl impact had

declined, and this could be determined from *a posteriori* analysis of benthos abundance.

## Units of analysis

### Fishes

Three levels of data were analysed:

1. Key genera (N=4) (following Sainsbury 1991): *Lethrinus*, *Lutjanus*, *Nemipterus*, *Saurida.* (Checks were made to identify the influential species that represented each genus to determine if aggregation at genus-level introduced bias due to uneven species distribution, e.g. if mixing shallow and deep species that may have confounded spatial patterns. The genera were strongly dominated by single species except Nemipterus, but *N. furcosus* was quite dominant and all *Nemipterus* species were scattered over the study area. Only *N. peronii* showed some concentrating to the west, but it was much less abundant than the other species.)

2. Informative species (N=27) (Table 20): this was an aggregated suite of species that combined: (a) Key Genera; (b) additional species that were top-ranked as typifying/distinguishing the primary inner/mid-shelf assemblages identified by the Regional Analysis (below in Results); (c) 'other' additional species of commercial interest, i.e. species examined routinely by WA Fisheries.

3. Inner/mid-shelf assemblages (N= 2) (summed biomass of the typifying species for each of the assemblages identified on the shelf (blue and red – see regional analysis, Section 7.3.1).

Input data were 4th root transformed standardised biomass (kg/ 30min tow), including absences as zero catch by tow. Note for assemblage analysis, data for typifying species of each assemblage were summed after 4th root transformation because assemblages were identified based on Bray-Curtis dissimilarity of 4th root transformed biomass data. Trends in biomass through time were identified using linear regressions in R package moderndive (Kim & Ismay, 2021) using function lm() and plotted using R tidyverse (Wickham et al., 2019) ggplot() with geom_smooth(method = "lm") to add regression lines with 95% confidence intervals (R Core Team, 2021).

**Table 20 The 27 informative species showing their membership of the two primary inner/ mid-shelf assemablages (blue and red – see Section 7.3.1), plus additional mostly differentiating species (black) and showing their classification into 'types' for predicting trend of biomass change with a rationale (developed from regional analysis, below)**

| Scientific namme | CAAB | Common Name | Type | Rationale |
|---|---|---|---|---|
| *Priacanthus hamrur* | 37326005 | Lunartail Bigeye | 1 | Typifying of Group 1 and differentiating species for assemblages |
| *Lutjanus vitta* | 37346003 | Brownstripe Snapper | 1 | Typifying of Group 1 and differentiating species for assemblages and established association with structured habitat |
| *Lutjanus sebae* | 37346004 | Red Emperor | 1 | Typifying of Group 1 and differentiating species for assemblages and established association with structured habitat |
| *Scolopsis monogramma* | 37347006 | Rainbow Monocle Bream | 2 | Typifying of Group 1 and differentiating species for assemblages |
| *Diagramma pictum* | 37350003 | Painted Sweetlips | 1 | Typifying of Group 1 and differentiating species for assemblages and established association with structured habitat |
| *Lethrinus nebulosus & Lethrinus sp.* | 37351904 | Spangled emperor | 1 | Typifying of Group 1 and differentiating species for assemblages and established association with structured habitat |
| *Argyrops bleekeri* | 37353006 | Frypan Bream | 1 | Typifying of Group 1 and differentiating species for assemblages and established association with structured habitat |
| *Parupeneus heptacanthus* | 37355004 | Opalescent Goatfish | 2 | Typifying of Group 1 and differentiating species for assemblages |
| *Parachaetodon ocellatus* | 37365003 | Ocellate Butterflyfish | 1 | Typifying of Group 1 and differentiating species for assemblages and established association with structured habitat |
| *Chaetodontoplus personifer* | 37365008 | Yellowtail Angelfish | 1 | Typifying of Group 1 and differentiating species for assemblages and established association with structured habitat |
| *Chaetodontoplus duboulayi* | 37365009 | Scribbled Angelfish | 1 | Typifying of Group 1 and differentiating species for assemblages and established association with structured habitat |
| *Choerodon cauteroma* | 37384005 | Bluespotted Tuskfish | 1 | Typifying of Group 1 and differentiating species for assemblages and established association with structured habitat |
| *Saurida undosquamis* | 37118001 | Largescale Saury | 2 | Typifying of Group 2 and differentiating species for assemblages, but ubiquitously abundant |
| *Saurida grandisquamis* | 37118016 | Grey Saury | 3 | Typifying of Group 2 and differentiating species for assemblages |
| *Nemipterus celebicus* | 37347004 | Celebes Threadfin Bream | 3 | Typifying of Group 2 and differentiating species for assemblages |
| *Nemipterus furcosus* | 37347005 | Rosy Threadfin Bream | 2 | Typifying of Group 2 and differentiating species for assemblages, but ubiquitously abundant |
| *Upeneus guttatus* | 37355008 | Orange-barred goatfish | 3 | Typifying of Group 2 and differentiating species for assemblages |
| *Pseudorhombus dupliciocellatus* | 37460004 | Three Twinspot Flounder | 3 | Typifying of Group 2 and differentiating species for assemblages |
| *Pseudorhombus diplospilus* | 37460015 | Bigtooth Twinspot Flounder | 3 | Typifying of Group 2 and differentiating species for assemblages |
| *Abalistes stellatus* | 37465011 | Starry Triggerfish | 2 | Typifying of Group 2 and differentiating species for assemblages, but ubiquitously abundant |
| *Epinephelus areolatus* | 37311009 | Yellowspotted Rockcod | 1 | Differentiating species for assemblages and established association with structured habitat |
| *Epinephelus multinotatus* | 37311010 | Rankin Cod | 1 | Differentiating species for assemblages and established association with structured habitat |
| *Plectropomus maculatus* | 37311012 | Barcheek Coral Trout | 1 | Differentiating species for assemblages and established association with structured habitat |
| *Pristipomoides multidens* | 37346002 | Goldband Snapper | 1 | Differentiating species for assemblages and established association with structured habitat |
| *Lutjanus malabaricus* | 37346007 | Saddletail Snapper | 1 | Differentiating species for assemblages and established association with structured habitat |
| *Pentapodus porosus* | 37347007 | Northwest Threadfin Bream | 3 | Differentiating species for assemblages |
| *Lutjanus erythropterus* | 37346005 | Crimson Snapper | 1 | Differentiating species for assemblages and established association with structured habitat |

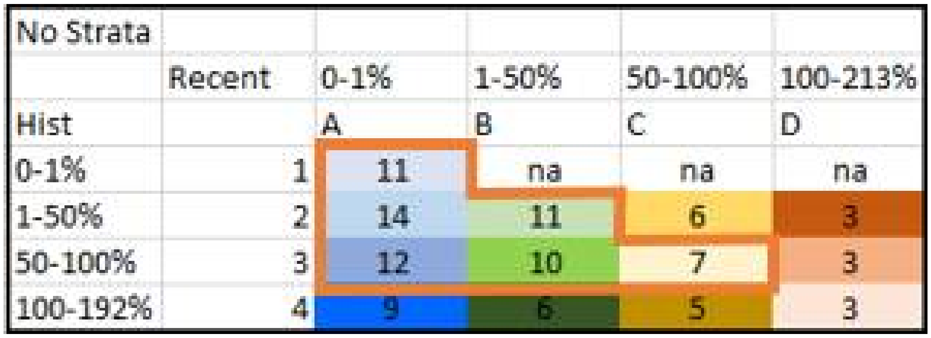
### Time periods

Data were analysed by year for the years in which there were data from spring-early summer surveys with full catch composition data, including for the 27 informative species.

### Areas

The Time series analysis was restricted to the area covered by the 2017 survey area. Within it, 11 sub-areas were analysed for changes in fish biomass: four of the Pilbara Fish Trawl Fishery management areas – Zone 2: PFTF Areas 1, 2, 3, 4; one adjacent area immediately west of the PFTF Zone 2 (Barrow); and six areas corresponding to contrasts in trawl effort — historical (1979-1985) vs recent (2005-2016) (Chapter 1) (Figure 162) – we selected three areas of contrasts (TC 3A, 3B, 2A) and three areas of non-contrast (TC 1A, 2B, 3C) where sufficient data were available across all years.

Because the trawl contrast (TC) areas are defined solely by contrasts in historic and recent trawl effort they provided an ability to examine trends in biomass independently of PFTF zoning, i.e. zoom into sub-areas defined only by trawl effort contrast, including to aggregate across PFTF Areas. Most importantly this was to zoom into areas of highest and continuing trawl effort (TC 3A), areas of relatively high trawl contrast (3A, 3B), and to depth-defined areas that were not captured by PFTF areas (TC 1A, 2A).



| No Strata | | | | | |
|---|---|---|---|---|---|
| | Recent | 0-1% | 1-50% | 50-100% | 100-213% |
| Hist | | A | B | C | D |
| 0-1% | 1 | 11 | na | na | na |
| 1-50% | 2 | 14 | 11 | 6 | 3 |
| 50-100% | 3 | 12 | 10 | 7 | 3 |
| 100-192% | 4 | 9 | 6 | 5 | 3 |

**Figure 162 Levels of contrast between historical (1979-1985) and recent (2005-2016) trawl effort in the 2017 study area. Numbers in cells are the number of 2017 samples in each sub-area. Orange polygon identifies the six areas suited to time-series analysis (based on adequate numbers of samples in pre-2017 surveys); see Chapter 4.**

<u>Characteristics of Pilbara Fish Trawl Fishery management areas</u>

- PFTF Area 1: Trawling continuously widespread, with relatively high effort compared to other areas in the Pilbara Fish Trawl Fishery Zone 2. Recent fishing appears concentrated in smaller patches – partly due to resolution of reporting – but some patches are new, indicating improved fishing knowledge and navigational ability over the duration of the time-series data.
- PFTF Area 2: Trawling still widespread, but relatively low effort compared to PFTF Area 1. There has been a substantial decline in trawl effort and effort distribution, including with trawling concentrated in a few smaller patches, including new patches.

- PFTF Area 3: Trawling was widespread, but with relatively low effort compared to PFTF Areas 1 and 2. Fully closed since 1998 following consistent trawling beforehand (1979 onwards).
- PFTF Area 4 - Trawling has always been limited in distribution with relatively low effort compared to other Areas. There have been only small changes in effort and effort distribution over time.

Characteristics of selected adjacent area

Barrow area: An area of high historical trawling effort compared to other areas in the Pilbara Fish Trawl Fishery Zone 2. Low effort since 1987 then closed to trawl fishery from 1993. Now contains the Monte Bello Marine Park and oil/gas infrastructure. This is the part of the 2017 survey area that overlaps with the adaptive management experiment (AME) Barrow zone.

Characteristics of trawl effort contrast (TC) areas

The contrasts in these areas capture a difference between the peak of foreign fishing ('historical' = 1979-1985) and effort from a decade some 20 years later, including the entire T2 and T3 periods ('recent' = 2005-2016) (Figure 162). Three areas represent contrasts (TC 3A, 3B, 2A) and three areas represent non-contrasts (TC 1A, 2B, 3C) (Figure 163). These are potentially very informative scenarios, but don't fully represent complex underlying patterns that vary within and between the areas contrasted – including environmental patterns.

Trawl effort contrasts:

- TC 3A [high —> low] has a strongly disjunct E-W distribution within the study area, but is outside the main trawl fishery area (Figure 163). Contrast may be confounded because fishing still occurred in E when W was closed – i.e. Barrow had a much longer period of recovery.
- TC 3B [high —> moderately low] extends broadly across study area and main trawl fishery area (Figure 163). Well sampled – magnitude of initial impact bigger than TC 2A.
- TC 2A [high —> low] extends broadly across study area – but is outside the main trawl fishery area (Figure 163). There was some trawling, especially in W, during T1, but shallow and mainly in the trap zone which was closed to trawling in 1993.

Trawl effort non-contrasts:

- TC 1A [low —> low] extends broadly across study area; very shallow and consistently little trawled through time (Figure 163).
- TC 2B [moderately low —> moderately low] extends broadly across study area and main trawl fishery area; has depth disjuncture, most is in deepest part of study area (Figure 163).

- TC 3C [high —> high] is concentrated in one part of the study area and is highly fragmented – continued trawling (Figure 163).

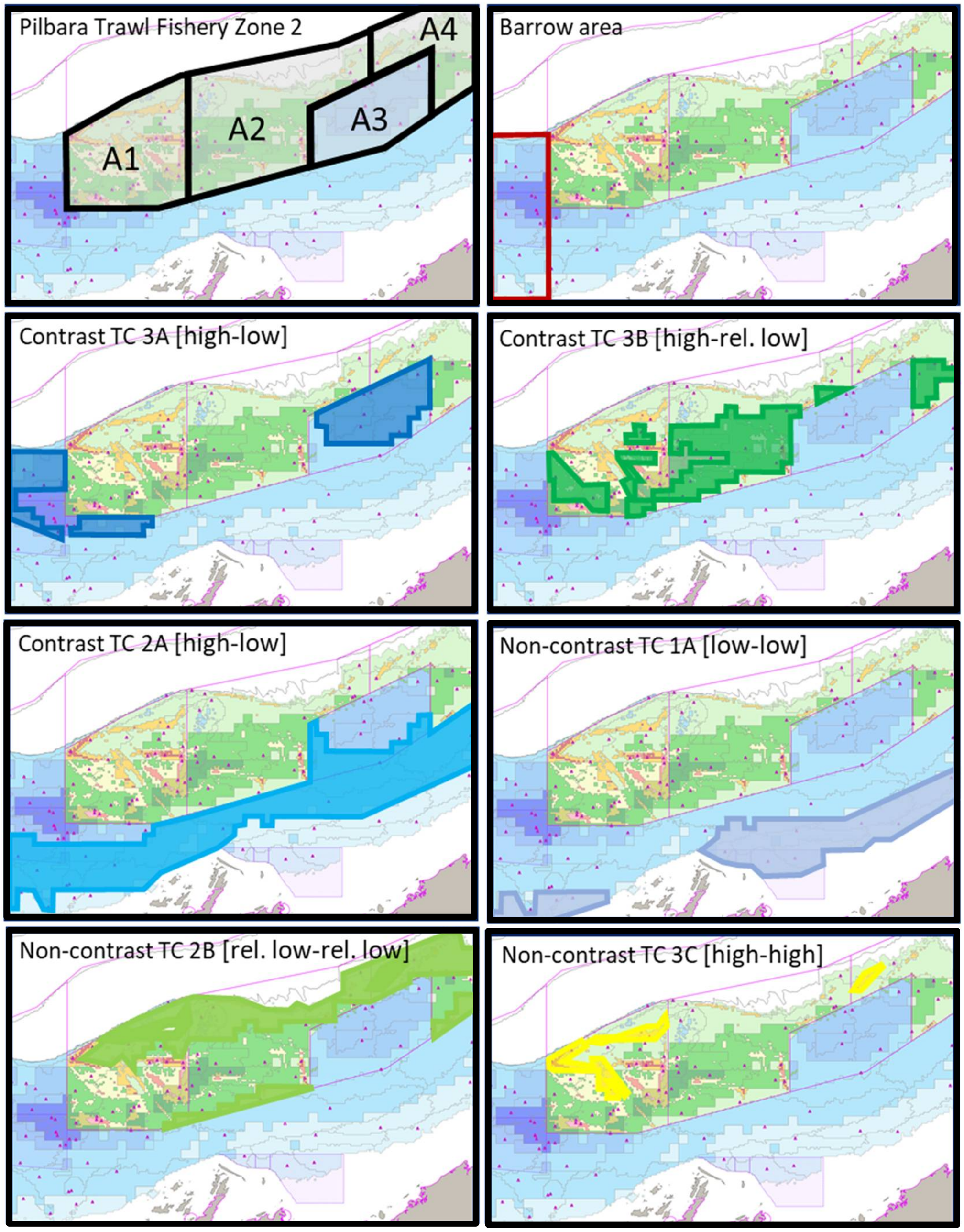


**Figure 163 Maps of the 11 areas analysed for changes in fish biomass: (a) Pilbara Fish Trawl Fishery management areas – Zone 2: PFTF Areas 1, 2, 3, 4; (b) an adjacent area (Barrow); and (c-h, respectively) trawl effort contrasts (1979-1985 vs 2005-2016) – three contrasts (TC 3A, 3B, 2A), and three non-contrasts (TC 1A, 2B, 3C)**

### Benthos

The benthos data used for the time-series analysis were derived from imagery because catch data were taken on relatively few surveys. Data from a camera mounted on the trawl headline were available for 10 surveys spanning 1983 to 2017 and therefore provided the best option for comparative analysis with changes in fish biomass.

A simple measure of benthos abundance was used: the frequency of occurrence of the presence of large benthos in the complete set of images taken along an individual transect = % occurrence of images containing large benthos per operation. This was because (1) the camera field-of-view was not sufficiently or consistently quantifiable, and (2) to avoid any inconsistency in scoring methodology stemming from changes (improvements) in image resolution over this time period. The trade-off for using a simple metric to avoid these sources of uncertainly was that changes in benthos abundance were not detected.

## Predicted temporal changes for species, assemablages and areas

Based on these hypotheses, we predicted, *a priori*, the following responses (signal) of increased fish biomass that would be superimposed on any positive response to reduced F. The aim was to differentiate a trend of strong +ve response to benthos recovery from other responses, not capture a wide range of possible responses.

#### Species-level responses

Three types of species responses were predicted (Figure 164, Table 20):

- Type 1 species: would show marked increased population abundance in response to benthos recovery; +ve trend is detected and significant (driven most notably by members of the relatively abundant genera *Lutjanus* and *Lethrinus*).
- Type 2 species: would show increased population abundance in response to benthos recovery, but less strongly; +ve trend is detected but non-significant.
- Type 3 species: may show change in population abundance, but not a +ve trend responding to benthos recovery and may be a -ve response to increased benthos; trend undetectable, or, if detected, typically non-significant +ve or -ve.

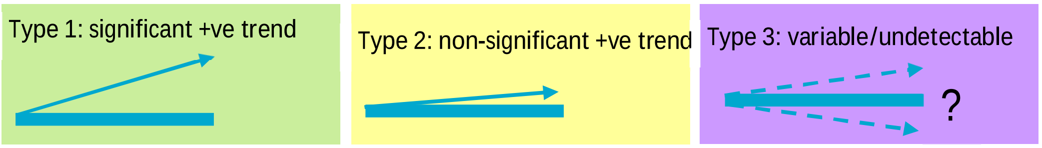


**Figure 164 Three theoretical responses (trends of change in biomass) of informative fish species to declining trawl impact on benthos. Type 1 species — significant positive trend due to strong association to structured benthic habitat; Type 2 species — a non-significant positive trend due to weak association to structured benthic habitat; Type 3 species — various changes in population abundance, but not a +ve trend responding to benthos recovery and may be a -ve response to increased benthos; trend undetectable, or, if detected, typically non-significant +ve or -ve.**

Assemblage-level responses:

- Structured habitat assemblage (blue): would show significant increase in aggregate population biomass stemming from dominance by Type 1 species, especially *Lutjanus* & *Lethrinus.*
- Unstructured habitat assemblage (red): would show change, often small increase, in population abundance stemming from a mix of dominance by Type 2 and Type 3 species and the strong influence of highly abundant ubiquitous species (*N. furcosus, S. undosquamis* and *A. stellatus*) all of which are most abundant in this assemblage.

Area-level responses:

The magnitude of response (number of species with significant responses) was expected to mirror the change in historical and recent trawl effort, but may also be influenced by benthos carrying capacity effects if they existed:

- Fishery management regions: PFTF Area 3 (closure) > PFTF Area 4, PFTF Area 2 > PFTF Area 1
- Selected areas (Barrow): Barrow > PFTF Area 1, PFTF Area 2
- Trawl effort contrasts: TC 3A > TC 3B, TC 2A (contrasts) >> TC 1A, TC 2B, TC 3C (non-contrasts); TC 3A ~ PFTF Area 3 (closure), Barrow; TC 3B ~ PFTF Area 1, PFTF Area 2

## 6.3 Results

### 6.3.1 Regional analysis

#### Richness, data reduction and sensitivity analyses

**Species richness**

The NWS fish fauna is highly species-rich: a tally of 553 species was caught in the T2/T3 surveys with 285-338 species per survey (Table 21). There was considerable turnover between surveys as indicated by numerous (61-88) singleton species per survey (Table 21) — a total of 127 singletons was identified across the T2/T3 surveys. A species rarefaction curve for the combined T2/T3 surveys was intitally extremely steep but had a very extended shallow incline after the first ~25% (~200) of trawl samples (Figure 165 a). These characteristics identified that within this rich species pool, about one third of species (~200) were uncommonly caught and slowly accumulated in the remaining ~75% of trawls (~600). Surprisingly, given the intensity of sampling effort, the presence of additional unsampled species was indicated by the curve failing to reach an asymptote. This may be driven in-part by evolving taxonomic knowledge and scrutiny, i.e. the addition of apparently new species, but does also reflect first-time captures of previously known and recognisable species. The cumulative weight on the other hand shows that most of the biomass sampled is represented by <200 species (Figure 165 b).

Three properties of the data set (1) high species richness, (2) a high proportion of uncommonly caught species, and (3) a high proportion of biomass contributed by relatively few species (Figure 160), collectively confirmed there would be benefit from reducing the number of species included in analyses.

Table 21 Summary of singletons and their contribution to the by survey number of species and biomass. For completeness the 1982, 1983 and 2017 surveys are shown here (grey text) but these data are not considered in the analyses presented in this section.

| Year | Survey | Number species | Number singleton species | Proportion of singletons | Total weight (kg) | Total weight of combined singletons (kg) | Weight of singletons as a proportion of total weight |
|---|---|---|---|---|---|---|---|
| 1982 | 8205 | 73 | 19 | 26.0 | 4501 | 117 | 2.6 |
| 1982 | 8206 | 76 | 24 | 31.6 | 5023 | 232 | 4.6 |
| 1983 | 8301 | 326 | 66 | 20.2 | 8406 | 141 | 1.7 |
| 1983 | 8302 | 50 | 8 | 16.0 | 3966 | 59 | 1.5 |
| 1983 | 8303 | 58 | 14 | 24.1 | 3225 | 62 | 1.9 |
| 1983 | 8304 | 290 | 63 | 21.7 | 7787 | 133 | 1.7 |
| 1983 | 8305 | 71 | 20 | 28.2 | 6083 | 243 | 4.0 |
| 1986 | 8606 | 350 | 73 | 20.9 | 14533 | 405 | 2.8 |
| 1987 | 8707 | 350 | 61 | 17.4 | 14961 | 156 | 1.0 |
| 1988 | 8805 | 351 | 75 | 21.4 | 12982 | 536 | 4.1 |
| 1989 | 8904 | 327 | 88 | 26.9 | 15482 | 292 | 1.9 |
| 1990 | 9002 | 331 | 74 | 22.4 | 18126 | 414 | 2.3 |
| 1991 | 9104 | 291 | 70 | 24.1 | 8339 | 259 | 3.1 |
| 1995 | 9508 | 312 | 84 | 26.9 | 15849 | 219 | 1.4 |
| 1997 | 9707 | 337 | 77 | 22.8 | 17288 | 300 | 1.7 |
| 2017 | 201705 | 293 | 58 | 19.8 | 15796 | 73 | 0.5 |

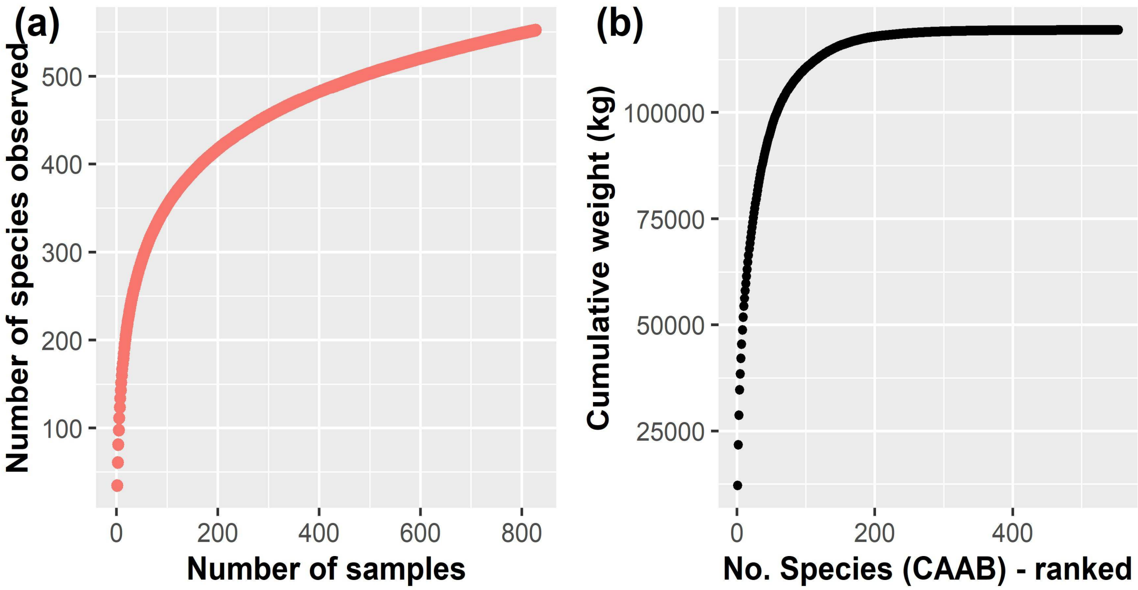


Figure 165 Data summary graphics for the combined T2/T3 surveys: (a) species accumulation curve; (b) cumulative catch weight by species

### Species reduction based on biomass

After removing singletons, species making small contributions to biomass in individual T2/T3 surveys were also removed (Figure 166). The top-ranked 50 species were judged to be too few to adequately represent total survey biomass (81% in 1988). Cut-offs at 100 and 150 species both appeared to adequately represent the samples, while species totals exceeding 200 made negligible additions to cumulative biomass. The 150 species cut-off was selected for species reduction because it represented >95% of biomass in 7 of 8 surveys. After reduction, the total of 254 species represented 46% of the total number (553) of species caught across T2/T3 surveys (Appendix F-1).

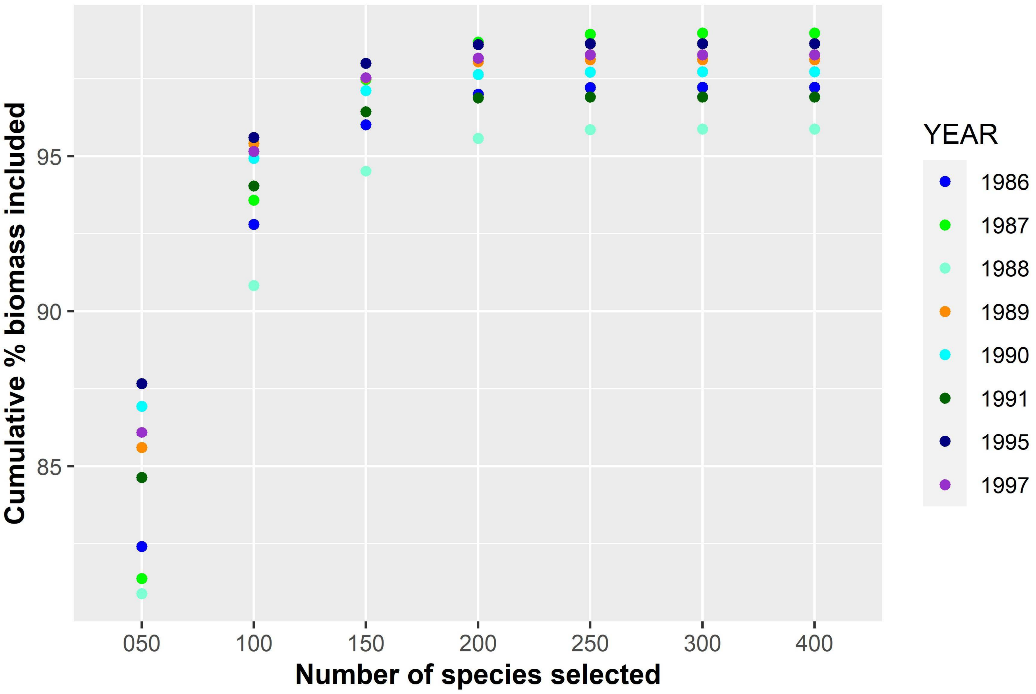


**Figure 166 Cumulative biomass represented by the top ranked species by biomass for each of the 8 surveys between 1986 and 1997 after singleton species (those occurring only once in a survey) were excluded. Selection was in steps of 50 species, with '400' indicating the full species pool for the given year (see Table 19)**

### Data transformation

Group-averaged clustering and MDS of untransformed, 2nd, 4th and 8th root transformed biomass data clearly distinguished depth-related sample groups; relatively little pattern emerged in untransformed data (Figure 167). The 4th root transform provided the most informative representation of ecological similarity between samples by strongly differentiating two groups in depths <100 m (mostly representing the core fishery depth range) and revealing a group of samples representing a paleocoastline, a known rocky habitat with characteristic fish species centred around 100 m depth. Additional groups of samples in depths >100 m occurred on the deep shelf and at the shelf edge. In contrast, structure within the core depth range was not apparent in the less severe (2nd root) transform; the paleocoastline was not evident in either the less severe (2nd root) or more severe (8th root) transforms (Figure 167). On this basis, the 4th root transformed data for the top-ranked 150 species by biomass was considered to be the base-case for further analysis.

**Table 22 Diagnostics of the results from multivariate analyses of the T2/T3 samples with different transformations of the catch weights and frequency of occurrence across the 8 T2/T3 surveys.**

| Treatment | Number species included | Threshold similarity | Number of groups with >4 samples | Number groups identified at threshold similarity | Number of groups identified by SIMPROF | MDS stress 2D | MDS stress 3D |
|---|---|---|---|---|---|---|---|
| **(a) Transformation (present in >=1 surveys)** | | | | | | | |
| Untransformed | 254 | 8.78 | 6 | 10 | 68 | 0.19 | 0.15 |
| 2nd root | 254 | 21.05 | 6 | 14 | 145 | 0.16 | 0.12 |
| **4th root** | **254** | **27.84** | **7** | **16** | **146** | **0.16** | **0.12** |
| 8th root | 254 | 28.71 | 6 | 11 | 130 | 0.16 | 0.12 |
| **(b) Occurrence by surveys (4th root transformed data)** | | | | | | | |
| present in all 8 surveys | 159 | 17.4 | 2 | 3 | 85 | 0.15 | 0.11 |
| present in >=7 surveys | 188 | 32.66 | 7 | 23 | 148 | 0.15 | 0.11 |
| present in >=6 surveys | 205 | 33.1 | 10 | 26 | 160 | 0.16 | 0.11 |
| present in all 5 surveys | 213 | 24.51 | 5 | 11 | 164 | 0.16 | 0.11 |
| present in >=4 surveys | 225 | 25.8 | 4 | 12 | 157 | 0.16 | 0.12 |
| present in >=3 surveys | 236 | 27.84 | 5 | 15 | 153 | 0.16 | 0.12 |
| present in >=2 surveys | 243 | 23.39 | 5 | 9 | 150 | 0.16 | 0.11 |
| **present in >=1 surveys** | **254** | **27.84** | **7** | **16** | **146** | **0.16** | **0.12** |

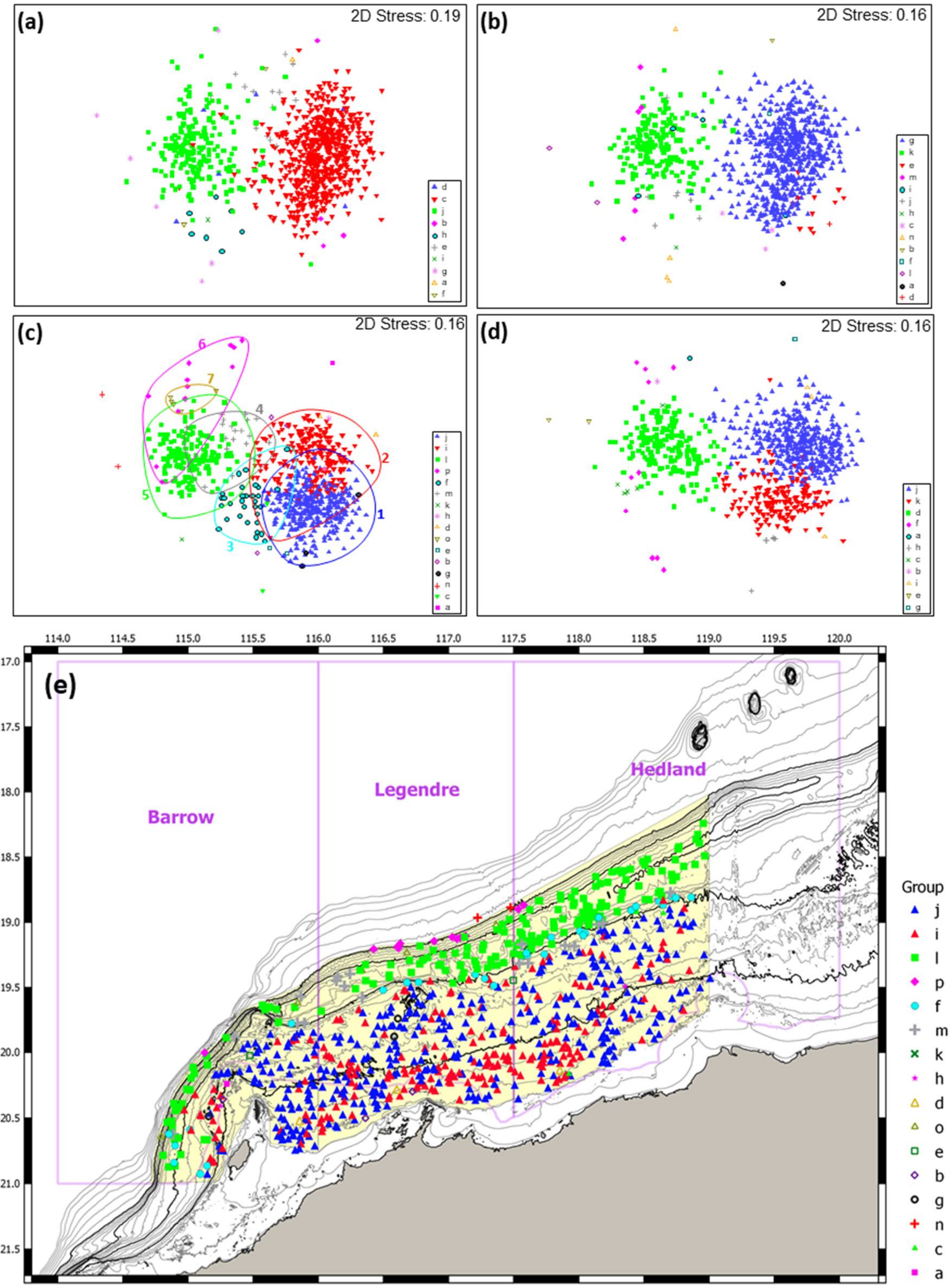


**Figure 167 Non-metric multidimensional scaling ordinations of the T2/T3 samples with catch weights (a) untransformed, (b) 2nd root transformed, (c) 4th root transformed and (d) 8th root transformed. The 7 main clusters identified in the 4th-root transformed data are identified in (c). The spatial distribution of the sample clusters identified in the 4th root transformed data is shown in (e).**

### Species reduction based on occurrence

Compared to the base-case, further species reduction based on species' occurrence across surveys (using 4th root transformed data for the top-ranked 150 species by biomass) did affect sample groupings and some of the sensitivity metrics based on the last non-significant SIMPROF split (Table 22).

Most noteworthy differences were at the most severe species reduction (occurence in all 8 surveys) where several values were markedly lower than the corresponding values at other occurences; in other cases there were fewer (4-5) significant groups using occurrences in 2-5 surveys (decreased structure in core depths) but an elevated (and unexplained) 10-group tally at 6 surveys (increased structure in core and deep depths). An occurrence cut-off at 7 surveys, the secondmost severe reduction, reduced the species pool from 254 to 188 compared to the base-case and generated the same number of sample groups (7) at a higher level of similarity (Table 22) that had a very similar grouping in multivariate space (Figure 168), but with a higher number of outliers. There was no apparent pattern (bias) among the 66 species excluded, e.g. towards large-bodied elasmobranchs and deep species. The excluded group did include sharks, rays and shelf-edge species but also very shallow species, pelagic species and species known to commonly occur at low abundance.

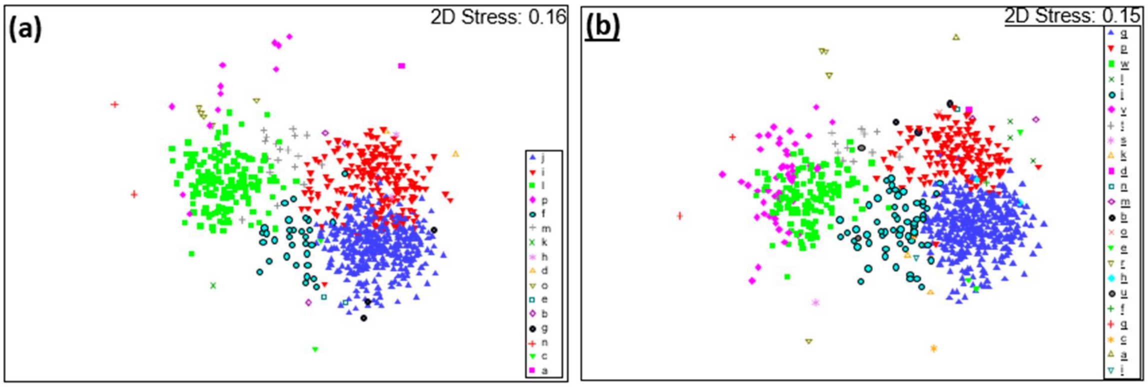


Figure 168 MDS (a) base-case, (b) base-case + occurrence in at least 7 surveys

## Species composition/ Faunal characteristics

The 254 species included in the base-case analysis represent 17 chondrychthyan and 64 bony fish families (Appendix F.1). Of these 81 families, 41 are represented by a single species, and 14 by two species. The Carangidae is the most diverse family with 24 species represented in the data, followed by Lujanidae (13 species), Nemipteridae (12), Lethrinidae and Mullidae (11 each) and Serranidae (10); the Dasyatidae family with 8 species was the most species diverse of the chondrychthyans.

The top 50 species by biomass included in the base-case analyses ranged in total catch weights between 580 and 12,183 kg. Most species, 44 of 50, were represented across all eight surveys and were observed frequently, present in 37 to 610 operations. However, the top 50 also included two dasyatid rays that were each caught in only 6 operations over 4 surveys, and *Pateobatis fai* a dasyatid ray only seen in 2 operations in the 1997 survey at a total catch weight of 620 kg.

In the top 50 species by biomass, the family Lujanidae is represented by seven species (two in the top 10), Nemipteridae by five species (two in the top 10), Mullidae by four and Lethrinidae by three species (one each in the top 10). The Synodontidae are only represented by two species in the top 50 by biomass, however, both these species have large total catch weights in the overall top 10: 6,970 kg (*Saurida undosquamis*) and 2,999 kg (*Saurida* cf. *filamentosa*) (Table 23).

**Table 23 List of the top 50 of 254 fish species ranked by total biomass recorded in 8 surveys between 1986 and 1997. The total species pool of 254 fish species for regional assemblage analyses is supplied in Appendix F.1. Shown are: ranked biomass, total occurrences (occ.), total weight, rank and occurrence by number of surveys. The four key genera are indicated (*).**

| Scientific name | Common name | Family | Key Gen. | CAAB | Total occ. | Total catch weight (kg) | Rank by biomass | Occ. in no. Surveys |
|---|---|---|---|---|---|---|---|---|
| *Lethrinus nebulosus & Lethrinus sp.* | Spangled emperor | Lethrinidae | * | 37351904 | 353 | 12183.3 | 1 | 8 |
| *Nemipterus furcosus* | Rosy Threadfin Bream | Nemipteridae | * | 37347005 | 532 | 9492.88 | 2 | 8 |
| *Saurida undosquamis* | Largescale Saury | Synodontidae | * | 37118001 | 609 | 6970.25 | 3 | 8 |
| *Abalistes stellatus* | Starry Triggerfish | Balistidae |  | 37465011 | 610 | 6019.79 | 4 | 8 |
| *Lutjanus sebae* | Red Emperor | Lutjanidae | * | 37346004 | 328 | 3727.34 | 5 | 8 |
| *Diagramma pictum* | Painted Sweetlips | Haemulidae |  | 37350003 | 245 | 3597.23 | 6 | 8 |
| *Pentapodus porosus* | Northwest Threadfin Bream | Nemipteridae |  | 37347007 | 253 | 3318.23 | 7 | 8 |
| *Saurida cf filamentosa* | Threadfin Saury | Synodontidae | * | 37118006 | 262 | 2998.39 | 8 | 8 |
| *Upeneus moluccensis* | Goldband Goatfish | Mullidae |  | 37355003 | 136 | 2957.4 | 9 | 8 |
| *Lutjanus vitta* | Brownstripe Snapper | Lutjanidae | * | 37346003 | 369 | 2587.93 | 10 | 8 |
| *Lutjanus malabaricus* | Saddletail Snapper | Lutjanidae | * | 37346007 | 149 | 1870.41 | 11 | 8 |
| *Selaroides leptolepis* | Yellowstripe Scad | Carangidae |  | 37337015 | 122 | 1789.2 | 12 | 8 |
| *Pristipomoides multidens* | Goldband Snapper | Lutjanidae |  | 37346002 | 188 | 1692.42 | 13 | 8 |
| *Parupeneus heptacanthus* | Opalescent Goatfish | Mullidae |  | 37355004 | 432 | 1690.54 | 14 | 8 |
| *Scolopsis monogramma* | Rainbow Monocle Bream | Nemipteridae |  | 37347006 | 282 | 1643.8 | 15 | 8 |
| *Argyrops bleekeri* | Frypan Bream | Sparidae |  | 37353006 | 448 | 1634.12 | 16 | 8 |
| *Lethrinus genivittatus* | Threadfin Emperor | Lethrinidae | * | 37351002 | 152 | 1501.52 | 17 | 8 |
| *Priacanthus hamrur* | Lunartail Bigeye | Priacanthidae |  | 37326005 | 452 | 1341.53 | 18 | 8 |
| *Chaetodontoplus duboulayi* | Scribbled Angelfish | Pomacanthidae |  | 37365009 | 260 | 1282.03 | 19 | 8 |
| *Pentaprion longimanus* | Longfin Silverbiddy | Gerreidae |  | 37349002 | 194 | 1209.18 | 20 | 8 |
| *Rhynchobatus spp.* | A wedgefish | Rhinidae |  | 37026900 | 94 | 1195.94 | 21 | 8 |
| *Ariomma indicum* | Indian Driftfish | Ariommatidae |  | 37447007 | 70 | 1131.69 | 22 | 8 |
| *Photopectoralis bindus* | Orangefin Ponyfish | Leiognathidae |  | 37341002 | 146 | 1128.75 | 23 | 8 |
| *Nemipterus bathybius* | Yellowbelly Threadfin Bream | Nemipteridae | * | 37347001 | 194 | 1103.39 | 24 | 8 |
| *Gymnocranius grandoculis* | Robinson's Seabream | Lethrinidae |  | 37351005 | 37 | 1071.42 | 25 | 8 |

| Scientific name | Common name | Family | Key Gen. | CAAB | Total occ. | Total catch weight (kg) | Rank by biomass | Occ. in no. Surveys |
|---|---|---|---|---|---|---|---|---|
| *Epinephelus multinotatus* | Rankin Cod | Serranidae | | 37311010 | 158 | 1065.35 | 26 | 8 |
| *Himantura spp.* | | Dasyatidae | | 37035902 | 47 | 1046.71 | 27 | 6 |
| *Upeneus guttatus* | Orange-barred goatfish | Mullidae | | 37355008 | 444 | 1033.63 | 28 | 8 |
| *Carangoides caeruleopinnatus* | Onion Trevally | Carangidae | | 37337021 | 255 | 1015.36 | 29 | 8 |
| *Lutjanus argentimaculatus* | Mangrove Jack | Lutjanidae | * | 37346015 | 11 | 1009.12 | 30 | 3 |
| *Lutjanus quinquelineatus* | Fiveline Snapper | Lutjanidae | * | 37346006 | 15 | 907.21 | 31 | 3 |
| *Bathytoshia lata* | Black Stingray | Dasyatidae | | 37035002 | 6 | 900 | 32 | 1 |
| *Priacanthus tayenus* | Purplespotted Bigeye | Priacanthidae | | 37326003 | 164 | 897.84 | 33 | 8 |
| *Choerodon cauteroma* | Bluespotted Tuskfish | Labridae | | 37384005 | 255 | 894.56 | 34 | 8 |
| *Nemipterus celebicus* | Celebes Threadfin Bream | Nemipteridae | * | 37347004 | 503 | 846.33 | 35 | 8 |
| *Taeniurops meyeni* | Blotched Fantail Ray | Dasyatidae | | 37035017 | 6 | 835 | 36 | 2 |
| *Netuma thalassina* | Giant Sea Catfish | Ariidae | | 37188001 | 104 | 793.68 | 37 | 8 |
| *Chaetodontoplus personifer* | Yellowtail Angelfish | Pomacanthidae | | 37365008 | 368 | 781.99 | 38 | 8 |
| *Siganus fuscescens* | Black Rabbitfish | Siganidae | | 37438001 | 189 | 739.07 | 39 | 8 |
| *Sargocentron rubrum* | Red Squirrelfish | Holocentridae | | 37261001 | 78 | 704.1 | 40 | 8 |
| *Stegostoma tigrinum* | Zebra Shark | Stegostomatidae | | 37013006 | 19 | 685.2 | 41 | 6 |
| *Platax batavianus* | Humphead Batfish | Ephippidae | | 37362002 | 195 | 647.43 | 42 | 8 |
| *Lutjanus sp. (in Yearsley. Last & Ward. 1999)* | Russell's snapper | Lutjanidae | * | 37346012 | 184 | 640.1 | 43 | 8 |
| *Pristotis obtusirostris* | Gulf Damsel | Pomacentridae | | 37372001 | 292 | 625.03 | 44 | 8 |
| *Pateobatis fai* | Pink Whipray | Dasyatidae | | 37035024 | 2 | 620 | 45 | 1 |
| *Upeneus australiae* | Australian Goatfish | Mullidae | | 37355032 | 136 | 608.66 | 46 | 8 |
| *Epinephelus areolatus* | Yellowspotted Rockcod | Serranidae | | 37311009 | 278 | 596.87 | 47 | 8 |
| *Pterocaesio chrysozona* | Yellowband Fusilier | Caesionidae | | 37346009 | 173 | 584.55 | 48 | 8 |
| *Pseudorhombus dupliciocellatus* | Three Twinspot Flounder | Paralichthyidae | | 37460004 | 439 | 583.78 | 49 | 8 |
| *Glaucosoma buergeri* | Northern Pearl Perch | Glaucosomatidae | | 37320001 | 126 | 579.61 | 50 | 8 |

### Assemblage patterns

Depth-related pattern dominated the structure of fish assemblages on the regional continental shelf; there was no evidence of longitudinal pattern at this scale (Figure 169). The base-case analysis clearly distinguished sample Groups 1 and 2 as inner/mid-shelf assemblages in ~25-100 m depths, Groups 3 and 4 as assemblages associated with a prominent paleocoastline at ~100 m, and Group 5 as a deep shelf assemblage in ~100-150 m — a pattern that was strongly preserved even after more severe species reduction by the 7-survey occurrence cut-off (Figure 169). The remaining deeper samples from > ~150 m represented another assemblage at the shelf-edge — but its structure was less clearly distinguished and less consistently mirrored in the two analyses. The shelf-edge assemblage was represented by Groups 6 and 7 in the base-case analysis, and by several outlier samples in both analyses (Figure 169).

The relatively unstable structure of the shelf-edge assemblage is explained by having relatively few samples from a steep and narrow area of seabed at the boundary between continental shelf and slope biomes. Sample grouping at the paleocoastline was predicted from knowledge of its geomorphology — a depth band of steep seabed (relative to the adjacent shallow and deep shelf) composed of rocky substratum with abundant megabenthos, and fishery characteristics — selected commercially important species at elevated abundances. The most striking pattern was the strongly mixed spatial distributions of samples comprising the two inner/mid-shelf assemblages. This indicated strong differentiation in species composition, but without any broad spatial sub-structure.

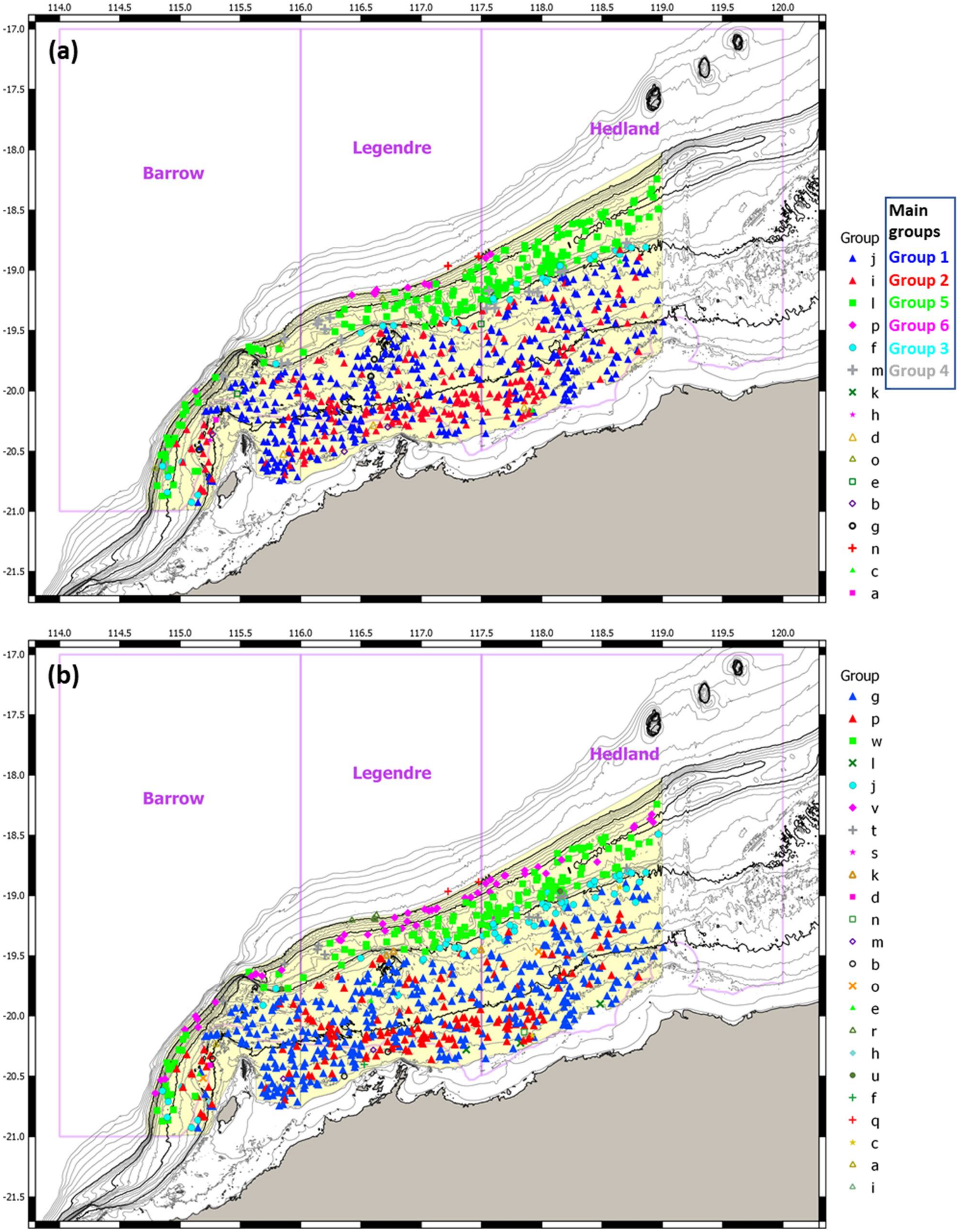


**Figure 169 Maps of the spatial distribution of the multivariate groups (a) base-case; (b) base-case + occurrence. The 6 main assemblages discussed below are identified in (a) as Groups 1 & 2: inner/mid-shelf; Groups 3 & 4 paeleocoastline, and Groups 5 & 6 shelf/ shelf-edge.**

## Informative species

### Inner/mid-shelf assemblages

The species with greatest influence on assemblage structure were mostly abundant species that both typified one or other group — 12 in Group 1 (blue), and 8 in Group 2 (red) — and contributed strongly to distinguishing groups (Table 24). The most influential species were from the genera *Lethrinus* and *Lutjanus* in Group 1 and *Nemipterus* and *Saurida,* and *Abalistes stellatus,* in Group 2. Other prominent groups were mullids, which were abundant in both groups (*Parupeneus heptacanthus* in Group 1 and *Upeneus guttatus* in Group 2), and bothids (*Pseudorhombus dupliciocellatus* and *P. diplospilus*) which were abundant in Group 2. Another 19 species contributed strongly to distinguishing the groups,

Notably, three species (*Nemipterus furcosus, Saurida undosquamis, Abalistes stellatus)* were typical in both groups because they were ubiquitously abundant — but also distinguished the groups because they were considerably more abundant in Group 2 (Table 24). The robustness of this outcome was demonstrated by only minor differences resulting from using the reduced species-pool based on occurrence, e.g. 29 of the 30 top-ranked distinguishing species are common to both analyses (Table 24).

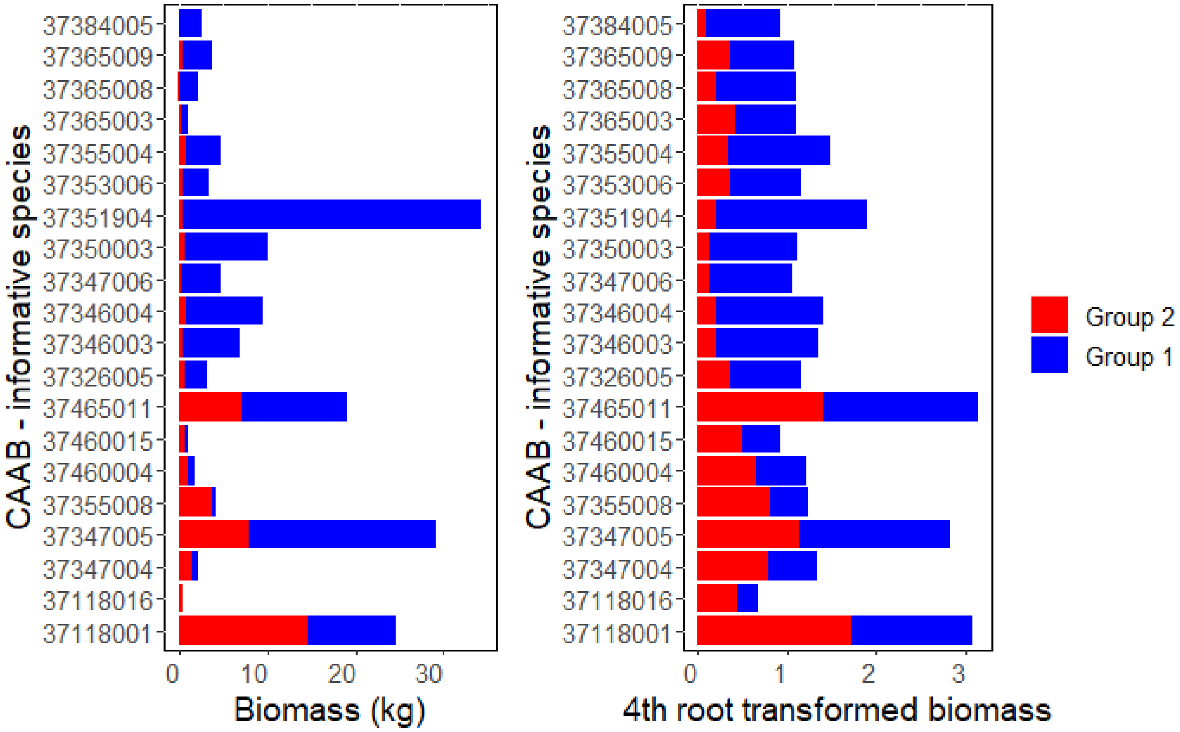


**Figure 170 Distribution of the (a) raw and (b) 4th root transformed biomass of the 20 typefying species of the two inner/mid-shelf communities (groups 1 - blue and 2 - red) identified in a SIMPER analysis of the base-case. The species names are listed against the CAAB in Table 24.**

**Table 24 The 40 most informative species that typify and distinguish the two primary inner/mid-shelf assemblages as identified by average abundance (biomass) in transformed data across samples within cluster groups for base-case and base-case+occurrence scenarios. Species are ranked in order of importance to distinguishing assemblages (base-case data), with the 20 most important typifying species coloured based on Group membership (1 - blue and 2 - red); species important to typifying both groups are matched to the group where they are most abundant.**

| | | | Typifying species | | | | Distinguishing species | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Base-case | | + occurrence | | Base-case | | + occurrence | | |
| CAAB | Species | Common name | Grp 2 red | Grp 1 blue | Grp 2 red | Grp 1 blue | blue v red | Rank | blue v red | Rank | |
| 37351904 | Lethrinus nebulosus & Lethrinus sp. | Spangled emperor | | 6.17 | | 5.8 | 3.2 | 1 | 3.36 | 1 | |
| 37346004 | Lutjanus sebae | Red Emperor | | 4.27 | | 4 | 2.42 | 2 | 2.52 | 2 | |
| 37347005 | Nemipterus furcosus | Rosy Threadfin Bream | 8.43 | 7.28 | 8.46 | 7.42 | 2.21 | 3 | 2.35 | 3 | * |
| 37346003 | Lutjanus vitta | Brownstripe Snapper | | 4.42 | | 4.2 | 2.19 | 4 | 2.34 | 4 | |
| 37355004 | Parupeneus heptacanthus | Opalescent Goatfish | | 4.82 | | 4.8 | 2.01 | 5 | 2.24 | 5 | |
| 37350003 | Diagramma pictum | Painted Sweetlips | | 2.56 | | 2.49 | 2.01 | 6 | 2.07 | 6 | |
| 37347007 | Pentapodus porosus | Northwest Threadfin Bream | | | | | 1.79 | 7 | 1.91 | 7 | |
| 37347006 | Scolopsis monogramma | Rainbow Monocle Bream | | 2.8 | | 2.99 | 1.74 | 8 | 1.9 | 8 | |
| 37118001 | Saurida undosquamis | Largescale Saury | 18.02 | 5.75 | 19.76 | 6.04 | 1.69 | 9 | 1.74 | 10 | * |
| 37365008 | Chaetodontoplus personifer | Yellowtail Angelfish | | 3.41 | | 3.3 | 1.66 | 10 | 1.77 | 9 | |
| 37384005 | Choerodon cauteroma | Bluespotted Tuskfish | | 2.55 | | 2.56 | 1.63 | 11 | 1.72 | 11 | |
| 37353006 | Argyrops bleekeri | Frypan Bream | | 2.58 | | 2.42 | 1.54 | 12 | 1.58 | 13 | |
| 37326005 | Priacanthus hamrur | Lunartail Bigeye | | 2.42 | | 2.37 | 1.51 | 13 | 1.57 | 15 | |
| 37355008 | Upeneus guttatus | orange-barred goatfish | 4.86 | | 4.57 | | 1.5 | 14 | 1.62 | 12 | |
| 37365009 | Chaetodontoplus duboulayi | Scribbled Angelfish | | | | 1.81 | 1.48 | 15 | 1.58 | 14 | |
| 37311009 | Epinephelus areolatus | Yellowspotted Rockcod | | | | | 1.29 | 16 | 1.26 | 19 | |
| 37460004 | Pseudorhombus dupliciocellatus | Three Twinspot Flounder | 4.77 | | 5.32 | | 1.29 | 17 | 1.38 | 16 | |
| 37465011 | Abalistes stellatus | Starry Triggerfish | 14.07 | 8.92 | 15.09 | 8.98 | 1.24 | 18 | 1.29 | 17 | * |
| 37311010 | Epinephelus multinotatus | Rankin Cod | | | | | 1.23 | 19 | 1.22 | 21 | |
| 37347004 | Nemipterus celebicus | Celebes Threadfin Bream | 6.32 | | 6.31 | | 1.22 | 20 | 1.27 | 18 | |
| 37372001 | Pristotis obtusirostris | Gulf Damsel | | | | | 1.17 | 21 | 1.25 | 20 | |
| 37337021 | Carangoides caeruleopinnatus | Onion Trevally | | | | | 1.15 | 22 | 1.1 | 28 | |
| 37460015 | Pseudorhombus diplospilus | Bigtooth Twinspot Flounder | 2.67 | | 3.19 | | 1.12 | 23 | 1.19 | 23 | |
| 37337022 | Carangoides gymnostethus | Bludger Trevally | | | | | 1.11 | 24 | 1.18 | 24 | |
| 37365003 | Parachaetodon ocellatus | Ocellate Butterflyfish | | 2.49 | | 2.59 | 1.09 | 25 | 1.2 | 22 | |
| 37362002 | Platax batavianus | Humphead Batfish | | | | | 1.09 | 26 | 1.06 | 30 | |
| 37466005 | Ostracion nasus | Shortnose Boxfish | | | | | 1.07 | 27 | 1.11 | 27 | |
| 37351002 | Lethrinus genivittatus | Threadfin Emperor | | | | | 1.06 | 28 | 1.12 | 25 | |
| 37438001 | Siganus fuscescens | Black Rabbitfish | | | | | 1.06 | 29 | 1.12 | 26 | |
| 37351010 | Gymnocranius elongatus | Swallowtail Seabream | | | | | 1.01 | 30 | 0.95 | 35 | |
| 37365004 | Coradion chrysozonus | Orangebanded Coralfish | | | | | 0.98 | 31 | 1.07 | 29 | |
| 37118016 | Saurida grandisquamis | Grey Saury | 2.71 | | | | 0.96 | 32 | 1.04 | 31 | |
| 37386001 | Scarus ghobban | Bluebarred Parrotfish | | | | | 0.96 | 33 | 0.96 | 34 | |
| 37346012 | Lutjanus sp. (in Yearsley. Last & Wa | Russell's snapper | | | | | 0.94 | 34 | 0.89 | 40 | |
| 37346009 | Pterocaesio chrysozona | Yellowband Fusilier | | | | | 0.93 | 35 | 0.94 | 36 | |
| 37337015 | Selaroides leptolepis | Yellowstripe Scad | | | | | 0.93 | 36 | 1 | 33 | |
| 37460011 | Pseudorhombus spinosus | Spiny Flounder | | | | | 0.92 | 37 | 1 | 32 | |
| 37384004 | Choerodon cephalotes | Purple Tuskfish | | | | | 0.89 | 38 | 0.93 | 37 | |
| 37311012 | Plectropomus maculatus | Barcheek Coral Trout | | | | | 0.89 | 39 | 0.89 | 41 | |
| 37465020 | Pseudomonacanthus peroni | Potbelly Leatherjacket | | | | | 0.88 | 40 | 0.89 | 42 | |

## Paleocoastline assemblages

In the base-case analysis, the most informative 40 species characterising Group 3 (cyan) and Group 4 (grey) included abundant species that both typified one or other group (13 in Group 3, and 7 in Group 4), and contributed strongly to distinguishing groups (Table 25). Group 3 was dominated by commercial species: Lutjanidae (*Lutjanus* spp. and *Pristipomoides multidens*) and *Agryrops*, *Glaucosoma*, *Epinephelus* and a variety of other (non-commercial) species that were also informative on the inner/mid-shelf — including the mullid *P. heptacanthus* that strongly typified Group 1. Group 4 was dominated primarily by species of *Nemipterus* and *Saurida*; the species were mostly the same species as those characterising the inner/mid-shelf Group 2, but there was a turnover of the most dominant: *S. undosquamis* replaced by *S. filamentosa*, and *N. furcosus* by *N. celebicus*. As for the inner/mid-shelf, *Abalistes stellatus* was abundant but typical in only Group 3. Another 20 species contributed strongly to distinguishing the groups. There were greater differences in the outcome from using the reduced species-pool based on occurrence compared to the inner/mid-shelf outcome, but the result was judged to be similarly robust based on the 16 top-ranked distinguishing species being common to both analyses (Table 25).

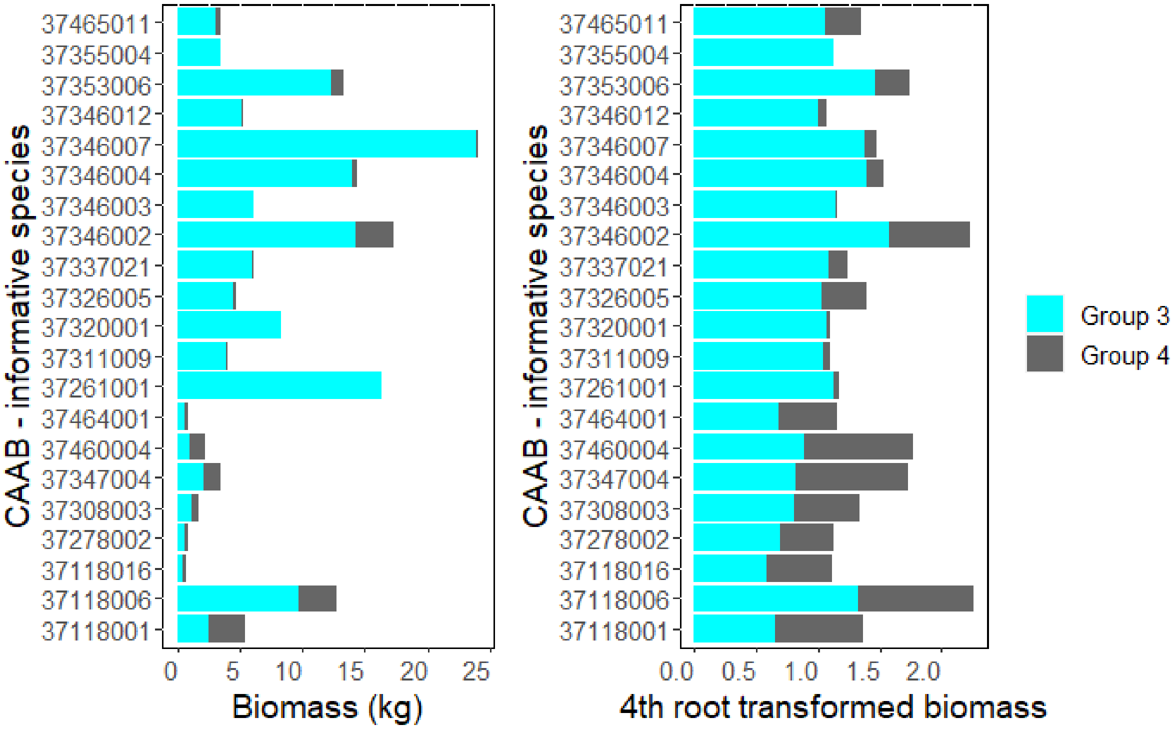


**Figure 171 Distribution of the (a) raw and (b) 4th root transformed biomass of the 20 typefying species of the two paeleocoastline communities (groups 3 - cyan and 4 - grey) identified in a SIMPER analysis of the base-case. The species names are listed against the CAAB inTable 25.**

**Table 25 The 40 most informative typifying and distinguishing paeleocoastline species. Highlighted are the 20 typefying species coloured based on the group (3 - cyan and 4 – grey) where they are more abundant.**

| | | | Typifying species | | | | Distinguishing species | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Base-case | | + occurrence | | Base-case | | + occurrence | |
| CAAB | Species | Common name | Grp 3 cyan | Grp 4 grey | Grp 3 cyan | Grp 4 grey | cyan v grey | Rank | cyan v grey | Rank |
| 37346007 | Lutjanus malabaricus | Saddletail Snapper | 3.72 | | | | 2.78 | 1 | 2.18 | 11 |
| 37353006 | Argyrops bleekeri | Frypan Bream | 4.82 | | 5.06 | | 2.64 | 2 | 3.03 | 3 |
| 37346004 | Lutjanus sebae | Red Emperor | 4.05 | | 3.23 | | 2.62 | 3 | 2.54 | 4 |
| 37346002 | Pristipomoides multidens | Goldband Snapper | 5.66 | | 4.77 | | 2.59 | 4 | 3.14 | 1 |
| 37355004 | Parupeneus heptacanthus | Opalescent Goatfish | 4.61 | | 3.83 | | 2.4 | 5 | 2.38 | 7 |
| 37346003 | Lutjanus vitta | Brownstripe Snapper | 3.44 | | 3.38 | | 2.31 | 6 | 2.45 | 6 |
| 37261001 | Sargocentron rubrum | Red Squirrelfish | 2.53 | | | | 2.22 | 7 | 1.69 | 16 |
| 37320001 | Glaucosoma buergeri | Northern Pearl Perch | 2.82 | | 2.57 | | 2.2 | 8 | 2.17 | 12 |
| 37311009 | Epinephelus areolatus | Yellowspotted Rockcod | 3.77 | | 4.2 | | 2.16 | 9 | 2.51 | 5 |
| 37337021 | Carangoides caeruleopinnatus | Onion Trevally | 3.24 | | 3.64 | | 2.12 | 10 | 2.38 | 8 |
| 37346012 | Lutjanus sp. (in Yearsley. Last & | Russell's snapper | 2.6 | | | | 1.98 | 11 | 1.8 | 14 |
| 37465011 | Abalistes stellatus | Starry Triggerfish | 3.92 | | 5.94 | | 1.94 | 12 | 3.07 | 2 |
| 37118006 | Saurida cf filamentosa | Threadfin Saury | 4.49 | 11.19 | 4.98 | 9.04 | 1.85 | 13 | 2.22 | 9 |
| 37349002 | Pentaprion longimanus | Longfin Silverbiddy | | | | | 1.73 | 14 | 2.04 | 13 |
| 37326005 | Priacanthus hamrur | Lunartail Bigeye | 3.12 | | 3.05 | | 1.73 | 15 | 1.8 | 15 |
| 37118001 | Saurida undosquamis | Largescale Saury | | 5.62 | 3.22 | 8.11 | 1.7 | 16 | 2.19 | 10 |
| 37346019 | Pristipomoides typus | Sharptooth Snapper | | | | | 1.68 | 17 | | |
| 37351005 | Gymnocranius grandoculis | Robinson's Seabream | | | | | 1.67 | 18 | | |
| 37351007 | Lethrinus lentjan | Redspot Emperor | | | | | 1.67 | 19 | 1.28 | 24 |
| 37355003 | Upeneus moluccensis | Goldband Goatfish | | | | | 1.34 | 20 | 1.49 | 18 |
| 37326003 | Priacanthus tayenus | Purplespotted Bigeye | | | | | 1.33 | 21 | | |
| 37347004 | Nemipterus celebicus | Celebes Threadfin Bream | 2.69 | 13.3 | 4.29 | 14.21 | 1.23 | 22 | 1.23 | 26 |
| 37188001 | Netuma thalassina | Giant Sea Catfish | | | | | 1.23 | 23 | 1.15 | 28 |
| 37308003 | Dactyloptena macracanthus | Mottled Flying Gurnard | 2.99 | 4.6 | 3.11 | | 1.18 | 24 | 1.47 | 19 |
| 37347010 | Parascolopsis tanyactis | Longray Monocle Bream | | | | | 1.18 | 25 | 1.1 | 31 |
| 37347001 | Nemipterus bathybius | Yellowbelly Threadfin Bream | | | | | 1.12 | 26 | | |
| 37346005 | Lutjanus erythropterus | Crimson Snapper | | | | | 1.1 | 27 | | |
| 37026900 | Rhynchobatus spp. | #N/A | | | | | 1.07 | 28 | | |
| 37467008 | Lagocephalus inermis | Smooth Golden Toadfish | | | | 5.05 | 1.03 | 29 | 1.62 | 17 |
| 37365008 | Chaetodontoplus personifer | Yellowtail Angelfish | | | | | 1.02 | 30 | 1.14 | 29 |
| 37278002 | Fistularia petimba | Rough Flutemouth | | 4.46 | | 8.14 | 1.01 | 31 | | |
| 37466007 | Lactoria diaphana | Roundbelly Cowfish | | | | | 1 | 32 | 1.29 | 22 |
| 37464001 | Trixiphichthys weberi | Blacktip Tripodfish | | 4.6 | 2.64 | | 0.98 | 33 | 1.24 | 25 |
| 37355008 | Upeneus guttatus | orange-barred goatfish | | | | | 0.96 | 34 | 1.2 | 27 |
| 37311015 | Epinephelus amblycephalus | Banded Grouper | | | | | 0.94 | 35 | | |
| 37118016 | Saurida grandisquamis | Grey Saury | | 5.89 | | | 0.94 | 36 | | |
| 37337013 | Carangoides equula | Whitefin Trevally | | | | | 0.93 | 37 | 1.29 | 23 |
| 37351010 | Gymnocranius elongatus | Swallowtail Seabream | | | | | 0.93 | 38 | 1.31 | 21 |
| 37347005 | Nemipterus furcosus | Rosy Threadfin Bream | | | | | | 39 | 1.33 | 20 |
| 37401901 | Champsodon spp. | 0 | | | | 4.57 | | 40 | 1.13 | 30 |

### Deep shelf/shelf-edge assemblages

These assemblages contained fewer species overall in the base-case analysis but a large number (39) were informative — in part because three groups (vs two) were being distinguished. A total of 16 species collectively characterised the three groups, 7 species in Group 5 (green), 6 in Group 6 (pink) and 3 in Group 7 (brown); again, these included highly abundant species that both typified one or more groups and contributed strongly to distinguishing groups (Table 26). Group 5 species were dominated by *Nemipterus virgatus*, *N. bathybius* and *Saurida filamentosa*, Group 6 by *Dentex spariformis* and *Acropoma japonicum*, and Group 7 also by *Saurida filamentosa* and *Nemipterus bathybius* plus *Carangoides equula* (Table 26). A relatively large number (29) of informative species mostly distinguished between the two major Groups 5 and 6, and several also distinguished between these groups and Group 7; the remaining 10 species mostly distinguished Groups 5 and 7 (Table 26). Compared to shallower depths, there were greater differences when comparing the base-case to the reduced species-pool based on occurrence for the deep shelf/shelf-edge, but the result was judged to be similarly robust 29 of the 31 distinguishing species in the reduced species pool overlaps with those in the base-case analysis (Table 26).

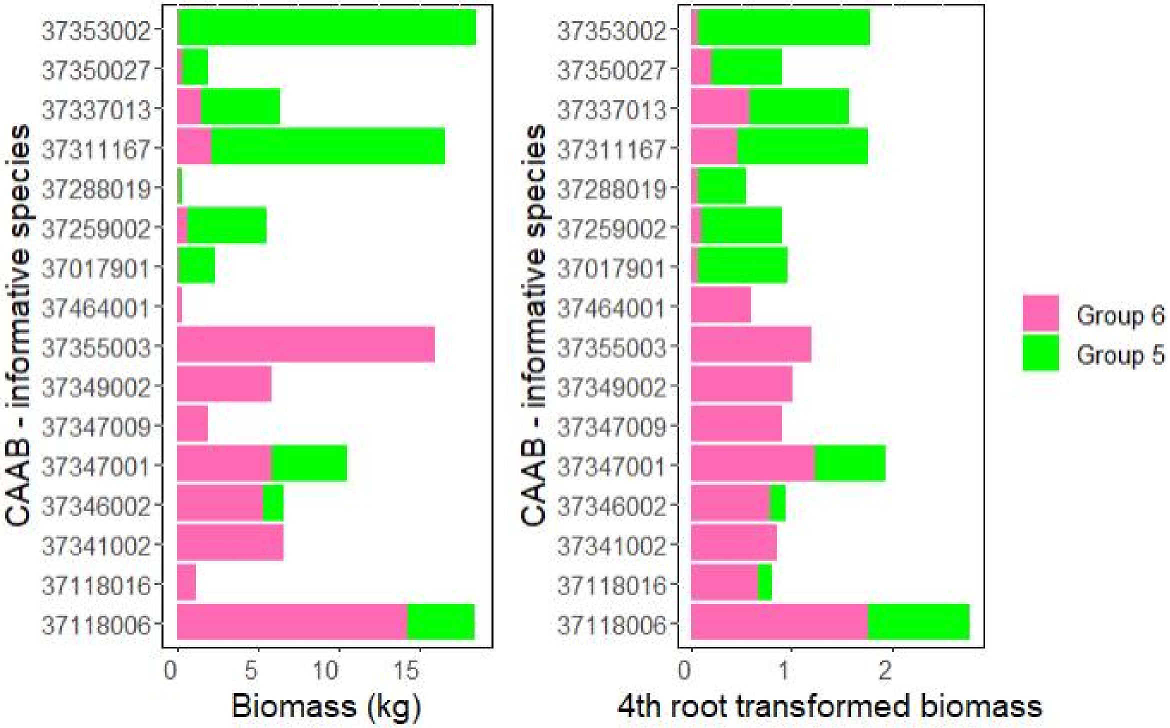


**Figure 172 Distribution of the (a) raw and (b) 4th root transformed biomass of the 20 typefying species of the two deep communities (groups 5 – green, 6 – pink) identified in a SIMPER analysis of the base-case. The species names are listed against the CAAB in Table 26.**

**Table 26 The 35 most informative typifying and distinguishing deep species. Highlighted are the 16 typefying species coloured based on the group (5 – green, 6 – pink) where they are more abundant.**

| | | | Typifying species | | | | Distinguishing species | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Base-case | | + occurrence | | Base-case | | + occurrence | |
| CAAB | Species | Common name | Grp 5 green | Grp 6 pink | Grp 5 green | Grp 6 pink | green v pink | Rank | green v pink | Rank |
| 37353002 | Dentex spariformis | Yellowback Bream | | 17.21 | | | 4.77 | 1 | 2.05 | 14 |
| 37311167 | Acropoma japonicum | Japanese Seabass | | 10.95 | | 4.99 | 3.37 | 2 | 2.99 | 6 |
| 37355003 | Upeneus moluccensis | Goldband Goatfish | 6.14 | | 7.62 | | 3.29 | 3 | 4.44 | 1 |
| 37118006 | Saurida cf filamentosa*** | Threadfin Saury | 16.71 | 6.51 | 15.39 | 19.54 | 3.01 | 4 | 2.23 | 13 |
| 37349002 | Pentaprion longimanus | Longfin Silverbiddy | 5.97 | | 7.94 | | 2.86 | 5 | 4.03 | 2 |
| 37347001 | Nemipterus bathybius*** | Yellowbelly Threadfin Bream | 10.28 | | 8.68 | 15.4 | 2.83 | 6 | 2.59 | 9 |
| 37347009 | Nemipterus virgatus | Golden Threadfin Bream | 6.88 | | 6.42 | | 2.66 | 7 | 2.54 | 10 |
| 37017901 | Mustelus spp. | gummy shark | | 7.71 | | | 2.64 | 8 | | |
| 37341002 | Photopectoralis bindus | Orangefin Ponyfish | 4.58 | | 5.4 | | 2.46 | 9 | 3.33 | 4 |
| 37346002 | Pristipomoides multidens | Goldband Snapper | 3.61 | | | | 2.39 | 10 | 3.14 | 5 |
| 37337013 | Carangoides equula | Whitefin Trevally | | 7.86 | | 13.49 | 2.21 | 11 | 3.43 | 3 |
| 37259002 | Monocentris japonica | Japanese Pineapplefish | | 3.77 | | | 2.18 | 12 | 1.58 | 21 |
| 37350027 | Hapalogenys dampieriensis | [a grunter bream] | | 4.12 | | | 1.99 | 13 | 1.52 | 22 |
| 37326003 | Priacanthus tayenus | Purplespotted Bigeye | | | 5.03 | | 1.93 | 14 | 2.92 | 7 |
| 37326005 | Priacanthus hamrur | Lunartail Bigeye | | | | 5.1 | 1.89 | 15 | 2.35 | 12 |
| 37118016 | Saurida grandisquamis | Grey Saury | 3.98 | | | | 1.78 | 16 | 2.39 | 11 |
| 37464001 | Trixiphichthys weberi | Blacktip Tripodfish | 4.61 | | 5.13 | | 1.74 | 17 | 1.83 | 16 |
| 37267004 | Antigonia capros | Robust Deepsea Boarfish | | | | | 1.71 | 18 | | |
| 37447007 | Ariomma indicum | Indian Driftfish | | | | | 1.62 | 19 | 2.71 | 8 |
| 37288019 | Satyrichthys rieffeli | Spotted Armour Gurnard | | 4.66 | | | 1.57 | 20 | | |
| 37326001 | Priacanthus macracanthus | Spotted Bigeye | | | | | 1.44 | 21 | 1.83 | 17 |
| 37287009 | Neosebastes occidentalis | Orangebanded Gurnard Perch | | | | | 1.44 | 22 | | |
| 37267001 | Antigonia rubescens | Sharpsnout Deepsea Boarfish | | | | | 1.44 | 23 | | |
| 37208001 | Lophiomus setigerus | Broadhead Goosefish | | | | | 1.42 | 24 | | |
| 37018007 | Carcharhinus plumbeus | Sandbar Shark | | | | | 1.38 | 25 | | |
| 37020901 | Squalus spp. | greeneye dogfish | | | | | 1.33 | 26 | | |
| 37467008 | Lagocephalus inermis | Smooth Golden Toadfish | | | | | 1.31 | 27 | 2 | 15 |
| 37038009 | Urolophus westraliensis | Brown Stingaree | | | | | 1.3 | 28 | | |
| 37188001 | Netuma thalassina | Giant Sea Catfish | | | | | 1.26 | 29 | 1.82 | 18 |
| 37355002 | Upeneus torres | Japanese Goatfish | | | | | | | 1.82 | 19 |
| 37353006 | Argyrops bleekeri | Frypan Bream | | | | | | | 1.77 | 20 |
| 37308003 | Dactyloptena macracanthus | Mottled Flying Gurnard | | | | | | | 1.5 | 23 |
| 37347004 | Nemipterus celebicus | Celebes Threadfin Bream | | | | | | | 1.48 | 24 |
| 37288015 | Lepidotrigla sp. 2 [in Sainsbury e | mottled red spot gurnard | | | | | | | 1.46 | 25 |
| 37401901 | Champsodon spp. | 0 | | | | 5.06 | | | 1.44 | 26 |

## Benthos abundance

Benthos data from imagery (frequency of presence of large, small and mini benthos averaged over all images in an operation) was not available for all trawl operations for all assemblages: availability ranged between 58% and 66% for the inner/mid shelf and paeleocoastline communities and 50% for the deep communities (group 6) and only 36% (group 5). Because missing data were due to random effects such as camera malfunction, there is no expectation of bias in the sub-sets of data available for analysis.

There was a general depth effect, with benthos abundance declining as the depth of fish assemblages increased (Figure 173, left to right). The inner/ mid-shelf fish assemblages were generally associated with high levels of benthos, and higher levels were observed at locations (trawl operations) where the blue assemblage (associated to structural benthos) were dominant compared to the red assemblage (not associated to structural benthos) – although the variance in observed abundances was high in most cases (fish assemablages and benthos classes).

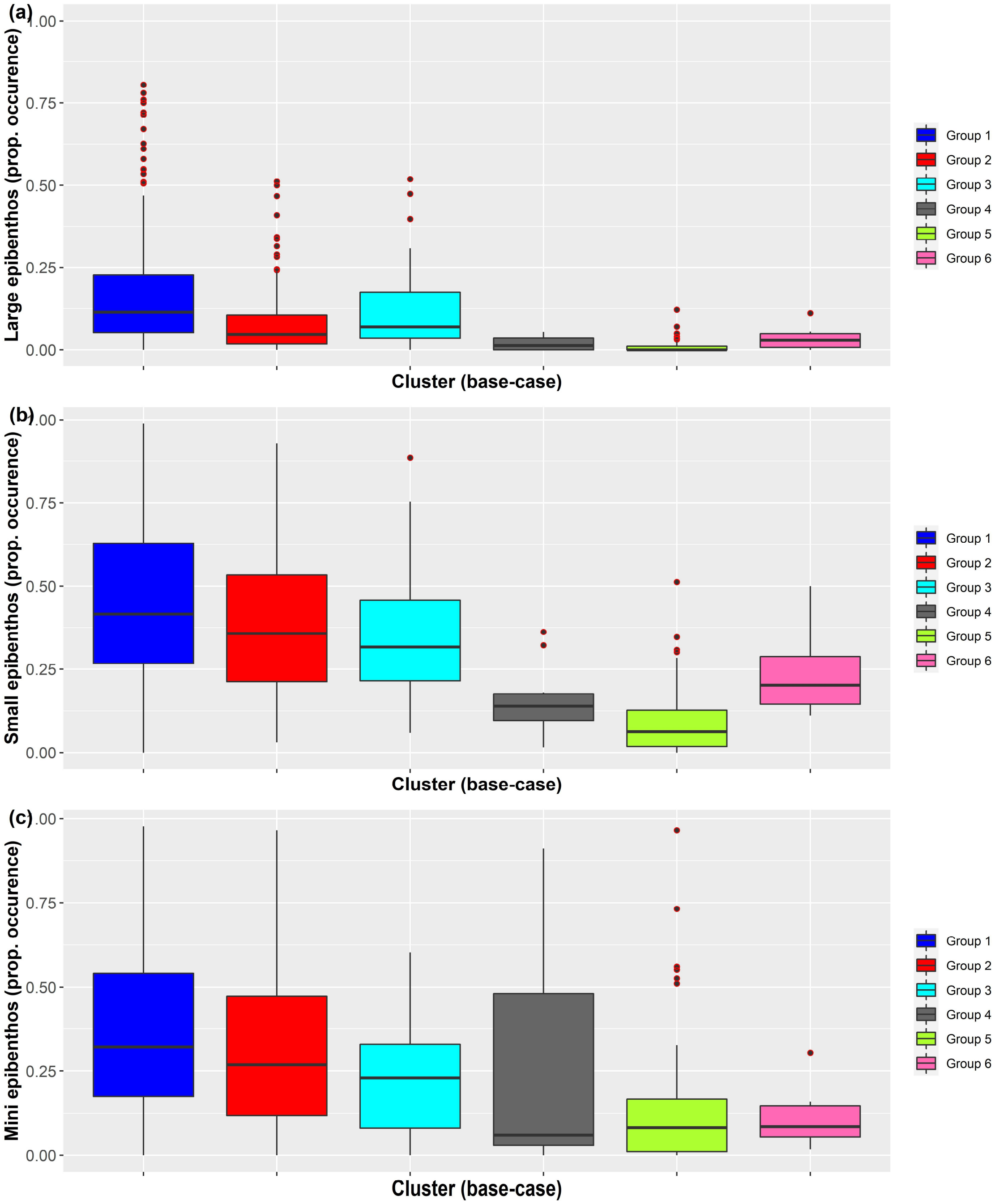


**Figure 173 Distribution of abundances of (a) large, (b) small and (c) mini benthos by trawl operation in the main groups identified in the base-case analysis of the fish communities (colours match the assemblages colours in Figure 169.**

## 6.3.2 Time series analysis

### Temporal changes in benthos abundance

Abundance of large benthos (% occurrence of images containing large benthos per trawl operation) increased in all of the five areas defined by fishery regulations — four areas in the Pilbara Fish Trawl Fishery (PFTF) Zone 2 plus the westernmost Barrow area (Figure 174). The increases in benthos were significant and greatest in PFTF Areas A1 and A2, least (non - significant and barely discernible) in the trawl closure PFTF Area 3, similarly small in PFTF Area 4, and somewhat intermediate (distinctly increasing but non-significant) in Barrow (Figure 174). These trends were not consistent with patterns of change in trawl effort — particularly in PFTF Area A1 where trawling effort remains relatively high and PFTF that is closed to trawling.

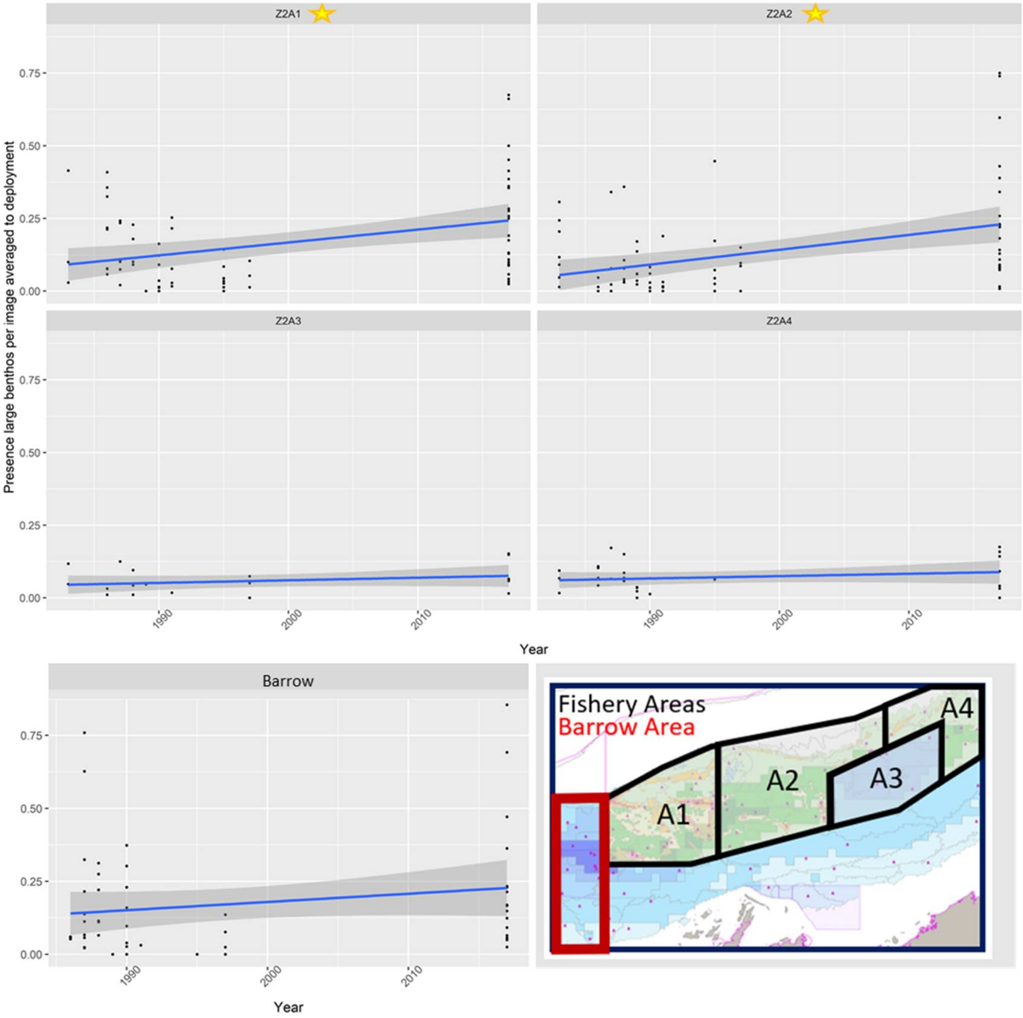


Figure 174 Time-series trend in abundance (percent occurrence in images per trawl operation) of large benthos in survey data for PFTF Zone 2 Areas 1 to 4 and in the Barrow area. Significance of linear regression indicated by star (gold star < 0.05; green star < 0.1; no star >0.1). Map inset shows the location of the areas as shown in Figure 163.

Abundance of large benthos also increased in all six trawl contrast (TC) areas defined solely by contrasts in historic and recent trawl effort (contrasts, TC Areas 3A, 3B, 2A, and non-contrasts TC Areas 1A, 2B, 3C) (Figure 175). The increases were significant in five of the six areas, and only non-significant in TC Area 1A which provided a non-contrast of very low historical and recent trawling in the shallowest part of the study area (Figure 174). The patterns in TC Areas mirrored those in PFTF Areas, but provided different insights because they were independenly defined. Thus, the surprisingly strong increase of benthos seen in PFTF Area 1 remained strongly evident (significant) in TC Area 3C even after zooming into the smaller sub-areas in which high historical and recent trawling is concentrated (Figure 175). There was also an increase in benthos in TC 3B, which contrasted high historical to moderate recent trawl effort across PFTF Areas 1, 2 and 4, but less significantly. The significant increase of benthos in TC 3A — a high-low contrast that drew data from both the PFTF A3 closure and Barrow Area — appeared to be inconsistent with the PFTF analysis, but was clearly driven by the increased benthos in Barrow. The TC areas that represented trawl effort contrast in relation to depth showed no change in benthos in TC 1A (shallowest area, unchanged low trawl effort), but significant increases in TC 2A (shallow area, high to low effort) and TC 2B (deep area of core fishery, with unchanged moderately low effort) (Figure 175).

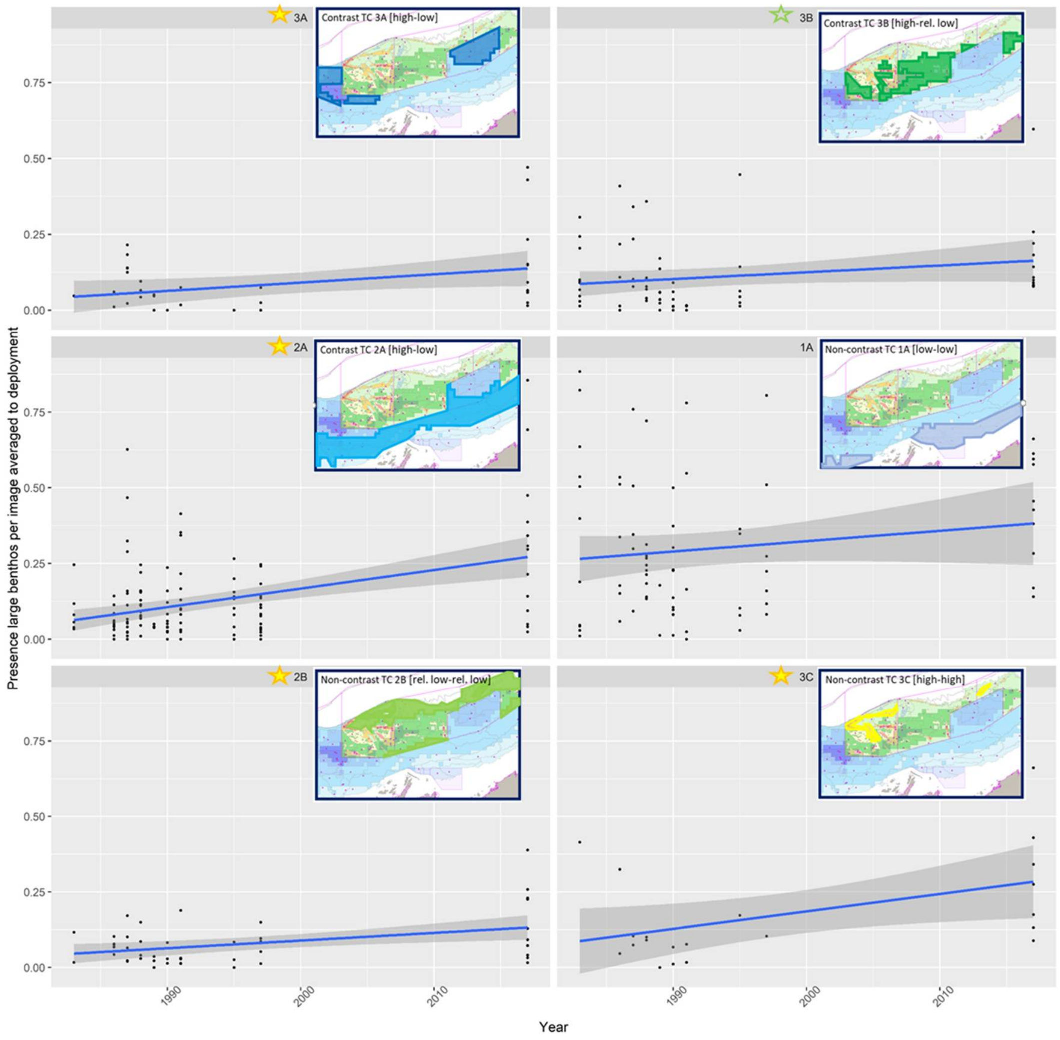


**Figure 175 Time-series trend in abundance (percent occurrence in images per trawl operation) of large benthos in survey data for six trawl contrasts. Significance of linear regression indicated by star (gold star < 0.05; green star < 0.1; no star >0.1). Map insets show the approximate location of the areas as shown in Figure 163.**

Examining the magnitude of change of benthos in addition to recovery trend showed there was a 'carrying capacity' signal in the data, i.e. a greater potential for benthos recovery in areas where there was most benthos pre-fishery, independently of trawl effort contrasts (Figure 176 & Figure 177). Thus, benthos abundances in the core fishery areas PFTF A1 and A2 were intermediate when surveyed during the 1980s fishery era (relative to PFTF Area 3 & 4 and Barrow), but showed relatively strong recovery which was also apparent in trawl contrast areas TC 3B and TC 3C. Benthos abundance in the non-core fishery area PFTF A3 closure and A4 Areas was considerably lower than others, indicating they had low structured habitat in the early era of the fishery, and relatively low potential for increase.

Carrying capacity also had a depth signal with less benthos as depth increases. This was visible in the TC areas with TC 1A (shallowest) > TC 2A (shallow) > TC 2B (deep). The lack of significant increase in the abundance of benthos in TC 1A was clearly due to it having a high abundance (greater than all other areas) and being least affected by trawling. Nonetheless, the modest increase may indicate a higher level of historical trawl impact than was captured in the trawl effort contrast. There is no corresponding signal from TC 1A in any PFTF Area because there is no overlap between them.

Overall, the observations were consistent with the hypotheses of widespread increase in benthos as the level and spatial extent of trawl effort declined (i.e. no area showed a decrease), and that pre-fishery benthos carrying capacity had influenced changes. Thus, the trends for benthos recovery did not simply follow the patterns of contrast in historical and recent trawling effort; large increases were observed in areas where trawl impact had declined (TC 2A, 3B) but also where there appeared to be a higher potential for benthos recovery — conspicuously in TC 3C where trawling remains relatively high, but is more concentrated in spatial extent.

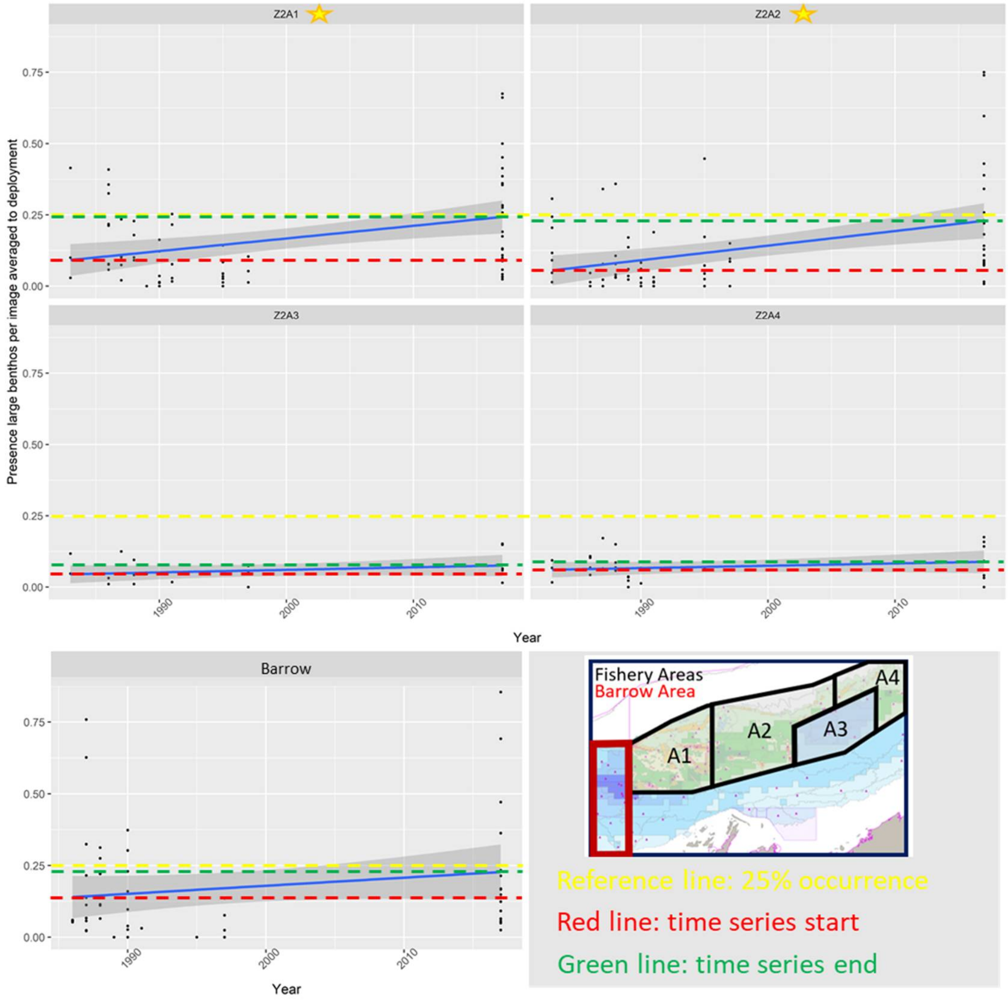


**Figure 176 Time-series trend in abundance (percent occurrence in images per trawl operation) of large benthos in survey data for PFTF Zone 2 Areas 1 to 4 and in the Barrow area, highlighting the series sta and end points aging the 25% reference line. Significance of linear regression indicated by star (gold star < 0.05; green star < 0.1; no star >0.1). Map inset shows the location of the areas as shown in Figure 163.**

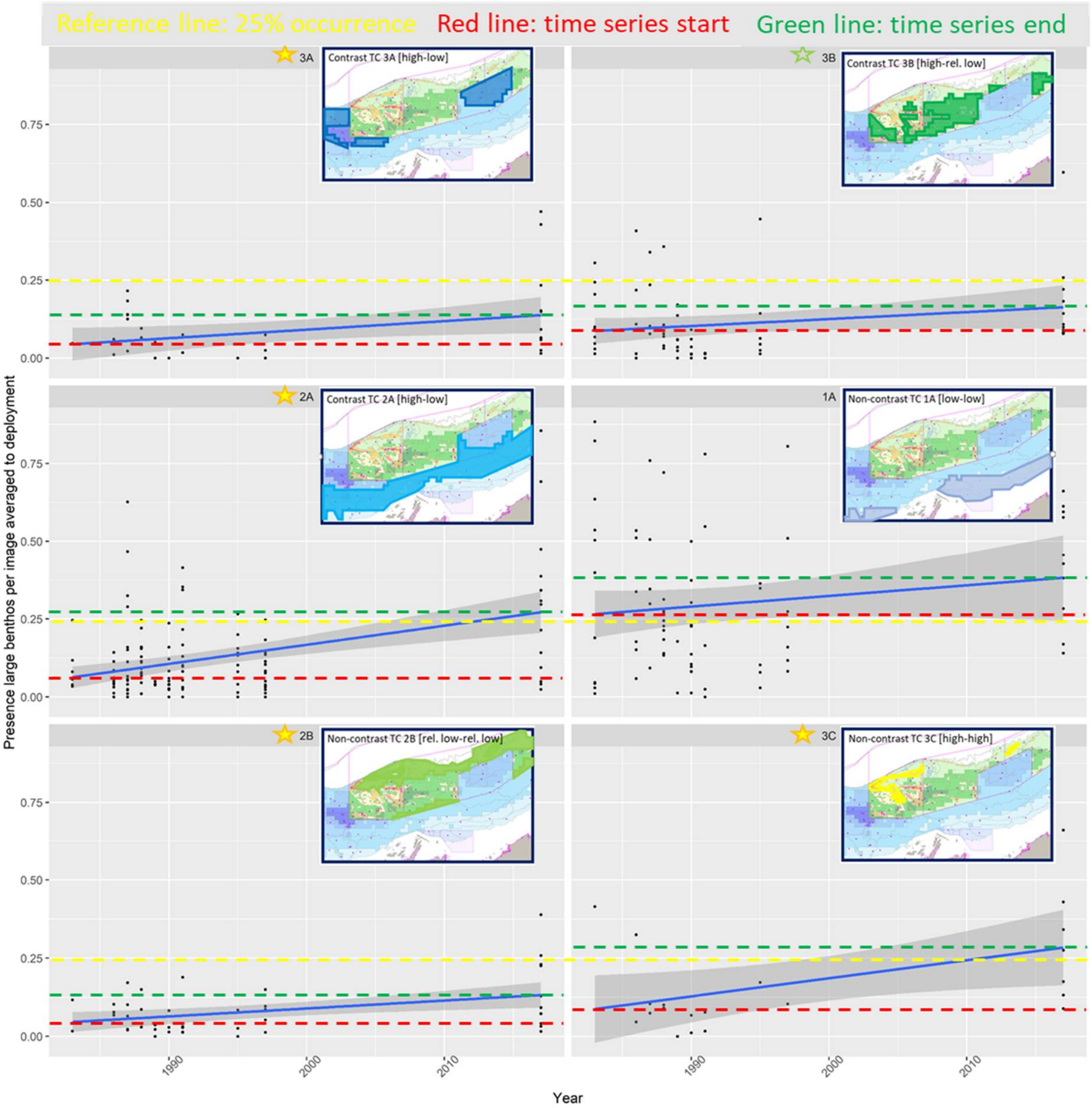


**Figure 177 Time-series trend in abundance (percent occurrence in images per trawl operation) of large benthos in survey data for six trawl contrasts, highlighting the series sta and end points aging the 25% reference line. Significance of linear regression indicated by star (gold star < 0.05; green star < 0.1; no star >0.1). Map insets show the approximate location of the areas as shown in Figure 163.**

## Temporal changes in fish biomass

Time-series plots of fish biomass (kg per 30 minute tow) and linear regression results are provided separately for each of the 11 analysis areas for (1) Key Genera (N= 4), (2) Informative species (N=27), and (3) inner/mid-shelf assemblages (N=2) in Appendix F.2. One example is provided here (Figure 178, Figure 179, Figure 180) for the first area (PFTF Area 1) and the results for all areas are summarised in Table 27.

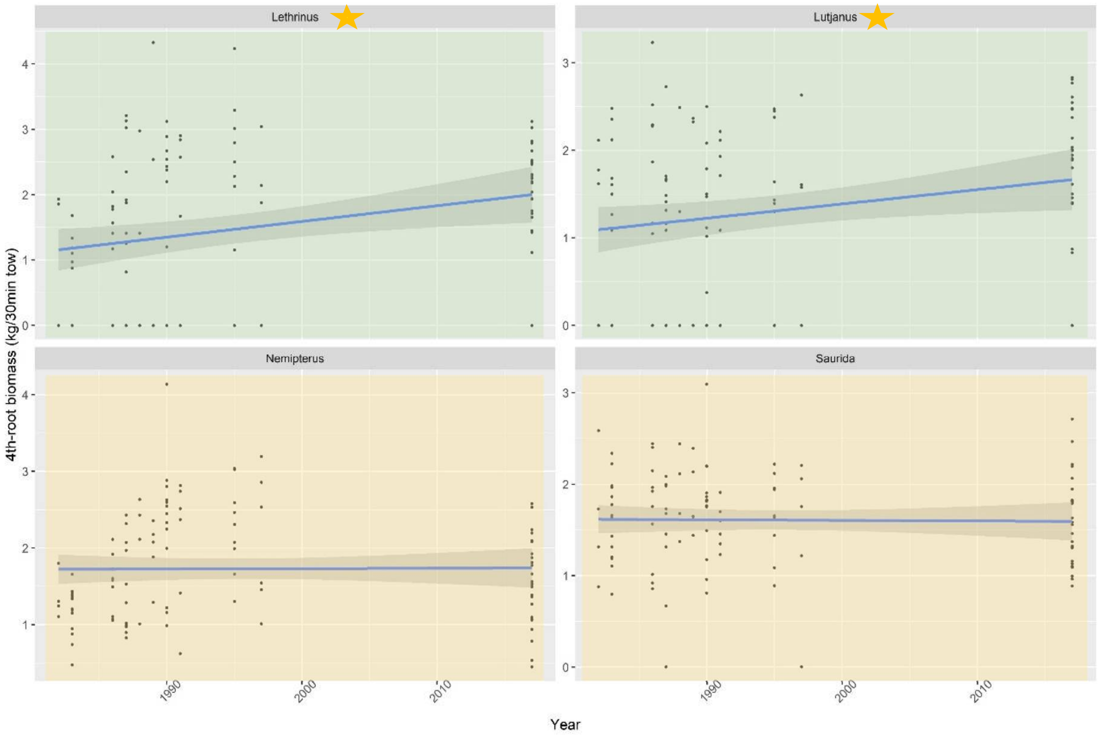


Figure 178 Time-series trend in biomass of the four Key Genera in survey data for PFTF Area 1. Significance of linear regression indicated by star (gold star < 0.05; green star < 0.1; no star >0.1); data = catch rate (kg per 30 min trawl tow, 4th root transformed).

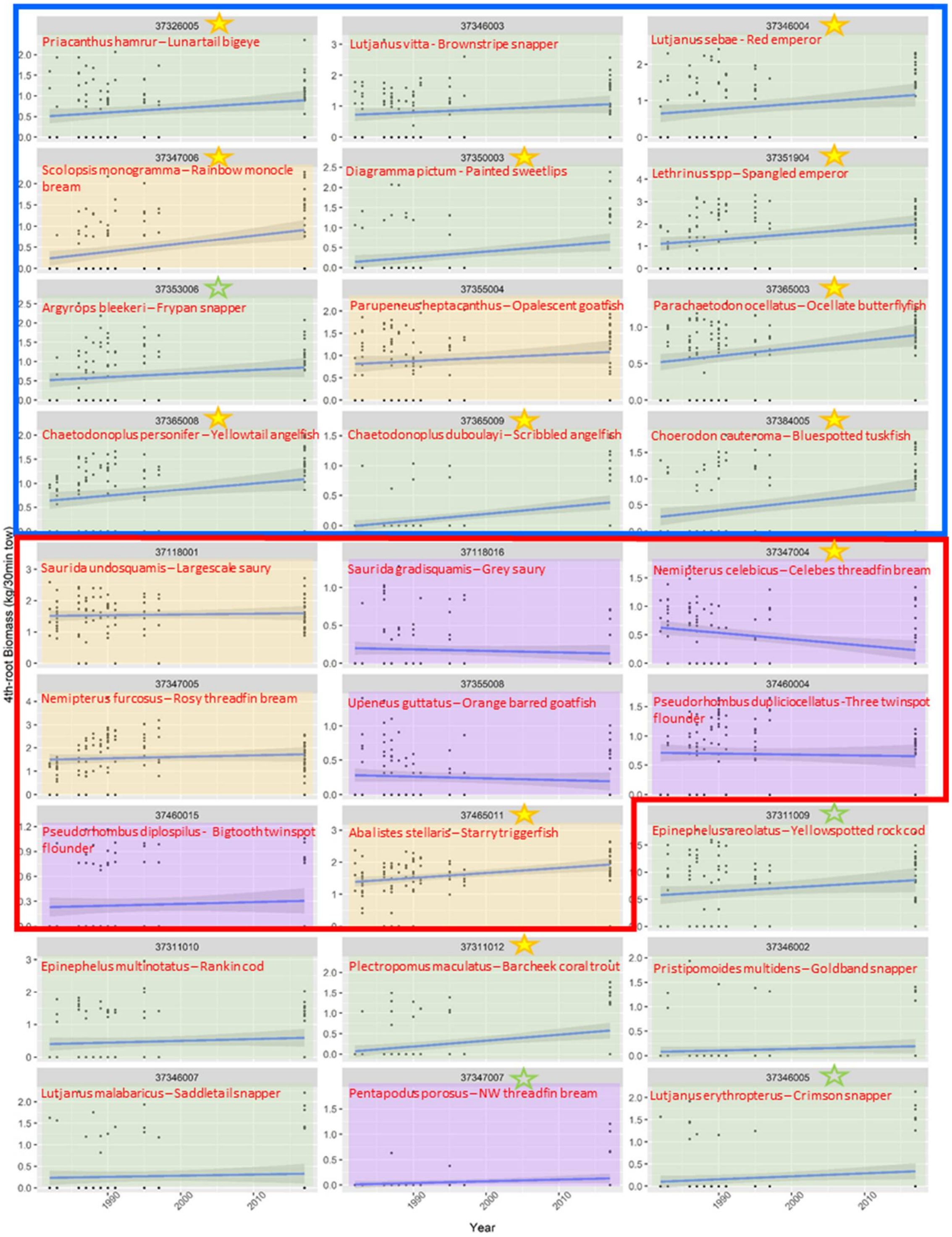


**Figure 179 Time-series trend in biomass of the 27 informative species in survey data for PFTF Area 1. Significance of linear regression indicated by star (gold star < 0.05; green star < 0.1; no star >0.1); data = catch rate (kg per 30 min trawl tow, 4th root transformed).**

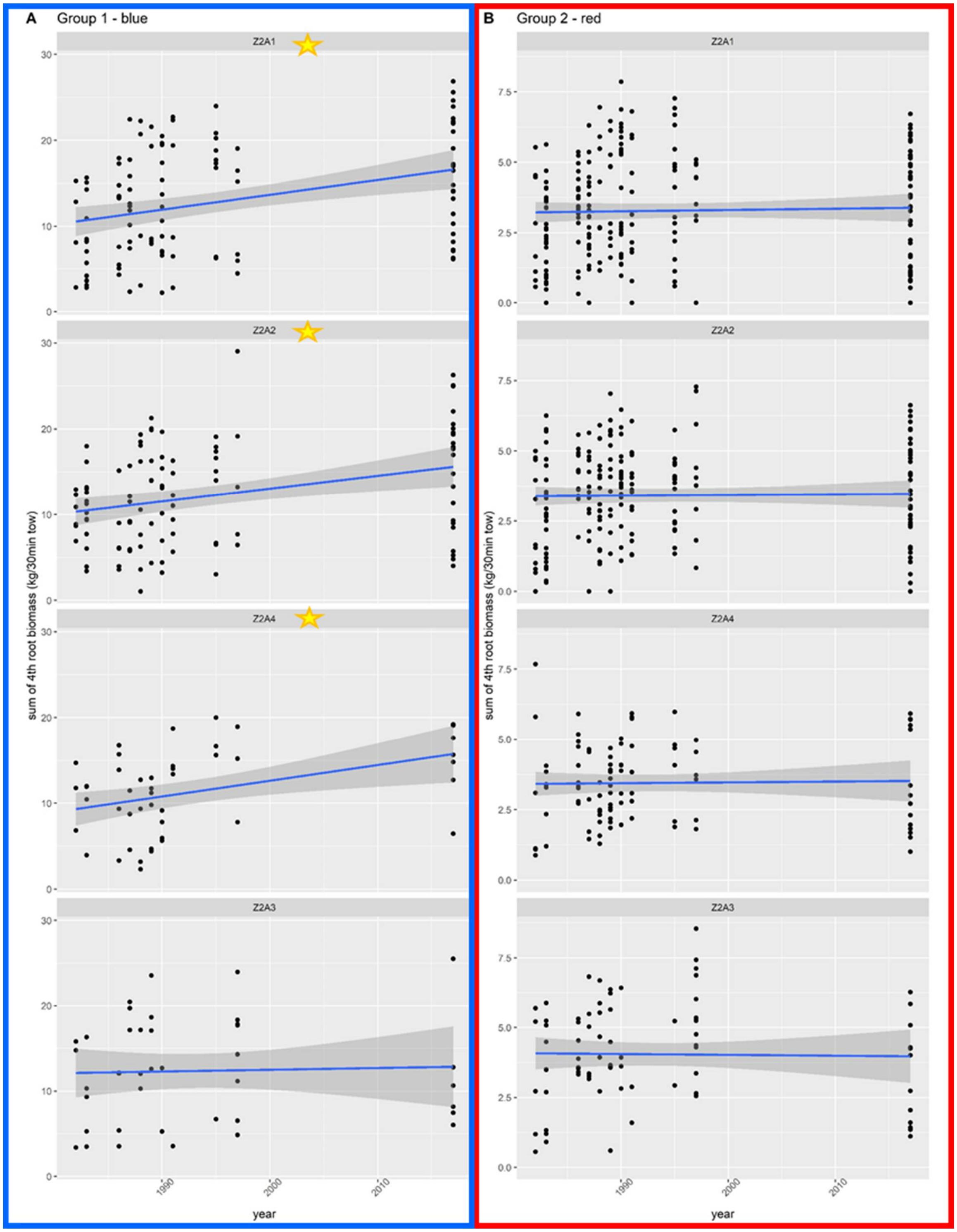


Figure 180 Time-series trend in biomass of the four Key Genera in survey data for PFTF Area 1. Significance of linear regression indicated by star (gold star < 0.05; green star < 0.1; no star >0.1); data = catch rate (kg per 30 min trawl tow, 4th root transformed).

**Table 27 Predicted and observed changes in biomass of fishes in 11 areas within the study area sampled by the 2017 survey. Changes in fish biomass were calculated for three units of analysis: key genera (N=4) (following Sainsbury, 1997), the primary inner/ mid-shelf assemblages identified on this tropical shelf (N=2), and three groups of fish Types defined in relation to their predicted changes in abundance (biomass) through time (N=27). Numbers in cells for fish types are species counts, with significance level shown in cell (**= p<0.05; *= p<0.1). Heat mapping indicates significant increases (green), significant decreases (pink) and non-significant changes (grey); significant heat mapping for fish Types reflects a response by the majority of species. Linear regression plots and results are collated in Appendix F.2.**

| | | | | **Pilbara Trawl Fishery (Zone 2) areas** | | | | **Selected** | **Trawl effort contrasts** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Code** | | **A1** | **A2** | **A3 (closure)** | **A4** | **Barrow** | **TC 3A** | **TC 3B** | **TC 2A** | **TC 1A** | **TC 2B** | **TC 3C** |
| | | **Contrast** | | **hi - hi** | **mod. - low** | **mod. - nil** | **mod. - low** | **high - low** | **high - low** | **high - mod. low** | **mod. low - low** | **low - low** | **mod. low - mod. low** | **high - high** |
| **Predicted overall response** | | **Relative change in biomass** | | Mostly non-significant increases, limited mainly to Type 2 & 3 species | Mixed significant/ non-significant increases; significant increases include Type 1 species | Significant increases, many species – including many Type 1 species | Significant increases, many species – including some Type 1 species | Significant increases, many species - including many Type 1 species | Significant increases, many species – including many Type 1 species | Mostly non-significant increases; significant increases include Type 1 species | Mostly non-significant increases; significant increases include Type 1 species | Mostly non-significant increases; significant increases include Type 1 species | Mostly non-significant increases; significant increases include Type 1 species | Mostly non-significant increases, limited mainly to Type 2 & 3 species |
| **Observed response** | **Unit of analysis** | **Fish group/ type** | **N** | | | | | | | | | | | |
| | **Key Genera** | *Lethrinus* | 1 | 🟩 ** | 🟩 ** | | 🟩 ** | 🟥 ** | | 🟩 ** | | | | |
| | | *Lutjanus* | 1 | 🟩 ** | 🟩 ** | | 🟩 ** | 🟥 ** | | 🟩 ** | | | | |
| | | *Nemipterus* | 1 | | 🟩 * | | | | | | | | | |
| | | *Saurida* | 1 | | | | | 🟩 ** | | | | | | 🟥 ** |
| | **Assemblage** | Habitat associated | 1 | 🟩 ** | 🟩 ** | | 🟩 ** | 🟥 ** | | 🟩 ** | | 🟩 * | 🟩 ** | |
| | | Not habitat associated | 1 | | | | | | | | | | | |
| | **Fish species** | Type 1 # increase | 16 | 🟩 16: 9**/ 3* | 🟩 16: 6**/ 6* | 6: 3** | 🟩 14: 4**/ 4* | 2 | 5: 3** | 🟩 16: 12**/ 2* | 4: 3** | 🟩 8: 3**/ 3* | 🟩 15: 3**/ 1* | 🟩 13: 4**/ 2* |
| | | Type 1 # decrease | | 0 | 0 | 5: 2**/ 1* | 1 | 🟥 12: 6**/ 2* | 5: 1** | 0 | 5: 1* | 3 | 1 | 1 |
| | | Type 2 # increase | 5 | 🟩 3: 2** | 🟩 4: 3** | 1: 1** | 🟩 4: 3** | 1: 1** | 1 | 🟩 4: 3**/1* | 1 | 2 | 🟩 4: 1**/ 2* | 🟩 4: 1** |
| | | Type 2 # decrease | | 0 | 1 | 1: 1* | 1 | 🟥 4: 2** | 3: 1* | 1 | 3 | 3 | 1 | 1: 1* |
| | | Type 3 # increase | 6 | 1: 1* | 2 | 2: 1** | 2: 1** | 2: 1** | 1: 1* | 2: 1* | 2: 1** | 3 | 4 | 3 |
| | | Type 3 # decrease | | 🟥 4: 1** | 2: 1** / 1* | 🟥 4: 1** | 2: 1** | 🟥 4: 1** | 🟥 3: 3** | 2: 1**/ 1* | 3 | 1 | 2: 1** | 2 |
| | | **Relative change in biomass** | | Increases in most species, many significant - including many Type 1 species | Increases in most species, many significant - including many Type 1 species | Mixed trajectories of increase and decrease; few significant | Increases in most species, many significant - including many Type 1 species | Decreases in most species, many significant - including Type 1 species | Mixed trajectories of increase and decrease; few significant | Increases in most species, many significant - including many Type 1 species | Mixed trajectories of increase and decrease; few significant | Mixed trajectories of increase and decrease; few significant | Increases in most species, many significant - including many Type 1 species | Increases in most species, many significant - including many Type 1 species |
| **Fit to prediction** | | | | Observed increases in biomass exceed prediction, but are consistent with strong benthos recovery | Observed increases in biomass exceed prediction, but are consistent with strong benthos recovery | Decreases in biomass where significant increases predicted; patterns inconsistent with some recovery of benthos | Significant observed increases in biomass match prediction, although limited recovery of benthos | Significant decreases in biomass where increases predicted, but consistent with negligable benthos recovery | Decreases in biomass where increases predicted; not explained by patterns of benthos abundance | Observed increases in biomass exceed prediction and are not well explained by modest benthos recovery | Predicted increases in biomass not observed, and benthos recovery higher than expected. | Mostly non-signficant increases in biomass match prediction, and consistent with modest benthos recovery. | Observed increases in biomass exceed prediction, but are consistent with significant benthos recovery | Observed increases in biomass exceed prediction, but are consistent with strong benthos recovery |

Patterns of biomass change in the five areas defined by fishery regulations — four areas in the Pilbara Fish Trawl Fishery (PFTF) Zone 2 plus the westernmost Barrow area — were mostly inconsistent or contrary to predictions based simply on changes in trawl effort alone (Table 27). The largest contrary observation was in Barrow where there was a general and strong decrease in fish biomass; this was significant in two of four genera, the habitat-associated assemblage, and Type 1, Type 2 and Type 3 species (Table 27). A total of 12 of 16 Type 1 species showed decreases, eight of which were significant — including the relatively abundant *L. sebae* and *Lethrinus* species complex. Significantly increased biomass was observed only in the genus *Saurida* (driven mostly by *S. undosquamis*) and one flounder species (*P. dupliciocellatus*) – species characterising the assemblage without association to structured benthic habitat. Barrow was the only area of the eleven analysed to show an overall pattern of decreased biomass. This is particularly notable because the Barrow area represents a strong contrast from high to low trawl effort — low since 1987 then closed from 1993 (as also reflected by TC Area 4A in the trawl contrast design) — and now contains the Monte Bello Marine Park. The result was not explained by taking patterns of benthos change into account because there was a modest (non-significant) increase in benthos abundance in this area (Figure 174) and relatively high abundance compared to PFTF Areas 3 and 4 (Figure 176).

Patterns in PFTF Area A3 — an area closed to trawling for ~20 years — were also contrary to the prediction of significantly increased biomass across many species, particularly those associated with structured benthic habitat (Type 1 species) (Table 27). Significant increases were seen in five individual species but in only one (*A. bleekeri*) characteristic of the habitat-associated assemblage. Otherwise, there were increases for *P. multidens* and *L. malabaricus*, but flat or negative trajectories for other Type 1 species including the *Lethrinus* species complex. There were no significant signals of increase at fish group level (genus or assemblage), a mix of mostly non-significant trajectories across species Types, and an overall decrease in Type 3 species. This is particularly notable because PFTF Area 3 has been managed as a long-term trawl closure within the PFTF Zone 2. The results are, however, consistent with the change of benthos in PFTF Area 3 where the smallest change (non -significant and barely discernible increase) was observed (Figure 174) and abundance was relatively low compared to all other areas except PFTF Area 4 (Figure 176).

Increases in fish biomass in PFTF Areas A1 and A2 — both areas where trawling remains widespread, and in PFTF A1 where recent effort remains high relative to other areas — had strong increases in biomass which exceeded predictions (Table 27). Three of the four key genera (*Lethrinus*, *Lutjanus* and *Nemipterus*), the habitat-associated assemblage, and many Type 1 and Type 2 species, showed strong increases where only small increases were predicted. Changes in biomasses of some relatively highly abundant individual species influenced the patterns seen at genus and assemblage level — most notably the *Lethrinus* species complex which has a considerably larger raw biomass than any other species. Notwithstanding, these significant trends were evident for key genera and assemblages even when data were 4th-root transformed to de-emphasise the influence of such species. The larger than expected increases are, however, consistent with the degree of benthos recovery which was significant in both areas (Figure 174). The magnitude of increase in PFTF Area A1 (Figure 176), where trawling remains relatively high, indicated its relatively high potential for recovery (the carrying capacity effect), and that whilst trawling remains relatively high, its intensity and spatial extent had contracted over the time period analysed.

Patterns of biomass increase in PFTF Area A4 were more consistent with the prediction of modest increases based on this area's low contrast in trawling history (consistent and relatively low exposure historically and recently), but still somewhat stronger (Table 27). The trajectories of biomass increase mirrored those in PFTF Area 1 and were identical to those in PFTF Area A2 across virtually all species, assemblages and key genera. Interestingly, however, these increases did not match the patterns of benthos abundance which were characterised by a negliable increase (Figure 174), and low level relative to other areas (Figure 176).

Six trawl contrast (TC) areas defined solely by contrasts in historic and recent trawl effort, which were defined independently of PFTF zoning, provided alternative spatial units in which to examine trends in biomass. Three each provided contrasts (TC Areas 3A, 3B, 2A) and non-contrasts (TC Areas 1A, 2B, 3C) (Figure 163).

Among the contrasts, patterns observed in TC Area 3A — the largest contrast of historically high to recent low trawl effort — were contrary to the prediction based on trawl effort contrast alone (Table 27). Rather than significant increases in biomass in many species, including the Type 1 habitat associated species, there were no significant signals of increase at fish group level (genus or assemblage), a mix of mostly non-significant trajectories across species Types, and an overall decrease in Type 3 species. The majority of the data for contrast TC Area 3A were drawn from Barrow and PFTF Area 3 closure and therefore provide another reflection of the biomass decreases identified in both areas — but here the result is more explicitly linked to a quantitative contrast in trawling. The result is therefore consistent with the patterns of benthos abundance in the PFTF Area 3A closure where there was a relatively low level and change was indiscernible, but not consistent with Barrow where there was a modest (non-significant) increase to a relatively high level (Figure 174 and Figure 176).

In TC Area 3B — a contrast of high to moderately low trawl effort across most of the fishery area — the changes observed were more consistent with the predicted trajectory, but markedly stronger (Table 27). Notably, biomass increased in all 16 Type 1 species, and four of the five Type 2 species; 18 of these 20 increases were significant. Accordingly, biomass also increased significantly in the key genera *Lethrinus* and *Lutjanus*, and the habitat-associated assemblage. This result is, however, entirely consistent with the increased biomass observed in PFTF Areas 1, 2 and 4 — from where the TC Area 3B data are drawn, and consistent with the relatively high recovery of benthos in PFTF Areas 1 and 2 (Figure 175). Benthos recovery was, however, only weakly significant and benthos abundance relatively low in the sub-areas defined by the TC 3B contrast (Figure 175 and Figure 177). The importance of contrast area TC 3B is that it emphasises the high to moderately low contrast in trawling *within* those larger fishery areas. In other words, contrast TC Area 3B magnifies the strong effects of benthic habitat recovery. The positive response by fish communities — including all Type 1 species with an association to structured benthic habitat — is stronger in these sub-areas than in any other part of the study area.

Contrast Area TC 2A lies shoreward of the PFTF managed zone in relatively shallow water and has historically supported a trap fishery. Its low exposure to trawling is reflected here by a moderately low to low trawling contrast. Small increases in biomass were predicted, and individual species did show a mix of trajectories of increased and decreased biomasses (Table 27). However, few were significant, and while increases outnumbered decreases they were from minor species. Accordingly, changes at assemblage and genus level were non-significant. This result was not consistent with the observation of a significant increase in benthos abundance to a relatively high level in TC 2A (Figure 175 and Figure 177). These observations are inconsistent with the predicted increase in fish biomass and perhaps reflect both the ongoing selective removal of Type 1 species by the trap fishery and a higher level of historical trawl impact than was captured in the trawl effort contrast.

Among the non-contrasting areas, negligible to small changes in biomass were predicted in TC Area 1A because it represented a non-contrast of very low historical and recent trawling in the shallowest areas of the study area. Observations were generally consistent with this, with a mix of trajectories that including several increases in Type 1 species some of which were significant (Table 27). This is generally consistent with the modest (distinct but non-significant) increase in benthos abundance to what is the highest level of all areas (Figure 175 and Figure 177).

The non-contrast TC Area 2B represented an unchanged level of moderately low trawl effort in the deepest part of the study area, mostly seaward of the primary trawling grounds. While only small biomass increases were predicted here (likely due to an overall regional-scale reduction in fishing mortality), the biomass of the habitat-associated assemblage increased significantly (Table 27). This was based on increases in the great majority of Type 1 species, albeit with few significant increases of individual species. On this basis, the observation was not consistent with the prediction based on trawl effort contrast, but was consistent with the significant recovery of benthos, albeit to a relatively low abundance compared to shallower areas of the fishery (Figure 175 and Figure 177).

The TC Area 3C, which provided a non-contrast of high historical and high recent trawling effort, was made up by several small sub-areas embedded mostly in the most heavily trawled PFTF Area A1. It therefore represented a fine spatial-scale focus on the most heavily and consistently trawled parts of the study area. On this basis, the prediction was for only small increases in biomass limited mainly to Type 2 and Type 3 species. Observation of increased biomass in many (13/16) Type 1 species, six of which were significant, were somewhat inconsistent with the prediction based soley on trawl effort contrast (Table 27) — although increases were mainly minor (non-commercial) species with the exception of *P. maculatus.* This inconsistency may be explained by changes in benthos abundance characterised by a significant increase to a level that was relatively high compared to other core fishery areas, and exceeded only by the shallow inshore areas TC 1A and 2A (Figure 175 and Figure 177).

## 6.4 Discussion

### 6.4.1 Assemblage structure

A process of species reduction successfully identified sub-sets of species to analyse for assemblage structure from the total of 553 species in the T2/T3 surveys: 254 species based on ranked biomass (base-case) and 188 when occurrence was added. These reductions had the effect of reducing noise from species that contributed only small proportions of total biomass and were uncommonly caught, and produced highly consistent assemblage patterns on the regional continental shelf. Structure was strongly dominated by depth, and there was no evidence of longitudinal pattern at this scale. Two inner/mid-shelf assemblages in ~25–100 m depths were prominent; their strongly mixed spatial distributions across individual samples indicated strong differentiation in species composition, but without any broad spatial sub-structure, i.e. association with a mosaic of habitat types. Two other assemblages were associated with a prominent paleocoastline at ~100 m—a depth band of steep seabed composed of rocky substratum with relatively abundant megabenthos (compared to the adjacent shallow and deep shelf). A single stable deep shelf assemblage occurred in ~100-150 m depths, and two less stable shelf-edge assemblages occurred in > ~150 m. Their instability stemmed from being represented by relatively few samples from a steep and narrow area of seabed at the boundary between continental shelf and slope biomes.

Informative species having the greatest influence on assemblage structure were mostly abundant species that both typified one or other group and contributed strongly to distinguishing groups.

An analysis of benthos co-occurring with fish assemblages (based on imagery from a camera on the trawl headline) showed there was high variance in observed benthos abundances among fish assemablages and benthos classes, but evidence of a general depth effect. Thus, the inner/ mid-shelf fish assemblages were associated with higher levels of benthos than deeper assemblages, and generally, benthos abundance declined as the depth of fish assemblages increased. In relation to the time-series analysis, it was noteworthy that higher levels of benthos were observed at locations (trawl operations) where the assemblage associated to structural benthos was dominant and lower levels of benthos where the assemblage not associated to structural benthos was dominant.

### 6.4.2 Time series

Significant changes in the abundance of large benthos and the population biomass of demersal fishes occurred in the study area between 1985 and 2017 as total trawl effort declined and the spatial extent of trawling contracted. An increased abundance of large benthos observed in most areas substantiated the hypothesis that widespread increase (recovery) of benthos would follow the decline in bottom trawling (see also Chapter 5).

Increases and decreases in fish biomass were observed across the sub-areas analysed — in key genera, the two primary inner/mid-shelf assemblages, and many individual informative species—and, overall, there were more significant increases than decreases (Table 27). These results indicate there had been a regional-scale increase in the aggregate fishery stock since trawling declined from its peak in the mid-1970s—an observation consistent with an overall reduction in fishing mortality. Most significant increases were observed in species with association to structured benthic habitat. These species drove the significant positive responses observed in several areas (core fishery areas PFTF Areas A1, A2 and non-core area A4) and trawl contrast areas (TC 3B, 2B, 3C), including at genus and assemblage-levels (Table 27). These results provided support for the hypothesis that biomass of benthic habitat-associated fishes had increased as a positive response to recovery of habitat provided by structural benthos—a signal that was evident despite noise from other likely drivers of changes in biomass that were unmeasured (reduced fishing mortality) or unknown (e.g. inter- and intra-specific effects such as predation and competition).

But, despite the prominence of increased biomass among fishes with associations to structural benthic habitat, a striking feature of the results was that several positive and negative responses of fishes to benthos recovery did not correspond to predictions of change based simply on trawling history. We hypothesised that changes in fish biomass would generally mirror the contrast in trawl effort, with the largest increases in biomass co-located with the largest decreases in trawling. However, significant biomass increases occurred in the core fishery areas PFTF Areas 1 and 2 (and to a lesser extent within trawl contrasts TC Areas 3B and 3C) where recent trawling remains relatively high, while no significant increases were observed in the PFT Area 3 trawl closure. In addition, there was a significantly decreased fish biomass in Barrow where trawling had declined from high to zero. These findings appear to be mainly explained by greater than expected increases of benthos in some areas where contrasts between historical and recent trawl effort are relatively low, including where trawling remains high. Thus, there were correspondingly significant increases of benthos in PFTF Areas 1 and 2 where significant increases in fish biomass were not predicted, but a barely discernible increased benthos abundance in the PFT Area 3 closure where there was little change in fish biomass despite a significant increase being predicted. The effects of benthos increases in PFTF Areas 1 and 2 can be further understood by examining the TC areas that lay within them. Thus, zooming to where trawl exposure remains high (TC 3C) shows that benthos recovery was significant and reached a high abundance relative to all other areas except the shallow inshore area TC 1A. Zooming into where trawl contrast is high to low (TC 3B) also showed recovery, albeit weakly significant and to a lower abundance.

These results provided support for the hypothesis that the magnitude of the signals—increased fish biomass and recovery of benthos—were influenced by the pre-fishery benthos carrying capacity, i.e. greater increases occurred in areas with higher potential to recover. It appears that trawling has preferentially targeted the same areas of the fishery throughout its history, i.e. continued to use what have proven to be the best trawling grounds, and that these areas are characterised by relatively high levels of structural benthic habitat that experienced relatively high impact but have had relatively high recovery of benthos. In turn, this has led to a greater than expected increase in the biomass of fishes associated with habitats with elements of hard seabed structure.

This explanation is mirrored to a lesser extent in PFTF Area 2 (and therefore TC 3B), and is also corroborated by the lack of significant increase of fish biomass in the PFTF Area 3 closure. It appears the closure was located where benthos abundance was relatively very low early in the fishery and had little potential for recovery, perhaps because the area had relatively little value for the trawl fishery.

The observations in Barrow are unexplained: this area has a high to low trawl contrast and some recovery of benthos (albeit non-significant) but was the only area that showed a decline in fish biomass. The decline was significant in all groups with the exception of *Saurida* — which showed a significant increased biomass.

## 6.5 Conclusions

Data from 17 historical research surveys on the North West Shelf were thoroughly evaluated and processed to generate a quality-assured data set that was used to:

1. determine regional-scale patterns in fish assemblage structure in the entire survey area — the “regional” analysis (Objective 1)
2. identify changes in fish assemblage structure in the sub-regional study area surveyed in 2017 based on a time-series analysis of historical survey data — the “time-series analysis” (Objective 2)

The regional analysis used data from a sub-set of eight historical research surveys with standard sampling characteristics undertaken between 1986 and 1997. The surveys were made during a relative lull in trawling effort between 1986 and 1991 when the extent and intensity of foreign trawling rapidly declined and then concluded and as the domestic trawl fishery commenced and its footprint expanded and then stabilised, but before fishery spatial management zoning was introduced. These data provide a “time-integrated” regional-scale description of the continental shelf fish assemblages that smoothed the temporal effects of annually variable trawl effort intensity and distribution, and environment variation.

The time-series (by year) analysis used data from three additional survey years (1982, 1983, and 2017), but was limited to the sub-regional study area surveyed in 2017. The surveys in 1982 and 1983 occurred when foreign trawl activity was intense and widespread in the region but concentrated in the sub-regional survey area. The analysis examined changes in the composition and distribution of inner/ mid- shelf fish assemblages identified by the ‘time-integrated’ regional analysis.

Fish assemblages were strongly structured by depth, and there was no evidence of longitudinal pattern at sub-regional scale. Informative species (mostly with high relative abundance) were identified for the purpose of characterising assemblage composition. Two inner/mid-shelf assemblages in ~25-100 m depths were prominent, and strongly differentiated by species-habitat associations — to either structured benthic habitat (genera *Lethrinus* and *Lutjanus*) or unstructured habitat (genera *Nemipterus* and *Saurida,* and *Abalistes stellatus*). These assemblages had no broad spatial sub-structure, but were highly mixed at the scale of individual trawl samples, indicating association with a mosaic of habitats existing at fine spatial scales. Two other assemblages were associated with a prominent steep rocky paleocoastline at ~100 m depth, and a single stable deep-shelf assemblage occurred beyond the paleocoastline in ~100-150 m. In greater depths (> ~150 m), two less-stable assemblages were classified within relatively few samples from the steep and narrow continental shelf edge.

For time-series analysis, the 2017 survey area was segmented into five fishery management areas of the Pilbara Fish Trawl Fishery (PFTF) and six areas characterised by a variety of contrasts between historical and recent trawl effort (Chapter 4). This enabled signals of benthos recovery and changes in fish biomass to be interpreted in relation to trawling history, the patterns to be compared between areas, and signals of change corroborated.

Signals of change in fish biomass – particularly species with associations to structured benthic habitats — were detected against a background of considerable noise stemming from unmeasured and unknown environmental and ecological effects. Widespread significant increases in fish biomass were consistent with an overall reduction in fishing mortality, but the prominence of species with associations to structured benthic habitat provided support for the hypothesis that biomass increases were a positive response to benthos recovery. This was corroborated by a general increase in the abundance of large benthos consistent with a decreased impact from bottom trawling as the intensity and spatial extent of trawl effort declined over the period of analysis (1983 to 2017) (and see Chapter 5).

Several within-area changes in fish biomass did not, however, correspond to predictions of trend based on trawling history — these included a significant biomass increase in the core fishery PFTF Area 1 where trawling remains relatively high, and, conversely, no significant increase in the PFFT Area 3 trawl closure—where benthos appeared to have remained consistently low, or have declined (see Chapter 2). Areas where changes in fish biomass were inconsistent with predictions corresponded to areas where there were also unforeseen changes in abundance of large benthos—with co-located large increases in fish and benthos apparently reflecting areas with a higher pre-fishery carrying capacity and greater-than-expected recovery potential. A notable example was the aggregated sub-areas of PFTF Area 1 where high trawling effort had been consistently located throughout the duration of the fishery (trawl contrast area TC 3C). These aggregated areas appear to be the locations of the region's best trawling grounds, and therefore our data suggest they are characterised by habitats with elements of hard seabed structure, and that their relatively high potential for benthos recovery supported a greater than predicted increase in the biomass of structured habitat-associated fishes.

In contrast, the low biomass of habitat-associated fishes and lack of significant increase of fish biomass in the PFTF Area 3 closure correlate with a low carrying capacity (low benthos abundance and low potential for recovery), perhaps indicating the trawl closure was located where there was relatively little value for the fishery. Our findings differ somewhat from those of Langlois et al. (2021) whose 2010 study using baited remote underwater video found evidence of higher biomass and/or abundance of some target fish species including *Lutjanus sebae* and *Epinephelus multinotatus* in PFTF Area 3 as compared to other PFTF areas. The reasons for these differences warrant further examination of fish habitat dynamics in PFTF Area 3 but are most likely to reflect differences in time frames, methodology, scale of observations and how habitat varied at the sites were selected for sampling in the two studies. It is possible the Langlois et al. (2021) sampled sites with greater hard structure/more rugged seabed that could be trawled across in our study and there for the differences in findings might simply reflect the known relationship between complex three-dimensional seabed structure and abundance of the fish species. Langlois et al. (2021) compare biomass/abundance *between* areas at one point in time (2010). Our study examines trends *within* areas over a much longer period (1983 to 2017).

Our findings are interpreted as an indication that this area did not have historically high levels of benthic filter feeder habitat relative to other areas and despite the closure and thus, its capacity to recover from trawling was not as great as other areas. Langlois et al. (2021) found only subtle changes in benthic filter feeder benthos and given the differences in methodology (our 2 km x 20 m trawl swath camera survey and trawl fish catch versus their fixed site, baited remote camera survey seven years earlier), the conclusions/interpretations about seabed benthos between the two studies can be regarded as being largely consistent.

The significant decline in biomass in all fish groups (with the exception of *Saurida*) in the Barrow area—the only area showing decline—is unexplained. Sites surveyed in 2017 showed a much lower abundance of filter feeder and structured habitat than previous time periods (Chapter 2). The decline in fish biomass may be linked to limited recovery of benthos, (although there is limited evidence that this was ever an area of very high benthic filter feeder abundance) despite having a ‘high to low’ trawl contrast and being largely within the Montebello Marine Park which has been closed since 1993. There appears to be an unmeasured driver of change in that has not affected adjacent areas to the east.

One factor not considered in our study is any system wide effect of the aggregating influence of oil and gas infrastructure, in particular pipelines, (Bond et al. 2018; McLean et al. 2020). McLean et al. (2021) also found that targetted commercial fish species were more abundant near pipelines than in areas of naturally occurring filter feeder habitat. We are only aware of anecdontal reports of trap fishers targetting oil and gas pipelines on the NWS but targetted trapping of fish along such artificial structures is well known in other parts of the world (e.g. Rouse et al. 2018).

Comparisons with the results of the earlier adaptive management experiment (Sainsbury 1991) and the current long-term study are consistent. The intentions of the adaptive management experiment (Sainsbury 1991) were to examine the recovery of the seabed habitats and rebuild fish stocks. The short-term review of the experiment confirmed both of these improvements (Sainsbury et al. 1997) but could not determine the longer-term effects. The 2017 survey has confirmed and refined the extent of the seabed recovery, and it has confirmed and refined stock rebuilding.

# 7 North West Shelf Ecosystem Trophodynamics Model

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## 7.1 Introduction

The waters of the North West Shelf (NWS) of Australia have been fished since 1950s by national and foreign trawlers (Japanese, Taiwanese, Russian fleets; Branford, 1984). In mid 1970s, the trawling and demersal fisheries reached a peak that resulted in the establishment in 1979 of the 200 nautical mile Australian Fishing Zone (AFZ) to regulate foreign fleet activities beyond 12 nautical miles (Sainsbury, 1987). A substantial decline in CPUE in the Taiwanese trawling fleet in 1985s suggested that the declining catch could be explained by a decreasing abundance of the benthic fish communities of the region (Branford, 1984). Fishing pressure increased from 1984 as domestic trap and trawl fleets activities were established. To protect these species, in 1988 the Australian government restricted areas in the NWS that were accessible to foreign fleets (Jernakoff and Sainsbury, 1990). Foreign vessels have not trawled on the region since 1989 and the current Australian fishery is operated over a much smaller area with a fewer vessels with modest landings. For example, in 2015 they caught 1,779 tonnes.

To get a better understanding of the direct impacts of trawling on sea floor organism (e.g. sea sponges and sea fans) and demersal target finfish groups (e.g. serranids, lutjanids, lethrinids), a series of comprehensives trawl surveys and stock assessments were conducted by CSIRO from 1978 to 1991. Foreign trawling caused extensive impact on benthic and fish communities (Jernakoff and Sainsbury, 1990). For example, the lethrinids, lutjanids and serranids were quite depleted by 1986 and the species composition of the catches changed significantly from the early 1970s (Jernakoff and Sainsbury, 1990). These changes suggested that the NWS system was not in equilibrium and important changes of demersal communities (invertebrates and finfishes) resulted by trawling before 1988.  After 1990s, it was assumed that the NWS system reached a point of the least rate of change where fishing continuing at the relatively low 1987 rates (Bulman, 2006).

To understand the recovery of the NWS, a scientific expedition conducted in late 2017 by CSIRO investigated the species composition, size and biomass of fish in the region; also the sea bed habitats (including types and abundance of organisms living in the sea floor) were quantify during the re-survey of the NWS. In this study, we used this biological information to gain knowledge of how these communities are organized in food webs and key aspects of ecosystem functions and other trophic process are still far from comprehensive. We developed an Ecosystem model of the NWS (using Ecopath with Ecosim software) to quantify: (1) ecosystem attributes and trophic structures; (2) ecological role of sea floor organism (e.g. sea sponges and sea fans), top predators and keystone species; and (3) we used model scenarios to evaluate impacts of trawling.

## 7.2 Objectives

1. Evaluate how food webs and the fisheries they support are likely to be influenced by trawling in the NWS.

2. Investigate how changes in abundance of key benthic species (e.g. marine sponges, corals) are likely to influence other species.

3. Identify useful indicators of ecosystem response to changes in the environment and management systems.

## 7.3 Methods

### 7.3.1 Study area

The North West Shelf (NWS) model area is situated between 18 and 21°S on the northwest coast of Australia (Figure 181), and covers a total area of about 46,770 square km. The model domain includes the Pilbara offshore bioregion and the southern-most part of the North West Shelf bioregion (IMCRA Technical Group, 1998). The NWS region is characterized by a very dynamic oceanography subject to several tropical cyclones every year, seasonal monsoons, a large tide regimen and interannual variability from El Nino and La Nina events (Condie et al., 2003). The contour depth range included in the model was between 20-100m, and species considered included demersal fishes and habitat-forming invertebrates.

### 7.3.2 Ecopath with Ecosim (EwE)

The structure of the EwE model is largely subjective, and it was tailored to satisfy specific requirements of the investigation in this study. The NWS model contains 73 functional groups, including two non-living groups such as dissolved organic matter (DOM) and organic detritus (Table 28). A number of functional groups were defined for species of significance to commercial or recreational fishing fishers (e.g. Lethrinidae, Carangidae, and Lutjanidae). The model also represents sharks, rays, sea snakes, turtles, commercial and non-commercial invertebrates and plants. See section below for more details of the functional groups, mortalities and fisheries data (gear types and landings) included in the model.

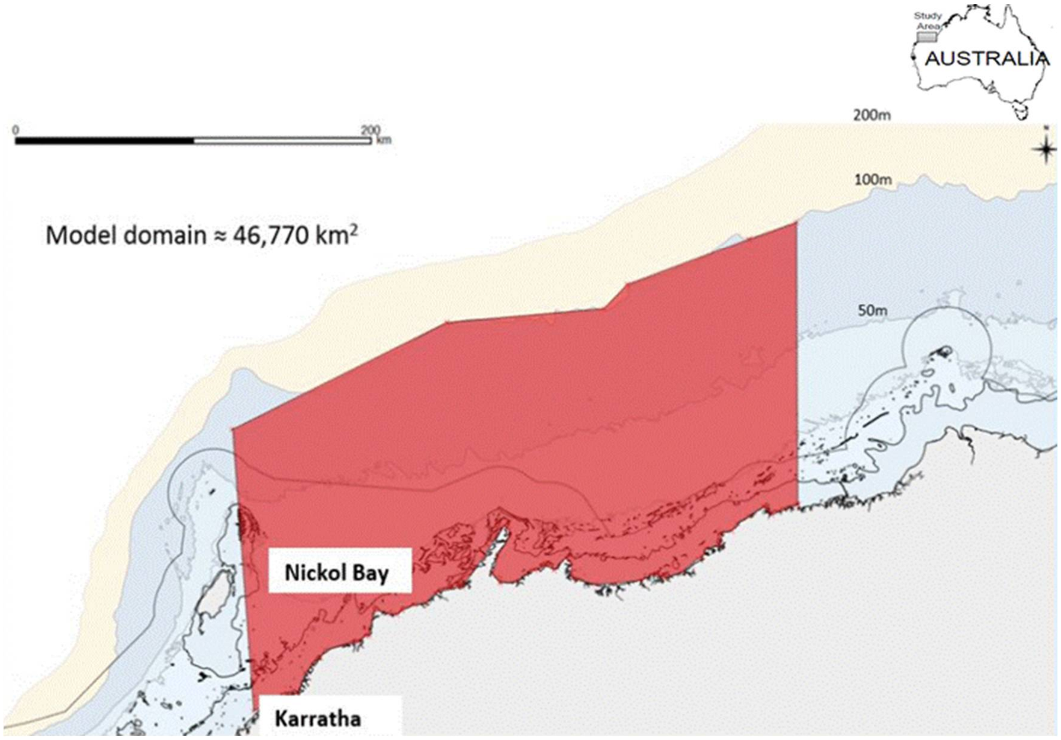


**Figure 181. The NWS model domain (red area) with approx. 46,770 square km. The model represents the foodweb of the demersal fish assembles and habitat forming invertebrates in the depth range from 20 to 100m.**

The EwE modelling software is a free software (under the terms of the GNU General Public Licence), and downloadable online (www.ecopath.org) with more than 400 EwE models for aquatic systems (and a few terrestrial systems) published worldwide (Colléter et al., 2015). EwE creates a static mass-balanced snapshot of the resources and their interactions, including biomass and energy flows. This will help us to elucidate the structure and functioning of the NWS system. The Ecopath model is based on a set of linear equations that quantify the trophic flows among the components of the system (living and non-living species or functional groups). Ecopath uses a series of simultaneous linear equations, one for each functional group to quantify the energetic flows among trophic groups according to the law of conservation of mass or energy (Equation 1). The net production of a functional group equals the total mass removed by its predators and fisheries plus its net migration and its energy or mass that flows to detritus. The master equation is described as:

*Production – Predation - Other mortality – Exports + import = 0*

Or;

*Production= mortality (Fishing + Predation + Other) + Biomass accumulation + Net Migration*

$$B_i \cdot (P/B)_i = Y_i + \sum_{j=1}^{n} B_j \cdot (Q/B)_j \cdot DC_{ji} + E_i + BA_i + B_i (P/B)_i \cdot (1 - EE_i)$$ ...Equation 1

Where, $B_i$ and $B_j$ are biomasses of prey (*i*) and predator (*j*), respectively;

$P/B_i$ is the production/biomass ratio;

$Y_i$ is the total fishery catch rate of group (*i*);

$Q/B_j$ is the consumption/biomass ratio;

$DC_{ij}$ is the fraction of prey (*i*) in the average diet of predator (*j*);

$E_i$ is the net migration rate (emigration – immigration); and

$BA_i$ is the biomass accumulation rate for group (*i*).

$EE_i$ is the ecotrophic efficiency; the fraction of group mortality explained in the model.

The consumption rate within a group equals the sum of production, respiration and unassimilated food, as in equation 2.

Conservation of energy between groups:

$$B \cdot (Q/B) = B \cdot (P/B) + (1 - GS) \cdot Q - (1 - TM) \cdot P + B \cdot (Q/B) \cdot GS \quad \text{... Equation 2}$$

Where GS is the proportion of food unassimilated; and TM is the trophic mode expressing the degree of heterotrophy; 0 and 1 represent autotrophs and heterotrophs, respectively. Intermediate values represent facultative consumers.

EwE uses a set of algorithms (Christensen et al., 2009) to simultaneously solve n linear equations of the form in equation 1, where n is the number of functional groups. Under the assumption of mass-balance, Ecopath can estimate missing parameters. This allows modellers to select their inputs. EwE uses the constraint of mass-balance to infer qualities of uncertain ecosystem components based on our knowledge of well-understood groups. It places piecemeal information on a framework that allows us to analyse the compatibility of data, and it offers heuristic value by providing scientists a forum to summarize what is known about the ecosystem and to identify gaps in knowledge.

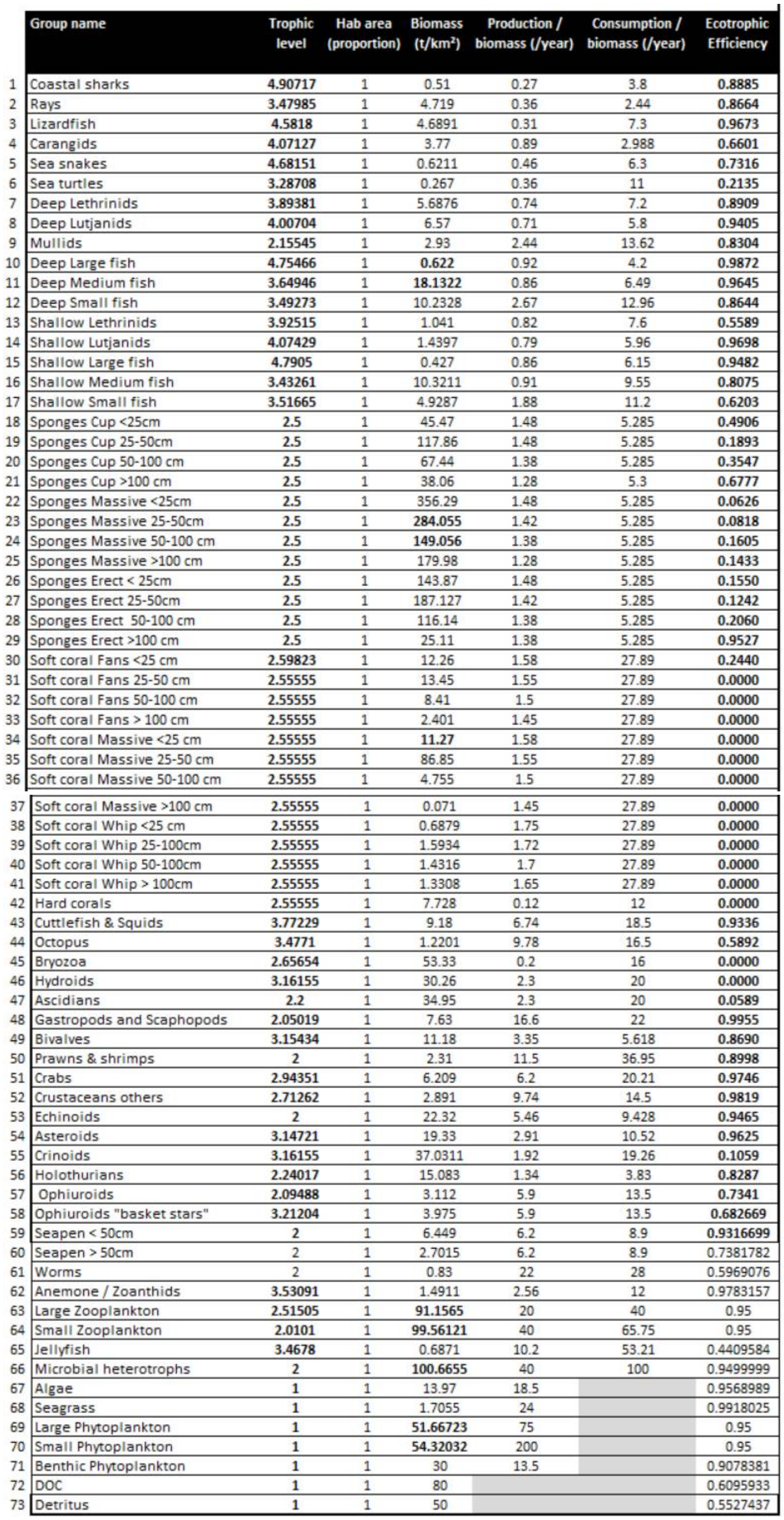
The input data for any functional group are: P/B, Q/B, B, EE and diet composition (DC); however, EwE requires DC as an input while any one of the other parameters can be estimated by mass balance if the other three are known. Normally EE is estimated, but in cases when biomass is unknown, it is possible to obtain an estimate by assuming about EE (0.95, for example).

Ecosim (Walters et al., 1997) adds temporal dynamics into the Ecopath models and was used to predict changes in biomass in response to changes in fishing pressure defined by mortality and fishing effort. A key component of Ecosim modelling is its ability to simulate predator-prey interactions on a temporal arena under the foraging arena theory, which splits the availability of a prey group's biomass to each predator group into several vulnerable and invulnerable states (Ahrens et al., 2012). In Ecosim, vulnerabilities (v) are assigned to individual predator/prey relationships, indicating whether the biomass of a group is controlled primarily by predators or prey. In Ecosim, vulnerabilities range from 1 to ∞; when v takes high values ('top down'), a high proportion of the biomass is vulnerable to predation. If v is closer to 1.0 ('bottom up'), prey have the opportunity to find refuge from predators. Initially, the vs during the fitting process were allocated from 1.0 to 10.0 and the final vs of each group were set during the tuning of the model with time-series of catch per effort (CPUE) for the main target species in the Kimberley.

### 7.3.3 Input data and information sources

This section describes the general methodology used to assign functional groups their basic parameters required by the EwE model. The data needs of EwE can be summarized as follows. Four data points are required for each functional group: biomass (in $t \cdot km^{-2}$), the ratio of production over biomass (P/B; in $yr^{-1}$), the ratio of consumption over biomass (Q/B; in $yr^{-1}$), and ecotrophic efficiency (EE; unitless). EwE also provides an input field representing the ratio of production over consumption (P/Q; unitless), which users may alternatively use to infer either P/B or Q/B based on the other. Each functional group requires 3 out of 4 of these input parameters and the remaining parameter is estimated using the mass-balance relationship in equations 1 and 2. The production/biomass (P/B) and consumption/biomass (Q/B) ratios (year $^{-1}$) are basic input parameters in EwE. The P/B ratio (year $^{-1}$) for non-target species is equivalent to natural mortality (M, year$^{-1}$; Pauly, 1980) and it was estimated using the empirical equation prediction of natural mortality proposed in Pauly (1980). P/B For commercial exploited finfish groups was estimated adding fishing mortality (F, year $^{-1}$) to M rates. The estimates of food consumption rates (Q/B, year $^{-1}$) for most fish and invertebrate groups were obtained from empirical equations proposed in Palomares and Pauly (1998). We used these empirical formulae as a proxy of mortalities and consumption rates. The four basic input parameters for each of the 73 functional groups in the model are presented in Table 29. A biomass accumulation rate may be entered optionally; the default setting assumes a zero-rate instantaneous biomass change. No biomass accumulation was used in this study. Biomasses of fish and invertebrates in the model were estimated mainly from a local study conducted in October 2017 on board of the R/V Investigator. Figure 182 and Figure 183 show the total trawl weights in grams for both vertebrates and invertebrates recovered during the 2017 voyage. Table 28shows the biomasses ($g/m^2$) obtained during this survey and used in the model.

**Table 28. Basic parameters of the mass-balanced NWS model. Bold numbers were parameters calculated by EwE**



| | Group name | Trophic level | Hab area (proportion) | Biomass (t/km²) | Production / biomass (/year) | Consumption / biomass (/year) | Ecotrophic Efficiency |
|---|---|---|---|---|---|---|---|
| 1 | Coastal sharks | **4.90717** | 1 | 0.51 | 0.27 | 3.8 | **0.8885** |
| 2 | Rays | **3.47985** | 1 | 4.719 | 0.36 | 2.44 | **0.8664** |
| 3 | Lizardfish | **4.5818** | 1 | 4.6891 | 0.31 | 7.3 | **0.9673** |
| 4 | Carangids | **4.07127** | 1 | 3.77 | 0.89 | 2.988 | **0.6601** |
| 5 | Sea snakes | **4.68151** | 1 | 0.6211 | 0.46 | 6.3 | **0.7316** |
| 6 | Sea turtles | **3.28708** | 1 | 0.267 | 0.36 | 11 | **0.2135** |
| 7 | Deep Lethrinids | **3.89381** | 1 | 5.6876 | 0.74 | 7.2 | **0.8909** |
| 8 | Deep Lutjanids | **4.00704** | 1 | 6.57 | 0.71 | 5.8 | **0.9405** |
| 9 | Mullids | **2.15545** | 1 | 2.93 | 2.44 | 13.62 | **0.8304** |
| 10 | Deep Large fish | **4.75466** | 1 | **0.622** | 0.92 | 4.2 | **0.9872** |
| 11 | Deep Medium fish | **3.64946** | 1 | **18.1322** | 0.86 | 6.49 | **0.9645** |
| 12 | Deep Small fish | **3.49273** | 1 | 10.2328 | 2.67 | 12.96 | **0.8644** |
| 13 | Shallow Lethrinids | **3.92515** | 1 | 1.041 | 0.82 | 7.6 | **0.5589** |
| 14 | Shallow Lutjanids | **4.07429** | 1 | 1.4397 | 0.79 | 5.96 | **0.9698** |
| 15 | Shallow Large fish | **4.7905** | 1 | 0.427 | 0.86 | 6.15 | **0.9482** |
| 16 | Shallow Medium fish | **3.43261** | 1 | 10.3211 | 0.91 | 9.55 | **0.8075** |
| 17 | Shallow Small fish | **3.51665** | 1 | 4.9287 | 1.88 | 11.2 | **0.6203** |
| 18 | Sponges Cup <25cm | **2.5** | 1 | 45.47 | 1.48 | 5.285 | **0.4906** |
| 19 | Sponges Cup 25-50cm | **2.5** | 1 | 117.86 | 1.48 | 5.285 | **0.1893** |
| 20 | Sponges Cup 50-100 cm | **2.5** | 1 | 67.44 | 1.38 | 5.285 | **0.3547** |
| 21 | Sponges Cup >100 cm | **2.5** | 1 | 38.06 | 1.28 | 5.3 | **0.6777** |
| 22 | Sponges Massive <25cm | **2.5** | 1 | 356.29 | 1.48 | 5.285 | **0.0626** |
| 23 | Sponges Massive 25-50cm | **2.5** | 1 | **284.055** | 1.42 | 5.285 | **0.0818** |
| 24 | Sponges Massive 50-100 cm | **2.5** | 1 | **149.056** | 1.38 | 5.285 | **0.1605** |
| 25 | Sponges Massive >100 cm | **2.5** | 1 | 179.98 | 1.28 | 5.285 | **0.1433** |
| 26 | Sponges Erect < 25cm | **2.5** | 1 | 143.87 | 1.48 | 5.285 | **0.1550** |
| 27 | Sponges Erect 25-50cm | **2.5** | 1 | 187.127 | 1.42 | 5.285 | **0.1242** |
| 28 | Sponges Erect 50-100 cm | **2.5** | 1 | 116.14 | 1.38 | 5.285 | **0.2060** |
| 29 | Sponges Erect >100 cm | **2.5** | 1 | 25.11 | 1.38 | 5.285 | **0.9527** |
| 30 | Soft coral Fans <25 cm | **2.59823** | 1 | 12.26 | 1.58 | 27.89 | **0.2440** |
| 31 | Soft coral Fans 25-50 cm | **2.55555** | 1 | 13.45 | 1.55 | 27.89 | **0.0000** |
| 32 | Soft coral Fans 50-100 cm | **2.55555** | 1 | 8.41 | 1.5 | 27.89 | **0.0000** |
| 33 | Soft coral Fans > 100 cm | **2.55555** | 1 | 2.401 | 1.45 | 27.89 | **0.0000** |
| 34 | Soft coral Massive <25 cm | **2.55555** | 1 | **11.27** | 1.58 | 27.89 | **0.0000** |
| 35 | Soft coral Massive 25-50 cm | **2.55555** | 1 | 86.85 | 1.55 | 27.89 | **0.0000** |
| 36 | Soft coral Massive 50-100 cm | **2.55555** | 1 | 4.755 | 1.5 | 27.89 | **0.0000** |
| 37 | Soft coral Massive >100 cm | **2.55555** | 1 | 0.071 | 1.45 | 27.89 | **0.0000** |
| 38 | Soft coral Whip <25 cm | **2.55555** | 1 | 0.6879 | 1.75 | 27.89 | **0.0000** |
| 39 | Soft coral Whip 25-100cm | **2.55555** | 1 | 1.5934 | 1.72 | 27.89 | **0.0000** |
| 40 | Soft coral Whip 50-100cm | **2.55555** | 1 | 1.4316 | 1.7 | 27.89 | **0.0000** |
| 41 | Soft coral Whip > 100cm | **2.55555** | 1 | 1.3308 | 1.65 | 27.89 | **0.0000** |
| 42 | Hard corals | **2.55555** | 1 | 7.728 | 0.12 | 12 | **0.0000** |
| 43 | Cuttlefish & Squids | **3.77229** | 1 | 9.18 | 6.74 | 18.5 | **0.9336** |
| 44 | Octopus | **3.4771** | 1 | 1.2201 | 9.78 | 16.5 | **0.5892** |
| 45 | Bryozoa | **2.65654** | 1 | 53.33 | 0.2 | 16 | **0.0000** |
| 46 | Hydroids | **3.16155** | 1 | 30.26 | 2.3 | 20 | **0.0000** |
| 47 | Ascidians | **2.2** | 1 | 34.95 | 2.3 | 20 | **0.0589** |
| 48 | Gastropods and Scaphopods | **2.05019** | 1 | 7.63 | 16.6 | 22 | **0.9955** |
| 49 | Bivalves | **3.15434** | 1 | 11.18 | 3.35 | 5.618 | **0.8690** |
| 50 | Prawns & shrimps | **2** | 1 | 2.31 | 11.5 | 36.95 | **0.8998** |
| 51 | Crabs | **2.94351** | 1 | 6.209 | 6.2 | 20.21 | **0.9746** |
| 52 | Crustaceans others | **2.71262** | 1 | 2.891 | 9.74 | 14.5 | **0.9819** |
| 53 | Echinoids | **2** | 1 | 22.32 | 5.46 | 9.428 | **0.9465** |
| 54 | Asteroids | **3.14721** | 1 | 19.33 | 2.91 | 10.52 | **0.9625** |
| 55 | Crinoids | **3.16155** | 1 | 37.0311 | 1.92 | 19.26 | **0.1059** |
| 56 | Holothurians | **2.24017** | 1 | 15.083 | 1.34 | 3.83 | **0.8287** |
| 57 | Ophiuroids | **2.09488** | 1 | 3.112 | 5.9 | 13.5 | **0.7341** |
| 58 | Ophiuroids "basket stars" | **3.21204** | 1 | 3.975 | 5.9 | 13.5 | **0.682669** |
| 59 | Seapen < 50cm | **2** | 1 | 6.449 | 6.2 | 8.9 | **0.9316699** |
| 60 | Seapen > 50cm | 2 | 1 | 2.7015 | 6.2 | 8.9 | 0.7381782 |
| 61 | Worms | 2 | 1 | 0.83 | 22 | 28 | 0.5969076 |
| 62 | Anemone / Zoanthids | **3.53091** | 1 | 1.4911 | 2.56 | 12 | 0.9783157 |
| 63 | Large Zooplankton | **2.51505** | 1 | **91.1565** | 20 | 40 | 0.95 |
| 64 | Small Zooplankton | **2.0101** | 1 | **99.56121** | 40 | 65.75 | 0.95 |
| 65 | Jellyfish | **3.4678** | 1 | 0.6871 | 10.2 | 53.21 | 0.4409584 |
| 66 | Microbial heterotrophs | **2** | 1 | **100.6655** | 40 | 100 | 0.9499999 |
| 67 | Algae | **1** | 1 | 13.97 | 18.5 | | 0.9568989 |
| 68 | Seagrass | **1** | 1 | 1.7055 | 24 | | 0.9918025 |
| 69 | Large Phytoplankton | **1** | 1 | **51.66723** | 75 | | 0.95 |
| 70 | Small Phytoplankton | **1** | 1 | **54.32032** | 200 | | 0.95 |
| 71 | Benthic Phytoplankton | **1** | 1 | 30 | 13.5 | | 0.9078381 |
| 72 | DOC | **1** | 1 | 80 | | | 0.6095933 |
| 73 | Detritus | **1** | 1 | 50 | | | 0.5527437 |

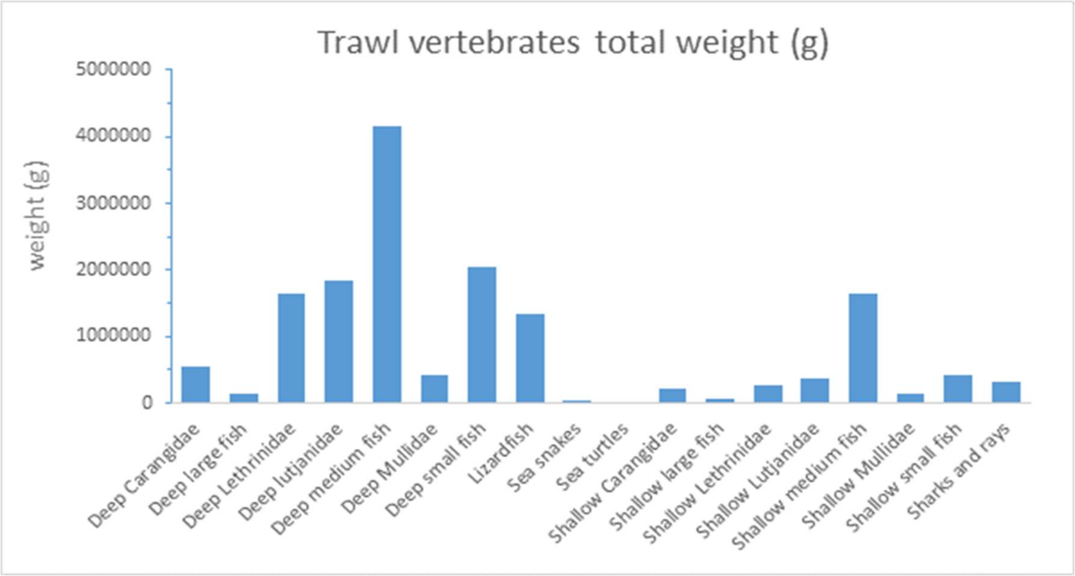


**Figure 182. Trawl total weight (grams) for vertebrates obtained during 2017 voyage on board of R/V Investigator in the NWS.**

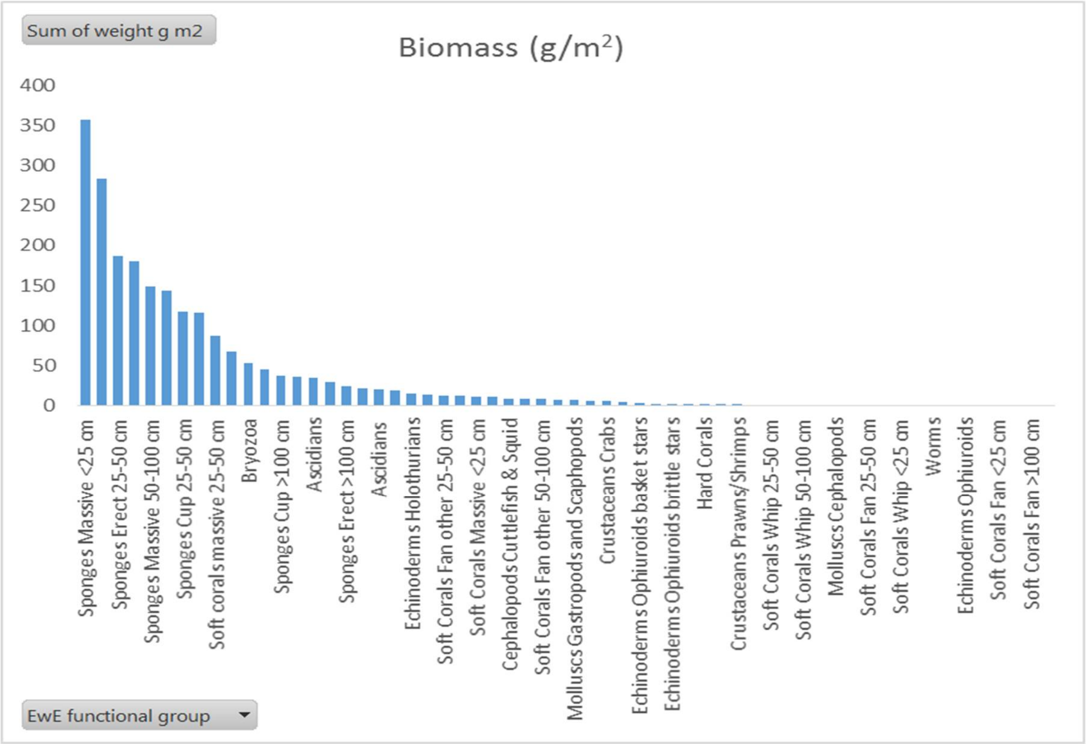


**Figure 183. Trawl total weight (grams) for invertebrates obtained during the 2017 voyage on board of the R/V Investigator in the NWS.**

### 7.3.4 Diet Composition (DC)

The diet composition matrix was assembled as percentage weight or volume of the annual fraction that each prey contributes to the overall diet of the predator (according to the methodology recommend by Christensen et al., 2004, 2008). Several local reports were employed to assemble this matrix of feeding interactions. As some data from NWS were not available, missing values were taken for the relevant species from adjacent areas (Kimberley, Ningaloo, and Gulf of Carpentaria) (Table 29). EwE will use tis diet matrix to estimate trophic interactions and predation rates based on Equations 1 and 2.

### 7.3.5 Fisheries gear types and landings

The fishing gear types included the NWS model were selected based on the operating fleets reported in the region by Western Australia Department of Primary Industries and Regional Development (former Department of Fisheries). The gear structure proposed for the model included six gear types for both commercial and recreational fisheries. A total of five gear types represent the commercial fisheries of the region with the following gears: Pilbara Demersal Trawl Scalefish, Pilbara Trap Managed Fishery, Pilbara Line Managed Fishery, Nickol Bay Prawn Managed Fishery and Pilbara Developing Crab Fishery. In the case of recreational fishing, only one gear is included in the model: Near-shore beach boat. Most of the commercial fisheries catch data used in the model were estimated from the fisheries statistics reported (annual reports; DIRP, 2015) by the Western Australia Department of Primary Industries and Regional Development. The fisheries data included the total catch (tonnes), gear types and species fished within each of the relevant districts in which the Department of Fisheries manages and reports fisheries statistics in Western Australia. According to this organization, the region of the NWS is included in the North Coast Bioregion. Most of the Western Australia state's smaller prawn trawl fisheries are also based in this region. Table 30 presents the commercial and recreational landings included in the model from the main six fleets operating in the NWS from 2014 to 2016.

### 7.3.6 Data quality of the model

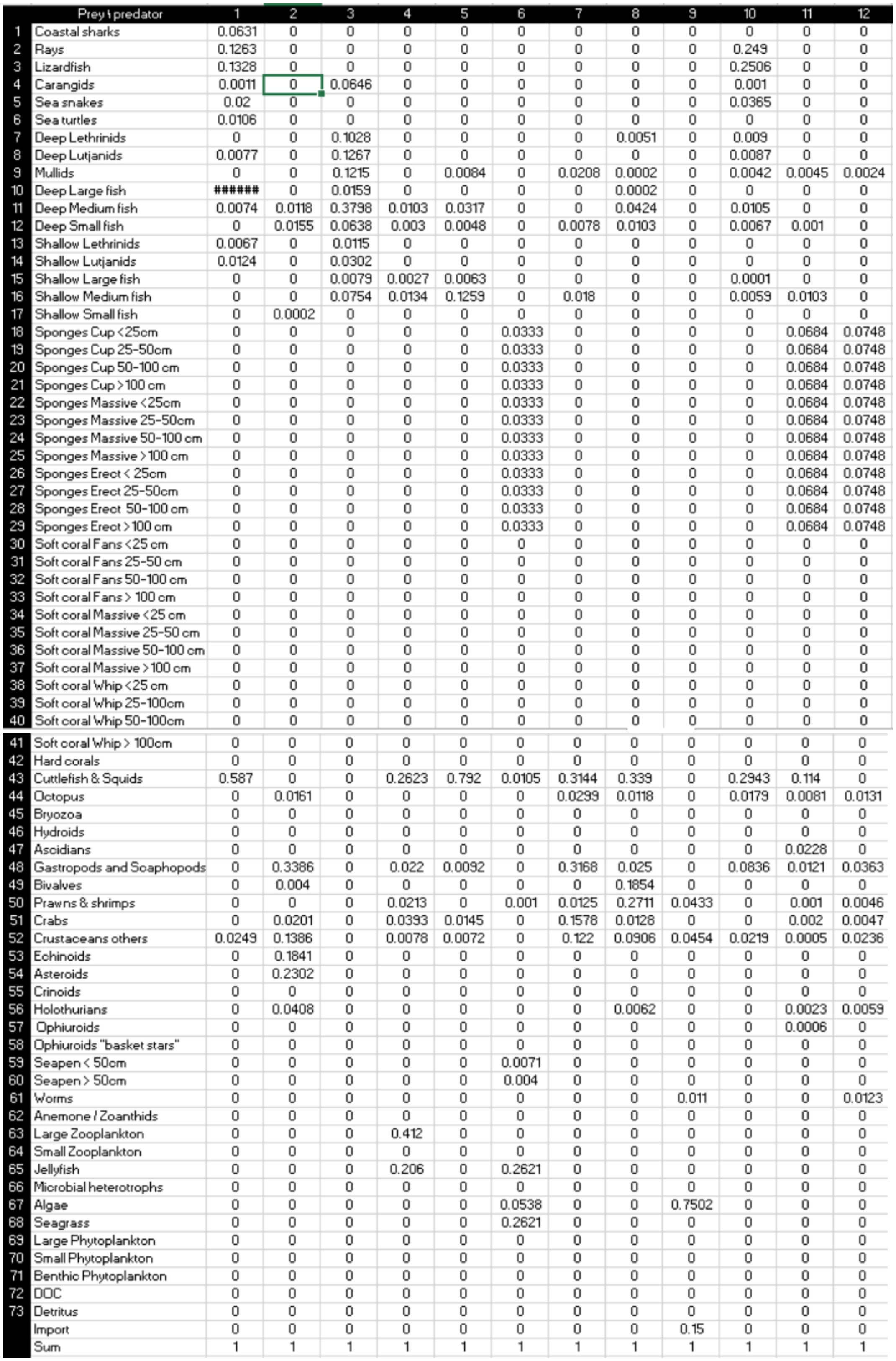
The 'pedigree' routine in Ecopath, functions as a sensitivity analysis for documenting the effect of inputs on estimated parameters and their quality (Walters et al., 2005). The pedigree index (P) measures the amount of local data used (i.e., minor uncertainty in the inputs) among the five basic categories of models: Biomass (B), Production to biomass (P/B), the ratio of consumption to biomass (Q/B), and diets and catches for each of the functional groups (Walters et al., 2005). The range of P is from 0 for data not rooted locally to 1.0 for data that are fully rooted in local data (Christensen et al., 2004). The pedigree Index for the NWS model was calculated using the following expression:

$$P = \sum_{i=1}^{n} \frac{I_{ij}}{n}$$

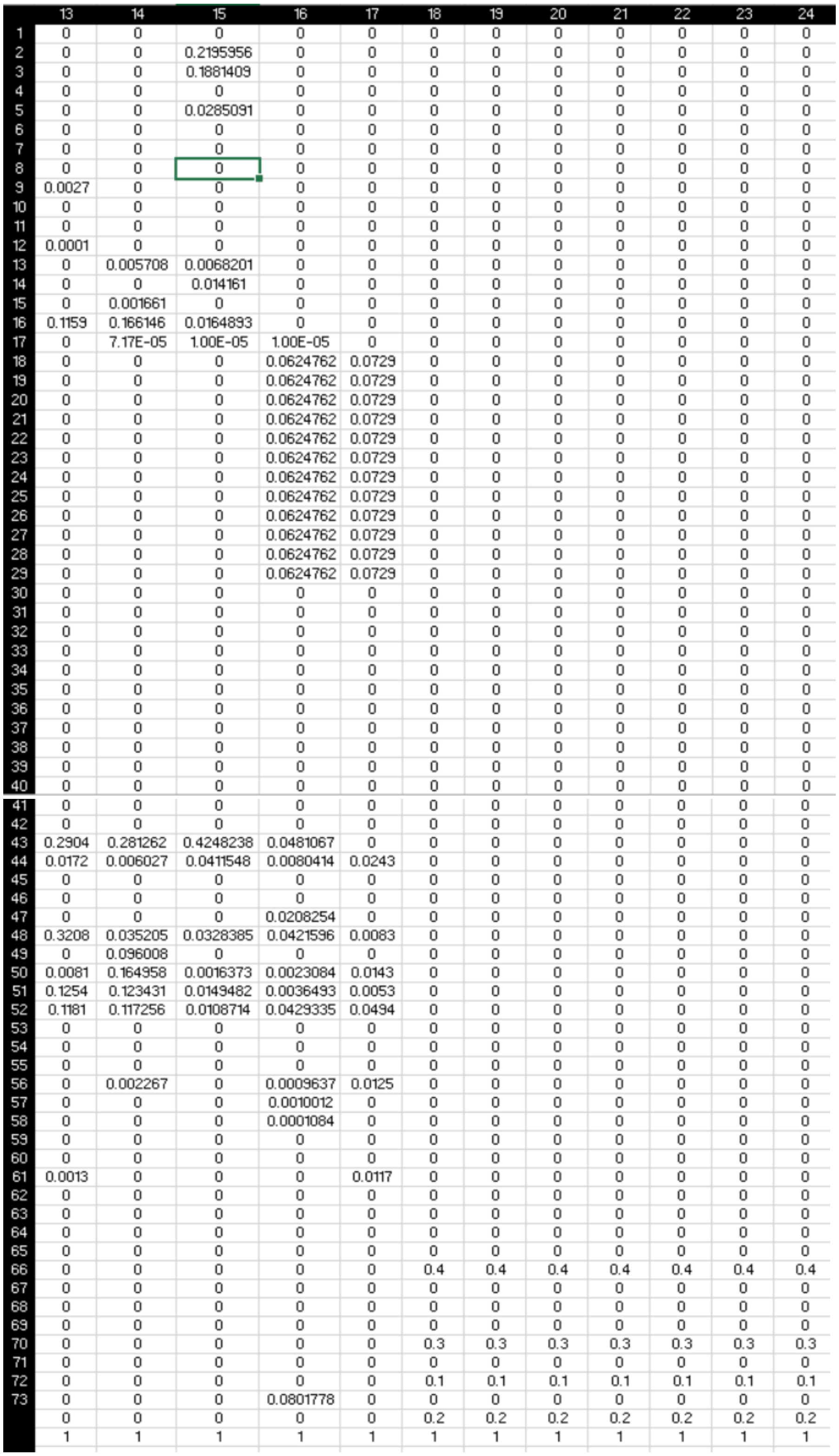
Where I*ij* is the pedigree index value for group I and parameter j for each of the living groups in the ecosystem; j can represent either B, P/B, Q/B and Y or diet.

The pedigree of an Ecopath input represents the origin a given input. There is a pre-defined table in Ecopath for each type of input parameters. The Ecoranger module of Ecopath (Walters et al., 2005, 2009) can subsequently pick up the confidence intervals from the pedigree tables and use these as prior probability distributions for all input data.

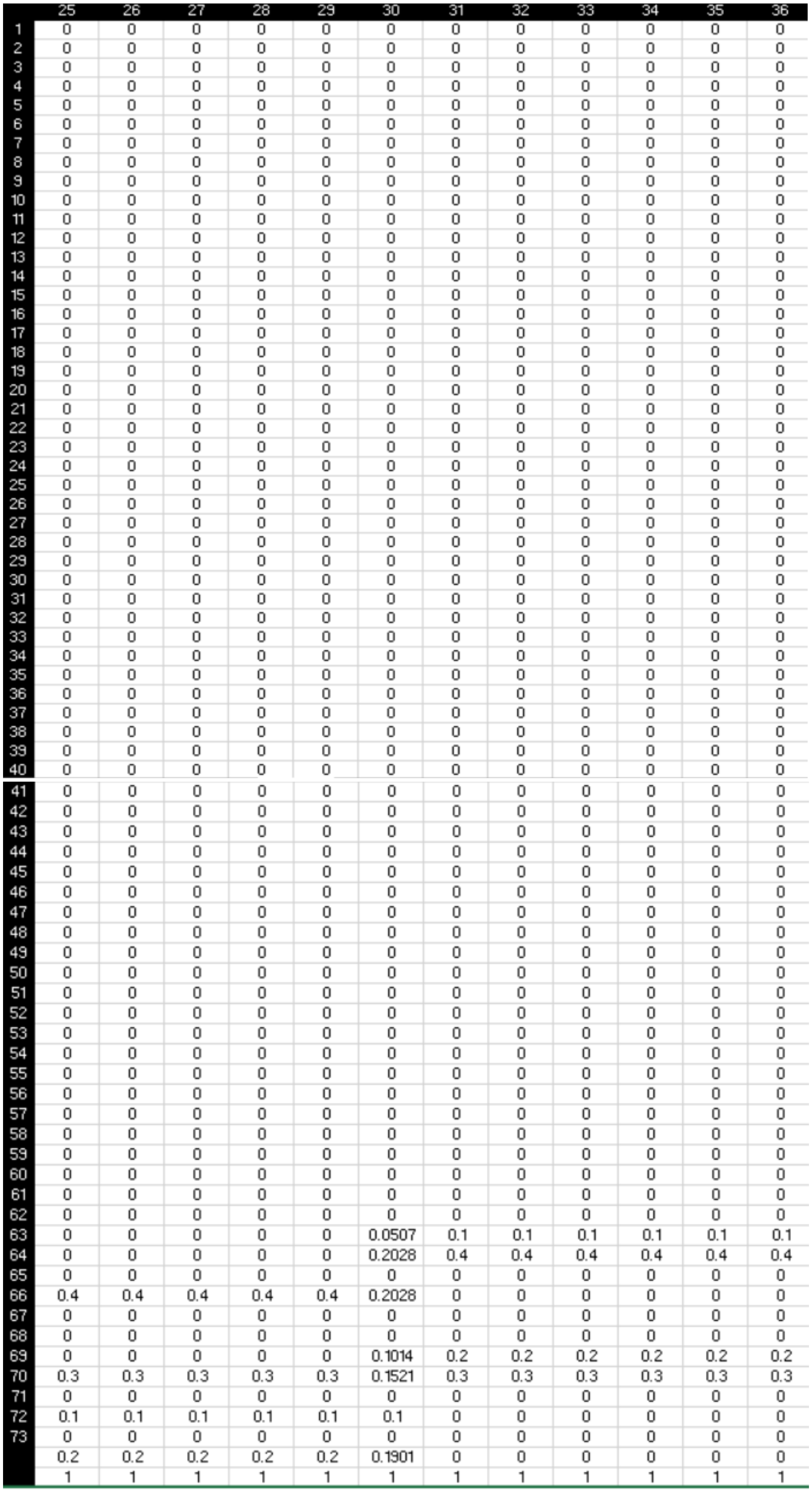
## Table 29. Diet matrix used in the mass-balanced NWS model. Continues several pages.



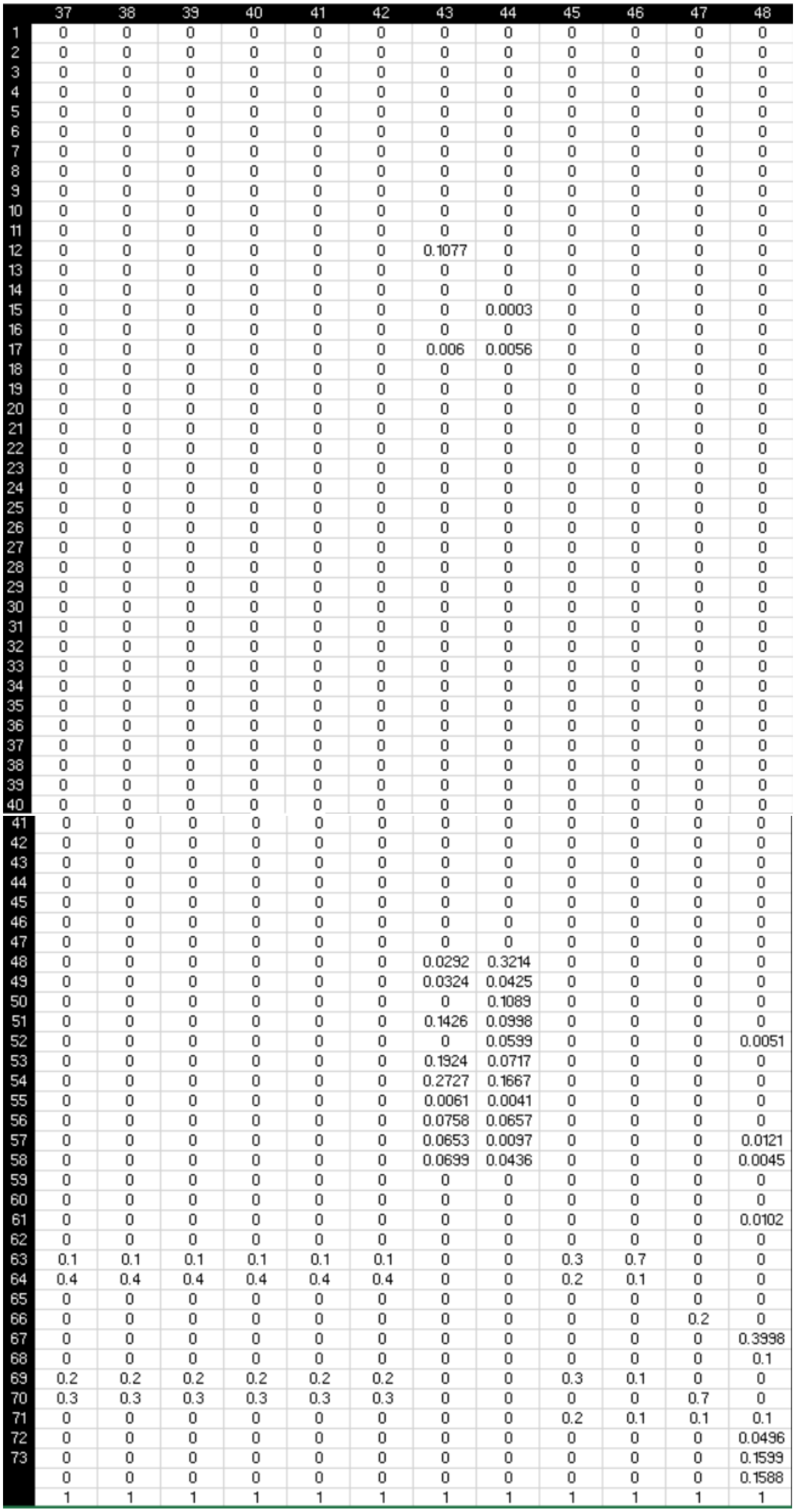
|  | Prey \ predator | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Coastal sharks | 0.0631 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | Rays | 0.1263 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.249 | 0 | 0 |
| 3 | Lizardfish | 0.1328 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.2506 | 0 | 0 |
| 4 | Carangids | 0.0011 | 0 | 0.0646 | 0 | 0 | 0 | 0 | 0 | 0 | 0.001 | 0 | 0 |
| 5 | Sea snakes | 0.02 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0365 | 0 | 0 |
| 6 | Sea turtles | 0.0106 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | Deep Lethrinids | 0 | 0 | 0.1028 | 0 | 0 | 0 | 0 | 0.0051 | 0 | 0.009 | 0 | 0 |
| 8 | Deep Lutjanids | 0.0077 | 0 | 0.1267 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0087 | 0 | 0 |
| 9 | Mullids | 0 | 0 | 0.1215 | 0 | 0.0084 | 0 | 0.0208 | 0.0002 | 0 | 0.0042 | 0.0045 | 0.0024 |
| 10 | Deep Large fish | ###### | 0 | 0.0159 | 0 | 0 | 0 | 0 | 0.0002 | 0 | 0 | 0 | 0 |
| 11 | Deep Medium fish | 0.0074 | 0.0118 | 0.3798 | 0.0103 | 0.0317 | 0 | 0 | 0.0424 | 0 | 0.0105 | 0 | 0 |
| 12 | Deep Small fish | 0 | 0.0155 | 0.0638 | 0.003 | 0.0048 | 0 | 0.0078 | 0.0103 | 0 | 0.0067 | 0.001 | 0 |
| 13 | Shallow Lethrinids | 0.0067 | 0 | 0.0115 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14 | Shallow Lutjanids | 0.0124 | 0 | 0.0302 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 15 | Shallow Large fish | 0 | 0 | 0.0079 | 0.0027 | 0.0063 | 0 | 0 | 0 | 0 | 0.0001 | 0 | 0 |
| 16 | Shallow Medium fish | 0 | 0 | 0.0754 | 0.0134 | 0.1259 | 0 | 0.018 | 0 | 0 | 0.0059 | 0.0103 | 0 |
| 17 | Shallow Small fish | 0 | 0.0002 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 18 | Sponges Cup <25cm | 0 | 0 | 0 | 0 | 0 | 0.0333 | 0 | 0 | 0 | 0 | 0.0684 | 0.0748 |
| 19 | Sponges Cup 25-50cm | 0 | 0 | 0 | 0 | 0 | 0.0333 | 0 | 0 | 0 | 0 | 0.0684 | 0.0748 |
| 20 | Sponges Cup 50-100 cm | 0 | 0 | 0 | 0 | 0 | 0.0333 | 0 | 0 | 0 | 0 | 0.0684 | 0.0748 |
| 21 | Sponges Cup >100 cm | 0 | 0 | 0 | 0 | 0 | 0.0333 | 0 | 0 | 0 | 0 | 0.0684 | 0.0748 |
| 22 | Sponges Massive <25cm | 0 | 0 | 0 | 0 | 0 | 0.0333 | 0 | 0 | 0 | 0 | 0.0684 | 0.0748 |
| 23 | Sponges Massive 25-50cm | 0 | 0 | 0 | 0 | 0 | 0.0333 | 0 | 0 | 0 | 0 | 0.0684 | 0.0748 |
| 24 | Sponges Massive 50-100 cm | 0 | 0 | 0 | 0 | 0 | 0.0333 | 0 | 0 | 0 | 0 | 0.0684 | 0.0748 |
| 25 | Sponges Massive >100 cm | 0 | 0 | 0 | 0 | 0 | 0.0333 | 0 | 0 | 0 | 0 | 0.0684 | 0.0748 |
| 26 | Sponges Erect < 25cm | 0 | 0 | 0 | 0 | 0 | 0.0333 | 0 | 0 | 0 | 0 | 0.0684 | 0.0748 |
| 27 | Sponges Erect 25-50cm | 0 | 0 | 0 | 0 | 0 | 0.0333 | 0 | 0 | 0 | 0 | 0.0684 | 0.0748 |
| 28 | Sponges Erect 50-100 cm | 0 | 0 | 0 | 0 | 0 | 0.0333 | 0 | 0 | 0 | 0 | 0.0684 | 0.0748 |
| 29 | Sponges Erect >100 cm | 0 | 0 | 0 | 0 | 0 | 0.0333 | 0 | 0 | 0 | 0 | 0.0684 | 0.0748 |
| 30 | Soft coral Fans <25 cm | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 31 | Soft coral Fans 25-50 cm | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 32 | Soft coral Fans 50-100 cm | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 33 | Soft coral Fans > 100 cm | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 34 | Soft coral Massive <25 cm | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 35 | Soft coral Massive 25-50 cm | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 36 | Soft coral Massive 50-100 cm | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 37 | Soft coral Massive >100 cm | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 38 | Soft coral Whip <25 cm | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 39 | Soft coral Whip 25-100cm | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 40 | Soft coral Whip 50-100cm | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 41 | Soft coral Whip > 100cm | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 42 | Hard corals | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 43 | Cuttlefish & Squids | 0.587 | 0 | 0 | 0.2623 | 0.792 | 0.0105 | 0.3144 | 0.339 | 0 | 0.2943 | 0.114 | 0 |
| 44 | Octopus | 0 | 0.0161 | 0 | 0 | 0 | 0 | 0.0299 | 0.0118 | 0 | 0.0179 | 0.0081 | 0.0131 |
| 45 | Bryozoa | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 46 | Hydroids | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 47 | Ascidians | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0228 | 0 |
| 48 | Gastropods and Scaphopods | 0 | 0.3386 | 0 | 0.022 | 0.0092 | 0 | 0.3168 | 0.025 | 0 | 0.0836 | 0.0121 | 0.0363 |
| 49 | Bivalves | 0 | 0.004 | 0 | 0 | 0 | 0 | 0 | 0.1854 | 0 | 0 | 0 | 0 |
| 50 | Prawns & shrimps | 0 | 0 | 0 | 0.0213 | 0 | 0.001 | 0.0125 | 0.2711 | 0.0433 | 0 | 0.001 | 0.0046 |
| 51 | Crabs | 0 | 0.0201 | 0 | 0.0393 | 0.0145 | 0 | 0.1578 | 0.0128 | 0 | 0 | 0.002 | 0.0047 |
| 52 | Crustaceans others | 0.0249 | 0.1386 | 0 | 0.0078 | 0.0072 | 0 | 0.122 | 0.0906 | 0.0454 | 0.0219 | 0.0005 | 0.0236 |
| 53 | Echinoids | 0 | 0.1841 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 54 | Asteroids | 0 | 0.2302 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 55 | Crinoids | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 56 | Holothurians | 0 | 0.0408 | 0 | 0 | 0 | 0 | 0 | 0.0062 | 0 | 0 | 0.0023 | 0.0059 |
| 57 | Ophiuroids | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0006 | 0 |
| 58 | Ophiuroids "basket stars" | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 59 | Seapen < 50cm | 0 | 0 | 0 | 0 | 0 | 0.0071 | 0 | 0 | 0 | 0 | 0 | 0 |
| 60 | Seapen > 50cm | 0 | 0 | 0 | 0 | 0 | 0.004 | 0 | 0 | 0 | 0 | 0 | 0 |
| 61 | Worms | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.011 | 0 | 0 | 0.0123 |
| 62 | Anemone / Zoanthids | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 63 | Large Zooplankton | 0 | 0 | 0 | 0.412 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 64 | Small Zooplankton | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 65 | Jellyfish | 0 | 0 | 0 | 0.206 | 0 | 0.2621 | 0 | 0 | 0 | 0 | 0 | 0 |
| 66 | Microbial heterotrophs | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 67 | Algae | 0 | 0 | 0 | 0 | 0 | 0.0538 | 0 | 0 | 0.7502 | 0 | 0 | 0 |
| 68 | Seagrass | 0 | 0 | 0 | 0 | 0 | 0.2621 | 0 | 0 | 0 | 0 | 0 | 0 |
| 69 | Large Phytoplankton | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 70 | Small Phytoplankton | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 71 | Benthic Phytoplankton | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 72 | DOC | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 73 | Detritus | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
|  | Import | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.15 | 0 | 0 | 0 |
|  | Sum | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |



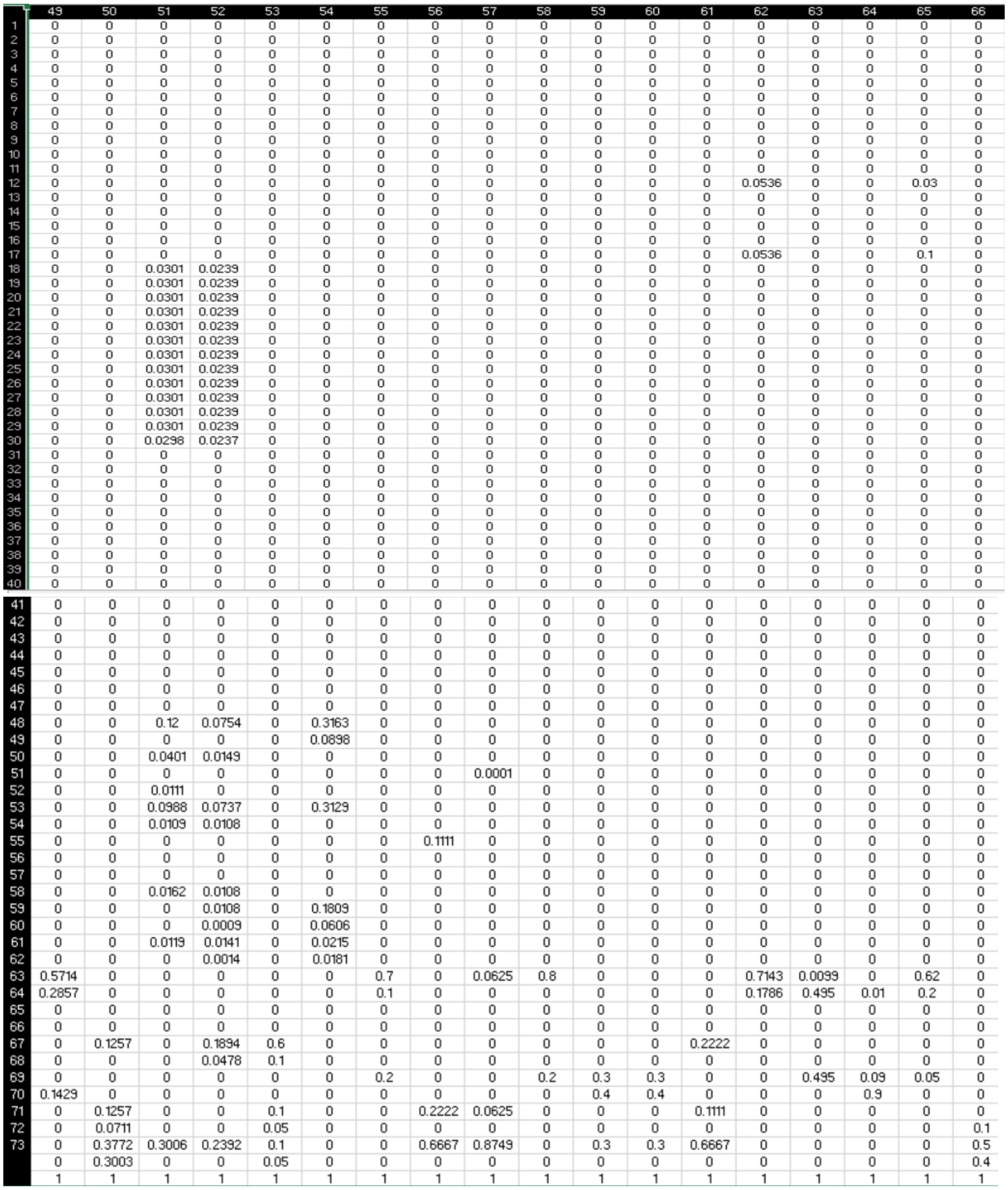
| | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0.2195956 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0.1881409 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0.0285091 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 0.0027 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | 0.0001 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 13 | 0 | 0.005708 | 0.0068201 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14 | 0 | 0 | 0.014161 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 15 | 0 | 0.001661 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 16 | 0.1159 | 0.166146 | 0.0164893 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 17 | 0 | 7.17E-05 | 1.00E-05 | 1.00E-05 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 18 | 0 | 0 | 0 | 0.0624762 | 0.0729 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 19 | 0 | 0 | 0 | 0.0624762 | 0.0729 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 0 | 0 | 0 | 0.0624762 | 0.0729 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 21 | 0 | 0 | 0 | 0.0624762 | 0.0729 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 22 | 0 | 0 | 0 | 0.0624762 | 0.0729 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 23 | 0 | 0 | 0 | 0.0624762 | 0.0729 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 24 | 0 | 0 | 0 | 0.0624762 | 0.0729 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 25 | 0 | 0 | 0 | 0.0624762 | 0.0729 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 26 | 0 | 0 | 0 | 0.0624762 | 0.0729 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 27 | 0 | 0 | 0 | 0.0624762 | 0.0729 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 28 | 0 | 0 | 0 | 0.0624762 | 0.0729 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 29 | 0 | 0 | 0 | 0.0624762 | 0.0729 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 30 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 31 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 32 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 33 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 34 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 35 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 36 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 37 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 38 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 39 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 40 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 41 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 42 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 43 | 0.2904 | 0.281262 | 0.4248238 | 0.0481067 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 44 | 0.0172 | 0.006027 | 0.0411548 | 0.0080414 | 0.0243 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 45 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 46 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 47 | 0 | 0 | 0 | 0.0208254 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 48 | 0.3208 | 0.035205 | 0.0328385 | 0.0421596 | 0.0083 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 49 | 0 | 0.096008 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 50 | 0.0081 | 0.164958 | 0.0016373 | 0.0023084 | 0.0143 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 51 | 0.1254 | 0.123431 | 0.0149482 | 0.0036493 | 0.0053 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 52 | 0.1181 | 0.117256 | 0.0108714 | 0.0429335 | 0.0494 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 53 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 54 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 55 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 56 | 0 | 0.002267 | 0 | 0.0009637 | 0.0125 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 57 | 0 | 0 | 0 | 0.0010012 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 58 | 0 | 0 | 0 | 0.0001084 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 59 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 61 | 0.0013 | 0 | 0 | 0 | 0.0117 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 62 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 63 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 64 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 65 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 66 | 0 | 0 | 0 | 0 | 0 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| 67 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 68 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 69 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 70 | 0 | 0 | 0 | 0 | 0 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| 71 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 72 | 0 | 0 | 0 | 0 | 0 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| 73 | 0 | 0 | 0 | 0.0801778 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 0 | 0 | 0 | 0 | 0 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |



|  | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 21 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 22 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 23 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 26 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 27 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 28 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 29 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 30 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 31 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 32 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 33 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 34 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 35 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 36 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 37 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 38 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 39 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 40 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 41 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 42 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 43 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 44 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 45 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 46 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 47 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 48 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 49 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 50 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 51 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 52 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 53 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 54 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 55 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 56 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 57 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 58 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 59 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 61 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 62 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 63 | 0 | 0 | 0 | 0 | 0 | 0.0507 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| 64 | 0 | 0 | 0 | 0 | 0 | 0.2028 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| 65 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 66 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.2028 | 0 | 0 | 0 | 0 | 0 | 0 |
| 67 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 68 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 69 | 0 | 0 | 0 | 0 | 0 | 0.1014 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| 70 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.1521 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| 71 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 72 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 73 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
|  | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.1901 | 0 | 0 | 0 | 0 | 0 | 0 |
|  | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |



| | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1077 | 0 | 0 | 0 | 0 | 0 |
| 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0003 | 0 | 0 | 0 | 0 |
| 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0.006 | 0.0056 | 0 | 0 | 0 | 0 |
| 18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 21 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 22 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 23 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 26 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 27 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 28 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 29 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 30 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 31 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 32 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 33 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 34 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 35 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 36 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 37 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 38 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 39 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 40 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 41 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 42 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 43 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 44 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 45 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 46 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 47 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 48 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0292 | 0.3214 | 0 | 0 | 0 | 0 |
| 49 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0324 | 0.0425 | 0 | 0 | 0 | 0 |
| 50 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1089 | 0 | 0 | 0 | 0 |
| 51 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1426 | 0.0998 | 0 | 0 | 0 | 0 |
| 52 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0599 | 0 | 0 | 0 | 0.0051 |
| 53 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1924 | 0.0717 | 0 | 0 | 0 | 0 |
| 54 | 0 | 0 | 0 | 0 | 0 | 0 | 0.2727 | 0.1667 | 0 | 0 | 0 | 0 |
| 55 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0061 | 0.0041 | 0 | 0 | 0 | 0 |
| 56 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0758 | 0.0657 | 0 | 0 | 0 | 0 |
| 57 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0653 | 0.0097 | 0 | 0 | 0 | 0.0121 |
| 58 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0699 | 0.0436 | 0 | 0 | 0 | 0.0045 |
| 59 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 61 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0102 |
| 62 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 63 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0 | 0 | 0.3 | 0.7 | 0 | 0 |
| 64 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0 | 0 | 0.2 | 0.1 | 0 | 0 |
| 65 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 66 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.2 | 0 |
| 67 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.3998 |
| 68 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1 |
| 69 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0 | 0 | 0.3 | 0.1 | 0 | 0 |
| 70 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0 | 0 | 0 | 0 | 0.7 | 0 |
| 71 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.2 | 0.1 | 0.1 | 0.1 |
| 72 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0496 |
| 73 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1599 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1588 |
| | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |



|  | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0536 | 0 | 0 | 0.03 | 0 |
| 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0536 | 0 | 0 | 0.1 | 0 |
| 18 | 0 | 0 | 0.0301 | 0.0239 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 19 | 0 | 0 | 0.0301 | 0.0239 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 0 | 0 | 0.0301 | 0.0239 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 21 | 0 | 0 | 0.0301 | 0.0239 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 22 | 0 | 0 | 0.0301 | 0.0239 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 23 | 0 | 0 | 0.0301 | 0.0239 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 24 | 0 | 0 | 0.0301 | 0.0239 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 25 | 0 | 0 | 0.0301 | 0.0239 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 26 | 0 | 0 | 0.0301 | 0.0239 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 27 | 0 | 0 | 0.0301 | 0.0239 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 28 | 0 | 0 | 0.0301 | 0.0239 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 29 | 0 | 0 | 0.0301 | 0.0239 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 30 | 0 | 0 | 0.0298 | 0.0237 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 31 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 32 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 33 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 34 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 35 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 36 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 37 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 38 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 39 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 40 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 41 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 42 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 43 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 44 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 45 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 46 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 47 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 48 | 0 | 0 | 0.12 | 0.0754 | 0 | 0.3163 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 49 | 0 | 0 | 0 | 0 | 0 | 0.0898 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 50 | 0 | 0 | 0.0401 | 0.0149 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 51 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0001 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 52 | 0 | 0 | 0.0111 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 53 | 0 | 0 | 0.0988 | 0.0737 | 0 | 0.3129 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 54 | 0 | 0 | 0.0109 | 0.0108 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 55 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1111 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 56 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 57 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 58 | 0 | 0 | 0.0162 | 0.0108 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 59 | 0 | 0 | 0 | 0.0108 | 0 | 0.1809 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 60 | 0 | 0 | 0 | 0.0009 | 0 | 0.0606 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 61 | 0 | 0 | 0.0119 | 0.0141 | 0 | 0.0215 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 62 | 0 | 0 | 0 | 0.0014 | 0 | 0.0181 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 63 | 0.5714 | 0 | 0 | 0 | 0 | 0 | 0.7 | 0 | 0.0625 | 0.8 | 0 | 0 | 0 | 0.7143 | 0.0099 | 0 | 0.62 | 0 |
| 64 | 0.2857 | 0 | 0 | 0 | 0 | 0 | 0.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1786 | 0.495 | 0.01 | 0.2 | 0 |
| 65 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 66 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 67 | 0 | 0.1257 | 0 | 0.1894 | 0.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.2222 | 0 | 0 | 0 | 0 | 0 |
| 68 | 0 | 0 | 0 | 0.0478 | 0.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 69 | 0 | 0 | 0 | 0 | 0 | 0 | 0.2 | 0 | 0 | 0.2 | 0.3 | 0.3 | 0 | 0 | 0.495 | 0.09 | 0.05 | 0 |
| 70 | 0.1429 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.4 | 0.4 | 0 | 0 | 0 | 0.9 | 0 | 0 |
| 71 | 0 | 0.1257 | 0 | 0 | 0.1 | 0 | 0 | 0.2222 | 0.0625 | 0 | 0 | 0 | 0.1111 | 0 | 0 | 0 | 0 | 0 |
| 72 | 0 | 0.0711 | 0 | 0 | 0.05 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1 |
| 73 | 0 | 0.3772 | 0.3006 | 0.2392 | 0.1 | 0 | 0 | 0.6667 | 0.8749 | 0 | 0.3 | 0.3 | 0.6667 | 0 | 0 | 0 | 0 | 0.5 |
|  | 0 | 0.3003 | 0 | 0 | 0.05 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.4 |
|  | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

### Table 30. Mean commercial and recreational catch (t/km$^2$) from 2014 to 2016 estimated for the EwE NWS model domain based on data published by Western Australia DPIRD (Former Department of Fisheries).

| Group name | Pilbara Demersal Trawl Scalefish t km$^{-2}$ | Pilbara Trap Managed Fishery t km$^{-2}$ | Pilbara Line Managed Fishery t km$^{-2}$ | Nickol Prawn Managed Fishery t km$^{-2}$ | Pilbara Developing Crab Fishery t km$^{-2}$ | Recreational Near-shore beach t km$^{-2}$ | Total t km$^{-2}$ |
|---|---|---|---|---|---|---|---|
| Coastal sharks | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Rays | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Lizardfish | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Carangids | 0 | 0 | 0 | 0 | 0 | 1.00E-05 | 1.00E-05 |
| Sea snakes | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sea turtles | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Deep Lethrinids | 0.0107 | 0.00346 | 0.000902 | 0 | 0 | 0 | 0.015062 |
| Deep Lutjanids | 0.01 | 0.00325 | 0.000848 | 0 | 0 | 0 | 0.014098 |
| Mullids | 0 | 0 | 0 | 0 | 0 | 1.00E-05 | 1.00E-05 |
| Deep Large fish | 0.0094 | 0.00306 | 0.000798 | 0 | 0 | 0 | 0.013258 |
| Deep Medium fish | 0.00336 | 0.00109 | 0.000284 | 0 | 0 | 0 | 0.004734 |
| Deep Small fish | 0.00273 | 0.000884 | 2.30E-05 | 0 | 0 | 0 | 0.003637 |
| Shallow Lethrinids | 0.00266 | 0.000864 | 0.000225 | 0 | 0 | 2.00E-05 | 0.003769 |
| Shallow Lutjanids | 0.0054 | 0.00175 | 0.000457 | 0 | 0 | 2.00E-05 | 0.007627 |
| Shallow Large fish | 0.000531 | 0.000172 | 4.50E-05 | 0 | 0 | 0.0002 | 0.000948 |
| Shallow Medium fish | 0.00429 | 0.00139 | 0.000363 | 0 | 0 | 1.00E-05 | 0.006053 |
| Shallow Small fish | 0.00177 | 0.000572 | 0.000149 | 0 | 0 | 1.00E-05 | 0.002501 |
| Sponges Cup <25cm | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sponges Cup 25-50cm | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sponges Cup 50-100 cm | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sponges Cup >100 cm | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sponges Massive <25cm | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sponges Massive 25-50cm | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sponges Massive 50-100 cm | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sponges Massive >100 cm | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sponges Erect < 25cm | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sponges Erect 25-50cm | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sponges Erect 50-100 cm | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sponges Erect >100 cm | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Soft coral Fans <25 cm | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Soft coral Fans 25-50 cm | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Soft coral Fans 50-100 cm | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Soft coral Fans > 100 cm | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Soft coral Massive <25 cm | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Soft coral Massive 25-50 cm | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Soft coral Massive 50-100 cm | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Soft coral Massive >100 cm | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Soft coral Whip <25 cm | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Soft coral Whip 25-100cm | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Soft coral Whip 50-100cm | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Soft coral Whip <25 cm | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Soft coral Whip 25-100cm | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Soft coral Whip 50-100cm | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Soft coral Whip > 100cm | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Hard corals | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cuttlefish & Squids | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Octopus | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bryozoa | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Hydroids | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Ascidians | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Gastropods and Scaphopods | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bivalves | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Prawns & shrimps | 0 | 0 | 0 | 0.00323 | 0 | 0 | 0.00323 |
| Crabs | 0 | 0 | 0 | 0 | 0.003 | 0 | 0.003 |
| Crustaceans others | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Echinoids | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Asteroids | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Crinoids | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Holothurians | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Ophiuroids | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Ophiuroids "basket stars" | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Seapen < 50cm | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Seapen > 50cm | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Worms | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Anemone / Zoanthids | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Large Zooplankton | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Small Zooplankton | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Jellyfish | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Microbial heterotrophs | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Algae | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Seagrass | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Large Phytoplankton | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Small Phytoplankton | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Benthic Phytoplankton | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| DOC | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Detritus | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sum | 0.050841 | 0.016492 | 0.004094 | 0.00323 | 0.003 | 0.00028 | 0.077937 |

### 7.3.7 Pre-balance diagnostics of the NWS model (PREBAL)

In accordance with Heymans et al. (2016), we analysed the performance of the NWS model by running a set of pre-balanced (PREBAL) diagnostics routine. These diagnostics are based on biological and fisheries principles and it is recommended to conduct them before balance the model (Link, 2010; Heymans et al., 2016). These diagnostics, including the slopes of biomass ratios, vital rates, total production and consumption based on trophic levels, are based on biological and fisheries principles and they are recommended to check for thermodynamic and ecological principles that the model should be in agreement as proposed by Heymans et al. (2016).

The NWS model has been evaluated for the quality of the input data through the following PREBAL diagnostics:

a. *Biomass per trophic level:* The PREBAL criteria include the distribution of biomass per trophic level. It is expected that the slope of the biomass (on a long scale) decline by 5-10% across all the taxa arrayed by trophic level (Link, 2010). The PREBAL-NWS displayed a declining slope of the biomass (Figure 184). Values above and below the slope-line were checked for data integrity before initiating the mass-balance of the model. The biomass estimates of these groups were checked before the mass-balancing.

b. *Respiration/Assimilation Biomass (RA/AS) <1.0:* the proportion of biomass lost through respiration in the model (in EwE respiration is used to balance energy fluxes) cannot be higher than the biomass of food assimilated. As a rule, r-selected species (short life spans, lower trophic levels) are more likely to invest a large energy intake into growth and reproduction resulting in an RA/AS ratio below 1.0. In contrast, k-selected species (long-life spans, higher trophic levels) are expected to invest a relatively small proportion of energy intake in somatic and gonadal tissue production, are expected to have ratios close to 1.0. In the PREBAL-NWS model the higher values of RA/AS ratios were displayed by the higher trophic groups (Coastal sharks, rays, lizardfish, sea snakes, deep large fish, Lethrinids and Lutjanids), and as expected, values of RA/AS lower than 1.0 were showed by the groups within trophic level of two and three (Figure 185).

c. *Annual Production/Biomass (P/B):* In the model, the instantaneous mortality equals total production over mean biomass (Christensen and Walters, 2004), this means that total morality (Z) = (production/biomass) = P/B. As expected, the distribution of the ratios of P/B in the model has a negative slope (Figure 186). This outcome was expected because many lower trophic level groups (r-selected species) have short life spans characterized by higher mortality rates.

d. *Production to Consumption ratio (P/Q) or the gross food conversion:* P/Q in the model indicates that a group cannot produce more than a fraction of what it has eaten, based on the 2nd law of thermodynamics (Link, 2010). Because consumption is expected to be between two to ten times higher than production, in most cases, P/Q ratios will range between 0.05 to 0.5 (except for fast growing organisms and corals) as shown in Figure 187. Most of the P/Q values of the 66 consumer groups in the model were within the range of 0.05 to 0.5 (except for Bryozoa and hard corals) (Figure 187). Groups with P/Q values higher than 0.3 were checked again their input values such as biomasses, mortalities, consumption, predation rates (based on diet matrix) before initiate the balance of the model.

These PREBALs diagnostics are only meant to be the first check of the model before beginning the mass-balance process where further parameterization of some groups was conducted. Overall, the performance of the PREBAL diagnostics indicated that our pre-balanced model was in general thermodynamically consistent.

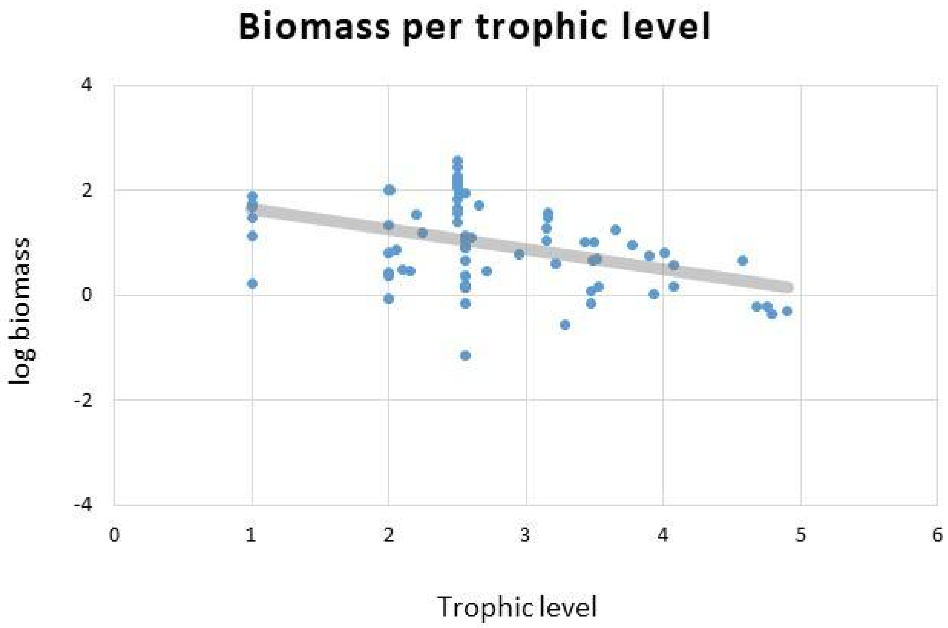


Figure 184. PREBAL diagnostics of the NWS model showing the distribution of biomass per trophic level

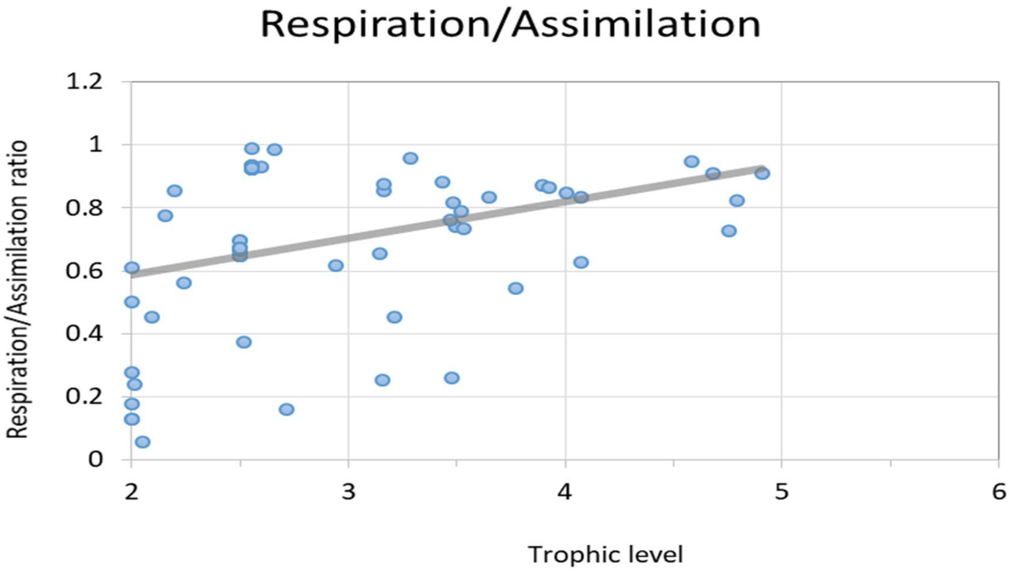


**Figure 185. PREBAL of the NWS model showing Respiration to Assimilation ratio (RA/AS) for all non-producer groups. It is expected that RA/AS is closer to 1 for higher trophic groups level groups.**

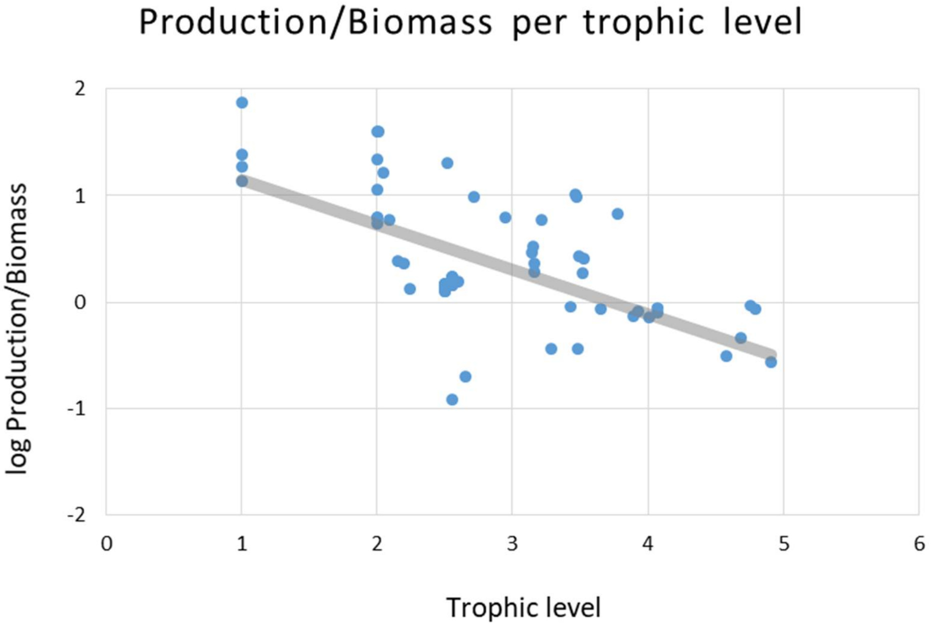


**Figure 186. Distribution of the Production / Biomass ratios by trophic level of the NWS model. The negative slope displayed is expected as lower trophic groups have in general higher mortality rates.**

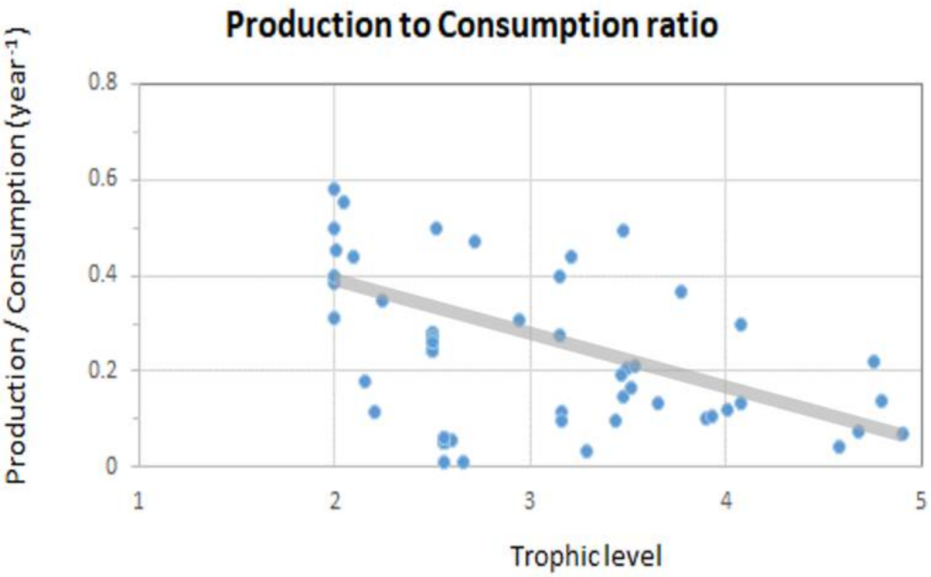
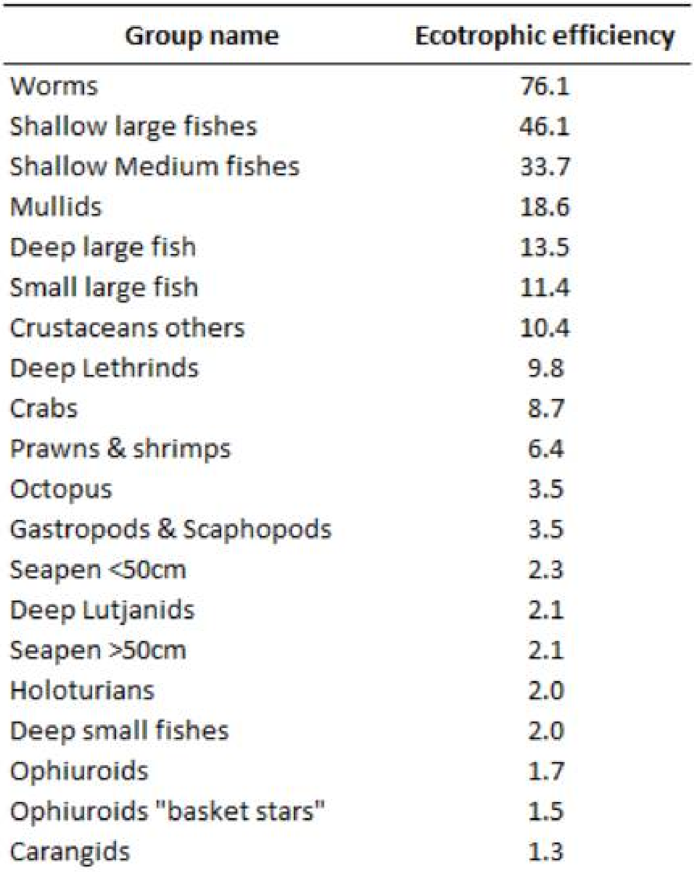


Figure 187. Distribution of the ratios of Production to Consumption (P/Q) values predicted by the model. It is expected that consumption must be between 2 to 10 higher than production.

### 7.3.8 Balancing the NWS model

Once the basic EwE parameters have been entered and the PREBAL diagnostic verified, the model requires mass-balancing to maintain the laws thermodynamics (Christensen et al., 2004). During the balancing of the model, we used the Ecotrophic Efficiency (EE) as a measure of the proportion of production that is utilized in the system by predation or fishing. EE cannot exceed 1.0 (it is not possible to consume more than is produced). As a general rule (Heymans et al., 2016), EE values near to 1.0 are expected for groups whose production is consumed by predator or removed by the fishery while values near to 0.0 are expected for groups with low predation rates (e.g. top predators like sharks) or not targeted by a fishery. Checks on EE values, and thermodynamic and ecological general rules in the PREBAL-NWS were used to highlight groups in the pre-balanced model that need to be adjusted within biologically plausible limits to achieve mass-balance of the flows in the food-web. We manually reduced predation mortality rates of groups with unrealistic EEs (worms, crustaceans others, bivalves, shallow and deep large fishes, among others) as suggested by Heymans et al. (2016). Table 31 presents the unrealistic EE generated during the first run of the PREBAL model, showing approximately 27% of the groups were out of balance (20 out of 73) are represented by fish and invertebrate groups. The model was balanced using a series of iterative steps. In all cases, in the first attempt to balance the model, we examined values of the ecotrophic efficiency (EE) that exceed 1.0 for some functional groups as presented in Table 28. The model was balanced manually to ensure that changes to the input parameters were kept within biological reasonable limits. The first step was to reduce the predation on the groups that were out of balance but maintaining the original values of biomass for groups with local biomass estimates. The second step was to adjust consumption rates (Q/B) and production rates (P/B) to achieve mass-balance, where changes of less than 10% were applied to those groups out of balance. Finally, we minimized cannibalism within groups (i.e. sharks) and liberate this energy to other groups (following Christensen et al., 2008). It is important to mention that the process required to build the NWS EwE model is essentially open-ended. The parameters used in the model have been revised and there is a possibility that new estimates along the project could replace some of the basic input parameters. The basic input parameters of the mass-balanced NWS model are presented in Table 28.

Table 31. Values of Ecotrophic Efficiency (EE) higher than 1 estimated by EwE for the NWS model. Values of EE>1 are unrealistic and they were adjusted manually by reducing predation rates on the diet matrix of these groups.



| Group name | Ecotrophic efficiency |
|---|---|
| Worms | 76.1 |
| Shallow large fishes | 46.1 |
| Shallow Medium fishes | 33.7 |
| Mullids | 18.6 |
| Deep large fish | 13.5 |
| Small large fish | 11.4 |
| Crustaceans others | 10.4 |
| Deep Lethrinds | 9.8 |
| Crabs | 8.7 |
| Prawns & shrimps | 6.4 |
| Octopus | 3.5 |
| Gastropods & Scaphopods | 3.5 |
| Seapen <50cm | 2.3 |
| Deep Lutjanids | 2.1 |
| Seapen >50cm | 2.1 |
| Holoturians | 2.0 |
| Deep small fishes | 2.0 |
| Ophiuroids | 1.7 |
| Ophiuroids "basket stars" | 1.5 |
| Carangids | 1.3 |

### 7.3.9 Network analysis

We used routines from the network analysis proposed by Ulanowicz (1986) and Ulanowicz and Puccia (1990) such as the mixed trophic impact (MTI) and energy transfer within the system. MTI analysis was used to assess the direct and indirect trophic interactions among compartments, including impacts of fishery practices throughout the NWS (Ulanowicz and Puccia, 1990; Christensen et al., 2005). MTI evaluates the effect of small increases in the biomass of one group on the biomass of the other groups, and thus provides a form of sensitivity analysis. The MTI included the 73 groups in the model. To present graphically the MTI results, a selected group of 33 groups (top predators, finfishes, target species, sponges and other invertebrates, zooplankton and phytoplankton) were used to represent the food web. Also, to explore the ecological role played by the groups within the NWS, we estimate a keystone species index (KSi) as proposed by Libralato et al. (2006):

$$KS_i = \log[\varepsilon_i * (1\text{-}p_i)]$$

where $\varepsilon_i$= overall effect of group *i* of the model on other groups calculated by the MTI, and $p_i$ represents the contribution of biomass from species i or functional group *i* with respect to the total biomass of the NWS food web. The network analysis (Ulanowicz, 1986) allowed us to estimate these ecosystem indices: a) total system throughput, b) mean transfer efficiency (%) between trophic levels, c) Finn's cycling index (FCI) (Finn, 1980), d) Finn's mean path length (FML) (Finn, 1980), e) connectance index and f) Omnivory index. The estimated net primary production, phytoplankton and zooplankton biomasses, total catches, mean trophic level of the catch, gross efficiency, the primary production required to sustain the fisheries and total biomass (excluding detritus), system overhead were also calculated (Christensen et al., 2005).

### 7.3.10 Simulations of temporal dynamics

Ecosim is time dynamic simulation module of EwE developed for policy exploration (Christensen and Walters, 2004). Biomass dynamics are described as:

$$\frac{dB_i}{dt} = g_i \sum_j \mathrm{Qji} - \sum_j \mathrm{Qij} + I_i - (M_i + F_i + e_i)B_i \quad (2)$$

where $dB_i/dt$ = change in biomass of Group i; gi = net growth efficiency; $Q_{ji}$ = consumption of Group *j* by Group i; $Q_{ij}$ is the consumption of Group *i* by Group *j*; $I_i$ = immigration of Group *i*; *Mi* and $F_i$ are the natural and fishing mortality rates of Group *i*, respectively; $e_i$ is the emigration of Group *i*; and B = biomass of Group *i*.

The biomass flows between groups are calculated in Ecosim by the 'foraging arena' concept (Christensen and Walters, 2004), in which the biomass of one group is divided into components that are vulnerable and invulnerable to predation. The maximum mortality rate that a predator can exert on a prey is determined by the vulnerability (v) parameter in Ecosim. High values of v (top-down control with v values >3) mean that predator consumption can control biomass, whereas a low value of v means prey biomass controls predator biomass (bottom-up control with v values <3).

The possible effect of related fishing on the biomass of the major groups in the system was evaluated in Ecosim by simulating the two scenarios to investigate:

1. Impact of fishing on the system by reducing the current fishing effort to zero and then simulating forward for 20 years.

2. Impact of fishing on the system by increasing current fishing effort 100% and projecting 20 years.

3. Ecological role of keystone groups in the system (Lizardfish, cuttlefish, Asteroids, and “Large Deep Fish”) by reducing 90% their biomass and projecting them over 20 years.

4. Ecological role of habitat-forming species by reducing 50% the biomass of sponges, corals and seagrass in the system and run the food web model for 20 years.

5. Business as usual by keeping all fishing efforts as 2016-17 and run the food web model for 20 years.

Table 32 presents the duration and rationale of the five scenarios tested.

**Table 32. Description of the baseline, fishing and ecological scenarios used to explore the dynamics of the NWS system.**

| | Scenario | Rationale |
|---|---|---|
| **Fishing pressure** | 1. BUA (Business as Usual): keep all fishing efforts at 2016-17 levels | Long-term effects of commercial fishing |
| | 2. Reduce all current fishing effort to zero and then simulate forward for 20 years | Long-term effects of commercial fishing |
| | 3. Current fishing pressure doubled for 10 years ("stress" period) and then, fishing pressure is returned to initial state for a further 10 years ("recovery" period) | Recovery time from fishing |
| **Ecology** | 4. Reduction of 90% biomass of keystone groups (Lizardfish, cuttlefish, Asteroids, large deep fish) | Ecological role of structuring groups (top-down control) |
| **Habitat modification** | 5. Reduction 50% of habitat-forming species (sponges, corals, seagrass) | Ecological role |

### 7.3.11 Model Indicators

The EwE foodweb of the NWS includes 71 living functional groups (and two detritus groups), which represent one or more species. A smaller number of indicators is needed to simplify our understanding of the overall system response to model dynamic scenarios. Six types of indicators were used to summarise and highlight the outputs of the foodweb model (see Table 38 for details). These are the six indicators used:

1. **Meta groups:** a combination of functional groups in the foodweb model. These included:

a. Target species: Carangids, Lethrinids, Lutjanids, prawns and Shrimps

b. Fish trophic level 2 to 3: small and medium fish in shallow and deep waters

2. **Keystone groups:** defined as “relative low biomass species with a structuring role in the food web” (Libralato et al., 2006) and identified by EwE. Here, a Keystone species in the

NWS food web are defined as structuring species by processes associated with predation (top-down forces):

a. Lizardfish

b. Cuttlefish and squids

c. Sharks

d. Asteroids

3. **Charismatic species:** specific functional groups in EwE food web which hold a particular social or ecological value (i.e. high conservation):

a. Sea snakes

b. Sea turtles

4. **Habitat forming groups:** functional groups which define habitats such as sponges, corals

5. Other invertebrates. A combination of functional groups representing all other invertebrates not listed above.

6. **Ecosystem level indicators:** selected to reflect the state of the overall food web rather of some of its components. These include:

a. Total biomass

b. Total catch

c. Kempton Diversity Index (Q) for food webs: This Index has been designed to measure species in the middle of the abundance distribution of these kind of models (Kempton and Taylor, 1976).

## 7.4 Results

### 7.4.1 Energy and mass flows

After the PREBAL analysis and tuning, the NWS model was used to calculate the trophic level (TL) aggregation for the 71 living groups, showing that the system spans in more than four trophic levels (Figure 188). The foodweb diagram of this ecosystem, including size proportional biomasses and trophic links is presented in Figure 188. The top predators were represented coastal sharks (e.g. *Carcharhinus coatesi*, *Loxodon macrorhinus*), lizardfish (e.g. *Synodus dermatogenys*, *S. hoshinonis*, *S. indicus*), sea snakes (*Aipysurus eydouxii*, *A. laevis*, *Acalyptophis peronii*), and some large fish (e.g. *Shyraena putnamae, Rachycentron canadum*) (Figure 188). Around 70% of the number of functional groups occurred at trophic level lower than 3.5, suggesting that the NWS is dominated by lower trophic groups (Figure 189).

We used the network analysis proposed by Ulanowics (1986) to quantify ecosystem attributes and functioning of the NWS. The network analysis built in EwE does not produce dynamic results and cannot predict how the biomass would change with time. However, this analysis provides valuable information about the structure of the NWS system, by providing a snapshot, underlining which parts of this ecosystem play a major role. An important attribute of the system is the distribution of the total biomass by trophic level. It provides a baseline against which future changes can be measured. For example, it could be used to evaluate possible changes of detecting loss in biomass of top predators in the NWS (e.g. sharks, lizard fish, sea snakes).

Figure 189 presents the distribution of the total biomass by trophic level in the NWS, where more than 60% of the total biomass in the system was located within the first two trophic levels (primary producers, filter feeders, herbivores and most invertebrates), suggesting that the NWS system is mainly dominated by lower trophic levels. The highest contribution to the total biomass in the model was from filter feeders and soft corals, comprising about 69% of the total biomass in the system. Trophic level 2 to 2.9, which includes sponges, corals, ascidians, gastropods, holothuroids, ophiuroids, and sea pen, comprised about 76% of the total biomass in the system (2,654 $t/km^2$), showing the dominance of benthic groups in this foodweb.

The myriad of trophic interactions, mass and energy flows in the NWS system showed that the mean transfer efficiency for the system originating from primary producers and detritus was 16.7% ± 4.8%. The total estimated energy flow from primary producers (TLI) to TLII (mainly invertebrates) was 22,697 $t\cdot km^{-2}$ year $^{-1}$, where 70% was primary producers (15,912 $t\cdot km^{-2}$ year $^{-1}$) and 29.8% from detritus (6,785 912 $t\cdot km^{-2}$ year $^{-1}$). The overall detritivore: herbivore ratio for the four TLs in the system was 0.66, suggesting that herbivory is more important than detritivory in the NWS (Figure 190). The total energy throughput in the system was 60,006 $t\cdot km^{-2}$ year $^{-1}$ from which 47% (28,269 $t\cdot km^{-2}$ year $^{-1}$) was consumed by predators at TL I, indicating a strong trophic interaction between primary producers (TL I) and benthic invertebrates and fish within TL II. The total energy consumed by predation declined from TL II to TL IV (Figure 190), where 20% of the total system throughput (12,357 $t\cdot km^{-2}$ year $^{-1}$), which it is lower than that from predation on TL I (47%). The mean trophic efficiency in the NWS ecosystem was 13%.

### 7.4.2 Mixed Trophic Impact analysis

Results of this routine highlighted the importance of lower trophic groups, particularly invertebrates such as cuttlefish, squids, prawns, and crabs (Figure 191). Detritus, DOM and microbial heterotrophs has a positive impact on most of the lower trophic groups, emphasizing its importance as a component in the base of this food web. Among the fish groups, the “Lizardfish” group (i.e. *Synodus dermatogenys*, *S. hoshinonis*, S. indicus) and “Deep large fish” (i.e. Barracuda, Sphyrnidae) had a large negative impact on prey groups, including turtles and finfish target species (i.e. Emperors, *Lethrinus* spp; Snappers, *Lutjanus* spp). In this trophic analysis, habitat-forming species such as sponges, and corals showed a modest positive impact on the food web (Figure 191) as they are not an important source of food rather by providing refuge from predators.

### 7.4.3 Keystone groups

The Keystone index calculated based on the relative total impacts (RTI) according to the Valls et al. (2015) methodology were highest for Lizardfish (RTI = 1.02), Cuttlefish & Squids (RTI=0.78), Sharks (RTI= 0.74) and Asteroids (RTI=0.71) as shown in Figure 192. These groups also showed the highest Keystone index values as calculated by the Libralato et al. (2006) methodology. The groups of Asteroids and Gastropods/Scaphopods had high RTI values (0.53 and 0.42, respectively), but they had a higher biomass than Lizardfish, Cuttlefish, and Sharks indicating an important role as prey and therefore may be defined as habitat structure forming groups (sponges, corals and seagrass) in this foodweb from top down forces associated with predation.

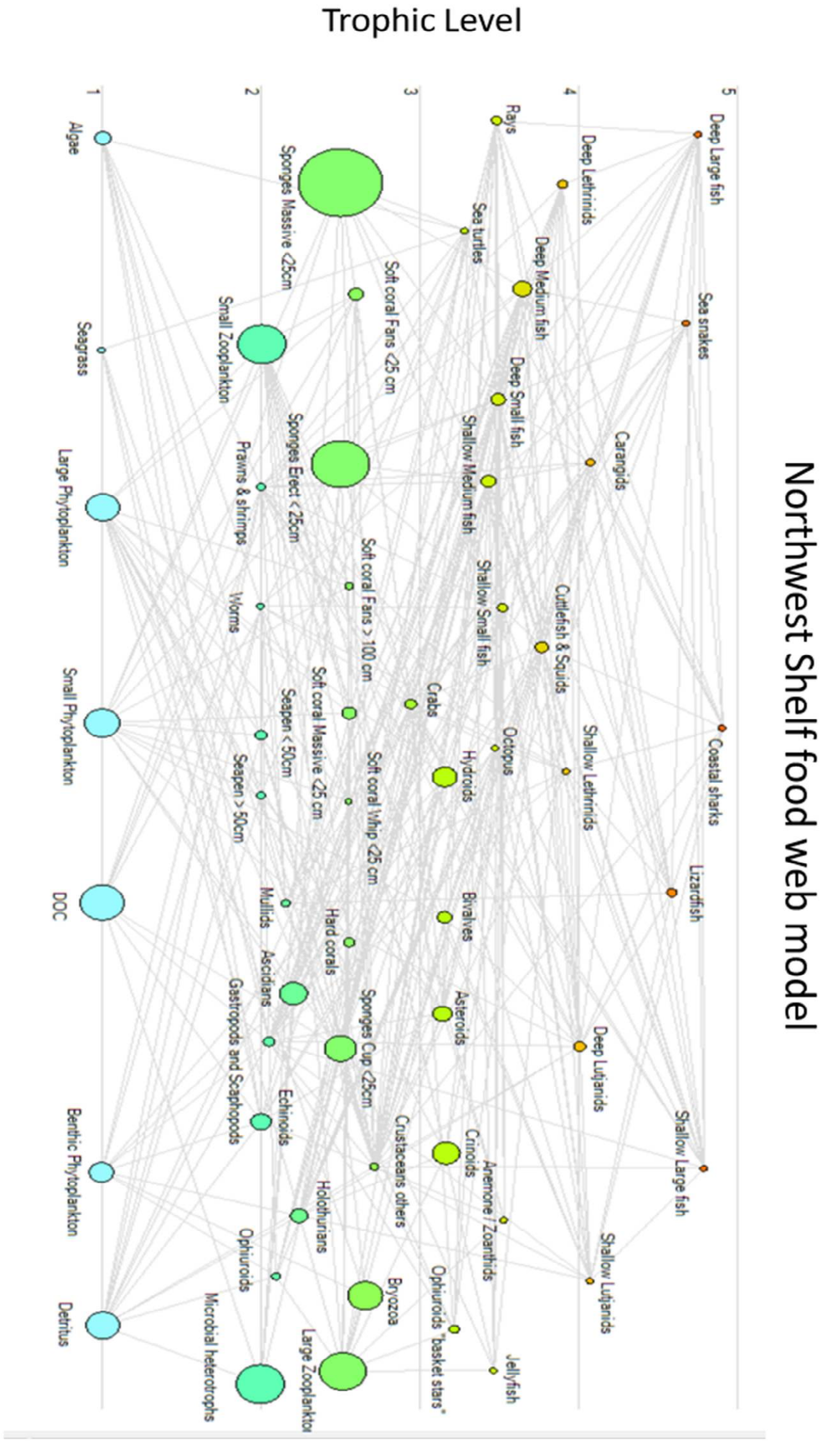


Figure 188. Food web diagram of the NWS ecosystem. Functional groups are indicated in circles with size proportional to their biomass. Colour of the circles represents the trophic level. The trophic links among groups are indicated by grey lines.

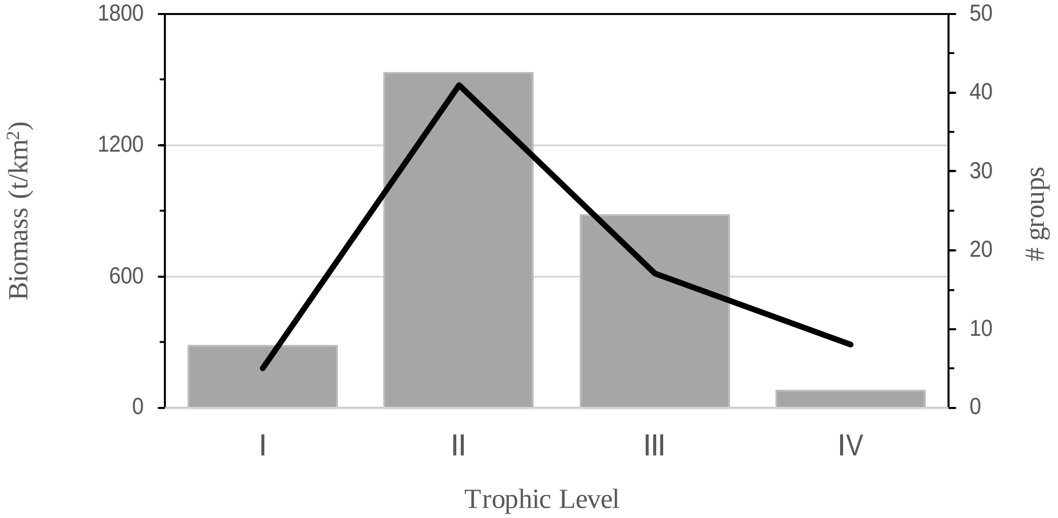


Figure 189. Distribution of total biomass (t/km$^2$) by trophic level in the NWS model (grey bars). The black line represents the trophic aggregation of the 71 living groups, shows that the system is largely controlled by lower trophic levels.

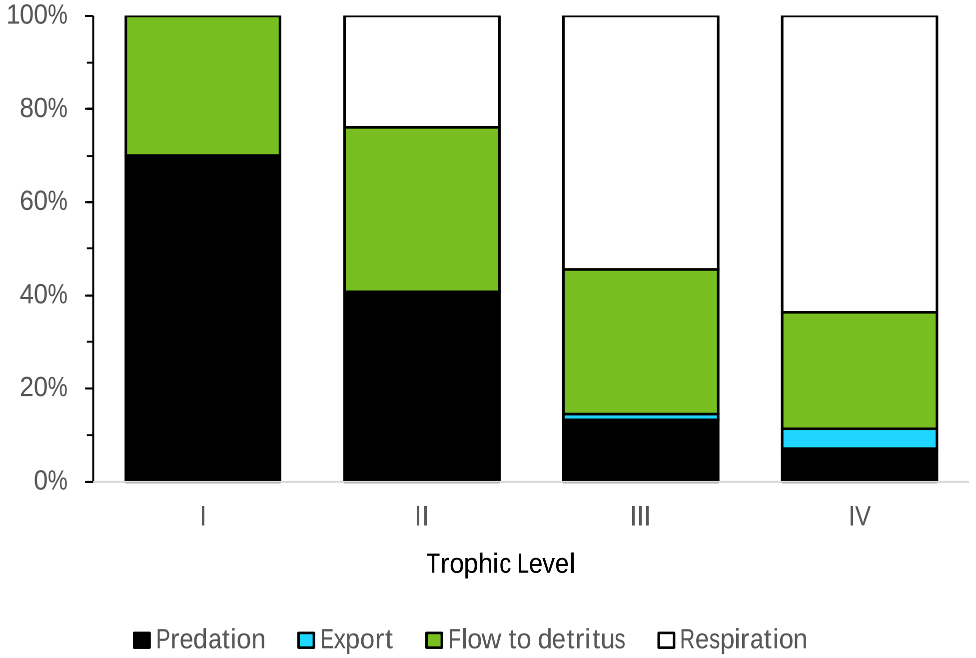


Figure 190. The proportion of the main energy flows (%) for each trophic level in the NWS model

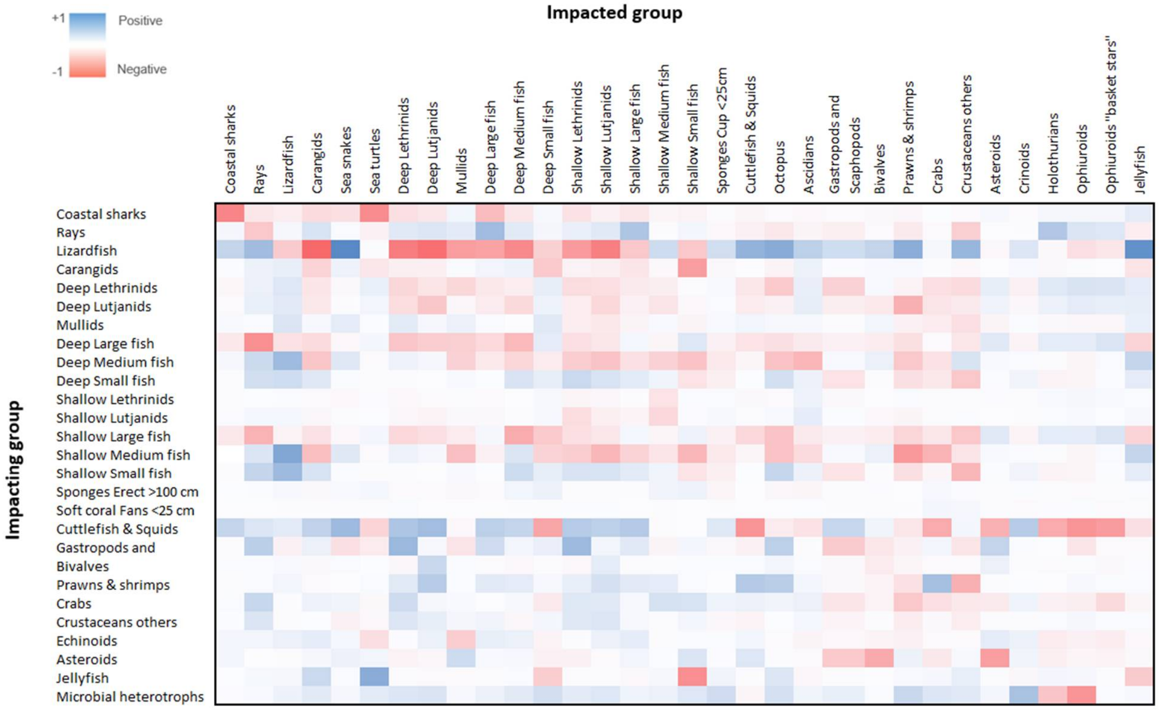


**Figure 191. The mixed trophic impact analysis for selected groups of the NWS model. Negative impacts are shown in red colour, positive impacts in blue and no impacts in white. Intensity of the colour is proportional to the degree of the trophic impacts.**

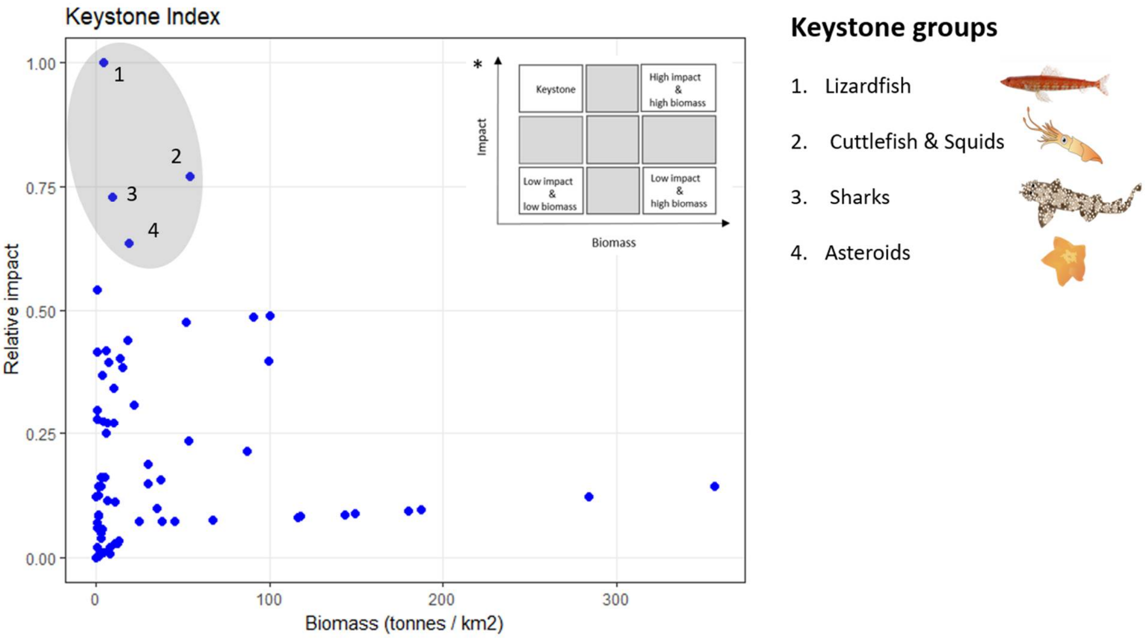


**Figure 192. Relationship between relative total impact and relative biomass of the functional groups used to define the Keystone groups in the NWS model (right). * Conceptual identification of Keystone species (Valls et al., 2015).**

### 7.4.4 Temporal dynamic simulations: the impact of fishing

The effect of fishing on the food web was explored using a set of scenarios as presented in Table 32. Results from Scenario 1 "Business as Usual" (where all fishing efforts were kept as 2016/17 for 20 years) showed a modest change in the biomass of target species with a mean increment of 19% respectively to the biomass estimated in 2017 for these groups (Figure 193). The Sea Snakes group showed the largest change in the system by increasing 36% its biomass and "Hard Corals" was the only group that declined (2%) under this scenario as shown in Figure 193. Overall, most of the group indicators increased between 5% and 20% over the 20-year period simulated (Figure 193). The results suggest that fishing for 20 years under this fishing effort resulted in the model that both the total biomass and overall diversity (measured by Kempton Q's Index) in the system increased 19% and 4%, respectively (Figure 193). The simulated biomass changes for all the groups in this scenario are presented in Table 33.

Results from scenario 2 "No fishing" (close all commercial fisheries in the system and simulate effects for 20-year period) suggested significant changes in the abundance of target groups with a mean increment of 64% of their biomass compared with that estimated in 2017 (Figure 193). Also, an important increment in the biomass (47%) of large finfish groups, associated with predator species, was found in the simulations of this scenario (Figure 193). As result of the indirect trophic interactions, the abundance of small "other invertebrates" group showed a modest increment of its biomass (11%). The results of this scenario suggest that closing of commercial fishing could impact positively on non-target species such as turtles and sharks (Figure 193). Total biomass and diversity of the whole system increased 18% and 6% after 20 years, respectively (Figure 193). The simulated biomass changes for all the groups under these conditions are presented in Table 34.

Results from Scenario 3 "Recovery time from fishing" (simulated increment of fishing pressure doubled for 10 years – "stress period"- and then, fishing effort is returned to initial state for a further 10 years – "recovery period") suggested small increments in the abundance of target groups (mean = 9%) after the "recovery time" of 10 years (Figure 193). Important reductions (up to 10%) in the biomass of groups such as "Hard corals", "Sharks", "Cuttlefish & Squid" and "Fish Trophic Level >3.1" were predicted by the model (Figure 193). Total biomass was predicted by the model to increase 11% and the diversity of the system (measured by Kempton Q's Index) to declined 7% to that estimated in 2017 (Figure 193). The simulated biomass changes for all the groups under these conditions are presented in Table 35.

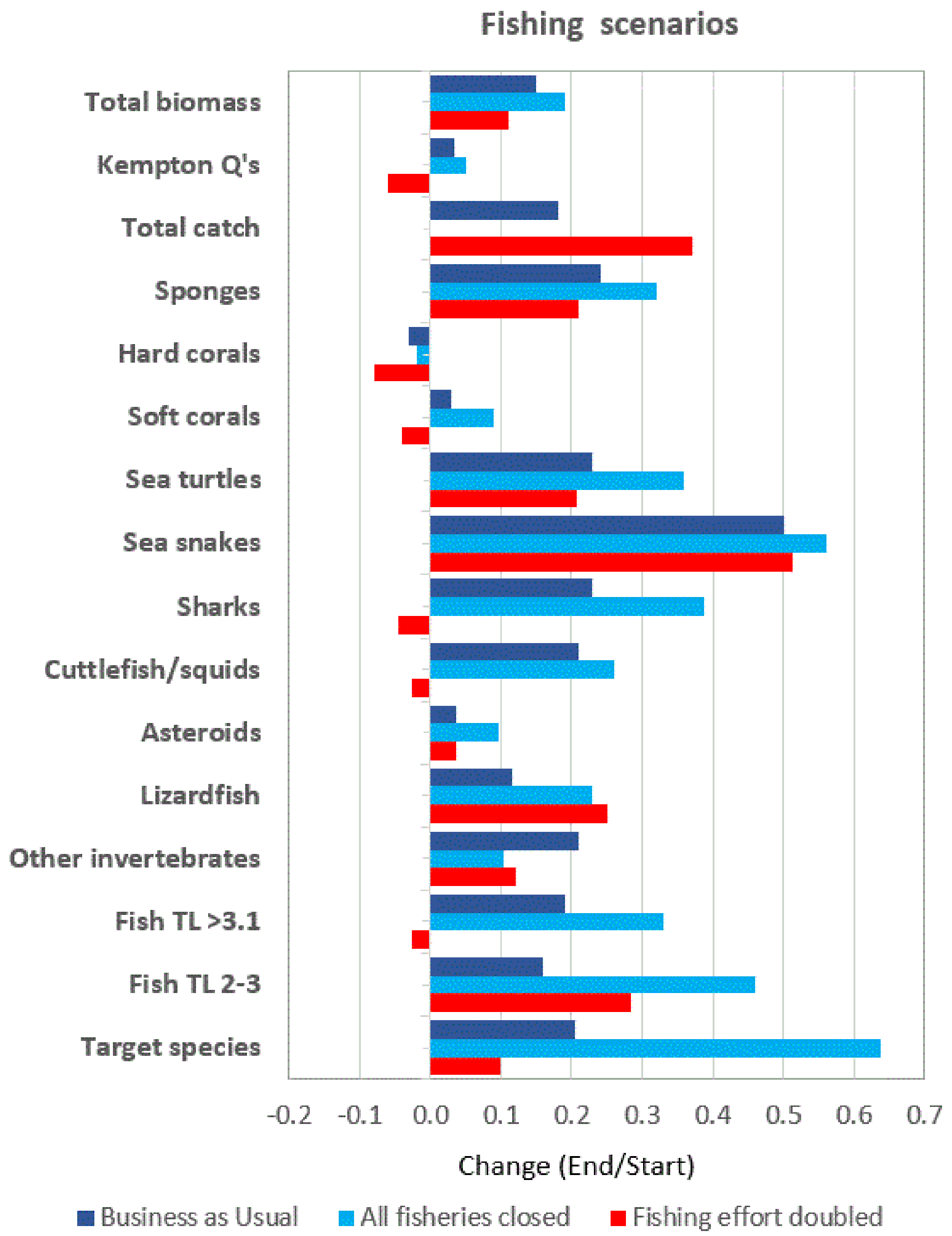


Figure 193. Proportion of change in the biomass of the indicators of the NWS after 20 years of simulation under different fishing scenarios. Details of these scenarios are presented in Table 32.

### 7.4.5 Temporal dynamic simulations: the role of Keystone and habitat-forming groups

The ecological role of keystone groups was explored in the model by reducing 90% the biomass of the top four Keystones groups (as defined in methods.) over a 20-year period. Results of this scenario predicted significant changes in the abundance of “Target species” and “Fish TL >3.1” groups with an increment of 48% and 61% in their biomasses, respectively (Figure 194). Some indirect trophic impacts from the reduction of top predators were detected by a reduction of 2% of small fish (prey of larger fish) located within trophic level 2 to 3 (Figure 194). No major changes in the diversity of the system (<2%) were predicted by the model. The simulated biomass changes for all the groups under these conditions are presented in Table 36.

Results from Scenario 5 “Role of habitat-forming species” (reduction 50% in the biomass of habitat-forming species such as “Sponges”, “ Corals”, “Seagrass”) predicted an important changes in the abundance of turtles and small fishes (“Fish TL 2-3” group ) with a loss of 21% and 16% in their biomasses, respectively (Figure 195). The total biomass and diversity of the system were also negatively impacted by the loss of habitat-forming species. The system loss 27% in its biomass and 2% in its diversity after 20 years (Figure 195). The simulated biomass changes for all the groups under these conditions are presented in Table 37.

The results of the EwE NWS model development and selected scenarios have been summarized and presented in the Pilbara Symposium (13 July 2019; Fremantle Western Australia).

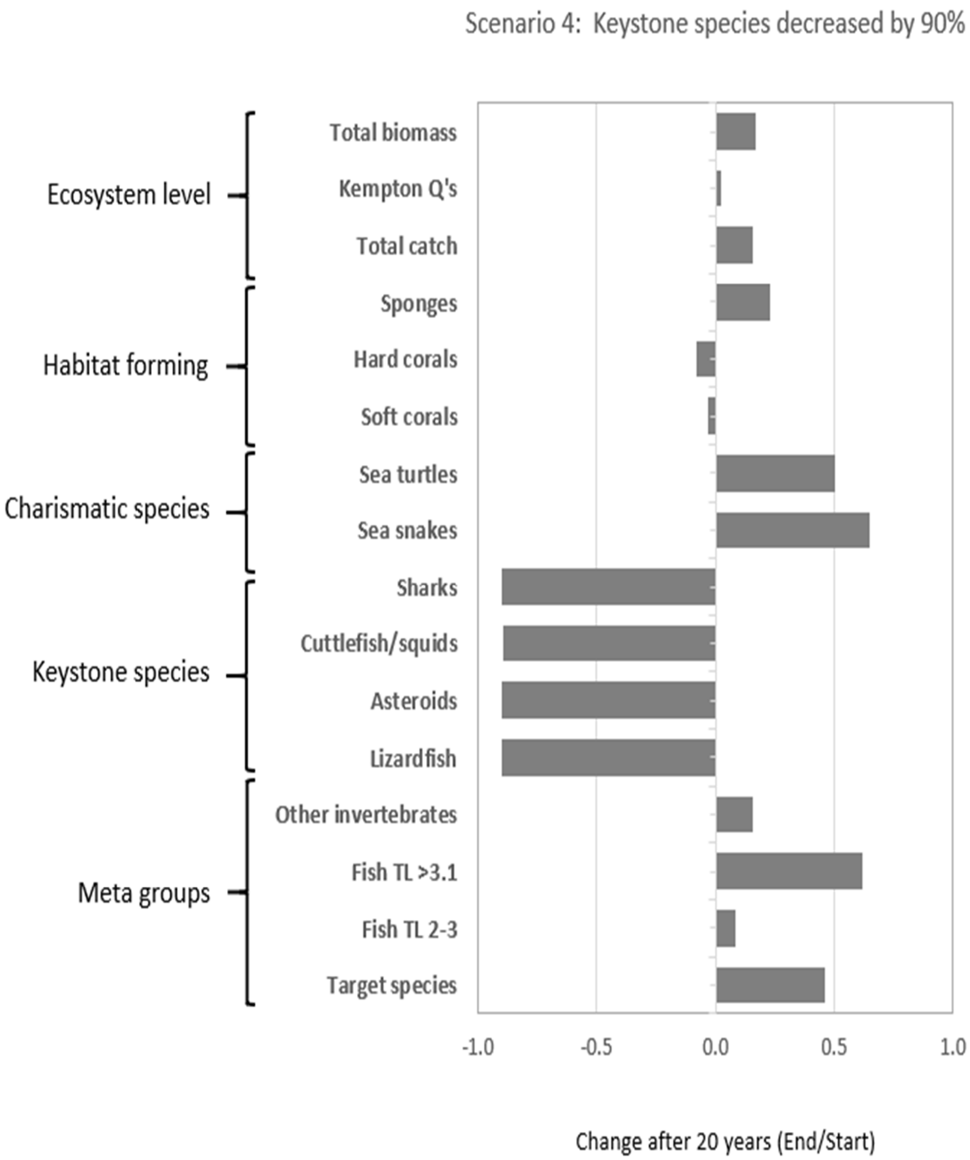


**Figure 194. Proportion of change in the biomass of the indicators of the NWS model after 20 years of reducing 90% the biomass of keystone groups ("Lizardfish", "Cuttlefish/Squid", "Asteroids" and "Large deep fish". See Table 32 for details.**

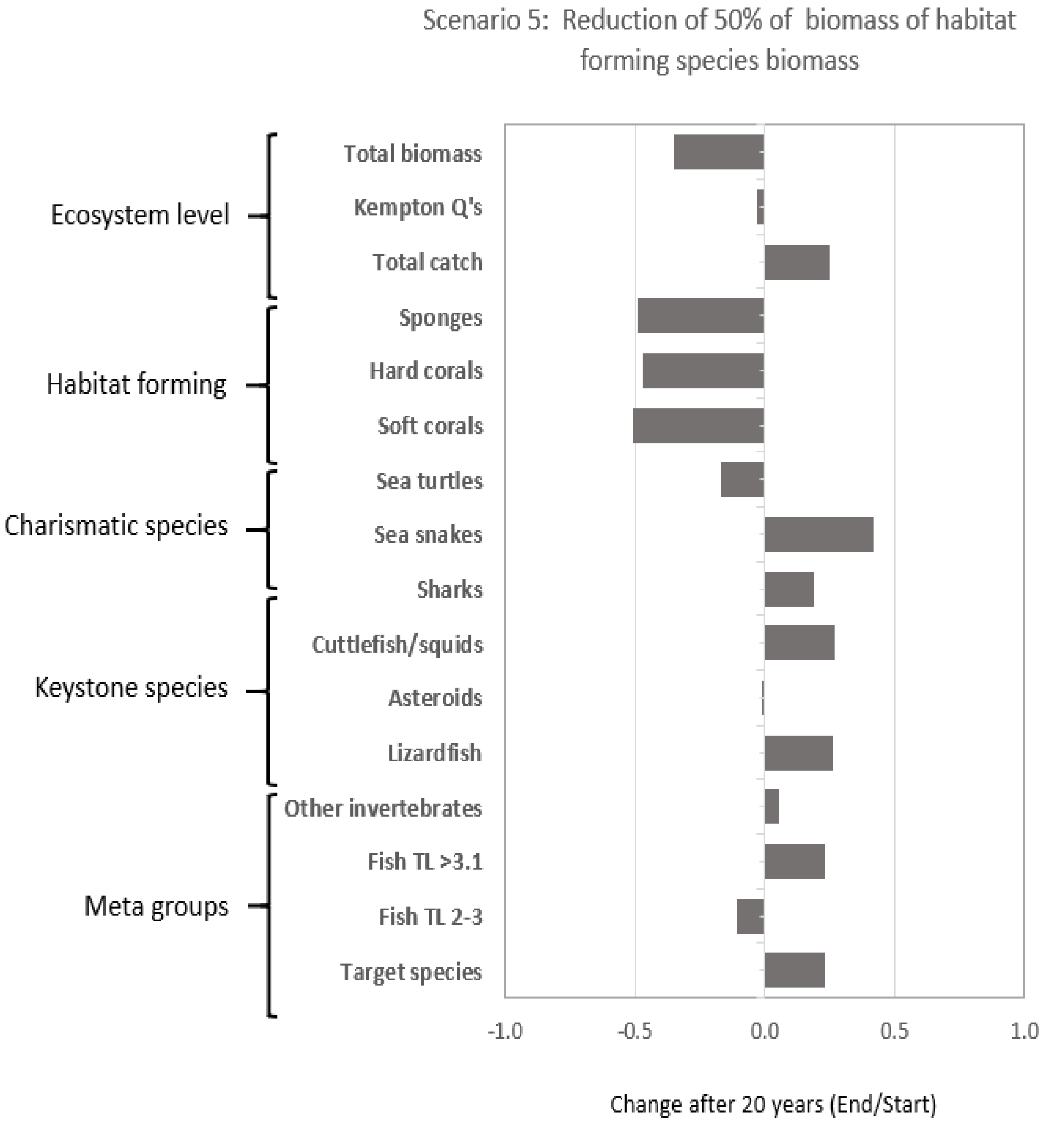


**Figure 195. Proportion of changes in the biomass of the indicator groups of the NWS model after 20 years of reducing 50% the biomass of habitat-forming groups sponges, corals, seagrass). See Table 32 for details of this scenario.**

**Table 33. Results from Ecosim Scenario # 1 Business as Usual. All fishing efforts were kelp at the same level as 2017 and run it over 20 years**

| | Group name | Biomass (start) | Biomass (end) | Biomass (E/S) |
|---|---|---|---|---|
| 1 | Coastal sharks | 0.513 | 0.631 | 1.230 |
| 2 | Rays | 4.795 | 5.938 | 1.238 |
| 3 | Lizardfish | 4.688 | 5.417 | 1.155 |
| 4 | Carangids | 3.832 | 4.079 | 1.064 |
| 5 | Sea snakes | 0.630 | 0.950 | 1.508 |
| 6 | Sea turtles | 0.266 | 0.327 | 1.230 |
| 7 | Deep Lethrinids | 5.936 | 7.668 | 1.292 |
| 8 | Deep Lutjanids | 6.903 | 8.720 | 1.263 |
| 9 | Mullids | 2.917 | 2.396 | 0.821 |
| 10 | Deep Large fish | 0.629 | 0.839 | 1.333 |
| 11 | Deep Medium fish | 18.080 | 19.473 | 1.077 |
| 12 | Deep Small fish | 10.040 | 11.004 | 1.096 |
| 13 | Shallow Lethrinids | 1.089 | 1.535 | 1.409 |
| 14 | Shallow Lutjanids | 1.509 | 2.042 | 1.353 |
| 15 | Shallow Large fish | 0.433 | 0.591 | 1.365 |
| 16 | Shallow Medium fish | 10.573 | 12.993 | 1.229 |
| 17 | Shallow Small fish | 4.931 | 5.043 | 1.023 |
| 18 | Sponges Cup <25cm | 55.376 | 67.270 | 1.215 |
| 19 | Sponges Cup 25-50cm | 144.632 | 178.777 | 1.236 |
| 20 | Sponges Cup 50-100 cm | 81.440 | 101.669 | 1.248 |
| 21 | Sponges Cup >100 cm | 45.082 | 55.489 | 1.231 |
| 22 | Sponges Massive <25cm | 438.618 | 544.373 | 1.241 |
| 23 | Sponges Massive 25-50cm | 346.962 | 435.529 | 1.255 |
| 24 | Sponges Massive 50-100 cm | 180.829 | 228.134 | 1.262 |
| 25 | Sponges Massive >100 cm | 215.725 | 277.760 | 1.288 |
| 26 | Sponges Erect < 25cm | 176.702 | 218.695 | 1.238 |
| 27 | Sponges Erect 25-50cm | 228.333 | 286.219 | 1.254 |
| 28 | Sponges Erect 50-100 cm | 140.744 | 177.203 | 1.259 |
| 29 | Sponges Erect >100 cm | 29.896 | 34.904 | 1.167 |
| 30 | Soft coral Fans <25 cm | 13.772 | 14.884 | 1.081 |
| 31 | Soft coral Fans 25-50 cm | 13.484 | 12.075 | 0.896 |
| 32 | Soft coral Fans 50-100 cm | 8.430 | 7.556 | 0.896 |
| 33 | Soft coral Fans > 100 cm | 2.407 | 2.159 | 0.897 |
| 34 | Soft coral Massive <25 cm | 11.299 | 10.113 | 0.895 |
| 35 | Soft coral Massive 25-50 cm | 87.067 | 77.970 | 0.896 |
| 36 | Soft coral Massive 50-100 cm | 4.767 | 4.272 | 0.896 |
| 37 | Soft coral Massive >100 cm | 0.071 | 0.064 | 0.897 |
| 38 | Soft coral Whip <25 cm | 0.690 | 0.616 | 0.893 |
| 39 | Soft coral Whip 25-100cm | 1.598 | 1.427 | 0.893 |
| 40 | Soft coral Whip 50-100cm | 1.435 | 1.282 | 0.893 |
| 41 | Soft coral Whip > 100cm | 1.334 | 1.193 | 0.894 |
| 42 | Hard corals | 7.730 | 7.516 | 0.972 |
| 43 | Cuttlefish & Squids | 10.302 | 12.384 | 1.202 |
| 44 | Octopus | 1.515 | 1.832 | 1.209 |
| 45 | Bryozoa | 53.320 | 51.655 | 0.969 |
| 46 | Hydroids | 30.279 | 28.776 | 0.950 |
| 47 | Ascidians | 39.954 | 37.658 | 0.943 |
| 48 | Gastropods and Scaphopods | 8.924 | 9.781 | 1.096 |
| 49 | Bivalves | 11.249 | 9.847 | 0.875 |
| 50 | Prawns & shrimps | 3.617 | 4.259 | 1.178 |
| 51 | Crabs | 7.994 | 11.779 | 1.473 |
| 52 | Crustaceans others | 3.621 | 4.994 | 1.379 |
| 53 | Echinoids | 22.820 | 23.233 | 1.018 |
| 54 | Asteroids | 20.871 | 21.631 | 1.036 |
| 55 | Crinoids | 37.158 | 34.971 | 0.941 |
| 56 | Holothurians | 18.287 | 28.011 | 1.532 |
| 57 | Ophiuroids | 5.474 | 6.757 | 1.234 |
| 58 | Ophiuroids "basket stars" | 3.843 | 3.274 | 0.852 |
| 59 | Seapen < 50cm | 8.171 | 9.756 | 1.194 |
| 60 | Seapen > 50cm | 3.435 | 4.045 | 1.178 |
| 61 | Worms | 1.383 | 1.618 | 1.170 |
| 62 | Anemone / Zoanthids | 1.496 | 1.662 | 1.111 |
| 63 | Large Zooplankton | 91.621 | 88.870 | 0.970 |
| 64 | Small Zooplankton | 100.405 | 89.701 | 0.893 |
| 65 | Jellyfish | 0.694 | 0.843 | 1.215 |
| 66 | Microbial heterotrophs | 185.074 | 145.556 | 0.786 |
| 67 | Algae | 13.164 | 13.492 | 1.025 |
| 68 | Seagrass | 1.614 | 1.570 | 0.973 |
| 69 | Large Phytoplankton | 51.509 | 53.326 | 1.035 |
| 70 | Small Phytoplankton | 54.636 | 50.508 | 0.924 |
| 71 | Benthic Phytoplankton | 29.476 | 28.388 | 0.963 |

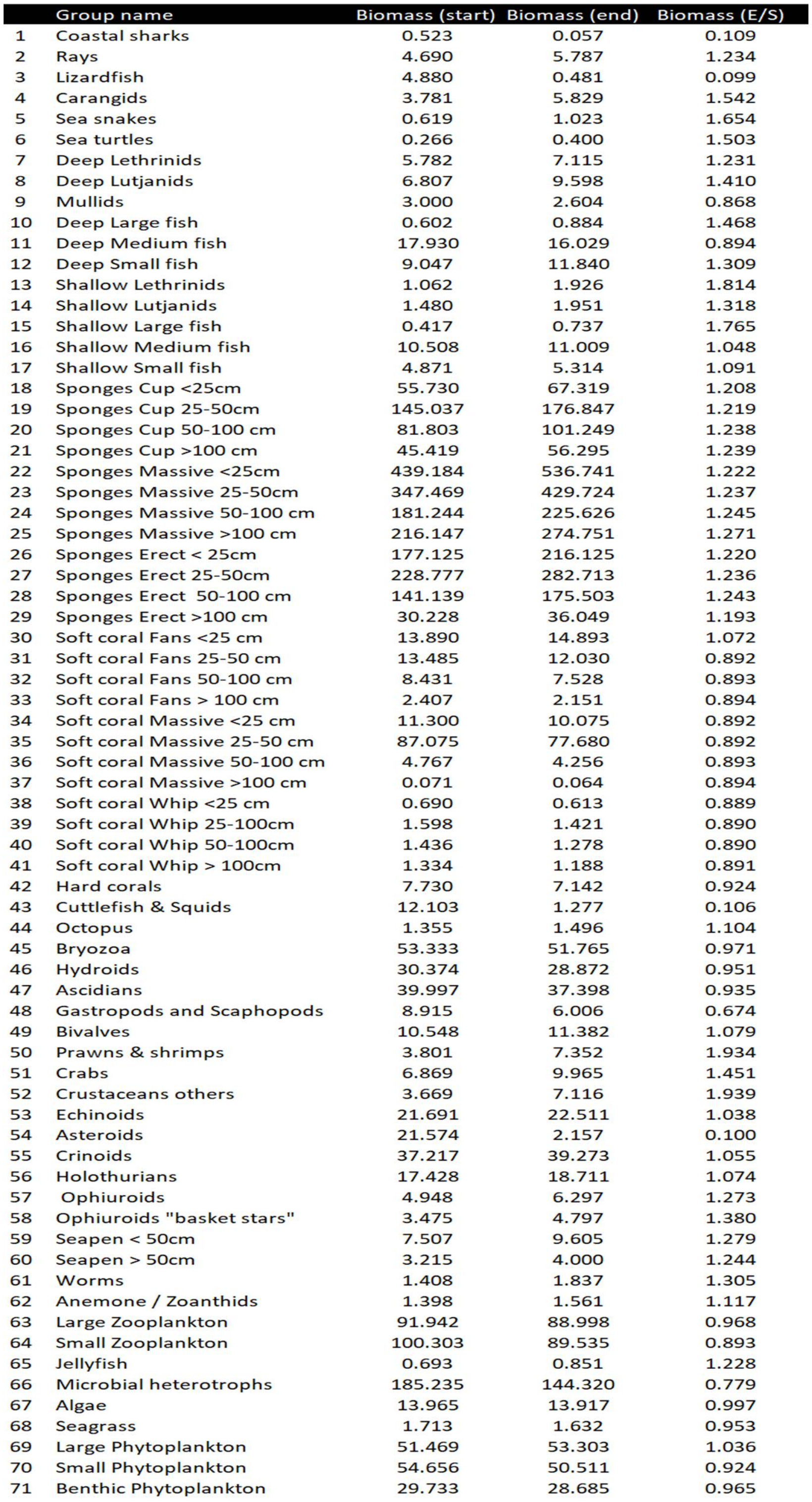
## Table 34. Results from Ecosim Scenario 2 where all fisheries are closed, and the system is projected over 20 years

| | Group name | Biomass (start) | Biomass (end) | Biomass (E/S) |
|---|---|---|---|---|
| 1 | Coastal sharks | 0.513 | 0.711 | 1.386 |
| 2 | Rays | 4.793 | 5.705 | 1.190 |
| 3 | Lizardfish | 4.687 | 5.793 | 1.236 |
| 4 | Carangids | 3.832 | 4.514 | 1.178 |
| 5 | Sea snakes | 0.630 | 0.987 | 1.568 |
| 6 | Sea turtles | 0.266 | 0.361 | 1.357 |
| 7 | Deep Lethrinids | 5.943 | 8.088 | 1.361 |
| 8 | Deep Lutjanids | 6.909 | 9.286 | 1.344 |
| 9 | Mullids | 2.917 | 2.702 | 0.926 |
| 10 | Deep Large fish | 0.635 | 0.842 | 1.325 |
| 11 | Deep Medium fish | 18.083 | 25.568 | 1.414 |
| 12 | Deep Small fish | 10.043 | 15.946 | 1.588 |
| 13 | Shallow Lethrinids | 1.091 | 1.574 | 1.442 |
| 14 | Shallow Lutjanids | 1.513 | 2.259 | 1.493 |
| 15 | Shallow Large fish | 0.434 | 0.578 | 1.333 |
| 16 | Shallow Medium fish | 10.574 | 14.821 | 1.402 |
| 17 | Shallow Small fish | 4.931 | 7.110 | 1.442 |
| 18 | Sponges Cup <25cm | 55.375 | 67.342 | 1.216 |
| 19 | Sponges Cup 25-50cm | 144.631 | 184.071 | 1.273 |
| 20 | Sponges Cup 50-100 cm | 81.439 | 102.418 | 1.258 |
| 21 | Sponges Cup >100 cm | 45.081 | 54.266 | 1.204 |
| 22 | Sponges Massive <25cm | 438.618 | 567.472 | 1.294 |
| 23 | Sponges Massive 25-50cm | 346.961 | 451.127 | 1.300 |
| 24 | Sponges Massive 50-100 cm | 180.828 | 233.868 | 1.293 |
| 25 | Sponges Massive >100 cm | 215.724 | 283.159 | 1.313 |
| 26 | Sponges Erect < 25cm | 176.701 | 225.921 | 1.279 |
| 27 | Sponges Erect 25-50cm | 228.332 | 295.270 | 1.293 |
| 28 | Sponges Erect 50-100 cm | 140.743 | 180.897 | 1.285 |
| 29 | Sponges Erect >100 cm | 29.895 | 33.606 | 1.124 |
| 30 | Soft coral Fans <25 cm | 13.772 | 15.421 | 1.120 |
| 31 | Soft coral Fans 25-50 cm | 13.484 | 12.357 | 0.916 |
| 32 | Soft coral Fans 50-100 cm | 8.430 | 7.727 | 0.917 |
| 33 | Soft coral Fans > 100 cm | 2.407 | 2.206 | 0.917 |
| 34 | Soft coral Massive <25 cm | 11.299 | 10.354 | 0.916 |
| 35 | Soft coral Massive 25-50 cm | 87.067 | 79.791 | 0.916 |
| 36 | Soft coral Massive 50-100 cm | 4.767 | 4.369 | 0.917 |
| 37 | Soft coral Massive >100 cm | 0.071 | 0.065 | 0.917 |
| 38 | Soft coral Whip <25 cm | 0.690 | 0.632 | 0.916 |
| 39 | Soft coral Whip 25-100cm | 1.598 | 1.464 | 0.916 |
| 40 | Soft coral Whip 50-100cm | 1.435 | 1.315 | 0.916 |
| 41 | Soft coral Whip > 100cm | 1.334 | 1.223 | 0.916 |
| 42 | Hard corals | 7.730 | 7.699 | 0.996 |
| 43 | Cuttlefish & Squids | 10.297 | 13.004 | 1.263 |
| 44 | Octopus | 1.514 | 1.638 | 1.082 |
| 45 | Bryozoa | 53.320 | 51.768 | 0.971 |
| 46 | Hydroids | 30.279 | 29.815 | 0.985 |
| 47 | Ascidians | 39.954 | 39.509 | 0.989 |
| 48 | Gastropods and Scaphopods | 8.922 | 9.326 | 1.045 |
| 49 | Bivalves | 11.247 | 9.816 | 0.873 |
| 50 | Prawns & shrimps | 3.616 | 3.949 | 1.092 |
| 51 | Crabs | 7.994 | 10.900 | 1.364 |
| 52 | Crustaceans others | 3.619 | 4.342 | 1.200 |
| 53 | Echinoids | 22.822 | 23.584 | 1.033 |
| 54 | Asteroids | 20.873 | 22.927 | 1.098 |
| 55 | Crinoids | 37.158 | 36.007 | 0.969 |
| 56 | Holothurians | 18.288 | 28.361 | 1.551 |
| 57 | Ophiuroids | 5.475 | 7.014 | 1.281 |
| 58 | Ophiuroids "basket stars" | 3.844 | 3.672 | 0.955 |
| 59 | Seapen < 50cm | 8.170 | 9.056 | 1.108 |
| 60 | Seapen > 50cm | 3.434 | 3.813 | 1.110 |
| 61 | Worms | 1.383 | 1.602 | 1.158 |
| 62 | Anemone / Zoanthids | 1.496 | 1.648 | 1.102 |
| 63 | Large Zooplankton | 91.621 | 89.496 | 0.977 |
| 64 | Small Zooplankton | 100.405 | 92.418 | 0.920 |
| 65 | Jellyfish | 0.694 | 0.782 | 1.126 |
| 66 | Microbial heterotrophs | 185.075 | 158.766 | 0.858 |
| 67 | Algae | 13.164 | 13.577 | 1.031 |
| 68 | Seagrass | 1.614 | 1.627 | 1.008 |
| 69 | Large Phytoplankton | 51.509 | 52.946 | 1.028 |
| 70 | Small Phytoplankton | 54.636 | 51.216 | 0.937 |
| 71 | Benthic Phytoplankton | 29.477 | 28.749 | 0.975 |

### Table 35. Results from Ecosim Scenario 3 where fishing effort is doubled over 20 years

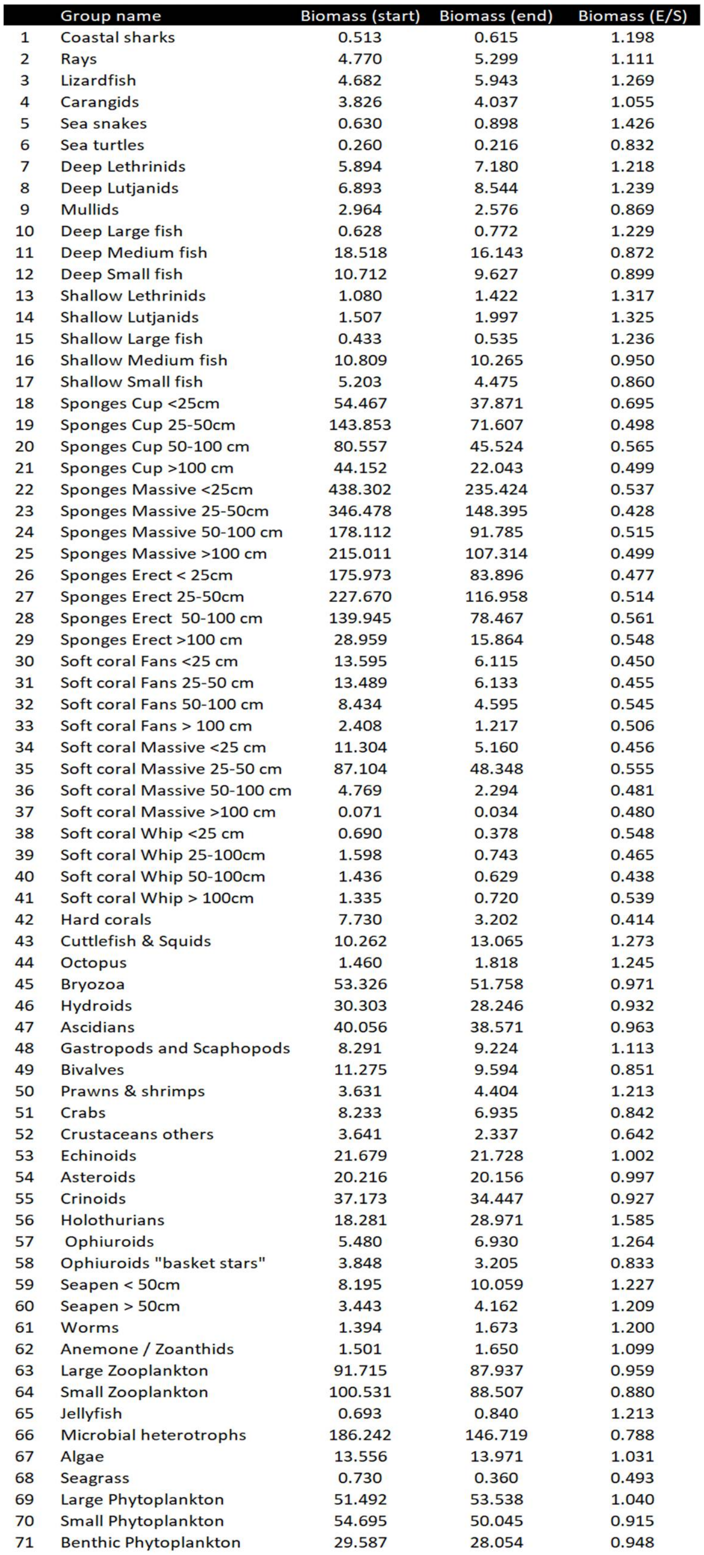
| | Group name | Biomass (start) | Biomass (end) | Biomass (E/S) |
|---|---|---|---|---|
| 1 | Coastal sharks | 0.513 | 0.490 | 0.954 |
| 2 | Rays | 4.795 | 5.947 | 1.240 |
| 3 | Lizardfish | 4.688 | 5.872 | 1.252 |
| 4 | Carangids | 3.832 | 4.078 | 1.064 |
| 5 | Sea snakes | 0.630 | 0.952 | 1.511 |
| 6 | Sea turtles | 0.266 | 0.321 | 1.207 |
| 7 | Deep Lethrinids | 5.936 | 5.364 | 0.904 |
| 8 | Deep Lutjanids | 6.903 | 6.217 | 0.901 |
| 9 | Mullids | 2.917 | 3.395 | 1.164 |
| 10 | Deep Large fish | 0.629 | 0.604 | 0.959 |
| 11 | Deep Medium fish | 18.080 | 21.462 | 1.187 |
| 12 | Deep Small fish | 10.040 | 15.001 | 1.494 |
| 13 | Shallow Lethrinids | 1.089 | 1.134 | 1.041 |
| 14 | Shallow Lutjanids | 1.509 | 1.640 | 1.087 |
| 15 | Shallow Large fish | 0.433 | 0.429 | 0.991 |
| 16 | Shallow Medium fish | 10.573 | 12.994 | 1.229 |
| 17 | Shallow Small fish | 4.931 | 6.043 | 1.226 |
| 18 | Sponges Cup <25cm | 55.377 | 67.272 | 1.215 |
| 19 | Sponges Cup 25-50cm | 144.632 | 178.777 | 1.236 |
| 20 | Sponges Cup 50-100 cm | 81.440 | 101.670 | 1.248 |
| 21 | Sponges Cup >100 cm | 45.082 | 55.492 | 1.231 |
| 22 | Sponges Massive <25cm | 438.618 | 544.366 | 1.241 |
| 23 | Sponges Massive 25-50cm | 346.962 | 435.524 | 1.255 |
| 24 | Sponges Massive 50-100 cm | 180.829 | 228.134 | 1.262 |
| 25 | Sponges Massive >100 cm | 215.725 | 277.759 | 1.288 |
| 26 | Sponges Erect < 25cm | 176.702 | 218.694 | 1.238 |
| 27 | Sponges Erect 25-50cm | 228.333 | 286.217 | 1.254 |
| 28 | Sponges Erect 50-100 cm | 140.744 | 177.203 | 1.259 |
| 29 | Sponges Erect >100 cm | 29.896 | 34.907 | 1.168 |
| 30 | Soft coral Fans <25 cm | 13.772 | 14.884 | 1.081 |
| 31 | Soft coral Fans 25-50 cm | 13.484 | 12.075 | 0.896 |
| 32 | Soft coral Fans 50-100 cm | 8.430 | 7.556 | 0.896 |
| 33 | Soft coral Fans > 100 cm | 2.407 | 2.159 | 0.897 |
| 34 | Soft coral Massive <25 cm | 11.299 | 10.113 | 0.895 |
| 35 | Soft coral Massive 25-50 cm | 87.067 | 77.970 | 0.896 |
| 36 | Soft coral Massive 50-100 cm | 4.767 | 4.272 | 0.896 |
| 37 | Soft coral Massive >100 cm | 0.071 | 0.064 | 0.897 |
| 38 | Soft coral Whip <25 cm | 0.690 | 0.616 | 0.893 |
| 39 | Soft coral Whip 25-100cm | 1.598 | 1.427 | 0.893 |
| 40 | Soft coral Whip 50-100cm | 1.435 | 1.282 | 0.893 |
| 41 | Soft coral Whip > 100cm | 1.334 | 1.193 | 0.894 |
| 42 | Hard corals | 7.730 | 7.161 | 0.926 |
| 43 | Cuttlefish & Squids | 10.302 | 10.026 | 0.973 |
| 44 | Octopus | 1.515 | 1.832 | 1.210 |
| 45 | Bryozoa | 53.320 | 51.654 | 0.969 |
| 46 | Hydroids | 30.279 | 28.775 | 0.950 |
| 47 | Ascidians | 39.954 | 37.657 | 0.943 |
| 48 | Gastropods and Scaphopods | 8.924 | 9.783 | 1.096 |
| 49 | Bivalves | 11.249 | 9.850 | 0.876 |
| 50 | Prawns & shrimps | 3.617 | 4.261 | 1.178 |
| 51 | Crabs | 7.994 | 11.780 | 1.474 |
| 52 | Crustaceans others | 3.621 | 4.995 | 1.380 |
| 53 | Echinoids | 22.820 | 23.231 | 1.018 |
| 54 | Asteroids | 20.871 | 21.630 | 1.036 |
| 55 | Crinoids | 37.158 | 34.971 | 0.941 |
| 56 | Holothurians | 18.287 | 28.006 | 1.531 |
| 57 | Ophiuroids | 5.474 | 6.756 | 1.234 |
| 58 | Ophiuroids "basket stars" | 3.843 | 3.273 | 0.852 |
| 59 | Seapen < 50cm | 8.171 | 9.757 | 1.194 |
| 60 | Seapen > 50cm | 3.435 | 4.046 | 1.178 |
| 61 | Worms | 1.383 | 1.618 | 1.170 |
| 62 | Anemone / Zoanthids | 1.496 | 1.662 | 1.111 |
| 63 | Large Zooplankton | 91.621 | 88.869 | 0.970 |
| 64 | Small Zooplankton | 100.405 | 89.701 | 0.893 |
| 65 | Jellyfish | 0.694 | 0.844 | 1.215 |
| 66 | Microbial heterotrophs | 185.074 | 145.553 | 0.786 |
| 67 | Algae | 13.164 | 13.493 | 1.025 |
| 68 | Seagrass | 1.614 | 1.570 | 0.973 |
| 69 | Large Phytoplankton | 51.509 | 53.327 | 1.035 |
| 70 | Small Phytoplankton | 54.636 | 50.508 | 0.924 |
| 71 | Benthic Phytoplankton | 29.476 | 28.388 | 0.963 |

## Table 36. Results from Ecosim Scenario 4 where biomass of Keystone groups was reduced by 90% over 20 years



| | Group name | Biomass (start) | Biomass (end) | Biomass (E/S) |
|---|---|---|---|---|
| 1 | Coastal sharks | 0.523 | 0.057 | 0.109 |
| 2 | Rays | 4.690 | 5.787 | 1.234 |
| 3 | Lizardfish | 4.880 | 0.481 | 0.099 |
| 4 | Carangids | 3.781 | 5.829 | 1.542 |
| 5 | Sea snakes | 0.619 | 1.023 | 1.654 |
| 6 | Sea turtles | 0.266 | 0.400 | 1.503 |
| 7 | Deep Lethrinids | 5.782 | 7.115 | 1.231 |
| 8 | Deep Lutjanids | 6.807 | 9.598 | 1.410 |
| 9 | Mullids | 3.000 | 2.604 | 0.868 |
| 10 | Deep Large fish | 0.602 | 0.884 | 1.468 |
| 11 | Deep Medium fish | 17.930 | 16.029 | 0.894 |
| 12 | Deep Small fish | 9.047 | 11.840 | 1.309 |
| 13 | Shallow Lethrinids | 1.062 | 1.926 | 1.814 |
| 14 | Shallow Lutjanids | 1.480 | 1.951 | 1.318 |
| 15 | Shallow Large fish | 0.417 | 0.737 | 1.765 |
| 16 | Shallow Medium fish | 10.508 | 11.009 | 1.048 |
| 17 | Shallow Small fish | 4.871 | 5.314 | 1.091 |
| 18 | Sponges Cup <25cm | 55.730 | 67.319 | 1.208 |
| 19 | Sponges Cup 25-50cm | 145.037 | 176.847 | 1.219 |
| 20 | Sponges Cup 50-100 cm | 81.803 | 101.249 | 1.238 |
| 21 | Sponges Cup >100 cm | 45.419 | 56.295 | 1.239 |
| 22 | Sponges Massive <25cm | 439.184 | 536.741 | 1.222 |
| 23 | Sponges Massive 25-50cm | 347.469 | 429.724 | 1.237 |
| 24 | Sponges Massive 50-100 cm | 181.244 | 225.626 | 1.245 |
| 25 | Sponges Massive >100 cm | 216.147 | 274.751 | 1.271 |
| 26 | Sponges Erect < 25cm | 177.125 | 216.125 | 1.220 |
| 27 | Sponges Erect 25-50cm | 228.777 | 282.713 | 1.236 |
| 28 | Sponges Erect 50-100 cm | 141.139 | 175.503 | 1.243 |
| 29 | Sponges Erect >100 cm | 30.228 | 36.049 | 1.193 |
| 30 | Soft coral Fans <25 cm | 13.890 | 14.893 | 1.072 |
| 31 | Soft coral Fans 25-50 cm | 13.485 | 12.030 | 0.892 |
| 32 | Soft coral Fans 50-100 cm | 8.431 | 7.528 | 0.893 |
| 33 | Soft coral Fans > 100 cm | 2.407 | 2.151 | 0.894 |
| 34 | Soft coral Massive <25 cm | 11.300 | 10.075 | 0.892 |
| 35 | Soft coral Massive 25-50 cm | 87.075 | 77.680 | 0.892 |
| 36 | Soft coral Massive 50-100 cm | 4.767 | 4.256 | 0.893 |
| 37 | Soft coral Massive >100 cm | 0.071 | 0.064 | 0.894 |
| 38 | Soft coral Whip <25 cm | 0.690 | 0.613 | 0.889 |
| 39 | Soft coral Whip 25-100cm | 1.598 | 1.421 | 0.890 |
| 40 | Soft coral Whip 50-100cm | 1.436 | 1.278 | 0.890 |
| 41 | Soft coral Whip > 100cm | 1.334 | 1.188 | 0.891 |
| 42 | Hard corals | 7.730 | 7.142 | 0.924 |
| 43 | Cuttlefish & Squids | 12.103 | 1.277 | 0.106 |
| 44 | Octopus | 1.355 | 1.496 | 1.104 |
| 45 | Bryozoa | 53.333 | 51.765 | 0.971 |
| 46 | Hydroids | 30.374 | 28.872 | 0.951 |
| 47 | Ascidians | 39.997 | 37.398 | 0.935 |
| 48 | Gastropods and Scaphopods | 8.915 | 6.006 | 0.674 |
| 49 | Bivalves | 10.548 | 11.382 | 1.079 |
| 50 | Prawns & shrimps | 3.801 | 7.352 | 1.934 |
| 51 | Crabs | 6.869 | 9.965 | 1.451 |
| 52 | Crustaceans others | 3.669 | 7.116 | 1.939 |
| 53 | Echinoids | 21.691 | 22.511 | 1.038 |
| 54 | Asteroids | 21.574 | 2.157 | 0.100 |
| 55 | Crinoids | 37.217 | 39.273 | 1.055 |
| 56 | Holothurians | 17.428 | 18.711 | 1.074 |
| 57 | Ophiuroids | 4.948 | 6.297 | 1.273 |
| 58 | Ophiuroids "basket stars" | 3.475 | 4.797 | 1.380 |
| 59 | Seapen < 50cm | 7.507 | 9.605 | 1.279 |
| 60 | Seapen > 50cm | 3.215 | 4.000 | 1.244 |
| 61 | Worms | 1.408 | 1.837 | 1.305 |
| 62 | Anemone / Zoanthids | 1.398 | 1.561 | 1.117 |
| 63 | Large Zooplankton | 91.942 | 88.998 | 0.968 |
| 64 | Small Zooplankton | 100.303 | 89.535 | 0.893 |
| 65 | Jellyfish | 0.693 | 0.851 | 1.228 |
| 66 | Microbial heterotrophs | 185.235 | 144.320 | 0.779 |
| 67 | Algae | 13.965 | 13.917 | 0.997 |
| 68 | Seagrass | 1.713 | 1.632 | 0.953 |
| 69 | Large Phytoplankton | 51.469 | 53.303 | 1.036 |
| 70 | Small Phytoplankton | 54.656 | 50.511 | 0.924 |
| 71 | Benthic Phytoplankton | 29.733 | 28.685 | 0.965 |

**Table 37. Results from Scenario 5 where the biomass of habitat-forming species (sponges, corals, seagrass) were reduced 50% over 20 years.**



| | Group name | Biomass (start) | Biomass (end) | Biomass (E/S) |
|---|---|---|---|---|
| 1 | Coastal sharks | 0.513 | 0.615 | 1.198 |
| 2 | Rays | 4.770 | 5.299 | 1.111 |
| 3 | Lizardfish | 4.682 | 5.943 | 1.269 |
| 4 | Carangids | 3.826 | 4.037 | 1.055 |
| 5 | Sea snakes | 0.630 | 0.898 | 1.426 |
| 6 | Sea turtles | 0.260 | 0.216 | 0.832 |
| 7 | Deep Lethrinids | 5.894 | 7.180 | 1.218 |
| 8 | Deep Lutjanids | 6.893 | 8.544 | 1.239 |
| 9 | Mullids | 2.964 | 2.576 | 0.869 |
| 10 | Deep Large fish | 0.628 | 0.772 | 1.229 |
| 11 | Deep Medium fish | 18.518 | 16.143 | 0.872 |
| 12 | Deep Small fish | 10.712 | 9.627 | 0.899 |
| 13 | Shallow Lethrinids | 1.080 | 1.422 | 1.317 |
| 14 | Shallow Lutjanids | 1.507 | 1.997 | 1.325 |
| 15 | Shallow Large fish | 0.433 | 0.535 | 1.236 |
| 16 | Shallow Medium fish | 10.809 | 10.265 | 0.950 |
| 17 | Shallow Small fish | 5.203 | 4.475 | 0.860 |
| 18 | Sponges Cup <25cm | 54.467 | 37.871 | 0.695 |
| 19 | Sponges Cup 25-50cm | 143.853 | 71.607 | 0.498 |
| 20 | Sponges Cup 50-100 cm | 80.557 | 45.524 | 0.565 |
| 21 | Sponges Cup >100 cm | 44.152 | 22.043 | 0.499 |
| 22 | Sponges Massive <25cm | 438.302 | 235.424 | 0.537 |
| 23 | Sponges Massive 25-50cm | 346.478 | 148.395 | 0.428 |
| 24 | Sponges Massive 50-100 cm | 178.112 | 91.785 | 0.515 |
| 25 | Sponges Massive >100 cm | 215.011 | 107.314 | 0.499 |
| 26 | Sponges Erect < 25cm | 175.973 | 83.896 | 0.477 |
| 27 | Sponges Erect 25-50cm | 227.670 | 116.958 | 0.514 |
| 28 | Sponges Erect 50-100 cm | 139.945 | 78.467 | 0.561 |
| 29 | Sponges Erect >100 cm | 28.959 | 15.864 | 0.548 |
| 30 | Soft coral Fans <25 cm | 13.595 | 6.115 | 0.450 |
| 31 | Soft coral Fans 25-50 cm | 13.489 | 6.133 | 0.455 |
| 32 | Soft coral Fans 50-100 cm | 8.434 | 4.595 | 0.545 |
| 33 | Soft coral Fans > 100 cm | 2.408 | 1.217 | 0.506 |
| 34 | Soft coral Massive <25 cm | 11.304 | 5.160 | 0.456 |
| 35 | Soft coral Massive 25-50 cm | 87.104 | 48.348 | 0.555 |
| 36 | Soft coral Massive 50-100 cm | 4.769 | 2.294 | 0.481 |
| 37 | Soft coral Massive >100 cm | 0.071 | 0.034 | 0.480 |
| 38 | Soft coral Whip <25 cm | 0.690 | 0.378 | 0.548 |
| 39 | Soft coral Whip 25-100cm | 1.598 | 0.743 | 0.465 |
| 40 | Soft coral Whip 50-100cm | 1.436 | 0.629 | 0.438 |
| 41 | Soft coral Whip > 100cm | 1.335 | 0.720 | 0.539 |
| 42 | Hard corals | 7.730 | 3.202 | 0.414 |
| 43 | Cuttlefish & Squids | 10.262 | 13.065 | 1.273 |
| 44 | Octopus | 1.460 | 1.818 | 1.245 |
| 45 | Bryozoa | 53.326 | 51.758 | 0.971 |
| 46 | Hydroids | 30.303 | 28.246 | 0.932 |
| 47 | Ascidians | 40.056 | 38.571 | 0.963 |
| 48 | Gastropods and Scaphopods | 8.291 | 9.224 | 1.113 |
| 49 | Bivalves | 11.275 | 9.594 | 0.851 |
| 50 | Prawns & shrimps | 3.631 | 4.404 | 1.213 |
| 51 | Crabs | 8.233 | 6.935 | 0.842 |
| 52 | Crustaceans others | 3.641 | 2.337 | 0.642 |
| 53 | Echinoids | 21.679 | 21.728 | 1.002 |
| 54 | Asteroids | 20.216 | 20.156 | 0.997 |
| 55 | Crinoids | 37.173 | 34.447 | 0.927 |
| 56 | Holothurians | 18.281 | 28.971 | 1.585 |
| 57 | Ophiuroids | 5.480 | 6.930 | 1.264 |
| 58 | Ophiuroids "basket stars" | 3.848 | 3.205 | 0.833 |
| 59 | Seapen < 50cm | 8.195 | 10.059 | 1.227 |
| 60 | Seapen > 50cm | 3.443 | 4.162 | 1.209 |
| 61 | Worms | 1.394 | 1.673 | 1.200 |
| 62 | Anemone / Zoanthids | 1.501 | 1.650 | 1.099 |
| 63 | Large Zooplankton | 91.715 | 87.937 | 0.959 |
| 64 | Small Zooplankton | 100.531 | 88.507 | 0.880 |
| 65 | Jellyfish | 0.693 | 0.840 | 1.213 |
| 66 | Microbial heterotrophs | 186.242 | 146.719 | 0.788 |
| 67 | Algae | 13.556 | 13.971 | 1.031 |
| 68 | Seagrass | 0.730 | 0.360 | 0.493 |
| 69 | Large Phytoplankton | 51.492 | 53.538 | 1.040 |
| 70 | Small Phytoplankton | 54.695 | 50.045 | 0.915 |
| 71 | Benthic Phytoplankton | 29.587 | 28.054 | 0.948 |

## Table 38. The five model indicators (Metagroups, Keystone, Charismatic, Habitat forming and Invertebrates) species, used to classify the functional groups of the NWS model.

| Model Indicator | Functional group | Trophic Level |
|---|---|---|
| Keystone groups | Coastal sharks | **4.91** |
| | Lizardfish | **4.58** |
| | Cuttlefish & Squids | **3.77** |
| | Asteroids | **3.15** |
| Metagroups | Rays | **3.48** |
| | Carangids | **4.07** |
| | Sea turtles | **3.29** |
| | Deep Lethrinids | **3.89** |
| | Deep Lutjanids | **4.01** |
| | Mullids | **2.16** |
| | Deep Large fish | **4.75** |
| | Deep Medium fish | **3.65** |
| | Deep Small fish | **3.49** |
| | Shallow Lethrinids | **3.93** |
| | Shallow Lutjanids | **4.07** |
| | Shallow Large fish | **4.79** |
| | Shallow Medium fish | **3.43** |
| | Shallow Small fish | **3.52** |
| | Prawns & shrimps | **2.00** |
| Charismatic species | Sea snakes | **4.68** |
| | Sea turtles | **3.29** |
| Habitat forming | Sponges Cup <25cm | **2.50** |
| | Sponges Cup 25-50cm | **2.50** |
| | Sponges Cup 50-100 cm | **2.50** |
| | Sponges Cup >100 cm | **2.50** |
| | Sponges Massive <25cm | **2.50** |
| | Sponges Massive 25-50cr | **2.50** |
| | Sponges Massive 50-100 | **2.50** |
| | Sponges Massive >100 cr | **2.50** |
| | Sponges Erect < 25cm | **2.50** |
| | Sponges Erect 25-50cm | **2.50** |
| | Sponges Erect 50-100 cn | **2.50** |
| | Sponges Erect >100 cm | **2.50** |
| | Soft coral Fans <25 cm | **2.60** |
| | Soft coral Fans 25-50 cm | **2.56** |
| | Soft coral Fans 50-100 cn | **2.56** |
| | Soft coral Fans > 100 cm | **2.56** |
| | Soft coral Massive <25 cr | **2.56** |
| | Soft coral Massive 25-50 | **2.56** |
| | Soft coral Massive 50-10( | **2.56** |
| | Soft coral Massive >100 c | **2.56** |
| | Soft coral Whip <25 cm | **2.56** |
| | Soft coral Whip 25-100cn | **2.56** |
| | Soft coral Whip 50-100cn | **2.56** |
| | Soft coral Whip > 100cm | **2.56** |
| | Hard corals | **2.56** |
| | Seagrass | **1.00** |
| | Octopus | **3.48** |
| Invertebrates | Bryozoa | **2.66** |
| | Hydroids | **3.16** |
| | Ascidians | **2.20** |
| | Gastropods and Scaphopc | **2.05** |
| | Bivalves | **3.15** |
| | Crabs | **2.94** |
| | Crustaceans others | **2.71** |
| | Echinoids | **2.00** |
| | Asteroids | **3.15** |
| | Crinoids | **3.16** |
| | Holothurians | **2.24** |
| | Ophiuroids | **2.09** |
| | Ophiuroids "basket stars" | **3.21** |
| | Seapen < 50cm | **2.00** |
| | Seapen > 50cm | **2.00** |
| | Worms | **2.00** |
| | Anemone / Zoanthids | **3.53** |
| | Large Zooplankton | **2.52** |
| | Small Zooplankton | **2.01** |
| | Jellyfish | **3.47** |
| | Microbial heterotrophs | **2.00** |
| | Algae | **1.00** |
| | Seagrass | **1.00** |
| | Large Phytoplankton | **1.00** |
| | Small Phytoplankton | **1.00** |
| | Benthic Phytoplankton | **1.00** |

## 7.5 Discussion

The first steps in answering key questions about the structure and functioning of the NWS was the construction of the dynamic Ecopath with Ecosim model for the present-day conditions (2017). The model describes the energy and mass fluxes, the trophic interactions of predators, prey and fisheries.  One of the values of the Ecopath model (snapshot of the food web) is to characterize the NWS by a greater benthic than water productivity and the dominance in biomass of lower trophic level benthic consumers in the ecosystem. Also, the model identified the ecological role of keystone groups defined as structuring species by processes associated with predation (top-down forces). The network of species connections within the food web is useful for a better understanding of ecological roles of target finfish species (lethrinids, lutjanids) and charismatic species (e.g. turtles, sea snakes) in the NWS. This network analysis gives a set of nodes and their linkages to identify trophic patterns from prey and predator perspectives.

The model synthesizes the biological data of the 100 sites sampled (using fish trawls and epibenthic sleds) in 2017 on board the R/V Investigator to assembled abundance, biomass and size/age composition of the demersal fish community and epibenthic habitat forming invertebrates (e.g. sponges and corals) in the region. Results from the Ecopath model showed that the NWS Shelf is dominated by lower trophic groups (70% of the functional groups occurred at trophic level lower than 3.5), but some minor top-down trophic interactions associated with Lizardfish and other predators were identified. The estimates of ecosystem attributes, including mass fluxes, depend on the quality of the data of the input parameters (Plaganyi et al., 2004).

The quality of the data used in the model was estimated thorough the Pedigree Index, which estimates how much data comes from the model domain (Heymans et al., 2016). The overall Pedigree Index for the NWS model was 0.73, a high value compared with those estimated to other similar shelf Ecopath models in Australia (Gribble, 2003; Bulma, 2006) and to other 150 Ecopath models worldwide (0.16 – 0.71; Morissette et al., 2006).  The major uncertainties in the input data were for biological information of some pelagic groups (e.g. lutjanids, mullids,) and benthic species (e.g. sea pens, holothurians, crabs). Addressing these knowledge gaps with more and better biological data would enhance the predictions and results of our models for understanding the NWS.

The mean transfer efficiency in the NWS ecosystem mode was 13%, a value that is close to the average transfer efficiency often assumed for aquatic ecosystems (Christensen and Walters, 2004). The Mixed trophic impacts analysis showed the importance of lower trophic groups, particularly invertebrates such cuttlefish, prawns, crabs and gastropods as an important food source to higher trophic levels. Detritus, DOC and microbial heterotrophs has a positive impact on most of the lower trophic groups, emphasizing its importance as a component in the base of this food web. Analysis of the relative trophic impacts on the system highlighted that “Lizardfish” group (i.e. *Synodus dermatogenys*, *S. hoshinonis*, *S. indicus*) and “Deep large fish” (i.e. Barracuda, Sphyrnidae) had a large negative impact on prey groups, including turtles and finfish target species, indicating that they are potential

Keystone species. In this trophic analysis, habitat-forming species such as sponges, and corals showed a modest positive impact on the food web (Figure 187) as they are not an important source of food rather by providing refuge from predators. There is evidence that abundance of sponges on tropical ecosystems are positively correlates with tropical reef fish species richness, biomass, abundance and trophic structure (Seemann et al., 2018). The results from this study are likely to underestimate the sensitivity of the NWS to changes in the biomass of habitat-forming species, mainly sponges and corals, because the spatial dynamics associated with habitat utilisation and habitat quality were not explored in this study. To assess the importance of increased protection from sponges and corals (enhancing the survival of fish and crustacean species) is recommended to develop a spatial dynamic ecosystem model (Ecospace) for this system.

The total biomass harvested by fisheries in the NWS system was low (0.078 t· $km^{-2}$), but the mean trophic level of the catch was high (3.61), markedly higher than the average estimate of catch trophic level for global coast and reef system worldwide of 2.54 (Pauly et al., 1998). Those findings are similar to those from the same region in 2006 (Bulman, 2006). The high trophic level of the catch suggested that the fisheries operating in the NWS are highly selective, targeting finfishes at the top of the foodweb. Fisheries in the current system have a direct impact on the population of target species, and an indirect impact on non-target species as shown from by results of the mixed trophic impacts analyses and the Ecosim predictions. The fishing pressure in the system is low, the five fleets operating in 2017 removed less 0.1% of the total biomass. The dynamic simulations of the fishing scenarios (Ecosim model) identified important top-down interactions resulting from reductions in fishing mortalities of fishes at the top of the food web e.g. sharks, Lizardfish, Lutjanids. The fisheries in the system have a direct impact on the abundance of target species, and an indirect impact on non-target groups (mainly small fishes and invertebrates). For example, the Ecosim simulation of closing all fisheries over 20 years resulted in an estimated 64% more biomass of target species and 18% increase in the overall biomass of the system. This scenario revealed interesting consequence top-down interactions with an increased in predation rates from target finfishes (Lethrinids, Carangids, Lutjanids) on lower trophic level fish species (Fish TL 2-3), resulting in some indirect positive impacts (increase in biomass) on invertebrates. It has been documented that fisheries have the potential to change the structure and function of ecosystem by removing top predators (Pauly et al., 1998; Heymans et al., 2016)

The temporal ecosystem model developed in this study integrates the data available in the NWS and it provides a summary of our current knowledge of the biomass, consumption, production food web and trophic flows in the region. The model is a tool for testing hypotheses with respect to trophic and non-trophic interactions of different species and fishing pressures. This study has shown the complexity of the NWS, pointing out the relevance of the lower trophic groups and habitat forming species (e.g. sponges, corals). This is particularly important because understanding the processes and interactions within the system, including the role of low and high trophic level groups and impact of fishing can promote and support plans for conservation and management. Both science and management should examine pathways of cumulative effects for a more robust support of decision-making actions aimed at maintaining resources and ecosystem services.

### 7.5.1 Conclusion

The model developed in this study integrates the data available in the region and it provides a summary of our current knowledge of the biomass, consumption, production food web and trophic flows in the NWS ecosystem. This modelling work highlighted the complexity of NWS ecology, clarified the role of lower trophic groups in food web support, and demonstrated ecological impacts of different fishing impact scenarios.

This study has shown the complexity of the NWS, pointing out the relevance of the lower trophic groups and habitat forming species (e.g. sponges, corals and seagrass). This is particularly important because understanding the processes and interactions within the system, including the role of low and high trophic level groups and impact of fishing can promote and support plans for conservation and management

Uncertainty around model parameters is one of the major limitations in the predictions made by the EwE model. The sensitivity analysis indicated that the NWS model was sensitive to changes in the biomass of lower trophic levels (e.g. prawns, gastropods, crustaceans, octopus) and to a lesser extent, changes in top predators (e.g. large finfish species). Hence, obtaining more and better information of abundance for benthic producers is a critical aspect for the future.

# Appendix A Detailed description of survey design and methodology

## A.1 Study design and site selection methodology

### A.1.1 Data sources

A series of existing data sources were compiled in order to carry out a comprehensive spatial stratification of the study area:

#### Historical trawl fishing effort

Trawl effort data for the Taiwanese pair-trawl fleet was originally sourced from AFMA logbook data compilation. This contains trawl records from foreign trawlers that had been collated in the “AFZIS” data base between 1974 and 1987, and in the “radio-reporting” database (1979–1990). Prior to 1979, trawl effort had been reported on 30-minute grid cells, whereas from 1979 onwards trawl effort was reported as trawl start and end positions with trawl durations, although the resolution and quality of these positions was variable (noting also that these were prior to GPS). The start–end positions and duration data from 1979 to 1987 were linear-interpolated, then gridded and aggregated at 0.01 degree by Franzis Althaus (CSIRO O&A Hobart). However, while this resolution was satisfactory for other AFMA fisheries following implementation of GPS, it was too fine for the historical Taiwanese pair-trawl effort data. Hence, these data were aggregated further to 0.05 degrees and averaged for the period 1979–1985 inclusive.

#### Recent trawl fishing effort (Pilbara Fish Trawl Fishery)

Trawl effort data for the domestic Pilbara Fish Trawl fleet (otter trawls) were provided by DPIRD and originally compiled from vessel logbook data, for the period from 2005 when shot-by-shot effort data became available, and 2016. The start–end positions and tow durations of the individual trawls were linear-interpolated then gridded and aggregated at 0.01 degree. For the purposes of the survey design, these data were averaged to give the mean annual effort in hours per grid cell. The hours of effort were re-scaled to swept area, by multiplying by average trawl-speed and swept-width between the doors, then divided by grid-cell area to give swept area ratio.

#### Environmental data

A range of mapped environmental data layers had been collated by a previous project (originally the CERF Marine Biodiversity Hub) and progressively updated by a series of subsequent projects, most recently FRDC 2016-039. These environmental layers included: bathymetry DEM (depth, slope, aspect, terrain topography membership); sediments (%mud, sand, gravel, carbonate); seabed shear-stress; bottom-water attributes (temperature, salinity, $O_2$, $NO_3$, $PO_4$, Si); ocean colour derived variables (e.g. SST, Chl k490, PAR, NPP, epoc & b_irr); with seasonal ranges where applicable — a total of 40 variables. The layers were all gridded at 0.01 d and mapped for the entire EEZ; subsequently subsetted to the Pilbara NWS study area.

## Biological survey data

Biological data from historical NWS Effects of Trawling (EoT) Project surveys from 1982 to 1997 were used in analyses to quantify relationships between biological composition and environmental gradients, as well as both historical and recent trawl effort.

A random-stratified sampling design was implemented in 1982 (Sainsbury 1987) and maintained consistently through to the 1997 survey.  The design was based on 19 strata representing: three spatial areas (Legendre, Hedland, Barrow, see Figure 159); depth (shallow, middle, deep); and substratum type (shelly sand, sand, silty sand, undefined). The random sampling in 1982 and 1983 was restricted to the Legendre and Hedland regions – strata 1-16 (Figure 159). In 2017, the sampling area was restricted to the central zone of the NWS and new strata were defined (see Chapter 4).

These surveys conducted trawl sampling, using a McKenna trawl on two RV *Southern Surveyor* voyages (SS199508: 108 stations; SS199707: 106 stations), and Frank & Bryce trawls on 11 FRV *Soela* voyages (SO198205 to SO198805: 1096 stations) and two RV *Southern Surveyor* voyages (SS199002: 133 stations; SS199104: 101 stations). Identification and quantification of these trawl samples focussed primarily on fishes, with some identification of discrete invertebrates at high taxonomic levels. Sponges were quantified at the phylum level only on the two McKenna trawl voyages.

On most voyages (10 of 15), a 35 mm still film camera was fitted to the headline of many trawls and provided images of sessile benthos on the seabed ahead of the trawl net. Photos were available for 583 stations (of a total of 1544 trawls) and typically about 80 photos were available for each, although this ranged widely. The imagery of the 10 voyages was annotated in a series of annotation efforts over the years using protocols outlined in an internal report by Troje & Campbell (1989), and early annotation data were used in analyses presented by Sainsbury (1991) and Sainsbury et al (1997). In short, the photos were annotated for features, topography and sediment type categories and for counts of three size-classes of benthos: large (>25cm) and small (5 – 25cm) (Apx A Table 1). The two larger classes were further identified into broad taxa and 12 morpho-types: sponges (lump, cup, branched, flat, finger); Coral (soft coral, gorgonian, sea pen, whip); hydroids (fluffy, stringy); Crinoid; and unknown (Apx A Table 1) (Troje & Campbell 1989). The last annotator – Franzis Althaus (CSIRO O&A) compiled, documented and databased the final data set in a CSIRO ORACLE database under the NWSJEMS project (NWSJEMS 2007).

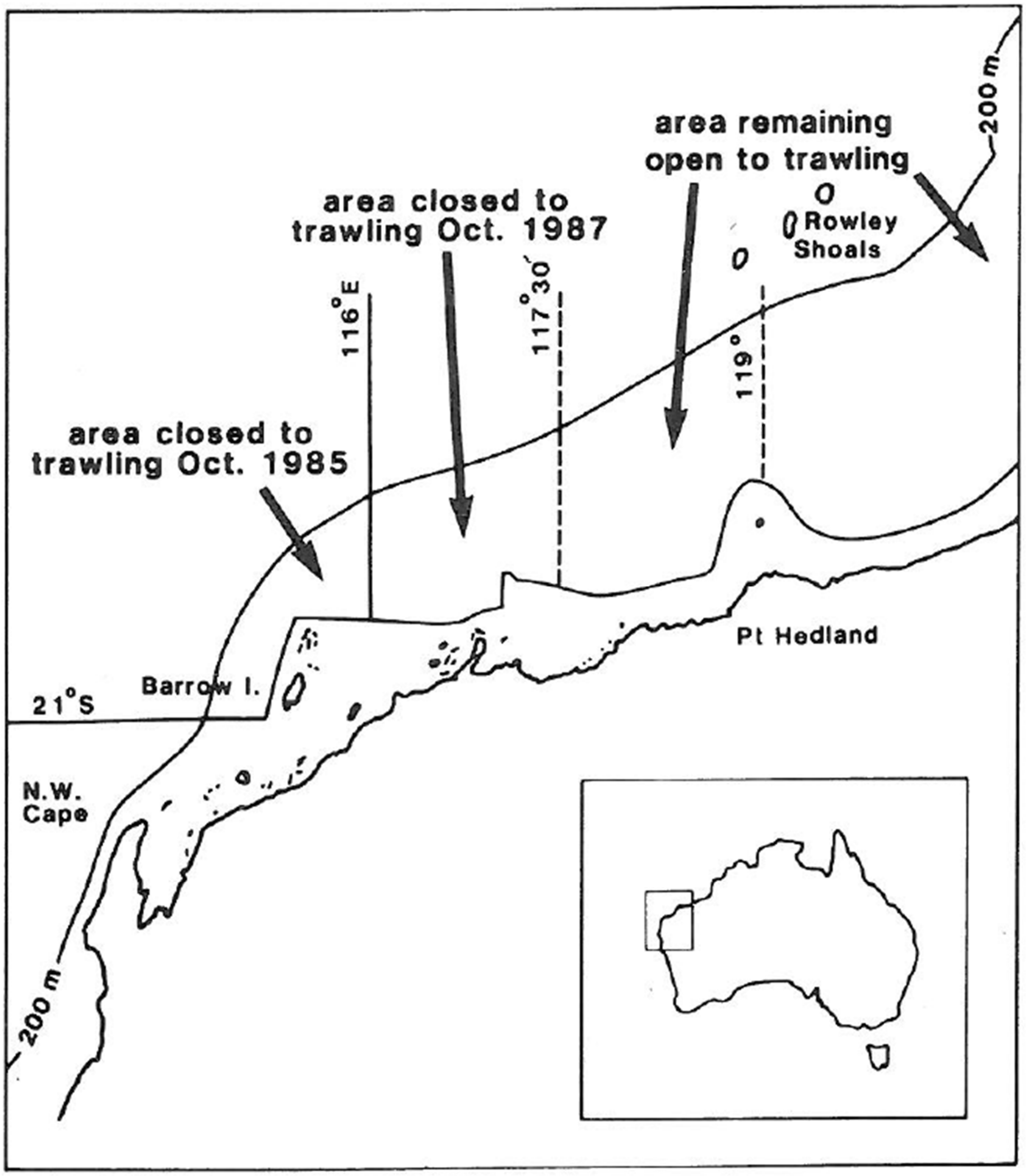


Figure showing the spatial strata used in the 1982 to 1997 voyages (from Sainsbury 1991). The three areas indicated by the bolded arrows reflect the zoning areas for the experimental adaptive management experiment conducted between 1986 and 1991 (see Sainsbury et al. 1997). In this current study we have referred to these three areas from west to east as the Barrow, Legendre and Hedland subregions.

## Determination of sampling strata for 2017 voyage

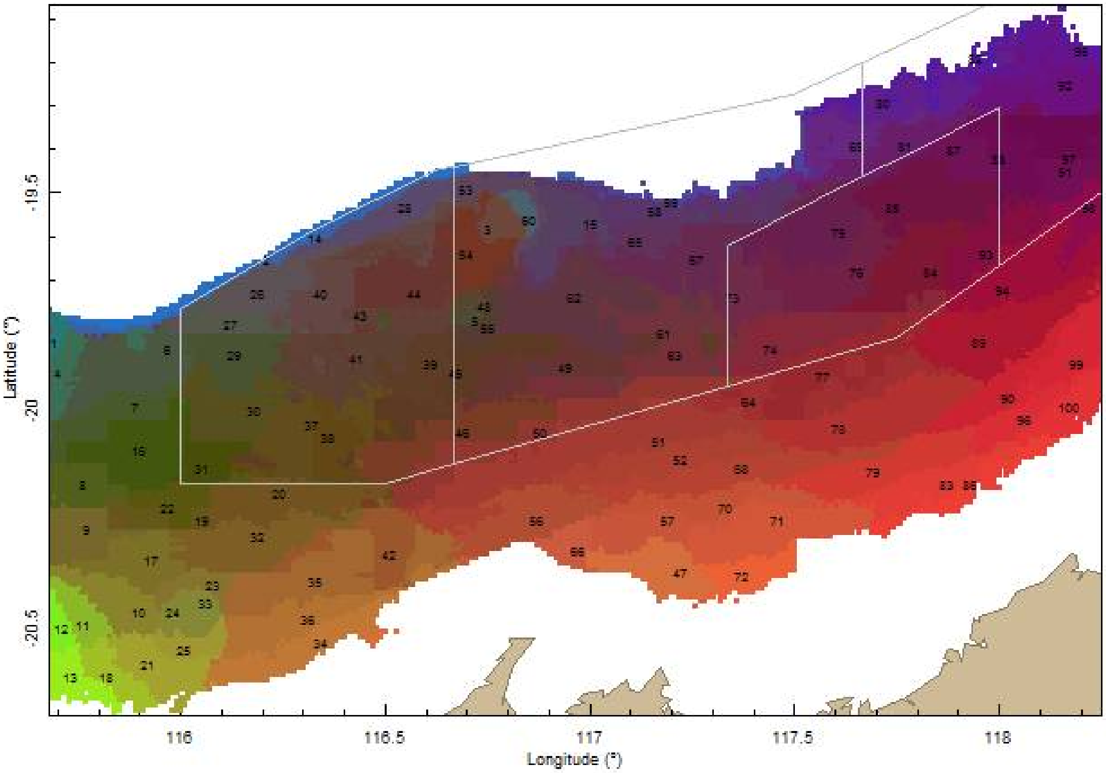
For the 15 voyages between 1982 and 1997 a random stratified sampling approach across a broad area of the NWS was used as described above. For the 2017 study, we had a single voyage and we elected to use a different method based around stratifying a smaller, central part of the original study area into 100 spatial areas using a much more extensive set of physical, chemical and biological attributes than were available in the earlier study. The 2017 survey was designed to re-sample areas that had been subject to high levels of pair-trawling but then closed and remained untrawled — as well as other trawl contrasts, and environmental gradients that may influence benthos distributions. The trawling effort level contrasts for both historical and recent trawl effort included zero/low, low/medium, medium/high and high. Areas in the higher trawl effort categories were relatively rare, particularly for the recent effort and especially the high-historical and high-recent combination, but all contrasts were allocated at least a minimum number of stations. To enable stratification to account for important environmental gradients, analyses were conducted to quantify the influence of multiple variables on the abundance composition of demersal communities. The study area was first stratified by the trawl-effort contrasts, and each combination was stratified by important environmental gradients and clustered into a number of groups corresponding to the required number of stations for each contrast. Stations were then selected from each cluster group, prioritising locations previously sampled by earlier surveys that had recorded catches of benthos, otherwise the most central cell for each cluster was selected. Further, offshore oil and gas infrastructure have navigation exclusion zones, which had to be excluded from selection for sampling.

The biological, environmental and trawl effort data were analysed using R package gradientForest (Ellis et al. 2012) to quantify the magnitude and shape of relationships between biological composition and gradients in the environment. These compositional turnover curves were used to transform the multi-dimensional environmental space of the study area (i.e. the mapped environmental variables) to a multi-dimensional biological space where increasing distance between points reflects increasing differences in biological composition as associated with the environmental gradients. The biological space provides the basis of the stratification of the study. For example, if a representative sampling of the region's biodiversity was desired, then simply clustering the biological space into a number of groups equal to the expected number of stations would provide a suitable stratification.

However, in this study, the primary objective was to quantify the extent of recovery in sessile benthos and fish populations. Hence, a key contrast (or strata) was in areas that had been trawled heavily by the Taiwanese and later untrawled following the cessation of foreign trawl fishing. Other important contrasts were between such areas and those areas that continued to be trawled by the domestic fishery, as well as those areas that were not fished by either fleets. Thus, the first step was to establish the effort contrasts and then determine the number of stations to be sampled in each. This process included excluding areas which could not be sampled due to obstacles including the intensive array of undersea communications cables, oil and gas pipes and well heads.

The trawl effort intensity (average annual grid swept ratio: F-ratio) of both the historical and recent fishing was divided into categories representing zero, low, medium and high potential impact on benthos (i.e. F-ratio = [0, 0.01] [0.01, 0.5] [0.5, 1.0] [1.0, 2.0]) and the entire study grid of 24,371 cells was assigned into one of 16 possible categories. Three categories did not exist (i.e. historical= zero with recent=low, medium or high) and some categories were rare (i.e. recent=medium or high; historical=high). The total number of stations planned in the survey was 100 and these were initially distributed in proportion to the number of grid cells in each category to the power of ⅓, with some subsequent adjustment of allocation to ensure a minimum of three and to up-weight the key contrast of high historical and zero recent effort.

The second step was to cluster each effort category into a number of groups corresponding to the number of sites to be allocated, where clustering was based on the transformed biological space described above. These cluster groups within effort categories provided the strata for the survey. Within each strata, the medoid grid cell was identified as a candidate most typical site, where the medoid is defined as the cell having the minimum sum of distances (in biological space) to all other cells in the same strata.



**Map of initial clustering of the transformed biological space, representing a first-order stratification — number 1-100 indicates medoid grid-cells, which could provide sampling stations representative of the environmental gradients.**

## A.1.2 Site selection

### Site selection principles and rules

Having established the 0.01 degree (1111 m) grid extent for the study and determined which grid cells comprised each of the 100 strata — and the position of the medoid in each strata (as described above) — a series of rules were applied to select the actual sites to be sampled. These rules were established to enable, where possible, comparison with historical scientific trawl data collected in 1963 and 1964 (Masuda et al. 1964; Suzuki et al. 1964) and between 1982 and 1997 by CSIRO (Sainsbury 1987 [which also includes a summary of Japanese and other surveys on the NWS]; Althaus et al. 2006; Fulton et al. 2006). Firstly, if the start position for an Oshoru Maru trawl fell within the strata, it was selected as the site. If there was no corresponding Oshoru Maru site, the midpoint of the closest to medoid RV *Southern Surveyor* 1995 or 1997 trawl that fell within the strata was chosen. Priority was given to these three voyages because they had collected quantitative biomass data on sponge catches in trawls. If no SS1995 or SS1997 voyage trawl fell within the strata, the midpoint of the closest to medoid other CSIRO 1982-1997 voyage trawl for which headline camera photos of benthos were collected at the site (subject to a minimum of 40 photos) were selected. If there were no historic research trawls in the strata then the medoid cell was selected as the site.

By this process, 100 sites were selected for the study. Following this, and immediately prior to the voyage, a feasibility/risk assessment was undertaken by Bridge Officers from the RV *Investigator* resulting in 6 of the original 100 sites being ruled invalid. These were moved sufficiently to avoid the obstacle by 1 nm but always remained within the same strata. Only one other site was moved. Site 6 was moved 3.4 nm south of its original position to match a historical research trawl (SO1983_04_64) inside the Dampier MP while remaining within the same strata.

### Tow transect selection

Where possible, the selected sites were treated as the midpoint of the trawl transect. The primary consideration in trawl and sled transect selection was to remain within strata. The trawl and sled transects were selected blind to the substrate type and bottom topography. Once a transect was selected it was swath mapped at 70–100 kHz using a Kongsberg EM710 multibeam acoustic swath mapper so that any trawl hazards could be assessed before deploying the net. Any sharp changes in depths on hard bottom which indicated ledges greater than 1 m depth change in 10 m transect length were avoided (to minimise chance of net damage and camera loss) by changing the transect bearing. In general, tow direction was dictated by wind direction with most trawl and sled tows done with the ship heading into the wind. Some latitude around this, particularly when winds were light, provided flexibility to avoid hazards (a 1 nm buffer was maintained around pipelines, abandoned well heads and drill holes) and remain in small strata or strata with complex shapes. In a few cases a curved or dog-legged trawl line had to be set to avoid oil and gas infrastructure hazards and remain within strata. All other tows were straight.

# A.2 Trawl and sled operations and gear configuration

## A.2.1 Trawl design, set up and operation

### Trawl headline camera

The trawl headline camera consisted of a Canon M5 mirrorless camera and a Quantum QFlash Trio QF8 flash in waterproof housings mounted on a sturdy acrylic and stainless steel frame. Two laser beams fixed at 25 cm apart were added to provide a scale to all photographs. Photograph interval was set at 4 seconds equating to every 4.6 m at 3 knots. Depth activation/deactivation was programmed into the camera to avoid excessive memory or battery use during net streaming. A GoPro 5 video camera in a Nimar housing rated to 200 m was also fixed to the camera frame. Additional floats were added to the trawl headline to compensate for the mass of the camera.

### Trawl set up and operation

The CSIRO Semi V Wing trawl net (McKenna trawl net) was used for all trawls. Trawl navigation lines were established, consisting of a 2 km lead in to an on-bottom position and a 4 km trawl track. On approach to the trawl line, the cod-end was paid out at 5–6 knots and when the net was off the drum the trawl headline camera frame was attached to the trawl headline with shackles along with the Marport sensors. The camera was turned on, the net was then paid out and the trawl doors attached. Depending on water depth, the net was towed with doors fixed until approximately 600 m from the on-bottom position and then with the vessel slowed to 4–5 knots, 50 m of wire was paid out. At a point calculated based on vessel speed and depth, wire was then paid out at a wire:depth ratio of 3.5:1.

Figure showing trawl headline camera

As the net did not have its own USBL system, the following provides an estimate of the position of the doors and net relative to the vessel position. The length of the back chains from boards (15 m), sweep length (90 m) and bridles (45 m) gives a total of 150 m, which when the doors are fully spread equates to approximately 140 m from the centre of the footrope to an imaginary line between the two boards. The position of the doors relative to the ship's position was calculated using Pythagorean Theorem with the depth and amount of wire out as two sides of a right-angle triangle and accocunting for the distance from the stern to the ship's GPS (60 m). No attempt was made to compensate for the spread of the two winch wires which are 9 m apart at the stern and may be as much as 100 m apart at the doors. For example, in 80 m depth with 270 m of wire out, this was a distance of 318 m. When added to the distance between the boards and the net of 140 m (see above), this total distance (458 m in the above example) was recorded in the ship's event logger as the layback distance from the ship's position (ship's GPS) to the centre of the net headline with the boards fully spread. The ship's position was recorded in the ship's event logger at three times on each trawl: the time when the doors touched the bottom, the time the boards were fully spread, and at the time the boards lifted from the bottom. The timing of each of these events was provided using a Marport net monitoring system (see below). The above records make it possible to estimate the position of the boards and the net relative to the ship's position at each important phase of the fishing operation.

With the boards fully spread at approximately 90 m (range 80 m–100 m) and the net width at fishing about 19 m wide (as it bows back from it's full length of 26 m), the effective fishing swept width will be about 90 m for fish and about 19 m for benthic invertebrates. Of the 100 sites trawled, major net tearing occurred at only one site (Site W3), however, the catch was regarded as representative and quantitatively valid. There were compromised trawls (net tangle) at three sites, but two of these were repeated on an adjacent line offset by 200 m leaving only the catch at site W29 regarded as invalid.

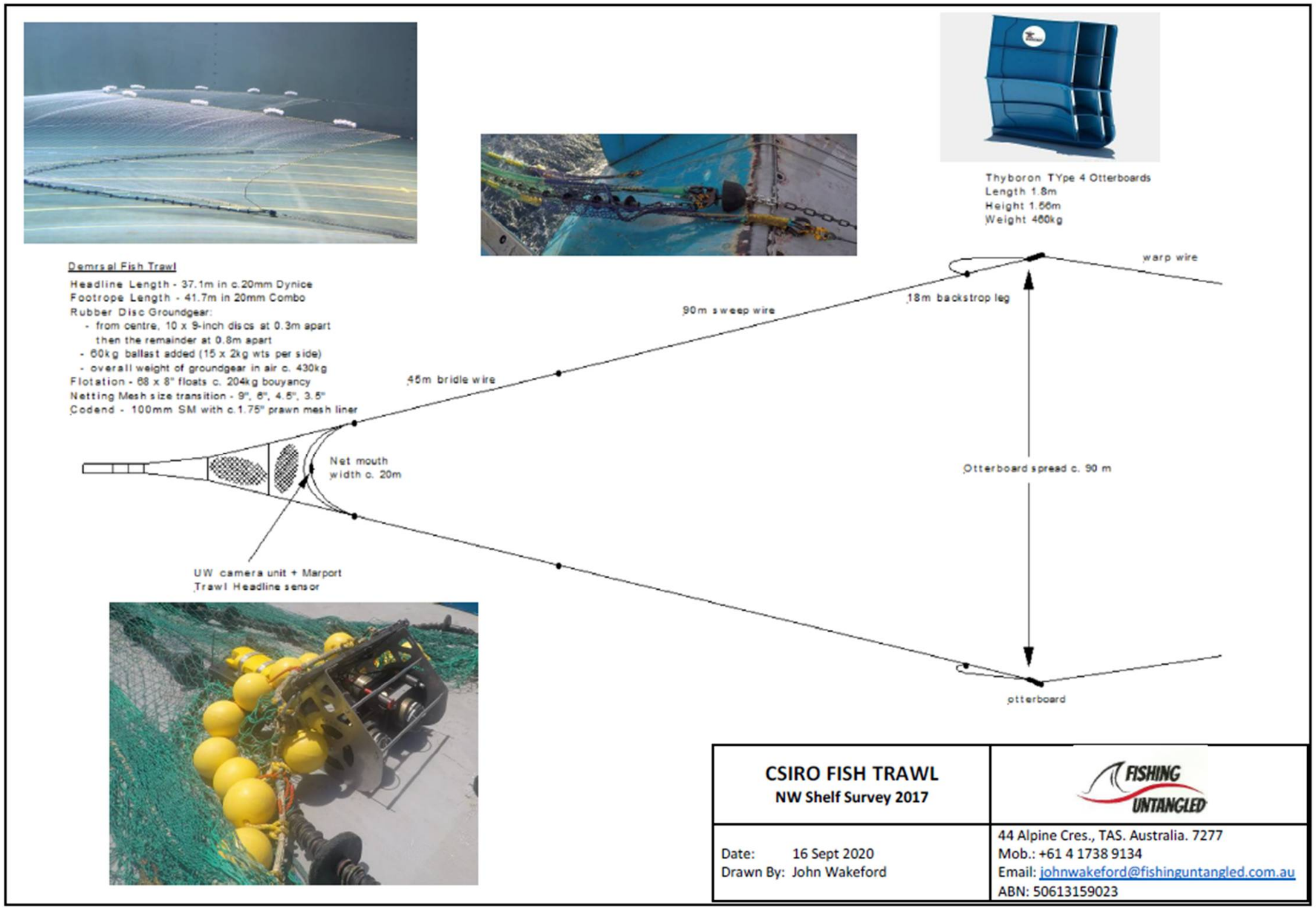


Figure showing configuration of McKenna trawl net as used on IV2017_05

### Trawl net monitoring system

A Marport net monitoring system with acoustic sensors on both doors and the centre of the net headline provided a measure of board spread and net headline height above the seabed.

### A.2.2 Sled design, set up and operation

The epibenthic sled was the same as used on previous surveys on other vessels in the Kimberley and the Pilbara (e.g. Fry et al. 2008; Pitcher et al. 2016). This consised of a galvanised steel frame with an opening, measuring 1.5 m wide by 0.5 m high, and 20 mm steel mesh base, top and sides with a depth of 1.0 m. A heavy nylon codend (18 mm square mesh, 30 mm stretched) was attached to the back of the sled to collect the sample. The length of the chain bridle on each side was 1.0 m. A GoPro 5 video camera in a Nimar housing rated to 200 m and lighted by a Keldan video light was mounted inside the sled to check that the sled was fishing effectively.

A sled line was plotted central and parallel to the planned trawl line, offset by 100 to ensure the trawl and sled did not overlap each other. The vessel approached the start of the sled line at 2 knots before slowing to 1 knot as the sled was lowered (at 60 m per minute) and maintained this speed for the duration of the tow.

### Trawl and sled distance and duration

Trawl transects were 30 minutes in duration at 3 knots speed over ground (usually about 2,800–3,000 m depending on average speed of tow). Sleds were initially run for 200 m at 1 knot, but after only light catches were obtained in the first few sites, this was increased to 400 m at 1 knot.

## A.3 Handling of trawl and sled catches, sorting and vouchering

### A.3.1 Trawl catch handling and invertebrate sorting and vouchering

The codend was emptied into between one and four 600–800 L “mega bins”, containing AQUI-S fish anaesthetic at a concentration of 100–150 mg/L in sea water, on the after deck near the stern ramp and then wheeled under cover of either the sheltered science area or a canvas gazebo on the starboard side of the after deck. Sponges and large fans were separated from fish which were allowed time to anaesthetise (usually about 20 minutes). During this time, sponges and octocoral soft corals were sorted into morphotypes (massive, cup, erect for sponges and whips, fans, dendronephthid) and size categories (< 25 cm, 25–50 cm, 50–100 cm, > 100 cm). Counts and weights of each combination of morphotype and size category were recorded. Weights and counts of some soft coral and sponge species that were particularly abundant in some sites were estimated by averaging numbers and weights of the individuals contained in three of the sorting bins and multiplying this by the total number of full bins. In other cases, where individuals of certain species (e.g. sponge species of *Callyspongia, Amphimedon, Chondropsis*) were extremely fragmented but still recognisable, the number of individuals was estimated by dividing the total weight by individual weight of complete individuals found among the catch. Any fragments broken from main colonies of sponges and soft corals were weighed together (not separated into morphotypes). Other invertebrates were sorted from the catch then into groups with bulk weights and counts recorded. Cephalopods were anaesthetised in a solution of magnesium chloride mixed at a concentration of 58.5 g/L $MgCl_2$ in sea water. The taxonomic level of these groups varied according to abundance and the amount of material to be sorted, but as a minimum the following groups were separated: anthozoans, bryozoa, hydroids, colonial ascidians, solitary ascidians, asteroids, ophiuroids, echinoids, crinoids, holothuroids, bivalves, gastropods, squid, cuttlefish, octopus, crabs and shrimps. Vouchers of all crustaceans, echinoderms and molluscs were retained and vouchers of the most abundant sponges and octocorals were retained. In the case of sites which fell within the Dampier and Montebello MPs, an attempt was made to voucher all sponge and octocoral species collected. At other sites, vouchers of selected specimens from unknown species and those selected for chemistry studies were also kept. All counts and weights were entered into the catch database. During the sorting process photographs were taken of the catch. Some of the individual voucher specimens were photographed separately. Most sponges and soft corals separated for vouchering were assigned a unique barcode and photographed individually. A representative fragment of the specimen was preserved in alcohol, but in few cases the whole specimen was preserved frozen. Some specimens or fragments of specimens were retained frozen for biological analyses (e.g. stable isotopes) and linked to the preserved voucher (if any) in the database.

### A.3.2 Sled catch handling, sorting and vouchering

Sled catches were much smaller with the codend was emptied into 60 L tubs and baskets on the back deck. Invertebrates were sorted, counted, weighed, photographed and vouchered as described above for trawls. Large sponges and baskets of sponges and other biota were weighed on a motion compensating POLS P-15/S-210 electronic balance (±20 g accuracy) or a Mettler spring balance. Small and individual invertebrates were weighed on a motion compensating Marel M1100 balance (0.5 g accuracy). Fish were only captured by sleds incidentally and were counted and weighed collectively and frozen for later identification and individual vouchering. Some specimens were retained frozen for biological analyses (e.g. stable isotopes). Where captured alive, fish were anaesthetised in concentrations of AQUI-S as described above, but in smaller containers.

### A.3.3 Trawl-caught fish and Pharaoh Cuttlefish (*Sepia pharaonis*)

All trawl-caught fish were sorted to species, identified and a count and bulk weight of each species was obtained using a motion compensating POLS P-15/S-185 electronic balance (±20 g accuracy). Length and weight of up to 100 fish of each species from each trawl catch were taken using motion compensating scales (Marel M1100, ±2 g accuracy) and electronic fish measuring boards which logged directly into the catch database. Once a total of 500 individual length and weight measurements had been taken, the length of an additional 100 fish from each species in each trawl catch were taken. Large elasmobranchs (> 1 m) were released alive after measuring and tissue samples were taken from either the disc margin, dorsal or caudal fin. Individual lengths and weights of Pharaoh Cuttlefish (*Sepia pharaonis*) were also made. Batches of very small fish species were individually reweighed on the more accurate Marel balance to improve precision of length-weight relationships. For some commercially significant species, additional data from a subset of the total catch on reproductive state (macroscopic scale) were recorded and histological samples taken from Pearl Perch (*Glaucosoma* buergeri), Coral Trout (*Plectropomus maculatus*) and Yellow Spot Rock Cod (*Epinephelus areolatus*). Otoliths (approx. 2500) were retained from over 20 species and guts were also retained from a subset of these fish. Some specimens (or tissue) were retained frozen for molecular analyses and/or other biological analyses (e.g. stable isotopes).

Representatives of the majority of fish species were retained as taxonomic voucher specimens for the CSIRO Australian National Fish Collection (ANFC, Hobart). However, almost all large (> 1 m) sharks and rays landed alive were fin-clipped and released. One large specimen of an unidentified stingray (*Urogymnus* sp.) was retained as a voucher specimen due to doubt about its identity. It was later identified as the Porcupine Ray (*U. asperrimus*).

### A.3.4 Trawl caught reptiles

The trawl captured four turtles and 59 sea snakes. Turtles were photographed to enable identification and returned quickly to the water alive. Sea snakes were photographed, measured (total length) and weighed (± 20 g accuracy) and a tissue sample taken from the tail for molecular analysis and frozen. Those captured alive were then released (55), those that were dead (four) were retained and frozen.

### A.3.5 Collecting and animal ethics permits

Sampling and methods of handling fish and other animals was carried out in accordance with CSIRO Wildlife and Large Animal - Animal Ethics Committee approval 2017_17, the Australian Fisheries Management Authority scientific permit 1003509, Australian Department of National Parks permits E2017-0134 and AU-COM2017-378, and the Western Australian Department of Biodiversity, Conservation and Attractions permit number 08-0011252-1.

## A.4 Other sampling and equipment used

### A.4.1 Tow video camera

In order to characterise the seabed before and after trawling, a live wire real-time view tow video camera was deployed along the trawl line at some sites. The tow video system consisted of a large tow body with Canon 1DX digital still camera and a Canon C300 video camera in housings rated to 3000 m depth. Lighting for both video and stills was provided by four Deep Sea Power and Light 3150 Sealite video lights. A forward-looking Hitachi video camera, long-range altimeter (Kongsberg Mesotech 1007D) and Druck PMP 5074 pressure sensor assisted the on-board winch operator to keep the camera above the seabed and avoid obstacles ahead of the camera as the vessel moved at 2.5 knots.

### A.4.2 Zooplankton sampling

Zooplankton was collected at each site with oblique bongo net tows (50 cm diameter) with 100 $\mu$m mesh nets. The net was towed from 5–10 m off the bottom to the surface. All tows were done at night. Samples for biomass and species composition were preserved in 5% formalin. Samples for stable isotopes were size fractionated onboard (100–150, 150–250, 250–355, 355–1,000, 1,000–3,000 and 3,000 micron) and stored in -20$^{o}$C.

### A.4.3 Grab Sampling

A Smith McIntyre Grab was deployed at each site on the sled line to sample for chl-*a*, stable isotopes and sediment grain size. Three syringe core subsamples of 0–2 cm depth and 2–5 cm depth were taken for chl-*a* analyses and stored in -80°C. One syringe core sample of 0–5 cm depth was taken for stable isotopes and stored in -20$^{o}$C. A 1 L scoop sample was taken for sediment grain size and stored in -20$^{o}$C.

### A.4.4 CTD and water column sampling

Water samples at 70 sites were collected using a 36 x 12 L Niskin bottle rosette with profiles of conductivity and temperature (Seabird SBE 9/11 dual-sensor unit), PAR (400–700 nm; Biospherical Instruments QCP-2300), fluorescence (Chelsea Instruments Aquatracka™ fluorometer), transmission (Wetlabs C–Star™), DO (Seabird 43 series optode) and nitrate (Satlanic ISUS sensor) determined concurrently. Water samples at each site were collected from between 3 and 6 nominal depths (surface [~ 3 m], 10 m, 25 m, 50 m, the chlorophyll maximum, where present, and 5 m from bottom) and analysed for DO, salinity, nutrients, chl-*a* (size fractionated), phytoplankton community structure, particulate organic carbon and particulate nitrogen, and environmental DNA.

Replicate 10 mL water samples of unfiltered seawater from each depth were analysed for dissolved inorganic nutrients (nitrate + nitrite [hereafter nitrate], ammonia, phosphate and silicate) by segmented flow injection analysis (Seal AA3HR auto-analyser), with detection by absorbance at specific wavelengths for silicate [CSIRO Method 1 V01 - Molybdate], nitrate [CSIRO Method 3 V01] and phosphate [CSIRO Method 2 V01], and by fluorescence for ammonia (Watson et al., 2005). Detection limits were 0.02 µM for all inorganic nutrient species, with a standard error of < 0.7%.

One L of seawater from each depth was vacuum-filtered onto a Whatman 25 mm diameter GF/F filter (nominal pore size of 0.7 µm) and analysed for chl-*a* and phaeopigment (represents the total chl-*a* fraction). A further 2 L of sample was filtered onto a 25 mm diameter, 5 µm Nitex mesh and analysed for chl-*a* and phaeopigment (the > 5 µm fraction). Filters and screens were stored in liquid nitrogen until analysis. Pigments were extracted in 90% acetone overnight and analysed using a calibrated Turner Designs model 10AU fluorometer and the acidification technique of Parsons et al. (1989). The < 5 µm fraction was calculated as the difference between the total and > 5 µm fractions.

Suspended particulate matter (SPM) samples were collected from surface and chlorophyll maximum or the bottom (if no chlorophyll maximum was present) from each of the CTD casts. Four L of sample water was vacuum-filtered onto a pre-weighed glass fibre filter (47 mm, 0.7 µm, Whatman GF/F) and stored in cool, dark conditions until analysis.

Four L of the surface water sample and chlorophyll maximum or the bottom (if no chlorophyll maximum was present) were filtered onto a 25 mm, 0.7 µm, Whatman GF/F and stored in liquid nitrogen until analysis. Phytoplankton pigments were extracted and analysed by High Performance Liquid Chromatography (HPLC) with a Waters-Alliance system following the protocol detailed in Hooker et al., (2009).

At each CTD cast site, 3 x 1 L replicates of sample water collected 5 m from the bottom were filtered onto a 47 mm, 0.22 or 0.45 µm Pall membrane filter using a peristaltic pump to collect samples for environmental DNA of fishes. When analysed, this was compared directly with the fish catch species diversity from the demersal trawls.

### A.4.5 Turbulence profiles

In order to measure the micro-scale turbulence, the Vertical Micro-structure Profiles (VMP-250) with two shear probes and one FP07 thermistor was deployed at 73 sites. The instrument was powered by an internal polymer lithium-ion battery of nominally 14.8 V and 2.2 Ah capacity. Brushes required to achieve the desired fall rate between 0.4–0.9 m/s. The instrument was turned on by attaching a magnet to the front bulkhead and waiting for confirmation that the LED was ‘ON’. The instrument was then lowered to below the sea surface, ensuring enough slack in the deployment rope to allow a free-fall, but ensuring the total rope length was less than the actual depth. The instrument was released and when the rope was taut, the instrument was recovered to the sea surface. This was repeated to obtain three profiles at each site. When the instrument was back on deck, the power was turned off and returned to the workroom, connected to the computer, and data downloaded.

## A.5 Analyses of trawl headline camera images

Images of the seabed were selected between the on-bottom and off-bottom times of the trawl. For most trawls this was a distance of about 2 km (covered in 30 minutes). Every fifth image was selected for analysis (1 image/~ 22 m) and the benthic composition and abundance were obtained by scoring points overlaid on each benthic invertebrate visible on the image using TransectMeasure software (www.seagis.com.au). For each image, the type of substrate was recorded and the underlying taxon was identified as per the classification in the table below for each superimposed point, by a trained analyst with access to a range of appropriate reference resources. These classifications and scoring criteria were the same as those used for previous research carried out on the NWS (Sainsbury 1988; 1991). Benthic invertebrates present in the corners of the images and/or not entirely showing on the images were not scored. The output containing all scored points per image was then exported as a text file for each site and all text files were combined into an Excel spreadsheet for comparison. For the analyses presented in this report no attempt was made to correct for variation in frame (image) area caused by differences in the distance of the camera from the bottom and angle of camera view. In the absence of correcting for these factors, the data scored from the images can be used for qualitative comparisons of habitat type as is done in this report rather than quantitative comparisons of biota density. Fish are shown in the table below but were not scored in images.

**Apx Table 1 North West Shelf benthic image classification categories. For origin of this classification method see text sections above and Troje and Campbell (1989).**

| Category | Description |
|---|---|
| Boundary | Marked change in either topography or sediment type within the frame |
| Ridge | A hill in the frame |
| Furrow | Ditch present |
| Pothole | Holes present (e.g. large feeding marks of fish) |
| Flat | Bottom is either flat or only irregularly pockmarked by fish feeding |
| Rock | Large individual rock(s), different to rubble |
| Fine_Ripple | Regular ripples: > 4 ripples per 1 m |
| Large_Ripple | Large ripples: 1–4 ripples per 1 m |
| V_LG_Ripple | Very large ripples: < 1 ripple per 1 m |
| Silt | Clouds of sediment kicked up by the gear can be seen in the photo |
| Fine_Sand | Grains can be distinguished up to the 1 m mark (second row of grid) |
| Coarse_Sand | Grains can be distinguished up to the 1.5 m mark (third row of grid) |
| Rubble | Sediment coarser than gravel |
| LG_Lump | Number of large lump shaped objects; mostly sponge (> 25 cm) |
| LG_Cup | Number of large cup shaped sponges (> 25 cm) |
| LG_Branch | Number of large branched/erected sponges (in 3D) not interlacing (> 25 cm) |
| LG_Flat | Number of large fan shaped or convoluted objects (in 2D); mostly sponge (> 25 cm) |
| LG_Alcyon | Number of large cauliflower-shaped, fleshy looking organisms (alcyonarians > 25 cm) |
| LG_Gorgon | Number of large fan shaped or convoluted objects; lacy, brittle looking organisms (gorgonians > 25 cm) |
| LG_Seapen | Number of large whitish/yellow, often ghostly objects; sometimes shaped like a quill, or a stalk with a ball at the base (> 25 cm) |
| LG_Whip | Number of large whitish or reddish long 'sticks'; may spiral at the end (> 25 cm) |

| | |
|---|---|
| LG_Hydro | Number of large stringy objects, ghostly greenish/brown long stemmed objects resembling feathers; often circular scouring at the base (mostly hydroids > 25 cm) |
| LG_Crino | Number of large crinoids; several stick-like arms coming from a central base (> 25 cm) |
| LG_Others | Number of large objects not fitting in the rest of the large categories (> 25 cm) |
| Mini_Abund (<5 cm) | Abundance of small organisms < 5 cm (Grouping categories ranked 1:1–4 items; 2: 5–7 items; 3: 8 or more items) |
| SM_Lump | Number of small lump shaped objects; mostly sponge (5–25 cm) |
| SM_Cup | Number of small cup shaped sponges (5–25 cm) |
| SM_Branch | Number of small branched/erected sponges (in 3D) not interlacing (5–25 cm) |
| SM_Flat | Number of small fan shaped or convoluted objects (in 2D); mostly sponge (5–25 cm) |
| SM_Alcyon | Number of small cauliflower-shaped, fleshy looking organisms (alcyonarians: 5–25 cm) |
| SM_Gorgon | Number of small fan shaped or convoluted objects; lacy, brittle looking organisms (gorgonians: 5–25 cm) |
| SM_Seapen | Number of small whitish/yellow, often ghostly objects; sometimes shaped like a quill, or a stalk with a ball at the base (5–25 cm) |
| SM_Whip | Number of small whitish or reddish long 'sticks'; may spiral at the end (5–25 cm) |
| SM_Hydro | Number of small stringy objects, ghostly greenish/brown long stemmed objects resembling feathers; often circular scouring at the base (mostly hydroids: 5–25 cm) |
| SM_Crino | Number of small crinoids; several stick-like arms coming from a central base (5–25 cm) |
| SM_Others | Number of small objects not fitting in the rest of the large categories (5–25 cm) |
| Coral trout | Presence of Coral trout |
| Lizard | Presence of Lizardfish |
| Lethrinid | Presence of Lethrinidae species |
| Lutjanid | Presence of Lutjanidae species |
| Big red fish | Presence of Big red fish (*Lutjanus sebae*) |
| Nemipterid | Presence of Nemipteridae species |
| Trigg | Presence of Triggerfish |
| Shark and Ray | Presence of Shark(s) and Ray(s) |
| Squirrel fish | Presence of Squirrelfish |
| Cuttle | Presence of Cuttlefish |
| Squid | Presence of Squid |

# Appendix B Detailed list of operations by date, site and gear type during the RV *Investigator* voyage in 2017 (INV2017_05)

## B.1 List of operations

The details of each operation at each site surveyed during the 2017 RV *Investigator* voyage are given in the table below.

**Apx Table 2 Sampling gear and instrument deployments undertaken on the RV *Investigator* voyage INV2017_05.**

| Operation | Station name | Date | Time (UTC) | Type | Depth (m) | Equipment |
|---|---|---|---|---|---|---|
| 1 | 0 | 11-Oct-17 | 6:08 | Catch | 50 | McKenna demersal fish trawl nets |
| 2 | OM20 | 11-Oct-17 | 13:09 | Catch | 50 | McKenna demersal fish trawl nets |
| 3 | W74 | 12-Oct-17 | 4:48 | Catch | 85 | McKenna demersal fish trawl nets |
| 4 | W74 | 12-Oct-17 | 6:28 | CTD Cast | 76 | CTD - Seabird 911 with 36 Bottle Rosette |
| 5 | W74 | 12-Oct-17 | 6:51 | Turbulence probe | 76 | VMP Microstructure profiler |
| 6 | W88 | 12-Oct-17 | 8:54 | Catch | 84 | McKenna demersal fish trawl nets |
| 7 | W67 | 12-Oct-17 | 11:30 | Benthos | 74 | WHOI epibenthic Biological sled |
| 8 | W67 | 12-Oct-17 | 12:52 | Sediment Grab | 74 | Smith McIntyre grab |
| 9 | W67 | 12-Oct-17 | 13:18 | Plankton |  | Bongo Nets |
| 10 | W57 | 12-Oct-17 | 14:44 | Benthos | 76 | WHOI epibenthic Biological sled |
| 11 | W57 | 12-Oct-17 | 15:28 | Sediment Grab | 76 | Smith McIntyre grab |
| 12 | W88 | 12-Oct-17 | 17:01 | Benthos | 80 | WHOI epibenthic Biological sled |
| 13 | W88 | 12-Oct-17 | 17:47 | Sediment Grab | 80 | Smith McIntyre grab |
| 14 | W74 | 12-Oct-17 | 18:41 | Benthos | 82 | WHOI epibenthic Biological sled |
| 15 | W74 | 12-Oct-17 | 19:15 | Sediment Grab | 80 | Smith McIntyre grab |
| 16 | W74 | 12-Oct-17 | 19:47 | Plankton |  | Bongo Nets |
| 17 | W67 | 12-Oct-17 | 21:48 | Catch |  | McKenna demersal fish trawl nets |
| 18 | W67 | 13-Oct-17 | 0:00 | CTD Cast | 73 | CTD - Seabird 911 with 36 Bottle Rosette |
| 19 | W67 | 13-Oct-17 | 0:35 | Turbulence probe | 73 | VMP Microstructure profiler |
| 20 | W57 | 13-Oct-17 | 2:00 | Catch | 76 | McKenna demersal fish trawl nets |
| 21 | W57 | 13-Oct-17 | 3:12 | CTD Cast | 74 | CTD - Seabird 911 with 36 Bottle Rosette |
| 22 | W57 | 13-Oct-17 | 3:28 | Turbulence probe | 74 | VMP Microstructure profiler |
| 23 | W36 | 13-Oct-17 | 5:45 | Catch | 73 | McKenna demersal fish trawl nets |
| 24 | W25 | 13-Oct-17 | 8:55 | Catch |  | McKenna demersal fish trawl nets |
| 25 | W25 | 13-Oct-17 | 10:08 | CTD Cast |  | CTD - Seabird 911 with 36 Bottle Rosette |
| 26 | W25 | 13-Oct-17 | 10:30 | Turbulence probe | 43 | VMP Microstructure profiler |
| 27 | W25 | 13-Oct-17 | 11:01 | Benthos | 52 | WHOI epibenthic Biological sled |
| 28 | W25 | 13-Oct-17 | 11:32 | Sediment Grab |  | Smith McIntyre grab |
| 29 | W25 | 13-Oct-17 | 12:09 | Plankton |  | Bongo Nets |
| 30 | W36 | 13-Oct-17 | 13:50 | Plankton |  | Bongo Nets |
| 31 | W36 | 13-Oct-17 | 14:15 | Benthos |  | WHOI epibenthic Biological sled |
| 32 | W36 | 13-Oct-17 | 14:44 | Sediment Grab |  | Smith McIntyre grab |
| 33 | W24 | 13-Oct-17 | 16:58 | Benthos |  | WHOI epibenthic Biological sled |
| 34 | W24 | 13-Oct-17 | 17:47 | Sediment Grab |  | Smith McIntyre grab |
| 35 | W24 | 13-Oct-17 | 17:59 | Plankton |  | Bongo Nets |
| 36 | W11 | 13-Oct-17 | 18:40 | Plankton | 39 | Bongo Nets |

| | | | | | | |
|---|---|---|---|---|---|---|
| 37 | W11 | 13-Oct-17 | 19:30 | Benthos | 36 | WHOI epibenthic Biological sled |
| 38 | W11 | 13-Oct-17 | 21:01 | Sediment Grab | 36 | Smith McIntyre grab |
| 39 | W11 | 13-Oct-17 | 22:00 | Catch | 38 | McKenna demersal fish trawl nets |
| 40 | W11 | 14-Oct-17 | 0:15 | CTD Cast | 37 | CTD - Seabird 911 with 36 Bottle Rosette |
| 41 | W11 | 14-Oct-17 | 0:45 | Turbulence probe | 35 | VMP Microstructure profiler |
| 42 | W24 | 14-Oct-17 | 0:56 | Catch | | McKenna demersal fish trawl nets |
| 43 | W23 | 14-Oct-17 | 5:03 | Catch | 63 | McKenna demersal fish trawl nets |
| 44 | W56 | 14-Oct-17 | 8:04 | Catch | 60 | McKenna demersal fish trawl nets |
| 45 | W56 | 14-Oct-17 | 9:44 | CTD Cast | | CTD - Seabird 911 with 36 Bottle Rosette |
| 46 | W56 | 14-Oct-17 | 10:13 | Turbulence probe | | VMP Microstructure profiler |
| 47 | W56 | 14-Oct-17 | 10:24 | Sediment Grab | 60 | Smith McIntyre grab |
| 48 | W56 | 14-Oct-17 | 10:33 | Plankton | | Bongo Nets |
| 49 | W56 | 14-Oct-17 | 11:04 | Benthos | | WHOI epibenthic Biological sled |
| 50 | W21 | 14-Oct-17 | 13:44 | Benthos | | WHOI epibenthic Biological sled |
| 51 | W21 | 14-Oct-17 | 14:19 | Sediment Grab | | Smith McIntyre grab |
| 52 | W21 | 14-Oct-17 | 14:37 | Plankton | | Bongo Nets |
| 53 | W52 | 14-Oct-17 | 16:12 | Plankton | | Bongo Nets |
| 54 | W52 | 14-Oct-17 | 16:52 | Benthos | | WHOI epibenthic Biological sled |
| 55 | W52 | 14-Oct-17 | 17:14 | Sediment Grab | | Smith McIntyre grab |
| 56 | W54 | 14-Oct-17 | 18:18 | Benthos | 70 | WHOI epibenthic Biological sled |
| 57 | W54 | 14-Oct-17 | 19:00 | Sediment Grab | 70 | Smith McIntyre grab |
| 58 | W54 | 14-Oct-17 | 19:22 | Plankton | 70 | Bongo Nets |
| 59 | W54 | 14-Oct-17 | 21:54 | Catch | 70 | McKenna demersal fish trawl nets |
| 60 | W21 | 15-Oct-17 | 0:49 | Catch | 60 | McKenna demersal fish trawl nets |
| 61 | W21 | 15-Oct-17 | 2:12 | CTD Cast | 55 | CTD - Seabird 911 with 36 Bottle Rosette |
| 62 | W21 | 15-Oct-17 | 2:52 | Turbulence probe | 55 | VMP Microstructure profiler |
| 63 | W52 | 15-Oct-17 | 4:22 | Catch | 67 | McKenna demersal fish trawl nets |
| 64 | W52 | 15-Oct-17 | 5:41 | CTD Cast | | CTD - Seabird 911 with 36 Bottle Rosette |
| 65 | W52 | 15-Oct-17 | 5:57 | Turbulence probe | | VMP Microstructure profiler |
| 66 | W53 | 15-Oct-17 | 6:59 | Catch | | McKenna demersal fish trawl nets |
| 67 | W53 | 15-Oct-17 | 8:38 | CTD Cast | | CTD - Seabird 911 with 36 Bottle Rosette |
| 68 | W53 | 15-Oct-17 | 9:01 | Turbulence probe | | VMP Microstructure profiler |
| 69 | W53 | 15-Oct-17 | 9:39 | Sediment Grab | 75 | Smith McIntyre grab |
| 70 | W53 | 15-Oct-17 | 9:50 | Benthos | | WHOI epibenthic Biological sled |
| 71 | W53 | 15-Oct-17 | 10:43 | Plankton | | Bongo Nets |
| 72 | W55 | 15-Oct-17 | 11:00 | Plankton | | Bongo Nets |
| 73 | W55 | 15-Oct-17 | 11:44 | Benthos | | WHOI epibenthic Biological sled |
| 74 | W55 | 15-Oct-17 | 12:15 | Sediment Grab | | Smith McIntyre grab |
| 75 | W33 | 15-Oct-17 | 15:02 | Benthos | | WHOI epibenthic Biological sled |
| 76 | W33 | 15-Oct-17 | 15:45 | Sediment Grab | | Smith McIntyre grab |
| 77 | W33 | 15-Oct-17 | 16:00 | Plankton | | Bongo Nets |
| 78 | W33 | 15-Oct-17 | 16:39 | CTD Cast | | CTD - Seabird 911 with 36 Bottle Rosette |
| 79 | W35 | 15-Oct-17 | 18:33 | Plankton | 90 | Bongo Nets |
| 80 | W35 | 15-Oct-17 | 19:00 | Benthos | 92 | WHOI epibenthic Biological sled |
| 81 | W35 | 15-Oct-17 | 20:16 | Sediment Grab | 91 | Smith McIntyre grab |
| 82 | W35 | 15-Oct-17 | 20:37 | Benthos | 92 | WHOI epibenthic Biological sled |
| 83 | W35 | 15-Oct-17 | 21:05 | Plankton | 91 | Bongo Nets |
| 84 | W35 | 15-Oct-17 | 22:17 | Catch | 1164 | McKenna demersal fish trawl nets |
| 85 | W33 | 16-Oct-17 | 1:01 | Catch | 95 | McKenna demersal fish trawl nets |
| 86 | W33 | 16-Oct-17 | 1:57 | CTD Cast | 94 | CTD - Seabird 911 with 36 Bottle Rosette |
| 87 | W33 | 16-Oct-17 | 2:44 | Turbulence probe | 94 | VMP Microstructure profiler |
| 88 | W39 | 16-Oct-17 | 4:11 | Catch | 46 | McKenna demersal fish trawl nets |
| 89 | W39 | 16-Oct-17 | 5:32 | CTD Cast | 86 | CTD - Seabird 911 with 36 Bottle Rosette |
| 90 | W39 | 16-Oct-17 | 5:59 | Turbulence probe | 86 | VMP Microstructure profiler |
| 91 | W55 | 16-Oct-17 | 7:00 | Catch | 70 | McKenna demersal fish trawl nets |
| 92 | W55 | 16-Oct-17 | 8:20 | CTD Cast | | CTD - Seabird 911 with 36 Bottle Rosette |
| 93 | W55 | 16-Oct-17 | 8:48 | Turbulence probe | | VMP Microstructure profiler |
| 94 | W66 | 16-Oct-17 | 11:14 | Benthos | | WHOI epibenthic Biological sled |
| 95 | W66 | 16-Oct-17 | 12:17 | Sediment Grab | | Smith McIntyre grab |

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|---|---|---|---|---|---|---|
| 96 | W66 | 16-Oct-17 | 12:41 | Plankton |  | Bongo Nets |
| 97 | W39 | 16-Oct-17 | 15:15 | Plankton |  | Bongo Nets |
| 98 | W39 | 16-Oct-17 | 15:32 | Benthos |  | WHOI epibenthic Biological sled |
| 99 | W39 | 16-Oct-17 | 16:18 | Sediment Grab |  | Smith McIntyre grab |
| 100 | W34 | 16-Oct-17 | 17:51 | Benthos |  | WHOI epibenthic Biological sled |
| 101 | W34 | 16-Oct-17 | 18:25 | Sediment Grab |  | Smith McIntyre grab |
| 102 | W34 | 16-Oct-17 | 18:35 | Plankton |  | Bongo Nets |
| 103 | W34 | 16-Oct-17 | 19:59 | CTD Cast |  | CTD - Seabird 911 with 36 Bottle Rosette |
| 104 | W73 | 16-Oct-17 | 20:00 | Plankton | 86 | Bongo Nets |
| 105 | W73 | 16-Oct-17 | 21:11 | Benthos | 80 | WHOI epibenthic Biological sled |
| 106 | W73 | 16-Oct-17 | 21:55 | Sediment Grab | 79 | Smith McIntyre grab |
| 107 | W73 | 16-Oct-17 | 22:44 | Catch Failed | 60 | McKenna demersal fish trawl nets |
| 108 | W73 | 17-Oct-17 | 0:26 | Catch | 86 | McKenna demersal fish trawl nets |
| 109 | W34 | 17-Oct-17 | 1:52 | Catch | 89 | McKenna demersal fish trawl nets |
| 110 | W66 | 17-Oct-17 | 5:15 | Catch | 75 | McKenna demersal fish trawl nets |
| 111 | W65 | 17-Oct-17 | 8:11 | Catch | 61 | McKenna demersal fish trawl nets |
| 112 | W65 | 17-Oct-17 | 10:02 | Turbulence probe |  | VMP Microstructure profiler |
| 113 | W65 | 17-Oct-17 | 10:14 | CTD Cast |  | CTD - Seabird 911 with 36 Bottle Rosette |
| 114 | W65 | 17-Oct-17 | 11:06 | Benthos |  | WHOI epibenthic Biological sled |
| 115 | W65 | 17-Oct-17 | 11:26 | Sediment Grab |  | Smith McIntyre grab |
| 116 | W65 | 17-Oct-17 | 11:55 | Plankton |  | Bongo Nets |
| 117 | W22 | 17-Oct-17 | 14:24 | Plankton |  | Bongo Nets |
| 118 | W22 | 17-Oct-17 | 14:53 | Benthos |  | WHOI epibenthic Biological sled |
| 119 | W22 | 17-Oct-17 | 15:23 | Sediment Grab |  | Smith McIntyre grab |
| 120 | W9 | 17-Oct-17 | 17:30 | Benthos |  | WHOI epibenthic Biological sled |
| 121 | W9 | 17-Oct-17 | 18:07 | Sediment Grab |  | Smith McIntyre grab |
| 122 | W9 | 17-Oct-17 | 18:19 | Plankton |  | Bongo Nets |
| 123 | W10 | 17-Oct-17 | 19:54 | Plankton | 30 | Bongo Nets |
| 124 | W10 | 17-Oct-17 | 20:08 | Benthos | 31 | WHOI epibenthic Biological sled |
| 125 | W10 | 17-Oct-17 | 20:38 | Sediment Grab | 32 | Smith McIntyre grab |
| 126 | W10 | 17-Oct-17 | 22:02 | Catch | 33 | McKenna demersal fish trawl nets |
| 127 | W9 | 18-Oct-17 | 0:33 | Catch | 39 | McKenna demersal fish trawl nets |
| 128 | W9 | 18-Oct-17 | 1:36 | CTD Cast | 40 | CTD - Seabird 911 with 36 Bottle Rosette |
| 129 | W9 | 18-Oct-17 | 1:53 | Turbulence probe | 40 | VMP Microstructure profiler |
| 130 | W22 | 18-Oct-17 | 4:07 | Catch | 50 | McKenna demersal fish trawl nets |
| 131 | W22 | 18-Oct-17 | 4:58 | CTD Cast | 49 | CTD - Seabird 911 with 36 Bottle Rosette |
| 132 | W22 | 18-Oct-17 | 5:34 | Turbulence probe | 57 | VMP Microstructure profiler |
| 133 | W45 | 18-Oct-17 | 7:45 | Catch | 57 | McKenna demersal fish trawl nets |
| 134 | W45 | 18-Oct-17 | 8:57 | CTD Cast | 57 | CTD - Seabird 911 with 36 Bottle Rosette |
| 135 | W45 | 18-Oct-17 | 9:20 | Turbulence probe | 57 | VMP Microstructure profiler |
| 136 | W45 | 18-Oct-17 | 9:56 | Benthos | 65 | WHOI epibenthic Biological sled |
| 137 | W45 | 18-Oct-17 | 10:26 | Sediment Grab | 61 | Smith McIntyre grab |
| 138 | W45 | 18-Oct-17 | 11:03 | Plankton | 61 | Bongo Nets |
| 139 | W42 | 18-Oct-17 | 12:17 | Plankton | 61 | Bongo Nets |
| 140 | W42 | 18-Oct-17 | 12:42 | Benthos | 61 | WHOI epibenthic Biological sled |
| 141 | W42 | 18-Oct-17 | 13:18 | Sediment Grab | 62 | Smith McIntyre grab |
| 142 | W64 | 18-Oct-17 | 15:25 | Benthos | 71 | WHOI epibenthic Biological sled |
| 143 | W64 | 18-Oct-17 | 15:54 | Sediment Grab | 70 | Smith McIntyre grab |
| 144 | W64 | 18-Oct-17 | 16:02 | Plankton | 57 | Bongo Nets |
| 145 | W30 | 18-Oct-17 | 17:57 | Plankton | 56 | Bongo Nets |
| 146 | W30 | 18-Oct-17 | 18:26 | Benthos | 56 | WHOI epibenthic Biological sled |
| 147 | W30 | 18-Oct-17 | 19:09 | Sediment Grab | 56 | Smith McIntyre grab |
| 148 | W30 | 18-Oct-17 | 19:13 | CTD Cast | 56 | CTD - Seabird 911 with 36 Bottle Rosette |
| 149 | W42 | 18-Oct-17 | 21:46 | Catch | 59 | McKenna demersal fish trawl nets |
| 150 | W64 | 19-Oct-17 | 1:15 | Catch | 70 | McKenna demersal fish trawl nets |
| 151 | W64 | 19-Oct-17 | 2:28 | CTD Cast | 70 | CTD - Seabird 911 with 36 Bottle Rosette |
| 152 | W64 | 19-Oct-17 | 2:49 | Turbulence probe | 69 | VMP Microstructure profiler |
| 153 | W30 | 19-Oct-17 | 4:15 | Catch | 57 | McKenna demersal fish trawl nets |
| 154 | W30 | 19-Oct-17 | 5:26 | CTD Cast | 57 | CTD - Seabird 911 with 36 Bottle Rosette |

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|---|---|---|---|---|---|---|
| 155 | W30 | 19-Oct-17 | 5:59 | Turbulence probe | 56 | VMP Microstructure profiler |
| 156 | W7 | 19-Oct-17 | 6:03 | Catch | 44 | McKenna demersal fish trawl nets |
| 157 | W7 | 19-Oct-17 | 8:41 | CTD Cast | 44 | CTD - Seabird 911 with 36 Bottle Rosette |
| 158 | W7 | 19-Oct-17 | 9:02 | Turbulence probe | 44 | VMP Microstructure profiler |
| 159 | W7 | 19-Oct-17 | 10:36 | Benthos | 46 | WHOI epibenthic Biological sled |
| 160 | W7 | 19-Oct-17 | 10:55 | Sediment Grab | 46 | Smith McIntyre grab |
| 161 | W7 | 19-Oct-17 | 11:10 | Plankton | 46 | Bongo Nets |
| 162 | W4 | 19-Oct-17 | 13:23 | Plankton | 34 | Bongo Nets |
| 163 | W4 | 19-Oct-17 | 13:41 | Benthos | 32 | WHOI epibenthic Biological sled |
| 164 | W4 | 19-Oct-17 | 14:43 | Sediment Grab | 34 | Smith McIntyre grab |
| 165 | W6 | 19-Oct-17 | 16:49 | Benthos | 30 | WHOI epibenthic Biological sled |
| 166 | W6 | 19-Oct-17 | 17:13 | Sediment Grab | 30 | Smith McIntyre grab |
| 167 | W6 | 19-Oct-17 | 17:32 | Plankton | 30 | Bongo Nets |
| 168 | W5 | 19-Oct-17 | 19:35 | Plankton | 38 | Bongo Nets |
| 169 | W5 | 19-Oct-17 | 20:12 | Benthos | 38 | WHOI epibenthic Biological sled |
| 170 | W5 | 19-Oct-17 | 20:41 | Sediment Grab | 37 | Smith McIntyre grab |
| 171 | W5 | 19-Oct-17 | 21:58 | Catch | 65 | McKenna demersal fish trawl nets |
| 172 | W6 | 20-Oct-17 | 0:46 | CTD Cast | 31 | CTD - Seabird 911 with 36 Bottle Rosette |
| 173 | W6 | 20-Oct-17 | 1:02 | Turbulence probe | 31 | VMP Microstructure profiler |
| 174 | W6 | 20-Oct-17 | 1:40 | Catch | 64 | McKenna demersal fish trawl nets |
| 175 | W4 | 20-Oct-17 | 4:19 | CTD Cast | 33 | CTD - Seabird 911 with 36 Bottle Rosette |
| 176 | W4 | 20-Oct-17 | 4:35 | Turbulence probe | 33 | VMP Microstructure profiler |
| 177 | W4 | 20-Oct-17 | 5:24 | Catch | 57 | McKenna demersal fish trawl nets |
| 178 | W8 | 20-Oct-17 | 8:14 | CTD Cast | 35 | CTD - Seabird 911 with 36 Bottle Rosette |
| 179 | W8 | 20-Oct-17 | 8:27 | Turbulence probe | 35 | VMP Microstructure profiler |
| 180 | W71 | 20-Oct-17 | 11:12 | Plankton | 63 | Bongo Nets |
| 181 | W71 | 20-Oct-17 | 11:44 | Benthos | 71 | WHOI epibenthic Biological sled |
| 182 | W71 | 20-Oct-17 | 12:07 | Sediment Grab | 71 | Smith McIntyre grab |
| 183 | W87 | 20-Oct-17 | 14:08 | Benthos | 71 | WHOI epibenthic Biological sled |
| 184 | W87 | 20-Oct-17 | 14:36 | Sediment Grab | 71 | Smith McIntyre grab |
| 185 | W87 | 20-Oct-17 | 15:02 | Plankton | 71 | Bongo Nets |
| 186 | W63 | 20-Oct-17 | 16:17 | Plankton | 75 | Bongo Nets |
| 187 | W63 | 20-Oct-17 | 16:30 | Benthos | 74 | WHOI epibenthic Biological sled |
| 188 | W63 | 20-Oct-17 | 17:14 | Sediment Grab | 73 | Smith McIntyre grab |
| 189 | W72 | 20-Oct-17 | 18:44 | Benthos | 59 | WHOI epibenthic Biological sled |
| 190 | W72 | 20-Oct-17 | 19:22 | Sediment Grab | 58 | Smith McIntyre grab |
| 191 | W72 | 20-Oct-17 | 19:31 | Plankton | 58 | Bongo Nets |
| 192 | W71 | 20-Oct-17 | 21:45 | Catch | 62 | McKenna demersal fish trawl nets |
| 193 | W87 | 20-Oct-17 | 23:44 | Catch | 56 | McKenna demersal fish trawl nets |
| 194 | W87 | 21-Oct-17 | 2:31 | CTD Cast | 70 | CTD - Seabird 911 with 36 Bottle Rosette |
| 195 | W63 | 21-Oct-17 | 4:38 | Catch | 73 | McKenna demersal fish trawl nets |
| 196 | W63 | 21-Oct-17 | 5:42 | CTD Cast | 73 | CTD - Seabird 911 with 36 Bottle Rosette |
| 197 | W63 | 21-Oct-17 | 6:07 | Turbulence probe | 72 | VMP Microstructure profiler |
| 198 | W72 | 21-Oct-17 | 7:54 | Catch | 47 | McKenna demersal fish trawl nets |
| 199 | W72 | 21-Oct-17 | 8:58 | CTD Cast | 55 | CTD - Seabird 911 with 36 Bottle Rosette |
| 200 | W72 | 21-Oct-17 | 9:18 | Turbulence probe | 59 | VMP Microstructure profiler |
| 201 | W60 | 21-Oct-17 | 11:25 | Benthos | 66 | WHOI epibenthic Biological sled |
| 202 | W60 | 21-Oct-17 | 11:48 | Sediment Grab | 66 | Smith McIntyre grab |
| 203 | W60 | 21-Oct-17 | 12:11 | Turbulence probe | 65 | VMP Microstructure profiler |
| 204 | W60 | 21-Oct-17 | 12:27 | Plankton | 65 | Bongo Nets |
| 205 | W76 | 21-Oct-17 | 13:25 | Plankton | 60 | Bongo Nets |
| 206 | W76 | 21-Oct-17 | 13:48 | Benthos | 61 | WHOI epibenthic Biological sled |
| 207 | W76 | 21-Oct-17 | 14:05 | Turbulence probe | 62 | VMP Microstructure profiler |
| 208 | W76 | 21-Oct-17 | 14:25 | Sediment Grab | 62 | Smith McIntyre grab |
| 209 | W86 | 21-Oct-17 | 16:06 | Benthos | 67 | WHOI epibenthic Biological sled |
| 210 | W86 | 21-Oct-17 | 16:28 | Sediment Grab | 67 | Smith McIntyre grab |
| 211 | W86 | 21-Oct-17 | 16:37 | Turbulence probe | 68 | VMP Microstructure profiler |
| 212 | W86 | 21-Oct-17 | 16:59 | Plankton | 68 | Bongo Nets |
| 213 | W85 | 21-Oct-17 | 18:57 | Plankton | 63 | Bongo Nets |

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| 214 | W85 | 21-Oct-17 | 19:14 | Turbulence probe | 59 | VMP Microstructure profiler |
| 215 | W85 | 21-Oct-17 | 19:33 | Benthos | 62 | WHOI epibenthic Biological sled |
| 216 | W85 | 21-Oct-17 | 20:17 | Sediment Grab | 64 | Smith McIntyre grab |
| 217 | W85 | 21-Oct-17 | 20:29 | CTD Cast | 64 | CTD - Seabird 911 with 36 Bottle Rosette |
| 218 | W85 | 21-Oct-17 | 20:37 | Turbulence probe | 64 | VMP Microstructure profiler |
| 219 | W85 | 21-Oct-17 | 22:02 | Catch | 47 | McKenna demersal fish trawl nets |
| 220 | W85 | 21-Oct-17 | 23:55 | CTD Cast | 64 | CTD - Seabird 911 with 36 Bottle Rosette |
| 221 | W85 | 22-Oct-17 | 0:02 | Turbulence probe | 64 | VMP Microstructure profiler |
| 222 | W86 | 22-Oct-17 | 2:06 | Catch | 49 | McKenna demersal fish trawl nets |
| 223 | W76 | 22-Oct-17 | 4:08 | CTD Cast | 60 | CTD - Seabird 911 with 36 Bottle Rosette |
| 224 | W76 | 22-Oct-17 | 4:43 | Turbulence probe | 60 | VMP Microstructure profiler |
| 225 | W76 | 22-Oct-17 | 4:43 | CTD Cast | 60 | CTD - Seabird 911 with 36 Bottle Rosette |
| 226 | W76 | 22-Oct-17 | 5:06 | Catch | 51 | McKenna demersal fish trawl nets |
| 227 | W60 | 22-Oct-17 | 7:50 | Catch | 54 | McKenna demersal fish trawl nets |
| 228 | W60 | 22-Oct-17 | 9:05 | CTD Cast | 61 | CTD - Seabird 911 with 36 Bottle Rosette |
| 229 | W60 | 22-Oct-17 | 9:49 | Turbulence probe | 61 | VMP Microstructure profiler |
| 230 | W69 | 22-Oct-17 | 11:44 | Benthos | 54 | WHOI epibenthic Biological sled |
| 231 | W69 | 22-Oct-17 | 12:13 | Sediment Grab | 58 | Smith McIntyre grab |
| 232 | W69 | 22-Oct-17 | 12:14 | Turbulence probe | 58 | VMP Microstructure profiler |
| 233 | W69 | 22-Oct-17 | 12:35 | Plankton | 55 | Bongo Nets |
| 234 | W44 | 22-Oct-17 | 14:14 | Plankton | 63 | Bongo Nets |
| 235 | W44 | 22-Oct-17 | 14:25 | Benthos | 63 | WHOI epibenthic Biological sled |
| 236 | W44 | 22-Oct-17 | 14:51 | Turbulence probe | 64 | VMP Microstructure profiler |
| 237 | W44 | 22-Oct-17 | 15:08 | Sediment Grab | 64 | Smith McIntyre grab |
| 238 | W77 | 22-Oct-17 | 16:43 | Benthos | 66 | WHOI epibenthic Biological sled |
| 239 | W77 | 22-Oct-17 | 17:13 | Sediment Grab | 66 | Smith McIntyre grab |
| 240 | W77 | 22-Oct-17 | 17:26 | Turbulence probe | 66 | VMP Microstructure profiler |
| 241 | W77 | 22-Oct-17 | 17:41 | Plankton | 65 | Bongo Nets |
| 242 | W40 | 22-Oct-17 | 18:54 | Plankton | 66 | Bongo Nets |
| 243 | W40 | 22-Oct-17 | 19:16 | Benthos | 65 | WHOI epibenthic Biological sled |
| 244 | W40 | 22-Oct-17 | 19:44 | Sediment Grab | 65 | Smith McIntyre grab |
| 245 | W40 | 22-Oct-17 | 19:51 | Turbulence probe | 65 | VMP Microstructure profiler |
| 246 | W69 | 22-Oct-17 | 22:07 | Catch | 54 | McKenna demersal fish trawl nets |
| 247 | W69 | 22-Oct-17 | 23:49 | CTD Cast | 60 | CTD - Seabird 911 with 36 Bottle Rosette |
| 248 | W69 | 23-Oct-17 | 0:27 | Turbulence probe | 60 | VMP Microstructure profiler |
| 249 | W44 | 23-Oct-17 | 1:48 | Catch | 55 | McKenna demersal fish trawl nets |
| 250 | W44 | 23-Oct-17 | 2:47 | CTD Cast | 66 | CTD - Seabird 911 with 36 Bottle Rosette |
| 251 | W44 | 23-Oct-17 | 3:19 | Turbulence probe | 66 | VMP Microstructure profiler |
| 252 | W77 | 23-Oct-17 | 4:08 | Catch | 55 | McKenna demersal fish trawl nets |
| 253 | W77 | 23-Oct-17 | 5:17 | CTD Cast | 66 | CTD - Seabird 911 with 36 Bottle Rosette |
| 254 | W77 | 23-Oct-17 | 5:46 | Turbulence probe | 66 | VMP Microstructure profiler |
| 255 | W92 | 23-Oct-17 | 10:31 | Turbulence probe | 62 | VMP Microstructure profiler |
| 256 | W92 | 23-Oct-17 | 11:01 | Benthos | 62 | WHOI epibenthic Biological sled |
| 257 | W92 | 23-Oct-17 | 11:22 | Sediment Grab | 62 | Smith McIntyre grab |
| 258 | W92 | 23-Oct-17 | 11:43 | Plankton | 62 | Bongo Nets |
| 259 | W62 | 23-Oct-17 | 13:26 | Plankton | 59 | Bongo Nets |
| 260 | W62 | 23-Oct-17 | 13:51 | Benthos | 59 | WHOI epibenthic Biological sled |
| 261 | W62 | 23-Oct-17 | 14:10 | Sediment Grab | 59 | Smith McIntyre grab |
| 262 | W62 | 23-Oct-17 | 14:23 | Turbulence probe | 59 | VMP Microstructure profiler |
| 263 | W20 | 23-Oct-17 | 16:34 | Benthos | 49 | WHOI epibenthic Biological sled |
| 264 | W20 | 23-Oct-17 | 17:02 | Sediment Grab | 49 | Smith McIntyre grab |
| 265 | W20 | 23-Oct-17 | 17:09 | Turbulence probe | 49 | VMP Microstructure profiler |
| 266 | W20 | 23-Oct-17 | 17:26 | Plankton | 49 | Bongo Nets |
| 267 | W8 | 23-Oct-17 | 18:51 | Turbulence probe | 37 | VMP Microstructure profiler |
| 268 | W8 | 23-Oct-17 | 19:01 | Plankton | 37 | Bongo Nets |
| 269 | W8 | 23-Oct-17 | 19:19 | Benthos | 37 | WHOI epibenthic Biological sled |
| 270 | W8 | 23-Oct-17 | 19:42 | Sediment Grab | 36 | Smith McIntyre grab |
| 271 | W8 | 23-Oct-17 | 21:27 | Catch | 37 | McKenna demersal fish trawl nets |
| 272 | W20 | 24-Oct-17 | 0:18 | Catch | 46 | McKenna demersal fish trawl nets |

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| 273 | W20 | 24-Oct-17 | 1:50 | CTD Cast | 46 | CTD - Seabird 911 with 36 Bottle Rosette |
| 274 | W20 | 24-Oct-17 | 2:10 | Turbulence probe | 47 | VMP Microstructure profiler |
| 275 | W62 | 24-Oct-17 | 3:31 | Catch | 58 | McKenna demersal fish trawl nets |
| 276 | W62 | 24-Oct-17 | 4:39 | CTD Cast | 58 | CTD - Seabird 911 with 36 Bottle Rosette |
| 277 | W62 | 24-Oct-17 | 5:14 | Turbulence probe | 58 | VMP Microstructure profiler |
| 278 | W92 | 24-Oct-17 | 6:36 | Catch | 64 | McKenna demersal fish trawl nets |
| 279 | W92 | 24-Oct-17 | 7:44 | CTD Cast | 62 | CTD - Seabird 911 with 36 Bottle Rosette |
| 280 | W92 | 24-Oct-17 | 8:15 | Turbulence probe | 62 | VMP Microstructure profiler |
| 281 | W84 | 24-Oct-17 | 10:41 | Benthos | 56 | WHOI epibenthic Biological sled |
| 282 | W84 | 24-Oct-17 | 11:18 | Sediment Grab | 56 | Smith McIntyre grab |
| 283 | W84 | 24-Oct-17 | 11:30 | Plankton | 56 | Bongo Nets |
| 284 | W90 | 24-Oct-17 | 12:27 | Plankton | 58 | Bongo Nets |
| 285 | W90 | 24-Oct-17 | 12:38 | Benthos | 56 | WHOI epibenthic Biological sled |
| 286 | W90 | 24-Oct-17 | 13:21 | Sediment Grab | 56 | Smith McIntyre grab |
| 287 | W100 | 24-Oct-17 | 15:10 | Benthos | 56 | WHOI epibenthic Biological sled |
| 288 | W100 | 24-Oct-17 | 15:37 | Sediment Grab | 57 | Smith McIntyre grab |
| 289 | W100 | 24-Oct-17 | 15:49 | Plankton | 57 | Bongo Nets |
| 290 | W19 | 24-Oct-17 | 17:52 | Plankton | 44 | Bongo Nets |
| 291 | W19 | 24-Oct-17 | 18:01 | Benthos | 44 | WHOI epibenthic Biological sled |
| 292 | W19 | 24-Oct-17 | 18:36 | Sediment Grab | 43 | Smith McIntyre grab |
| 293 | W51 | 24-Oct-17 | 20:20 | Benthos | 52 | WHOI epibenthic Biological sled |
| 294 | W51 | 24-Oct-17 | 21:19 | Plankton | 51 | Bongo Nets |
| 295 | W51 | 24-Oct-17 | 21:21 | Sediment Grab | 52 | Smith McIntyre grab |
| 296 | W51 | 24-Oct-17 | 21:56 | Catch | 51 | McKenna demersal fish trawl nets |
| 297 | W19 | 25-Oct-17 | 0:16 | Catch | 40 | McKenna demersal fish trawl nets |
| 298 | W100 | 25-Oct-17 | 4:52 | Catch | 56 | McKenna demersal fish trawl nets |
| 299 | W100 | 25-Oct-17 | 6:43 | CTD Cast | 56 | CTD - Seabird 911 with 36 Bottle Rosette |
| 300 | W100 | 25-Oct-17 | 7:13 | Turbulence probe | 56 | VMP Microstructure profiler |
| 301 | W84 | 25-Oct-17 | 8:03 | Catch | 57 | McKenna demersal fish trawl nets |
| 302 | W84 | 25-Oct-17 | 10:17 | CTD Cast | 55 | CTD - Seabird 911 with 36 Bottle Rosette |
| 303 | W84 | 25-Oct-17 | 10:22 | Turbulence probe | 55 | VMP Microstructure profiler |
| 304 | W91 | 25-Oct-17 | 12:20 | Benthos | 62 | WHOI epibenthic Biological sled |
| 305 | W91 | 25-Oct-17 | 12:46 | Sediment Grab | 63 | Smith McIntyre grab |
| 306 | W91 | 25-Oct-17 | 13:08 | Turbulence probe | 63 | VMP Microstructure profiler |
| 307 | W91 | 25-Oct-17 | 13:23 | Plankton | 63 | Bongo Nets |
| 308 | W91 | 25-Oct-17 | 14:05 | Video | 63 | Deep Towed Camera System |
| 309 | W93 | 25-Oct-17 | 16:06 | Plankton | 66 | Bongo Nets |
| 310 | W93 | 25-Oct-17 | 16:38 | Benthos | 66 | WHOI epibenthic Biological sled |
| 311 | W93 | 25-Oct-17 | 16:58 | Sediment Grab | 66 | Smith McIntyre grab |
| 312 | W93 | 25-Oct-17 | 17:13 | Turbulence probe | 66 | VMP Microstructure profiler |
| 313 | W96 | 25-Oct-17 | 18:36 | Benthos | 64 | WHOI epibenthic Biological sled |
| 314 | W96 | 25-Oct-17 | 19:07 | Sediment Grab | 62 | Smith McIntyre grab |
| 315 | W96 | 25-Oct-17 | 19:31 | Turbulence probe | 62 | VMP Microstructure profiler |
| 316 | W96 | 25-Oct-17 | 19:31 | Plankton | 62 | Bongo Nets |
| 317 | W95 | 25-Oct-17 | 21:09 | Plankton | 61 | Bongo Nets |
| 318 | W95 | 25-Oct-17 | 21:14 | Benthos | 61 | WHOI epibenthic Biological sled |
| 319 | W95 | 25-Oct-17 | 22:27 | Catch | 59 | McKenna demersal fish trawl nets |
| 320 | W95 | 26-Oct-17 | 0:07 | CTD Cast | 62 | CTD - Seabird 911 with 36 Bottle Rosette |
| 321 | W95 | 26-Oct-17 | 0:31 | Turbulence probe | 62 | VMP Microstructure profiler |
| 322 | W95 | 26-Oct-17 | 0:48 | Sediment Grab | 61 | Smith McIntyre grab |
| 323 | W91 | 26-Oct-17 | 1:32 | Catch | 62 | McKenna demersal fish trawl nets |
| 324 | W91 | 26-Oct-17 | 2:51 | Turbulence probe | 62 | VMP Microstructure profiler |
| 325 | W93 | 26-Oct-17 | 4:09 | Catch | 80 | McKenna demersal fish trawl nets |
| 326 | W40 | 26-Oct-17 | 6:39 | Catch | 79 | McKenna demersal fish trawl nets |
| 327 | W40 | 26-Oct-17 | 8:11 | CTD Cast | 68 | CTD - Seabird 911 with 36 Bottle Rosette |
| 328 | W40 | 26-Oct-17 | 8:25 | Turbulence probe | 67 | VMP Microstructure profiler |
| 329 | W70 | 26-Oct-17 | 10:55 | Benthos | 58 | WHOI epibenthic Biological sled |
| 330 | W70 | 26-Oct-17 | 11:26 | Sediment Grab | 56 | Smith McIntyre grab |
| 331 | W70 | 26-Oct-17 | 11:40 | Plankton | 57 | Bongo Nets |

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| 332 | W61 | 26-Oct-17 | 14:15 | Benthos | 64 | WHOI epibenthic Biological sled |
| 333 | W61 | 26-Oct-17 | 14:39 | Sediment Grab | 64 | Smith McIntyre grab |
| 334 | W61 | 26-Oct-17 | 14:49 | Plankton | 65 | Bongo Nets |
| 335 | W28 | 26-Oct-17 | 16:26 | Plankton | 64 | Bongo Nets |
| 336 | W28 | 26-Oct-17 | 16:37 | Benthos | 64 | WHOI epibenthic Biological sled |
| 337 | W28 | 26-Oct-17 | 17:08 | Sediment Grab | 64 | Smith McIntyre grab |
| 338 | W41 | 26-Oct-17 | 18:18 | Benthos | 63 | WHOI epibenthic Biological sled |
| 339 | W41 | 26-Oct-17 | 18:43 | Sediment Grab | 63 | Smith McIntyre grab |
| 340 | W41 | 26-Oct-17 | 18:55 | Plankton | 63 | Bongo Nets |
| 341 | W31 | 26-Oct-17 | 20:52 | Benthos | 57 | WHOI epibenthic Biological sled |
| 342 | W31 | 26-Oct-17 | 21:21 | Sediment Grab | 57 | Smith McIntyre grab |
| 343 | W31 | 26-Oct-17 | 21:49 | Catch | 80 | McKenna demersal fish trawl nets |
| 344 | W41 | 27-Oct-17 | 0:14 | Catch | 80 | McKenna demersal fish trawl nets |
| 345 | W41 | 27-Oct-17 | 1:29 | CTD Cast | 62 | CTD - Seabird 911 with 36 Bottle Rosette |
| 346 | W41 | 27-Oct-17 | 1:50 | Turbulence probe | 62 | VMP Microstructure profiler |
| 347 | W28 | 27-Oct-17 | 2:42 | Catch | 80 | McKenna demersal fish trawl nets |
| 348 | W28 | 27-Oct-17 | 4:02 | CTD Cast | 64 | CTD - Seabird 911 with 36 Bottle Rosette |
| 349 | W28 | 27-Oct-17 | 4:35 | Turbulence probe | 65 | VMP Microstructure profiler |
| 350 | W61 | 27-Oct-17 | 5:00 | Catch | 81 | McKenna demersal fish trawl nets |
| 351 | W61 | 27-Oct-17 | 6:15 | CTD Cast | 66 | CTD - Seabird 911 with 36 Bottle Rosette |
| 352 | W61 | 27-Oct-17 | 6:45 | Turbulence probe | 66 | VMP Microstructure profiler |
| 353 | W12 | 27-Oct-17 | 11:55 | Benthos | 104 | WHOI epibenthic Biological sled |
| 354 | W12 | 27-Oct-17 | 12:43 | Sediment Grab | 100 | Smith McIntyre grab |
| 355 | W12 | 27-Oct-17 | 12:55 | Turbulence probe | 100 | VMP Microstructure profiler |
| 356 | W12 | 27-Oct-17 | 13:21 | Plankton | 100 | Bongo Nets |
| 357 | W26 | 27-Oct-17 | 14:55 | Plankton | 115 | Bongo Nets |
| 358 | W26 | 27-Oct-17 | 15:24 | Benthos | 103 | WHOI epibenthic Biological sled |
| 359 | W26 | 27-Oct-17 | 15:57 | Sediment Grab | 83 | Smith McIntyre grab |
| 360 | W26 | 27-Oct-17 | 16:04 | Turbulence probe | 94 | VMP Microstructure profiler |
| 361 | W29 | 27-Oct-17 | 17:56 | Benthos | 84 | WHOI epibenthic Biological sled |
| 362 | W29 | 27-Oct-17 | 18:24 | Sediment Grab | 81 | Smith McIntyre grab |
| 363 | W29 | 27-Oct-17 | 18:34 | Turbulence probe | 81 | VMP Microstructure profiler |
| 364 | W29 | 28-Oct-17 | 6:48 | Plankton | 80 | Bongo Nets |
| 365 | W32 | 27-Oct-17 | 19:56 | Plankton | 69 | Bongo Nets |
| 366 | W32 | 27-Oct-17 | 20:16 | Benthos | 69 | WHOI epibenthic Biological sled |
| 367 | W32 | 27-Oct-17 | 20:36 | Sediment Grab | 70 | Smith McIntyre grab |
| 368 | W32 | 27-Oct-17 | 20:47 | Turbulence probe | 70 | VMP Microstructure profiler |
| 369 | W32 | 27-Oct-17 | 21:48 | Catch | 81 | McKenna demersal fish trawl nets |
| 370 | W29 | 28-Oct-17 | 0:16 | CTD Cast | 103 | CTD - Seabird 911 with 36 Bottle Rosette |
| 371 | W29 | 28-Oct-17 | 0:41 | Turbulence probe | 103 | VMP Microstructure profiler |
| 372 | W29 | 28-Oct-17 | 1:21 | Catch Failed | 60 | McKenna demersal fish trawl nets |
| 373 | W26 | 28-Oct-17 | 3:39 | Catch | 82 | McKenna demersal fish trawl nets |
| 374 | W26 | 28-Oct-17 | 4:59 | CTD Cast | 84 | CTD - Seabird 911 with 36 Bottle Rosette |
| 375 | W26 | 28-Oct-17 | 5:45 | Turbulence probe | 85 | VMP Microstructure profiler |
| 376 | W12 | 28-Oct-17 | 6:19 | Catch | 82 | McKenna demersal fish trawl nets |
| 377 | W12 | 28-Oct-17 | 7:52 | CTD Cast | 95 | CTD - Seabird 911 with 36 Bottle Rosette |
| 378 | W12 | 28-Oct-17 | 8:19 | Turbulence probe | 95 | VMP Microstructure profiler |
| 379 | W27 | 28-Oct-17 | 10:55 | Benthos | 72 | WHOI epibenthic Biological sled |
| 380 | W27 | 28-Oct-17 | 11:25 | Sediment Grab | 72 | Smith McIntyre grab |
| 381 | W27 | 28-Oct-17 | 11:35 | Turbulence probe | 71 | VMP Microstructure profiler |
| 382 | W27 | 28-Oct-17 | 12:02 | Plankton | 72 | Bongo Nets |
| 383 | W37 | 28-Oct-17 | 14:02 | Plankton | 83 | Bongo Nets |
| 384 | W37 | 28-Oct-17 | 14:23 | Benthos | 80 | WHOI epibenthic Biological sled |
| 385 | W37 | 28-Oct-17 | 14:51 | Sediment Grab | 80 | Smith McIntyre grab |
| 386 | W37 | 28-Oct-17 | 14:53 | Turbulence probe | 80 | VMP Microstructure profiler |
| 387 | W38 | 28-Oct-17 | 16:33 | Benthos | 74 | WHOI epibenthic Biological sled |
| 388 | W38 | 28-Oct-17 | 16:59 | Sediment Grab | 74 | Smith McIntyre grab |
| 389 | W38 | 28-Oct-17 | 17:12 | Turbulence probe | 74 | VMP Microstructure profiler |
| 390 | W38 | 28-Oct-17 | 17:27 | Plankton | 75 | Bongo Nets |

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| 391 | W38 | 28-Oct-17 | 17:48 | Turbulence probe | 75 | VMP Microstructure profiler |
| 392 | W96 | 28-Oct-17 | 20:47 | Turbulence probe | 63 | VMP Microstructure profiler |
| 393 | W96 | 28-Oct-17 | 21:01 | CTD Cast | 63 | CTD - Seabird 911 with 36 Bottle Rosette |
| 394 | W96 | 28-Oct-17 | 21:59 | Catch | 57 | McKenna demersal fish trawl nets |
| 395 | W38 | 29-Oct-17 | 1:23 | Catch | 79 | McKenna demersal fish trawl nets |
| 396 | W38 | 29-Oct-17 | 2:56 | CTD Cast | 74 | CTD - Seabird 911 with 36 Bottle Rosette |
| 397 | W38 | 29-Oct-17 | 3:14 | Turbulence probe | 74 | VMP Microstructure profiler |
| 398 | W27 | 29-Oct-17 | 4:36 | Catch | 57 | McKenna demersal fish trawl nets |
| 399 | W37 | 29-Oct-17 | 7:37 | Catch | 58 | McKenna demersal fish trawl nets |
| 400 | W37 | 29-Oct-17 | 9:15 | CTD Cast | 80 | CTD - Seabird 911 with 36 Bottle Rosette |
| 401 | W37 | 29-Oct-17 | 9:17 | Turbulence probe | 80 | VMP Microstructure profiler |
| 402 | W43 | 29-Oct-17 | 10:53 | Benthos | 78 | WHOI epibenthic Biological sled |
| 403 | W43 | 29-Oct-17 | 11:19 | Sediment Grab | 79 | Smith McIntyre grab |
| 404 | W43 | 29-Oct-17 | 11:28 | Plankton | 79 | Bongo Nets |
| 405 | W68 | 29-Oct-17 | 13:47 | Plankton | 75 | Bongo Nets |
| 406 | W68 | 29-Oct-17 | 14:07 | Benthos | 74 | WHOI epibenthic Biological sled |
| 407 | W68 | 29-Oct-17 | 14:32 | Sediment Grab | 74 | Smith McIntyre grab |
| 408 | W89 | 29-Oct-17 | 16:41 | Benthos | 61 | WHOI epibenthic Biological sled |
| 409 | W89 | 29-Oct-17 | 17:12 | Sediment Grab | 62 | Smith McIntyre grab |
| 410 | W89 | 29-Oct-17 | 17:20 | Plankton | 62 | Bongo Nets |
| 411 | W59 | 29-Oct-17 | 18:21 | Benthos | 60 | WHOI epibenthic Biological sled |
| 412 | W59 | 29-Oct-17 | 18:54 | Sediment Grab | 60 | Smith McIntyre grab |
| 413 | W90 | 29-Oct-17 | 19:57 | Video | 57 | Deep Towed Camera System |
| 414 | W90 | 29-Oct-17 | 21:43 | Catch | 57 | McKenna demersal fish trawl nets |
| 415 | W89 | 30-Oct-17 | 0:08 | CTD Cast | 58 | CTD - Seabird 911 with 36 Bottle Rosette |
| 416 | W89 | 30-Oct-17 | 0:35 | Turbulence probe | 59 | VMP Microstructure profiler |
| 417 | W89 | 30-Oct-17 | 1:48 | Catch | 58 | McKenna demersal fish trawl nets |
| 418 | W59 | 30-Oct-17 | 4:05 | Catch | 59 | McKenna demersal fish trawl nets |
| 419 | W59 | 30-Oct-17 | 5:21 | CTD Cast | 58 | CTD - Seabird 911 with 36 Bottle Rosette |
| 420 | W59 | 30-Oct-17 | 5:33 | Turbulence probe | 59 | VMP Microstructure profiler |
| 421 | W70 | 30-Oct-17 | 7:11 | Catch | 55 | McKenna demersal fish trawl nets |
| 422 | W70 | 30-Oct-17 | 8:25 | CTD Cast | 55 | CTD - Seabird 911 with 36 Bottle Rosette |
| 423 | W70 | 30-Oct-17 | 8:51 | Turbulence probe | 57 | VMP Microstructure profiler |
| 424 | W90 | 30-Oct-17 | 9:28 | Video | 57 | Deep Towed Camera System |
| 425 | W59 | 30-Oct-17 | 11:44 | Plankton | 60 | Bongo Nets |
| 426 | W75 | 30-Oct-17 | 13:03 | Plankton | 60 | Bongo Nets |
| 427 | W75 | 30-Oct-17 | 13:20 | Benthos | 60 | WHOI epibenthic Biological sled |
| 428 | W75 | 30-Oct-17 | 13:44 | Sediment Grab | 59 | Smith McIntyre grab |
| 429 | W75 | 30-Oct-17 | 13:56 | Turbulence probe | 59 | VMP Microstructure profiler |
| 430 | W94 | 30-Oct-17 | 15:30 | Benthos | 61 | WHOI epibenthic Biological sled |
| 431 | W94 | 30-Oct-17 | 15:58 | Sediment Grab | 61 | Smith McIntyre grab |
| 432 | W94 | 30-Oct-17 | 16:09 | Turbulence probe | 61 | VMP Microstructure profiler |
| 433 | W94 | 30-Oct-17 | 16:19 | Catch | 60 | Bongo Nets |
| 434 | W58 | 30-Oct-17 | 18:17 | Plankton | 71 | Bongo Nets |
| 435 | W58 | 30-Oct-17 | 18:37 | Benthos | 72 | WHOI epibenthic Biological sled |
| 436 | W58 | 30-Oct-17 | 19:00 | Sediment Grab | 74 | Smith McIntyre grab |
| 437 | W48 | 30-Oct-17 | 20:56 | Benthos | 74 | WHOI epibenthic Biological sled |
| 438 | W48 | 30-Oct-17 | 21:21 | Benthos | 73 | Smith McIntyre grab |
| 439 | W48 | 30-Oct-17 | 21:59 | Catch | 73 | McKenna demersal fish trawl nets |
| 440 | W58 | 31-Oct-17 | 0:35 | Catch | 73 | McKenna demersal fish trawl nets |
| 441 | W58 | 31-Oct-17 | 1:43 | Plankton | 82 | Bongo Nets |
| 442 | W58 | 31-Oct-17 | 2:36 | CTD Cast | 71 | CTD - Seabird 911 with 36 Bottle Rosette |
| 443 | W58 | 31-Oct-17 | 2:52 | Turbulence probe | 71 | VMP Microstructure profiler |
| 444 | W68 | 31-Oct-17 | 3:53 | Catch | 73 | McKenna demersal fish trawl nets |
| 445 | W68 | 31-Oct-17 | 5:16 | CTD Cast | 73 | CTD - Seabird 911 with 36 Bottle Rosette |
| 446 | W68 | 31-Oct-17 | 5:39 | Turbulence probe | 73 | VMP Microstructure profiler |
| 447 | W43 | 31-Oct-17 | 7:09 | Catch | 89 | McKenna demersal fish trawl nets |
| 448 | W43 | 31-Oct-17 | 8:39 | CTD Cast | 89 | CTD - Seabird 911 with 36 Bottle Rosette |
| 449 | W43 | 31-Oct-17 | 9:07 | Turbulence probe | 87 | VMP Microstructure profiler |

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|---|---|---|---|---|---|---|
| 450 | W47 | 31-Oct-17 | 11:18 | Catch | 78 | WHOI epibenthic Biological sled |
| 451 | W47 | 31-Oct-17 | 12:05 | Catch | 78 | Smith McIntyre grab |
| 452 | W47 | 31-Oct-17 | 12:24 | Plankton | 78 | Bongo Nets |
| 453 | W13 | 31-Oct-17 | 14:02 | Plankton | 81 | Bongo Nets |
| 454 | W13 | 31-Oct-17 | 14:24 | Benthos | 83 | WHOI epibenthic Biological sled |
| 455 | W13 | 31-Oct-17 | 14:46 | Benthos | 81 | Smith McIntyre grab |
| 456 | W46 | 31-Oct-17 | 16:16 | Benthos | 83 | WHOI epibenthic Biological sled |
| 457 | W46 | 31-Oct-17 | 16:44 | Benthos | 84 | Smith McIntyre grab |
| 458 | W46 | 31-Oct-17 | 16:56 | Plankton | 84 | Bongo Nets |
| 459 | W48 | 31-Oct-17 | 18:26 | Plankton | 74 | Bongo Nets |
| 460 | W78 | 31-Oct-17 | 19:51 | Plankton | 73 | Bongo Nets |
| 461 | W78 | 31-Oct-17 | 20:06 | Benthos | 72 | WHOI epibenthic Biological sled |
| 462 | W78 | 31-Oct-17 | 20:32 | Benthos | 72 | Smith McIntyre grab |
| 463 | W78 | 31-Oct-17 | 21:38 | Catch | 72 | McKenna demersal fish trawl nets |
| 464 | W46 | 1-Nov-17 | 0:35 | Catch | 84 | McKenna demersal fish trawl nets |
| 465 | W46 | 1-Nov-17 | 1:54 | Catch | 83 | CTD - Seabird 911 with 36 Bottle Rosette |
| 466 | W46 | 1-Nov-17 | 2:14 | Turbulence probe | 84 | VMP Microstructure profiler |
| 467 | W13 | 1-Nov-17 | 4:05 | Catch | 80 | McKenna demersal fish trawl nets |
| 468 | W13 | 1-Nov-17 | 5:14 | CTD Cast | 81 | CTD - Seabird 911 with 36 Bottle Rosette |
| 469 | W13 | 1-Nov-17 | 5:40 | Turbulence probe | 81 | VMP Microstructure profiler |
| 470 | W47 | 1-Nov-17 | 6:52 | Catch | 76 | McKenna demersal fish trawl nets |
| 471 | W47 | 1-Nov-17 | 7:54 | Catch | 76 | CTD - Seabird 911 with 36 Bottle Rosette |
| 472 | W47 | 1-Nov-17 | 8:27 | Turbulence probe | 76 | VMP Microstructure profiler |
| 473 | W79 | 1-Nov-17 | 10:49 | Benthos | 70 | WHOI epibenthic Biological sled |
| 474 | W79 | 1-Nov-17 | 11:15 | Benthos | 67 | Smith McIntyre grab |
| 475 | W79 | 1-Nov-17 | 11:25 | Turbulence probe | 67 | VMP Microstructure profiler |
| 476 | W79 | 1-Nov-17 | 11:46 | Plankton | 69 | Bongo Nets |
| 477 | W80 | 1-Nov-17 | 12:28 | Plankton | 67 | Bongo Nets |
| 478 | W80 | 1-Nov-17 | 12:40 | Catch | 67 | WHOI epibenthic Biological sled |
| 479 | W80 | 1-Nov-17 | 13:17 | Benthos | 68 | Smith McIntyre grab |
| 480 | W80 | 1-Nov-17 | 13:26 | Turbulence probe | 68 | VMP Microstructure profiler |
| 481 | W83 | 1-Nov-17 | 15:29 | Catch | 62 | WHOI epibenthic Biological sled |
| 482 | W83 | 1-Nov-17 | 15:53 | Benthos | 62 | Smith McIntyre grab |
| 483 | W83 | 1-Nov-17 | 16:03 | Turbulence probe | 62 | VMP Microstructure profiler |
| 484 | W83 | 1-Nov-17 | 16:13 | Plankton | 62 | Bongo Nets |
| 485 | W81 | 1-Nov-17 | 17:48 | Catch | 60 | Bongo Nets |
| 486 | W81 | 1-Nov-17 | 18:05 | Benthos | 61 | WHOI epibenthic Biological sled |
| 487 | W81 | 1-Nov-17 | 18:30 | Catch | 61 | Smith McIntyre grab |
| 488 | W81 | 1-Nov-17 | 18:34 | Catch | 61 | VMP Microstructure profiler |
| 489 | W82 | 1-Nov-17 | 19:50 | Catch | 59 | WHOI epibenthic Biological sled |
| 490 | W82 | 1-Nov-17 | 20:13 | Benthos | 59 | Smith McIntyre grab |
| 491 | W82 | 1-Nov-17 | 20:27 | Plankton | 59 | Bongo Nets |
| 492 | W82 | 1-Nov-17 | 21:01 | Turbulence probe | 60 | VMP Microstructure profiler |
| 493 | W82 | 1-Nov-17 | 21:46 | Catch | 60 | McKenna demersal fish trawl nets |
| 494 | W81 | 1-Nov-17 | 23:31 | CTD Cast | 66 | CTD - Seabird 911 with 36 Bottle Rosette |
| 495 | W81 | 1-Nov-17 | 23:49 | Turbulence probe | 66 | VMP Microstructure profiler |
| 496 | W81 | 2-Nov-17 | 0:26 | Catch Failed | 60 | McKenna demersal fish trawl nets |
| 497 | W81 | 2-Nov-17 | 2:19 | Catch | 63 | McKenna demersal fish trawl nets |
| 498 | W80 | 2-Nov-17 | 4:40 | Catch | 65 | McKenna demersal fish trawl nets |
| 499 | W80 | 2-Nov-17 | 5:47 | Catch | 65 | VMP Microstructure profiler |
| 500 | W79 | 2-Nov-17 | 6:33 | Catch | 66 | McKenna demersal fish trawl nets |
| 501 | W79 | 2-Nov-17 | 7:49 | Catch | 68 | CTD - Seabird 911 with 36 Bottle Rosette |
| 502 | W79 | 2-Nov-17 | 8:10 | Catch | 68 | VMP Microstructure profiler |
| 503 | W50 | 2-Nov-17 | 11:41 | Photo | 55 | Deep Towed Camera System |
| 504 | W50 | 2-Nov-17 | 12:48 | Benthos | 55 | WHOI epibenthic Biological sled |
| 505 | W50 | 2-Nov-17 | 13:15 | Benthos | 55 | Smith McIntyre grab |
| 506 | W50 | 2-Nov-17 | 13:28 | Plankton | 55 | Bongo Nets |
| 507 | W97 | 2-Nov-17 | 14:27 | Catch | 56 | Bongo Nets |
| 508 | W97 | 2-Nov-17 | 14:44 | Benthos | 56 | WHOI epibenthic Biological sled |

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|---|---|---|---|---|---|---|
| 509 | W97 | 2-Nov-17 | 15:09 | Benthos | 55 | Smith McIntyre grab |
| 510 | W98 | 2-Nov-17 | 16:12 | Catch | 57 | WHOI epibenthic Biological sled |
| 511 | W98 | 2-Nov-17 | 16:50 | Catch | 56 | Smith McIntyre grab |
| 512 | W98 | 2-Nov-17 | 17:02 | Catch | 56 | Bongo Nets |
| 513 | W99 | 2-Nov-17 | 18:01 | Plankton | 55 | Bongo Nets |
| 514 | W99 | 2-Nov-17 | 18:19 | Benthos | 55 | WHOI epibenthic Biological sled |
| 515 | W99 | 2-Nov-17 | 18:45 | Catch | 54 | Smith McIntyre grab |
| 516 | W75 | 2-Nov-17 | 20:21 | Catch | 59 | WHOI epibenthic Biological sled |
| 517 | W75 | 2-Nov-17 | 21:02 | Catch | 57 | CTD - Seabird 911 with 36 Bottle Rosette |
| 518 | W75 | 2-Nov-17 | 21:36 | Catch | 57 | McKenna demersal fish trawl nets |
| 519 | W94 | 2-Nov-17 | 23:57 | Catch | 61 | McKenna demersal fish trawl nets |
| 520 | W94 | 3-Nov-17 | 2:03 | CTD Cast | 57 | CTD - Seabird 911 with 36 Bottle Rosette |
| 521 | W94 | 3-Nov-17 | 2:23 | Turbulence probe | 60 | VMP Microstructure profiler |
| 522 | W83 | 3-Nov-17 | 2:54 | Catch | 61 | McKenna demersal fish trawl nets |
| 523 | W83 | 3-Nov-17 | 4:12 | CTD Cast | 63 | CTD - Seabird 911 with 36 Bottle Rosette |
| 524 | W83 | 3-Nov-17 | 4:40 | Turbulence probe | 60 | VMP Microstructure profiler |
| 525 | W99 | 3-Nov-17 | 5:08 | Catch | 54 | McKenna demersal fish trawl nets |
| 526 | W98 | 3-Nov-17 | 7:13 | Catch | 48 | McKenna demersal fish trawl nets |
| 527 | W98 | 3-Nov-17 | 8:52 | CTD Cast | 53 | CTD - Seabird 911 with 36 Bottle Rosette |
| 528 | W98 | 3-Nov-17 | 9:12 | Turbulence probe | 53 | VMP Microstructure profiler |
| 529 | W17 | 3-Nov-17 | 11:41 | Catch | 47 | WHOI epibenthic Biological sled |
| 530 | W17 | 3-Nov-17 | 12:09 | Catch | 48 | Smith McIntyre grab |
| 531 | W17 | 3-Nov-17 | 12:23 | Catch | 47 | Bongo Nets |
| 532 | W3 | 3-Nov-17 | 14:57 | Plankton | 36 | Bongo Nets |
| 533 | W3 | 3-Nov-17 | 15:06 | Benthos | 35 | WHOI epibenthic Biological sled |
| 534 | W3 | 3-Nov-17 | 15:54 | Benthos | 35 | Smith McIntyre grab |
| 535 | W18 | 3-Nov-17 | 18:26 | Benthos | 38 | WHOI epibenthic Biological sled |
| 536 | W18 | 3-Nov-17 | 18:53 | Benthos | 38 | Smith McIntyre grab |
| 537 | W18 | 3-Nov-17 | 19:02 | Catch | 37 | Bongo Nets |
| 538 | W17 | 3-Nov-17 | 20:34 | Video | 46 | Deep Towed Camera System |
| 539 | W17 | 3-Nov-17 | 21:55 | Catch | 45 | McKenna demersal fish trawl nets |
| 540 | W18 | 4-Nov-17 | 0:50 | CTD Cast | 37 | CTD - Seabird 911 with 36 Bottle Rosette |
| 541 | W18 | 4-Nov-17 | 1:07 | Turbulence probe | 37 | VMP Microstructure profiler |
| 542 | W18 | 4-Nov-17 | 1:20 | Catch Failed | 42 | McKenna demersal fish trawl nets |
| 543 | W18 | 4-Nov-17 | 3:13 | Catch | 37 | McKenna demersal fish trawl nets |
| 544 | W97 | 4-Nov-17 | 6:23 | Catch | 52 | McKenna demersal fish trawl nets |
| 545 | W50 | 4-Nov-17 | 8:07 | Catch | 54 | McKenna demersal fish trawl nets |
| 546 | W17 | 4-Nov-17 | 10:37 | Catch | 46 | Deep Towed Camera System |
| 547 | W3 | 4-Nov-17 | 12:39 | Photo | 35 | Deep Towed Camera System |
| 548 | W2 | 4-Nov-17 | 15:24 | Benthos | 36 | WHOI epibenthic Biological sled |
| 549 | W2 | 4-Nov-17 | 16:04 | Sediment Grab | 32 | Smith McIntyre grab |
| 550 | W2 | 4-Nov-17 | 16:18 | Plankton | 35 | Bongo Nets |
| 551 | W15 | 4-Nov-17 | 17:50 | Plankton | 32 | Bongo Nets |
| 552 | W15 | 4-Nov-17 | 18:04 | Catch | 30 | WHOI epibenthic Biological sled |
| 553 | W15 | 4-Nov-17 | 18:29 | Benthos | 30 | Smith McIntyre grab |
| 554 | W1 | 4-Nov-17 | 20:41 | Catch | 34 | WHOI epibenthic Biological sled |
| 555 | W1 | 4-Nov-17 | 21:51 | Benthos | 38 | Smith McIntyre grab |
| 556 | W1 | 4-Nov-17 | 22:02 | Catch | 36 | McKenna demersal fish trawl nets |
| 557 | W15 | 4-Nov-17 | 23:49 | Catch | 33 | McKenna demersal fish trawl nets |
| 558 | W15 | 5-Nov-17 | 2:30 | CTD Cast | 33 | CTD - Seabird 911 with 36 Bottle Rosette |
| 559 | W15 | 5-Nov-17 | 2:39 | Turbulence probe | 35 | VMP Microstructure profiler |
| 560 | W2 | 5-Nov-17 | 3:05 | Catch | 36 | McKenna demersal fish trawl nets |
| 561 | W2 | 5-Nov-17 | 5:04 | CTD Cast | 35 | CTD - Seabird 911 with 36 Bottle Rosette |
| 562 | W2 | 5-Nov-17 | 6:03 | Turbulence probe | 35 | VMP Microstructure profiler |
| 563 | W3 | 5-Nov-17 | 6:05 | CTD Cast | 35 | CTD - Seabird 911 with 36 Bottle Rosette |
| 564 | W3 | 5-Nov-17 | 7:01 | Turbulence probe | 34 | VMP Microstructure profiler |
| 565 | W16 | 5-Nov-17 | 10:34 | Benthos | 43 | WHOI epibenthic Biological sled |
| 566 | W16 | 5-Nov-17 | 11:32 | Benthos | 43 | Smith McIntyre grab |
| 567 | W16 | 5-Nov-17 | 11:45 | Plankton | 43 | Bongo Nets |

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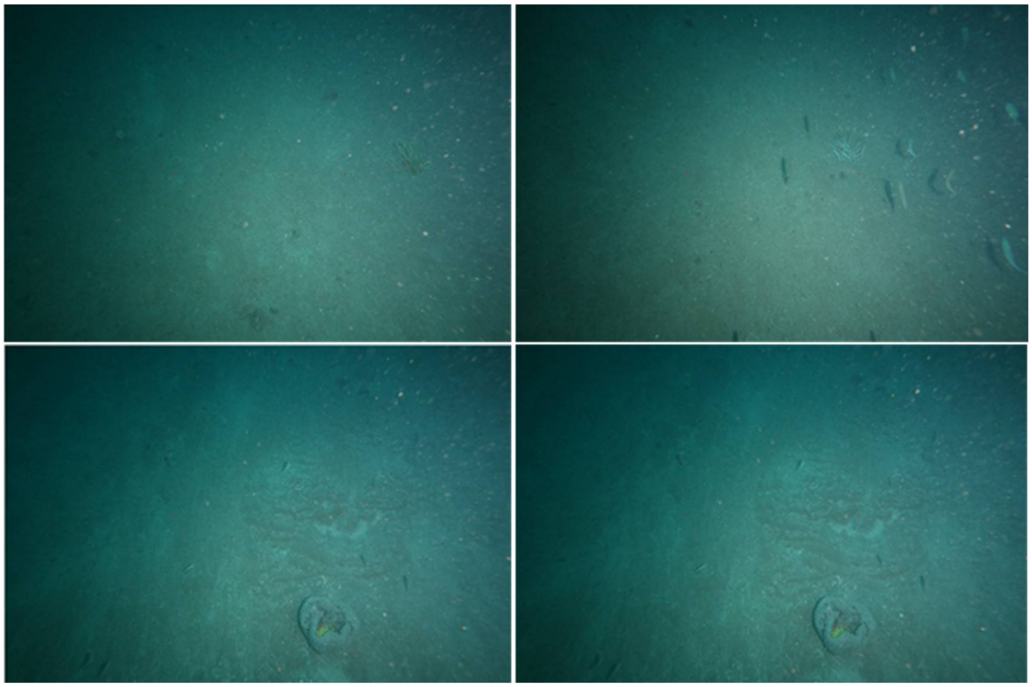
|---|---|---|---|---|---|---|
| 568 | W16 | 5-Nov-17 | 12:28 | Catch | 45 | Deep Towed Camera System |
| 569 | W14 | 5-Nov-17 | 15:23 | Catch | 51 | Deep Towed Camera System |
| 570 | W14 | 5-Nov-17 | 16:30 | Catch | 50 | Bongo Nets |
| 571 | W14 | 5-Nov-17 | 17:07 | Benthos | 50 | WHOI epibenthic Biological sled |
| 572 | W14 | 5-Nov-17 | 17:44 | Catch | 50 | Smith McIntyre grab |
| 573 | W49 | 5-Nov-17 | 19:10 | Benthos | 61 | WHOI epibenthic Biological sled |
| 574 | W49 | 5-Nov-17 | 19:35 | Catch | 61 | Smith McIntyre grab |
| 575 | W49 | 5-Nov-17 | 19:42 | Catch | 61 | Bongo Nets |
| 576 | W49 | 5-Nov-17 | 20:09 | CTD Cast | 59 | CTD - Seabird 911 with 36 Bottle Rosette |
| 577 | W49 | 5-Nov-17 | 20:40 | Catch | 61 | VMP Microstructure profiler |
| 578 | W49 | 5-Nov-17 | 21:56 | Catch | 57 | McKenna demersal fish trawl nets |
| 579 | W14 | 5-Nov-17 | 23:32 | Catch | 45 | McKenna demersal fish trawl nets |
| 580 | W16 | 6-Nov-17 | 2:42 | Catch | 37 | McKenna demersal fish trawl nets |
| 581 | W3 | 6-Nov-17 | 4:54 | Catch | 37 | McKenna demersal fish trawl nets |
| 582 | W3 | 6-Nov-17 | 6:54 | Video | 31 | Deep Towed Camera System |
| 583 | W16 | 6-Nov-17 | 10:54 | Video | 43 | Deep Towed Camera System |
| 584 | W14 | 6-Nov-17 | 12:41 | Catch | 49 | Deep Towed Camera System |

# Appendix C Representative seabed images typical of each site surveyed during the RV *Investigator* voyage in 2017 (INV2017_05)

## C.1 Sites inshore of the commercial trawl fishery (including within the Dampier MP)



**Appx Figure 1. Site W1 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2926, subset 2 – IMG_2896, subset 3 – IMG_3001, subset 4 – IMG_3261. Red dots indicate biota/substrate scored in each image.**

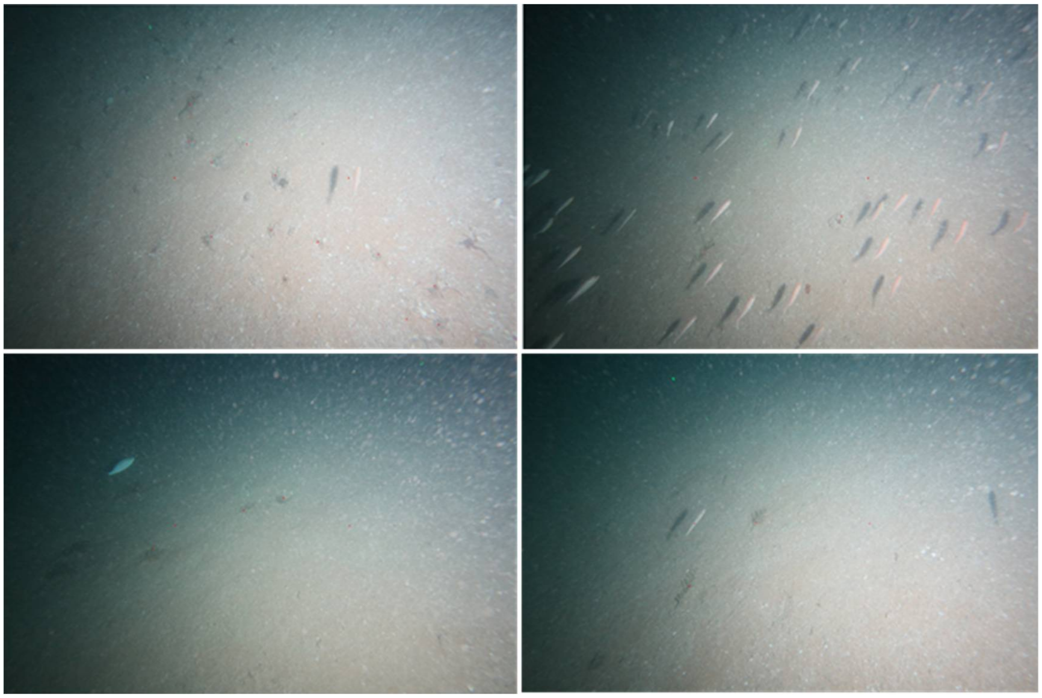
Appx Figure 2. Site W2 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2884, subset 2 – IMG_3035, subset 3 – IMG_3220, subset 4 – IMG_3426. Red dots indicate biota/substrate scored in each image

Appx Figure 3. Site W3 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_3556, subset 2 – IMG_3656, subset 3 – IMG_3746, subset 4 – IMG_3957. Red dots indicate biota/substrate scored in each image

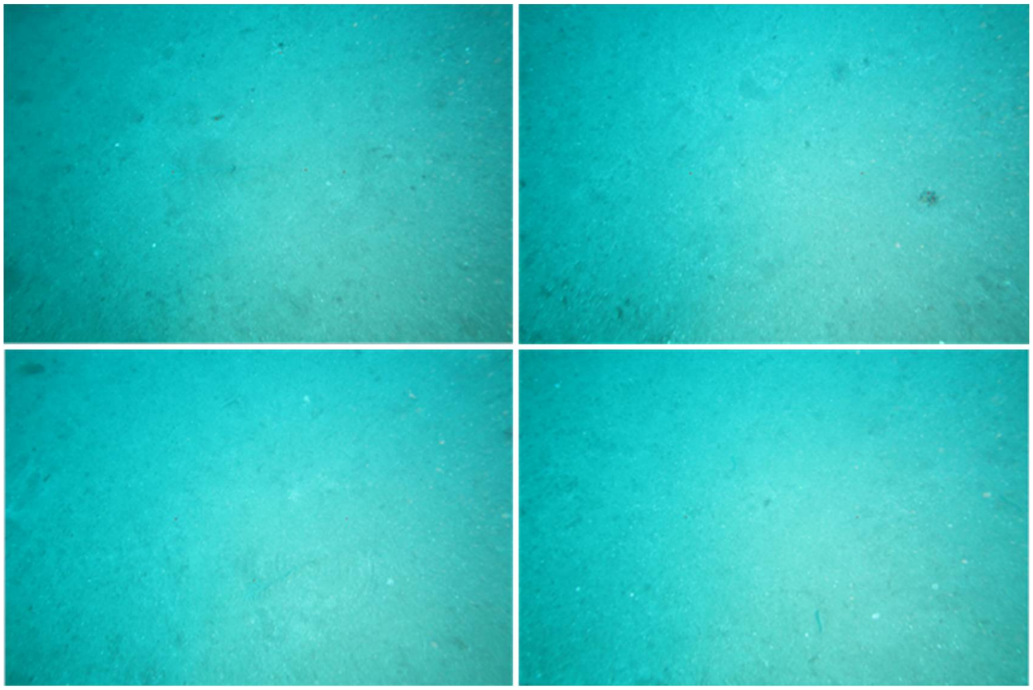
Appx Figure 4. Site W4 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2888, subset 2 – IMG_2998, subset 3 – IMG_3158, subset 4 – IMG_3313. Red dots indicate biota/substrate scored in each image

Appx Figure 5. Site W5 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2054, subset 2 – IMG_2114, subset 3 – IMG_2369, subset 4 – IMG_2414. Red dots indicate biota/substrate scored in each image.

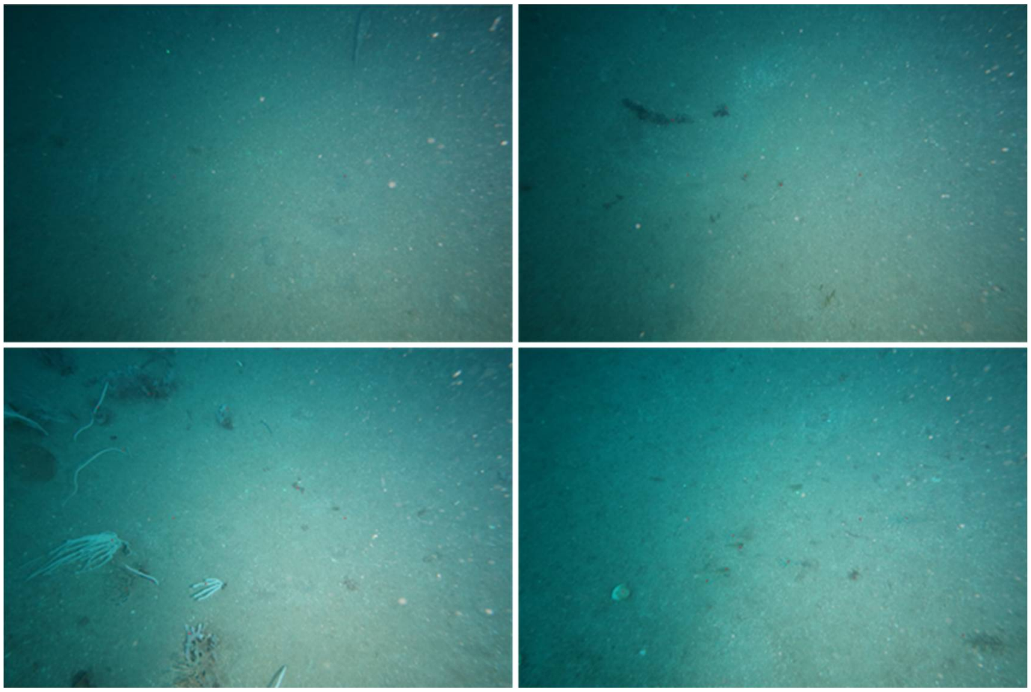
**Appx Figure 6. Site W6 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2880, subset 2 – IMG_3112, subset 3 – IMG_3296, subset 4 – IMG_3442. Red dots indicate biota/substrate scored in each image.**



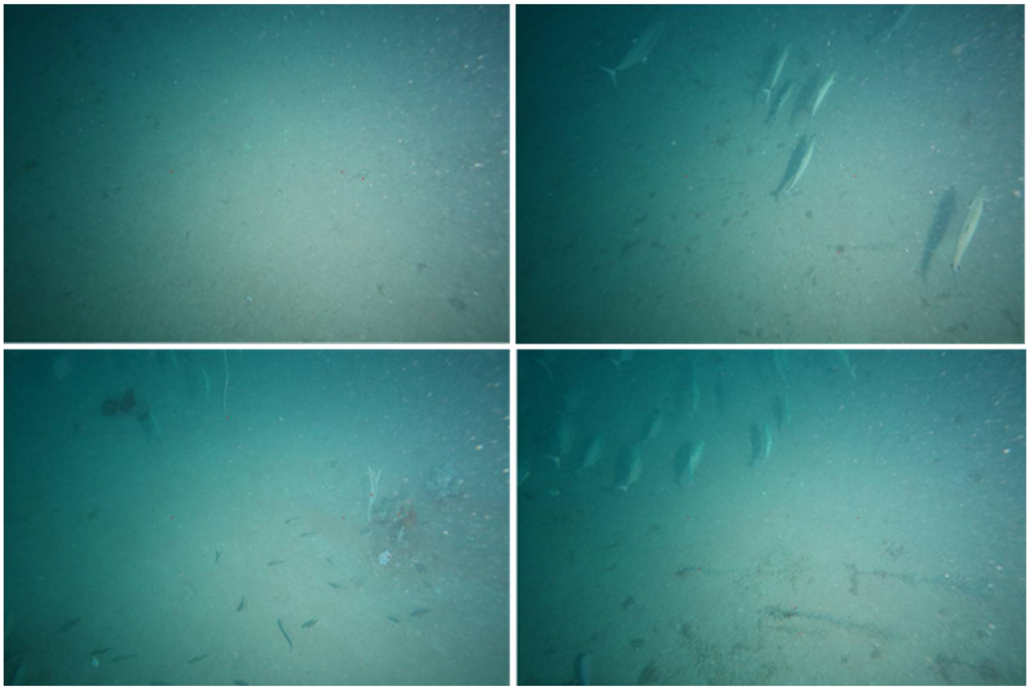
**Appx Figure 7. Site W8 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2866, subset 2 – IMG_3011, subset 3 – IMG_3267, subset 4 – IMG_3403. Red dots indicate biota/substrate scored in each image.**



Appx Figure 8. Site W9 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_1867, subset 2 – IMG_2163, subset 3 – IMG_2208, subset 4 – IMG_2328. Red dots indicate biota/substrate scored in each image.



Appx Figure 9. Site W10 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_1876, subset 2 – IMG_2001, subset 3 – IMG_2235, subset 4 – IMG_2370. Red dots indicate biota/substrate scored in each image.

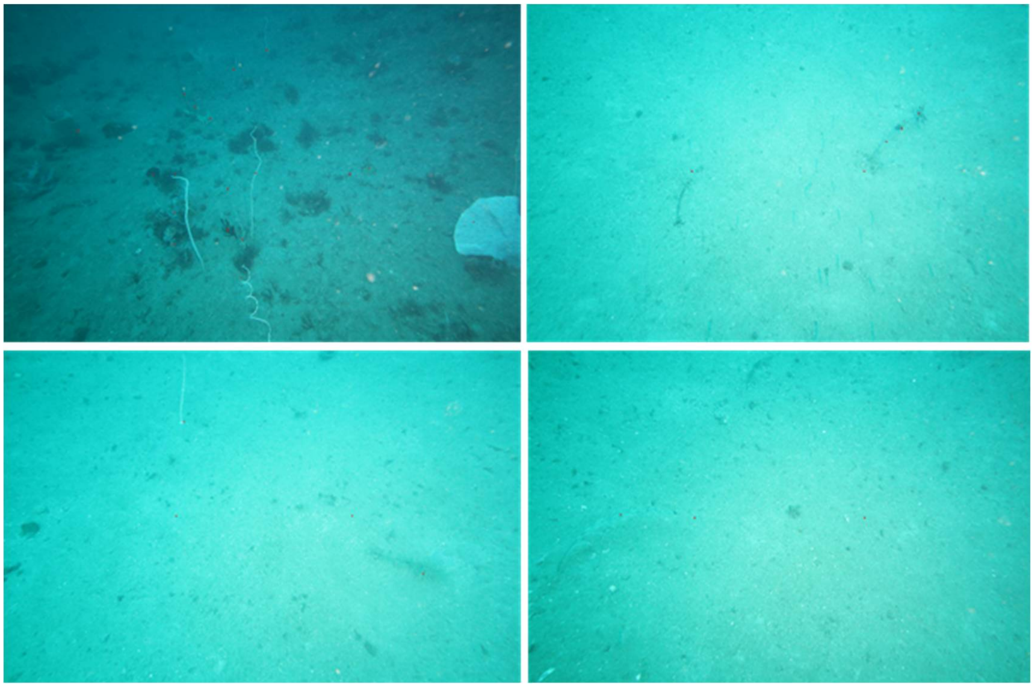


Appx Figure 10. Site W11 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_0353, subset 2 – IMG_0493, subset 3 – IMG_0673, subset 4 – IMG_0738. Red dots indicate biota/substrate scored in each image.

Appx Figure 11. Site W15 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2883, subset 2 – IMG_3029, subset 3 – IMG_3104, subset 4 – IMG_3300. Red dots indicate biota/substrate scored in each image.

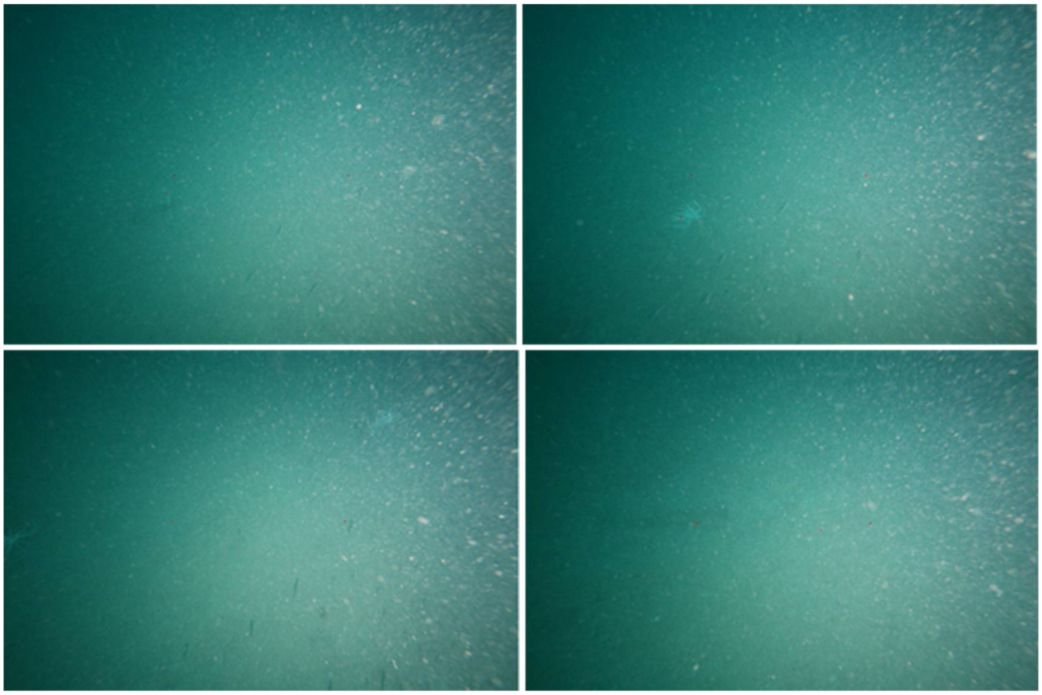
Appx Figure 12. Site W16 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_3647, subset 2 – IMG_3807, subset 3 – IMG_3992, subset 4 – IMG_4062. Red dots indicate biota/substrate scored in each image.

Appx Figure 13. Site W17 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2845, subset 2 – IMG_3000, subset 3 – IMG_3210, subset 4 – IMG_3325. Red dots indicate biota/substrate scored in each image.

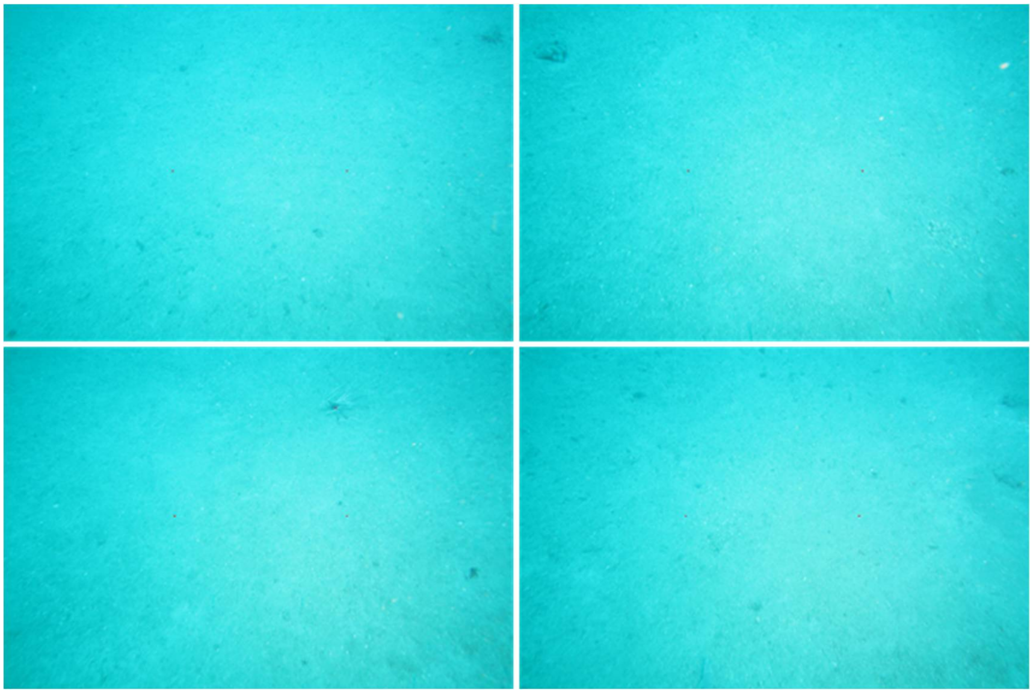


Appx Figure 14. Site W18 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2809, subset 2 – IMG_2920, subset 3 – IMG_3085, subset 4 – IMG_3375. Red dots indicate biota/substrate scored in each image.

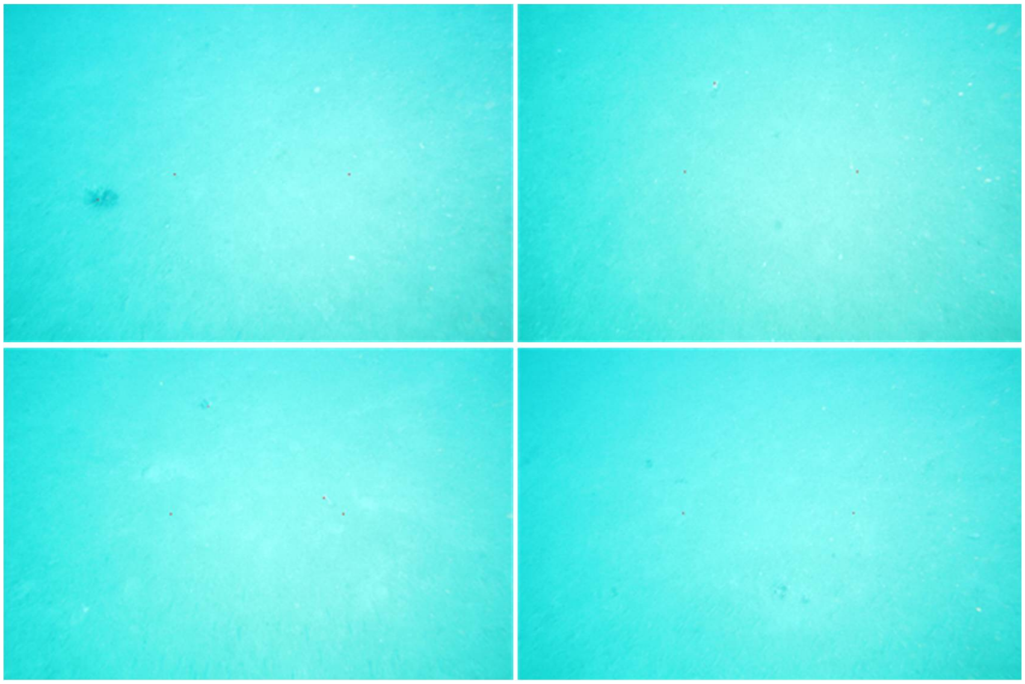
Appx Figure 15. Site W19 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_0086, subset 2 – IMG_0266, subset 3 – IMG_0416, subset 4 – IMG_0581. Red dots indicate biota/substrate scored in each image.



Appx Figure 16. Site W20 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2943, subset 2 – IMG_3018, subset 3 – IMG_3213, subset 4 – IMG_3443. Red dots indicate biota/substrate scored in each image.

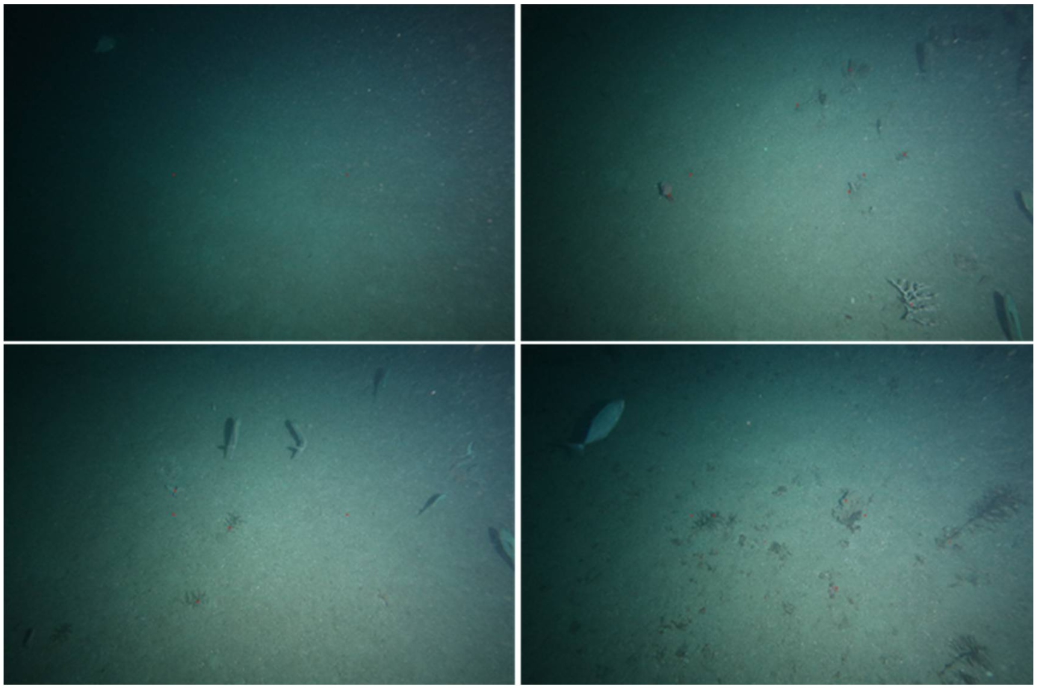


Appx Figure 17. Site W22 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_1880, subset 2 – IMG_2076, subset 3 – IMG_2261, subset 4 – IMG_2392. Red dots indicate biota/substrate scored in each image.



**Appx Figure 18. Site W24 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_1057, subset 2 – IMG_1202, subset 3 – IMG_1322, subset 4 – IMG_1442. Red dots indicate biota/substrate scored in each image.**

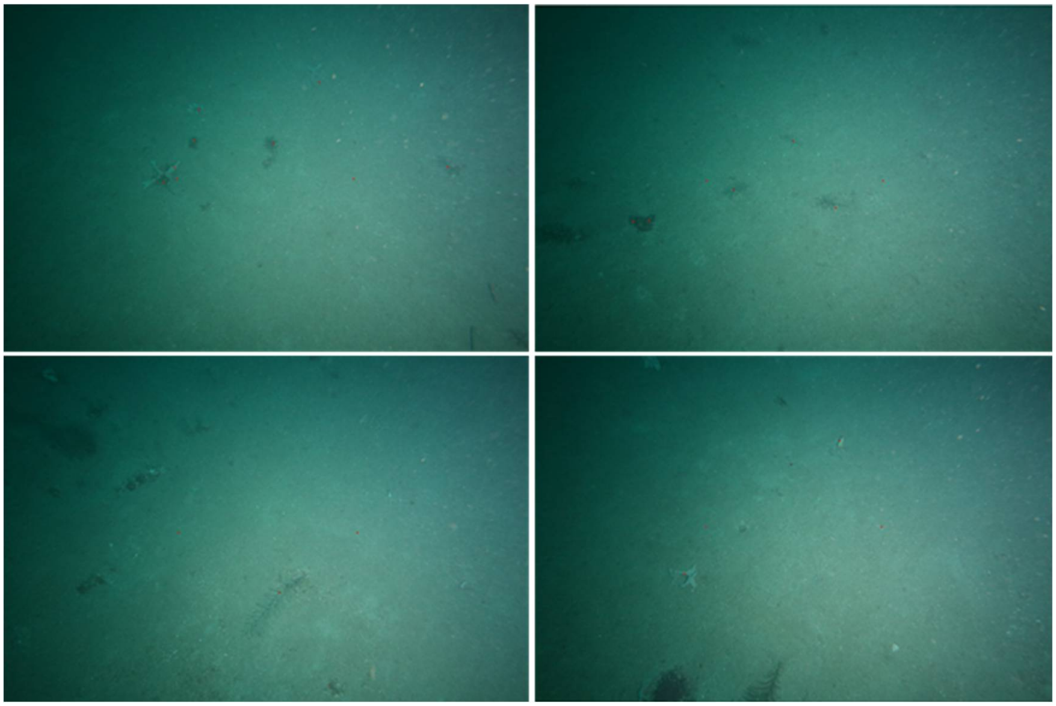
**Appx Figure 19. Site W25 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_1884, subset 2 – IMG_2049, subset 3 – IMG_2209, subset 4 – IMG_2364. Red dots indicate biota/substrate scored in each image.**



Appx Figure 20. Site W51 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_0174, subset 2 – IMG_0299, subset 3 – IMG_0420, subset 4 – IMG_0615. Red dots indicate biota/substrate scored in each image.

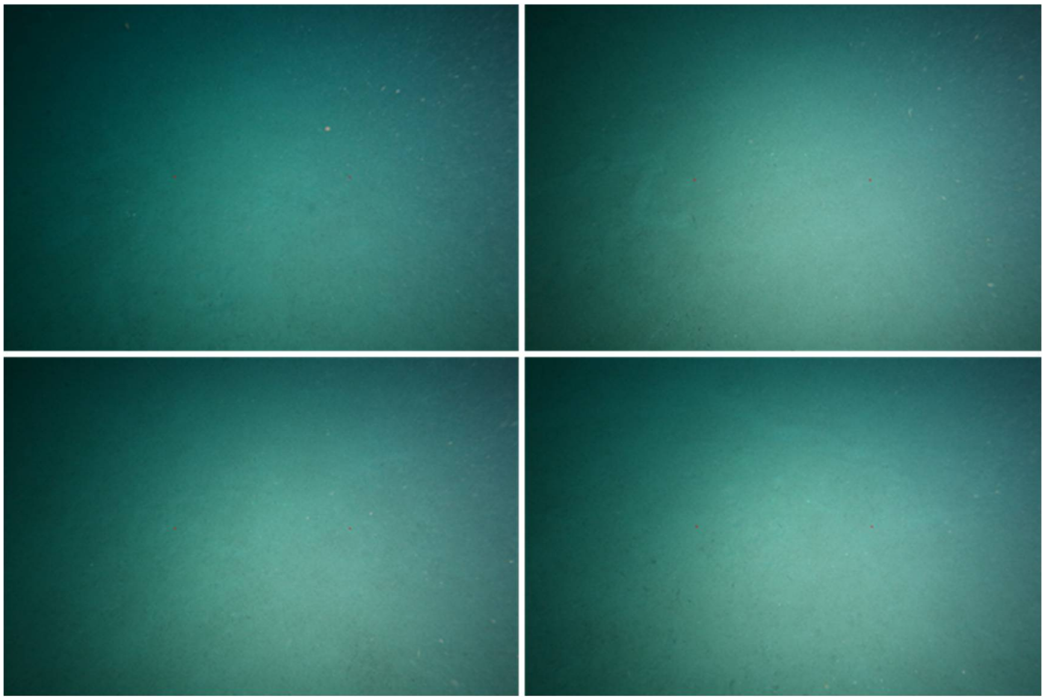
Appx Figure 21. Site W98 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_3724, subset 2 – IMG_3874, subset 3 – IMG_3974, subset 4 – IMG_4104. Red dots indicate biota/substrate scored in each image.

Appx Figure 22. Site W99 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2867, subset 2 – IMG_3007, subset 3 – IMG_3197, subset 4 – IMG_3372. Red dots indicate biota/substrate scored in each image.

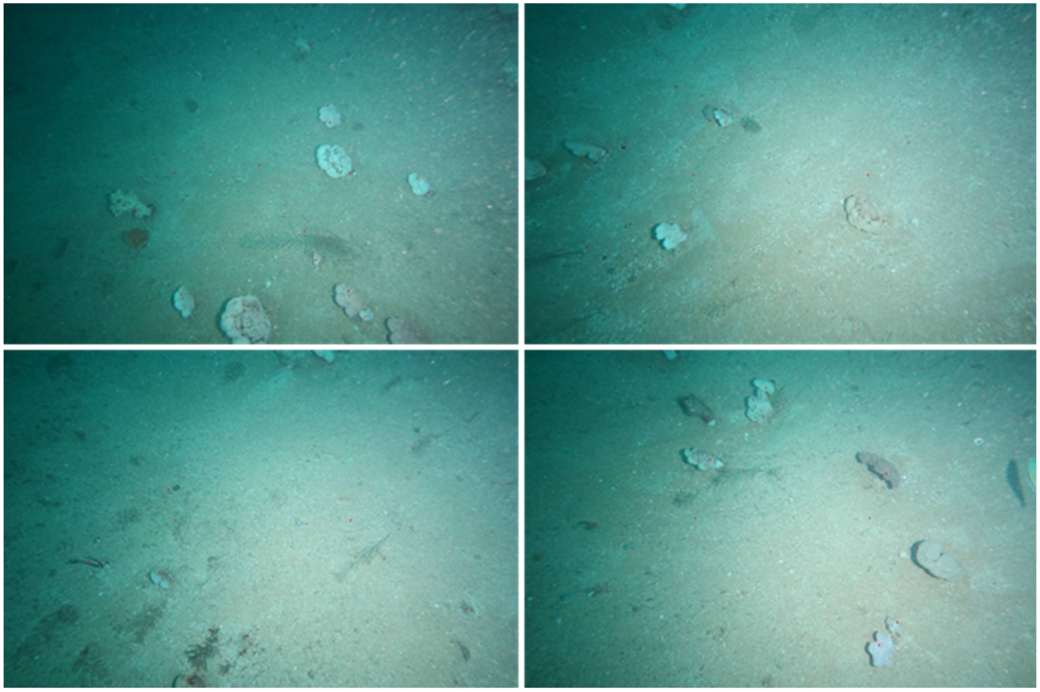


Appx Figure 23. Site W100 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_0049, subset 2 – IMG_0209, subset 3 – IMG_0420, subset 4 – IMG_0576. Red dots indicate biota/substrate scored in each image.

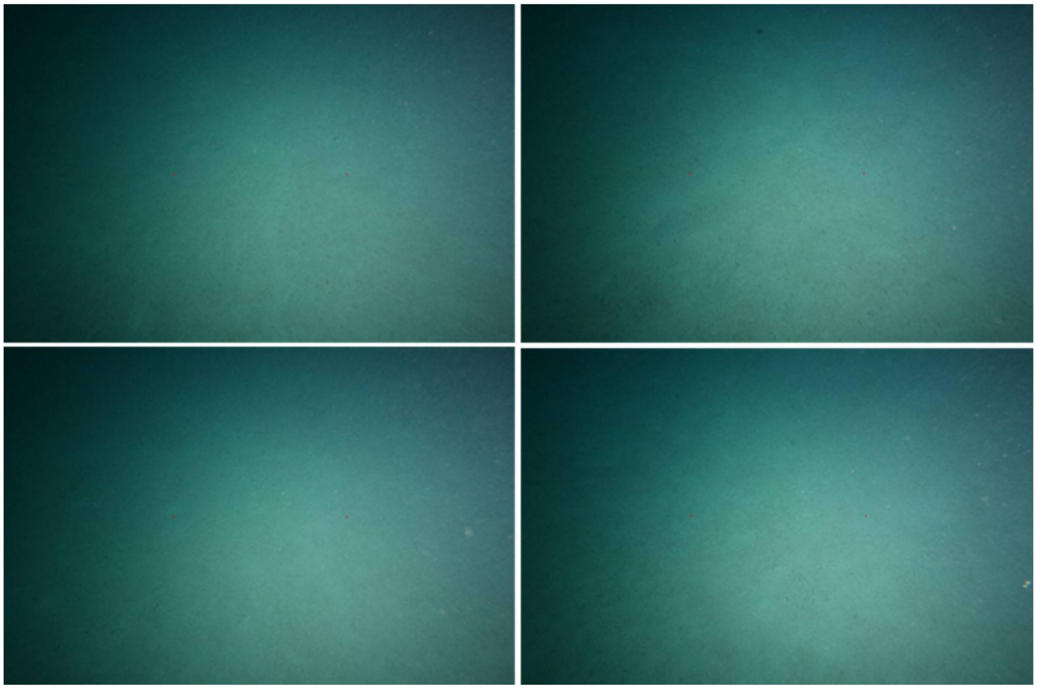
## C.2 Sites west of the commercial trawl fishery (including within the Montebello MP).



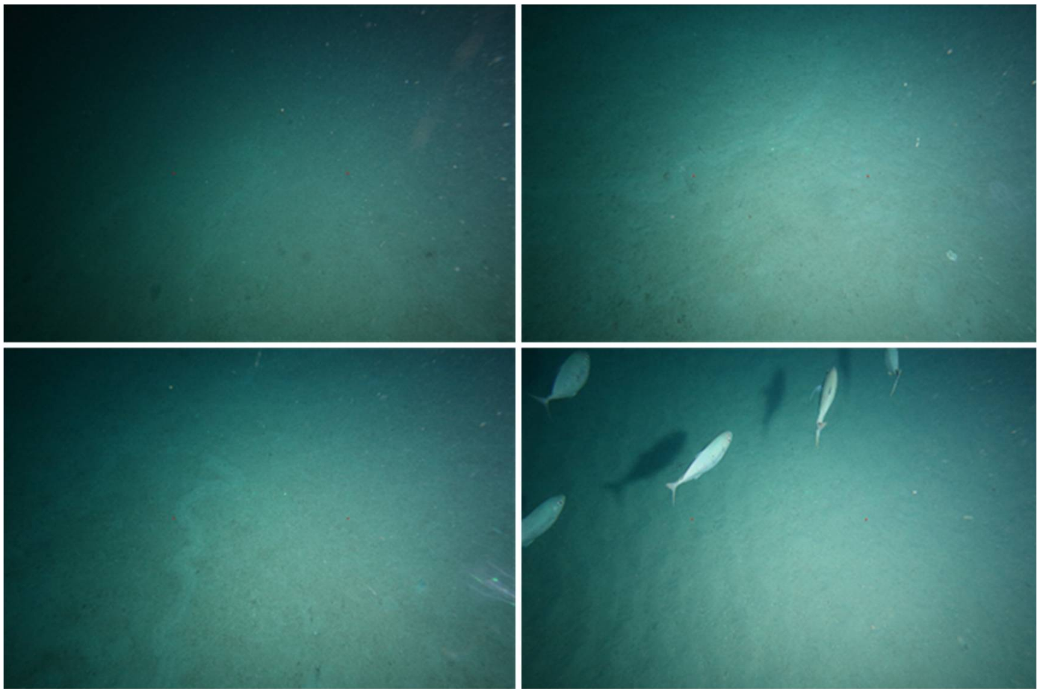
**Appx Figure 24. Site W13 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2866, subset 2 – IMG_3031, subset 3 – IMG_3186, subset 4 – IMG_3356. Red dots indicate biota/substrate scored in each image.**



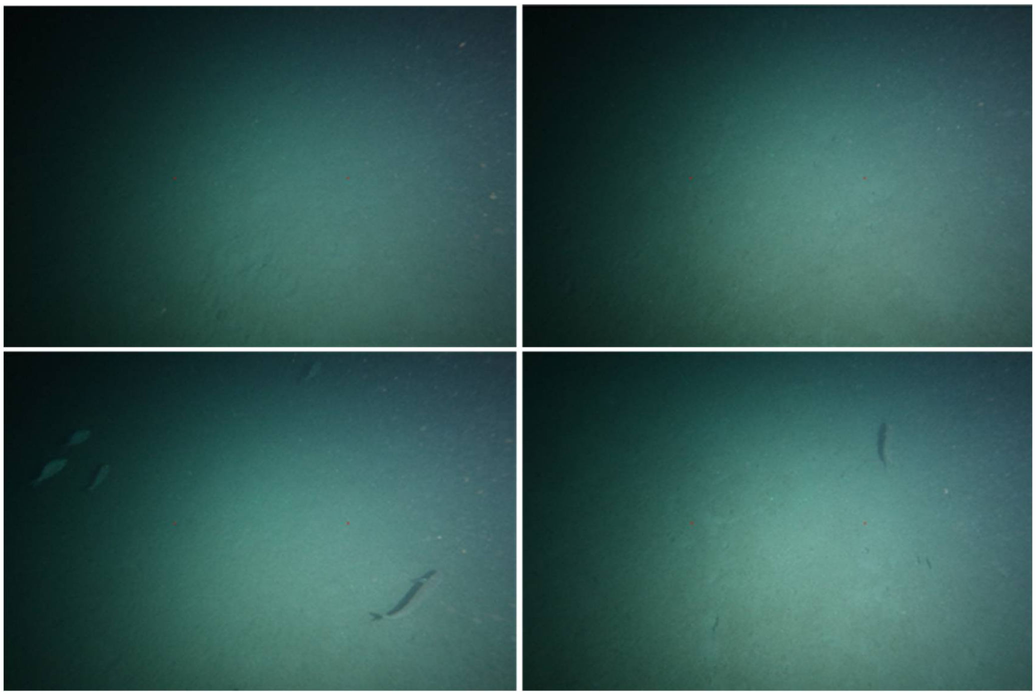
**Appx Figure 25. Site W14 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_3616, subset 2 – IMG_3736, subset 3 – IMG_3921, subset 4 – IMG_4021. Red dots indicate biota/substrate scored in each image.**



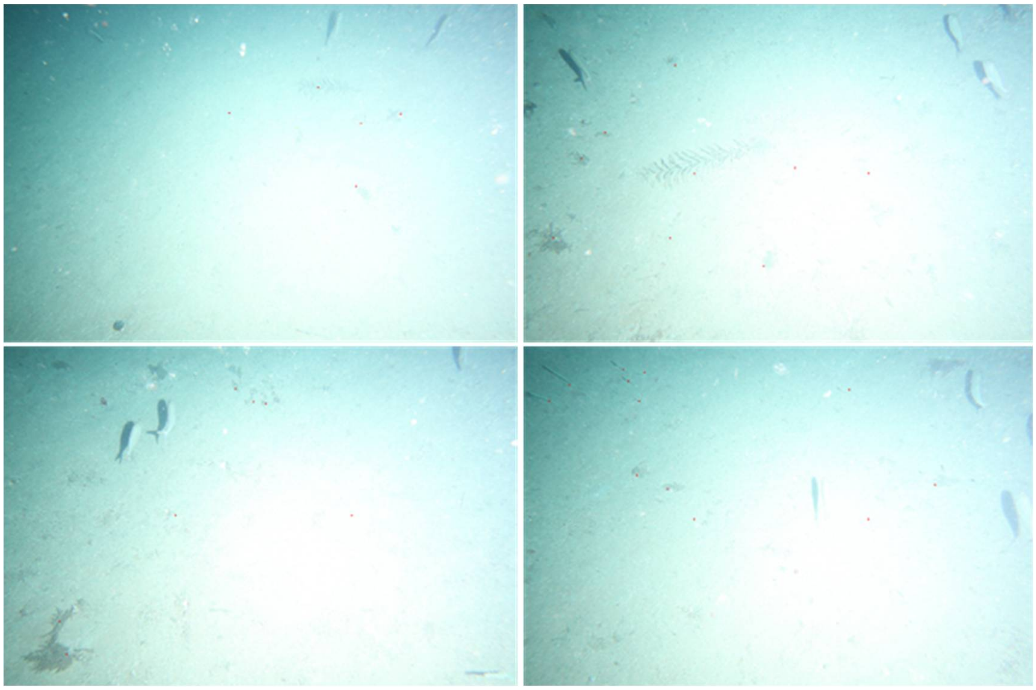
Appx Figure 26. Site W46 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2940, subset 2 – IMG_3055, subset 3 – IMG_3215, subset 4 – IMG_3355. Red dots indicate biota/substrate scored in each image.



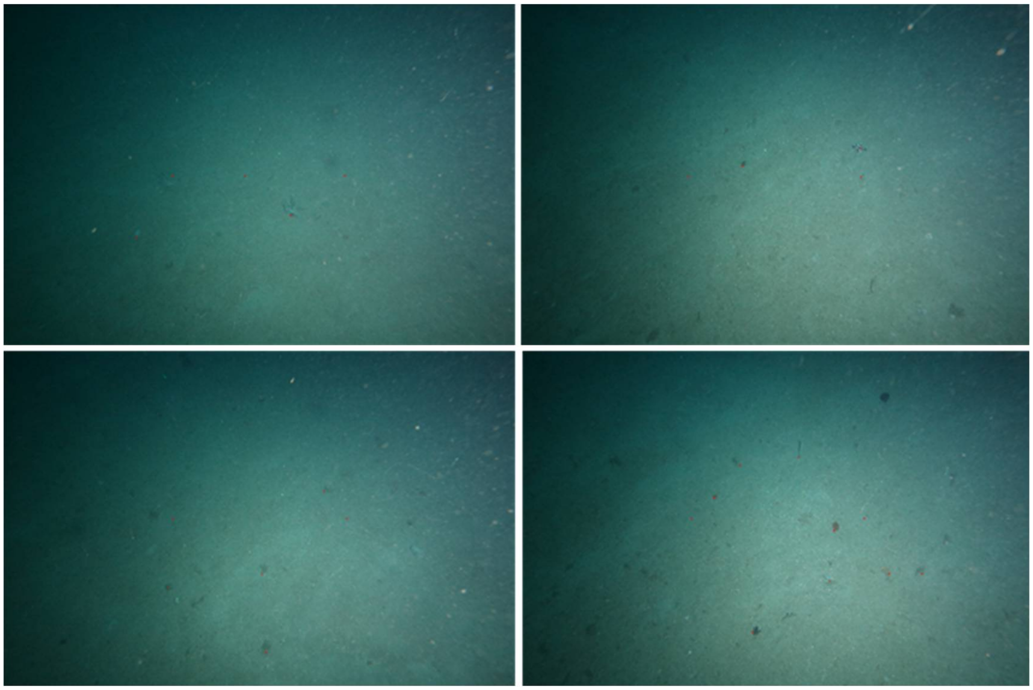
Appx Figure 27. Site W47 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2847, subset 2 – IMG_2992, subset 3 – IMG_3097, subset 4 – IMG_3262. Red dots indicate biota/substrate scored in each image.



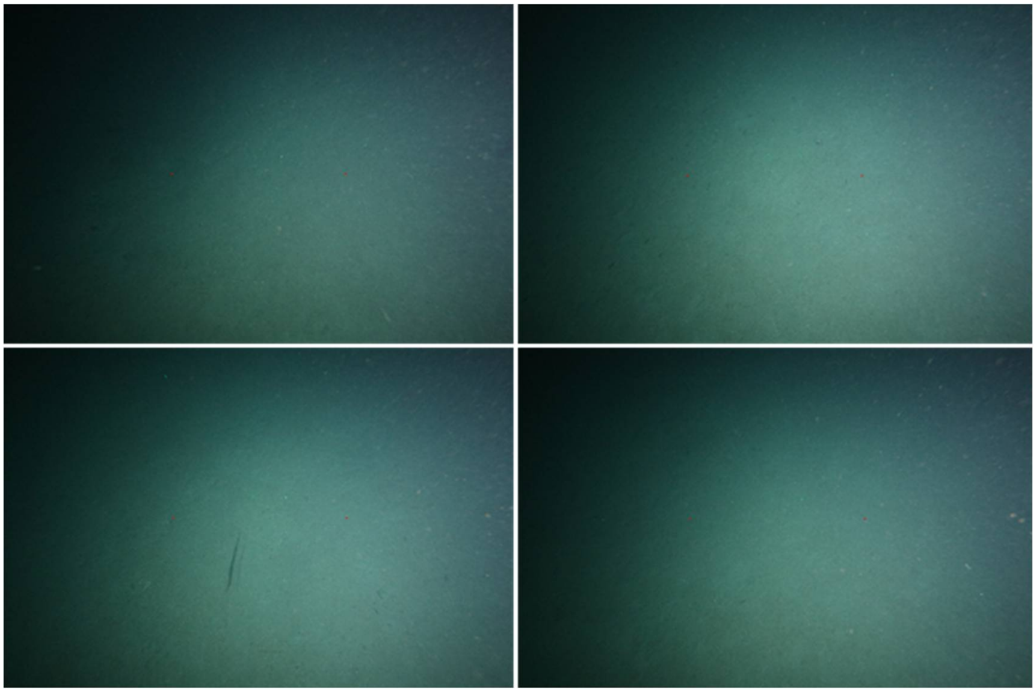
Appx Figure 28. Site W48 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2880, subset 2 – IMG_2995, subset 3 – IMG_3135, subset 4 – IMG_3310. Red dots indicate biota/substrate scored in each image.



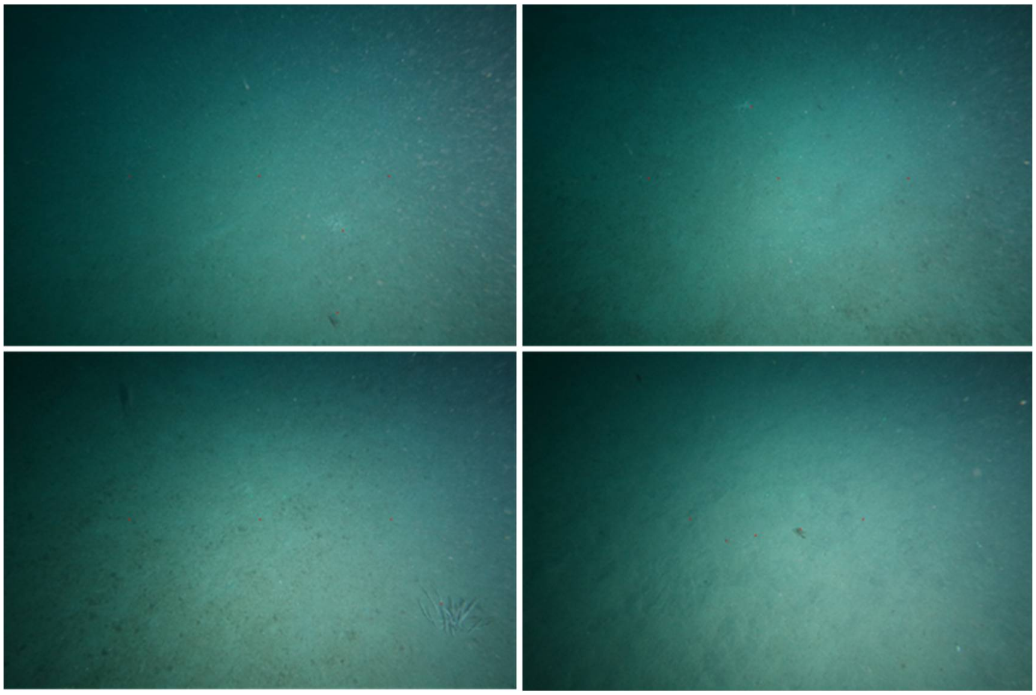
Appx Figure 29. Site W49 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2915, subset 2 – IMG_3070, subset 3 – IMG_3145, subset 4 – IMG_3351. Red dots indicate biota/substrate scored in each image.



**Appx Figure 30. Site W50 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_3831, subset 2 – IMG_3956, subset 3 – IMG_4071, subset 4 – IMG_4201. Red dots indicate biota/substrate scored in each image.**



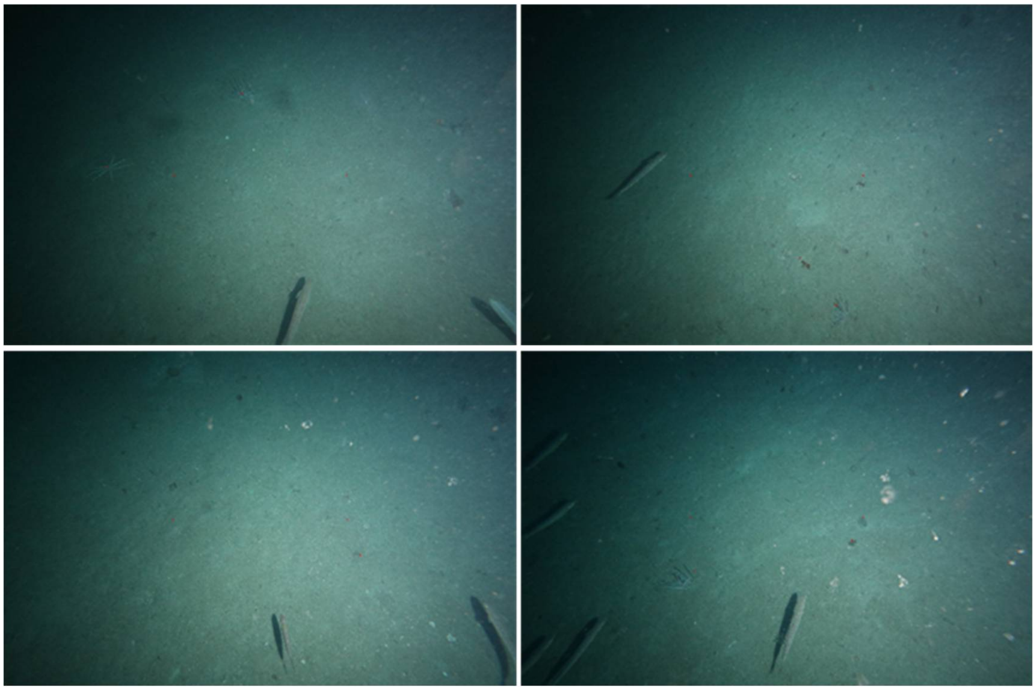
**Appx Figure 31. Site W78 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2853, subset 2 – IMG_2988, subset 3 – IMG_3133, subset 4 – IMG_3278. Red dots indicate biota/substrate scored in each image.**



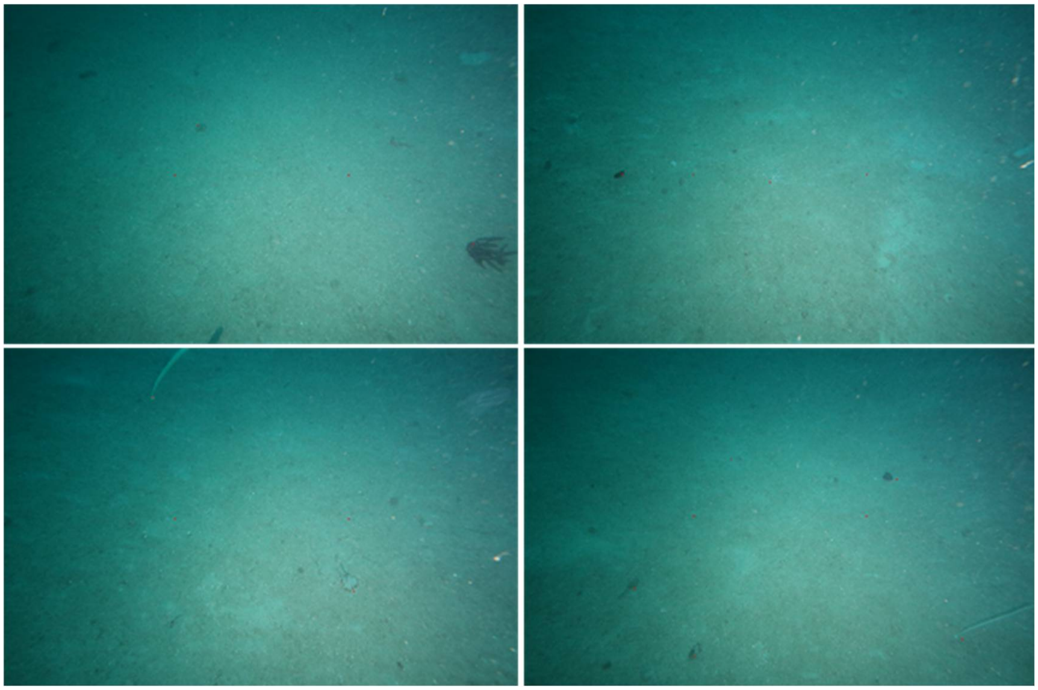
Appx Figure 32. Site W79 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2944, subset 2 – IMG_3074, subset 3 – IMG_3234, subset 4 – IMG_3389. Red dots indicate biota/substrate scored in each image.

Appx Figure 33. Site W80 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2891, subset 2 – IMG_3116, subset 3 – IMG_3262, subset 4 – IMG_3438. Red dots indicate biota/substrate scored in each image.

Appx Figure 34. Site W81 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2905, subset 2 – IMG_3030, subset 3 – IMG_3155, subset 4 – IMG_3315. Red dots indicate biota/substrate scored in each image.

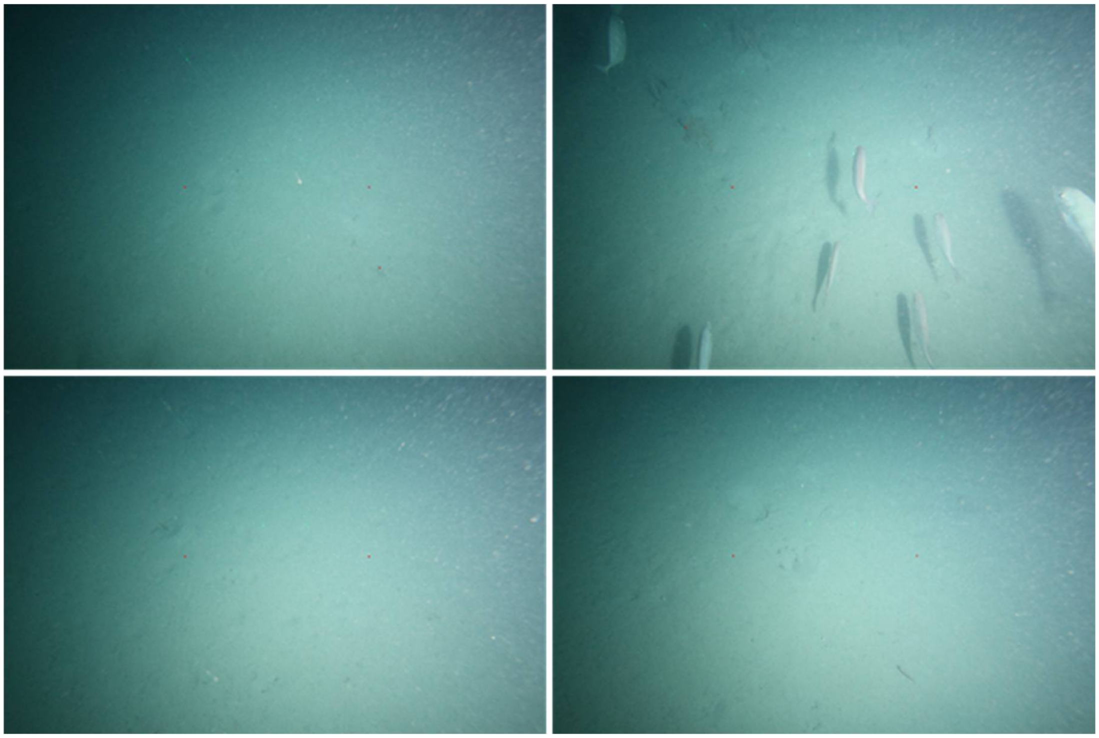


Appx Figure 35. Site W82 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2814, subset 2 – IMG_2979, subset 3 – IMG_3104, subset 4 – IMG_3262. Red dots indicate biota/substrate scored in each image.

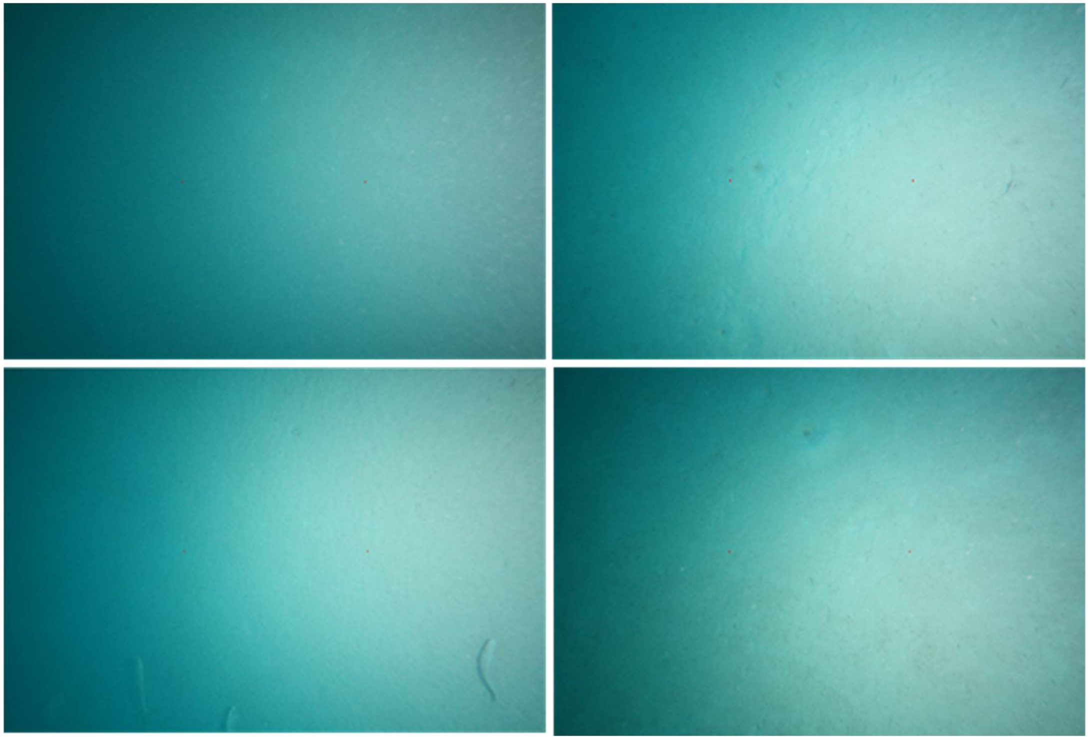


**Appx Figure 36. Site W97 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2881, subset 2 – IMG_2986, subset 3 – IMG_3191, subset 4 – IMG_3387. Red dots indicate biota/substrate scored in each image.**

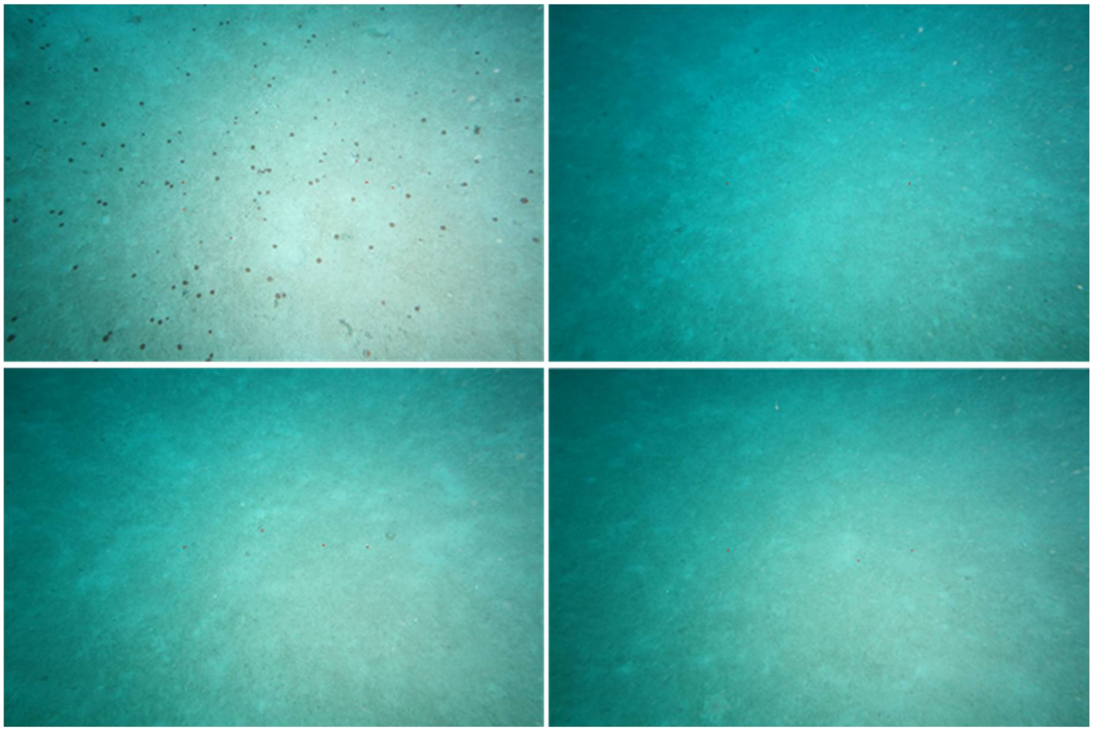
## C.3 Sites in the Pilbara Fish Trawl Fishery Area 1 (including PFTF Area 6)



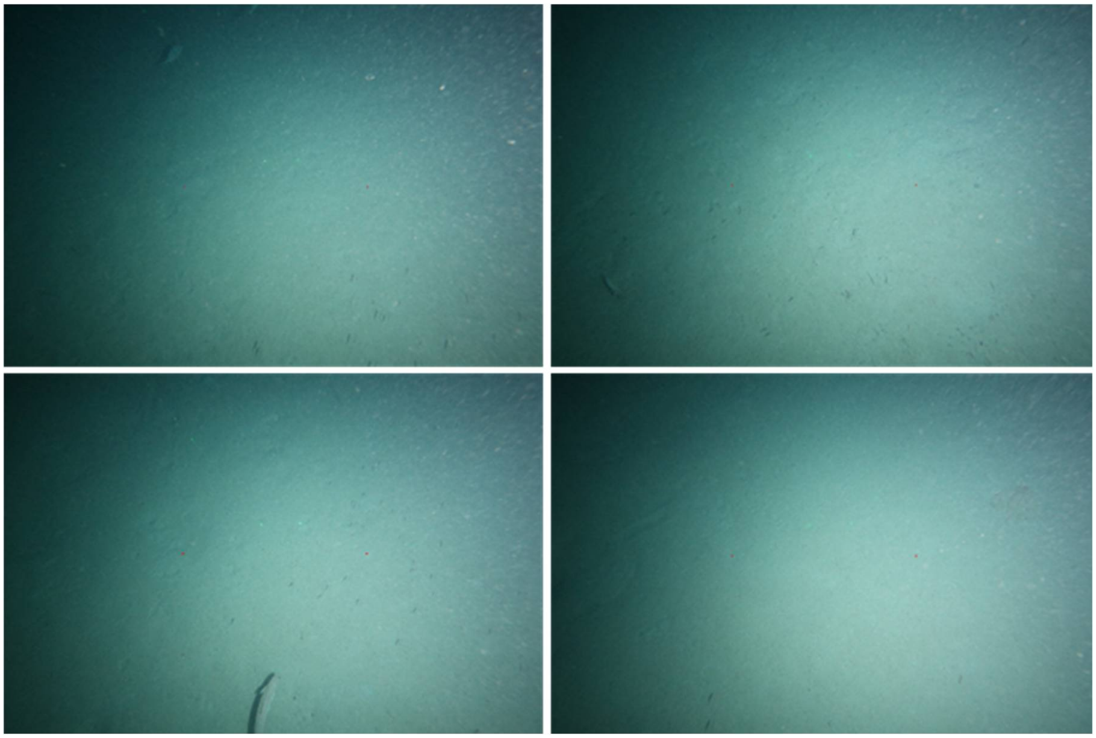
**Appx Figure 37. Site W12 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_0201, subset 2 – IMG_0341, subset 3 – IMG_0507, subset 4 – IMG_0647. Red dots indicate biota/substrate scored in each image.**



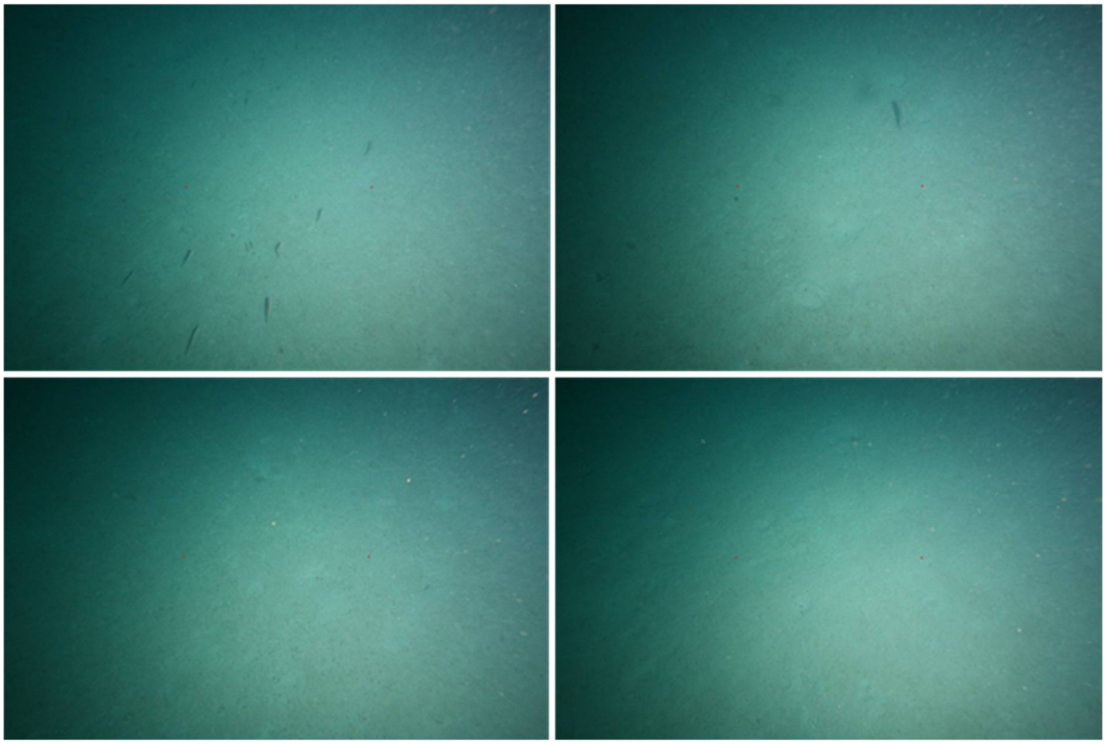
**Appx Figure 38. Site W27 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_0206, subset 2 – IMG_0347, subset 3 – IMG_0522, subset 4 – IMG_0662. Red dots indicate biota/substrate scored in each image.**



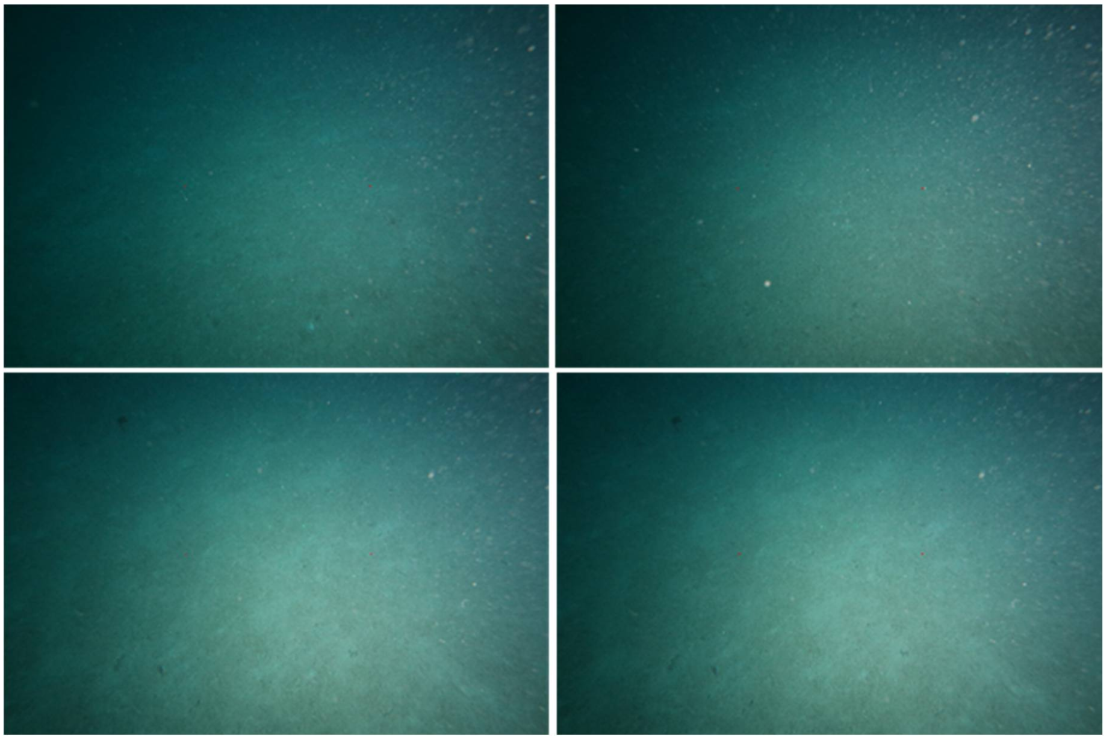
Appx Figure 39. Site W28 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_0058, subset 2 – IMG_0203, subset 3 – IMG_0383, subset 4 – IMG_0608. Red dots indicate biota/substrate scored in each image.



Appx Figure 40. Site W37 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2899, subset 2 – IMG_3079, subset 3 – IMG_3244, subset 4 – IMG_3359. Red dots indicate biota/substrate scored in each image.

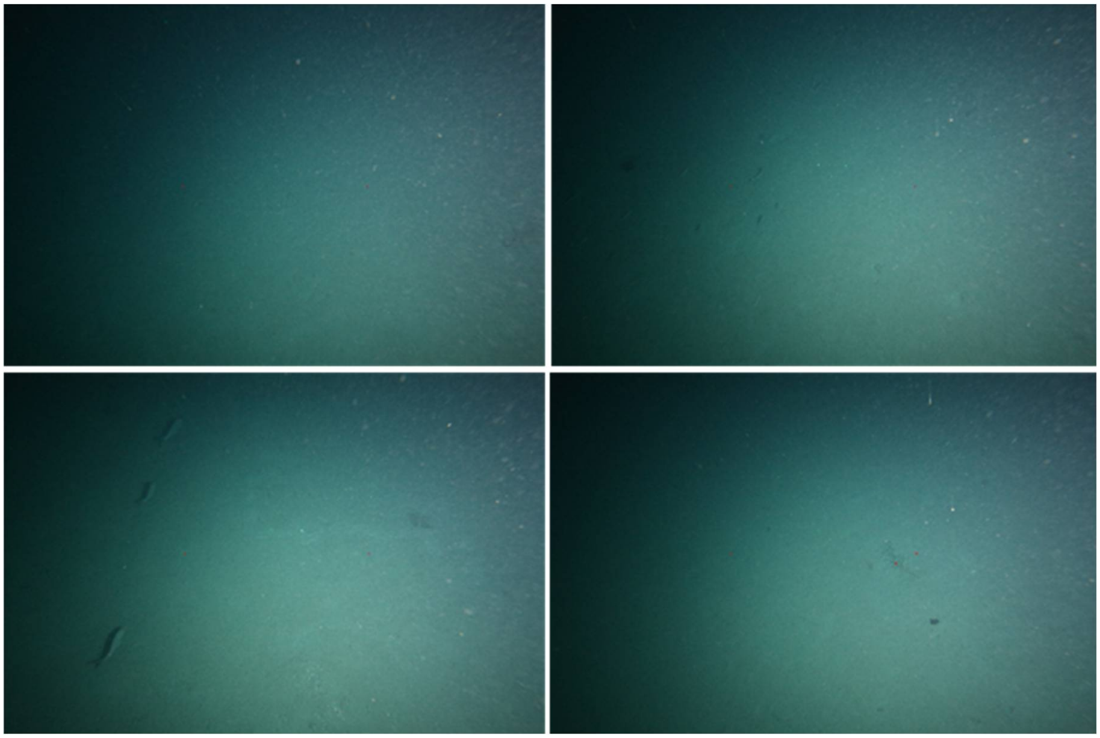


**Appx Figure 41. Site W38 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2861, subset 2 – IMG_2986, subset 3 – IMG_3141, subset 4 – IMG_3271. Red dots indicate biota/substrate scored in each image.**

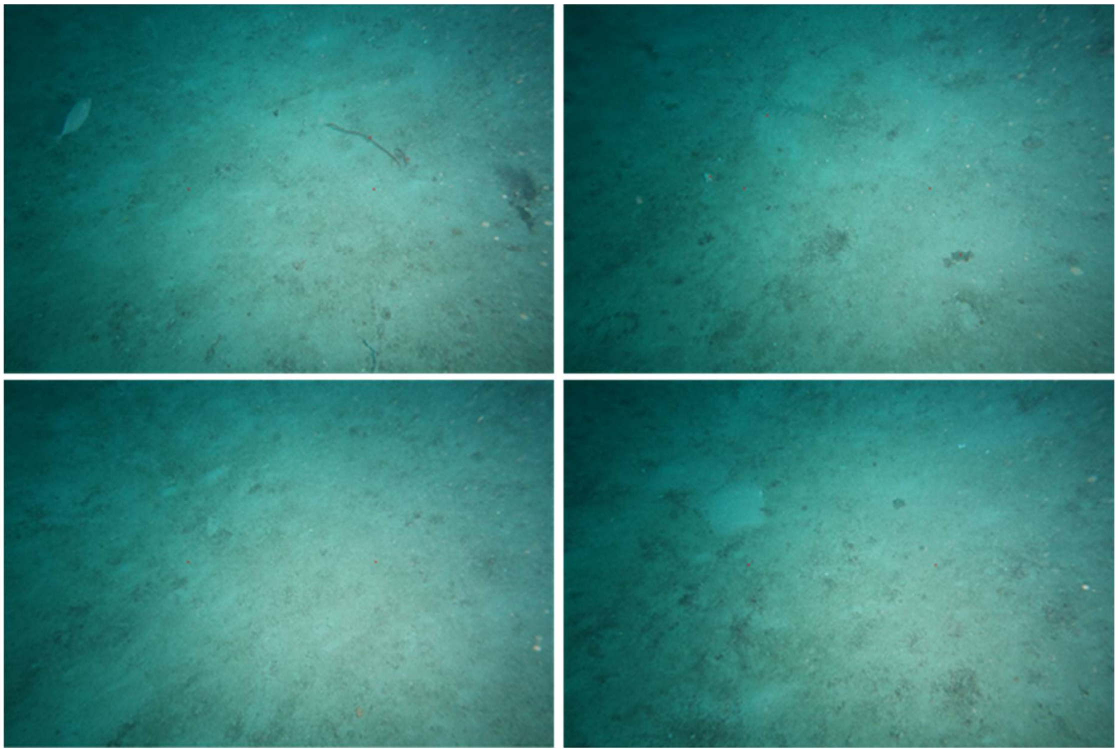


**Appx Figure 42. Site W40 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2867, subset 2 – IMG_2977, subset 3 – IMG_3157, subset 4 – IMG_3322. Red dots indicate biota/substrate scored in each image.**

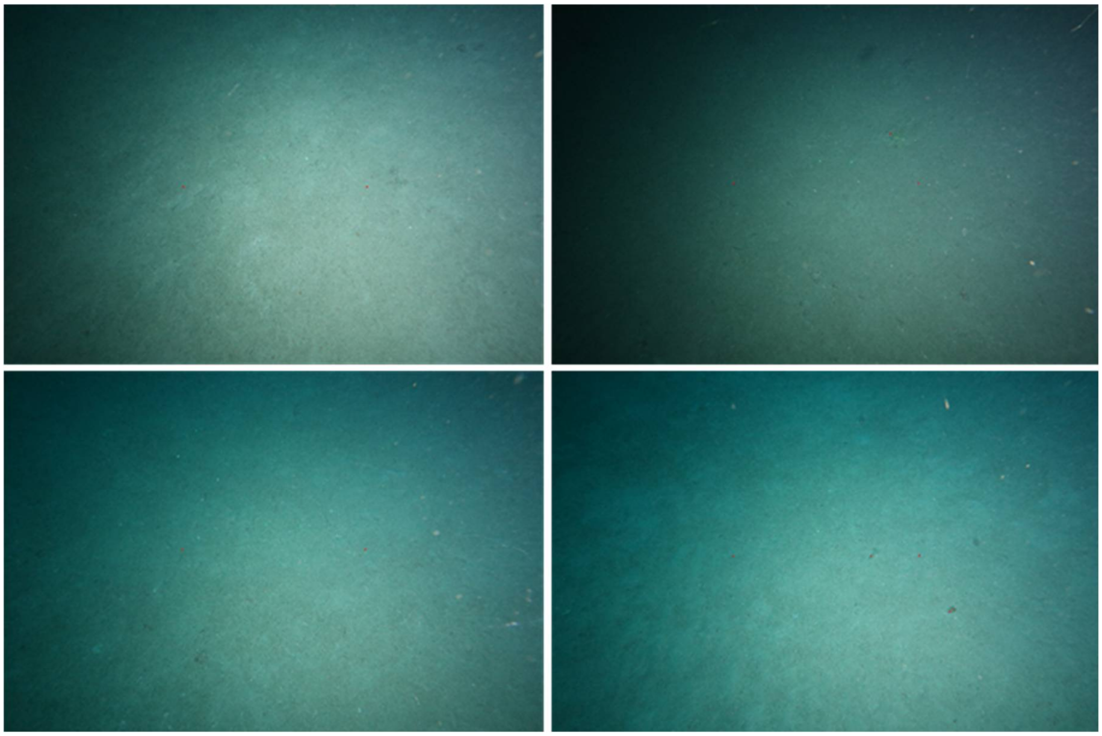
Appx Figure 43. Site W41 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2911, subset 2 – IMG_3097, subset 3 – IMG_3217, subset 4 – IMG_3342. Red dots indicate biota/substrate scored in each image.



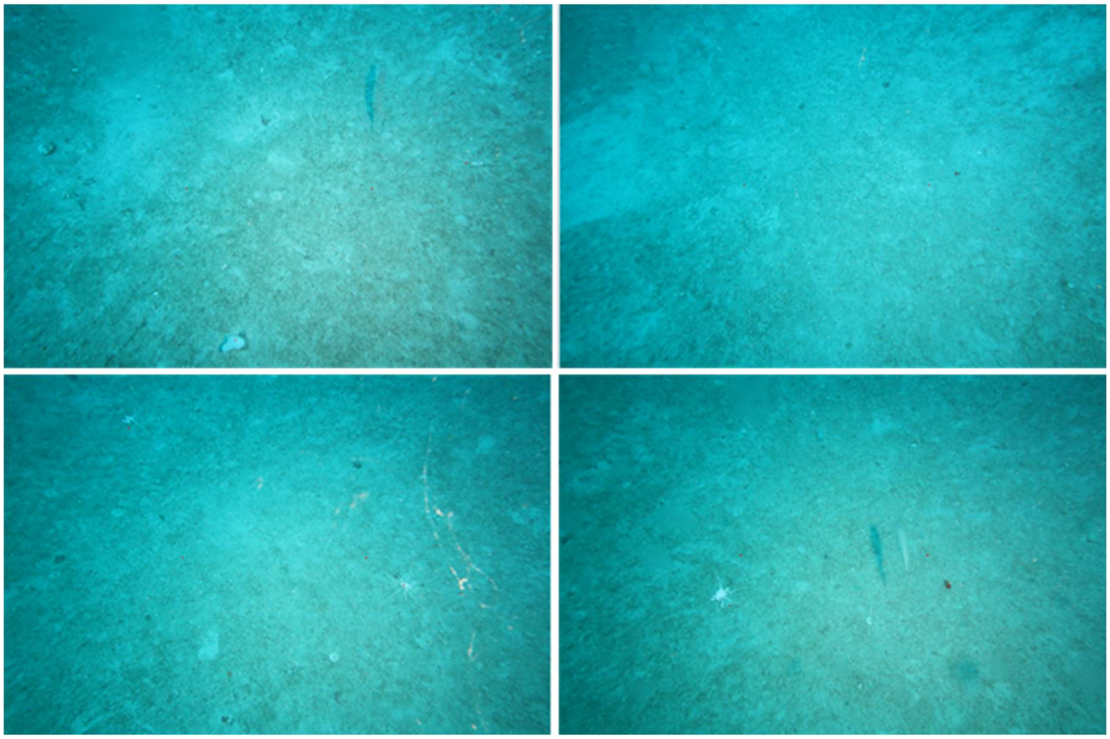
Appx Figure 44. Site W43 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_1028, subset 2 – IMG_1193, subset 3 – IMG_1313, subset 4 – IMG_1483. Red dots indicate biota/substrate scored in each image.



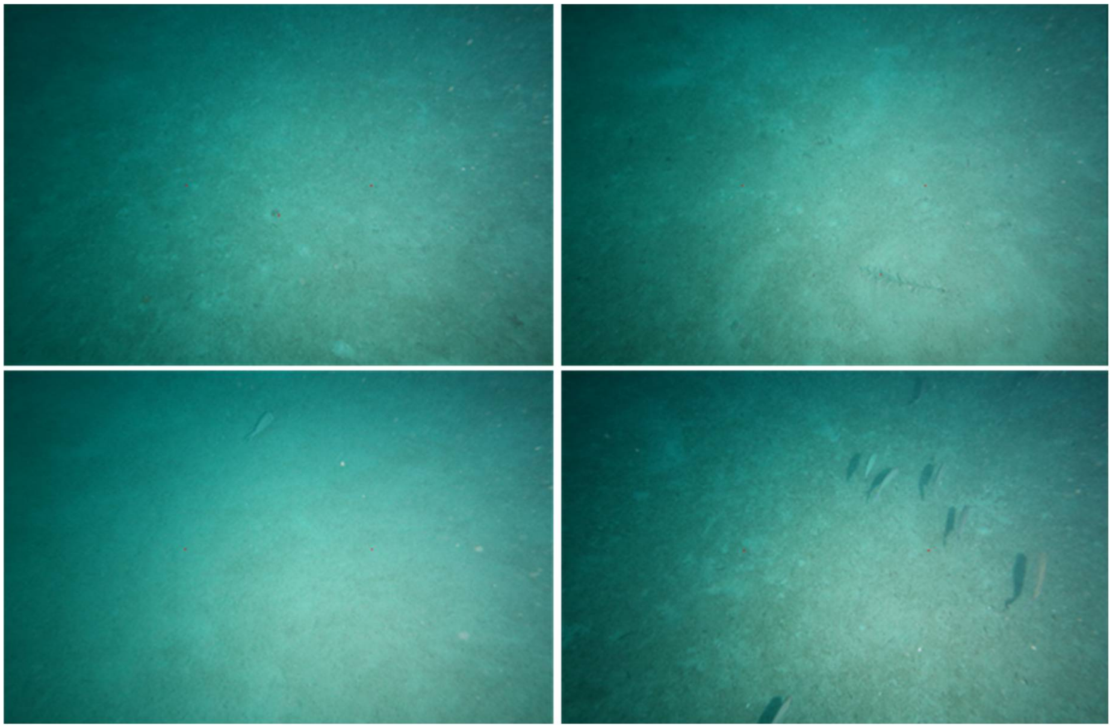
Appx Figure 45. Site W44 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2982, subset 2 – IMG_3167, subset 3 – IMG_3277, subset 4 – IMG_3442. Red dots indicate biota/substrate scored in each image.



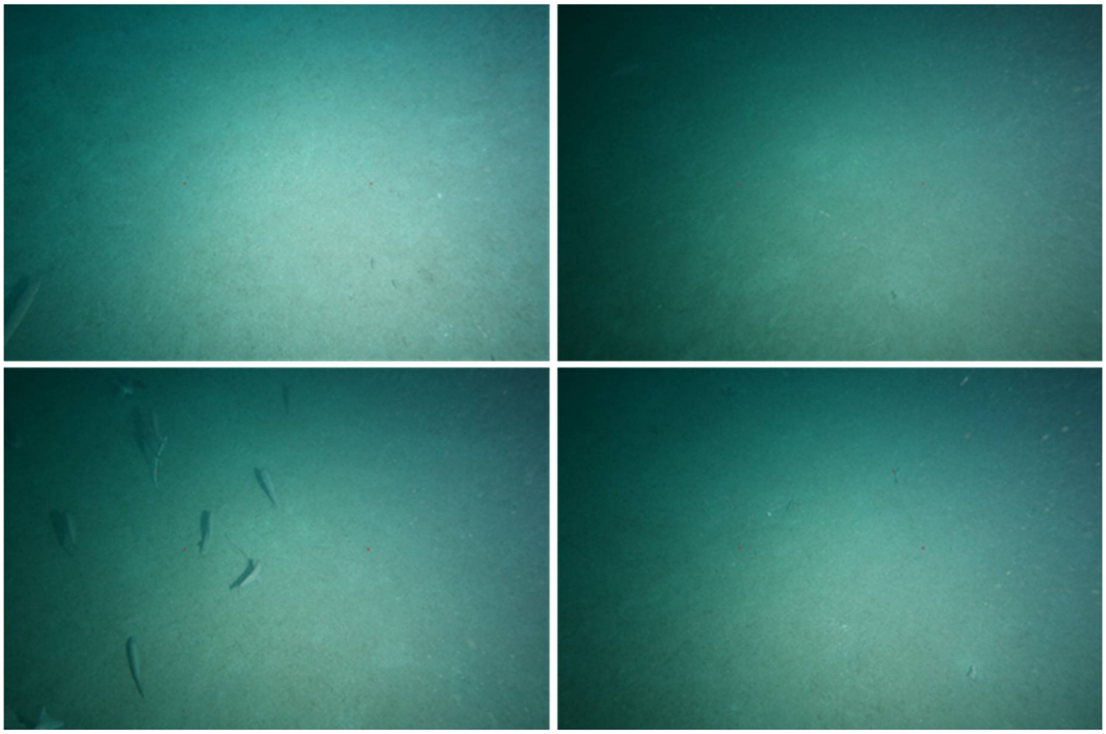
Appx Figure 46. Site W58 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2810, subset 2 – IMG_2925, subset 3 – IMG_3140, subset 4 – IMG_3305. Red dots indicate biota/substrate scored in each image.



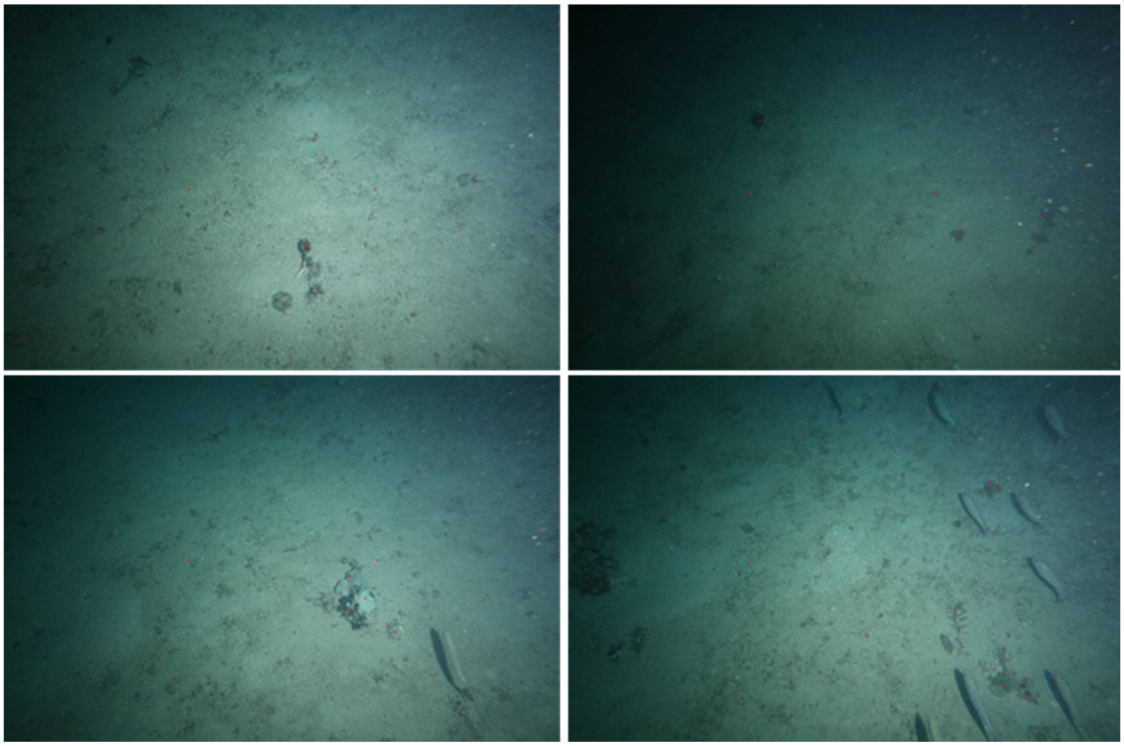
Appx Figure 47. Site W59 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2794, subset 2 – IMG_2974, subset 3 – IMG_3104, subset 4 – IMG_3289. Red dots indicate biota/substrate scored in each image.



Appx Figure 48. Site W61 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_0106, subset 2 – IMG_0236, subset 3 – IMG_0376, subset 4 – IMG_0506. Red dots indicate biota/substrate scored in each image.



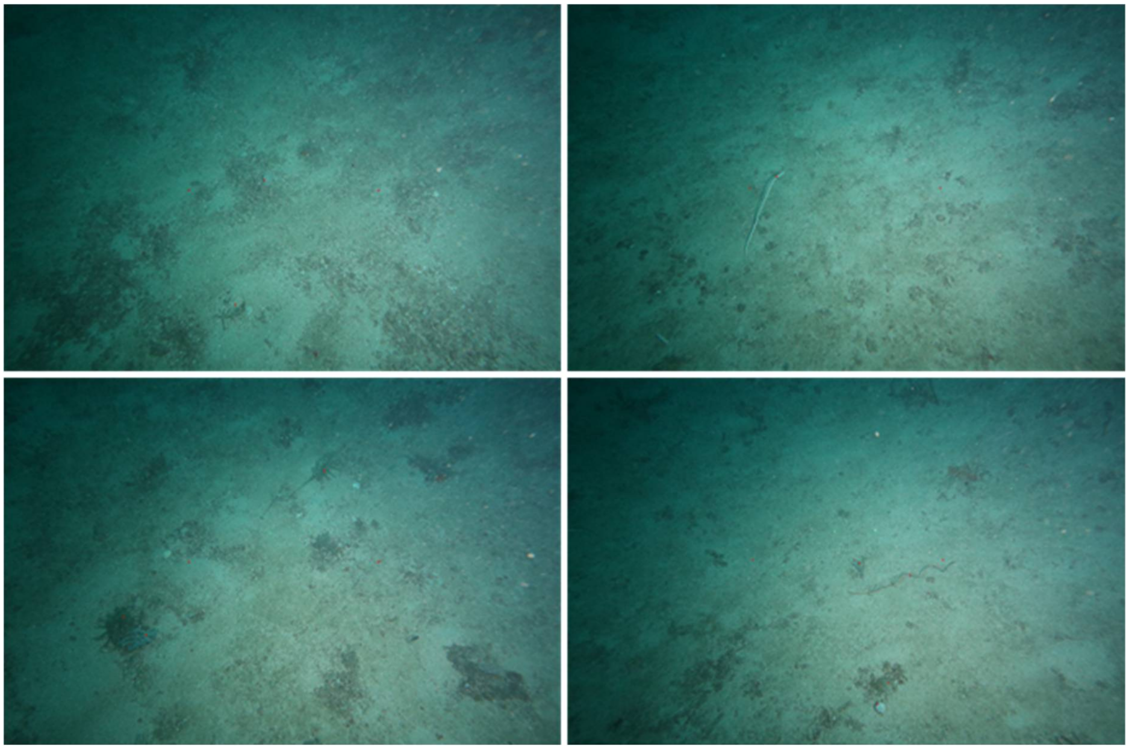
Appx Figure 49. Site W68 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_0079, subset 2 – IMG_0254, subset 3 – IMG_0390, subset 4 – IMG_0590. Red dots indicate biota/substrate scored in each image.



Appx Figure 50. Site W69 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2782, subset 2 – IMG_2923, subset 3 – IMG_3089, subset 4 – IMG_3245. Red dots indicate biota/substrate scored in each image.

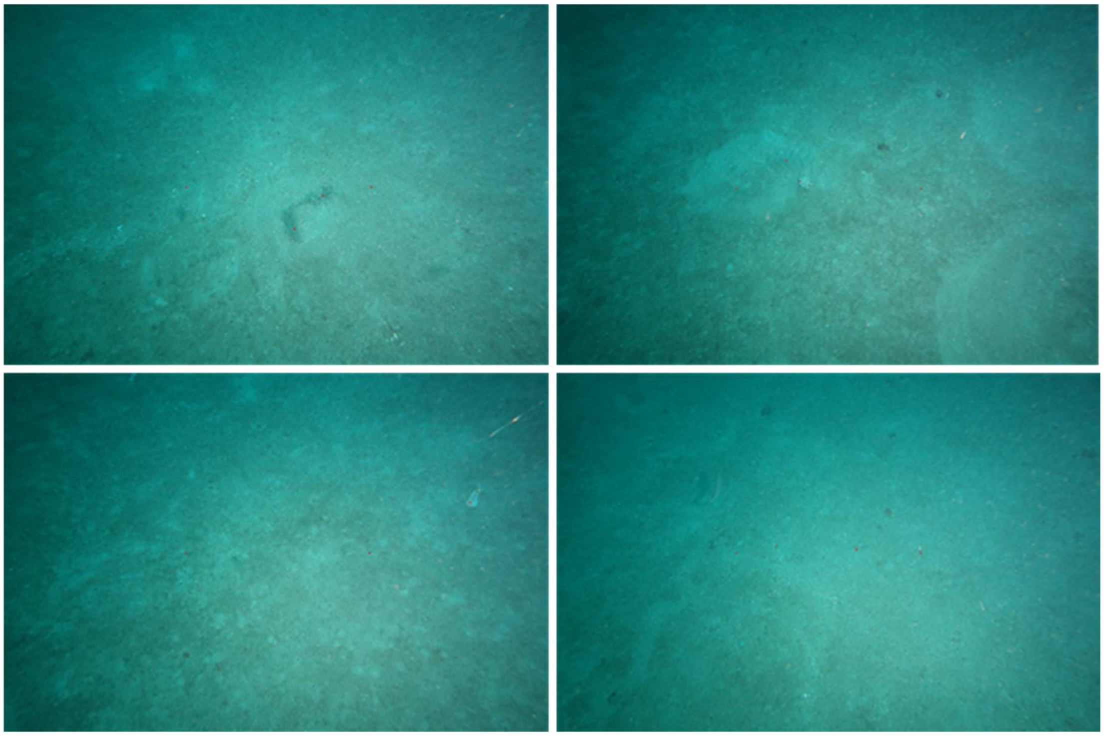
Appx Figure 51. Site W70 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2820, subset 2 – IMG_3026, subset 3 – IMG_3183, subset 4 – IMG_3329. Red dots indicate biota/substrate scored in each image.

Appx Figure 52. Site W75 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2782, subset 2 – IMG_2942, subset 3 – IMG_3082, subset 4 – IMG_3353. Red dots indicate biota/substrate scored in each image.

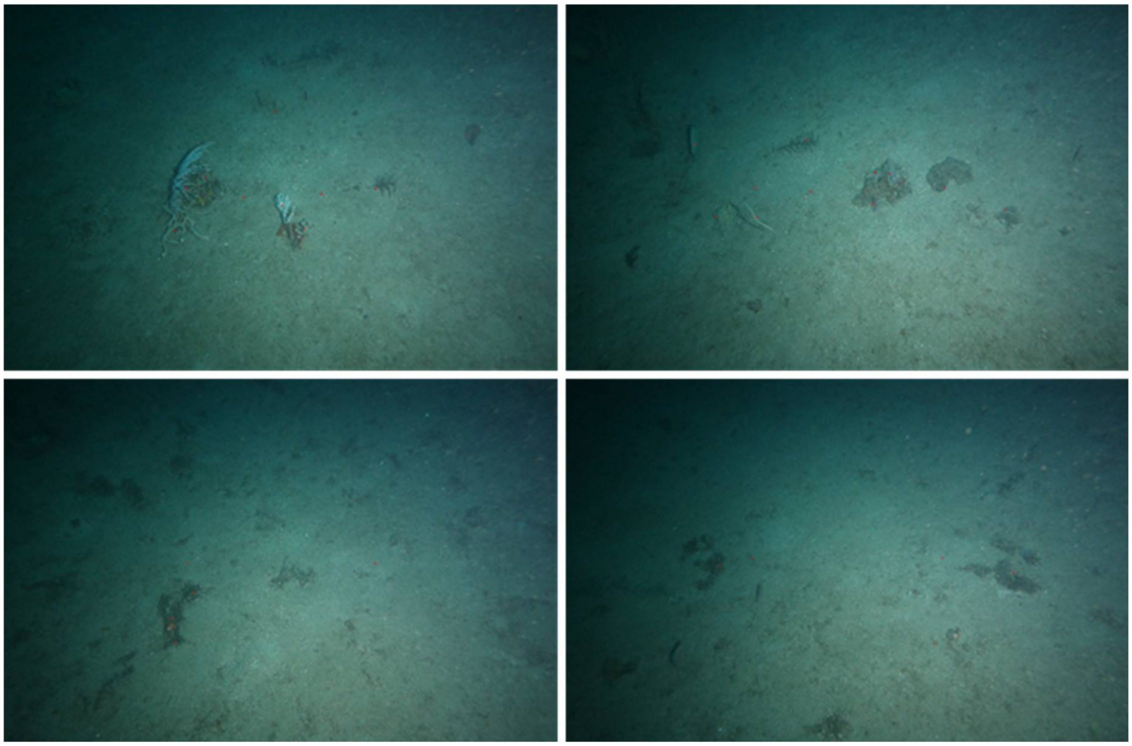


**Appx Figure 53. Site W76 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_0159, subset 2 – IMG_0294, subset 3 – IMG_0464, subset 4 – IMG_0634. Red dots indicate biota/substrate scored in each image.**

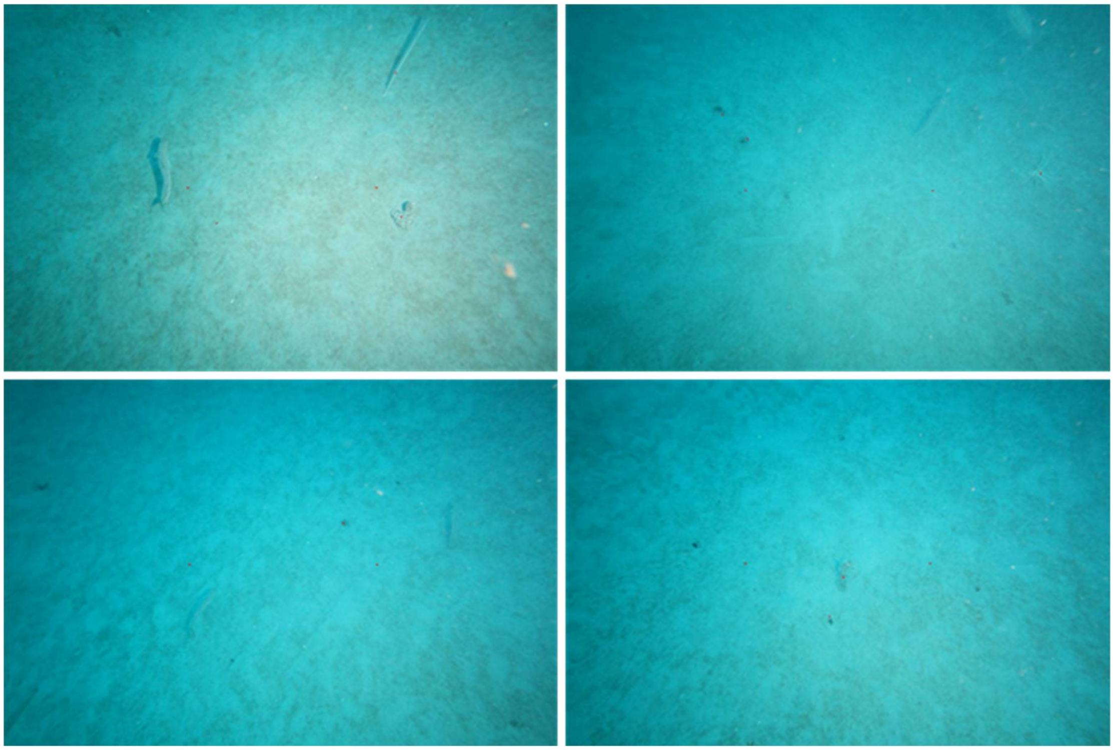
**Appx Figure 54. Site W77 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_0074, subset 2 – IMG_0209, subset 3 – IMG_0369, subset 4 – IMG_0524. Red dots indicate biota/substrate scored in each image.**



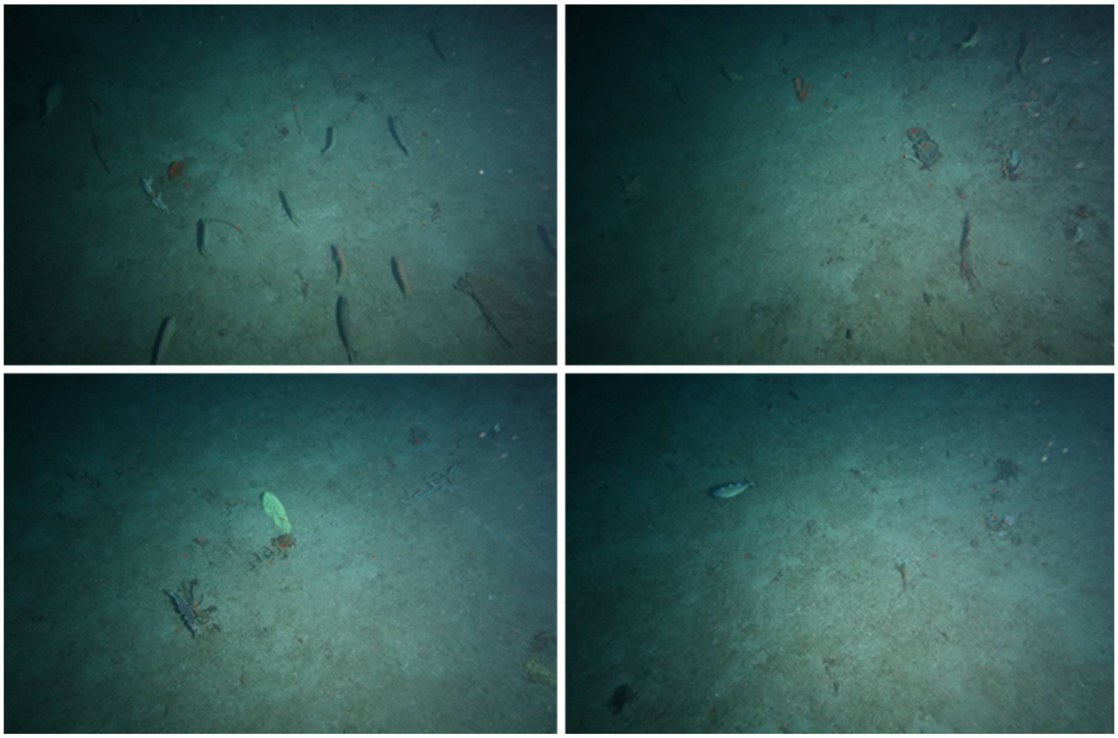
Appx Figure 55. Site W83 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2824, subset 2 – IMG_2874, subset 3 – IMG_2944, subset 4 – IMG_2994. Red dots indicate biota/substrate scored in each image.



Appx Figure 56. Site W84 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2824, subset 2 – IMG_3075, subset 3 – IMG_3165, subset 4 – IMG_3295. Red dots indicate biota/substrate scored in each image.

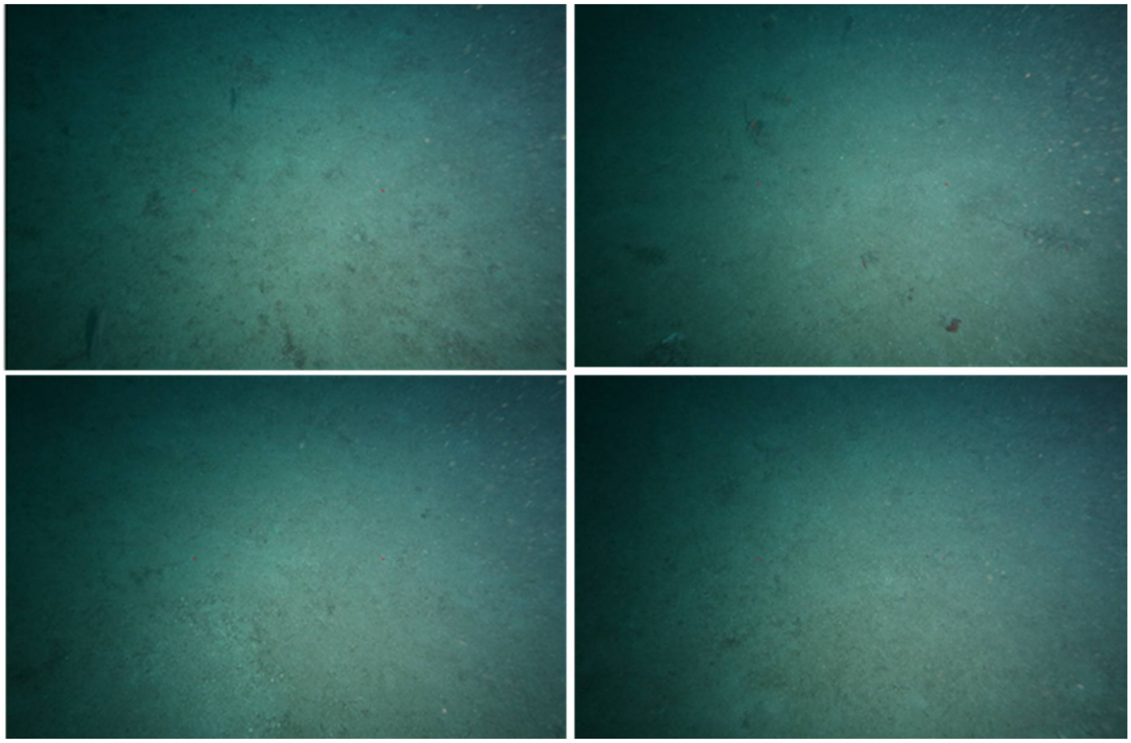


Appx Figure 57. Site W89 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_0029, subset 2 – IMG_0194, subset 3 – IMG_0249, subset 4 – IMG_0364. Red dots indicate biota/substrate scored in each image.



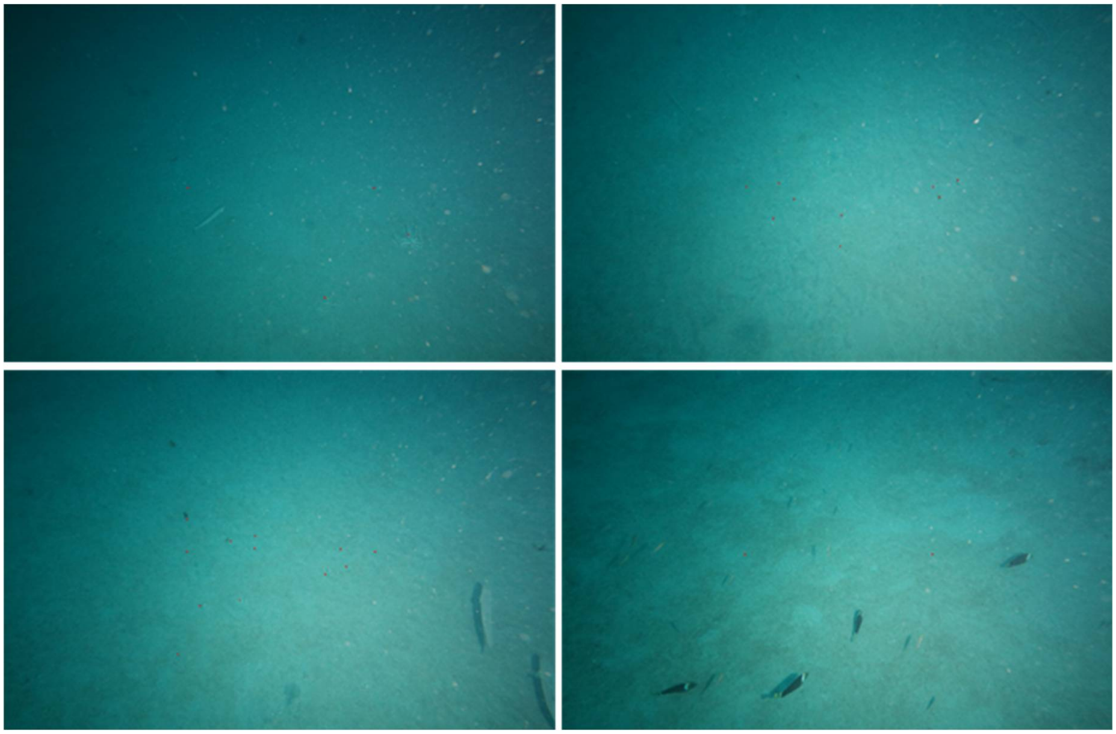
Appx Figure 58. Site W90 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2811, subset 2 – IMG_2936, subset 3 – IMG_3091, subset 4 – IMG_3303. Red dots indicate biota/substrate scored in each image.

Appx Figure 59. Site W91 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2890, subset 2 – IMG_2966, subset 3 – IMG_3108, subset 4 – IMG_3354. Red dots indicate biota/substrate scored in each image.

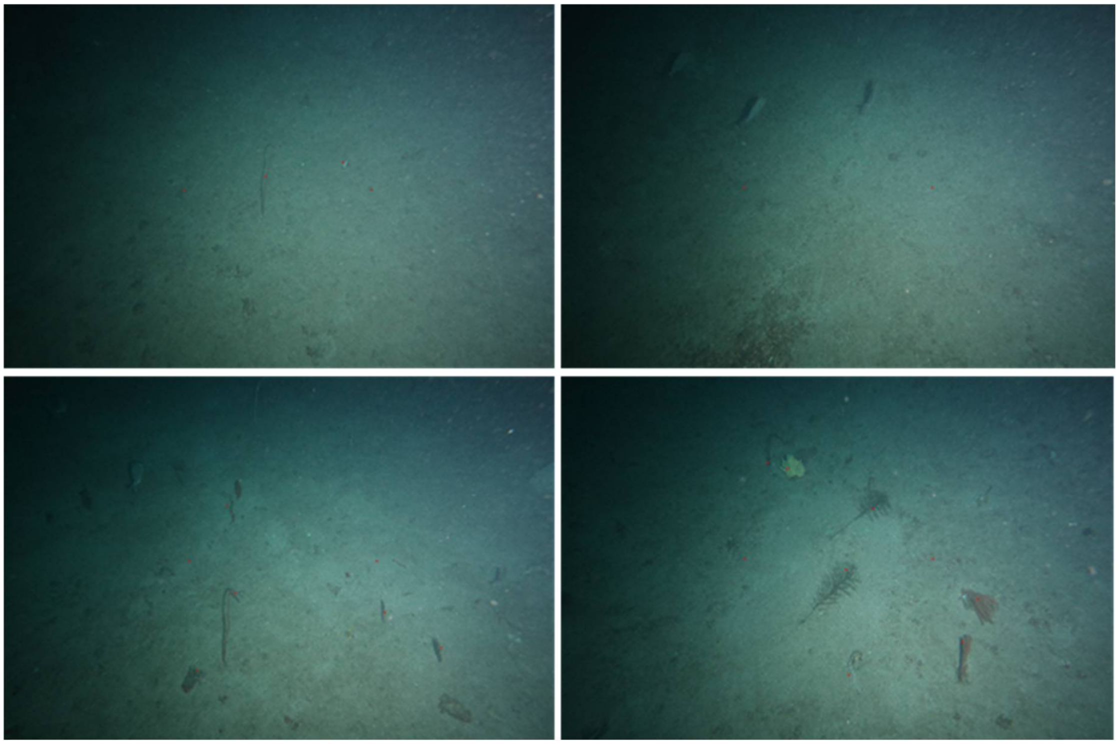


Appx Figure 60. Site W92 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_0071, subset 2 – IMG_0227, subset 3 – IMG_0382, subset 4 – IMG_0558. Red dots indicate biota/substrate scored in each image.

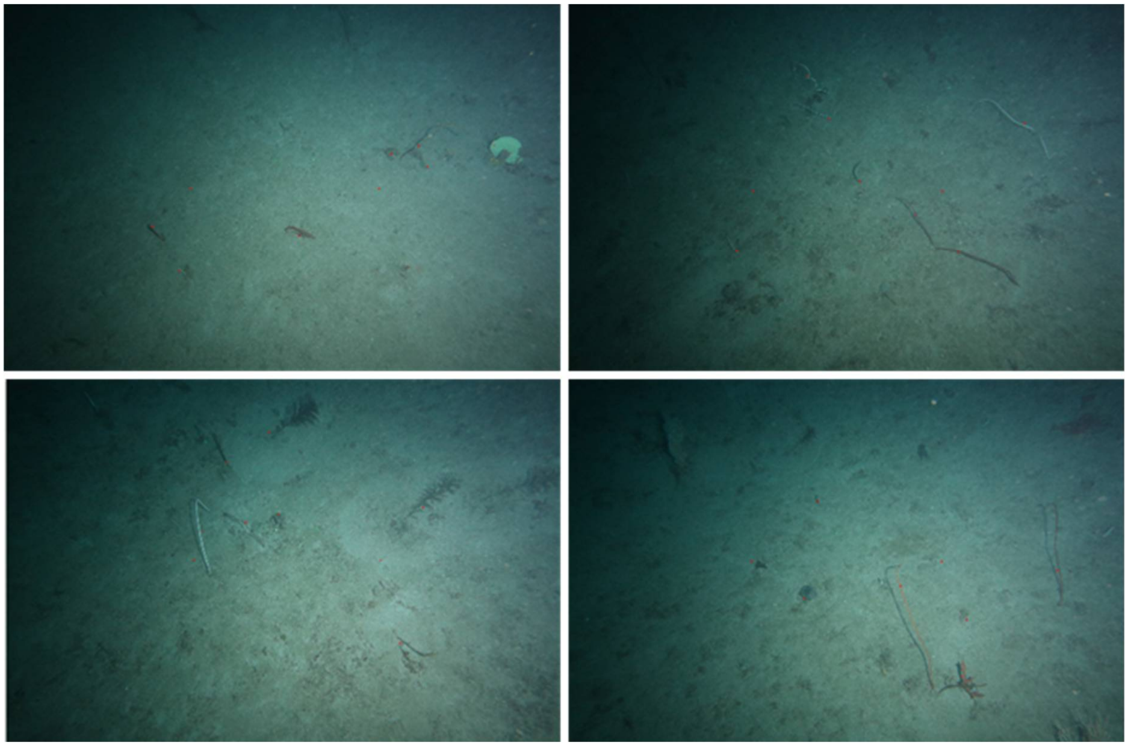
**Appx Figure 61. Site W93 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2771, subset 2 – IMG_2927, subset 3 – IMG_3058, subset 4 – IMG_3229. Red dots indicate biota/substrate scored in each image.**



**Appx Figure 62. Site W94 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2848, subset 2 – IMG_2978, subset 3 – IMG_3118, subset 4 – IMG_3289. Red dots indicate biota/substrate scored in each image.**

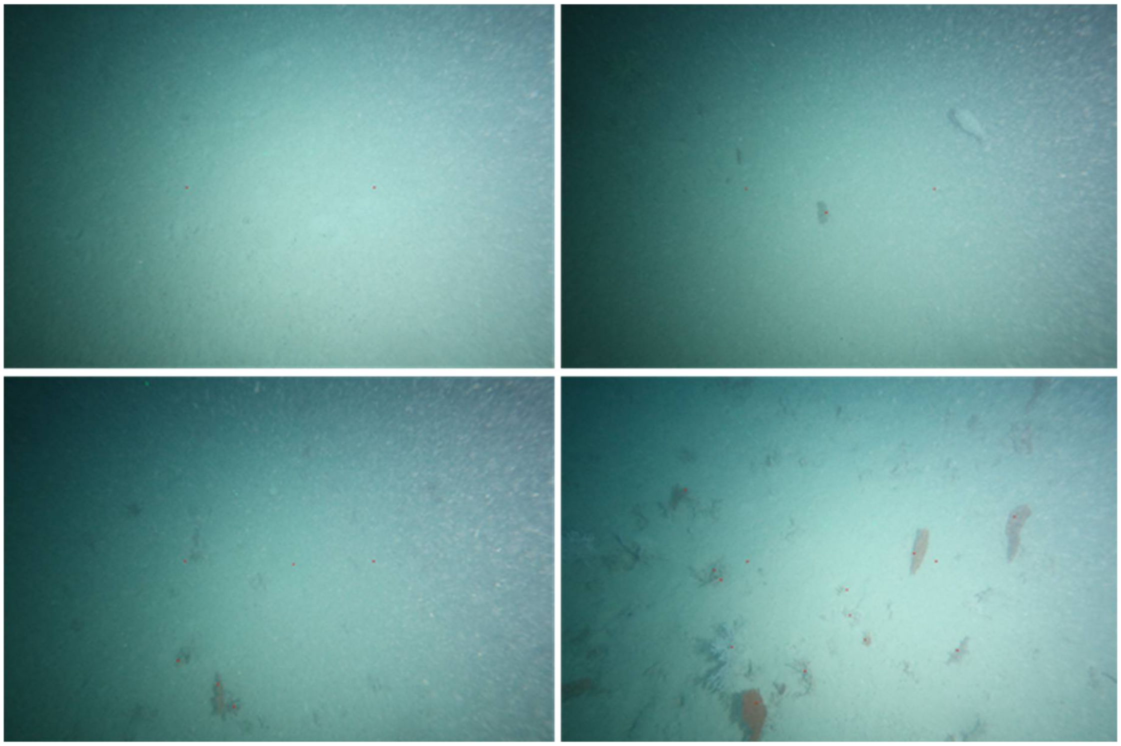


Appx Figure 63. Site W95 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2819, subset 2 – IMG_3004, subset 3 – IMG_3176, subset 4 – IMG_3306. Red dots indicate biota/substrate scored in each image.

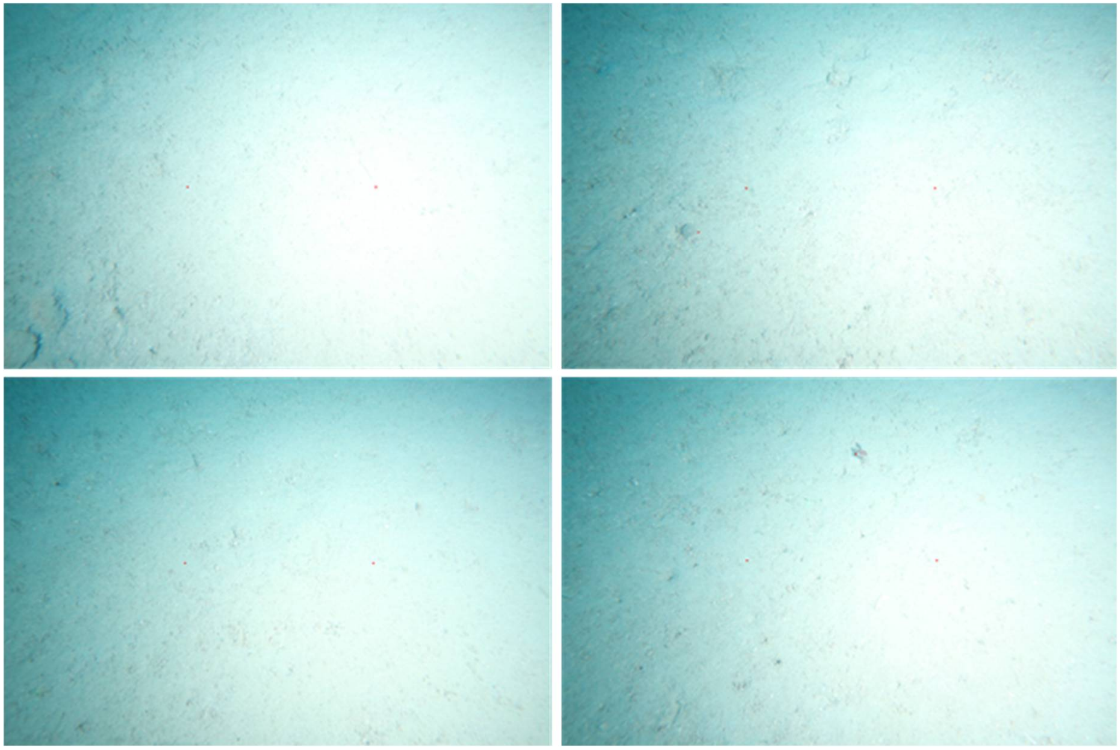


Appx Figure 64. Site W96 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2789, subset 2 – IMG_2919, subset 3 – IMG_3114, subset 4 – IMG_3239. Red dots indicate biota/substrate scored in each image.

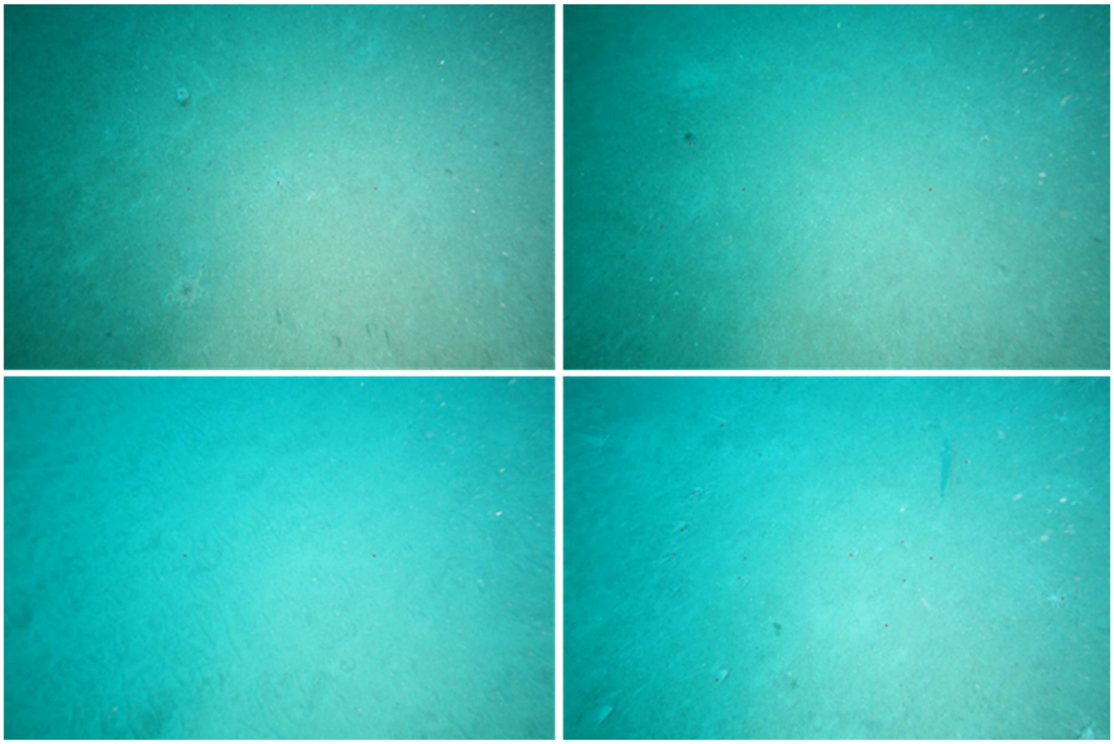
## C.4 Sites in Pibara Fish Trawl Fishery Area 2



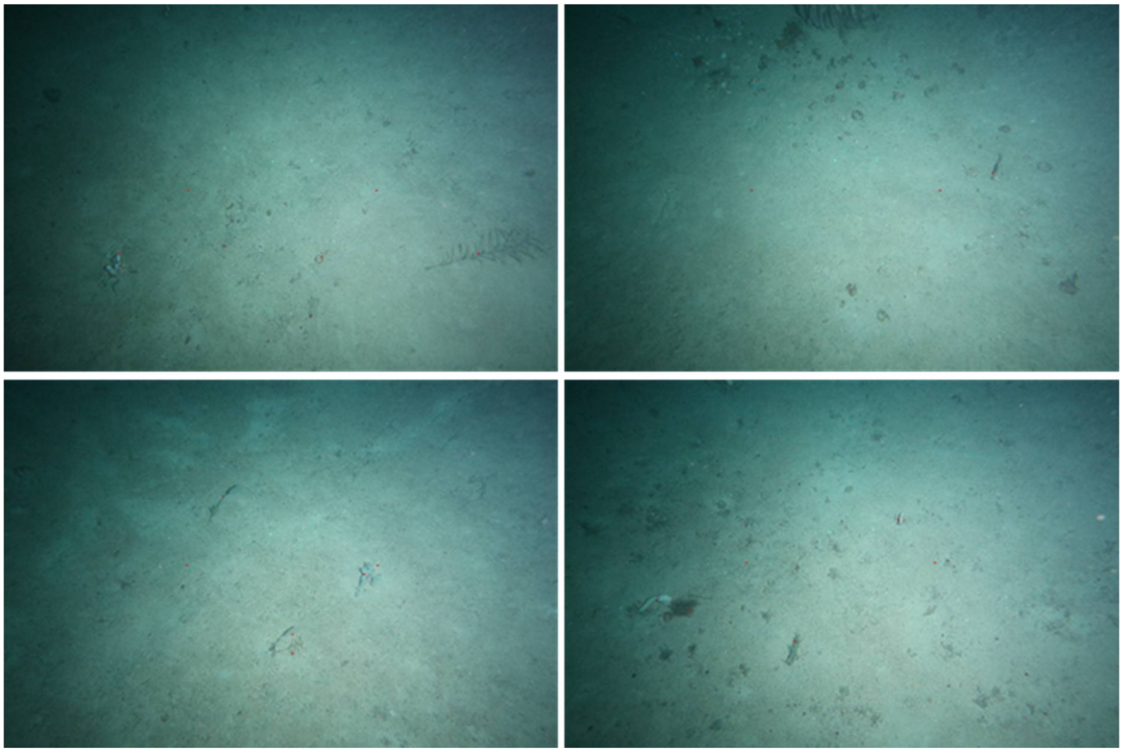
**Appx Figure 65. Site W26 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_0119, subset 2 – IMG_0249, subset 3 – IMG_0415, subset 4 – IMG_0525. Red dots indicate biota/substrate scored in each image.**



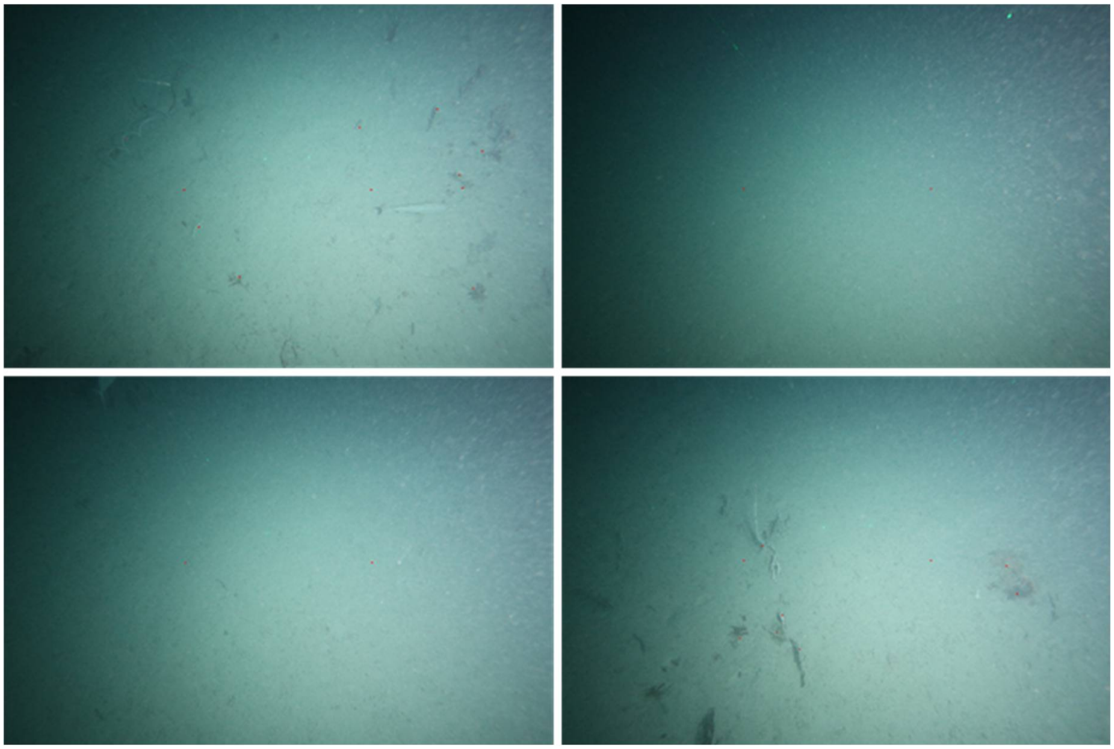
**Appx Figure 66. Site W29 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2885, subset 2 – IMG_2975, subset 3 – IMG_3110, subset 4 – IMG_3240. Red dots indicate biota/substrate scored in each image.**



Appx Figure 67. Site W30 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_0044, subset 2 – IMG_0190, subset 3 – IMG_0395, subset 4 – IMG_0556. Red dots indicate biota/substrate scored in each image.

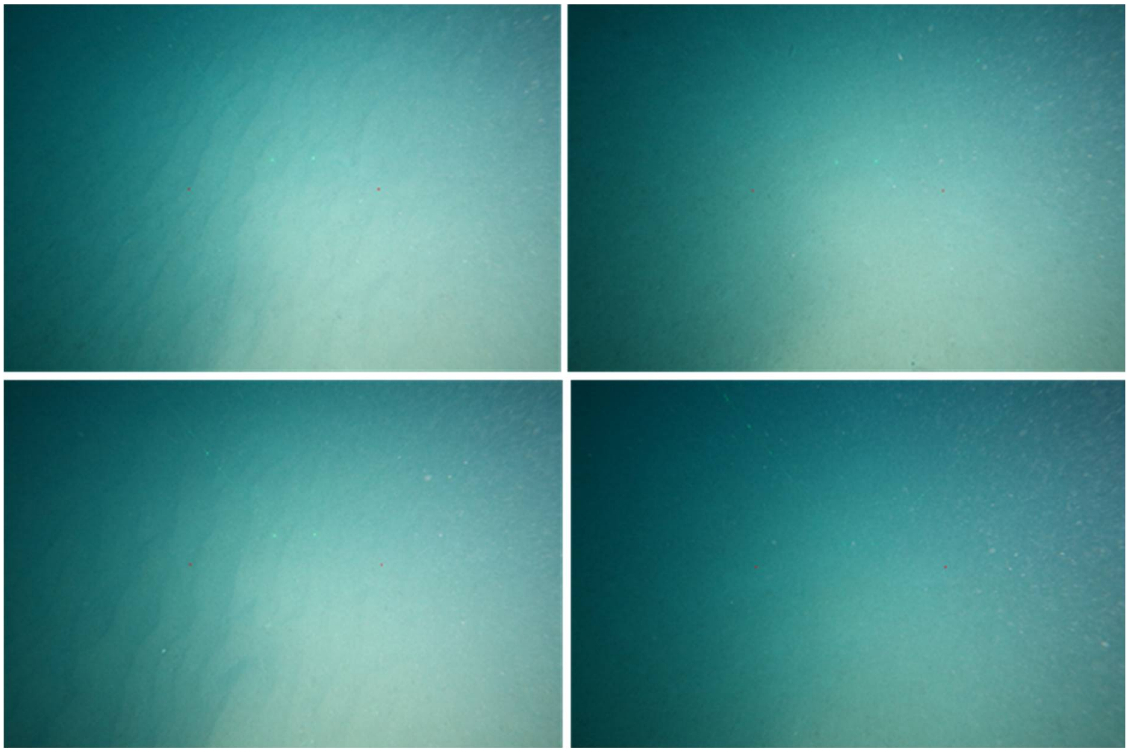


Appx Figure 68. Site W31 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2830, subset 2 – IMG_2976, subset 3 – IMG_3081, subset 4 – IMG_3231. Red dots indicate biota/substrate scored in each image.

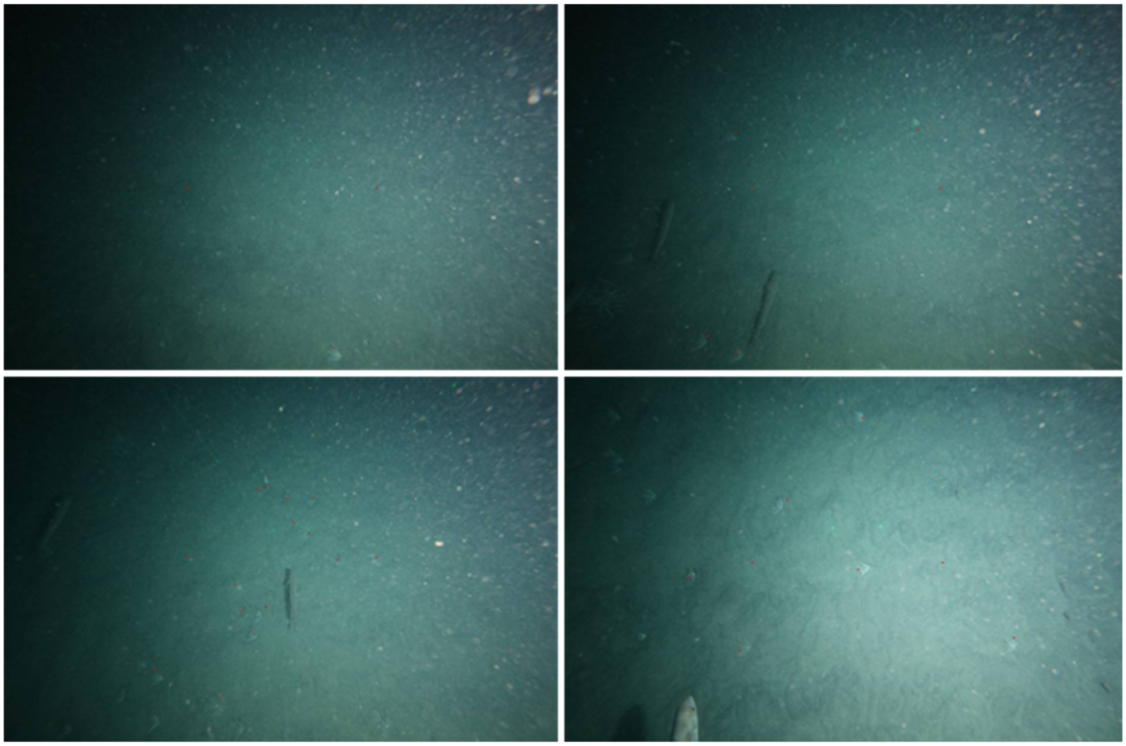


Appx Figure 69. Site W32 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2826, subset 2 – IMG_3037, subset 3 – IMG_3192, subset 4 – IMG_3289. Red dots indicate biota/substrate scored in each image.

Appx Figure 70. Site W33 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2882, subset 2 – IMG_3007, subset 3 – IMG_3127, subset 4 – IMG_3307. Red dots indicate biota/substrate scored in each image.

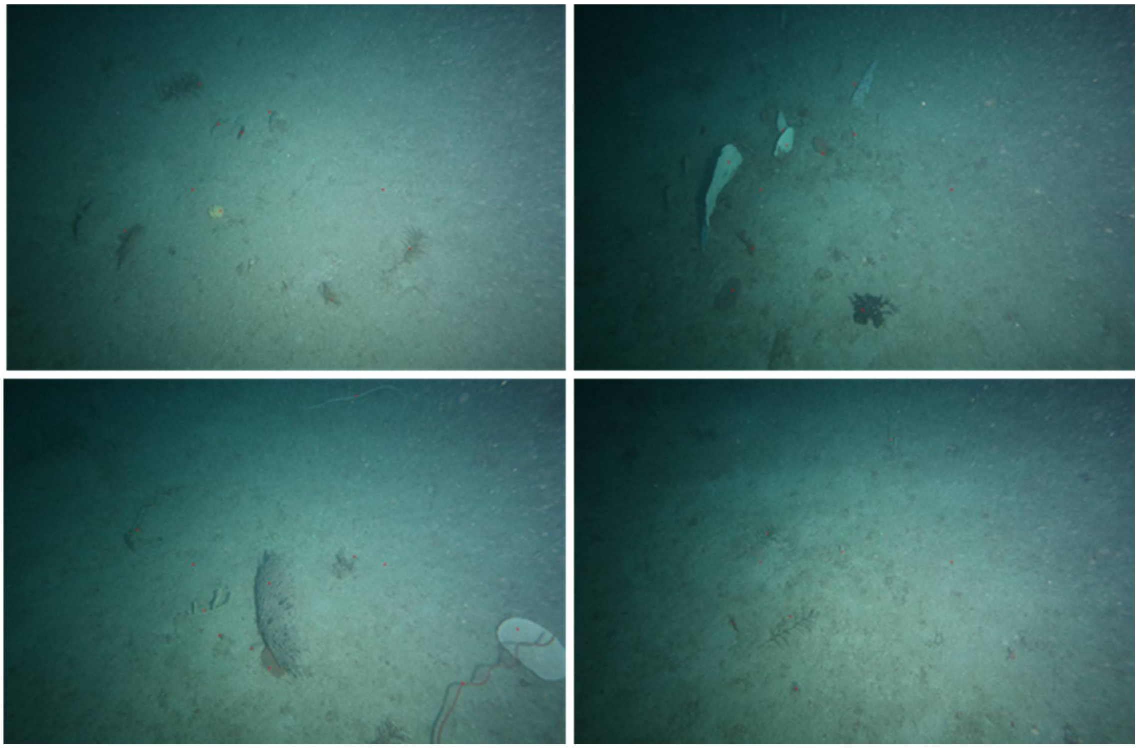


Appx Figure 71. Site W34 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_3766, subset 2 – IMG_3897, subset 3 – IMG_4007, subset 4 – IMG_4247. Red dots indicate biota/substrate scored in each image.

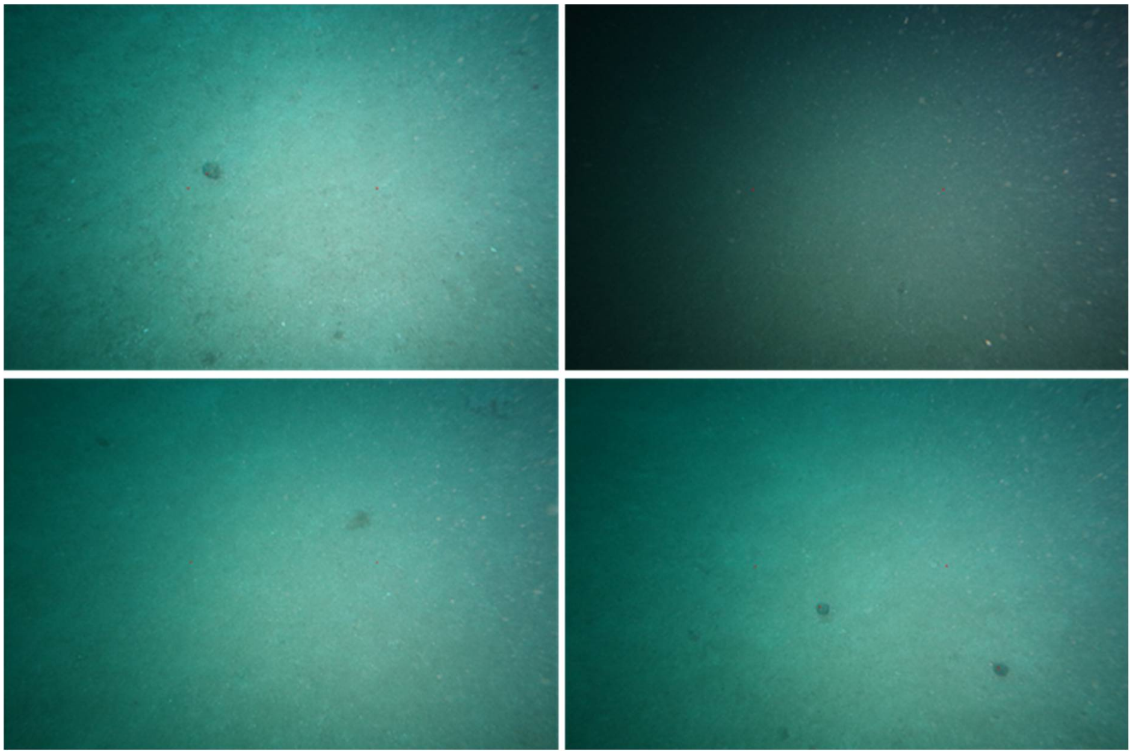


Appx Figure 72. Site W42 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_1762, subset 2 – IMG_2007, subset 3 – IMG_2117, subset 4 – IMG_2332. Red dots indicate biota/substrate scored in each image.

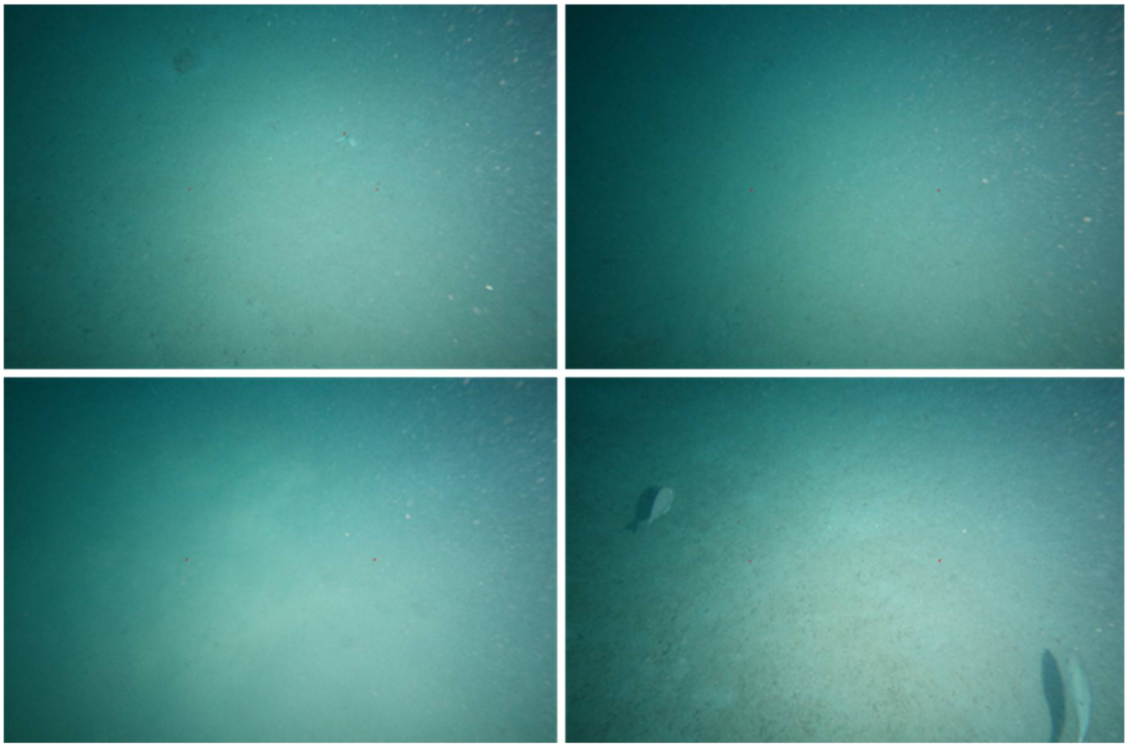
Appx Figure 73. Site W45 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_1963, subset 2 – IMG_2148, subset 3 – IMG_2298, subset 4 – IMG_2433. Red dots indicate biota/substrate scored in each image.



Appx Figure 74. Site W60 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2821, subset 2 – IMG_2963, subset 3 – IMG_3130, subset 4 – IMG_3215. Red dots indicate biota/substrate scored in each image.

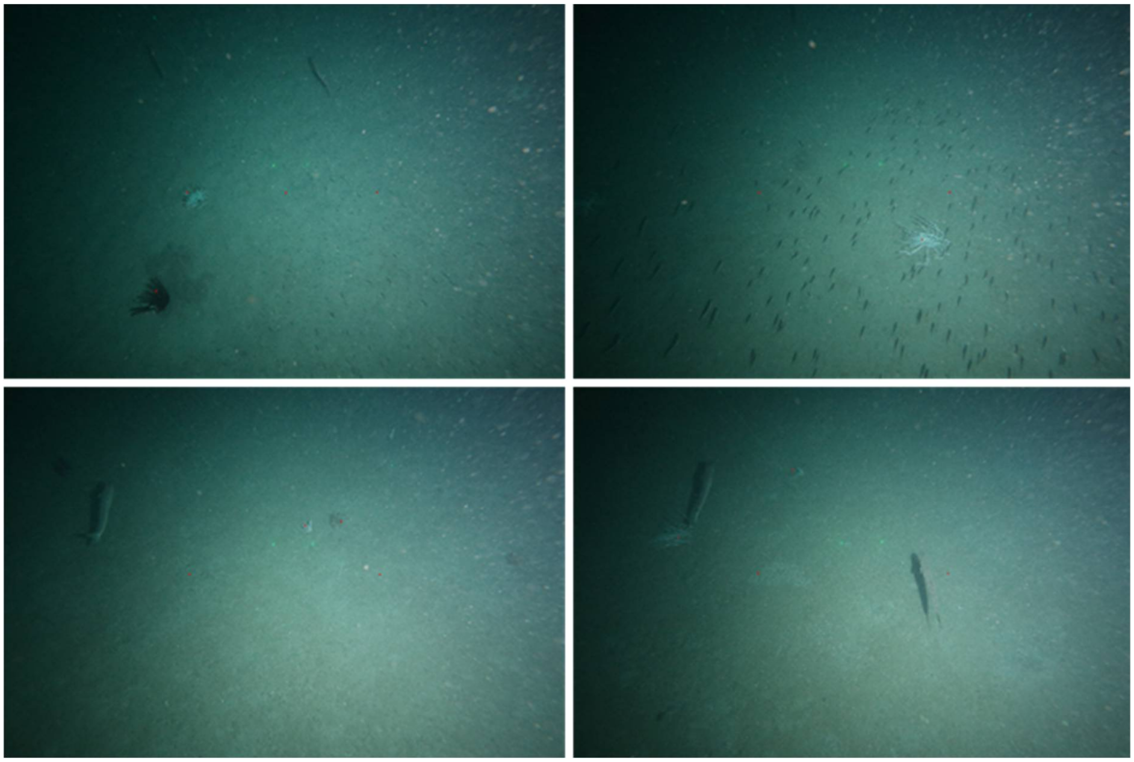


**Appx Figure 75. Site W62 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_0099, subset 2 – IMG_0254, subset 3 – IMG_0434, subset 4 – IMG_0584. Red dots indicate biota/substrate scored in each image.**



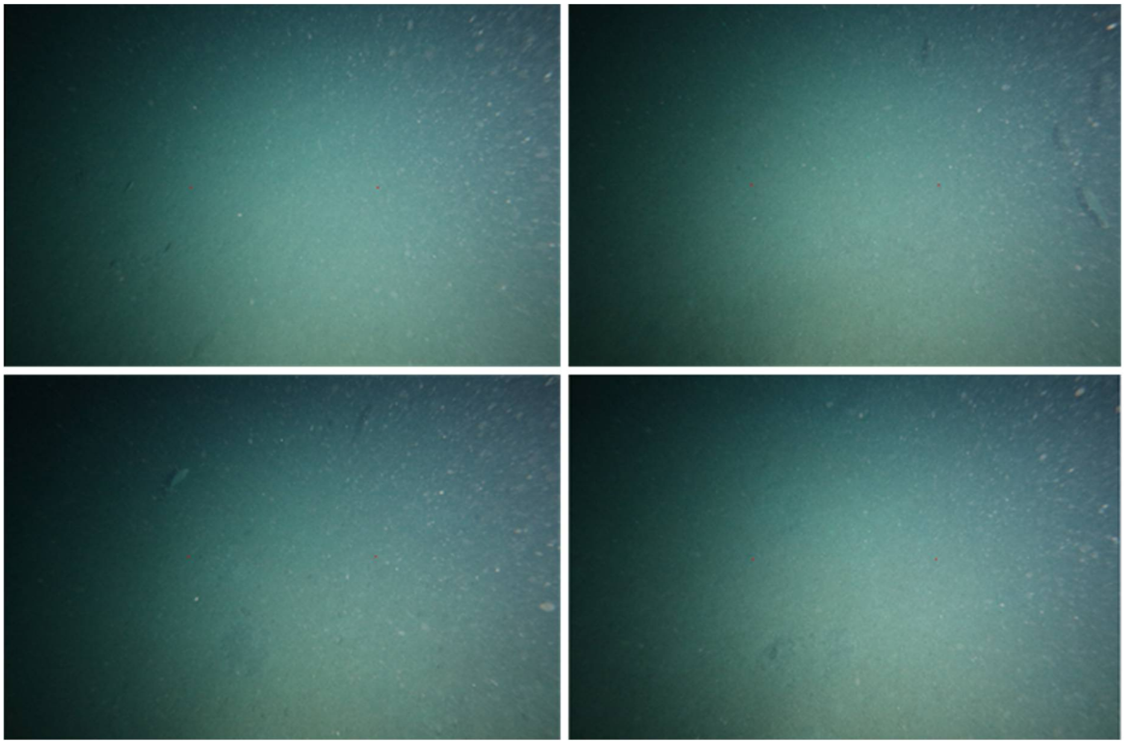
**Appx Figure 76. Site W63 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_0072, subset 2 – IMG_0223, subset 3 – IMG_0380, subset 4 – IMG_0562. Red dots indicate biota/substrate scored in each image.**

Appx Figure 77. Site W64 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_1760, subset 2 – IMG_1910, subset 3 – IMG_2072, subset 4 – IMG_2237. Red dots indicate biota/substrate scored in each image.

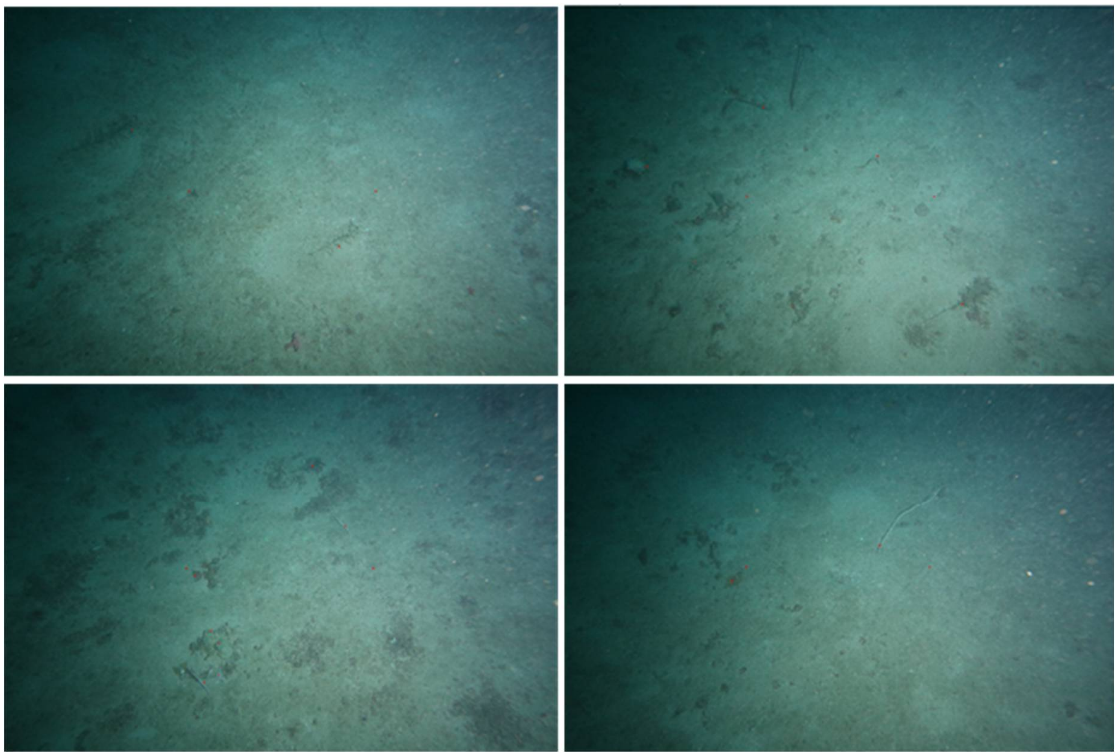


Appx Figure 78. Site W65 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_1872, subset 2 – IMG_2018, subset 3 – IMG_2168, subset 4 – IMG_2298. Red dots indicate biota/substrate scored in each image.

Appx Figure 79. Site W66 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_1875, subset 2 – IMG_2040, subset 3 – IMG_2185, subset 4 – IMG_2305. Red dots indicate biota/substrate scored in each image.

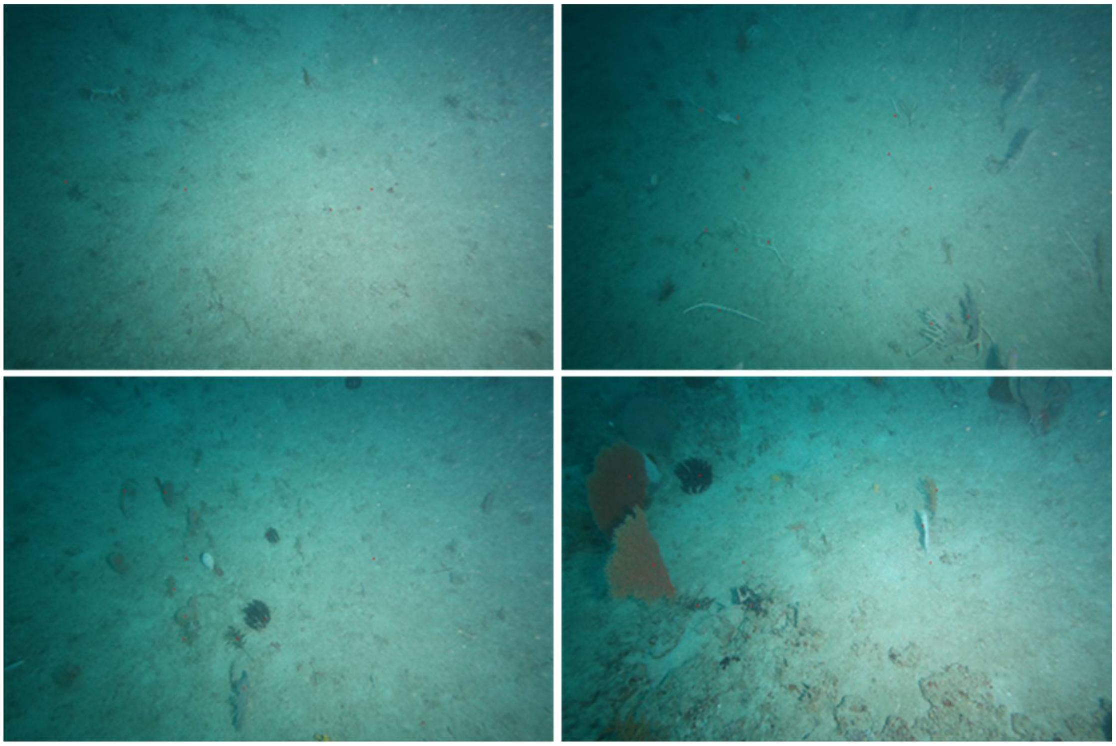


Appx Figure 80. Site W71 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2842, subset 2 – IMG_2982, subset 3 – IMG_3172, subset 4 – IMG_3297. Red dots indicate biota/substrate scored in each image.

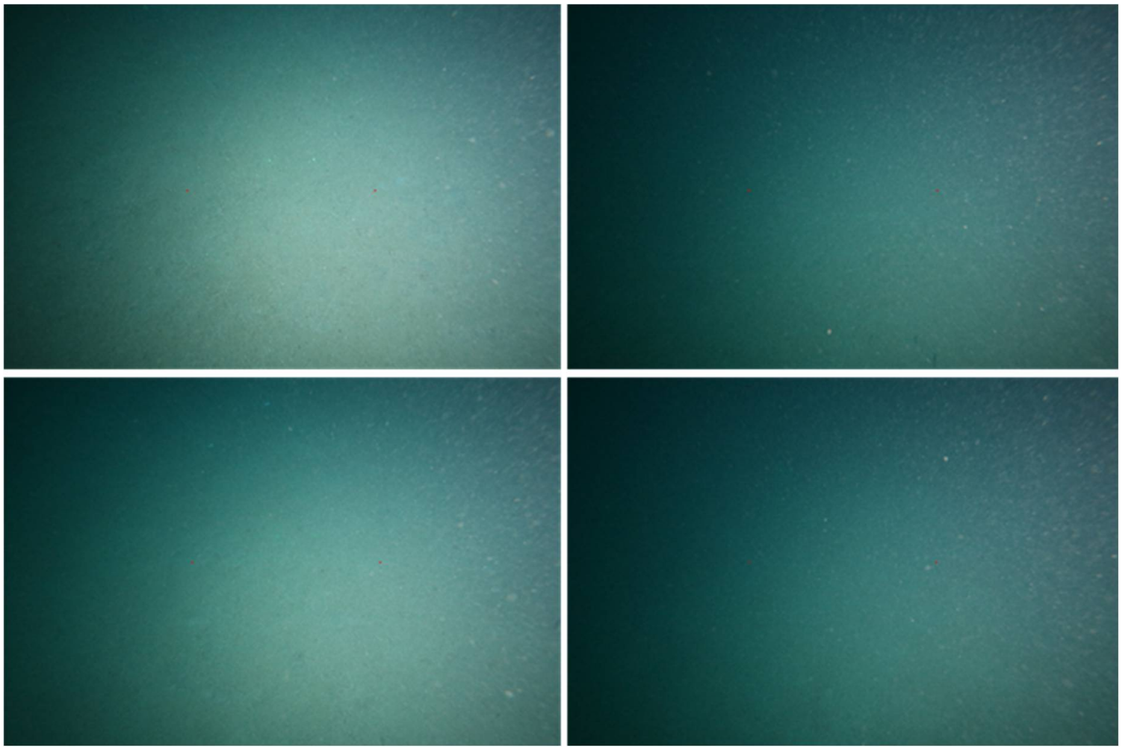


Appx Figure 81. Site W72 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2807, subset 2 – IMG_2982, subset 3 – IMG_3144, subset 4 – IMG_3264. Red dots indicate biota/substrate scored in each image.

Appx Figure 82. Site W73 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2950, subset 2 – IMG_3065, subset 3 – IMG_3190, subset 4 – IMG_3331. Red dots indicate biota/substrate scored in each image.

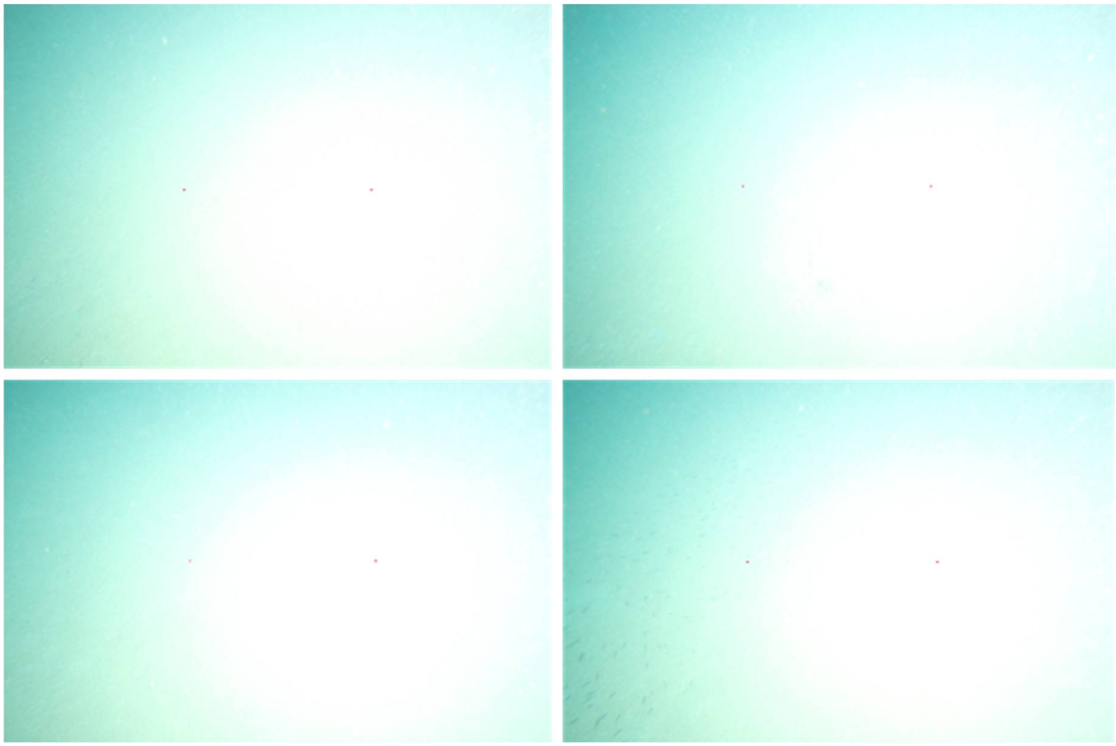


Appx Figure 83. Site W86 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2819, subset 2 – IMG_2959, subset 3 – IMG_3069, subset 4 – IMG_3251. Red dots indicate biota/substrate scored in each image.

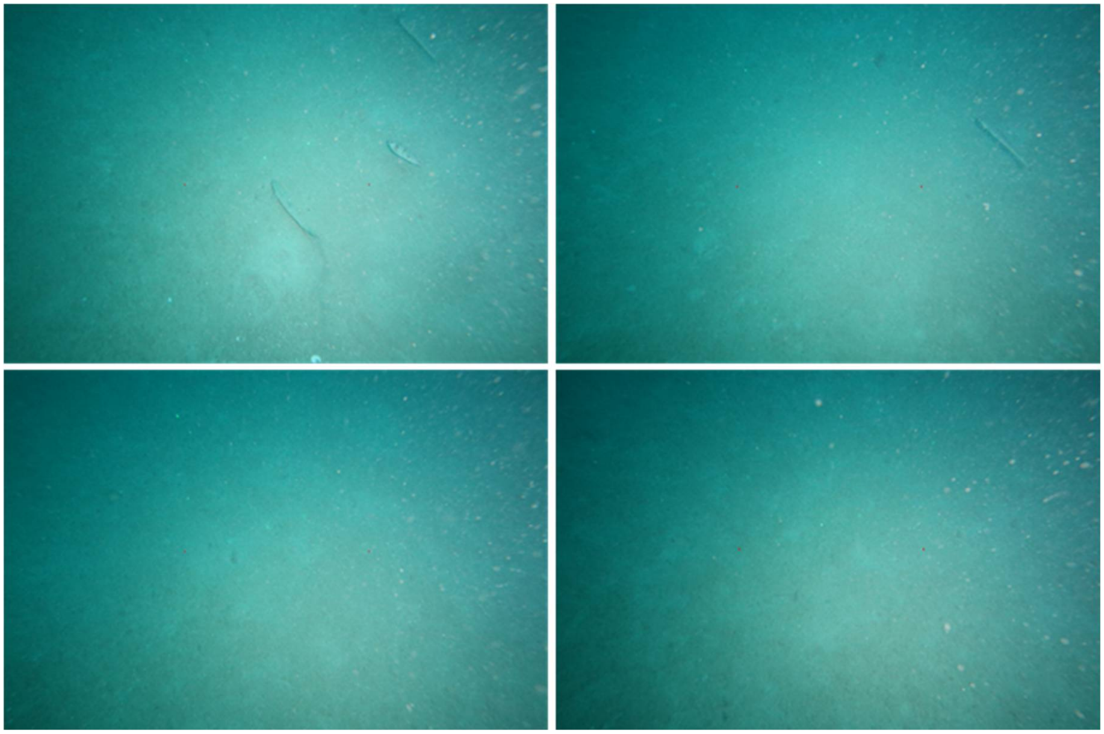


Appx Figure 84. Site W87 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_2797, subset 2 – IMG_2947, subset 3 – IMG_3102, subset 4 – IMG_3267. Red dots indicate biota/substrate scored in each image.

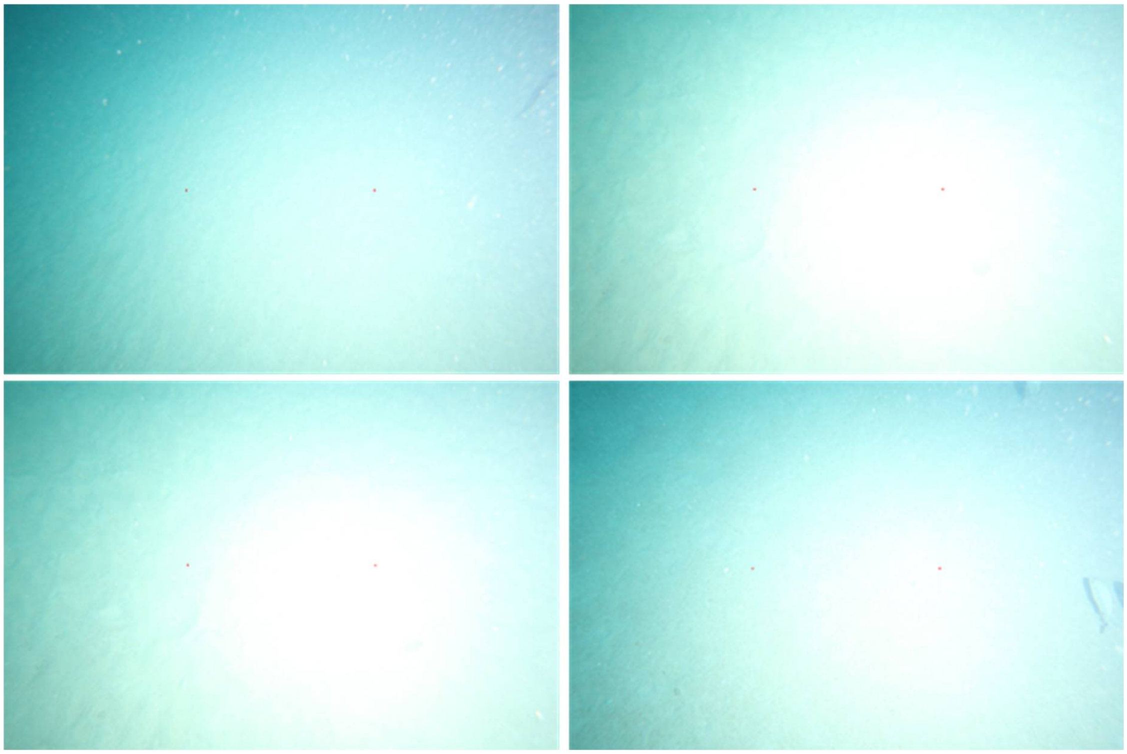
## C.5 Sites in Pilbara Fish Trawl Fishery Area 3 (currently closed to fishing)



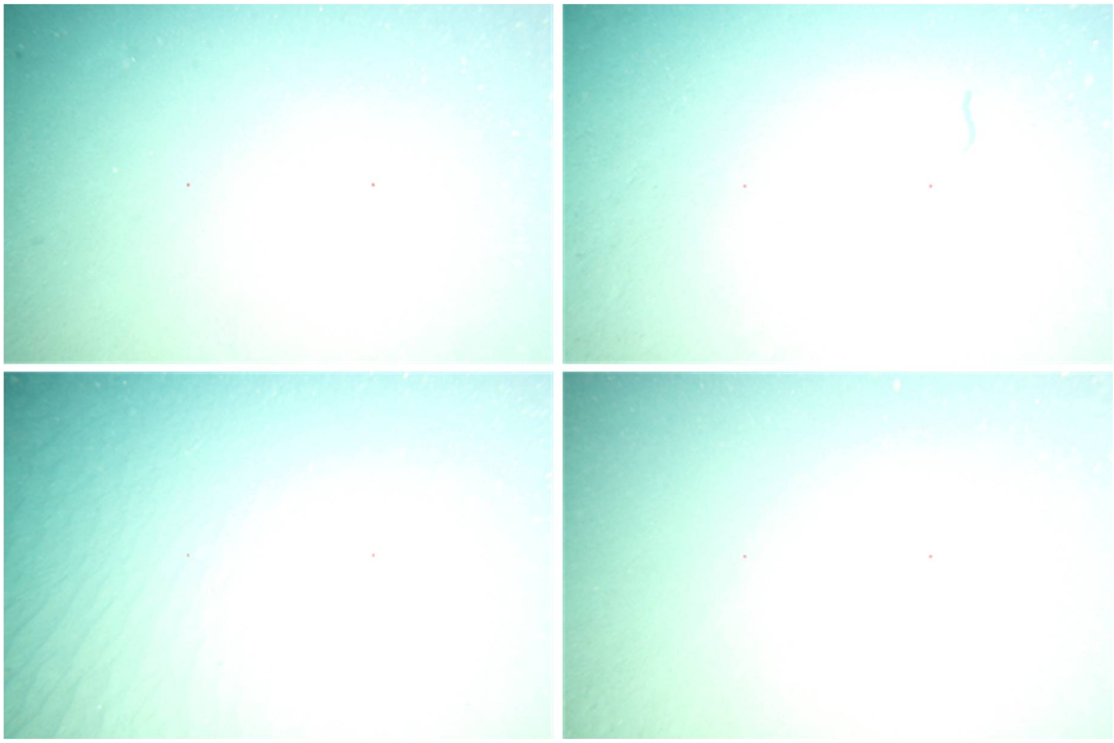
Appx Figure 85. Site W21 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_0948, subset 2 – IMG_1123, subset 3 – IMG_1238, subset 4 – IMG_1408. Red dots indicate biota/substrate scored in each image.



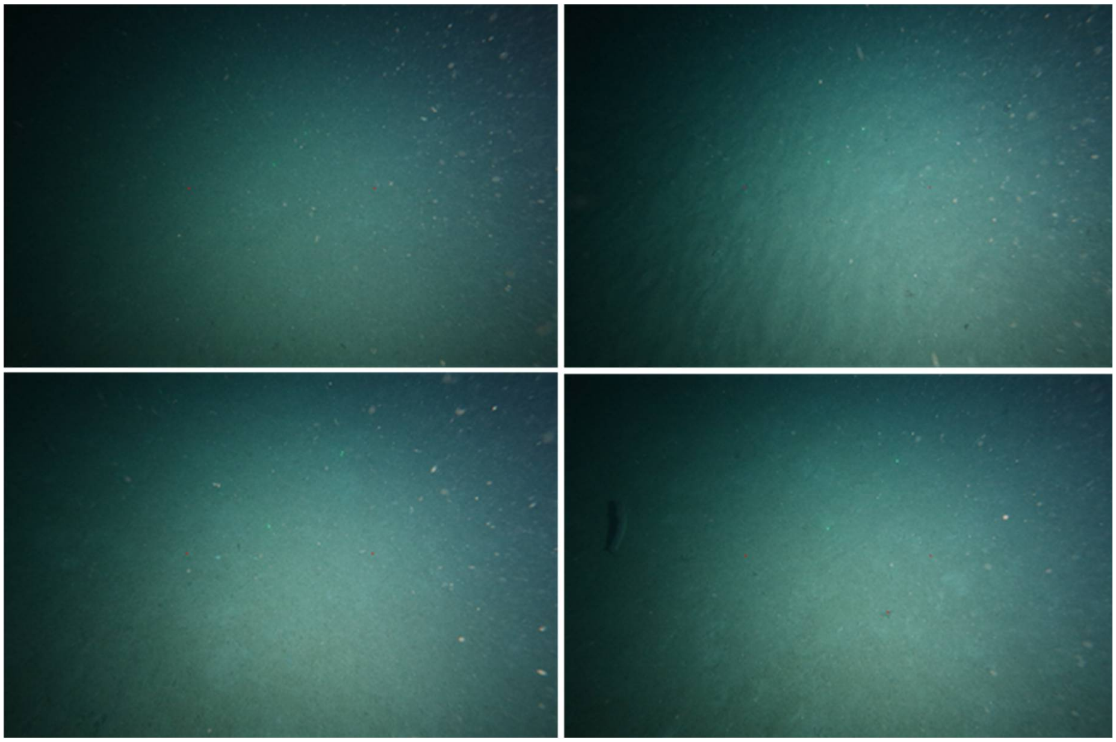
Appx Figure 86. Site W23 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_0955, subset 2 – IMG_1090, subset 3 – IMG_1270, subset 4 – IMG_1421. Red dots indicate biota/substrate scored in each image.



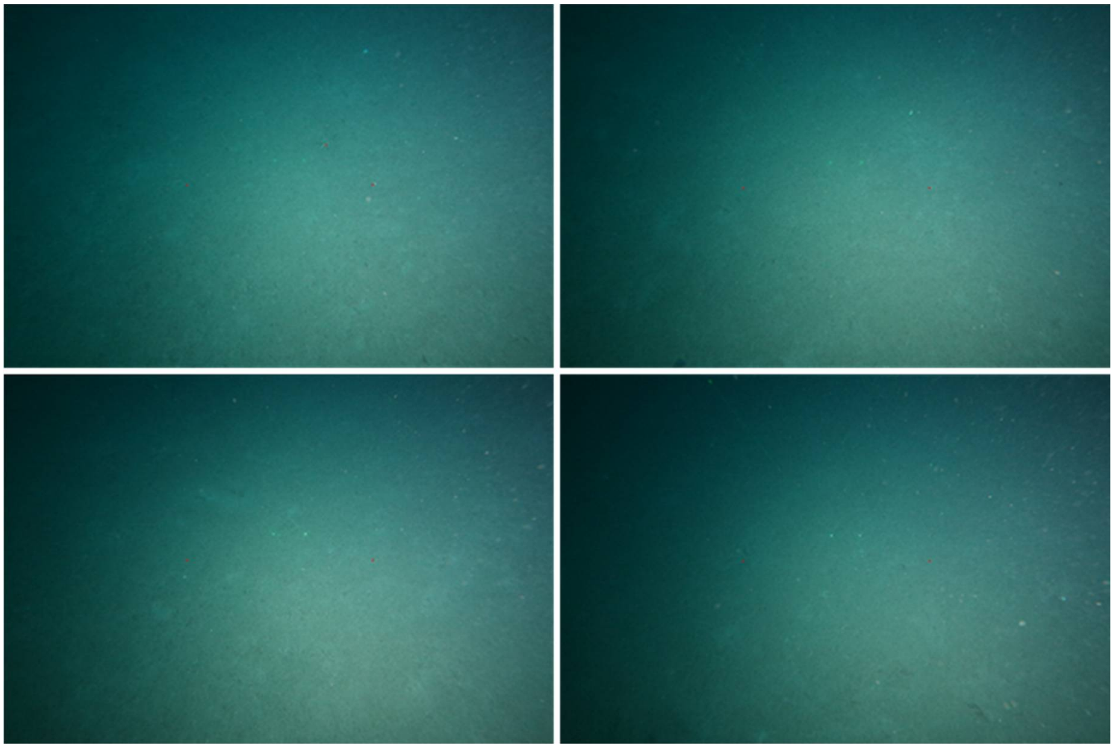
Appx Figure 87. Site W52 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_1848, subset 2 – IMG_2003, subset 3 – IMG_2218, subset 4 – IMG_2348. Red dots indicate biota/substrate scored in each image.



Appx Figure 88. Site W53 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_1858, subset 2 – IMG_2093, subset 3 – IMG_2283, subset 4 – IMG_2404. Red dots indicate biota/substrate scored in each image.

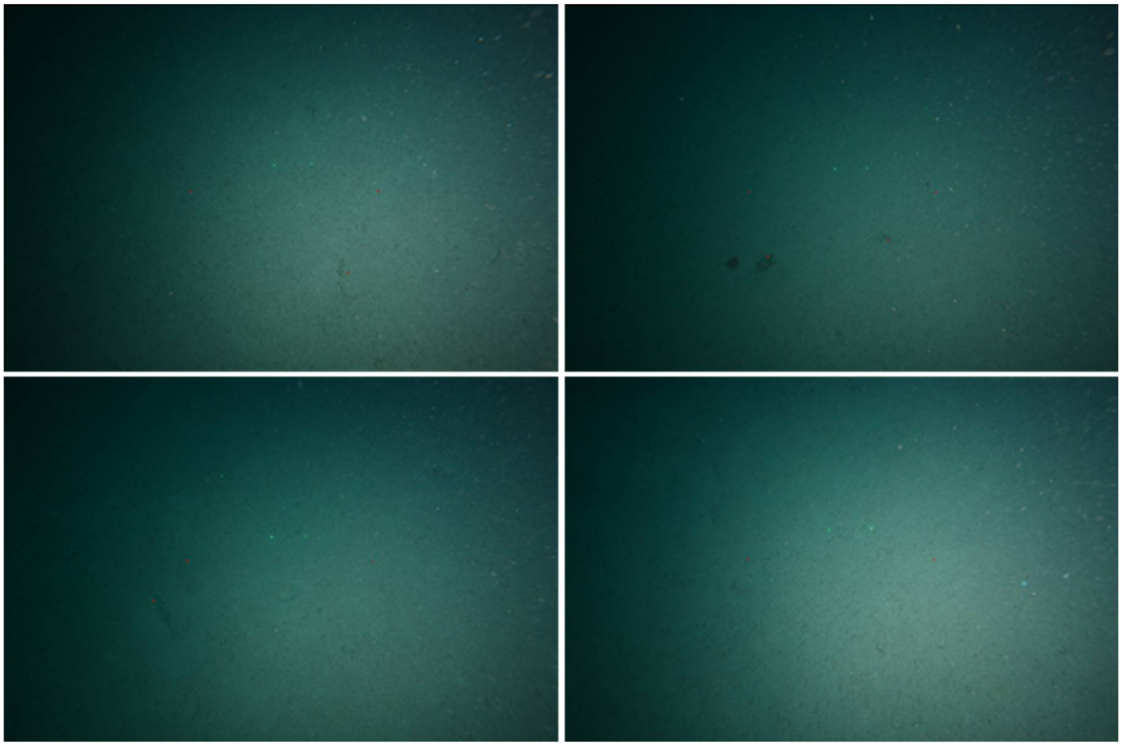


**Appx Figure 89. Site W54 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_0770, subset 2 – IMG_0901, subset 3 – IMG_1067, subset 4 – IMG_1242. Red dots indicate biota/substrate scored in each image.**



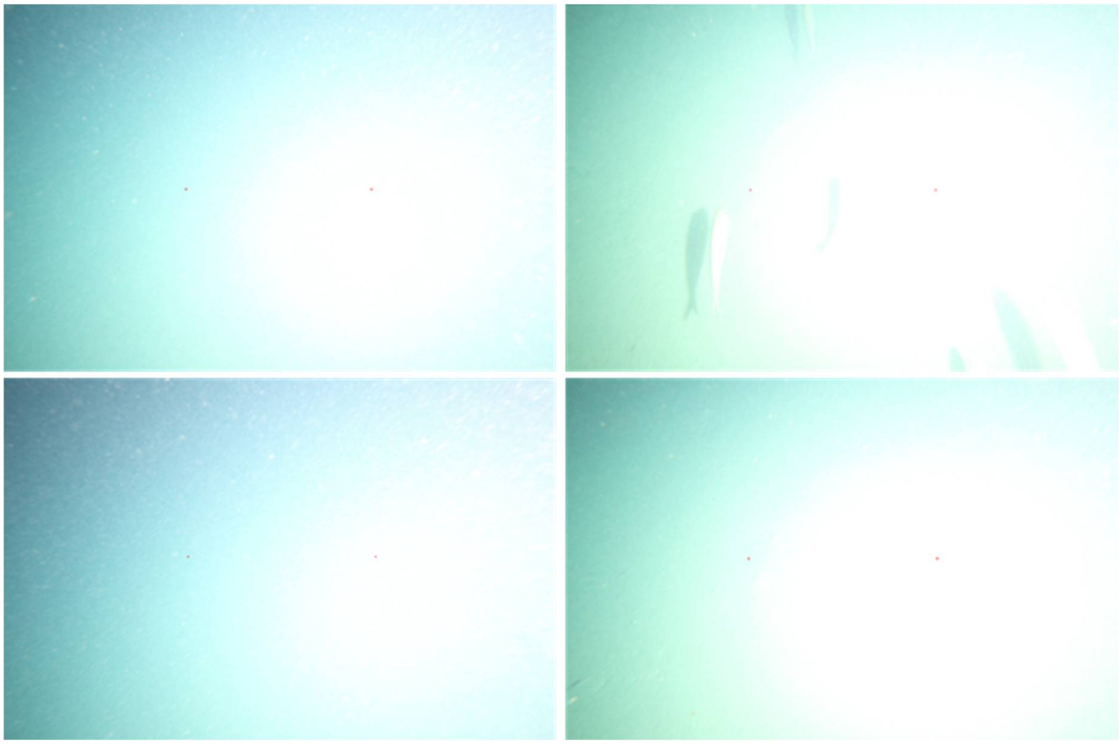
**Appx Figure 90. Site W55 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_1890, subset 2 – IMG_2045, subset 3 – IMG_2220, subset 4 – IMG_2365. Red dots indicate biota/substrate scored in each image.**

Appx Figure 91. Site W56 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_1976, subset 2 – IMG_2141, subset 3 – IMG_2291, subset 4 – IMG_2427. Red dots indicate biota/substrate scored in each image.

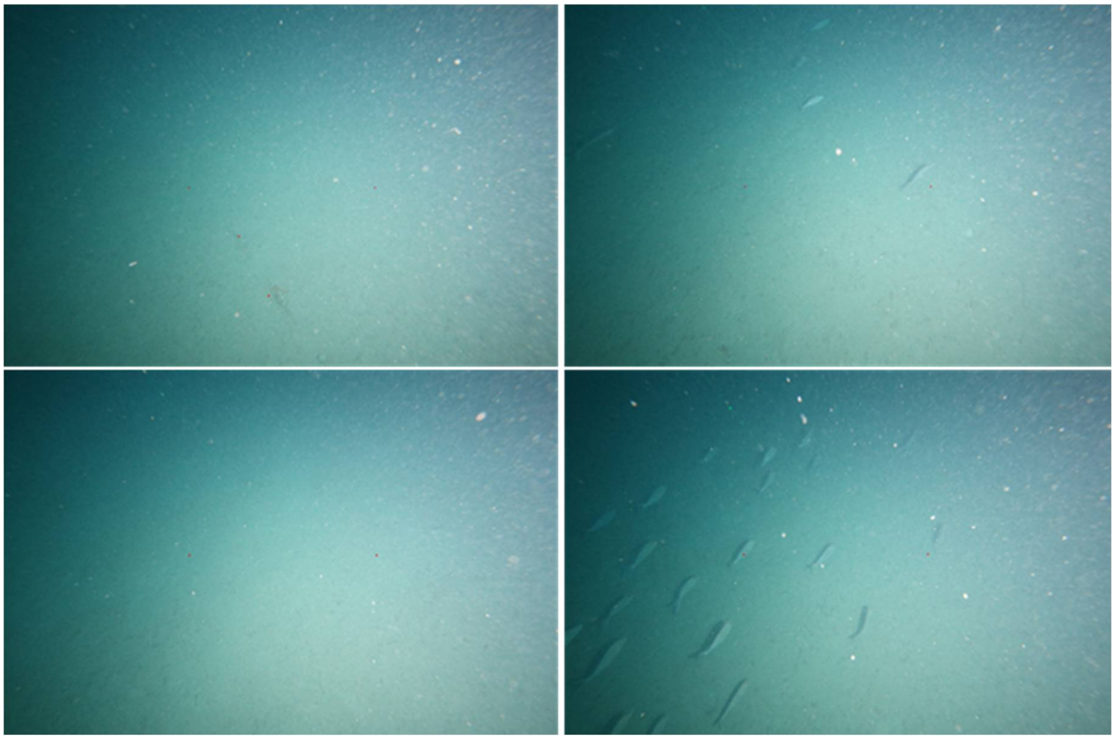


Appx Figure 92. Site W57 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_1260, subset 2 – IMG_1370, subset 3 – IMG_1480, subset 4 – IMG_1601. Red dots indicate biota/substrate scored in each image.

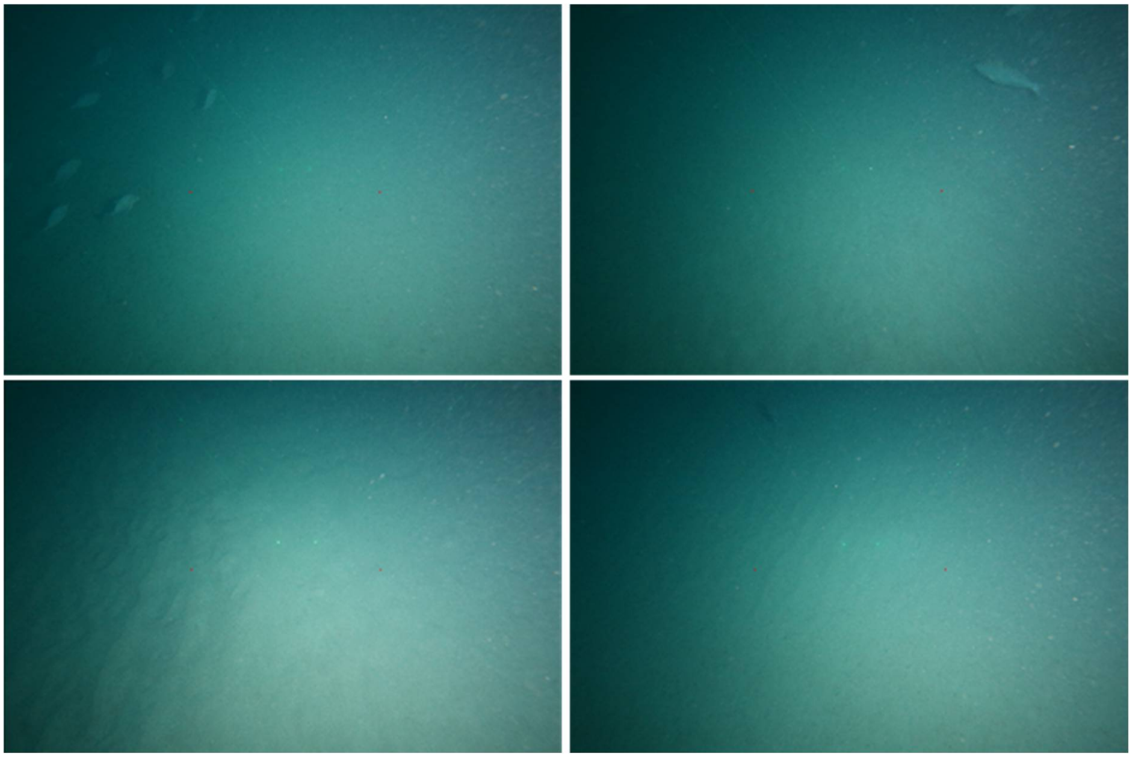
## C.6 Sites in Pilbara Fish Trawl Fishery Area 4



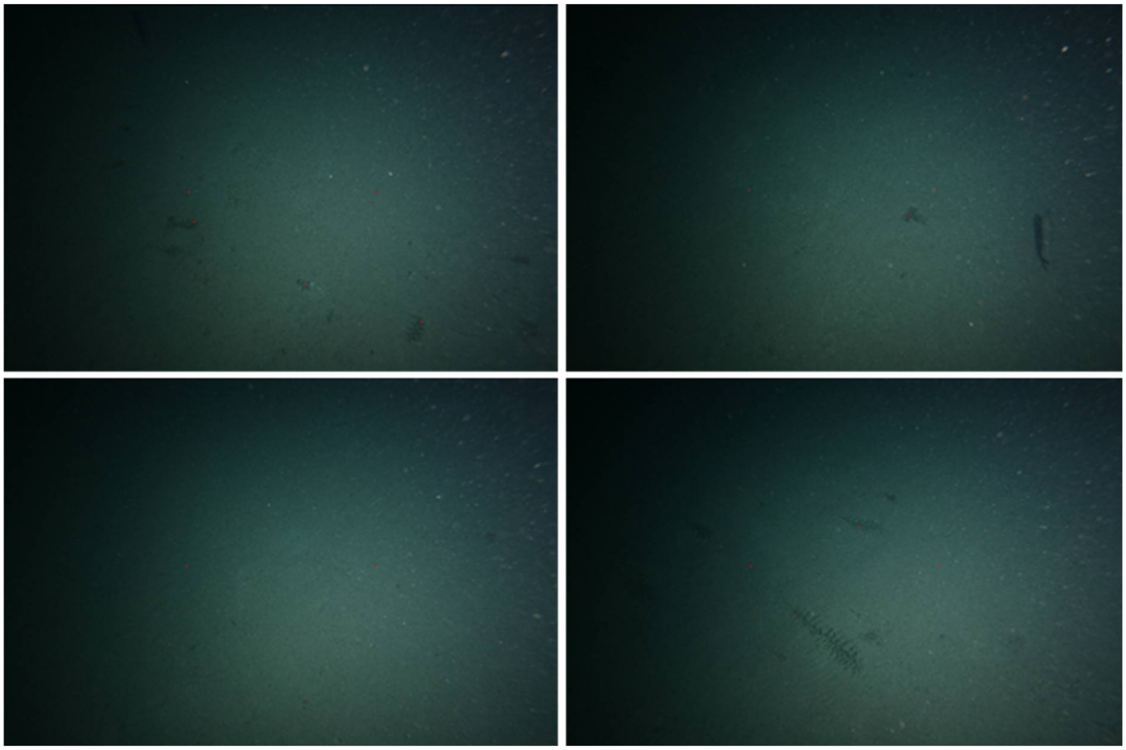
Appx Figure 93. Site W35 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_1879, subset 2 – IMG_2024, subset 3 – IMG_2199, subset 4 – IMG_2349. Red dots indicate biota/substrate scored in each image.



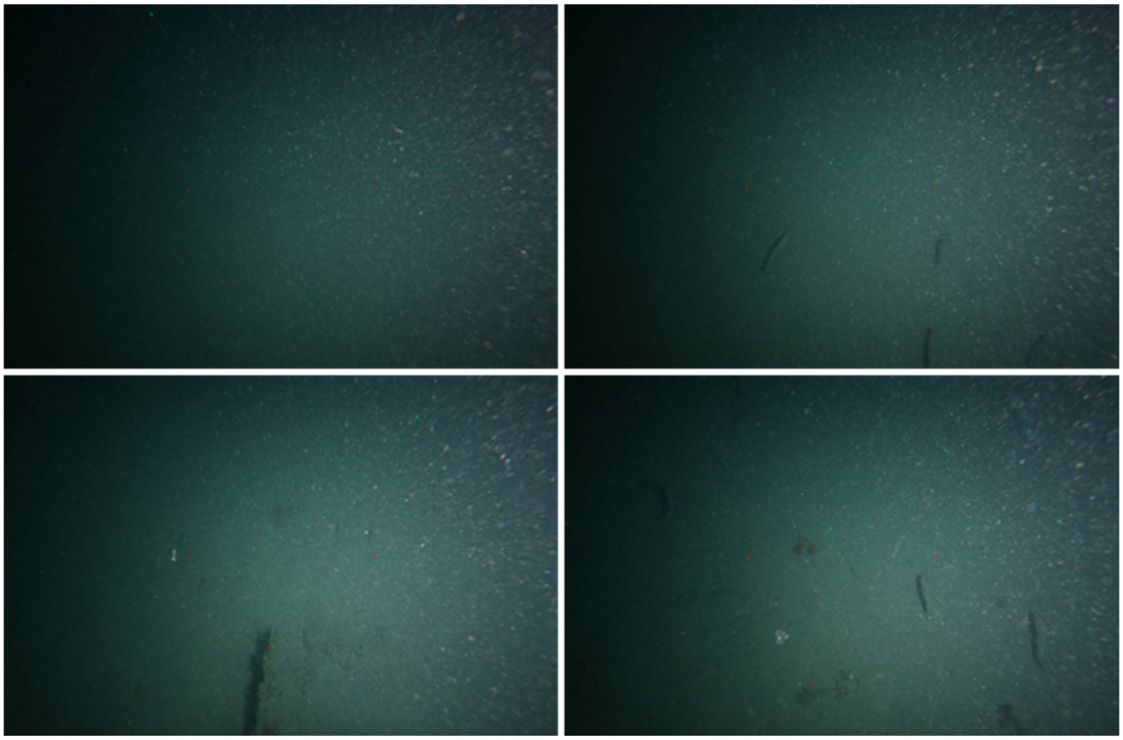
Appx Figure 94. Site W36 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_0924, subset 2 – IMG_1034, subset 3 – IMG_1194, subset 4 – IMG_1334. Red dots indicate biota/substrate scored in each image.



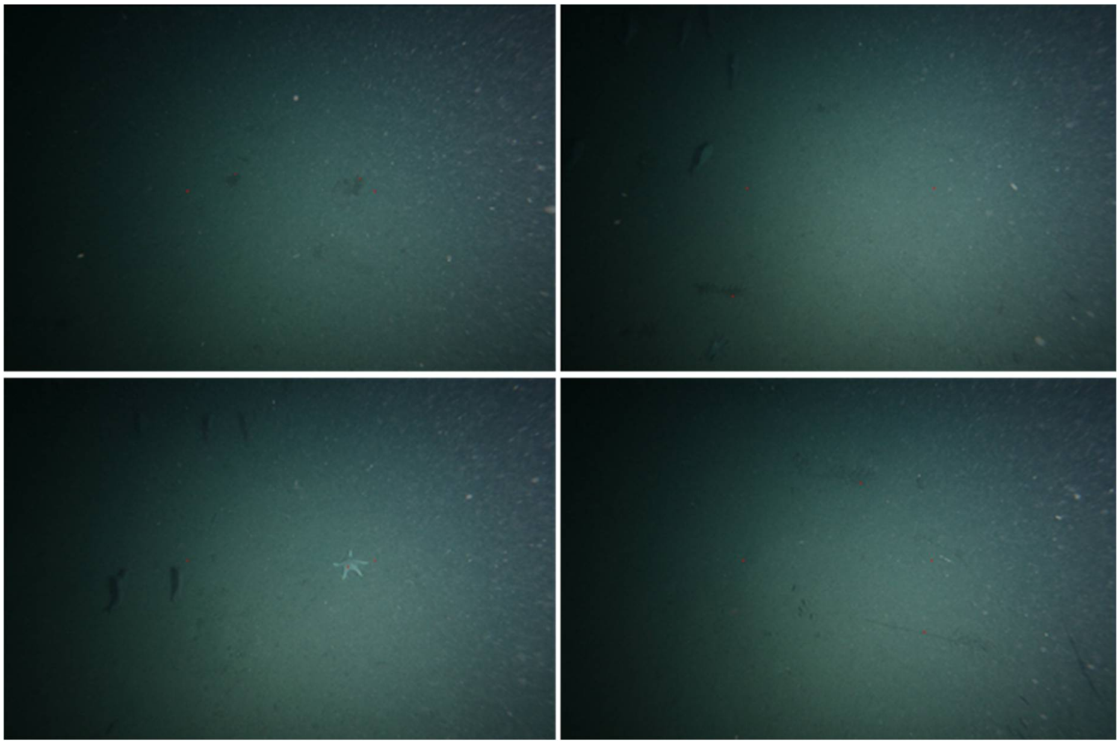
Appx Figure 95. Site W39 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_1943, subset 2 – IMG_2118, subset 3 – IMG_2264, subset 4 – IMG_2409. Red dots indicate biota/substrate scored in each image.



Appx Figure 96. Site W67 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_0757, subset 2 – IMG_0847, subset 3 – IMG_0917, subset 4 – IMG_1042. Red dots indicate biota/substrate scored in each image.



Appx Figure 97. Site W74 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_0787, subset 2 – IMG_0892, subset 3 – IMG_0947, subset 4 – IMG_1052. Red dots indicate biota/substrate scored in each image.



Appx Figure 98. Site W88 seabed images typical of each quartile subset of transect. From top left, subset 1 – IMG_1234, subset 2 – IMG_1359, subset 3 – IMG_1419, subset 4 – IMG_1539. Red dots indicate biota/substrate scored in each image

# Appendix D Full Species list of fish caught on the NWS on the RV *Investigator* voyage in 2017 (INV2017_05)

## D.1 Fish species listing

The full list of species collected in all 103 sites during the 2017 RV *Investigator* voyage (INV2017_05) is presented in the table below.

**Apx Table 3 Full Species list of fish caught on the NWS on the RV *Investigator* voyage INV2017-05.**

| CLASS | ORDER | FAMILY | SCIENTIFIC NAME | AUTHORITY |
|---|---|---|---|---|
| **ELASMOBRANCHII** | Orectolobiformes | Hemiscylliidae | *Chiloscyllium punctatum* | Müller & Henle, 1838 |
| **ELASMOBRANCHII** | Orectolobiformes | Stegostomatidae | *Stegostoma tigrinum* | (Forster, 1781) |
| **ELASMOBRANCHII** | Carcharhiniformes | Scyliorhinidae | *Atelomycterus fasciatus* | Compagno & Stevens, 1993 |
| **ELASMOBRANCHII** | Carcharhiniformes | Carcharhinidae | *Carcharhinus coatesi* | (Whitley, 1939) |
| **ELASMOBRANCHII** | Carcharhiniformes | Carcharhinidae | *Carcharhinus plumbeus* | (Nardo, 1827) |
| **ELASMOBRANCHII** | Carcharhiniformes | Carcharhinidae | *Loxodon macrorhinus* | Müller & Henle, 1839 |
| **ELASMOBRANCHII** | Carcharhiniformes | Carcharhinidae | *Rhizoprionodon acutus* | (Rüppell, 1837) |
| **ELASMOBRANCHII** | Carcharhiniformes | Hemigaleidae | *Hemigaleus australiensis* | White, Last & Compagno, 2005 |
| **ELASMOBRANCHII** | Carcharhiniformes | Hemigaleidae | *Hemipristis elongata* | (Klunzinger, 1871) |
| **ELASMOBRANCHII** | Rhinopristiformes | Rhinidae | *Rhynchobatus australiae* | Whitley, 1939 |
| **ELASMOBRANCHII** | Rhinopristiformes | Rhinidae | *Rhynchobatus palpebratus* | Compagno & Last, 2008 |
| **ELASMOBRANCHII** | Rhinopristiformes | Trygonorrhinidae | *Aptychotrema vincentiana* | (Haacke, 1885) |
| **ELASMOBRANCHII** | Rhinopristiformes | Rhinobatidae | *Rhinobatos sainsburyi* | Last, 2004 |
| **ELASMOBRANCHII** | Rhinopristiformes | Glaucostegidae | *Glaucostegus typus* | (Bennett, 1830) |
| **ELASMOBRANCHII** | Myliobatiformes | Dasyatidae | *Himantura australis* | Last, White & Naylor, 2016 |
| **ELASMOBRANCHII** | Myliobatiformes | Dasyatidae | *Himantura leoparda* | Manjaji-Matsumoto & Last, 2008 |
| **ELASMOBRANCHII** | Myliobatiformes | Dasyatidae | *Maculabatis astra* | (Last, Manjaji-Matsumoto & Pogonoski, 2008) |
| **ELASMOBRANCHII** | Myliobatiformes | Dasyatidae | *Megatrygon microps* | (Annandale, 1908) |
| **ELASMOBRANCHII** | Myliobatiformes | Dasyatidae | *Neotrygon australiae* | Last, White & Séret, 2016 |
| **ELASMOBRANCHII** | Myliobatiformes | Dasyatidae | *Neotrygon leylandi* | (Last, 1987) |
| **ELASMOBRANCHII** | Myliobatiformes | Dasyatidae | *Pastinachus ater* | (Macleay, 1883) |
| **ELASMOBRANCHII** | Myliobatiformes | Dasyatidae | *Pateobatis fai* | (Jordan & Seale, 1906) |
| **ELASMOBRANCHII** | Myliobatiformes | Dasyatidae | *Pateobatis jenkinsii* | (Annandale, 1909) |
| **ELASMOBRANCHII** | Myliobatiformes | Dasyatidae | *Taeniurops meyeni* | (Müller & Henle, 1841) |
| **ELASMOBRANCHII** | Myliobatiformes | Dasyatidae | *Urogymnus asperrimus* | (Bloch & Schneider, 1801) |
| **ELASMOBRANCHII** | Myliobatiformes | Gymnuridae | *Gymnura australis* | (Ramsay & Ogilby, 1886) |
| **ELASMOBRANCHII** | Myliobatiformes | Myliobatidae | *Aetomylaeus vespertilio* | (Bleeker, 1852) |
| **ACTINOPTERYGII** | Anguilliformes | Unknown | Unidentified Anguilliform larvae | N/A |

| | | | | |
|---|---|---|---|---|
| **ACTINOPTERYGII** | Anguilliformes | Muraenidae | *Gymnothorax cribroris* cf. | Whitley, 1932 |
| **ACTINOPTERYGII** | Anguilliformes | Muraenidae | *Gymnothorax mccoskeri* | Smith & Böhlke, 1997 |
| **ACTINOPTERYGII** | Anguilliformes | Muraenidae | *Gymnothorax moluccensis* | (Bleeker, 1864) |
| **ACTINOPTERYGII** | Anguilliformes | Muraenidae | *Gymnothorax mucifer* | Snyder, 1904 |
| **ACTINOPTERYGII** | Anguilliformes | Muraenidae | *Gymnothorax pseudothyrsoideus* | (Bleeker, 1852) |
| **ACTINOPTERYGII** | Anguilliformes | Muraenidae | *Gymnothorax thyrsoideus* | (Richardson, 1845) |
| **ACTINOPTERYGII** | Anguilliformes | Muraenidae | *Gymnothorax undulatus* | (Lacépède, 1803) |
| **ACTINOPTERYGII** | Anguilliformes | Congridae | *Ariosoma meeki* cf. | (Jordan & Snyder 1900) |
| **ACTINOPTERYGII** | Anguilliformes | Congridae | *Ariosoma scheelei* cf. | (Strömman, 1896) |
| **ACTINOPTERYGII** | Anguilliformes | Congridae | *Ariosoma* sp. | N/A |
| **ACTINOPTERYGII** | Anguilliformes | Ophichthidae | *Apterichtus nariculus* cf. | McCosker & Hibino 2015 |
| **ACTINOPTERYGII** | Anguilliformes | Ophichthidae | *Callechelys marmorata* | (Bleeker 1854) |
| **ACTINOPTERYGII** | Anguilliformes | Ophichthidae | *Scolecenchelys gymnota* | (Bleeker, 1857) |
| **ACTINOPTERYGII** | Clupeiformes | Clupeidae | *Amblygaster sirm* | (Walbaum, 1792) |
| **ACTINOPTERYGII** | Clupeiformes | Engraulidae | *Engraulis* sp. | N/A |
| **ACTINOPTERYGII** | Aulopiformes | Synodontidae | *Saurida argentea* | Macleay 1881 |
| **ACTINOPTERYGII** | Aulopiformes | Synodontidae | *Saurida filamentosa* cf. | Ogilby, 1910 |
| **ACTINOPTERYGII** | Aulopiformes | Synodontidae | *Saurida grandisquamis* | (Günther, 1864) |
| **ACTINOPTERYGII** | Aulopiformes | Synodontidae | *Saurida undosquamis* | (Richardson, 1848) |
| **ACTINOPTERYGII** | Aulopiformes | Synodontidae | *Saurida* sp. | N/A |
| **ACTINOPTERYGII** | Aulopiformes | Synodontidae | *Synodus dermatogenys* | Fowler, 1912 |
| **ACTINOPTERYGII** | Aulopiformes | Synodontidae | *Synodus hoshinonis* | Tanaka, 1917 |
| **ACTINOPTERYGII** | Aulopiformes | Synodontidae | *Synodus indicus* | (Day, 1873) |
| **ACTINOPTERYGII** | Aulopiformes | Synodontidae | *Synodus jaculum* | Russell & Cressey, 1979 |
| **ACTINOPTERYGII** | Aulopiformes | Synodontidae | *Synodus sageneus* | Waite, 1905 |
| **ACTINOPTERYGII** | Aulopiformes | Synodontidae | *Trachinocephalus trachinus* | (Temminck & Schlegel, 1846) |
| **ACTINOPTERYGII** | Siluriformes | Ariidae | *Netuma thalassina* cf. | (Rüppell, 1837) |
| **ACTINOPTERYGII** | Siluriformes | Plotosidae | *Euristhmus sandrae* | Murdy & Ferraris, 2006 |
| **ACTINOPTERYGII** | Siluriformes | Plotosidae | *Paraplotosus butleri* | Allen, 1998 |
| **ACTINOPTERYGII** | Batrachoidiformes | Batrachoididae | *Batrachomoeus dahli* | (Rendahl, 1922) |
| **ACTINOPTERYGII** | Batrachoidiformes | Batrachoididae | *Halophryne diemensis* | (Lesueur, 1824) |
| **ACTINOPTERYGII** | Batrachoidiformes | Batrachoididae | *Halophryne ocellatus* | Hutchins, 1974 |
| **ACTINOPTERYGII** | Lophiiformes | Lophiidae | *Lophiomus setigerus* | (Vahl, 1797) |
| **ACTINOPTERYGII** | Lophiiformes | Antennariidae | *Antennarius commerson* | (Latreille, 1804) |
| **ACTINOPTERYGII** | Lophiiformes | Antennariidae | *Antennarius striatus* | (Shaw, 1794) |
| **ACTINOPTERYGII** | Lophiiformes | Antennariidae | *Tathicarpus butleri* | Ogilby, 1907 |
| **ACTINOPTERYGII** | Lophiiformes | Tetrabrachiidae | *Tetrabrachium ocellatum* | Günther, 1880 |
| **ACTINOPTERYGII** | Lophiiformes | Ogcocephalidae | *Halieutaea indica* | Annandale & Jenkins, 1910 |
| **ACTINOPTERYGII** | Gadiformes | Bregmacerotidae | *Bregmaceros* sp. | N/A |
| **ACTINOPTERYGII** | Ophidiiformes | Ophidiidae | *Ophidion* sp. | N/A |
| **ACTINOPTERYGII** | Ophidiiformes | Carapidae | *Carapus mourlani* | (Petit, 1934) |
| **ACTINOPTERYGII** | Ophidiiformes | Carapidae | *Encheliophus gracilis* | (Bleeker, 1856) |
| **ACTINOPTERYGII** | Ophidiiformes | Carapidae | *Onuxodon fowleri* | (Smith 1955) |
| **ACTINOPTERYGII** | Beryciformes | Holocentridae | *Myripristis botche* | Cuvier, 1829 |
| **ACTINOPTERYGII** | Beryciformes | Holocentridae | *Sargocentron rubrum* | (Forsskål, 1775) |
| **ACTINOPTERYGII** | Lampriformes | Veliferidae | *Velifer hypselopterus* cf. | Bleeker 1879 |
| **ACTINOPTERYGII** | Syngnathiformes | Fistulariidae | *Fistularia commersonii* | Rüppell, 1838 |
| **ACTINOPTERYGII** | Syngnathiformes | Fistulariidae | *Fistularia petimba* | Lacépède, 1803 |

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| **ACTINOPTERYGII** | Syngnathiformes | Centriscidae | *Centriscus cristatus* | Linnaeus, 1758 |
| **ACTINOPTERYGII** | Syngnathiformes | Solenostomidae | *Solenostomus cyanopterus* | Bleeker, 1854 |
| **ACTINOPTERYGII** | Syngnathiformes | Syngnathidae | Syngnathidae (unidentified juvenile) | N/A |
| **ACTINOPTERYGII** | Syngnathiformes | Syngnathidae | *Halicampus grayi* | Kaup, 1856 |
| **ACTINOPTERYGII** | Syngnathiformes | Syngnathidae | *Hippocampus angustus* | Günther, 1870 |
| **ACTINOPTERYGII** | Syngnathiformes | Syngnathidae | *Hippocampus spinosissimus* | Weber, 1913 |
| **ACTINOPTERYGII** | Syngnathiformes | Syngnathidae | *Hippocampus zebra* | Whitley, 1964 |
| **ACTINOPTERYGII** | Syngnathiformes | Syngnathidae | *Solegnathus* sp. 2 | [of Kuiter, 2000] |
| **ACTINOPTERYGII** | Syngnathiformes | Dactylopteridae | *Dactyloptena macracanthus* | (Bleeker, 1854) |
| **ACTINOPTERYGII** | Syngnathiformes | Dactylopteridae | *Dactyloptena orientalis* | (Cuvier, 1829) |
| **ACTINOPTERYGII** | Syngnathiformes | Dactylopteridae | *Dactyloptena papilio* | Ogilby, 1910 |
| **ACTINOPTERYGII** | Syngnathiformes | Pegasidae | *Eurypegasus draconis* | (Linnaeus, 1766) |
| **ACTINOPTERYGII** | Scorpaeniformes | Apistidae | *Apistus carinatus* | (Bloch & Schneider, 1801) |
| **ACTINOPTERYGII** | Scorpaeniformes | Scorpaenidae | *Dendrochirus brachypterus* | (Cuvier, 1829) |
| **ACTINOPTERYGII** | Scorpaeniformes | Scorpaenidae | *Dendrochirus zebra* | (Cuvier, 1829) |
| **ACTINOPTERYGII** | Scorpaeniformes | Scorpaenidae | *Pterois* n. sp. | Matsunuma, in preparation |
| **ACTINOPTERYGII** | Scorpaeniformes | Scorpaenidae | *Pterois russelii* | Bennett, 1831 |
| **ACTINOPTERYGII** | Scorpaeniformes | Scorpaenidae | *Pterois volitans* | (Linnaeus 1758) |
| **ACTINOPTERYGII** | Scorpaeniformes | Scorpaenidae | *Neomerinthe erostris* | (Alcock, 1896) |
| **ACTINOPTERYGII** | Scorpaeniformes | Scorpaenidae | *Pteroidichthys amboinensis* | Bleeker, 1856 |
| **ACTINOPTERYGII** | Scorpaeniformes | Scorpaenidae | *Pteroidichthys noronhai* | (Fowler, 1938) |
| **ACTINOPTERYGII** | Scorpaeniformes | Scorpaenidae | *Scorpaena* n. sp. | Wibowo & Motomura, in preparation. |
| **ACTINOPTERYGII** | Scorpaeniformes | Scorpaenidae | *Scorpaenodes smithi* | Eschmeyer & Rama-Rao, 1972 |
| **ACTINOPTERYGII** | Scorpaeniformes | Scorpaenidae | *Scorpaenopsis neglecta* | Heckel, 1837 |
| **ACTINOPTERYGII** | Scorpaeniformes | Scorpaenidae | *Scorpaenopsis venosa* | (Cuvier, 1829) |
| **ACTINOPTERYGII** | Scorpaeniformes | Tetrarogidae | *Cottapistus cottoides* | (Linnaeus, 1758) |
| **ACTINOPTERYGII** | Scorpaeniformes | Tetrarogidae | *Liocranium pleurostigma* | (Weber, 1913) |
| **ACTINOPTERYGII** | Scorpaeniformes | Tetrarogidae | *Richardsonicthys leucogaster* | (Richardson, 1848) |
| **ACTINOPTERYGII** | Scorpaeniformes | Synanceiidae | *Erosa erosa* | (Langsdorf, 1829) |
| **ACTINOPTERYGII** | Scorpaeniformes | Synanceiidae | *Inimicus didactylus* | (Pallas, 1769) |
| **ACTINOPTERYGII** | Scorpaeniformes | Synanceiidae | *Inimicus sinensis* | (Valenciennes, 1833) |
| **ACTINOPTERYGII** | Scorpaeniformes | Synanceiidae | *Minous roseus* | Matsunuma & Motomura 2018 |
| **ACTINOPTERYGII** | Scorpaeniformes | Triglidae | *Lepidotrigla japonica* cf. | (Bleeker, 1857) |
| **ACTINOPTERYGII** | Scorpaeniformes | Triglidae | *Lepidotrigla* sp. (long fin west) | [of Gomon, pers. comm.] |
| **ACTINOPTERYGII** | Scorpaeniformes | Aploactinidae | *Paraploactis kagoshimensis* cf. | (Ishikawa 1904) |
| **ACTINOPTERYGII** | Scorpaeniformes | Platycephalidae | *Cymbacephalus bosschei* | (Bleeker, 1860) |
| **ACTINOPTERYGII** | Scorpaeniformes | Platycephalidae | *Cymbacephalus nematophthalmus* | (Günther, 1860) |
| **ACTINOPTERYGII** | Scorpaeniformes | Platycephalidae | *Inegocia japonica* | (Cuvier, 1829) |
| **ACTINOPTERYGII** | Scorpaeniformes | Platycephalidae | *Onigocia grandisquama* | (Regan, 1908) |
| **ACTINOPTERYGII** | Scorpaeniformes | Platycephalidae | *Onigocia* sp. | N/A |
| **ACTINOPTERYGII** | Scorpaeniformes | Platycephalidae | *Platycephalus endrachtensis* | Quoy & Gaimard, 1825 |
| **ACTINOPTERYGII** | Scorpaeniformes | Platycephalidae | *Platycephalus westraliae* | (Whitley, 1938) |
| **ACTINOPTERYGII** | Scorpaeniformes | Platycephalidae | *Rogadius patriciae* | Knapp, 1987 |
| **ACTINOPTERYGII** | Scorpaeniformes | Platycephalidae | *Rogadius pristiger* | (Cuvier, 1829) |
| **ACTINOPTERYGII** | Scorpaeniformes | Platycephalidae | *Rogadius tuberculatus* | (Cuvier, 1829) |
| **ACTINOPTERYGII** | Scorpaeniformes | Platycephalidae | *Thysanophrys chiltonae* | Schultz, 1966 |

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| **ACTINOPTERYGII** | Perciformes | Serranidae | *Cephalopholis boenak* | (Bloch, 1790) |
| **ACTINOPTERYGII** | Perciformes | Serranidae | *Cephalopholis sonnerati* | (Valenciennes, 1828) |
| **ACTINOPTERYGII** | Perciformes | Serranidae | *Chromileptes altivelis* cf. | (Valenciennes, 1828) |
| **ACTINOPTERYGII** | Perciformes | Serranidae | *Diploprion bifasciatum* | Cuvier, 1828 |
| **ACTINOPTERYGII** | Perciformes | Serranidae | *Epinephelus amblycephalus* | (Bleeker, 1857) |
| **ACTINOPTERYGII** | Perciformes | Serranidae | *Epinephelus areolatus* | (Forsskål, 1775) |
| **ACTINOPTERYGII** | Perciformes | Serranidae | *Epinephelus bilobatus* | Randall & Allen, 1987 |
| **ACTINOPTERYGII** | Perciformes | Serranidae | *Epinephelus coioides* | (Hamilton, 1822) |
| **ACTINOPTERYGII** | Perciformes | Serranidae | *Epinephelus fasciatus* | (Forsskål, 1775) |
| **ACTINOPTERYGII** | Perciformes | Serranidae | *Epinephelus multinotatus* | (Peters, 1876) |
| **ACTINOPTERYGII** | Perciformes | Serranidae | *Epinephelus rivulatus* | (Valenciennes, 1830) |
| **ACTINOPTERYGII** | Perciformes | Serranidae | *Epinephelus sexfasciatus* | (Valenciennes, 1828) |
| **ACTINOPTERYGII** | Perciformes | Serranidae | *Plectranthias* n. sp. | Gill, Pogonoski, Moore & Johnson, in preparation |
| **ACTINOPTERYGII** | Perciformes | Serranidae | *Plectropomus maculatus* | (Bloch, 1790) |
| **ACTINOPTERYGII** | Perciformes | Serranidae | *Pseudanthias rubrizonatus* | (Randall, 1983) |
| **ACTINOPTERYGII** | Perciformes | Serranidae | *Tosana* sp. | Gill et al in preparation |
| **ACTINOPTERYGII** | Perciformes | Pseudochromidae | *Congrogadus spinifer* | (Borodin, 1933) |
| **ACTINOPTERYGII** | Perciformes | Pseudochromidae | *Pseudochromis howsoni* | Allen, 1995 |
| **ACTINOPTERYGII** | Perciformes | Pseudochromidae | *Pseudochromis quinquedentatus* | McCulloch, 1926 |
| **ACTINOPTERYGII** | Perciformes | Pseudochromidae | *Pseudochromis reticulatus* | Gill & Woodland, 1992 |
| **ACTINOPTERYGII** | Perciformes | Glaucosomatidae | *Glaucosoma buergeri* | Richardson, 1845 |
| **ACTINOPTERYGII** | Perciformes | Glaucosomatidae | *Glaucosoma magnificum* | (Ogilby, 1915) |
| **ACTINOPTERYGII** | Perciformes | Terapontidae | *Terapon jarbua* | (Forsskål, 1775) |
| **ACTINOPTERYGII** | Perciformes | Priacanthidae | *Priacanthus hamrur* | (Forsskål, 1775) |
| **ACTINOPTERYGII** | Perciformes | Priacanthidae | *Priacanthus tayenus* | Richardson, 1846 |
| **ACTINOPTERYGII** | Perciformes | Apogonidae | *Apogonichthyoides atripes* | (Ogilby, 1911) |
| **ACTINOPTERYGII** | Perciformes | Apogonidae | *Apogonichthyoides brevicaudatus* | (Weber, 1909) |
| **ACTINOPTERYGII** | Perciformes | Apogonidae | *Apogonichthyoides umbratilis* | Fraser & Allen, 2010 |
| **ACTINOPTERYGII** | Perciformes | Apogonidae | *Apogonichthyoides* sp. | N/A |
| **ACTINOPTERYGII** | Perciformes | Apogonidae | *Gymnapogon velum* | Fraser, 2019 |
| **ACTINOPTERYGII** | Perciformes | Apogonidae | *Gymnapogon* sp. | N/A |
| **ACTINOPTERYGII** | Perciformes | Apogonidae | *Jaydia argyrogaster* | (Weber, 1909) |
| **ACTINOPTERYGII** | Perciformes | Apogonidae | *Jaydia smithi* | (Kotthaus 1970) |
| **ACTINOPTERYGII** | Perciformes | Apogonidae | *Ostorhinchus cavitensis* | (Jordan & Seale, 1907) |
| **ACTINOPTERYGII** | Perciformes | Apogonidae | *Ostorhinchus fasciatus* | (White, 1790) |
| **ACTINOPTERYGII** | Perciformes | Apogonidae | *Ostorhinchus monospilus* cf. | (Fraser, Randall & Allen, 2002) |
| **ACTINOPTERYGII** | Perciformes | Apogonidae | *Ostorhinchus semilineatus* | (Temminck & Schlegel, 1843) |
| **ACTINOPTERYGII** | Perciformes | Apogonidae | *Ostorhinchus septemstriatus* | (Günther, 1880) |
| **ACTINOPTERYGII** | Perciformes | Apogonidae | *Ostorhinchus* sp. 2 | [of Sainsbury et al 1985] |
| **ACTINOPTERYGII** | Perciformes | Apogonidae | *Pristiapogon fraenatus* | (Valenciennes, 1832) |
| **ACTINOPTERYGII** | Perciformes | Apogonidae | *Pseudamia gelatinosa* | Smith 1956 |
| **ACTINOPTERYGII** | Perciformes | Apogonidae | *Rhabdamia gracilis* | (Bleeker, 1856) |
| **ACTINOPTERYGII** | Perciformes | Apogonidae | *Siphamia tubifer* | Weber, 1909 |
| **ACTINOPTERYGII** | Perciformes | Sillaginidae | *Sillago ingenuua* | McKay, 1985 |
| **ACTINOPTERYGII** | Perciformes | Rachycentridae | *Rachycentron canadum* | (Linnaeus, 1766) |
| **ACTINOPTERYGII** | Perciformes | Echeneidae | *Echeneis naucrates* | Linnaeus, 1758 |
| **ACTINOPTERYGII** | Perciformes | Carangidae | *Alectis ciliaris* | (Bloch, 1787) |

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| **ACTINOPTERYGII** | Perciformes | Carangidae | *Alepes apercna* | Grant, 1987 |
| **ACTINOPTERYGII** | Perciformes | Carangidae | *Atule mate* | (Cuvier, 1833) |
| **ACTINOPTERYGII** | Perciformes | Carangidae | *Carangoides caeruleopinnatus* | (Rüppell, 1830) |
| **ACTINOPTERYGII** | Perciformes | Carangidae | *Carangoides chrysophrys* | (Cuvier, 1833) |
| **ACTINOPTERYGII** | Perciformes | Carangidae | *Carangoides equula* | (Temminck & Schlegel, 1844) |
| **ACTINOPTERYGII** | Perciformes | Carangidae | *Carangoides fulvoguttatus* | (Forsskål, 1775) |
| **ACTINOPTERYGII** | Perciformes | Carangidae | *Carangoides gymnostethus* | (Cuvier, 1833) |
| **ACTINOPTERYGII** | Perciformes | Carangidae | *Carangoides malabaricus* | (Bloch & Schneider, 1801) |
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| **ACTINOPTERYGII** | Perciformes | Carangidae | *Caranx ignobilis* | (Forsskål, 1775) |
| **ACTINOPTERYGII** | Perciformes | Carangidae | *Decapterus macrosoma* | Bleeker, 1851 |
| **ACTINOPTERYGII** | Perciformes | Carangidae | *Decapterus russelli* | (Rüppell, 1830) |
| **ACTINOPTERYGII** | Perciformes | Carangidae | *Gnathanodon speciosus* | (Forsskål, 1775) |
| **ACTINOPTERYGII** | Perciformes | Carangidae | *Parastromateus niger* | (Bloch, 1795) |
| **ACTINOPTERYGII** | Perciformes | Carangidae | *Scomberoides tol* | (Cuvier, 1832) |
| **ACTINOPTERYGII** | Perciformes | Carangidae | *Selar crumenophthalmus* | (Bloch, 1793) |
| **ACTINOPTERYGII** | Perciformes | Carangidae | *Selaroides leptolepis* | (Cuvier, 1833) |
| **ACTINOPTERYGII** | Perciformes | Carangidae | *Seriolina nigrofasciata* | (Rüppell, 1829) |
| **ACTINOPTERYGII** | Perciformes | Carangidae | *Ulua mentalis* | (Cuvier, 1833) |
| **ACTINOPTERYGII** | Perciformes | Leiognathidae | *Aurigequula longispina* | (Valenciennes, 1835) |
| **ACTINOPTERYGII** | Perciformes | Leiognathidae | *Equulites elongatus* | (Günther, 1874) |
| **ACTINOPTERYGII** | Perciformes | Leiognathidae | *Photopectoralis* sp. | N/A |
| **ACTINOPTERYGII** | Perciformes | Bramidae | *Brama pauciradiata* | Fujita & Last, 1995 |
| **ACTINOPTERYGII** | Perciformes | Caesionidae | *Dipterygonotus balteatus* | (Valenciennes, 1830) |
| **ACTINOPTERYGII** | Perciformes | Caesionidae | *Pterocaesio chrysozona* | (Cuvier, 1830) |
| **ACTINOPTERYGII** | Perciformes | Lutjanidae | *Lutjanus argentimaculatus* | (Forsskål, 1775) |
| **ACTINOPTERYGII** | Perciformes | Lutjanidae | *Lutjanus carponotatus* | (Richardson, 1842) |
| **ACTINOPTERYGII** | Perciformes | Lutjanidae | *Lutjanus erythropterus* | Bloch, 1790 |
| **ACTINOPTERYGII** | Perciformes | Lutjanidae | *Lutjanus lemniscatus* | (Valenciennes, 1828) |
| **ACTINOPTERYGII** | Perciformes | Lutjanidae | *Lutjanus lutjanus* | Bloch, 1790 |
| **ACTINOPTERYGII** | Perciformes | Lutjanidae | *Lutjanus malabaricus* | (Bloch & Schneider, 1801) |
| **ACTINOPTERYGII** | Perciformes | Lutjanidae | *Lutjanus russellii* | (Bleeker, 1849) |
| **ACTINOPTERYGII** | Perciformes | Lutjanidae | *Lutjanus sebae* | (Cuvier, 1828) |
| **ACTINOPTERYGII** | Perciformes | Lutjanidae | *Lutjanus vitta* | (Quoy & Gaimard, 1824) |
| **ACTINOPTERYGII** | Perciformes | Lutjanidae | *Pristipomoides multidens* | (Day, 1871) |
| **ACTINOPTERYGII** | Perciformes | Lutjanidae | *Pristipomoides typus* | Bleeker, 1852 |
| **ACTINOPTERYGII** | Perciformes | Lutjanidae | *Symphorus nematophorus* | (Bleeker, 1860) |
| **ACTINOPTERYGII** | Perciformes | Nemipteridae | *Nemipterus bathybius* | Snyder 1911 |
| **ACTINOPTERYGII** | Perciformes | Nemipteridae | *Nemipterus celebicus* | (Bleeker, 1854) |
| **ACTINOPTERYGII** | Perciformes | Nemipteridae | *Nemipterus furcosus* | (Valenciennes, 1830) |
| **ACTINOPTERYGII** | Perciformes | Nemipteridae | *Nemipterus nematopus* | (Bleeker, 1851) |
| **ACTINOPTERYGII** | Perciformes | Nemipteridae | *Nemipterus peronii* | (Valenciennes, 1830) |
| **ACTINOPTERYGII** | Perciformes | Nemipteridae | *Nemipterus virgatus* | Houttuyn, 1782) |
| **ACTINOPTERYGII** | Perciformes | Nemipteridae | *Nemipterus zysron* | (Bleeker, 1856) |
| **ACTINOPTERYGII** | Perciformes | Nemipteridae | *Parascolopsis tanyactis* | Russell, 1986 |
| **ACTINOPTERYGII** | Perciformes | Nemipteridae | *Pentapodus nagasakiensis* | (Tanaka, 1915) |
| **ACTINOPTERYGII** | Perciformes | Nemipteridae | *Pentapodus porosus* | (Valenciennes, 1830) |

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| **ACTINOPTERYGII** | Perciformes | Nemipteridae | *Scolopsis meridiana* | Nakamura, Russell, Moore & Motomura, 2018 |
| **ACTINOPTERYGII** | Perciformes | Nemipteridae | *Scolopsis monogramma* | (Kuhl & van Hasselt, 1830) |
| **ACTINOPTERYGII** | Perciformes | Gerreidae | *Pentaprion longimanus* | (Cantor, 1850) |
| **ACTINOPTERYGII** | Perciformes | Haemulidae | *Diagramma pictum* | (Thunberg, 1792) |
| **ACTINOPTERYGII** | Perciformes | Haemulidae | *Plectorhinchus gibbosus* | (Lacépède, 1802) |
| **ACTINOPTERYGII** | Perciformes | Haemulidae | *Pomadasys kaakan* | (Cuvier, 1830) |
| **ACTINOPTERYGII** | Perciformes | Lethrinidae | *Gymnocranius elongatus* | Senta, 1973 |
| **ACTINOPTERYGII** | Perciformes | Lethrinidae | *Gymnocranius grandoculis* | (Valenciennes, 1830) |
| **ACTINOPTERYGII** | Perciformes | Lethrinidae | *Lethrinus genivittatus* | Valenciennes, 1830 |
| **ACTINOPTERYGII** | Perciformes | Lethrinidae | *Lethrinus laticaudis* | Alleyne & Macleay, 1877 |
| **ACTINOPTERYGII** | Perciformes | Lethrinidae | *Lethrinus lentjan* | (Lacépède, 1802) |
| **ACTINOPTERYGII** | Perciformes | Lethrinidae | *Lethrinus nebulosus* | (Forsskål, 1775) |
| **ACTINOPTERYGII** | Perciformes | Lethrinidae | *Lethrinus olivaceus* | Valenciennes, 1830 |
| **ACTINOPTERYGII** | Perciformes | Lethrinidae | *Lethrinus punctulatus* | Macleay, 1878 |
| **ACTINOPTERYGII** | Perciformes | Lethrinidae | *Lethrinus ravus* | Carpenter & Randall, 2003 |
| **ACTINOPTERYGII** | Perciformes | Lethrinidae | *Lethrinus variegatus* | Valenciennes, 1830 |
| **ACTINOPTERYGII** | Perciformes | Sparidae | *Argyrops bleekeri* | Oshima, 1927 |
| **ACTINOPTERYGII** | Perciformes | Mullidae | *Parupeneus chrysopleuron* | (Temminck & Schlegel, 1843) |
| **ACTINOPTERYGII** | Perciformes | Mullidae | *Parupeneus heptacanthus* | (Lacépède, 1802) |
| **ACTINOPTERYGII** | Perciformes | Mullidae | *Parupeneus indicus* | (Shaw, 1803) |
| **ACTINOPTERYGII** | Perciformes | Mullidae | *Upeneus australiae* | Kim & Nakaya, 2002 |
| **ACTINOPTERYGII** | Perciformes | Mullidae | *Upeneus guttatus* | (Day, 1868) |
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| **ACTINOPTERYGII** | Perciformes | Mullidae | *Upeneus margarethae* | Uiblein & Heemstra, 2010 |
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| **ACTINOPTERYGII** | Perciformes | Mullidae | *Upeneus tragula* | Richardson, 1846 |
| **ACTINOPTERYGII** | Perciformes | Pempherididae | *Parapriacanthus ransonneti* cf. | Steindachner, 1870 |
| **ACTINOPTERYGII** | Perciformes | Ephippidae | *Platax batavianus* | Cuvier, 1831 |
| **ACTINOPTERYGII** | Perciformes | Ephippidae | *Platax pinnatus* | (Linnaeus, 1758) |
| **ACTINOPTERYGII** | Perciformes | Chaetodontidae | *Chaetodon assarius* | Waite, 1905 |
| **ACTINOPTERYGII** | Perciformes | Chaetodontidae | *Chaetodon aureofasciatus* | Macleay, 1878 |
| **ACTINOPTERYGII** | Perciformes | Chaetodontidae | *Chelmon marginalis* | Richardson, 1842 |
| **ACTINOPTERYGII** | Perciformes | Chaetodontidae | *Coradion altivelis* | McCulloch, 1916 |
| **ACTINOPTERYGII** | Perciformes | Chaetodontidae | *Coradion chrysozonus* | (Cuvier, 1831) |
| **ACTINOPTERYGII** | Perciformes | Chaetodontidae | *Heniochus acuminatus* | (Linnaeus, 1758) |
| **ACTINOPTERYGII** | Perciformes | Chaetodontidae | *Heniochus diphreutes* | Jordan, 1903 |
| **ACTINOPTERYGII** | Perciformes | Chaetodontidae | *Parachaetodon ocellatus* | (Cuvier, 1831) |
| **ACTINOPTERYGII** | Perciformes | Pomacanthidae | *Chaetodontoplus duboulayi* | (Günther, 1867) |
| **ACTINOPTERYGII** | Perciformes | Pomacanthidae | *Chaetodontoplus personifer* | (McCulloch, 1914) |
| **ACTINOPTERYGII** | Perciformes | Pomacanthidae | *Pomacanthus imperator* | (Bloch, 1787) |
| **ACTINOPTERYGII** | Perciformes | Pomacanthidae | *Pomacanthus sexstriatus* | (Cuvier, 1831) |
| **ACTINOPTERYGII** | Perciformes | Pomacentridae | *Amblypomacentrus breviceps* | (Schlegel & Müller, 1839) |
| **ACTINOPTERYGII** | Perciformes | Pomacentridae | *Chromis fumea* | (Tanaka, 1917) |
| **ACTINOPTERYGII** | Perciformes | Pomacentridae | *Neopomacentrus cyanomos* | (Bleeker, 1856) |
| **ACTINOPTERYGII** | Perciformes | Pomacentridae | *Pomacentrus nagasakiensis* | Tanaka 1917 |
| **ACTINOPTERYGII** | Perciformes | Pomacentridae | *Pristotis obtusirostris* | (Günther, 1862) |

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|---|---|---|---|---|
| **ACTINOPTERYGII** | Perciformes | Cirrhitidae | *Cirrhitichthys aprinus* cf. | (Cuvier, 1829) |
| **ACTINOPTERYGII** | Perciformes | Cirrhitidae | *Cyprinocirrhites polyactis* | (Bleeker, 1874) |
| **ACTINOPTERYGII** | Perciformes | Sphyraenidae | *Sphyraena forsteri* | Cuvier, 1829 |
| **ACTINOPTERYGII** | Perciformes | Sphyraenidae | *Sphyraena jello* | Cuvier, 1829 |
| **ACTINOPTERYGII** | Perciformes | Sphyraenidae | *Sphyraena putnamae* | Jordan & Seale, 1905 |
| | | | | |
| **ACTINOPTERYGII** | Perciformes | Labridae | *Anampses lennardi* | Scott, 1959 |
| **ACTINOPTERYGII** | Perciformes | Labridae | *Bodianus solatus* | Gomon, 2006 |
| **ACTINOPTERYGII** | Perciformes | Labridae | *Choerodon cauteroma* | Gomon & Allen, 1987 |
| **ACTINOPTERYGII** | Perciformes | Labridae | *Choerodon cephalotes* | (Castelnau, 1875) |
| **ACTINOPTERYGII** | Perciformes | Labridae | *Choerodon monostigma* | Ogilby, 1910 |
| **ACTINOPTERYGII** | Perciformes | Labridae | *Choerodon schoenleinii* | (Valenciennes, 1839) |
| **ACTINOPTERYGII** | Perciformes | Labridae | *Choerodon sugillatum* | Gomon, 1987 |
| **ACTINOPTERYGII** | Perciformes | Labridae | *Choerodon vitta* | Ogilby, 1910 |
| **ACTINOPTERYGII** | Perciformes | Labridae | *Coris pictoides* | Randall & Kuiter, 1982 |
| **ACTINOPTERYGII** | Perciformes | Labridae | *Iniistius opalus* | Fukui, 2018 |
| **ACTINOPTERYGII** | Perciformes | Labridae | *Iniistius* sp. (damaged) | N/A |
| **ACTINOPTERYGII** | Perciformes | Labridae | *Labroides dimidiatus* | (Valenciennes, 1839) |
| **ACTINOPTERYGII** | Perciformes | Labridae | *Leptojulis cyanopleura* | (Bleeker, 1853) |
| **ACTINOPTERYGII** | Perciformes | Labridae | *Oxycheilinus orientalis* | (Günther, 1862) |
| **ACTINOPTERYGII** | Perciformes | Labridae | *Stethojulis interrupta* | (Bleeker, 1851) |
| **ACTINOPTERYGII** | Perciformes | Labridae | *Suezichthys soelae* | Russell, 1985 |
| **ACTINOPTERYGII** | Perciformes | Scaridae | *Scarus ghobban* | Forsskål, 1775 |
| **ACTINOPTERYGII** | Perciformes | Pinguipedidae | *Parapercis alboguttata* | (Günther, 1872) |
| **ACTINOPTERYGII** | Perciformes | Pinguipedidae | *Parapercis nebulosa* | (Quoy & Gaimard, 1825) |
| **ACTINOPTERYGII** | Perciformes | Pinguipedidae | *Parapercis rubromaculata* | Ho, Chang & Shao, 2012 |
| **ACTINOPTERYGII** | Perciformes | Pinguipedidae | *Parapercis snyderi* | Jordan & Starks, 1905 |
| **ACTINOPTERYGII** | Perciformes | Pinguipedidae | *Parapercis xanthozona* | (Bleeker, 1849) |
| **ACTINOPTERYGII** | Perciformes | Uranoscopidae | *Ichthyscopus insperatus* | Mees, 1960 |
| **ACTINOPTERYGII** | Perciformes | Uranoscopidae | *Uranoscopus bicinctus* cf. | Temminck & Schlegel, 1843 |
| **ACTINOPTERYGII** | Perciformes | Uranoscopidae | *Uranoscopus cognatus* | Cantor, 1849 |
| **ACTINOPTERYGII** | Perciformes | Champsodontidae | *Champsodon vorax* cf. | Günther, 1867 |
| **ACTINOPTERYGII** | Perciformes | Blenniidae | *Xiphasia setifer* | Swainson, 1839 |
| **ACTINOPTERYGII** | Perciformes | Ammodytidae | *Bleekeria* sp. | N/A |
| **ACTINOPTERYGII** | Perciformes | Callionymidae | *Callionymus australis* | Fricke, 1983 |
| **ACTINOPTERYGII** | Perciformes | Callionymidae | *Dactylopus dactylopus* | (Valenciennes, 1837) |
| **ACTINOPTERYGII** | Perciformes | Gobiidae | Gobiidae - undifferentiated | N/A |
| **ACTINOPTERYGII** | Perciformes | Gobiidae | *Bathygobius* sp. | (Hoese, in preparation.) |
| **ACTINOPTERYGII** | Perciformes | Gobiidae | *Eviota* sp. | N/A |
| **ACTINOPTERYGII** | Perciformes | Gobiidae | *Larsonella* sp. | N/A |
| **ACTINOPTERYGII** | Perciformes | Gobiidae | *Lubricogiobius ornatus* | Fourmanoir, 1966 |
| **ACTINOPTERYGII** | Perciformes | Gobiidae | *Pleurosicya boldinghi* | Weber, 1913 |
| **ACTINOPTERYGII** | Perciformes | Gobiidae | *Priolepis cincta* | (Regan, 1908) |
| **ACTINOPTERYGII** | Perciformes | Gobiidae | *Priolepis nuchifasciata* | (Günther, 1873) |
| **ACTINOPTERYGII** | Perciformes | Gobiidae | *Priolepis profunda* | (Weber, 1909) |
| **ACTINOPTERYGII** | Perciformes | Gobiidae | *Sueviota larsonae* cf. | Winterbottom & Hoese, 1988 |
| **ACTINOPTERYGII** | Perciformes | Microdesmidae | *Ptereleotris monoptera* | Randall & Hoese 1985 |
| **ACTINOPTERYGII** | Perciformes | Acanthuridae | *Acanthurus grammoptilus* | Richardson, 1843 |

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| **ACTINOPTERYGII** | Perciformes | Acanthuridae | *Acanthurus mata* | Cuvier, 1829 |
| **ACTINOPTERYGII** | Perciformes | Acanthuridae | *Naso fageni* | Morrow, 1954 |
| **ACTINOPTERYGII** | Perciformes | Acanthuridae | *Naso reticulatus* | Randall, 2001 |
| **ACTINOPTERYGII** | Perciformes | Acanthuridae | *Naso unicornis* | (Forsskål, 1775) |
| **ACTINOPTERYGII** | Perciformes | Siganidae | *Siganus fuscescens* | (Houttuyn, 1782) |
| **ACTINOPTERYGII** | Perciformes | Scombridae | *Cybiosarda elegans* | (Whitley, 1935) |
| **ACTINOPTERYGII** | Perciformes | Scombridae | *Rastrelliger kanagurta* | (Cuvier, 1816) |
| **ACTINOPTERYGII** | Perciformes | Scombridae | *Scomberomorus queenslandicus* | Munro, 1943 |
| **ACTINOPTERYGII** | Perciformes | Trichiuridae | *Trichiurus lepturus* cf. | Linnaeus, 1758 |
| **ACTINOPTERYGII** | Pleuronectiformes | Psettodidae | *Psettodes erumei* | (Bloch & Schneider, 1801) |
| **ACTINOPTERYGII** | Pleuronectiformes | Bothidae | *Asterorhombus intermedius* cf. | (Bleeker, 1866) |
| **ACTINOPTERYGII** | Pleuronectiformes | Bothidae | *Asterorhombus* sp. | N/A |
| **ACTINOPTERYGII** | Pleuronectiformes | Bothidae | *Crossorhombus azureus* | (Alcock, 1889) |
| **ACTINOPTERYGII** | Pleuronectiformes | Bothidae | *Engyprosopon grandisquama* | (Temminck & Schlegel, 1846) |
| **ACTINOPTERYGII** | Pleuronectiformes | Bothidae | *Engyprosopon* sp. | N/A |
| **ACTINOPTERYGII** | Pleuronectiformes | Bothidae | *Grammatobothus pennatus* | (Ogilby, 1913) |
| **ACTINOPTERYGII** | Pleuronectiformes | Bothidae | *Grammatobothus polyophthalmus* | (Bleeker, 1866) |
| **ACTINOPTERYGII** | Pleuronectiformes | Bothidae | *Parabothus* sp. (juvenile) | N/A |
| **ACTINOPTERYGII** | Pleuronectiformes | Bothidae | *Psettina variegata* cf. | (Fowler, 1933) |
| **ACTINOPTERYGII** | Pleuronectiformes | Paralichthyidae | *Pseudorhombus argus* | Weber, 1913 |
| **ACTINOPTERYGII** | Pleuronectiformes | Paralichthyidae | *Pseudorhombus arsius* | (Hamilton, 1822) |
| **ACTINOPTERYGII** | Pleuronectiformes | Paralichthyidae | *Pseudorhombus diplospilus* | Norman, 1926 |
| **ACTINOPTERYGII** | Pleuronectiformes | Paralichthyidae | *Pseudorhombus dupliciocellatus* | Regan, 1905 |
| **ACTINOPTERYGII** | Pleuronectiformes | Paralichthyidae | *Pseudorhombus elevatus* | Ogilby, 1912 |
| **ACTINOPTERYGII** | Pleuronectiformes | Paralichthyidae | *Pseudorhombus jenynsii* | (Bleeker, 1855) |
| **ACTINOPTERYGII** | Pleuronectiformes | Paralichthyidae | *Pseudorhombus quinquocellatus* | Weber & de Beaufort, 1929 |
| **ACTINOPTERYGII** | Pleuronectiformes | Paralichthyidae | *Pseudorhombus spinosus* | McCulloch, 1914 |
| **ACTINOPTERYGII** | Pleuronectiformes | Pleuronectidae | *Samaris cristatus* | Gray, 1831 |
| **ACTINOPTERYGII** | Pleuronectiformes | Soleidae | *Aseraggodes melanospilus* | (Bleeker, 1854) |
| **ACTINOPTERYGII** | Tetraodontiformes | Triacanthidae | *Trixiphichthys weberi* | (Chaudhuri, 1910) |
| **ACTINOPTERYGII** | Tetraodontiformes | Balistidae | *Abalistes stellatus* | (Anonymous, 1798) |
| **ACTINOPTERYGII** | Tetraodontiformes | Balistidae | *Pseudobalistes fuscus* | (Bloch & Schneider 1801) |
| **ACTINOPTERYGII** | Tetraodontiformes | Balistidae | *Sufflamen fraenatum* | (Latreille, 1804) |
| **ACTINOPTERYGII** | Tetraodontiformes | Balistidae | *Xanthichthys lineopunctatus* | (Hollard, 1854) |
| **ACTINOPTERYGII** | Tetraodontiformes | Monacanthidae | *Aluterus monoceros* | (Linnaeus, 1758) |
| **ACTINOPTERYGII** | Tetraodontiformes | Monacanthidae | *Anacanthus barbatus* | Gray, 1831 |
| **ACTINOPTERYGII** | Tetraodontiformes | Monacanthidae | *Brachaluteres taylori* | Woods, 1966 |
| **ACTINOPTERYGII** | Tetraodontiformes | Monacanthidae | *Cantherhines fronticinctus* | (Günther, 1866) |
| **ACTINOPTERYGII** | Tetraodontiformes | Monacanthidae | *Chaetodermis penicilligerus* | (Cuvier, 1817) |
| **ACTINOPTERYGII** | Tetraodontiformes | Monacanthidae | *Eubalichthys caeruleoguttatus* | Hutchins, 1977 |
| **ACTINOPTERYGII** | Tetraodontiformes | Monacanthidae | *Monacanthus chinensis* | (Osbeck, 1765) |
| **ACTINOPTERYGII** | Tetraodontiformes | Monacanthidae | *Paramonacanthus choirocephalus* | (Bleeker, 1852) |
| **ACTINOPTERYGII** | Tetraodontiformes | Monacanthidae | *Paramonacanthus filicauda* | (Günther, 1880) |
| **ACTINOPTERYGII** | Tetraodontiformes | Monacanthidae | *Paramonacanthus pusillus* | (Rüppell, 1829) |
| **ACTINOPTERYGII** | Tetraodontiformes | Monacanthidae | *Paramonacanthus* spp. | N/A |
| **ACTINOPTERYGII** | Tetraodontiformes | Monacanthidae | *Pseudomonacanthus elongatus* | Fraser-Brunner, 1940 |
| **ACTINOPTERYGII** | Tetraodontiformes | Monacanthidae | *Pseudomonacanthus peroni* | (Hollard, 1854) |

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| **ACTINOPTERYGII** | Tetraodontiformes | Ostraciidae | *Lactoria cornuta* | (Linnaeus, 1758) |
| **ACTINOPTERYGII** | Tetraodontiformes | Ostraciidae | *Lactoria diaphana* | (Bloch & Schneider, 1801) |
| **ACTINOPTERYGII** | Tetraodontiformes | Ostraciidae | *Lactoria fornasini* | (Bianconi, 1846) |
| **ACTINOPTERYGII** | Tetraodontiformes | Ostraciidae | *Ostracion cubicus* | Linnaeus, 1758 |
| **ACTINOPTERYGII** | Tetraodontiformes | Ostraciidae | *Ostracion nasus* | Bloch, 1785 |
| **ACTINOPTERYGII** | Tetraodontiformes | Ostraciidae | *Ostracion rhinorhynchus* | Bleeker, 1852 |
| **ACTINOPTERYGII** | Tetraodontiformes | Ostraciidae | *Tetrosomus gibbosus* | (Linnaeus, 1758) |
| **ACTINOPTERYGII** | Tetraodontiformes | Tetraodontidae | *Arothron hispidus* | (Linnaeus, 1758) |
| **ACTINOPTERYGII** | Tetraodontiformes | Tetraodontidae | *Canthigaster cyanospilota* | Randall, Williams & Rocha 2008 |
| **ACTINOPTERYGII** | Tetraodontiformes | Tetraodontidae | *Canthigaster rivulata* | (Temminck & Schlegel, 1850) |
| **ACTINOPTERYGII** | Tetraodontiformes | Tetraodontidae | *Feroxodon multistriatus* | (Richardson, 1854) |
| **ACTINOPTERYGII** | Tetraodontiformes | Tetraodontidae | *Lagocephalus lunaris* | (Bloch & Schneider, 1801) |
| **ACTINOPTERYGII** | Tetraodontiformes | Tetraodontidae | *Lagocephalus sceleratus* | (Gmelin, 1789) |
| **ACTINOPTERYGII** | Tetraodontiformes | Tetraodontidae | *Lagocephalus suezensis* | Clark & Gohar, 1953 |
| **ACTINOPTERYGII** | Tetraodontiformes | Tetraodontidae | *Torquigener pallimaculatus* | Hardy, 1983 |
| **ACTINOPTERYGII** | Tetraodontiformes | Tetraodontidae | *Torquigener parcuspinus* | Hardy, 1983 |
| **ACTINOPTERYGII** | Tetraodontiformes | Diodontidae | *Cyclichthys orbicularis* | (Bloch, 1785) |
| **ACTINOPTERYGII** | Tetraodontiformes | Diodontidae | *Diodon holocanthus* | Linnaeus, 1758 |
| **ACTINOPTERYGII** | Tetraodontiformes | Diodontidae | *Lophodiodon calori* | (Bianconi, 1854) |
| **ACTINOPTERYGII** | Tetraodontiformes | Diodontidae | *Tragulichthys jaculiferus* | (Cuvier, 1818) |

# Appendix E Data tables giving site locations referred to in this report

## E.1 Data tables giving site locations referred to in this report

In various parts of the report maps and graphs refer to sample sites. The tables below provide the GPS coordinates for each site.

**Apx Table 4 Sites sampled during the 2017 *Investigator* voyage (INV2017_05). 'Net on bottom': net in contact with seabed. 'Net open': doors spread and towed net fishing effectively. 'Net off bottom': net left seabed and no longer fishing effectively. 'Net spread': average width of doors when net is fishing. 'Net layback': distance between stern of vessel and net. See Appendix A for full details on trawl methods.**

| Site | Operation number | Start depth (m) | Net onbottom lat (deg) | Net onbottom long (deg) | Net open lat (deg) | Net open long (deg) | Net offbottom lat (deg) | Net offbottom long (deg) | Bottom distance towed (m) | Net spread (m) | Net layback from vessel (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| W1 | 556 | 27.1 | -20.527 | 115.760 | -20.561 | 115.760 | -20.556 | 115.760 | 3203.8 | 76.2 | 357.5 |
| W2 | 560 | 29.3 | -20.571 | 116.035 | -20.571 | 116.070 | -20.571 | 116.065 | 3208.4 | 76.1 | 357.4 |
| W3 | 581 | 28.1 | -20.560 | 116.125 | -20.560 | 116.159 | -20.560 | 116.154 | 3030.0 | 76.1 | 357.3 |
| W4 | 177 | 23.0 | -20.352 | 117.218 | -20.376 | 117.193 | -20.372 | 117.197 | 3129.9 | 77.8 | 366.7 |
| W5 | 171 | 31.3 | -20.190 | 117.377 | -20.203 | 117.345 | -20.201 | 117.350 | 3052.3 | 78.2 | 367.5 |
| W6 | 174 | 24.5 | -20.334 | 117.365 | -20.357 | 117.341 | -20.354 | 117.344 | 3127.8 | 74.4 | 350.1 |
| W7 | 156 | 37.9 | -20.133 | 117.181 | -20.133 | 117.216 | -20.133 | 117.211 | 3108.2 | 82.8 | 391.0 |
| W8 | 271 | 27.7 | -20.310 | 116.990 | -20.310 | 116.951 | -20.310 | 116.956 | 3566.1 | 78.1 | 367.2 |
| W9 | 127 | 31.8 | -20.148 | 117.732 | -20.165 | 117.700 | -20.163 | 117.705 | 3293.6 | 80.1 | 376.6 |
| W10 | 126 | 26.6 | -20.151 | 117.936 | -20.168 | 117.906 | -20.166 | 117.910 | 3181.7 | 73.1 | 342.2 |
| W11 | 39 | 28.5 | -19.894 | 118.216 | -19.926 | 118.204 | -19.922 | 118.206 | 3330.7 | 76.1 | 357.2 |
| W12 | 376 | 93.4 | -19.465 | 116.566 | -19.489 | 116.537 | -19.483 | 116.544 | 3089.0 | 112.5 | 536.5 |
| W13 | 467 | 73.6 | -19.905 | 115.786 | -19.929 | 115.759 | -19.924 | 115.765 | 3100.0 | 100.2 | 469.7 |
| W14 | 579 | 41.5 | -20.346 | 115.757 | -20.348 | 115.723 | -20.348 | 115.729 | 2984.7 | 83.2 | 390.2 |
| W15 | 557 | 25.8 | -20.621 | 115.924 | -20.624 | 115.889 | -20.624 | 115.894 | 3170.7 | 74.3 | 348.7 |
| W16 | 580 | 37.4 | -20.413 | 115.859 | -20.437 | 115.832 | -20.433 | 115.836 | 3285.5 | 82.2 | 385.8 |
| W17 | 539 | 38.7 | -20.334 | 116.120 | -20.364 | 116.102 | -20.359 | 116.105 | 3266.8 | 82.2 | 385.6 |
| W18abort | 542 | 32.7 | -20.494 | 116.033 | -20.505 | 116.010 | -20.503 | 116.015 | 2103.0 | 78.1 | 366.2 |
| W18redo | 543 | 31.5 | -20.497 | 116.023 | -20.514 | 115.990 | -20.511 | 115.995 | 3336.9 | 78.2 | 366.8 |
| W19 | 297 | 33.5 | -20.382 | 116.283 | -20.407 | 116.257 | -20.404 | 116.261 | 3314.1 | 79.1 | 371.0 |
| W20 | 272 | 39.5 | -20.185 | 116.876 | -20.211 | 116.849 | -20.207 | 116.853 | 3401.9 | 84.1 | 395.6 |
| W21 | 60 | 49.1 | -19.831 | 117.736 | -19.848 | 117.705 | -19.846 | 117.710 | 3160.2 | 86.0 | 403.6 |
| W22 | 130 | 42.2 | -20.042 | 117.454 | -20.058 | 117.425 | -20.055 | 117.430 | 2896.1 | 84.1 | 394.9 |
| W23 | 43 | 55.9 | -19.607 | 118.013 | -19.623 | 117.984 | -19.621 | 117.989 | 2953.2 | 88.3 | 412.7 |
| W24 | 42 | 33.7 | -19.727 | 118.239 | -19.753 | 118.229 | -19.748 | 118.231 | 2480.9 | 76.0 | 355.9 |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| W25 | 24 | 44.3 | -19.676 | 118.226 | -19.710 | 118.213 | -19.704 | 118.215 | 3294.7 | 86.2 | 404.8 |
| W26 | 373 | 96.4 | -19.436 | 116.703 | -19.459 | 116.677 | -19.453 | 116.684 | 2723.6 | 115.9 | 562.3 |
| W27 | 398 | 64.5 | -19.687 | 116.341 | -19.720 | 116.331 | -19.713 | 116.333 | 3028.8 | 96.4 | 460.9 |
| W28 | 347 | 56.4 | -19.667 | 116.551 | -19.691 | 116.525 | -19.687 | 116.529 | 3117.2 | 92.1 | 432.5 |
| W29 | 372 | 71.4 | -19.455 | 116.777 | -19.477 | 116.745 | -19.473 | 116.751 | 3358.2 | 102.3 | 481.8 |
| W30 | 153 | 50.8 | -20.000 | 117.046 | -20.000 | 117.080 | -20.000 | 117.074 | 2966.7 | 87.2 | 408.6 |
| W31 | 343 | 49.2 | -19.541 | 116.746 | -19.571 | 116.723 | -19.566 | 116.727 | 3407.2 | 90.2 | 424.3 |
| W32 | 369 | 64.7 | -19.490 | 116.811 | -19.512 | 116.788 | -19.507 | 116.793 | 2657.2 | 99.4 | 471.3 |
| W33 | 85 | 86.8 | -19.304 | 117.622 | -19.320 | 117.592 | -19.316 | 117.599 | 2761.1 | 109.1 | 512.7 |
| W34 | 109 | 82.4 | -19.426 | 117.567 | -19.442 | 117.537 | -19.439 | 117.544 | 2776.1 | 106.0 | 497.9 |
| W35 | 84 | 85.8 | -19.234 | 117.915 | -19.252 | 117.883 | -19.248 | 117.890 | 2994.6 | 106.0 | 496.6 |
| W36 | 23 | 64.8 | -19.426 | 118.150 | -19.457 | 118.136 | -19.451 | 118.139 | 2965.6 | 96.1 | 450.9 |
| W37 | 399 | 72.8 | -19.705 | 116.150 | -19.731 | 116.122 | -19.726 | 116.128 | 3226.9 | 100.2 | 470.2 |
| W38 | 395 | 67.0 | -19.819 | 116.249 | -19.825 | 116.213 | -19.824 | 116.220 | 3106.4 | 98.1 | 460.8 |
| W39 | 88 | 79.8 | -19.373 | 117.715 | -19.393 | 117.687 | -19.388 | 117.694 | 2780.3 | 105.9 | 499.0 |
| W40 | 326 | 60.1 | -19.799 | 116.467 | -19.806 | 116.432 | -19.804 | 116.439 | 2977.7 | 96.2 | 452.4 |
| W41 | 344 | 54.7 | -19.634 | 116.577 | -19.654 | 116.548 | -19.651 | 116.553 | 3091.6 | 91.2 | 428.1 |
| W42 | 149 | 52.2 | -19.876 | 117.314 | -19.902 | 117.290 | -19.897 | 117.294 | 3125.8 | 86.3 | 412.8 |
| W43 | 447 | 72.6 | -19.775 | 116.044 | -19.781 | 116.010 | -19.782 | 116.017 | 2927.3 | 101.1 | 474.9 |
| W44 | 249 | 56.8 | -19.789 | 116.561 | -19.808 | 116.528 | -19.805 | 116.534 | 3297.4 | 92.2 | 432.4 |
| W45 | 133 | 56.5 | -19.784 | 117.295 | -19.809 | 117.271 | -19.804 | 117.276 | 3044.1 | 91.8 | 432.0 |
| W46 | 464 | 77.7 | -19.896 | 115.705 | -19.919 | 115.680 | -19.914 | 115.686 | 2861.2 | 104.2 | 488.9 |
| W47 | 470 | 69.8 | -19.933 | 115.838 | -19.959 | 115.810 | -19.954 | 115.815 | 3287.2 | 99.2 | 465.1 |
| W48 | 439 | 66.2 | -19.989 | 115.894 | -20.015 | 115.869 | -20.010 | 115.874 | 3115.5 | 97.1 | 455.7 |
| W49 | 578 | 53.0 | -20.199 | 115.789 | -20.205 | 115.752 | -20.204 | 115.758 | 3283.2 | 89.2 | 418.2 |
| W50 | 545 | 46.2 | -20.253 | 115.976 | -20.253 | 115.941 | -20.253 | 115.947 | 3106.8 | 87.2 | 409.7 |
| W51 | 296 | 44.0 | -20.195 | 116.452 | -20.221 | 116.425 | -20.217 | 116.429 | 3429.3 | 86.2 | 404.7 |
| W52 | 63 | 58.8 | -19.674 | 117.632 | -19.691 | 117.600 | -19.688 | 117.605 | 3192.2 | 92.1 | 431.4 |
| W53 | 66 | 67.0 | -19.499 | 117.649 | -19.516 | 117.618 | -19.513 | 117.624 | 2984.9 | 96.2 | 450.9 |
| W54 | 59 | 63.2 | -19.608 | 117.650 | -19.625 | 117.618 | -19.621 | 117.625 | 3027.6 | 94.1 | 441.2 |
| W55 | 91 | 65.2 | -19.489 | 117.686 | -19.505 | 117.657 | -19.502 | 117.662 | 2870.4 | 94.1 | 440.7 |
| W56 | 44 | 52.4 | -19.704 | 117.841 | -19.720 | 117.811 | -19.717 | 117.816 | 3003.9 | 86.2 | 402.8 |
| W57 | 20 | 67.8 | -19.384 | 117.936 | -19.418 | 117.923 | -19.413 | 117.925 | 3383.4 | 96.2 | 450.4 |
| W58 | 440 | 64.9 | -19.946 | 116.055 | -19.970 | 116.029 | -19.965 | 116.035 | 3006.2 | 98.2 | 461.5 |
| W59 | 418 | 52.2 | -20.059 | 116.261 | -20.083 | 116.236 | -20.079 | 116.241 | 3042.9 | 90.1 | 423.4 |
| W60 | 227 | 58.5 | -19.791 | 116.726 | -19.813 | 116.697 | -19.809 | 116.703 | 3160.5 | 94.2 | 442.6 |
| W61 | 350 | 57.9 | -19.701 | 116.523 | -19.726 | 116.497 | -19.721 | 116.502 | 3145.0 | 93.1 | 437.6 |
| W62 | 275 | 51.9 | -20.050 | 116.751 | -20.073 | 116.726 | -20.069 | 116.731 | 3006.9 | 89.2 | 418.3 |
| W63 | 195 | 67.1 | -19.796 | 116.826 | -19.821 | 116.799 | -19.816 | 116.805 | 3115.2 | 98.2 | 461.2 |
| W64 | 150 | 62.9 | -19.789 | 117.095 | -19.814 | 117.069 | -19.809 | 117.074 | 3214.4 | 94.1 | 441.1 |
| W65 | 111 | 54.2 | -19.871 | 117.268 | -19.889 | 117.235 | -19.886 | 117.240 | 3376.9 | 86.1 | 402.2 |
| W66 | 110 | 66.3 | -19.588 | 117.322 | -19.606 | 117.290 | -19.602 | 117.296 | 3200.6 | 98.1 | 461.4 |
| W67 | 17 | 67.6 | -19.381 | 118.041 | -19.412 | 118.029 | -19.407 | 118.031 | 2977.6 | 96.2 | 450.7 |
| W68 | 444 | 66.5 | -19.865 | 116.143 | -19.887 | 116.116 | -19.883 | 116.121 | 2983.4 | 99.2 | 466.1 |
| W69 | 246 | 49.8 | -19.739 | 116.655 | -19.767 | 116.631 | -19.763 | 116.634 | 3330.9 | 87.2 | 408.5 |
| W70 | 421 | 50.7 | -20.025 | 116.400 | -20.055 | 116.385 | -20.049 | 116.387 | 3039.4 | 91.1 | 428.9 |
| W71 | 192 | 54.5 | -19.967 | 116.794 | -19.992 | 116.768 | -19.988 | 116.772 | 3253.4 | 88.2 | 412.5 |
| W72 | 198 | 51.2 | -19.746 | 116.728 | -19.769 | 116.699 | -19.765 | 116.704 | 3274.7 | 89.1 | 418.6 |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| W73abort | 107 | 72.2 | -19.473 | 117.592 | -19.483 | 117.573 | -19.480 | 117.579 | 1567.2 | 79.3 | 500.6 |
| W73redo | 108 | 72.8 | -19.476 | 117.586 | -19.493 | 117.555 | -19.490 | 117.561 | 3023.2 | 103.1 | 485.2 |
| W74 | 3 | 70.4 | -19.338 | 118.217 | -19.362 | 118.207 | -19.357 | 118.209 | 2265.2 | 92.1 | 429.9 |
| W75 | 518 | 52.8 | -20.104 | 116.196 | -20.135 | 116.180 | -20.130 | 116.182 | 3147.4 | 89.1 | 418.2 |
| W76 | 226 | 55.1 | -19.797 | 116.651 | -19.807 | 116.614 | -19.806 | 116.621 | 3308.5 | 92.1 | 433.2 |
| W77 | 252 | 58.6 | -19.784 | 116.509 | -19.796 | 116.472 | -19.794 | 116.479 | 3309.2 | 92.2 | 432.0 |
| W78 | 463 | 65.5 | -20.048 | 115.797 | -20.072 | 115.822 | -20.067 | 115.817 | 2949.5 | 98.1 | 461.2 |
| W79 | 500 | 60.1 | -20.101 | 115.928 | -20.099 | 115.893 | -20.099 | 115.899 | 3046.3 | 92.2 | 431.7 |
| W80 | 498 | 59.0 | -20.110 | 115.949 | -20.110 | 115.914 | -20.110 | 115.921 | 2884.0 | 94.1 | 442.2 |
| W81abort | 496 | 55.3 | -20.180 | 115.954 | -20.180 | 115.919 | -20.180 | 115.926 | 2964.7 | 90.2 | 422.7 |
| W81redo | 497 | 55.4 | -20.178 | 115.952 | -20.178 | 115.918 | -20.178 | 115.925 | 2808.6 | 92.1 | 432.9 |
| W82 | 493 | 52.5 | -20.194 | 115.961 | -20.204 | 115.926 | -20.202 | 115.932 | 3208.7 | 89.2 | 418.1 |
| W83 | 522 | 55.3 | -20.130 | 116.063 | -20.130 | 116.027 | -20.130 | 116.034 | 3052.3 | 90.2 | 422.8 |
| W84 | 301 | 50.0 | -20.056 | 116.363 | -20.071 | 116.330 | -20.069 | 116.336 | 3192.4 | 86.1 | 403.4 |
| W85 | 219 | 55.1 | -19.915 | 116.696 | -19.939 | 116.670 | -19.935 | 116.675 | 3153.2 | 90.1 | 422.3 |
| W86 | 222 | 56.0 | -19.827 | 116.735 | -19.850 | 116.709 | -19.846 | 116.714 | 3049.6 | 93.1 | 437.8 |
| W87 | 193 | 63.4 | -19.841 | 116.905 | -19.865 | 116.879 | -19.861 | 116.884 | 3131.0 | 94.2 | 441.1 |
| W88 | 6 | 71.3 | -19.325 | 118.125 | -19.356 | 118.114 | -19.350 | 118.116 | 2933.0 | 96.2 | 449.5 |
| W89 | 417 | 54.1 | -20.092 | 116.176 | -20.102 | 116.143 | -20.100 | 116.149 | 3000.6 | 89.1 | 417.6 |
| W90 | 414 | 50.5 | -20.034 | 116.378 | -20.056 | 116.353 | -20.052 | 116.357 | 2987.3 | 89.2 | 418.7 |
| W91 | 323 | 55.8 | -19.984 | 116.624 | -20.010 | 116.601 | -20.005 | 116.606 | 3053.4 | 92.1 | 432.6 |
| W92 | 278 | 56.5 | -19.945 | 116.554 | -19.976 | 116.545 | -19.970 | 116.547 | 2923.9 | 94.2 | 443.0 |
| W93 | 325 | 58.5 | -19.936 | 116.665 | -19.960 | 116.639 | -19.956 | 116.644 | 3113.0 | 90.3 | 429.9 |
| W94 | 519 | 54.8 | -20.106 | 116.174 | -20.119 | 116.142 | -20.117 | 116.148 | 3032.1 | 91.1 | 427.9 |
| W95 | 319 | 54.3 | -19.922 | 116.628 | -19.947 | 116.603 | -19.942 | 116.608 | 3173.5 | 91.2 | 428.2 |
| W96 | 394 | 55.2 | -19.826 | 116.655 | -19.838 | 116.617 | -19.833 | 116.625 | 3311.7 | 93.2 | 438.2 |
| W97 | 544 | 46.4 | -20.238 | 116.003 | -20.263 | 115.976 | -20.259 | 115.980 | 3243.5 | 87.1 | 409.5 |
| W98 | 526 | 48.1 | -20.210 | 116.025 | -20.226 | 115.995 | -20.223 | 116.000 | 3024.7 | 85.1 | 398.6 |
| W99 | 525 | 47.9 | -20.220 | 116.062 | -20.220 | 116.026 | -20.220 | 116.032 | 3169.5 | 86.2 | 404.0 |
| W100 | 298 | 49.5 | -20.171 | 116.338 | -20.169 | 116.368 | -20.168 | 116.362 | 2527.1 | 89.2 | 419.1 |
| W0 | 1 | 41.7 | -18.324 | 121.469 | -18.341 | 121.446 | -18.337 | 121.451 | 2365.5 | 77.6 | 404.9 |
| OM20 | 2 | 43.3 | -18.704 | 121.038 | -18.726 | 121.007 | -18.723 | 121.011 | 3539.1 | 86.1 | 404.9 |

**Apx Table 5 GPS co-ordinates for historical sites surveyed during CSIRO 1982–1997 surveys. F&B is the Frank and Bryce design demersal trawl net, McK is the McKenn design demersal trawl net.**

| Year | Gear | STN_KEY | Long. Start | Lat. Start | Long. End | Lat. End | Depth Start (m) |
|---|---|---|---|---|---|---|---|
| 1983 | F&B | 83033 | | | 117.99500 | -20.13333 | 28 |
| 1983 | F&B | 83036 | | | 117.57500 | -19.84167 | 54 |
| 1983 | F&B | 830341 | 116.36333 | -19.69167 | 116.36333 | -19.68333 | 64 |
| 1983 | F&B | 830344 | 116.05833 | -20.36833 | 116.07000 | -20.38333 | 40 |
| 1983 | F&B | 830347 | 116.35167 | -20.00000 | 116.35500 | -20.02000 | 54 |
| 1983 | F&B | 830348 | 116.60500 | -20.18500 | 116.61167 | -20.22000 | 51 |
| 1983 | F&B | 830350 | 116.61167 | -20.29500 | 116.57833 | -20.29333 | 40 |
| 1983 | F&B | 830351 | 116.76667 | -20.26667 | 116.78667 | -20.26167 | 42 |
| 1983 | F&B | 830353 | 116.77000 | -20.00167 | 116.75833 | -19.96000 | 58 |
| 1983 | F&B | 830354 | 116.79667 | -19.82000 | 116.80167 | -19.78667 | 68 |
| 1983 | F&B | 830355 | 116.82500 | -19.71667 | 116.83500 | -19.69500 | 58 |
| 1983 | F&B | 830358 | 117.35000 | -20.10000 | 117.34167 | -20.12500 | 42 |
| 1983 | F&B | 830362 | 117.37000 | -20.33833 | 117.39167 | -20.32667 | 29 |
| 1983 | F&B | 830363 | 117.65500 | -20.19500 | 117.67500 | -20.17667 | 32 |
| 1983 | F&B | 830364 | 117.69167 | -20.20333 | 117.66167 | -20.20500 | 31 |
| 1983 | F&B | 830367 | 117.63000 | -19.50833 | 117.62167 | -19.50833 | 68 |
| 1983 | F&B | 830368 | 117.80000 | -19.58500 | 117.79167 | -19.55833 | 62 |
| 1983 | F&B | 830369 | 117.70167 | -19.71667 | 117.68000 | -19.73000 | 60 |
| 1983 | F&B | 830418 | 118.21333 | -19.37500 | 118.24000 | -19.38000 | 68 |
| 1983 | F&B | 830419 | 118.16000 | -19.34667 | 118.14500 | -19.36000 | 72 |
| 1983 | F&B | 830420 | 118.15333 | -19.19667 | 118.13500 | -19.16000 | 84 |
| 1983 | F&B | 830423 | 117.92500 | -19.39333 | 117.94333 | -19.40667 | 68 |
| 1983 | F&B | 830426 | 117.95167 | -20.15000 | 117.92667 | -20.16833 | 28 |
| 1983 | F&B | 830427 | 117.80667 | -20.12000 | 117.82167 | -20.13167 | 33 |
| 1983 | F&B | 830428 | 117.86167 | -20.04500 | 117.85000 | -20.06000 | 36 |
| 1983 | F&B | 830429 | 117.71167 | -19.96333 | 117.69167 | -19.96667 | 44 |
| 1983 | F&B | 830433 | 117.45333 | -20.06833 | 117.48167 | -20.06667 | 44 |
| 1983 | F&B | 830434 | 117.24667 | -20.20000 | 117.21333 | -20.20000 | 39 |
| 1983 | F&B | 830435 | 117.26667 | -20.21333 | 117.25000 | -20.23667 | 36 |
| 1983 | F&B | 830436 | 117.35333 | -20.35833 | 117.35167 | -20.33500 | 28 |
| 1983 | F&B | 830437 | 117.21667 | -20.32000 | 117.23167 | -20.33333 | 28 |
| 1983 | F&B | 830438 | 117.17167 | -20.31333 | 117.18000 | -20.33667 | 28 |
| 1983 | F&B | 830440 | 117.35500 | -19.66833 | 117.32667 | -19.65667 | 66 |
| 1983 | F&B | 830441 | 117.20667 | -19.75500 | 117.21833 | -19.77667 | 66 |
| 1983 | F&B | 830442 | 117.11500 | -19.71167 | 117.10000 | -19.73167 | 68 |
| 1983 | F&B | 830444 | 116.94500 | -19.93000 | 116.97000 | -19.92000 | 59 |
| 1983 | F&B | 830445 | 117.01167 | -20.03167 | 116.99667 | -20.04333 | 50 |
| 1983 | F&B | 830448 | 117.06500 | -20.16500 | 117.04667 | -20.18333 | 42 |
| 1983 | F&B | 830450 | 116.79667 | -20.05667 | 116.81000 | -20.08167 | 52 |
| 1983 | F&B | 830451 | 116.80500 | -20.13167 | 116.79333 | -20.14333 | 50 |
| 1983 | F&B | 830452 | 116.70000 | -20.25500 | 116.71667 | -20.24000 | 40 |
| 1983 | F&B | 830453 | 116.70333 | -20.26833 | 116.72000 | -20.25333 | 38 |

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|---|---|---|---|---|---|---|---|
| 1983 | F&B | 830455 | 116.63000 | -19.82833 | 116.60000 | -19.82833 | 58 |
| 1983 | F&B | 830456 | 116.52333 | -19.74833 | 116.54667 | -19.74167 | 61 |
| 1983 | F&B | 830457 | 116.75333 | -19.70167 | 116.76833 | -19.71500 | 56 |
| 1983 | F&B | 830458 | 116.80000 | -19.71000 | 116.76333 | -19.71833 | 58 |
| 1983 | F&B | 830467 | 116.11833 | -20.05833 | 116.11667 | -20.09000 | 67 |
| 1983 | F&B | 830469 | 116.00000 | -20.45667 | 116.00333 | -20.47833 | 38 |
| 1983 | F&B | 830482 | 117.56833 | -19.42000 | 117.55500 | -19.43333 | 82 |
| 1986 | F&B | 86063 | | | 117.80667 | -20.17333 | 27 |
| 1986 | F&B | 86065 | | | 117.78167 | -20.06833 | 33 |
| 1986 | F&B | 86067 | | | 117.56833 | -20.02167 | 41 |
| 1986 | F&B | 86068 | | | 117.44500 | -20.04667 | 42 |
| 1986 | F&B | 860610 | 117.84500 | -20.07167 | 117.86667 | -20.08833 | 36 |
| 1986 | F&B | 860611 | 117.72333 | -20.01333 | 117.74167 | -19.99667 | 42 |
| 1986 | F&B | 860613 | 117.29167 | -20.34667 | 117.27000 | -20.35000 | 24 |
| 1986 | F&B | 860614 | 117.21833 | -20.18500 | 117.24000 | -20.19500 | 37 |
| 1986 | F&B | 860615 | 117.17333 | -20.17167 | 117.21333 | -20.17167 | 40 |
| 1986 | F&B | 860629 | 115.79667 | -19.90000 | 115.79333 | -19.92000 | 74 |
| 1986 | F&B | 860631 | 115.82500 | -19.86000 | 115.84833 | -19.85667 | 76 |
| 1986 | F&B | 860633 | 115.96000 | -19.86333 | 115.96500 | -19.82500 | 72 |
| 1986 | F&B | 860644 | 116.10333 | -20.02833 | 116.10000 | -20.05000 | 60 |
| 1986 | F&B | 860645 | 116.45000 | -20.30333 | 116.42500 | -20.30333 | 40 |
| 1986 | F&B | 860646 | 116.66167 | -20.26500 | 116.65500 | -20.29000 | 39 |
| 1986 | F&B | 860647 | 116.71333 | -20.14500 | 116.72833 | -20.12667 | 47 |
| 1986 | F&B | 860649 | 116.64000 | -20.32167 | 116.61167 | -20.33500 | 36 |
| 1986 | F&B | 860659 | 116.19167 | -20.31667 | 116.16000 | -20.30833 | 39 |
| 1986 | F&B | 860661 | 116.28000 | -20.25833 | 116.30500 | -20.25167 | 41 |
| 1986 | F&B | 860662 | 116.31000 | -20.26500 | 116.33000 | -20.23833 | 40 |
| 1986 | F&B | 860663 | 116.25500 | -20.07000 | 116.21333 | -20.07833 | 50 |
| 1986 | F&B | 860664 | 116.44833 | -20.21833 | 116.44667 | -20.24500 | 44 |
| 1986 | F&B | 860665 | 116.52667 | -20.20667 | 116.53000 | -20.18000 | 43 |
| 1986 | F&B | 860666 | 116.54000 | -20.16833 | 116.54667 | -20.14333 | 48 |
| 1986 | F&B | 860668 | 116.88333 | -19.95500 | 116.90500 | -19.94500 | 52 |
| 1986 | F&B | 860670 | 117.82333 | -19.75833 | 117.84333 | -19.76500 | 52 |
| 1986 | F&B | 860671 | 117.87000 | -19.56667 | 117.84833 | -19.57333 | 60 |
| 1986 | F&B | 860672 | 118.00000 | -19.41833 | 118.02667 | -19.40500 | 68 |
| 1986 | F&B | 860673 | 118.12000 | -19.45333 | 118.15167 | -19.44833 | 65 |
| 1986 | F&B | 860674 | 117.90500 | -19.22000 | 117.87833 | -19.21833 | 82 |
| 1986 | F&B | 860686 | 117.15000 | -19.66500 | 117.17167 | -19.68667 | 70 |
| 1986 | F&B | 860687 | 117.15833 | -19.69833 | 117.17667 | -19.67000 | 70 |
| 1986 | F&B | 860690 | 116.44500 | -19.79333 | 116.46667 | -19.79833 | 60 |
| 1986 | F&B | 860693 | 116.62167 | -19.79667 | 116.64500 | -19.80167 | 58 |
| 1986 | F&B | 860695 | 116.60333 | -20.00833 | 116.61167 | -19.98500 | 57 |
| 1986 | F&B | 8606100 | 116.64667 | -19.80500 | 116.67167 | -19.81500 | 56 |
| 1986 | F&B | 8606102 | 116.34500 | -19.77167 | 116.37500 | -19.76167 | 64 |
| 1986 | F&B | 8606104 | 116.50833 | -19.52167 | 116.48833 | -19.51667 | 88 |
| 1986 | F&B | 8606133 | 118.11833 | -19.27000 | 118.09333 | -19.26333 | 67 |
| 1986 | F&B | 8606139 | 118.17667 | -19.85333 | 118.20333 | -19.86500 | 32 |
| 1987 | F&B | 87073 | | | 118.19500 | -20.02333 | 25 |

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|---|---|---|---|---|---|---|---|
| 1987 | F&B | 87077 | | | 117.77167 | -20.01667 | 40 |
| 1987 | F&B | 870710 | 117.36500 | -20.22833 | 117.33667 | -20.24500 | 33 |
| 1987 | F&B | 870711 | 117.35000 | -20.19667 | 117.38000 | -20.18500 | 34 |
| 1987 | F&B | 870712 | 117.29500 | -20.06833 | 117.29333 | -20.09667 | 44 |
| 1987 | F&B | 870713 | 117.28000 | -20.01167 | 117.30000 | -20.03500 | 48 |
| 1987 | F&B | 870714 | 117.25833 | -19.85833 | 117.25000 | -19.89500 | 56 |
| 1987 | F&B | 870717 | 117.04500 | -20.19500 | 117.04500 | -20.16833 | 40 |
| 1987 | F&B | 870718 | 116.91333 | -20.13167 | 116.92833 | -20.15333 | 46 |
| 1987 | F&B | 870719 | 116.84500 | -20.10833 | 116.83333 | -20.13833 | 47 |
| 1987 | F&B | 870720 | 116.78667 | -20.21833 | 116.80167 | -20.24333 | 42 |
| 1987 | F&B | 870728 | 118.26000 | -19.63167 | 118.24667 | -19.65333 | 42 |
| 1987 | F&B | 870730 | 118.24833 | -19.46333 | 118.26167 | -19.48500 | 65 |
| 1987 | F&B | 870759 | 117.67333 | -19.75333 | 117.67333 | -19.72333 | 54 |
| 1987 | F&B | 870762 | 117.72500 | -19.31167 | 117.71500 | -19.33833 | 85 |
| 1987 | F&B | 870764 | 116.40167 | -20.29833 | 116.42833 | -20.29333 | 41 |
| 1987 | F&B | 870767 | 116.22333 | -20.23000 | 116.24833 | -20.21500 | 46 |
| 1987 | F&B | 870769 | 116.58333 | -20.05167 | 116.60833 | -20.05167 | 54 |
| 1987 | F&B | 870775 | 116.51333 | -19.82000 | 116.49333 | -19.79167 | 59 |
| 1987 | F&B | 870776 | 116.56333 | -19.81000 | 116.55000 | -19.77667 | 57 |
| 1987 | F&B | 870780 | 116.76167 | -19.70000 | 116.74500 | -19.68667 | 53 |
| 1987 | F&B | 870781 | 116.56500 | -19.69667 | 116.54333 | -19.67667 | 57 |
| 1987 | F&B | 870790 | 116.67167 | -19.51500 | 116.64000 | -19.52167 | 59 |
| 1987 | F&B | 870794 | 116.14000 | -19.86500 | 116.11500 | -19.89000 | 68 |
| 1987 | F&B | 870795 | 116.25333 | -19.87833 | 116.24667 | -19.91333 | 64 |
| 1987 | F&B | 870796 | 115.70833 | -20.66500 | 115.73667 | -20.66167 | 22 |
| 1987 | F&B | 870797 | 115.89667 | -20.59667 | 115.87500 | -20.60333 | 30 |
| 1987 | F&B | 870798 | 115.88167 | -20.51167 | 115.91167 | -20.50167 | 34 |
| 1987 | F&B | 870799 | 115.69167 | -20.40500 | 115.69333 | -20.43333 | 37 |
| 1987 | F&B | 8707100 | 115.90000 | -20.45833 | 115.90667 | -20.48667 | 34 |
| 1987 | F&B | 8707109 | 115.75667 | -19.92000 | 115.78500 | -19.93000 | 75 |
| 1987 | F&B | 8707113 | 115.85167 | -20.29000 | 115.84833 | -20.25833 | 44 |
| 1987 | F&B | 8707117 | 115.69000 | -20.11333 | 115.72500 | -20.10833 | 66 |
| 1987 | F&B | 8707121 | 115.99000 | -20.01667 | 115.95667 | -20.01500 | 61 |
| 1987 | F&B | 8707123 | 115.81500 | -19.87167 | 115.81500 | -19.88833 | 78 |
| 1987 | F&B | 8707125 | 115.88500 | -19.84667 | 115.85333 | -19.83667 | 76 |
| 1987 | F&B | 8707128 | 116.98000 | -20.02000 | 116.95500 | -20.03500 | 50 |
| 1987 | F&B | 8707131 | 117.49500 | -19.32833 | 117.52500 | -19.34167 | 91 |
| 1988 | F&B | 88054 | | | 118.21667 | -19.81000 | 35 |
| 1988 | F&B | 88057 | | | 117.79833 | -19.75167 | 52 |
| 1988 | F&B | 88058 | | | 117.90333 | -19.88500 | 44 |
| 1988 | F&B | 88059 | | | 117.93167 | -20.00667 | 38 |
| 1988 | F&B | 880510 | 117.92500 | -20.06333 | 117.94500 | -20.09333 | 35 |
| 1988 | F&B | 880514 | 116.89167 | -20.30000 | 116.90000 | -20.27833 | 34 |
| 1988 | F&B | 880517 | 117.35667 | -20.10167 | 117.32667 | -20.10833 | 41 |
| 1988 | F&B | 880518 | 117.42833 | -20.02833 | 117.41333 | -20.02500 | 45 |
| 1988 | F&B | 880519 | 117.51000 | -20.13167 | 117.51000 | -20.15833 | 35 |
| 1988 | F&B | 880520 | 117.70833 | -19.99833 | 117.71000 | -20.05000 | 41 |
| 1988 | F&B | 880521 | 117.73833 | -20.21667 | 117.68333 | -20.20167 | 29 |

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|---|---|---|---|---|---|---|---|
| 1988 | F&B | 880537 | 118.02167 | -19.48333 | 118.01333 | -19.48333 | 67 |
| 1988 | F&B | 880541 | 117.06167 | -20.01667 | 117.06833 | -20.05333 | 50 |
| 1988 | F&B | 880542 | 117.01333 | -19.91667 | 117.01167 | -19.94500 | 58 |
| 1988 | F&B | 880543 | 117.31500 | -19.87833 | 117.36500 | -19.83500 | 57 |
| 1988 | F&B | 880544 | 117.31167 | -19.81333 | 117.34500 | -19.77667 | 61 |
| 1988 | F&B | 880545 | 117.47000 | -19.75333 | 117.49333 | -19.76333 | 60 |
| 1988 | F&B | 880546 | 117.26667 | -19.72833 | 117.23833 | -19.72333 | 64 |
| 1988 | F&B | 880547 | 116.46833 | -20.39833 | 116.44000 | -20.39500 | 37 |
| 1988 | F&B | 880548 | 116.42333 | -20.39000 | 116.44500 | -20.36333 | 38 |
| 1988 | F&B | 880549 | 116.50000 | -20.21667 | 116.49500 | -20.24167 | 47 |
| 1988 | F&B | 880552 | 116.79500 | -20.15833 | 116.78833 | -20.19333 | 43 |
| 1988 | F&B | 880553 | 116.11000 | -20.49833 | 116.07500 | -20.49833 | 30 |
| 1988 | F&B | 880554 | 116.14833 | -20.55333 | 116.11833 | -20.56167 | 30 |
| 1988 | F&B | 880556 | 116.07000 | -20.55667 | 116.09000 | -20.52500 | 31 |
| 1988 | F&B | 880557 | 115.88167 | -20.65833 | 115.85500 | -20.67000 | 22 |
| 1988 | F&B | 880558 | 115.85500 | -20.68333 | 115.86333 | -20.65333 | 22 |
| 1988 | F&B | 880560 | 115.71833 | -20.51500 | 115.71000 | -20.47000 | 34 |
| 1988 | F&B | 880561 | 115.90833 | -20.32833 | 115.93167 | -20.35667 | 44 |
| 1988 | F&B | 880562 | 115.93500 | -20.28000 | 115.90833 | -20.29167 | 49 |
| 1988 | F&B | 880563 | 116.22000 | -20.15000 | 116.24500 | -20.12000 | 53 |
| 1988 | F&B | 880564 | 116.18167 | -20.07667 | 116.15833 | -20.09667 | 53 |
| 1988 | F&B | 880572 | 116.54000 | -20.10000 | 116.56833 | -20.08333 | 51 |
| 1988 | F&B | 880573 | 116.59667 | -19.93667 | 116.59833 | -19.95667 | 55 |
| 1988 | F&B | 880575 | 116.89500 | -19.67000 | 116.90333 | -19.69333 | 75 |
| 1988 | F&B | 880576 | 116.91167 | -19.81000 | 116.94000 | -19.82833 | 64 |
| 1988 | F&B | 880577 | 117.15833 | -20.03833 | 117.18500 | -20.05333 | 47 |
| 1988 | F&B | 880599 | 118.10167 | -19.23500 | 118.07667 | -19.21000 | 84 |
| 1988 | F&B | 8805101 | 118.10667 | -19.32167 | 118.14000 | -19.35500 | 76 |
| 1988 | F&B | 8805102 | 118.11167 | -19.33333 | 118.10667 | -19.29333 | 74 |
| 1988 | F&B | 8805110 | 117.55833 | -19.31333 | 117.52500 | -19.32500 | 90 |
| 1988 | F&B | 8805114 | 117.35667 | -19.48667 | 117.33500 | -19.48500 | 80 |
| 1988 | F&B | 8805149 | 115.95167 | -19.89500 | 115.92500 | -19.90333 | 71 |
| 1989 | F&B | 890416 | 118.07700 | -20.01500 | 118.11500 | -20.00333 | 34 |
| 1989 | F&B | 890418 | 117.88700 | -19.91200 | 117.90500 | -19.96167 | 43 |
| 1989 | F&B | 890419 | 117.68000 | -19.94500 | 117.71333 | -19.91333 | 50 |
| 1989 | F&B | 890421 | 117.87200 | -20.12700 | 117.83667 | -20.14333 | 35 |
| 1989 | F&B | 890435 | 116.16167 | -19.86167 | 116.17667 | -19.89667 | 73 |
| 1989 | F&B | 890441 | 116.50000 | -20.30667 | 116.48333 | -20.33333 | 43 |
| 1989 | F&B | 890457 | 118.05167 | -19.22333 | 118.00833 | -19.23667 | 85 |
| 1989 | F&B | 890466 | 117.24833 | -19.66667 | 117.25167 | -19.62500 | 71 |
| 1989 | F&B | 890467 | 117.15667 | -19.62167 | 117.19833 | -19.61000 | 76 |
| 1989 | F&B | 890469 | 117.00333 | -19.67333 | 117.02833 | -19.69000 | 72 |
| 1989 | F&B | 890470 | 117.11000 | -19.86333 | 117.10833 | -19.89500 | 60 |
| 1989 | F&B | 890471 | 117.01500 | -19.81500 | 116.99833 | -19.76833 | 64 |
| 1989 | F&B | 890476 | 116.95333 | -19.80167 | 116.97667 | -19.83500 | 67 |
| 1989 | F&B | 890477 | 116.80667 | -19.70833 | 116.83500 | -19.73667 | 72 |
| 1989 | F&B | 890499 | 115.85333 | -19.90000 | 115.80667 | -19.89500 | 75 |
| 1989 | F&B | 8904115 | 117.70500 | -19.30000 | 117.74500 | -19.29667 | 89 |

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|---|---|---|---|---|---|---|---|
| 1989 | F&B | 8904119 | 117.90333 | -19.55333 | 117.89500 | -19.58333 | 63 |
| 1989 | F&B | 8904120 | 117.91500 | -19.60000 | 117.89000 | -19.56500 | 60 |
| 1989 | F&B | 8904121 | 118.09500 | -19.46667 | 118.07667 | -19.50000 | 68 |
| 1989 | F&B | 8904122 | 118.15000 | -19.31833 | 118.11667 | -19.33667 | 78 |
| 1989 | F&B | 8904125 | 118.20000 | -19.24833 | 118.16167 | -19.24667 | 81 |
| 1990 | F&B | 90025 | | | 118.23667 | -19.97833 | 22 |
| 1990 | F&B | 90027 | | | 117.99000 | -19.99167 | 33 |
| 1990 | F&B | 90028 | | | 117.87500 | -19.96333 | 40 |
| 1990 | F&B | 900210 | 117.64000 | -20.03667 | 117.61500 | -20.06500 | 40 |
| 1990 | F&B | 900211 | 117.37167 | -20.00500 | 117.34833 | -20.01667 | 46 |
| 1990 | F&B | 900212 | 117.36833 | -20.08667 | 117.37667 | -20.10833 | 40 |
| 1990 | F&B | 900213 | 117.30000 | -20.10000 | 117.27000 | -20.09333 | 40 |
| 1990 | F&B | 900214 | 117.24667 | -20.18833 | 117.26833 | -20.17833 | 39 |
| 1990 | F&B | 900223 | 116.98833 | -19.89500 | 116.96833 | -19.88333 | 60 |
| 1990 | F&B | 900224 | 116.57000 | -19.77667 | 116.57667 | -19.79667 | 57 |
| 1990 | F&B | 900225 | 116.60000 | -19.91000 | 116.57333 | -19.91000 | 57 |
| 1990 | F&B | 900227 | 116.40833 | -20.11833 | 116.39500 | -20.14167 | 50 |
| 1990 | F&B | 900229 | 116.26000 | -20.05333 | 116.24500 | -20.08000 | 54 |
| 1990 | F&B | 900230 | 116.26667 | -20.05833 | 116.26833 | -20.03000 | 54 |
| 1990 | F&B | 900231 | 116.24333 | -20.15833 | 116.22333 | -20.18333 | 51 |
| 1990 | F&B | 900236 | 116.04333 | -20.57000 | 116.02333 | -20.57333 | 29 |
| 1990 | F&B | 900238 | 115.80667 | -20.63333 | 115.80667 | -20.61000 | 27 |
| 1990 | F&B | 900240 | 115.78833 | -20.40333 | 115.78500 | -20.37833 | 41 |
| 1990 | F&B | 900241 | 115.75333 | -20.35167 | 115.75000 | -20.32667 | 43 |
| 1990 | F&B | 900253 | 117.30500 | -20.09000 | 117.30000 | -20.06000 | 43 |
| 1990 | F&B | 900254 | 117.36833 | -20.07333 | 117.38500 | -20.09833 | 43 |
| 1990 | F&B | 900266 | 118.19833 | -19.53333 | 118.20333 | -19.55833 | 60 |
| 1990 | F&B | 900267 | 118.07500 | -19.47667 | 118.08833 | -19.50000 | 66 |
| 1990 | F&B | 900269 | 118.20833 | -19.32500 | 118.22500 | -19.33833 | 76 |
| 1990 | F&B | 9002106 | 117.04333 | -19.45500 | 117.02500 | -19.47667 | 100 |
| 1990 | F&B | 9002107 | 117.00000 | -19.51000 | 117.03833 | -19.54500 | 78 |
| 1990 | F&B | 9002109 | 116.93833 | -19.74167 | 116.91667 | -19.72833 | 67 |
| 1990 | F&B | 9002110 | 116.81333 | -19.73667 | 116.80000 | -19.71333 | 66 |
| 1990 | F&B | 9002119 | 115.96667 | -20.26667 | 115.97000 | -20.23167 | 47 |
| 1990 | F&B | 9002123 | 116.03000 | -19.96333 | 116.05333 | -19.95500 | 66 |
| 1990 | F&B | 9002138 | 116.69000 | -19.45333 | 116.67167 | -19.47000 | 82 |
| 1990 | F&B | 9002141 | 116.60667 | -19.55667 | 116.58667 | -19.57500 | 63 |
| 1990 | F&B | 9002161 | 116.71000 | -20.20667 | 116.73167 | -20.21667 | 44 |
| 1990 | F&B | 9002162 | 115.92500 | -20.65000 | 115.93167 | -20.62167 | 26 |
| 1990 | F&B | 9002163 | 115.90667 | -20.60500 | 115.91333 | -20.62833 | 27 |
| 1990 | F&B | 9002164 | 115.74167 | -20.60000 | 115.71667 | -20.60667 | 26 |
| 1990 | F&B | 9002167 | 115.75833 | -20.66333 | 115.78000 | -20.65000 | 20 |
| 1990 | F&B | 9002168 | 116.01333 | -20.60000 | 116.04333 | -20.59833 | 26 |
| 1990 | F&B | 9002169 | 116.00667 | -20.54167 | 116.02500 | -20.52500 | 30 |
| 1990 | F&B | 9002174 | 117.71500 | -20.05500 | 117.74167 | -20.03667 | 40 |
| 1990 | F&B | 9002176 | 117.95000 | -20.05500 | 117.96833 | -20.03333 | 35 |
| 1991 | F&B | 910426 | 115.75833 | -20.27000 | 115.77833 | -20.28667 | 47 |
| 1991 | F&B | 910430 | 116.15333 | -19.75000 | 116.12667 | -19.73833 | 71 |

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|---|---|---|---|---|---|---|---|
| 1991 | F&B | 910437 | 116.36000 | -20.06167 | 116.34333 | -20.03167 | 52 |
| 1991 | F&B | 910439 | 116.26000 | -20.21333 | 116.25500 | -20.24000 | 48 |
| 1991 | F&B | 910441 | 116.04000 | -20.16833 | 116.04333 | -20.19667 | 54 |
| 1991 | F&B | 910444 | 116.41500 | -20.31167 | 116.42833 | -20.33500 | 41 |
| 1991 | F&B | 910445 | 116.77500 | -20.21500 | 116.80333 | -20.20667 | 44 |
| 1991 | F&B | 910446 | 116.65833 | -20.14833 | 116.67833 | -20.16833 | 49 |
| 1991 | F&B | 910447 | 116.64500 | -20.04167 | 116.63167 | -20.02167 | 54 |
| 1991 | F&B | 910448 | 116.60167 | -19.95667 | 116.58500 | -19.94000 | 56 |
| 1991 | F&B | 910449 | 116.57167 | -19.87500 | 116.59333 | -19.88333 | 58 |
| 1991 | F&B | 910450 | 116.81667 | -19.97833 | 116.82500 | -20.00167 | 56 |
| 1991 | F&B | 910451 | 116.87333 | -20.11000 | 116.89667 | -20.11500 | 47 |
| 1991 | F&B | 910458 | 117.10333 | -19.55500 | 117.08167 | -19.56500 | 75 |
| 1991 | F&B | 910460 | 116.86500 | -19.55167 | 116.89333 | -19.53667 | 74 |
| 1991 | F&B | 910461 | 116.80833 | -19.62000 | 116.78833 | -19.63667 | 46 |
| 1991 | F&B | 910462 | 116.86667 | -19.72667 | 116.87000 | -19.74833 | 73 |
| 1991 | F&B | 910463 | 116.95333 | -19.75500 | 116.97667 | -19.76833 | 66 |
| 1991 | F&B | 910464 | 117.25000 | -20.07167 | 117.22333 | -20.08000 | 44 |
| 1991 | F&B | 910466 | 116.99667 | -20.22333 | 117.03167 | -20.23500 | 36 |
| 1991 | F&B | 910467 | 116.99667 | -20.20167 | 117.00000 | -20.17333 | 38 |
| 1991 | F&B | 910469 | 117.30167 | -20.33833 | 117.31667 | -20.31333 | 27 |
| 1991 | F&B | 910470 | 117.32167 | -20.21000 | 117.33500 | -20.18333 | 35 |
| 1991 | F&B | 910471 | 117.49833 | -20.24833 | 117.51667 | -20.24667 | 30 |
| 1991 | F&B | 910472 | 117.49500 | -19.95667 | 117.48833 | -19.93167 | 45 |
| 1991 | F&B | 910473 | 117.48333 | -19.90833 | 117.48833 | -19.89500 | 50 |
| 1991 | F&B | 910474 | 117.60167 | -19.66167 | 117.61000 | -19.64167 | 61 |
| 1991 | F&B | 910476 | 117.37333 | -19.50500 | 117.38333 | -19.48167 | 79 |
| 1991 | F&B | 910489 | 117.79167 | -19.90667 | 117.77500 | -19.93500 | 44 |
| 1991 | F&B | 910490 | 117.76667 | -19.99833 | 117.79500 | -20.00333 | 41 |
| 1991 | F&B | 910491 | 117.71167 | -20.06000 | 117.73833 | -20.08833 | 40 |
| 1991 | F&B | 910493 | 117.72500 | -20.03500 | 117.73833 | -20.00333 | 41 |
| 1991 | F&B | 910494 | 117.91500 | -19.98000 | 117.92167 | -19.94833 | 38 |
| 1991 | F&B | 910495 | 117.97667 | -19.80000 | 118.01667 | -19.80333 | 46 |
| 1991 | F&B | 910496 | 118.04667 | -19.82500 | 118.04833 | -19.84833 | 42 |
| 1995 | McK | 95083 | | | 117.46167 | -20.06000 | 42 |
| 1995 | McK | 95084 | | | 117.37333 | -20.28000 | 27 |
| 1995 | McK | 95086 | | | 117.10500 | -20.15833 | 43 |
| 1995 | McK | 950819 | 115.76667 | -20.16167 | 115.79000 | -20.15833 | 61 |
| 1995 | McK | 950835 | 116.12167 | -20.35167 | 116.10333 | -20.34167 | 41 |
| 1995 | McK | 950837 | 116.06500 | -20.14667 | 116.05833 | -20.12167 | 55 |
| 1995 | McK | 950839 | 116.06500 | -20.02167 | 116.10000 | -20.02833 | 59 |
| 1995 | McK | 950841 | 116.45833 | -19.70167 | 116.48667 | -19.72167 | 62 |
| 1995 | McK | 950842 | 116.50000 | -19.71667 | 116.53333 | -19.69833 | 60 |
| 1995 | McK | 950843 | 116.55833 | -19.66167 | 116.55833 | -19.63333 | 56 |
| 1995 | McK | 950844 | 116.66000 | -19.51833 | 116.68333 | -19.52500 | 64 |
| 1995 | McK | 950845 | 116.69833 | -19.67667 | 116.69500 | -19.70500 | 46 |
| 1995 | McK | 950847 | 116.77000 | -19.78500 | 116.77000 | -19.81000 | 65 |
| 1995 | McK | 950848 | 116.75000 | -20.06167 | 116.72167 | -20.06833 | 52 |
| 1995 | McK | 950849 | 116.54667 | -20.05667 | 116.54667 | -20.02500 | 56 |

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|---|---|---|---|---|---|---|---|
| 1995 | McK | 950850 | 116.55000 | -19.95667 | 116.54500 | -19.98667 | 59 |
| 1995 | McK | 950851 | 116.30333 | -20.15167 | 116.29667 | -20.17667 | 51 |
| 1995 | McK | 950854 | 116.49667 | -20.30500 | 116.47333 | -20.31000 | 40 |
| 1995 | McK | 950855 | 116.52333 | -20.34833 | 116.55500 | -20.34833 | 39 |
| 1995 | McK | 950857 | 116.85333 | -20.20000 | 116.87500 | -20.19000 | 41 |
| 1995 | McK | 950865 | 117.24833 | -19.57500 | 117.25667 | -19.60167 | 74 |
| 1995 | McK | 950879 | 117.61667 | -19.30167 | 117.60500 | -19.32667 | 88 |
| 1995 | McK | 950880 | 117.57167 | -19.47000 | 117.59000 | -19.48500 | 80 |
| 1995 | McK | 950883 | 118.09333 | -19.71000 | 118.07333 | -19.73167 | 50 |
| 1995 | McK | 950884 | 118.10833 | -19.69500 | 118.09167 | -19.68333 | 52 |
| 1995 | McK | 950885 | 118.13167 | -19.66833 | 118.15833 | -19.68333 | 51 |
| 1995 | McK | 950886 | 118.17000 | -19.62667 | 118.19667 | -19.64000 | 56 |
| 1995 | McK | 950887 | 118.22000 | -19.74167 | 118.24667 | -19.76667 | 35 |
| 1995 | McK | 950894 | 117.93667 | -20.16333 | 117.91167 | -20.16667 | 25 |
| 1995 | McK | 950895 | 117.80833 | -20.23167 | 117.84000 | -20.21833 | 23 |
| 1995 | McK | 950896 | 117.83500 | -20.19833 | 117.86167 | -20.20667 | 28 |
| 1995 | McK | 950898 | 118.21333 | -20.01167 | 118.23000 | -19.96667 | 27 |
| 1995 | McK | 9508111 | 118.00167 | -19.40333 | 118.05000 | -19.41000 | 69 |
| 1997 | McK | 97071 | | | 116.97333 | -20.09833 | 44 |
| 1997 | McK | 97072 | | | 117.07167 | -20.00667 | 50 |
| 1997 | McK | 97075 | | | 116.80667 | -19.83000 | 69 |
| 1997 | McK | 970712 | 116.75000 | -19.46667 | 116.79000 | -19.45167 | 72 |
| 1997 | McK | 970713 | 116.73333 | -19.53333 | 116.73000 | -19.57000 | 50 |
| 1997 | McK | 970714 | 116.66833 | -19.71833 | 116.66167 | -19.74667 | 49 |
| 1997 | McK | 970715 | 116.62333 | -19.74833 | 116.59833 | -19.72833 | 53 |
| 1997 | McK | 970726 | 116.35000 | -19.67333 | 116.33167 | -19.70667 | 67 |
| 1997 | McK | 970731 | 115.95333 | -20.16667 | 115.93667 | -20.19167 | 56 |
| 1997 | McK | 970732 | 116.14333 | -20.21667 | 116.15333 | -20.19167 | 50 |
| 1997 | McK | 970739 | 115.66833 | -19.91500 | 115.70667 | -19.91167 | 79 |
| 1997 | McK | 970753 | 115.84833 | -20.42833 | 115.85333 | -20.40500 | 38 |
| 1997 | McK | 970754 | 115.85333 | -20.53500 | 115.85833 | -20.50833 | 33 |
| 1997 | McK | 970755 | 115.70667 | -20.61000 | 115.71833 | -20.57833 | 25 |
| 1997 | McK | 970756 | 116.04500 | -20.51167 | 116.00500 | -20.49667 | 32 |
| 1997 | McK | 970758 | 117.21667 | -20.37000 | 117.19500 | -20.35333 | 23 |
| 1997 | McK | 970761 | 117.45500 | -20.06000 | 117.42833 | -20.04333 | 43 |
| 1997 | McK | 970762 | 117.32333 | -20.06167 | 117.29000 | -20.06500 | 42 |
| 1997 | McK | 970764 | 116.51333 | -20.25000 | 116.49000 | -20.24500 | 44 |
| 1997 | McK | 970765 | 116.26500 | -20.39500 | 116.28500 | -20.37667 | 38 |
| 1997 | McK | 970766 | 116.41833 | -20.38833 | 116.45000 | -20.36167 | 38 |
| 1997 | McK | 970767 | 116.56167 | -20.33000 | 116.52667 | -20.33000 | 37 |
| 1997 | McK | 970768 | 117.46167 | -20.03667 | 117.45000 | -20.01667 | 42 |
| 1997 | McK | 970781 | 117.60667 | -19.66167 | 117.63333 | -19.70333 | 64 |
| 1997 | McK | 970782 | 117.81000 | -19.62167 | 117.84500 | -19.63167 | 60 |
| 1997 | McK | 970783 | 118.00500 | -19.61333 | 117.96667 | -19.63500 | 57 |
| 1997 | McK | 970784 | 117.55833 | -20.16333 | 117.54333 | -20.18333 | 33 |
| 1997 | McK | 970785 | 117.69167 | -20.15000 | 117.73000 | -20.16167 | 32 |
| 1997 | McK | 970786 | 117.70000 | -20.10833 | 117.74000 | -20.10333 | 33 |
| 1997 | McK | 970787 | 117.84333 | -20.05167 | 117.80833 | -20.05833 | 35 |

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|---|---|---|---|---|---|---|---|
| 1997 | McK | 970788 | 117.85500 | -19.90833 | 117.81833 | -19.92167 | 46 |
| 1997 | McK | 970789 | 117.71167 | -19.85000 | 117.73500 | -19.82667 | 51 |
| 1997 | McK | 9707102 | 117.81500 | -19.71333 | 117.84667 | -19.71333 | 53 |
| 1997 | McK | 9707103 | 118.29333 | -19.71000 | 118.08500 | -19.69333 | 50 |
| 1997 | McK | 9707104 | 118.14667 | -19.75667 | 118.11667 | -19.77500 | 43 |
| 1997 | McK | 9707105 | 118.27167 | -19.83167 | 118.24833 | -19.83167 | 33 |
| 1997 | McK | 9707106 | 118.27500 | -19.94833 | 118.25500 | -19.95500 | 26 |

# Appendix F Data tables and figures of fish analyses

## F.1 Fish species selected for analyses

Total species pool of 254 fish species for regional assemblage analyses showing ranked biomass, total occurrences (occ.), total weight, rank and occurrence by number of surveys. The four key genera are indicated (*).

**Apx Table 6. Total species pool of 254 fish species for regional assemblage analyses showing ranked biomass, total occurrences (occ.), total weight, rank and occurrence by number of surveys. The four key genera are indicated (*).**

| Scientific name | Common name | Family | Gen | CAAB | Total occ. | Total catch weight (kg) | Rank by biomass | Occ. in no. Surveys |
|---|---|---|---|---|---|---|---|---|
| *Lethrinus nebulosus & Lethrinus sp.* | Spangled emperor | Lethrinidae | * | 37351904 | 353 | 12183.3 | 1 | 8 |
| *Nemipterus furcosus* | Rosy Threadfin Bream | Nemipteridae | * | 37347005 | 532 | 9492.88 | 2 | 8 |
| *Saurida undosquamis* | Largescale Saury | Synodontidae | * | 37118001 | 609 | 6970.25 | 3 | 8 |
| *Abalistes stellatus* | Starry Triggerfish | Balistidae | | 37465011 | 610 | 6019.79 | 4 | 8 |
| *Lutjanus sebae* | Red Emperor | Lutjanidae | * | 37346004 | 328 | 3727.34 | 5 | 8 |
| *Diagramma pictum* | Painted Sweetlips | Haemulidae | | 37350003 | 245 | 3597.23 | 6 | 8 |
| *Pentapodus porosus* | Northwest Threadfin Bream | Nemipteridae | | 37347007 | 253 | 3318.23 | 7 | 8 |
| *Saurida cf filamentosa* | Threadfin Saury | Synodontidae | * | 37118006 | 262 | 2998.39 | 8 | 8 |
| *Upeneus moluccensis* | Goldband Goatfish | Mullidae | | 37355003 | 136 | 2957.4 | 9 | 8 |
| *Lutjanus vitta* | Brownstripe Snapper | Lutjanidae | * | 37346003 | 369 | 2587.93 | 10 | 8 |
| *Lutjanus malabaricus* | Saddletail Snapper | Lutjanidae | * | 37346007 | 149 | 1870.41 | 11 | 8 |
| *Selaroides leptolepis* | Yellowstripe Scad | Carangidae | | 37337015 | 122 | 1789.2 | 12 | 8 |
| *Pristipomoides multidens* | Goldband Snapper | Lutjanidae | | 37346002 | 188 | 1692.42 | 13 | 8 |
| *Parupeneus heptacanthus* | Opalescent Goatfish | Mullidae | | 37355004 | 432 | 1690.54 | 14 | 8 |
| *Scolopsis monogramma* | Rainbow Monocle Bream | Nemipteridae | | 37347006 | 282 | 1643.8 | 15 | 8 |
| *Argyrops bleekeri* | Frypan Bream | Sparidae | | 37353006 | 448 | 1634.12 | 16 | 8 |
| *Lethrinus genivittatus* | Threadfin Emperor | Lethrinidae | * | 37351002 | 152 | 1501.52 | 17 | 8 |
| *Priacanthus hamrur* | Lunartail Bigeye | Priacanthidae | | 37326005 | 452 | 1341.53 | 18 | 8 |
| *Chaetodontoplus duboulayi* | Scribbled Angelfish | Pomacanthidae | | 37365009 | 260 | 1282.03 | 19 | 8 |
| *Pentaprion longimanus* | Longfin Silverbiddy | Gerreidae | | 37349002 | 194 | 1209.18 | 20 | 8 |
| *Rhynchobatus spp.* | A wedgefish | Rhinidae | | 37026900 | 94 | 1195.94 | 21 | 8 |
| *Ariomma indicum* | Indian Driftfish | Ariommatidae | | 37447007 | 70 | 1131.69 | 22 | 8 |
| *Photopectoralis bindus* | Orangefin Ponyfish | Leiognathidae | | 37341002 | 146 | 1128.75 | 23 | 8 |
| *Nemipterus bathybius* | Yellowbelly Threadfin Bream | Nemipteridae | * | 37347001 | 194 | 1103.39 | 24 | 8 |
| *Gymnocranius grandoculis* | Robinson's Seabream | Lethrinidae | | 37351005 | 37 | 1071.42 | 25 | 8 |
| *Epinephelus multinotatus* | Rankin Cod | Serranidae | | 37311010 | 158 | 1065.35 | 26 | 8 |

| Scientific name | Common name | Family | Gen | CAAB | Total occ. | Total catch weight (kg) | Rank by biomass | Occ. in no. Surveys |
|---|---|---|---|---|---|---|---|---|
| *Himantura spp.* | | Dasyatidae | | 37035902 | 47 | 1046.71 | 27 | 6 |
| *Upeneus guttatus* | Orange-barred goatfish | Mullidae | | 37355008 | 444 | 1033.63 | 28 | 8 |
| *Carangoides caeruleopinnatus* | Onion Trevally | Carangidae | | 37337021 | 255 | 1015.36 | 29 | 8 |
| *Lutjanus argentimaculatus* | Mangrove Jack | Lutjanidae | * | 37346015 | 11 | 1009.12 | 30 | 3 |
| *Lutjanus quinquelineatus* | Fiveline Snapper | Lutjanidae | * | 37346006 | 15 | 907.21 | 31 | 3 |
| *Bathytoshia lata* | Black Stingray | Dasyatidae | | 37035002 | 6 | 900 | 32 | 1 |
| *Priacanthus tayenus* | Purplespotted Bigeye | Priacanthidae | | 37326003 | 164 | 897.84 | 33 | 8 |
| *Choerodon cauteroma* | Bluespotted Tuskfish | Labridae | | 37384005 | 255 | 894.56 | 34 | 8 |
| *Nemipterus celebicus* | Celebes Threadfin Bream | Nemipteridae | * | 37347004 | 503 | 846.33 | 35 | 8 |
| *Taeniurops meyeni* | Blotched Fantail Ray | Dasyatidae | | 37035017 | 6 | 835 | 36 | 2 |
| *Netuma thalassina* | Giant Sea Catfish | Ariidae | | 37188001 | 104 | 793.68 | 37 | 8 |
| *Chaetodontoplus personifer* | Yellowtail Angelfish | Pomacanthidae | | 37365008 | 368 | 781.99 | 38 | 8 |
| *Siganus fuscescens* | Black Rabbitfish | Siganidae | | 37438001 | 189 | 739.07 | 39 | 8 |
| *Sargocentron rubrum* | Red Squirrelfish | Holocentridae | | 37261001 | 78 | 704.1 | 40 | 8 |
| *Stegostoma tigrinum* | Zebra Shark | Stegostomatidae | | 37013006 | 19 | 685.2 | 41 | 6 |
| *Platax batavianus* | Humphead Batfish | Ephippidae | | 37362002 | 195 | 647.43 | 42 | 8 |
| *Lutjanus sp. (in Yearsley. Last & Ward. 1999)* | Russell's snapper | Lutjanidae | * | 37346012 | 184 | 640.1 | 43 | 8 |
| *Pristotis obtusirostris* | Gulf Damsel | Pomacentridae | | 37372001 | 292 | 625.03 | 44 | 8 |
| *Pateobatis fai* | Pink Whipray | Dasyatidae | | 37035024 | 2 | 620 | 45 | 1 |
| *Upeneus australiae* | Australian Goatfish | Mullidae | | 37355032 | 136 | 608.66 | 46 | 8 |
| *Epinephelus areolatus* | Yellowspotted Rockcod | Serranidae | | 37311009 | 278 | 596.87 | 47 | 8 |
| *Pterocaesio chrysozona* | Yellowband Fusilier | Caesionidae | | 37346009 | 173 | 584.55 | 48 | 8 |
| *Pseudorhombus dupliciocellatus* | Three Twinspot Flounder | Paralichthyidae | | 37460004 | 439 | 583.78 | 49 | 8 |
| *Glaucosoma buergeri* | Northern Pearl Perch | Glaucosomatidae | | 37320001 | 126 | 579.61 | 50 | 8 |
| *Acropoma japonicum* | Japanese Seabass | Acropomatidae | | 37311167 | 103 | 558.24 | 51 | 8 |
| *Selar boops* | Oxeye Scad | Carangidae | | 37337008 | 33 | 515.76 | 52 | 5 |
| *Scarus ghobban* | Bluebarred Parrotfish | Scaridae | | 37386001 | 154 | 475.47 | 53 | 8 |
| *Gnathanodon speciosus* | Golden Trevally | Carangidae | | 37337012 | 24 | 458.21 | 54 | 4 |
| *Plectropomus maculatus* | Barcheek Coral Trout | Serranidae | | 37311012 | 132 | 456.61 | 55 | 8 |
| *Lutjanus erythropterus* | Crimson Snapper | Lutjanidae | * | 37346005 | 60 | 455.04 | 56 | 8 |
| *Nemipterus virgatus* | Golden Threadfin Bream | Nemipteridae | * | 37347009 | 149 | 429.37 | 57 | 8 |
| *Lethrinus lentjan* | Redspot Emperor | Lethrinidae | * | 37351007 | 64 | 428.31 | 58 | 8 |
| *Carangoides gymnostethus* | Bludger Trevally | Carangidae | | 37337022 | 256 | 385.54 | 59 | 8 |
| *Choerodon cephalotes* | Purple Tuskfish | Labridae | | 37384004 | 161 | 377.9 | 60 | 8 |
| *Gymnocranius elongatus* | Swallowtail Seabream | Lethrinidae | | 37351010 | 226 | 362.15 | 61 | 8 |
| *Saurida grandisquamis* | Grey Saury | Synodontidae | * | 37118016 | 419 | 358.09 | 62 | 8 |
| *Carangoides chrysophrys* | Longnose Trevally | Carangidae | | 37337011 | 148 | 353.82 | 63 | 8 |
| *Carangoides equula* | Whitefin Trevally | Carangidae | | 37337013 | 206 | 348.08 | 64 | 8 |

| **Scientific name** | **Common name** | **Family** | **Gen** | **CAAB** | **Total occ.** | **Total catch weight (kg)** | **Rank by biomass** | **Occ. in no. Surveys** |
|---|---|---|---|---|---|---|---|---|
| *Nemipterus peronii* | Notched Threadfin Bream | Nemipteridae | * | 37347003 | 189 | 343.99 | 65 | 8 |
| *Hemigaleus australiensis* | Weasel Shark | Hemigaleidae | | 37018020 | 111 | 332.37 | 66 | 8 |
| *Epinephelus coioides* | Goldspotted Rockcod | Serranidae | | 37311007 | 34 | 314.12 | 67 | 7 |
| *Parachaetodon ocellatus* | Ocellate Butterflyfish | Chaetodontidae | | 37365003 | 399 | 301.79 | 68 | 8 |
| *Parupeneus indicus* | Yellowspot Goatfish | Mullidae | | 37355005 | 108 | 295.49 | 69 | 8 |
| *Rachycentron canadum* | Cobia | Rachycentridae | | 37335001 | 47 | 294.94 | 70 | 8 |
| *Carcharhinus plumbeus* | Sandbar Shark | Carcharhinidae | | 37018007 | 11 | 291.47 | 71 | 2 |
| *Gymnocranius griseus* | Grey Seabream | Lethrinidae | | 37351003 | 48 | 291.33 | 72 | 6 |
| *Maculabatis astra* | Blackspotted Whipray | Dasyatidae | | 37035020 | 17 | 277.4 | 73 | 2 |
| *Pseudorhombus diplospilus* | Bigtooth Twinspot Flounder | Paralichthyidae | | 37460015 | 287 | 264.6 | 74 | 8 |
| *Sphyraena putnamae* | Military Barracuda | Sphyraenidae | | 37382006 | 20 | 257.87 | 75 | 5 |
| *Lagocephalus sceleratus* | Silver Toadfish | Tetraodontidae | | 37467007 | 211 | 252.1 | 76 | 8 |
| *Dentex spariformis* | Yellowback Bream | Sparidae | | 37353002 | 22 | 245.28 | 77 | 6 |
| *Acanthurus grammoptilus* | Inshore Surgeonfish | Acanthuridae | | 37437002 | 117 | 230.37 | 78 | 8 |
| *Pomadasys kaakan* | Barred Javelin | Haemulidae | | 37350011 | 3 | 228.81 | 79 | 1 |
| *Ostracion nasus* | Shortnose Boxfish | Ostraciidae | | 37466005 | 256 | 227.46 | 80 | 8 |
| *Lethrinus variegatus* | Variegated Emperor | Lethrinidae | * | 37351014 | 19 | 223.94 | 81 | 6 |
| *Pristipomoides typus* | Sharptooth Snapper | Lutjanidae | | 37346019 | 38 | 218.87 | 82 | 5 |
| *Pomacanthus sexstriatus* | Sixband Angelfish | Pomacanthidae | | 37365010 | 59 | 217.94 | 83 | 8 |
| *Loxodon macrorhinus* | Sliteye Shark | Carcharhinidae | | 37018005 | 43 | 204.03 | 84 | 8 |
| *Sphyraena obtusata* | Yellowtail Barracuda | Sphyraenidae | | 37382007 | 21 | 201.13 | 85 | 2 |
| *Seriolina nigrofasciata* | Blackbanded Amberjack | Carangidae | | 37337014 | 171 | 200.86 | 86 | 8 |
| *Symphorus nematophorus* | Chinamanfish | Lutjanidae | | 37346017 | 40 | 200.45 | 87 | 7 |
| *Coradion chrysozonus* | Orangebanded Coralfish | Chaetodontidae | | 37365004 | 314 | 192.72 | 88 | 8 |
| *Rhina ancylostoma* | Shark Ray | Rhinidae | | 37026002 | 5 | 189.5 | 89 | 2 |
| *Carangoides malabaricus* | Malabar Trevally | Carangidae | | 37337005 | 58 | 184.66 | 90 | 5 |
| *Decapterus russelli* | Indian Scad | Carangidae | | 37337023 | 78 | 182.87 | 91 | 6 |
| *Epinephelus maculatus* | Highfin Grouper | Serranidae | | 37311011 | 137 | 177.51 | 92 | 7 |
| *Neotrygon australiae* | Bluespotted Maskray | Dasyatidae | | 37035004 | 63 | 174.74 | 93 | 8 |
| *Monocentris japonica* | Japanese Pineapplefish | Monocentrididae | | 37259002 | 29 | 172.89 | 94 | 4 |
| *Choerodon schoenleinii* | Blackspot Tuskfish | Labridae | | 37384010 | 28 | 170.35 | 95 | 5 |
| *Pseudomonacanthus peroni* | Potbelly Leatherjacket | Monacanthidae | | 37465020 | 197 | 168.65 | 96 | 8 |
| *Upeneus margarethae* | A goatfish | Mullidae | | 37355038 | 108 | 158.86 | 97 | 6 |
| *Rastrelliger kanagurta* | Mouth Mackerel | Scombridae | | 37441012 | 31 | 151.71 | 98 | 2 |
| *Pastinachus ater* | Cowtail Stingray | Dasyatidae | | 37035011 | 2 | 150 | 99 | 1 |
| *Trixiphichthys weberi* | Blacktip Tripodfish | Triacanthidae | | 37464001 | 245 | 142.07 | 100 | 8 |
| *Lactoria diaphana* | Roundbelly Cowfish | Ostraciidae | | 37466007 | 258 | 137.65 | 101 | 8 |
| *Dactyloptena macracanthus* | Mottled Flying Gurnard | Dactylopteridae | | 37308003 | 224 | 135.72 | 102 | 7 |
| *Sphyrna mokarran* | Great Hammerhead | Sphyrnidae | | 37019002 | 2 | 135 | 103 | 1 |

| **Scientific name** | **Common name** | **Family** | **Gen** | **CAAB** | **Total occ.** | **Total catch weight (kg)** | **Rank by biomass** | **Occ. in no. Surveys** |
|---|---|---|---|---|---|---|---|---|
| *Nemipterus nematopus* | Yellowtip Threadfin Bream | Nemipteridae | * | 37347002 | 36 | 134.5 | 104 | 4 |
| *Tragulichthys jaculiferus* | Longspine Porcupinefish | Diodontidae | | 37469004 | 101 | 134.38 | 105 | 8 |
| *Aptychotrema vincentiana* | Western Shovelnose Ray | Trygonorrhinidae | | 37027001 | 20 | 131.57 | 106 | 4 |
| *Aluterus monoceros* | Unicorn Leatherjacket | Monacanthidae | | 37465022 | 87 | 130.79 | 107 | 8 |
| *Pseudobalistes fuscus* | Yellowspotted Triggerfish | Balistidae | | 37465027 | 33 | 129.79 | 108 | 8 |
| *Lutjanus carponotatus* | Stripey Snapper | Lutjanidae | * | 37346011 | 30 | 127.95 | 109 | 6 |
| *Equulites elongatus* | Elongate Ponyfish | Leiognathidae | | 37341011 | 194 | 127.72 | 110 | 2 |
| *Sufflamen fraenatum* | Bridled Triggerfish | Balistidae | | 37465014 | 112 | 127.58 | 111 | 8 |
| *Parupeneus chrysopleuron* | Rosy Goatfish | Mullidae | | 37355016 | 117 | 126.7 | 112 | 6 |
| *Saurida argentea* | Shortfin Saury | Synodontidae | * | 37118005 | 90 | 126.5 | 113 | 7 |
| *Lagocephalus inermis* | Smooth Golden Toadfish | Tetraodontidae | | 37467008 | 118 | 126.07 | 114 | 8 |
| *Rhizoprionodon acutus* | Milk Shark | Carcharhinidae | | 37018006 | 36 | 124.85 | 115 | 7 |
| *Gymnura australis* | Australian Butterfly Ray | Gymnuridae | | 37037001 | 69 | 122.89 | 116 | 8 |
| *Lagocephalus lunaris* | Rough Golden Toadfish | Tetraodontidae | | 37467012 | 84 | 121.07 | 117 | 8 |
| *Lutjanus lutjanus* | Bigeye Snapper | Lutjanidae | * | 37346008 | 27 | 117.4 | 118 | 3 |
| *Pseudorhombus spinosus* | Spiny Flounder | Paralichthyidae | | 37460011 | 232 | 114.19 | 119 | 8 |
| *Neotrygon leylandi* | Painted Maskray | Dasyatidae | | 37035013 | 156 | 110.95 | 120 | 8 |
| *Antigonia capros* | Robust Deepsea Boarfish | Caproidae | | 37267004 | 5 | 110.84 | 121 | 2 |
| *Psettodes erumei* | Australian Halibut | Psettodidae | | 37457001 | 163 | 108.14 | 122 | 8 |
| *Rhinobatos sainsburyi* | Goldeneye Shovelnose Ray | Rhinobatidae | | 37027003 | 78 | 107.53 | 123 | 7 |
| *Sphyraena forsteri* | Blackspot Barracuda | Sphyraenidae | | 37382005 | 45 | 106.48 | 124 | 6 |
| *Lactoria cornuta* | Longhorn Cowfish | Ostraciidae | | 37466004 | 112 | 106.11 | 125 | 8 |
| *Glaucosoma magnificum* | Threadfin Pearl Perch | Glaucosomatidae | | 37320002 | 39 | 105.51 | 126 | 7 |
| *Fistularia petimba* | Rough Flutemouth | Fistulariidae | | 37278002 | 361 | 105.34 | 127 | 8 |
| *Lethrinus laticaudis* | Grass Emperor | Lethrinidae | * | 37351006 | 26 | 98.31 | 128 | 6 |
| *Atule mate* | Barred Yellowtail Scad | Carangidae | | 37337024 | 33 | 98.05 | 129 | 5 |
| *Diploprion bifasciatum* | Barred Soapfish | Grammistidae | | 37312002 | 101 | 94.37 | 130 | 7 |
| *Choerodon vitta* | Redstripe Tuskfish | Labridae | | 37384006 | 106 | 89.68 | 131 | 8 |
| *Chelmon marginalis* | Margined Coralfish | Chaetodontidae | | 37365007 | 135 | 88.86 | 132 | 8 |
| *Eubalichthys caeruleoguttatus* | Bluespotted Leatherjacket | Monacanthidae | | 37465018 | 119 | 85.85 | 133 | 6 |
| *Hapalogenys dampieriensis* | A grunter bream | Haemulidae | | 37350027 | 50 | 85.43 | 134 | 8 |
| *Selar crumenophthalmus* | Bigeye Scad | Carangidae | | 37337009 | 35 | 85.38 | 135 | 6 |
| *Grammatobothus spp.* | | Bothidae | | 37460909 | 287 | 84.99 | 136 | 7 |
| *Priacanthus macracanthus* | Spotted Bigeye | Priacanthidae | | 37326001 | 52 | 81.4 | 137 | 7 |
| *Echeneis naucrates* | Sharksucker | Echeneidae | | 37336001 | 114 | 81.27 | 138 | 7 |
| *Albula argentea* | Pacific Bonefish | Albulidae | | 37055001 | 2 | 80.24 | 139 | 1 |
| *Upeneus luzonius* | Luzon Goatfish | Mullidae | | 37355009 | 55 | 77.5 | 140 | 7 |

| **Scientific name** | **Common name** | **Family** | **Gen** | **CAAB** | **Total occ.** | **Total catch weight (kg)** | **Rank by biomass** | **Occ. in no. Surveys** |
|---|---|---|---|---|---|---|---|---|
| *Choerodon sugillatum* | Wedgetail Tuskfish | Labridae | | 37384009 | 211 | 73.83 | 141 | 6 |
| *Upeneus torres* | Japanese Goatfish | Mullidae | | 37355002 | 68 | 71.29 | 142 | 5 |
| *Carangoides fulvoguttatus* | Turrum | Carangidae | | 37337037 | 51 | 71.28 | 143 | 5 |
| *Lethrinus rubrioperculatus* | Spotcheek Emperor | Lethrinidae | * | 37351012 | 10 | 70.53 | 144 | 2 |
| *Lutjanus lemniscatus* | Darktail Snapper | Lutjanidae | * | 37346010 | 32 | 64.38 | 145 | 6 |
| *Trachinocephalus trachinus* | Painted Grinner | Synodontidae | | 37118002 | 262 | 61.14 | 146 | 5 |
| *Diodon holocanthus* | Freckled Porcupinefish | Diodontidae | | 37469005 | 35 | 60.48 | 147 | 6 |
| *Psenopsis humerosa* | Blackspot Butterfish | Centrolophidae | | 37445007 | 38 | 58.94 | 148 | 5 |
| *Decapterus macarellus* | Mackerel Scad | Carangidae | | 37337055 | 6 | 58.68 | 149 | 1 |
| *Trichiurus spp.* | A hairtail | Trichiuridae | | 37440901 | 59 | 58.28 | 150 | 5 |
| *Lethrinus olivaceus* | Longnose Emperor | Lethrinidae | * | 37351004 | 11 | 57.35 | 151 | 2 |
| *Pterois volitans* | Common Lionfish | Pteroidae | | 37287040 | 96 | 56.95 | 152 | 6 |
| *Choerodon monostigma* | Darkspot Tuskfish | Labridae | | 37384008 | 99 | 55.91 | 153 | 6 |
| *Heniochus diphreutes* | Schooling Bannerfish | Chaetodontidae | | 37365005 | 81 | 55.82 | 154 | 5 |
| *Mustelus spp.* | Gummy shark | Triakidae | | 37017901 | 23 | 55.56 | 155 | 4 |
| *Terapon theraps* | Largescale Grunter | Terapontidae | | 37321003 | 5 | 54.59 | 156 | 1 |
| *Lepidotrigla cf japonica* | red spot gurnard | Triglidae | | 37288010 | 267 | 53.26 | 157 | 6 |
| *Sphyraena pinguis* | Striped Barracuda | Sphyraenidae | | 37382001 | 37 | 53.23 | 158 | 5 |
| *Malakichthys levis* | Smooth Seabass | Acropomatidae | | 37311031 | 7 | 52.89 | 159 | 2 |
| *Velifer hypselopterus* | Highfin Veilfin | Veliferidae | | 37269002 | 76 | 49.37 | 160 | 5 |
| *Bodianus solatus* | A wrasse | Labridae | | 37384201 | 55 | 46.62 | 161 | 5 |
| *Caranx ignobilis* | Giant Trevally | Carangidae | | 37337027 | 3 | 46.59 | 162 | 1 |
| *Pseudorhombus argus* | Peacock Flounder | Paralichthyidae | | 37460038 | 81 | 45.13 | 163 | 3 |
| *Carcharhinus coatesi* | Whitecheek Shark | Carcharhinidae | | 37018009 | 14 | 44.71 | 164 | 5 |
| *Scolopsis meridiana* | Redspot Monocle Bream | Nemipteridae | | 37347008 | 50 | 44.38 | 165 | 4 |
| *Epinephelus amblycephalus* | Banded Grouper | Serranidae | | 37311015 | 19 | 44.18 | 166 | 4 |
| *Champsodon spp.* | | Champsodontidae | | 37401901 | 219 | 42.88 | 167 | 3 |
| *Eucrossorhinus dasypogon* | Tasselled Wobbegong | Orectolobidae | | 37013011 | 8 | 42.72 | 168 | 1 |
| *Pseudorhombus arsius* | Largetooth Flounder | Paralichthyidae | | 37460009 | 74 | 41.58 | 169 | 4 |
| *Lepidotrigla sp. 2 [in Sainsbury et al. 1985]* | mottled red spot gurnard | Triglidae | | 37288015 | 97 | 41.31 | 170 | 4 |
| *Plectorhinchus gibbosus* | Brown Sweetlips | Haemulidae | | 37350012 | 7 | 39.83 | 171 | 2 |
| *Feroxodon multistriatus* | Ferocious Puffer | Tetraodontidae | | 37467010 | 18 | 39.61 | 172 | 4 |
| *Arothron stellatus* | Starry Puffer | Tetraodontidae | | 37467014 | 17 | 38.61 | 173 | 3 |
| *Pseudomonacanthus elongatus* | Fourband Leatherjacket | Monacanthidae | | 37465029 | 49 | 37.64 | 174 | 4 |
| *Tetrosomus gibbosus* | Humpback Turretfish | Ostraciidae | | 37466006 | 194 | 37.01 | 175 | 5 |
| *Parupeneus ciliatus* | Diamondscale Goatfish | Mullidae | | 37355024 | 31 | 36.59 | 176 | 2 |
| *Pseudorhombus jenynsii* | Smalltooth Flounder | Paralichthyidae | | 37460002 | 69 | 34.73 | 177 | 3 |
| *Torquigener pallimaculatus* | Rusty-spotted Toadfish | Tetraodontidae | | 37467009 | 159 | 34.47 | 178 | 4 |
| *Uranoscopus cognatus* | Yellowtail Stargazer | Uranoscopidae | | 37400008 | 68 | 34.07 | 179 | 3 |
| *Cyclichthys spilostylus* | Spotbase Burrfish | Diodontidae | | 37469003 | 10 | 32.59 | 180 | 2 |

| Scientific name | Common name | Family | Gen | CAAB | Total occ. | Total catch weight (kg) | Rank by biomass | Occ. in no. Surveys |
|---|---|---|---|---|---|---|---|---|
| *Decapterus macrosoma* | Slender Scad | Carangidae | | 37337017 | 56 | 31.69 | 181 | 1 |
| *Chaetodermis penicilligerus* | Tasselled Leatherjacket | Monacanthidae | | 37465013 | 93 | 31.61 | 182 | 3 |
| *Parascolopsis tanyactis* | Longray Monocle Bream | Nemipteridae | | 37347010 | 85 | 30.25 | 183 | 4 |
| *Carangoides talamparoides* | Whitetongue Trevally | Carangidae | | 37337043 | 16 | 28.23 | 184 | 2 |
| *Ostracion rhinorhynchos* | Horn-nose Boxfish | Ostraciidae | | 37466009 | 16 | 26.95 | 185 | 3 |
| *Alepes apercna* | Smallmouth Scad | Carangidae | | 37337010 | 16 | 26.21 | 186 | 3 |
| *Uraspis uraspis* | Whitemouth Trevally | Carangidae | | 37337020 | 12 | 25.79 | 187 | 2 |
| *Branchiostegus sawakinensis* | Freckled Tilefish | Malacanthidae | | 37331001 | 31 | 25.28 | 188 | 4 |
| *Pseudorhombus quinquocellatus* | Five-eye Flounder | Paralichthyidae | | 37460025 | 94 | 24.88 | 189 | 3 |
| *Saurida longimanus* | Longfin Saury | Synodontidae | * | 37118014 | 44 | 24.58 | 190 | 3 |
| *Rhabdamia gracilis* | Slender Cardinalfish | Apogonidae | | 37327022 | 35 | 24.02 | 191 | 1 |
| *Caranx bucculentus* | Bluespotted Trevally | Carangidae | | 37337016 | 7 | 23.74 | 192 | 1 |
| *Gymnothorax cribroris cf (WA)* | Sieve Moray | Muraenidae | | 37060002 | 107 | 23.49 | 193 | 1 |
| *Epinephelus rivulatus* | Chinaman Rockcod | Serranidae | | 37311022 | 24 | 23.36 | 194 | 2 |
| *Dipterygonotus balteatus* | Mottled Fusilier | Caesionidae | | 37346013 | 64 | 22.58 | 195 | 2 |
| *Rhizoprionodon taylori* | Australian Sharpnose Shark | Carcharhinidae | | 37018024 | 8 | 21.75 | 196 | 1 |
| *Pseudorhombus elevatus* | Deep Flounder | Paralichthyidae | | 37460008 | 73 | 21 | 197 | 2 |
| *Zabidius novemaculeatus* | Shortfin Batfish | Ephippidae | | 37362003 | 6 | 20.35 | 198 | 1 |
| *Fistularia commersonii* | Smooth Flutemouth | Fistulariidae | | 37278001 | 76 | 20.02 | 199 | 1 |
| *Synodus sageneus* | Fishnet Lizardfish | Synodontidae | | 37118004 | 120 | 19.87 | 200 | 1 |
| *Lepidotrigla russelli* | Smooth Gurnard | Triglidae | | 37288016 | 37 | 19.72 | 201 | 1 |
| *Squalus spp.* | Greeneye dogfish | Squalidae | | 37020901 | 8 | 17.69 | 202 | 2 |
| *Herklotsichthys koningsbergeri* | Largespotted Herring | Clupeidae | | 37085007 | 2 | 17.63 | 203 | 1 |
| *Gymnocranius satoi* | spotted seabream | Lethrinidae | | 37351023 | 5 | 17.26 | 204 | 2 |
| *Satyrichthys rieffeli* | Spotted Armour Gurnard | Peristediidae | | 37288019 | 21 | 17.16 | 205 | 2 |
| *Pomadasys maculatus* | Blotched Javelin | Haemulidae | | 37350002 | 5 | 16.93 | 206 | 2 |
| *Chimaera ogilbyi* | Ogilby's Ghostshark | Chimaeridae | | 37042001 | 3 | 16.83 | 207 | 1 |
| *Caranx tille* | Tille Trevally | Carangidae | | 37337049 | 3 | 16.75 | 208 | 1 |
| *Pomacanthus imperator* | Emperor Angelfish | Pomacanthidae | | 37365014 | 22 | 16.68 | 209 | 1 |
| *Dactyloptena papilio* | Largespot Flying Gurnard | Dactylopteridae | | 37308001 | 61 | 16.62 | 210 | 1 |
| *Antigonia rubescens* | Sharpsnout Deepsea Boarfish | Caproidae | | 37267001 | 12 | 16.5 | 211 | 1 |
| *Squatina pseudocellata* | Western Angelshark | Squatinidae | | 37024005 | 7 | 16.49 | 212 | 1 |
| *Terapon jarbua* | Crescent Grunter | Terapontidae | | 37321002 | 38 | 16.31 | 213 | 1 |
| *Coradion altivelis* | Highfin Coralfish | Chaetodontidae | | 37365018 | 54 | 16.14 | 214 | 1 |
| *Scomberoides commersonnianus* | Giant Queenfish | Carangidae | | 37337032 | 5 | 15.99 | 215 | 1 |
| *Anampses lennardi* | Blue-and-yellow Wrasse | Labridae | | 37384016 | 56 | 15.81 | 216 | 1 |
| *Platycephalus westraliae* | Yellowtail Flathead | Platycephalidae | | 37296020 | 21 | 15.58 | 217 | 1 |

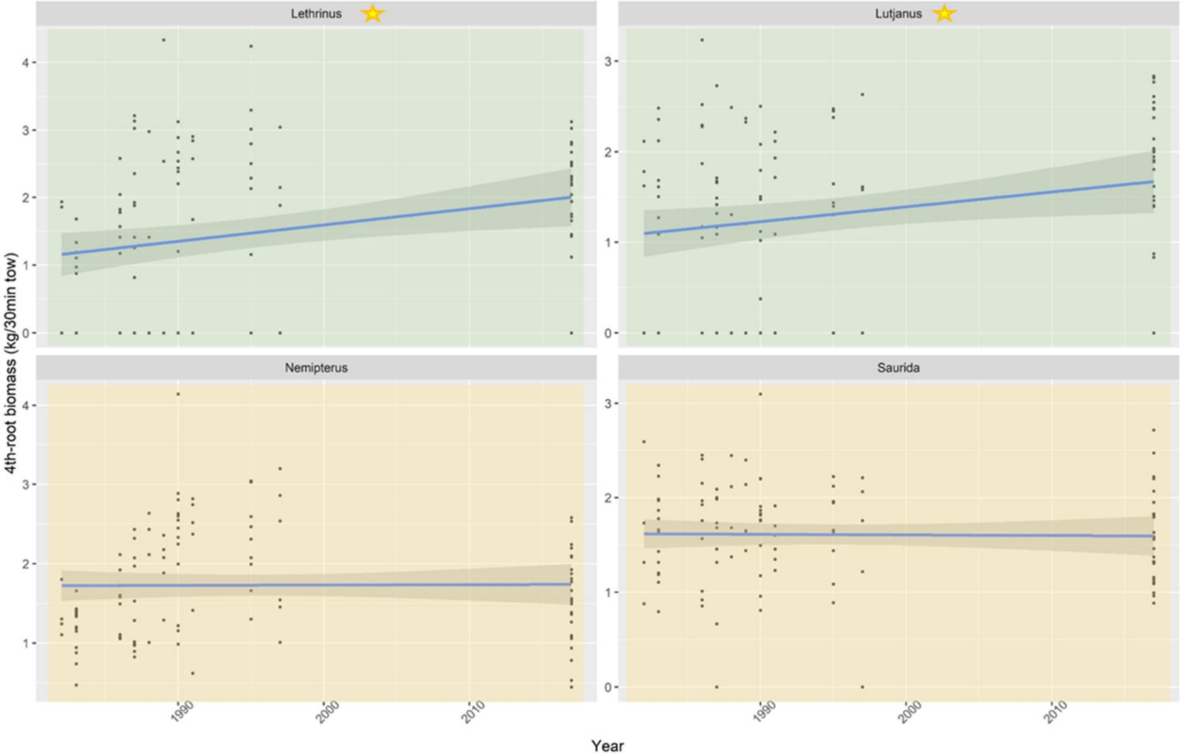
| Scientific name | Common name | Family | Gen | CAAB | Total occ. | Total catch weight (kg) | Rank by biomass | Occ. in no. Surveys |
|---|---|---|---|---|---|---|---|---|
| *Parastromateus niger* | Black Pomfret | Carangidae | | 37337072 | 19 | 15.54 | 218 | 3 |
| *Ostracion cubicus* | Yellow Boxfish | Ostraciidae | | 37466013 | 16 | 15.52 | 219 | 1 |
| *Parupeneus sp. [Last]* | yellow lined goatfish | Mullidae | | 37355006 | 2 | 15.51 | 220 | 1 |
| *Epinephelus quoyanus* | Longfin Rockcod | Serranidae | | 37311040 | 30 | 15.41 | 221 | 1 |
| *Dactyloptena peterseni* | Onespine Flying Gurnard | Dactylopteridae | | 37308002 | 25 | 15.39 | 222 | 2 |
| *Pterygotrigla elicryste* | Dwarf Gurnard | Triglidae | | 37288009 | 39 | 15.36 | 223 | 1 |
| *Dactyloptena orientalis* | Purple Flying Gurnard | Dactylopteridae | | 37308004 | 35 | 15.19 | 224 | 1 |
| *Ratabulus diversidens* | Freespine Flathead | Platycephalidae | | 37296011 | 15 | 15.17 | 225 | 1 |
| *Urolophus westraliensis* | Brown Stingaree | Urolophidae | | 37038009 | 9 | 14.95 | 226 | 1 |
| *Scomberomorus queenslandicus* | School Mackerel | Scombridae | | 37441014 | 13 | 14.54 | 227 | 1 |
| *Sillago analis* | Goldenline Whiting | Sillaginidae | | 37330003 | 24 | 14.14 | 228 | 2 |
| *Iniistius jacksonensis* | Keelhead Razorfish | Labridae | | 37384012 | 81 | 13.56 | 229 | 1 |
| *Engyprosopon maldivensis* | Olive Wide-eye Flounder | Bothidae | | 37460013 | 127 | 13.39 | 230 | 1 |
| *Aurigequula longispinis* | Longspine Ponyfish | Leiognathidae | | 37341004 | 15 | 13.03 | 231 | 1 |
| *Bovitrigla leptacanthus* | Bullhead Gurnard | Triglidae | | 37288014 | 9 | 12.84 | 232 | 1 |
| *Siganus punctatus* | Spotted Rabbitfish | Siganidae | | 37438003 | 7 | 12.35 | 233 | 1 |
| *Pentapodus nagasakiensis* | Japanese Threadfin Bream | Nemipteridae | | 37347012 | 56 | 12.07 | 234 | 1 |
| *Herklotsichthys lippa* | Smallspotted Herring | Clupeidae | | 37085008 | 9 | 11.91 | 235 | 1 |
| *Lophiomus setigerus* | Broadhead Goosefish | Lophiidae | | 37208001 | 32 | 11.02 | 236 | 1 |
| *Johnius borneensis* | River Jewfish | Sciaenidae | | 37354007 | 2 | 11 | 237 | 1 |
| *Malakichthys elegans* | Splendid Seabass | Acropomatidae | | 37311048 | 2 | 10.36 | 238 | 1 |
| *Epinephelus sexfasciatus* | Sixbar Grouper | Serranidae | | 37311017 | 33 | 9.91 | 239 | 1 |
| *Parascombrops philippinensis* | Sharptooth Seabass | Acropomatidae | | 37311028 | 22 | 9.83 | 240 | 1 |
| *Neosebastes occidentalis* | Orangebanded Gurnard Perch | Neosebastidae | | 37287009 | 16 | 9.61 | 241 | 1 |
| *Anoplocapros lenticularis* | Whitebarred Boxfish | Ostraciidae | | 37466010 | 6 | 9.51 | 242 | 2 |
| *Chiloscyllium punctatum* | Grey Carpetshark | Hemiscylliidae | | 37013008 | 6 | 9.44 | 243 | 1 |
| *Priacanthus fitchi* | Deepsea Bigeye | Priacanthidae | | 37326011 | 4 | 9.2 | 244 | 1 |
| *Heterodontus zebra* | Zebra Hornshark | Heterodontidae | | 37007002 | 6 | 8.79 | 245 | 1 |
| *Pelates quadrilineatus* | Fourline Striped Grunter | Terapontidae | | 37321001 | 7 | 8.36 | 246 | 1 |
| *Ulua aurochs* | Silvermouth Trevally | Carangidae | | 37337041 | 5 | 8.19 | 247 | 1 |
| *Gerres filamentosus* | Threadfin Silverbiddy | Gerreidae | | 37349003 | 15 | 8.1 | 248 | 1 |
| *Nemipterus isacanthus* | Teardrop Threadfin Bream | Nemipteridae | * | 37347019 | 2 | 7.17 | 249 | 1 |
| *Ostorhinchus fasciatus* | A cardinalfish]= | Apogonidae | | 37327158 | 36 | 7.02 | 250 | 1 |
| *Plectorhinchus flavomaculatus* | Goldspotted Sweetlips | Haemulidae | | 37350007 | 4 | 6.99 | 251 | 1 |
| *Paraulopus longianalis* | Yellow spotted cucumber fish | Paraulopidae | | 37120003 | 4 | 6.15 | 252 | 1 |
| *Heniochus acuminatus* | Longfin Bannerfish | Chaetodontidae | | 37365011 | 6 | 5.08 | 253 | 1 |
| *Epinephelus heniochus* | Threeline Rockcod | Serranidae | | 37311019 | 4 | 3.13 | 254 | 1 |

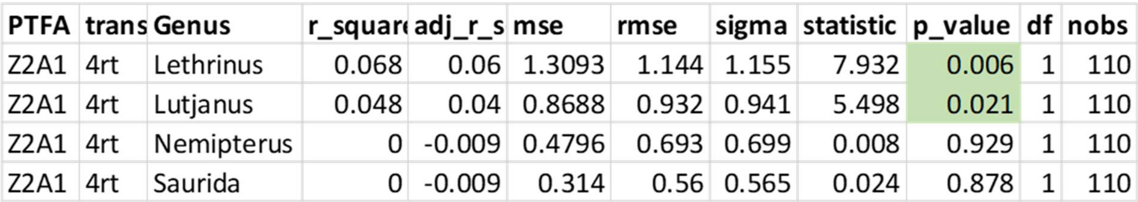
## F.2 Time series analysis plots

Collation of time-series plots and linear regression results of fish biomass (kg per 30 minute tow, 4th root transformed) for 4 PFTF Areas, the Barrow area and 6 TC areas for (1) Key Genera (N= 4), (2) Informative species (N=27), and (3) inner/mid-shelf assemblages (N=2).

### F.2.1 PTFA Areas

PTFA Z2A1:
Continuous
relatively high effort

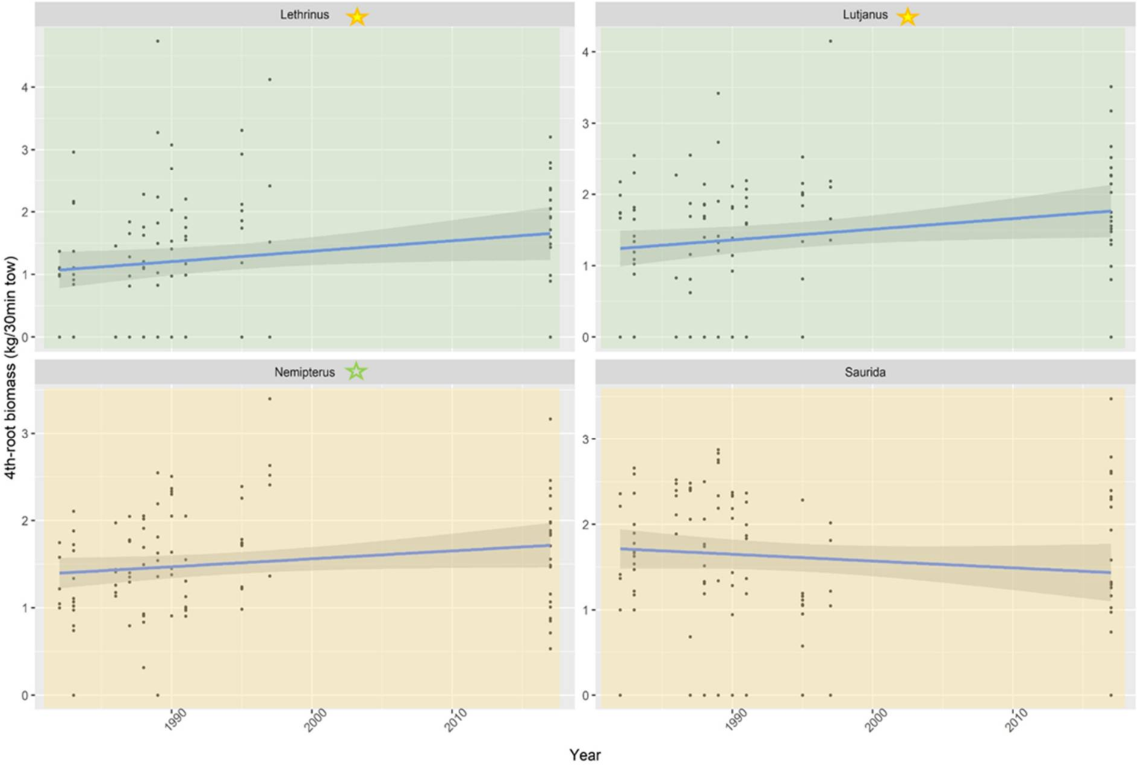


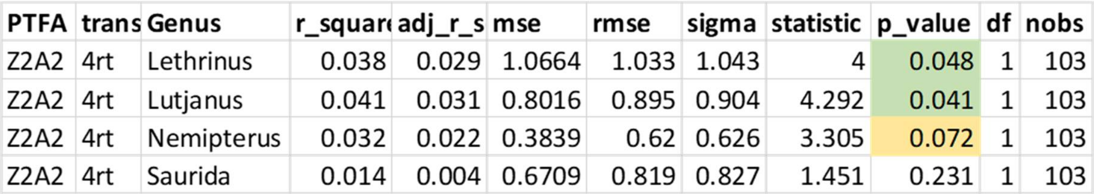


| PTFA | trans | Genus | r_square | adj_r_s | mse | rmse | sigma | statistic | p_value | df | nobs |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Z2A1 | 4rt | Lethrinus | 0.068 | 0.06 | 1.3093 | 1.144 | 1.155 | 7.932 | 0.006 | 1 | 110 |
| Z2A1 | 4rt | Lutjanus | 0.048 | 0.04 | 0.8688 | 0.932 | 0.941 | 5.498 | 0.021 | 1 | 110 |
| Z2A1 | 4rt | Nemipterus | 0 | -0.009 | 0.4796 | 0.693 | 0.699 | 0.008 | 0.929 | 1 | 110 |
| Z2A1 | 4rt | Saurida | 0 | -0.009 | 0.314 | 0.56 | 0.565 | 0.024 | 0.878 | 1 | 110 |

Apx Figure 1 PTFT Area 1 Key Genera (N= 4)

# PTFA Z2A2: Moderate/ low current effort

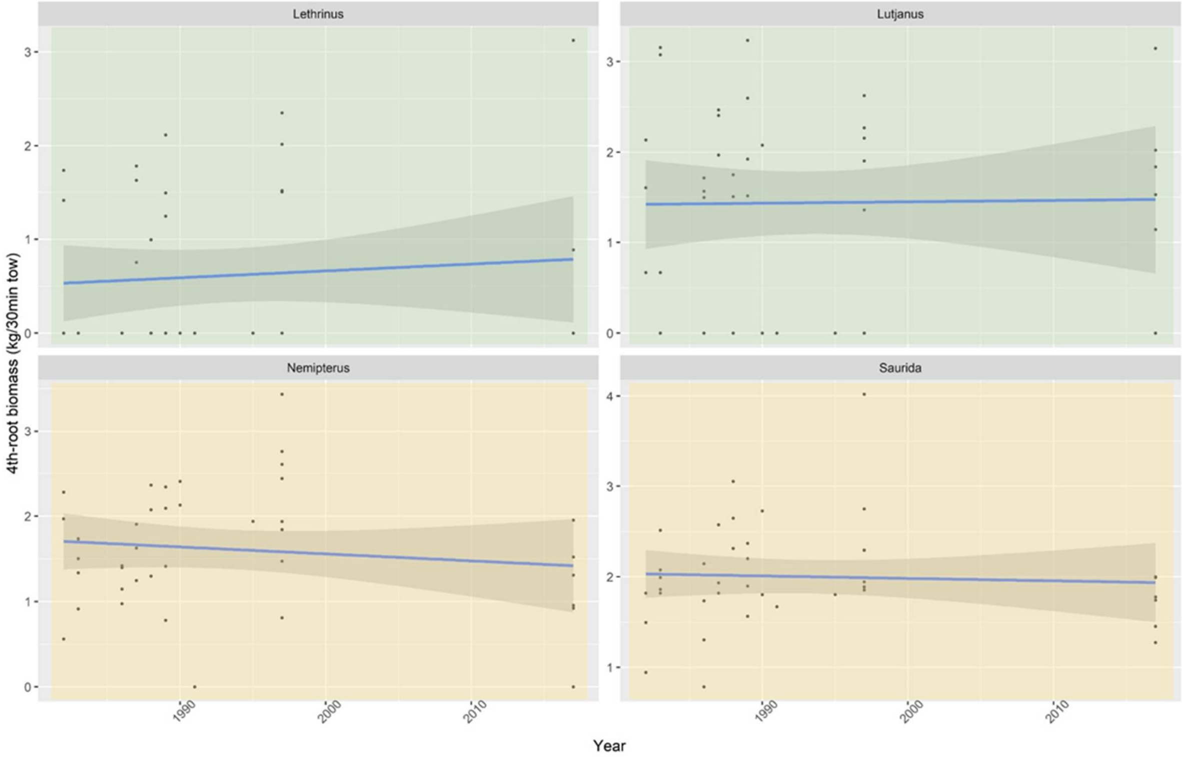


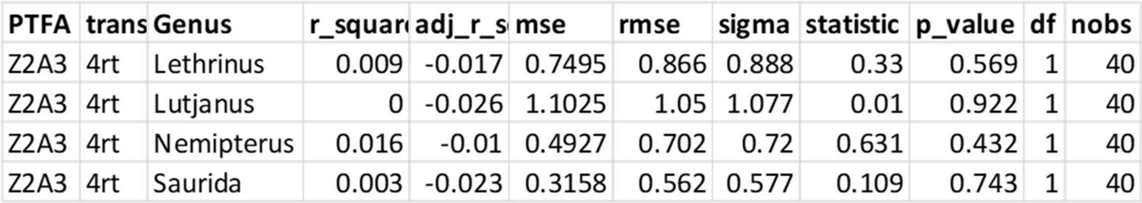


| PTFA | trans | Genus | r_squar | adj_r_s | mse | rmse | sigma | statistic | p_value | df | nobs |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Z2A2 | 4rt | Lethrinus | 0.038 | 0.029 | 1.0664 | 1.033 | 1.043 | 4 | 0.048 | 1 | 103 |
| Z2A2 | 4rt | Lutjanus | 0.041 | 0.031 | 0.8016 | 0.895 | 0.904 | 4.292 | 0.041 | 1 | 103 |
| Z2A2 | 4rt | Nemipterus | 0.032 | 0.022 | 0.3839 | 0.62 | 0.626 | 3.305 | 0.072 | 1 | 103 |
| Z2A2 | 4rt | Saurida | 0.014 | 0.004 | 0.6709 | 0.819 | 0.827 | 1.451 | 0.231 | 1 | 103 |

Apx Figure 2 PTFT Area 2 Key Genera (N= 4)

# PTFA Z2A3: Fishery closure

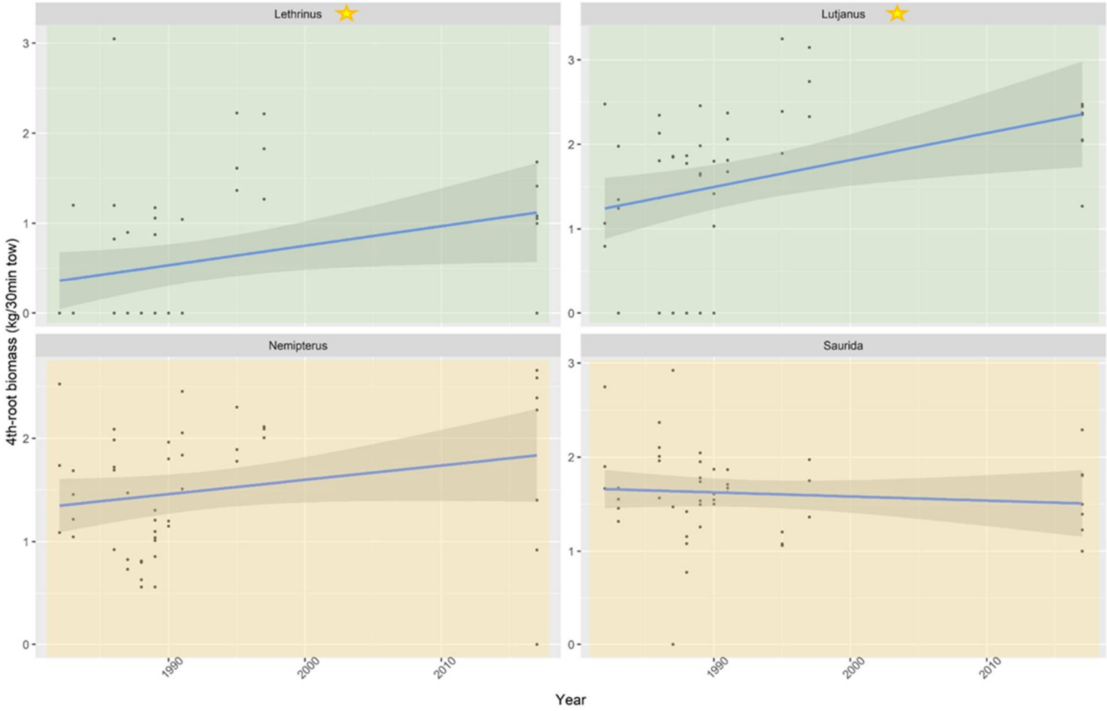




| PTFA | trans | Genus | r_squar | adj_r_s | mse | rmse | sigma | statistic | p_value | df | nobs |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Z2A3 | 4rt | Lethrinus | 0.009 | -0.017 | 0.7495 | 0.866 | 0.888 | 0.33 | 0.569 | 1 | 40 |
| Z2A3 | 4rt | Lutjanus | 0 | -0.026 | 1.1025 | 1.05 | 1.077 | 0.01 | 0.922 | 1 | 40 |
| Z2A3 | 4rt | Nemipterus | 0.016 | -0.01 | 0.4927 | 0.702 | 0.72 | 0.631 | 0.432 | 1 | 40 |
| Z2A3 | 4rt | Saurida | 0.003 | -0.023 | 0.3158 | 0.562 | 0.577 | 0.109 | 0.743 | 1 | 40 |

**Apx Figure 3 PFTF Area 3 Key Genera (N=4)**

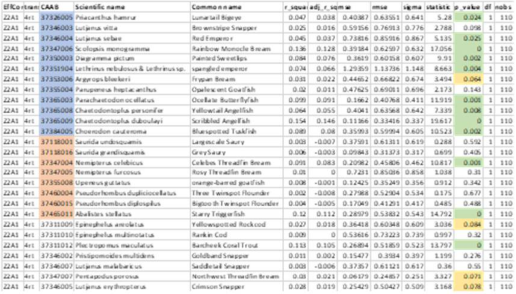
# PTFA Z2A4: Moderate/ low current effort



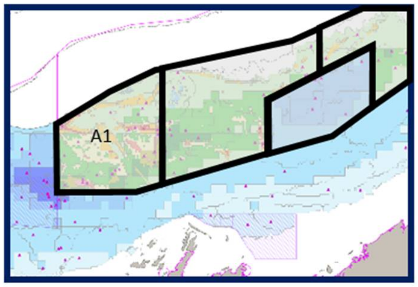
| PTFA | trans | Genus | r_squar | adj_r_s | mse | rmse | sigma | statistic | p_value | df | nobs |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Z2A4 | 4rt | Lethrinus | 0.09 | 0.069 | 0.5557 | 0.745 | 0.762 | 4.429 | 0.041 | 1 | 47 |
| Z2A4 | 4rt | Lutjanus | 0.141 | 0.122 | 0.7163 | 0.846 | 0.865 | 7.397 | 0.009 | 1 | 47 |
| Z2A4 | 4rt | Nemipterus | 0.057 | 0.036 | 0.3702 | 0.608 | 0.622 | 2.718 | 0.106 | 1 | 47 |
| Z2A4 | 4rt | Saurida | 0.01 | -0.012 | 0.2297 | 0.479 | 0.49 | 0.435 | 0.513 | 1 | 47 |

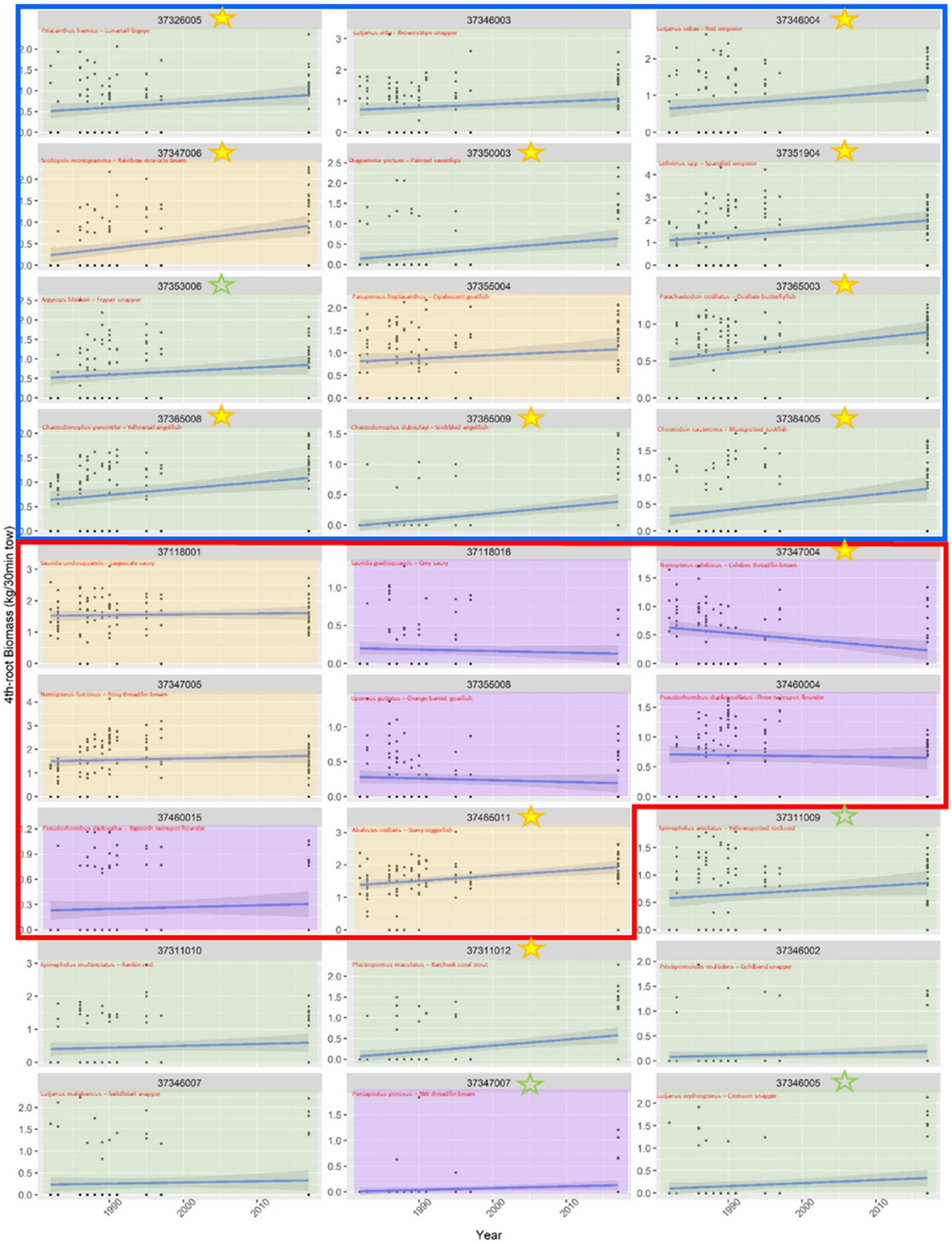
Apx Figure 4 PFTF Area 4 Key Genera (N=4)

# PTFA Z2A1: Continuous relatively high effort



| EffCo | rtran | CAAB | Scientific name | Common name | r_squar | adj_r_sq | mse | rmse | sigma | statistic | p_value | df | nobs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Z2A1 | 4rt | 37326005 | Priacanthus hamrur | Lunartail Bigeye | 0.047 | 0.038 | 0.40387 | 0.63551 | 0.641 | 5.28 | 0.024 | 1 | 110 |
| Z2A1 | 4rt | 37346003 | Lutjanus vitta | Brownstripe Snapper | 0.025 | 0.016 | 0.59156 | 0.76913 | 0.776 | 2.788 | 0.098 | 1 | 110 |
| Z2A1 | 4rt | 37346004 | Lutjanus sebae | Red Emperor | 0.045 | 0.037 | 0.73816 | 0.85916 | 0.867 | 5.135 | 0.025 | 1 | 110 |
| Z2A1 | 4rt | 37347006 | Scolopsis monogramma | Rainbow Monocle Bream | 0.136 | 0.128 | 0.39184 | 0.62597 | 0.632 | 17.056 | 0 | 1 | 110 |
| Z2A1 | 4rt | 37350003 | Diagramma pictum | Painted Sweetlips | 0.084 | 0.076 | 0.3619 | 0.60158 | 0.607 | 9.91 | 0.002 | 1 | 110 |
| Z2A1 | 4rt | 37351904 | Lethrinus nebulosus & Lethrinus sp. | spangled emperor | 0.074 | 0.066 | 1.29359 | 1.13736 | 1.148 | 8.663 | 0.004 | 1 | 110 |
| Z2A1 | 4rt | 37353006 | Argyrops bleekeri | Frypan Bream | 0.031 | 0.022 | 0.44652 | 0.66822 | 0.674 | 3.494 | 0.064 | 1 | 110 |
| Z2A1 | 4rt | 37355004 | Parupeneus heptacanthus | Opalescent Goatfish | 0.02 | 0.011 | 0.47625 | 0.69011 | 0.696 | 2.173 | 0.143 | 1 | 110 |
| Z2A1 | 4rt | 37365003 | Parachaetodon ocellatus | Ocellate Butterflyfish | 0.099 | 0.091 | 0.1662 | 0.40768 | 0.411 | 11.919 | 0.001 | 1 | 110 |
| Z2A1 | 4rt | 37365008 | Chaetodontoplus personifer | Yellowtail Angelfish | 0.064 | 0.055 | 0.4041 | 0.63568 | 0.642 | 7.339 | 0.008 | 1 | 110 |
| Z2A1 | 4rt | 37365009 | Chaetodontoplus duboulayi | Scribbled Angelfish | 0.154 | 0.146 | 0.11166 | 0.33416 | 0.337 | 19.617 | 0 | 1 | 110 |
| Z2A1 | 4rt | 37384005 | Choerodon cauteroma | Bluespotted Tuskfish | 0.089 | 0.08 | 0.35993 | 0.59994 | 0.605 | 10.523 | 0.002 | 1 | 110 |
| Z2A1 | 4rt | 37118001 | Saurida undosquamis | Largescale Saury | 0.003 | -0.007 | 0.37591 | 0.61311 | 0.619 | 0.288 | 0.592 | 1 | 110 |
| Z2A1 | 4rt | 37118016 | Saurida grandisquamis | Grey Saury | 0.006 | -0.003 | 0.09843 | 0.31373 | 0.317 | 0.699 | 0.405 | 1 | 110 |
| Z2A1 | 4rt | 37347004 | Nemipterus celebicus | Celebes Threadfin Bream | 0.091 | 0.083 | 0.20982 | 0.45806 | 0.462 | 10.817 | 0.001 | 1 | 110 |
| Z2A1 | 4rt | 37347005 | Nemipterus furcosus | Rosy Threadfin Bream | 0.01 | 0 | 0.7231 | 0.85036 | 0.858 | 1.038 | 0.31 | 1 | 110 |
| Z2A1 | 4rt | 37355008 | Upeneus guttatus | orange-barred goatfish | 0.008 | -0.001 | 0.12425 | 0.35249 | 0.356 | 0.912 | 0.342 | 1 | 110 |
| Z2A1 | 4rt | 37460004 | Pseudorhombus dupliciocellatus | Three Twinspot Flounder | 0.002 | -0.008 | 0.27988 | 0.52904 | 0.534 | 0.175 | 0.677 | 1 | 110 |
| Z2A1 | 4rt | 37460015 | Pseudorhombus diplospilus | Bigtooth Twinspot Flounder | 0.004 | -0.005 | 0.17049 | 0.41291 | 0.417 | 0.485 | 0.488 | 1 | 110 |
| Z2A1 | 4rt | 37465011 | Abalistes stellatus | Starry Triggerfish | 0.12 | 0.112 | 0.28979 | 0.53832 | 0.543 | 14.792 | 0 | 1 | 110 |
| Z2A1 | 4rt | 37311009 | Epinephelus areolatus | Yellowspotted Rockcod | 0.027 | 0.018 | 0.36418 | 0.60348 | 0.609 | 3.036 | 0.084 | 1 | 110 |
| Z2A1 | 4rt | 37311010 | Epinephelus multinotatus | Rankin Cod | 0.009 | 0 | 0.53616 | 0.73223 | 0.739 | 0.997 | 0.32 | 1 | 110 |
| Z2A1 | 4rt | 37311012 | Plectropomus maculatus | Barcheek Coral Trout | 0.113 | 0.105 | 0.26894 | 0.51859 | 0.523 | 13.797 | 0 | 1 | 110 |
| Z2A1 | 4rt | 37346002 | Pristipomoides multidens | Goldband Snapper | 0.011 | 0.002 | 0.15477 | 0.3934 | 0.397 | 1.199 | 0.276 | 1 | 110 |
| Z2A1 | 4rt | 37346007 | Lutjanus malabaricus | Saddletail Snapper | 0.003 | -0.006 | 0.37357 | 0.61121 | 0.617 | 0.36 | 0.55 | 1 | 110 |
| Z2A1 | 4rt | 37347007 | Pentapodus porosus | Northwest Threadfin Bream | 0.03 | 0.021 | 0.06179 | 0.24857 | 0.251 | 3.327 | 0.071 | 1 | 110 |
| Z2A1 | 4rt | 37346005 | Lutjanus erythropterus | Crimson Snapper | 0.028 | 0.019 | 0.25429 | 0.50427 | 0.509 | 3.168 | 0.078 | 1 | 110 |

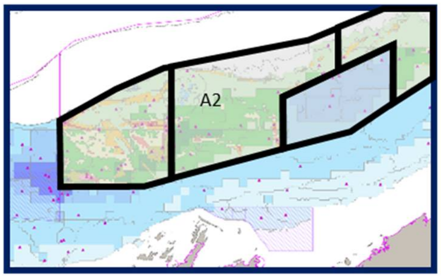




Apx Figure 5 PFTF Area 1 Informative species (N=27)

## PTFA Z2A2: Moderate/ low current effort

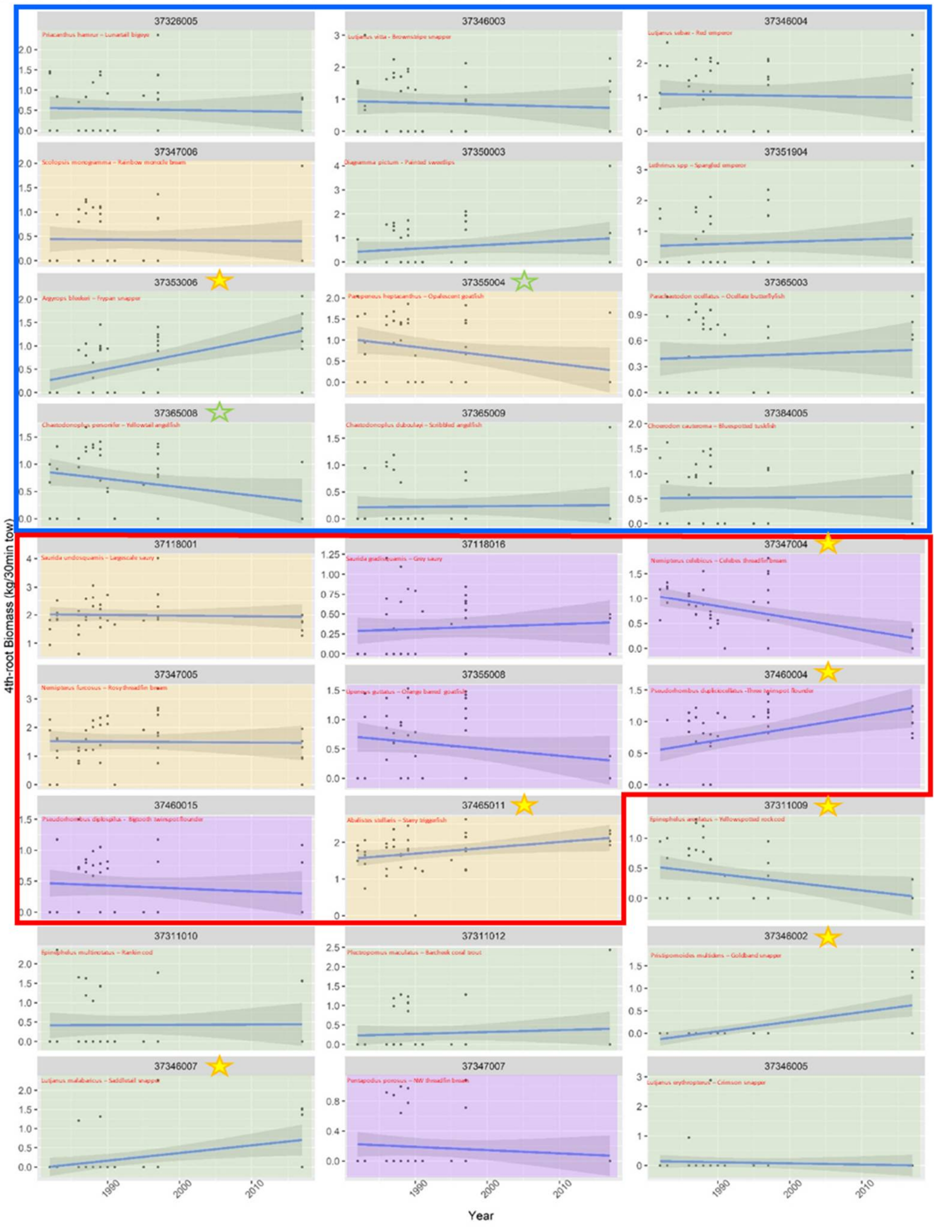
| EffCor | tran: | CAAB | Scientific name | Common name | r_squa | adj_r_sc | mse | rmse | sigma | statistic | p_value | df | nobs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Z2A2 | 4rt | 37326005 | Priacanthus hamrur | Lunartail Bigeye | 0.027 | 0.017 | 0.42049 | 0.64845 | 0.655 | 2.769 | 0.099 | 1 | 103 |
| Z2A2 | 4rt | 37346003 | Lutjanus vitta | Brownstripe Snapper | 0.013 | 0.003 | 0.63751 | 0.79844 | 0.806 | 1.288 | 0.259 | 1 | 103 |
| Z2A2 | 4rt | 37346004 | Lutjanus sebae | Red Emperor | 0.03 | 0.021 | 0.69253 | 0.83218 | 0.84 | 3.135 | 0.08 | 1 | 103 |
| Z2A2 | 4rt | 37347006 | Scolopsis monogramma | Rainbow Monocle Bream | 0.127 | 0.118 | 0.32448 | 0.56963 | 0.575 | 14.694 | 0 | 1 | 103 |
| Z2A2 | 4rt | 37350003 | Diagramma pictum | Painted Sweetlips | 0.252 | 0.245 | 0.45663 | 0.67575 | 0.682 | 34.011 | 0 | 1 | 103 |
| Z2A2 | 4rt | 37351904 | Lethrinus nebulosus & Lethrinus sp. | spangled emperor | 0.02 | 0.011 | 1.10231 | 1.04991 | 1.06 | 2.105 | 0.15 | 1 | 103 |
| Z2A2 | 4rt | 37353006 | Argyrops bleekeri | Frypan Bream | 0.147 | 0.138 | 0.38583 | 0.62115 | 0.627 | 17.368 | 0 | 1 | 103 |
| Z2A2 | 4rt | 37355004 | Parupeneus heptacanthus | Opalescent Goatfish | 0.014 | 0.004 | 0.43458 | 0.65923 | 0.666 | 1.427 | 0.235 | 1 | 103 |
| Z2A2 | 4rt | 37365003 | Parachaetodon ocellatus | Ocellate Butterflyfish | 0.028 | 0.018 | 0.17165 | 0.41431 | 0.418 | 2.922 | 0.09 | 1 | 103 |
| Z2A2 | 4rt | 37365008 | Chaetodontoplus personifer | Yellowtail Angelfish | 0.007 | -0.003 | 0.34239 | 0.58514 | 0.591 | 0.723 | 0.397 | 1 | 103 |
| Z2A2 | 4rt | 37365009 | Chaetodontoplus duboulayi | Scribbled Angelfish | 0.084 | 0.075 | 0.15723 | 0.39652 | 0.4 | 9.26 | 0.003 | 1 | 103 |
| Z2A2 | 4rt | 37384005 | Choerodon cauteroma | Bluespotted Tuskfish | 0.034 | 0.024 | 0.28432 | 0.53321 | 0.538 | 3.535 | 0.063 | 1 | 103 |
| Z2A2 | 4rt | 37118001 | Saurida undosquamis | Largescale Saury | 0.015 | 0.005 | 0.72647 | 0.85233 | 0.861 | 1.564 | 0.214 | 1 | 103 |
| Z2A2 | 4rt | 37118016 | Saurida grandisquamis | Grey Saury | 0.007 | -0.003 | 0.14815 | 0.3849 | 0.389 | 0.709 | 0.402 | 1 | 103 |
| Z2A2 | 4rt | 37347004 | Nemipterus celebicus | Celebes Threadfin Bream | 0.074 | 0.065 | 0.18891 | 0.43463 | 0.439 | 8.038 | 0.006 | 1 | 103 |
| Z2A2 | 4rt | 37347005 | Nemipterus furcosus | Rosy Threadfin Bream | 0.041 | 0.032 | 0.68828 | 0.82962 | 0.838 | 4.372 | 0.039 | 1 | 103 |
| Z2A2 | 4rt | 37355008 | Upeneus guttatus | orange barred goatfish | 0.028 | 0.018 | 0.28836 | 0.53699 | 0.542 | 2.89 | 0.092 | 1 | 103 |
| Z2A2 | 4rt | 37460004 | Pseudorhombus duplicioce llatus | Three Twinspot Flounder | 0.002 | -0.007 | 0.28539 | 0.53422 | 0.539 | 0.241 | 0.625 | 1 | 103 |
| Z2A2 | 4rt | 37460015 | Pseudorhombus diplospilus | Bigtooth Twinspot Flounder | 0.003 | -0.007 | 0.16249 | 0.40309 | 0.407 | 0.288 | 0.593 | 1 | 103 |
| Z2A2 | 4rt | 37465011 | Abalistes stellatus | Starry Triggerfish | 0.05 | 0.041 | 0.27711 | 0.52641 | 0.532 | 5.333 | 0.023 | 1 | 103 |
| Z2A2 | 4rt | 37311009 | Epinephelus areolatus | Yellowspotted Rockcod | 0.051 | 0.041 | 0.31893 | 0.56474 | 0.57 | 5.396 | 0.022 | 1 | 103 |
| Z2A2 | 4rt | 37311010 | Epinephelus multinotatus | Rankin Cod | 0.048 | 0.039 | 0.45589 | 0.6752 | 0.682 | 5.095 | 0.026 | 1 | 103 |
| Z2A2 | 4rt | 37311012 | Plectropomus maculatus | Barcheek Coral Trout | 0.092 | 0.083 | 0.27678 | 0.5261 | 0.531 | 10.282 | 0.002 | 1 | 103 |
| Z2A2 | 4rt | 37346002 | Pristipomoides multidens | Goldband Snapper | 0.034 | 0.025 | 0.40942 | 0.63986 | 0.646 | 3.606 | 0.06 | 1 | 103 |
| Z2A2 | 4rt | 37346007 | Lutjanus malabaricus | Saddletail Snapper | 0.014 | 0.004 | 0.42434 | 0.65142 | 0.658 | 1.443 | 0.233 | 1 | 103 |
| Z2A2 | 4rt | 37347007 | Pentapodus porosus | Northwest Threadfin Bream | 0 | -0.01 | 0.08782 | 0.29635 | 0.299 | 0.033 | 0.857 | 1 | 103 |
| Z2A2 | 4rt | 37346005 | Lutjanus erythropterus | Crimson Snapper | 0.027 | 0.018 | 0.21553 | 0.46425 | 0.469 | 2.819 | 0.096 | 1 | 103 |



Apx Figure 6 PFTF Area 2 Informative species (N=27)

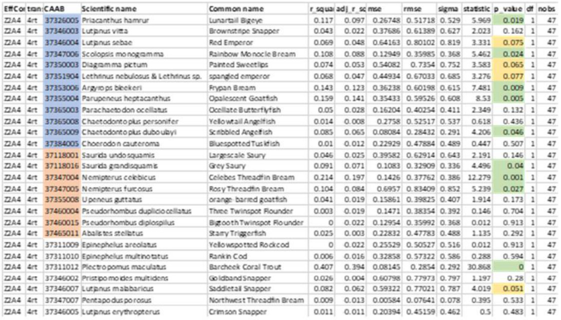
## PTFA Z2A3: Fishery closure

| EffCo | tran | CAAB | Scientific name | Common name | r_squa | adj_r_sc | mse | rmse | sigma | statistic | p_value | df | nobs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Z2A3 | 4rt | 37326005 | Priacanthus hamrur | Lunartail Bigeye | 0.002 | -0.024 | 0.38203 | 0.61809 | 0.634 | 0.092 | 0.763 | 1 | 40 |
| Z2A3 | 4rt | 37346003 | Lutjanus vitta | Brownstripe Snapper | 0.005 | -0.021 | 0.77111 | 0.87813 | 0.901 | 0.205 | 0.653 | 1 | 40 |
| Z2A3 | 4rt | 37346004 | Lutjanus sebae | Red Emperor | 0.001 | -0.025 | 0.82416 | 0.90783 | 0.931 | 0.048 | 0.827 | 1 | 40 |
| Z2A3 | 4rt | 37347006 | Scolopsis monogramma | Rainbow Monocle Bream | 0.001 | -0.026 | 0.30893 | 0.55581 | 0.57 | 0.023 | 0.881 | 1 | 40 |
| Z2A3 | 4rt | 37350003 | Diagramma pictum | Painted Sweetlips | 0.037 | 0.012 | 0.78086 | 0.88366 | 0.907 | 1.479 | 0.231 | 1 | 40 |
| Z2A3 | 4rt | 37351904 | Lethrinus nebulosus & Lethrinus sp. | spangled emperor | 0.009 | -0.017 | 0.74946 | 0.86572 | 0.888 | 0.33 | 0.569 | 1 | 40 |
| Z2A3 | 4rt | 37353006 | Argyrops bleekeri | Frypan Bream | 0.318 | 0.3 | 0.23915 | 0.48903 | 0.502 | 17.745 | 0 | 1 | 40 |
| Z2A3 | 4rt | 37355004 | Parupeneus heptacanthus | Opalescent Goatfish | 0.096 | 0.072 | 0.47916 | 0.69221 | 0.71 | 4.04 | 0.052 | 1 | 40 |
| Z2A3 | 4rt | 37365003 | Parachaetodon ocellatus | Ocellate Butterflyfish | 0.006 | -0.02 | 0.17588 | 0.41938 | 0.43 | 0.225 | 0.638 | 1 | 40 |
| Z2A3 | 4rt | 37365008 | Chaetodontoplus personifer | Yellowtail Angelfish | 0.09 | 0.066 | 0.28293 | 0.53191 | 0.546 | 3.763 | 0.06 | 1 | 40 |
| Z2A3 | 4rt | 37365009 | Chaetodontoplus duboulayi | Scribbled Angelfish | 0.001 | -0.026 | 0.19524 | 0.44187 | 0.453 | 0.029 | 0.866 | 1 | 40 |
| Z2A3 | 4rt | 37384005 | Choerodon cauteroma | Bluespotted Tuskfish | 0 | -0.026 | 0.37687 | 0.6139 | 0.63 | 0.01 | 0.922 | 1 | 40 |
| Z2A3 | 4rt | 37118001 | Saurida undosquamis | Largescale Saury | 0.002 | -0.024 | 0.32737 | 0.57216 | 0.587 | 0.078 | 0.781 | 1 | 40 |
| Z2A3 | 4rt | 37118016 | Saurida grandisquamis | Grey Saury | 0.009 | -0.017 | 0.12698 | 0.35635 | 0.366 | 0.334 | 0.567 | 1 | 40 |
| Z2A3 | 4rt | 37347004 | Nemipterus celebicus | Celebes Threadfin Bream | 0.286 | 0.267 | 0.1712 | 0.41376 | 0.425 | 15.209 | 0 | 1 | 40 |
| Z2A3 | 4rt | 37347005 | Nemipterus furcosus | Rosy Threadfin Bream | 0.001 | -0.026 | 0.60174 | 0.77572 | 0.796 | 0.022 | 0.884 | 1 | 40 |
| Z2A3 | 4rt | 37355008 | Upeneus guttatus | orange-barred goatfish | 0.053 | 0.028 | 0.28638 | 0.53514 | 0.549 | 2.109 | 0.155 | 1 | 40 |
| Z2A3 | 4rt | 37460004 | Pseudorhombus dupliciocellatus | Three Twinspot Flounder | 0.216 | 0.195 | 0.15845 | 0.39806 | 0.408 | 10.468 | 0.003 | 1 | 40 |
| Z2A3 | 4rt | 37460015 | Pseudorhombus diplospilus | Bigtooth Twinspot Flounder | 0.013 | -0.013 | 0.21231 | 0.46077 | 0.473 | 0.486 | 0.49 | 1 | 40 |
| Z2A3 | 4rt | 37465011 | Abalistes stellatus | Starry Triggerfish | 0.126 | 0.103 | 0.21362 | 0.46219 | 0.474 | 5.478 | 0.025 | 1 | 40 |
| Z2A3 | 4rt | 37311009 | Epinephelus areolatus | Yellowspotted Rockcod | 0.118 | 0.095 | 0.17281 | 0.4157 | 0.426 | 5.083 | 0.03 | 1 | 40 |
| Z2A3 | 4rt | 37311010 | Epinephelus multinotatus | Rankin Cod | 0 | -0.026 | 0.50794 | 0.7127 | 0.731 | 0.005 | 0.947 | 1 | 40 |
| Z2A3 | 4rt | 37311012 | Plectropomus maculatus | Barcheek Coral Trout | 0.009 | -0.017 | 0.31953 | 0.56527 | 0.58 | 0.356 | 0.554 | 1 | 40 |
| Z2A3 | 4rt | 37346002 | Pristipomoides multidens | Goldband Snapper | 0.36 | 0.343 | 0.10145 | 0.31852 | 0.327 | 21.355 | 0 | 1 | 40 |
| Z2A3 | 4rt | 37346007 | Lutjanus malabaricus | Saddletail Snapper | 0.155 | 0.133 | 0.26695 | 0.51667 | 0.53 | 6.987 | 0.012 | 1 | 40 |
| Z2A3 | 4rt | 37347007 | Pentapodus porosus | Northwest Threadfin Bream | 0.019 | -0.007 | 0.12368 | 0.35168 | 0.361 | 0.721 | 0.401 | 1 | 40 |
| Z2A3 | 4rt | 37346005 | Lutjanus erythropterus | Crimson Snapper | 0.008 | -0.018 | 0.21973 | 0.46876 | 0.481 | 0.322 | 0.574 | 1 | 40 |

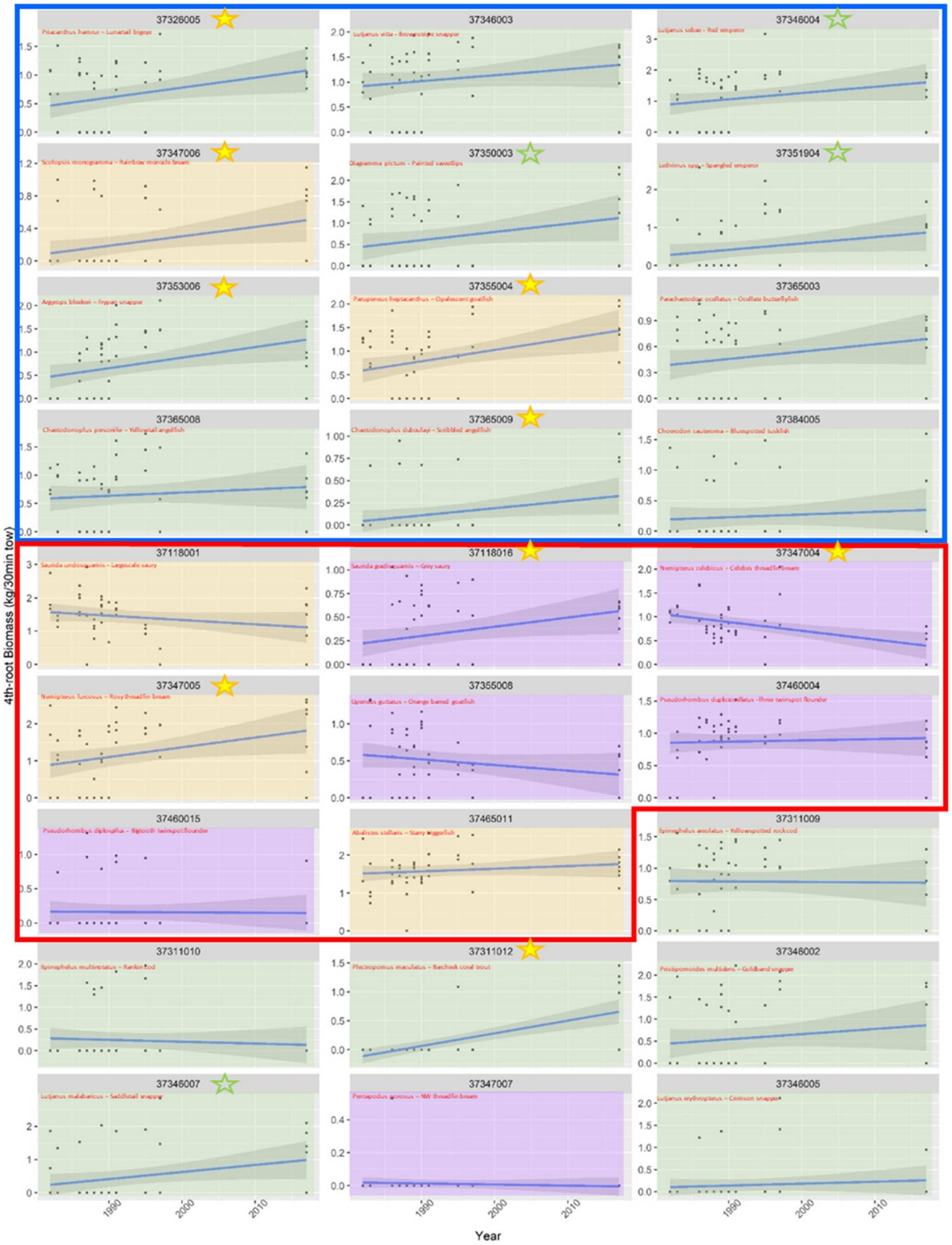


Apx Figure 7 PFTF Area 3 Informative species (N=27)

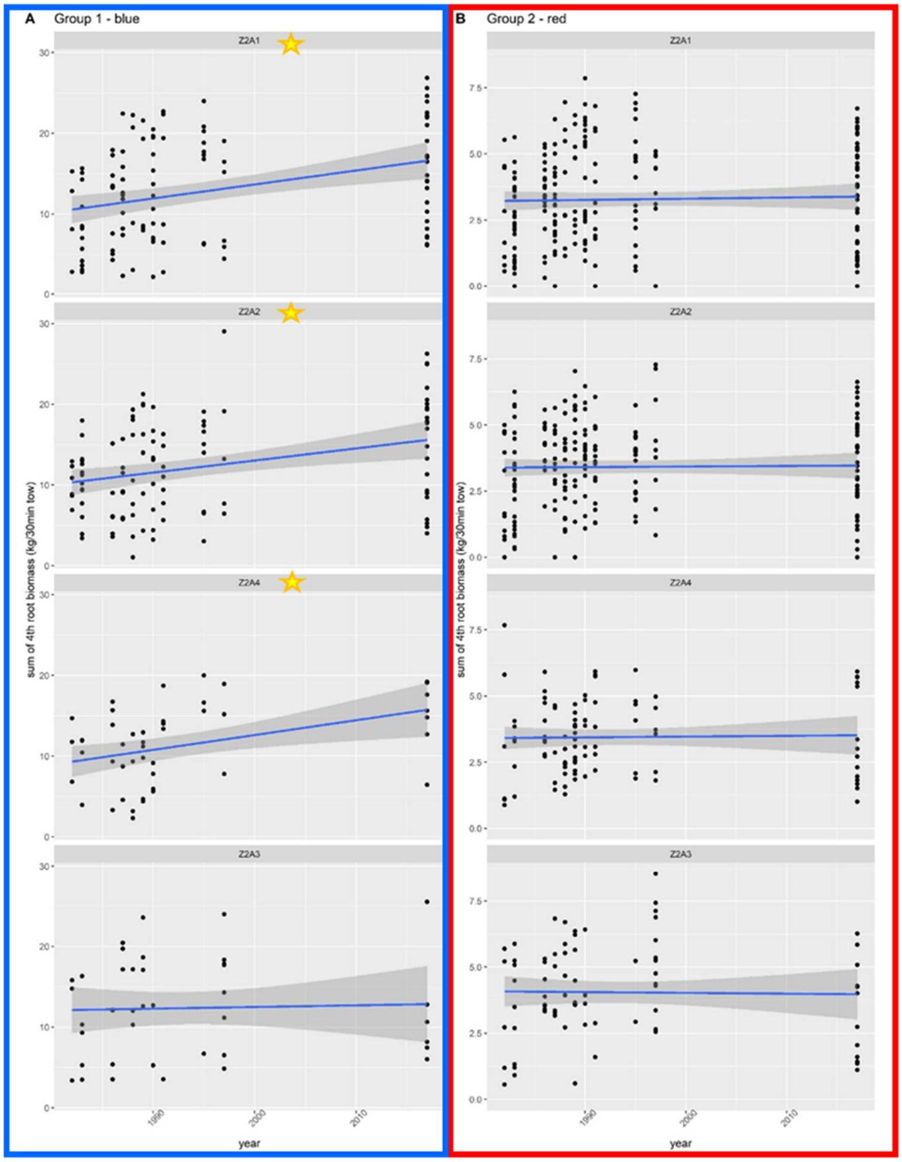
# PTFA Z2A4: Moderate/ low current effort



| EffCo | tran | CAAB | Scientific name | Common name | r_squa | adj_r_sc | mse | rmse | sigma | statistic | p_value | df | nobs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Z2A4 | 4rt | 37326005 | Priacanthus hamrur | Lunartail Bigeye | 0.117 | 0.097 | 0.26748 | 0.51718 | 0.529 | 5.969 | 0.019 | 1 | 47 |
| Z2A4 | 4rt | 37346003 | Lutjanus vitta | Brownstripe Snapper | 0.043 | 0.022 | 0.37686 | 0.61389 | 0.627 | 2.023 | 0.162 | 1 | 47 |
| Z2A4 | 4rt | 37346004 | Lutjanus sebae | Red Emperor | 0.069 | 0.048 | 0.64163 | 0.80102 | 0.819 | 3.331 | 0.075 | 1 | 47 |
| Z2A4 | 4rt | 37347006 | Scolopsis monogramma | Rainbow Monocle Bream | 0.108 | 0.088 | 0.12949 | 0.35985 | 0.368 | 5.462 | 0.024 | 1 | 47 |
| Z2A4 | 4rt | 37350003 | Diagramma pictum | Painted Sweetlips | 0.074 | 0.053 | 0.54082 | 0.7354 | 0.752 | 3.583 | 0.065 | 1 | 47 |
| Z2A4 | 4rt | 37351904 | Lethrinus nebulosus & Lethrinus sp. | spangled emperor | 0.068 | 0.047 | 0.44934 | 0.67033 | 0.685 | 3.276 | 0.077 | 1 | 47 |
| Z2A4 | 4rt | 37353006 | Argyrops bleekeri | Frypan Bream | 0.143 | 0.123 | 0.36238 | 0.60198 | 0.615 | 7.481 | 0.009 | 1 | 47 |
| Z2A4 | 4rt | 37355004 | Parupeneus heptacanthus | Opalescent Goatfish | 0.159 | 0.141 | 0.35433 | 0.59526 | 0.608 | 8.53 | 0.005 | 1 | 47 |
| Z2A4 | 4rt | 37365003 | Parachaetodon ocellatus | Ocellate Butterflyfish | 0.05 | 0.028 | 0.16204 | 0.40254 | 0.411 | 2.349 | 0.132 | 1 | 47 |
| Z2A4 | 4rt | 37365008 | Chaetodontoplus personifer | Yellowtail Angelfish | 0.014 | 0.008 | 0.2758 | 0.52517 | 0.537 | 0.618 | 0.436 | 1 | 47 |
| Z2A4 | 4rt | 37365009 | Chaetodontoplus duboulayi | Scribbled Angelfish | 0.085 | 0.065 | 0.08084 | 0.28432 | 0.291 | 4.206 | 0.046 | 1 | 47 |
| Z2A4 | 4rt | 37384005 | Choerodon cauteroma | Bluespotted Tuskfish | 0.01 | 0.012 | 0.22929 | 0.47884 | 0.489 | 0.447 | 0.507 | 1 | 47 |
| Z2A4 | 4rt | 37118001 | Saurida undosquamis | Largescale Saury | 0.046 | 0.025 | 0.39582 | 0.62914 | 0.643 | 2.191 | 0.146 | 1 | 47 |
| Z2A4 | 4rt | 37118016 | Saurida grandisquamis | Grey Saury | 0.091 | 0.071 | 0.1083 | 0.32909 | 0.336 | 4.496 | 0.04 | 1 | 47 |
| Z2A4 | 4rt | 37347004 | Nemipterus celebicus | Celebes Threadfin Bream | 0.214 | 0.197 | 0.1426 | 0.37762 | 0.386 | 12.279 | 0.001 | 1 | 47 |
| Z2A4 | 4rt | 37347005 | Nemipterus furcosus | Rosy Threadfin Bream | 0.104 | 0.084 | 0.6957 | 0.83409 | 0.852 | 5.239 | 0.027 | 1 | 47 |
| Z2A4 | 4rt | 37355008 | Upeneus guttatus | orange- barred goatfish | 0.041 | 0.019 | 0.15861 | 0.39825 | 0.407 | 1.914 | 0.173 | 1 | 47 |
| Z2A4 | 4rt | 37460004 | Pseudorhombus duplicicellatus | Three Twinspot Flounder | 0.003 | 0.019 | 0.1471 | 0.38354 | 0.392 | 0.146 | 0.704 | 1 | 47 |
| Z2A4 | 4rt | 37460015 | Pseudorhombus diplospilus | Bigtooth Twinspot Flounder | 0 | 0.022 | 0.12954 | 0.35992 | 0.368 | 0.012 | 0.913 | 1 | 47 |
| Z2A4 | 4rt | 37465011 | Abalistes stellatus | Starry Triggerfish | 0.025 | 0.003 | 0.22832 | 0.47783 | 0.488 | 1.135 | 0.292 | 1 | 47 |
| Z2A4 | 4rt | 37311009 | Epinephelus areolatus | Yellowspotted Rockcod | 0 | 0.022 | 0.25529 | 0.50527 | 0.516 | 0.012 | 0.913 | 1 | 47 |
| Z2A4 | 4rt | 37311010 | Epinephelus multinotatus | Rankin Cod | 0.006 | 0.016 | 0.32858 | 0.57322 | 0.586 | 0.288 | 0.594 | 1 | 47 |
| Z2A4 | 4rt | 37311012 | Plectropomus maculatus | Barcheek Coral Trout | 0.407 | 0.394 | 0.08145 | 0.2854 | 0.292 | 30.868 | 0 | 1 | 47 |
| Z2A4 | 4rt | 37346002 | Pristipomoides multidens | Goldband Snapper | 0.026 | 0.004 | 0.60798 | 0.77973 | 0.797 | 1.197 | 0.28 | 1 | 47 |
| Z2A4 | 4rt | 37346007 | Lutjanus malabaricus | Saddletail Snapper | 0.082 | 0.062 | 0.59322 | 0.77021 | 0.787 | 4.019 | 0.051 | 1 | 47 |
| Z2A4 | 4rt | 37347007 | Pentapodus porosus | Northwest Threadfin Bream | 0.009 | 0.013 | 0.00584 | 0.07641 | 0.078 | 0.395 | 0.533 | 1 | 47 |
| Z2A4 | 4rt | 37346005 | Lutjanus erythropterus | Crimson Snapper | 0.011 | 0.011 | 0.20394 | 0.45159 | 0.462 | 0.5 | 0.483 | 1 | 47 |



Apx Figure 8 PFTF Area 4 Informative species (N=27)

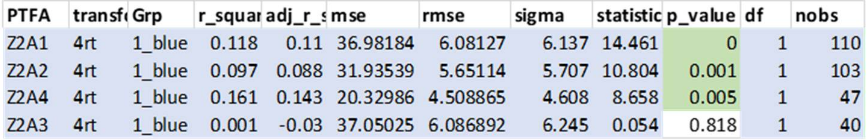


**PFTFA Z2A1**:
Relatively high effort through time

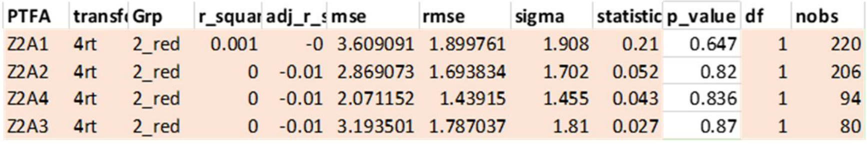
**PFTFA Z2A2**:
Moderate to low current effort

**PFTFA Z2A4**:
Moderate to low current effort

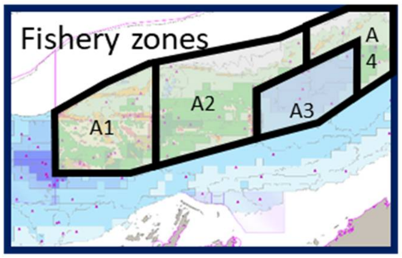
**PFTFA Z2A3**:
WA fishery closure



| PTFA | transf | Grp | r_squar | adj_r_s | mse | rmse | sigma | statistic | p_value | df | nobs |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Z2A1 | 4rt | 1_blue | 0.118 | 0.11 | 36.98184 | 6.08127 | 6.137 | 14.461 | 0 | 1 | 110 |
| Z2A2 | 4rt | 1_blue | 0.097 | 0.088 | 31.93539 | 5.65114 | 5.707 | 10.804 | 0.001 | 1 | 103 |
| Z2A4 | 4rt | 1_blue | 0.161 | 0.143 | 20.32986 | 4.508865 | 4.608 | 8.658 | 0.005 | 1 | 47 |
| Z2A3 | 4rt | 1_blue | 0.001 | -0.03 | 37.05025 | 6.086892 | 6.245 | 0.054 | 0.818 | 1 | 40 |

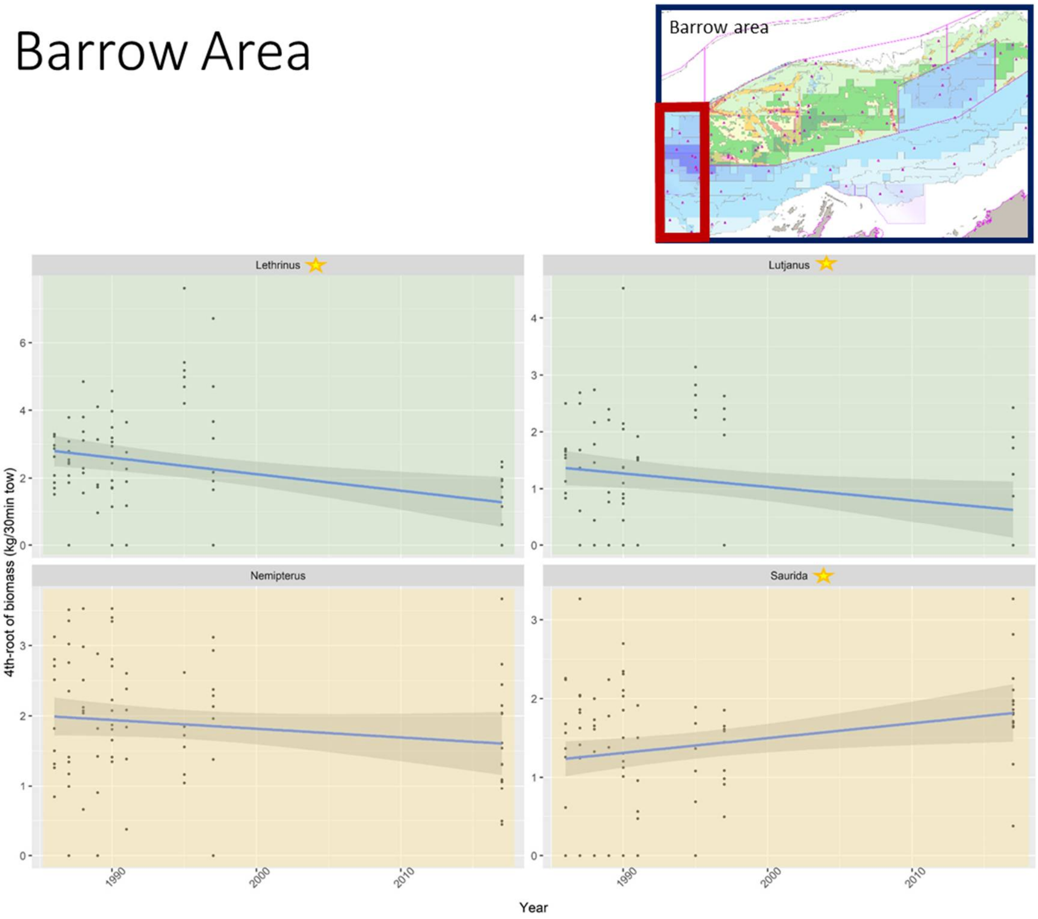


| PTFA | transf | Grp | r_squar | adj_r_s | mse | rmse | sigma | statistic | p_value | df | nobs |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Z2A1 | 4rt | 2_red | 0.001 | -0 | 3.609091 | 1.899761 | 1.908 | 0.21 | 0.647 | 1 | 220 |
| Z2A2 | 4rt | 2_red | 0 | -0.01 | 2.869073 | 1.693834 | 1.702 | 0.052 | 0.82 | 1 | 206 |
| Z2A4 | 4rt | 2_red | 0 | -0.01 | 2.071152 | 1.43915 | 1.455 | 0.043 | 0.836 | 1 | 94 |
| Z2A3 | 4rt | 2_red | 0 | -0.01 | 3.193501 | 1.787037 | 1.81 | 0.027 | 0.87 | 1 | 80 |



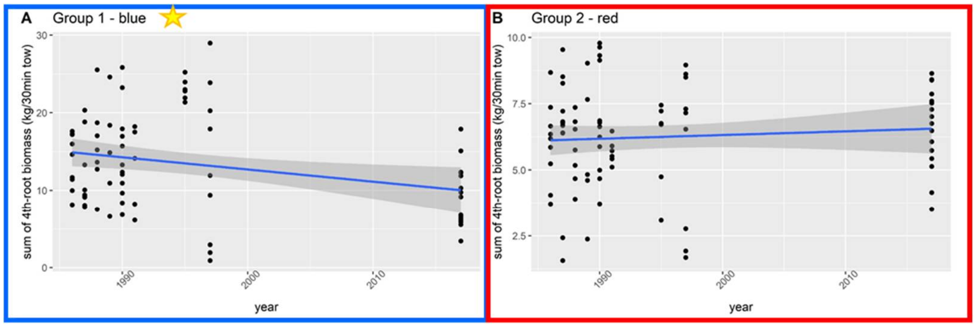
Apx Figure 9 PFTF Areas 1 to 4 Inner/mid-shelf assemblages (N=2)

### F.2.2 Barrow Area



| Area | transform | Genus | r_squared | adj_r_squ | mse | rmse | sigma | statistic | p_value | df | nobs |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Barrow | 4rt | Lethrinus | 0.113 | 0.102 | 2.331829 | 1.527033 | 1.546 | 10.063 | 0.002 | 1 | 81 |
| Barrow | 4rt | Saurida | 0.072 | 0.06 | 0.561084 | 0.749055 | 0.758 | 6.139 | 0.015 | 1 | 81 |
| Barrow | 4rt | Lutjanus | 0.063 | 0.051 | 1.044988 | 1.022247 | 1.035 | 5.295 | 0.024 | 1 | 81 |
| Barrow | 4rt | Nemipteru | 0.022 | 0.01 | 0.846882 | 0.920262 | 0.932 | 1.79 | 0.185 | 1 | 81 |

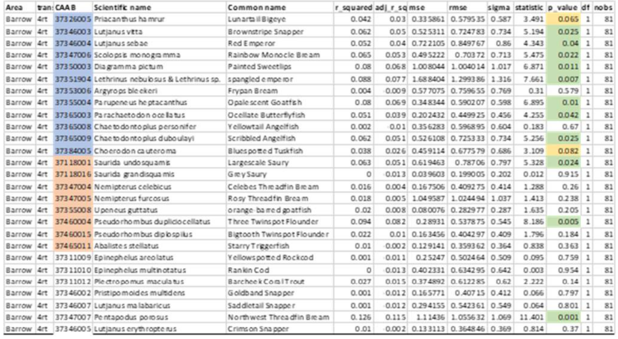
Apx Figure 10 Barrow Area Key Genera (N= 4)



| Area | transform | Grp | r_squared | adj_r_squ | mse | rmse | sigma | statistic | p_value | df | nobs |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Barrow | 4rt | 1_blue | 0.078 | 0.066 | 36.52662 | 6.043726 | 6.12 | 6.676 | 0.012 | 1 | 81 |
| Barrow | 4rt | 2_red | 0.007 | -0.006 | 3.666208 | 1.914734 | 1.939 | 0.528 | 0.47 | 1 | 81 |

Apx Figure 11 Barrow Area Inner/mid-shelf assemblages (N=2)

## Barrow area

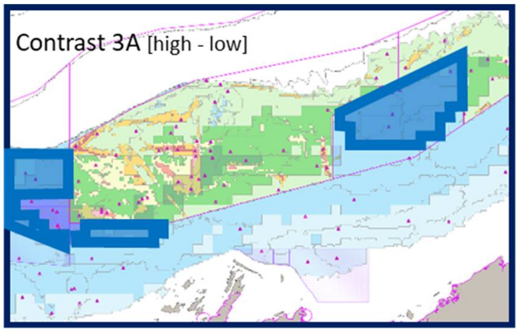


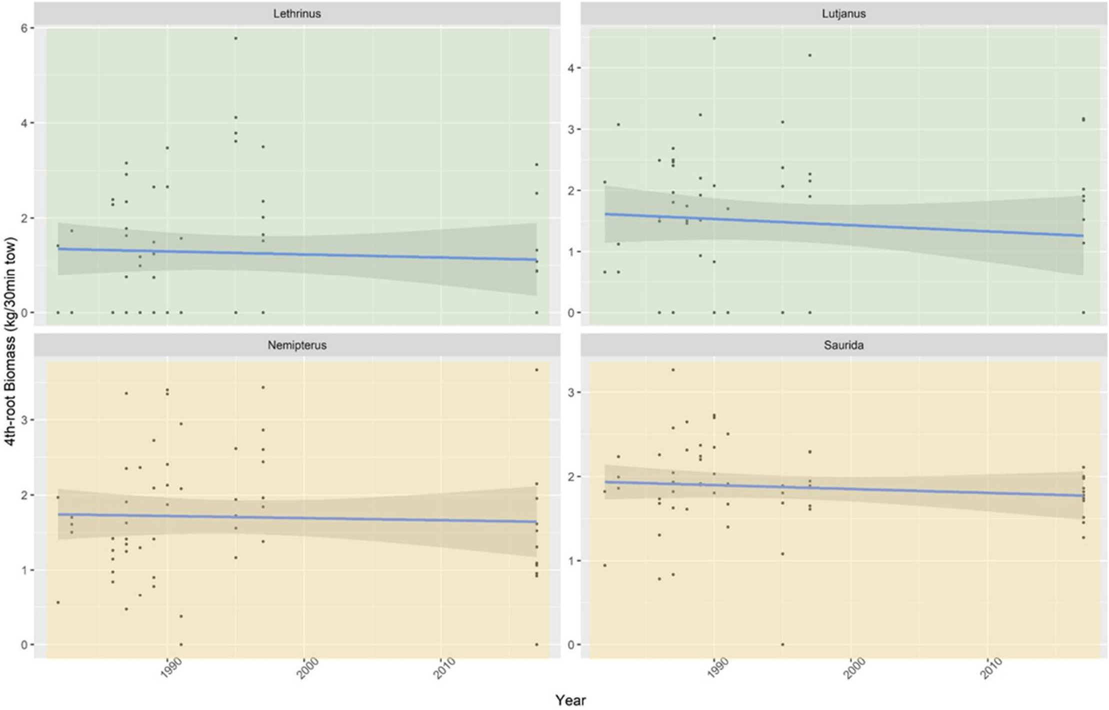
| Area | tran | CAAB | Scientific name | Common name | r_squared | adj_r_sq | mse | rmse | sigma | statistic | p_value | df | nobs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Barrow | 4rt | 37326005 | Priacanthus hamrur | Lunartail Bigeye | 0.042 | 0.03 | 0.335861 | 0.579535 | 0.587 | 3.491 | 0.065 | 1 | 81 |
| Barrow | 4rt | 37346003 | Lutjanus vitta | Brownstripe Snapper | 0.062 | 0.05 | 0.525311 | 0.724783 | 0.734 | 5.194 | 0.025 | 1 | 81 |
| Barrow | 4rt | 37346004 | Lutjanus sebae | Red Emperor | 0.052 | 0.04 | 0.722105 | 0.849767 | 0.86 | 4.343 | 0.04 | 1 | 81 |
| Barrow | 4rt | 37347006 | Scolopsis monogramma | Rainbow Monocle Bream | 0.065 | 0.053 | 0.495222 | 0.70372 | 0.713 | 5.475 | 0.022 | 1 | 81 |
| Barrow | 4rt | 37350003 | Diagramma pictum | Painted Sweetlips | 0.08 | 0.068 | 1.008044 | 1.004014 | 1.017 | 6.871 | 0.011 | 1 | 81 |
| Barrow | 4rt | 37351904 | Lethrinus nebulosus & Lethrinus sp. | spangled emperor | 0.088 | 0.077 | 1.688404 | 1.299386 | 1.316 | 7.661 | 0.007 | 1 | 81 |
| Barrow | 4rt | 37353006 | Argyrops bleekeri | Frypan Bream | 0.004 | -0.009 | 0.577075 | 0.759655 | 0.769 | 0.31 | 0.579 | 1 | 81 |
| Barrow | 4rt | 37355004 | Parupeneus heptacanthus | Opalescent Goatfish | 0.08 | 0.069 | 0.348344 | 0.590207 | 0.598 | 6.895 | 0.01 | 1 | 81 |
| Barrow | 4rt | 37365003 | Parachaetodon ocellatus | Ocellate Butterflyfish | 0.051 | 0.039 | 0.202432 | 0.449925 | 0.456 | 4.255 | 0.042 | 1 | 81 |
| Barrow | 4rt | 37365008 | Chaetodontoplus personifer | Yellowtail Angelfish | 0.002 | -0.01 | 0.356283 | 0.596895 | 0.604 | 0.183 | 0.67 | 1 | 81 |
| Barrow | 4rt | 37365009 | Chaetodontoplus duboulayi | Scribbled Angelfish | 0.062 | 0.051 | 0.526108 | 0.725333 | 0.734 | 5.256 | 0.025 | 1 | 81 |
| Barrow | 4rt | 37384005 | Choerodon cauteroma | Bluespotted Tuskfish | 0.038 | 0.026 | 0.459114 | 0.677579 | 0.686 | 3.109 | 0.082 | 1 | 81 |
| Barrow | 4rt | 37118001 | Saurida undosquamis | Largescale Saury | 0.063 | 0.051 | 0.619463 | 0.78706 | 0.797 | 5.328 | 0.024 | 1 | 81 |
| Barrow | 4rt | 37118016 | Saurida grandisquamis | Grey Saury | 0 | -0.013 | 0.039603 | 0.199005 | 0.202 | 0.012 | 0.915 | 1 | 81 |
| Barrow | 4rt | 37347004 | Nemipterus celebicus | Celebes Threadfin Bream | 0.016 | 0.004 | 0.167506 | 0.409275 | 0.414 | 1.288 | 0.26 | 1 | 81 |
| Barrow | 4rt | 37347005 | Nemipterus furcosus | Rosy Threadfin Bream | 0.018 | 0.005 | 1.049587 | 1.024494 | 1.037 | 1.413 | 0.238 | 1 | 81 |
| Barrow | 4rt | 37355008 | Upeneus guttatus | orange-barred goatfish | 0.02 | 0.008 | 0.080076 | 0.282977 | 0.287 | 1.635 | 0.205 | 1 | 81 |
| Barrow | 4rt | 37460004 | Pseudorhombus dupliciocellatus | Three Twinspot Flounder | 0.094 | 0.082 | 0.28931 | 0.537875 | 0.545 | 8.186 | 0.005 | 1 | 81 |
| Barrow | 4rt | 37460015 | Pseudorhombus diplospilus | Bigtooth Twinspot Flounder | 0.022 | 0.01 | 0.163456 | 0.404297 | 0.409 | 1.796 | 0.184 | 1 | 81 |
| Barrow | 4rt | 37465011 | Abalistes stellatus | Starry Triggerfish | 0.01 | -0.002 | 0.129141 | 0.359362 | 0.364 | 0.838 | 0.363 | 1 | 81 |
| Barrow | 4rt | 37311009 | Epinephelus areolatus | Yellowspotted Rockcod | 0.001 | -0.011 | 0.25247 | 0.502464 | 0.509 | 0.095 | 0.759 | 1 | 81 |
| Barrow | 4rt | 37311010 | Epinephelus multinotatus | Rankin Cod | 0 | -0.013 | 0.402331 | 0.634295 | 0.642 | 0.003 | 0.954 | 1 | 81 |
| Barrow | 4rt | 37311012 | Plectropomus maculatus | Barcheek Coral Trout | 0.027 | 0.015 | 0.374892 | 0.612285 | 0.62 | 2.222 | 0.14 | 1 | 81 |
| Barrow | 4rt | 37346002 | Pristipomoides multidens | Goldband Snapper | 0.001 | -0.012 | 0.165771 | 0.40715 | 0.412 | 0.066 | 0.797 | 1 | 81 |
| Barrow | 4rt | 37346007 | Lutjanus malabaricus | Saddletail Snapper | 0.001 | -0.012 | 0.294155 | 0.542361 | 0.549 | 0.064 | 0.801 | 1 | 81 |
| Barrow | 4rt | 37347007 | Pentapodus porosus | Northwest Threadfin Bream | 0.126 | 0.115 | 1.11436 | 1.055632 | 1.069 | 11.401 | 0.001 | 1 | 81 |
| Barrow | 4rt | 37346005 | Lutjanus erythropterus | Crimson Snapper | 0.01 | -0.002 | 0.133113 | 0.364846 | 0.369 | 0.814 | 0.37 | 1 | 81 |

Apx Figure 12 Barrow Area Informative species (N=27)

### F.2.3 Trawl effort contrasts/ non-contrasts areas

Contrast
TC 3A
[high —> low]

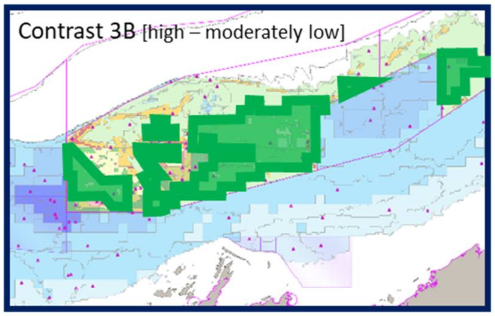


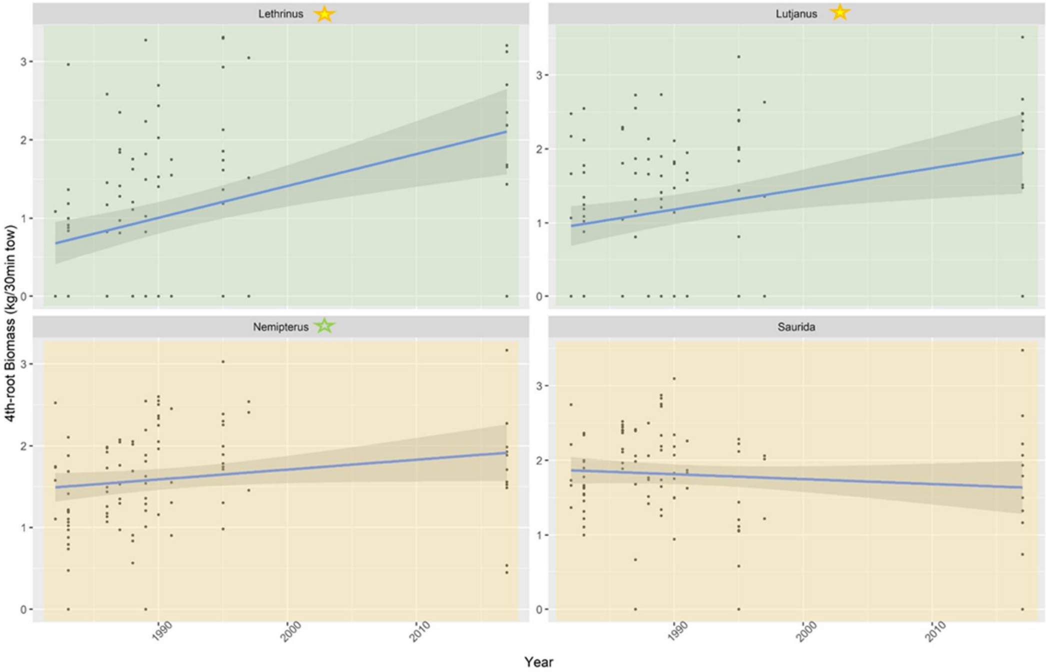


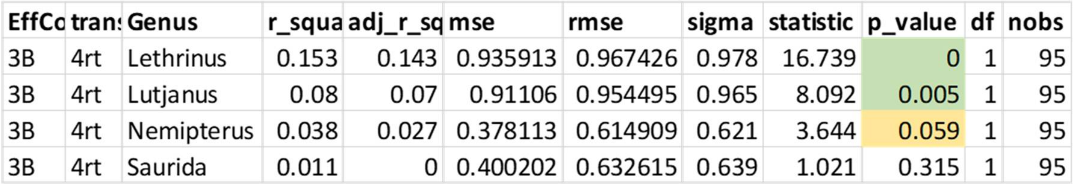
| EffCo | trans | Genus | r_squa | adj_r_sq | mse | rmse | sigma | statistic | p_value | df | nobs |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 3A | 4rt | Lethrinus | 0.003 | -0.015 | 1.902029 | 1.379141 | 1.403 | 0.168 | 0.683 | 1 | 59 |
| 3A | 4rt | Lutjanus | 0.01 | -0.007 | 1.359317 | 1.165897 | 1.186 | 0.585 | 0.448 | 1 | 59 |
| 3A | 4rt | Nemipterus | 0.002 | -0.016 | 0.709871 | 0.842538 | 0.857 | 0.087 | 0.769 | 1 | 59 |
| 3A | 4rt | Saurida | 0.011 | -0.006 | 0.26235 | 0.512201 | 0.521 | 0.629 | 0.431 | 1 | 59 |

Apx Figure 13 Contrast TC 3A Key Genera (N=4)

# Contrast TC 3B [high —> moderately low]



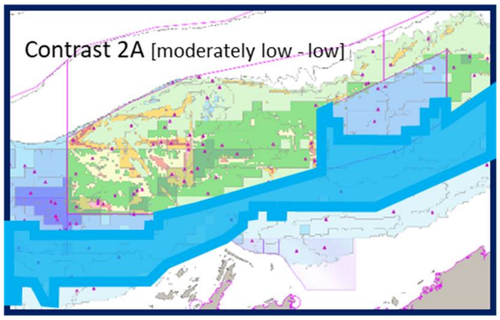


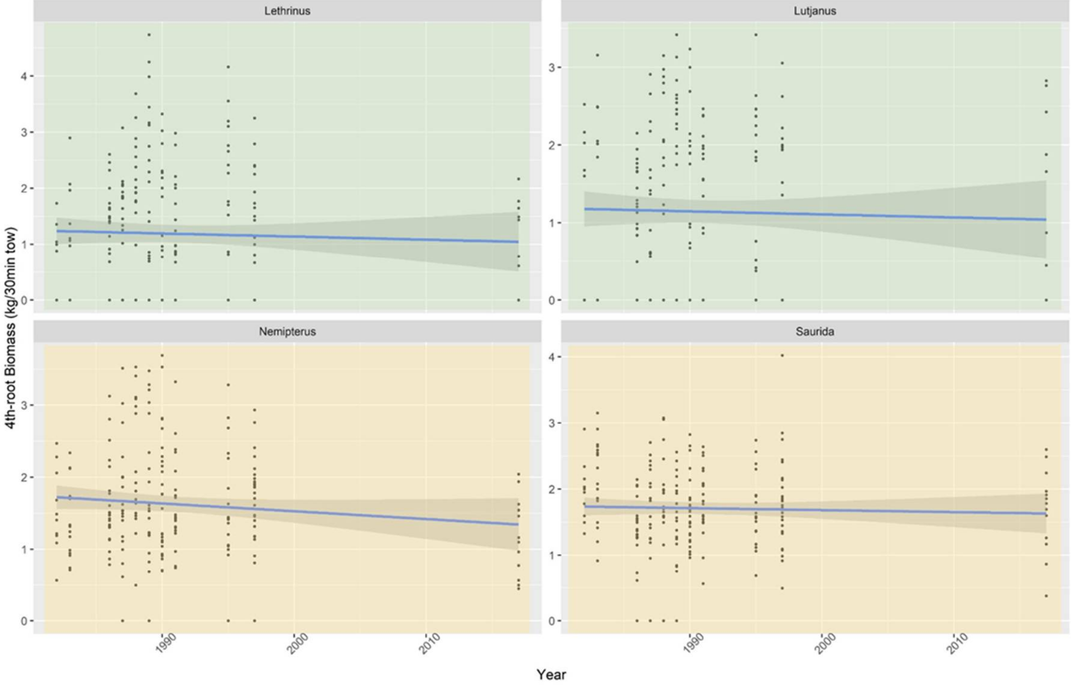


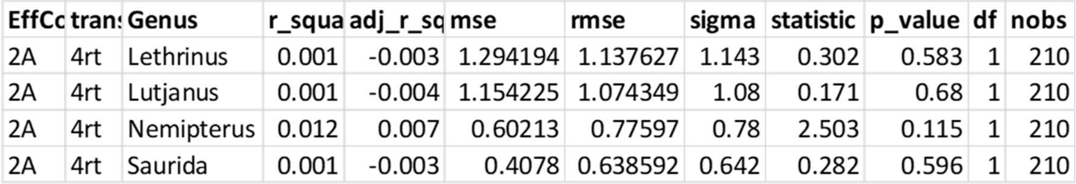
| EffCo | trans | Genus | r_squa | adj_r_sq | mse | rmse | sigma | statistic | p_value | df | nobs |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 3B | 4rt | Lethrinus | 0.153 | 0.143 | 0.935913 | 0.967426 | 0.978 | 16.739 | 0 | 1 | 95 |
| 3B | 4rt | Lutjanus | 0.08 | 0.07 | 0.91106 | 0.954495 | 0.965 | 8.092 | 0.005 | 1 | 95 |
| 3B | 4rt | Nemipterus | 0.038 | 0.027 | 0.378113 | 0.614909 | 0.621 | 3.644 | 0.059 | 1 | 95 |
| 3B | 4rt | Saurida | 0.011 | 0 | 0.400202 | 0.632615 | 0.639 | 1.021 | 0.315 | 1 | 95 |

Apx Figure 14 Contrast TC 3B Key Genera (N=4)

# Contrast
# TC 2A
# [moderately low
# —> low]



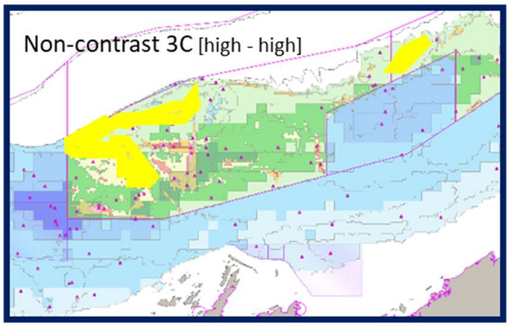


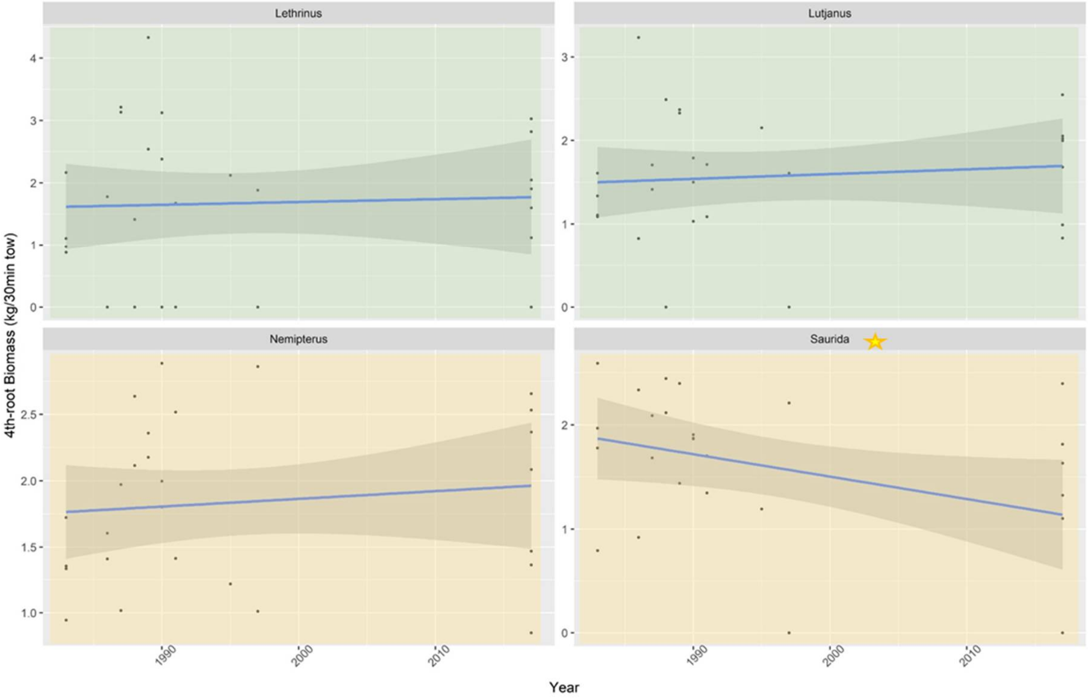


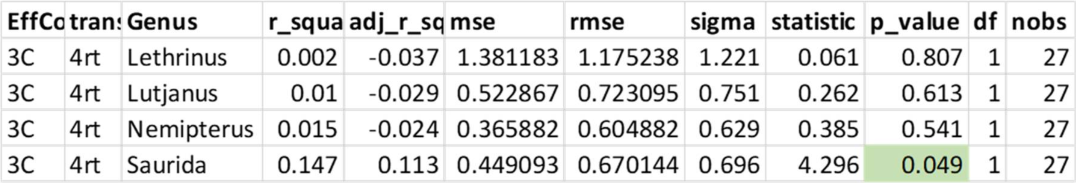
| EffCo | trans | Genus | r_squa | adj_r_sq | mse | rmse | sigma | statistic | p_value | df | nobs |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2A | 4rt | Lethrinus | 0.001 | -0.003 | 1.294194 | 1.137627 | 1.143 | 0.302 | 0.583 | 1 | 210 |
| 2A | 4rt | Lutjanus | 0.001 | -0.004 | 1.154225 | 1.074349 | 1.08 | 0.171 | 0.68 | 1 | 210 |
| 2A | 4rt | Nemipterus | 0.012 | 0.007 | 0.60213 | 0.77597 | 0.78 | 2.503 | 0.115 | 1 | 210 |
| 2A | 4rt | Saurida | 0.001 | -0.003 | 0.4078 | 0.638592 | 0.642 | 0.282 | 0.596 | 1 | 210 |

Apx Figure 15 Contrast TC 2A Key Genera (N=4)

# Non-contrast
# TC 3C
# [high —> high]

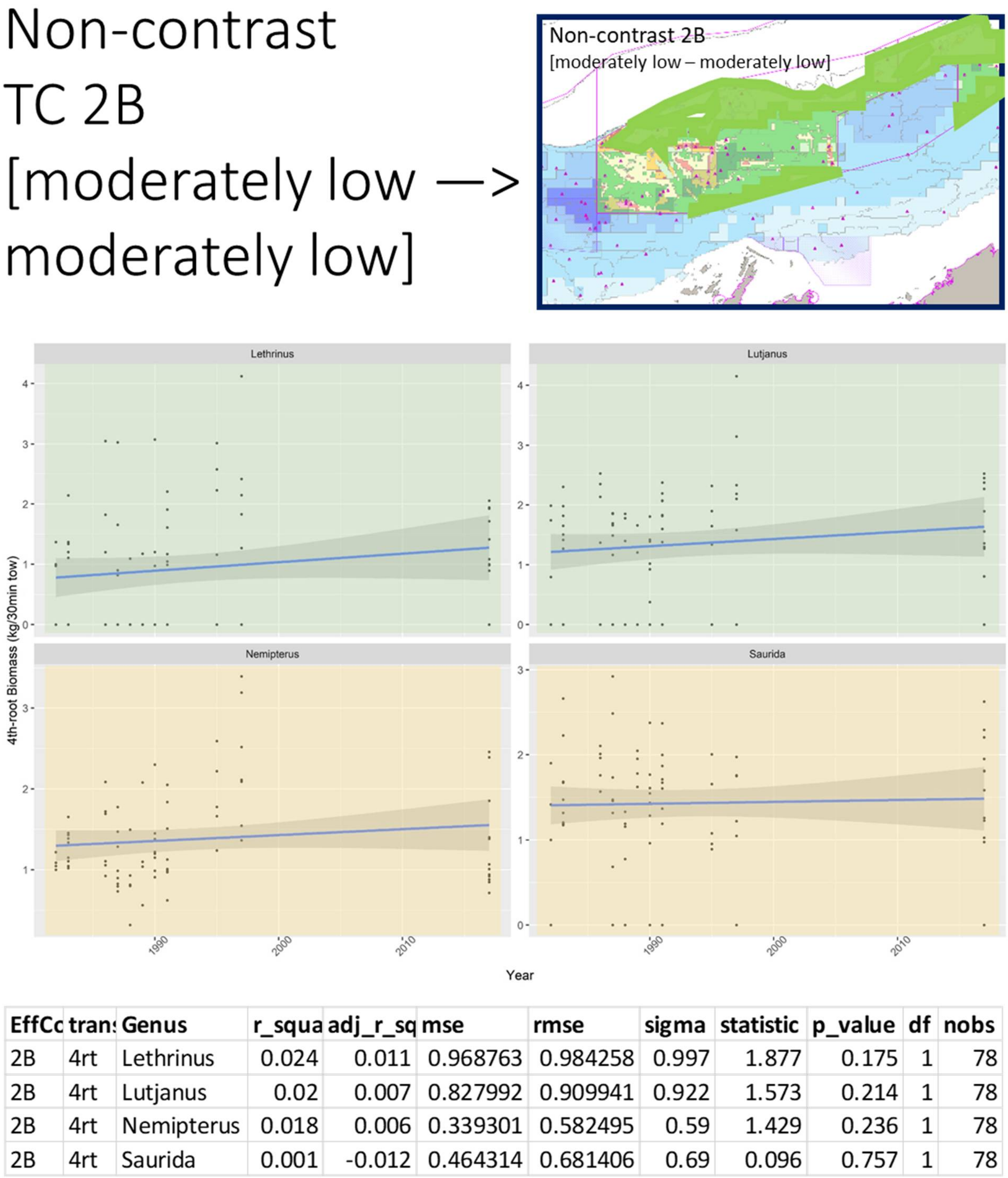






| EffCo | trans | Genus | r_squa | adj_r_sq | mse | rmse | sigma | statistic | p_value | df | nobs |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 3C | 4rt | Lethrinus | 0.002 | -0.037 | 1.381183 | 1.175238 | 1.221 | 0.061 | 0.807 | 1 | 27 |
| 3C | 4rt | Lutjanus | 0.01 | -0.029 | 0.522867 | 0.723095 | 0.751 | 0.262 | 0.613 | 1 | 27 |
| 3C | 4rt | Nemipterus | 0.015 | -0.024 | 0.365882 | 0.604882 | 0.629 | 0.385 | 0.541 | 1 | 27 |
| 3C | 4rt | Saurida | 0.147 | 0.113 | 0.449093 | 0.670144 | 0.696 | 4.296 | 0.049 | 1 | 27 |

Apx Figure 16 Non-contrast TC 3C Key Genera (N=4)

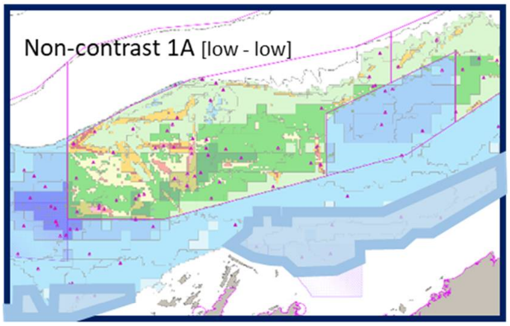


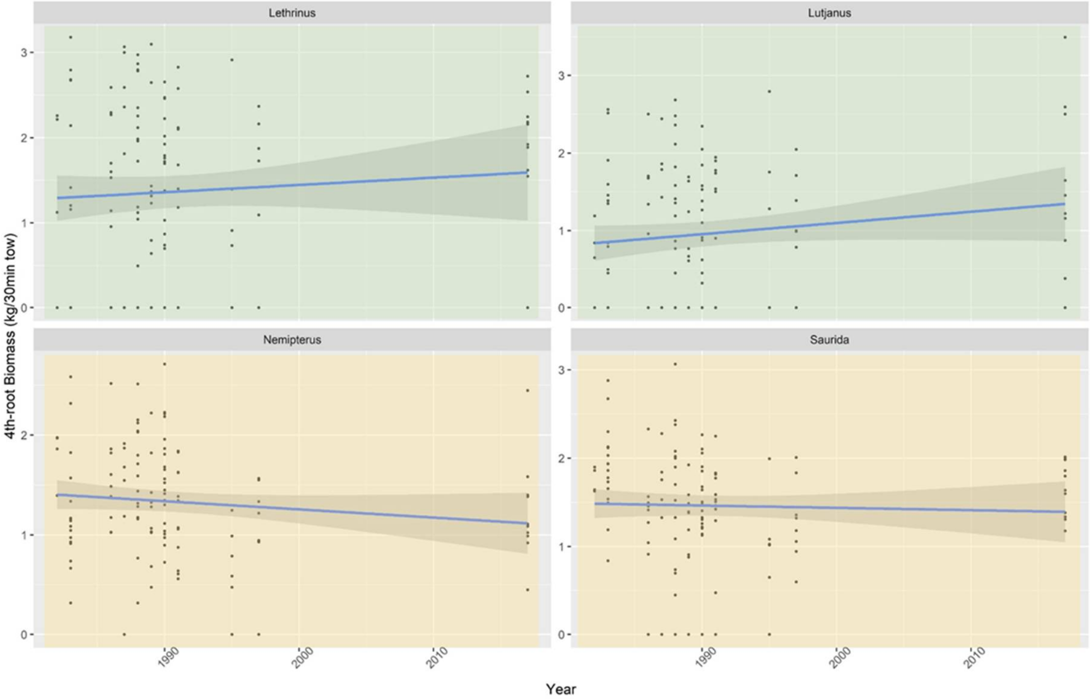
Non-contrast
TC 2B
[moderately low —> moderately low]

| EffCc | trans | Genus | r_squa | adj_r_sq | mse | rmse | sigma | statistic | p_value | df | nobs |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2B | 4rt | Lethrinus | 0.024 | 0.011 | 0.968763 | 0.984258 | 0.997 | 1.877 | 0.175 | 1 | 78 |
| 2B | 4rt | Lutjanus | 0.02 | 0.007 | 0.827992 | 0.909941 | 0.922 | 1.573 | 0.214 | 1 | 78 |
| 2B | 4rt | Nemipterus | 0.018 | 0.006 | 0.339301 | 0.582495 | 0.59 | 1.429 | 0.236 | 1 | 78 |
| 2B | 4rt | Saurida | 0.001 | -0.012 | 0.464314 | 0.681406 | 0.69 | 0.096 | 0.757 | 1 | 78 |

Apx Figure 17 Non-contrast TC 2B Key Genera (N=4)

# Non-contrast TC 1A [low —> low]



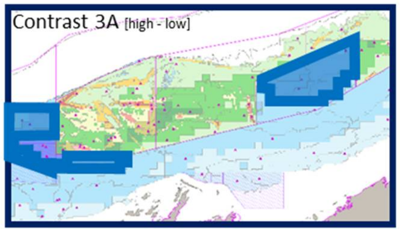


| EffCo | trans | Genus | r_squa | adj_r_sq | mse | rmse | sigma | statistic | p_value | df | nobs |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1A | 4rt | Lethrinus | 0.006 | -0.003 | 1.045343 | 1.02242 | 1.031 | 0.676 | 0.412 | 1 | 120 |
| 1A | 4rt | Lutjanus | 0.022 | 0.014 | 0.750195 | 0.866138 | 0.873 | 2.683 | 0.104 | 1 | 120 |
| 1A | 4rt | Nemipterus | 0.018 | 0.009 | 0.306725 | 0.553828 | 0.559 | 2.103 | 0.15 | 1 | 120 |
| 1A | 4rt | Saurida | 0.001 | -0.007 | 0.387816 | 0.622749 | 0.628 | 0.172 | 0.679 | 1 | 120 |

**Apx Figure 18 Non-contrast TC 1A Key Genera (N=4)**

# Contrast 3A [high—> low]

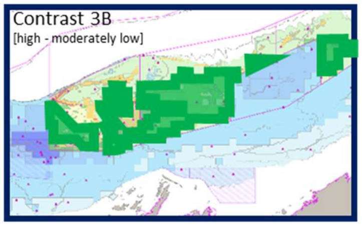
| EffCon | trans | CAAB | Scientific name | Common name | r_squar | adj_r_sq | mse | rmse | sigma | statistic | p_value | df | nobs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3A | 4rt | 37326005 | Priacanthus hamrur | Lunartail Bigeye | 0.013 | 0.005 | 0.43999 | 0.66332 | 0.675 | 0.73 | 0.396 | 1 | 59 |
| 3A | 4rt | 37346003 | Lutjanus vitta | Brownstripe Snapper | 0.008 | 0.009 | 0.7419 | 0.86134 | 0.876 | 0.471 | 0.495 | 1 | 59 |
| 3A | 4rt | 37346004 | Lutjanus sebae | Red Emperor | 0.017 | 0 | 0.89187 | 0.94439 | 0.961 | 0.978 | 0.327 | 1 | 59 |
| 3A | 4rt | 37347006 | Scolopsis monogramma | Rainbow Monocle Bream | 0.003 | 0.014 | 0.49428 | 0.70305 | 0.715 | 0.186 | 0.668 | 1 | 59 |
| 3A | 4rt | 37350003 | Diagramma pictum | Painted Sweetlips | 0.013 | 0.004 | 0.78425 | 0.88558 | 0.901 | 0.753 | 0.389 | 1 | 59 |
| 3A | 4rt | 37351904 | Lethrinus nebulosus & Lethrinus sp. | spangled emperor | 0.003 | 0.015 | 1.88177 | 1.37178 | 1.396 | 0.146 | 0.704 | 1 | 59 |
| 3A | 4rt | 37353006 | Argyrops bleekeri | Frypan Bream | 0.091 | 0.075 | 0.49731 | 0.7052 | 0.717 | 5.683 | 0.02 | 1 | 59 |
| 3A | 4rt | 37355004 | Parupeneus heptacanthus | Opalescent Goatfish | 0.06 | 0.043 | 0.56042 | 0.74861 | 0.762 | 3.621 | 0.062 | 1 | 59 |
| 3A | 4rt | 37365003 | Parachaetodon ocellatus | Ocellate Butterflyfish | 0 | 0.017 | 0.2018 | 0.44922 | 0.457 | 0.003 | 0.958 | 1 | 59 |
| 3A | 4rt | 37365008 | Chaetodontoplus personifer | Yellowtail Angelfish | 0.029 | 0.012 | 0.44384 | 0.66622 | 0.678 | 1.708 | 0.197 | 1 | 59 |
| 3A | 4rt | 37365009 | Chaetodontoplus duboulayi | Scribbled Angelfish | 0.015 | 0.002 | 0.23157 | 0.48122 | 0.49 | 0.893 | 0.349 | 1 | 59 |
| 3A | 4rt | 37384005 | Choerodon cauteroma | Bluespotted Tuskfish | 0 | 0.017 | 0.43406 | 0.65883 | 0.67 | 0.028 | 0.868 | 1 | 59 |
| 3A | 4rt | 37118001 | Saurida undosquamis | Largescale Saury | 0.009 | 0.009 | 0.32471 | 0.56983 | 0.58 | 0.498 | 0.483 | 1 | 59 |
| 3A | 4rt | 37118016 | Saurida grandisquamis | Grey Saury | 0.001 | 0.017 | 0.11672 | 0.34164 | 0.348 | 0.049 | 0.825 | 1 | 59 |
| 3A | 4rt | 37347004 | Nemipterus celebicus | Celebes Threadfin Bream | 0.141 | 0.126 | 0.22152 | 0.47066 | 0.479 | 9.325 | 0.003 | 1 | 59 |
| 3A | 4rt | 37347005 | Nemipterus furcosus | Rosy Threadfin Bream | 0 | 0.017 | 0.91758 | 0.9579 | 0.975 | 0.004 | 0.953 | 1 | 59 |
| 3A | 4rt | 37355008 | Upeneus guttatus | orange-barred goatfish | 0.076 | 0.06 | 0.18687 | 0.43228 | 0.44 | 4.715 | 0.034 | 1 | 59 |
| 3A | 4rt | 37460004 | Pseudorhombus dupliciocellatus | Three Twinspot Flounder | 0.054 | 0.038 | 0.13965 | 0.3737 | 0.38 | 3.271 | 0.076 | 1 | 59 |
| 3A | 4rt | 37460015 | Pseudorhombus diplospilus | Bigtooth Twinspot Flounder | 0.077 | 0.06 | 0.20426 | 0.45195 | 0.46 | 4.731 | 0.034 | 1 | 59 |
| 3A | 4rt | 37465011 | Abalistes stellatus | Starry Triggerfish | 0.024 | 0.007 | 0.23029 | 0.47989 | 0.488 | 1.401 | 0.242 | 1 | 59 |
| 3A | 4rt | 37311009 | Epinephelus areolatus | Yellowspotted Rockcod | 0.075 | 0.059 | 0.2761 | 0.52545 | 0.535 | 4.613 | 0.036 | 1 | 59 |
| 3A | 4rt | 37311010 | Epinephelus multinotatus | Rankin Cod | 0 | 0.017 | 0.53176 | 0.72922 | 0.742 | 0.013 | 0.908 | 1 | 59 |
| 3A | 4rt | 37311012 | Plectropomus maculatus | Barcheek Coral Trout | 0.004 | 0.014 | 0.36573 | 0.60476 | 0.615 | 0.206 | 0.652 | 1 | 59 |
| 3A | 4rt | 37346002 | Pristipomoides multidens | Goldband Snapper | 0.097 | 0.082 | 0.1552 | 0.39395 | 0.401 | 6.149 | 0.016 | 1 | 59 |
| 3A | 4rt | 37346007 | Lutjanus malabaricus | Saddletail Snapper | 0.069 | 0.053 | 0.41658 | 0.64543 | 0.657 | 4.23 | 0.044 | 1 | 59 |
| 3A | 4rt | 37347007 | Pentapodus porosus | Northwest Threadfin Bream | 0.001 | 0.017 | 0.23981 | 0.48971 | 0.498 | 0.041 | 0.841 | 1 | 59 |
| 3A | 4rt | 37346005 | Lutjanus erythropterus | Crimson Snapper | 0.018 | 0.001 | 0.20853 | 0.45665 | 0.465 | 1.069 | 0.306 | 1 | 59 |



Apx Figure 19 Contrast TC 3A Informative species (N=27)

Contrast 3B [high—> moderately low]

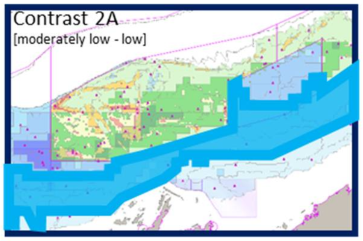
| EffCon | trans | CAAB | Scientific name | Common name | r_squar | adj_r_sq | mse | rmse | sigma | statistic | p_value | df | nobs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3B | 4rt | 37326005 | Priacanthus hamrur | Lunartail Bigeye | 0.016 | 0.005 | 0.31996 | 0.56565 | 0.572 | 1.51 | 0.222 | 1 | 95 |
| 3B | 4rt | 37346003 | Lutjanus vitta | Brownstripe Snapper | 0.042 | 0.032 | 0.58239 | 0.76315 | 0.771 | 4.067 | 0.047 | 1 | 95 |
| 3B | 4rt | 37346004 | Lutjanus sebae | Red Emperor | 0.077 | 0.067 | 0.70147 | 0.83754 | 0.846 | 7.777 | 0.006 | 1 | 95 |
| 3B | 4rt | 37347006 | Scolopsis monogramma | Rainbow Monocle Bream | 0.173 | 0.164 | 0.26801 | 0.5177 | 0.523 | 19.486 | 0 | 1 | 95 |
| 3B | 4rt | 37350003 | Diagramma pictum | Painted Sweetlips | 0.188 | 0.179 | 0.47406 | 0.68852 | 0.696 | 21.513 | 0 | 1 | 95 |
| 3B | 4rt | 37351904 | Lethrinus nebulosus & Lethrinus sp. | spangled emperor | 0.155 | 0.146 | 0.91153 | 0.95474 | 0.965 | 17.076 | 0 | 1 | 95 |
| 3B | 4rt | 37353006 | Argyrops bleekeri | Frypan Bream | 0.23 | 0.222 | 0.3649 | 0.60407 | 0.611 | 27.848 | 0 | 1 | 95 |
| 3B | 4rt | 37355004 | Parupeneus heptacanthus | Opalescent Goatfish | 0.033 | 0.023 | 0.46254 | 0.68011 | 0.687 | 3.223 | 0.076 | 1 | 95 |
| 3B | 4rt | 37365003 | Parachaetodon ocellatus | Ocellate Butterflyfish | 0.052 | 0.041 | 0.17356 | 0.41661 | 0.421 | 5.066 | 0.027 | 1 | 95 |
| 3B | 4rt | 37365008 | Chaetodontoplus personifer | Yellowtail Angelfish | 0.03 | 0.02 | 0.34115 | 0.58408 | 0.59 | 2.925 | 0.091 | 1 | 95 |
| 3B | 4rt | 37365009 | Chaetodontoplus duboulayi | Scribbled Angelfish | 0.045 | 0.035 | 0.10426 | 0.32289 | 0.326 | 4.428 | 0.038 | 1 | 95 |
| 3B | 4rt | 37384005 | Choerodon cauteroma | Bluespotted Tuskfish | 0.028 | 0.017 | 0.28604 | 0.53483 | 0.541 | 2.672 | 0.105 | 1 | 95 |
| 3B | 4rt | 37118001 | Saurida undosquamis | Largescale Saury | 0.011 | 0 | 0.42805 | 0.65425 | 0.661 | 1.044 | 0.31 | 1 | 95 |
| 3B | 4rt | 37118016 | Saurida grandisquamis | Grey Saury | 0.01 | -0.001 | 0.15047 | 0.3879 | 0.392 | 0.92 | 0.34 | 1 | 95 |
| 3B | 4rt | 37347004 | Nemipterus celebicus | Celebes Threadfin Bream | 0.076 | 0.066 | 0.20505 | 0.45283 | 0.458 | 7.636 | 0.007 | 1 | 95 |
| 3B | 4rt | 37347005 | Nemipterus furcosus | Rosy Threadfin Bream | 0.052 | 0.042 | 0.60484 | 0.77772 | 0.786 | 5.122 | 0.026 | 1 | 95 |
| 3B | 4rt | 37355008 | Upeneus guttatus | orange-barred goatfish | 0.03 | 0.02 | 0.29925 | 0.54703 | 0.553 | 2.878 | 0.093 | 1 | 95 |
| 3B | 4rt | 37460004 | Pseudorhombus dupliciocellatus | Three Twinspot Flounder | 0.035 | 0.025 | 0.25611 | 0.50607 | 0.511 | 3.397 | 0.068 | 1 | 95 |
| 3B | 4rt | 37460015 | Pseudorhombus diplospilus | Bigtooth Twinspot Flounder | 0.002 | -0.009 | 0.16538 | 0.40667 | 0.411 | 0.201 | 0.655 | 1 | 95 |
| 3B | 4rt | 37465011 | Abalistes stellatus | Starry Triggerfish | 0.118 | 0.109 | 0.24699 | 0.49698 | 0.502 | 12.493 | 0.001 | 1 | 95 |
| 3B | 4rt | 37311009 | Epinephelus areolatus | Yellowspotted Rockcod | 0.065 | 0.055 | 0.31582 | 0.56198 | 0.568 | 6.434 | 0.013 | 1 | 95 |
| 3B | 4rt | 37311010 | Epinephelus multinotatus | Rankin Cod | 0.05 | 0.04 | 0.54584 | 0.73881 | 0.747 | 4.926 | 0.029 | 1 | 95 |
| 3B | 4rt | 37311012 | Plectropomus maculatus | Barcheek Coral Trout | 0.063 | 0.053 | 0.24338 | 0.49333 | 0.499 | 6.287 | 0.014 | 1 | 95 |
| 3B | 4rt | 37346002 | Pristipomoides multidens | Goldband Snapper | 0.141 | 0.132 | 0.27899 | 0.5282 | 0.534 | 15.25 | 0 | 1 | 95 |
| 3B | 4rt | 37346007 | Lutjanus malabaricus | Saddletail Snapper | 0.086 | 0.076 | 0.36001 | 0.60001 | 0.606 | 8.754 | 0.004 | 1 | 95 |
| 3B | 4rt | 37347007 | Pentapodus porosus | Northwest Threadfin Bream | 0.001 | -0.01 | 0.0666 | 0.25807 | 0.261 | 0.07 | 0.793 | 1 | 95 |
| 3B | 4rt | 37346005 | Lutjanus erythropterus | Crimson Snapper | 0.033 | 0.023 | 0.10366 | 0.32196 | 0.325 | 3.185 | 0.078 | 1 | 95 |

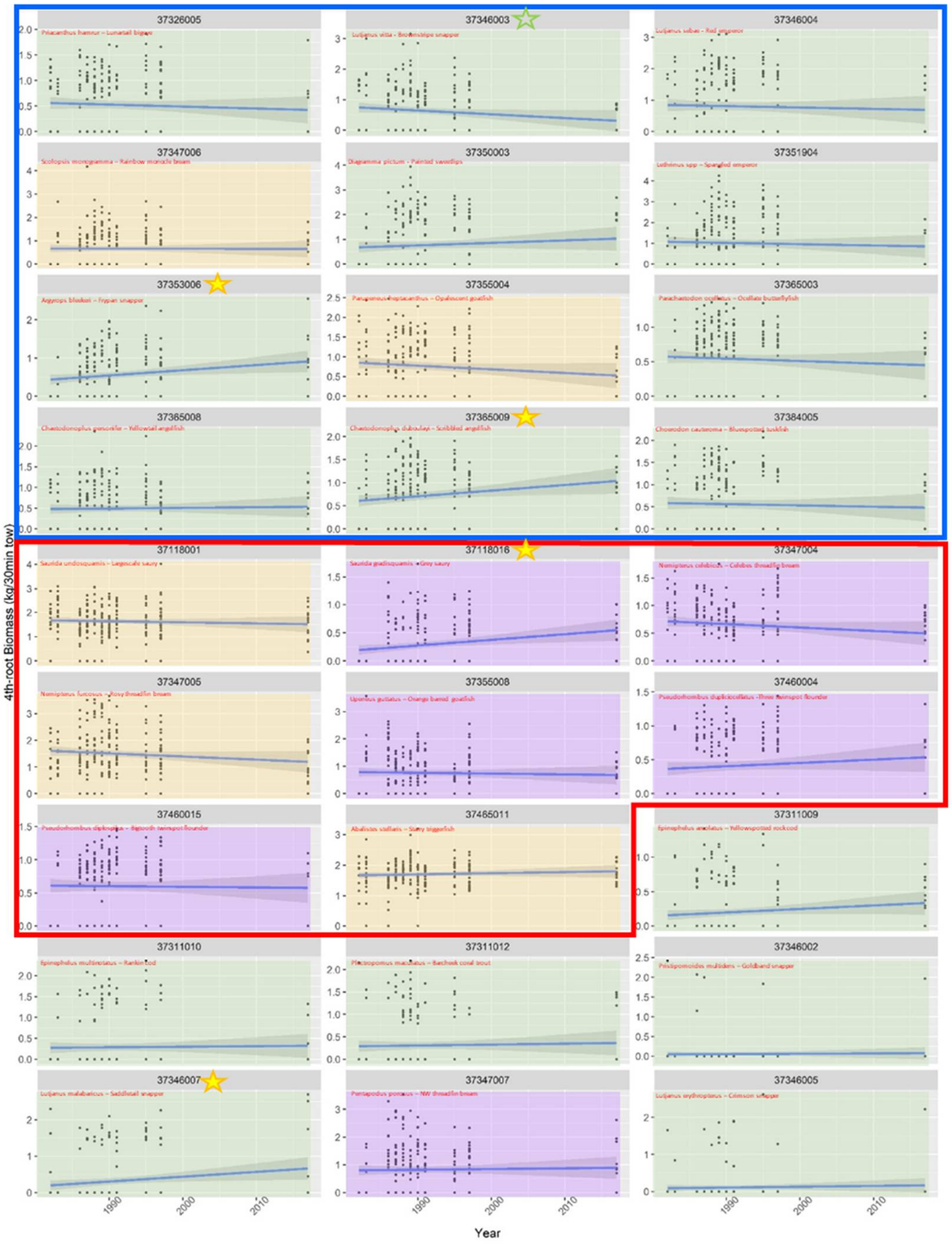


Apx Figure 20 Contrast TC 3B Informative species (N=27)

## Contrast 2A [moderately low —> low]

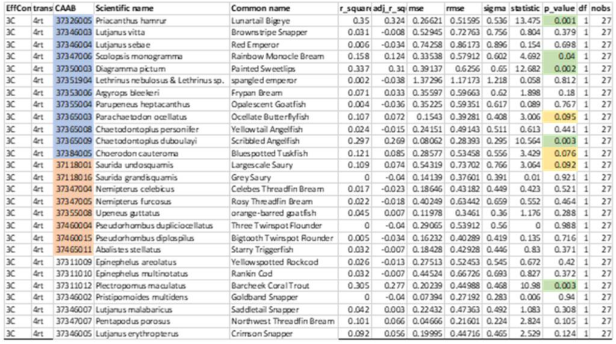
| EffCon | trans | CAAB | Scientific name | Common name | r_squar | adj_r_sq | mse | rmse | sigma | statistic | p_value | df | nobs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2A | 4rt | 37326005 | Priacanthus hamrur | Lunartail Bigeye | 0.003 | -0.002 | 0.31731 | 0.5633 | 0.566 | 0.602 | 0.439 | 1 | 210 |
| 2A | 4rt | 37346003 | Lutjanus vitta | Brownstripe Snapper | 0.016 | 0.012 | 0.57199 | 0.7563 | 0.76 | 3.481 | 0.063 | 1 | 210 |
| 2A | 4rt | 37346004 | Lutjanus sebae | Red Emperor | 0.001 | -0.003 | 0.89522 | 0.94616 | 0.951 | 0.285 | 0.594 | 1 | 210 |
| 2A | 4rt | 37347006 | Scolopsis monogramma | Rainbow Monocle Bream | 0 | -0.005 | 0.60508 | 0.77787 | 0.782 | 0.002 | 0.963 | 1 | 210 |
| 2A | 4rt | 37350003 | Diagramma pictum | Painted Sweetlips | 0.006 | 0.001 | 1.06318 | 1.0311 | 1.036 | 1.226 | 0.269 | 1 | 210 |
| 2A | 4rt | 37351904 | Lethrinus nebulosus & Lethrinus sp. | spangled emperor | 0.002 | -0.003 | 1.36709 | 1.16923 | 1.175 | 0.369 | 0.544 | 1 | 210 |
| 2A | 4rt | 37353006 | Argyrops bleekeri | Frypan Bream | 0.031 | 0.026 | 0.3541 | 0.59506 | 0.598 | 6.679 | 0.01 | 1 | 210 |
| 2A | 4rt | 37355004 | Parupeneus heptacanthus | Opalescent Goatfish | 0.011 | 0.006 | 0.47615 | 0.69004 | 0.693 | 2.307 | 0.13 | 1 | 210 |
| 2A | 4rt | 37365003 | Parachaetodon ocellatus | Ocellate Butterflyfish | 0.004 | -0.001 | 0.20872 | 0.45686 | 0.459 | 0.769 | 0.381 | 1 | 210 |
| 2A | 4rt | 37365008 | Chaetodontoplus personifer | Yellowtail Angelfish | 0.001 | -0.004 | 0.29491 | 0.54305 | 0.546 | 0.109 | 0.742 | 1 | 210 |
| 2A | 4rt | 37365009 | Chaetodontoplus duboulayi | Scribbled Angelfish | 0.025 | 0.02 | 0.36472 | 0.60392 | 0.607 | 5.296 | 0.022 | 1 | 210 |
| 2A | 4rt | 37384005 | Choerodon cauteroma | Bluespotted Tuskfish | 0.001 | -0.004 | 0.44684 | 0.66846 | 0.672 | 0.251 | 0.617 | 1 | 210 |
| 2A | 4rt | 37118001 | Saurida undosquamis | Largescale Saury | 0.003 | -0.002 | 0.47782 | 0.69124 | 0.695 | 0.54 | 0.463 | 1 | 210 |
| 2A | 4rt | 37118016 | Saurida grandisquamis | Grey Saury | 0.038 | 0.033 | 0.15895 | 0.39869 | 0.401 | 8.152 | 0.005 | 1 | 210 |
| 2A | 4rt | 37347004 | Nemipterus celebicus | Celebes Threadfin Bream | 0.011 | 0.007 | 0.20636 | 0.45427 | 0.456 | 2.376 | 0.125 | 1 | 210 |
| 2A | 4rt | 37347005 | Nemipterus furcosus | Rosy Threadfin Bream | 0.012 | 0.007 | 0.72491 | 0.85142 | 0.855 | 2.455 | 0.119 | 1 | 210 |
| 2A | 4rt | 37355008 | Upeneus guttatus | orange-barred goatfish | 0.001 | -0.004 | 0.54836 | 0.74051 | 0.744 | 0.211 | 0.646 | 1 | 210 |
| 2A | 4rt | 37460004 | Pseudorhombus dupliciocellatus | Three Twinspot Flounder | 0.007 | 0.002 | 0.21388 | 0.46247 | 0.465 | 1.416 | 0.235 | 1 | 210 |
| 2A | 4rt | 37460015 | Pseudorhombus diplospilus | Bigtooth Twinspot Flounder | 0 | -0.005 | 0.22863 | 0.47815 | 0.48 | 0.05 | 0.823 | 1 | 210 |
| 2A | 4rt | 37465011 | Abalistes stellatus | Starry Triggerfish | 0.004 | -0.001 | 0.2069 | 0.45486 | 0.457 | 0.842 | 0.36 | 1 | 210 |
| 2A | 4rt | 37311009 | Epinephelus areolatus | Yellowspotted Rockcod | 0.012 | 0.007 | 0.12825 | 0.35812 | 0.36 | 2.577 | 0.11 | 1 | 210 |
| 2A | 4rt | 37311010 | Epinephelus multinotatus | Rankin Cod | 0 | -0.005 | 0.37547 | 0.61275 | 0.616 | 0.063 | 0.802 | 1 | 210 |
| 2A | 4rt | 37311012 | Plectropomus maculatus | Barcheek Coral Trout | 0.001 | -0.004 | 0.34518 | 0.58752 | 0.59 | 0.159 | 0.69 | 1 | 210 |
| 2A | 4rt | 37346002 | Pristipomoides multidens | Goldband Snapper | 0 | -0.004 | 0.10511 | 0.32421 | 0.326 | 0.085 | 0.771 | 1 | 210 |
| 2A | 4rt | 37346007 | Lutjanus malabaricus | Saddletail Snapper | 0.025 | 0.02 | 0.43268 | 0.65778 | 0.661 | 5.231 | 0.023 | 1 | 210 |
| 2A | 4rt | 37347007 | Pentapodus porosus | Northwest Threadfin Bream | 0.001 | -0.004 | 0.73385 | 0.85665 | 0.861 | 0.113 | 0.737 | 1 | 210 |
| 2A | 4rt | 37346005 | Lutjanus erythropterus | Crimson Snapper | 0.002 | -0.003 | 0.17176 | 0.41444 | 0.416 | 0.368 | 0.545 | 1 | 210 |



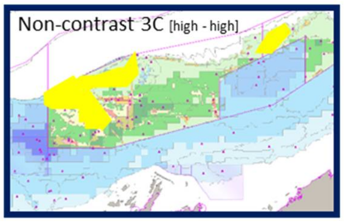


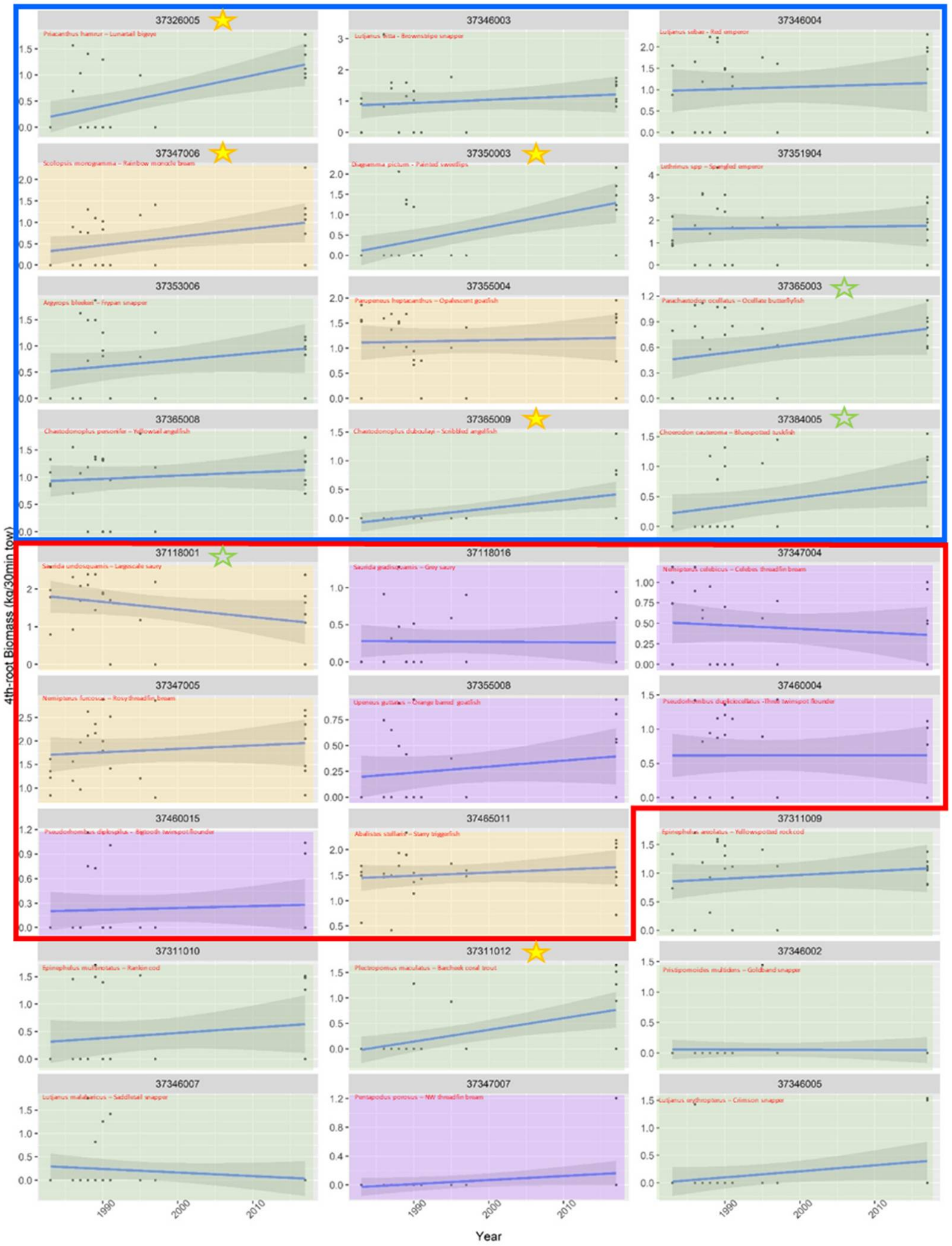
Apx Figure 21 Contrast TC 2A Informative species (N=27)

## Non-contrast 3C [high —> high]

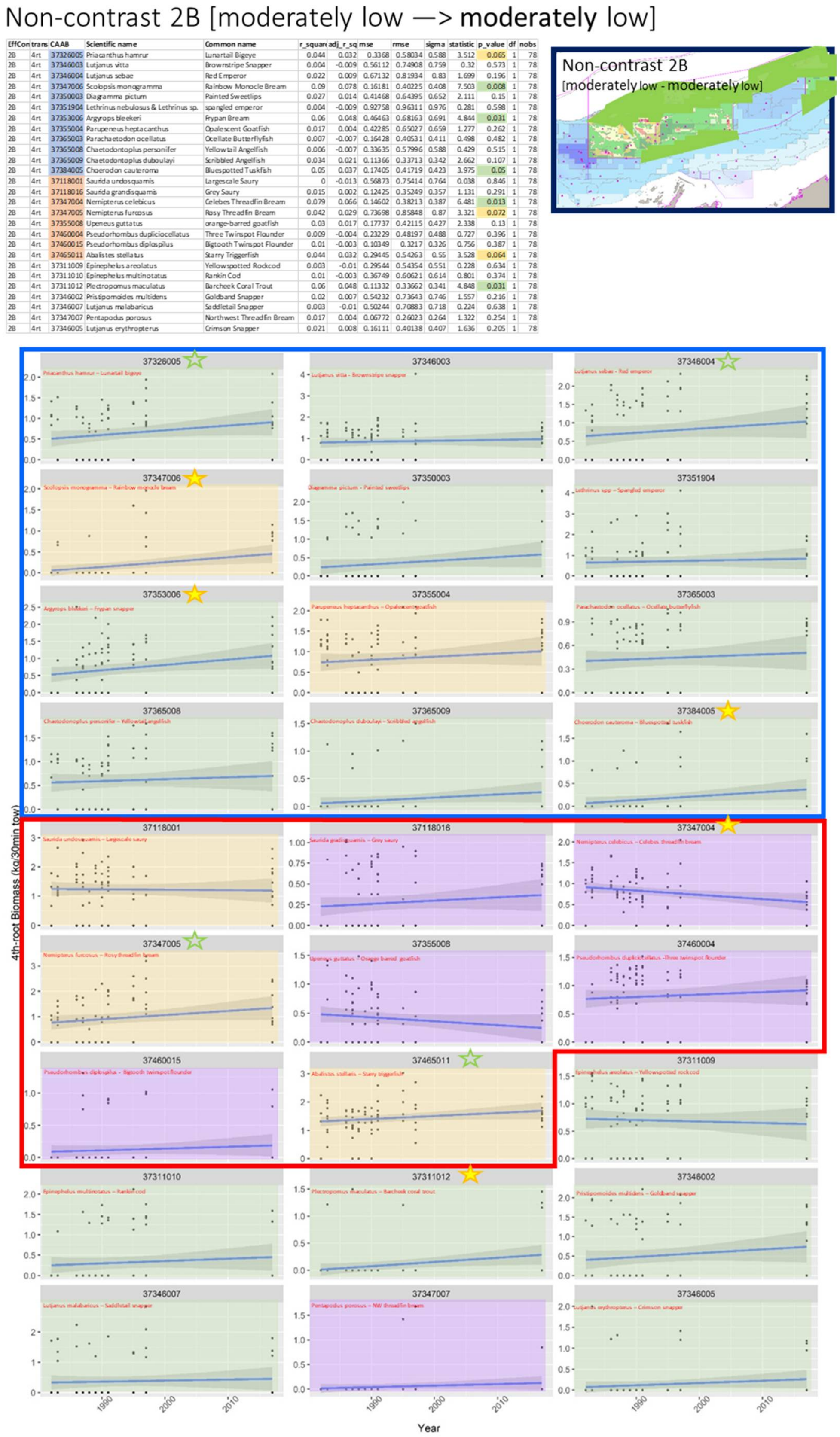


| EffCon | trans | CAAB | Scientific name | Common name | r_squar | adj_r_sq | mse | rmse | sigma | statistic | p_value | df | nobs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3C | 4rt | 37326005 | Priacanthus hamrur | Lunartail Bigeye | 0.35 | 0.324 | 0.26621 | 0.51595 | 0.536 | 13.475 | 0.001 | 1 | 27 |
| 3C | 4rt | 37346003 | Lutjanus vitta | Brownstripe Snapper | 0.031 | -0.008 | 0.52945 | 0.72763 | 0.756 | 0.804 | 0.379 | 1 | 27 |
| 3C | 4rt | 37346004 | Lutjanus sebae | Red Emperor | 0.006 | -0.034 | 0.74258 | 0.86173 | 0.896 | 0.154 | 0.698 | 1 | 27 |
| 3C | 4rt | 37347006 | Scolopsis monogramma | Rainbow Monocle Bream | 0.158 | 0.124 | 0.33538 | 0.57912 | 0.602 | 4.692 | 0.04 | 1 | 27 |
| 3C | 4rt | 37350003 | Diagramma pictum | Painted Sweetlips | 0.337 | 0.31 | 0.39137 | 0.6256 | 0.65 | 12.682 | 0.002 | 1 | 27 |
| 3C | 4rt | 37351904 | Lethrinus nebulosus & Lethrinus sp. | spangled emperor | 0.002 | -0.038 | 1.37296 | 1.17173 | 1.218 | 0.058 | 0.812 | 1 | 27 |
| 3C | 4rt | 37353006 | Argyrops bleekeri | Frypan Bream | 0.071 | 0.033 | 0.35597 | 0.59663 | 0.62 | 1.898 | 0.18 | 1 | 27 |
| 3C | 4rt | 37355004 | Parupeneus heptacanthus | Opalescent Goatfish | 0.004 | -0.036 | 0.35225 | 0.59351 | 0.617 | 0.089 | 0.767 | 1 | 27 |
| 3C | 4rt | 37365003 | Parachaetodon ocellatus | Ocellate Butterflyfish | 0.107 | 0.072 | 0.1543 | 0.39281 | 0.408 | 3.006 | 0.095 | 1 | 27 |
| 3C | 4rt | 37365008 | Chaetodontoplus personifer | Yellowtail Angelfish | 0.024 | -0.015 | 0.24151 | 0.49143 | 0.511 | 0.613 | 0.441 | 1 | 27 |
| 3C | 4rt | 37365009 | Chaetodontoplus duboulayi | Scribbled Angelfish | 0.297 | 0.269 | 0.08062 | 0.28393 | 0.295 | 10.564 | 0.003 | 1 | 27 |
| 3C | 4rt | 37384005 | Choerodon cauteroma | Bluespotted Tuskfish | 0.121 | 0.085 | 0.28577 | 0.53458 | 0.556 | 3.429 | 0.076 | 1 | 27 |
| 3C | 4rt | 37118001 | Saurida undosquamis | Largescale Saury | 0.109 | 0.074 | 0.54319 | 0.73702 | 0.766 | 3.064 | 0.092 | 1 | 27 |
| 3C | 4rt | 37118016 | Saurida grandisquamis | Grey Saury | 0 | -0.04 | 0.14139 | 0.37601 | 0.391 | 0.01 | 0.921 | 1 | 27 |
| 3C | 4rt | 37347004 | Nemipterus celebicus | Celebes Threadfin Bream | 0.017 | -0.023 | 0.18646 | 0.43182 | 0.449 | 0.423 | 0.521 | 1 | 27 |
| 3C | 4rt | 37347005 | Nemipterus furcosus | Rosy Threadfin Bream | 0.022 | -0.018 | 0.40249 | 0.63442 | 0.659 | 0.552 | 0.464 | 1 | 27 |
| 3C | 4rt | 37355008 | Upeneus guttatus | orange-barred goatfish | 0.045 | 0.007 | 0.11978 | 0.3461 | 0.36 | 1.176 | 0.288 | 1 | 27 |
| 3C | 4rt | 37460004 | Pseudorhombus dupliciocellatus | Three Twinspot Flounder | 0 | -0.04 | 0.29065 | 0.53912 | 0.56 | 0 | 0.988 | 1 | 27 |
| 3C | 4rt | 37460015 | Pseudorhombus diplospilus | Bigtooth Twinspot Flounder | 0.005 | -0.034 | 0.16232 | 0.40289 | 0.419 | 0.135 | 0.716 | 1 | 27 |
| 3C | 4rt | 37465011 | Abalistes stellatus | Starry Triggerfish | 0.032 | -0.007 | 0.18428 | 0.42928 | 0.446 | 0.83 | 0.371 | 1 | 27 |
| 3C | 4rt | 37311009 | Epinephelus areolatus | Yellowspotted Rockcod | 0.026 | -0.013 | 0.27513 | 0.52453 | 0.545 | 0.672 | 0.42 | 1 | 27 |
| 3C | 4rt | 37311010 | Epinephelus multinotatus | Rankin Cod | 0.032 | -0.007 | 0.44524 | 0.66726 | 0.693 | 0.827 | 0.372 | 1 | 27 |
| 3C | 4rt | 37311012 | Plectropomus maculatus | Barcheek Coral Trout | 0.305 | 0.277 | 0.20239 | 0.44988 | 0.468 | 10.98 | 0.003 | 1 | 27 |
| 3C | 4rt | 37346002 | Pristipomoides multidens | Goldband Snapper | 0 | -0.04 | 0.07394 | 0.27192 | 0.283 | 0.006 | 0.94 | 1 | 27 |
| 3C | 4rt | 37346007 | Lutjanus malabaricus | Saddletail Snapper | 0.042 | 0.003 | 0.22432 | 0.47363 | 0.492 | 1.083 | 0.308 | 1 | 27 |
| 3C | 4rt | 37347007 | Pentapodus porosus | Northwest Threadfin Bream | 0.101 | 0.066 | 0.04666 | 0.21601 | 0.224 | 2.824 | 0.105 | 1 | 27 |
| 3C | 4rt | 37346005 | Lutjanus erythropterus | Crimson Snapper | 0.092 | 0.056 | 0.19995 | 0.44716 | 0.465 | 2.529 | 0.124 | 1 | 27 |





Apx Figure 22 Non-contrast TC 3C Informative species (N=27)

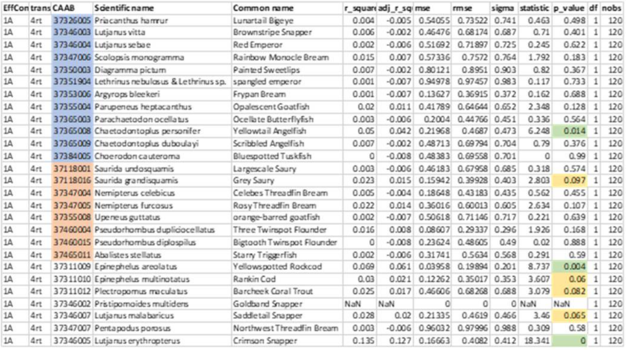


Non-contrast 2B [moderately low —> **moderately** low]

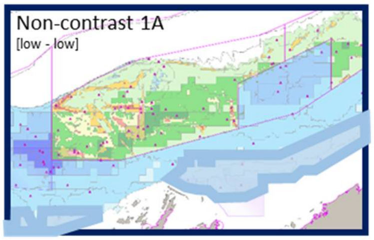
| EffCon | trans | CAAB | Scientific name | Common name | r_square | adj_r_sq | mse | rmse | sigma | statistic | p_value | df | nobs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2B | 4rt | 37326005 | Priacanthus hamrur | Lunartail Bigeye | 0.044 | 0.032 | 0.3368 | 0.58034 | 0.588 | 3.512 | 0.065 | 1 | 78 |
| 2B | 4rt | 37346003 | Lutjanus vitta | Brownstripe Snapper | 0.004 | -0.009 | 0.56112 | 0.74908 | 0.759 | 0.32 | 0.573 | 1 | 78 |
| 2B | 4rt | 37346004 | Lutjanus sebae | Red Emperor | 0.022 | 0.009 | 0.67132 | 0.81934 | 0.83 | 1.699 | 0.196 | 1 | 78 |
| 2B | 4rt | 37347006 | Scolopsis monogramma | Rainbow Monocle Bream | 0.09 | 0.078 | 0.16181 | 0.40225 | 0.408 | 7.503 | 0.008 | 1 | 78 |
| 2B | 4rt | 37350003 | Diagramma pictum | Painted Sweetlips | 0.027 | 0.014 | 0.41468 | 0.64395 | 0.652 | 2.111 | 0.15 | 1 | 78 |
| 2B | 4rt | 37351904 | Lethrinus nebulosus & Lethrinus sp. | spangled emperor | 0.004 | -0.009 | 0.92758 | 0.96311 | 0.976 | 0.281 | 0.598 | 1 | 78 |
| 2B | 4rt | 37353006 | Argyrops bleekeri | Frypan Bream | 0.06 | 0.048 | 0.46463 | 0.68163 | 0.691 | 4.844 | 0.031 | 1 | 78 |
| 2B | 4rt | 37355004 | Parupeneus heptacanthus | Opalescent Goatfish | 0.017 | 0.004 | 0.42285 | 0.65027 | 0.659 | 1.277 | 0.262 | 1 | 78 |
| 2B | 4rt | 37365003 | Parachaetodon ocellatus | Ocellate Butterflyfish | 0.007 | -0.007 | 0.16428 | 0.40531 | 0.411 | 0.498 | 0.482 | 1 | 78 |
| 2B | 4rt | 37365008 | Chaetodontoplus personifer | Yellowtail Angelfish | 0.006 | -0.007 | 0.33635 | 0.57996 | 0.588 | 0.429 | 0.515 | 1 | 78 |
| 2B | 4rt | 37365009 | Chaetodontoplus duboulayi | Scribbled Angelfish | 0.034 | 0.021 | 0.11366 | 0.33713 | 0.342 | 2.662 | 0.107 | 1 | 78 |
| 2B | 4rt | 37384005 | Choerodon cauteroma | Bluespotted Tuskfish | 0.05 | 0.037 | 0.17405 | 0.41719 | 0.423 | 3.975 | 0.05 | 1 | 78 |
| 2B | 4rt | 37118001 | Saurida undosquamis | Largescale Saury | 0 | -0.013 | 0.56873 | 0.75414 | 0.764 | 0.038 | 0.846 | 1 | 78 |
| 2B | 4rt | 37118016 | Saurida grandisquamis | Grey Saury | 0.015 | 0.002 | 0.12425 | 0.35249 | 0.357 | 1.131 | 0.291 | 1 | 78 |
| 2B | 4rt | 37347004 | Nemipterus celebicus | Celebes Threadfin Bream | 0.079 | 0.066 | 0.14602 | 0.38213 | 0.387 | 6.481 | 0.013 | 1 | 78 |
| 2B | 4rt | 37347005 | Nemipterus furcosus | Rosy Threadfin Bream | 0.042 | 0.029 | 0.73698 | 0.85848 | 0.87 | 3.321 | 0.072 | 1 | 78 |
| 2B | 4rt | 37355008 | Upeneus guttatus | orange-barred goatfish | 0.03 | 0.017 | 0.17737 | 0.42115 | 0.427 | 2.338 | 0.13 | 1 | 78 |
| 2B | 4rt | 37460004 | Pseudorhombus dupliciocellatus | Three Twinspot Flounder | 0.009 | -0.004 | 0.23229 | 0.48197 | 0.488 | 0.727 | 0.396 | 1 | 78 |
| 2B | 4rt | 37460015 | Pseudorhombus diplospilus | Bigtooth Twinspot Flounder | 0.01 | -0.003 | 0.10349 | 0.3217 | 0.326 | 0.756 | 0.387 | 1 | 78 |
| 2B | 4rt | 37465011 | Abalistes stellatus | Starry Triggerfish | 0.044 | 0.032 | 0.29445 | 0.54263 | 0.55 | 3.528 | 0.064 | 1 | 78 |
| 2B | 4rt | 37311009 | Epinephelus areolatus | Yellowspotted Rockcod | 0.003 | -0.01 | 0.29544 | 0.54354 | 0.551 | 0.228 | 0.634 | 1 | 78 |
| 2B | 4rt | 37311010 | Epinephelus multinotatus | Rankin Cod | 0.01 | -0.003 | 0.36749 | 0.60621 | 0.614 | 0.801 | 0.374 | 1 | 78 |
| 2B | 4rt | 37311012 | Plectropomus maculatus | Barcheek Coral Trout | 0.06 | 0.048 | 0.11332 | 0.33662 | 0.341 | 4.848 | 0.031 | 1 | 78 |
| 2B | 4rt | 37346002 | Pristipomoides multidens | Goldband Snapper | 0.02 | 0.007 | 0.54232 | 0.73643 | 0.746 | 1.557 | 0.216 | 1 | 78 |
| 2B | 4rt | 37346007 | Lutjanus malabaricus | Saddletail Snapper | 0.003 | -0.01 | 0.50244 | 0.70883 | 0.718 | 0.224 | 0.638 | 1 | 78 |
| 2B | 4rt | 37347007 | Pentapodus porosus | Northwest Threadfin Bream | 0.017 | 0.004 | 0.06772 | 0.26023 | 0.264 | 1.322 | 0.254 | 1 | 78 |
| 2B | 4rt | 37346005 | Lutjanus erythropterus | Crimson Snapper | 0.021 | 0.008 | 0.16111 | 0.40138 | 0.407 | 1.636 | 0.205 | 1 | 78 |

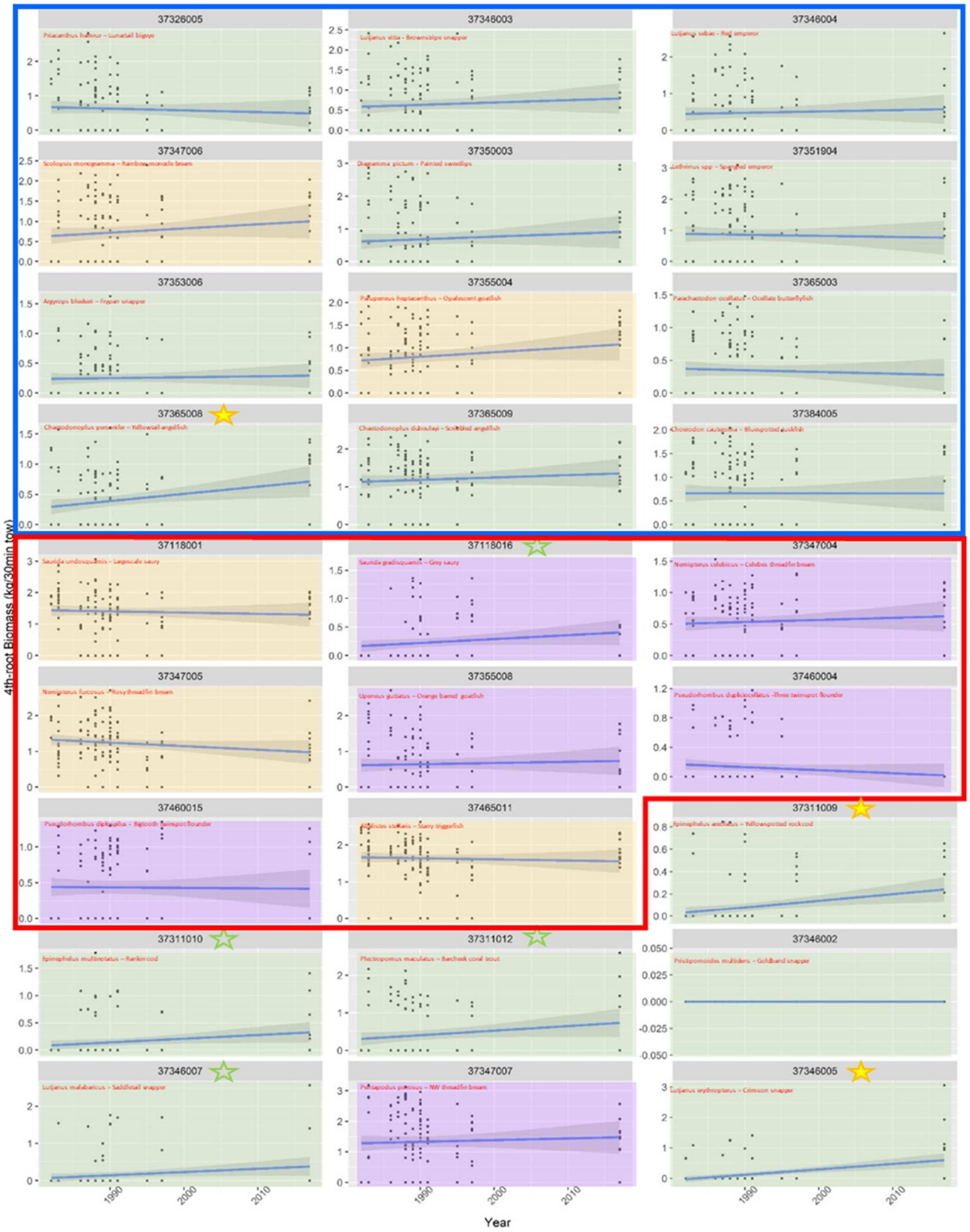
Apx Figure 23 Non-contrast TC 2B Informative species (N=27)

## Non-contrast 1A [low —> low]

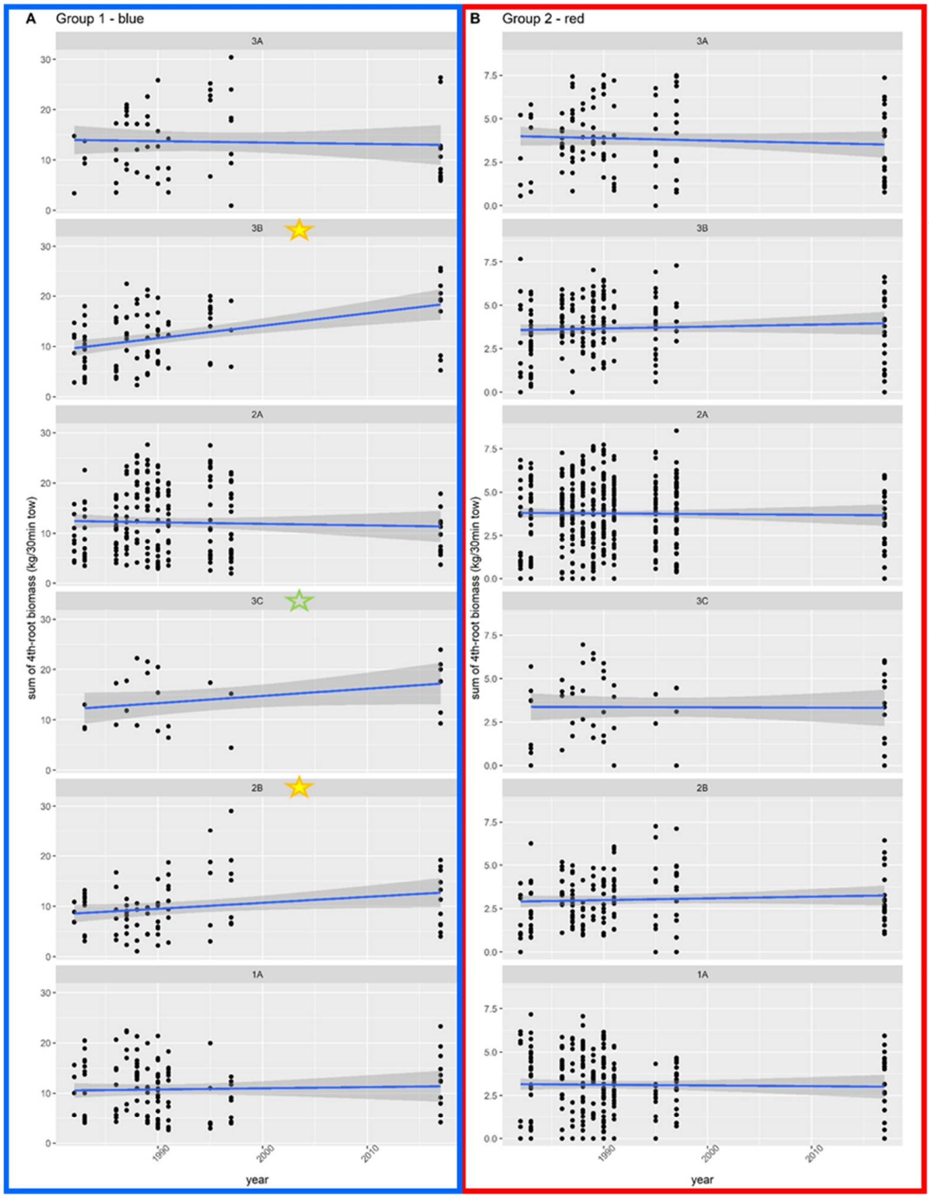


| EffCon | trans | CAAB | Scientific name | Common name | r_squar | adj_r_sq | mse | rmse | sigma | statistic | p_value | df | nobs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1A | 4rt | 37326005 | Priacanthus hamrur | Lunartail Bigeye | 0.004 | -0.005 | 0.54055 | 0.73522 | 0.741 | 0.463 | 0.498 | 1 | 120 |
| 1A | 4rt | 37346003 | Lutjanus vitta | Brownstripe Snapper | 0.006 | -0.002 | 0.46476 | 0.68174 | 0.687 | 0.71 | 0.401 | 1 | 120 |
| 1A | 4rt | 37346004 | Lutjanus sebae | Red Emperor | 0.002 | -0.006 | 0.51692 | 0.71897 | 0.725 | 0.245 | 0.622 | 1 | 120 |
| 1A | 4rt | 37347006 | Scolopsis monogramma | Rainbow Monocle Bream | 0.015 | 0.007 | 0.57336 | 0.7572 | 0.764 | 1.792 | 0.183 | 1 | 120 |
| 1A | 4rt | 37350003 | Diagramma pictum | Painted Sweetlips | 0.007 | -0.002 | 0.80121 | 0.8951 | 0.903 | 0.82 | 0.367 | 1 | 120 |
| 1A | 4rt | 37351904 | Lethrinus nebulosus & Lethrinus sp. | spangled emperor | 0.001 | -0.007 | 0.94978 | 0.97457 | 0.983 | 0.117 | 0.733 | 1 | 120 |
| 1A | 4rt | 37353006 | Argyrops bleekeri | Frypan Bream | 0.001 | -0.007 | 0.13627 | 0.36915 | 0.372 | 0.162 | 0.688 | 1 | 120 |
| 1A | 4rt | 37355004 | Parupeneus heptacanthus | Opalescent Goatfish | 0.02 | 0.011 | 0.41789 | 0.64644 | 0.652 | 2.348 | 0.128 | 1 | 120 |
| 1A | 4rt | 37365003 | Parachaetodon ocellatus | Ocellate Butterflyfish | 0.003 | -0.006 | 0.2004 | 0.44766 | 0.451 | 0.336 | 0.564 | 1 | 120 |
| 1A | 4rt | 37365008 | Chaetodontoplus personifer | Yellowtail Angelfish | 0.05 | 0.042 | 0.21968 | 0.4687 | 0.473 | 6.248 | 0.014 | 1 | 120 |
| 1A | 4rt | 37365009 | Chaetodontoplus duboulayi | Scribbled Angelfish | 0.007 | -0.002 | 0.48713 | 0.69794 | 0.704 | 0.79 | 0.376 | 1 | 120 |
| 1A | 4rt | 37384005 | Choerodon cauteroma | Bluespotted Tuskfish | 0 | -0.008 | 0.48383 | 0.69558 | 0.701 | 0 | 0.99 | 1 | 120 |
| 1A | 4rt | 37118001 | Saurida undosquamis | Largescale Saury | 0.003 | -0.006 | 0.46183 | 0.67958 | 0.685 | 0.318 | 0.574 | 1 | 120 |
| 1A | 4rt | 37118016 | Saurida grandisquamis | Grey Saury | 0.023 | 0.015 | 0.15942 | 0.39928 | 0.403 | 2.803 | 0.097 | 1 | 120 |
| 1A | 4rt | 37347004 | Nemipterus celebicus | Celebes Threadfin Bream | 0.005 | -0.004 | 0.18648 | 0.43183 | 0.435 | 0.562 | 0.455 | 1 | 120 |
| 1A | 4rt | 37347005 | Nemipterus furcosus | Rosy Threadfin Bream | 0.022 | 0.014 | 0.36016 | 0.60013 | 0.605 | 2.634 | 0.107 | 1 | 120 |
| 1A | 4rt | 37355008 | Upeneus guttatus | orange-barred goatfish | 0.002 | -0.007 | 0.50618 | 0.71146 | 0.717 | 0.221 | 0.639 | 1 | 120 |
| 1A | 4rt | 37460004 | Pseudorhombus dupliciocellatus | Three Twinspot Flounder | 0.016 | 0.008 | 0.08607 | 0.29337 | 0.296 | 1.926 | 0.168 | 1 | 120 |
| 1A | 4rt | 37460015 | Pseudorhombus diplospilus | Bigtooth Twinspot Flounder | 0 | -0.008 | 0.23624 | 0.48605 | 0.49 | 0.02 | 0.888 | 1 | 120 |
| 1A | 4rt | 37465011 | Abalistes stellatus | Starry Triggerfish | 0.002 | -0.006 | 0.31741 | 0.5634 | 0.568 | 0.291 | 0.59 | 1 | 120 |
| 1A | 4rt | 37311009 | Epinephelus areolatus | Yellowspotted Rockcod | 0.069 | 0.061 | 0.03958 | 0.19894 | 0.201 | 8.737 | 0.004 | 1 | 120 |
| 1A | 4rt | 37311010 | Epinephelus multinotatus | Rankin Cod | 0.03 | 0.021 | 0.12262 | 0.35017 | 0.353 | 3.607 | 0.06 | 1 | 120 |
| 1A | 4rt | 37311012 | Plectropomus maculatus | Barcheek Coral Trout | 0.025 | 0.017 | 0.46606 | 0.68268 | 0.688 | 3.079 | 0.082 | 1 | 120 |
| 1A | 4rt | 37346002 | Pristipomoides multidens | Goldband Snapper | NaN | NaN | 0 | 0 | 0 | NaN | NaN | 1 | 120 |
| 1A | 4rt | 37346007 | Lutjanus malabaricus | Saddletail Snapper | 0.028 | 0.02 | 0.21335 | 0.4619 | 0.466 | 3.46 | 0.065 | 1 | 120 |
| 1A | 4rt | 37347007 | Pentapodus porosus | Northwest Threadfin Bream | 0.003 | -0.006 | 0.96032 | 0.97996 | 0.988 | 0.309 | 0.58 | 1 | 120 |
| 1A | 4rt | 37346005 | Lutjanus erythropterus | Crimson Snapper | 0.135 | 0.127 | 0.16663 | 0.4082 | 0.412 | 18.341 | 0 | 1 | 120 |





**Apx Figure 24 Non-contrast TC 1A Informative species (N=27)**



## Contrast

TC 3A
[high —> low]

TC 3B
[high —>
moderately low]

TC 2A
[moderately low
—> low]

## Non-contrast

TC 3C
[high—> high]

TC 3B
[moderately low—>
moderately low]

TC 1A
[low—> low]

| EffCo | trans | Grp | r_squar | adj_r_sq | mse | rmse | sigma | statistic | p_value | df | nobs |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 3A | 4rt | 1_blue | 0.002 | -0.015 | 49.4465 | 7.0318 | 7.154 | 0.122 | 0.728 | 1 | 59 |
| 3B | 4rt | 1_blue | 0.176 | 0.167 | 29.2301 | 5.4065 | 5.464 | 19.808 | 0 | ★ 1 | 95 |
| 2A | 4rt | 1_blue | 0.001 | -0.003 | 43.7309 | 6.6129 | 6.645 | 0.272 | 0.603 | 1 | 210 |
| 2B | 4rt | 1_blue | 0.057 | 0.044 | 27.8887 | 5.281 | 5.35 | 4.576 | 0.036 | ★ 1 | 78 |
| 3C | 4rt | 1_blue | 0.11 | 0.075 | 27.733 | 5.2662 | 5.473 | 3.102 | 0.09 | ☆ 1 | 27 |
| 1A | 4rt | 1_blue | 0.001 | -0.007 | 31.1999 | 5.5857 | 5.633 | 0.17 | 0.681 | 1 | 120 |

| EffCo | trans | Grp | r_squar | adj_r_sq | mse | rmse | sigma | statistic | p_value | df | nobs |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 3A | 4rt | 2_red | 0.006 | -0.002 | 3.86244 | 1.9653 | 1.982 | 0.749 | 0.389 | 1 | 118 |
| 3B | 4rt | 2_red | 0.004 | -0.001 | 2.81425 | 1.6776 | 1.686 | 0.835 | 0.362 | 1 | 190 |
| 2A | 4rt | 2_red | 0 | -0.002 | 3.46421 | 1.8612 | 1.866 | 0.113 | 0.737 | 1 | 420 |
| 2B | 4rt | 2_red | 0.005 | -0.001 | 2.23882 | 1.4963 | 1.506 | 0.805 | 0.371 | 1 | 156 |
| 3C | 4rt | 2_red | 0 | -0.019 | 3.87612 | 1.9688 | 2.006 | 0.006 | 0.938 | 1 | 54 |
| 1A | 4rt | 2_red | 0 | -0.004 | 3.10296 | 1.7615 | 1.769 | 0.107 | 0.744 | 1 | 240 |

Apx Figure 25 Contrast and non-contrast TC Areas Inner/mid-shelf assemblages (N=2)

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