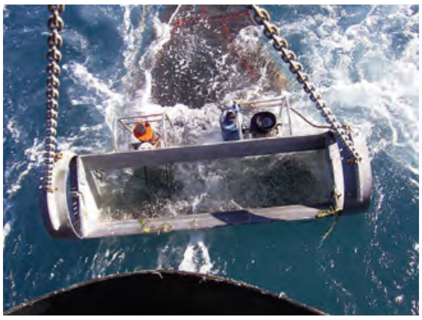
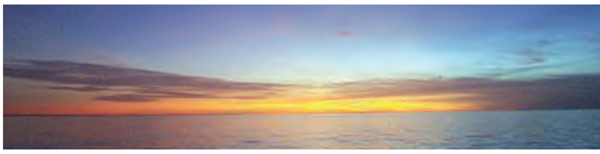
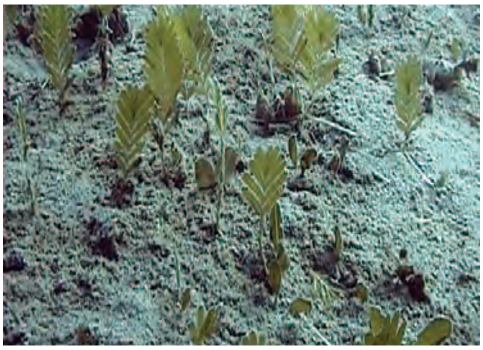
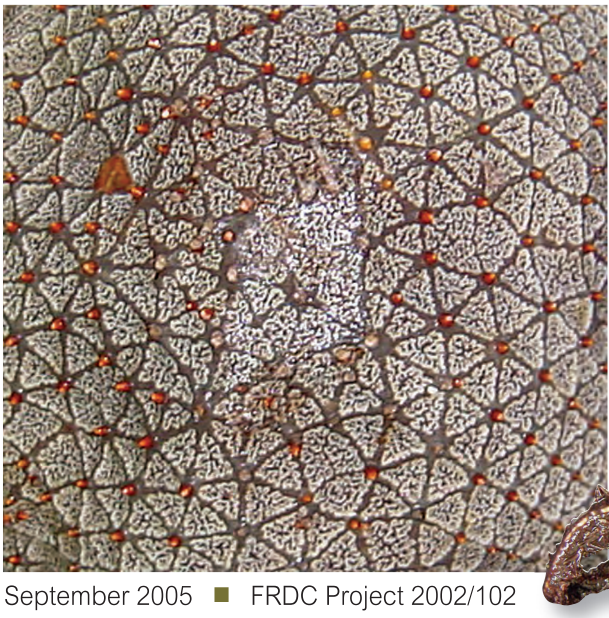






Quantifying the Effects of Trawling on Seabed Fauna in the Northern Prawn Fishery



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CONTENTS

Appendices

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Deckhands: Phil Royal, Tristan Lock, Llew Reid, Sidney Borjesson
Cooks: Sherry Johnson, Laurence Chadwick, Kate O'Brien, Lauren Wright, Georgie Francis

CONTENTS

Appendices

CHAPTER 1. NON TECHNICAL SUMMARY

FRDC Project 2002/102

Quantifying the effects of trawling on seabed fauna in the Northern Prawn Fishery

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1.1 Objectives

1. Determine the spatial and temporal extent of overall fishing effort at a fine scale (~1 n mile resolution) using VMS data (up to 2002) for the entire NPF.
2. Measure the rate of depletion of seabed organisms following exposure to known trawling intensities in experimental plots in two regions within the GoC.
3. Measure the rate of recovery of seabed biota for two years following the depletion experiment.
4. Use an NPF trawl simulation model to evaluate alternative options for achieving environmental and fisheries objectives.

1.2 Need

This project was originally identified as a high priority research area by NORMAC because under the Environmental Protection and Biodiversity Conservation Act (EPBC Act), Australian fisheries are required to demonstrate their environmental sustainability. Industry offered special funding to support the research and FRDC was asked to manage the project. CSIRO agreed to carry out the work, it developed the scope of the work and the experimental design and contributed to the funding.

Trawlers in the NPF concentrate their fishing on areas of highest prawn density. Intensive trawling of small areas is a feature of the tiger and endeavour prawn fishery. Around 20% of the catch is prawns, the rest is animals collected from the seabed as bycatch. Prawn trawls are selective and a major part of the study was determining the proportion of the seabed biota that is removed by trawling.

1.3 Fine scale maps of trawling effort

Analysis of VMS data from all NPF trawlers between 1999 and 2004 showed that only 17% of the Managed Area of the NPF was trawled at all. We refer to this area as the *fished area* of the NPF. On average, 31% of 1-n-mile grid squares in the fished area had at least 1 hour of trawling in a year, and 11% had at least 10 hours. The small proportion of the NPF that was intensively trawled contributed a large proportion of the total NPF prawn catch. For example, on average during 1999–2004, 14% of the fished area of the NPF (2.4% of the managed area) was trawled at least 6 h/n mile^2 in a given year, but contributed 83% of prawn catches in that year.

1.4 Depletion of seabed fauna by prawn trawls

Two experiments were carried out in which the seabed was trawled intensively to simulate commercial fishing. The prawn trawl was found to be selective and was inefficient at catching most groups except for crustaceans. A single pass of a prawn trawl removed on average 12% of the seabed biota. At this rate, approximately half the seabed biota would be removed after 6 trawls. Intensive commercial trawling results in much higher rates of repeated trawling over small areas. Because of the selectivity of the trawl, the impact of trawling varies depending upon the type of biota.

We used samples taken by an epi-benthic sled to demonstrate the effect of trawling. However, because of the patchy distribution of the epibenthos over the seabed, we found that low numbers of samples (3 samples in a trawled area) were, for many groups of epibenthos, insufficient to demonstrate an effect. When we repeated the experiment using higher numbers of samples, the effect was clear.

1.5 Recovery of seabed fauna from trawl depletion

Multivariate analyses of the benthic assemblages indicated that for the most part changes in composition and abundance were related to seasonal factors rather than impacts of trawling and subsequent recovery. Analyses of individual taxa indicated depletion and recovery in a number of the sessile or slow moving taxa such as Gymnolaemata, Hydrozoa, Echinoidea and Phaeophyta. These taxa appeared to have recovered from the impacts quite rapidly—within 6 to 12 months.

1.6 Modelling the effects of prawn trawls on the seabed fauna

A trawl impact model originally developed for the East Coast fishery (Ellis et al., in prep.) was further adapted for the NPF. We have now incorporated depletion rates for GoC seabed biota (rather than GBR biota as was done in a previous version), added five years of 1-n-mile resolution VMS data to better describe spatial and temporal fishing effort and compensated for variable effort creep. These refinements have allowed us to be more confident in the model outputs, although there are still further improvements to be made.

We demonstrated that the model outputs are sensitive to the trawl depletion rates, confirming our hypothesis that it was important to obtain estimates of depletion for the GoC biota rather than just use those from the GBR. We also ran the model for a number of fishing effort scenarios for the Mornington Island region. These demonstrated that as expected the greatest impact is on the more vulnerable taxa and the impact on all taxa is greater in the high effort areas.

1.7 Outcomes achieved

- The project compiled fine scale resolution (1-nautical-mile) maps of trawl effort in the NPF using 6 years of data derived from satellite-based tracking of trawlers.
- We used fine scale trawl effort information to illustrate changing patterns of the use of trawl grounds over this period as well as the major contribution to the tiger and endeavour prawn catch made by small areas (‘hotspots’).
- The average trawl depletion rate for all taxa combined was 12%. Highest depletion rates were 37% for brown algae (Phaeophyta) and the lowest were 1.7% for starfish (asteroids) to the west of Mornington Island.
- Provided sufficient replicate samples are collected, the epibenthic sled can be used for demonstrating trawl impacts on heavily fished grounds.
- NPF-derived data on prawn trawl depletion rates and recovery rates of various groups of epibenthos were used in a mathematical model that predicts the effects of changes in trawl effort on the seabed fauna. Previously these calculations were based on experiments on the Great Barrier Reef region which has a different fauna.
- We have established a reference specimen and photographic catalogue of the seabed invertebrate fauna on trawl grounds in the southern Gulf of Carpentaria. This will be a valuable tool for future research in the region.

1.8 Keywords

Fine scale mapping of trawl effort; satellite tracking of fishing vessels; trawl impacts; trawl depletion; seabed fauna dynamics; modelling impacts of trawling

CHAPTER 2. INTRODUCTION

Mick Haywood, Burke Hill

2.1 Background to the Project

Tropical and subtropical marine faunas are characterised by having complex communities in which most species are rare, have patchy distributions and may vary significantly over time. Fisheries rely on catching components of this fauna. It is clear that the magnitude of the effects of fishing operations depends upon the nature of the gear, the intensity of the fishing and the type of benthic habitat and communities impacted. In some fisheries, such as diver-caught abalone, the fishing method is highly selective and the effect on the habitat is minimal. Trawling by contrast, although targeting a few species, catches and/or may damage many others. In prawn trawling for example, the incidental catch of other species commonly amounts to significantly more than the target species. Apart from capturing biota the trawl can have other impacts, for example individuals may be crushed by the fishing gear and partial excavation and damage of organisms living near the surface of the sediment can attract scavengers (Britton and Marten 1994). Trawling may also act to modify habitat (Sainsbury et al. 1997), change the sedimentation pattern (Churchill 1998) or benthic algal production and nutrient cycling (Mayer et al. 1991). A crucial objective of managing fisheries is to ensure that the fishery does not change the habitat in such a way that the target species is adversely affected. We do not generally monitor fishery habitats; we use the catch of the target species as a proxy for health of the species as well as the health of the habitat. The problem with this approach is that if catches of the target species decline, we respond as if the target species lived in isolation and we react by measures such as reducing the catch. This may alleviate the problem because a reduction in effort may benefit the environment but it may not if the habitat has changed (Roughgarden and Smith, 1996).

Trawling for prawns in the Gulf of Carpentaria started in the 1960s. The fishing grounds expanded with the discovery of more prawn resources and now cover a vast area stretching along thousands of kilometres of the northern Australian coastline. It is managed by the Commonwealth as the Northern Prawn Fishery (NPF) and covers an area of approximately 770,000 km^2. Previous research has shown that the seabed of the NPF supports a large and diverse fauna (Long and Poiner, 1994; Long et al. 1995; Hill et al. 2002). Although trawlers are targeting prawns, their catch includes a large amount of these seabed animals – generally around 80% of the catch consists of animals that are not prawns (Stobutzki et al. 2000). We do not know what effect the removal of these animals has on the seabed environment but we suspect the answer is complex. Stobutzki et al. (2001) for example showed that the tolerance of fish to trawling varied significantly between species. We have a considerable amount of information on the composition of bycatch in this fishery but almost no understanding of what is happening on the seabed. The fishing industry recognised the need for information on the impacts of trawling on seabed biota and in 2003 asked CSIRO to conduct a research project into this topic.

Trawlers in the NPF tow two nets, each with a head rope of around 26 m although this varies with the size of the vessel. Each net is spread by two otter boards, most commonly Bison Boards weighing around 500 kg each (Sterling and Bishop, 1999). The foot rope of the net is made of 10 to 12 mm diameter steel cable and has a ground chain suspended below it by drop chains that are 230 to 260 mm long and made of 8 to 10 mm chain. The ground chain is of 10 to 12.5 mm stainless chain weighing 2 to 4 kg/m. The trawls are towed at 3 to 3.5 knots which is 1.5 to 1.8 m/sec. This is a substantial amount of heavy gear travelling across the surface of the seabed and it is likely to have a severe impact on any biota that it encounters. The gear will pass over buried animals with probably little or no impact. Some of the biota will encounter the ground chain and then pass under the foot rope. Some will be lifted up over the foot rope and be caught in the net. Sessile or attached biota will be hit by the gear and the effect will depend on the type of biota. Wassenberg et al. (2002) found that 80% of sponges less than 300 mm high went under a fish trawl but 70% of broad based sponges larger than 500 mm high passed into the net. Over 90% of gorgonians passed under the net. It is clear that the impact of a trawl is complex and will vary between different elements of the seabed biota. Trawl boards for example have been shown to impact some buried animals such as bivalves but the path of the boards is narrow relative to that of a trawl and so the effect is far less. The catch in the net is only part of the biota that has encountered the gear. We know very little about the effect of this gear on seabed biota that is not captured in the net and in designing a study on this aspect we needed to use sampling gear that was capable of capturing biota not normally caught in prawn trawls.

We were aware from previous studies that most of the NPF is not trawled at all. About 8.5% of the managed area is closed to fishing either permanently or seasonally, but less than 20% of the area is actually trawled. (Figure 2-1)

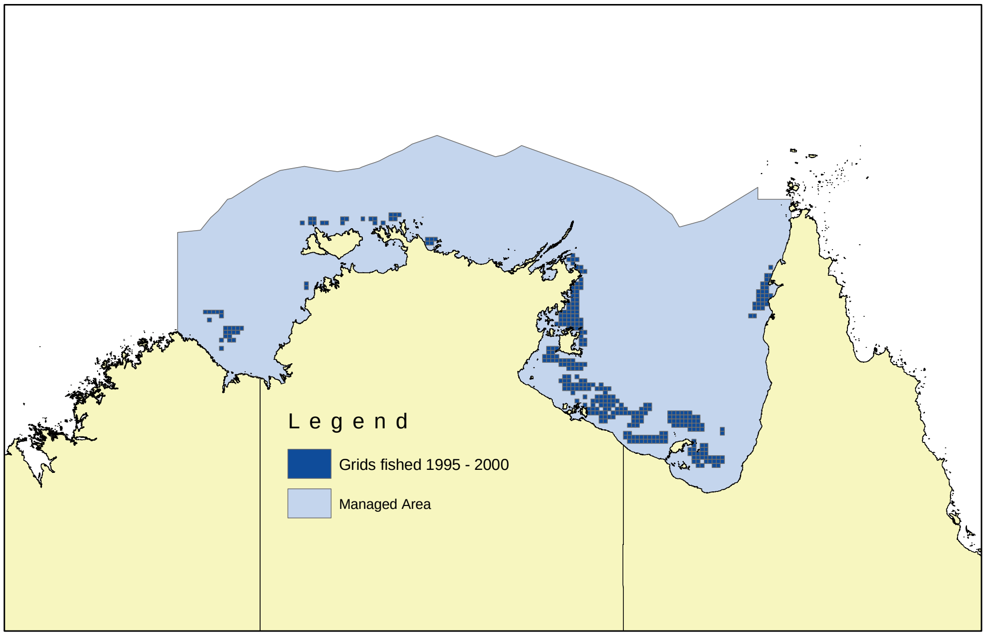

Figure 2-1: Extent of trawl grounds (shaded squares) within the NPF area. For confidentiality reasons the number of grid cells displayed has been restricted to those with at least 10 days of effort or to those that were fished by at least 5 boats between 1996 and 2000 inclusive and hence the area shown as fished here does not represent all of the fished area. Figure from Haywood (2002).

When we look closer at the areas that are fished, we find that trawling is even more targeted than would be suggested by Figure 2-1. An example of one area in the NPF is shown in Figure 2-2. The large open grid shown in Figure 2-2 is the 6 nm grid, the resolution at which fishers report their daily fishing effort and catches to the Australian Fisheries Management Authority (AFMA). Information derived from the Satellite-based vessel monitoring system (VMS) has been used to increase the resolution of the spatial distribution to 1 nm as shown by the smaller, blue grid (Haywood, 2002). The figure shows that the fishing effort is highly targeted at this scale. This is not unexpected since skippers of trawlers are under pressure to maximise the value of fishing time and to do so they preferentially fish areas known historically to give high catch rates. Prawns are not evenly distributed across the seabed, they form concentrations and the industry has developed techniques to locate and target these concentrations.

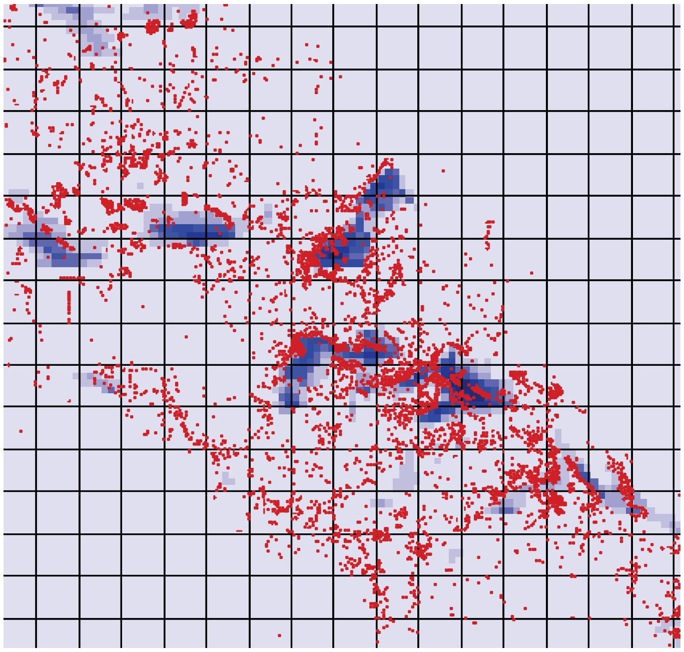

Figure 2-2: Distribution of trawl effort (higher levels of effort are characterised by increasing darkness of blue) in part of the NPF. Red areas are 'untrawlable grounds'. The open grid squares are 6 x 6 nm and effort resolution is 1 nm. Figure from Haywood (2002)

This ability to focus effort into small areas was made possible by the introduction of satellite-based position finding in the 1980s. GPS and plotter units enabled skippers to electronically record and store detailed information on trawl grounds including records of their tracks. Concurrent with the recording of areas of high catches, skippers also recorded the distribution of areas of seabed that were unfavourable for trawling because of the presence of physical obstacles to the nets. These areas became known as the untrawlable grounds and they play a major part in deciding where trawling can or cannot take place. The red areas in Fig 1.2 are untrawlable grounds. We do not understand the mechanism but there appears to be a relationship between the presence of untrawlable grounds and the distribution of prawns since many of the areas of highest prawn density are found near these grounds. Recent research into the nature of the untrawlable grounds by Geosciences Australia, CSIRO and the National Oceans Office has revealed that many are live coral reefs.

The focus of interest for this study is the tiger prawn fishery, because the techniques involved in fishing for tiger prawns are more likely to present a threat to other benthos than those employed fishing for banana prawns. Generally fishing for banana prawns involves a great deal of time searching for aggregations using the vessel's echo sounder. Once a school is located, the nets are deployed and the school is fished intensively for a short period of time. Banana prawn nets also tend to be setup so that they fish more lightly on the seabed compared to tiger prawn nets.

Tiger prawns are generally more widely dispersed over the seabed compared to banana prawns and unlike banana prawn aggregations; they cannot be detected on the echo sounder. Consequently, fishers search for tiger prawns using their nets rather than the sounder. The trawls used in the NPF consist of two nets which are towed for about three hours before being lifted. Between the two main nets is a small 'try net' ~ 4 m wide – which is retrieved at intervals of between 20 to 40 minutes. The fishers use the catch rate of the try net as an indication of the concentration of prawns on the seabed. If the try net catch is low, then the trawler will move on to another possible area. If the catch is reasonable, then trawling continues. Finding prawns relies on two techniques. Firstly there is the knowledge of where concentrations have previously been found – this is well illustrated in Figure 2-3 – trawlers operate in areas known to produce high catch rates. Skippers explore areas by combing an area using more or less parallel tracks. If they find a concentration they target it using the second technique which involves the actual fishing strategy adopted when they are on a potential fishing ground. This is illustrated in Figure 2-3 which shows the track of a single trawler fishing between reefs over 7 nights. The fishing pattern is very clear – the skipper has visited a series of areas and fished each intensively before moving on.

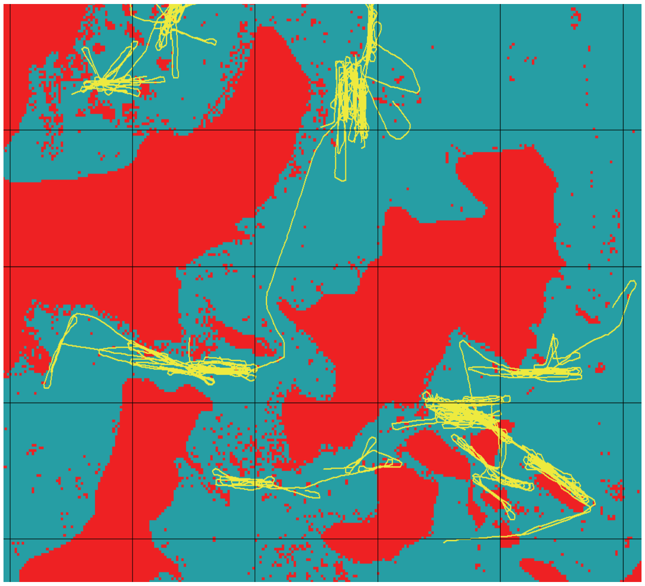

Figure 2-3: Track of a single trawler over 7 nights. Red areas are untrawlable grounds. The open grids depict the 1 × 1 nm grid at which the fishers report their daily catch and effort to AFMA. Data compiled by CSIRO from plotter information provided by a NPF skipper.

Skippers steer the trawler over the area of high concentration checking the try net catch periodically. When the catch in the try net drops, the vessel is turned so it runs back over the concentration. If the catch rates are satisfactory, the skipper may continue fishing the same area for the whole night. Examples of this behaviour are shown in Figure 2-3 and Figure 2-4.

The result of this fishing pattern is a high degree of concentration of effort in a small area (Figure 2-4) with surrounding areas receiving very little or no trawling. In some cases small areas can be subjected to quite intense trawling in a relatively short period of time e.g. the area shown in Figure 2-4b was trawled 32 times by a single vessel over a period of four nights.

In recent years some skippers have been adopting a technique known as “line fishing”. This style of fishing involves picking a “line” of perhaps 3 to 4 nm long and repeatedly fishing along its length, sometimes for as long as 3 weeks by which time the “line” may have extended in length to be as much as 15 nm long (NPF fisher, pers. comm.). The key difference between the more traditional method of fishing for tiger prawns and the “line fishing” technique is that “line” fishers believe they can increase their catch rates merely by fishing along the same “line” regardless of the initial catch rates from their try gear. A more traditional fisher would generally move on to search for more profitable catch rates once the try net catch rates were lower than a certain threshold. A typical night would consist of 3 to 4 shots with 4 laps of a “line” done each shot and the fisher may remain on the same ground for anything between 3 to 7 nights i.e. between 36 to 112 passes over the same ground. This varies depending on the bottom type; in some areas the nets scrape off the surface silt, exposing underlying rocks which may snag the nets after a few passes.

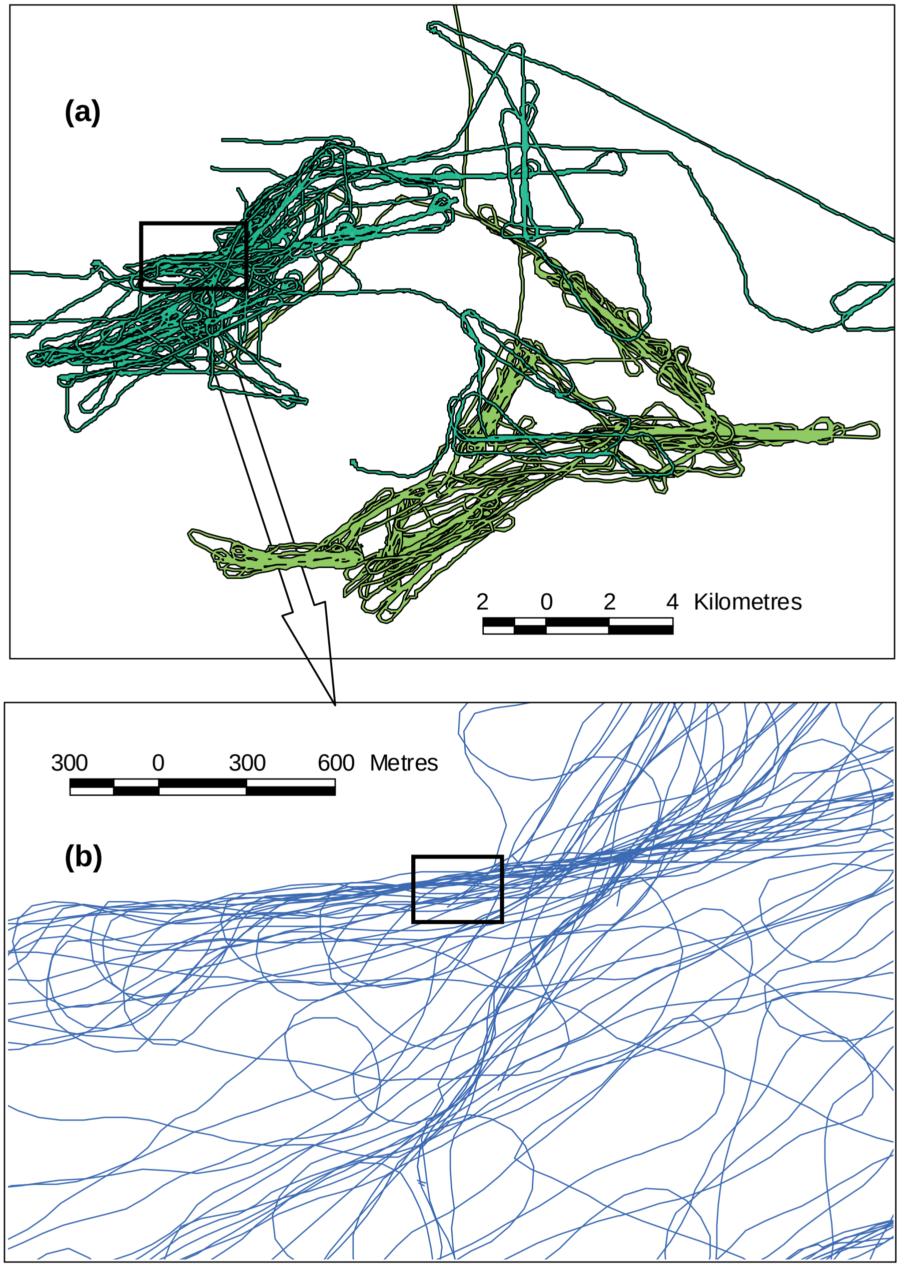

Figure 2-4: (a) Tracks of two trawlers recorded over 10 nights. The track width is drawn to scale to represent the path affected by a pair of 12 fathom otter trawl. (b) A detail (as shown by the small box in [a]) of one of the trawler's tracks (width not to scale) showing an area that has been traversed 32 times in an area that is about 150 m across (small box). This data was collected from the GPS plotters of two commercial vessels and supplied voluntarily to CSIRO by the skippers.

In general the distribution of trawling effort in the NPF can be characterised as being highly concentrated both on the scale of the whole fishery (Figure 2-2) and at the local scale, within the 6 × 6 nm grid cells (Figure 2-2, Figure 2-3 and Figure 2-4). Die (et al. 2001) summarised the situation thus *'About 10% of the NPF is trawled and only a small proportion of this trawled area is fished heavily (>100 days of fishing per year).'* This difference in trawl intensity was a key point in developing the present study. The overarching thrust of the present project was to determine the impact of such high intensity trawling on the seabed biota. In planning how to measure the impact, we decided against surveying the seabed biota of existing trawl grounds and stratifying it according to trawl effort. The problem is basically one of scale. We have broad-scale information on the fishery-wide distribution of trawling from the NPF daily logbook records and we have a finer scale of resolution provided by the Vessel Monitoring System data (see Chapter 4). However, neither of these data would provide us with the confidence to assign sampling sites accurately to specific levels of trawling intensity because of the very clumped nature of the distribution of trawling effort at the fine scale (Figs. 1.3 and 1.4).

Our approach was to identify an area that was trawlable, but presently not trawled and then reproduce the high intensity trawling typical of the fishery. This would enable us to determine whether or not there was a measurable depletion of the seabed fauna. We would then monitor this experimentally trawled area for two years to establish how the seabed fauna responded to trawling.

The design of the experiment had an inherent difficulty, namely how to sample the experimentally trawled area without impacting on it. Sampling it with a trawl, for example, would result in a further trawl impact. We decided to use an epi-benthic sled to sample the sites after the trawl impact. We wanted to follow the plot for two years after the initial trawl impact but each time we towed an epi-benthic sled through the plots, we would be impacting the seabed. We set up a design that would allow us to take successive epi-benthic sled samples over two years with each sample being from an area that had previously not been sampled. It would mean however, that we could take only three samples from every experimental plot at each sampling period. If we took more samples, the area of the impact would need to be expanded considerably and this would result in the costs of the project becoming excessive. This limitation was to cause problems in the analysis with respect to the power to identify an impact. Consequently in 2005 we modified by project and carried out a second impact experiment in which we increased the number of trawls to 30 in a single larger plot and we also increased the number of epi-benthic samples by taking 30 before trawling and 30 after trawling. Because of the large scale of this second experiment we could not carry out any replication so it was limited to one plot.

The study would incorporate two other components in order to broaden its scope and applicability. Firstly we needed to identify the extent of trawl effort at a higher level of resolution than given by the logbook system which operates on a 6 nm grid square. This information would be used in deciding whether the ‘hot spots’ targeted by the fishery are the same year after year or whether new areas are involved. Die et al. (2001) showed that the spatial distribution of the most visited grids did not change greatly between years in the period 1993 to 1997. Their analysis was based on the very large 6 × 6 min grid squares of the log book system and we did not know whether the distribution of fishing within these squares changed. Since that time there has also been a large decrease in effort in terms of numbers of vessels and length of fishing season. VMS data enables us to map the distribution of effort more accurately than could be done using logbook information alone. This should reveal whether high intensity areas are constant from year to year. The information would also be used in identifying an area where the experiment could be carried out. Secondly we would use the information gained in the experiment in a model that could be used by managers for predicting the likely effects on the seabed fauna if there were changes to effort in the fishery. Although we have previously used such a model in the NPF (Ellis and Pantus, 2002), we did not have data on the depletion and recovery rates of impacted benthos on the NPF fauna. The experimental approach would enable to measure these rates accurately and use them in an updated version of the model.

2.2 Need

Assessment of the effects of fishing and its environmental impacts are key research areas identified as high priority for Australia’s fisheries management and funding agencies. Australian fisheries are required to demonstrate their environmental sustainability through an assessment process. This requirement is being driven by the Environmental Protection and Biodiversity Conservation Act (EPBC Act) and by industry through the need for meeting standards for certification e.g. accreditation by the Marine Stewardship Council. To date there has been no study of the effects of trawling on the seabed invertebrate communities in the NPF. A CSIRO-QDPI study of the impacts of trawling on inter-reef seabed communities in the northern Great Barrier Reef (GBR) (Poiner et al. 1998) showed that in inter-reefal areas, trawling caused an overall depletion of seabed fauna of between 5 to 24% for each trawl and the effect was cumulative. However, this inter-reef seabed is not typical of most prawn trawl grounds, which are muddier and have a different fauna. The CSIRO-QDPI study recommended that a future study should quantify the response of soft-sediment fauna to trawl disturbance. This proposal aims to do this and addresses the NPF High Priority Research Area 'Effects of fishing (improved efficiency in fishing gear and techniques in order to reduce bycatch and discarding and environmental impacts on the benthos)'.

An environmentally sustainable prawn fishery in northern Australia requires the development and evaluation of conservation and management options for the seabed and indicators for the status of the seabed and impacts of the fishery. To achieve this, we need to know:

- The fine-scale spatial extent of the fishing effort within the NPF
- The mortality rates of different species of seabed fauna under different fishing impact intensities.
- The rate of recovery of impacted seabed fauna.
- The likely response of the seabed fauna to different management options such as changes in effort or spatial or temporal closures.

This project will attempt to address these questions in the following way:

- Compilation and mapping of the available VMS data will provide an accurate depiction of the overall combined fishing effort over the whole of the fishing grounds for a much longer period (5 years) than previously done (3 months).
- The repeat trawl experiment will provide estimates of trawl-induced mortality rates of various components of the seabed biota.
- The recovery of the fauna following trawling will be estimated by monitoring the impacted sites at 6-monthly intervals for 2 years after the repeat trawl experiment.
- These data will be incorporated into the Trawl Impacts Model and the responses of seabed fauna to a variety of management options will be modelled.

2.3 Objectives

The overall design for the study was summarised into four objectives.

1. Determine the spatial and temporal extent of overall fishing effort at a fine scale trawl effort (~1 nm resolution) using VMS data (up to 2002) for the entire NPF

In an earlier project (FRDC 2000/160) we developed a technique that combined data from the AFMA Vessel Monitoring System (VMS) with trawl effort information to produce high resolution maps of the distribution of trawl effort in parts of the NPF (Haywood, 2002). The VMS system records the position of every trawler in the fleet at irregular intervals (hours). The procedure corrected this spatial information to eliminate for example periods when a trawler was not trawling because it was either stationary or travelling too fast to be trawling. Logbook effort in the NPF is recorded on a 6 nm grid square basis. We used the VMS data to partition this effort into 1 nm grid squares – a 36 fold improvement in resolution. Project FRDC 2000/160 described the method for doing this and presented examples of its application. At that time the only VMS data we had available was for a three month period in the second half of 2000. Considerably more data is now available and we were able to analyse all VMS data from five years (1999-2004) for the entire NPF.

This fine scale effort data was to be used in determining the locations for the experimental component of the project (Objective 2). We wanted an area that had previously been trawled but was no longer fished. The VMS data analyses were also to be used to create a trawl intensity profile for the entire NPF as well as to examine the distribution of 'hotspots' and how this changes from year to year.

2. Measure the rate of depletion of seabed biota following exposure to known trawling intensities in experimental plots in two regions within the GoC

A study by CSIRO on the GBR (Poiner et al. 1998) showed that a single pass of a prawn trawl removes between 5 and 24% of the seabed biota depending on species – the highest rates were for gorgonians. The problem with extrapolating the results of the GBR study to the NPF was that the fauna is quite different. A multidimensional scaling (MDS) plot of the benthic invertebrates from the two areas is shown in Figure 2-5. The GBR invertebrate fauna is obviously very different to that of Torres Straits and nine regions of the NPF. The differences are statistically highly significant (ANOSIM test in PRIMER; Clarke and Warwick 2001) at the 1% level. Given this difference in fauna composition, we needed to measure prawn trawl depletion rates in the NPF. If the data were to be applied to predictive models for the region, it would be inappropriate to use GBR data derived for a different fauna.

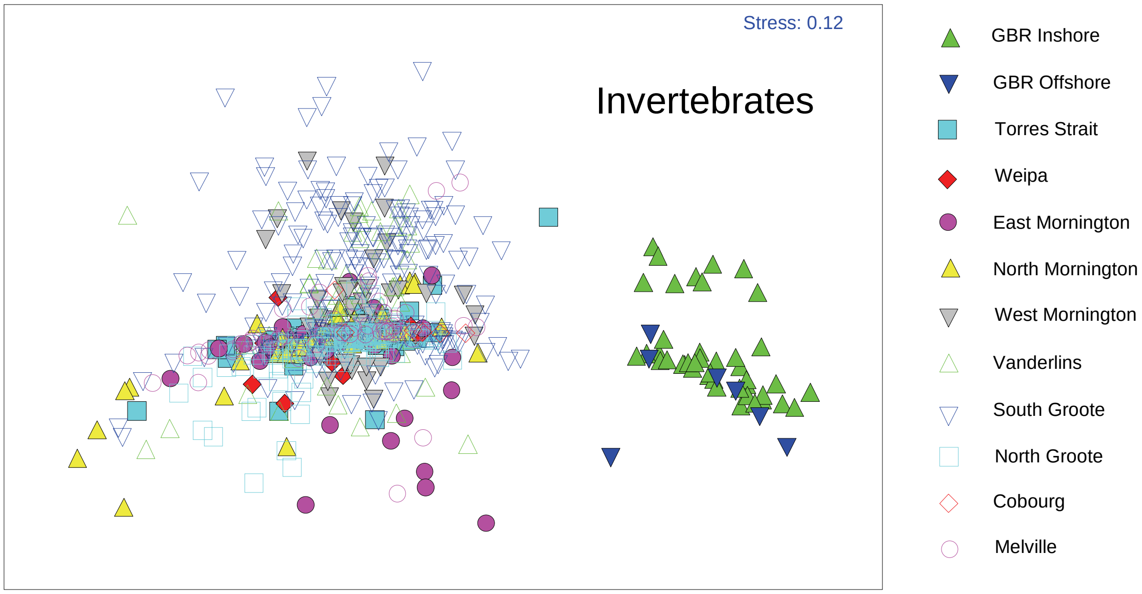

Figure 2-5: MDS plot created from a species similarity matrix produced using 17 invertebrate taxonomic groups from trawls in the northern Great Barrier Reef (GBR), Torres Strait, and nine regions in the Northern Prawn Fishery. Figure from Hill et al. 2002.

Although we intended to do the study on the soft sediment seabed characteristic of the NPF, we know there are considerable differences between the nature of the seabed in various parts of the fishery. We decided to carry out our experiment in two areas having different physical characteristic with respect to depth and sediment type. In each area we planned to carry out three replicated multiple trawl depletions. There were to be three trawl intensities – 0 (control), 4× and 20× to replicate the different intensities of trawling that occur in the fishery. The areas were to be sampled before and after trawling by means of an epi-benthic sled. The results would be used to calculate the rate of depletion of the seabed biota by a trawl and clearance rates for the major taxa.

3. Measure the rate of recovery of seabed biota for two years following the depletion experiment

Following on the depletion experiment, we intended to monitor the experimental plots in order to measure the rate at which the seabed fauna recovered. This was to be done at six monthly intervals for 2 years. Samples would be taken from the areas impacted by the trawling and nearby control (untrawled) plots to enable us to distinguish the recovery of impacted biota from natural fluctuations in the benthos. We could not use trawls for this monitoring as they would cause additional depletion so we used a small epibenthic sled.

4. Use an NPF trawl simulation model to evaluate alternative options for achieving environmental and fisheries objectives

Ellis and Pantus (2001) developed a model that assesses the condition of the seabed fauna on the basis of the amount of trawling to which it has been exposed. The model uses data the spatial and temporal patterns of fishing effort, the rate at which benthic animals are removed by trawling as well as the rate at which they recover from trawling. The model was originally developed for the Great Barrier Reef. In a later project (Ellis and Pantus, 2002) the model was applied to the NPF in a preliminary estimate of the effects of trawling in that area. Information on the rate of removal and recovery of benthic animals was based on data collected on the Great Barrier Reef. At the time it was acknowledged that this was not an accurate way of using the model because of differences in the composition of the fauna and the trawl gear used in the NPF compared to the Queensland East coast. A central aim of the current project is to obtain accurate information on the rate at which the seabed fauna is removed by trawls (Objective 2).

The Ellis and Pantus model used the information derived in the first three objectives as inputs to estimate the status of seabed biota exposed to differing levels of trawling. The model requires inputs on the composition of the sea bed biota, the rate at which the biota is removed by trawling, the rate at which it recovers following trawling, as well as data on the amount of trawling that has taken place in each area. Once the model has been set up, it is possible to use future effort as an input variable to estimate the impact on the seabed biota. This will allow the effect of changes in total effort or effort patterns to be predicted by managers. The NPF has seen substantial changes in effort over its forty year history. In the past two decades management has endeavoured to reduce effort in response to increasing efficiency of the fleet and concerns about the status of stocks of some species. There has for example, been a reduction in the number of trawlers from over 250 in the early 1980s to less than 90 in 2005. Monitoring of the effects of these effort reductions has largely been through estimates of the stock size of commercial prawns and the economics of the fleet. The results of the present project will allow the effects on the seabed fauna to be included in this evaluation.

2.4 Variation to the Project

When we analysed the results of the epi-benthic sled samples taken before and after the trawl impact experiment, we discovered a high level of variation between the three epibenthic samples taken from each plot both before and after trawling. Even though the depletion experiment showed a significant removal of biota, the results of the epi-benthic sampling were often equivocal because of the combination of low sample numbers and high variability of the biota. We sought and obtained permission from FRDC to change the final (2 years after trawling) recovery monitoring cruise to a second high intensity trawl depletion with a considerably enhanced level of epi-benthic sampling. Limitations on funding and facilities restricted this second experiment to one area but we intended to apply a much higher pre- and post sampling effort to this area in order to obtain a higher level of confidence in the results.

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CHAPTER 3. CONCLUSIONS AND OUTCOMES

Mick Haywood, Burke Hill

3.1 Fine-scale distribution of Trawl Effort

An analysis of the tracks of commercial trawlers from the Northern Prawn Fishery showed a high degree of concentration of effort into ‘hotspots’. Repeated trawls may commonly occur over the same small area in short periods of time. A repetition of 30 times in a week is not uncommon.

Six years (1999–2004) of VMS data for the NPF fleet showed that, over this period, only 17% of the managed area of the NPF was fished. We refer to this area as the *fished area* of the NPF. In a given year, trawling intensity was less than 1 h/n mile^2 in the majority of grid cells (1 n mile^2) in the fished area. An average of 31% of the fished area had at least 1 hour of trawling in a given year and an average of 11% had at least 10 hours of trawling. Intensively trawled areas (‘hotspots’) were defined as having at least 6 h of trawling per n mile^2 in a given year. In the period 1999–2004, yearly ‘hotspots’ made up an average of 14% of the fished area. The area to the north of Groote Eylandt had most of the hotspot activity. A total of 37% of the fished area was classified as hotspot in at least 1 year; 12% was in hotspots in at least 50% of years and 3% was in hotspots every year. Partitioning the catch of the ‘tiger fishery’ according to the fine scale grid showed that an average of 91% of the catch of tiger and endeavour prawns came from the average 14% of the fished area that was in hotspots. This is an extremely high proportion and demonstrates that fishing hotspots are a major source of prawns for the fishery. The health of these areas including the effects of intensive trawling is obviously crucial for the sustainability of the fishery.

3.2 Nature of the Biota

The biota of the study areas around Mornington Island is highly diverse with hundreds of species but in terms of biomass, it is dominated by sponges in the east and seagrass in the west. There were very large regional differences in the biota. The study area to the east of Mornington Island had twice as many taxa and seven times the biomass compared to the western study area. The waters to the west were shallow (around 12 m) and had extensive seagrass whereas to the east the depths were around 30 m and there was no seagrass. Seasonal changes were found in the plant groups. Seagrasses – mainly *Halophila spinulosa* – were more abundant in summer than winter whereas the algal groups were more abundant in winter. There were large variations in the biomass of components of the seabed biota that were not related to seasons. Large changes in size composition were found between six monthly samplings but with few exceptions, these could not be explained. Recruitment of juveniles was found in a few species but this recruitment did not occur on an annual basis. The overall picture is of a highly dynamic biota that is continually changing and not simply following a seasonal pattern

3.3 Effects of Trawling

An analysis of the catch of the epibenthic sled compared to the prawn trawl showed that the latter is very inefficient at catching most of the seabed biota. The taxa caught with the highest efficiency by the trawl were crustaceans (123%), sponges (Desmospongiae; 22%), crinoids (19%) and cephalopods (18%). The low efficiency of the prawn trawl means that the impact of prawn trawls on most of the seabed biota is limited to some extent although some groups (e.g. Gymnolaemata) which are not retained efficiently by the nets appeared to suffer considerable damage.

Side scan sonar was able to detect trawl tracks on the seabed immediately after trawling, but we could not detect an effect of trawling two months after the experiment using swath mapping or six months after using an EY500 scientific echo sounder. Seabed photography showed recent trawl tracks but in these soft sediments they are obliterated by bioturbation and so probably do not have a long life.

Despite use of a skilled skipper, differential GPS and acoustic tracking, it proved difficult to trawl precisely over previously trawled tracks. In the first experiment, in the 20 repeat trawl lanes, replication was no higher than 12 times and this only in limited areas. In the second experiment in which we trawled 30 times, we were more successful and obtained a repetition of between 15 and 25 times over a large area. Our analysis showed that this non-coincidence of trawls has a major effect on estimates of the biomass on the seabed and the rate of depletion by a trawl. After allowing for non-coincidence, we estimated an average depletion rate of 12% from a single pass of a trawl for all biota combined.

3.4 Recovery

The benthic assemblages of the south-eastern Gulf of Carpentaria appear to undergo significant natural variation in terms of abundance of individuals and species composition. These changes make it difficult to detect what may be relatively subtle changes as a community undergoes recovery from an impact such as trawling. Multivariate analyses of the benthic assemblages indicated that for the most part changes in composition and abundance were related to seasonal factors rather than impacts of trawling and subsequent recovery. Analyses of individual taxa indicated depletion and recovery in a number of the sessile or slow moving taxa such as Gymnolaemata, Hydrozoa, Echinoidea and Phaeophyta. These taxa appeared to have recovered from the impacts quite rapidly - within 6 to 12 months. Many of the taxa found in our study area are mobile and because of the small scale of this experiment and the fact that the surrounding areas had not been trawled for at least 8 years means that it is likely that recovery of these taxa would largely have been as a result of immigration from the surrounding area.

3.5 Conclusions

Trawling for prawns is a highly targeted activity in the Northern Prawn Fishery; consequently trawl impacts are restricted to a small proportion of the fishery. These small areas are subject to very intense trawling and are responsible for a major part of the catch of tiger and endeavour prawns. Prawn trawls are selective in what they catch and so their impacts are unequal, with some groups such as bivalves being impacted relatively lightly while others such as crustaceans, bryozoans (Gymnolaemata) and sponges being significantly impacted even at low levels of trawling. The seabed biota proved to be highly variable spatially and temporally making it difficult to identify recovery from trawling. The seabed fauna in the experimental area was made up mostly of mobile animals and we suspect that recovery takes place mainly through immigration from adjacent untrawled areas.

Given the small proportion of the fishery that is trawled, the selective nature of the trawl and the low proportion of attached – and therefore most vulnerable – taxa in the study area around Mornington Island, we conclude that the overall impact of trawling in this region is low. It is likely that the composition of the benthos in other areas of the NPF is quite different to that in the Mornington Island region. In areas having a higher proportion of sessile biota, the impacts may be more significant. A current FRDC project (“Effects of Trawling on the benthos and diversity of the Northern Prawn Fishery”) is characterising benthos across the Gulf of Carpentaria and should be able to provide information on areas which are likely to be more vulnerable, based on the composition of the benthos. The reduction of effort that has taken place in the fishery in recent decades would also have contributed to a lessening of trawl impacts on the seabed fauna. Questions still remain on whether intensive trawling may have long term impacts that could affect the high prawn yield of the ‘hotspots’.

3.6 Outcomes

One of the major outcomes of this project was quantitative estimates of the impacts of intensive trawling on the seabed biota of the NPF trawl grounds. By measuring the lack of coincidence of the repeated trawls in our experimental treatments, we have been able to correct for non-coincidence of the trawls and to demonstrate that without this correction depletion rates would be severely underestimated and initial biomass would be overestimated.

By analysing six years of Vessel Monitoring System (VMS) data provided by AFMA, we have greatly improved our understanding of the fine-scale spatial and temporal distribution of trawling effort. This information was used in the present project as an input to the trawl impact model (see below) and has also proved invaluable in planning the sample design of another project: “Benthic Trawling, Biodiversity and Ecosystem Indicators: Towards a Spatial Management System”.

In a previous project (FRDC 2000/160), we demonstrated the value of a trawl impact model for testing the consequences of a variety of fishery management options for benthic populations. However, this model used depletion rates estimated for seabed biota in the Great Barrier Reef Marine Park. We have demonstrated that the biota in the GBR are quite different to those in the NPF and therefore could be expected to have different depletion rates. By incorporating the depletion rates measured for NPF biota and including six years of fine-scale fishing effort data (VMS), we can be more confident that the results from the trawl impact model are more accurate and will allow forecasting of the likely consequences of a range of fisheries and conservation management options for industry and the environment.

The depletion rates of NPF by-product species estimated in this project will be used in a new FRDC-funded project: “Assessing data poor resources: Evaluating management strategy for NPF by-product”.

The small proportion of the NPF that was intensively trawled contributed a large proportion of the total NPF prawn catch—particularly the catches of tiger and endeavour prawns. For example, on average during 1999–2004, 14% of the fished area of the NPF (2.4% of the managed area) was trawled at least 6 h/n mile^2 in a given year, but contributed 83% of prawn catches in that year.

Although the proportion of the NPF that is intensively trawled is small, the impacts of trawling in those areas must still be carefully managed for two reasons. First, the NPF is not homogeneous in terms of biodiversity: some habitats and species may occur only in the prawn trawling grounds, and will need to be protected if vulnerable to trawling. Second, long-term sustainability of the prawn catch may depend on the health of the ecosystems that support the prawns, and therefore on management of the impacts of trawling on those ecosystems.

CHAPTER 4. FINE-SCALE DISTRIBUTION OF TRAWL EFFORT

Wayne Rochester, Mick Haywood

Summary

- VMS data for all NPF vessels for the period 1999 to 2004 have been obtained from AFMA. Data from 1998, the first year of VMS operation, were not considered to be of high enough quality for incorporation into this analysis.
- The methods developed in FRDC Project 2000/120 were used for generating maps of the fine scale distribution of effort in the NPF.
- The resulting maps have a resolution of one nautical mile, which is 36 times greater than that of maps derived from fishing logbooks.
- The total area of all 1-n-mile grid cells in which trawling was recorded during 1999–2004 was 130,000 km^2. This is 17% of the 771,000 km^2 total managed area of the NPF. In this chapter we refer to this area as the *fished area* of the NPF.
- The frequency distribution of trawling intensity was highly skewed, and trawling in most cells was at the lower end of the range. In every year, trawling was less than 1 h/n mile^2 in the majority of grid cells in the fished area.
- An average of 31% of grid cells in the fished area had at least 1 hour of trawling in a given year and an average of 11% had at least 10 hours of trawling.
- Intensively trawled areas (‘hotspots’) were defined as having at least 6 h of trawling per n mile^2 in a given year.
- In the period 1999–2004, an average of 14% of the fished area was classified as hotspot each year. A total of 37% of the fished area was classified as hotspot in at least one year.
- Hotspots tended to change with time: 12% of the fished area was hotspot in at least 50% of years and only 3% was hotspot every year.
- The small proportion of the NPF that was intensively trawled contributed a large proportion of the total NPF prawn catch. For example, the average 14% of the fished area classified as hotspot during 1999–2004 contributed an average of 83% of yearly prawn catches.

NOTE: All VMS derived data are confidential and cannot be released without the permission of AFMA.

4.1 Introduction

The Australian Fisheries Management Authority (AFMA) collects a daily record of each fisher’s catch and position through the logbook program. The positional information is recorded at a resolution of 6 nautical miles. In 1998, AFMA introduced the Vessel Monitoring System (VMS) which utilized automatic location communicators (ALC) into the NPF and a subset of the fleet used them on a trial basis. Since 1999, all vessels in the NPF have been required to have an ALC installed and operating at all times (AFMA 2003a). The ALC transmits the vessel's identification code, the vessel's location and the time to AFMA via satellite at times determined by AFMA. The polling frequency varies from seconds to hours. The ALC can also transmit the vessel's current speed and bearing; however, that option requires transmission of a second data packet at an additional cost and is rarely enabled by AFMA. The primary purpose of the VMS is to ensure compliance with fisheries management regulations. It is also used to collect data for management and research purposes (AFMA 2003b).

Haywood (2002) developed methods to use the VMS data to partition trawl effort into a 1-n-mile square grid. This represents a 36-fold increase in resolution over the 6-n-mile square grid currently used for recording effort. At the time of the Haywood’s (2002) work, only 3 months of data were available. We now have all the data for the years 1999 to 2004. Data for 1998 are available, but as this was the start of the full scale use of VMS they have some defects. As the data sets lengthen it will be possible to do a variety of analyses such as examining whether the areas fished change with time. In this chapter we illustrate the spatial patterns of fishing in the NPF over the years 1999 to 2004, examine the change in trawling patterns in terms of the change in the distribution of trawling ‘hotspots’ and determined just how important these ‘hotspots’ were to the fishery as a whole.

4.2 Methods

4.2.1 Maps of fishing effort

Maps of the fine scale distribution of fishing effort for the NPF were generated using AFMA VMS data with a method based on that of Haywood (2002). The VMS data available for analysis effectively comprises records of vessel identification, location and time. The speed and bearing data are unreliable and not used in our analyses. The data do not contain information on how the vessel moved between each poll (e.g. a straight or contorted path) or whether the vessel was trawling, searching, steaming etc.

The fishing effort maps we generated were GIS rasters containing the number of hours of trawling in each 1-n-mile grid cell. (More precisely, the grid cells were 1 minute of latitude by 1 minute of longitude, which in the tropics is close to 1 by 1 n mile.) To generate the maps, we estimated the track of each fishing vessel, divided the track into trawling and non-trawling sections (based on the time of day and year), and calculated the time each trawling section spent in each grid cell. To estimate the track of a fishing vessel, we connected each pair of consecutive VMS polls with a straight (great circle) line. The vessel's speed between the two polls was estimated as the length of the line divided by the time between the polls. A line was discarded if (a) the time between polls was five or more hours, (b) the speed was zero or (c) the speed was 2 m/s (3.9 knots) or more. Each line was split into equal segments no more than 0.1 n mile in length or 5 minutes in duration. If the time at which the vessel would have been at the mid-point of a segment fell within a valid fishing time, then the time the vessel would have spent on the segment was added to the grid cell beneath the mid-point of the segment. Valid fishing times were determined by fishing seasons and daytime fishing restrictions (Table 4-1).

Table 4-1: Fishing seasons and times of the day during which fishing is allowed in the geographic zones in Figure 4-1. Dates and times are UTC.

		Season 1				Season 2			
Year	Zone	Start	End	Open	Close	Start	End	Open	Close
1998	1	31/03 2230	01/06 0230	0000	0000	04/08 0830	15/11 2230	0000	0000
1998	2	31/03 2230	01/06 0230	0000	0000	04/08 0830	15/11 2230	0830	2230
1998	3	31/03 2200	01/06 0200	0000	0000	04/08 0800	15/11 2200	0800	2200
1998	4	31/03 2200	01/06 0200	0000	0000	04/08 0800	15/11 2200	0000	0000
1999	1	31/03 2230	01/06 0230	0000	0000	04/08 0830	15/11 2230	0000	0000
1999	2	31/03 2230	01/06 0230	0000	0000	04/08 0830	15/11 2230	0830	2230
1999	3	31/03 2200	01/06 0200	0000	0000	04/08 0800	15/11 2200	0800	2200
1999	4	31/03 2200	01/06 0200	0000	0000	04/08 0800	15/11 2200	0000	0000
2000	1	31/03 2200	27/05 0200	0000	0000	04/08 0830	08/11 2200	0000	0000
2000	2	31/03 2200	27/05 0200	0000	0000	04/08 0830	08/11 2200	0830	2230
2000	3	31/03 2200	27/05 0200	0000	0000	04/08 0830	08/11 2200	0800	2200
2000	4	31/03 2200	27/05 0200	0000	0000	04/08 0830	08/11 2200	0000	0000
2001	1	31/03 2200	27/05 0200	0000	0000	04/08 0830	08/11 2200	0000	0000
2001	2	31/03 2200	27/05 0200	0000	0000	04/08 0830	08/11 2200	0830	2230
2001	3	31/03 2200	27/05 0200	0000	0000	04/08 0830	08/11 2200	0800	2200
2001	4	31/03 2200	27/05 0200	0000	0000	04/08 0830	08/11 2200	0000	0000
2002	1	31/03 2200	13/05 0200	0000	0000	01/09 0830	30/11 2200	0000	0000
2002	2	31/03 2200	13/05 0200	0000	0000	01/09 0830	30/11 2200	0830	2230
2002	3	31/03 2200	13/05 0200	0000	0000	01/09 0830	30/11 2200	0800	2200
2002	4	31/03 2200	13/05 0200	0000	0000	01/09 0830	30/11 2200	0000	0000
2003	1	31/03 2200	13/05 0200	0000	0000	01/09 0830	30/11 2200	0000	0000
2003	2	31/03 2200	13/05 0200	0000	0000	01/09 0830	30/11 2200	0830	2230
2003	3	31/03 2200	13/05 0200	0000	0000	01/09 0830	30/11 2200	0800	2200
2003	4	31/03 2200	13/05 0200	0000	0000	01/09 0830	30/11 2200	0000	0000
2004	1	14/04 2200	26/05 0200	0000	0000	01/09 0830	30/11 2200	0000	0000
2004	2	14/04 2200	26/05 0200	0000	0000	01/09 0830	30/11 2200	0830	2230
2004	3	14/04 2200	26/05 0200	0000	0000	01/09 0830	30/11 2200	0800	2200
2004	4	14/04 2200	26/05 0200	0000	0000	01/09 0830	30/11 2200	0000	0000

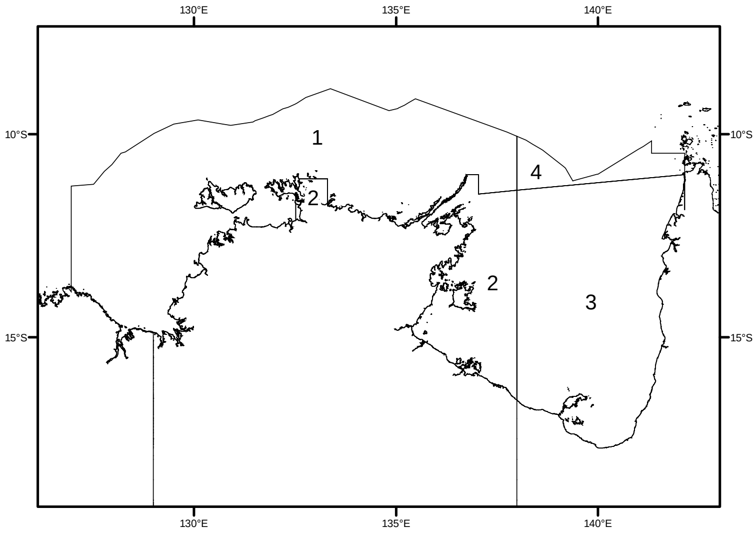

Figure 4-1: The four zones used in the VMS analysis

This method for estimating fishing effort from VMS data has limitations. Because a vessel may have taken a path other than a straight line between the polls, our straight line path (a) may only partially match the real path of the vessel, (b) may underestimate the length of the path traversed by the vessel, and (c) may underestimate the speed of the vessel. Note that (a) and (b) would affect which particular grid cells the trawling time was allocated to, but not the total trawling time that was added to the grid.

The use of vessel speed to filter out non-trawling activity is imperfect because vessels may carry out other activities at speeds less than the maximum trawling speed.

4.2.2 Temporal changes in the spatial pattern of trawling

Environmental impacts of trawling depend on both the spatial pattern of trawling and year-to-year changes in the trawling pattern. For example, if the pattern of trawling was the same every year, then the impact would be relatively focused and intense: some sites would be trawled intensively every year, whereas others would never be trawled. Conversely, if the pattern was very different every year, then the impact would be relatively widespread and moderate: most sites would be trawled only infrequently.

We examined the change in trawling pattern in terms of the change in the distribution of trawling hotspots. A trawling hotspot was defined as an area that experienced at least 6 h/n mile^2 of trawling in the year of interest. The threshold was arbitrary, but corresponds to trawling of about 30% of the seabed (assuming a swept path of 35 m and a trawling speed of 3 knots).

4.2.3 Prawn catch and fishing effort

To examine the importance of trawling hotspots to the fishery, we estimated the percentage of the NPF prawn catch that was caught in areas with trawling intensities above a range of thresholds. Prawn catches were obtained from the statistically augmented NPF logbook dataset (Dichmont et al. 2001), which records catch and effort on 6-n-mile grid cells. To estimate catches in the 1-n-mile grid cells of the VMS effort maps, we took the catch from each 6-n-mile logbook cell, and distributed that catch among the 36 1-n-mile VMS grid cells by assuming that, within a 6-n-mile grid cell, catch is proportional to VMS effort.

We performed two analyses to check the robustness of the estimates. First, we checked the sensitivity to the assumption that catch is proportional to VMS effort by instead assuming that, within a 6-n-mile grid cell, catch is not related to VMS effort, except that it is still zero where VMS effort is zero. Second, we calculated the estimates using the 6-n-mile resolution logbook data for both catch and effort. To make the analysis comparable to that based on VMS effort, we scaled the logbook effort so that the total for the whole NPF equalled total VMS effort. Total logbook effort was about twice total VMS effort, which is reasonable because the fishing effort of a vessel in the logbook data is the number of days in which the vessel fished, whereas in the VMS data it is the actual time the vessel spent fishing, and vessels will often fish less than 24 h/day.

4.3 Results

4.3.1 Map resolution

An example of the results of partitioning effort by 1-n-mile grid squares is given in Figure 4-2, which shows the aggregated effort for the period 1999 to 2004. On such a large scale there is little advantage in having a resolution of 1 n mile. Even if we make the area smaller as in Figure 4-3, little additional information is gained over the conventional 6-n-mile grid resolution. If we restrict the area considerably, the amount of information given by the high resolution effort grid increases substantially as can be seen in Figure 4-4.

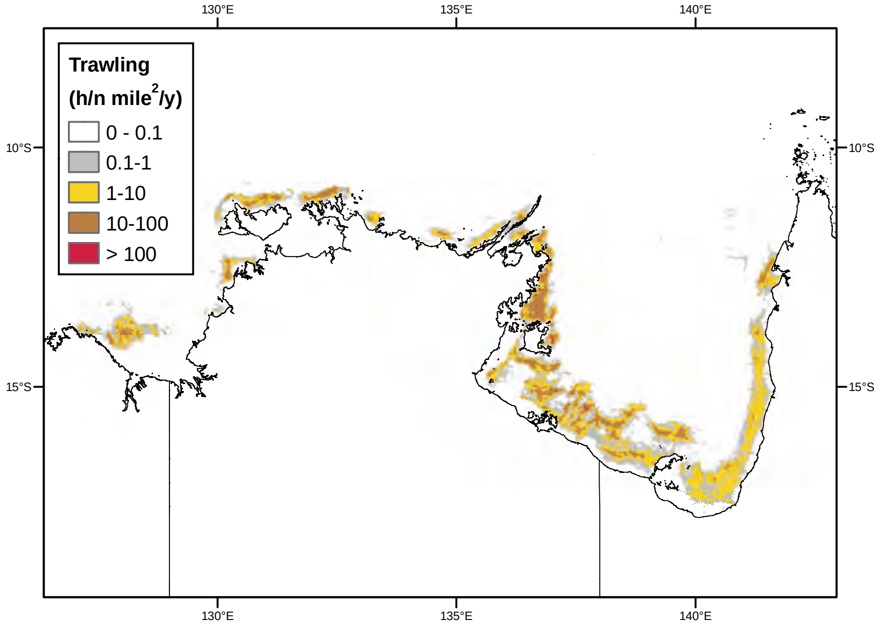

Figure 4-2: Compilation of VMS data for the period 1999–2004 for the entire NPF. The VMS data have been aggregated to 1-nautical-mile resolution. The value of each 1-n-mile cell is the average number of hours spent by vessels within that cell per year over the 5-year period.

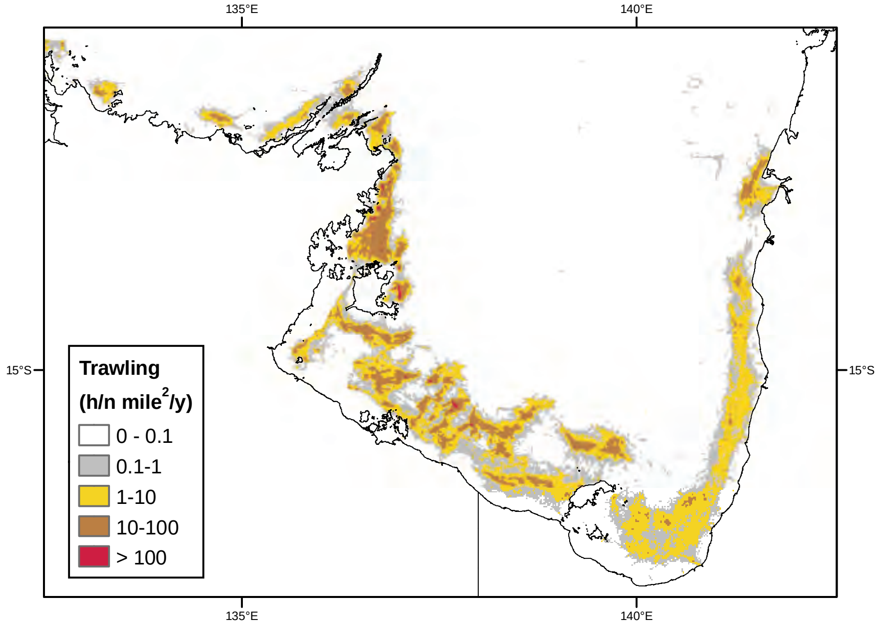

Figure 4-3: Distribution of trawl effort in the Gulf of Carpentaria at a resolution of 1 n mile. Map based on VMS data from 1999 to 2004.

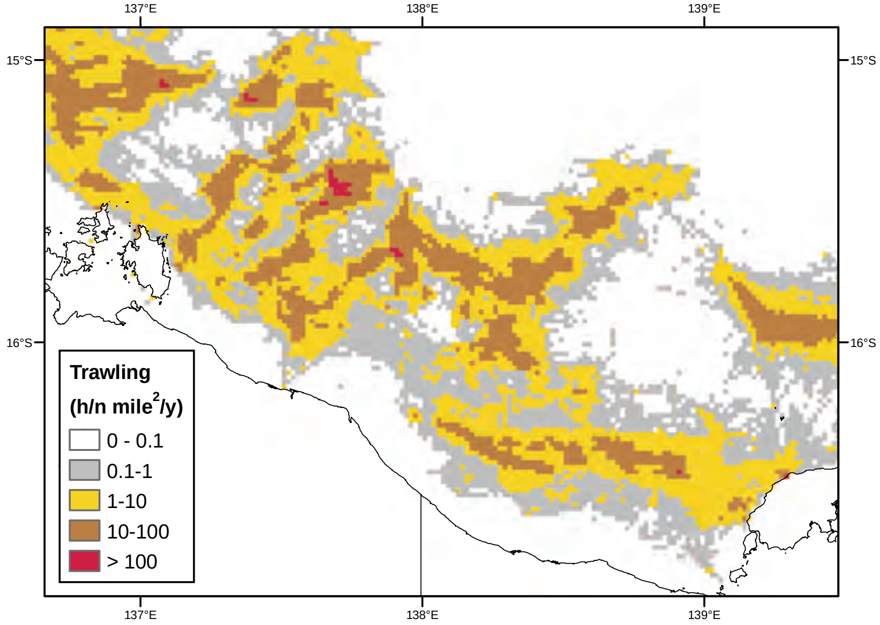

Figure 4-4: Example of fine scale (1-n-mile grid) distribution of trawl effort in one area of the NPF (Sir Edward Pellew Group to Mornington Island)

4.3.2 Spatial pattern of trawling

The total area of all 1-n-mile grid cells in which trawling was recorded during 1999–2004 was 130,000 km^2. This area will be referred to in this chapter as the *fished area* of the NPF, and covers 17% of the 771,000 km^2 managed area of the NPF. Areas affected by trawling activity will be compared to the fished area rather than the managed area because the fished area better represents the area that is utilised and impacted by prawn fishers. The managed area extends out to the boundary of the Exclusive Economic Zone and includes large areas that are not trawling grounds (e.g. in deep water). The fished area is not a definitive estimate of the real fished area of the NPF. First, our fished area contains some spurious untrawled areas that were not filtered out by our VMS gridding algorithm. Second, the real fished area changes with time: areas outside of our fished area will have been trawled before the 1999–2004 period of the VMS data we used to estimate that area.

Trawling within the trawled cells ranged from a few seconds to over 100 hours in a year. The frequency distribution of trawling intensity was highly skewed, and trawling in most cells was at the lower end of the range (Figure 4-5). In every year, trawling was less than 1 h/n mile^2 in the majority of cells in the fished area.

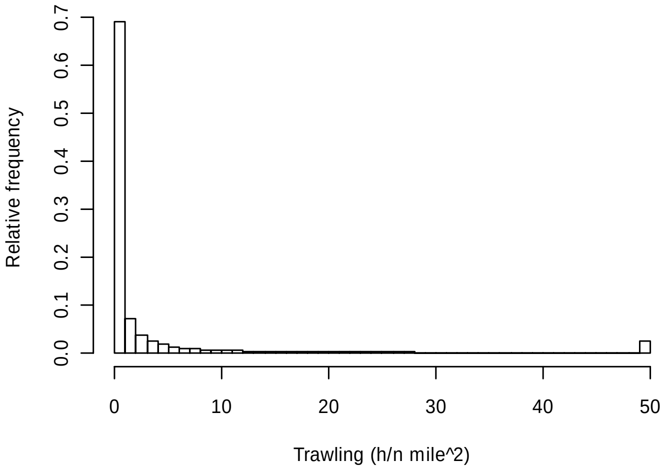

Figure 4-5: Frequency distribution of yearly trawling in 1-n-mile grid cells of the fished area of the NPF from 1999 to 2004. The rightmost bar includes cells with trawling intensities greater than 50 h/n mile^2.

Because of the wide variation of trawling intensity within the trawled area of the NPF, the above estimate of the area of seabed affected by trawling will not be appropriate for all questions. In some cases we will be interested only in areas that have been subjected to moderate or high intensities of trawling. Figure 4-6 shows how the estimate of the affected area declines as the lower cut-off trawling intensity is increased. Example cut-off trawling intensities (per n mile^2) and average areas are 1 minute, 73,000 km^2 (56% of the fished area); 1 hour, 40,000 km^2 (31%); and 10 hours, 14,000 km^2 (11%).

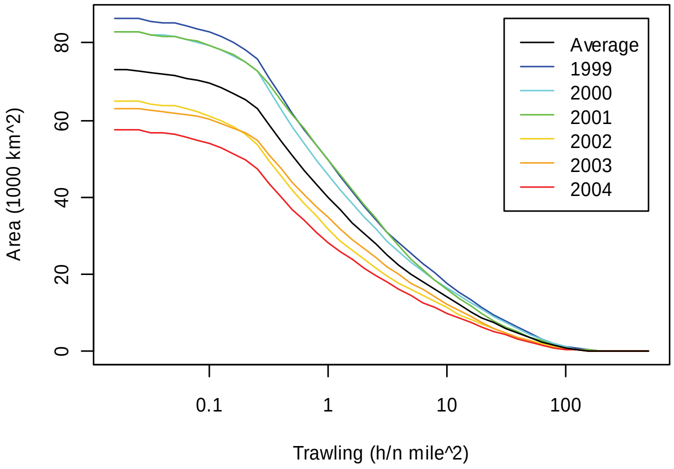

Figure 4-6: Graph of the area of 1-n-mile grid cells against the minimum yearly trawling of the cells. The graph indicates how the size of the estimated trawled area varies with the lower cut-off used to distinguish trawled and untrawled cells.

4.4 Temporal changes in the spatial pattern of trawling

The average area classified as hotspot during 1999–2004 was 18,400 km^2 (14% of the fished area; Figure 4-8a). The total area classified as a hotspot for at least one year in 1999–2004 was 48,300 km^2 (37% of the fished area). Of that area, 16,200 km^2 (12% of the fished area) was a hotspot in at least 50% of years and 3300 km^2 (3%) was a hotspot every year (Figure 4-7).

In any given year an average of 55% of the hotspot area was common to that of the previous year (Figure 4-8a). A similar proportion of the hotspot area for each year was common to that of 1999 (Figure 4-8b). That is, about half the hotspot area changed from year to year, but there was no substantial continuing drift away from the hotspots of 1999. The general decline in hotspot area was associated with a general decline in the estimated total number of hours of trawling in the NPF (r^2 = 0.97).

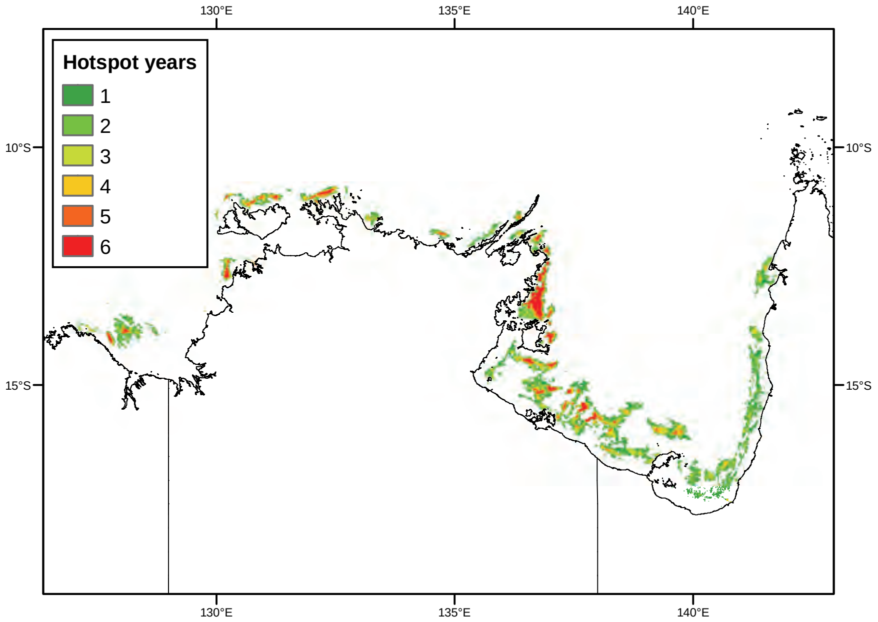

Figure 4-7: The number of years that each 1-n-mile grid cell was classified as a hotspot from 1999 to 2004.

Figure 4-8: Change in hotspot locations from (a) the previous year and (b) 1999. For each bar the total height indicates the total hotspot area, the shaded part indicates the area of continuing hotspots, and the unshaded area indicates the area of new hotspots.

4.4.1 Prawn catch and fishing effort

Figure 4-9 shows the average percentage of the NPF prawn catch that was estimated to have been caught in 1-n-mile grid cells with yearly trawling above a range of values from 1999 to 2004. The average percentage of prawns caught in hotspots as defined above (i.e. yearly trawling at least 6 h/n mile^2) was as follows: all prawns, 83%; tiger prawns, 91%; endeavour prawns, 91%; banana prawns, 78%; and king prawns, 73%. The pattern of catches varied among the prawn species. For example, tiger and endeavour prawn catches were more concentrated in high trawling areas than was the banana prawn catch (Figure 4-9).

Note that this does not mean that 83% of prawns were caught in the most productive 14% of the fished area (the average hotspot area). The required area will be smaller because the most intensively trawled areas are not always the most productive. From the 1-n-mile resolution catch grids created for this analysis, an average of 90% of prawns were estimated to have been caught in the each year's most productive 14% of the fished area.

The analysis was moderately sensitive to the assumption that, within a 6-n-mile grid cell, catch is proportional to VMS effort. When we assumed that, within a 6-n-mile grid cell, catch is not related to VMS effort, but still zero where VMS effort is zero, the catch was less concentrated in high trawling areas, and an average of 56% of all prawns were caught in hotspots.

Results from the analysis were compatible with those obtained from logbook data only. When the analysis was performed with logbook data for both catch and effort, the catch was less concentrated in high trawling areas, and an average of 78% of all prawns were caught in hotspots. We expect this figure to be lower than that from the VMS analysis (83%) because the VMS analysis resolves a wider range of effort within each logbook grid cell and distributes catch according to that effort. If the VMS estimate had been dramatically higher than the logbook estimate, we would have been less comfortable because the difference is so dependant on the assumption that catch is proportional to VMS effort. Results became more sensitive to this assumption at higher estimated trawling rates. For example, the average percentage of all prawns caught in areas with yearly trawling of at least 24 h was estimated to have been 57% by the VMS analysis and 35% by the logbook analysis.

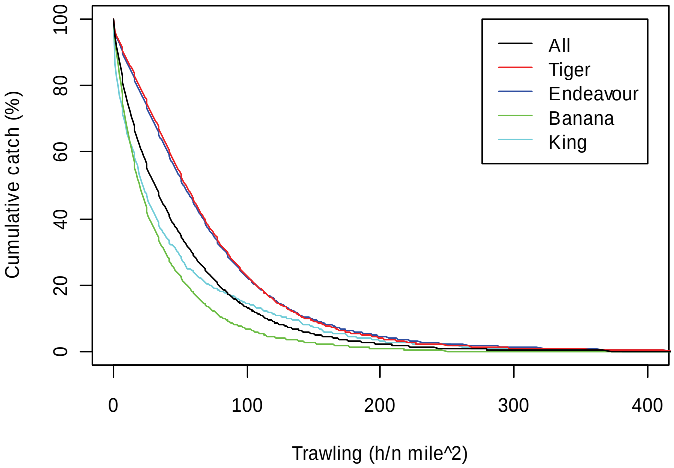

Figure 4-9: Average percentage of prawn catch caught in grid cells with yearly trawling at least that on the horizontal axis from 1999 to 2004.

4.5 Discussion

The VMS system operated by AFMA has now been in place for seven years. Apart from its use in monitoring the position of trawlers where it has reduced surveillance costs, it has become an important source of information about the spatial distribution of trawl effort. In the present project, we used high resolution effort distribution data to decide on the positioning of our study sites. More recently a large scale study of the effects of trawling on the benthos and biodiversity of the NPF made extensive use of this high resolution information in deciding where sampling of the benthos should take place (Bustamante and Rothlisberg: Effects of trawling on the benthos and biodiversity of the Northern Prawn Fishery; see Appendix B).

Analysis of the VMS data reveals that the majority (83%) of the managed area of the NPF was not trawled at all during 1999–2004. For our analysis, we defined the fished area of the NPF as the 17% in which trawling had been recorded in 1999–2004. Trawling intensity in the fished area varied considerably but was highly skewed. The majority of grid cells in the fished area were trawled for less than one hour in any given year. An average of 31% of cells had at least one hour of trawling and only 11% had at least 10 hours of trawling. One hour of trawling in a grid cell equates to a swept area of approximately 6% of the cell; 10 hours equates to approximately 60%. The actual percentage of the cell impacted will usually be smaller than the swept area due to overlapping trawl tracks.

Only a small proportion of the fished area therefore experienced trawling intensities that were moderate or high relative to those experienced in other fisheries. Jones (1992), for example, reported that in parts of the Baltic Sea, up to 19% of the areas studied had trawl tracks and in the Netherlands, heavily fished areas, every square metre of seabed is trawled on average at least seven times per year. Krost et al. (1990) found that the entire seabed in the most heavily fished areas in Kiel Bay is disturbed by otter boards at least once per year. If we assume that the more intensively a grid is trawled, the greater the impact on the seabed biota, it can be seen that the highest intensity impact is even more limited than the overall impact. We have shown in the Introduction that, in some areas, the trawling pattern is to concentrate fishing in a very limited area known as a hotspot. We defined a hotspot as an area in which there was at least 6 h/n mile^2 of trawling in the year of interest. In the period 1999–2004, the average area classified as hotspot was 14% of the fished area, and the total area classified as hotspot in at least one year was 37%. The impact on the seabed of hotspots will be related to whether or not they are fished year after year or whether they change. We examined these possibilities by examining the extent to which they changed over time. We found that only 12% of the fished area was classified as hotspot in at least 50% of the years and only 3% was classified as hotspot every year.

The small proportion of the NPF that was intensively trawled contributed a large proportion of the total NPF prawn catch—particularly the catches of tiger and endeavour prawns. For example, the average 14% of the fished area classified as hotspot from 1999 to 2004 contributed an average of 83% of prawn catches during that period.

Although the proportion of the NPF that is intensively trawled is small, the impacts of trawling in those areas must still be carefully managed for two reasons. First, the NPF is not all the same in terms of biodiversity: some habitats and species may occur only in the prawn trawling grounds, and will need to be protected if vulnerable to trawling. Second, long-term sustainability of the prawn catch may depend on the health of the ecosystems that support the prawns, and therefore on management of the impacts of trawling on those ecosystems.

Our overall conclusion is that only a minor proportion of the NPF is trawled at all and that the skewed distribution of trawling means that a major part of the area that is trawled is fished only lightly. There are areas—hotspots—that are trawled intensively but they tend to change from year to year and only a very small proportion of the fished area of the NPF (3%) makes up the same hotspot every year.

4.6 References

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CHAPTER 5. PHYSICAL AND BIOLOGICAL CHARACTERISTICS OF THE STUDY SITES

Mick Haywood, Burke Hill, Scott Gordon, Petra Kuhnert, Anthea Donovan, Sue Cheers, Wayne Rochester

5.1 Choice of Study Sites

Mick Haywood

Summary

- Sites for the experiment were chosen to meet the following criteria:
  - Relatively soft sediment seabed
  - Capable of being worked in windy conditions in winter
  - Economic steaming distance from home port
  - Previously trawled commercially but no longer trawled
- Mornington Island was selected as the study area because of lower wave heights in winter and proximity to the home port of the chartered trawler.
- One site was chosen to the west of Mornington and one to the east of Mornington

5.1.1 Introduction

In deciding where to carry out the project we had to consider certain constraints. The first of these was that we wanted to measure the effects of trawling in two areas that were substantially different. The second constraint was that the areas had to be capable of being worked in winter when there are strong south-easterly winds in the Gulf of Carpentaria. Thirdly, we had to contain costs by not having to spend a long time steaming between stations. Finally, we felt that it was important that the sites be located on areas of the seabed that had been trawled in the past, but had not been trawled in recently. This is because our aim was to measure depletion and recovery rates of the taxa that are characteristic of prawn trawl grounds and also it was necessary to locate our control lanes as close as possible to the lanes that were trawled. Previous studies have made inferences on the effects of trawling by comparing trawled areas with lightly or untrawled areas (e.g. Gibbs et al. 1980, Collie et al. 1997) but this usually means the areas are separated by km and variation at these scales is just as likely to be due to natural causes as it is to trawling. We also needed to ensure that our study area would not be trawled commercially during the period following our initial trawling as we were monitoring the recovery of the benthos for 2 years. So it was prudent to select an area that was not presently attractive to the fishers making it easier for us to establish an area closed to the fishery around the study area.

5.1.2 Methods

We used the following sources of information in identifying areas that would meet the constraints set out above:

1. The Surrogates Research Project (Hill et al. 2002) provided information on seabed sediments and on seabed current stress in the NPF. This data could be used to identify contrasting areas in soft sediment areas.
2. The Surrogates Project had also modelled wave height throughout the NPF (Condie and Mansbridge, 2002). This enabled us to predict the likely wave activity in different potential areas.
3. The home port of the chartered vessel used in the project would determine the general area of the study.
4. NPF Logbook data supplied by the Australian Fisheries Management Authority enabled us to select areas that had been fished previously, but not in the past 10 years.

5. The Surrogates Project and the new round of VMS analysis carried out for the current project (see Chapter 3), in combination with the fishers' electronic maps of untrawlable ground collected as part of the FRDC Tiger prawn stock recruitment project gave information on the fine scale distribution of trawl effort.

We had originally considered working around either Groote Eylandt or Mornington Island (Figure 5.1-1). At that stage we did not know where the base for the trawler would be – it could come from the east coast of Queensland in which case Groote and Mornington are equidistant. The successful tender came from Raptis and Sons using a trawler that would operate out of Karumba in the southeast Gulf. This immediately made Groote Eylandt an unattractive choice because of the considerably greater steaming time from Karumba.

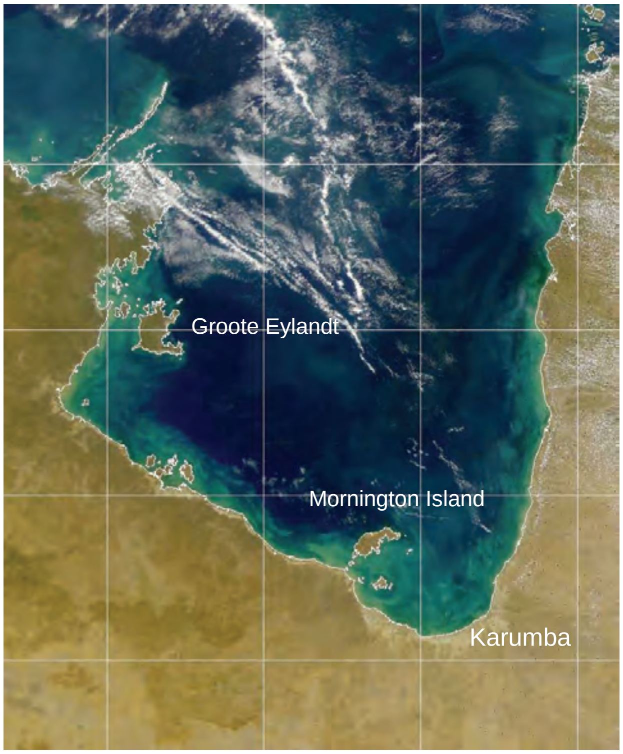

Figure 5.1-1: Gulf of Carpentaria showing the positions of Groote Eylandt and Mornington Island. Satellite photo from the SeaWiFs Project, NASA/Goddard Space Flight Centre and Orbimage.

We also had reservations about sea conditions around Groote in winter. There is a long fetch for south easterly winds and modelling for the Surrogates Project (Condie and Mansbridge, 2002) had shown that wave height is greater in the northwest than elsewhere in the Gulf (Figure 5.1-2). Rough sea conditions would reduce the accuracy of our position fixing and placement of the sampling gear.

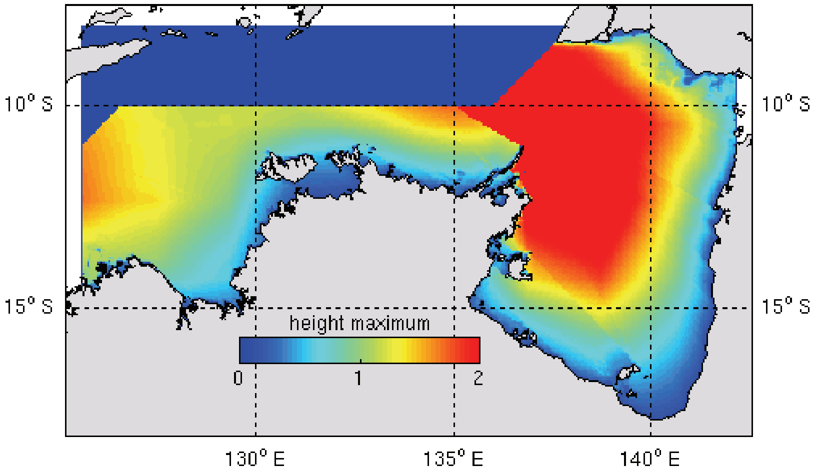

Figure 5.1-2: Maximum wave heights computed for the NPF region. Source: Condie and Mansbridge (2002).

Mornington Island by contrast is relatively close to Karumba and is not exposed to strong wave action in either summer or winter. Modelling of seabed current stress for the Surrogates Project also showed a high contrast between western and eastern Mornington Island (area in the bottom right of the Gulf of Carpentaria in Figure 5.1-3).

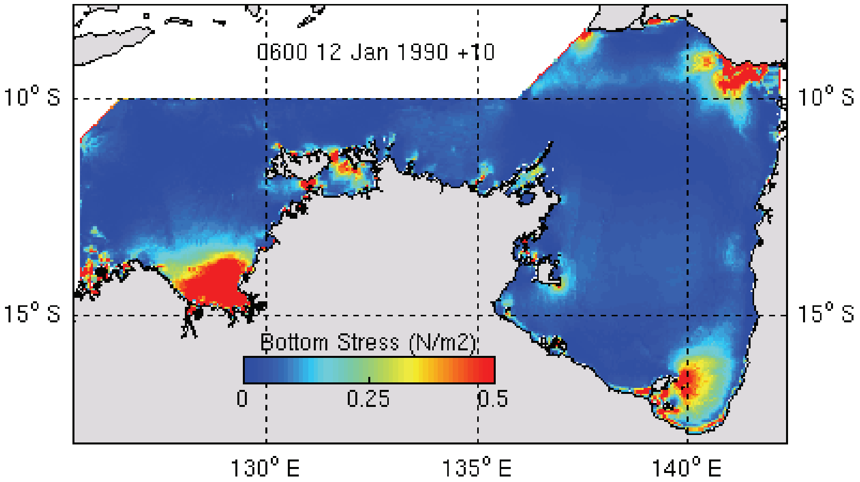

Figure 5.1-3: Seabed current stress in the NPF. Source: Condie and Mansbridge (2002)

There is high seabed current stress to the east of the island but low stress on the west. The water is also shallower on the east. Thus we had indications of different physical conditions on the two sides of the island within a relatively short distance in terms of steaming time. Accordingly we decided to position one experimental area to the west and the other to the east of Mornington Island.

The final factor that we used in deciding the location of the experimental trawls was trawl effort. We used the AFMA logbook database to identify 6 × 6 nm grids around Mornington Island where fishing had not occurred since 1993. There were several grids to the east and west of Mornington Island that qualified, but those to the western side contained a large amount of untrawlable ground (Figure 5.1-4). Discussions with several fishers indicated there was trawlable ground to the south of these grids and examination of the AFMA logbook data showed there had been little fishing effort there in recent years.

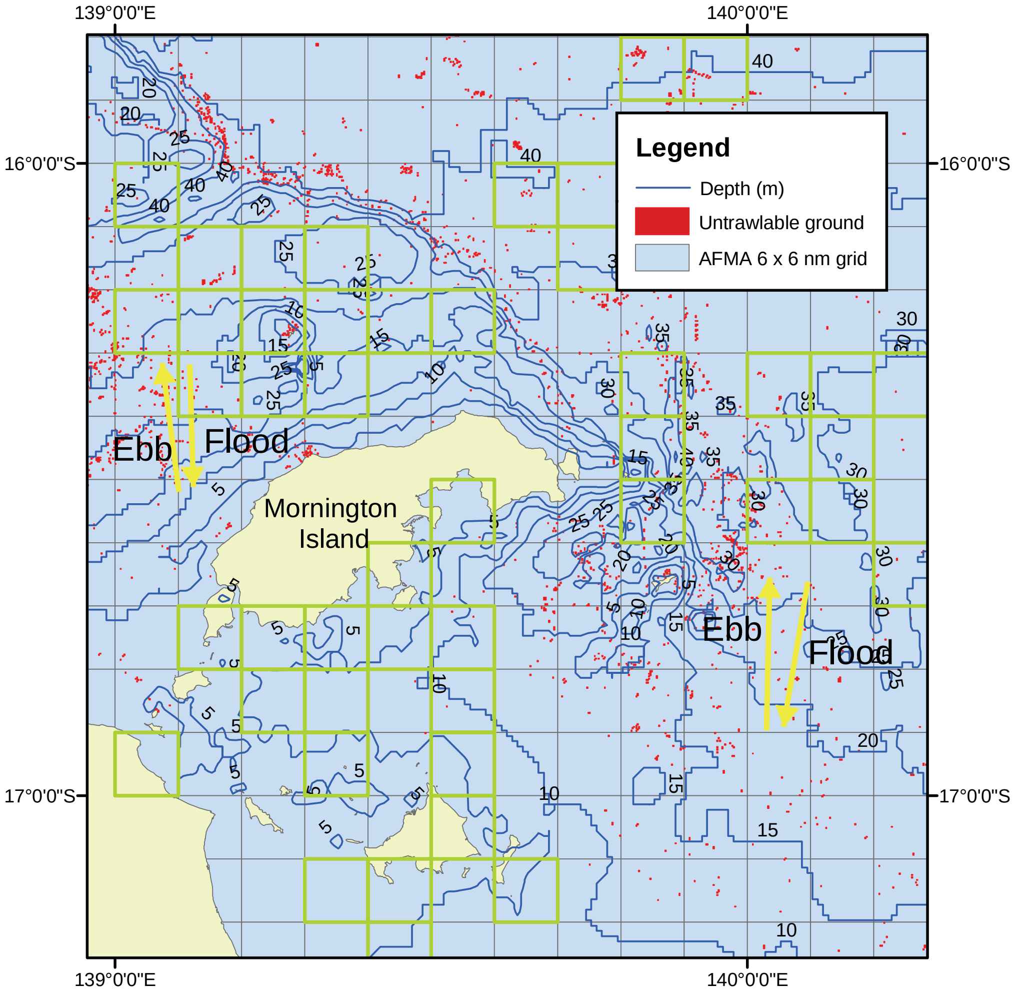

Figure 5.1-4: Untrawlable ground and areas not fished for the past 10 years around Mornington Island. The large grid of open cells represents the 6 x 6 nm grid used by AFMA to collected daily catch records from the NPF fleet. Green-bordered cells are those that have been fished in the past, but have not been fished since 1993. The arrows show the prevailing tidal current directions on the eastern and western sides of the island.

The VMS data for the areas east and west of Mornington Island showed there was an area in the high current stress zone to the east of the island that had not been trawled recently and was clear of untrawlable ground (Figure 5.1-5). However, on the western side of the island there appeared to be very little area that had not been trawled and was free of untrawlable ground. We discussed this with several NPF skippers. They felt that the routine we used to exclude steaming tracks from the VMS dataset had not been completely successful. According to them, the seemingly high effort area extending from the west coast of Mornington Island did not reflect fishing activity, but was the tracks of vessels steaming into Biri Beach to liaise with mother ships which moor there. Consequently, we decided to locate our sites along this steaming track in the west and in the high current stress area away from current fishing grounds in the east (Figure 5.1-6).

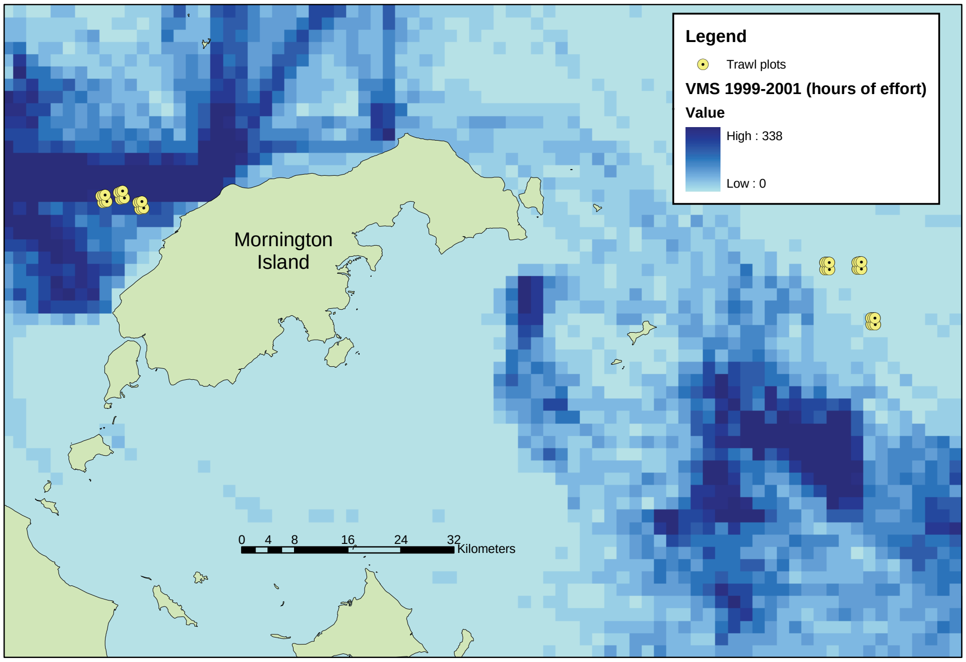

Figure 5.1-5: Distribution of fishing effort around Mornington Island between 1999 and 2001. Information derived from VMS records supplied by AFMA.

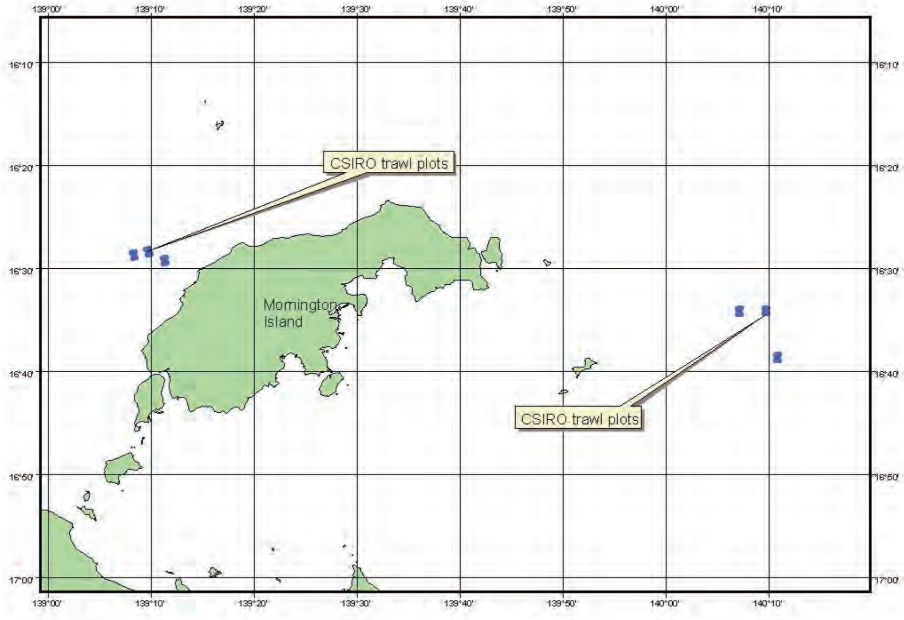

Figure 5.1-6: Two areas near Mornington Island used for the experimental study

When the vessel arrived on station west of Mornington, we found that the chosen site was unsatisfactory because of untrawlable bottom – coral - and so the site was moved south. The new site depth was 7-13 m with a bottom of gravely sand. There was a surprising amount of seagrass over a large area, mainly *Halophia spinulosa* but also some *H. ovalis* (Figure 5.1-7).

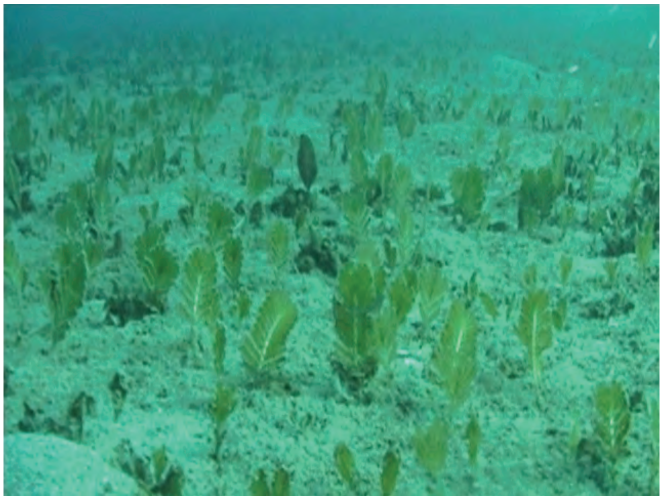

Figure 5.1-7: Seagrass on seabed to west of Mornington Island

We are not sure whether the area was previously trawled because VMS data only goes back to 1998. The presence of high densities of seagrass is not a good indicator because *H.* s*pinulosa* appears to be a rapid recolonizer. The site east of Mornington proved to be satisfactory. The depth is 28-30 m and the bottom is of fairly hard muddy sand. There were a large number of sponges in the area suggesting the area had not been trawled recently (Figure 5.1-8).

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Figure 5.1-8: Sponge on seabed to east of Mornington Island

5.1.3 References

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CHAPTER 5. PHYSICAL AND BIOLOGICAL CHARACTERISTICS OF THE STUDY SITES

5.2 Description of Study Sites

Mick Haywood, Burke Hill, Scott Gordon

Summary

Characteristics of sites:

West Mornington
- Mean depth 12.3 m but the depth of the inshore section was 8 to 10 m compared to 13 to 16 m offshore.
- Seabed current stress low
- Substrate of poorly sorted slightly gravelly sand with a low (3%) mud (<63µm) content
- Mean acoustic roughness 0.55, hardness $9.22e^{-0.04}$
- Relatively flat seabed characterized by extensive seagrass

East Mornington
- Seabed very level with depth varying between 28 and 30 m and a mean of 31.2 m
- Seabed current stress high
- Substrate of poorly sorted gravelly muddy sand with a moderate (13%) mud (<63 µm) content
- Mean acoustic roughness 0.14, hardness $8.5e^{-.05}$
- Relatively flat seabed with sparse biota
- Dominant biota is sponges

5.2.1 Introduction

We chose areas to the west and to the east of Mornington Island for our study sites. The basis of the choice was information on history of fishing, depth, seabed current stress and accessibility (See Chapter 5.1). Once the study commenced, we were able to collect additional information on the sites. We sampled the seabed biota and the results are given in Chapter 6.3. We used acoustic equipment to obtain information on depth, seabed structure and acoustic hardness and roughness. We characterised the seabed sediments and carried out underwater video to visualise the seabed. This information combined with previous modelling of seabed current stress and wave height is presented here as part of the description of the two study areas.

5.2.2 Methods

5.2.2.1 Broad scale seabed structure

We used an Imaginex Model 858 Side scan sonar (Figure 5.2-1) to obtain information on the seabed structure of the study sites. The sonar was towed over all of the sites prior to the impact trawls being carried out in March 2003.

Figure 5.2-1: Side scan sonar used for surveying the experimental sites

5.2.2.2 Seabed – substrate composition

Sediment samples were collected by means of pipe dredges (Figure 5.2-2). The dredges were 600 mm long and 90 mm internal diameter. A dredge was attached on either side of the epi-benthic sled by 3 m lengths of chain.

Figure 5.2-2: Pipe dredge used for sampling sediment. The dredge was towed from the chain bridle at the left. The pipe is sealed at the opposite end.

In both areas, we took three sediment samples in each of the 6 experimentally trawled lanes and another three from the adjacent control lanes. This gave a total of 27 samples from each study area. Samples were frozen on board. In the laboratory they were thawed, dried for 24 h at 50^{o}C and separated into components using dry sieves on a shaker to obtain information on sediment grain size distribution. The data on weight by sieve category was then analysed using the GRADISTAT program developed by Blott and Pyne (2001) which is based on analysis from Folk (1966) and Folk and Ward (1957). This computerised program gives increased accuracy over the former graphical methods as well as considerably decreased the time taken to do the analysis.

5.2.2.3 Seabed – depth and acoustic properties

We used acoustic surveys to describe the seabed properties (acoustic roughness and hardness) and also to establish whether we could distinguish acoustically between trawled and un-trawled seabed.

A Simrad EY500 portable scientific echo sounder was used to collect the acoustic data on the research cruise in August 2003. The EY500 transmits a pulse of high frequency sound that is reflected back by seabed targets including epi-benthic organisms such as coral and sponges, as well as the seabed itself. The reflected acoustic signal was converted to electrical signals by the echo sounder transducer and stored digitally for later analysis. Position was logged for the acoustic track with GPS. Over the duration of the voyage approximately 1.2 gigabytes of acoustic echogram data were recorded.

We processed the large volume of digitised acoustic echogram data by means of the software program ECHO (Waring et al. 1994) (Figure 5.2-3) developed by CSIRO. Initial quality assurance and post-processing stages included: editing the echograms for bad data; removing background noise (including sea state and background acoustic noise, man-made acoustic and electrical noise), and setting threshold values for analysis layers for seabed signals of interest.

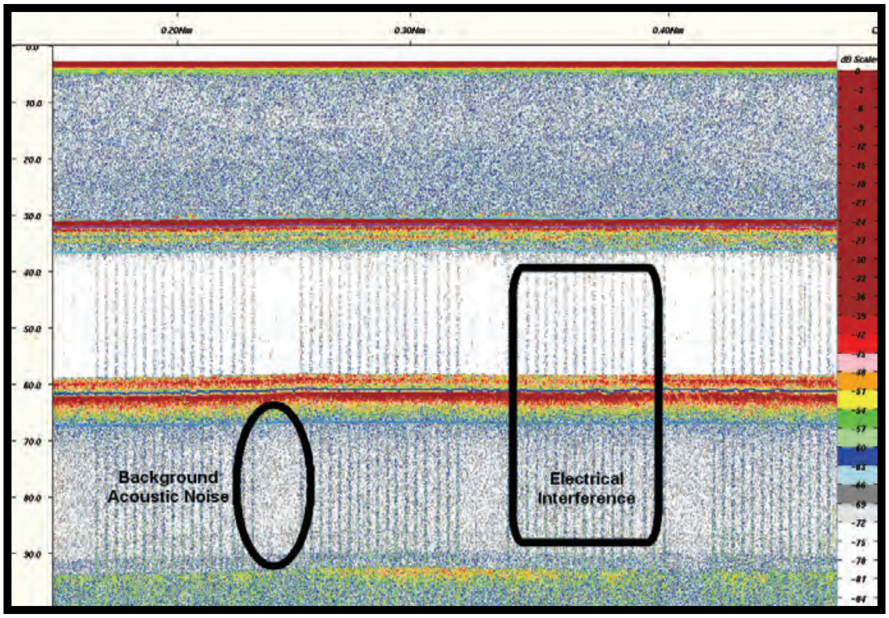


Figure 5.2-3: Screen Capture of ECHO acoustics analysis software showing Simrad EY500 echogram data before quality assurance, cleaning and analysis. This screen capture shows significant components of the acoustic echogram signal including background noise and electrical interference.

The seabed bottom layer was automatically defined from the EY500 bottom pick and the data checked for quality. Bad bottom pick data were edited out of the echograms. An analysis overlay was developed for two layers referred to as the first (acoustic roughness) and second (acoustic hardness) seabed echoes (Figure 5.2-4) using a constant beam angle to account for spreading effects.

This analysis overlay allowed the integration of seabed targets of interest regardless of depth variations. This layer was then integrated along the echo sounder ping (vertically on the echogram worksheet) and then along the ship track over a 5 ping interval (horizontally on the echogram worksheet) to produce geo-referenced acoustic indices.

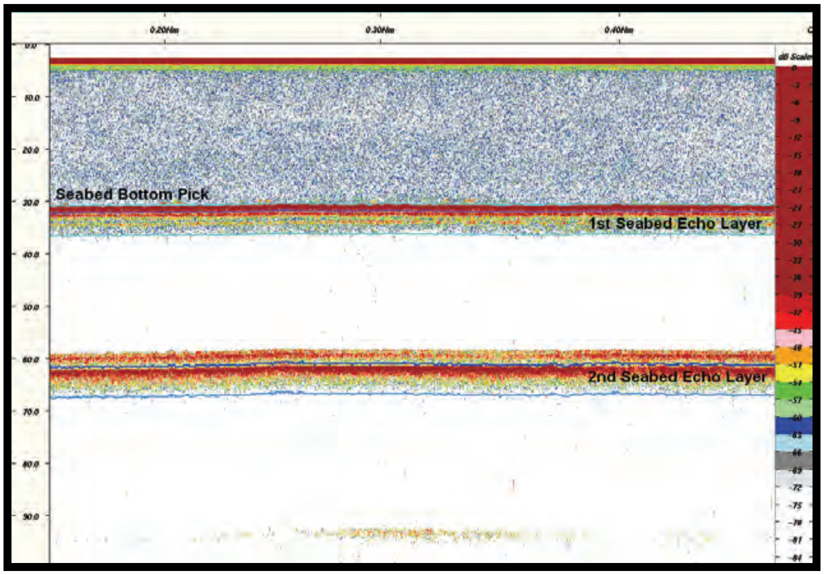


Figure 5.2-4: Screen Capture of ECHO acoustics analysis software showing the QA / cleaned Simrad EY500 echogram data, seabed bottom pick, as well as first (acoustic roughness) and second (acoustic hardness) echo analysis layers.

5.2.2.4 Photography of seabed

We used two systems for recording pictures of the seabed. In the first, a Sony DCR-TRV16E Digital Video Recorder (Handycam) was housed in an underwater housing. The housing was initially held in a protective frame attached to the upper side of the epi-benthic sled (Figure 5.2-5) but the quality of the images was poor because the visibility was quite low and the camera was too far from the seabed. We then tried drifting the camera independently of the sled.

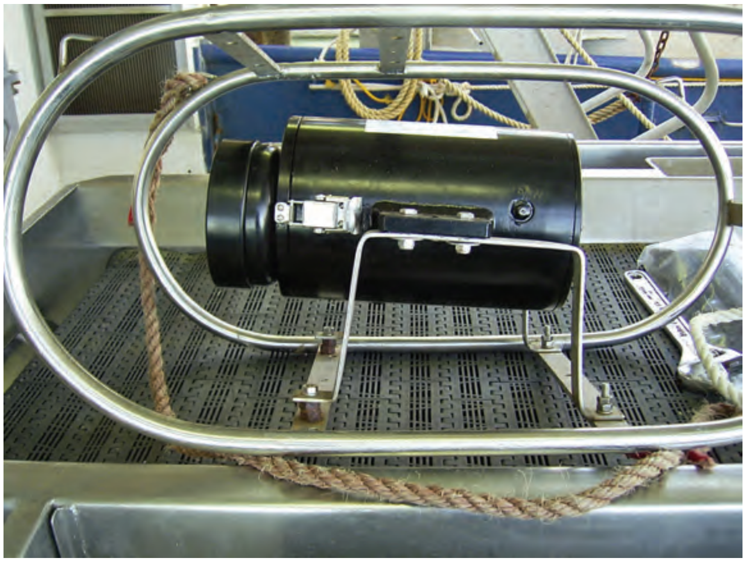


Figure 5.2-5: Housing for the Handycam in a protective frame attached to the top of the epi-benthic sled.

The camera was lowered from the trawler which was allowed to drift across the line of the trawl tracks. An acoustic beacon was attached to the camera frame to track the camera.

The second system consisted of a SeaViewer Sea-drop 650 Series colour underwater camera connected to the surface by means of an 80 m umbilical. The underwater unit had a built in LED light source powered from the surface. We used a Sony DCR-TRV16E Digital Video Recorder (Handycam) for recording images on the surface.

Poor underwater visibility and equipment problems proved to be an ongoing problem. In August 2004, unusually clear water enabled us to obtain video of the seabed to the west of Mornington. On the eastern side visibility was generally poor but in February 2005 conditions were unusually good with a long period of calm weather and we obtained video of the site of the second trawling experiment using the Sea-drop camera. The MiniDV tapes were transcribed to digital DVD for archiving. Still pictures were extracted from the video.

5.2.3 Results: Description of Study Areas

5.2.3.1 **Seabed – substrate composition**

The substrate composition of the study areas to the east and west of Mornington Island are summarised in Table 5.2-1 and Table 5.2-2. This data is based on the average values of 27 samples from each area. The data for each sample is given in Appendix G.

Table 5.2-1: Characteristics of the substrate of the sampling sites east of Mornington Island. Mean values based on 27 samples.

SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **EMN**

ANALYST & DATE: ,

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Muddy Sand

SEDIMENT NAME: Very Fine Gravelly Coarse Silty Fine Sand

	μm	φ
MODE 1:	187.5	2.500
MODE 2:		
MODE 3:		
D_{10}:	33.30	-0.557
MEDIAN or D_{50}:	217.2	2.203
D_{90}:	1471.6	4.909
(D_{90} / D_{10}):	44.20	-8.806
(D_{90} - D_{10}):	1438.3	5.466
(D_{75} / D_{25}):	3.051	2.318
(D_{75} - D_{25}):	288.3	1.610

GRAIN SIZE DISTRIBUTION

GRAVEL:	7.1%	COARSE SAND:	6.6%
SAND:	79.9%	MEDIUM SAND:	21.8%
MUD:	13.0%	FINE SAND:	39.8%
		V FINE SAND:	5.3%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	2.2%
COARSE GRAVEL:	0.0%	COARSE SILT:	2.2%
MEDIUM GRAVEL:	0.5%	MEDIUM SILT:	2.2%
FINE GRAVEL:	1.5%	FINE SILT:	2.2%
V FINE GRAVEL:	5.2%	V FINE SILT:	2.2%
V COARSE SAND:	6.4%	CLAY:	2.2%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	603.1	205.2	2.285	250.4	1.998	Medium Sand
SORTING (σ):	1131.4	4.738	2.244	3.882	1.957	Poorly Sorted
SKEWNESS (Sk):	3.979	-0.585	0.585	0.060	-0.060	Symmetrical
KURTOSIS (K):	20.85	3.580	3.580	2.003	2.003	Very Leptokurtic

Table 5.2-2: Characteristics of the substrate of the sampling sites west of Mornington Island. Mean values based on 27 samples.

SAMPLE STATISTICS

SAMPLE IDENTITY: **WMN** ANALYST & DATE: SC, Mar 2004

SAMPLE TYPE: Unimodal, Poorly Sorted TEXTURAL GROUP: Slightly Gravelly Sand

SEDIMENT NAME: Slightly Very Fine Gravelly Medium Sand

	µm	ϕ	GRAIN SIZE DISTRIBUTION			
MODE 1:	375.0	1.500	GRAVEL:	1.1%	COARSE SAND:	17.9%
MODE 2:			SAND:	95.8%	MEDIUM SAND:	44.1%
MODE 3:			MUD:	3.2%	FINE SAND:	25.9%
D_{10}:	133.9	0.302			V FINE SAND:	4.2%
MEDIAN or D_{50}:	324.7	1.623	V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.5%
D_{90}:	810.9	2.901	COARSE GRAVEL:	0.0%	COARSE SILT:	0.5%
(D_{90} / D_{10}):	6.056	9.593	MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.5%
$(D_{90} - D_{10})$:	677.0	2.598	FINE GRAVEL:	0.2%	FINE SILT:	0.5%
(D_{75} / D_{25}):	2.405	2.198	V FINE GRAVEL:	0.9%	V FINE SILT:	0.5%
$(D_{75} - D_{25})$:	280.9	1.266	V COARSE SAND:	3.5%	CLAY:	0.5%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic µm	Geometric µm	Logarithmic ϕ	Geometric µm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	444.0	300.3	1.735	320.2	1.643	Medium Sand
SORTING (σ):	449.9	2.510	1.328	2.063	1.045	Poorly Sorted
SKEWNESS (Sk):	5.670	-1.623	1.623	-0.063	0.063	Symmetrical
KURTOSIS (K):	55.46	8.921	8.921	1.146	1.146	Leptokurtic

Both areas had a substrate of poorly sorted medium sand. The main difference between the areas is that in the east the substrate contained significant amounts of fine to very fine gravel. This gravel is mainly shell grit. East of Mornington the substrate had a greater proportion of silt – in essence the substrate is muddier. This composition is reflected in the triangular distribution diagrams, Figure 5.2-6 and Figure 5.2-7. Only the Gravel – Mud – Sand diagrams are shown because the Sand – Clay – Silt diagrams were nearly identical with all points grouped at the Sand apex. The summary histogram in Figure 5.2-8, shows the higher proportion of fine material (63µ and <63µm) and coarse particles (1000 and 2000µm) in the study sites in the east compared to the west.

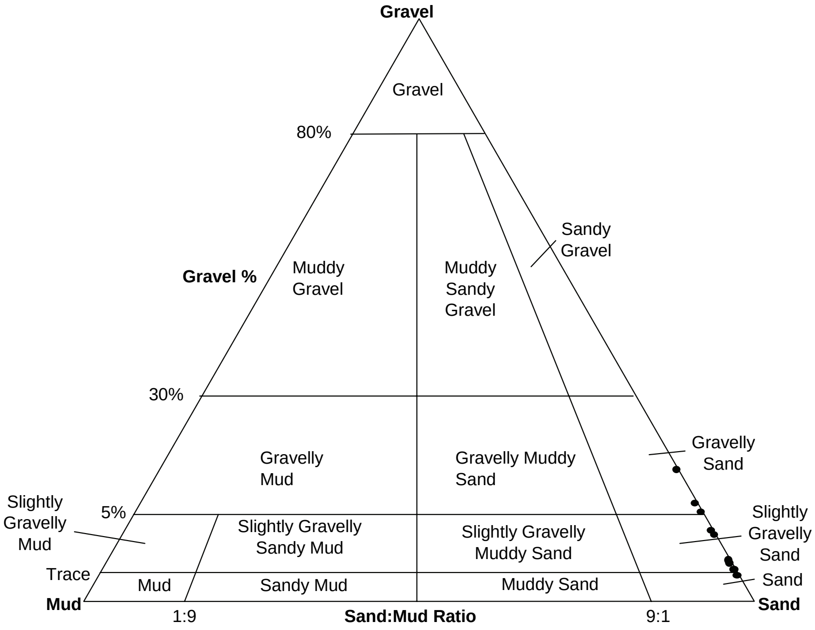


Figure 5.2-6: Gravel – Mud – Sand distribution for sediment samples collected from the study area west of Mornington Island. Individual samples are shown as black dots which are all grouped on the Sand – Gravel axis.

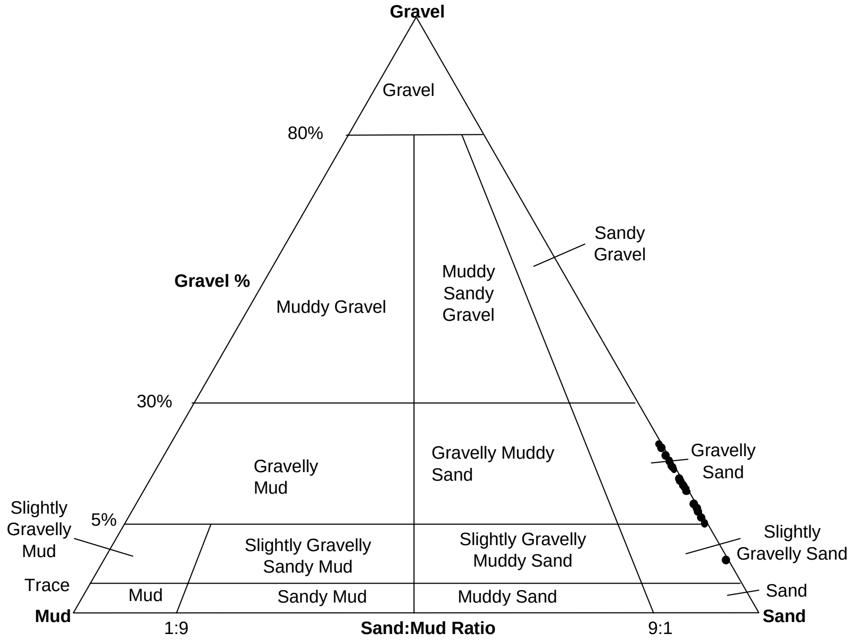


Figure 5.2-7: Gravel – Mud – Sand distribution for sediment samples collected from the study area east of Mornington Island. Individual samples are shown as black dots which are all grouped on the Sand – Gravel axis.

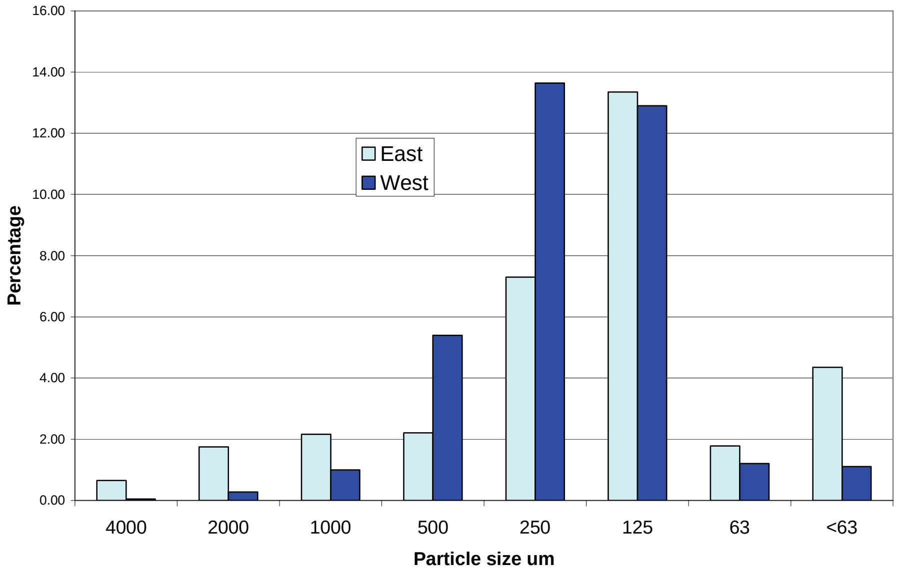


Figure 5.2-8: Particle size distribution of sediment samples from the study sites to the east and west of Mornington Island.

5.2.3.2 Seabed – depth and acoustic properties

High-density acoustic echogram data were collected from the seabed in the study areas to the east and west of Mornington Island (Figure 5.2-9) in August 2003 for analysis as a potential indicator of seabed habitat and the effect of trawling on these habitats. Echograms were obtained from all experimental lanes – high and low impact as well as the un-trawled controls.

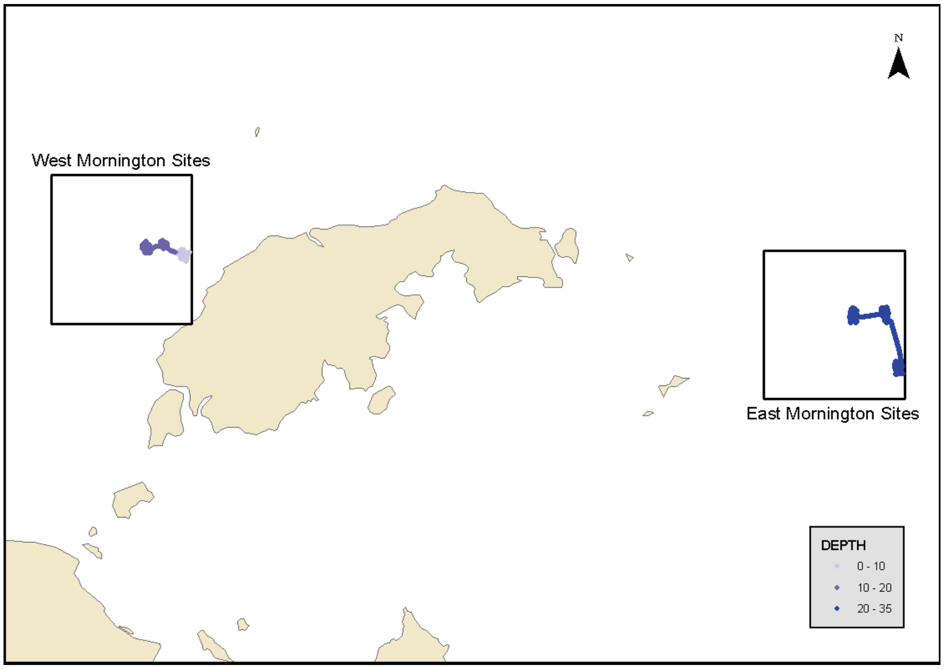


Figure 5.2-9: Sample sites east and west of Mornington Island. Blue spots and tracks show where acoustic profiles were collected.

The echogram analysis produced a total of 85571 records of depth and seabed acoustic indices over the entire study area. Basic descriptive statistics and histograms for each of the two study areas are shown in Table 5.2-3 & Figure 5.2-10.

Table 5.2-3: Descriptive statistics for acoustic indices generated from echogram analysis

		N	Mean	S.E.	Median	Std Dev	Min	Max
West Mornington	**Depth**	54055	31.22	3.23E-03	31.20	0.75	23.7	32.90
	Roughness	54055	0.55	1.38E-03	0.49	0.32	2.60E-05	5.22
	Hardness	54055	9.22E-04	3.51E-06	6.91E-04	8.15E-04	0.00	1.67E-02
East Mornington	**Depth**	31516	12.32	1.28E-02	13.30	2.27	7.9	15.50
	Roughness	31516	0.14	7.48E-04	0.10	0.13	4.73E-03	5.25
	Hardness	31516	8.50E-05	6.56E-07	4.90E-05	1.17E-04	1.00E-06	4.93E-03

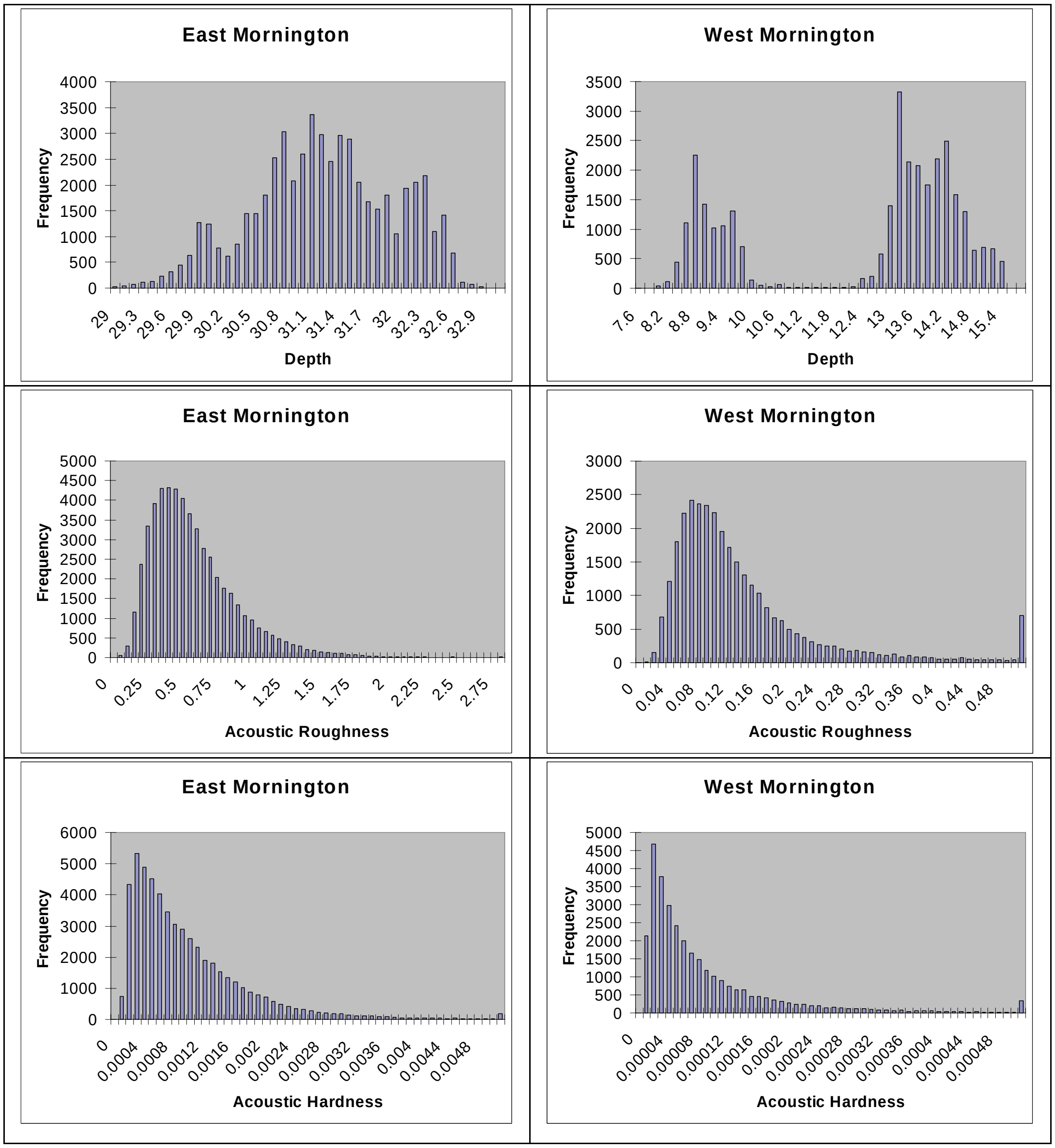


Figure 5.2-10: Histograms of depth and derived acoustic indices (acoustic roughness & acoustic hardness) for the east and west Mornington Island study areas.

The east Mornington Island site was the deeper of the two study areas with a mean depth of 31.2 m compared with the west Mornington Island site mean depth of 12.3 m. The seabed in the east was fairly level with a depth range of 28 to 32 m. The west Mornington Island site by contrast had two distinct levels - a deeper section to the west with a depth of 13 to 16 m and a shallower in-shore area to the east with a depth of 8 to 10 m. The overall average depth of the western site was 12.3 m.

Acoustic indices for the two study areas showed that the western site was both rougher and harder acoustically than the eastern site. This indicates a difference in the underlying substrate between the two areas. The results of the acoustic analysis are presented in a geographic context in Figure 5.2-11. In Chapter 5, we have used position information from the trawl monitoring system to geolocate control and trawl lanes with co-located acoustic data in order to assess the efficacy of the acoustic indices in measuring trawl effect.

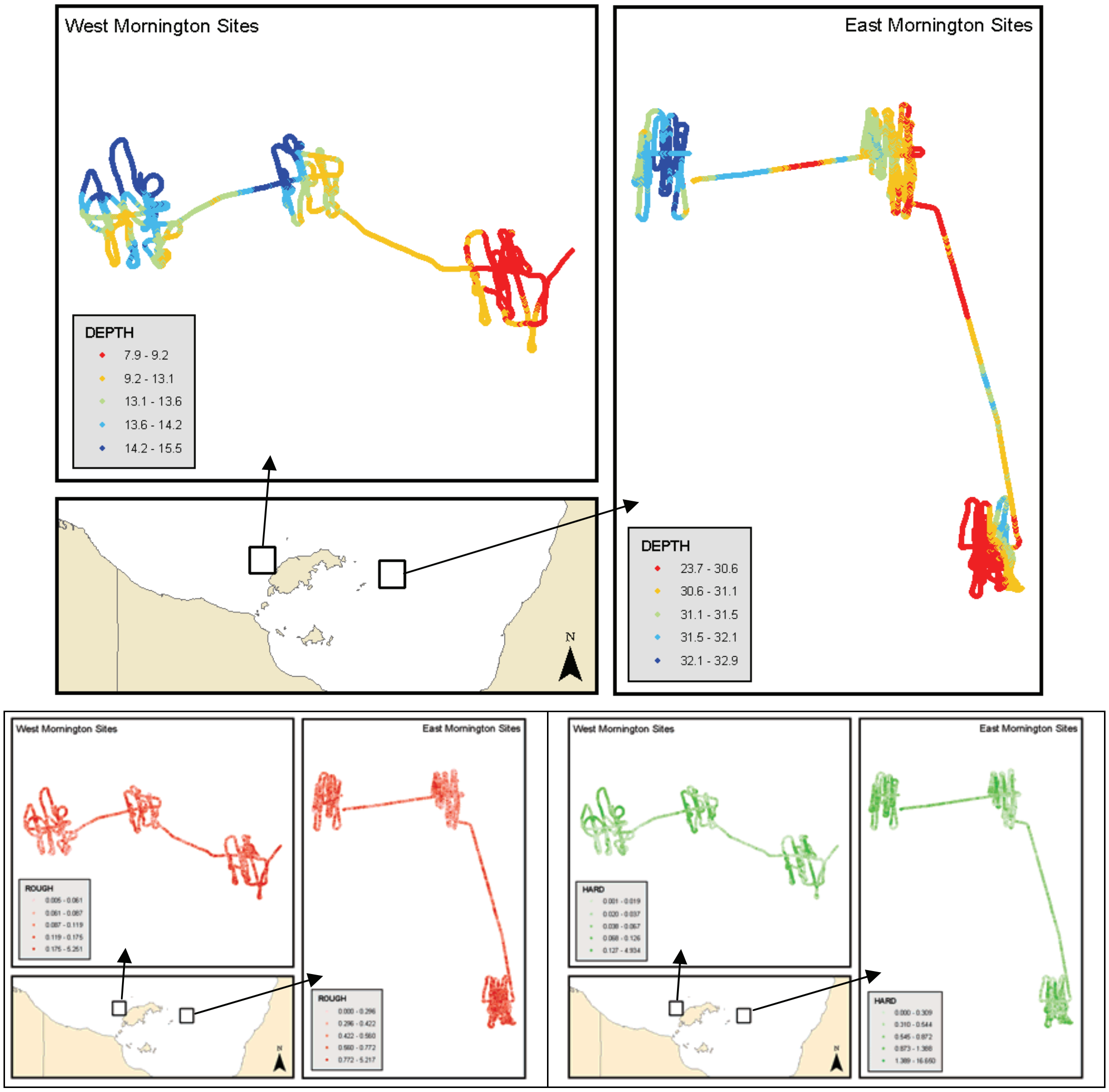


Figure 5.2-11: Maps of depth and derived acoustic indices (acoustic roughness & acoustic hardness) for vessel tracks over the east and west Mornington Island study areas

The acoustic information from the tracks between the sites shows the acoustic roughness and hardness in each area is relatively constant indicating that the three study sites in each area are fairly homogenous with respect to acoustic properties.

5.2.3.3 **Broadscale seabed structure**

The information from the side scan sonar showed the study sites to be very level with no noticeable structure (Figure 5.2-12).

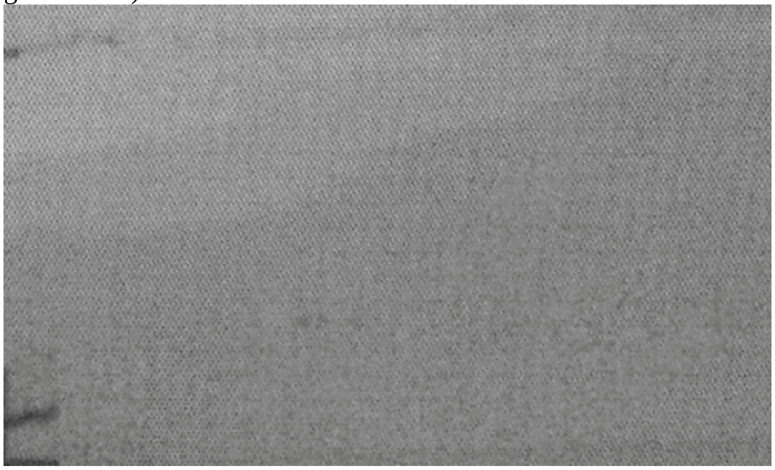


Figure 5.2-12: Example of acoustic mapping of one of the eastern study sites. The grey scale shows a vertical difference of <3 m between the top left and bottom right corners of the area.

5.2.3.4 **Photography of seabed**

Underwater photography was limited by the poor visibility. The problem is that these relatively inshore waters are turbid most of the time. In the summer months it appears to be due to runoff from the heavy monsoon rainfall. In winter winds are strong and the shallow water is stirred up. This can be seen in Figure 5.2-13. The pale areas in the water are turbid plumes which move around with the strong tidal currents in the region. The water to the west of Mornington is clearer than to the east. In August 2004 we recorded several hours of underwater video in this western region. Weather conditions in February 2005 were exceptionally calm and we obtained about two hours of underwater video in the deeper water on the study site to the east of Mornington. The mud content of the seabed in this area is high is easily stirred up. Offshore the water is considerably clearer.

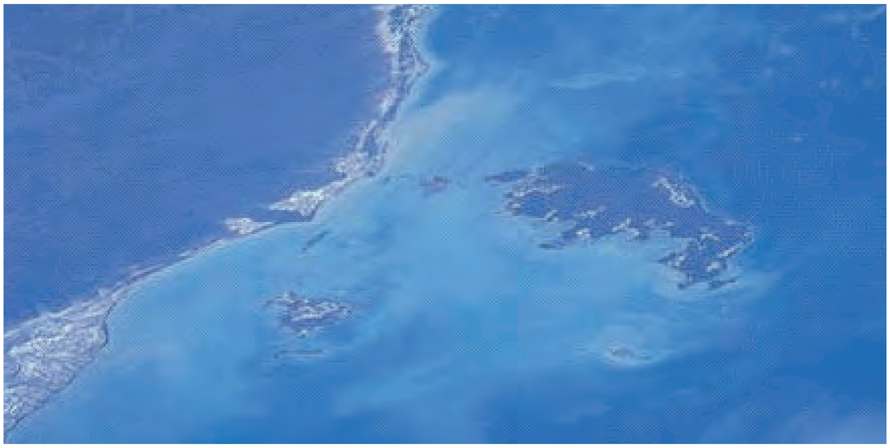


Figure 5.2-13: View of Mornington Island area showing plumes of turbid water. Earth Sciences and Image Analysis, NASA-Johnson Space Center. "Earth from Space - Image Information." http://eol.jsc.nasa.gov/sseop/EFS/photoinfo.pl?PHOTO=STS048-616-32>

5.2.3.4.1 Seabed to the west of Mornington Island

Underwater photography of the area west of Mornington shows a fairly level area (Figure 5.2-14). The substrate is soft muddy sand with signs of bioturbation – mounds and burrows. Sea grasses – mainly *Halophila spinulosa* were common as were colonies of Bryozoa (Gymnolaemata).

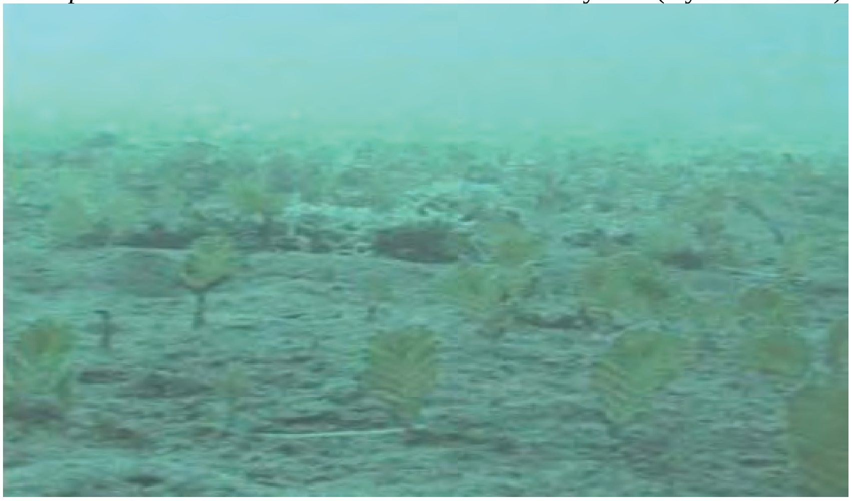


Figure 5.2-14: Seabed to the west of Mornington Island in August 2004.

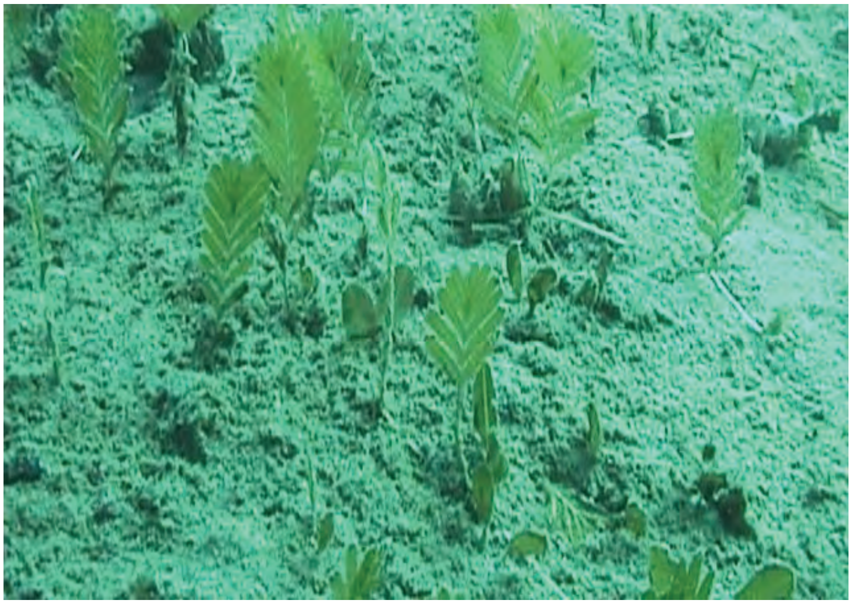


Figure 5.2-15: Close-up of sea grasses on the seabed to the west of Mornington Island.

A close up of the sea grasses is shown in Figure 5.2-15. The delicate branched species of seagrass is *Halophila spinulosa*, the single bladed species is *H. ovalis*. These sea grasses were a consistent feature of the area from March 2003 but the amount varied quite significantly (See Chapter 5.3). The texture of the substrate suggests it has been extensively worked over by animals.

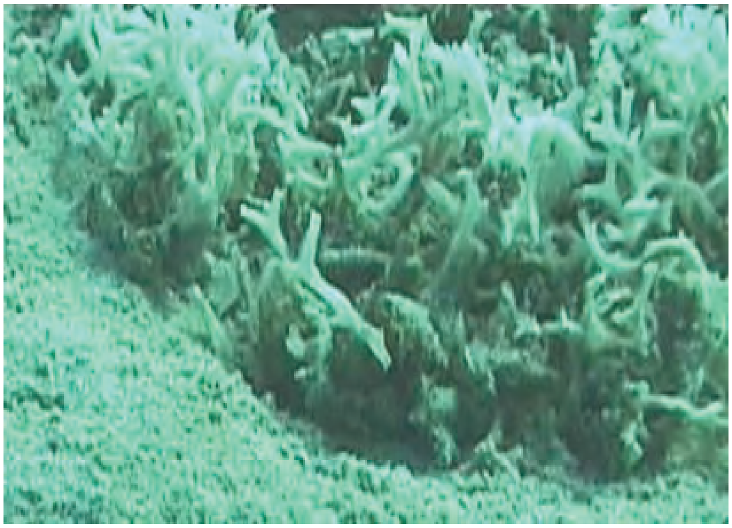


Figure 5.2-16: Closeup of the bryozoan *Thalamsporella cf labita* on the seabed west of Mornington Island, August 2004.

The bryozoan *Thalamsporella cf labita* (Figure 5.2-16) had been recorded in small amounts from west of Mornington in previous surveys but it was very abundant in August 2004. This bryozoan is very delicate and the samples collected in the epi-benthic sled are always fragmented, this was the first time we had seen the intact colonies.

Figure 5.2-17: Crinoid on sandy seabed west of Mornington Island.

Figure 5.2-17 shows a crinoid and Figure 5.2-18 two types of gastropod egg masses. Mobile animals such as crabs and fish were not seen in the underwater video possibly a combination of day time photography and the animals moving away or burying in front of the large camera setup which was moving quite slowly.

Figure 5.2-18: Two different types of Gastropod egg masses on the seabed west of Mornington Island.

5.2.3.4.2 Seabed to the East of Mornington Island

The underwater video taken of the seabed around the study site to the east of Mornington before trawling in February showed a mainly featureless plain (Figure 5.2-19) which is mostly very level but more rough in places possibly because of disturbance by animals (Figure 5.2-20). The high mud content of the substrate was very evident from massive clouds of sediment whenever the camera gear touched the bottom.

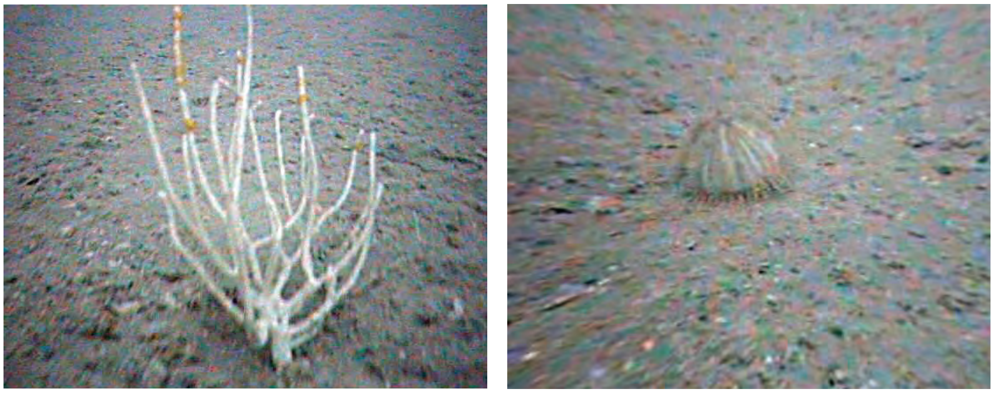
Figure 5.2-19: Typical seabed to east of Mornington Island.

Figure 5.2-20: Seabed to east of Mornington Island – apparent bioturbation.

The most conspicuous epifauna were sponges (Figure 5.2-21). As noted in Chapter 5.3 there are a large number of species in this area.

Figure 5.2-21: Sponge on seabed east of Mornington Island, February 2005.

Sponges and gorgonians were not obviously attached to a solid substrate (Figure 5.2-22a) but it is possible that the larval stages settled on one of the numerous shell fragments that litter the seabed. Few mobile animals were seen.



a **b**

Figure 5.2-22: (a) Gorgonian (*Alertigorgia orientalis*). The yellow objects on the gorgonian are ophiuroids. (b) Echinoid.

The most common were echinoids (Figure 5.2-22) and a few fish. The latter were wary of the camera and most were seen only because of the cloud of sediment they raised as they swam away. Burrows were quite common in the seabed (Figure 5.2-23).

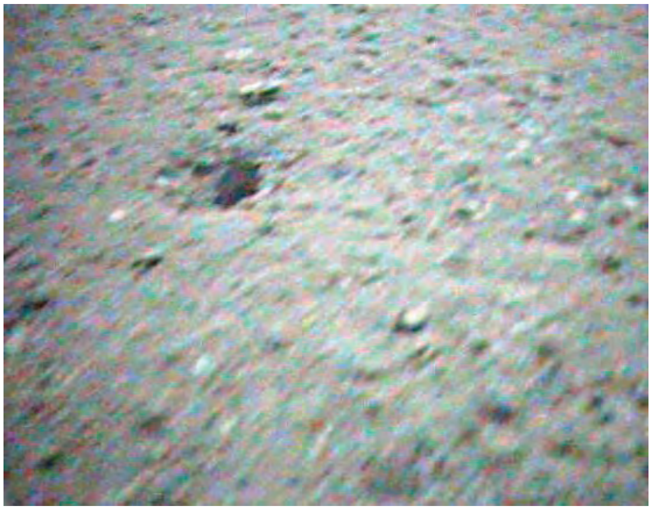


Figure 5.2-23: Burrow in seabed to east of Mornington Island, February 2005

The seabed biota is described in detail in Chapter 5.3.

5.2.4 Discussion

A key issue in designing this study was that it should examine the effects of trawling on soft substrate areas. A previous major study of this type carried out by CSIRO on the Queensland east coast (Poiner et al. 1998) had used an area in which soft sediments alternated with areas of low reef and sponge garden. These rocky areas supported an extensive attached fauna. Trawling in the Northern Prawn Fishery is by contrast, nearly entirely in areas of soft sediments. Ellis (2002) modelled the sediment distribution in the Gulf of Carpentaria. He showed that the major sediment type was sand with the percentage varying from around 20% to the north of Groote Eylandt up to 80% in the eastern Gulf. Mud content varied similarly from between 60 and 80% north of Groote Eylandt to around 20% in the east. There are extensive areas of reef mainly in the southern and western Gulf of Carpentaria (Die et al. 2001). They are commonly referred to as the ‘untrawlable grounds’. Their extent is significant, totalling around 28% of the area of the fishing grounds. These areas are avoided by fishers to avoid hooking their nets although they trawl intensively between the reefs (see Introduction). Consequently, the trawl fishery occurs predominantly over soft sediments. In choosing sites for the experimental study, we wanted areas of soft sediment. As shown above, we succeeded in this since the study sites were predominantly sandy with some gravel or mud.

In designing the experiment we were aware that the seabed of the NPF varies quite widely and we decided to choose two areas with different characteristics so the results of the study would have a fairly wide application. The areas to the west and east of Mornington proved to be very different. In the west the water is shallow (8 to 15 m depth). It is a region of low seabed current stress and the substrate has a low mud content (3%). The area to the east by contrast is relatively deep (28 to 30 m), is subjected to high seabed current stress and has a moderate (13%) mud content. The acoustic properties of the seabed also differed between west and east. The seabed was acoustically rougher and harder in the west than in the east. Physical differences between the two sites are reflected in the biota (Chapter 5.3).

The results of the acoustic survey were disappointing. Although it showed that the areas to the east and west had different acoustic properties, we did not learn much more from the data. Acoustic data can be collected very rapidly without stopping the ship but without ground truthing it is difficult to interpret the results. Pinn and Robertson (2003) have questioned the value of this type of acoustic data and shown that interpretation of biodiversity information from acoustics is dependent on track spacing and pixel size. The problem relates to the wide variation in substrate types within a small area. Hill et al. (2002) showed that at least in the Gulf of Carpentaria, the relationship between biodiversity and substrate types is not close. Consequently the relationship between acoustic data and biodiversity becomes tenuous.

Photography of the seabed showed the contrast between the two study areas. To the west we had shallow, well lit waters and a seabed with a rich cover of seagrass. To the east, there was no seagrass and the main features on the muddier substrate were sponges. We saw few fish in either area and suspect that the camera gear and its towing lines scared them away. We were not optimistic about being able to obtain underwater photographs in the usually turbid waters of the southern Gulf of Carpentaria but despite many setbacks, we did finally obtain reasonable video. We had not intended to do quantitative video and the material we collected does not lend itself to analysis of the seabed epifauna but the results we have had in this project suggest that it may be possible to obtain useful information about some elements of the seabed fauna. Video would be most suitable for sponges, which are large, conspicuous and do not move away from the camera. Other groups that may be censused in this way are gorgonians, bryozoans – at least the larger colonies, crinoids and the larger regular echinoids as well as seagrass. The animals that could not be censused using video include those species that burrow, are small or avoid the camera.

5.2.5 References

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Thalassinid mounds on the seabed west of Mornington Island

CHAPTER 5. PHYSICAL AND BIOLOGICAL CHARACTERISTICS OF THE STUDY SITES

Burke Hill, Mick Haywood, Petra Kuhnert, Anthea Donovan, Sue Cheers, Wayne Rochester

5.3 The Biota

Summary

COMPOSITION OF BIOTA

- The study area to the east of Mornington Island had twice as many taxa and seven times the biomass compared to the western study area
- In terms of density of biomass on the seabed the east was dominated by sponges and the west by seagrass
- Cluster analysis and multidimensional scaling indicated significant differences in the faunal composition between the two areas
- 90% of the dissimilarity is accounted for by 10 taxa of which 7 are sponges

CHARACTERISTICS OF SAMPLING GEAR

- An analysis of the catch of the epi-benthic sled compared to the prawn trawl showed that the latter is very inefficient at catching most of the seabed biota
- The taxa caught with the highest efficiency by the trawl were crustaceans, sponges (Desmospongiae) and cephalopods
- The low efficiency of the prawn trawl means that the impact of prawn trawls on most of the seabed biota is limited but this will be related to the frequency of trawling

SPATIAL DISTRIBUTION

- The seabed fauna had an extremely patchy distribution

SEASONAL VARIATION

- There were no apparent seasonal changes in the biomass of individual animal taxa but this may be affected by inadequate sampling given the patchy distribution.
- Seasonal changes were found in the plant groups. Seagrasses – mainly *Halophila spinulosa* - were more abundant in summer than winter whereas the algal groups were more abundant in winter
- There were large variations in the biomass of components of the seabed biota that were not related to seasons
- When the biota was aggregated there was a seasonal signal (Chapter 6)

The overall picture is of a highly dynamic biota that is continually changing but not simply following a seasonal pattern

SIZE SPECTRUM

- Large changes in size composition were found between 6-monthly samplings but with few exceptions, these could not be explained
- Recruitment of juveniles was found in a few species but this recruitment did not occur on an annual basis

5.3.1 Introduction

In common with most shallow tropical marine habitats, the seabed of the Gulf of Carpentaria has a rich biota. Our knowledge of the biota comes from two main sources. Long et al. (1995) made an extensive survey of the seabed biota of the Gulf of Carpentaria using a 3 m wide beam trawl or Church dredge towed for approximately 1500 m at a 107 stations across the entire Gulf of Carpentaria. Their data – the first of its kind in the NPF, provided a great deal of useful information about the fauna. The second source of information is the studies of bycatch from prawn trawling (see review in Stobutzki et al. 2000). During this study bycatch was collected from the 10 major commercial regions in the NPF and Torres Strait using prawn trawls. These two sampling methods are not directly comparable. Poiner et al. (1998) showed that prawn trawls were selective and did not collect representative samples of the seabed biota. They also showed that a dredge or epi-benthic sled caught a wider range of seabed biota. In 2005, CSIRO undertook a second major survey of the Gulf of Carpentaria (see Appendix B – Related Research). This involved 124 epi-benthic sled samples in three regions. Sampling sites were stratified according to historical trawl effort. One objective of that study was to establish whether there was a relationship between effort and seabed fauna. The data from this survey had not been analysed when the present project was being written up and so was not available for comparison. There are problems in comparing the Long (1995) and Stobutzki (2000) data sets with that collected in the present study. The main ones are the large distances between samples in the published data and the lack of seasonal data. The Gulf of Carpentaria is a large, remote area and the logistic difficulties and the cost of sampling are daunting. This has limited the sampling that can be carried out. In the present study we had a unique opportunity to collect samples more intensively than previously. We were able to collect multiple samples from small areas and to repeat this sampling over four successive seasons. The compromise was that our study was limited to two areas – east and west of Mornington. We cannot claim that our study is representative of the Gulf as a whole but we suggest that the trends we observed are probably applicable more generally.

As part of our experimental design, our study included a total of 126 control epi-benthic sled samples taken from sites that had not been subjected to commercial prawn trawling for at least eight years. These samples were collected from either outside the experimentally trawled lanes or from the lanes before trawling took place. They therefore represent a suite of samples from seabed unaffected by trawling for many years. In addition we made a large number of trawls in the study areas to the east and west of Mornington Island during the impact experiment. This large collection of samples has provided a rare opportunity to describe the seabed biota of part of the Gulf of Carpentaria not sampled by the surveys by either Long et al. (1995) or Bustamante (op. cit.). We have used this data here to describe the seabed fauna of part of the Northern Prawn Fishery, its size composition and its seasonal variability.

Although the Gulf of Carpentaria is in the tropics, it experiences distinct seasonal changes. Nearly all the rain falls in the wet season (November to April). At this time water temperatures are around 30^{o}C. In the dry season there is virtually no rainfall and water temperatures fall to around 22 to 24^{o}C. These strong seasonal changes might have affects on the seabed biota and could affect interpretations of recovery rates. The control samples that we collected at six monthly intervals as part of the recovery monitoring enable us to determine whether significant seasonal changes did occur. This information will be useful in future studies in the region where the cost of sampling is so high that it is not usually feasible to sample on a seasonal basis except in small areas but the possibility of seasonal variations could affect interpretations of sampling.

5.3.2 Methods

5.3.2.1 Collection and processing of samples

The fauna of the two study areas was collected by means of a prawn trawl during the impact experiment (see Chapter 6.1) and by means of an epi-benthic sled during the pre-and post-impact phase of the experiment. The trawl consisted of two standard 12 fathom commercial tiger prawn nets each with a spread of 17.6 m. The trawl was towed for a distance of one kilometre at a speed of 3 to 3.5 knots.

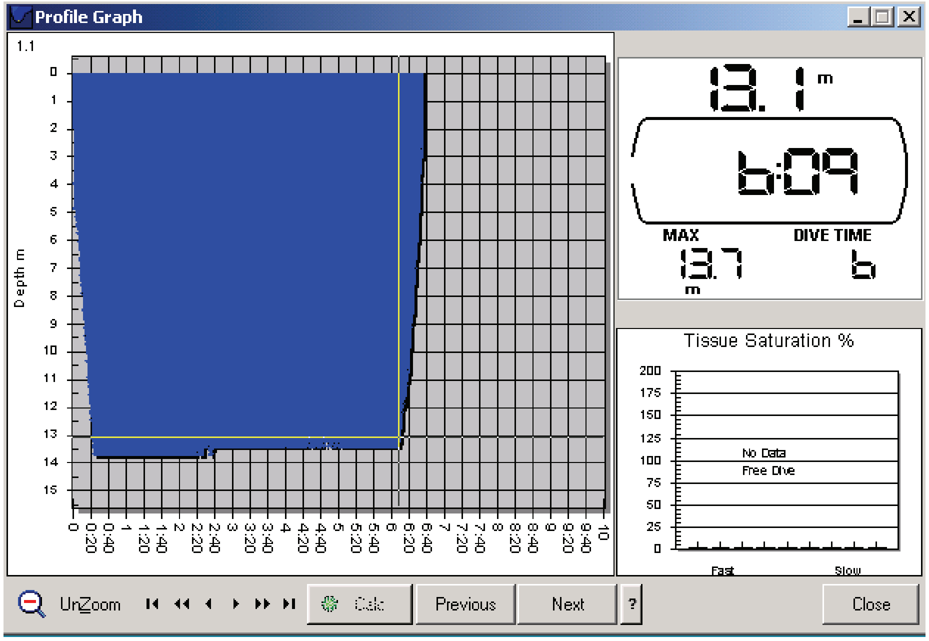
We used a scaled down Church epi-benthic sled made of galvanized steel and weighing 250 kg. The sled was 1.5 m wide with a vertical opening of 500 mm and a length of 1 m. The sides were solid steel plate with top and bottom panels of 20 mm square steel mesh (Figure 5.3-1).

Figure 5.3-1: Epi-benthic sled used for sampling seabed fauna

The sled was fitted with bag net made of heavy twine with a 10 mm square opening. The one meter long skids were 150 mm broad and rounded in the front to assist in preventing the sled from sinking into the substratum so that we sampled the animals living on the surface of the seabed rather than digging up the substrate. This is the key difference between an epi-benthic sled and a dredge. A heavy bar at the base of the front was set an angle of 30^o to lift seabed fauna into the sled. The sled was linked to a trawl wire by a chain bridle (13 mm links). We towed the sled over the stern at a speed of around 1 m/sec for 4 minutes so it covered a distance of about 250m. We designed the sled so that it would still sample if upside down. For example the skids ran right around the front from bottom to top and the angled bar at the front and the steel mesh behind the bar was duplicated on the top of the opening. However, we did not have a single case of the dredge turning over in several hundred deployments.

It was important to know accurately what distance the epi-benthic sled was towed along the seabed in order to standardise the catches. We did this by measuring the time the sled spent on the seabed each time it was towed and combining this with the speed of the trawler as measured by the GPS system. The time the sled spent on the seabed was measured using a Suunto Model D3 dive logger. The dive logger was put into a protective housing attached to the epi-benthic sled frame and set to record depth (to an accuracy of 0.3 m) at one second intervals. Recording began automatically when the logger was immersed to 1.2 m.

Time-depth data from the logger was downloaded onto a computer using software supplied by Suunto. We exported this data into SAS and wrote a program to identify the times when the epi-benthic sled reached and left the seabed. The data was then archived in an Oracle database. An example of a time-depth record obtained when testing the system is given in Figure 5.3-2.



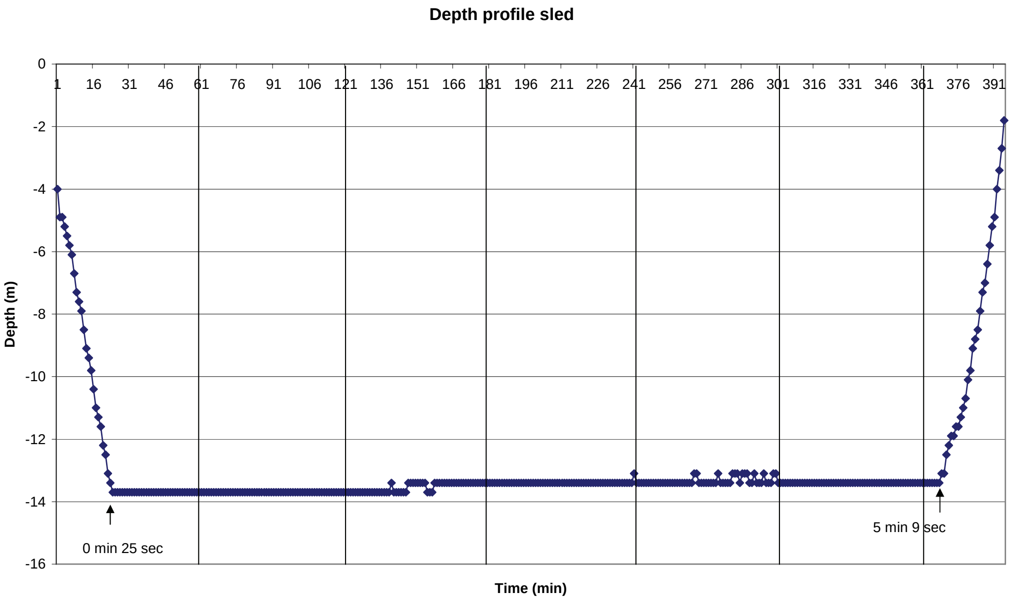


Figure 5.3-2: Time depth record for the epi-benthic sled

The upper half of Figure 5.3-2 shows the display using the software supplied by Suunto. The depth at any chosen time is given digitally on the top right. The lower figure shows a printout of the same data after exporting to an Excel file. The sled reached the seabed 25 sec after leaving the surface and left the seabed 4 min 44 sec later. Because the timer in the Suunto was synchronised with the GPS system, we could calculate the exact distance the sled travelled on the seabed and use this to standardise the catch rates of the biota. The catch was emptied onto a sorting table (Figure 5.3-3).

Figure 5.3-3: Mesh tray used for preliminary sorting of epi-benthic sled samples at sea.

The sorting tray had three layers of mesh each 1000 × 900 mm fitted into removable trays with side walls 125 mm high. The uppermost tray had a heavy grid of 90 mm square mesh, the middle was of 50 mm mesh and the lowest was of 10 mm mesh. The catch, including mud was washed on the mesh using a deck hose and any lumps were broken by hand. Animals retained on the meshes were put into labelled plastic bags for analysis. We kept the entire epi-benthic sled catch for analysis except for large sponges and large animals, there was no sub-sampling. Sponges were weighed, photographed and a small piece of tissue was taken for identification and they were then dumped away from the study area (Figure 5.3-4). Other large animals were also identified, weighed, photographed and put back into the sea (Figure 5.3-5).

Figure 5.3-4: An example of a large sponge caught in the prawn trawl. Tissue samples were taken from sponges for later identification

Figure 5.3-5: Large animals caught by the sled (gastropod 1.1 kg, asteroid 2.85 kg)

Samples were frozen at sea immediately after collection and kept frozen until they were sorted at the Cleveland Marine Laboratories. A summary of the samples available for analysis is given in Table 5.3-1.

Table 5.3-1: Biological samples used for analyses. Half of the samples are from west of Mornington Island and half from east of the island

Date	Trawl samples	Epibenthic sled samples
March 2003	12 initial trawls from impact experiments	72 control and pre-impact samples
August 2003	0	18 post trawling controls
March 2004	0	18 post trawling controls
August 2004	0	18 post trawling controls

The samples were sorted into taxonomic groups. We had originally planned to identify material to Family level but decided to improve on this where feasible given limitations on time and availability of taxonomic texts and specialists. The level of identification used is shown in Table 5.3-2

Table 5.3-2: Level of identification used for epi-benthic sled and trawl samples as well as the method of measurement used for that taxon. Weights are of wet animals.

Phylum/taxon	Level of identification	Measurement
Porifera	Family minimum but many to genus and species	Whole animal photographed, weighed and sub sampled at sea
Coelenterata		
Anthozoa	Family minimum, some to genus and species	Weight
Hydrozoa	Class	Length and weight
Alcyonacea	Family	Weight
Pennatulacea	Family minimum, some to genus	Length and weight
Gorgonacea	Genus and species	Weight (often fragmented)
Polychaeta	Habit (e.g. tube dwelling or free living), some to genus and species	Length and weight
Crustacea	Malacostraca to family, genus and species, others to infraorder	Length/width and weight
Mollusca		
Bivalvia	Family minimum, most to genus, some to species	Length and weight
Gastropoda	Family minimum, most to genus, some to species	Length and weight
Cephalopoda	Family minimum, most to genus and species	Length and weight
Echinodermata		
Asteroidea	Family minimum, many to genus, a few to species	Length and weight
Echinoidea	Family	Length and weight
Holothuroidea	Family minimum, a few to genus and species	Length and weight
Ophiuroidea	Class	Length and weight
Crinoidea	Class	Weight
Bryozoa	Class except for a few	Weight of all fragments
Ascidiacea	Phylum except for a few	Weight, length on some
Fish	Species except for a few rare genera	Standard length and weight
Algae	Genus and species	Weight
Seagrasses	Genus and species	Weight

Animals that could not be identified in the sorting process were assigned a code number pending examination by specialists. In the field, every trawl or epi-benthic sample was given a unique Operation Number (OPNO). This OPNO was used in the provisional identification and tracking of animals which could not be identified without further reference to a specialist. Thus Crinoid OPNO

57b refers to the second unidentified crinoid from Operation Number 57. This biases analyses in which the number of taxa is a component of the analyses because there are more taxa recorded in cases where identification is difficult – for example crinoids and ophiuroids. It does not affect analyses based on total numbers of individuals or weight of taxa recorded at the family or higher level.

The main taxonomic texts used in identification are given below in the References. We were assisted in identifications by specialists from the Queensland Museum. We compiled a specimen and photographic reference collection of invertebrates in order to speed up identification. The specimen collection has been archived at the Cleveland Marine Laboratories. Specimens were photographed by means of a Fuji Finepix S2 Pro 6.2 mega pixel digital camera fitted with a Nikon AF Micro Nikkor 105 mm lens and mounted on a copying stand with incandescent lights. The camera was linked to a computer running Fuji's Camera Shooting software package that allowed photographs to be saved directly to file. Photographs were enhanced if necessary using Adobe Photoshop and names or coding added. These photographs will be of great assistance in future projects in northern Australia. Examples of the fauna are shown in Figure 5.3-6.

Wherever possible we measured each specimen – length and or wet weight (Table 5.3-2). The numbers of each taxon were also recorded. Some taxa could not be measured or counted – for example fragments of animals or colonial forms such as Ascidiacea. Some species could readily be identified from the reference literature on the basis of their distinctive morphology. Those we could not identify have been sent to the Queensland Museum for specialist analysis.

Records were entered into an Oracle database using an Access form front end. Error checking consisted of range checks and validation routines applied through the forms and a system of double-entry. The data was entered twice by separate operators and the tables compared to check for discrepancies. Once the errors were fixed the corrected version of the data was copied into final versions of the tables which were used in the analyses. Details on the storage of the data are given in Appendix F at the end of the Report. A total of 21,152 specimens were identified (Table 5.3-3).

Table 5.3-3: Numbers of specimens identified from each sample set

Sampling period	Sampling device	Specimens identified
Before trawling (summer 2003)	Epi-benthic sled	2368
Trawl impact (summer 2003)	Prawn trawl	6976
After trawl impact (summer 2003)	Epi-benthic sled	3165
6 months after trawl impact (winter 2003)	Epi-benthic sled	3323
12 months after trawl impact (summer 2004)	Epi-benthic sled	3473
18 months after trawl impact (winter 2004)	Epi-benthic sled	1847

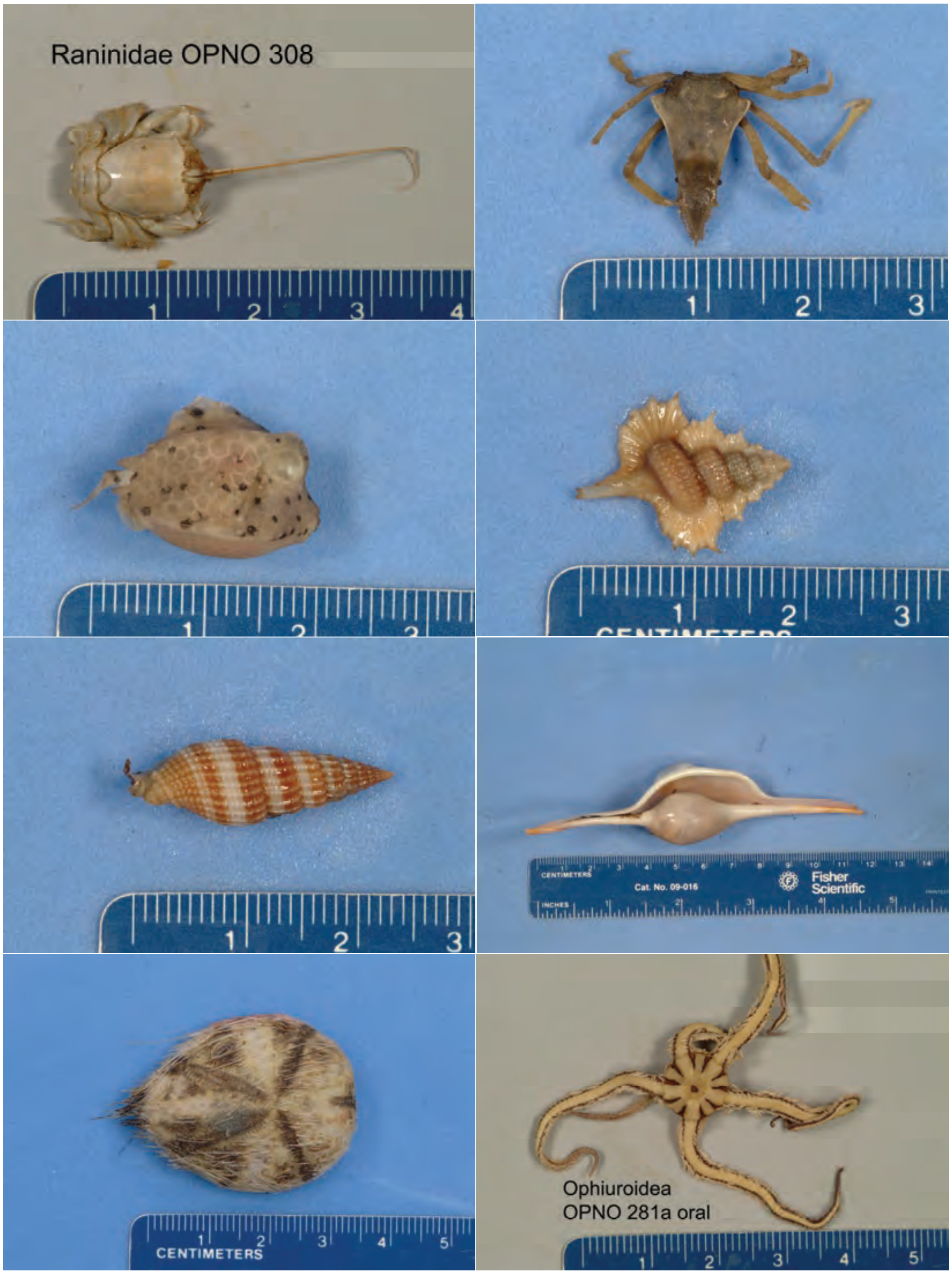


Figure 5.3-6: Examples of animals in the reference collection. Final photographs were labelled.

5.3.2.2 **Composition of the biota**

We caught a total of 43 778 individuals, 34 880 by the sled and 8898 by the trawl and identified 950 taxa. The physical conditions to the east and west of Mornington Islands were quite different (see Chapter 5.2) and we have presented data on the fauna for both regions. In view of the greater efficiency of the epi-benthic sled compared to the prawn trawl (see below), we used sled samples for to characterise the benthos. We limited the analysis to epi-benthic sled samples collected before trawling from all plots and locations and immediately after trawling from the control plots. We did not use information from sled hauls made on the experimental plots after trawling because the catches would presumably have been influenced by trawling.

We compared the benthic assemblages from east and west Mornington using a combination of univariate and multivariate techniques. For the comparison of catch rates of broad groups of biota, catch weights of all taxa were summed by taxonomic Class and density expressed as g/ha. For the multivariate analyses, the catches of individual taxa were standardised using the swept area of each sled tow and expressed as a density (g/ha). A sample/taxon matrix was created using the density data and transformed using a 4th root transformation. This transformation is suitable for highly skewed data and avoids giving undue weighting to the more common taxa. For the cluster, MDS and ANOSIM analyses this data was then converted into a Bray-Curtis dissimilarity matrix using the PRIMER (Clarke and Warwick 2001) computer package.

The Bray-Curtis dissimilarity between species *i* and *l* across *j* samples is:

$$S'_{il} = 100\left\{\frac{\sum_{j=1}^{n}\left|y_{ij} - y_{lj}\right|}{\sum_{j=1}^{n}\left(y_{ij} - y_{lj}\right)}\right\}$$

The MDS plots provide a visual representation of the dissimilarities species assemblages found at the two regions examined in this study. The species assemblages are presented on a two-dimensional plot such that the matrix of Euclidean distances among them approximates as closely as possible some function of the Bray-Curtis dissimilarity matrix. The measure used to indicate the goodness-of-fit of an MDS to the original matrix of dissimilarities is termed *stress*.

$$stress = \sqrt{\sum_j \sum_k \left(d_{jk} - \hat{d}_{jk}\right)^2 \Big/ \sum_j \sum_k d_{jk}^{\,2}}$$

where $\hat{d}_{jk}$ is the distance predicted from the fitted regression line corresponding to dissimilarity δ_{jk}. A large value for *stress* indicates a high degree of scatter in the plot and may be thought of as a measure of the difficulty involved in compressing all the sample relationships into 2 dimensional space (Clarke and Warwick 2001). The rough rule of thumb regarding the interpretation of stress values is as follows:
Stress <0.5 – an excellent representation of the relationships between the data points.
Stress < 0.1 – corresponds to a good ordination with no real prospect of misleading interpretation.
Stress <0.2 – means a potentially useful 2 dimensional representation.
Stress >0.3 – indicates the points on the plot are close to being arbitrarily placed on the plot. (Clarke and Warwick 2001).

We tested for the statistical differences between the assemblages east and west of Mornington using the ANOSIM (analysis of similarities) test described by Clarke and Green (1988). This test is based on a simple non-parametric permutation procedure applied to the rank similarity matrix underlying the ordination of the samples. The statistic calculated by the test is *R*:

$$R = \frac{\left(\bar{r}_b - \bar{r}_w\right)}{1/2\,M}$$

where $\bar{r}_b$ is the average of all rank similarities arising from all pairs of replicates between different the different treatment groups (in this case east and west Mornington) and $\bar{r}_w$ is the average of all the rank similarities among of all pairs of replicates within treatment groups and $M = n(n - 1)/2$ where *n* is the total number of samples. If the null hypothesis H_0: “There is no significant difference between the groups” is true, then there will be little change in the average value of R if the labels identifying the replicate samples are arbitrarily rearranged. This forms the basis for the permutation test of H_0; the labels are rearranged arbitrarily a large number of times and R is calculated following each relabelling. This generates a null distribution of R and the significance level for R is calculated by comparing the observed value of R to its permutation distribution. The R statistic generally falls between 0 and 1 and provides a measure of the degree of separation between the groups. Where $R = 0$, the groups are impossible to tell apart, $R<0.25$ indicates the groups are barely distinguishable, $R>0.5$ the groups are separable, but overlapping, if $R>0.75$ then the groups are well separated and if $R=1$, then all within group samples are more similar to each other than they are to any of the between group samples.

5.3.2.3 Comparison between the trawl and the epi-benthic sled

The trawl data used was from the first impact experiment carried out in February 2003 and in each case we only used the catch data from the first trawl of each series because the catches from subsequent trawls from the same site would be biased. Thus we had 6 trawl samples and 27 epi-benthic sled samples from each study area. Catches from the trawl and sled were grouped at the taxonomic Class level, standardised by the swept area and expressed as density (g/ha). The efficiency of the trawl compared to the sled was estimated by dividing the trawl density by that of the sled and multiplying by 100.

5.3.2.4 Spatial Distribution of Seabed Biota

Prior to this project, benthic sampling carried out in the Gulf of Carpentaria has been in the form of isolated samples, typically many kilometres apart. There was no information on finer scale distribution patterns. In the second trawl experiment (described in detail in Chapter 6.3) we collected 30 epi-benthic sled samples prior to trawling. Fifteen of these came from inside the 1000 × 100 m plot and 15 from just outside of it. The position of each sample was accurately known because the sled carried an acoustic tracking beacon and we could reference its position relative to that of the trawler which was using a high accuracy differential GPS. The planned position of the sled samples is shown in Figure 5.3-7.

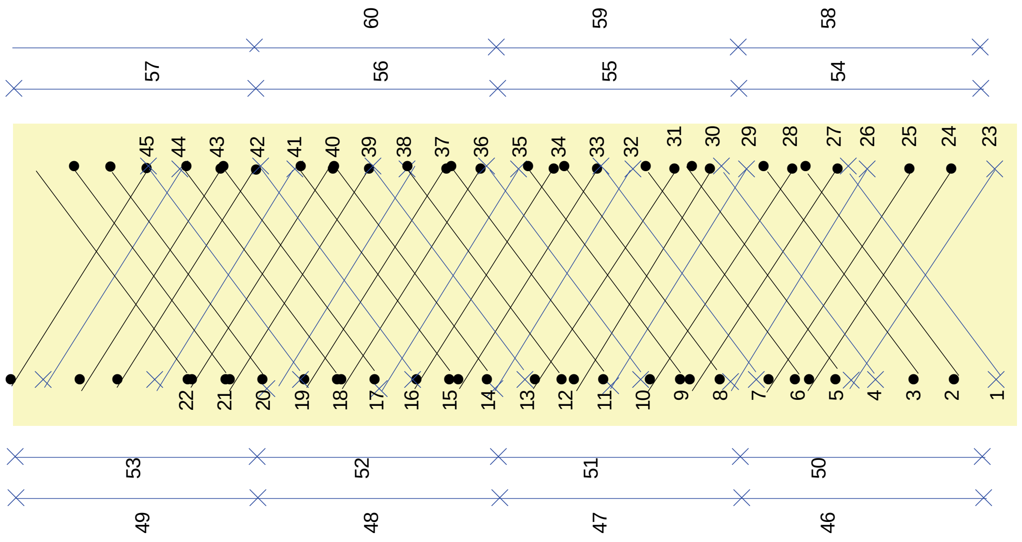


Figure 5.3-7: Planned tracks (blue) for epi-benthic sled samples to be collected prior to the second trawl impact experiment. The shaded area is 1000 m long and 100 m wide.

The relatively high density of these dredge samples gave us an opportunity to examine the fine-scale spatial distribution of the benthic community in this small area to the east of Mornington Island. The dredge tracks as recorded using the dive logger described in the previous section were between 97 and 269 m long.

The dredge is an integrating sampling device in that it collects specimens from along the full extent of its path and we have no way of identifying at which point along the path any particular individual specimen was captured. We used the mid-point of each dredge track as an approximation of the location of each dredge sample and calculated the density (g/ha) of each Class of biota in the catch. To illustrate the distribution of the biota across the study area, we interpolated the surface between the sampling points using inverse distance weighting. This is the simplest interpolation technique and the value for each interpolated point is derived from a weighted average of the observed values within a defined neighbourhood, with the weights decreasing with increasing distance from the interpolated point. In our case we defined the neighbourhood as the 12 nearest observed values; we used a cell size of 10 m and a boundary which was set to be 20 m outside the extent of the dredge tracks.

5.3.2.5 **Size Spectra**

During the sorting of the samples, each individual specimen was identified, weighed and its length measured. For each taxon, we agreed on a consistent characteristic to measure and record as length e.g. carapace length for decapod Crustacea. The data consists of lengths and weights of twenty-seven taxa sampled in the Mornington region by epi-benthic sled. Many of the taxa were known only at the genus level with an OPNO number indicating a probable separate species. We had chosen the 30 most abundant taxa but prawns, sponges and one species of bug were removed from the dataset due to a limited number of observations. The taxa are listed in Table 5.3-4 along with their common name and the size spectra are given in Appendix G.

Table 5.3-4: Listing of taxa from the NPF effects of trawling database used to examine the seasonal and inter-annual variation in size spectra.

Species Name/Code	Group		Species Name/Code	Group
Hydroid OPNO 184	Hydroid		*Stellaster sp OPNO 118*	Star fish
Tubeworm OPNO 006	Tubeworm		*Ophiuroidea OPNO 118*	Brittle star
Melaxinaea vitrea	Bivalve		*Ophiuroidea OPNO 171b*	Brittle star
Malleus malleus	Bivalve		*Ophiuroidea OPNO 171c*	Brittle star
Amusium pleuronectes	Bivalve		*Temnopleuridae OPNO 142*	Urchin
Annachlamys flabellate	Bivalve		*Temnopleuridae OPNO 203a*	Urchin
Spondylidae OPNO 193	Bivalve		*Temnopleuridae OPNO 203b*	Urchin
Cardiidae OPNO 151	Bivalve		*Laganidae OPNO 142a*	Urchin
Strombus sp OPNO 142	Gastropod		*Shizasteridae OPNO 224*	Star fish
Chicoreus sp OPNO 184	Gastropod		*Brissidae OPNO 006*	Urchin
Cerithiidae OPNO 142	Gastropod		*Matuta interms*	Crab
Smaragdinellidae OPNO 118	Nudibranch		*Matuta granulosa*	Crab
Ludiidae OPNO 006	Starfish		*Portunus pelagicus*	Crab
Astropectinidae OPNO 142	Starfish		*Portunus rubromarginatus*	Crab

Specimens were collected using an epi-benthic sled at four different time periods: before trawling, immediately after trawling, six months after trawling and twelve months after trawling. These periods correspond to the seasons as follows: Summer 2003 (Before and Immediately After), winter 2003 (6 months after), summer 2004 (12 months after) and winter 2004 (18 months after). The data are presented for three locations for the area west of Mornington (Locations 3, 5 and 6) and for three for the area east of Mornington (9, 10 and 12) and the points in the figures are colour coded accordingly.

5.3.2.6 Seasonal Variation in Seabed Biota

The trawling experiment was carried out to the east of Mornington Island and to the west of the Island. In each area there were three experimental plots. An experimental plot consisted of three lanes – one was trawled 20 times, one was trawled 4 times and one was a control. We collected three epi-benthic samples from each lane before the sampling. After the trawl impact, we collected a further three control sled samples from outside each trawled area. The results from the before and after control samples have been amalgamated to give a single Time Zero value made up of 54 samples. The experimental areas were visited at six month intervals for the following 18 months and on each occasion three control sled samples were collected from each plot. The sampling regime is shown in Table 5.3-5. Biota in the catch was weighed individually and we have summed the weights for the major groups and expressed the density of the catch as g/ha.

Table 5.3-5: Sampling regime using epi-benthic sled showing the number of control samples collected. The before and after control samples were amalgamated for the analysis of seasonal trends

Time	East Mornington	West Mornington
Zero – start of the experiment	3 control samples before impact from each of 6 experimental plots (20x and 4x trawl impact) plus 3 control plots (total of 27 samples) 3 control samples after impact from each control plot (total of 9 samples)	3 control samples before impact from each of 6 experimental plots (20x and 4x trawl impact) plus 3 control plots (total of 27 samples) 3 control samples after impact from each control plot (total of 9 samples)
6 months	3 control samples from 3 plots (9 samples)	3 control samples from 3 plots (9 samples)
12 months	3 control samples from 3 plots (9 samples)	3 control samples from 3 plots (9 samples)
18 months	3 control samples from 3 plots (9 samples)	3 control samples from 3 plots (9 samples)

As a simple measure of range, we calculated the ratio between the lowest biomass (mean of 9 samples) and the highest biomass.

5.3.3 Results

5.3.3.1 Composition of the biota

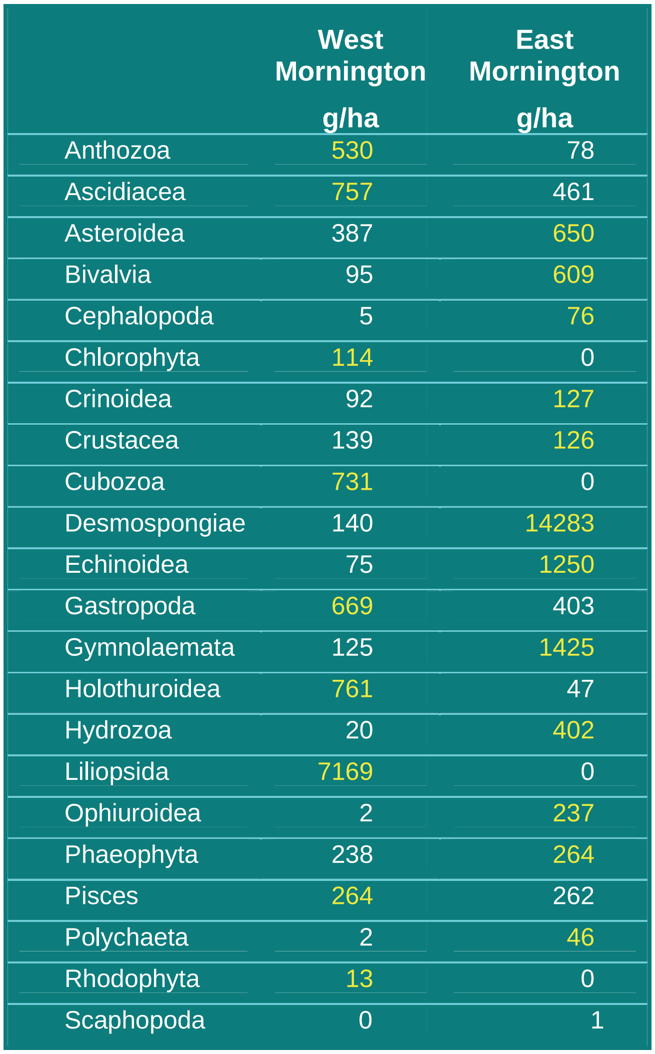
There were a total of 428 different taxa identified from the catches of the 'Before' sleds and the immediately 'After' sleds in the control lanes. The benthic community to the east of Mornington Island appeared to be slightly more diverse than that in the west (Table 5.3-6).

Table 5.3-6: Numbers of taxa collected from each location. Data based on the catches from the 'Before' sled hauls combined with those from the immediately 'After' sled hauls from the control lanes.

Region	West Mornington			East Mornington		
Location	3	5	6	9	10	12
Number of taxa	156	81	123	146	163	183

In terms of biomass per hectare, overall catches on the western side of Mornington were only about 60% of those found to the east of Mornington Island. When the taxa were grouped to Class level the Desmospongiae (sponges) were the most dominant in terms of catch rates (g/ha) and the catches to the east of Mornington Island were an order of magnitude greater than those caught in the west (Table 5.3-7).

Table 5.3-7: A comparison of the catch rates (g/ha) of the taxa (grouped to Class level) caught in the 'Before' sled hauls from all treatments and the 'After' sled hauls from the control lanes from east and west of Mornington Island. The dominant sample in each pair is highlighted in yellow.



	West Mornington g/ha	East Mornington g/ha
Anthozoa	530	78
Ascidiacea	757	461
Asteroidea	387	650
Bivalvia	95	609
Cephalopoda	5	76
Chlorophyta	114	0
Crinoidea	92	127
Crustacea	139	126
Cubozoa	731	0
Desmospongiae	140	14283
Echinoidea	75	1250
Gastropoda	669	403
Gymnolaemata	125	1425
Holothuroidea	761	47
Hydrozoa	20	402
Liliopsida	7169	0
Ophiuroidea	2	237
Phaeophyta	238	264
Pisces	264	262
Polychaeta	2	46
Rhodophyta	13	0
Scaphopoda	0	1

There was high diversity of large sponges in the study area to the east of Mornington Island, examples are shown
Figure 5.3-8.

Figure 5.3-8: Examples of sponges caught on study sites to east of Mornington Island

The diversity is not surprising. Hooper et al. (2002) reported there are at least 2324 species of Porifera in northern Australia. The taxonomic difficulties of this group is reflected by the fact that in a major review of the sponge fauna of the region these authors stated that over 70% of species could not be assigned to a known taxon. The southern and eastern Gulf of Carpentaria is estimated to have between 200 and 300 species of Porifera belonging to between 50 and 80 genera. Bryozoans (Gymnolaemata) and echinoids were the other dominant groups caught in the east. To the west of Mornington, sea grasses (Liliopsida), holothurians and ascidians were the most dominant groups in terms of catch rate (Table 5.3-7).

Cluster analysis (Figure 5.3-9) and multidimensional scaling (Figure 5.3-10) confirmed the clear difference between the benthic communities found to the east and west. Note from the cluster analysis in Fig. 4.3.9 that all sites from each area (east and west) cluster together and that the replicate sites from the western side of Mornington Island tend to be more similar to each other than those from the eastern side of Mornington. Also, in the west, the benthic assemblages at locations 3 and 6 are more closely related to each other than those at location 5. In the east, all samples from location 12 tended to group together, whereas those from locations 9 and 10 were interspersed, some being closer to those from location 12 than their replicates from locations 9 and 10 (Figure 5.3-10).

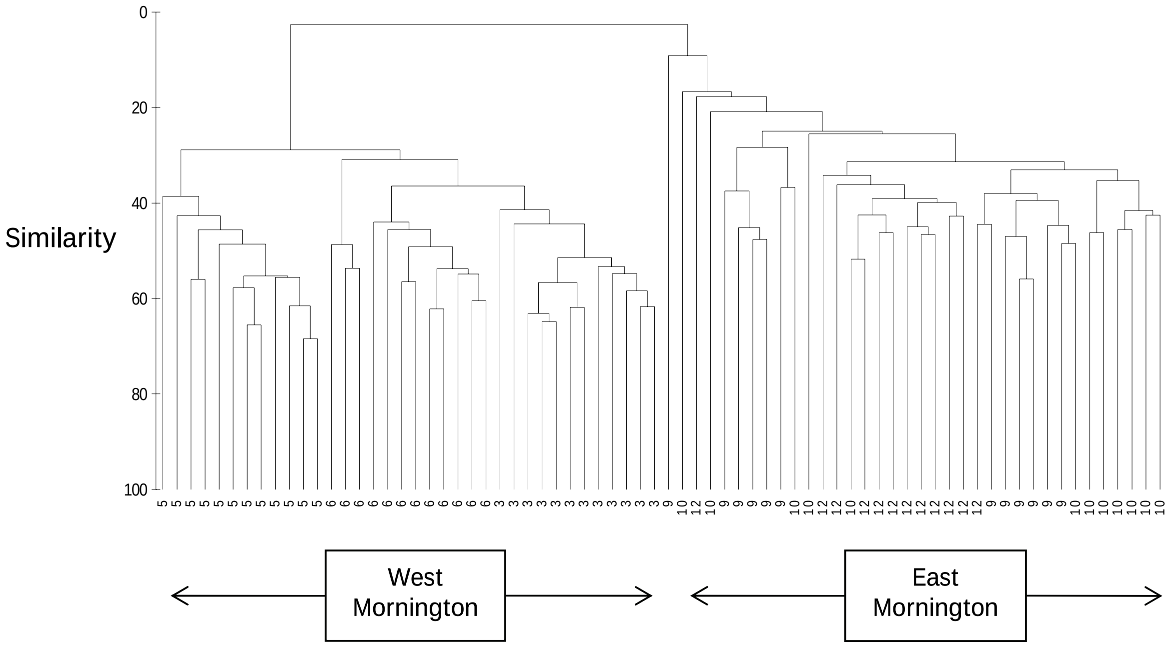


Figure 5.3-9: Dendrogram generated by the catch rates of biota captured in the epi-benthic sled (Bray-Curtis similarity of the square root of the catch rate [g/ha]). Data used in this analysis were all the 'Before' sled samples and the sled samples taken immediately after trawling on the Control lanes. The labels identify the location of each sample.

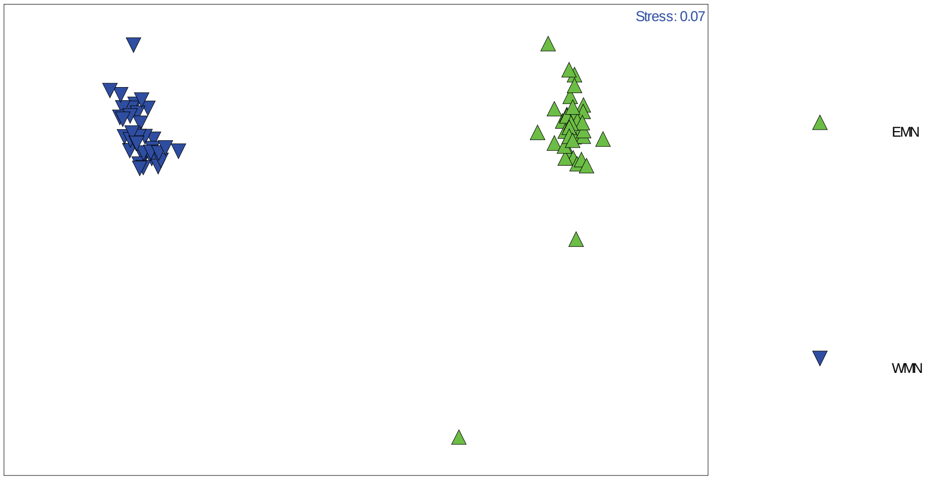


Figure 5.3-10: MDS (Bray-Curtis dissimilarity, fourth root transformation [g/ha]) generated by the catch rates of biota captured in the epi-benthic sled. Data used in this analysis were all the 'Before' samples and the samples taken immediately after trawling on the Control lanes. EMN = East Mornington, WMN = West Mornington.

An ANOSIM (Clarke and Green 1988) analysis of the Bray-Curtis dissimilarity matrix indicated there were significant differences between the benthic assemblages from the two areas (R = 0.99; p = 0.01). We used a SIMPER (Clarke 1993) analysis to characterise the taxa responsible for the differences between the assemblages from east and west of Mornington Island. This analysis computes the average dissimilarity between all pairs of samples between each area (east and west) and then breaks this average down into separate contributions from each separate taxon to the average dissimilarity. A measure of how consistently each taxon contributes to the average dissimilarity between the two areas is the standard deviation of the dissimilarity over all pairs of samples. If the average dissimilarity for a taxon is large and its standard deviation is small, then the ratio of these two (Diss/SD) will be large, indicating that this taxon not only contributes to the dissimilarity between the two areas, but that it does so consistently and is therefore a good discriminating species.

The average dissimilarity between the biota of experimental trawl sites to the east and west of Mornington Island is given in Table 5.3-8. Only the taxa contributing to 50% of the dissimilarity are shown. The taxa which comprise the bulk of the dissimilarity are, not surprisingly, those that are found in relatively high densities in one region, and are absent in the other e.g. *Halophila spinulosa*, Bryozoan OPNO 171b, Temnopleuridae OPNO 203a and *Malleus malleus* (Table 5.3-9). The taxa identified as best at discriminating the two regions are *Halophila spinulosa*, *Malleus malleus* and *Chicoreus* sp OPNO 184 (Table 5.3-9). It is interesting to note that the taxa that were more abundant in the west than the east were plants e.g. *Halophila spinulosa*, *H. ovalis* and *Caulerpa brachypus*. The other taxa that were more abundant in the west included the ascidian *Clavelina* sp. OPNO 142, the asteroid Astropectinidae OPNO 142, the holothurian *Stichopus horrens*, the crab *Matuta granulosa*, the gastropod *Strombus* sp OPNO 142 and the crab *Parthenope nodosus*

Table 5.3-8: Average dissimilarity Av. CR. = Average catch rate (g/ha); Av. Diss = Average Dissimilarity; Diss/SD = Average Dissimilarity/the Standard Deviation of the Dissimilarities; % Contrib = the percentage contribution of each taxon to the dissimilarity between the two assemblages; Cum. % = the cumulative percentage contribution of each taxon to the dissimilarity between the two assemblages.

Species	EMN Av. CR	WMN Av. CR	Av. Diss	Diss/ SD	Contrib %	Cum. %
Halophila spinulosa	0	13853.2	9.01	2.12	9.3	9.3
Bryozoan OPNO 171b	4812.3	0	3.04	0.65	3.1	12.4
Temnopleuridae OPNO 203a	2356.6	0	2.84	1.06	2.9	15.3
Malleus malleus	1409.5	0	2.64	1.81	2.7	18.0
Bryozoan OPNO 203	712.8	0.2	1.91	1.38	2.0	20.0
Hydroid OPNO 184	661.5	0.6	1.72	0.99	1.8	21.7
Stellaster sp OPNO 118	582.0	96.3	1.6	1.26	1.6	23.4
Spondylidae OPNO 193	601.2	6.4	1.58	1.12	1.6	25.0
Temnopleuridae OPNO 203b	598.7	0	1.55	1.05	1.6	26.6
Oceanapia sp.	2932.8	4.6	1.54	0.46	1.6	28.2
Halophila ovalis	0	285.3	1.52	1.26	1.6	29.7
Clavelina sp OPNO 142	0	926.4	1.51	0.76	1.6	31.3
Ircinia 1	10551.2	0	1.45	0.26	1.5	32.8
Astropectinidae OPNO 142	2.4	236.8	1.29	1.31	1.3	34.1
Ircinia 3	17064.9	0	1.26	0.17	1.3	35.4
Chicoreus sp OPNO 184	287.6	0	1.25	1.74	1.3	36.7
Annachlamys flabellata	394.1	0	1.23	0.97	1.3	37.9
Bryozoan OPNO 142b	237.2	154.7	1.17	0.41	1.2	39.1
Ophiuroidea OPNO 171c	244.8	0	1.09	1.37	1.1	40.3
Melaxinaea vitrea	388.1	0	1.07	0.96	1.1	41.4
Stichopus horrens	0	760.7	1.07	0.48	1.1	42.5
Ophiuroidea OPNO 006	201.7	2.4	1.07	1.45	1.1	43.6
Stellaster sp OPNO 006b	521.6	0	1.01	0.67	1.0	44.6
Stellaster sp OPNO 006a	499.3	83.0	0.93	0.48	1.0	45.6
Matuta granulosa	0	267.3	0.9	0.65	0.9	46.5
Halichondriidae 1	498.5	0	0.87	0.5	0.9	47.4
Strombus sp OPNO 142	67.8	190.1	0.86	0.94	0.9	48.3
Parthenope nodosus	44.8	180.0	0.81	0.98	0.8	49.1
Caulerpa brachypus	0	203.6	0.8	1.04	0.8	49.9
Brissidae OPNO 006	358.3	0	0.8	0.65	0.8	50.7

Table 5.3-9: Dominant area (west or east of Mornington Island) for 26 species of seabed animals

Class or Family	Species	Dominant area	Appendix G Fig reference
Hydrozoa	Hydroid OPNO 184	East	G.2-1
Polychaeta	Tubeworm OPNO 006	East	G.2-2
Asteroidea	Ludiidae OPNO 006	East	G.2-13
	Astropectinidae OPNO 142	West	G.2-14
Ophiuroidea	Ophiuroidea OPNO 171b	East	G.2-16
	Ophiuroidea OPNO 171c	East	G.2-17
	Ophiuroidea OPNO 006	East	G.2-18
Echinoidea	Brissidae OPNO 006	East	G.2-24
	Temnopleuridae OPNO 142	West	G.2-19
	Temnopleuridae OPNO 203a	East	G.2-20
	Temnopleuridae OPNO 203b	East	G.2-21
	Schizasteridae OPNO 224	East	G.2-23
	Laganidae OPNO 142a	East	G.2-22
Bivalvia	Malleus malleus	East	G.2-4
	Amusium pleuronectes	East	G.2-5
	Annachlamys flabellata	East	G.2-6
	Spondylidae OPNO 193	East	G.2-7
	Cardiidae OPNO 151	West	G.2-8
	Melaxinaea vitrea	East	G.2-3
Gastropoda	Strombus OPNO 142	West	G.2-9
	Chicoreus OPNO 184	East	G.2-10
	Cerithiidae OPNO 142	West	G.2-11
	Smaragdinellidae OPNO 151	West	G.2-12
Brachyura	Matuta inermis	West	G.2-25
	Portunus pelagicus	West	G.2-26
	Portunus rubromarginatus	West	G.2-28

More species were dominant in the east (17 species) than in the west (9 species).

5.3.3.2 Comparison between the catch from prawn trawls and the epi-benthic sled

We compared the catch efficiencies of the sled and trawl using the catches from all the control sled hauls done before trawling and the control sled hauls done immediately after trawling from all locations and the catch from the first trawl done on each 4 and 20 trawl treatment lanes. The two gear types differed markedly in their catches, both in terms of the diversity of taxa caught and the biomass of the various each of the major groups. Overall there were a total of 351 taxa identified; of these 329 were caught by the sled and 96 caught in the trawl. Only 22 of the taxa caught in the trawls were not also caught by the sled, but 255 of the sled-caught taxa were not caught by the trawls.

Table 5.3-10: Mean catch rates (g/ha) of the various classes of benthic flora and fauna caught on the 4 and 20 trawl treatment lanes from the 3 ‘Before’ epi-benthic sleds and the first trawl done on each lane. Data combined from east and west Mornington sites.

	Density (g/ha)		Percent efficiency of trawl relative to sled
	Epi-benthic sled	Trawl	
Anthozoa	145	10	7.0
Ascidiacea	1000	35	3.5
Asteroidea	552	59	10.7
Bivalvia	407	19	4.7
Cephalopoda	780	143	18.3
Chlorophyta	91	0	0.0
Crinoidea	249	48	19.2
Crustacea	146	179	122.7
Cubozoa	25926	0	0.0
Desmospongiae	10207	2255	22.1
Echinoidea	1003	46	4.6
Gastropoda	819	3	0.3
Gymnolaemata	685	1	0.2
Holothuroidea	1240	170	13.7
Hydrozoa	303	5	1.5
Liliopsida	7050	0	0.0
Ophiuroidea	222	4	1.7
Phaeophyta	342	0	0.0
Pisces	221	0	0.0
Polychaeta	37	28	77.7
Rhodophyta	9	0	0.0
Scaphopoda	10	0	0.0

The results of the comparison between the catch of the prawn trawl and the epi-benthic sled are given in Table 5.3-10. The results are expressed as percentage efficiency for the trawl based on the catch of the trawl as a percentage of the catch of the sled for the same taxon. We used data from only the first trawl of the series because depletion by successive trawls might bias the result. We expressed the result as the efficiency of the trawl relative to the epi-benthic sled.

The results show that for most groups, the trawl is not as efficient as the epi-benthic sled. The group with the highest trawl efficiency is the Crustacea. This is hardly surprising given that the trawl is designed to catch crustaceans and to minimize the catch of non-target species which form most of those listed in the table. This suggests that for benthos other than crustaceans, measurements of biomass density on based on prawn trawls are likely to be seriously under estimated.

These estimates compare well with those of Poiner et al. (1998) especially when we take into account that Poiner et al. (1998) worked in the GBR and they were using a large dredge and trawl net. Based on these results, we would expect to detect trawl impacts most readily on those groups which were caught with a high relative efficiency relative to the sled i.e. Crustacea, Cephalopoda (but not really relevant as they are highly mobile), Desmospongiae, Polychaeta, Holothuroidea, Crinoidea and Asteroidea. However, it is possible that some groups may be significantly impacted by trawling although not retained as part of the catch.

5.3.3.3 **Spatial Distribution of Seabed Biota**

The spatial distribution of all Classes of benthic biota in the study area was very patchy. Examples of four major groups are shown in Figure 5.3-11. The figure suggests that the biota in the centre and at the two ends of the plot was richer than in the two intermediate areas. If this patchiness is characteristic of the seabed biota of the Gulf of Carpentaria, it will affect the design of sampling studies of the biota. Such a patchy spatial distribution would affect not only the values obtained for individual taxa, it could also affect estimates of biodiversity. Replication of samples on some form of spatial pattern would be needed for accurate descriptions of the biota. Further small scale studies of seabed biota distribution are needed to obtain a broader picture of the true situation in the Gulf of Carpentaria.

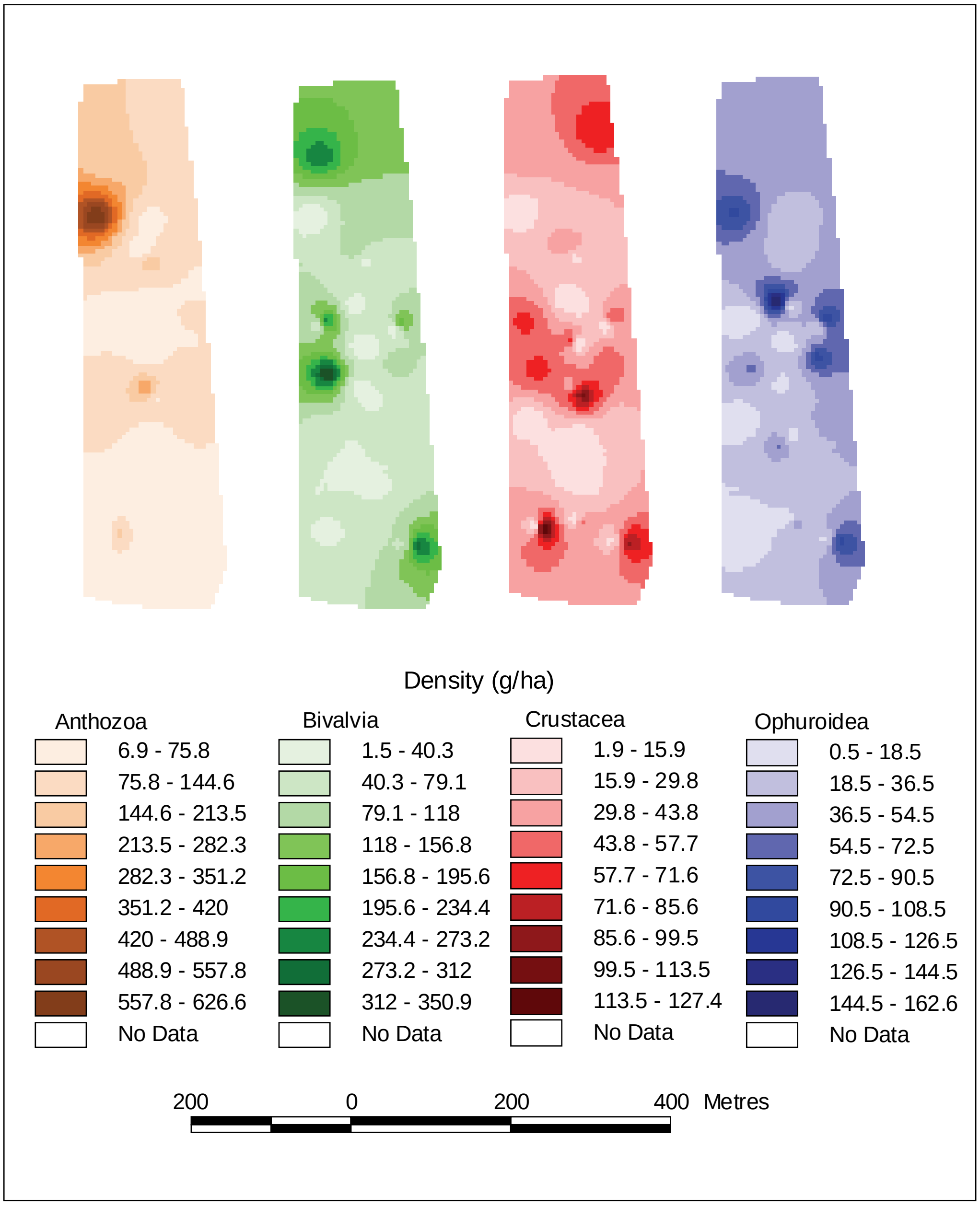


Figure 5.3-11: Interpolated surfaces of the fine-scale distribution of Anthozoa, Bivalvia, Crustacea and Ophiuroidea generated from 15 epi-benthic sled tows conducted before experimental trawling during February 2005 at a site to the east of Mornington Island.

5.3.3.4 **Size Spectra**

5.3.3.4.1 Linear relationship between length and weight

As expected, there appears to be strong linear relationships between the log of the length of each species and the log of their weight, indicating that as the weight of the species increases (on the log scale), the length increases also (on the log scale) (Appendix H).

5.3.3.4.2 Patterns in the size composition with time

The various species showed a wide range of size spectra with a few remaining fairly constant throughout the sampling period but many showed large shifts in size composition. There is generally no consistent pattern as illustrated by the figures and the following interpretations of some of the figures given in Appendix G:

Hydroid OPNO 184: Very few were found at west Mornington. At east Mornington, there was a large number and a wide size range present at location 12 at the start but the numbers at this location gradually dropped whereas the numbers increased at Location 10. This species appears to have a very patchy distribution given that the locations are quite close together.

Tubeworm OPNO 006: A wide range of sizes was caught throughout the study period although numbers tended to decline markedly during the winter (6 and 18 months after trawling).

Melaxinaea vitrea: A very wide size distribution was present at east Mornington throughout the study, although the smaller individuals were not present during the winter samplings (6 and 12 months after the beginning of the experiment).

Malleus malleus: Only found at east Mornington. There was a marked shift in size composition – smaller individuals were present at the start than in the following 18 months.

Annachlamys flabellate: Although present at the start, they were not captured after 6 months. After 12 months they reappeared in a wide size range but after another 6 months there were no more of the small individuals.

Cardiidae OPNO 151: A very large pulse of juveniles was found at 6 months but none were collected after a further 6 months. Very few were collected at 18 months.

Strombus OPNO 142: At west Mornington they were present in large numbers at the start and after 6 months but the numbers then declined and after 18 months only two individuals were caught. The large increase in numbers that occurred after 6 months was not seen at east Mornington where only one individual was caught at that time.

Cerithiidae OPNO 142: At west Mornington, the numbers increased from the start to 6 months when there were large numbers across a wide size range. The size range then diminished along with the numbers.

Ludiidae OPNO 006: The size range collected immediately after trawling was much larger than that before trawling due to an increase in the number of small animals. Very few of these smaller animals were picked up during any of the remaining samplings.

Astropecten OPNO 142: The size range at 6 and 18 months was larger than at the start or at 12 months. The smaller individuals were absent from the first and 12 months after samplings.

Stellaster OPNO 118: At west Mornington the size range at 6 months was larger than at the other sampling periods but this was not the case at east Mornington where the size range was at this time was smaller than at the start and at 12 months.

Ophiuroidea: Were caught predominantly at the east Mornington locations and have very broad size ranges, e.g. Ophiuroidea OPNO 171b, OPNO 171c and OPNO 006.

Temnopleuridae : Temnopleuridae OPNO 142 was only caught at west Mornington where the size range was nearly uniform across all sampling periods. Conversely, Temnopleuridae OPNO 203a and OPNO 203b were caught only at east Mornington and their size range changed quite markedly. In the case of the latter, smaller individuals made up most of the population at 12 and 18 months but were virtually absent at the start and after 6 months.

Schizasteridae OPNO 224: This species was not found either area at the start or after 18 months but was quite common at east Mornington after 6 and 18 months. The population showed a major shift in size between these two periods – mostly large animals at 6 months but mostly much smaller at 12 months.

One of the main reasons for recording sizes in the study was that studies in other parts of the world have shown that size selective fishing mortality results in mean size of individuals falling and there is a shift in species composition towards those with a small body size (review by Jennings and Kaiser 1998, Greenstreet and Rogers 2000). Nicholson and Jennings (2004) point out that the effects of fishing on size spectra are relatively slow, usually taking at least a decade to become evident. Our one off impact is not likely to produce an effect and there is no sign of one in our data. Nevertheless we considered it worthwhile collecting this data from an apparently unfished population as a reference that could be used in studies of the biota of heavily fished areas.

5.3.3.4.3 Juvenile Recruitment

The size composition of some species showed pulses of small individuals. We cannot be sure that this represents recruitment of juveniles although they appear to be (Table 5.3-11). In most cases this was not an annual event. In seven species the 'juveniles' appeared in one year but not in the following one. Astropectinidae OPNO 142 and Temnopleuridae OPNO 203a were the only two of the 26 species examined that showed an apparent seasonal 'recruitment'. Astropectinidae OPNO 142 'recruited' in winter whereas Temnopleuridae OPNO 203a 'recruited' in summer.

Table 5.3-11: Apparent juvenile recruitment patterns seen in the size analysis in Appendix G.

Class or Family	Species	'Recruitment' pattern
Bivalvia	Annachlamys flabellata	Large number of juveniles in east in summer 2004 but not in 2003 (Figure G.2-6)
	Cardiidae OPNO 151	Large numbers of juveniles in west in winter 2003 but not in 2004 (Figure G.2-8)
Asteroidea	Luidiidae OPNO 006	Juveniles present in summer 2003 in east but not in following summer (Figure G.2-13)
	Astropectinidae OPNO 142	Large number of juveniles in winter 2003 in the west with smaller numbers in winter 2004 (Figure G.2-14)
	Stellaster OPNO 118	Numerous juveniles in west in winter 2003 but not in following winter and none seen in the east (Figure G.2-15)
Echinoidea	Schizasteridae OPNO 224	In the east, adults were abundant in winter 2003 and the juveniles in summer 2004. They were virtually absent at other times and not collected in the west (Figure G.2-23)
	Temnopleuridae OPNO 203a	'Juveniles" appeared to be more abundant in the east in summer 2003 and 2004 than at other times (Figure G.2-20).
	Temnopleuridae OPNO 203b	Small animals common in summer and winter 2004 but not in 2003. (Figure G.2-21)
	Brissidae OPNO 006	Large numbers of small individuals present in summer 2004 but not in 2003 (Figure G.2-24)

5.3.4 Seasonal Variation in Seabed Biota

The results of the analyses are presented in Appendix G. The majority of species did not show major changes in biomass over the sampling period but there were quite large changes in population biomass in a few species (Table 5.3-12). Only one of these appears to be a seasonal change – the tubeworm OPNO 006.

Table 5.3-12: Population trends shown by some species in the epi-benthic sled samples. Figure numbers refer to Appendix G.

Class or Family	Species	Trend
Polychaeta	Tubeworm OPNO 006	Abundant in summer but only low numbers in winter samples (Figure G.2-2)
Gastropoda	Strombus OPNO 142	In the west, the biomass increased 6 months after the start but then declined markedly whereas in the east they were only found in appreciable numbers at the start (Figure G.2-9)
Echinodea	Laganidae OPNO 142a	In the east only present in summer (0 and 12 months). In the west they were present in all seasons (Figure G.2-22)
Gastropoda	Smaragdinellidae OPNO 151	Found mainly in the west. Numbers were high at the start but gradually declined in subsequent samplings (Figure G.2-12)

The changes are difficult to interpret. We do not understand why a sessile animal such as a tubeworm should show an apparent seasonal difference in biomass unless it is a very short lived species. A clear increase in biomass of the gastropod Strombus OPNO 142 in winter in the west was not mirrored in the east. Similarly, the echinoid Laganidae OPNO 142a was present only in summer in the east in both years whereas in the west it was present in all samplings.

The occurrence of a seasonal effect in the major taxa is shown in Table 5.3-13. The absence of seasonal variation in biomass in the major taxonomic groups was surprising since we know for example, that there are large seasonal variations in some groups such as the penaeids. In contrast to the animals, all three plant groups did show seasonal changes with higher biomasses for seagrasses in summer and in winter for the algae. Although we did not see seasonal trends in the biomass of seabed biota, most organisms showed quite a large variation in biomass between sampling. The algae for example varied between 76 kg/ha in winter 2003 and 15 g/ha in the following summer. Sponges showed a high ratio – over 40 times in both areas. The problem with sponges is that they are large and so the catch of a single sponge makes a very large difference in the mass. The variation in numbers is far less – 1.5× for East Mornington and 1.4× for West Mornington. Since sponges are static and relatively slow growing, this variation is probably a result of sampling and not of any biological significance.

Table 5.3-13: Seabed biota from east and west of Mornington Island showing in which area the taxon predominated, the presence or absence of a seasonal effect in abundance and the ratio in biomass between the smallest and largest

Taxon	*Dominant area*	*Seasonal Effect*	*Ratio from high to low*	
			East M	**West M**
Desmospongiae	East Mornington	No	42.0	43.8
Gastropoda	Varies	No	5.7	19.9
Asteroidea	Varies	No	2.3	4.6
Bivalves	East Mornington	No	5.3	2.8
Crustacea	Varies	No	2.9	2.1
Echinoidea	East Mornington	No	3.0	1.9
Gymnolaemata	Varies	No	5.9	40.8
Crinoidea	East Mornington	No	2.3	5.6
Holothuroidea	Varies	No	16.1	7.4
Anthozoa	Varies	No	9.5	3.3
Ascidiacea	West Mornington	No	6.1	5.0
Hydrozoa	Varies	No	5.9	24.7
Seagrasses	West Mornington	High in summer	3.1	8.9
Algae	West Mornington	High in winter	na	5091

There was a very large variation in the Gymnolaemata (Bryozoa) at West Mornington. As can be seen in Appendix G, Figure G.2-7, the biomass of Gymnolaemata was very low in the first four sampling periods – generally around 100 g/ha. In the last sampling period, the amount rose dramatically to over 5 kg/ha. This was a real event and can be seen in underwater photographs taken in the area at that time (Figure 5.3-12).

Figure 5.3-12: Seabed west of Mornington Island in August 2004 showing the large numbers of Gymnolaemata (Bryozoa) colonies present at that time

Some of the variations are very large. Appendix G Figure G.2-8 shows holothurians varying between 15 kg/ha to a nil catch 12 months later west of Mornington. Although not as large, similar changes in abundance occur in several other groups, e.g. gastropods, echinoids, anthozoans, crinoids and ascidians. Most of these variations were not statistically different. Figure 5.3-13 shows the biomass of penaeids at the two sites.

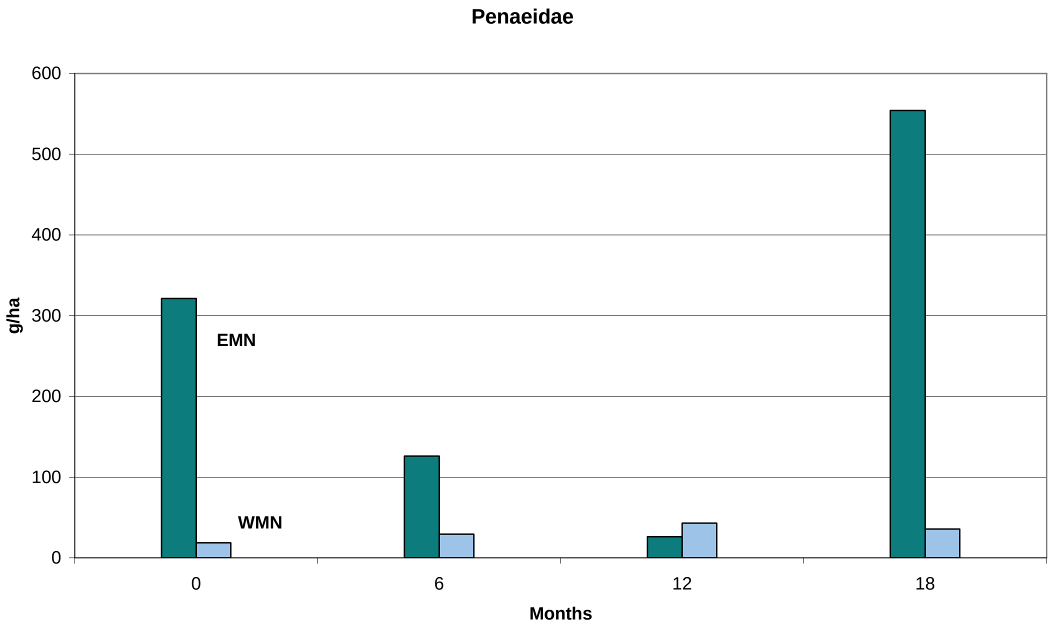


Figure 5.3-13: Biomass of penaeids at West and East Mornington sites at six month intervals starting from summer 2003.

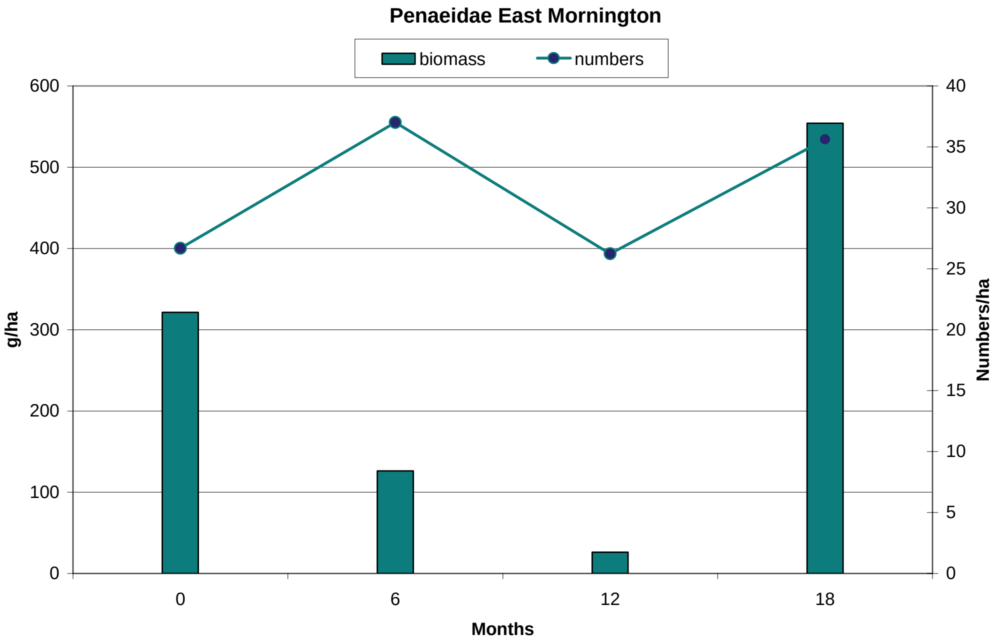


Figure 5.3-14: Biomass and numbers of penaeids captured on the site east of Mornington at six month intervals starting from summer 2003.

The biomass of penaeids showed little variation at West Mornington, but at the East Mornington site there was a very large range, from only 26 g/ha twelve months after the start of the experiment to 554 g/ha six months later. The numbers of penaeids per ha did not show the same large variation (Figure 5.3-14).

The variance of the data in most cases are also very large especially in the case of the biomass where the standard deviations exceed the mean in three out of the four cases (Table 5.3-14).

Table 5.3-14: Mean and standard deviation of numbers and biomass of penaeids caught per ha on site east of Mornington Island.

	Mean Numbers	SD	Mean Biomass	SD
Summer 2003	26.7	1.06	321.4	429.26
Winter 2003	37.0	32.94	136.1	143.22
Summer 2004	26.2	10.82	26.3	15.20
Winter 2004	35.6	17.98	554.3	1022.51

5.3.5 Discussion

5.3.5.1 Composition of the biota

The biota in the two study areas were dominated by Desmospongiae (Porifera) to the east and Liliopsida (seagrass) to the west of Mornington Island (Figure 5.3-15).

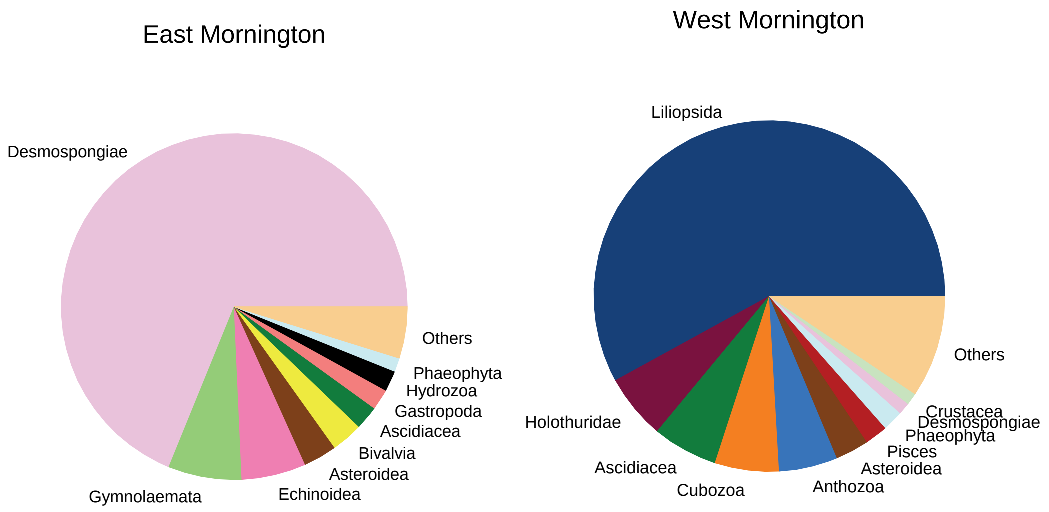


Figure 5.3-15: Composition of biota making up the total biomass by weight in the study areas to the east and west of Mornington Island. Data used in this plot were all the 'Before' sled samples and the sled samples taken immediately after trawling on the Control lanes.

Sponges in the family Desmospongiae comprised almost 70% of the biomass of the seabed east of Mornington Island. In general the numbers of taxa were greater in the east than the west and the total biomass in the east was approximately 1.7 × that in the west. These differences are reflected by the results of cluster analysis and by multidimensional scaling. It is interesting to note that the taxa which contribute most to the dissimilarity in benthic assemblages between the two regions are not only those that are found in relatively high densities in one region, but not the other; these discriminating taxa also tend to be found more consistently throughout a region. For example, both *Halophila spinulosa* (West Mornington) and Ircinia 1 (East Mornington) are only found in a single region, but *H. spinulosa* contributes 9.3% of the dissimilarity between the two regions whereas Ircinia 1 contributes only 1.5%. This apparent discrepancy can be explained by the fact that *H. spinulosa* was widely distributed across the seabed and found on 18 of a total of the 36 sled hauls made in the west, whereas the sponge Ircinia 1 was found on only 4 of the 36 hauls made in the east

We do not know the reason for these differences but the eastern site was deeper (28 to 30 m) compared to the western (8 to 16 m), had a higher seabed current stress and a higher content of mud

(13% compared to 3%). While the biomass of sponges in the east was larger, the numbers were in fact quite low. The mean numbers captured in the west were 24.1 per ha and 31.5 in the east. This is quite a sparse distribution with mean nearest neighbour distances of 20.3 m and 17.8 m respectively.

Many of the large sponges that we collected appeared not to have been attached to the seabed. This finding was reinforced by our collections before and after the cyclone in 2003. The weights of sponges caught in the 20 repeat trawls on site 9 are shown in Figure 5.3-16. Trawling commenced on this site on 11 March and 11 trawls were carried out. Although catches showed considerable variability, there was a general downward trend up to trawl number 11. Cyclone Craig then forced the ship to seek shelter because of high winds and dangerous seas. When trawling recommenced on the 14th March, catches of sponges were much higher and then tapered off again. Our impression is that the sponges caught on the 14th were not attached to the seabed and may have been rolled about during the high seas associated with the cyclone. This is not unexpected given the shallow water in the southern Gulf of Carpentaria. Sponges that were either dislodged by wave action caused by the cyclone or were already unattached could have been washed into the previously trawled lane resulting in a higher catch.

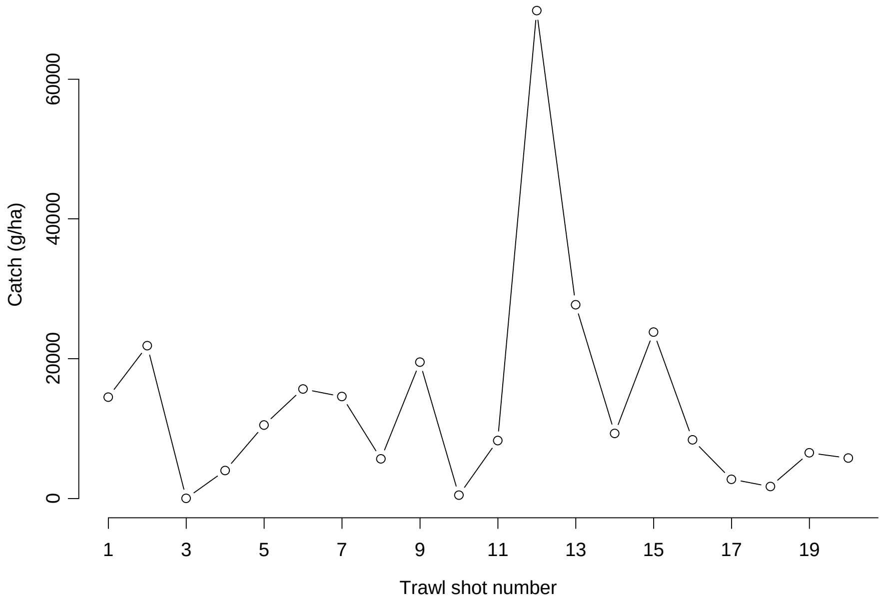


Figure 5.3-16: Weight of sponges caught in successive trawl shots on site 9, March 2003

Sponges that are rolled around on the seabed by wave action are very likely to be damaged. Cyclones are common in this area (Figure 5.3-17) and in shallow water the wave and current action may be able to dislodge sponges. This could mean that damage from cyclones may occur quite frequently in the southern Gulf of Carpentaria.

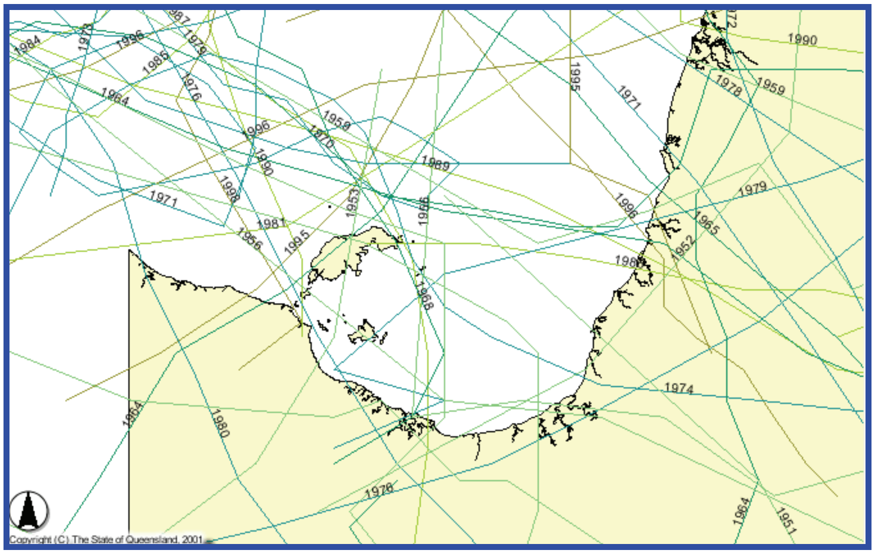


Figure 5.3-17: Tracks of cyclones in the south eastern Gulf of Carpentaria in last 50 years. Data from Queensland Fisheries Service CHRIS website (http://acaweb.dpi.qld.gov.au)

Sponges can cope with some physical damage. Fenner (1991) found that sponges responded rapidly to minor hurricane damage and recovery was largely complete after 21 months. Wilkinson and Cheshire (1988) found high doubling rates of less than 10 months for five species of young sponges but growth rates were slower for larger individuals. Kaiser M (1998) has suggested that trawling may be a minor part of disturbance in high energy shallow environments but increasingly becomes more important as trawling moves into deeper lower energy environments. Communities exposed to frequent storm damage may become adapted to cope, for example by being dominated by resistant species or fast growing species. Kirby-Smith and Ustach (1986) found surprisingly little damage to epifaunal communities at a depth of 30 m following a hurricane and they hypothesized that the community was pre-adapted to storm damage. We suspect that the large stalked sponges such as the one shown in the lower left corner in Figure **5.3-8** are less likely to able to survive being detached than the more robust compact species. It is possible however that all of the unattached sponges that we found after the cyclone would have eventually died. At this stage we cannot reasonably conclude that there is a population of living unattached sponges in the Gulf of Carpentaria.

5.3.5.2 **Differences between prawn trawl and epi-benthic sled catches**

The comparison between the catch by the prawn trawl and that of the epi-benthic sled showed that the trawl is far less efficient as a sampling device for the seabed biota. The only taxa that were captured with a high efficiency by the trawl were crustaceans, some sponges (Desmospongiae), polychaetes and cephalopods. Even these few taxa were not caught more efficiently by the trawl consistently between sites. Poiner et al. (1998) found a similar low efficiency for prawn trawls in a study of the inter-reef fauna of the Great Barrier Reef. They concluded that the catch of a prawn trawl gives a misleading impression of the nature of the benthos. We would agree with their assessment, despite the significant differences between their inter-reefal communities and the soft-bottom communities sampled in this project. They also showed that prawn trawls were selective with respect to the fish they caught. This selectivity of the prawn trawl needs to be taken into account when considering the impact of trawling because it means that not all components of the seabed biota are impacted equally. We do not know how efficient the epi-benthic sled is at catching seabed biota, although it is unlikely to be 100%. This means that the efficiency of a prawn trawl at removing seabed biota is even less than the figures we have presented. An additional consequence is that descriptions of the seabed biota are affected by the equipment used to collect samples. Wassenberg et al. (1997) for example showed that the description of the composition of fish communities was different when based on samples collected from a prawn or a fish trawl.

5.3.5.3 **Spatial Distribution**

Our study of a small area (1000 × 100 m) showed considerably patchiness in the seabed biota. This patchiness has not previously been reported for the Gulf of Carpentaria although it is a common feature of seabed biota. We do not know if patchiness is characteristic of the Gulf of Carpentaria but suspect this is the case. We know from studies in other areas, that even in areas where the substrate and the depth are uniform there may be significant patchiness in the seabed fauna. Parry et al. (2003) for example found patchiness in the distribution of seabed mega fauna in a shallow water bay with a homogeneous sub littoral muddy sand. The patchiness was not the same in succeeding years suggesting biogenic factors may have a major role in determining spatial distribution. The patchiness of the seabed biota needs to be considered when interpreting the results of seabed sampling. Single samples can give very different values for the seabed biota depending on where and when they are taken

5.3.5.4 **Seasonal Variations**

Our study lasted for 18 months which gave us data for two summers (wet seasons) and two winters (dry seasons). We could not detect strong seasonal changes in abundance in the animal groups in the two study areas. Although the major taxon groups did not show seasonal trends, they nearly all showed substantial variations in biomass between sampling periods. These variations could be an order of magnitude over 6 or 12 months. In some cases, animals that were relatively abundant at one time were not collected at all at another. The ratio between the high and low biomass records was between 2 and 8 for most groups but was as high as over 20 for a few. The bryozoans demonstrate this very clearly. They were a minor component of the biota on the three initial samplings but in August 2004 they had become the most obvious benthic organism.

Because of the patchy spatial distribution of the seabed biota, it is possible that some or even a large part of the variation that we found between sampling periods was due to sampling error. The patchy spatial distribution could lead to large differences between samples taken even quite close together at the same time. This variability may also be obscuring real seasonal signals. A formal statistical analysis that addresses these issues is presented in Chapter 7 – Recovery.

In contrast to the animals, all three plant groups showed a strong seasonal variation in biomass. This was evident in the seagrasses and algae. Kenyon et al. (1997) found seasonal variation in the biomass of the seagrass *Enhalus acoroides* at Groote Eylandt in the western Gulf of Carpentaria. The biomass was higher in summer due to more rapid shoot growth and the presence of longer leaves. Experimental studies (CSIRO, 1996) showed that the growth rate of *Enhalus acoroides* is directly related to temperature with the fastest rates occurring when the plants were kept at 30^{o}C.

5.3.5.5 **Size spectra**

We found quite large variations in the size composition of several taxa over the 18 months of the study. In a very few cases we could identify juvenile recruitment but this does not appear to be consistent from year to year. We could not explain most of the size changes.

5.3.5.6 **Comparison with previous studies in the Gulf of Carpentaria**

When comparing the seabed biota composition we need to take the different sampling gears into account. The two previous major surveys of the seabed biota of the Gulf of Carpentaria relied on different sampling equipment. Stobutzki et al. (2000) carried out prawn trawl bycatch surveys in the ten main trawl grounds of the NPF and Torres Strait in 1997/1998. Bycatch was collected from a total of 401 trawls each of 30 min duration. Long et al. (1995) reported on the results of a survey of the benthic fauna of the Gulf of Carpentaria in which 107 stations were sampled by means of a benthic dredge. The prawn trawl benthos and that collected across the GoC differed significantly to that collected around Mornington Island in the present study (Table 5.3-15). In both previous studies echinoderms (especially echinoids) dominated the benthic biomass with a relatively minor contribution from sponges (Table 5.3-15). This contrasts with the present study in which echinoderms only comprised 11% of the biomass and sponges (Porifera) dominated in the east and seagrasses (Liliopsida) dominated in the west.

Table 5.3-15: Prawn trawl bycatch composition (percentage biomass) from East and West Mornington and from the several sites in the NPF (Data from Stobutzki et al. 2000)

	Percent			
	Stobutzki	Long	East Mornington	West Mornington
Echinodermata	40	61	11	11
Crustacea	27	3	1	1
Porifera	11	14	69	1
Mollusca	8	4	5	6
Ascidiacea	0	2	2	6
Ctenophora	8	0	0	0
Cnidaria	6	0	0	0
Zoantharia	0	7	0	0
Liliopsida	0	0	0	58

Stobutzki et al. (2000) did not pursue the analysis of their invertebrate samples but they did analyse the teleost and elasmobranch bycatch. They found statistically significant differences between the various regions that were greater than the seasonal differences within a region.

We cannot interpret these differences other than to say they may reflect regional differences. The recent survey by Bustamante et al. (see Appendix B) may shed further light on the distribution of the seabed fauna of the Gulf but that survey was also restricted to particular areas because of the cost of carrying out more widespread surveys. At this stage we can only conclude that the seabed biota varies considerably regionally and that sponges, crustaceans and echinoids are the main components but their relative contribution is different from area to area.

5.3.6 Conclusion

A clear conclusion from this study is that the biota of the seabed of the Gulf of Carpentaria is complex, varies significantly from region to region, has marked small scale spatial variation in abundance and some components show rapid and unexplained changes in biomass. The results of different surveys show little consistency in the composition of the seabed fauna. Sponges, seagrasses, bryozoans and echinoids appear to be the four groups that occur in the largest amounts but their contribution varies between different areas and other groups such as gastropods can be present in very large numbers. These differences are not surprising since the NPF and the Gulf of Carpentaria are not uniform habitats.

Figure 5.3-18 shows that the mud content of the seabed of the Gulf of Carpentaria varies quite considerably with values ranging between 0% and nearly 100%. Many studies have shown that substrate type and especially percentage mud is a major factor in determining the composition of the seabed biota (Yates et al. 1993, van Hoey et al. 2004). Other factors may also be important. Venables et al. (2002) established that there was a significant relationship between the seabed invertebrate fauna of the Gulf and temperature and oxygen. This is probably related to thermocline formation in summer in the deeper waters of the Gulf.

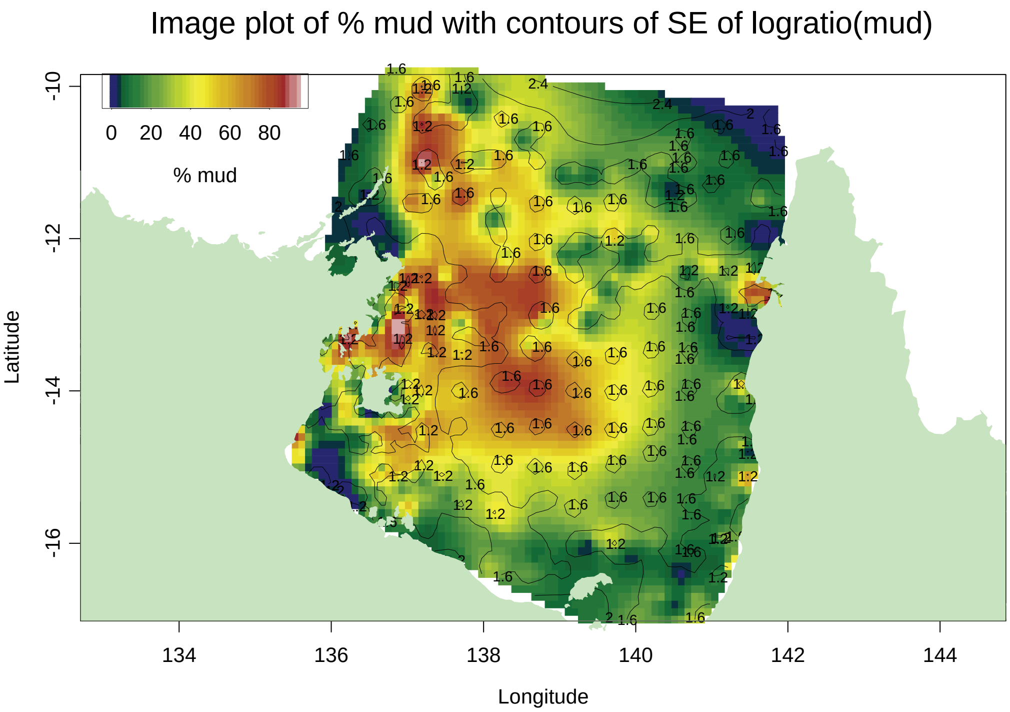


Figure 5.3-18: Kriged surface for percentage mud with standard errors on log-ratio scale shown by contours. Figure from Ellis (2002).

Our 18 month series of samples showed that the composition of the benthic assemblages varies quite markedly over periods as short as six months. These changes were not consistent between the two study sites. We could not explain these large variations; few are related to juvenile recruitment. In fact we found little sign of recruitment and even where we did; it was not repeated on an annual basis. We suspect that some of the changes are an artefact resulting from small sample sizes of biota that have a patch distribution. The plant groups by contrast did show clear seasonal cycles. Given this complexity, further studies of the seabed biota need very clear objectives that take into account the high spatial and temporal variability that exists in this biota. The possibility that part of the sponge population is not attached but free to be moved around on the seabed during cyclones is surprising. Further studies are needed to confirm whether this is happening and identify which species of sponge can live unattached.

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CHAPTER 6. IMPACTS OF TRAWLING EXPERIMENTS

6.1 First Trawl Impact Experiment – Design and execution, detection of physical impacts

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Scott Gordon, Burke Hill

Summary

Experimental design

An experiment was designed to quantify the results of targeted trawling in which an area approximately 1 km × 50 m was trawled repeatedly

- Preliminary analysis of day and night catch rates indicated that crustaceans were the only invertebrates that were more catchable at night. For of logistic reasons we decided to trawl during the daytime
- The repeat trawl experiment was repeated three times in two areas, one to the east and one to the west of Mornington Island
- A high impact of 20 trawls was selected in order to obtain a trawl coverage of at least 10 replicates over the same ground
- A low impact of 4 trawls was also carried out at each site
- An epi-benthic sled was used to sample areas before and after trawling

Results

- Despite use of a skilled skipper and acoustic tracking, it proved difficult to trawl precisely over previously trawled tracks. In the 20 trawl lanes, replication was no higher than 12 times and this only occurred in limited areas
- Detection of trawl activity on the seabed:
  1. We could not detect effect of high intensity trawling after six months using acoustic methods
  2. Side scan sonar could detect trawl tracks on seabed immediately after trawling
  3. Seabed photography showed recent trawl tracks but they were obliterated by bioturbation and so probably do not have a long life
- Trawling in the east was interrupted by a cyclone. When trawling resumed, we found high catch rates of sponges. They might have been dislodged by the cyclone or there may be a population of unattached sponges that can be moved around under turbulent conditions

6.1.1 Introduction

As shown in Chapter 2, the tiger prawn fishery in the NPF uses a strategy of targeting concentrations of prawns. Once a concentration is found, it is trawled repeatedly. We designed an experiment to replicate this strategy and to measure the effect of repeated trawling on the seabed biota. The experiment would be to establish a series of lanes that would be trawled repeatedly using standard commercial trawl nets. Before and after trawling the areas would be sampled by means of an epi-benthic sled. We have described in Chapter 5.1 the procedure for selection of the sites. Here we describe more of the background to the study including the choice between trawling during the day or at night, the design of the experiment, the tracking of the trawl and sled. We also wanted to test three methods of possibly identifying whether or not trawling had taken place in an area. We did this by means of an acoustic survey (using RoxAnn), side scan sonar and seabed photography of the area that had been intensively trawled. We were not confident of being able to obtain seabed photography given the poor visibility most of the time in the study area. The assessment of the trawl impact is described in the next chapter as well as the ability of epi-benthic sled sampling to identify trawling impacts.

6.1.2 Methods

6.1.2.1 Day/night comparison of catch rates of invertebrates

In carrying out the depletion experiment we had a choice of doing the work during the day or at night. Fishing for tiger prawns is a night time fishery but we were mainly interested in sessile and near sessile and slow moving animals such as sponges, gorgonians, bivalves and echinoderms which should be equally catchable at night or during the day. Catch rates of squid and fish are much higher during the day than at night but we were not attempting to measure the impacts on these groups because their considerable mobility. We were planning to impact relatively small areas and fish and squid would be able to rapidly move in and out of these experimental areas. We had data from previous studies giving catch information from trawls carried out during the day and at night and we decided to use this in making the decision on when to trawl.

During 1997, CSIRO made a total of 464 research trawls throughout various parts of the NPF with a pair of Florida Flyers prawn trawls (Stobutzki et al, 2000, Cruise SS9708). The material from these trawls had been analysed. One hundred and eighty seven shots were made during the day and 277 were made at night. To obtain a broad-scale impression of the differences in catch rates of invertebrates between day and night, the invertebrate taxa were grouped into phyla or classes and the catch rates of each taxon by day/night were graphed (see Figure 6.1-1).

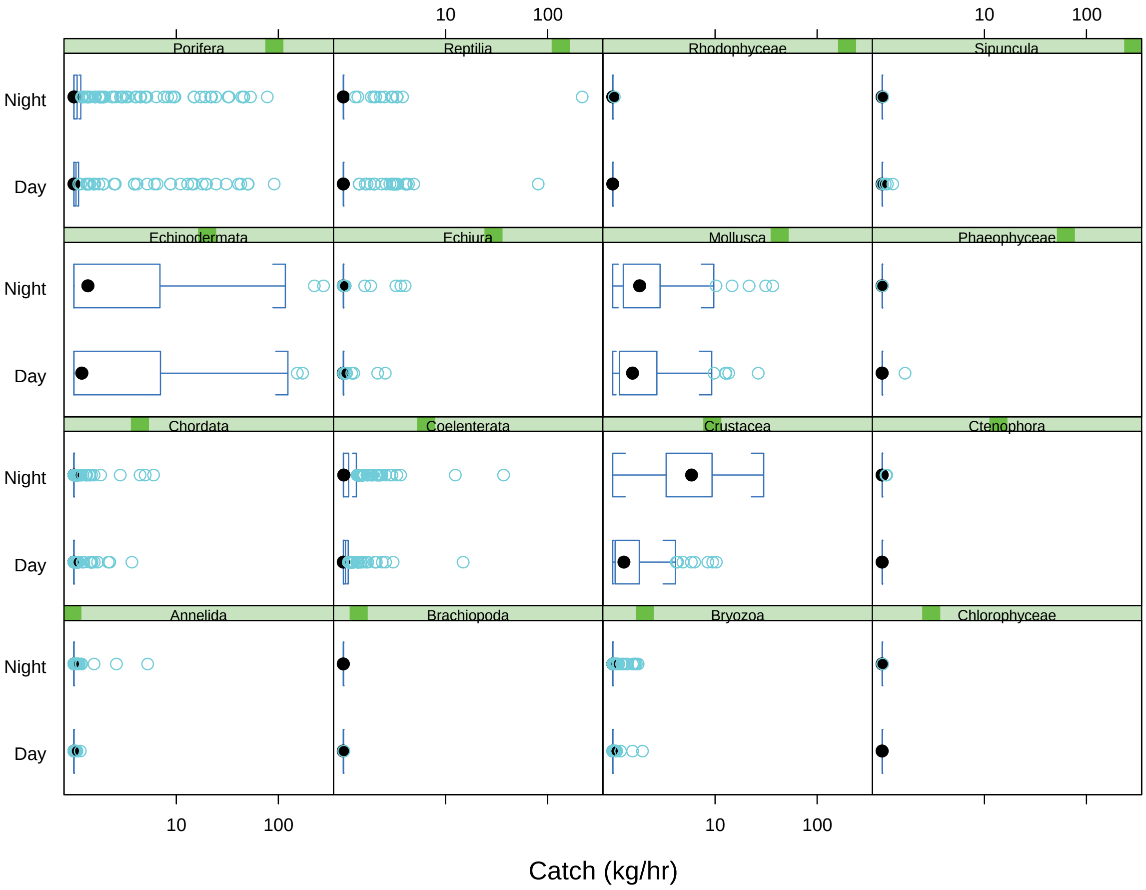

Figure 6.1-1: Day/night comparison (boxplots) of catch rates of invertebrate bycatch taxa from all trawls (SS9708). The filled circle represents the median, the box gives the 25th and 75th percentiles, the whiskers extend to 1.5 times the inter-quartile range and the open circles are points that can be considered outliers.

Overall, the only group that appears to have markedly higher catch rates during the night compared to the day are the crustaceans. However, this analysis is fairly coarse because day and night trawls were not evenly dispersed throughout the fishery; in some areas only night trawls were made.

A second analysis was carried using paired trawls that were made within 1 km of each other; one during the day and one during the night. There were 48 such pairs of trawls in the dataset. The daytime catch rates of each taxon were plotted against the corresponding night-time catch rates at each site (Figure 6.1-2). The catch rates have been scaled by dividing the catch rates within each phylum by the mean catch rate for that taxon. This was done purely to allow all taxa to be graphed on the same scale, so the numbers are relatively meaningless. Sites (open circles) that lie above the 45º dotted line represent sites where the daytime catch rate of that particular taxon was greater than the night-time catch rate.

Unlike the broad-scale analysis above, it is not clear whether any of the groups other than crustaceans consistently have higher catch rates during either the day or night. Crustaceans appear to be more catchable during the night. Most of the crustaceans have a high degree of mobility and so are of less interest in this project than the sessile or slow moving animals. Based on this information we decided that there would not be a significant disadvantage if we conducted our trawling during daylight.

We looked at crustaceans in more detail because they show the greatest contrast in day vs. night-time catch rates. Note that eight families were taken only during night-time shots, whereas three families were taken only in daytime. As with the analysis that included all phyla, we have extracted the paired day/night trawls and compared the catch rates of all Crustacean families (Figure 6.1-3, Table 6.1-1).

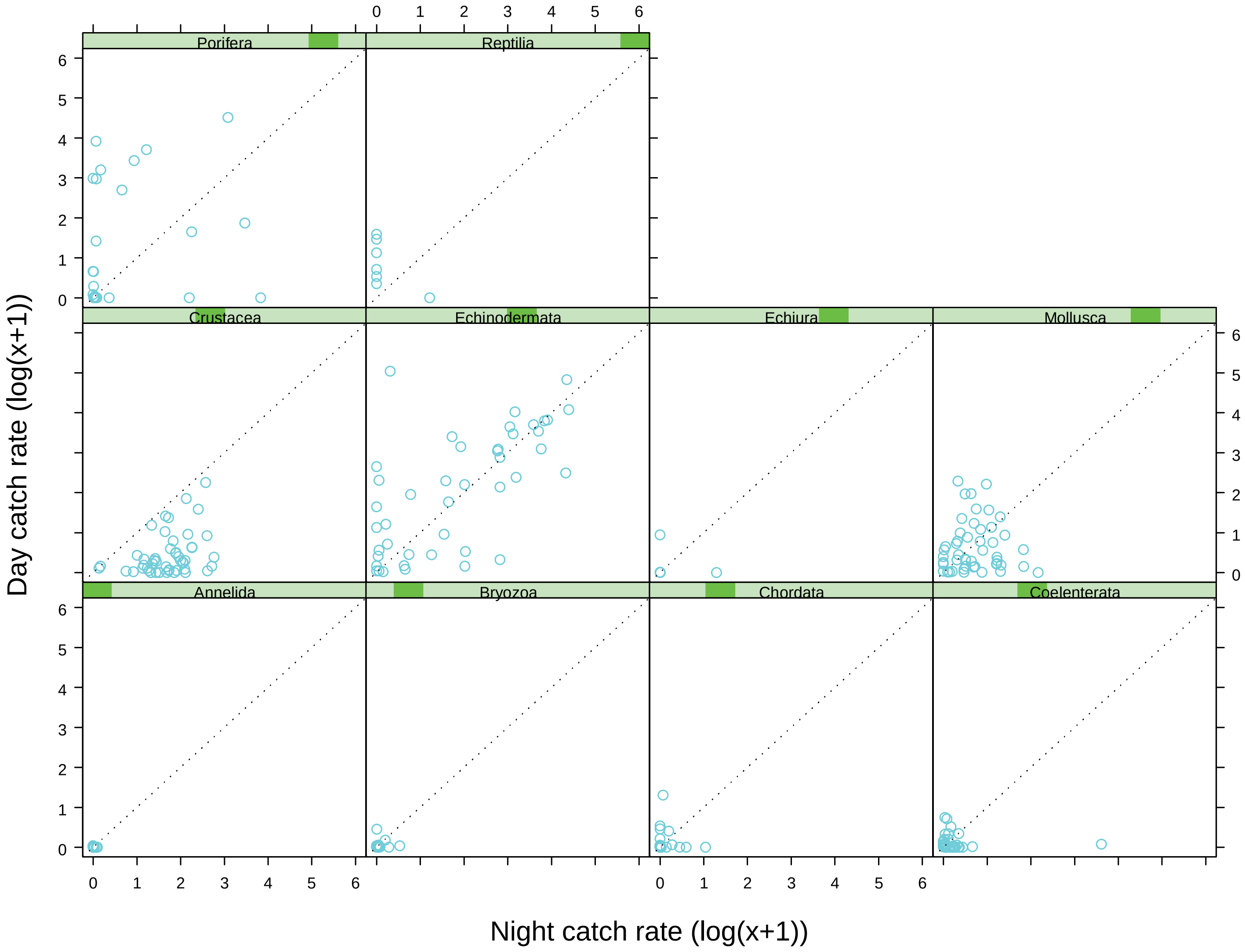

Figure 6.1-2: Scaled day & night catch rates of bycatch taxa at 48 pairs of sites throughout the NPF.

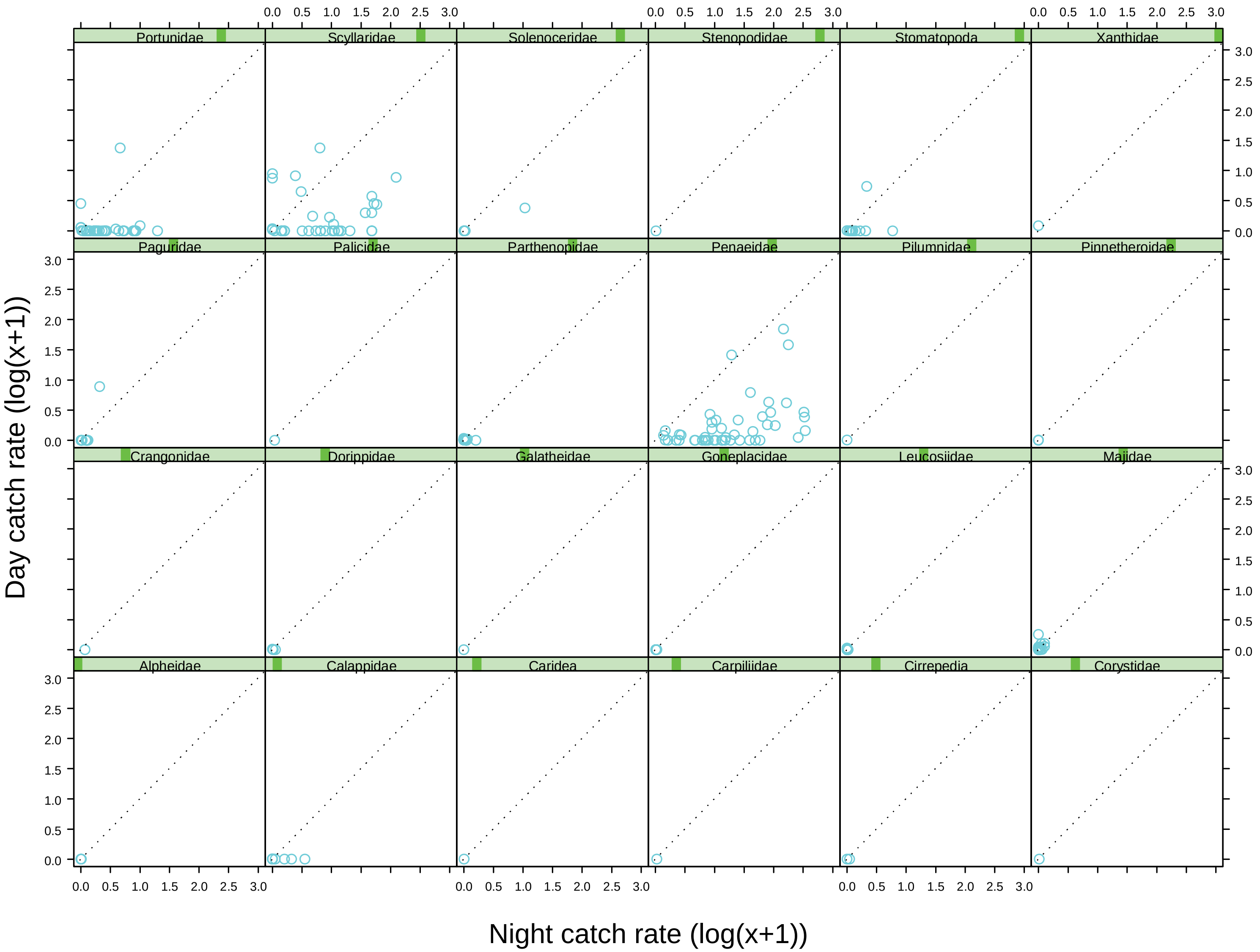

Figure 6.1-3: Day & night catch rates (log transformed) of Crustacea at 48 paired sites throughout the NPF.

Table 6.1-1 : Mean catch rates (kg/h) and t-test of Crustacean families at the 48 paired day/night trawl sites. Families having significantly different catch rates during the day compared to the night are shown in yellow. DF = degrees of freedom.

Family	Day	Night	DF	t value	p
Alpheidae	0.000195	0.029177	47	-0.98	0.3320
Calappidae	0.000000	0.000039	47	-1.64	0.1076
Caridea	0.000000	0.000950	47	-1.00	0.3224
Cirrepedia	0.000000	0.000223	47	-1.00	0.2923
Corystidae	0.000000	0.001460	47	-1.00	0.3224
Crangonidae	0.000219	0.001448	47	-1.00	0.3224
Dorippidae	0.000019	0.000000	50	-1.05	0.2990
Galatheidae	0.000076	0.001135	41	1.00	0.3232
Goneplacidae	0.001979	0.001363	47	-1.99	0.0519
Leucosiidae	0.017991	0.008807	66	0.51	0.6121
Majidae	0.017117	0.008689	58	1.08	0.2835
Paguridae	0.000005	0.000242	47	0.48	0.6356
Palicidae	0.000000	0.000803	47	-1.00	0.3224
Parthenopidae	0.002346	0.008742	51	-1.26	0.2138
Penaeidae	0.501717	3.452997	59	-6.02	<0.0001
Pinnotheridae	0.000095	0.000000	41	1.30	0.2013
Portunidae	0.089843	0.470378	86	-3.34	0.0012
Scyllaridae	0.310543	1.347130	60	-3.85	0.0003
Solenoceridae	0.010990	0.038475	54.9	-0.70	0.4866
Stenopodidae	0.000000	0.000162	47	-1.00	0.3224
Stomatopoda	0.012998	0.028712	89	-0.82	0.4139
Xanthidae	0.002112	0.000480	41	1.00	0.3232

These data suggest that with the exception of the very mobile crustaceans (penaeids, portunid crabs and scyllarids) there is little difference between night and day catches of crustaceans and more importantly, no difference for the near sessile or slow moving taxa.

Given this data, we concluded that there was only a marginal advantage in carrying out the trawls at night. These advantages had to be offset against doing the work during the day. There were two advantages to the latter. Firstly we could carry out more trawls during the day than at night because the dawn and dusk periods give catches more like day than night. This difference when we are considering a large number of trawls adds up to a considerable difference in cost. The project was already under cost restraints as well as a narrow time window for the use of the chartered commercial vessel. We had an upper limit of 21 days use. Setting this against the time needed for the depletion experiment it was clear that we could not complete the work if we trawled at night.

The second advantage related to the complexity of the depletion experiment. We were expecting a commercial skipper to trawl to a far higher level of navigational accuracy than normal. He would be expected to monitor the position of the trawl continuously from a computer display in addition to his normal navigation and to correct the position of the vessel in order to keep the trawl on track. At the same time he would be expected to be aware of the time that the trawl was on the seabed more precisely than during normal fishing operations. We wished to weigh the material removed from each lane of the plot on each trawl shot and so the time the trawl spent on the seabed was critical. In addition the vessel was operating other gear unfamiliar to the skipper and crew – the epi-benthic sled, the side scan sonar, video camera, as well as the system used for monitoring the position of the trawl relative to the boat (which used an overboard transceiver) and the sophisticated GPS monitoring system for tracking the boat. By conducting our operations during the day we believed we would maximise our chances of success.

6.1.3 Experimental design

Burridge et al. (2003) showed that in the GBR region prawn trawls removed on average 10% of the seabed biota although there was considerable variation between taxa. This means that seven trawls should remove around 50% of the biota and 14 trawls should remove around 75%. We wanted an impact of this order – 50 to 75% removal. To achieve this would mean coverage of up to 14 trawls over the same area. However, we realised that given the practical problems of navigation at sea and the fact that the trawl would not necessarily follow the path of the ship accurately, we needed to make more trawls to ensure that we really did have a high impact. We chose 20 as a reasonable compromise between high impact and cost of carrying out trawling.

The experimental design consisted of lanes of seabed exposed to three different levels of trawling: – nil trawls (control), 4 trawls (low impact) and 20 trawls (high impact). Each lane would be sampled by means of an epi-benthic sled before and after trawling. The before sampling would be done in the gap between the trawl nets to avoid disturbance of the area to be trawled. The design is summarised in Table 6.1-2.

Table 6.1-2: Design of the trawl impact experiment.

Treatment	Pre-impact sampling	Impact	Post-impact sampling
Control	3 sled samples	No trawling	3 sled samples
Low impact	3 sled samples	4 trawls	3 sled samples
High impact	3 sled samples	20 trawls	3 sled samples

The experiment would be replicated six times but because we wanted to test whether there were differences in response of seabed with different characteristics, we chose two sampling areas with three sets of lanes in each. We established three sites to the east and three to the west of Mornington Island.

6.1.3.1 **Sampling**

Sampling of the lanes prior to and after trawling would be by an epi-benthic sled (see Chapter 4.3). Subsequent follow up sampling to monitor recovery would also be by the sled. This meant that no trawling would be carried out on the lanes subsequent to the initial impact. Because we did not want the post-impact monitoring to be affected by the sled, we needed to know exactly where the sled was deployed so that we could avoid running it over ground that had previously been sampled. This meant that we required accurate position fixing for the initial trawl impacts as well as the path followed by the sled each time it was deployed.

The lanes were 1 nautical mile (nm) in length. The width was the spread of two 12 fathom (= 43.9 m) nets with a gap between them. The towing blocks for the trawls were 27.4 m apart. The fleet master of A. Raptis and Sons stated that the nets spread to 70% of their head rope length and we used this estimate in our planning. In August 2004 we measured the actual spread using acoustic tracking and were able to factor in the value into our calculations of the impact area. Although we would have preferred to have no gap between the nets, it was necessary to prevent the inner trawl boards from entangling. The gap was estimated to be 12 m wide, we were able to measure the actual width in August 2004. The trawl nets had their TEDs and BRDs removed in order to provide more complete samples of the catch. This removal was done under a scientific permit from AFMA. The 700 kg Bison trawl boards were supplied by Raptis and Sons who also provided the 22.3 m prawn trawler *Arnhem Pearl* under charter to CSIRO for the field work.

Prior to the study we had no data that could be used for a power analysis to decide how many epi-benthic sled samples were needed to demonstrate a trawl impact. We decided to take 3 samples in each lane before the trawling and another 3 after the trawling. The rationale for this number was that each epi-benthic sled sample would cover a width of 1.5 m and a distance of 250 m, a total area of 375 m^2 with three replicates giving a total sample area of 1125 m^2. Although it would have been desirable to have more samples there were practical constraints on the number of epi-benthic sled samples we could fit into the trawl lanes in the two year recovery monitoring phase given the large area each one sampled. If we wanted to collect more epi-benthic sled samples we would have to make the trawl lanes larger which would have cost considerably more in vessel charter time. Analysis of epi-benthic sled samples is also costly and we were conscious of needing to keep down the total cost of the study. We decided that 3 samples in each lane would be a cost effective number that should be adequate to provide a robust estimate of effect.

In the field we pre-sampled the sites by means of three 250 m long tows of the epi-benthic sled. We then ran the twin trawls four times over the first low impact site and 20 times over the heavy impact lane. Finally we carried out post impact sampling using the sled. This process was repeated for the three experimental sites after which the vessel moved to the second experimental area where the process was repeated on a further three sites. At the end of every trawl shot, the catch from each net was dumped separately onto the sorting tray of the trawler. Fish were removed and the remaining invertebrates were put into lug baskets which were weighed. Catches were not subsampled but on most shots we processed the catch from only one net. When the catch was very low we kept the catch from both nets but the samples were kept separate. It was not possible to do all 20 trawls on a lane in one day and so the work was continued through a second day. We decided that we should not carry out post sampling of a lane until 24 hours after the trawling was complete. Previous CSIRO work on scavenging in Torres Strait (Hill and Wassenberg, 1990) indicated this would be an adequate delay to allow damaged animals to be scavenged. Post sampling was carried out using the epi-benthic sled. We collected three epi-benthic sled samples from each trawl impacted lane and from the control area. The position of the trawl and the epi-benthic sled on the seabed was monitored by an acoustic tracking system (See Chapter 6.4).

Processing of biological samples involved removal and discarding of all teleosts and elasmobranchs. Sponges were photographed and a small sample of tissue was taken and the rest of the animal was discarded away from the trawl sites. The remaining invertebrates were put into plastic bags in cartons and frozen for processing at CSIRO Cleveland Marine Laboratories.

6.1.3.2 **Tracking of gear**

In an effort to obtain a more accurate map of the intensity of the impacts we were creating with the repeated trawls, we have modelled the trawl intensity based on the ship's position and the configuration of the fishing gear. We assumed each net spread to 15.4 m with a 12.06 m gap between the two nets.

During the trawl experiment, the vessel's position was recorded every 5 seconds using the GPS. We extracted from the GPS records the positional information that corresponded to each trawl using the start and end time of each trawl. This data was loaded into a GIS and each trawl track converted into a line. The resulting coverage was projected to Universal Transverse Mercator Zone 54 to facilitate accurate length and area measurements.

The trawl tracks were then converted to polygons having a width of 15.4 m (70% of the head rope length). The individual track polygons were then overlaid and the number of times each part of the seabed was trawled was estimated.

6.1.3.3 **Acoustic detection of trawling activity**

The efficacy of acoustic techniques for measuring trawl effect was examined using data obtained from the experimental site six months after the trawl impact. Data was collected with the Simrad EY500 portable scientific echo sounder. The EY500 transmits a pulse of high frequency (120 kHz) sound that is reflected back by the seabed, the reflected acoustic signal was converted to electrical signals by the echo sounder transducer and stored digitally for later analysis. The acoustic sampling covered all trawl lanes described in the experimental design. The position information from the vessels GPS was used to geolocate the control and trawl impact lanes with the collocated acoustic data.

The EY500 echogram data was analysed using the CSIRO ECHO software to generate depth-corrected acoustic indices over a 5 ping interval. Three acoustic indices of mean area backscatter strength were produced, one which related to the entire first acoustic seabed echo [denoted: SA], another which integrates the tail portion of the first echo [denoted: Tail] (related to acoustic roughness), and the other which integrates the entire second echo [denoted: Second] (related to acoustic hardness). Position information and operation start and stop times for the epi-benthic sled transects performed during field sampling, was used to cross-reference the acoustic index data. The number of acoustic index data points generated over a sample transect varied from 70 to 350, with a mean value of 270 records. The resulting acoustic index data, as well as along track depth profiles, was then summarized for each of the experimental sampling transects using mean and standard deviation statistics. Thus eight pieces of acoustic information (Depth mean, Depth standard deviation, SA mean, SA standard deviation, Tail mean, Tail standard deviation, Second mean, Second standard deviation) were produced for each sampling instance, and were tested as a predictor of trawl effect.

6.1.3.4 **Side scan imaging of trawled areas**

We towed a Imaginex Model 858 Side Scan Sonar over three of the experimentally trawled lanes immediately after trawling to see if we could identify any sign of trawling activity.

6.1.3.5 **Swath imaging of trawl tracks**

During May 2003, the RV Southern Surveyor was conducting a cruise through the southern Gulf of Carpentaria for GeoScience Australia which provided us with an opportunity to map the seabed of our study area to the east of Mornington Island using a Simrad/Kongsberg EM300 multibeam swath mapping instrument. The trawl plots were swath mapped on 14th May 2003, approximately 2 months after the trawling had been done on these sites. We were only able to swath the eastern region because the western region was too shallow for the RV Southern Surveyor.

6.1.3.6 Visible effects of trawling

We were not able to photograph the visible effects of trawling on the seabed in the experimental area. However, in 2005, CSIRO undertook a major benthic survey in Torres Strait in which many thousands of photographs were taken of the seabed using a drop camera. This system used a Canon EOS 20D 8 Mega Pixel Digital SLR with an EF-S10-22mm wide angle lens and two Canon Speedlite 550 EX strobes. The camera was mounted inside a pressure housing. During a transect the camera automatically took a photo every 5 seconds. Some of these photographs were in areas subject to prawn trawling and showed the tracks of prawn trawl gear and are presented here.

6.1.4 Results

The cruise started on 1st March and ended on the 18th March. It was interrupted for two days by Cyclone Craig. We established 6 locations where we created a range of trawling impacts. At each location we set out three 1 nm long trawl lanes, consisting of a control (0 trawls), low impact (4 trawls) and high impact (20 trawls) lane. The vessel was steered as carefully as possible by an experienced skipper using differential GPS in an effort to ensure the repeated trawls were laid down on top of each other. However, current, wind, chop and swell interacted with the vessel to make this almost impossible. The calculated tracks of the trawl on the 20 and 4 times lanes for site 6 is shown in Figure 6.1-4.

None of the experimental area was trawled the maximum number of times on either the 20 or 4 trawls treatments at Location 6 (Figure 6.1-4). This was the case for all the locations. In fact for the 20 trawls treatment only 14.5 to 23.5 % of the total area was trawled more than 10 times and between 0.3 – 5.3 % was trawled more than 15 times (Figure 6.1-5). On the 4 trawls treatments between 24.3 to 37.2 % of the total area trawled was trawled more than twice. We had expected this to occur and this was the basis of our decision to trawl 20 times in order to obtain a significant impact. It also illustrates the difficulty of overlying trawl tracks and the importance of having some measure of the track followed.

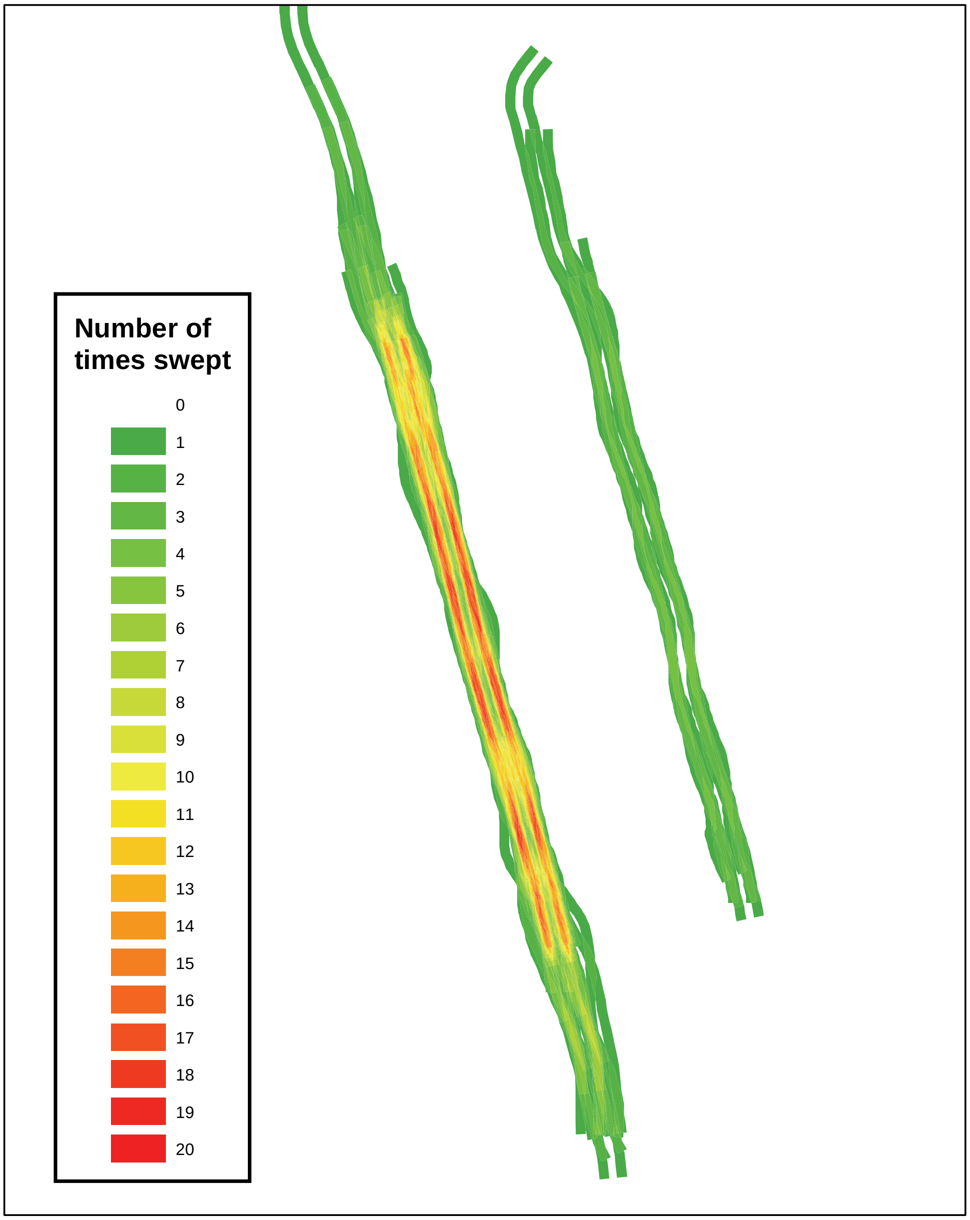

Figure 6.1-4: Trawl intensity map of the 20 times (left) and 4 times (right) trawled treatments at location 6.

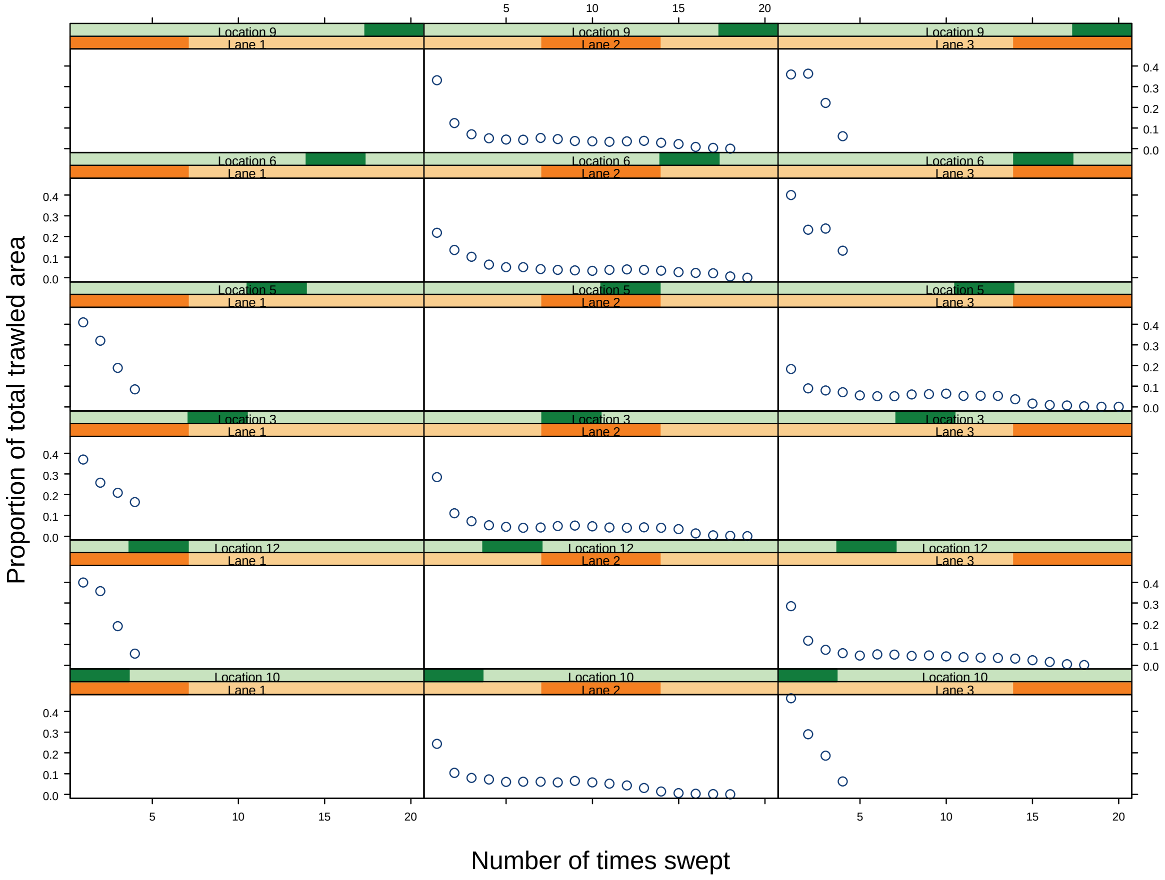

Figure 6.1-5: Proportion of the total area trawled at each lane by the number of times swept. Note that in all cases (except for the controls) the highest proportion of the lane was only trawled once. There are six lanes for each trawl intensity (zero for control, four times for light trawling and 20 times for high intensity)

6.1.4.1 **Trawl catch and the effect of the cyclone**

The invertebrate biomass taken by the trawls was generally much less at the shallow sites to the west of Mornington Island (6.3 to 13.4 m) than those taken in the deeper east Mornington sites (27 to 31.2 m) [Figure 6.1-6]. This was largely because sponges were commonly caught in the east, whereas they were rarely caught in the west. There was no clear evidence of a steady decline in total invertebrate biomass at any of the 4 trawls treatments. However, there was some suggestion of a decline on the 20 trawls treatments at locations 3, 10 and 12. Biomass at location 9 appeared to be declining until trawling stopped after 12 shots due to the approach of Cyclone Craig. When trawling recommenced 2 days later the biomass taken in the thirteenth shot was almost four times that taken in shot 1. Most of this appeared to be due to an increased catch of sponges which had been washed into the experimental area by the cyclone. These sponges were alive.

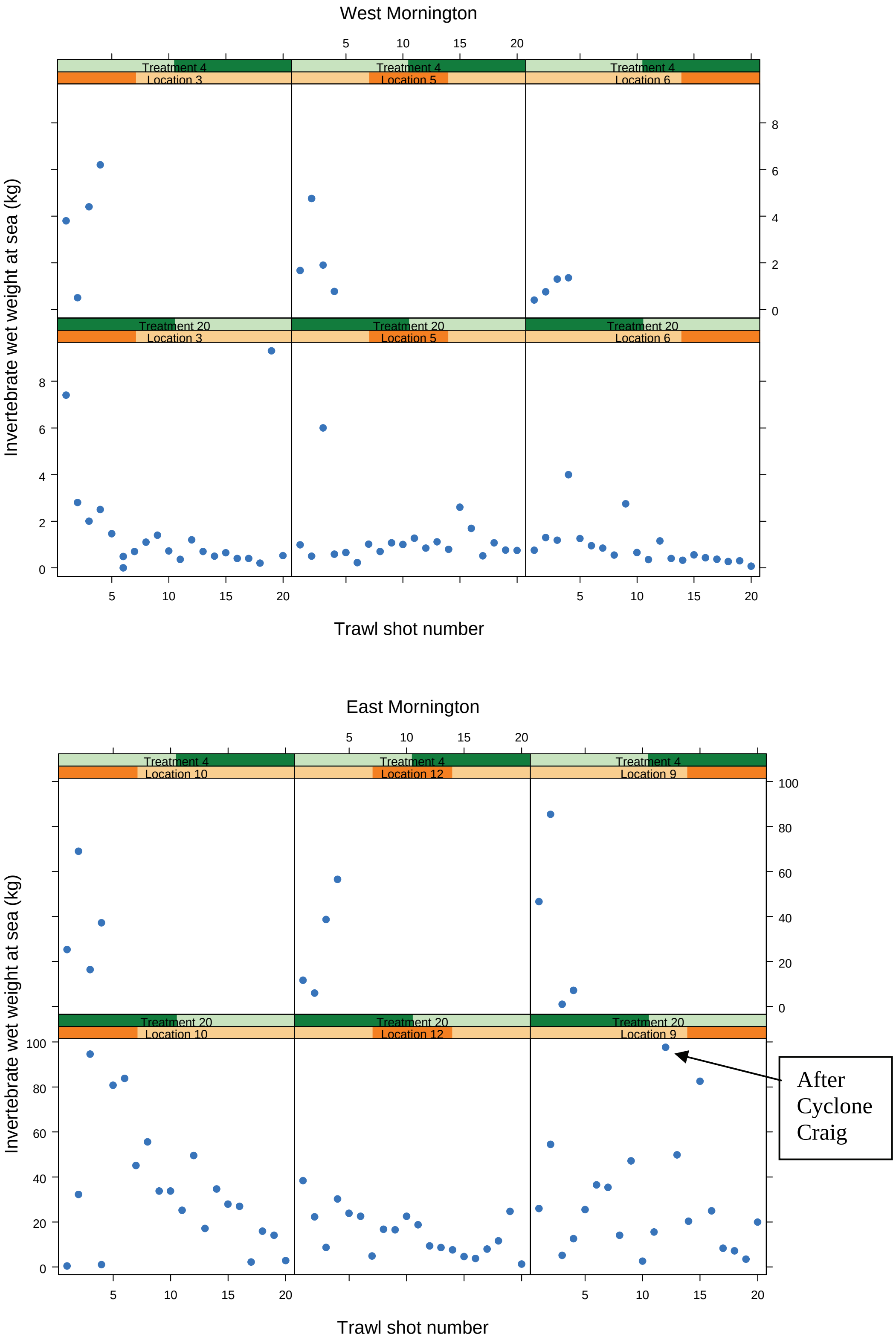

Figure 6.1-6: Total weight of invertebrates in trawl shots taken on the experimental trawl plots to the west and east of Mornington Island. Trawling at Location 9 ceased for 2 days between shots 12 and 13 because of Cyclone Craig.

6.1.4.2 Ability to detect trawl impacts using acoustics

The three acoustic indices for each geographic region and trawl treatment in the experiment are summarised in Figure 6.1-7. There is a large difference between the values of these acoustic indices obtained at the two geographic regions, suggesting that the seabed structure is different; this is also true across the three sample locations within each region. Thus for completeness, the effects of region and location were included in subsequent statistical analyses of trawl impact prediction. These results also suggest that there is a high variance for the acoustic indices and that there is some level of irregularity in the values obtained when taking into account the trawl impact experimental treatment.

A nested analysis of variance (ANOVA) was used to test the performance of each acoustic index as a predictor of trawl impact. The ANOVA took into account the nested / hierarchical design and included the acoustic indices as response variables, the trawl intensity as the experimental treatment, with location and region as a nested control variable and also took into account interactions between the variables. The results of the eight ANOVA's are presented in Table 6.1-3 as the statistical significance (F-statistic) of each term in the analysis.

Table 6.1-3: Acoustic predictors of trawl effect / intensity; results of nested analysis of variance: significance (probability: F-statistic) [* p < 0.1, ** p < 0.05, *** p < 0.01, **** p < 0.001].

Acoustic Response Variable	Experimental Treatment: Trawl Intensity (0, 4, 20)	Control: Nested Location & Region	Treatment & Control Interaction
Depth Mean	0.0035***	0.0000****	0.0000****
Depth Standard Deviation	0.6958	0.0000****	0.0197**
SA Mean	0.3759	0.0000****	0.0031***
SA Standard Deviation	0.2304	0.0000****	0.0117**
Tail Mean	0.1473	0.0000****	0.0414**
Tail Standard Deviation	0.3453	0.5397	0.4715
Second Mean	0.0048***	0.0000****	0.0000****
Second Standard Deviation	0.4056	0.0000****	0.0981

The results of the ANOVA clearly suggest that region and location may be predicted with all acoustic indices and are highly statistically significant; except for the standard deviation measure of the Tail index. The only acoustic index predictor of trawl intensity which had any level of statistical significance was the mean measure of the second echo (or acoustic hardness); though even this predictor was not as significant as either the nested location and region or the interaction terms. This result shows that most of the variance in the acoustic indices obtained during sampling is explained by the location and region factors of the experiment, and to a lesser extent by the interaction between these factors and the experimental treatment of trawl intensity. Even when these significant non-treatment factors are taken into account, the trawl intensity applied during experimental treatment does not explain any statistical significant variation in acoustic indices.

The results of this analysis of acoustic indicators show that they were unable to detect the difference between no trawl, light trawl and heavy trawl impacts six months after the experiment was conducted.

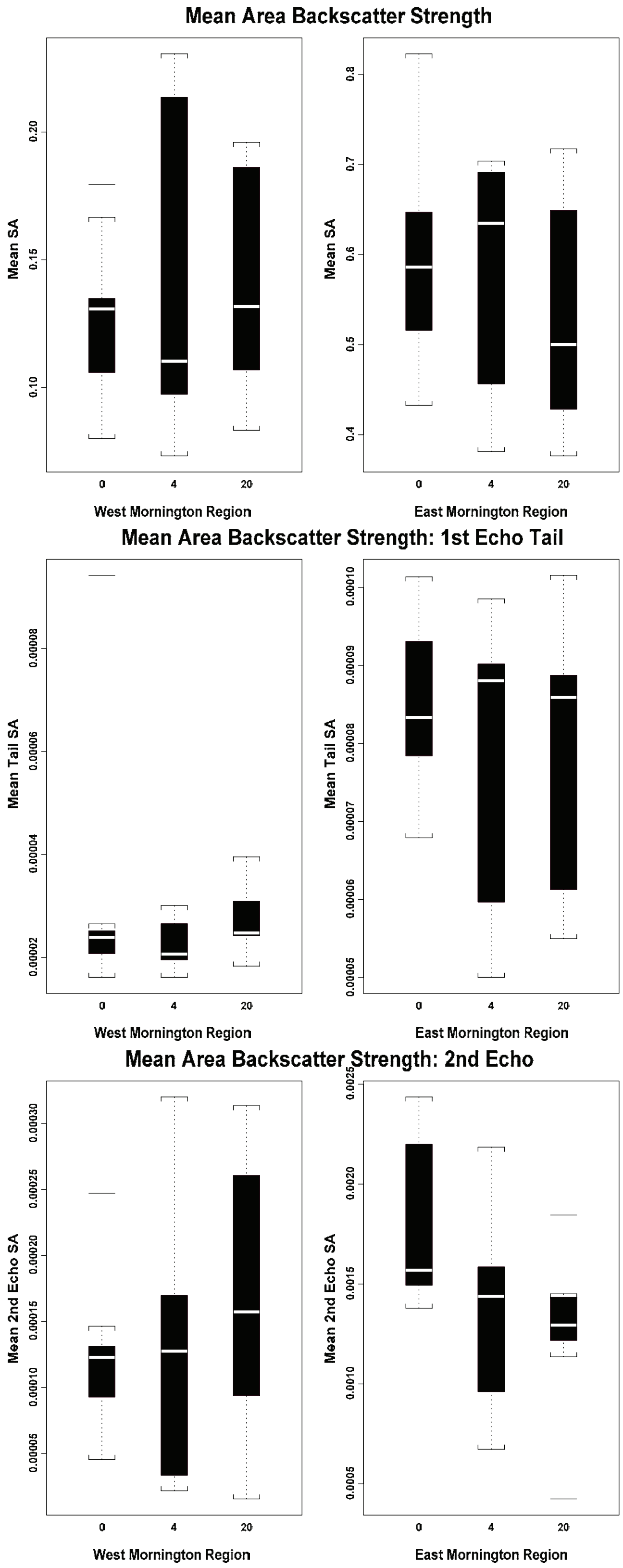

Figure 6.1-7: Acoustic Mean Area Backscatter Strength indices summarised by geographic region and experimental treatment.

6.1.4.3 **Side scan imaging of trawl tracks**

The side scan sonar showed the tracks of the otter boards on the seabed immediately after trawling. Unfortunately the quality of the images was very poor and because of ongoing problems with the unit we did not repeat the observations after 6 months so we do not know how long the tracks remain visible.

6.1.4.4 **Swath imaging of trawl tracks**

The swath images were taken at 1m resolution and provide detailed topography of the seabed of the eastern study area (Figures Figure 6.1-8 to Figure 6.1-10). The seabed was very flat and featureless at all locations with the maximum relief of 3.20 m occurring across Location 12. We were not able to distinguish any otter board marks on the seabed from the swath images.

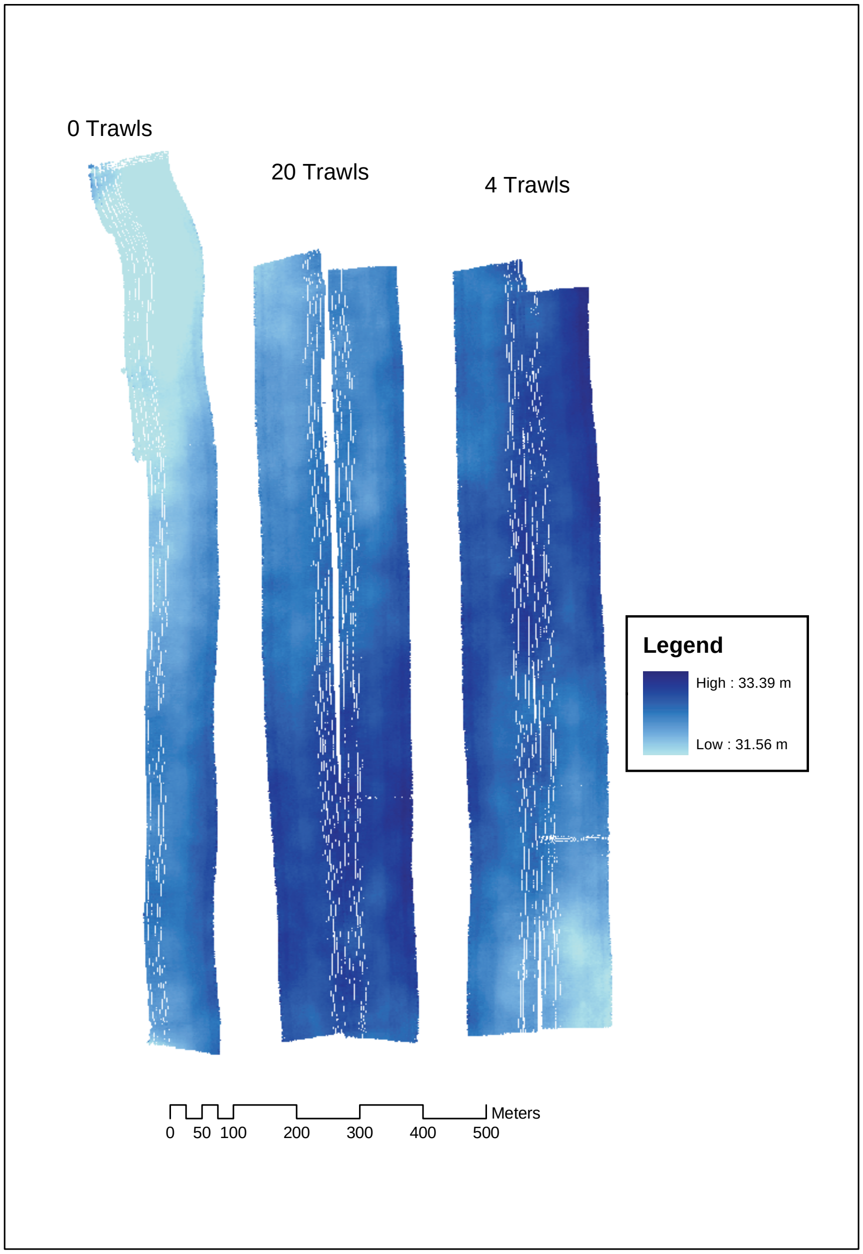

Figure 6.1-8: Swath map of the trawl lanes on the seabed at Location 9. Data acquired by Geoscience Australia.

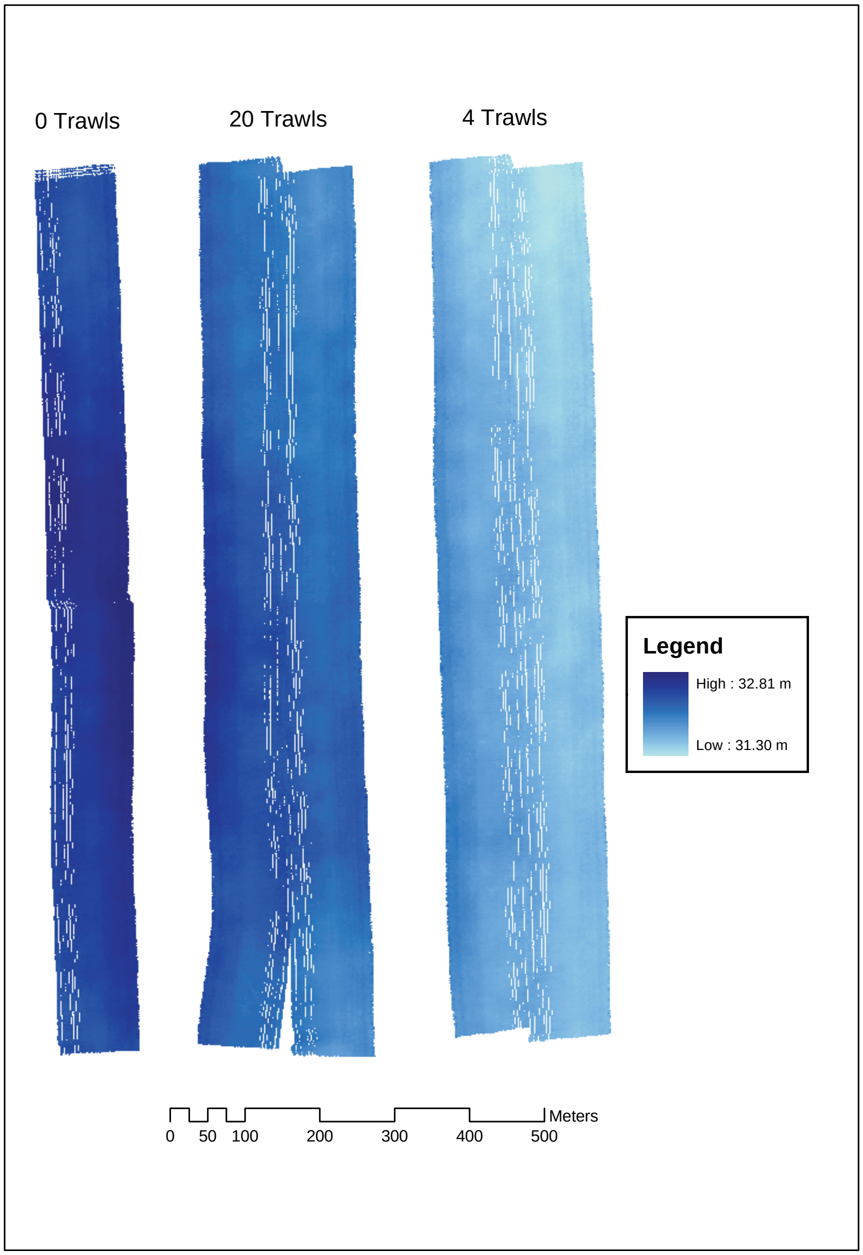

Figure 6.1-9: Swath map of the trawl lanes on the seabed at Location 10. Data acquired by Geoscience Australia.

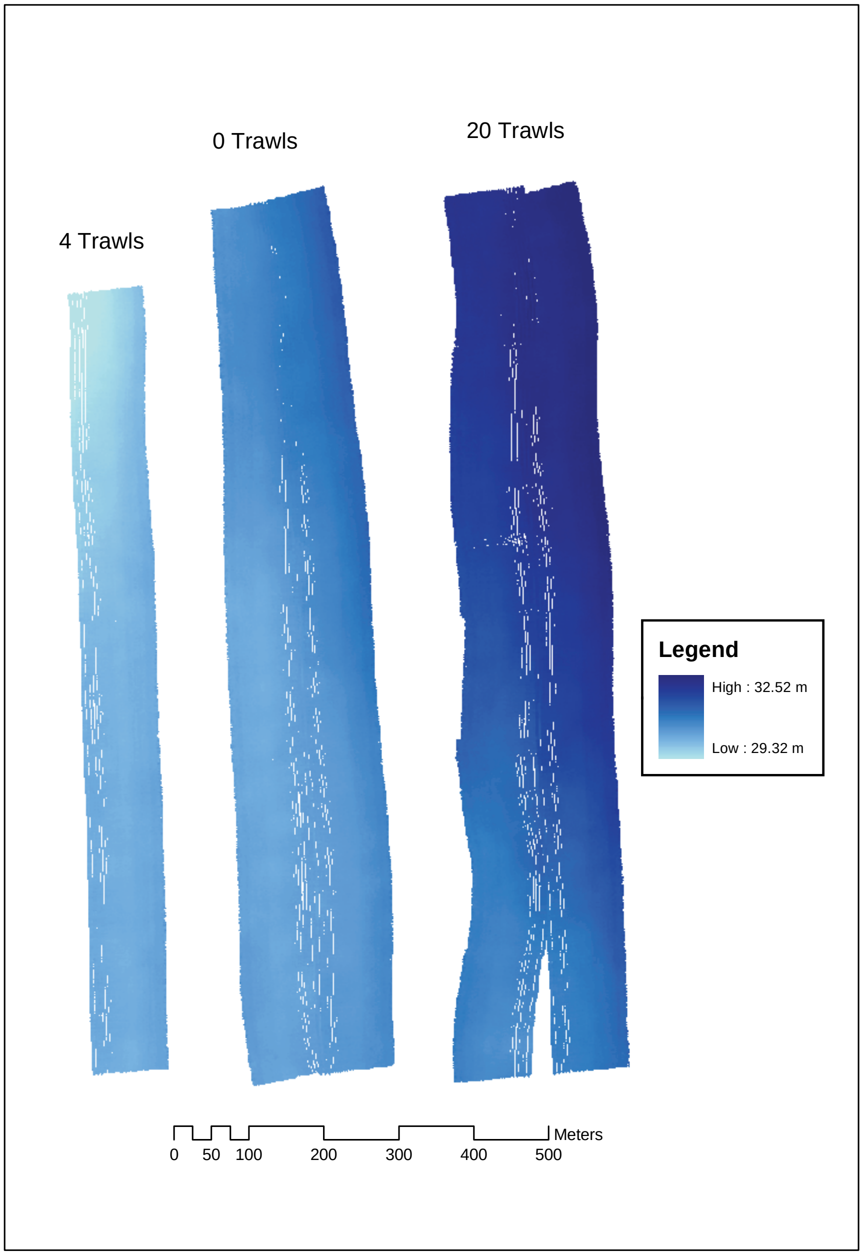

Figure 6.1-10: Swath map of the trawl lanes on the seabed at Location 12. Data acquired by Geoscience Australia.

6.1.4.5 **Visible effects of trawling**

Trawl doors have a greater physical impact on the seabed than does the net although the area of impact is far smaller. Typical trawl otter board tracks are shown in Figure 6.1-11 from Torres Strait.

The two red points in Figure 6.1-8 are laser spots that are 27.5 cm apart. Using these scaling points, we can calculate that the width of the track made by the trawl boards is around 15-18 cm. The shape of the track is the result of the complex hydrodynamic forces around the board including a vortex behind the board (Gilkinson et al. 1998).

Figure 6.1-11: Track made by an otter board on the seabed. A soft coral (top left) has apparently been bent over by the board (Photo from Torres Strait 2005)

The visible effects of the trawl net are less distinct and were not detected but the chains in front of the net do disturb the seabed (Figure 6.1-12). Because of the much greater width of the chains, the area showing their effect is much larger than that of the boards. The pressure exerted by the chains is much less than the boards and so the grooves and ridges are shallower and smaller.

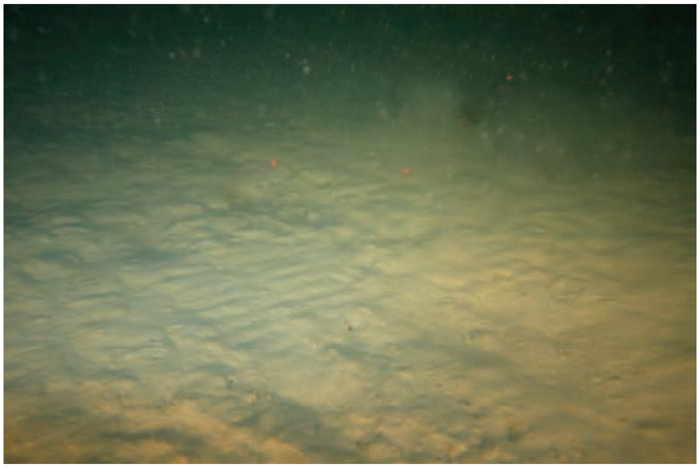

Figure 6.1-12: Marks left by trawl net chains on seabed (left to right) crossing older tracks (bottom right to top left). (Photo from Torres Strait 2005)

Trawl tracks are eventually obliterated by the activity of the benthic fauna, especially the burrowing species (Figure 6.1-13). The rate at which the tracks are obliterated depends on the seabed fauna and so is likely to vary between areas but given the soft nature of the sediments, the process is probably quite rapid.

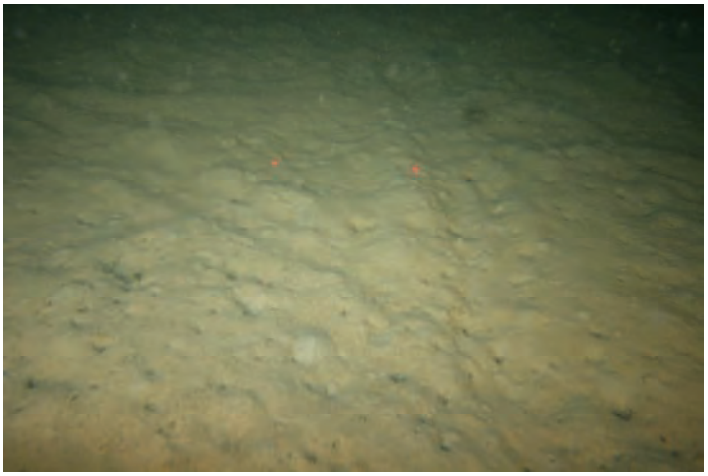

Figure 6.1-13: Possible crisscrossing old trawl board tracks that are being obscured by bioturbation. (Photo from Torres Strait 2005)

6.1.5 Discussion

We used differential GPS to position the vessel with an accuracy <1m for 95% of time. Skippers in the NPF who fish for tiger prawns are skilled in positioning their vessel over the fishing grounds. Using computer-based chart plotting systems they have accurate information on previous tracks of the vessel and can use these in planning their tracks. We found however that even with a skilled skipper, it was difficult to pilot the vessel over the same line.

Knowing the position of the vessel does not mean that the position of the trawl is also known. Because the trawl wire is a flexible connection, the trawl and boat can move independently to some extent. In deep water this can result in a substantial difference in track between the two. Engås et al. (2000) found deviations of 27 to 213 m when trawling in deep water in the Barents Sea. Modern acoustic tracking equipment enables the position of the trawl gear to be plotted relative to the ship (McKeown and Gordon DC, 1997). We used this system in our experiment and found that because we were operating in shallow water, the track of the trawl and vessel was fairly close but they do not correspond exactly. The result of these various discrepancies is that successive trawl tracks are not coincident. This non-coincidence has not been taken into account in most research of this nature because of the difficulty of establishing the position of the trawl or other sampling gear. We used an acoustic tracking system and so we have a fairly good idea of the position of the trawl. Despite trawling 20 times over the ‘same track’ most of the area was trawled less than 10 times. In the following chapter, we have analysed trawl depletion rates separately for coincidental and non-coincidental trawls to show the differences.

Two months after trawling the swath mapping confirmed our impression of the seafloor topography of the eastern study sites and was unable to detect any visible disturbance of the seabed due to trawling. This is probably not surprising since the resolution of the swath imagery was only 1 m, which although very useful for broad topography is probably too coarse to reveal the fine-scale disturbance we might expect from trawl nets and boards.

After six months, our acoustic system could not detect signs of furrows dug by the trawl doors on our intensively trawled lanes. The RoxAnn system has been shown to be capable of detecting the effects of trawling on the seabed in areas where very heavy fishing gear is used. Humborstad et al. (2004) carried out experimental trawling using Rockhopper gear (with 21” long steel bobbins and boards weighing 2300 kg each. They found changes in the acoustic hardness of the seabed that were consistent with a possible re-suspension of the sediment and a homogenizing effect from the trawl doors and ground gear ploughing the area. The result was an increase in acoustic roughness and a decrease in acoustic hardness. Prawn trawl gear used in the NPF is much lighter, there are no bobbins and the boards weigh up to 500 kg each. We conducted an acoustic survey 6 months after trawling whereas Humborstad did so immediately after trawling. In 20 to 40m depth off Barcelona in Spain, Palanques et al. (2001) found that the furrows made by otter trawl doors persisted for at least 1 year on the seabed, however the substrate in this case was fine mud in contrast to the sandy sediments in the present study. We suggest the lower weight prawn trawl gear coupled with intensive bioturbation in shallow tropical water was the reason that trawling was not detectable on our intensively trawled plots after 6 months.

Furrowing caused by the impact of the trawl doors on the substrate may not be the most significant impact on the seabed. The chains and foot ropes of otter trawls act to smooth soft substrate seabeds, obliterating small-scale topographic relief such as the mounds and depressions left by burrowing callianasid shrimp (Kaiser et al. 2002). Small-scale topographic heterogeneity has been considered to be important in controlling the diversity and composition of benthic infaunal communities (Hall 1994).

Trawlers in parts of the NPF take large quantities of sponges as by catch. It is usually assumed that these have been detached from the seabed by the trawl and that they probably don’t survive. Following Cyclone Craig we found more sponges on the study plot than before. These sponges appeared to be alive although there was some abrasion damage. We suggest two possible explanations of these unattached sponges. Firstly that previously attached sponges were dislodged by the cyclone and washed onto the trawled lanes. Although they were apparently alive when we captured them they would eventually have died. The second explanation is that some species of sponge exist in an unattached form. The plastic nature and remodelling characteristics of sponge morphology enable them to adapt to their environment to some degree. Sessile and non-sessile morphs of the same species of desmosponge (*Geodia cydonium*) have been reported in the Mediterranean Sea (Mercurio et al. 2006) and the non-sessile form was able to roll across the seabed. The authors felt that this was an adaptation enabling the sponge to exist on soft substrates, particularly where the anoxic layer was very close to the sediment surface. By being able to roll about, the sponges avoided sinking into the substrate and coming into contact with the anoxic layer (Mercurio et al. 2006).

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CHAPTER 6. IMPACTS OF TRAWLING EXPERIMENTS

6.1 First Trawl Impact Experiment – Design and execution, detection of physical impacts

Mick Haywood, Charis Burridge,
Scott Gordon, Burke Hill

Summary

Experimental design

An experiment was designed to quantify the results of targeted trawling in which an area approximately 1 km × 50 m was trawled repeatedly

- Preliminary analysis of day and night catch rates indicated that crustaceans were the only invertebrates that were more catchable at night. For of logistic reasons we decided to trawl during the daytime
- The repeat trawl experiment was repeated three times in two areas, one to the east and one to the west of Mornington Island
- A high impact of 20 trawls was selected in order to obtain a trawl coverage of at least 10 replicates over the same ground
- A low impact of 4 trawls was also carried out at each site
- An epi-benthic sled was used to sample areas before and after trawling

Results

- Despite use of a skilled skipper and acoustic tracking, it proved difficult to trawl precisely over previously trawled tracks. In the 20 trawl lanes, replication was no higher than 12 times and this only occurred in limited areas
- Detection of trawl activity on the seabed:
    1. We could not detect effect of high intensity trawling after six months using acoustic methods
    2. Side scan sonar could detect trawl tracks on seabed immediately after trawling
    3. Seabed photography showed recent trawl tracks but they were obliterated by bioturbation and so probably do not have a long life
- Trawling in the east was interrupted by a cyclone. When trawling resumed, we found high catch rates of sponges. They might have been dislodged by the cyclone or there may be a population of unattached sponges that can be moved around under turbulent conditions

6.1.1 Introduction

As shown in Chapter 2, the tiger prawn fishery in the NPF uses a strategy of targeting concentrations of prawns. Once a concentration is found, it is trawled repeatedly. We designed an experiment to replicate this strategy and to measure the effect of repeated trawling on the seabed biota. The experiment would be to establish a series of lanes that would be trawled repeatedly using standard commercial trawl nets. Before and after trawling the areas would be sampled by means of an epi-benthic sled. We have described in Chapter 5.1 the procedure for selection of the sites. Here we describe more of the background to the study including the choice between trawling during the day or at night, the design of the experiment, the tracking of the trawl and sled. We also wanted to test three methods of possibly identifying whether or not trawling had taken place in an area. We did this by means of an acoustic survey (using RoxAnn), side scan sonar and seabed photography of the area that had been intensively trawled. We were not confident of being able to obtain seabed photography given the poor visibility most of the time in the study area. The assessment of the trawl impact is described in the next chapter as well as the ability of epi-benthic sled sampling to identify trawling impacts.

6.1.2 Methods

6.1.2.1 Day/night comparison of catch rates of invertebrates

In carrying out the depletion experiment we had a choice of doing the work during the day or at night. Fishing for tiger prawns is a night time fishery but we were mainly interested in sessile and near sessile and slow moving animals such as sponges, gorgonians, bivalves and echinoderms which should be equally catchable at night or during the day. Catch rates of squid and fish are much higher during the day than at night but we were not attempting to measure the impacts on these groups because their considerable mobility. We were planning to impact relatively small areas and fish and squid would be able to rapidly move in and out of these experimental areas. We had data from previous studies giving catch information from trawls carried out during the day and at night and we decided to use this in making the decision on when to trawl.

During 1997, CSIRO made a total of 464 research trawls throughout various parts of the NPF with a pair of Florida Flyers prawn trawls (Stobutzki et al, 2000, Cruise SS9708). The material from these trawls had been analysed. One hundred and eighty seven shots were made during the day and 277 were made at night. To obtain a broad-scale impression of the differences in catch rates of invertebrates between day and night, the invertebrate taxa were grouped into phyla or classes and the catch rates of each taxon by day/night were graphed (see Figure 6.1-1).

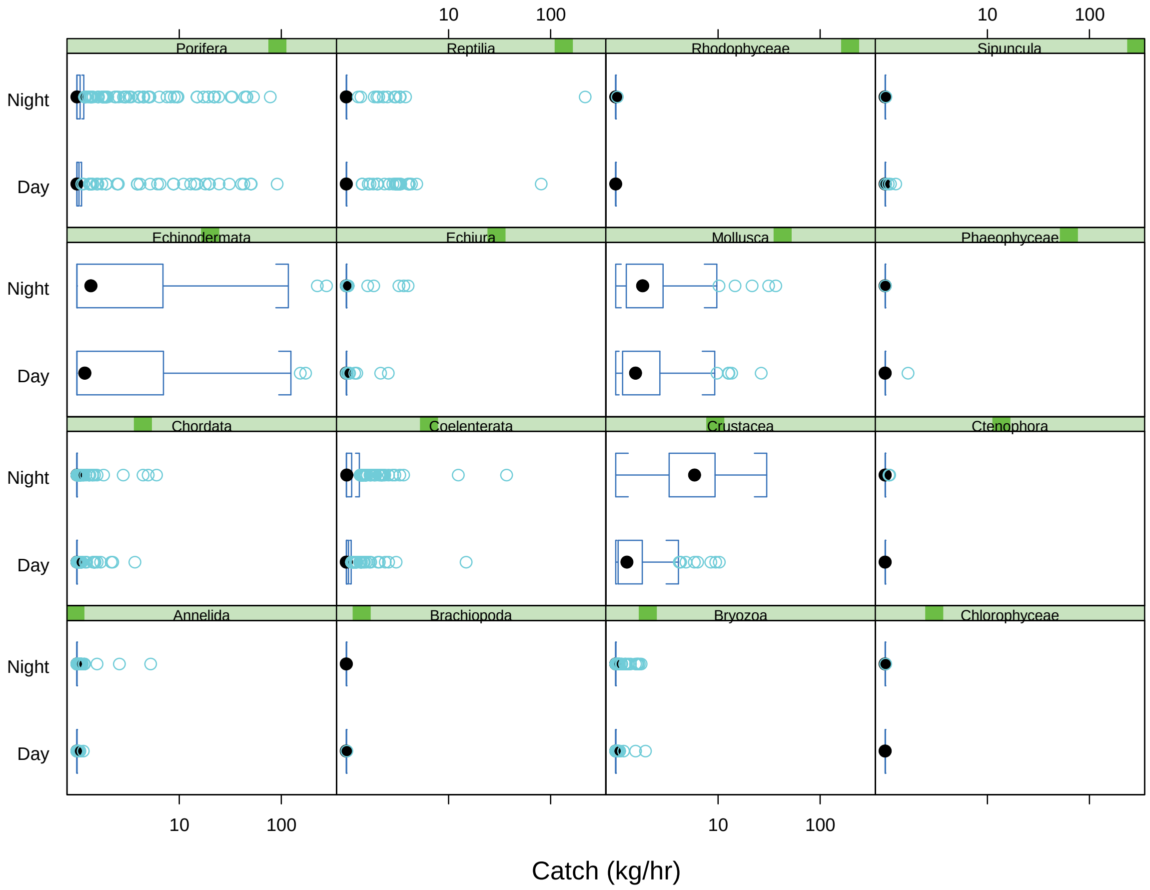


Figure 6.1-1: Day/night comparison (boxplots) of catch rates of invertebrate bycatch taxa from all trawls (SS9708). The filled circle represents the median, the box gives the 25th and 75th percentiles, the whiskers extend to 1.5 times the inter-quartile range and the open circles are points that can be considered outliers.

Overall, the only group that appears to have markedly higher catch rates during the night compared to the day are the crustaceans. However, this analysis is fairly coarse because day and night trawls were not evenly dispersed throughout the fishery; in some areas only night trawls were made.

A second analysis was carried using paired trawls that were made within 1 km of each other; one during the day and one during the night. There were 48 such pairs of trawls in the dataset. The daytime catch rates of each taxon were plotted against the corresponding night-time catch rates at each site (Figure 6.1-2). The catch rates have been scaled by dividing the catch rates within each phylum by the mean catch rate for that taxon. This was done purely to allow all taxa to be graphed on the same scale, so the numbers are relatively meaningless. Sites (open circles) that lie above the 45º dotted line represent sites where the daytime catch rate of that particular taxon was greater than the night-time catch rate.

Unlike the broad-scale analysis above, it is not clear whether any of the groups other than crustaceans consistently have higher catch rates during either the day or night. Crustaceans appear to be more catchable during the night. Most of the crustaceans have a high degree of mobility and so are of less interest in this project than the sessile or slow moving animals. Based on this information we decided that there would not be a significant disadvantage if we conducted our trawling during daylight.

We looked at crustaceans in more detail because they show the greatest contrast in day vs. night-time catch rates. Note that eight families were taken only during night-time shots, whereas three families were taken only in daytime. As with the analysis that included all phyla, we have extracted the paired day/night trawls and compared the catch rates of all Crustacean families (Figure 6.1-3, Table 6.1-1).

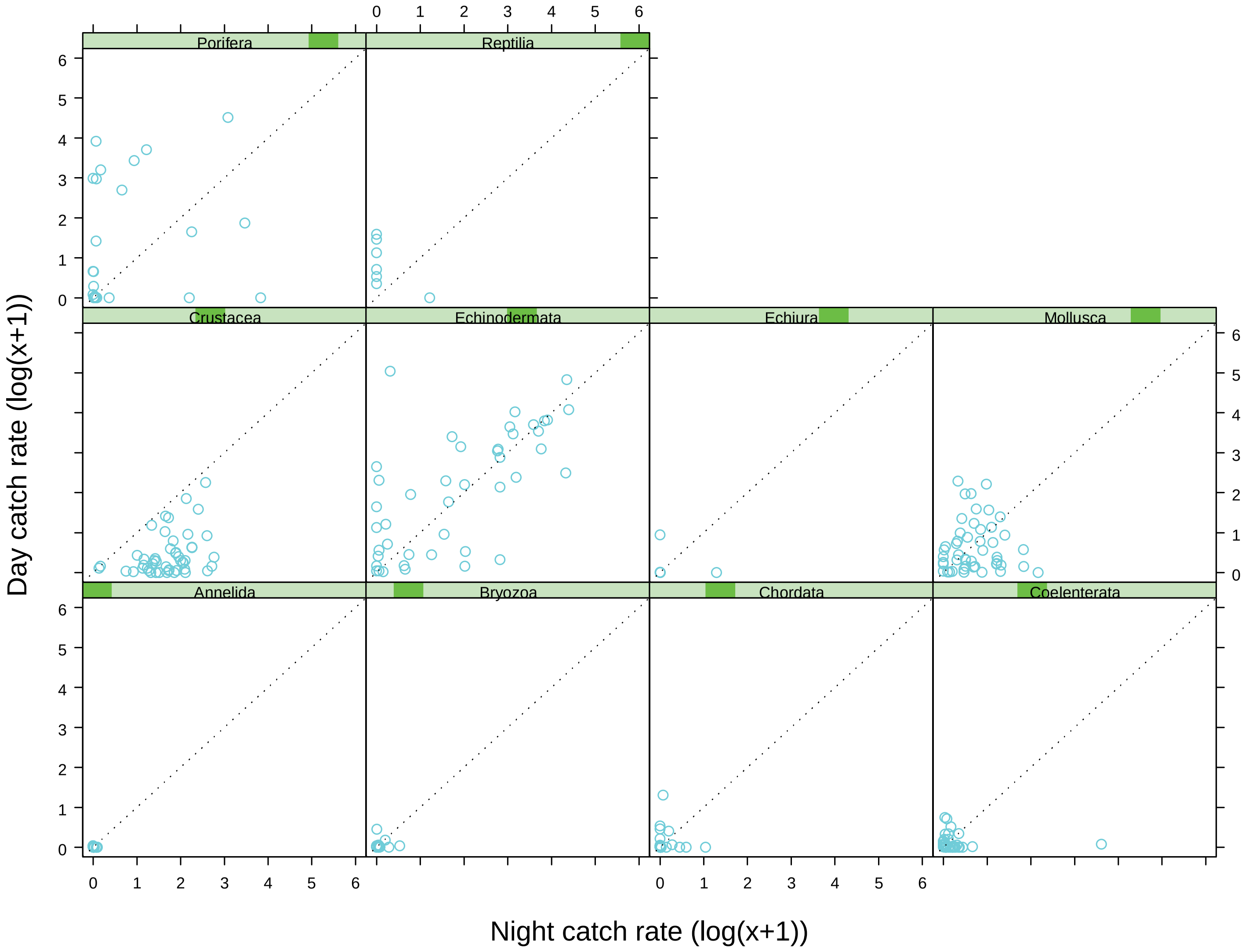


Figure 6.1-2: Scaled day & night catch rates of bycatch taxa at 48 pairs of sites throughout the NPF.

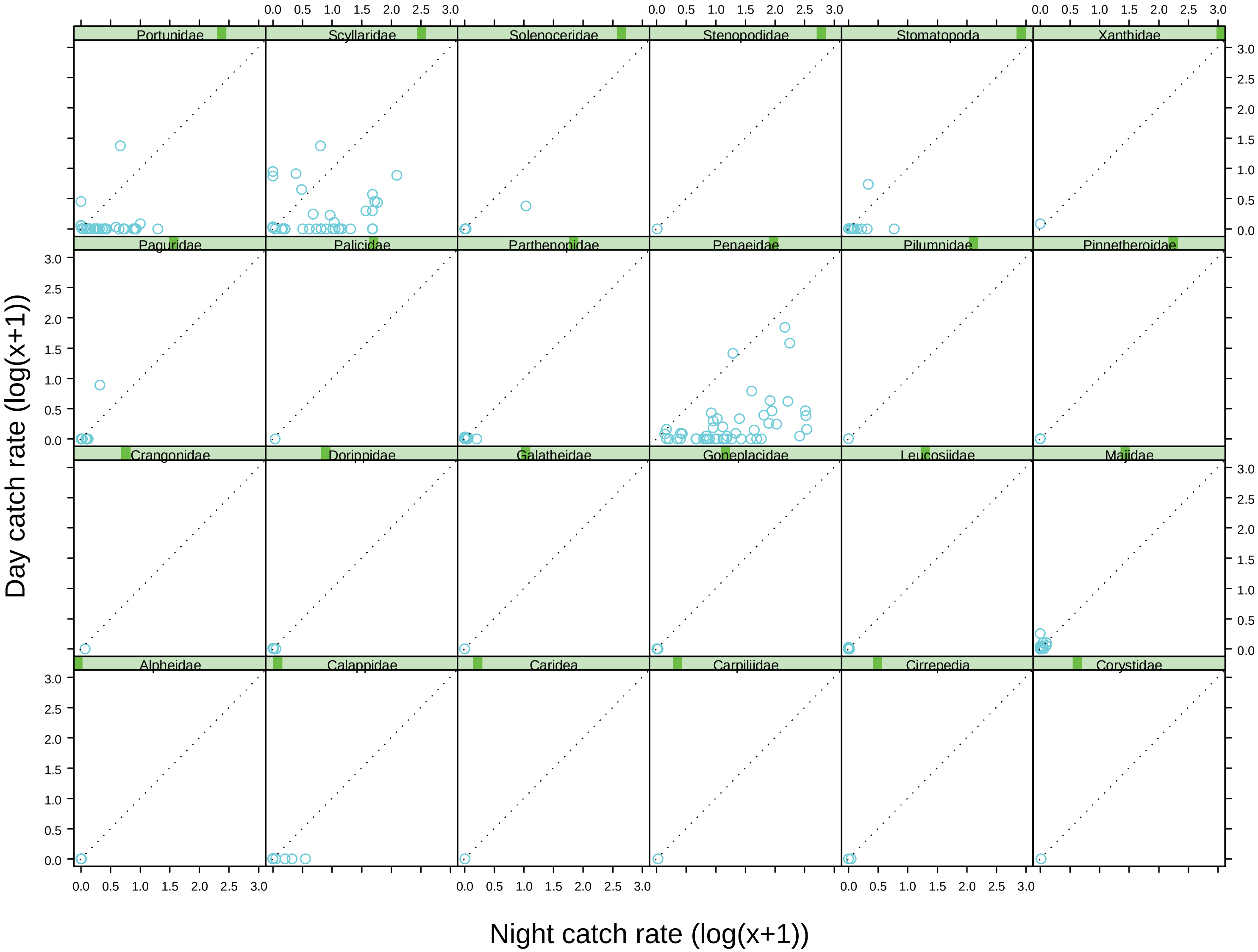


Figure 6.1-3: Day & night catch rates (log transformed) of Crustacea at 48 paired sites throughout the NPF.

Table 6.1-1 : Mean catch rates (kg/h) and t-test of Crustacean families at the 48 paired day/night trawl sites. Families having significantly different catch rates during the day compared to the night are shown in yellow. DF = degrees of freedom.

Family	Day	Night	DF	t value	p
Alpheidae	0.000195	0.029177	47	-0.98	0.3320
Calappidae	0.000000	0.000039	47	-1.64	0.1076
Caridea	0.000000	0.000950	47	-1.00	0.3224
Cirrepedia	0.000000	0.000223	47	-1.00	0.2923
Corystidae	0.000000	0.001460	47	-1.00	0.3224
Crangonidae	0.000219	0.001448	47	-1.00	0.3224
Dorippidae	0.000019	0.000000	50	-1.05	0.2990
Galatheidae	0.000076	0.001135	41	1.00	0.3232
Goneplacidae	0.001979	0.001363	47	-1.99	0.0519
Leucosiidae	0.017991	0.008807	66	0.51	0.6121
Majidae	0.017117	0.008689	58	1.08	0.2835
Paguridae	0.000005	0.000242	47	0.48	0.6356
Palicidae	0.000000	0.000803	47	-1.00	0.3224
Parthenopidae	0.002346	0.008742	51	-1.26	0.2138
Penaeidae	0.501717	3.452997	59	-6.02	<0.0001
Pinnotheridae	0.000095	0.000000	41	1.30	0.2013
Portunidae	0.089843	0.470378	86	-3.34	0.0012
Scyllaridae	0.310543	1.347130	60	-3.85	0.0003
Solenoceridae	0.010990	0.038475	54.9	-0.70	0.4866
Stenopodidae	0.000000	0.000162	47	-1.00	0.3224
Stomatopoda	0.012998	0.028712	89	-0.82	0.4139
Xanthidae	0.002112	0.000480	41	1.00	0.3232

These data suggest that with the exception of the very mobile crustaceans (penaeids, portunid crabs and scyllarids) there is little difference between night and day catches of crustaceans and more importantly, no difference for the near sessile or slow moving taxa.

Given this data, we concluded that there was only a marginal advantage in carrying out the trawls at night. These advantages had to be offset against doing the work during the day. There were two advantages to the latter. Firstly we could carry out more trawls during the day than at night because the dawn and dusk periods give catches more like day than night. This difference when we are considering a large number of trawls adds up to a considerable difference in cost. The project was already under cost restraints as well as a narrow time window for the use of the chartered commercial vessel. We had an upper limit of 21 days use. Setting this against the time needed for the depletion experiment it was clear that we could not complete the work if we trawled at night.

The second advantage related to the complexity of the depletion experiment. We were expecting a commercial skipper to trawl to a far higher level of navigational accuracy than normal. He would be expected to monitor the position of the trawl continuously from a computer display in addition to his normal navigation and to correct the position of the vessel in order to keep the trawl on track. At the same time he would be expected to be aware of the time that the trawl was on the seabed more precisely than during normal fishing operations. We wished to weigh the material removed from each lane of the plot on each trawl shot and so the time the trawl spent on the seabed was critical. In addition the vessel was operating other gear unfamiliar to the skipper and crew – the epi-benthic sled, the side scan sonar, video camera, as well as the system used for monitoring the position of the trawl relative to the boat (which used an overboard transceiver) and the sophisticated GPS monitoring system for tracking the boat. By conducting our operations during the day we believed we would maximise our chances of success.

6.1.3 Experimental design

Burridge et al. (2003) showed that in the GBR region prawn trawls removed on average 10% of the seabed biota although there was considerable variation between taxa. This means that seven trawls should remove around 50% of the biota and 14 trawls should remove around 75%. We wanted an impact of this order – 50 to 75% removal. To achieve this would mean coverage of up to 14 trawls over the same area. However, we realised that given the practical problems of navigation at sea and the fact that the trawl would not necessarily follow the path of the ship accurately, we needed to make more trawls to ensure that we really did have a high impact. We chose 20 as a reasonable compromise between high impact and cost of carrying out trawling.

The experimental design consisted of lanes of seabed exposed to three different levels of trawling: – nil trawls (control), 4 trawls (low impact) and 20 trawls (high impact). Each lane would be sampled by means of an epi-benthic sled before and after trawling. The before sampling would be done in the gap between the trawl nets to avoid disturbance of the area to be trawled. The design is summarised in Table 6.1-2.

Table 6.1-2: Design of the trawl impact experiment.

Treatment	Pre-impact sampling	Impact	Post-impact sampling
Control	3 sled samples	No trawling	3 sled samples
Low impact	3 sled samples	4 trawls	3 sled samples
High impact	3 sled samples	20 trawls	3 sled samples

The experiment would be replicated six times but because we wanted to test whether there were differences in response of seabed with different characteristics, we chose two sampling areas with three sets of lanes in each. We established three sites to the east and three to the west of Mornington Island.

6.1.3.1 **Sampling**

Sampling of the lanes prior to and after trawling would be by an epi-benthic sled (see Chapter 4.3). Subsequent follow up sampling to monitor recovery would also be by the sled. This meant that no trawling would be carried out on the lanes subsequent to the initial impact. Because we did not want the post-impact monitoring to be affected by the sled, we needed to know exactly where the sled was deployed so that we could avoid running it over ground that had previously been sampled. This meant that we required accurate position fixing for the initial trawl impacts as well as the path followed by the sled each time it was deployed.

The lanes were 1 nautical mile (nm) in length. The width was the spread of two 12 fathom (= 43.9 m) nets with a gap between them. The towing blocks for the trawls were 27.4 m apart. The fleet master of A. Raptis and Sons stated that the nets spread to 70% of their head rope length and we used this estimate in our planning. In August 2004 we measured the actual spread using acoustic tracking and were able to factor in the value into our calculations of the impact area. Although we would have preferred to have no gap between the nets, it was necessary to prevent the inner trawl boards from entangling. The gap was estimated to be 12 m wide, we were able to measure the actual width in August 2004. The trawl nets had their TEDs and BRDs removed in order to provide more complete samples of the catch. This removal was done under a scientific permit from AFMA. The 700 kg Bison trawl boards were supplied by Raptis and Sons who also provided the 22.3 m prawn trawler *Arnhem Pearl* under charter to CSIRO for the field work.

Prior to the study we had no data that could be used for a power analysis to decide how many epi-benthic sled samples were needed to demonstrate a trawl impact. We decided to take 3 samples in each lane before the trawling and another 3 after the trawling. The rationale for this number was that each epi-benthic sled sample would cover a width of 1.5 m and a distance of 250 m, a total area of 375 m^2 with three replicates giving a total sample area of 1125 m^2. Although it would have been desirable to have more samples there were practical constraints on the number of epi-benthic sled samples we could fit into the trawl lanes in the two year recovery monitoring phase given the large area each one sampled. If we wanted to collect more epi-benthic sled samples we would have to make the trawl lanes larger which would have cost considerably more in vessel charter time. Analysis of epi-benthic sled samples is also costly and we were conscious of needing to keep down the total cost of the study. We decided that 3 samples in each lane would be a cost effective number that should be adequate to provide a robust estimate of effect.

In the field we pre-sampled the sites by means of three 250 m long tows of the epi-benthic sled. We then ran the twin trawls four times over the first low impact site and 20 times over the heavy impact lane. Finally we carried out post impact sampling using the sled. This process was repeated for the three experimental sites after which the vessel moved to the second experimental area where the process was repeated on a further three sites. At the end of every trawl shot, the catch from each net was dumped separately onto the sorting tray of the trawler. Fish were removed and the remaining invertebrates were put into lug baskets which were weighed. Catches were not subsampled but on most shots we processed the catch from only one net. When the catch was very low we kept the catch from both nets but the samples were kept separate. It was not possible to do all 20 trawls on a lane in one day and so the work was continued through a second day. We decided that we should not carry out post sampling of a lane until 24 hours after the trawling was complete. Previous CSIRO work on scavenging in Torres Strait (Hill and Wassenberg, 1990) indicated this would be an adequate delay to allow damaged animals to be scavenged. Post sampling was carried out using the epi-benthic sled. We collected three epi-benthic sled samples from each trawl impacted lane and from the control area. The position of the trawl and the epi-benthic sled on the seabed was monitored by an acoustic tracking system (See Chapter 6.4).

Processing of biological samples involved removal and discarding of all teleosts and elasmobranchs. Sponges were photographed and a small sample of tissue was taken and the rest of the animal was discarded away from the trawl sites. The remaining invertebrates were put into plastic bags in cartons and frozen for processing at CSIRO Cleveland Marine Laboratories.

6.1.3.2 **Tracking of gear**

In an effort to obtain a more accurate map of the intensity of the impacts we were creating with the repeated trawls, we have modelled the trawl intensity based on the ship's position and the configuration of the fishing gear. We assumed each net spread to 15.4 m with a 12.06 m gap between the two nets.

During the trawl experiment, the vessel's position was recorded every 5 seconds using the GPS. We extracted from the GPS records the positional information that corresponded to each trawl using the start and end time of each trawl. This data was loaded into a GIS and each trawl track converted into a line. The resulting coverage was projected to Universal Transverse Mercator Zone 54 to facilitate accurate length and area measurements.

The trawl tracks were then converted to polygons having a width of 15.4 m (70% of the head rope length). The individual track polygons were then overlaid and the number of times each part of the seabed was trawled was estimated.

6.1.3.3 **Acoustic detection of trawling activity**

The efficacy of acoustic techniques for measuring trawl effect was examined using data obtained from the experimental site six months after the trawl impact. Data was collected with the Simrad EY500 portable scientific echo sounder. The EY500 transmits a pulse of high frequency (120 kHz) sound that is reflected back by the seabed, the reflected acoustic signal was converted to electrical signals by the echo sounder transducer and stored digitally for later analysis. The acoustic sampling covered all trawl lanes described in the experimental design. The position information from the vessels GPS was used to geolocate the control and trawl impact lanes with the collocated acoustic data.

The EY500 echogram data was analysed using the CSIRO ECHO software to generate depth-corrected acoustic indices over a 5 ping interval. Three acoustic indices of mean area backscatter strength were produced, one which related to the entire first acoustic seabed echo [denoted: SA], another which integrates the tail portion of the first echo [denoted: Tail] (related to acoustic roughness), and the other which integrates the entire second echo [denoted: Second] (related to acoustic hardness). Position information and operation start and stop times for the epi-benthic sled transects performed during field sampling, was used to cross-reference the acoustic index data. The number of acoustic index data points generated over a sample transect varied from 70 to 350, with a mean value of 270 records. The resulting acoustic index data, as well as along track depth profiles, was then summarized for each of the experimental sampling transects using mean and standard deviation statistics. Thus eight pieces of acoustic information (Depth mean, Depth standard deviation, SA mean, SA standard deviation, Tail mean, Tail standard deviation, Second mean, Second standard deviation) were produced for each sampling instance, and were tested as a predictor of trawl effect.

6.1.3.4 **Side scan imaging of trawled areas**

We towed a Imaginex Model 858 Side Scan Sonar over three of the experimentally trawled lanes immediately after trawling to see if we could identify any sign of trawling activity.

6.1.3.5 **Swath imaging of trawl tracks**

During May 2003, the RV Southern Surveyor was conducting a cruise through the southern Gulf of Carpentaria for GeoScience Australia which provided us with an opportunity to map the seabed of our study area to the east of Mornington Island using a Simrad/Kongsberg EM300 multibeam swath mapping instrument. The trawl plots were swath mapped on 14th May 2003, approximately 2 months after the trawling had been done on these sites. We were only able to swath the eastern region because the western region was too shallow for the RV Southern Surveyor.

6.1.3.6 Visible effects of trawling

We were not able to photograph the visible effects of trawling on the seabed in the experimental area. However, in 2005, CSIRO undertook a major benthic survey in Torres Strait in which many thousands of photographs were taken of the seabed using a drop camera. This system used a Canon EOS 20D 8 Mega Pixel Digital SLR with an EF-S10-22mm wide angle lens and two Canon Speedlite 550 EX strobes. The camera was mounted inside a pressure housing. During a transect the camera automatically took a photo every 5 seconds. Some of these photographs were in areas subject to prawn trawling and showed the tracks of prawn trawl gear and are presented here.

6.1.4 Results

The cruise started on 1st March and ended on the 18th March. It was interrupted for two days by Cyclone Craig. We established 6 locations where we created a range of trawling impacts. At each location we set out three 1 nm long trawl lanes, consisting of a control (0 trawls), low impact (4 trawls) and high impact (20 trawls) lane. The vessel was steered as carefully as possible by an experienced skipper using differential GPS in an effort to ensure the repeated trawls were laid down on top of each other. However, current, wind, chop and swell interacted with the vessel to make this almost impossible. The calculated tracks of the trawl on the 20 and 4 times lanes for site 6 is shown in Figure 6.1-4.

None of the experimental area was trawled the maximum number of times on either the 20 or 4 trawls treatments at Location 6 (Figure 6.1-4). This was the case for all the locations. In fact for the 20 trawls treatment only 14.5 to 23.5 % of the total area was trawled more than 10 times and between 0.3 – 5.3 % was trawled more than 15 times (Figure 6.1-5). On the 4 trawls treatments between 24.3 to 37.2 % of the total area trawled was trawled more than twice. We had expected this to occur and this was the basis of our decision to trawl 20 times in order to obtain a significant impact. It also illustrates the difficulty of overlying trawl tracks and the importance of having some measure of the track followed.

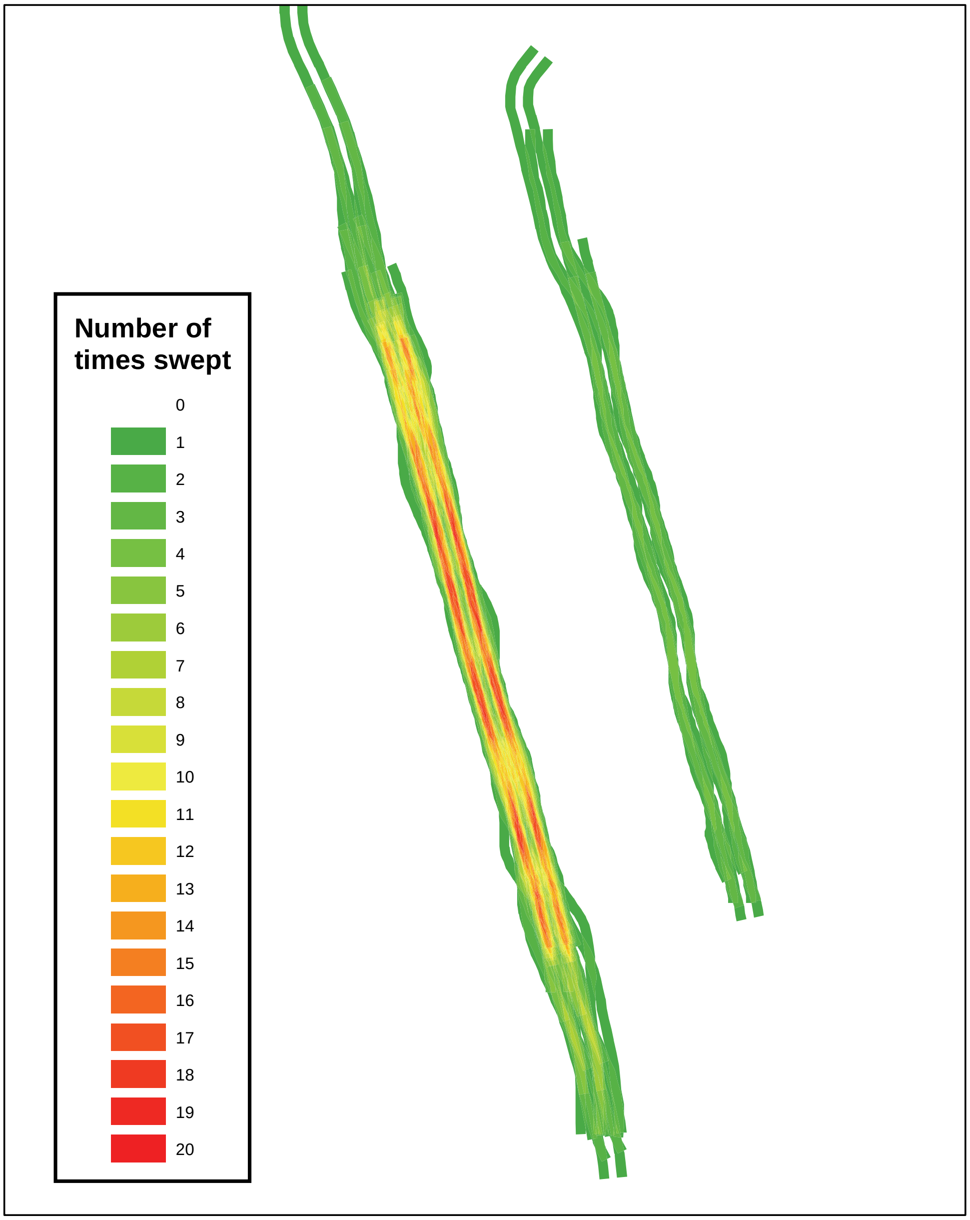


Figure 6.1-4: Trawl intensity map of the 20 times (left) and 4 times (right) trawled treatments at location 6.

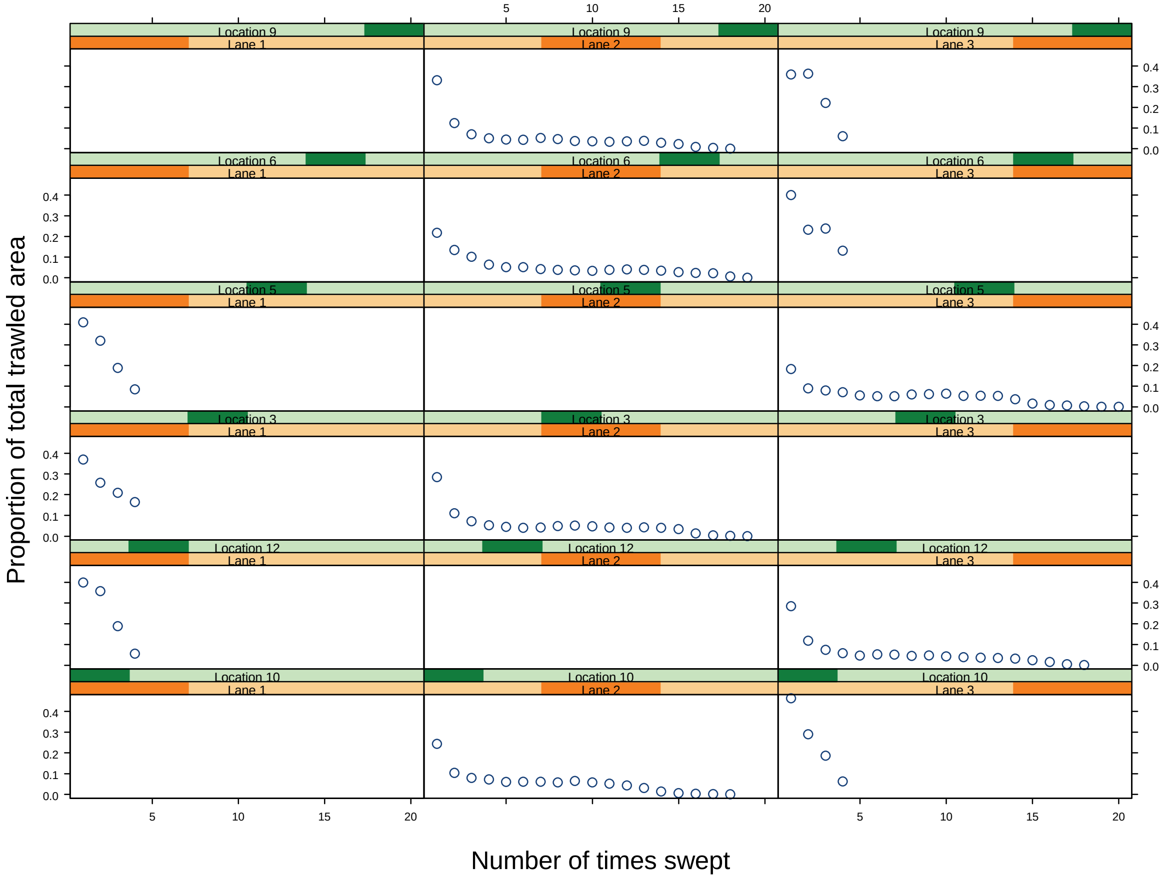
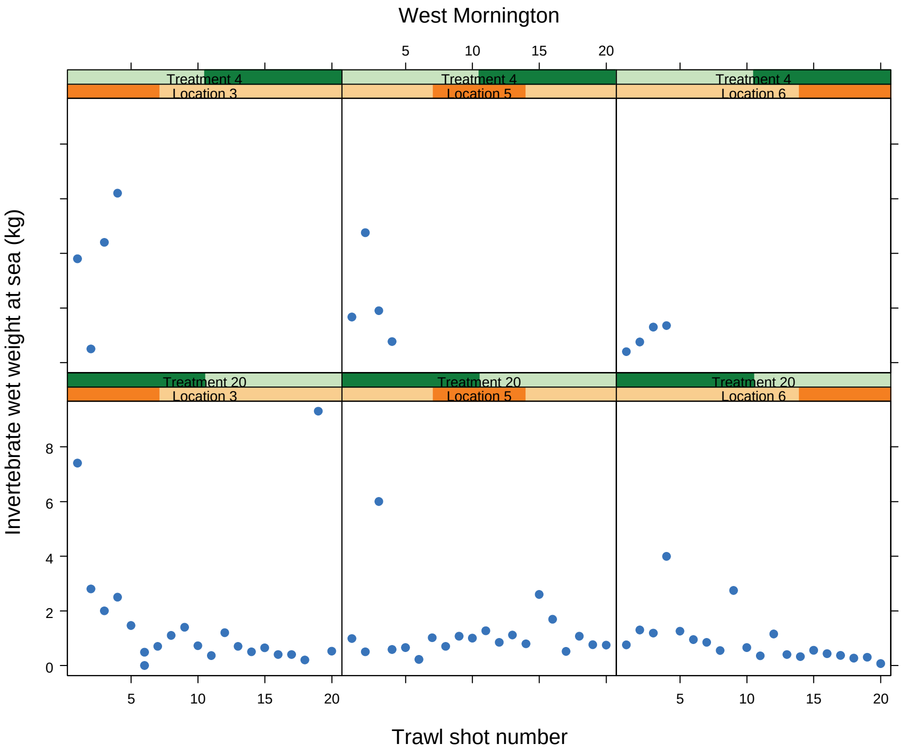


Figure 6.1-5: Proportion of the total area trawled at each lane by the number of times swept. Note that in all cases (except for the controls) the highest proportion of the lane was only trawled once. There are six lanes for each trawl intensity (zero for control, four times for light trawling and 20 times for high intensity)

6.1.4.1 **Trawl catch and the effect of the cyclone**

The invertebrate biomass taken by the trawls was generally much less at the shallow sites to the west of Mornington Island (6.3 to 13.4 m) than those taken in the deeper east Mornington sites (27 to 31.2 m) [Figure 6.1-6]. This was largely because sponges were commonly caught in the east, whereas they were rarely caught in the west. There was no clear evidence of a steady decline in total invertebrate biomass at any of the 4 trawls treatments. However, there was some suggestion of a decline on the 20 trawls treatments at locations 3, 10 and 12. Biomass at location 9 appeared to be declining until trawling stopped after 12 shots due to the approach of Cyclone Craig. When trawling recommenced 2 days later the biomass taken in the thirteenth shot was almost four times that taken in shot 1. Most of this appeared to be due to an increased catch of sponges which had been washed into the experimental area by the cyclone. These sponges were alive.



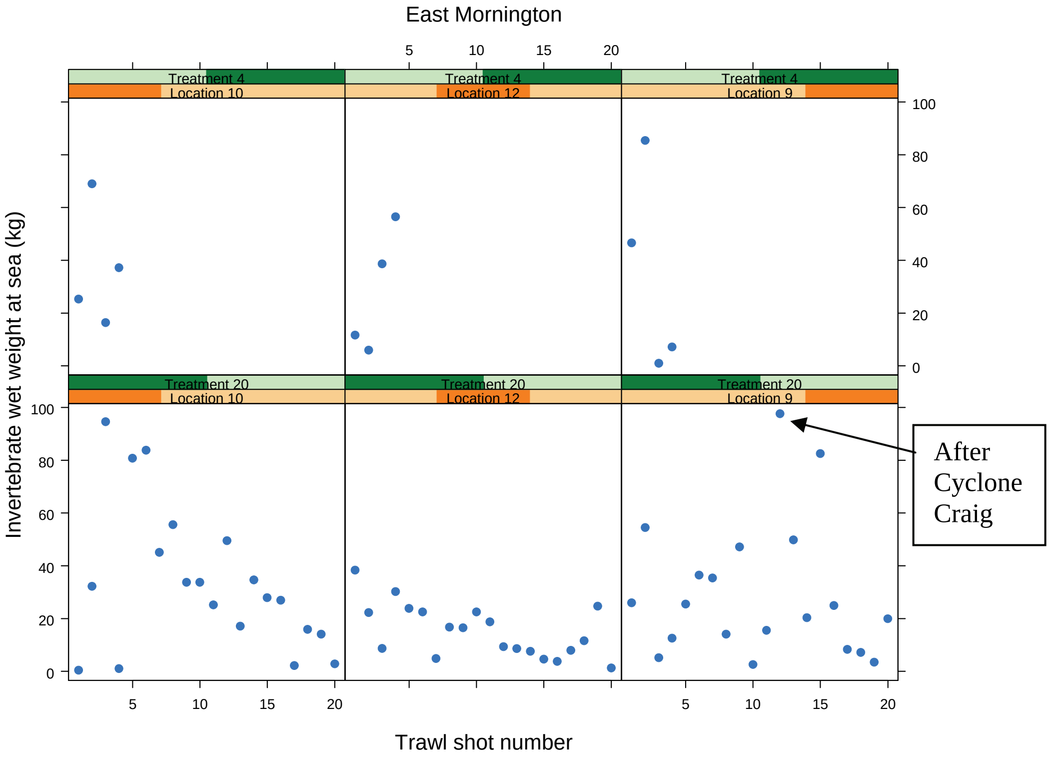


Figure 6.1-6: Total weight of invertebrates in trawl shots taken on the experimental trawl plots to the west and east of Mornington Island. Trawling at Location 9 ceased for 2 days between shots 12 and 13 because of Cyclone Craig.

6.1.4.2 Ability to detect trawl impacts using acoustics

The three acoustic indices for each geographic region and trawl treatment in the experiment are summarised in Figure 6.1-7. There is a large difference between the values of these acoustic indices obtained at the two geographic regions, suggesting that the seabed structure is different; this is also true across the three sample locations within each region. Thus for completeness, the effects of region and location were included in subsequent statistical analyses of trawl impact prediction. These results also suggest that there is a high variance for the acoustic indices and that there is some level of irregularity in the values obtained when taking into account the trawl impact experimental treatment.

A nested analysis of variance (ANOVA) was used to test the performance of each acoustic index as a predictor of trawl impact. The ANOVA took into account the nested / hierarchical design and included the acoustic indices as response variables, the trawl intensity as the experimental treatment, with location and region as a nested control variable and also took into account interactions between the variables. The results of the eight ANOVA's are presented in Table 6.1-3 as the statistical significance (F-statistic) of each term in the analysis.

Table 6.1-3: Acoustic predictors of trawl effect / intensity; results of nested analysis of variance: significance (probability: F-statistic) [* p < 0.1, ** p < 0.05, *** p < 0.01, **** p < 0.001].

Acoustic Response Variable	Experimental Treatment: Trawl Intensity (0, 4, 20)	Control: Nested Location & Region	Treatment & Control Interaction
Depth Mean	0.0035***	0.0000****	0.0000****
Depth Standard Deviation	0.6958	0.0000****	0.0197**
SA Mean	0.3759	0.0000****	0.0031***
SA Standard Deviation	0.2304	0.0000****	0.0117**
Tail Mean	0.1473	0.0000****	0.0414**
Tail Standard Deviation	0.3453	0.5397	0.4715
Second Mean	0.0048***	0.0000****	0.0000****
Second Standard Deviation	0.4056	0.0000****	0.0981

The results of the ANOVA clearly suggest that region and location may be predicted with all acoustic indices and are highly statistically significant; except for the standard deviation measure of the Tail index. The only acoustic index predictor of trawl intensity which had any level of statistical significance was the mean measure of the second echo (or acoustic hardness); though even this predictor was not as significant as either the nested location and region or the interaction terms. This result shows that most of the variance in the acoustic indices obtained during sampling is explained by the location and region factors of the experiment, and to a lesser extent by the interaction between these factors and the experimental treatment of trawl intensity. Even when these significant non-treatment factors are taken into account, the trawl intensity applied during experimental treatment does not explain any statistical significant variation in acoustic indices.

The results of this analysis of acoustic indicators show that they were unable to detect the difference between no trawl, light trawl and heavy trawl impacts six months after the experiment was conducted.

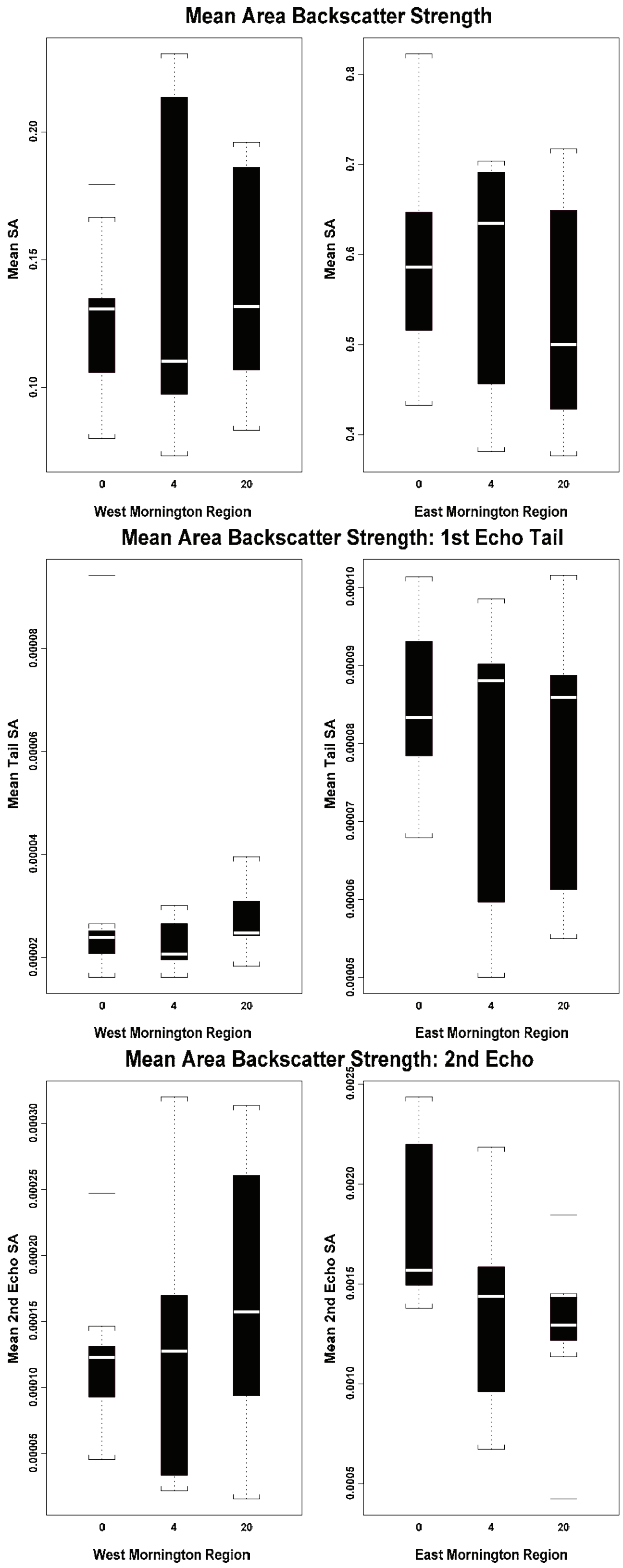


Figure 6.1-7: Acoustic Mean Area Backscatter Strength indices summarised by geographic region and experimental treatment.

6.1.4.3 **Side scan imaging of trawl tracks**

The side scan sonar showed the tracks of the otter boards on the seabed immediately after trawling. Unfortunately the quality of the images was very poor and because of ongoing problems with the unit we did not repeat the observations after 6 months so we do not know how long the tracks remain visible.

6.1.4.4 **Swath imaging of trawl tracks**

The swath images were taken at 1m resolution and provide detailed topography of the seabed of the eastern study area (Figures Figure 6.1-8 to Figure 6.1-10). The seabed was very flat and featureless at all locations with the maximum relief of 3.20 m occurring across Location 12. We were not able to distinguish any otter board marks on the seabed from the swath images.

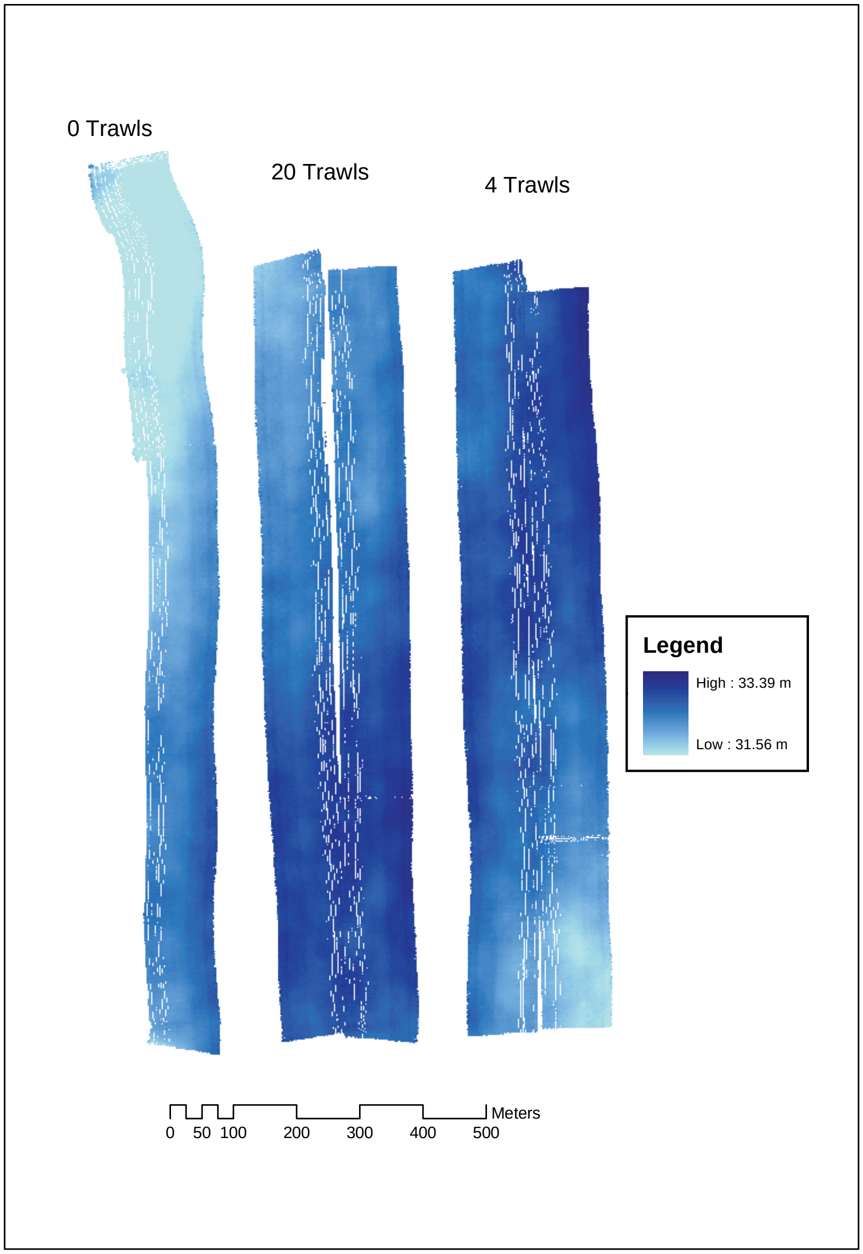


Figure 6.1-8: Swath map of the trawl lanes on the seabed at Location 9. Data acquired by Geoscience Australia.

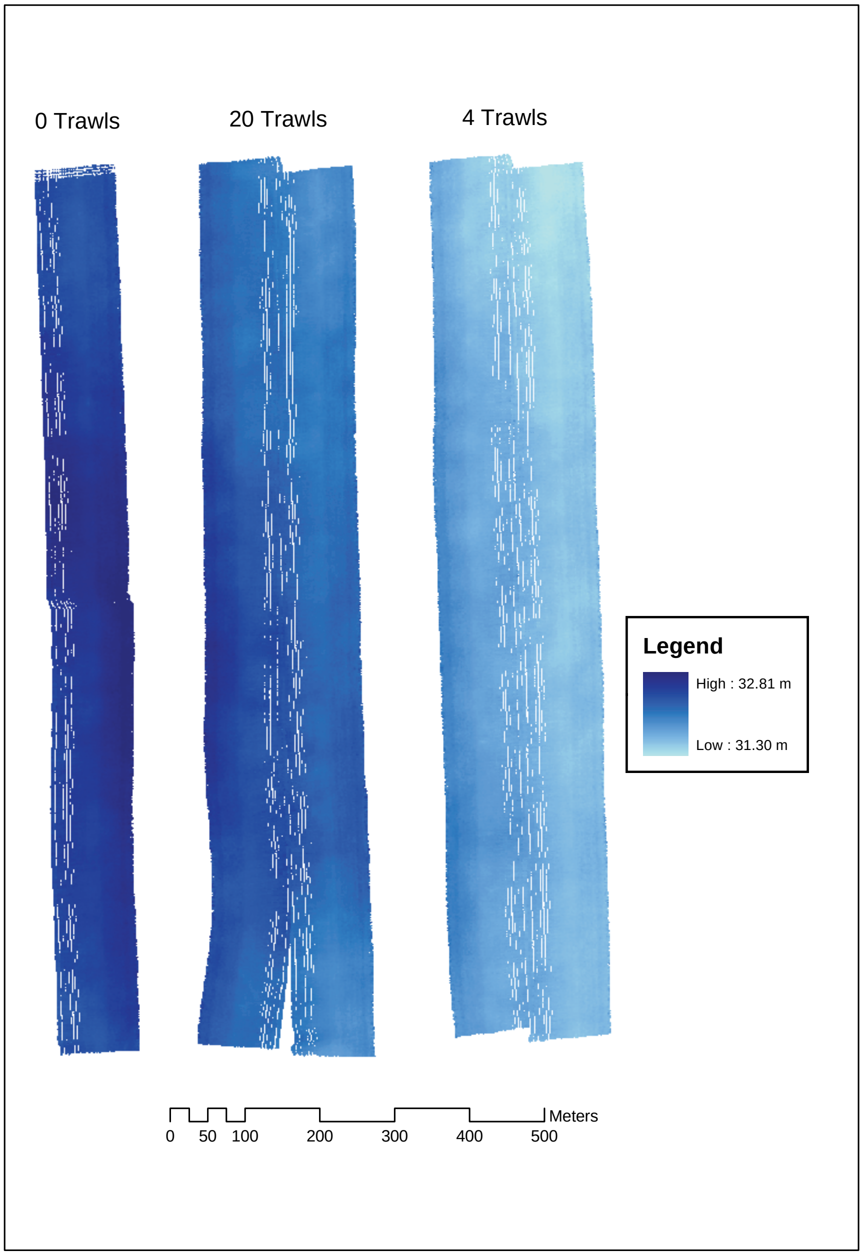


Figure 6.1-9: Swath map of the trawl lanes on the seabed at Location 10. Data acquired by Geoscience Australia.

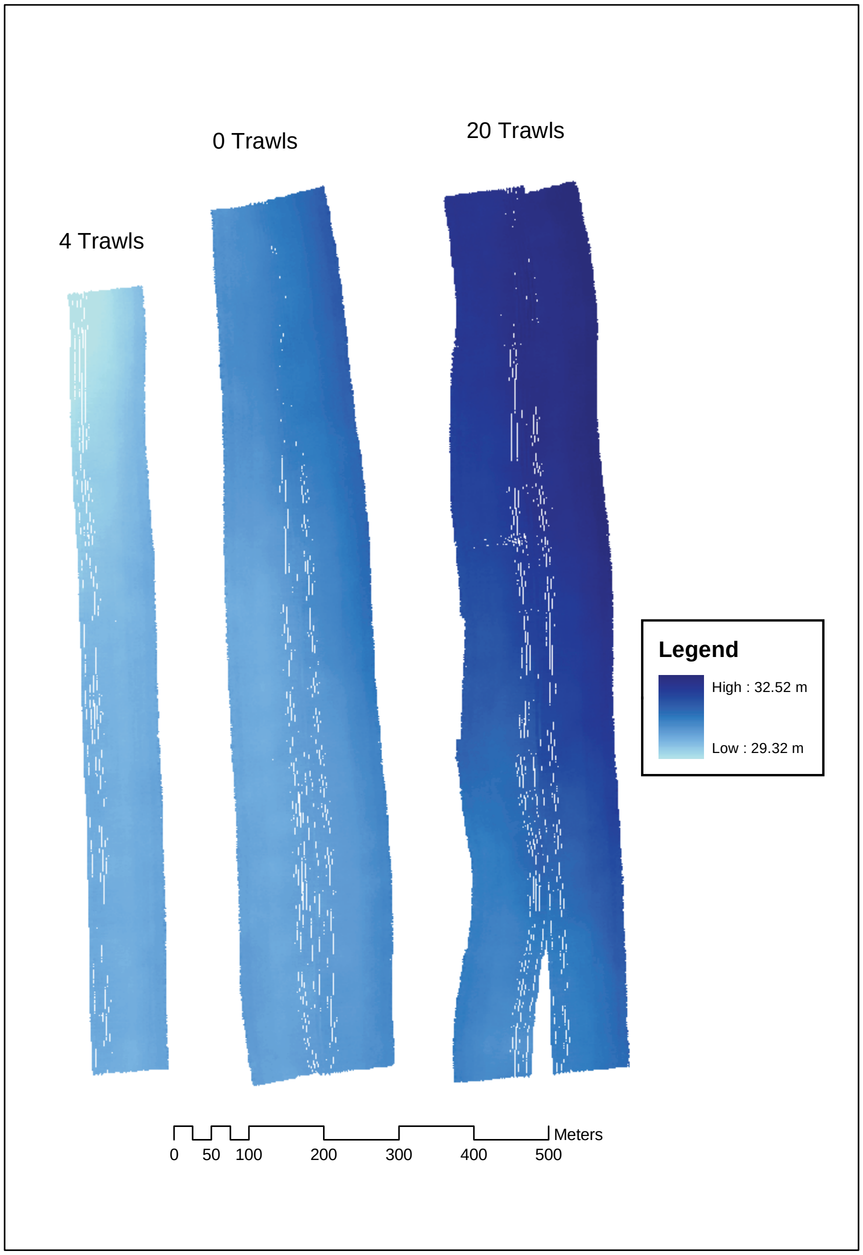


Figure 6.1-10: Swath map of the trawl lanes on the seabed at Location 12. Data acquired by Geoscience Australia.

6.1.4.5 **Visible effects of trawling**

Trawl doors have a greater physical impact on the seabed than does the net although the area of impact is far smaller. Typical trawl otter board tracks are shown in Figure 6.1-11 from Torres Strait.

The two red points in Figure 6.1-8 are laser spots that are 27.5 cm apart. Using these scaling points, we can calculate that the width of the track made by the trawl boards is around 15-18 cm. The shape of the track is the result of the complex hydrodynamic forces around the board including a vortex behind the board (Gilkinson et al. 1998).

Figure 6.1-11: Track made by an otter board on the seabed. A soft coral (top left) has apparently been bent over by the board (Photo from Torres Strait 2005)

The visible effects of the trawl net are less distinct and were not detected but the chains in front of the net do disturb the seabed (Figure 6.1-12). Because of the much greater width of the chains, the area showing their effect is much larger than that of the boards. The pressure exerted by the chains is much less than the boards and so the grooves and ridges are shallower and smaller.

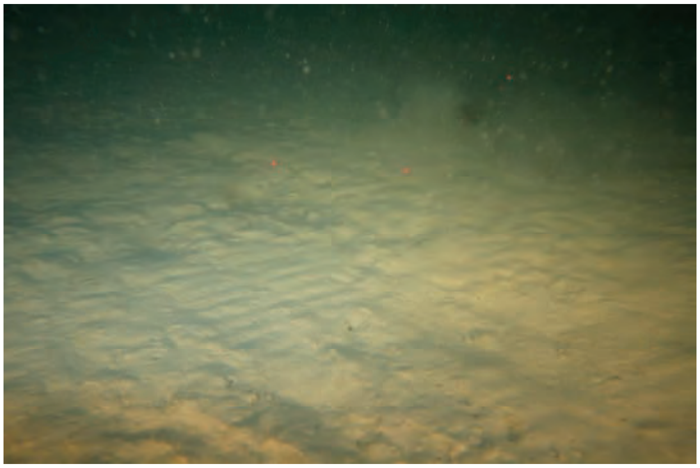


Figure 6.1-12: Marks left by trawl net chains on seabed (left to right) crossing older tracks (bottom right to top left). (Photo from Torres Strait 2005)

Trawl tracks are eventually obliterated by the activity of the benthic fauna, especially the burrowing species (Figure 6.1-13). The rate at which the tracks are obliterated depends on the seabed fauna and so is likely to vary between areas but given the soft nature of the sediments, the process is probably quite rapid.

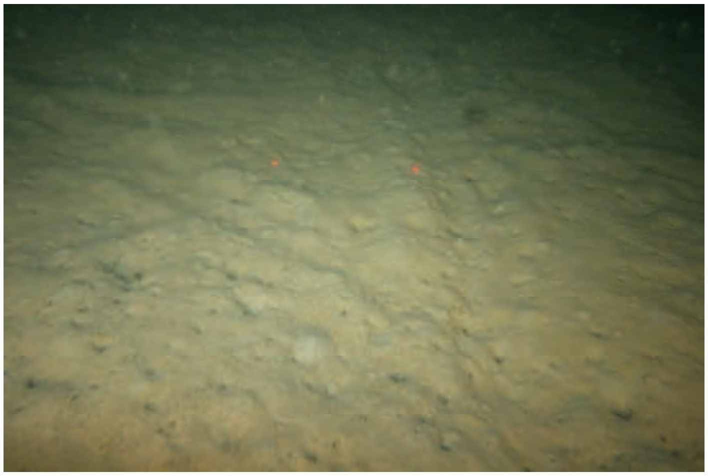


Figure 6.1-13: Possible crisscrossing old trawl board tracks that are being obscured by bioturbation. (Photo from Torres Strait 2005)

6.1.5 Discussion

We used differential GPS to position the vessel with an accuracy <1m for 95% of time. Skippers in the NPF who fish for tiger prawns are skilled in positioning their vessel over the fishing grounds. Using computer-based chart plotting systems they have accurate information on previous tracks of the vessel and can use these in planning their tracks. We found however that even with a skilled skipper, it was difficult to pilot the vessel over the same line.

Knowing the position of the vessel does not mean that the position of the trawl is also known. Because the trawl wire is a flexible connection, the trawl and boat can move independently to some extent. In deep water this can result in a substantial difference in track between the two. Engås et al. (2000) found deviations of 27 to 213 m when trawling in deep water in the Barents Sea. Modern acoustic tracking equipment enables the position of the trawl gear to be plotted relative to the ship (McKeown and Gordon DC, 1997). We used this system in our experiment and found that because we were operating in shallow water, the track of the trawl and vessel was fairly close but they do not correspond exactly. The result of these various discrepancies is that successive trawl tracks are not coincident. This non-coincidence has not been taken into account in most research of this nature because of the difficulty of establishing the position of the trawl or other sampling gear. We used an acoustic tracking system and so we have a fairly good idea of the position of the trawl. Despite trawling 20 times over the 'same track' most of the area was trawled less than 10 times. In the following chapter, we have analysed trawl depletion rates separately for coincidental and non-coincidental trawls to show the differences.

Two months after trawling the swath mapping confirmed our impression of the seafloor topography of the eastern study sites and was unable to detect any visible disturbance of the seabed due to trawling. This is probably not surprising since the resolution of the swath imagery was only 1 m, which although very useful for broad topography is probably too coarse to reveal the fine-scale disturbance we might expect from trawl nets and boards.

After six months, our acoustic system could not detect signs of furrows dug by the trawl doors on our intensively trawled lanes. The RoxAnn system has been shown to be capable of detecting the effects of trawling on the seabed in areas where very heavy fishing gear is used. Humborstad et al. (2004) carried out experimental trawling using Rockhopper gear (with 21" long steel bobbins and boards weighing 2300 kg each. They found changes in the acoustic hardness of the seabed that were consistent with a possible re-suspension of the sediment and a homogenizing effect from the trawl doors and ground gear ploughing the area. The result was an increase in acoustic roughness and a decrease in acoustic hardness. Prawn trawl gear used in the NPF is much lighter, there are no bobbins and the boards weigh up to 500 kg each. We conducted an acoustic survey 6 months after trawling whereas Humborstad did so immediately after trawling. In 20 to 40m depth off Barcelona in Spain, Palanques et al. (2001) found that the furrows made by otter trawl doors persisted for at least 1 year on the seabed, however the substrate in this case was fine mud in contrast to the sandy sediments in the present study. We suggest the lower weight prawn trawl gear coupled with intensive bioturbation in shallow tropical water was the reason that trawling was not detectable on our intensively trawled plots after 6 months.

Furrowing caused by the impact of the trawl doors on the substrate may not be the most significant impact on the seabed. The chains and foot ropes of otter trawls act to smooth soft substrate seabeds, obliterating small-scale topographic relief such as the mounds and depressions left by burrowing callianasid shrimp (Kaiser et al. 2002). Small-scale topographic heterogeneity has been considered to be important in controlling the diversity and composition of benthic infaunal communities (Hall 1994).

Trawlers in parts of the NPF take large quantities of sponges as by catch. It is usually assumed that these have been detached from the seabed by the trawl and that they probably don’t survive. Following Cyclone Craig we found more sponges on the study plot than before. These sponges appeared to be alive although there was some abrasion damage. We suggest two possible explanations of these unattached sponges. Firstly that previously attached sponges were dislodged by the cyclone and washed onto the trawled lanes. Although they were apparently alive when we captured them they would eventually have died. The second explanation is that some species of sponge exist in an unattached form. The plastic nature and remodelling characteristics of sponge morphology enable them to adapt to their environment to some degree. Sessile and non-sessile morphs of the same species of desmosponge (*Geodia cydonium*) have been reported in the Mediterranean Sea (Mercurio et al. 2006) and the non-sessile form was able to roll across the seabed. The authors felt that this was an adaptation enabling the sponge to exist on soft substrates, particularly where the anoxic layer was very close to the sediment surface. By being able to roll about, the sponges avoided sinking into the substrate and coming into contact with the anoxic layer (Mercurio et al. 2006).

6.1.6 References

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CHAPTER 6. IMPACTS OF TRAWLING EXPERIMENTS

6.2 Analysis of the effects of repeated trawling on seabed biota

Petra Kuhnert, Geoff Laslett, Burke Hill, Mick Haywood, Wayne Rochester

Summary

- Trawl catch data was subjected to several different analyses to deal with the complexity of the data
- Estimates of depletion rates were calculated initially assuming trawls were coincident. As the trawls were not being exactly aligned over each other, an additional model was constructed to adjust for non-coincidence. Adjustment was also made for the effect of a cyclone that occurred during the experiment
- Using the Burridge model (assumes coincidence of trawls), the estimated mean depletion rate for all taxa and locations combined was 9.3% (s.d. 4.2%)
- Allowing for non-coincidence of trawls increased estimated depletion rates (to 12% for all taxa combined) and decreased the estimated initial biomass
- Depletion rates for Gymnolaemata, crinoids and hydrozoans were higher than those measured in the Great Barrier Reef region, those for ophiuroids were lower but they were the same for porifera, crustaceans, ascidians, asteroids and bivalves
- Samples taken by the epi-benthic sled only identified an effect of trawling in a limited number of taxa. This is thought to be due to the high degree of spatial variability of the spatial distribution of many of the benthic organisms over the seabed, in combination with low sample numbers

6.2.1 Introduction

The primary aim of this project was to determine the effect on the seabed biota of repeated trawling. We proposed to do this by an experiment in which we repeatedly trawled discrete areas. The experiment is described in Chapter 6.1. Briefly it consisted of six replicates in each of which there was a lane that was trawled 20 times (high intensity), another that was trawled 4 times (low intensity) as well as an adjoining control area. We used an epi-benthic sled to sample the experimental lanes both before and after trawling. As shown in Chapter 6.1, the repeated trawl tracks did not coincide and most of the intensively trawled area was in fact trawled less than 10 times. This complicates the analysis of the extent of the impact. The key questions that we want to address in this analysis are as follows:

1. Did the experiment show depletion of the seabed biota by a prawn trawl and what was the extent of any depletion?
2. Is the estimate of depletion measure altered by allowing for non-coincidence of trawls?
3. Did the samples collected by the epi-benthic sled show a trawl impact?

Following the high and low intensity repeated trawling, we collected three epi-benthic sled samples from each plot. Comparison of these samples with those collected before trawling would show whether or not sled samples could be used for measuring a trawl impact. The number of sled samples was limited because originally, the plots were to be monitored for the following 24 months to estimate recovery following a trawl impact. We considered it important that the sled tracks did not crossover each other as this would confound our recovery estimates. Given that each original trawled plot was approximately 100 × 1000 m we could only fit 16 × 250 m long sled transects within each plot. Six of these transects were sampled before and immediately after the trawling and we sampled 3 each time we revisited the plots at 6 monthly intervals. We could not fit any more sled transects within the plots without having them cross over each other. This section includes the analysis of the before and after sled samples.

We used a variety of techniques for analysis. First, to provide baseline estimates of depletion rates that did not consider non-coincidence of trawls or epi-benthic sled data, we used a method developed by Burridge et al. (2003) for a repeat trawl experiment on the Great Barrier Reef, and which estimates depletion rates from trawl data only. Second, we developed a method to take into account non-coincidence of trawls (referred to here as the 'Laslett technique', the name being that of the author). Finally, we developed a method that considers non-coincidence of trawls and uses both trawl and epi-benthic sled data (the 'Kuhnert technique'). The Kuhnert method also considers possible effects of the cyclone that occurred during the trawl depletion experiment. Because the methods are quite complex, they are each described in separate results and methods sections. Additional detail on the methodology is provided in Appendix H.

6.2.2 Burridge technique

6.2.2.1 Methods

For most purposes, the most useful definition of depletion rate is the proportion of biomass removed by each trawl shot rather than the absolute weight removed. If our data included an accurate measurement of the initial weight of each taxon before trawling then the depletion rate could be calculated directly from the initial weight and the trawl catches. Because we do not have such an accurate measurement of the initial weight, we must estimate both the initial biomass and the depletion rate from the trawl catches alone. (Theoretically, the initial weights could be estimated from the epi-benthic sled samples taken before trawling. In practice, the samples do not estimate the initial weights accurately enough to enable calculation of depletion by direct calculation as described above. However, the epi-benthic sled samples can be used statistically to improve depletion estimates as in the Kuhnert method described below.)

Burridge et al. (2003) proposed a simple model for the measuring the depletion rate of benthic fauna in a repeat trawl survey. Let X_0 be the biomass of benthos present before trawling begins, and c_i the biomass of benthos caught during trawl *i*. The total amount of benthos caught prior to trawl *i* is

$$T_i = \begin{cases} \sum_{j=1}^{i-1} c_j & \text{if } i > 1; \\ 0 & \text{otherwise} \end{cases}$$

The Burridge et al. (2003) model is

$$c_i = q_i(X_0 - T_i),$$

where

$$q_i \sim \text{Beta}(\alpha, \beta)$$

is the proportion of remaining benthos caught in trawl *i*. In this model the depletion rate varies from trawl to trawl, with mean $\pi = \alpha/(\alpha+\beta)$ and variance $\pi^2(1-\pi)/(\pi+\alpha)$. For the data that the authors examined (benthos from inter-reefal areas on the Great Barrier Reef), the mean depletion rate varied from 4% for algae to 20% for gastropods. The coefficient of variation of q_i was usually between 50% and 70%.

Interpretation of depletion patterns is complex because they vary from site to site and among species. Also, catches from a site are often dominated by one or two taxa, and the depletion pattern of all species combined may not reflect the patterns of the rarer or smaller taxa. To enable interpretation of site and taxon effects, depletion rates were estimated for all locations combined and for each location separately, and for taxa combined in taxonomic and functional groups. The taxonomic groups were all taxa from kingdom down to species that were present in at least 10 of the total 120 trawl shots in the experiment. The functional groups were benthic animals, benthic sessile animals, benthic mobile animals and pelagic animals. To address particular questions, modified functional groups were also defined as needed to exclude rare or heavy taxa (e.g. trumpet shells) or dominant taxa (e.g. sponges).

6.2.2.2 **Results**

Approximately 14 times more biomass (invertebrates and plants only) was removed by the trawls in the eastern sites (697.4 kg) compared to the western sites (49.5 kg; Table 6.2-1). The total biomass of all classes other than Holothuria was greater in the deep water eastern sites. Sponges dominated the biomass caught in both areas, forming 88.6% of the eastern biomass and 45.5% of the biomass in the west. Crustaceans formed the second highest catch: 7.5% in the east and 38.2% in the west.

The detailed results of depletion estimates by taxon are given on the CDROM accompanying the report. Trawling at location 9 was interrupted for two days between shots 11 and 12 by a cyclone, and the catch of the first shot following the cyclone was over twice that of any other shot. Results for 'all locations combined' therefore include locations 3, 5, 6, 10 and 12, but not location 9.

The depletion rate for all locations and taxa combined was 9.3% (s.d. 4.2%). The catches declined reasonably steadily from the first to the last shot, as expected when the depletion rate is constant as our estimation method assumes (Figure 6.2-1). In terms of biomass, the catches and the depletion estimate were dominated by the two eastern locations, which contributed 89% of the total catch for the combined locations. Taxonomically, the catches were dominated by sponges, which represented 86% of the total catch weight.

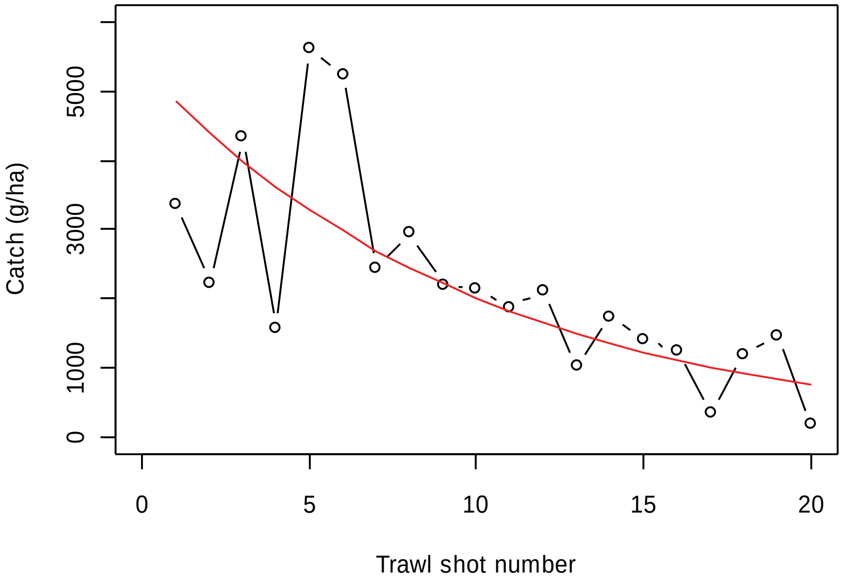


Figure 6.2-1: Trawl catches of all locations and taxa combined. The red line indicates the fitted values from the depletion rate analysis.

The five locations varied in depletion pattern and species composition. With all taxa combined, no location showed the consistent pattern of declining catches that would result from a relatively constant depletion rate. Locations 3, 6 and 10 had visibly declining trends (e.g. Figure 6.2-2) and estimated mean depletion rates of 12–17% (s.d. 7–13%). In some cases the depletion rates were erratic, with large spikes caused by the capture of relatively large uncommon taxa. For example the trumpet shell (*Syrinx aruanus*) is a large uncommon gastropod, and the single individual caught at location 5 on the fourth trawl resulted in a large spike in the depletion rate of the total biomass at this location (Figure 6.2-2). Locations 5 and 12 had no visible declining trend and depletion rates could not be estimated. The catches of the eastern locations (9, 10 and 12) were all dominated by sponges (over 85% of the catch). At the western locations (3, 5 and 6), sponges ranged from rare to dominant, but a substantial proportion of the catch was always crabs (23–52%) and other taxa such as squid.

Table 6.2-1: Total biomass (kg) removed at each treatment (4 or 20 trawls) at each location at the east and west Mornington experimental sites.

	Total biomass (kg)											
	East Mornington						West Mornington					
	LOCATION						LOCATION					
	9		10		12		3		5		6	
	No. of trawls		No. of trawls		No. of trawls		No. of trawls		No. of trawls		No. of trawls	
	4	20	4	20	4	20	4	20	4	20	4	20
Anthozoa	0.066	0.065	0.006	.	0.033	0.058	0.007	.	.	0.026	.	.
Ascidiacea	.	0.065	0.082	.	0.015	0.025	0.103	0.174	.	0.003	0.017	0.009
Asteroidea	0.148	.	0.694	0.032	5.267	1.098	0.464	0.069	0.103	0.001	.	.
Bivalvia	0.951	0.168	0.435	0.219	0.45	2.01	0.027	0.015	0.075	0.005	.	.
Cephalopoda	0.791	0.74	0.585	1.004	0.633	0.136	0.368	0.362	1.597	0.28	0.02	0.362
Crinoidea	0.015	.	0.038	0.012	0.041	0.102	0.035	.	.	.	.	0.009
Crustacea	12.976	3.327	10.87	3.004	10.796	11.467	3.614	3.109	4.303	1.579	3.128	3.208
Desmospongiae	124.228	82.302	118.725	127.107	94.901	70.74	0.019	15	1.9	5.6	.	0.005
Echinoidea	0.055	0.274	1.239	0.05	0.744	0.104	0.003	0.002	.	.	0	.
Gastropoda	0.016	0.004	6.724	0.004	0.012	0.02	0.007	0.01	0.01	0.018	.	2.806
Gymnolaemata	0.086	0.062	0.031	0.019	0.121	0.023	.	0.001	.	.	0.002	.
Holothuroidea	.	.	.	.	0.013	0.049	0.09	0.251	0.444	0.199	.	0.075
Hydrozoa	0.065	0.018	0.024	0.029	0.088	0.421	.	.	0.001	0.001	.	.
Liliopsida	.	.	.	.	.	.	0.001	.	.	.	.	.
Oligochaete	.	.	0.004	.	.	.	.	.	.	.	.	.
Ophiuroidea	0.115	0.099	0.281	0.007	0.119	0.012	.	.	.	.	.	.
Polychaeta	0.083	.	.	.	.	.	.	.	.	.	.	0.005
Total	139.594	87.124	139.738	131.488	113.235	86.266	4.739	18.993	8.433	7.711	3.169	6.478

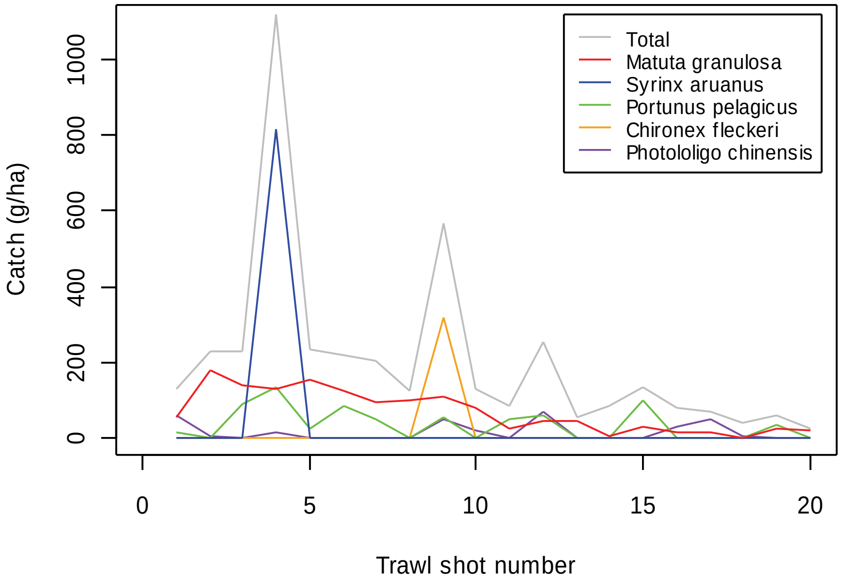


Figure 6.2-2: Trawl catches of all taxa at location 6. The catches of the top six taxa at the location are also indicated. (*Matuta* and *Portunus* are crabs, *Syrinx* is a gastropod, *Chironex* is a jellyfish and *Photololigo* is a squid.)

Although the bulk of the weight of the trawl catches was made up of only a small number of taxa (over 90% of the total catch was sponges and crabs), many more taxa were present in a large proportion of catches. Common taxa included Penaeidae (present in 37% of all 120 shots), Brachyura (98%), Scyllaridae (62%), Ascidiacea (40%), Hydrozoa (54%), Echinoidea (37%), Stelleroidea (70%), Gymnolaemata (43%), Bivalvia (61%), Cephalopoda (79%), Gastropoda (49%) and Porifera (58%).

Depletion patterns varied among taxa. The pattern of declining catches that is consistent with a constant depletion rate was shown by Crustacea (3 of the 5 locations at which the taxon was reasonably common, mean depletion rate 7.1%, Figure 6.2-3), *Clavelina* (the most common ascidian, 2 of 2 locations, 8.2%) and Porifera (3 of 5 locations, 10.1%). The variance to mean ratio was higher for Porifera (s.d. 107–177% of the mean) than for Crustacea (59–91%) and *Clavelina* (48–95%).

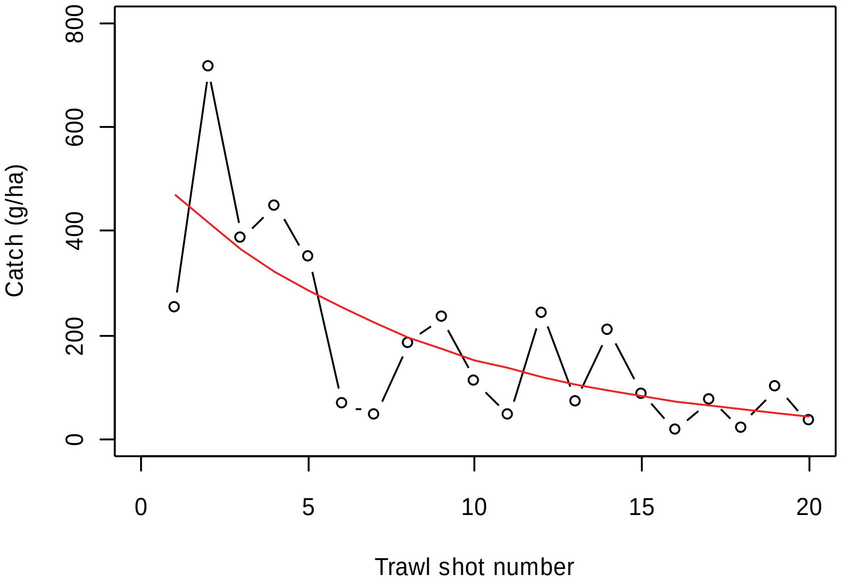


Figure 6.2-3: Trawl catches of Crustacea at location 3. The red line indicates the fitted values from the depletion rate analysis.

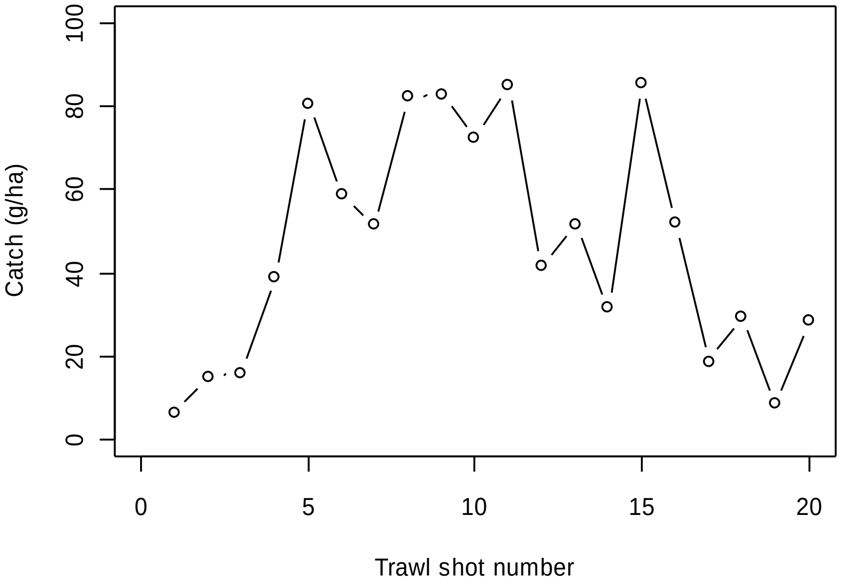


Figure 6.2-4: Trawl catches of Hydrozoa at Location 12.

The depletion rates for various taxa are given in Table 6.2-2

Table 6.2-2: Depletion rates (and standard error [SE]) for the various taxa caught in prawn trawls. The depletion rate (pi) can be converted to a percentage depletion by multiplying the pi value by 100.

Taxon	Depletion rate (pi)	SE
Desmospongiae	0.123	0.039
Ophiuroidea	0.031	0.113
Holothuroidea	0.164	0.094
Asteroidea	0.109	0.064
Crinoidea	0.105	0.105
Echinoidea	0.022	0.101
Gymnolaemata	-	-
Alcyonacea	-	-
Hydrozoa	-	-
Crustacea	0.148	0.015
Gorgonacea	0.069	0.129
Gastropoda	-	-
Bivalvia	0.133	0.061
Ascidiacea	0.066	0.137

Depletion rates could not be estimated for Hydrozoa (Figure 6.2-4) and Gymnolaemata using this technique because the rate appeared to peak at intermediate shots rather than remain constant. We have previously found this pattern of removal in other taxa in other studies and it may be a result of the animals either reacting to the initial trawls or becoming more vulnerable in some way. Although we cannot summarise depletion of these taxa with a constant depletion rate, we can summarise it in other ways (e.g. number of shots to achieve 50% depletion). Depletion rates could not be estimated for Gastropoda either, because there was no apparent trend in the catches between shots.

6.2.3 Laslett technique

The model proposed by Burridge et al. (2003) implicitly assumes that the repeat trawling runs directly overlie each other. As we have shown in Chapter 6.1, in our experiment they did not. The distribution of c_i (the biomass of benthos caught during trawl *i*) is consequently very complex, depending on the precise spatial pattern of the repeat trawls. Here we suggest a treatment of this problem; full details of the method are given in Appendix H.

6.2.3.1 Methods

6.2.3.1.1 Theory for coincident trawls: Expected depletion

Consider an area of ground *A* with initial density of benthos *b*. The total amount of benthos is *B*=*Ab*. Here *B* corresponds to X_0 in the Burridge et al. notation. The expected catch from (depletion by) a trawl run that completely covers *A* is

$$C_1 = \pi B$$

and the expected catch from trawl *n* is

$$C_n = \pi(1-\pi)^{n-1} B. \qquad (6.2.3.1)$$

6.2.3.1.2 Theory for coincident trawls: Depletion in terms of random variables

This is only for the case for a constant depletion rate ($q_i = \pi$) in the Burridge et al. (2003) setting. However, it can be generalised to their full case where the depletion rate varies from trawl to trawl. Thus, let

$$c_1 = q_1 B.$$

The catch in trawl *n* is then

$$c_n = B q_n \prod_{i=1}^{n-1} (1 - q_i). \qquad (6.2.3.2)$$

6.2.3.1.3 Theory for non-coincident trawls: Expected depletion

Now suppose that we have a large area A broken up into m subareas A_i. Subarea A_i has a trawling history $(I_{i1}, I_{i2}, \ldots)$, where $I_{ij} = 1$ if area A_i is covered by trawl run j, and 0 if it is missed. A subarea cannot be partially trawled during a run. Indeed, that is how the subareas are defined.

We define

$$n_{ij} = \sum_{k=1}^{j} I_{ik}$$

It is the total number of trawl runs covering A_i up to and including run j. Then

$$C_{j+1} = \sum_{i=1}^{m} \pi (1-\pi)^{n_{ij}} I_{i,j+1} B_i = \pi b \sum_{i=1}^{m} (1-\pi)^{n_{ij}} I_{i,j+1} A_i. \qquad (6.2.3.3)$$

This is the mean. It depends on two unknown parameters b and π.

6.2.3.1.4 Theory for non-coincident trawls: Depletion in terms of random variables

We can, of course, write down the formula for the actual depletion. First consider a single area A, which is either covered or not covered by the i th trawl. Let $I_i = 1$ if area A is covered by trawl i and $I_i = 0$ otherwise.

Then, by the same method as that used to establish (6.2.3.2), we have

$$c_n = B I_n q_n \prod_{i=1}^{n=1} (1 - I_i q_i).$$

Now return to the real situation where the area trawled can be broken up into m subareas A_i. We have

$$c_{j+1} = b \sum_{i=1}^{m} A_i q_{j+1} I_{i,j+1} \prod_{k=1}^{j} (1 - q_k I_{ik}). \qquad (6.2.3.4)$$

The theoretical variance of c_n is

$$\mathrm{Var}[c_n] = \mathrm{E}[c_n^2] - C_n^2, \qquad (6.2.3.5)$$

where

$$\mathrm{E}[c_{j+1}^2] = b^2 \pi^2 \frac{1+\alpha}{\pi+\alpha} \sum_{i=1}^{m} \sum_{p=1}^{m} A_i A_p I_{i,j+1} I_{p,j+1} \prod_{k=1}^{j} \left(1 - \pi (I_{ik} + I_{pk}) + \pi^2 \frac{1+\alpha}{\pi+\alpha} I_{ik} I_{pk} \right). \qquad (6.2.3.6)$$

and C_n is given by (6.2.3.3).

6.2.3.1.5 Estimating depletion parameters

To create a practical method for estimating depletion parameters based on this theory, we used a Gaussian model and a simpler, approximate definition of the variance. The Gaussian model was

$$c_j \sim \mathrm{N}(C_j, \mathrm{Var}[c_j])$$

where c_j the actual data, C_n is the mean trawl catch given by (6.2.3.3) and

Var[cn] = a0Cn2.

This approximation of the variance features a constant coefficient of variation. If there are n trawls, the log-likelihood is (apart from an additive constant)

$$-\frac{1}{2}\sum_{j=1}^{n}\log \mathrm{Var}[c_j] - \frac{1}{2}\sum_{j=1}^{n}\frac{(c_j - C_j)^2}{\mathrm{Var}[c_j]}. \qquad (6.2.3.7)$$

The parameters are estimated by maximising the log-likelihood.

6.2.3.2 **Results**

We illustrate the method on real data using Crustacea from Location 3. A plot of the data is shown in Figure 6.2-5. We have chosen this data set because there is a general decline in the trawl biomass per unit area with increasing trawl number.

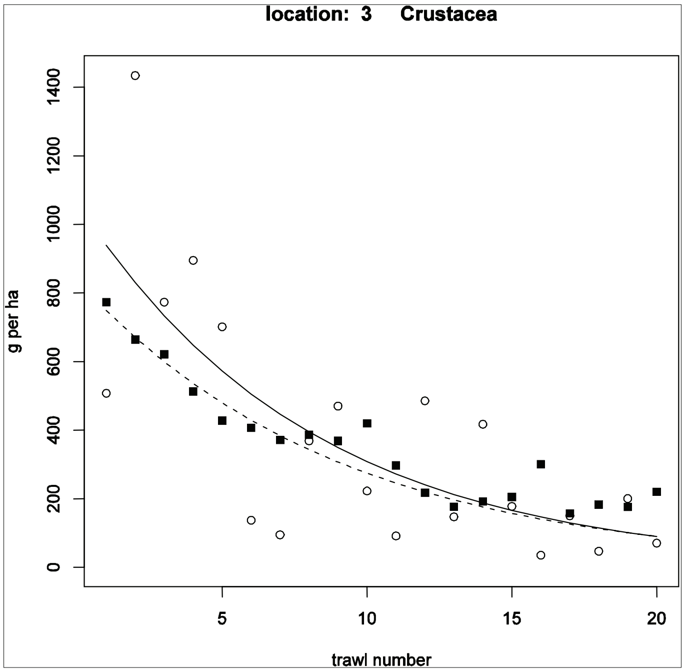


Figure 6.2-5: Catch per unit area for Crustacea from the 20 trawl treatment in Location 3 (West Mornington). The solid line is the fitted depletion curve from the Burridge et al. (2003) model fitted using the published Beta distribution method, the broken line is the same model fitted with a constant coefficient of variation, and the solid squares are the fitted values from the Laslett non-coincident trawl model.

The parameter estimates obtained by fitting the Burridge et al. (2003) model and the Laslett non-coincident trawl model (labelled NC4) are shown in Table 6.2-3.

Table 6.2-3: Initial biomass (b) and depletion rate (π) parameter estimates for Crustacea at Location 3.

	Parameter			
Model	***b***	**s.e.**	**π**	**s.e.**
Burridge	8058.4	364.5	0.117	0.027
NC4	3485.9	560.5	0.222	0.052

The non-coincidence model produces a much smaller estimate of the initial biomass and a larger estimate of the depletion rate than the Burridge et al. (2003) model.

The fitted curves and values are also shown in Figure 6.2-5. To the eye there is no real difference between the fits. Essentially each model fits the data equally well in qualitative terms. Thus models cannot be distinguished on their fit to the data. The model allowing non-coincidence of trawls does not improve the fit: it plays a much more subtle role. Note that the fitted values for the non-coincidence model do not fall on a smooth curve. Rather, they reflect the somewhat erratic spatial nature of the trawls.

We repeated this type of analysis on several other data sets (

Table 6.2-5). The results reinforce our previous conclusions. In one case, Asteroidea at Location 12, the depletion rate decreases with the non-coincidence model. However, the depletion data in that case are quite variable. The non-coincidence models have been fitted assuming a constant coefficient of variation. This assumption is not compulsory, and the fits may well change (even improve) using other variance structures. We have investigated other variance models, but no clear pattern for the residual variance has emerged. We believe that this is an important issue, though.

Table 6.2-4: Parameter estimates for selected locations and classes

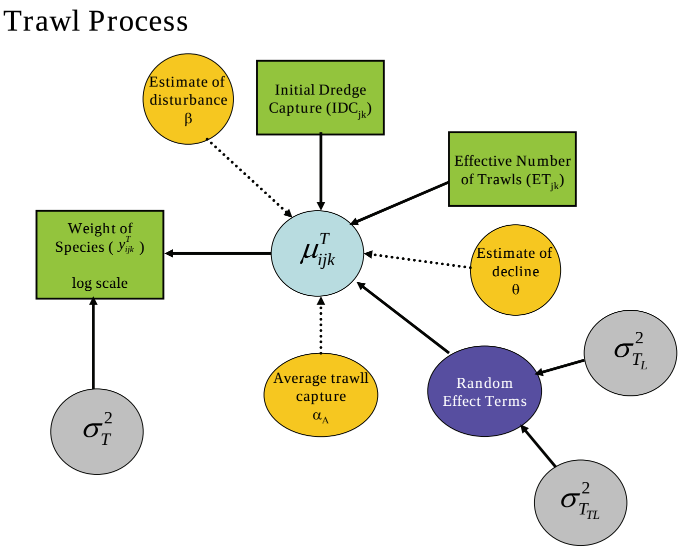
			Parameter			
Location	**Class**	**Model**	***b***	**s.e.**	**π**	**s.e.**
3	Ascidiacea					
		Burridge	603.5	52.2	0.083	0.021
		NC4	274.5	46.8	0.164	0.045
6	Ascidiacea					
		Burridge	16.0	0.3	0.169	0.061
		NC4	6.4	2.8	0.321	0.127
6	Crustacea					
		Burridge	4989.8	237.2	0.121	0.032
		NC4	2271.0	321.4	0.228	0.064
12	Asteroidea					
		Burridge	1265.7	47.1	0.145	0.034
		NC4	811.5	231.2	0.126	0.044
12	Bivalvia					
		Burridge	1950.1	47.1	0.145	0.034
		NC4	774.8	174.5	0.484	0.123
12	Crinoidea					
		Burridge	70.1	4.6	0.119	0.049
		NC4	30.6	12.9	0.793	0.252
12	Crustacea					
		Burridge	9982.1	976.1	0.089	0.029
		NC4	4391.8	801.6	0.190	0.037

6.2.4 Kuhnert technique

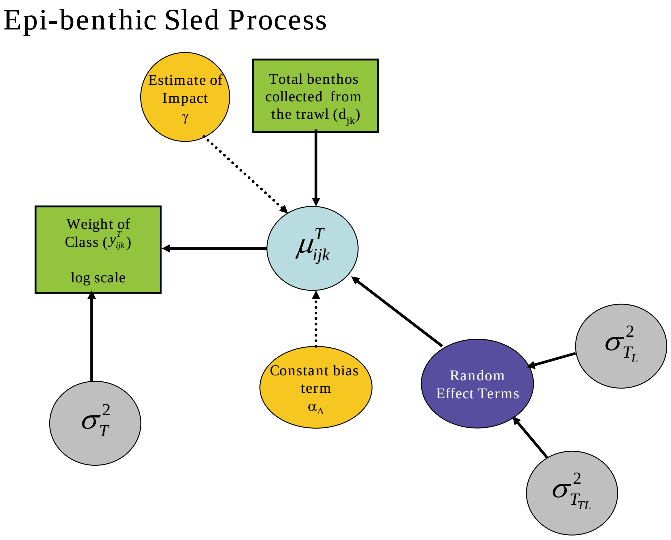
This technique uses all of the available data including the two levels of trawl intensity (high – 20× and medium – 4×) as well as the data from the epi-benthic sled and a term is introduced to account for the effects of the cyclone. Two statistical models are considered for this analysis. These aim to model the trawl and epi-benthic sled processes separately and subsequently investigate whether any significant decline due to trawling occurred and what impact (if any) was incurred by trawling as identified through the epi-benthic sled.

6.2.4.1 Methods

Figure 6.2-6a and b show conceptual models of the trawl and epi-benthic sled processes. Both of these models will be explained in more detail in the following sections.



(a)



(b)

Figure 6.2-6: Conceptual diagram of the two processes: trawl and epi-benthic sled. Fig (a) shows the trawl process given the initial epi-benthic sled capture, while Fig (b) shows the epi-benthic sled process post trawling to determine whether the epi-benthic sled is a useful monitoring tool and whether a significant impact from trawling had taken place

6.2.4.2 Trawl Process given the initial capture by the epi-benthic sled

The model of the trawl process is shown in Figure 6.2-6a. It contains a mixture of fixed and random effect terms to model the trawl process and specifically, the decline (if any) observed over the effective number of times the area has been trawled, ET. In this model $y_{T_{ijk}}$ represents the weight (g/ha) of the species (on the log scale) captured by the *i*-th shot in the *j*-th location at the *k*-th treatment level. In this model, only two treatments are investigated: 4 trawls and 20 trawls. The mean, $\mu_{T_{ijk}}$ is modelled in terms of fixed effects that take into account any disturbance or influence caused by the epi-benthic sled β; a decline θ (if any) that is measured over the effective area trawled; and an overall constant term α_T that is an indication of the average trawl capture.

One of the limitations of the Laslett non-coincident trawl model described in the previous section is that it depends on the specific spatial arrangement of the trawled sub-areas at each particular site. In order to be able to generalise this across all sites we needed to develop an approximation to Laslett Technique. Accommodating for non-coincidence in this model is extremely important since an area that you believe is being trawled intensely, say twenty times, may realistically only be trawled moderately, say six or seven times, therefore altering the estimate of the decline and the interpretation of how trawling is affecting the species.

The method developed to estimate the effective trawl number may be explained as follows. If the total area of trawl *n* is *A* and we divide the area *A* into a number of subareas *Ak* where subarea *AK* has been trawled exactly *k* times (including the current trawl). Note that *Ak* may consist of disjoint subareas.

The effective trawl number is then:

$$ETN = \frac{A1 + 2\times A2 + 3\times A3 + ... + n\times An}{A} \quad \text{Note that } A = A1 + A2 + A3 + \ldots + An. \qquad (6.2.3.8)$$

6.2.4.3 **Epi-benthic sled process**

The component that models the epi-benthic sled process and hence determines if a significant impact occurred is shown in Figure 6.2-6b This model incorporates a constant term α_A which represents an overall estimate of the mean weight of the species captured across locations and treatments; and a measure of impact, *d* which represents the log weight per hectare of all species caught in the trawls (for trawled sites) and epi-benthic sled (for the control site) at the previous stages of this sequential monitoring process. (Note, zeros were not an issue here.) The size and direction of the impact is estimated through the parameter γ. If γ is negative and significant, this suggests that for every kilogram per hectare of benthos the trawl removes, a decline in the class as measured by the sled, is observed.

Random effect terms accounting for variability between locations l_{jk}^{A} and between treatments within a location tl_{jk}^{A} are also included in the model. The model for this component of the model can be formally written as:

$$
\begin{aligned}
&\log(y_{jk}^{BA}) \sim \mathrm{N}(\mu_{jk}^{BA}, \sigma_A^2) \quad j = 1,\ldots, n_{\text{location}}. \quad k = 1,\ldots, n_{\text{treatment}}.\\
&\mu_{jk}^{BA} = \alpha_{BA} + \gamma d_{jk} + l_j^{BA} + tl_{jk}^{BA} \qquad (6.2.3.9)\\
&l_j^{BA} \sim \mathrm{N}(0, \sigma_{A_l}^2), \quad tl_{jk}^{BA} \sim \mathrm{N}(0, \sigma_{A_{tl}}^2)
\end{aligned}
$$

Here y_{jk}^{BA} represents the weight of benthos caught by the sled (before or after trawling) for the class or functional group at the *j*-th location and *k*-th treatment plot.

6.2.4.4 **Accommodating cyclonic activity**

During the eastern survey, cyclone Craig passed near Mornington Island. The “before” epi-benthic sled samples were collected well before the cyclone hit. However, only 11 of the 20 trawl shots at location 9 were completed prior to the cyclone. The remainder of the trawls, including trawls at locations 10 and 12 were completed two days after the cyclone. The “after” samples were then collected using the epi-benthic sled.

To accommodate for changes in benthos due to cyclonic conditions, an additional term $\lambda\, c_{ijk}$ has been included in the model for the trawl process (Equation 6.2.3.8) for sites in east Mornington. The cyclone term represents part of the fixed component of the trawl model to allow for the effect of cyclonic activity on species groups, in addition to trawling effort. This variable takes on the value 1 for the location and treatments which were affected by the cyclone and zero otherwise.

Similarly, to accommodate for cyclonic activity in the sled model, we also include a similar term $\lambda_D c_{ijk}^{D}$, where c_{jk}^{D} is a binary variable indicating whether the cyclone impacted the site.

6.2.4.5 **Implementing and evaluating proposed models**

The statistical programming language, R (Ihaka and Gentleman, 1996) was used to obtain estimates for the parameters in each of the models by fitting a linear mixed effects model using the lme function, which is part of the nlme library. The main parameters of interest are highlighted in blue in Equations 6.2.3.8-6.2.3.9 and they are also summarized in

Table 6.2-5.

Confidence intervals for the parameter estimates were obtained using the `intervals` function, which is also part of the `nlme` library in R. Information on this function and mixed effects models in general can be found in Pinheiro and Bates (2000). Confidence intervals which do not include zero indicate a significant effect.

Residuals from each model were examined for outliers and ill-fitting observations. In particular, plots of residuals versus fitted values were produced for each model along with quantile-quantile plots of the residuals to check for Normality assumptions.

6.2.4.6 **Zero-inflation**

Weights recorded for some classes and functional groups exhibit zero-inflation. To accommodate excess zeros in the above models for these species, a two-component modelling approach was adopted. This involved converting the weights into presence/absence data and modelling the probability of presence of the class or functional group and then conditional on that class or functional group being present, the log weight is modelled using a Normal distribution. Fixed and random effects for each model are included into each model as shown in Equations 6.2.3.8 and 6.2.3.9 for each process investigated. Note, by modelling the process in this way, we acknowledge that there can be some difficulties with the fit of the model as the experimental design may no longer be balanced, that is, having an unequal number of locations and treatments when modelling the process conditional on the class or functional group being there may result in poor fits.

Table 6.2-5: Parameters of interest in statistical models of trawl and epi-benthic sled processes.

Model Component	Parameter	Interpretation
Trawl | Initial Epi-benthic sled	α_T	Overall log mean weight (g/ha) of species as captured by the trawl
	β	A measure of how much the epi-benthic sled influenced the trawl capture. This is a measure of disturbance. If $\beta = 0$ this indicates that the epi-benthic sled had no influence on what was picked up by the trawl.
	λ^T	Cyclone effect
	θ	Estimate of decline adjusted for non-coincidence of trawls.
Post Epi-benthic sled | (Initial Epi-benthic sled + Trawl)	α_{BA}	Constant bias
	λ^D	Estimate of the effect of the “impact” where impact is defined as the weight (kg/ha) of benthos removed by the trawl at trawled sites. For non-trawled sites (treatment=0) “impact” is defined as 0 weight

6.2.4.7 **Analysis of sites in the west Mornington region**

6.2.4.7.1 Exploratory analysis of classes and functional groups

Boxplots summarising the epi-benthic sled catch rates of the various taxonomic Classes and functional groups before and after trawling are given in Figures 6.2-7 to 6.2-10. The box plots corresponding to the epi-benthic sleds prior to trawling are shown in orange, while those summarising post trawling epi-benthic sled captures are shown in blue. Medians are indicated by the horizontal lines shown on each box plot with extreme and outlying points indicated by the whiskers extending from the 25th and 75th percentiles (edges of the box).

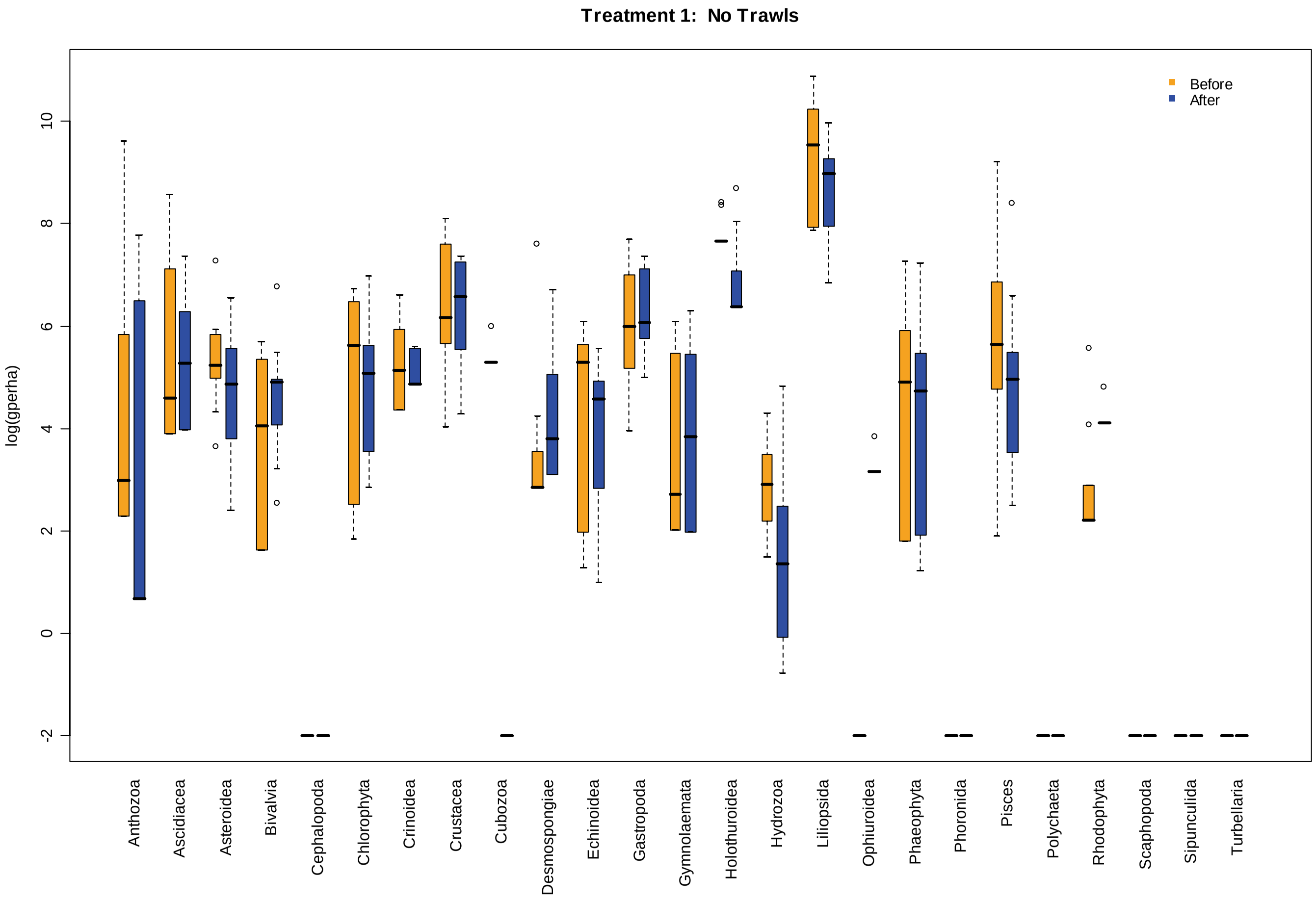


Figure 6.2-7: Comparison of epi-benthic sled captures taken before and after impact for 25 classes summarised across locations for treatment 1 (no trawl plots) in West Mornington.

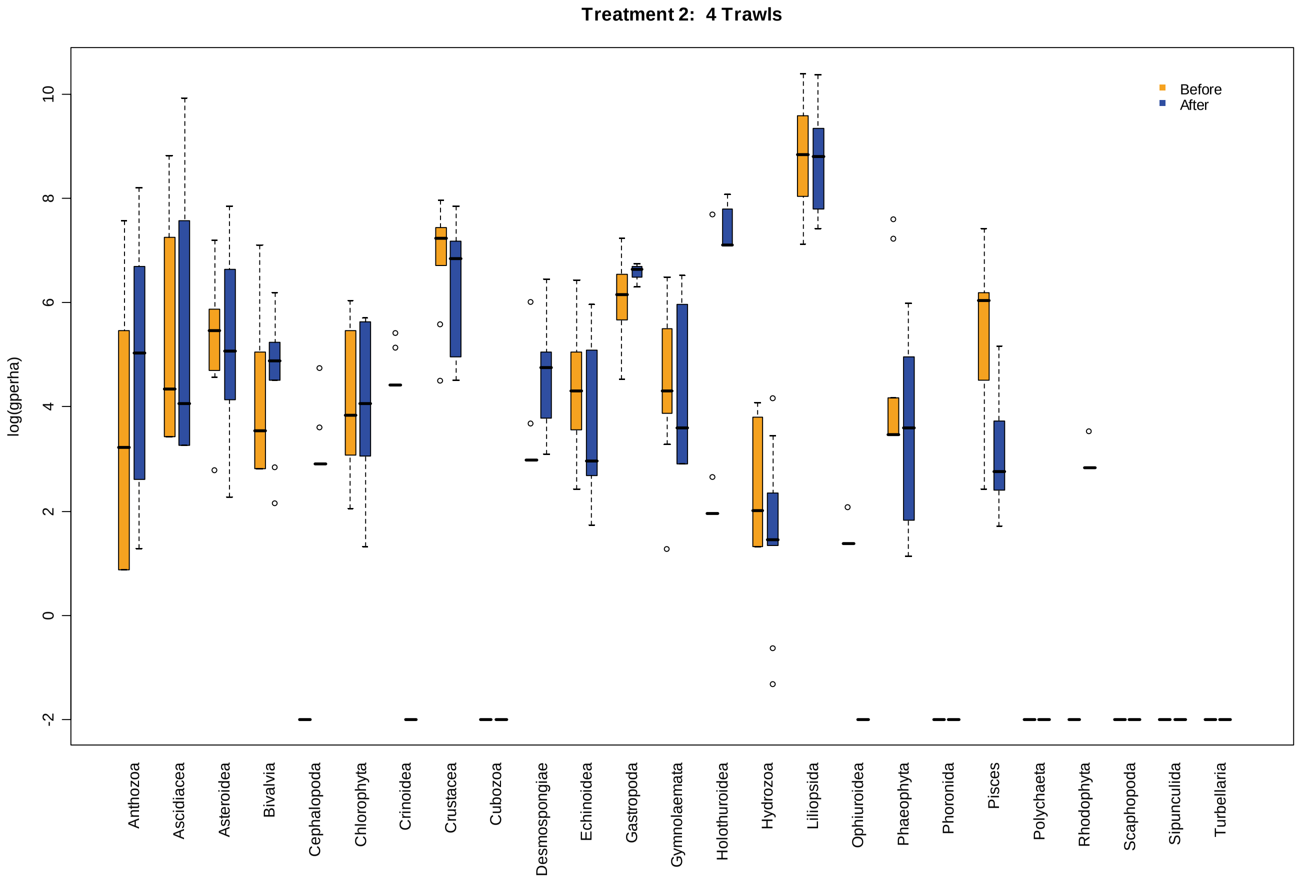


Figure 6.2-8: Comparison of epi-benthic sled captures taken before and after impact for 25 classes summarised across locations for treatment 2 (four trawl plots) in West Mornington.

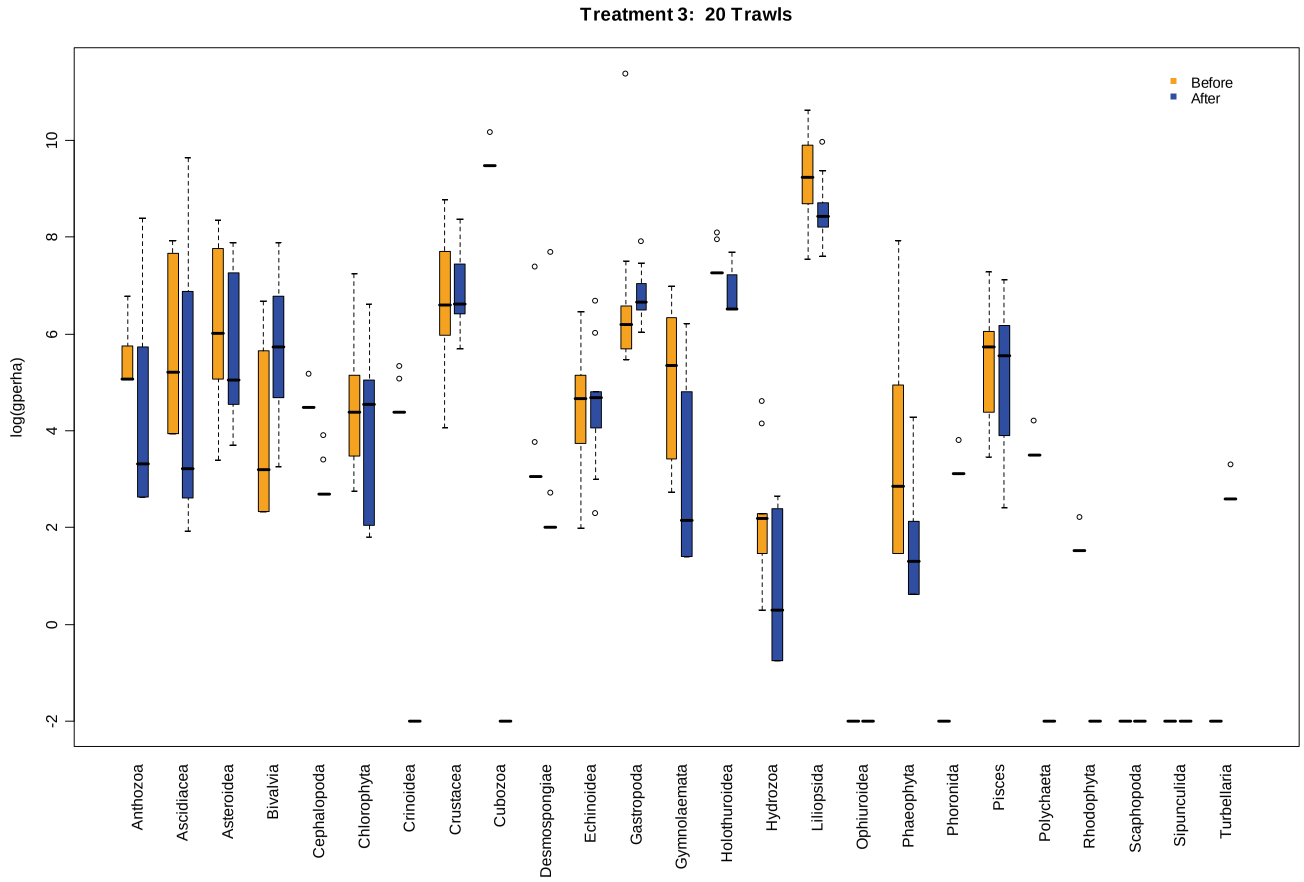


Figure 6.2-9: Comparison of epi-benthic sled captures taken before and after impact for 25 classes summarised across locations for treatment 2 (twenty trawl plots) in West Mornington.

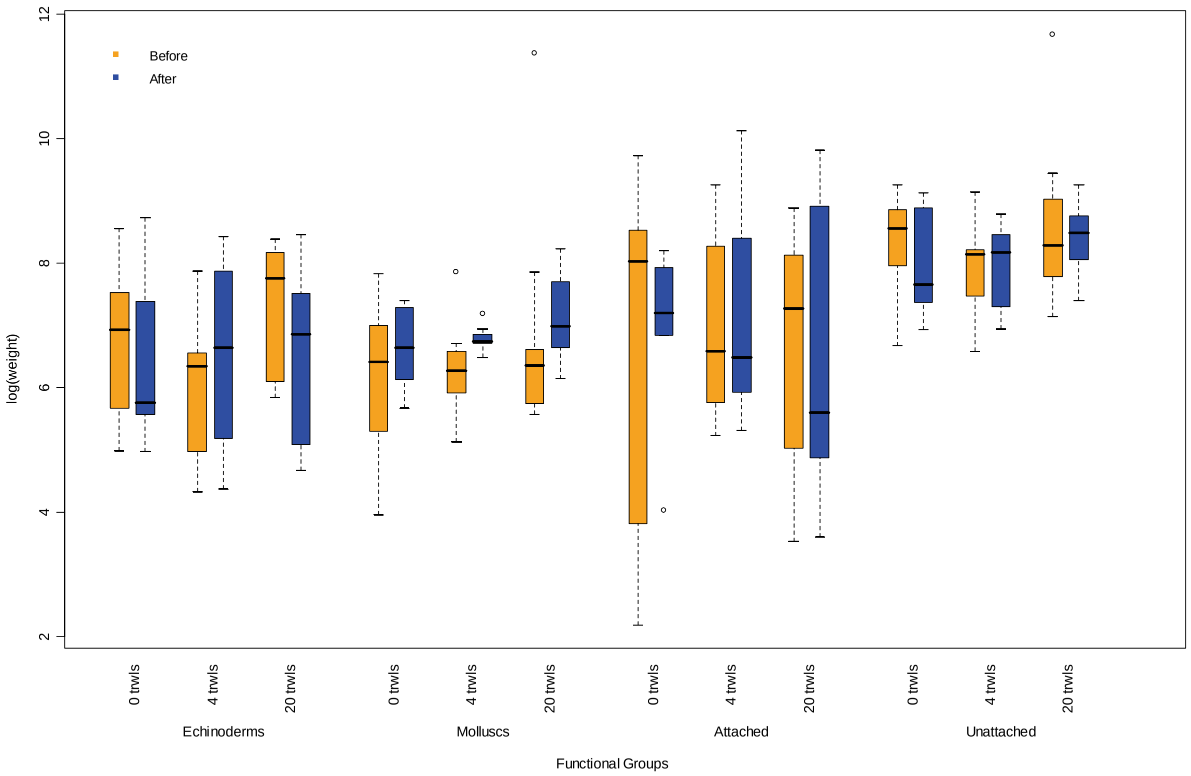


Figure 6.2-10: Comparison of epi-benthic sled captures taken before and after impact for the four functional groups summarised across locations in West Mornington. All three treatment groups are shown on the one plot

6.2.4.7.1.1 Implementation of the model and results

The models outlined above were applied to the west Mornington data to determine if any significant declines and impacts were evident. Appendix H contains a detailed tabulation of the estimates for each model along with 95% confidence intervals, where appropriate. (Occasionally confidence intervals could not be calculated for some fixed effects and some variance components that were close to zero.) Note that for some classes and functional groups, the results from a two-component analysis are presented. Other classes/function groups that did not exhibit zero-inflation in the data were analysed using a single model (log-Normal). Only those classes that had sufficient data were used in this analysis.

6.2.4.7.1.2 Trawl process

For all models of the trawl process, no model showed any significant “disturbance” or influence by the initial epi-benthic sled. This suggests that the initial epi-benthic sled (“before” samples) had no influence on what the trawl caught.

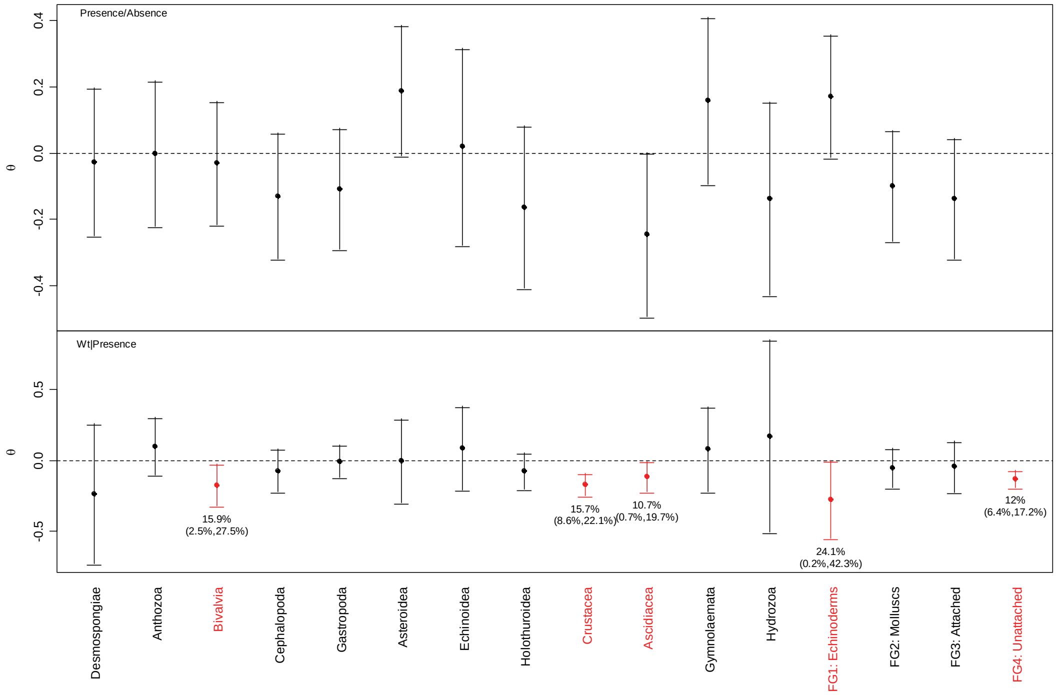


Figure 6.2-11: Estimates of decline, (θ) for various species classes and functional groups identified in the trawl dataset. The top graph shows estimates of decline for the presence/absence model. The second graph presents results from the conditional model. Significant declines are highlighted in red. Estimates of the percentage decline are also shown for significant terms in the model.

Figure 6.2-11 summarises the estimates of decline θ, for twelve classes and four functional groups which could be modeled. The top plot shows the estimate of decline for the presence/absence component of the model along with 95% confidence intervals. The bottom plot shows the estimate of decline for the model of the weight of each class and functional group, conditional on it being observed. Significant declines represent those estimates which have a confidence interval that does not include zero (dotted line). These are highlighted in red. For any significant decline, the percentage decline and corresponding confidence interval is reported beneath each estimate. The percentage declines were evaluated by exponentiating the value of the estimate and the 95% confidence interval and then subtracting from one. So the decline in biomass after one trawl can be represented by $y_0(1-\exp(n\vartheta))$, where y_0 represents the initial biomass and n represents the number of trawls performed, which in this case is one. Note that Crustacea and the unattached functional group had no zero values recorded and therefore do not have an estimate of decline for the presence/absence component of the model.

We summarise the interesting findings from the analysis below.

- No significant estimates of decline are shown in the top plot, although there is a suggestion that as the effective number of trawls increase, the probability of catching Echinoderms, Gymnolaemata and Asteroidea increase, while the probability of catching Ascidiacea and Holothuroidea have a tendency to decrease.

- In the second plot, declines are evident for the following classes and functional groups:
  - **Bivalvia:** 15.9% (2.5%, 27.5%)
  - **Crustacea:** 15.7% (8.6%, 22.1%)
  - **Ascidiacea:** 10.7% (0.7%, 19.7%)
  - **Echinoderms:** 24.1% (0.2%, 42.3%)
  - **Unattached species:** 12% (6.4%, 17.2%)

  Note the wide confidence interval for echinoderms suggesting some uncertainty in the estimate of decline, despite being significant. All other classes and functional groups indicate that there is no significant decline from trawling.

- Random effects for most models suggested some variation between locations. However, most variation, showed substantial “unexplained” variation as indicated by estimates of σ.

6.2.4.7.1.3 Epi-benthic sled process

Figure 6.2-12 summarises the estimates of “impact” in the epi-benthic sled model for fourteen classes and four functional groups. Estimates and 95% confidence intervals are shown with significant impacts representing those whose estimate of impact does not include zero (highlighted in red). Note that some estimates are not available for some classes and functional groups. This was either because there were no zero values recorded, or estimates could not be provided from the model.

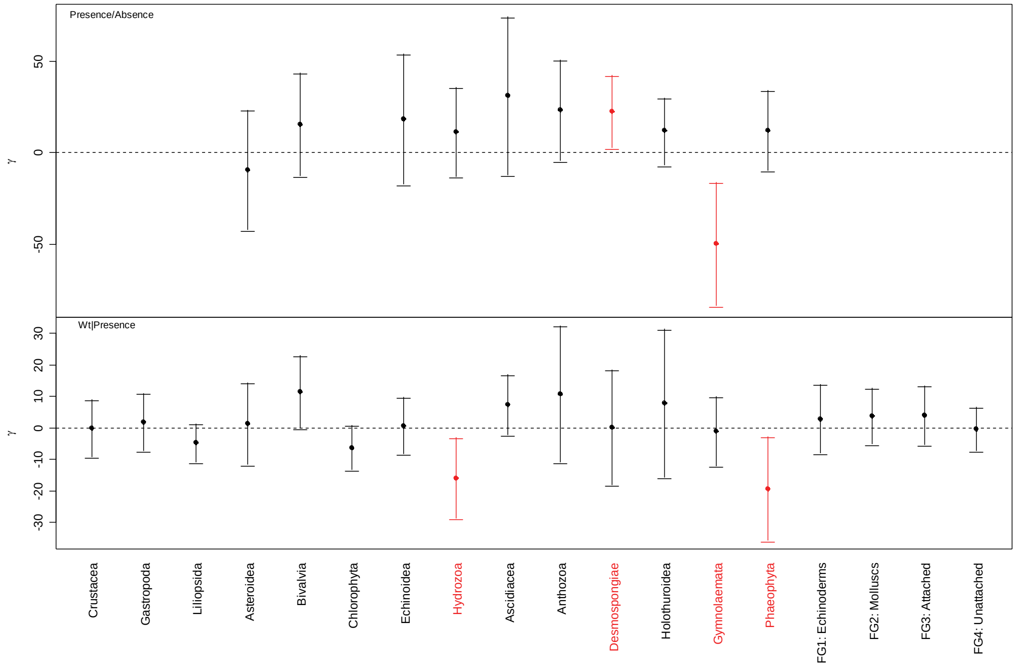


Figure 6.2-12: Estimates of impact, (γ) for various species classes and functional groups identified in the catches of the epi-benthic sled in West Mornington. The top graph shows estimates of decline for the presence/absence model. The second graph presents results from the conditional model. Significant impacts are highlighted in red. Estimates of the percentage impact are also shown for significant terms in the model.

The interesting findings from the analysis are summarised below.

- Significant impacts were noted for the following classes:
    - **Hydrozoa:** For every additional kilogram per hectare of total benthos removed by the trawl, we observe a decline of nearly 100% (95.3%, 100%) in hydrozoans captured by the epi-benthic sled, given that they are located in the area.
    - **Desmospongiae:** For every additional kilogram per hectare of total benthos removed by the trawl, the probability of capturing sponges using the epi-benthic sled increases.
    - **Gymnolaemata:** For every additional kilogram per hectare of total benthos removed by the trawl, the probability of capturing species of this class decreases dramatically.
    - **Phaeophyta:** For every additional kilogram per hectare of total benthos removed by the trawl, we observe a decline of nearly 100% in Phaeophyta captured by the epi-benthic sled, given that Phaeophyta are located in the area.

  All other impacts are negligible.
- Random effects for most models of the sled process indicate some variation between locations and between treatments within a location. However, like the previous analysis, most variation was absorbed into σ indicating fairly substantial "unexplained" variation.

6.2.4.7.1.4 Residual plots

Residual plots for both models indicated that better fits were observed for the epi-benthic sled model than the trawl. Instances where residual plots showed ill fitting points usually resulted in very wide confidence intervals for some estimates.

6.2.4.8 **Analysis of sites in the east Mornington region**

6.2.4.8.1 Exploratory analysis of classes and functional groups

Figure 6.2-13, Figure 6.2-14, Figure 6.2-15 and Figure 6.2-16 summarise the epi-benthic sled data (before and after) using boxplots for each class and functional group. The figures break the information into the three treatments (0, 4 and 20 trawls). There are substantial differences in median weight captures before and after at the 4 and 20 treatment lots. Large differences are particularly obvious for ascidians, Desmospongiae, echinoids and hydrozoans.

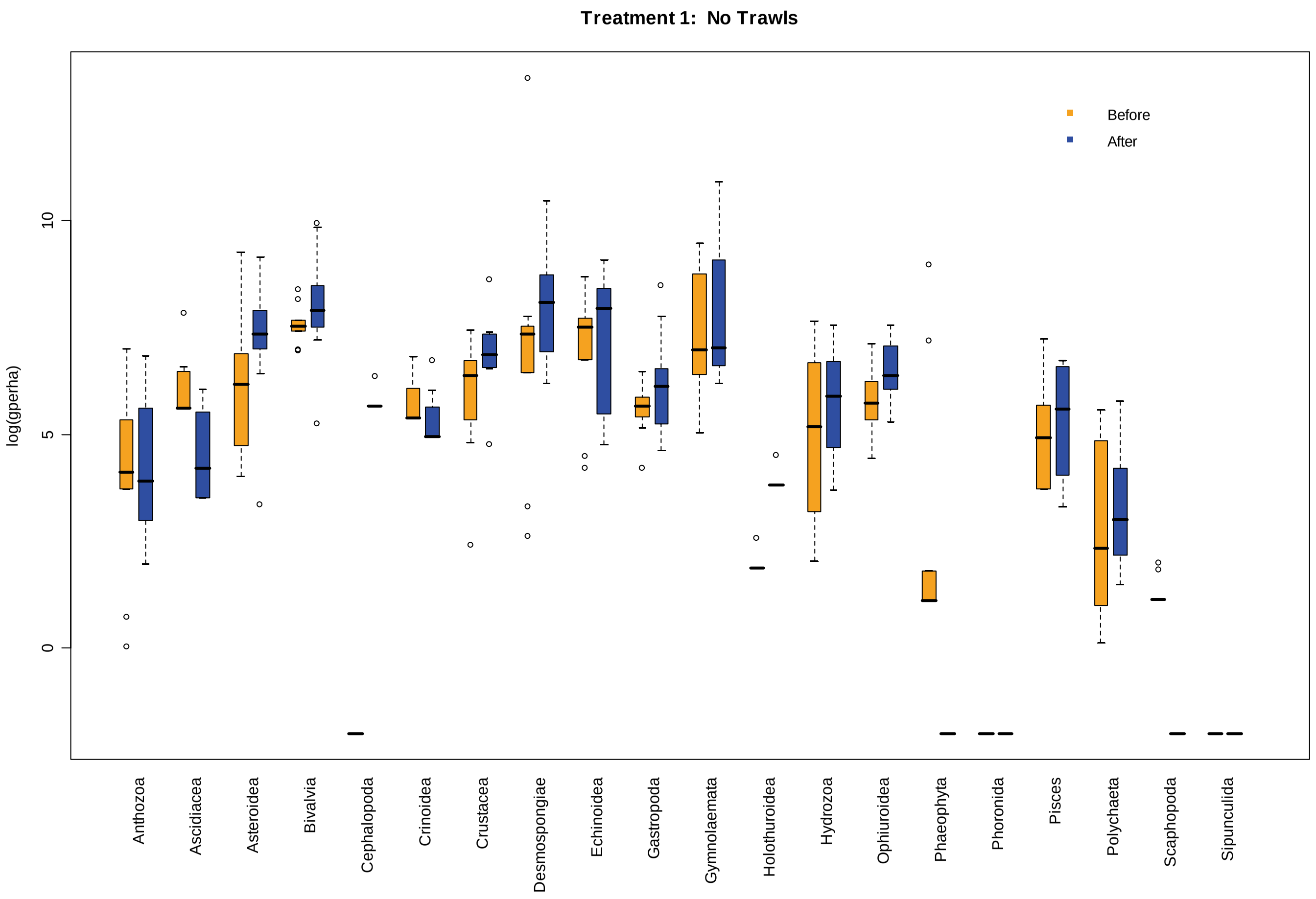


Figure 6.2-13: Comparison of epi-benthic sled captures taken before and after impact for 20 classes summarised across locations for treatment 1 (no trawl plots) in East Mornington.

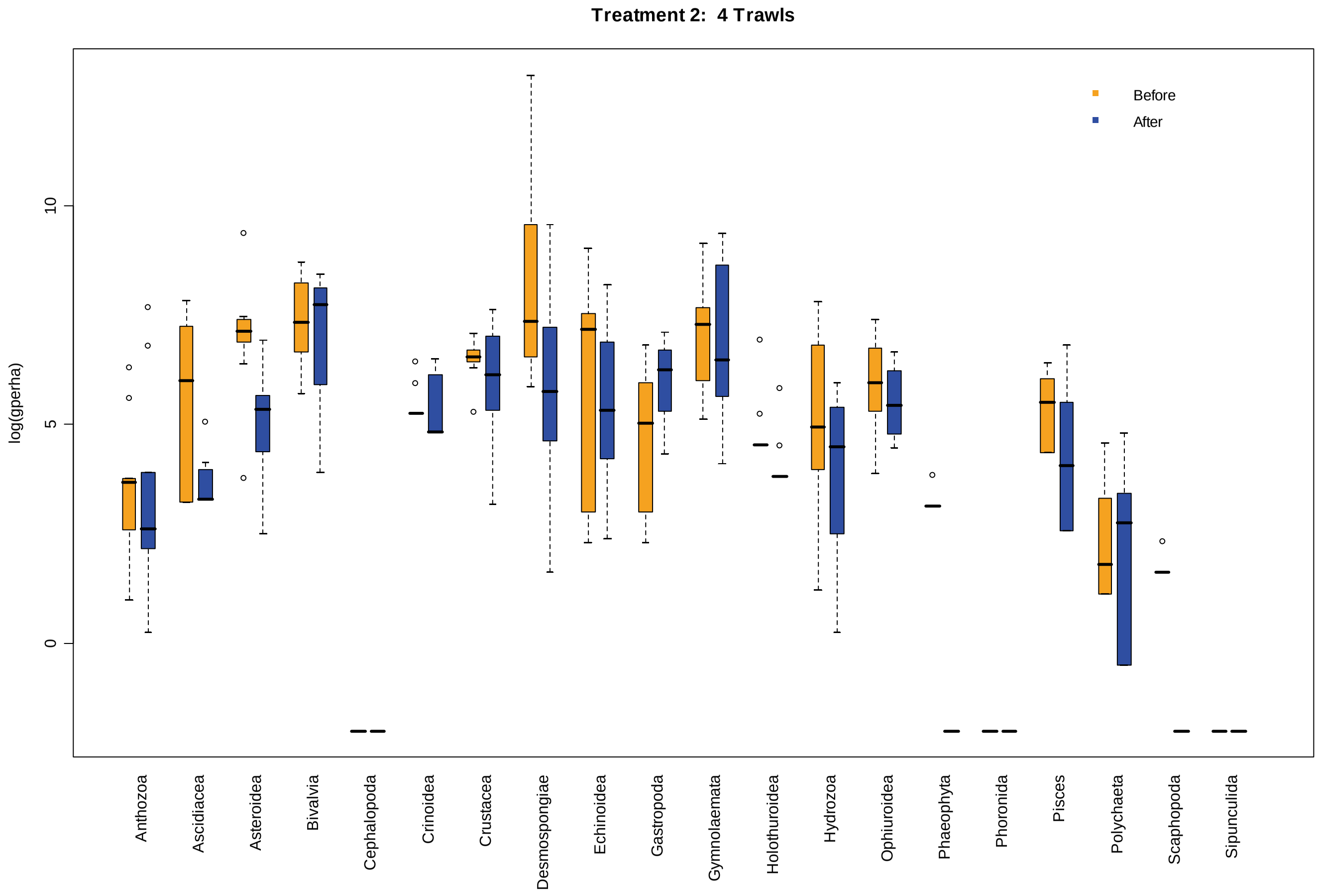


Figure 6.2-14: Comparison of epi-benthic sled captures taken before and after impact for 20 classes summarised across locations for treatment 2 (four trawl plots) in East Mornington.

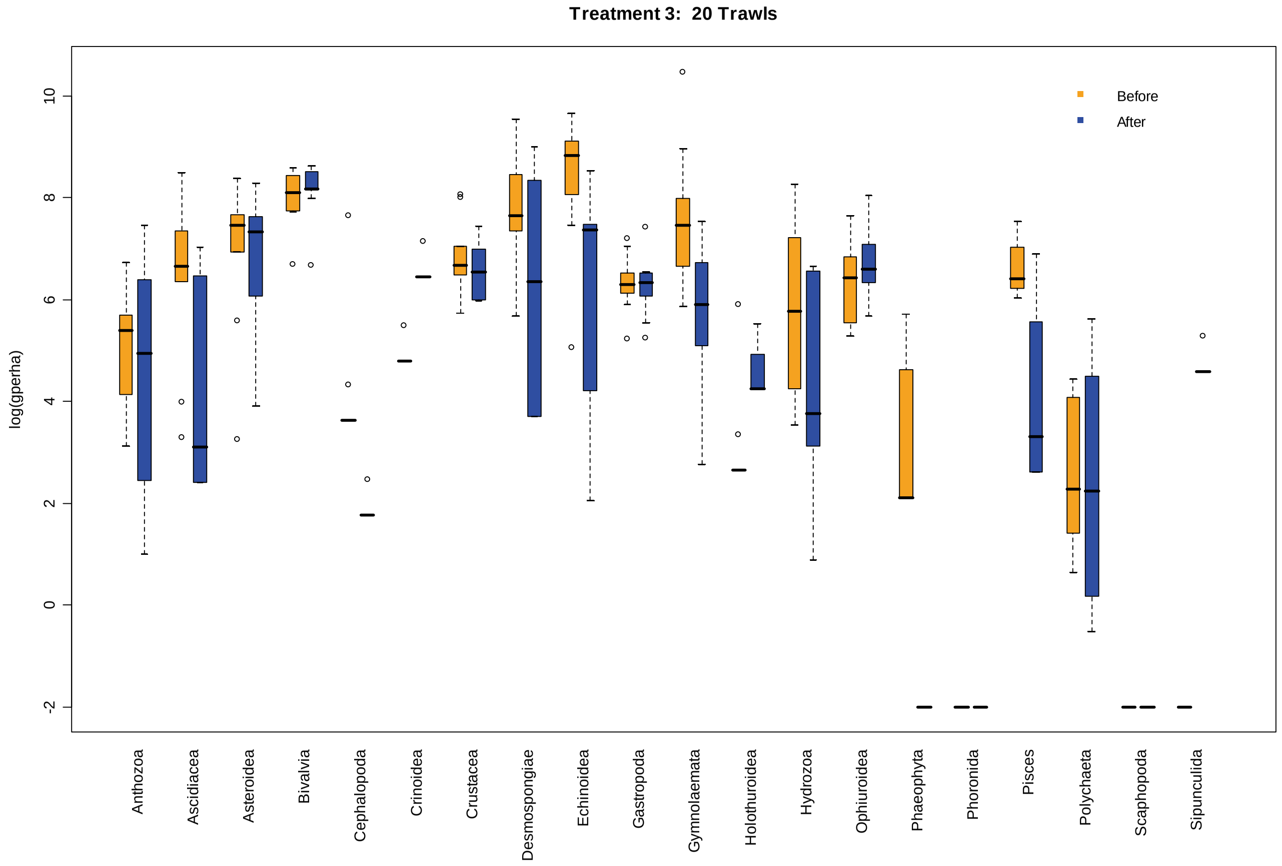


Figure 6.2-15: Comparison of epi-benthic sled captures taken before and after impact for 20 classes summarised across locations for treatment 2 (twenty trawl plots) in East Mornington.

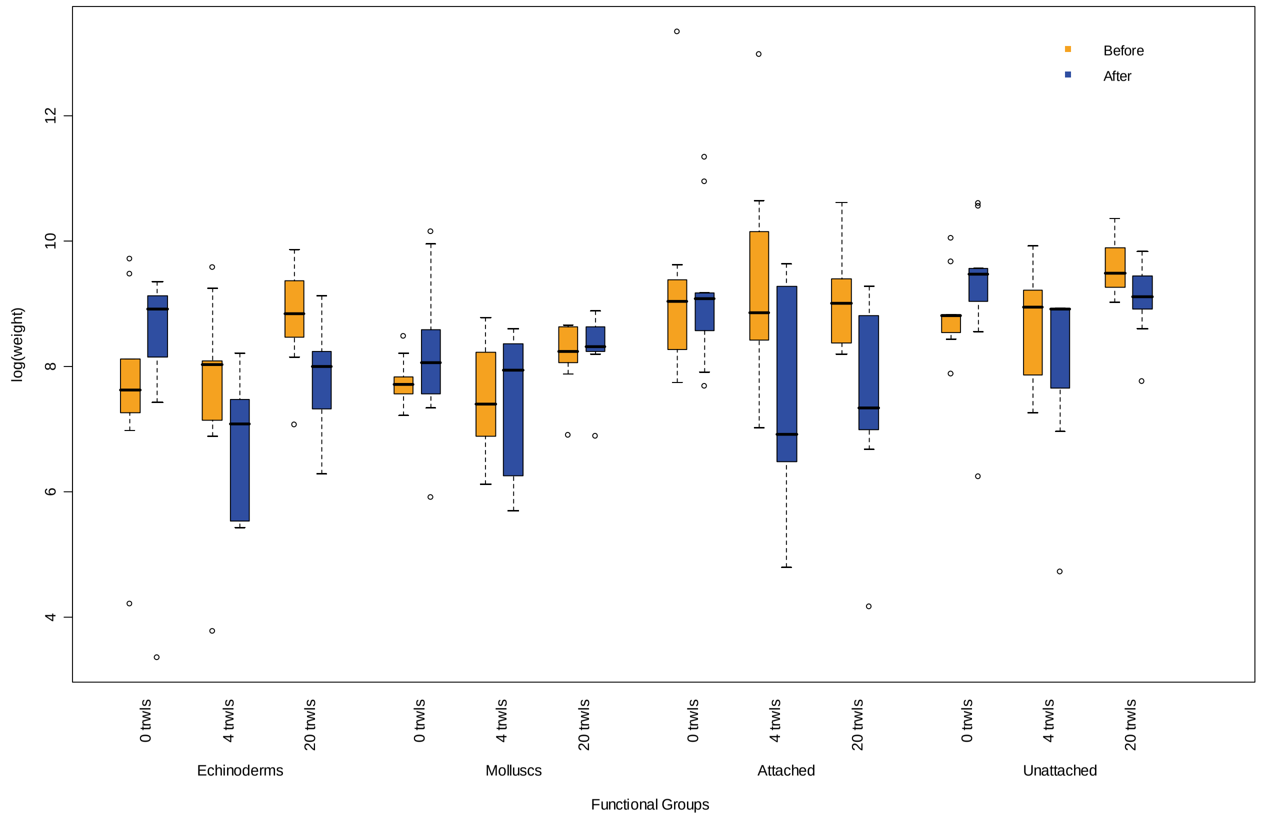


Figure 6.2-16: Comparison of epi-benthic sled captures taken before and after impact for the four functional groups summarised across locations in East Mornington. All three treatment groups are shown on the one plot.

6.2.4.8.1.1 Implementation of the model and results

The models were applied to the east Mornington data to determine if any significant declines and impacts were evident. Appendix H contains a detailed tabulation of the estimates for each model along with 95% confidence intervals, where appropriate. (Occasionally confidence intervals could not be calculated for some fixed effects and some variance components that were close to zero). Note that for some classes and functional groups, the results from a two-component analysis are presented. Other classes/functional groups that did not exhibit zero-inflation in the data were analysed using a single model (log-Normal). Only those classes that had sufficient data were used in this analysis.

6.2.4.8.1.2 Trawl process

Figure 6.2-17 summarises the estimate of decline for the model of the trawl process for twelve classes and four functional groups. As stated above, to accommodate for the cyclone, a specific “cyclone” term was included in the model. The purpose of this term was to tease out any effects that were specifically due to the cyclone and hence, be able to evaluate any declines detected from trawling.

Results indicate that some classes were affected by the cyclone, while for others, the effect of the cyclone did not appear to make any significant impact to their probability of presence or their abundance. It is interesting to note that most classes showing a significant impact from the cyclone also were impacted by the trawl. This was not always the case though (see Crinoidea below).

Highlights from the analysis include:

- *Crustacea* were more abundant after the cyclone hit (Appendix H), resulting in a larger catch rate and hence a larger decline from trawling (11.5%, [3.1%, 19.2%]) as shown in Figure 6.2-17.
- *Echinoidea* had a higher probability of presence after the cyclone (Appendix H), resulting in a larger catch rate and hence a larger decline (p=0.362, [0.3, 0.43]) from trawling as shown in Figure 6.2-17.
- *Crinoidea* also had a higher probability of presence after the cyclone (Appendix H). However this did not seem to impact on their decline due to trawling (p=0.879, [0.78, 0.94]).
- *Bivalvia* had a lower probability of presence after the cyclone (Appendix H). The estimate of decline due to trawling indicates that as trawling effort increases, the chance of seeing more Bivalvia increases (p=0.952, [0.86, 0.98]). However, given that bivalves are present in the trawled area, as trawling increases, the amount of bivalves decrease (10.9%, [0.4%, 20.2%, after 1 trawl]. This is an interesting finding as it indicates the following
    - The cyclone had a devastating affect on bivalves
    - Trawling causes bivalves to appear more in the trawled area.
    - If bivalves are present in the trawled area, they will decline on average by 12.2% as trawling increases by one unit.
- *Unattached* species showed an increase in abundance after the cyclone (p=0.68, [0.54, 0.79]), resulting in a larger catch rate and hence a larger decline from trawling as shown in Figure 6.2-17.

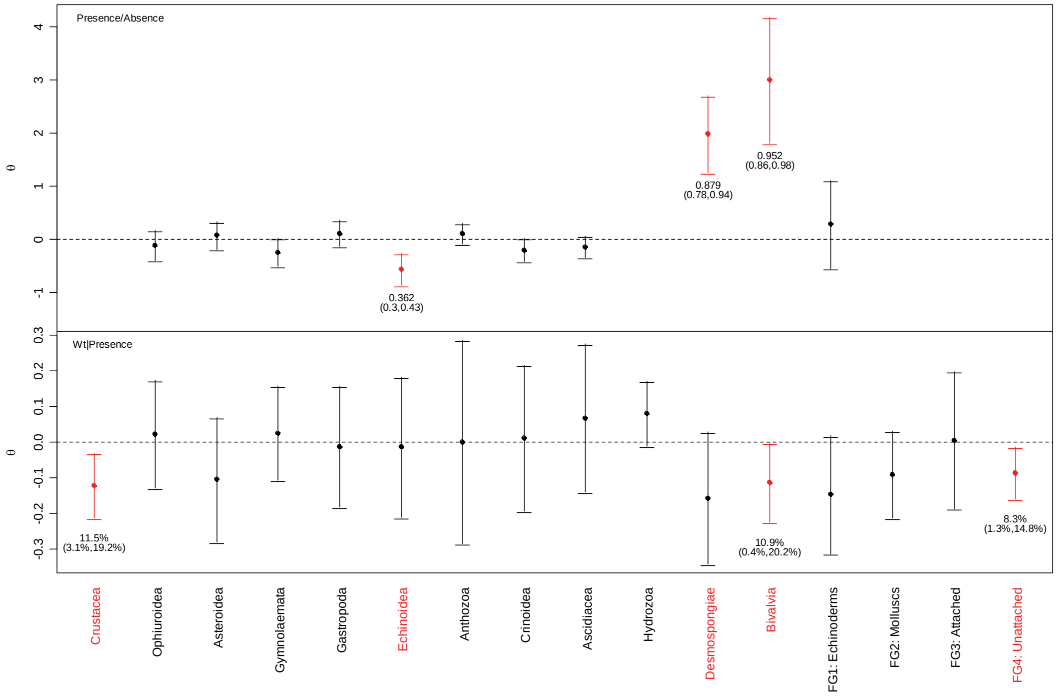


Figure 6.2-17: Estimates of decline (θ), for various species classes and functional groups identified in the trawl dataset for east Mornington. The top graph shows estimates of decline for the presence/absence model. The second graph presents results from the conditional model. Significant declines are highlighted in red. Estimates of the percentage decline are also shown for significant terms in the model.

As in the trawl models presented above, random effects suggested some variation between locations. However, most variation, showed substantial "unexplained" variation as indicated by estimates of σ .

6.2.4.8.1.3 Epi-benthic sled process

Figure 6.2-18 summarises the results for the "impact" term (γ) in the model of the sled process. An impact term was included in the model to tease out any effect or impact due to the cyclone (λ).

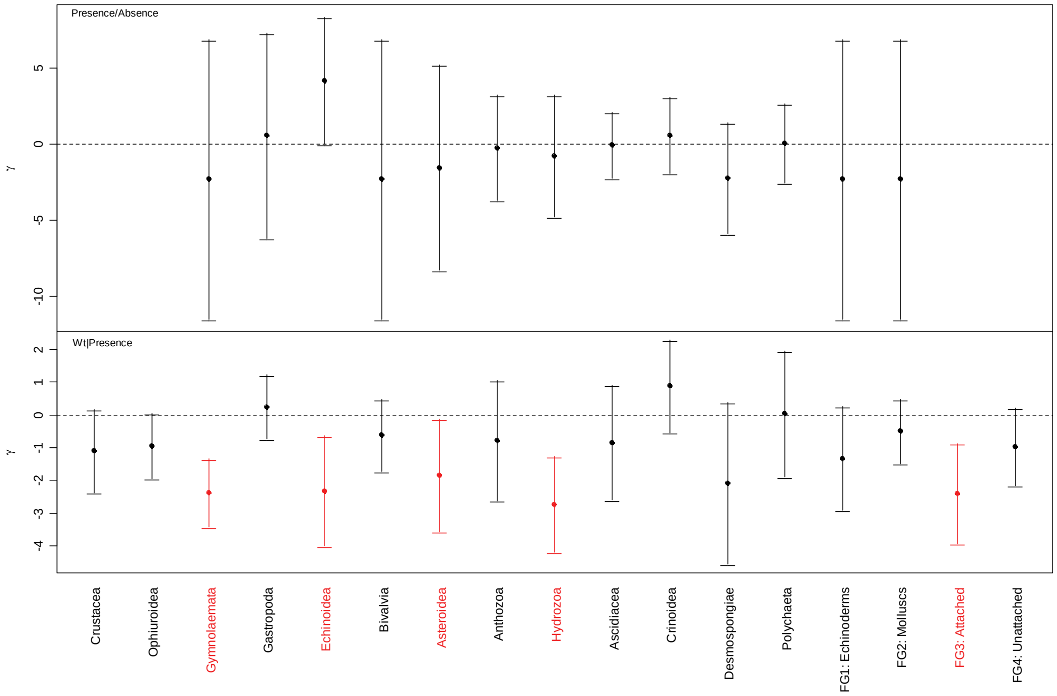


Figure 6.2-18: Estimates of impact, (γ) for various species classes and functional groups identified in the trawl dataset for east Mornington. The top graph shows estimates of decline for the presence/absence model. The second graph presents results from the conditional model. Significant impacts are highlighted in red. Estimates of the percentage impact are also shown for significant terms in the model.

Highlights from the analysis include:

- No significant impacts are noted in the upper plot suggesting that as the amount of benthos removed by the trawl increases, this neither increases nor decreases the chance of picking up that class or functional group using the sled. However, given that a particular class or functional group is present, the amount captured by the sled seems to be lower for some classes and functional groups. Significant impacts include:
    - **Gymnolaemata:** shows a significant "impact" suggesting that for every 1kg/ha increase in benthos captured by the trawl, we are likely to see a decline (91%, [74%, 97%]) of species in this class as observed by the sled.
    - **Echinoidea:** shows a significant "impact" suggesting that for every 1kg/ha increase in benthos captured by the trawl, we are likely to see a decline (90%, [48%, 98%]) of species in this class as observed by the sled.
    - **Asteroidea:** shows a significant "impact" suggesting that for every 1kg/ha increase in benthos captured by the trawl, we are likely to see a decline of species (84%, [13%, 97%]) in this class as observed by the sled.
    - **Hydrozoa:** shows a significant "impact" suggesting that for every 1kg/ha increase in benthos captured by the trawl, we are likely to see a decline of species (94%, [72%, 98%] in this class as observed by the sled.
    - **Attached species:** shows a significant "impact" suggesting that for every 1kg/ha increase in benthos captured by the trawl, we are likely to see a decline of species (91%, [58%, 98%]) in this functional group as observed by the sled.
- Ascideans were the only class that appeared to be adversely affected by the cyclone.

6.2.4.8.1.4 Residual Plots

Residual plots for both models indicated that better fits were observed for the epi-benthic sled model than the trawl. Instances where residual plots were showing ill fitting points usually resulted in very wide confidence intervals for some estimates.

6.2.5 Estimating depletion rates for 'problem' taxa

6.2.5.1 Methods

We felt that the Kuhnert technique probably gave the most accurate estimates of the trawl depletion rates. However, as mentioned earlier, this technique is sensitive to zero-inflated data and in many cases we were not able to determine depletion rates for particular taxa. For many of these taxa, estimates were available from the Burridge technique. However, these estimates were not good substitutes because they did not consider non-coincidence of trawls and were systematically lower than those from the Kuhnert technique. We therefore used a simple, approximate method developed by Geoff Laslett. The model described in equation 6.2.3.1 was fitted to trawl catches and effective trawl numbers (as defined in section 6.2.4.2) with least squares estimation. Depletion rates for the following classes were estimated in this manner: Echinoidea, Crinoidea, Holothuroidea, Asteroidea, Ophiuroidea and Desmospongiae.

The cumulative catches of Hydrozoa and Gymnolaemata did not show a progressive decline, but rather a humped pattern (Figure 6.2-4) and so were not amenable to any of the other techniques for estimating depletion, which assume a relatively constant average depletion rate. For these taxa we used a cumulative catch analysis technique, which assumed that the taxa were close to 100% depleted by the 20th trawl. The effective trawl number (ETN) by which 75% of the catch had occurred was estimated and then a depletion rate which would have resulted in 75% depletion by that ETN was calculated. Because of the humped catch distribution, this method overestimates the catch rates in the first few trawls and under-estimates the catch rates in the last few trawls, but overall provides a reasonable approximation.

The cumulative catch curves for Gastropoda and Anthozoa showed no sign of depletion and so it was not possible to estimate depletion rates for these classes.

6.2.5.2 Results

Only the catches of Echinoidea and Ophiuroidea from the east Mornington locations (Figure 6.2-1 and Figure 6.2-23) were used in the estimation of depletion rates since the catches were very low in west Mornington.

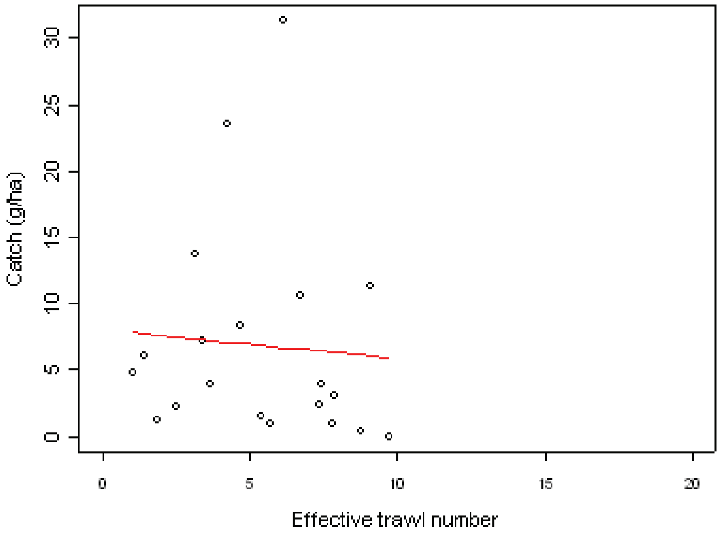


Figure 6.2-19: Trawl catches of Echinoidea at east Mornington plotted against effective trawl number rather than actual trawl number.

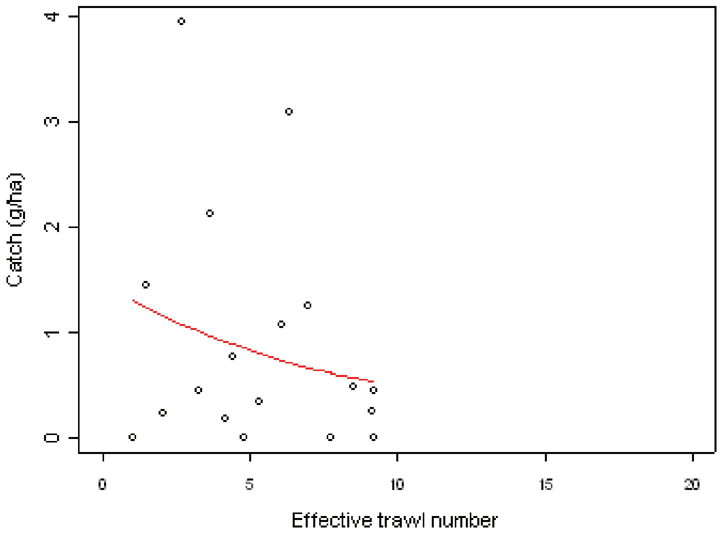


Figure 6.2-20: Trawl catches of Crinoidea from both east and west Mornington combined plotted against effective trawl number rather than actual trawl number.

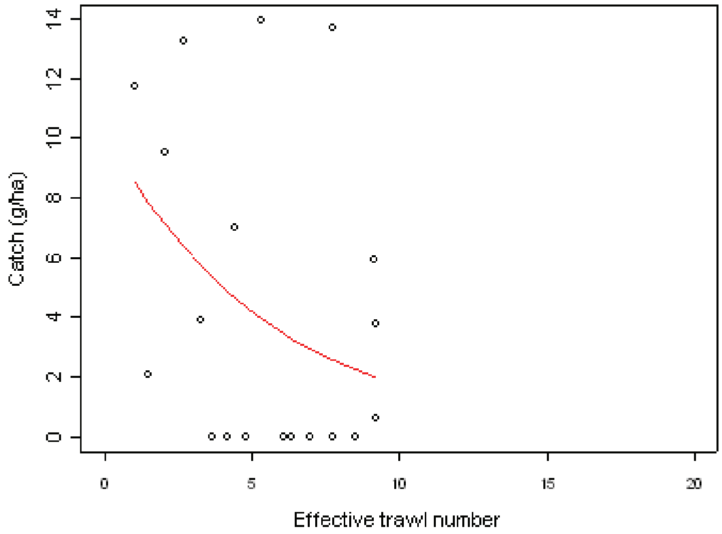


Figure 6.2-21: Trawl catches of Holothuroidea from both east and west Mornington combined plotted against effective trawl number rather than actual trawl number.

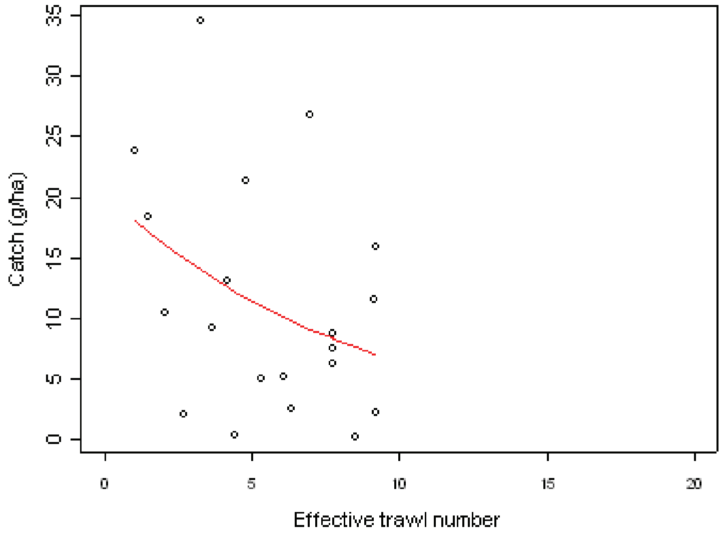


Figure 6.2-22: Trawl catches of Asteroidea from both east and west Mornington combined plotted against effective trawl number rather than actual trawl number.

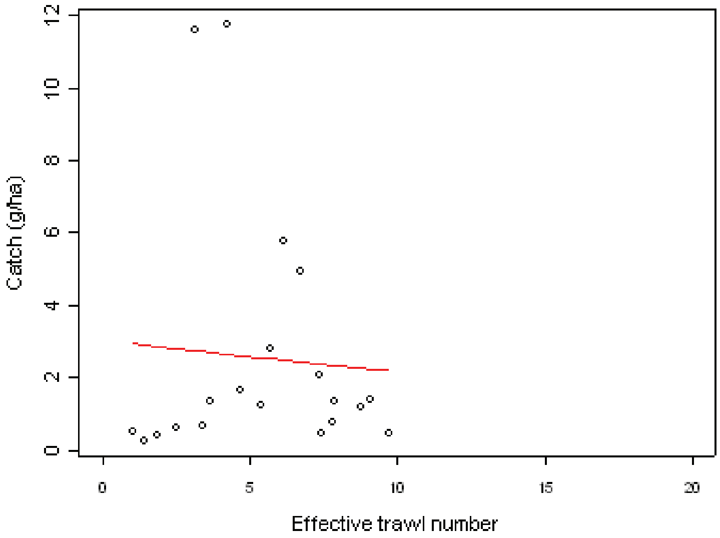


Figure 6.2-23: Trawl catches of Ophiuroidea from both east Mornington plotted against effective trawl number rather than actual trawl number.

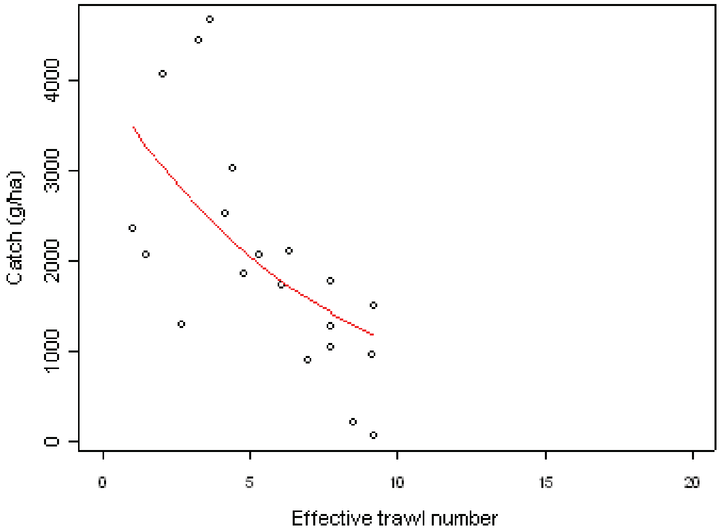


Figure 6.2-24: Trawl catches of Desmospongiae from both east and west Mornington combined plotted against effective trawl number rather than actual trawl number.

Catches of virtually all the echinoids, crinoids and ophiuroids all started out quite low, increased markedly during the intermediate trawls and tended to decline fairly sharply during the later trawls (Figure 6.2-19, Figure 6.2-20 and Figure 6.2-23). In contrast, the catches of holothurians and asteroids tended to be quite erratic throughout the series of trawls (Figure 6.2-21 and Figure 6.2-22), whereas those of the Desmospongiae tended to decline fairly steadily (Figure 6.2-24).

Using the cumulative catch analysis technique the depletion rates for Hydrozoa and Gymnolaemata were estimated to be 19.8 and 21.3% respectively.

6.2.6 Discussion

For most groups of benthos, the cumulative trawl catch data indicated that a general depletion was occurring within the area being trawled. Nevertheless there was a considerable variation in catches. One reason for the variation is that the trawl tracks were not perfectly superimposed and occasionally part of a trawl would pass over untrawled sea bed, perhaps encountering a patch of benthos. Our application of the effective trawl number should have addressed this phenomenon. Another possibility is that the repeated trawling activity was actually attracting mobile scavenging species into the trawled area from outside. There was a suggestion that this may have been occurring for portunid crabs at the eastern locations where numbers caught increased towards the end of the 20 trawls series. The portunid crab *Portunus pelagicus* was the most common scavenger attracted to baits that were designed to simulate prawn trawl discards during field experiments in Moreton Bay, SE Queensland (Wassenberg and Hill 1987). In Newfoundland, scavenging snow crabs (*Chionoecetes opilio*) were observed moving onto trawled areas after 6 trawls (Prena et al. 1999). Although we did not discard our catches in the within 1 km of our trawled area, it is likely that some benthic fauna were injured by the trawl, but not retained by it and these along with the sediment plume generated by the trawl may have acted to attract scavenging species.

Some taxa, notably Hydrozoa had a humped catch distribution, with catch rates in the first few trawls being quite low. After several trawls catches increased and then tapered off towards then end of the series. These animals are usually firmly attached to the seabed and it is possible that it takes several impacts from the trawl before they are dislodged and captured by the nets.

A comparison of depletion rates for major taxa measured in the northern GBR with those found in the present study is given in Table 6.2-6. Porifera, crustaceans, ascidians, asteroids, bivalves had similar depletion rates. Gymnolaemata, crinoids and hydrozoans had higher depletion rates in the GoC than on the GBR, whereas ophiuroids were significantly lower in the GoC. We do not know if these differences are simply due to natural variation or whether these differences are real. It is likely that for some groups at least depletion rates do vary regionally. For example in our study which was conducted on soft sediment most of the sponges were not attached only to shell fragments and not to the seabed. It is likely that these sponges would be captured more readily by a trawl than those that are commonly found in the inter-reefal areas of the GBR which are generally firmly attached to rock or reef substrate. We were unable to estimate the depletion rates for gastropods, or anthozoans (gorgonians and alcyonaceans) in the present study. This is because the catches of these groups by the trawls were quite sporadic and very low (generally < 100 g/ha for gastropoda and < 10 g/ha for anthozoans). Although the density of these groups may be relatively low on the seabed in this region, the trawl was also very inefficient at capturing them compared to the epi-benthic sled (7% for anthozoans and 0.3% for gastropods; see Chapter 5.3).

Table 6.2-6: Comparison of depletion rates (percentages) for major benthic biota taxa as measured in the northern Great Barrier Reef (GBR) and in the present study in the southern Gulf of Carpentaria (GoC)

	Depletion Rate (%)	
Taxon	**GBR**	**GoC**
Gastropods	20	-
Gorgonians	15	-
Porifera	12	12
Crustaceans	13	14
Echinoids	14	3
Ascidians	11	11
Asteroids	10	11
Gymnolaemata	9	21
Bivalves	9	11
Ophiuroids	9	3
Crinoids	8	11
Holothuroids	11	16
Alcyonaceans	9	-
Hydrozoans	8	20

During the preliminary analyses of the result of this experiment we analysed the “before” and “after” epi-benthic sled data (without the inclusion of the trawl data) using a BACI (Before-After-Control-Impact) analysis. The results suggested that the only impacts detected were for Gymnolaemata at the 5% significance level and Phaeophyta and Ascidiacea at the 10% significance level on the 20 trawl plots. Given the amount of benthos removed by the trawls and the obvious depletion from many of the cumulative catch curves we felt it was necessary to try and combine the information from the trawl catches with the epi-benthic sled in order to demonstrate the trawl impacts, hence the analysis we have referred to as the ‘Kuhnert technique’ in the results section.

Results from both the east and west Mornington regions revealed some interesting results despite problems with zero-inflation and having to account for a cyclone half way through the survey. Some significant declines and impacts were noted for some classes but not others and it is difficult to determine whether the latter is because there is no “real” impact evident or simply that we did not have sufficient statistical power to detect an impact in an environment where most benthos has a very patchy distribution on the seafloor.

Summaries of findings from the trawl models fitted to data from east and west Mornington are provided below:

- *West Mornington*
    - As the effective number of trawls increased, the probability of seeing Echinoderms and the Gymnolaemata and Asteroidea classes increased, while the probability of seeing Ascidiacea and Holothuroidea classes decreased.

    - Declines were evident for Bivalvia, Crustacea, Ascidiacea, Echinoderms and species in the unattached functional group.

- *East Mornington*
    - In east Mornington Crustacea and species in the unattached functional groups were more abundant after the cyclone hit, resulting in a larger catch rate and a larger decline from trawling.
    - Echinoidea had a higher probability of presence after the cyclone, resulting in a larger catch rate and hence a larger decline in terms of the probability of presence.
    - Crinoidea also had a higher probability of presence after the cyclone. However this did not seem to impact on their decline due to trawling.
    - Bivalvia had a lower probability of presence after the cyclone (close to zero). The estimate of decline due to trawling indicated that as trawling effort increased, the chance of seeing more Bivalvia increased. However, given that bivalves are present in the trawled area, as trawling increases, the amount of bivalves decreased.

Summaries of findings from the sled models fitted to data from east and west Mornington are provided below:

- *West Mornington*
    - Significant impacts were noted for Hydrozoa, Desmospongiae, Gymnolaemata and Phaeophyta.

- *East Mornington*
    - In east Mornington, as the amount of benthos removed by the trawl increased, this neither increased nor decreased the chance of picking up any of the classes or functional groups using the sled. However, given that a particular class or functional group is present, the amount captured by the sled seemed to be lower for some classes and functional groups. Significant impacts in the east included Gymnolaemata, Echinoidea, Asteroidea, Hydrozoa and species in the attached functional group.
    - Ascideans were the only class that appeared to be adversely affected by the cyclone in east Mornington.

6.2.7 Further considerations

Zero-inflated data is common in many marine datasets. In this report, we have attempted to address zero-inflated data by fitting a two-component model, where the first component models the presence or absence of the species under consideration and the second component models abundance (in this case weight (g/ha)) given that the species is present using a log-Normal distribution. In this report we chose to log the weights and model these using a Normal distribution. As mentioned in Section 2, this can be tricky when fitting random effects models, especially when the amount of zero-inflation is quite high. In the latter instance, estimation of the variances of the random effects and getting predictions for the random effects can be quite difficult. This was reflected in some of the residual plots (not shown) that were investigated as part of the modelling process. We believe that further research into this area is required.

The models themselves produced some interesting findings, some of which can be explained biologically. Others however, highlight areas where further research is required. The latter is particularly true for bivalves, which show some interesting behaviour in the presence of trawling.

Although there were some interesting findings from these models, there were also many classes and functional groups that did not show any impact. These results should be interpreted with caution as it is difficult to determine whether "no significant impact" is a real effect. Possible reasons for finding a non-significant impact when one exists include:

- Lack of statistical power.

- Analysis is compromised somewhat by the amount of zero-inflation and how this is dealt with in the analysis.

It is recommended that future studies of benthic assemblages incorporate a pilot phase to allow researchers to determine the appropriate sampling effort. The issue of zero-inflation should be addressed as a separate research topic as it applies to other applications in the marine science area.

6.2.8 Acknowledgments

Comments and suggestions from Dr Bill Venables relating to the analysis and interpretation of results is greatly appreciated.

6.2.9 References

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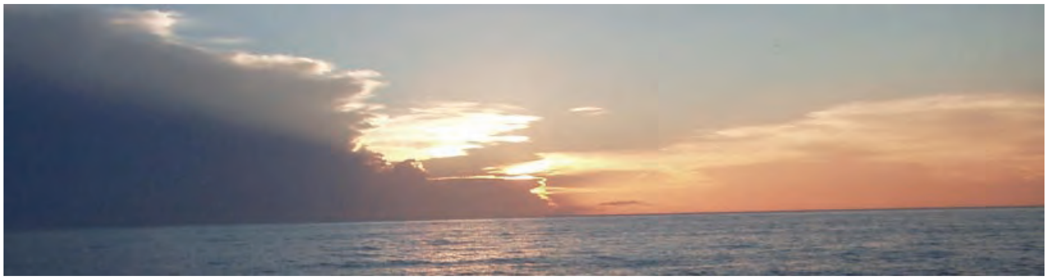


CHAPTER 6. IMPACTS OF TRAWLING EXPERIMENTS

6.3 Second Trawl Impact Experiment

Mick Haywood, Petra Kuhnert, Charis Burridge, Wayne Rochester

Summary

A second trawl experiment was carried out in February 2005 in a plot measuring 1000 x 100 m east of Mornington Island

- Prior to trawling, 30 epi-benthic sled samples were collected from the area, half of these were from inside the experimental plot and half just outside
- A total of 60 trawls were then made along the full length of the plot
- After trawling, 30 epi-benthic sled samples were collected from inside the plot
- The acoustic tracking system showed that trawl replication ranged between 15 and 25 times for around 40% of the plot
- Several taxa were significantly depleted by trawling: Gymnolaemata by 60%, Crustacea and Asteroidea by 65%, Echinoidea by 80% and Hydrozoa by 95%. Phaeophyta were depleted by nearly 100%
- Porifera were not significantly depleted but this result was almost certainly related to the low numbers of sponges at the site
- Five families of bivalves showed an increase as did one family of gastropods and two of echinoids. The reason for this is not known but it may be the result of seabed disturbance by the trawl

6.3.1 Introduction

As described Chapter 2, a feature of the Northern Prawn Fishery is highly targeted trawling in which relatively small areas are trawled repeatedly. In Chapter 4 we showed that these ‘hotspots’ are extremely important to the fishery – in recent years 14% of the area fished contributed an average of 83% of the annual prawn catches. The aim of the present study is to describe and measure the effect of intensive trawling on seabed fauna. The trawl impact experiment described in Chapter 6.1 attempted to do this using a six replicate plot design with two different levels of trawling. The results however were ambiguous. We considered that it would be worthwhile to repeat the experiment but to incorporate the information we had obtained in the first experiment. The weaknesses that we found in the first experiment were in two areas. Firstly taking three epi-benthic sled samples from a plot before and after it was trawled provided insufficient information on the sea bed biota because of the very high variation between samples, which is presumably a result of the patchy nature of the fine-scale distribution of the biota over the seabed. The second was that despite trawling the plots twenty times, the actual level of impact was much lower – around ten as a maximum, because the trawl could not be accurately positioned so that successive trawl shots were placed over the previous ones.

We obtained the agreement of FRDC to carry out a new impact experiment in February 2005. In this experiment we would increase substantially the number of epi-benthic sled samples as well as the number of trawl shots. Because of cost constraints we could do the experiment on only one site but we considered that the information when added to that from the first impact experiment should provide a much clearer picture of the effects of trawling on the seabed biota.

The study was designed to replicate the effect of targeted trawling by repeatedly trawling over the same stretch of seabed. In the first experiment we estimated depletion rates and we decided not to repeat this measurement in the second experiment in order to save costs. In this second experiment we would quantify the effect of trawling by collecting many more epi-benthic sled samples of the trawled areas before and after trawling. The advantage of the epi-benthic sled as a sampling tool is that it collects animals that may have been affected by the trawl but are not necessarily collected by the trawl. In Chapter 5.3 we demonstrated that for most groups of benthos, the efficiency of the prawn trawl was relatively low compared to the epi-benthic sled. Values ranged from 0 for Scaphopoda, algae, seagrass, Cubozoa to 122.7 % efficiency for Crustacea, and were < 20 % for 20 out of 22 of the taxonomic Classes examined. We have assumed that the epi-benthic sled is an effective sampling tool for most sessile and relatively slow-moving invertebrates and macrophytes.

6.3.2 Methods

6.3.2.1 Experimental design and field work

The basic design was to repeatedly trawl a single experimental plot that had previously been sampled using the epi-benthic sled. After the trawling, the plot was re-sampled using the epi-benthic sled. The experiment used a plot 1000 m long by 100 m wide to the east of Mornington Island. Pre-trawling sampling consisted of 15 epi-benthic sled samples inside the plot and 15 just adjacent but outside of the plot (blue lines in Figure 6.3-1).

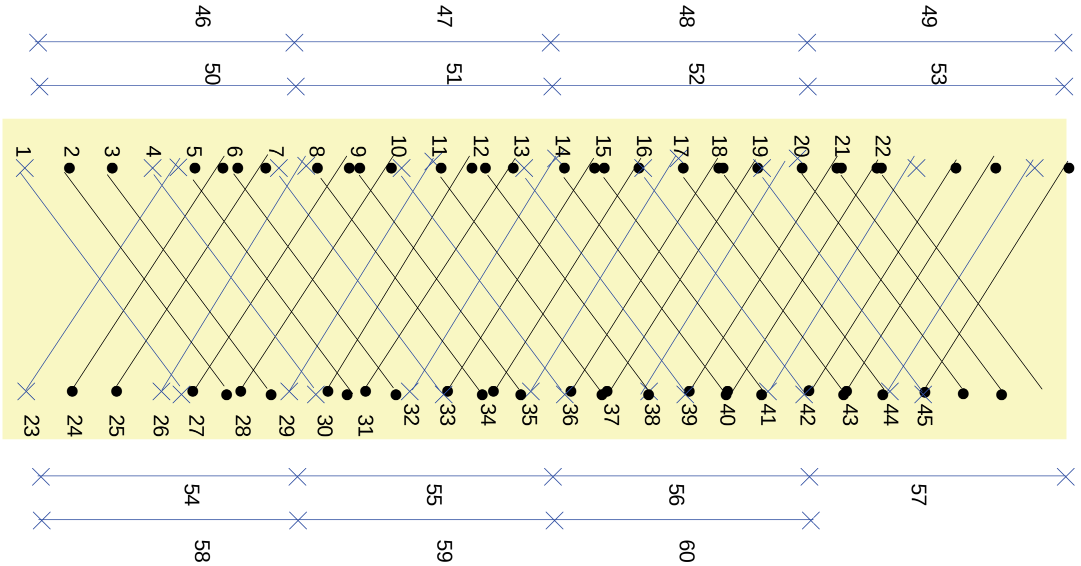


Figure 6.3-1: The trawl plot (pale yellow) and the "before" (blue lines) and "after" dredge (black lines) tracks. Note that this figure is not drawn to scale.

We did not want to disturb the plot more than absolutely necessary before trawling but we considered that we did need some samples from inside it. We planned to make 60 repeat trawls of the full length of the plot, half of these on each side. Our measurements using acoustic beacons fixed to the trawl nets showed that each net deployed by the chartered commercial trawler spread 17.6 m on average and the gap between the nets was 12 m. This means that the trawls cover a path of 48 m width in a single pass and 25% of this path would not be trawled at all. Since the experimental plot was 100 m wide, a trawl replication of 60 times would result in an average of 30 trawls over each piece of seabed but we would expect a range of trawl intensities because it is not feasible to position the trawls exactly behind the trawler.

The experiment was carried out in February 2005. The experimental plot was about 300 m to the east of the original east Mornington study site in this area (Location 12). The 15 pre-trawl epi-benthic sled samples from the plot and another 15 from just outside were all collected on the first day. The 60 trawls were carried out over the following two days. The trawl pattern was to trawl up the plot on one side, turn the vessel and trawl down the opposite side to give a coverage of 30 trawls over most of the plot. The material in the trawl nets was dumped well away from the experimental plot. Vessel speed ranged between 2.9 and 3.4 knots during the trawling. We used the Tracklink system (described in Chapter 6.4) to monitor the position of the trawl. Unfortunately, once again the system did not work as well as expected; there was intermittent interference with the signal from the inner starboard transponder. We have used data that we could obtain from the Tracklink together with accurate positions of the vessel derived from the differential GPS system, to plot the tracks of the trawls.

After trawling, the plot was sampled by taking 30 epi-benthic sled samples. Using only a single transponder beacon on the sled gave more acceptable position plotting. The start and end points for each sled track were determined using the dive logger described in Chapter 5.3.The density of epi-benthic sled sampling represented a ten-fold increase in sampling compared to the sampling regime of the first experiment.

As had been done with previous samples, all the epi-benthic material was frozen and transported to the CSIRO Marine laboratories at Cleveland for analysis. We identified biota to species if possible; otherwise we identified taxa to the lowest possible level e.g. family and then assigned a unique code based on the operation number as described in Chapter 5.3. The biota was then weighed and the information recorded onto the database. It is possible that the trawl impacted some taxa by causing sub-lethal damage rather than dislodging them and retaining them in the cod end. In order to examine whether this was occurring, we examined each specimen for damage.

6.3.2.2 **Analysis of the Epi-benthic sled Data**

Data provided from the trawl impact experiment consisted of 2699 rows of information about weights and number of species captured by the epi-benthic sled for each operation number. For analysis, this dataset was converted to a site by class matrix and a site by family matrix, which recognized when species at the family and class level were absent. This exercise resulted in two datasets. The first contains information about the weights for each of the 18 classes for operation numbers conducted prior to the trawl and post trawling. This dataset was obtained by summing weights recorded for species at the class level for each operation number. In instances where no information was observed at a particular class, a weight of zero was recorded. The second dataset was constructed in a similar way and consists of weight captures observed at the family level for each class.

6.3.2.3 **Trawl Impact using the Bootstrap**

To provide a measure of change in epi-benthic sled captures after trawling relative to what was captured before, the difference of the 80th percentile of the log weights was evaluated for each class and each family within a class. This is referred to hereafter as the “percentile log difference”. This difference is represented by the following expression

$$\begin{gathered} D_p = \hat{x}_A - \hat{x}_B \\ \text{where} \\ \hat{x}_A = \log(x_A^{80th}),\ \hat{x}_B = \log(x_B^{80th}) \end{gathered} \tag{0.1}$$

where x_A^{80th} and x_B^{80th} represents the 80th percentile of the weights after and before trawling respectively.

The median (50th percentile) was originally considered for this analysis but due to the clumped nature of the data and the fact that we want to identify appreciable trawl differences when the large catches are reduced to something smaller, the 80th percentile was deemed more appropriate. The 80th percentile is able to capture sizable differences in catches more than can the median, which will have a tendency to ignore information in the tails of the distribution.

To test whether there is a significant percentile log difference in weights a bootstrap test statistic was constructed. This involved sampling with replacement ten thousand times from weights recorded before and after trawling for each class and each family within a class and calculating the expression shown in Equation (0.1). The bootstrap was used to develop a distribution of D_p, from which 95% confidence intervals could be calculated. A confidence interval that includes zero suggests no significant difference between the 80th percentile before and after trawling. Furthermore, exponentiation of the median bootstrapped difference allows examination of the percentage increase or decrease in the 80th percentile after trawling. Confidence intervals were obtained using the bias corrected and accelerated (BCa) confidence interval described in Efron and Tibshirini (1993) as it has been shown to have some attractive theoretical properties and it is considered more accurate in some cases than standard percentile methods.

6.3.2.4 **Within plot spatial distribution of benthos**

The results from the first experiment indicated that the spatial distribution of the benthos on the seabed was very patchy and indeed this patchiness was probably a major contributing factor in the failure of the first experiment to demonstrate a significant impact on many of the groups of benthos examined. In the second experiment we had a relatively large number of samples from the area to be trawled and so we decided to use this information to characterise the fine-scale distribution of the benthos before and after the trawling. We did this by interpolating the distribution of each of the major taxonomic Classes across the study area.

The sled may be regarded as an integrating sampling device in the sense that it collects samples from the length of a two-dimensional surface (the track), but the it is impossible to determine the location along the track where individual components of the catch were taken. We decided to use the midpoint of each sled track as an approximation for the location of all the benthos collected by each sled haul. We acknowledge that this is a relatively crude approximation, but given the spacing between the individual hauls, we did not regard it as unreasonable. From the information collected by the dive computer attached to the sled, the tracks during this experiment ranged from 97 to 269 m in length (Figure 6.3-5).

The interpolation method used was inverse distance weighting. This is a relatively simple technique which works by creating a neighbourhood (in our case, the 12 nearest points) around each interpolated point and a weighted average of the quantity of interest (in this, the case density of each Class) is calculated. The weights are a decreasing function of distance in the form:

$w(d) = {}^{1}\!/_{d^P}$ where $w(d)$ is the weight, d is distance and the value of P is 2.

6.3.3 Results

6.3.3.1 **Field work**

The vessel tracks during the second depletion experiment are shown in Figure 6.3-2. The tracks are based on positions from the vessel-based GPS system and the Tracklink acoustic tracking system (see Chapter 6.4). The two clusters of tracks result from the trawl being towed up one side of the plot, the trawler then turning around and then towing the trawl down the other side of the plot. This was repeated 30 times on each side – a total of 60 trawl shots. The trawl intensity profile generated by this trawl pattern is shown in Figure 6.3-3. Fifty-one percent of the total area trawled was trawled 16 times or less; only 6% of the area was trawled more than 28 times (Figure 6.3-4).

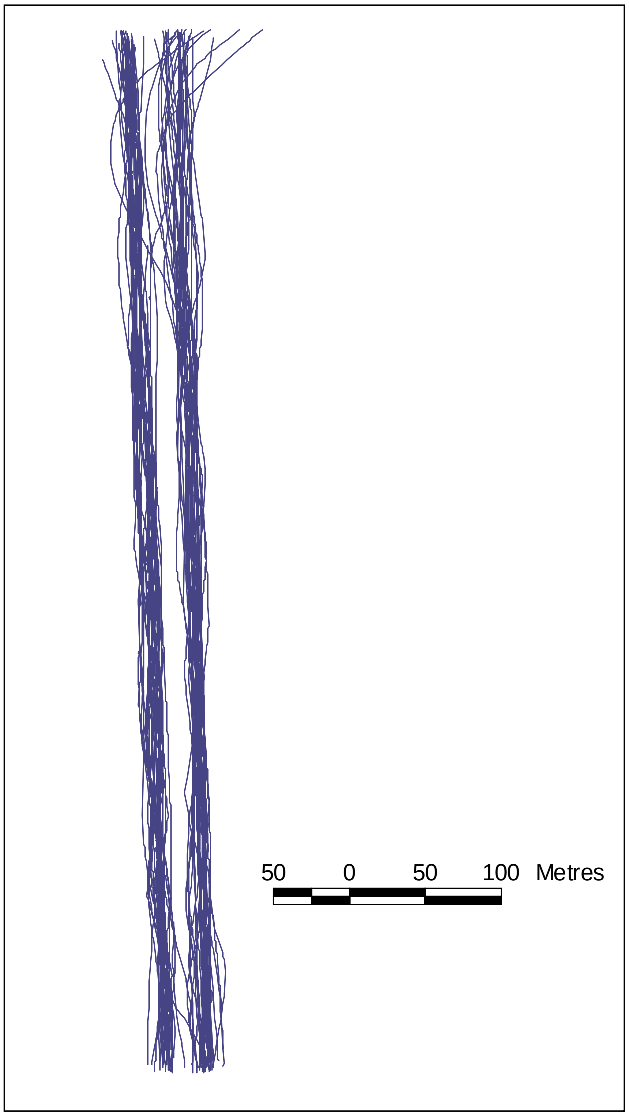


Figure 6.3-2: Vessel tracks recorded during the trawl-down phase of the February 2005 experiment.

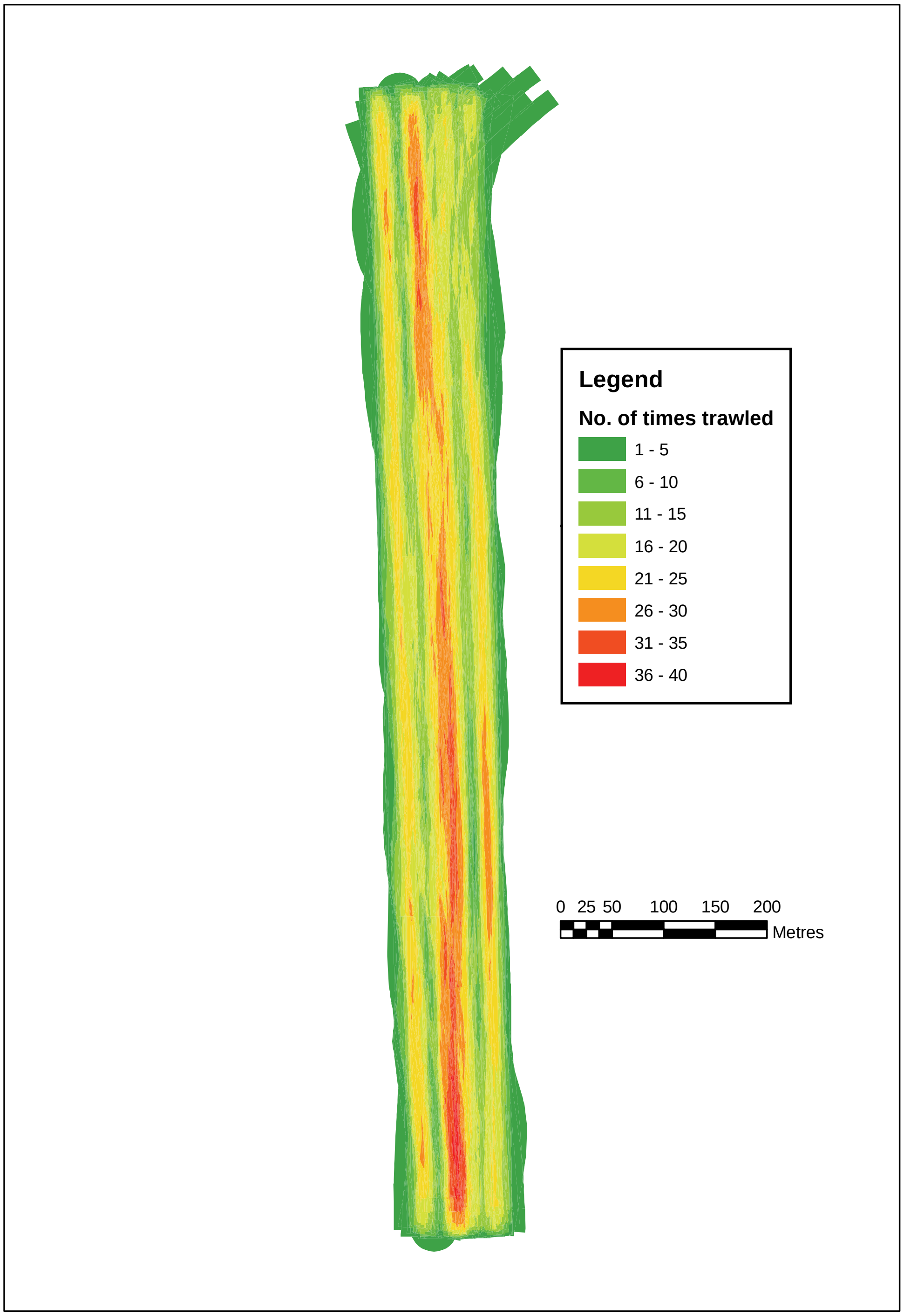


Figure 6.3-3: Trawl intensity profile generated from the second trawl experiment conducted in February 2005 to the east of Mornington Island.

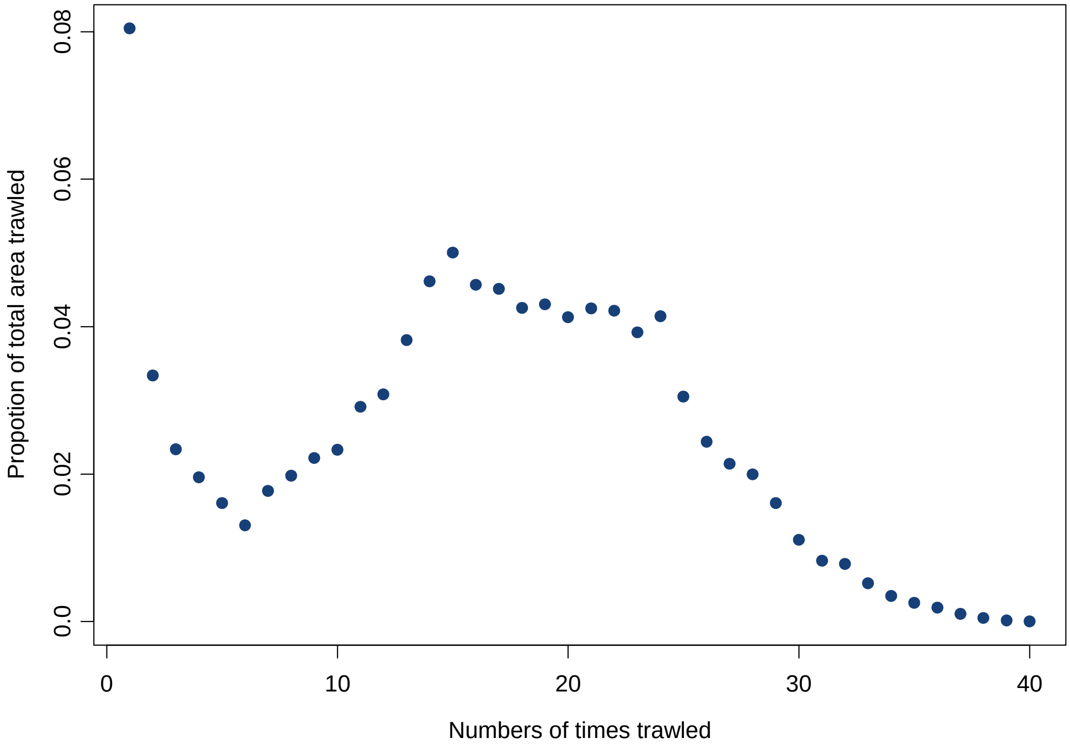


Figure 6.3-4: Plot showing the proportion of the total area trawled between 1 and 40 times during the second trawl experiment conducted to the east of Mornington Island in February 2005.

The waypoints and track of the epi-benthic sled that was used for sampling the biota before and after the trawl impact, are shown in Figure 6.3-5.

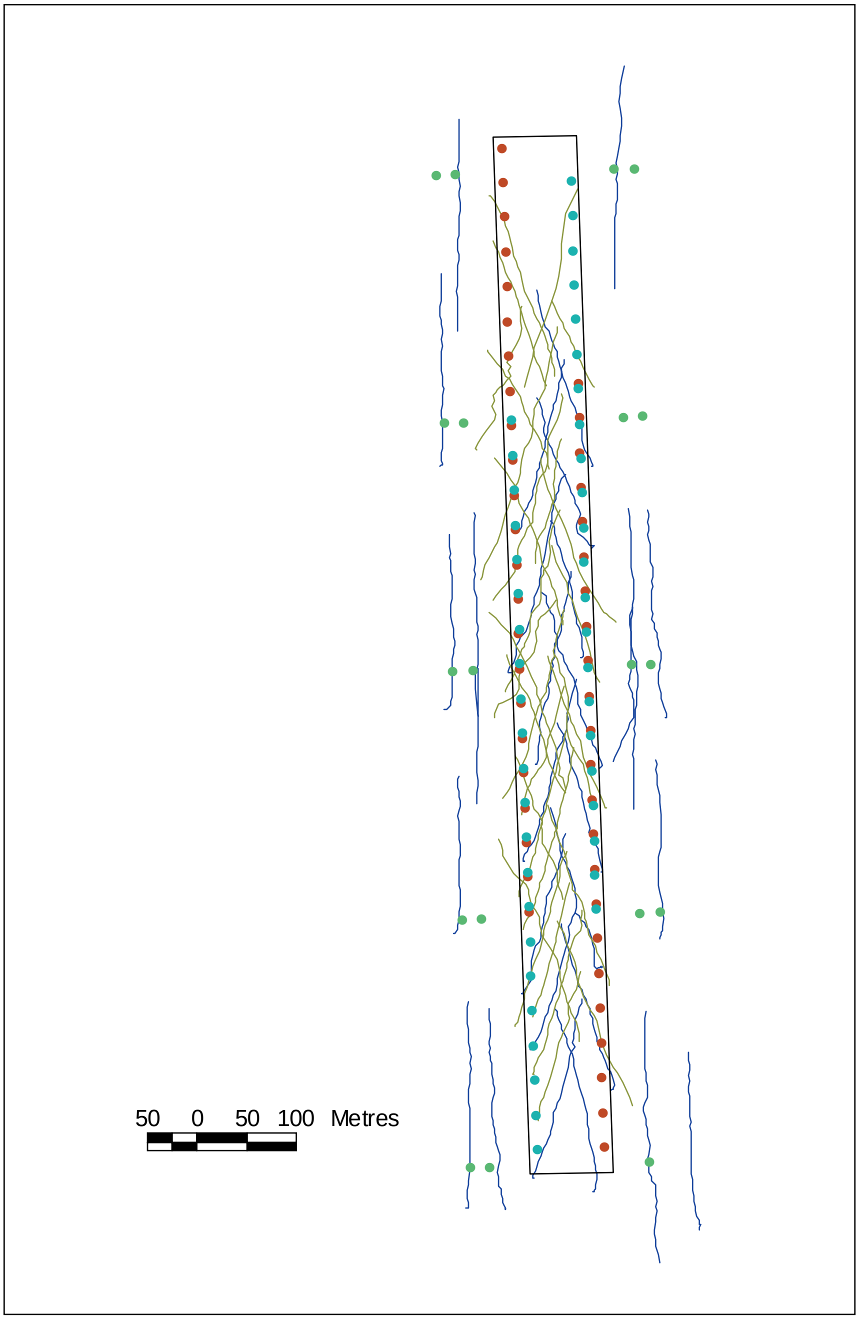


Figure 6.3-5: Before and after epi-benthic sled waypoints (circles) and the epi-benthic sled tracks (lines) as recorded by differential GPS and the Tracklink acoustic positioning system during the February 2005 field experiment.

6.3.3.2 Statistical Analysis

The results from the bootstrap analysis are presented in Appendix H. Appendix H, section H.13 presents tabulated values of the observed and bootstrapped percentile differences and corresponding 95% confidence intervals computed using the BCa method described in the previous section. Box plots of the observed epi-benthic sled captures (g/ha) on the log scale are shown in Appendix H, section H.14. These are constructed at the class level and also at the family level for each class. Each box plot shows the median (represented by a circle), the 80th percentile (represented by a cross), the 25th and 75th percentiles of the distribution (extent of the box), points within 1.5 times the inter-quartile range (whisker) and extreme or unusual observations (points beyond the whisker).

Box plots that are coloured indicate significant differences in the 80th percentile of the log epi-benthic sled captures after impact compared to those species captured before.

6.3.3.2.1 Analysis at the Class level

Figure 6.3-6 shows the results from bootstrapping the percentile differences for the 18 classes identified in the trawled area. A dotted line is drawn at 0 indicating no change or difference in the 80th percentile of the log epi-benthic sled captures after trawling compared to what was caught before trawling.

The medians were computed from the bootstrapped differences and are indicated by black points on the plots. Confidence intervals are drawn as segments from the lower to the upper 95% limit and those highlighted in red indicate that a significant difference had been identified. These correspond to the following classes: Hydrozoa, Gymnolaemata, Asteroidea, Echinoidea, Crustacea, Pisces, Phaeophyta and Holothuroidea. Holothuroidea is the only classes that appear to be positively affected by the trawl, that is, a significantly higher weight of that class was noted after trawling. Note that the confidence interval for this class is extremely wide, indicating some uncertainty around this estimate. There is a suggestion of an increase in ascidians after trawling, but this is not significant. The remaining classes appear to decline once the area was trawled. For example Gymnolaemata was depleted by about 60%, Crustacea and Asteroidea by approximately 65%, Pisces and Echinoidea by approximately 80% and Hydrozoa by about 95%. A depletion of nearly 100% was noted for Phaeophyta.

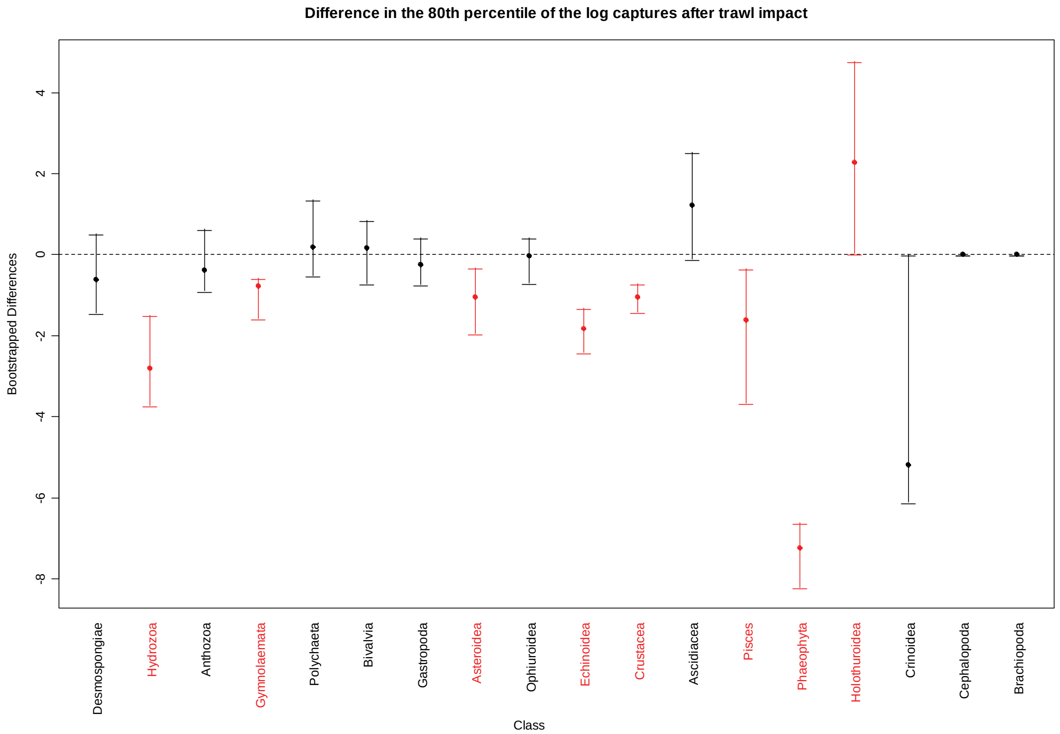


Figure 6.3-6: Bootstrapped differences of the log weights at the 80th percentile captured before and after trawling for 18 classes sampled in the February survey. Classes highlighted in red indicate significant differences in epi-benthic sled captures. Confidence intervals above the dotted line at zero indicate an increase in the 80th percentile of log epi-benthic sled captures after trawling compared to what was captured before. Similarly, confidence intervals below the dotted line indicate a decrease in the 80th percentile of log epi-benthic sled captures.

6.3.3.2.2 Analysis at the Family level

Appendix H summarises the analysis conducted by at the level of Family. Appendix H, section H.13 presents tabulation of the results showing the bootstrapped percentile log differences and corresponding 95% confidence intervals. Significant changes in percentile log weights are indicated in bold font in each table. Appendix H, section H.14 contains box plot summaries of the raw data, highlighting significant findings by coloured boxes.

Table 6.3-1 summarises the significant findings at the family level. As well as listing the bootstrapped estimates, the effect after impact is indicated by an up arrow (increase) or a down arrow (decrease). Significant families identified in the Bivalvia class all show an increase in epi-benthic sled weight at the 80th percentile after impact relative to before. This is also true for the Gastropoda, Ascidiacea and Holothuroidea. Only two families (Brissidae and Shizasteridae) showed notable increases in weight at the 80th percentile for Echinoids. Temnopleuridae showed a marked decline (approximate 90% decrease). All other families shown in Table 6.3-1 showed significant declines, some close to 100% (Sargassaceae and Cynoglossidae).

Table 6.3-1: Significant bootstrap results summarised at the family level

Class/Family	Effect after Impact	Sample Difference $\hat{x}_A - \hat{x}_B$	Bootstrapped Difference $\tilde{x}_A - \tilde{x}_B$	95% CI	
				Lower	Upper
Anthozoa					
Ellisellidae	↓	-0.7530	-0.7334	-1.16	-0.20
Hydrozoa					
Other	↓	-2.8548	-2.7856	-3.74	-1.53
Gymnolaemata					
Other	↓	-0.8714	-0.7916	-1.54	-0.57
Asterpodea					
Goniasetridae	↓	-1.2505	-1.2596	-2.82	-0.43
Bivalvia					
Nuculidae	↑	2.7253	2.7253	2.26	3.56
Glycymerididae	↑	1.0783	1.1800	0.14	2.15
Veneridae	↑	2.3237	2.4154	0.66	4.75
Mytilidae	↑	1.9031	1.8307	0.49	3.82
Tellinidae	↑	2.1597	2.1597	1.47	3.04
Gastropoda					
Cancellariidae	↑	2.3843	2.2040	0.07	3.14
Echinoidea					
Temnopleuridae	↓	-2.5413	-2.5603	-3.22	-1.99
Brissidae	↑	1.5645	1.5914	0.52	2.83
Shizasteridae	↑	4.6265	4.6265	4.18	5.30
Crustacea					
Majidae	↓	-1.3424	-1.2826	-2.69	-0.35
Ascidiacea					
Other	↑	3.5545	3.3568	2.16	4.42
Phaeophyta					
Sargassaceae	↓	-5.6418	-5.6418	-6.53	-4.92
Pisces					
Cynoglossidae	↓	-3.7955	-3.4625	-5.11	-0.85
Holothuroidea					
Other	↑	2.3183	2.2884	0.31	2.81

6.3.3.3 **Within plot spatial distribution of benthos**

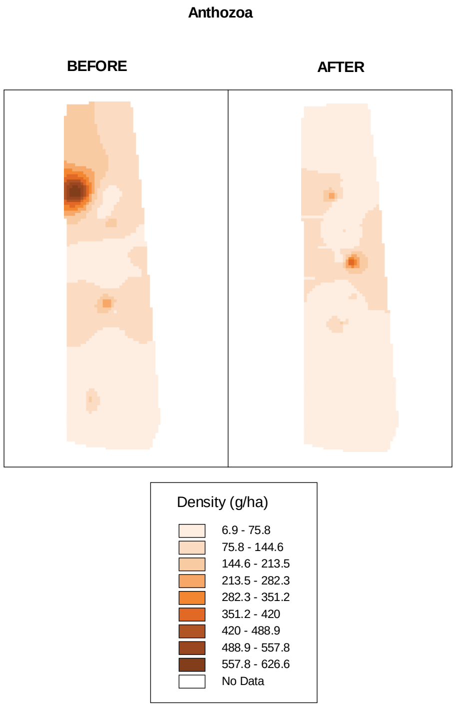
All of the Classes of epibenthos are quite patchy in their distribution (

Figure 6.3-7). In some cases only a single sled sample contained a member of a group (e.g. ‘before’ Ascidiacea;

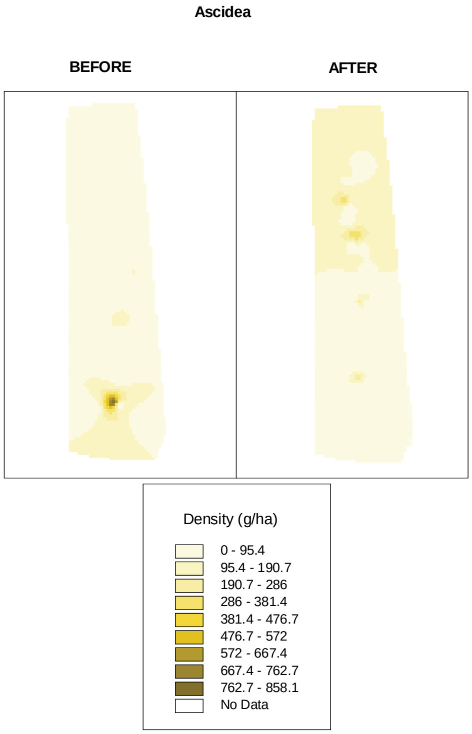
Figure 6.3-7), albeit at a very high density within that small area. Other groups such as Echinoids had a more even distribution across the study area, with one or two high density patches (Figure 6.3-6). From the images depicting the distribution before trawling it appears that there were aggregations of several of the groups at either end of the study area and a patch in the centre.

A comparison of the ‘before’ and ‘after’ images for each Class suggests that for many of the Classes (Anthozoa, Crinoidea, Asteroidea, Crustacea, Echinoidea, Gastropoda, Gymnolaemata, Hydrozoa and Phaeophyta) trawling has significantly depleted the benthos (

Figure 6.3-7). We have classified the responses of the benthos into one of several groups based on their depletion and the efficiency with which they are captured by the trawl relative to the epi-benthic sled (see Chapter 5.3).


Anthozoa


Crinoidea


Ascidea

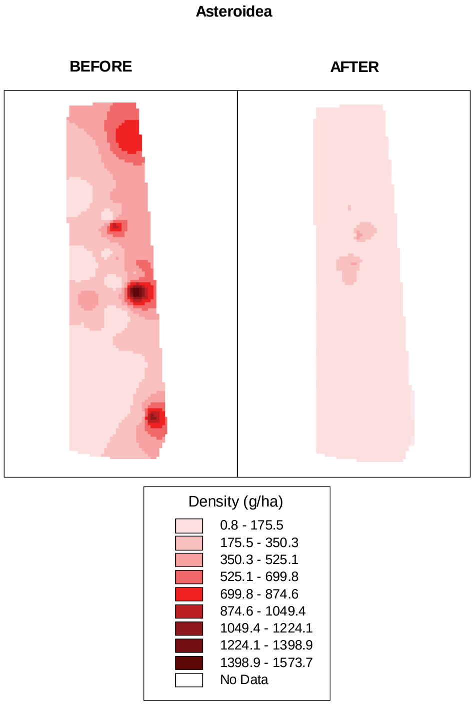

Asteroidea

Figure 6.3-7: Within plot spatial distribution of the various Classes of benthos “before” and “after” the second trawl experiment. The surfaces were estimated using Inverse Distance Weighting as described in the methods section.

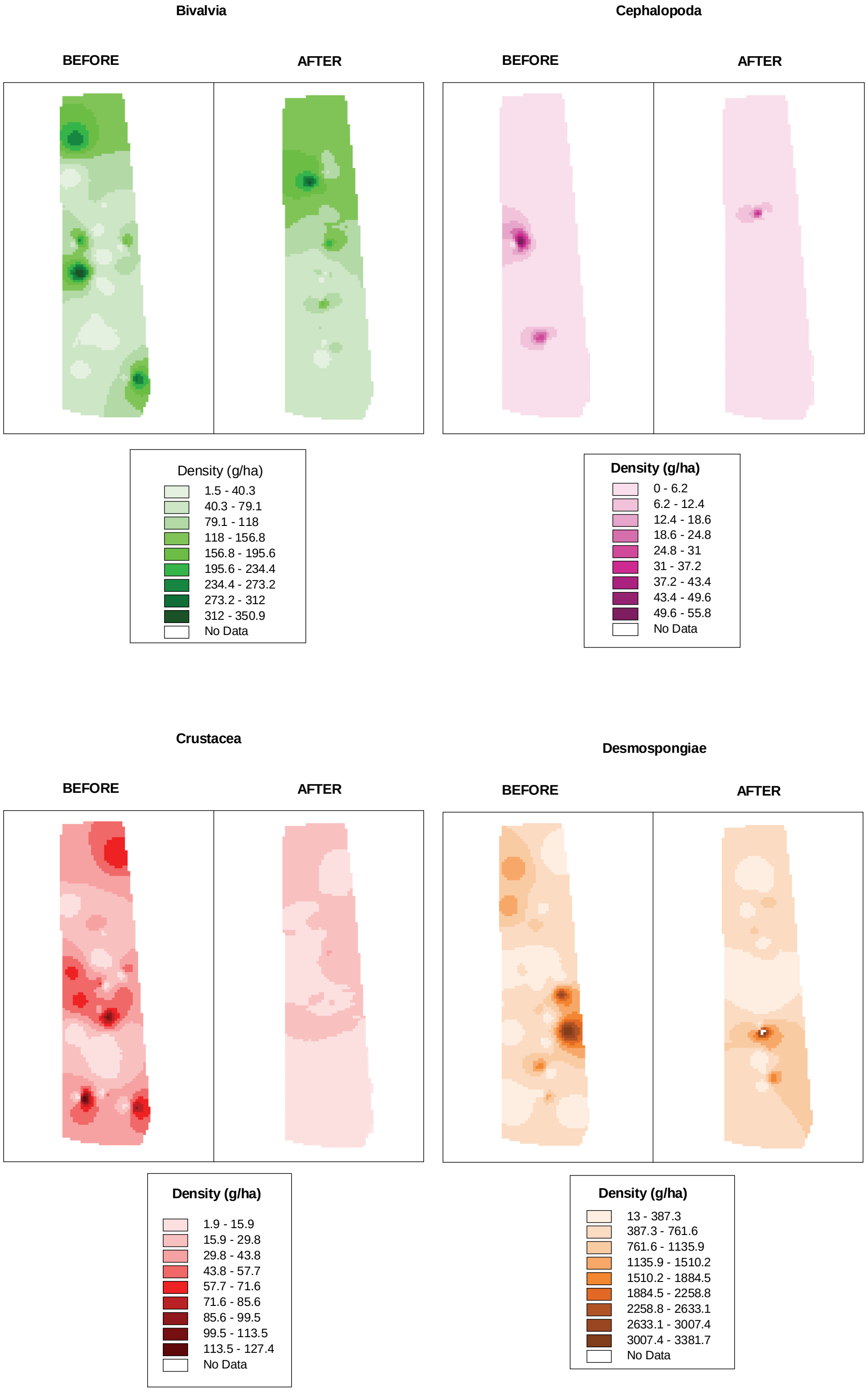
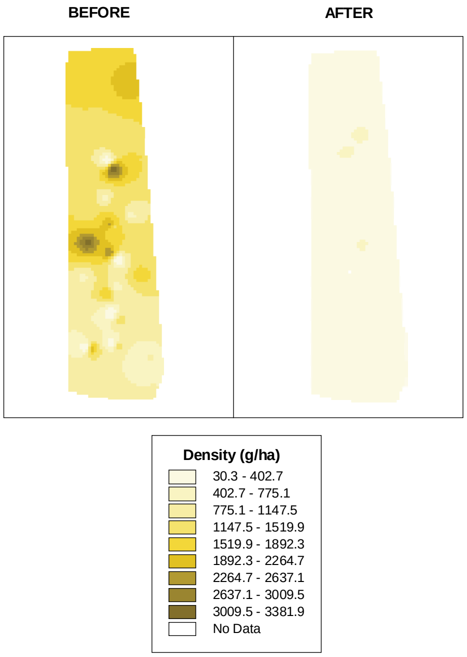
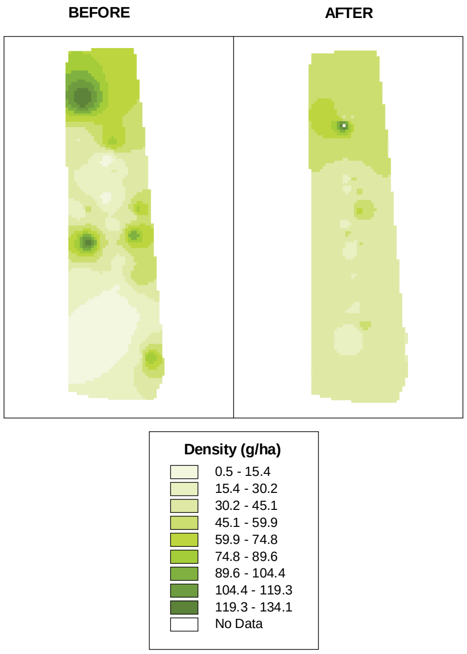


Figure 5.3.7 cont.

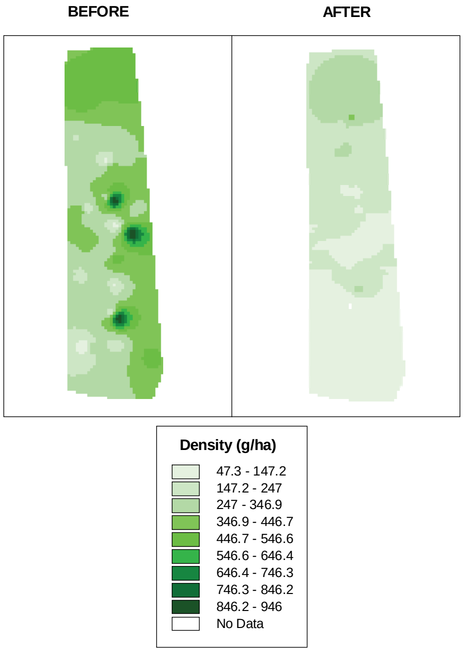
Echinoidea



Gastropoda



Gymnolaemata



Holothuroidea

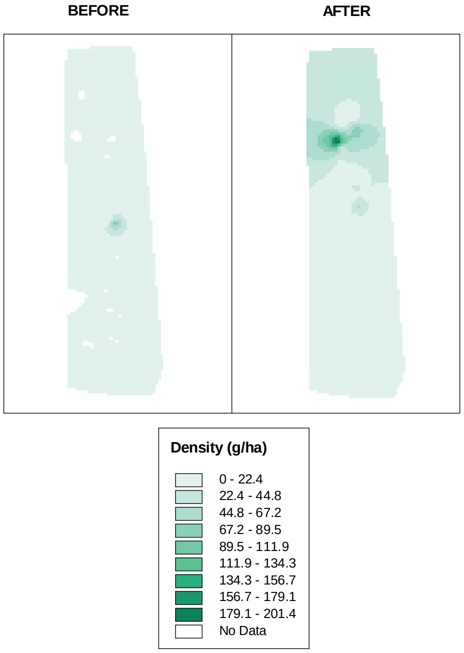
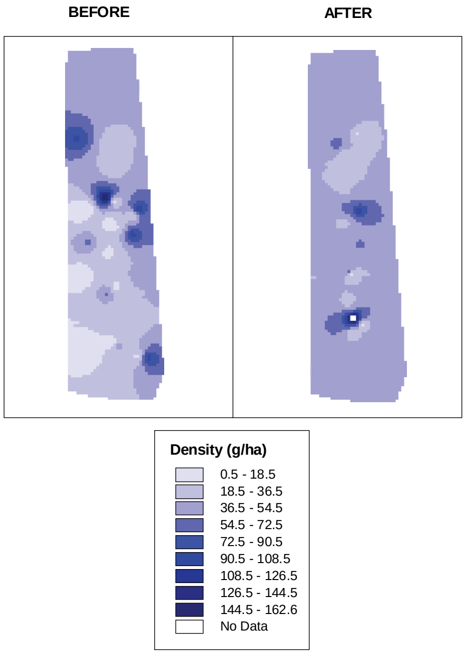
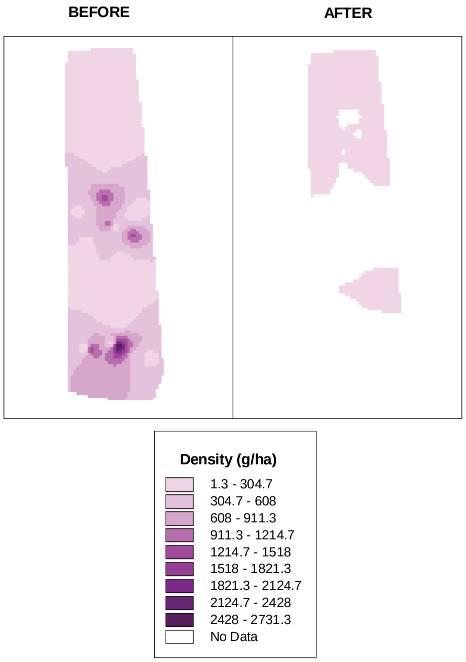


Figure 5.3.7 cont.

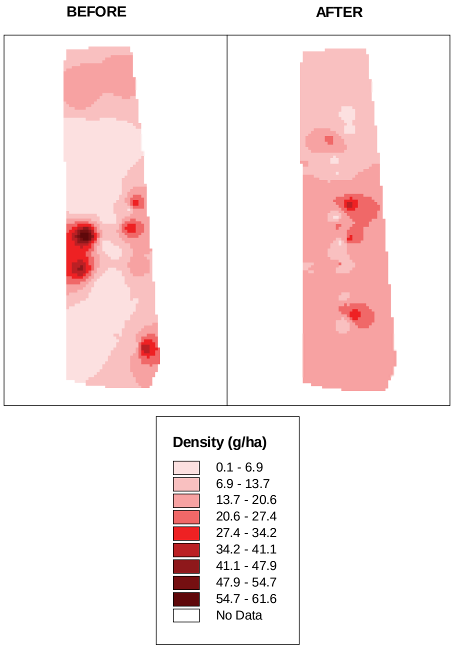
Ophuroidea



Phaeophyta



Polychaeta



Hydrozoa

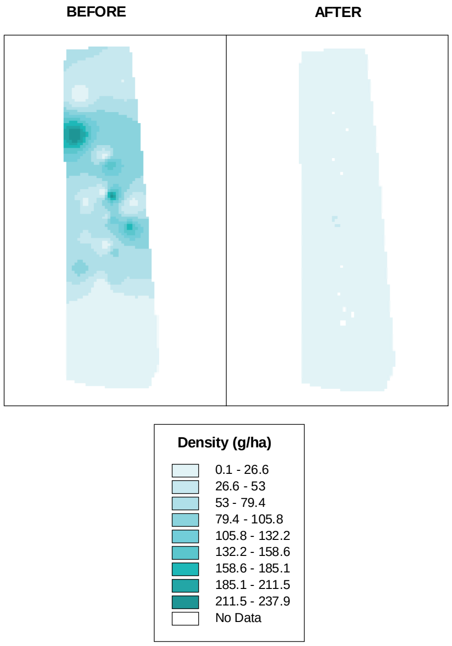


Figure 5.3.7 cont.

Table 6.3-2: Benthic Classes categorized according to their response to trawling and their catchability by the prawn trawl. * = Classes in which bootstrapped differences of the log weights at the 80th percentile captured before and after trawling were statistically significant.

Category	Class	Percent efficiency of trawl relative to sled
High depletion and moderate or high catchability	Crustacea* Crinoidea Asteroidea* Echinoidea* Anthozoa	122.7 19.2 10.7 4.6 7.0
High depletion but low catchability	Gymnolaemata* Hydrozoa* Phaeophyta*	0.2 1.5 0.0
Low depletion, but moderate or high catchability	Bivalvia Cephalopoda Holothuroidea* Desmospongiae Polychaeta	4.7 18.3 13.7 22.1 77.7
Low depletion and low catchability	Ascidiacea Ophiuroidea Gastropoda	3.5 1.7 0.3

In many cases we observed a marked depletion in the images depicting the spatial distribution of the various Classes of epibenthos before and after trawling and in most cases these were statistically significant (Table 6.3-2). There were some apparent anomalies however. For instance, the Anthozoa and Crinoidea have a relatively high catchability and the image plots suggested there was a reasonably high degree of depletion (anthozoans and crinoids), but the differences were not statistically different. The image plots and the confidence intervals around the differences in the weights captured before and after trawling (Figure 6.3-6 and

Figure 6.3-7) give some idea as to the reason for the lack of statistical significance. The image for Anthozoa shows that before trawling there was only a single sled haul that indicated a high density of anthozoans; the remainder of the study area had a relatively uniform, low cover of anthozoans, similar to what was observed after trawling. The differences in crinoid distribution before and after trawling appear fairly dramatic from the images, but were not significant due to the very large confidence interval around the estimate of the difference between before and after (Figure 6.3-6).

Both the image plots and the analysis of the differences between the log weight 80th percentiles indicated significant differences in the densities of Gymnolaemata, Hydrozoa and Phaeophyta despite the fact that the trawl is relatively inefficient at capturing these taxa. Gymnolaemata are generally quite fragile and being attached to the seabed tend to be crushed by the chains on the footrope of the trawl and thus are not retained in the trawl net which may explain why they are impacted by trawling , but do not appear to be caught very effectively by the trawl. Hydrozoans and the brown algae (Phaeophyta) have a similar growth form in the sense that both are attached to the seabed and have a pliable, branching thallus. Although both tended to be detached from the seabed by the trawl chains, they were not effectively retained in the trawl net because they became snared and draped over the chains (Figure 6.3-8).

Figure 6.3-8: Brown algae and a sponge snared in the net chains.

Bivalvia, Cephalopoda, Desmospongiae, Holothuroidea and Polychaeta all have moderate to high catchability by the trawl and yet were not depleted significantly, in fact the density of holothurians increased after trawling. Cephalopods are highly mobile and have the ability to move in and out of the study area quickly and so we would not expect them to show any meaningful response. The initial densities of the other groups were all relatively low and their distribution across the study area was very patchy; both these factors may have contributed to the lack of a significant level of depletion by trawling.

6.3.3.4 **Damage caused by the trawl**

There was some evidence that certain taxa had been damaged by the trawling activity. In particular the proportion of damaged sponges (Desmospongiae), echinoids, hydroids and ophiuroids were much greater after trawling than before, whilst the proportion of damaged ophiuroids and asteroids were slightly higher (Table 6.3-3). It is interesting to note that the numbers of damaged crustaceans and anthozoans were similar before and after trawling whilst the delicate bryozoans (Gymnolaemata) were all damaged before and after trawling.

Table 6.3-3: Percent damaged individuals of each taxonomic class caught in the sled before and after trawling.

	Percent damaged	
	Before	After
Anthozoa	93	87
Ascidiacea	4	9
Asteroidea	33	44
Bivalvia	0	2
Brachiopoda	0	0
Cephalopoda	0	0
Crinoidea	0	0
Crustacea	6	6
Desmospongiae	66	93
Echinoidea	6	35
Gastropoda	1	1
Gymnolaemata	100	100
Holothuroidea	0	0
Hydrozoa	55	84
Ophiuroidea	55	67
Phaeophyta	100	100
Pisces	2	0
Polychaeta	1	0

6.3.4 Discussion

The most significant finding in the second repeat trawl experiment was that the epi-benthic sled could show depletion from trawling. This contrasts with the first experiment in which the results from the epi-benthic sled were equivocal. The important difference between the experiments is the much higher number of epi-benthic sled samples in the second. In the first experiment we took only three samples from each plot because we were concerned that more samples would interfere with our ability to monitor a recovery following trawling and because the costs of the extra samples over all sites would have been prohibitive. In the second experiment we were not concerned with recovery and we could take 30 epi-benthic sled samples. The higher intensity of trawling probably also contributed to a greater impact. In the first experiment the high density trawl lanes were trawled 20 times but most of the trawl impact was less than 10 times. In this second experiment, trawling 30 times over the same ground resulted in a trawl density of between 15 and 25 times over a significant part of the study area.

The spatial plots showing the before and after condition reveal clear depletion in most groups. However, this is not the only response observed. The bootstrap analysis revealed a number of classes and families that significantly declined post trawling relative to what was captured prior to impact, but also showed that there were some classes and families that responded positively to this impact. The latter resulted in species becoming more abundant post trawling. This response differed between families. For example different families of echinoids appear to be positively affected by trawling (Brissidae and Shizasteridae), while other species are clearly affected by the impact (Temnopleuridae).

While it is obvious that biota removed from the seabed through trawling is impacted by the process, it is possible that some groups are damaged by the ground gear of the net but are not retained in the trawl. It is possible that capture by the sled can also cause damage, so we compared the numbers of damaged specimens caught in the sled both before and after trawling. We found there did appear to be damage caused to sponges (Desmospongiae), echinoids, hydroids and ophiuroids through trawling. For other more delicate groups e.g. the brown algae (Phaeophyta) and bryozoans (Gymnolaemata) all specimens were damaged when collected by the sled, even before they had not been subjected to trawling.

The seabed biota of the Gulf of Carpentaria has proved to be more variable spatially and temporally than we expected. We became aware of the high degree of variability as a result of the work carried out in the study and incorporated this information in the design of the second experiment. Experiments on the seabed biota in the Gulf using low sample numbers are unlikely to be successful. We attribute the difference in our ability to identify signals between the first and second experiments to the much more intense sampling in the second. Although at first sight the intensity of trawling appears unrealistic, in Chapter 2 we have shown that the industry does in fact trawl repeatedly over the same ground and the replication that we have used is well within the bounds of the real practice of the fishery.

6.3.5 References

Efron, B and Tibshirani, RJ (1993). An Introduction to the Bootstrap, Chapman and Hall, New York.

CHAPTER 6. IMPACTS OF TRAWLING EXPERIMENTS

Burke Hill, Mick Haywood, Greg Smith, Karl Forcey

6.4 Tracking of equipment

Summary

Separate systems were used for determining the position of the trawler and of gear on the seabed

Position fixing of trawler
- Continuous tracking of the boat was made using C-Plot
- A high accuracy differential GPS system – Omnistar – gave vessel position

Position fixing of gear on seabed
- Acoustic tracking data was used to measure net spread, distance between nets, position of trawls in second impact experiment and position of epi-benthic sled during sampling
- An acoustic system using an LXT and two beacons did not function satisfactorily on the first impact experiment
- A replacement Tracklink system with four beacons provided far greater accuracy than the LXT and was used in the later part of the project
- The Tracklink system also gave problems when more than one beacon was tracked
- Contrary to the claims by manufacturers we found acoustic tracking systems to be complex, prone to malfunction and requiring significant technical resources to operate in the field
- Despite the problems we did manage to obtain data on net spread and position of the epi-benthic sled. In shallow water the trawl followed the vessel path quite accurately

6.4.1 Introduction

We needed to know the path of th trawl and the sled over the sed bed as accurately as possible. Position fixing for this work has two components. The first is knowing the position of the vessel and the second is knowing where the gear is on the seabed relative to the vessel. Vessel position was obtained from a differential GPS-based system. The position of the gear on the seabed was determined using an acoustic tracking system which measured the bearing and angle of signals from transponders attached to the gear.

6.4.1.1 Determining the position of the vessel

The trawlers were fitted with a system known as C-Plot. This is a Windows based charting, plotting and navigation system. It accepts inputs from GPS and sounders and can be used to continuously record the position of the vessel. Positions using conventional GPS receivers are accurate to between 3 and 5 m. C-Plot is highly reliable and we used C-Plot data when the more sophisticated tracking systems failed. Even with the turning off of Selective Availability (SA) by the US, GPS positions are affected by errors in the orbits of the satellites as well as distortions induced by atmospheric effects. These can be compensated by means of a differential system in which reference ground stations continuously monitor their apparent GPS position and broadcast corrections to the GPS signals.

We subscribed to the Omnistar differential GPS system which provides sub-metre accuracy. Under static conditions on land, the system gave position to within 30 cm, at sea the accuracy was <1 m for 95% of time. We used their Seastar Model hardware. The system checked position ten times a second which is ten times faster than a conventional GPS. The high rate of data acquisition proved to be a problem because of the large amount of data that had to be processed and there appears little advantage in having such a high rate.

6.4.1.2 **Acoustic tracking systems**

In 2003 the position of the trawl relative to the vessel was measured using an ORE LXT system. This is an Ultra Short Base Line (USBL) acoustic tracking system that measures the bearing and distance from the vessel of beacons attached to the gear. The system consisted of a deck unit and two beacons. The LXT system was claimed to be able to measure the position of beacons to an accuracy of around 1m at a distance of 150 m. The system requires an accurate reference compass to give the heading of the boat and it also needs a Vertical Reference Unit (VRU) to monitor pitch and roll of the boat to provide continuous corrections to position calculations. The system was bulky (Figure 6.4-1) and the only place we could find on the boat where there was air conditioned space was in the skipper's cabin. Air conditioning was essential. On the first cruise the air conditioning system broke down and the LXT deck unit stopped working until the AC was repaired. It was never the same afterwards.

Figure 6.4-1: Setup on board ship with the LXT system. On the left is a rack with a UPS (black), the small box on the left above this is the Seastar (differential GPS) and above this to the right is a computer for data storage. On the right of the picture the blue box is the EY500 (echo-sounder) with the deck unit of the LXT to the left.

The GPS antenna was mounted on top of a pole fixed to the side of the trawler. The reference compass was attached to the bottom of the pole with the transducer for the LXT system. This meant that all positions were defined relative to the pole. The electronic compass and pitch and roll sensors were in a water proof housing. On the first cruise, the reference electronic compass flooded because of damage to the connector in heavy seas following Cyclone Craig and we decided that in future this equipment would be mounted above water – we could correct for the difference.

During the first trawl impact experiment, the LXT system initially worked satisfactorily and the beacons were monitored sequentially at 2 sec intervals. Their performance then deteriorated and we could monitor on only one channel so we changed to switching between the two beacons every 60 secs. Later in the cruise we could monitor only one beacon. Position fixing of the epi-benthic sled worked well using a single LXT beacon. Distance measuring of the LXT appeared to be accurate or at least highly repeatable – we did not have a method of validating the measurements. Bearing accuracy was only better than 5^{o}.

Because of the unreliability of the LXT system, it was replaced in 2004 by a Tracklink 1500 USBL (HA) with 4 transponders. The Tracklink is a USBL system with a positioning accuracy of 0.25^{o} with better than 0.5^{o} slant angle. It has a range of 1000 to 1500 m with an accuracy of 0.2 m. The Tracklink does not have dedicated deck unit but instead uses a laptop computer. This is a considerably better arrangement since the deck units have proven to be the weakest link in the system. It is easy to carry a backup laptop with the appropriate software and they also tend to be more reliable and rugged than the deck units. The result is also a more compact system that is easier to use on a chartered vessel (Figure 6.4-2).

Figure 6.4-2: Set up with the Tracklink. The blue box is an Octans Gyrocompass, in the foreground is the interface rack which has inputs from gyrocompass, GPS (the Seastar is strapped to the top of the rack), the pitch and roll sensor and the heading sensor (gyrocompass). The laptop computer is running the Tracklink and storing data. The large black cable is the connection to the transceiver.

The Tracklink system uses an underwater transceiver that exchanges data with the four transponder beacons. The transceiver unit was mounted on the end of a pole that could be attached to the side of the trawler (Figure 6.4-3). The transceiver has a 120 to 150^{o} receiver angle and so it was tilted to allow it to receive signals in shallow water.

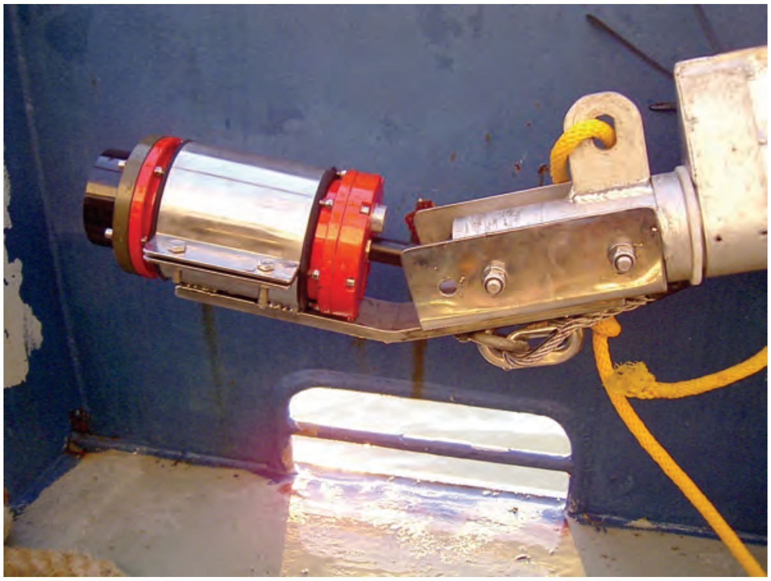


Figure 6.4-3: Transceiver mounted on end of pole that could be fixed to the side of the vessel

The Tracklink system can monitor up to 16 beacons, we had four. We mounted these in housings to protect them because they could be exposed to impacts from trawl boards or with the side of ship when launching or retrieving (Figure 6.4-4).

Figure 6.4-4: Foreground: Tracklink transponder. The transmitter/receiver antenna is in the black cylinder on the left end. The orange housing contains circuitry and batteries. Background: Transponder in protective housing.

The Tracklink was first used in August 2004 to obtain information on the spread of the nets and the gap between them. Because we had four transponders, we could place a transponder on the bridle on either side of each net (Figure 6.4-5).

Figure 6.4-5: Transponders attached to trawl bridles between the trawl boards and the nets. The transponder housings have been wrapped in foam to provide further protection

For trawling runs, transponders were positioned on the nets as follows:

Transponder 1 - Port, Outboard
Transponder 2 - Port, Inboard
Transponder 3 - Starboard, Inboard
Transponder 4 - Starboard, Outboard

At sea, we found the system would track only three of the transponders; the fourth was found to be faulty and was returned to the US for repair. In August 2004 we leased an Ixsea Octans 3000 fibre optic laser Gyrocompass with integral motion sensors as the reference compass and VRU for the Tracklink system. The Octans is a highly sophisticated instrument with no moving parts and which uses three fibre-optic gyrocompasses that give it a heading accuracy of 0.2 to 0.3^{o} and better than 0.02^{o} pitch and roll accuracy. Leasing costs for the instrument rose alarmingly during the course of the project and we subsequently bought our own equipment. This consisted of a Koden GPS compass which measures differences in the position of two antennas mounted on an arm to calculate heading to an accuracy of 0.5^{o} (Figure 6.4-6). Pitch and roll were measured by means of a Microstrain 3DM-G gyro-enhanced orientation sensor. This uses three vector magnetometers, three orthogonal accelerometers and three angular ratio gyros to measure pitch, roll and yaw in a 360^{o} range with a static accuracy of 0.5^{o}. The manufacturers state this can degrade to 5^{o} under dynamic conditions. We used the GPS compass and gyro VRU for the second impact experiment in February 2005.

Figure 6.4-6: Koden GPS compass in position on trawler. The GPS antennas are in the ends of the arms

The final schematic layout of the Tracklink system is shown in Figure 6.4-7.

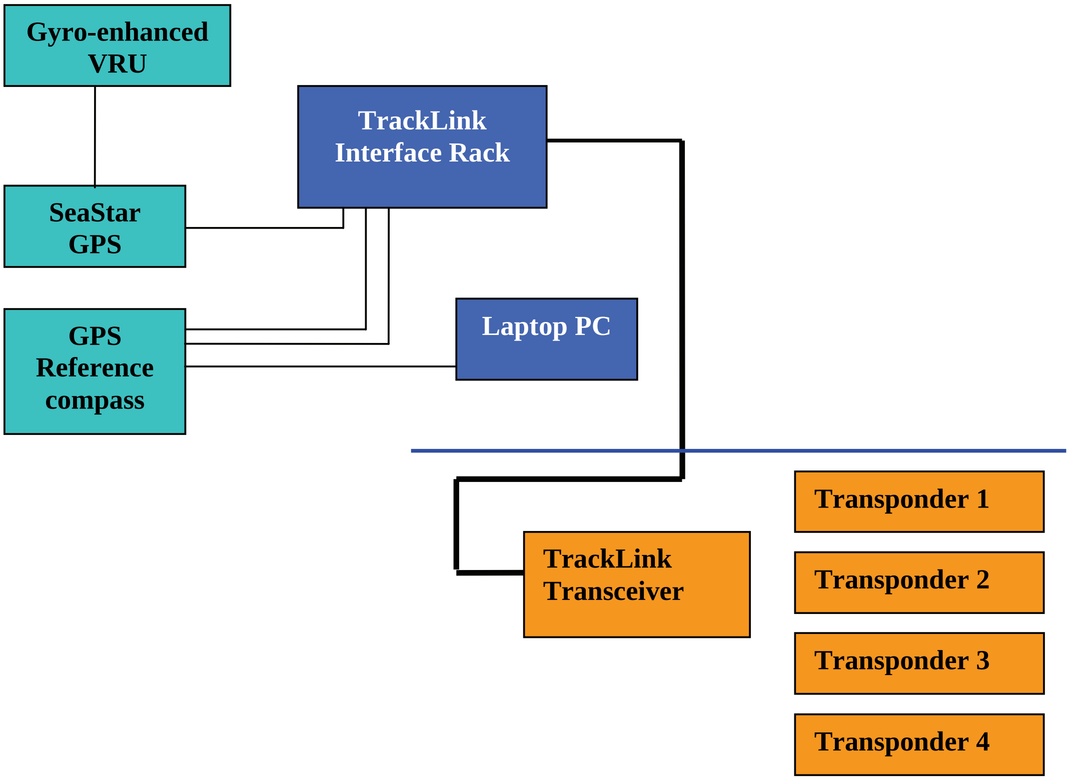


Figure 6.4-7: Layout for the Tracklink acoustic tracking system. The components below the blue line were underwater

6.4.2 Results

During the first trawl impact experiment, failures in the LXT acoustic tracking equipment meant we did not have complete information on the position of the trawl nets. We attempted to analyse the data that was available but the large number of errors in the data made the analysis extremely complex and we did not have confidence in the result. We did have information on the track of the trawler from the C-Plot and we constructed a trawl intensity profile for each experimental plot by assuming the path of the trawl nets across the seabed followed that of the trawler. We measured the distance between the ends of the booms and assumed the nets were directly behind the booms and that the spread of the net was 70% of the head rope length. In August 2004 we used the Tracklink to test assumptions regarding the net spread and the gap between the two nets on the seabed.

According to the Tracklink specification, the transponders were supposed to transmit at 1 signal per second, but they failed to do so, and only operated at 1 signal per 5 seconds. This was not a problem when only a single transponder was being interrogated while we were using the epi-benthic sled. However, when using the trawl we were interrogating 4 transponders, so we could only receive a signal once every 20 seconds from each transponder. For the trawling to the west of Mornington Island signals were only received from transponders 1, 2 and 4; in the east only transponders 2 and 4 functioned and even this reduced performance was intermittent. Despite altering the position of the transponders on the trawl and changing a range of instrument parameters, we could not improve the performance. Subsequently the equipment was returned to the manufacturer and they identified a fault in the power circuit which was repaired. In February 2005 we had a problem with noise in the system. Various attempts were made to try and isolate and remove the causes of transceiver noise as shown in the daily log but with the number of variables beyond our control, it was difficult to pinpoint exact causes. Possible sources of noise included; ship's speed, engine noise, tension of the stays, sea conditions and surface noise from water discharge. As a multi path spread spectrum system, none of these should in theory have much effect on noise levels but it would appear that they all do to some extent. We found that reducing trawl speed did significantly reduce noise. There was about ten times as much noise at 4.5 knots compared to 2.8 knots so the latter speed was used. On this cruise we ran the system at an interrogation time interval of 1.5 seconds.

Despite all the limitations of the gear, we did manage to obtain some useful information by using the Tracklink. This included the position of up to three beacons allowing us to measure net spread and distance between the inner trawl boards. We also obtained good data on the position of the epi-benthic sled.

6.4.2.1 How closely do the nets follow the path of the vessel?

In order to determine how closely the path of the nets followed that of the vessel, we measured the distance from each of the transponders on the net to the centreline of the vessel in August 2004 in the shallow waters to the west of Mornington Island. The variability in the distance between the Tracklink transponders and the centreline of the vessel was much less than that in the deeper waters to the east of Mornington Island (Figure 6.4-8, Table 6.4-1). Nevertheless, the track described by the nets in the east appeared to be less variable than the vessel track, accounting for the elevated variance in distance between vessel and transponder trajectories in the east (Figure 6.4-9). In the east, 240 m of trawl wire was used compared to 100 m in the west. Also, the seas were rougher in the east than the west. These factors would explain why the vessel track was more variable in the east than the west, whereas the trajectory of the nets, being under load and submerged about 200 m behind the vessel was dampened to some degree.

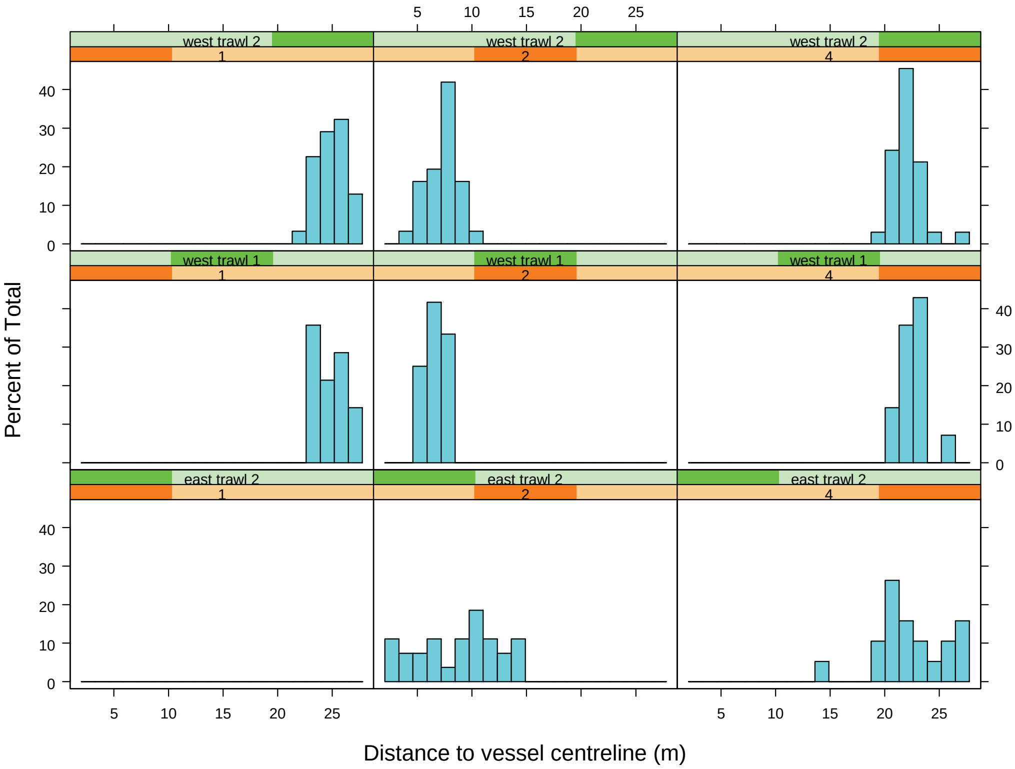


Figure 6.4-8: Histograms of the distance of each Tracklink transponder (1, 2 and 4) to the centreline of the vessel during trawling operations.

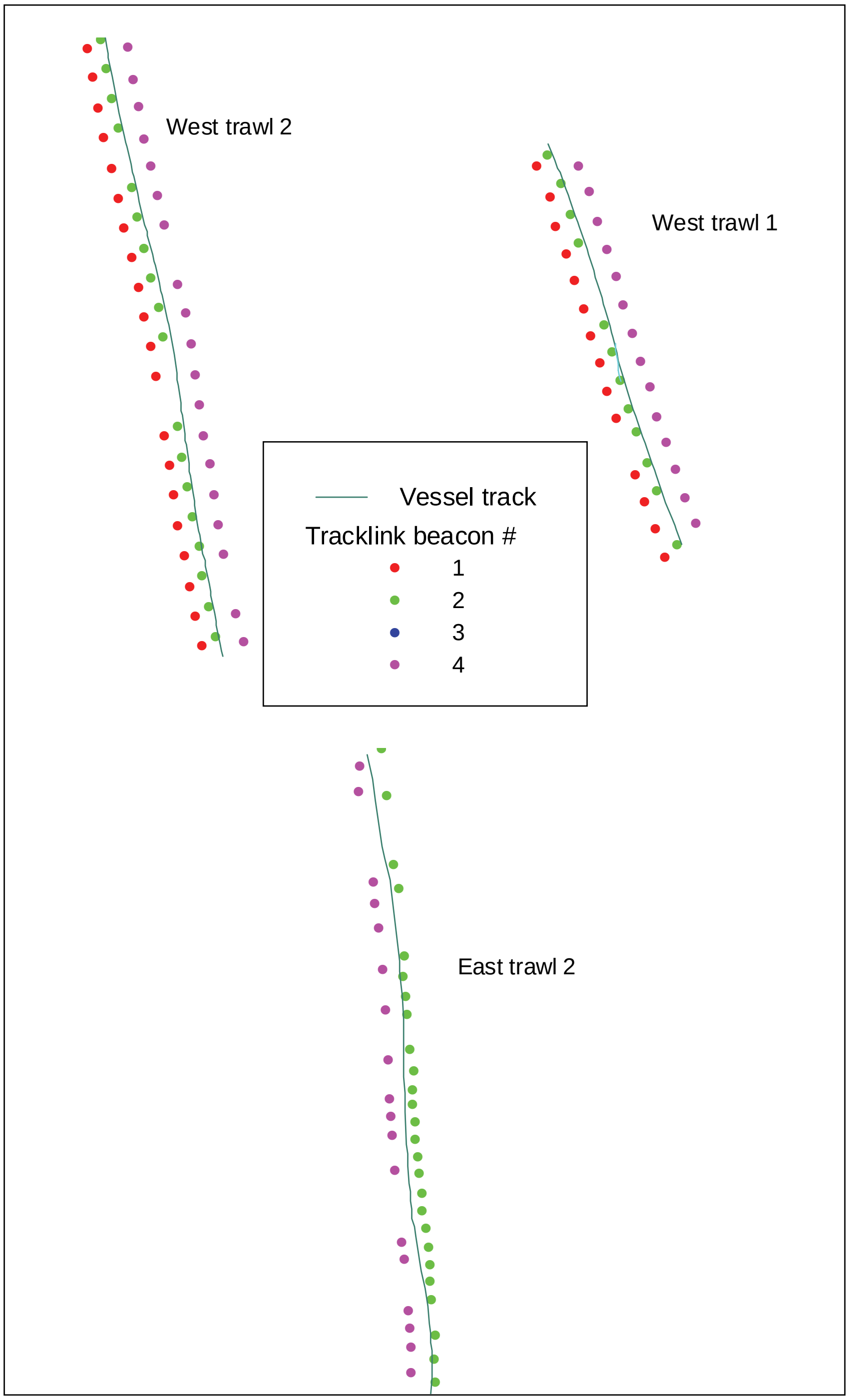


Figure 6.4-9: Tracks of the Tracklink beacons during trawling operations to the east (beacons 2 & 4 only) and west (beacons 1, 2 and 4 only) of Mornington Island during August 2004.

Table 6.4-1: Water depth, length of trawl and mean (± 1 SD) distance (m) of each Tracklink beacon from the centerline of the vessel

	Depth (m)	Length of trawl (m)	Beacon number		
			1	2	4
East trawl 2	25	501		9.1 ± 4.17	22.5 ± 3.42
West trawl 1	9	1260	24.6 ± 1.45	6.7 ± 1.08	22.6 ± 1.28
West trawl 2	9	842	24.9 ± 1.23	7.3 ± 1.33	22.0 ± 1.39

6.4.2.2 **Tracking the epi-benthic sled**

The Tracklink system enabled us to track the position of the epi-benthic sled to an accuracy of ± 1 m. This enables us to overlay each epi-benthic sled track on the trawl intensity profiles to give better estimates of the trawl intensity sampled by each epi-benthic sled shot. In a similar manner to that described above for the trawl tracks, it also gives us the opportunity to determine how closely the epi-benthic sled followed the vessel track.

We measured the distance between points polled every 5 seconds along the track of the epi-benthic sled and the vessel track (see Figure 6.4-10, Table 6.4-2). All the epi-benthic sled tracks were roughly aligned along a North-South axis and so we also determined whether the epi-benthic sled was to the east or west of the vessel track.

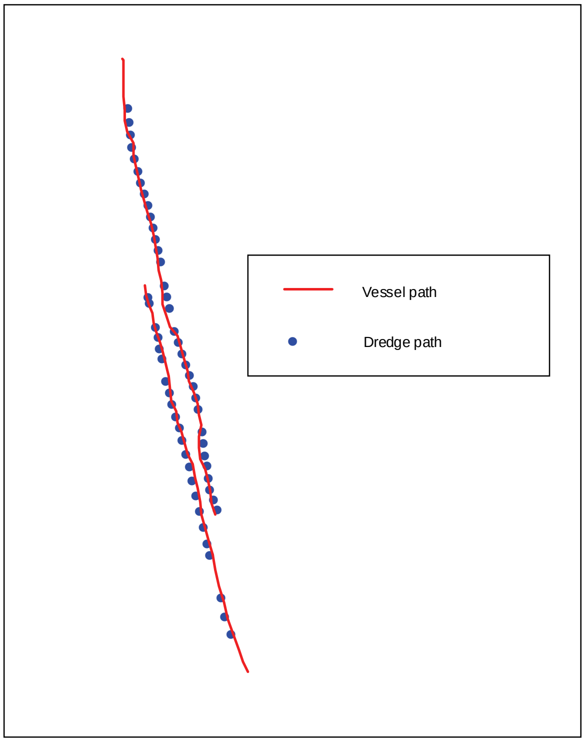


Figure 6.4-10: Examples of two epi-benthic sled and vessel paths from west of Mornington island.

Figure 6.4-10 shows that the epi-benthic sled is generally very close to the vessel path. Given the accuracy of the system, it would seem that our assumption on previous cruises that the epi-benthic sled was following the vessel path was reasonable.

Table 6.4-2: Mean distance (m ± 1 SD) of each epi-benthic sled path from the path described by the centreline of the vessel when operating at East Mornington. "East" or "West" refers to which side of the vessel path the epi-benthic sled was positioned

Sample no.	East	West
415	0.5 ± 0.48	0.3 ± 0.26
416	2.13 ± 0.96	0.2
417	1.25 ± 0.81	2.95 ± 2.01
418	2.73 ± 1.77	2.67 ± 1.23
419	2.62 ± 1.29	3.59 ± 2.66
420	2.73 ± 1.96	3.05 ± 1.31
421	0.29 ± 0.31	3.25 ± 2.29
422	2.45 ± 1.99	3.08 ± 2.1
423	3.08 ± 2.44	1.96 ± 2.77
424	1.13 ± 1.16	2.42 ± 1.41
425	0.88 ± 0.43	1.93 ± 1.27
426	2.91 ± 2.39	2.88 ± 1.61
427	1.42 ± 1.08	1.63 ± 0.71
428	3.83 ± 1.74	5.65 ± 4.06
429	5.81 ± 2.96	2.68 ± 2.12
430	2.14 ± 0.93	1.82 ± 0.78
431	0.83 ± 0.44	2.4 ± 1.6
432	0.74 ± 0.36	3.76 ± 3.08
433	0.71 ± 0.89	3.42 ± 1.68
434	1.03 ± 0.79	1.7 ± 0.86
435	3.25 ± 1.8	4.36 ± 3.7
436		1.24 ± 0.16
437	1.58 ± 0.92	1.98 ± 0.99
438	0.51 ± 0.71	2.31 ± 2.13
439	1.89 ± 1.27	2.11 ± 1.3
440	1.37 ± 0.77	2.39 ± 1.41
441	1.82 ± 1.32	2.1 ± 1.45
403	2.05 ± 1.45	2.82 ± 1.96

From Table 6.4-2 and Table 6.4-3 it can also be seen that there was often a bias to one side or the other; that is the epi-benthic sled often tracked slightly to the port or starboard of the vessel. This is probably due to either cross currents or wind. It is also interesting to note that despite the deeper water at the eastern sites, the deviation of the epi-benthic sled from the vessel path does not seem to be significantly greater.

Table 6.4-3: Mean distance (m ± 1 SD) of each epi-benthic sled path from the path described by the centreline of the vessel when operating at West Mornington. "East" or "West" refers to which side of the vessel path the epi-benthic sled was positioned

Sample no.	East	West
389	2.42 ± 0.96	
390	2.26 ± 1.38	0.08
391	2.78 ± 0.81	
393		0.92 ± 0.56
394	1.78 ± 1.2	0.56 ± 0.48
395	0.54 ± 0.49	0.47 ± 0.25
396	0.64 ± 0.47	1.54 ± 1.06
397	0.88 ± 0.87	0.34 ± 0.21
398	0.12 ± 0.17	1.5 ± 0.55
399	0.88 ± 0.78	0.61 ± 0.46
400		1.52 ± 0.99
401	0.4	1.34 ± 0.81
402	1.03 ± 0.45	0.9 ± 0.63
403	2.05 ± 1.45	2.82 ± 1.96

6.4.2.3 Net spread and gap between the nets

We had measurements from two transponders on a single net from the trawls done to the west of Mornington and we used these data to measure the net spread. Our estimate of the gap between the two nets is based on the assumption that the spread of the port and starboard nets was equivalent. The spread of a net was 17.6 ± 0.97 m (mean ± standard deviation). Since the transponders were mounted 20.8 m apart along the head rope of the net, this equates to a net spread of 85.6% which is approximately 15% greater than that estimated by industry. On long trawl durations the net spread probably reduces as the net fills. In our case we were dealing with 30 min duration trawls, not the 3 to 4 hours common in commercial fishing and so it is unlikely that this was a factor. The measured gap between the two nets (not the boards) was 11.9 ± 1.68 m. These data were used in our trawl intensity profiles.

6.4.3 Discussion

Acoustic tracking provides high quality data about the position of gear underwater. Unfortunately the tracking systems are expensive and complex and require a technician to set up to ensure correct operation. In our case we were using a chartered trawler and so the system had to be set up and tested before each cruise. When the system worked well, it required very little attention but problems had to be diagnosed by an electronics expertise and in some cases required liaison with the manufacturers.

We found that off the shelf acoustic tracking systems do not have the reliability we expected of such expensive equipment. The world market for the systems is relatively small by modern production standards and much of the field testing is actually done by the customers. Problems usually result in new software patches or even new circuit boards and involve expensive air freight of components back to the country of origin. The LXT system is advertised as a Low Cost System. It can track only two transponder beacons with a bearing accuracy of 5^o. The LXT we used was old and had become unreliable. The Tracklink system we purchased was a more expensive system with considerably better specifications. It had a bearing accuracy of 0.25^o and could track up to 16 transponder beacons at a range of 1000 to 1500m. In the case of the LXT we had to write software to integrate data from the VRU, this came as part of the Tracklink system. The latter also did not have a dedicated deck unit using instead a laptop computer with appropriate software.

When the equipment functions properly, it provides information on the position of gear on or above the seabed to a level of accuracy which is adequate for the type of work described here. More accurate systems are much larger and difficult to handle over the side of a small trawler. Despite all the problems, we do now have high quality data on the performance of prawn trawl nets as well as good data on the actual track of the gear that we used in the experiment.

The data we collected in this study has shown that it is difficult to lay trawl tracks over each other. Even though we used experienced commercial skippers who use the fishing pattern of multiple passes over the same ground, the trawl track deviated from the plan. In the past it has been assumed that repeat trawls were really covering the same ground, now we know this is unlikely. We also found that the trawl nets spread much wider than thought by industry. When we finally had the acoustic system operating satisfactorily we established that trawl nets and the epi-benthic sled followed the track of the trawler very accurately and as long as the track is straight, the vessel track can be taken as a good approximation of the trawl track – at least in shallow water down to 35 m depth.

6.4.3.1 Specifications

Specifications on the tracking systems can be obtained from the following websites:

LXT Acoustic tracking system (manufactured by ORE Offshore):
www.ore.com/navigationDataSheets/**lxt**.pdf

Tracklink 5000 (manufactured by LinkQuest Inc)
www.link-quest.com/html/trackLink_5000.htm

CHAPTER 7. RECOVERY OF THE SEABED BIOTA AFTER TRAWL DEPLETION AND SEASONAL CHANGES IN THE BIOTA

Wayne Rochester, Mick Haywood, Anthea Donovan

Summary

- Multivariate analyses indicated that seasonal affects had more impact on the abundance and composition of the benthic assemblages around Mornington Island and these affects were more pronounced in the western region.
- Analysis of individual taxa indicated depletion and recovery in a number of sessile or slow-moving taxa only (e.g. Gymnolaemata, Hydrozoa, Echinoidea and Phaeophyta).
- Recovery of these taxa appeared to have occurred within 6–12 months of trawling.
- Our estimates of recovery times are conservative because we estimated recovery by estimating residual depletion rather than by directly measuring recovery. Our ability to detect residual depletion was limited by high spatial and temporal variation and in some cases random sampling anomalies.

7.1 Introduction

The recovery dynamics of the seabed biota following a trawl impact is an extremely important factor in assessing the effects of trawling. We have previously had no information on the rate at which the biota recovers. In Chapter 6, we described how we repeatedly trawled a series of sites and showed how the various components of the seabed biota were depleted. We revisited the sites at six month intervals for 18 months following the depletion as part of the recovery monitoring. In this chapter we describe the condition of the seabed biota in the time following the depletion.

7.2 Methods

7.2.1 Collection of samples

As described in Chapter 6, there were three sites to the east of Mornington Island in the southern Gulf of Carpentaria and another three to the west of the island. At each site we trawled one 1000 m long lane 20 times and another 4 times. We collected three epi-benthic sled samples from each of these trawled lanes before and after they were trawled. We also collected three epi-benthic sled samples from the neighbouring untrawled area as controls. When we sampled the areas as part of the recovery monitoring, we collected three epi-benthic sled samples from each treatment at each site making a total of 54 samples each time.

The epi-benthic sled was 1.5 m wide (Chapter 5.3). We towed it for approximately 250 m but the exact distance was calculated by means of a depth meter that recorded depth at 1 sec intervals. The seabed biota was frozen and returned to the CSIRO Marine Laboratories at Cleveland for analysis (see Chapter 5.3 for description of the process). Wherever possible the number of individuals and their weight was recorded. The catch was expressed as grams per ha.

7.2.2 Data Analysis

7.2.2.1 Analyses of Species Assemblages

7.2.2.1.1 Non-metric Multidimensional scaling and Analysis of Similarity (ANOSIM)

The response of the species assemblages at each location and treatment were monitored over the 18 months of the experiment using non-metric multidimensional scaling (MDS) ordination plots, ANOSIM (Clarke and Warwick 2001) analyses and species dominance curves. The data used for these analyses were the catch rates of each of the taxa, arranged into taxon by site matrices for each region (East and West Mornington). For the MDS and ANOSIM analyses, these data were then converted into Bray-Curtis dissimilarity matrices using a fourth root transformation using the PRIMER v5 (Clarke and Warwick 2001) software package. The fourth root transformation was used to prevent highly abundant taxa from influencing the Bray-Curtis dissimilarity unduly (Clarke 1993).

The Bray-Curtis dissimilarity between species *i* and *l* across *j* samples is:

$$S_{il}^{'} = 100\left\{ \frac{\sum_{j=1}^{n} \left| y_{ij} - y_{lj} \right|}{\sum_{j=1}^{n} \left(y_{ij} - y_{lj} \right)} \right\}$$

The dissimilarity matrices were used to generate MDS plots for each location over time. The MDS plots provide a visual representation of the dissimilarities species assemblages found at each treatment over the 18 months of the study. The various treatment/time combinations of the species assemblages are presented on a two-dimensional plot such that the matrix of Euclidean distances among them approximates as closely as possible some function of the Bray-Curtis dissimilarity matrix. The measure used to indicate the goodness-of-fit of an MDS to the original matrix of dissimilarities is termed *stress*.

$$stress = \sqrt{\sum_j \sum_k \left(d_{jk} - \hat{d}_{jk} \right)^2 \Big/ \sum_j \sum_k d_{jk}^{\ 2}}$$

where $\hat{d}_{jk}$ is the distance predicted from the fitted regression line corresponding to dissimilarity δ_{jk}.
A large value for *stress* indicates a high degree of scatter in the plot and may be thought of as a measure of the difficulty involved in compressing all the sample relationships into 2 dimensional space (Clarke and Warwick 2001). The rough rule of thumb regarding the interpretation of stress values is as follows:
Stress <0.5 – an excellent representation of the relationships between the data points.
Stress < 0.1 – corresponds to a good ordination with no real prospect of misleading interpretation.
Stress <0.2 – means a potentially useful 2 dimensional representation.
Stress >0.3 – indicates the points on the plot are close to being arbitrarily placed on the plot. (Clarke and Warwick 2001).

We tested for the statistical differences between the treatments and times using ANOSIM (analysis of similarities) test described by Clarke and Green (1988). This test is based on a simple non-parametric permutation procedure applied to the rank similarity matrix underlying the ordination of the samples. The statistic calculated by the test is *R*:

$$R = \frac{\left(\bar{r}_b - \bar{r}_w \right)}{1/2\,M}$$

where $\bar{r}_b$ is the average of all rank similarities arising from all pairs of replicates between different treatment groups and $\bar{r}_w$ is the average of all the rank similarities among of all pairs of replicates within treatment groups and $M = n(n - 1)/2$ where n is the total number of samples. If the null hypothesis H_0: “There is no significant difference between the groups” is true, then there will be little change in the average value of R if the labels identifying the replicate samples are arbitrarily rearranged. This forms the basis for the permutation test of H_0; the labels are rearranged arbitrarily a large number of times and R is calculated following each relabelling. This generates a null distribution of R and the significance level for R is calculated by comparing the observed value of R to its permutation distribution. The R statistic generally falls between 0 and 1 and provides a measure of the degree of separation between the groups. Where $R = 0$, the groups are impossible to tell apart, $R<0.25$ indicates the groups are barely distinguishable, $R>0.5$ the groups are separable, but overlapping, if $R>0.75$ then the groups are well separated and if $R=1$, then all within group samples are more similar to each other than they are to any of the between group samples.

7.2.2.1.2 Abundance/biomass comparison curves

Ranked dominance curves are generated by ranking the taxa in decreasing order of their importance in terms of abundance or biomass expressed as a percentage of the total abundance of all species. The cumulative abundance is then plotted against the relative taxon rank. Plotting ranked abundance in terms of numbers and biomass on the same figure gives an indication of the level of disturbance of a benthic community (Warwick 1986). Under stable conditions, benthic communities are generally dominated (in terms of biomass) by *K*-selected species i.e. those which have a relatively large body size and long life span. While these species dominate the biomass they are generally occur in low numbers. Opportunistic taxa (*r*-selected species) on the other hand, generally are numerically dominant, but have a small body size and are short lived. When a community is stressed, the *K*-selected species are impacted more than the *r*-selected species and thus the distribution of the numbers of individuals among the benthic species should behave differently to the distribution of the biomass of those individuals.

For undisturbed communities, the biomass curve should always lie above the numbers curve, indicating higher diversity in terms of biomass rather than numbers (Figure 7-1 A). In a community that has undergone moderate disturbance, the populations of the *K*-selected taxa will have been eliminated, reducing the inequality in size between the numerical and biomass dominants (Figure 7-1 B). This will result in the biomass and numbers curves being close together and perhaps crossing each other. For communities under severe disturbance, one or a few of the small *r*-selected taxa will become increasingly dominant resulting in the numbers curve lying above the biomass curve (Figure 7-1 C).

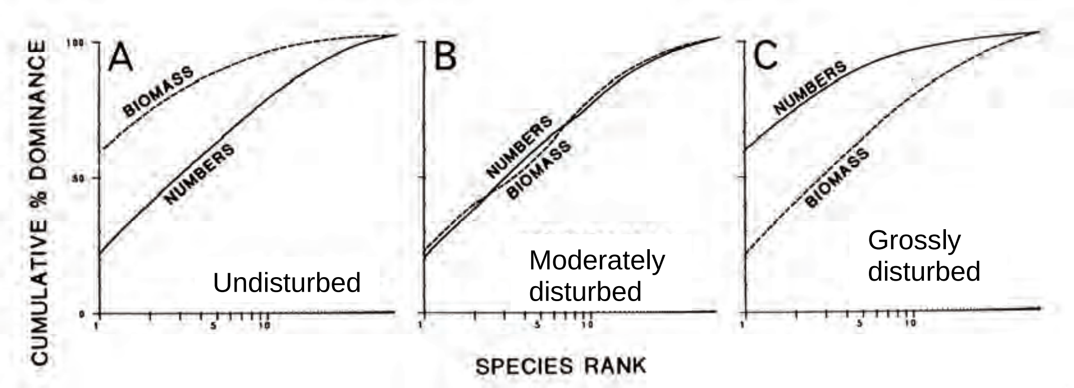


Figure 7-1: Hypothetical abundance/biomass curves for species biomass and numbers, showing undisturbed, moderately disturbed and grossly disturbed conditions. (Reproduced from Warwick 1986).

Clarke and Warwick (2001) suggest reducing these plots to a summary statistic *W*:

$$W = \sum_{i=1}^{S}(B_i - A_i) \Big/ \left[50(S - 1)\right]$$

where A_i and B_i are the abundance and biomass of each species rank (*i*) and *S* is the species richness (number of species). *W* can range from -1 to 1 and $W \rightarrow +1$ when the abundances across species are equal but the biomass is dominated by a single species $W \rightarrow -1$ in the opposite case. Under intermediate conditions, when the abundance and biomass curves are intertwined and close together will give *W* values approaching zero.

7.2.2.1.3 Change in size

We measured the length of all organisms captured by the benthic sled with a view to determining whether there were any changes in mean length as a result of trawling and if so, to follow the subsequent recovery over the subsequent 18 months. As each new taxon was sorted, the staff sorting the samples would decide upon a characteristic dimension that would be consistently possible to measure for the duration of the project e.g. carapace length for decapods. This was recorded and all subsequent specimens of the same taxon would be measured in the same manner.

Plots of specimen length versus time since trawling by region (east or west Mornington) were constructed for each treatment to determine whether trawling affected mean length and if so, whether the population increased in mean size during the following months.

7.2.2.2 **Recovery of individual taxa**

In this analysis we aimed to quantify the recovery rates of individual taxa following trawling. If the Gulf was in equilibrium during our 18-month experiment, then recovery of a taxon would mean a return to pre-trawling abundance. However, because abundance would have varied anyway due to other factors such as climate and successional changes, recovery instead means that the taxon has become as abundant as it would have been without trawling. Our untrawled control lanes provided data on what that abundance would have been. Our analysis strategy was then to estimate the effect of time on the abundance of the taxon, and then to estimate the additional effect of treatment (4 and 20 trawls). Because we had taken repeated measures from each lane, we used a linear mixed effects (LME) model to account for correlation among the samples of a lane (Pinheiro and Bates 2000). We modelled the catch as:

$$\log(y_{tTs} + c) = \alpha + \beta_t + \gamma_{tT} + b_s + b_{sT} + \varepsilon_{tTs}$$

$$b_s \sim \mathrm{N}(0, \sigma_1^2),\ b_{sT} \sim \mathrm{N}(0, \sigma_2^2),\ \varepsilon_{tTs} \sim \mathrm{N}(0, \sigma^2)$$

where t is the time, T is the treatment, s is the location, y_{tTs} is the catch, α is the mean catch, β_t is the fixed effect for the time, γ_{tT} is the fixed effect for the treatment within the time, b_s is the random effect for the location, b_{sT} is the random effect for the treatment (lane) within the location, ε_{tTs} is the residual error, σ_1^2 is the variance of the location random effect, σ_2^2 is the variance of the treatment within location random effect, σ^2 is the residual error variance and c is a constant (0.1 times the 10th percentile catch).

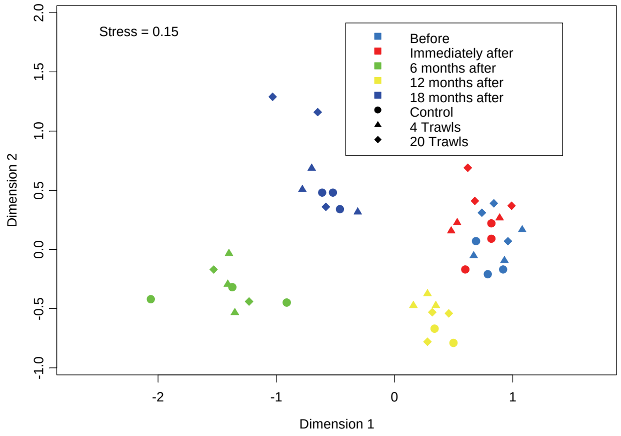
7.3 Results

7.3.1 Analyses of Species Assemblages

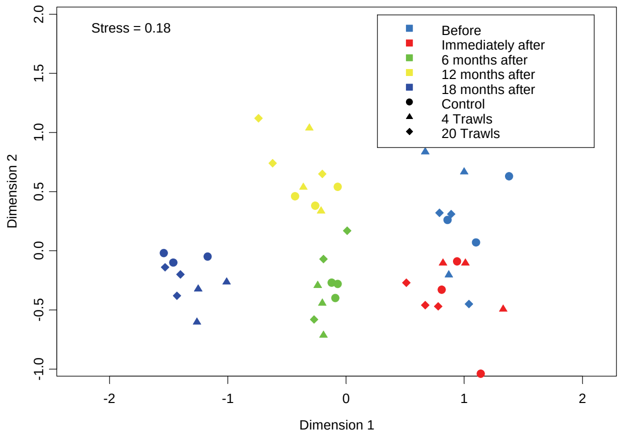
7.3.1.1 **Non-metric Multidimensional scaling and Analysis of Similarity (ANOSIM)**

West Mornington

Location 3



Location 5



Location 6

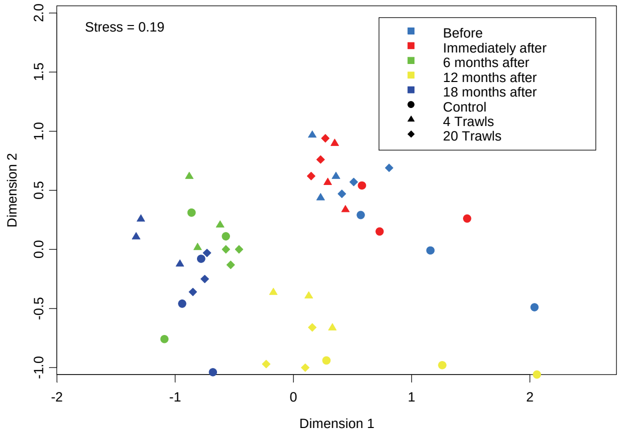


Figure 7-2: Non-metric multidimensional scaling plots of benthos collected by the epibenthic sled from sites in the West Mornington Island region. The data was 4th root transformed catch rates (g/ha) and converted to a Bray-Curits dissimilarity matrix before plotting. The colours indicate the time relative to the trawling impact and the symbols denote the different treatments.

The striking aspect of the MDS plots for West Mornington is that the seasonal aspect appears to be far more important in determining the characteristics of the species assemblages than the impacts of trawling (Figure 7-1). This is evident at all 3 locations with all the “Before” and “Immediately after” samples generally falling closer to each other than to any of the other samples, regardless of the trawling intensity. The other aspect which suggests that this is a seasonal component is the fact that the samples collected 6 and 18 months after the trawling experiment (winter) are generally clustered together and away from those collected “Before”, “Immediately after” and “12 months after”(summer) the trawling was completed.

The ANOSIM analysis confirmed the results from the MDS plots. There were significant differences in the composition of the species assemblages at all 3 locations in West Mornington across sampling times (Table 7-1; Global *R* - between times). The differences between assemblages were least (and usually not statistically different) between the “Before” and “Immediately after” samplings. The differences were also generally larger and more highly significant between the summer and winter samplings (Table 7-1).

Although not as evident from the plots, the overall differences between the trawl treatments were also statistically significant from each other (Table 7-1; Global *R* – between treatments). However the R values were much less (ranging from 0.084 to 0.393) than those for the differences between times, indicating that these differences were not as great as the seasonal differences.

Table 7-1: West Mornington - Results of ANOSIM comparisons of species assemblages at the different trawling intensities over time.

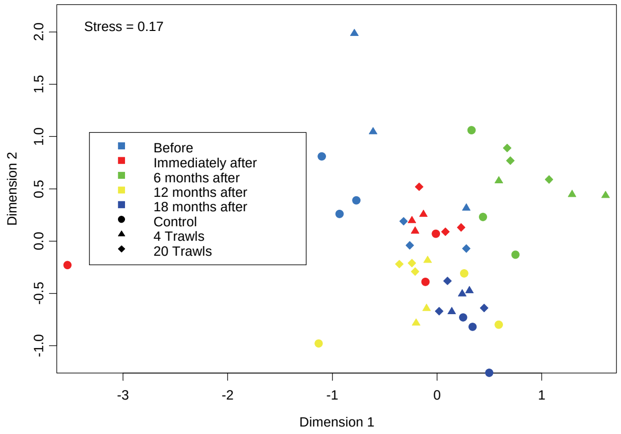
Location	Test	*R*	Significance level (%)
3	Global – between times	0.854	0.1
	Before, Immediately after	0.099	18.9
	Before, 6 months after	1	0.1
	Before, 12 months after	0.679	0.2
	Before, 18 months after	0.988	0.1
	Immediately after, 6 months after	1	0.2
	Immediately after, 12 months after	0.753	0.2
	Immediately after, 18 months after	1	0.1
	6 months after, 12 months after	1	0.2
	6 months after, 18 months after	0.956	0.1
	12 months after, 18 months after	1	0.3
	Global – between treatments	0.084	10.7
	0 trawls, 4 trawls	0.133	12.4
	0 trawls, 20 trawls	0.186	1.5
	4 trawls, 20 trawls	-0.024	61.2
5	Global – between times	0.942	0.1
	Before, Immediately after	0.296	1.4
	Before, 6 months after	0.951	0.2
	Before, 12 months after	0.926	0.1
	Before, 18 months after	1	0.1
	Immediately after, 6 months after	1	0.3
	Immediately after, 12 months after	1	0.4
	Immediately after, 18 months after	1	0.2
	6 months after, 12 months after	1	0.2
	6 months after, 18 months after	1	0.1
	12 months after, 18 months after	1	0.1
	Global – between treatments	0.356	0.1
	0 trawls, 4 trawls	0.378	0.5
	0 trawls, 20 trawls	0.185	0.1
	4 trawls, 20 trawls	0.556	3.4
6	Global – between times	0.769	0.1

Location	Test	*R*	Significance level (%)
	Before, Immediately after	0.111	25.8
	Before, 6 months after	0.988	0.3
	Before, 12 months after	0.741	0.5
	Before, 18 months after	0.975	0.1
	Immediately after, 6 months after	1	0.2
	Immediately after, 12 months after	0.765	0.3
	Immediately after, 18 months after	1	0.3
	6 months after, 12 months after	0.938	0.5
	6 months after, 18 months after	0.481	0.2
	12 months after, 18 months after	0.852	0.3
	Global – between treatments	0.393	0.1
	0 trawls, 4 trawls	0.496	0.1
	0 trawls, 20 trawls	0.341	0.1
	4 trawls, 20 trawls	0.519	0.1

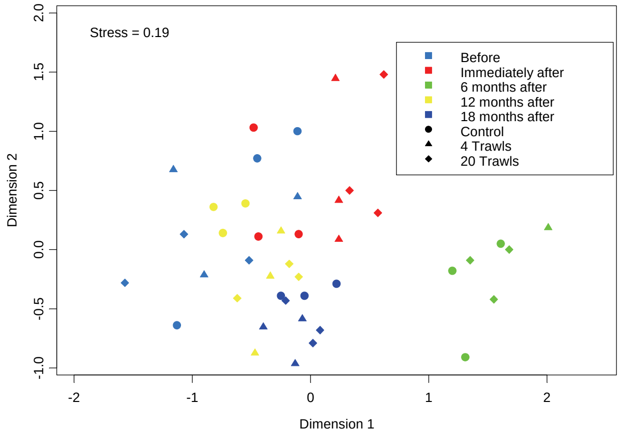
East Mornington

The patterns exhibited in the East Mornington region were not as clear as those in the west. From the MDS plots (Figure 7-3) species assemblages “Before” and “Immediately after” the trawling did not appear to be as different from each other as those “6 months after” trawling, although by “18 months after” the assemblages were closer to those collected at the start of the experiment, which contrasts to the pattern seen in West Mornington. Nevertheless, for most cases, all samples from a particular sampling time tended to cluster together, regardless of the treatment.

Location 9



Location 10



Location 12

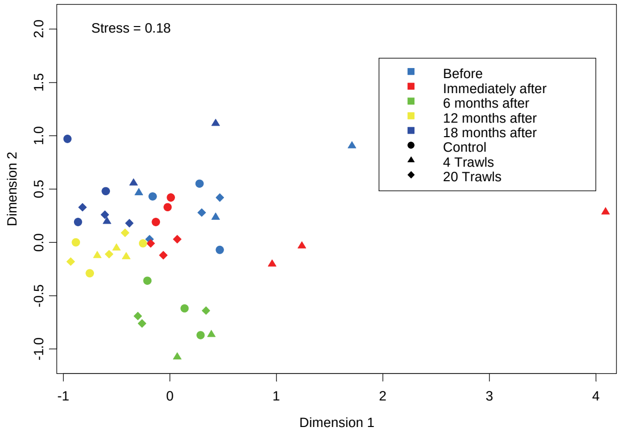


Figure 7-3: Non-metric multidimensional scaling plots of benthos collected by the epibenthic sled from sites in the East Mornington Island region. The data was 4th root transformed catch rates (g/ha) and converted to a Bray-Curits dissimilarity matrix before plotting. The colours indicate the time relative to the trawling impact and the symbols denote the different treatments.

Table 7-2: East Mornington - Results of ANOSIM comparisons of species assemblages at the different trawling intensities over time.

Location	Test	*R*	Significance level (%)
9	Global – between times	0.481	0.1
	Before, Immediately after	0.259	2.1
	Before, 6 months after	0.778	0.6
	Before, 12 months after	0.469	0.1
	Before, 18 months after	0.765	0.2
	Immediately after, 6 months after	0.593	0.4
	Immediately after, 12 months after	0.333	1.8
	Immediately after, 18 months after	0.63	0.7
	6 months after, 12 months after	0.654	0.3
	6 months after, 18 months after	0.79	0.3
	12 months after, 18 months after	0.383	1.0
	Global – between treatments	0.123	4.9
	0 trawls, 4 trawls	0.089	19.6
	0 trawls, 20 trawls	0.267	1.7
	4 trawls, 20 trawls	-0.007	52.8
10	Global – between times	0.586	0.1
	Before, Immediately after	0.358	0.7
	Before, 6 months after	0.778	0.5
	Before, 12 months after	0.173	7.4
	Before, 18 months after	0.58	0.1
	Immediately after, 6 months after	0.748	0.5
	Immediately after, 12 months after	0.58	0.3
	Immediately after, 18 months after	0.667	0.1
	6 months after, 12 months after	1.0	0.3
	6 months after, 18 months after	0.97	0.3
	12 months after, 18 months after	0.395	1.0
	Global – between treatments	0.06	17.6
	0 trawls, 4 trawls	0.086	22.2
	0 trawls, 20 trawls	0.141	5.6
	4 trawls, 20 trawls	-0.004	53.2
12	Global – between times	0.632	0.1

Location	Test	*R*	Significance level (%)
	Before, Immediately after	0.259	5.6
	Before, 6 months after	0.827	0.2
	Before, 12 months after	0.63	0.3
	Before, 18 months after	0.568	0.2
	Immediately after, 6 months after	0.728	0.5
	Immediately after, 12 months after	0.679	0.1
	Immediately after, 18 months after	0.654	0.1
	6 months after, 12 months after	0.84	0.2
	6 months after, 18 months after	0.889	0.3
	12 months after, 18 months after	0.457	0.1
	Global – between treatments	0.216	0.1
	0 trawls, 4 trawls	0.119	7.5
	0 trawls, 20 trawls	0.081	24.1
	4 trawls, 20 trawls	0.496	0.1

From the ANOSIM analyses, there were significant differences in the composition of the benthic species assemblages at all 3 locations in the east, although the R values were not as hight as those found in the west (Table 7-2; Global R – between times). Differences between assemblages ‘Before’ and ‘Immediately after’ trawling were statistically different or close to statistically different (location 12), but the magnitude of the differences was generally less than the differences at other times. The overall differences between treatments were generally not statistically different (except for the 0 and 20 trawl treatments at location 9) and the R values were always very low. These results suggest that seasonal differences in assemblage composition were greater than any changes caused by trawling, making it very difficult to identify any recovery of the benthic assemblages after trawling.

7.3.1.1.1 Abundance/biomass comparison curves

West Mornington

There was some evidence of an impact of trawling on the size structure of the benthic community from the abundance/biomass curves for west Mornington. The biomass curve was well above the abundance curve before trawling on the control (Figure 7-4), 4 trawl (Figure 7-5) and 20 trawl lanes (Figure 7-6). However, immediately after trawling, the curves converged on the 4 and 20 trawl lanes (W = 0.077 and 0.085), relative to the control lanes (W = 0.184). Six months after trawling the curves from all treatments had diverged with the biomass curve well above the abundance curve. Twelve months after trawling the curves remained well separated at the control and 20 trawl lanes, but had converged at the 4 trawl lanes. By 18 months after trawling the biomass curves dipped below the abundance curves on all 3 treatment lanes indicating some unknown disturbance.

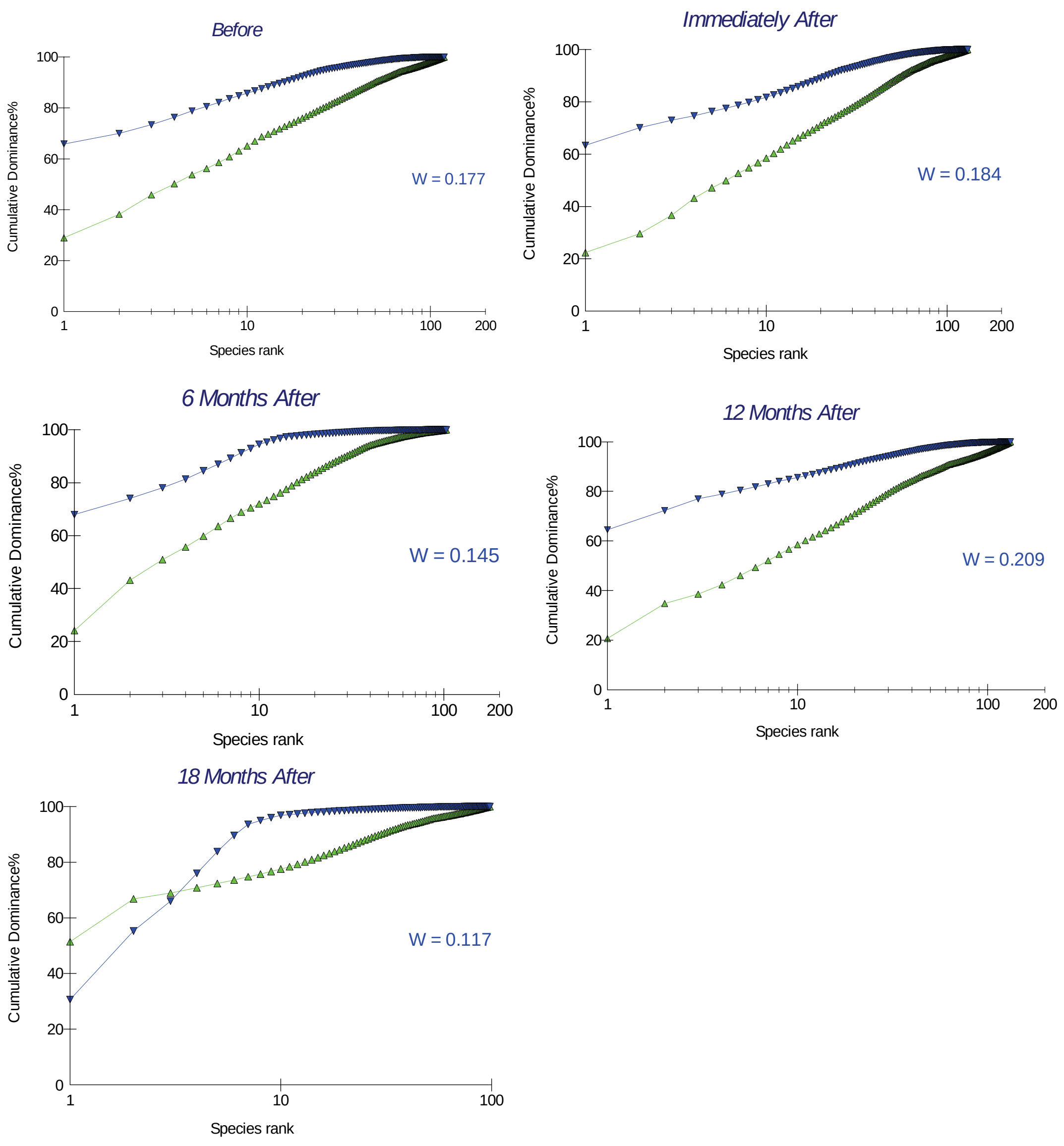


Figure 7-4: Abundance (▲) /biomass (▼) curves and *W* statistic for the control trawl lanes at the west Mornington sites.

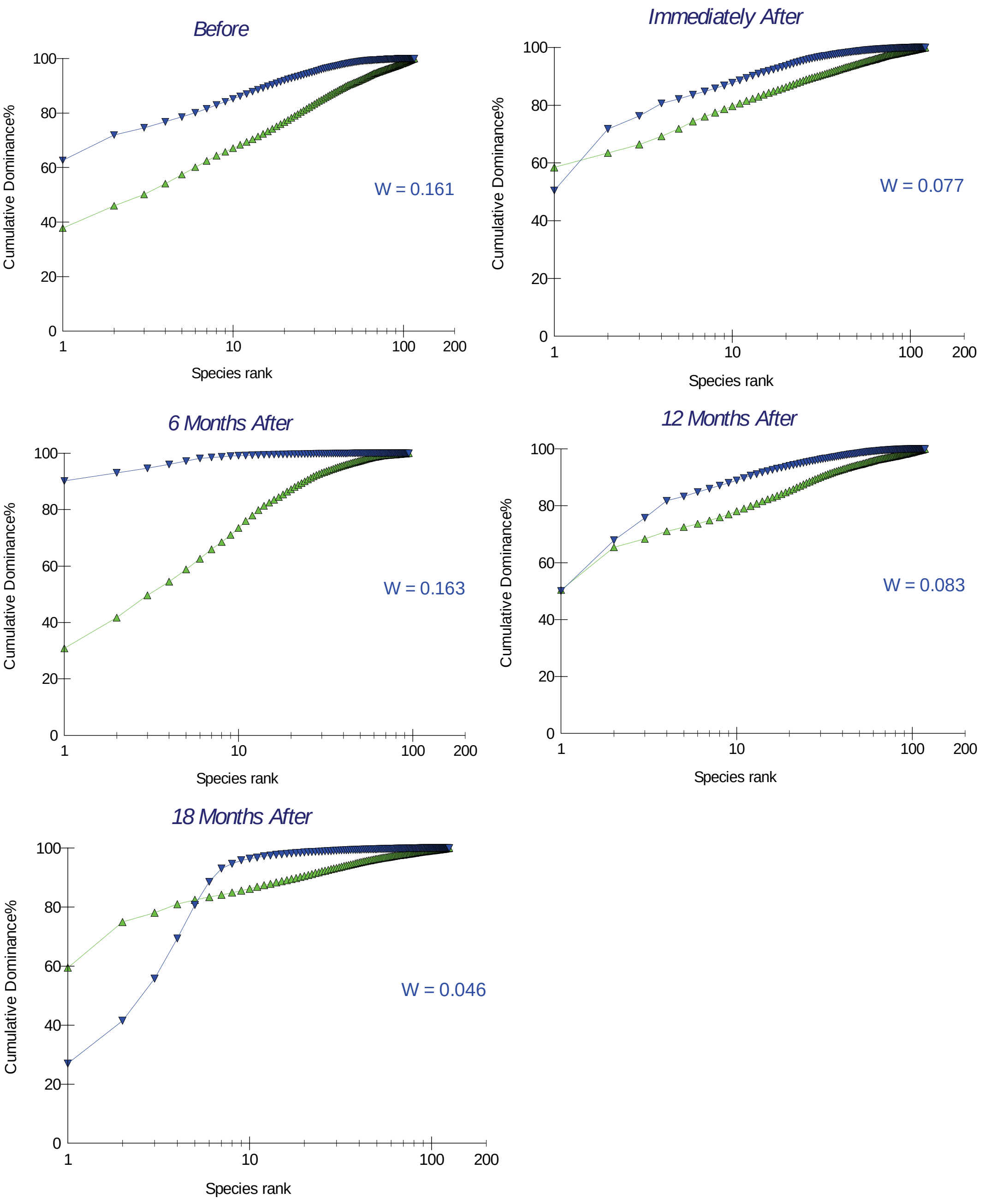


Figure 7-5: Abundance (▲) /biomass (▼) curves and *W* statistic for the 4 shot trawl lanes at the west Mornington sites.

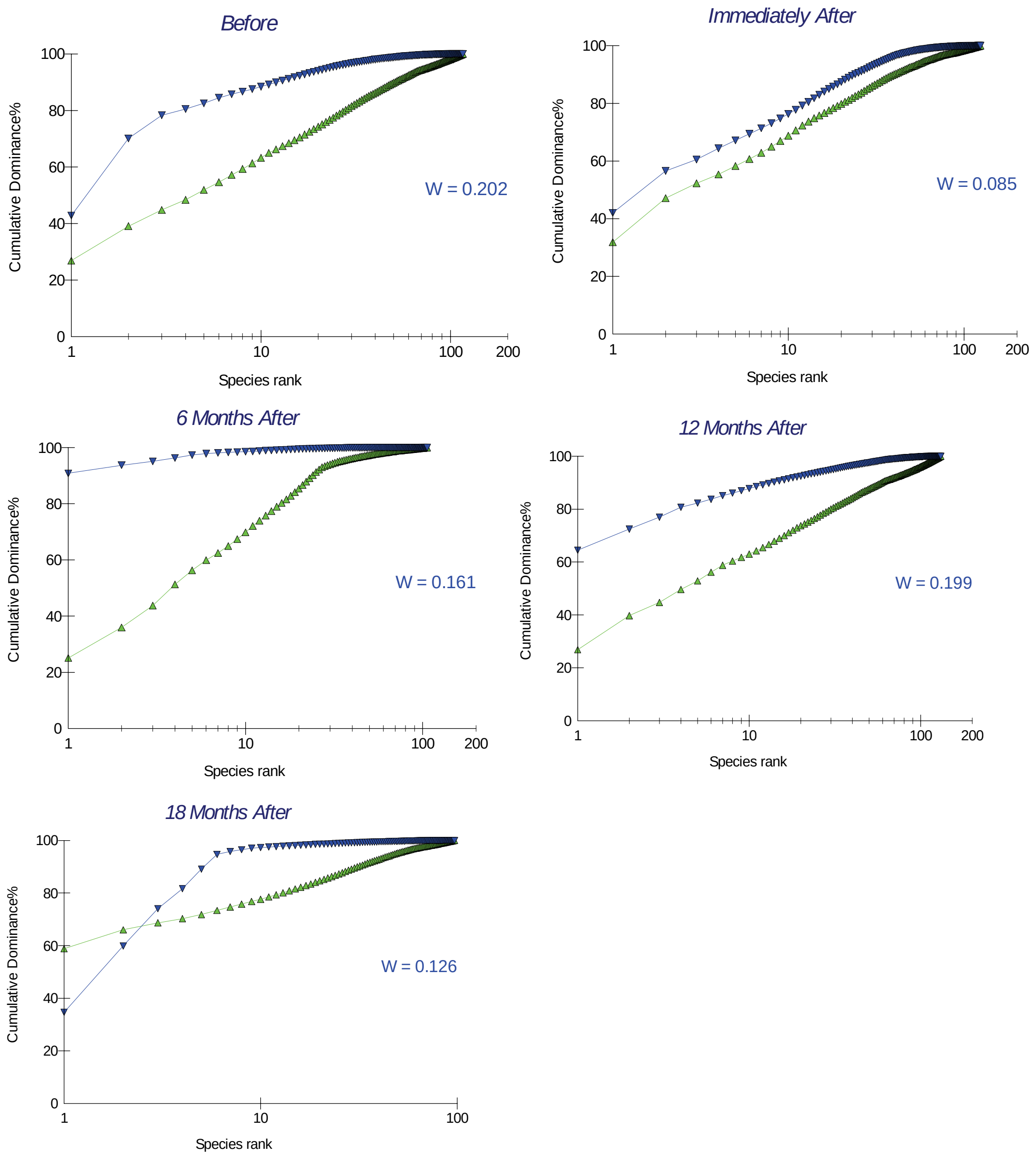


Figure 7-6: Abundance (▲)/biomass (▼) curves and *W* statistic for the 20 shot trawl lanes at the west Mornington sites.

East Mornington

The abundance/biomass curves at both the control and 4 trawl lanes were well separated before trawling and the biomass curve lay above the abundance curve (Figure 7-7 and Figure 7-8). However, on the 20 trawl lanes the biomass curve lay above the abundance curve, although the two were quite close together. Immediately following trawling, the curves for all treatments converged and the biomass curve dipped below the abundance curve for most of its length. The curves for all treatments remained fairly close together at 6 months after trawling, but by 12 months, those for the controls and 4 trawl treatments had diverged. By 18 months the curves had diverged further for the control and 20 trawl lanes, but converged for the 4 trawl lanes.

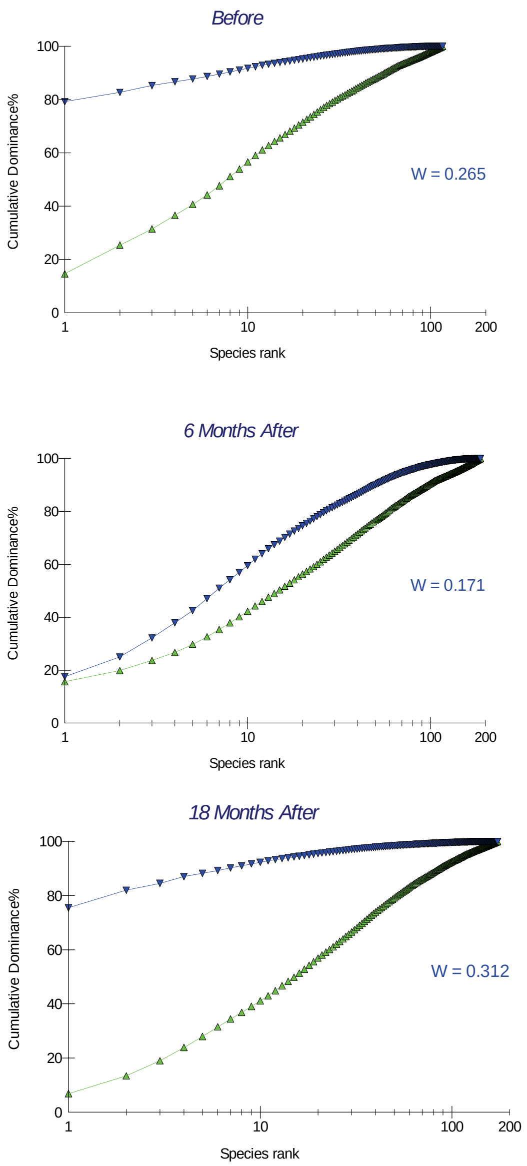


Figure 7-7: Abundance (▲) /biomass (▼) curves and *W* statistic for the control trawl lanes at the east Mornington sites.

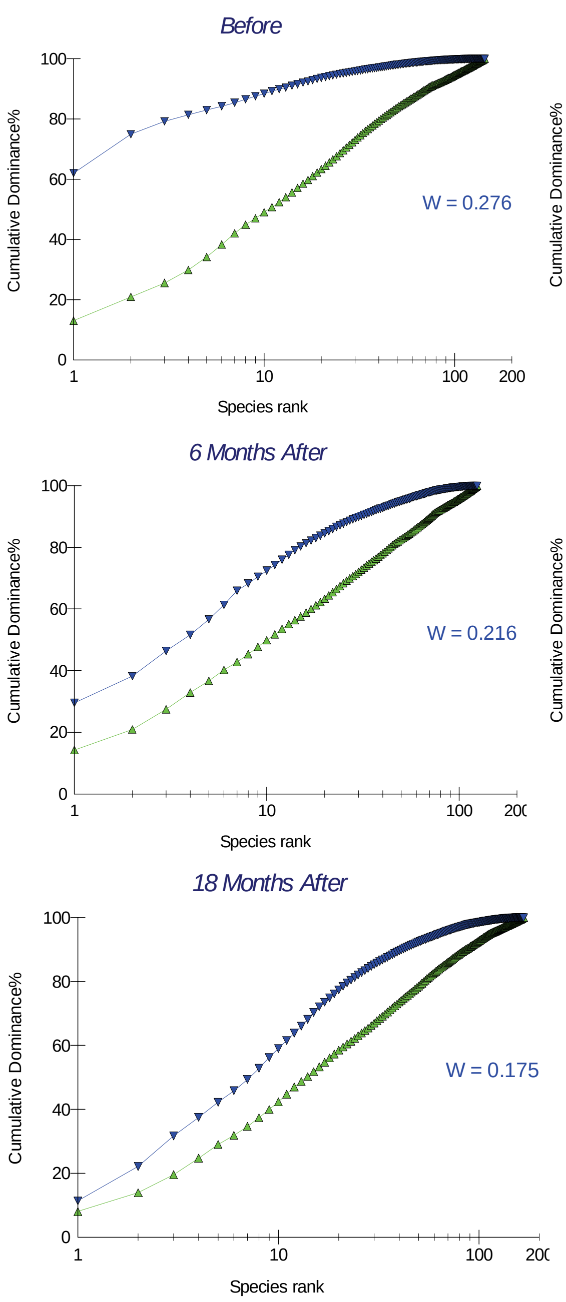


Figure 7-8: Abundance (▲) /biomass (▼) curves and *W* statistic for the 4 shot trawl lanes at the east Mornington sites.

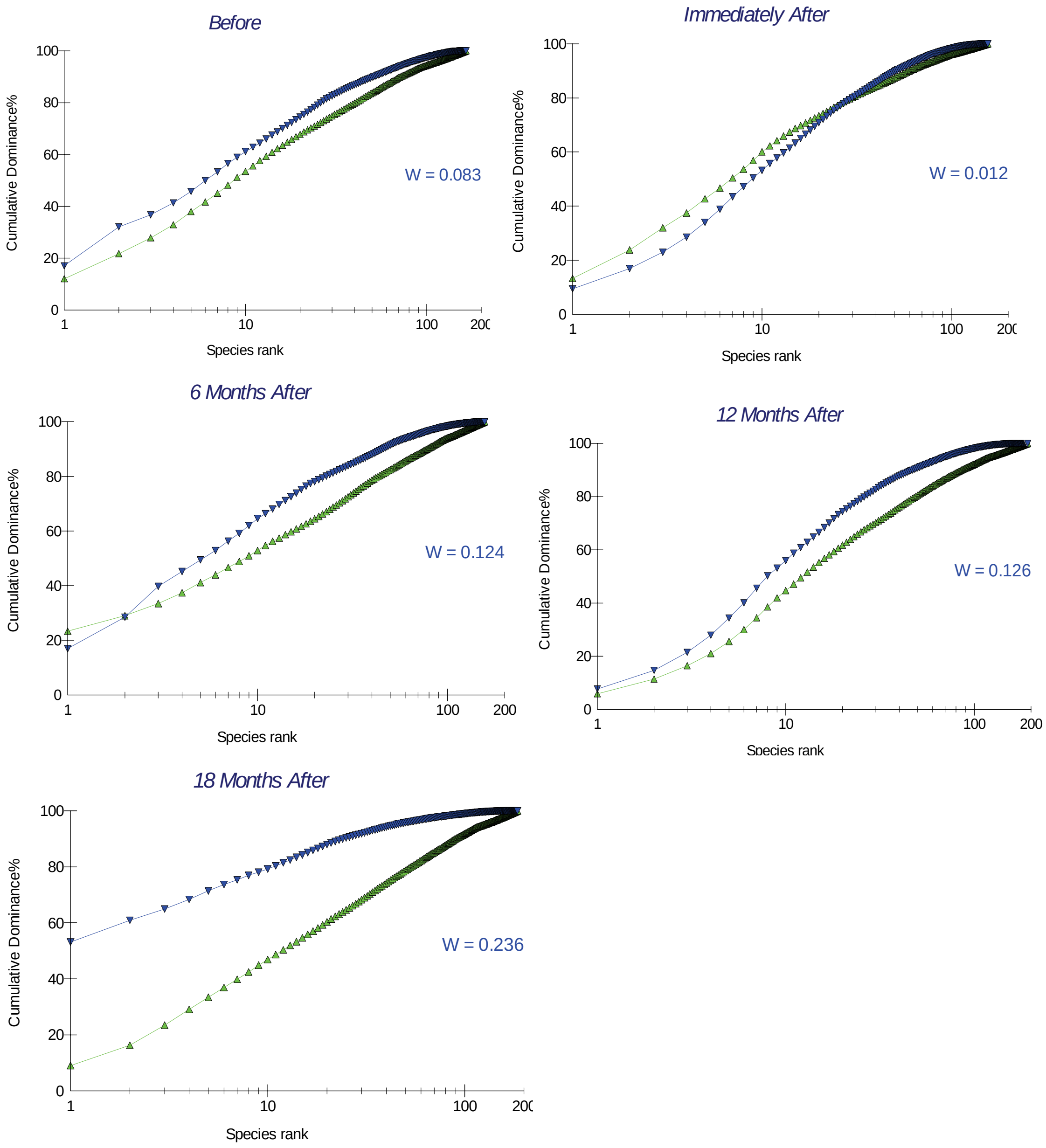


Figure 7-9: Abundance (▲) /biomass (▼) curves and *W* statistic for the 20 shot trawl lanes at the east Mornington sites.

7.3.1.1.2 Change in length

Plots of organism length against time since trawling by treatment (0, 4 or 20 trawls) and region (east or west Mornington) are given in Appendix I. In general, although mean length oscillated over time and in some cases the mean length of a taxa decreased by 6 months after trawling, this occurred on the control as well as the 4 and 20 trawl plots. Comments on the length trajectories of individual taxa are given below.

Hydroid OPNO 184 (east Mornington): The pattern over time was similar on the control, and 4 and 20 trawl plots (refer Appendix I). Mean length decreased slightly from 0 to 6 months then increased through to 12 and 18 months after trawling.

Stellaster sp OPNO 118: In east Mornington the mean length tended to increase form 0 to 18 months after trawling across all treatments and there appears to be 2 different-sized cohorts caught during most sampling periods (refer Appendix I). In west Mornington the numbers caught were very low, but the trend was for the mean length to increase from 6 to 18 months after trawling.

Brissidae OPNO 006 (east Mornington): Mean size tended to oscillate every 6 months in all treatments, being higher during winter (6 and 18 months after trawling) than summer (0 and 12 months after trawling), suggesting different cohorts moving through the study area (refer Appendix I).

Ophiuroidea OPNO 171c (east Mornington): There was virtually no change in mean size on any of the treatment plots over the 18 months of the study (refer Appendix I).

Tubeworm OPNO 006 (east Mornington): Numbers were generally low on all treatments 6 and 18 months after trawling with a wide size range caught at other times (refer Appendix I). There was no discernable change in mean length on any of the treatment plots throughout the 18 months of the study.

Asteropectinidae OPNO 142 (west Mornington): Highest numbers of these animals were caught immediately after and 6 months after trawling (refer Appendix I). There was little indication of a change in mean size on any of the treatment plots.

Ophiuroidea OPNO 006 (east Mornington): Although a wide size range (4 to 21 mm) of Ophiuroidea OPNO 006 were caught (refer Appendix I), the mean length remained relatively constant across all treatments throughout the study.

Malleus malleus (east Mornington): *M. malleus* increased in mean length during the first six months after trawling and then the mean length stabilised and remained relatively constant for the remainder of the study (refer Appendix I). However, this increase in mean size following trawling was observed across all treatments and so cannot be attributed to the trawling.

Cerithiidae OPNO 142 (west Mornington): The means length decreased on all treatment plots between 0 and six months after trawling and increased again by 12 months (refer Appendix I). Very few were caught during the 18 month sampling.

Temnopleuridae OPNO 142 (west Mornington): There was no discernable change in mean length on any of the treatment plots during the study (refer Appendix I).

Chicoreus sp OPNO 184 (east Mornington): There was no discernable change in mean length on any of the treatment plots during the study (refer Appendix I).

Melaxinaea vitrea (east Mornington): There was no discernable change in mean length on any of the treatment plots during the study (refer Appendix I).

Laganidae OPNO 142a: At the west Mornington sites mean length oscillated every 6 months, being higher in the summer (0 and 12 months after trawling) than the winter (6 and 18 months after trawling) (refer Appendix I). Laganidae OPNO 142a was only caught 0 and 12 months after trawling at east Mornington and the mean lengths were similar across all treatments (refer Appendix I).

Stellaster sp OPNO 118: At east Mornington there appeared to be several cohorts of *Stellaster* sp OPNO 118 moving through the study sites throughout the duration of the study (refer Appendix I) and the pattern of mean sizes of these cohorts appeared to be very similar across all treatments. Fewer animals were caught at west Mornington and there appeared to be a decrease in mean length in the first 6 months following trawling across all treatments, followed by an increase over the next 12 months (refer Appendix I).

Smaragdinellidae OPNO151 (west Mornington): Mean length tended to increase during the first 6 months after trawling on all treatments and then either remained stable for the remainder of the study (0 and 4 trawl treatment plots) or decreased slightly (20 trawl treatment plots) (refer Appendix I).

Cardiidae OPNO 151 (west Mornington): Mean lengths decreased dramatically on all treatment plots by 6 months after trawling and then increased by 12 months. Very few were caught at 18 months (refer Appendix I). Once again this signal suggests there are cohorts that are recruiting to the area appearing initially as small animals during winter (6 and 18 months after trawling), but there is nothing to suggest that trawling has affected the mean length.

Dardanus imbricatus: At west Mornington, the distribution of lengths of *D. imbricatus* over time on the 2 different treatment plots was similar with a slight decrease evident 6 months after trawling on the 20 trawl plots (refer Appendix I). Numbers at east Mornington were relatively low and the mean lengths did not show any consistent pattern over time across the treatment plots.

Spondylidae OPNO 193 (east Mornington): Mean lengths showed some tendency to increase 6 months after trawling on the control plots, but very few were caught on either the 4 or 20 trawl plots at this time (refer Appendix I). For the remainder of the study mean length increased on all treatments.

Ludiidae OPNO 006 (east Mornington): Mean size did not appear to change significantly across treatments or time (refer Appendix I).

Temnopleuridae OPNO 203b (east Mornington): The mean lengths decreased fairly steadily across all treatments from immediately after through 6 and 12 months after trawling and then remained steady at 18 months (refer Appendix I).

Parthenope nodosus (west Mornington): Mean length of *P. nodosus* remained relatively constant for the first 12 months of the study on all treatments and then decreased slightly after 18 months (refer Appendix I).

Arcania sp OPNO 008 (east Mornington): Apart from a few large animals appearing on the control plot after 6 months, the mean length of *Arcania* sp OPNO 008 appeared to be fairly constant on all treatments throughout the study (refer Appendix I).

Strombus sp OPNO 142: *Strombus* sp OPNO 142 were most abundant in the fist six months of the study. In west Mornington mean length remained fairly constant during this time and then appeared to increase on the control and 4 trawl plots and decrease slightly on the 20 trawl plots, however very few animals were caught at 12 and 18 months after trawling (refer Appendix I). At east Mornington most animals were caught immediately after trawling; none were caught 6 months after on any treatment plots and very few after that. Mean length did not appear to change during the study.

Shizasteridae OPNO 224: were only found at east Mornington and only during the winter months. The mean size 6 months after trawling was approximately 35 mm on all treatment plots and decreased to about 12 mm the following winter, suggesting recruitment of a new cohort; the larger individuals of the previous year were not caught on any of the treatment plots (refer Appendix I).

Temnopleuridae OPNO 203a (east Mornington): Mean length remained relatively constant on all treatment plots for the first 6 months of the study and appeared to increase after 12 months with the recruitment of a second cohort (refer Appendix I).

Leucosia ocellata (east Mornington): Mean length was constant on all treatment plots throughout the period of the study (refer Appendix I).

7.3.2 Recovery of individual taxa

7.3.2.1 **Background variation with time**

Epi-benthic sled catches varied with time in the absence of trawling and recovery, thus confirming the need to consider a time affect when estimating trawling and recovery effects. In the untrawled (control) lanes, the total catch of all taxa in epi-benthic sled samples from the western and eastern regions combined increased from 21 kg/ha to 56 kg/ha. The overall time effect was significant ($p = 0.011$), although the individual differences between the catches at each time were not (LME model of catch on time as a categorical variable).

The time effect varied between the western and eastern regions (see boxplots in Figure 7-10 and Figure 7-11). In an LME model of catch against time and region (both categorical), the interaction between time and region was significant ($p = 0.011$). The time effect also varied among taxa. For example, in the west, Phaeophyta (brown algae) had a seasonal pattern of high summer and low winter biomass, which was opposite to the low summer, high winter pattern of all taxa combined and Ascidiacea (the dominant animal) in that region. Individual taxa did not necessarily show the same changes in catch over time in the two regions. For example, between 6 and 18 months, Stelleroidea declined in the west ($p < 0.05$), but increased in the east ($p < 0.1$) (LME models of catch on time as a categorical variable).

7.3.2.2 **Depletion and recovery**

Depletion and recovery effects were estimated with the LME model of catch on time and treatment within time (see methods). The parameters of interest are the fixed effects for time and the fixed effects for the 4- and 20-trawl treatments within time. The fixed effect for time for time zero, before trawling and the fixed effects for treatment within time for the 0-trawl treatment were constrained to be zero. The fixed effects for time indicate the background variation in catch with time that was independent of trawling and recovery. The treatment within time effects indicate whether catches in the trawled lanes were higher or lower than those in the control lanes. We might expect, for example, that catches would be lower following trawling and then increase over time as the benthos recovered to eventually converge with those in the control lanes. We would also expect the effect to be greater in the 20-trawl treatment than in the 4-trawl treatment. In this case, the treatment within time effects would be zero before trawling, be negative immediately after trawling, and then move back towards zero over time. The negative shift for the 20-trawl treatment would be greater than that for the 4-trawl treatment.

For all taxa combined, the estimated treatment within time effects showed no depletion or recovery in the west (Figure 7-10). In the east the estimated effects were consistent with depletion followed by recovery by the 6-month survey (Figure 7-11). However, the estimates did not exactly match the expected pattern described above in that the effects were smaller in the 20-trawl treatment than in the 4-trawl treatment.

The depletion and recovery analysis was repeated for all taxa between kingdom and family (see Table 7-3 for results down to the class level). The estimated treatment within time effects for a number of taxa were consistent with depletion and recovery. However, the pattern was not always significant, was not always the same in the two regions, and did not always match that described above (e.g. effects were sometimes smaller in the 20-trawl treatment than in the 4-trawl treatment). The taxa with the clearest patterns were Gymnolaemata, Hydrozoa, Echinoidea and Phaeophyta.

For Gymnolaemata, the pattern was clearest in the east, where there was a significant depletion in both the 20- and 4-trawl treatments, and a recovery by the 12-month survey (Table 7-2, Figure 7-13). In the west, trawling appeared to increase biomass before it occurred rather than decrease biomass afterwards (Table 7-3, Figure 7-12). This impossible effect was caused by anomalously low catches in the control lanes at time zero. Knowing that, we can interpret the decline in the treatment within time effect following trawling to indicate a depletion effect.

Hydrozoa were abundant only in the east. In that region they showed depletion followed by recovery within 6 months (Table 7-3). Echinoidea were also abundant only in the east. In that region they showed a depletion followed by recovery within 6 months (Table 7-3). Phaeophyta were abundant only in the west. In that region they showed depletion followed by recovery within 6 months (Table 7-3).

7.3.2.3 **Sampling anomalies**

In a number of cases, estimation of depletion and recovery effects was prevented by sampling anomalies. For example, catches of a taxon in a region sometimes varied among the three treatments before trawling, thus increasing or decreasing the estimated depletion by trawling. Also, catches of a taxon in a region at time zero in the control lanes sometimes increased or decreased after trawling, thus increasing or decreasing the estimated depletion in the treatment lanes. Our LME model was able to identify such anomalies, but did not account for them when estimating depletion and recovery effects. It may be possible to improve some estimates by developing models that account for sampling anomalies such as these.

7.3.2.4 **Spatial variation**

The spatial variation in the catches of all taxa combined varied between the two regions. In the west, catches at a given location tended to be similar—even among treatments (Figures 7-6 to 7-10). In the east, variation within locations was closer to variation between locations (Figure 7-11). This observation is supported by a higher random effects term for location in the west. The different patterns in spatial variation reflect those of the dominant taxa (seagrass and algae in the west, sponges in the east; Figure 7-14).

Table 7-3: LME models for time and treatment in time effects for individual taxa. The table shows the treatment within time effects for the 4- and 20-trawl treatments. The effects for the 0-trawl treatment were constrained to be zero. The symbols are ––, significantly negative; –, negative; +, positive; ++, significantly positive. A blank indicates the effect was near zero (absolute value less than 0.1). B=Before trawling, A=After trawling, 6=6 months after, 12=12 months after and 18=18 months after.

		B				A				6				12				18			
		West		East		West		East		West		East		West		East		West		East	
Taxon	Level	4	20	4	20	4	20	4	20	4	20	4	20	4	20	4	20	4	20	4	20
Animalia	kingdom	–	+		+	+	+	––	–	+	–	–	–	+	–	+	–	++	+	–	–
Polychaeta	class		+	–	–			–	–			+	++	––	––	–	–	+		–	–
Crustacea	subphylum	+		+	+	–	+	–	–	+	–	––	–	+	–	+	+	+		–	–
Ascidiacea	class	+	+	+	++	+		–		+	–	–	–	++	+	–	–	+	+	–	+
Actinopterygii	class	–	–		++	––	+	–	–	+		–	+		–	–	–	+	++	+	+
Anthozoa	class	–	–	–	+	+	+	–	+	+	+	–	–	–	–	+	–	+	+	+	+
Hydrozoa	class	–	–		+	+	–	––	–		+	–	–	+		+	+	+		–	
Echinodermata	phylum	–	+		++			––	–	+	–	–	+	+	+	+		++	+		–
Crinoidea	class	––	––	–	–	–	–	+	–			–	–	–	–	+	–	+	+	–	+
Echinoidea	class	+	+	–	+	–	+	––	–	+	+	–	+		+	+		++	+	–	–
Holothuroidea	class	–		+	+		–	+	+	+	–	–	+	+	+	–	–	+	+	+	+
Stelleroidea	class	+	+	+	+	+	+	––	–	–	–	––	–	+	–	++	+	+		+	+
Gymnolaemata	phylum	+	+	–	+	–	–	––	––	+	+	––	–	+		+	+	+	–	+	+
Mollusca	phylum	+	+	–	+	+	+	––		–	–	––		–	–	+	+	+	–	–	+
Bivalvia	class	+	+	–	+		+	––	+	+	+	––		–		+	+	+	+	–	+
Cephalopoda	class		+		++	+	+	–	–				+		+	+		+	–	–	–
Gastropoda	class		+	––	+	+	+	–		–	–	––	–	–	–			+	+	–	+
Porifera	phylum	–	–	+	+	+	–	–	–	–	+	–	–	–		+	+	+	–	–	–
Plantae	kingdom	–	–	–		–	–			+	–	–	–		–	+	–	+		–	–
Chlorophyta	division	–				–	–			–	–			+	+			–		––	––
Phaeophyta	division	–	–	––		–	––					–	–	+	+	+		+		+	+
Rhodophycota	division	––	––			–	–					–	–			–					
Magnoliophyta	division	–	–				–			+					–	–	–	+	–	–	–

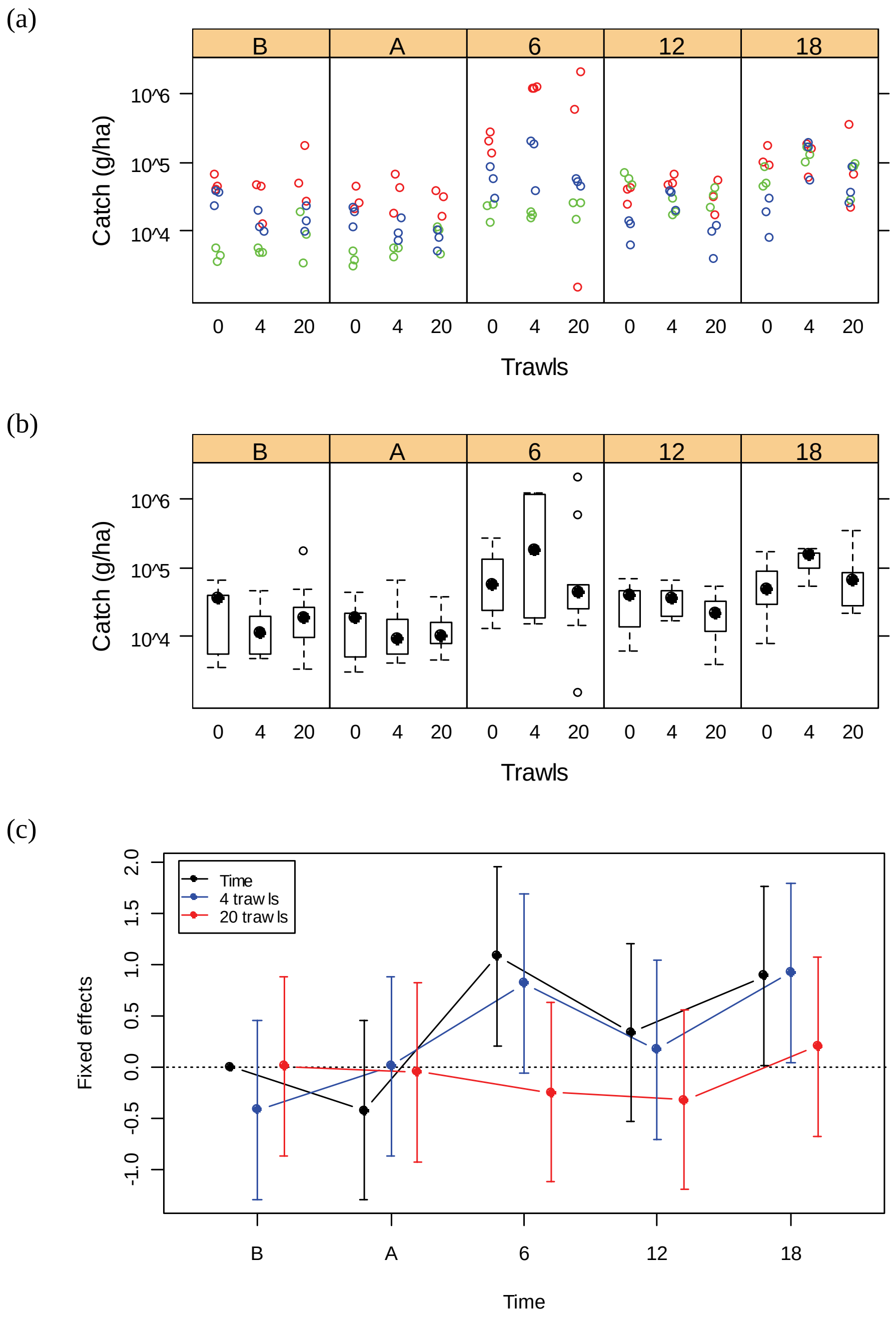


Figure 7-10: LME model for time and treatment effects for all taxa in the western region: (a) catch by time, treatment and location (colours); (b) catch by time and treatment; and (c) fixed effects estimates for time and treatment within time. In (a) and (b), zero catches are plotted as half the smallest non-zero catch. In (c) the error bars indicate 95% confidence intervals. The time effect for time B and the treatment within time effects for 0 trawls are constrained to be zero. B=Before trawling, A=After trawling, 6=6 months after, 12=12 months after and 18=18 months after.

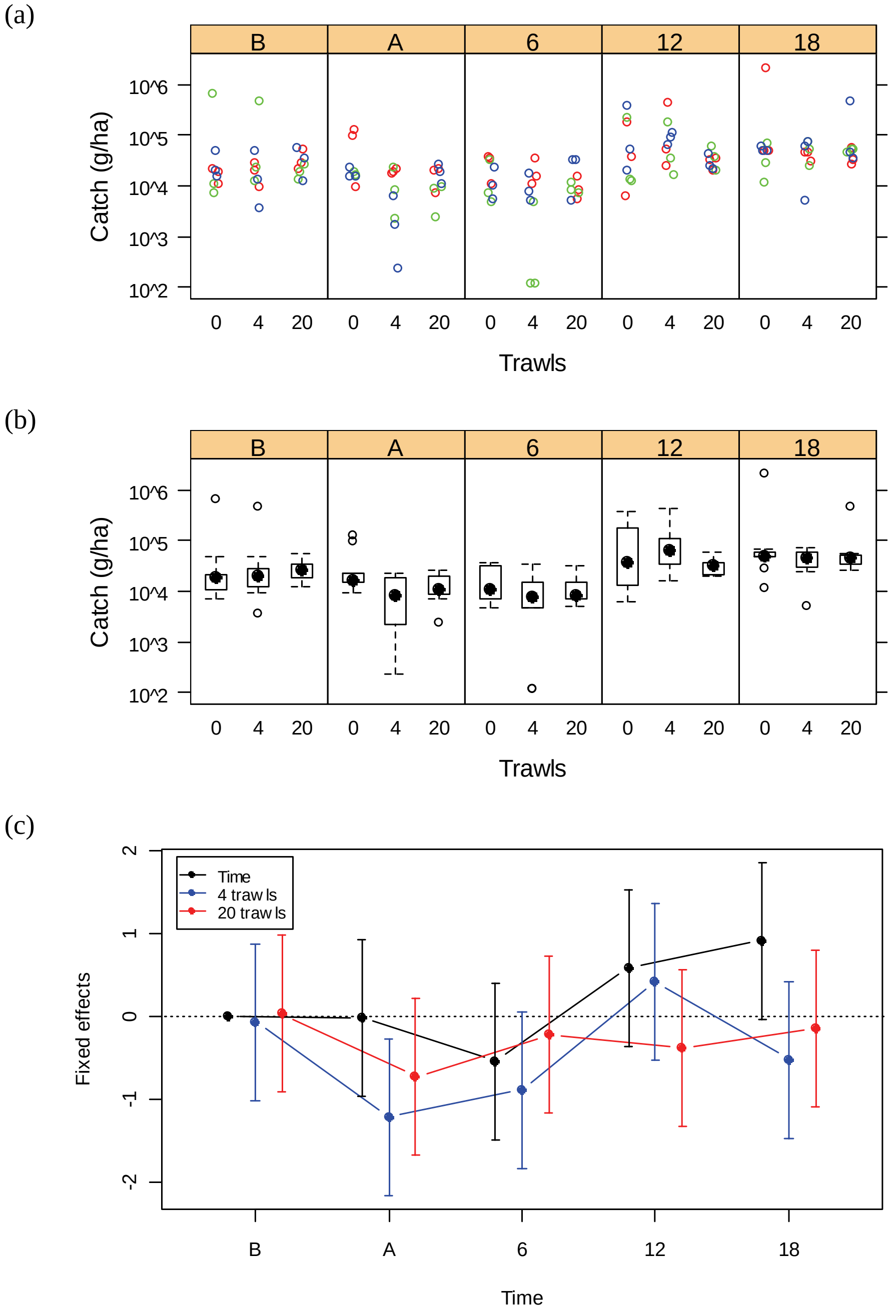


Figure 7-11: LME model for time and treatment effects for all taxa in the eastern region: (a) catch by time, treatment and location (colours); (b) catch by time and treatment; and (c) fixed effects estimates for time and treatment within time. In (a) and (b), zero catches are plotted as half the smallest non-zero catch. In (c) the error bars indicate 95% confidence intervals. The time effect for time B and the treatment within time effects for 0 trawls are constrained to be zero. B=Before trawling, A=After trawling, 6=6 months after, 12=12 months after and 18=18 months after.

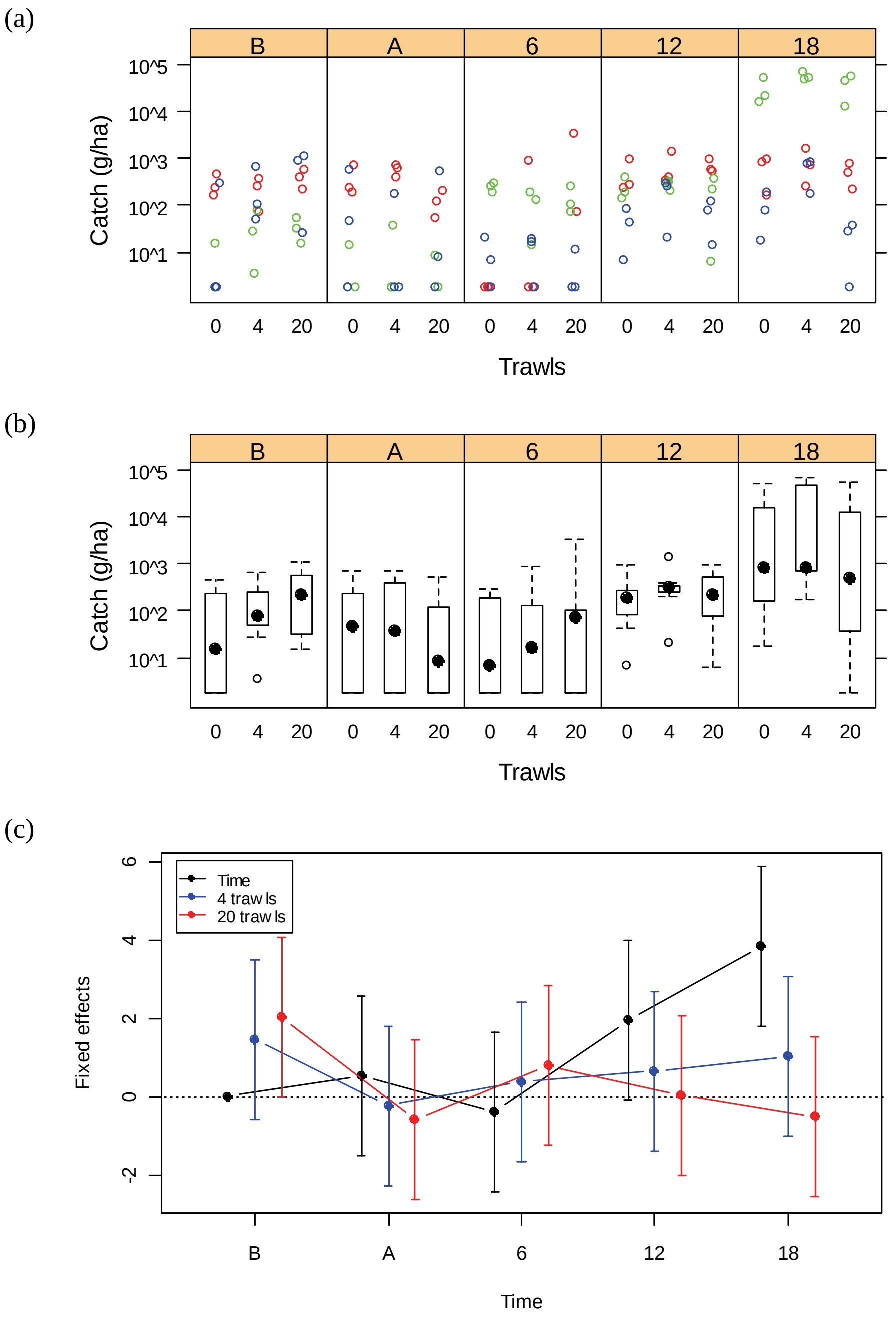


Figure 7-12: LME model for time and treatment effects for Gymnolaemata in the western region: (a) catch by time, treatment and location (colours); (b) catch by time and treatment; and (c) fixed effects estimates for time and treatment within time. In (a) and (b), zero catches are plotted as half the smallest non-zero catch. In (c) the error bars indicate 95% confidence intervals. The time effect for time B and the treatment within time effects for 0 trawls are constrained to be zero. B=Before trawling, A=After trawling, 6=6 months after, 12=12 months after and 18=18 months after.

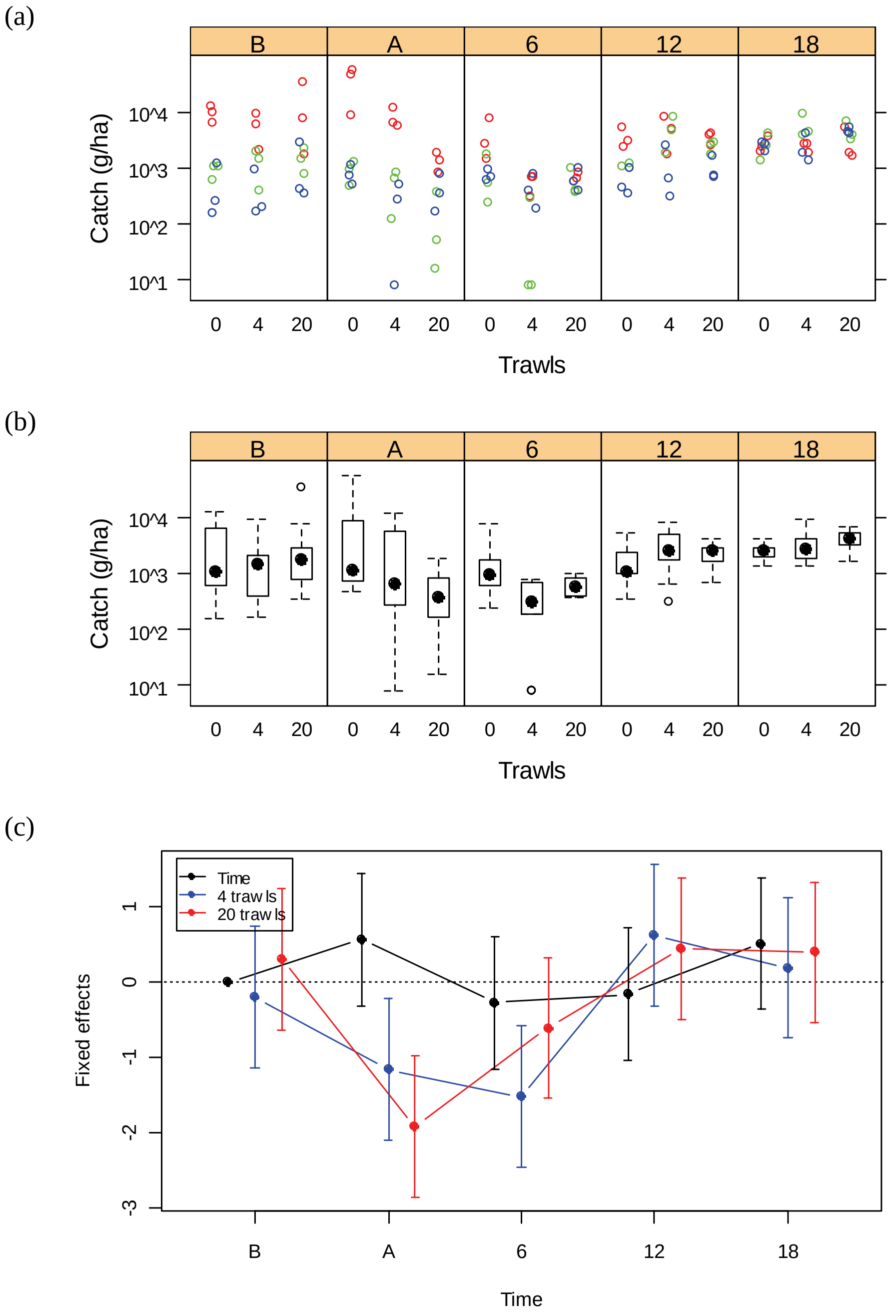
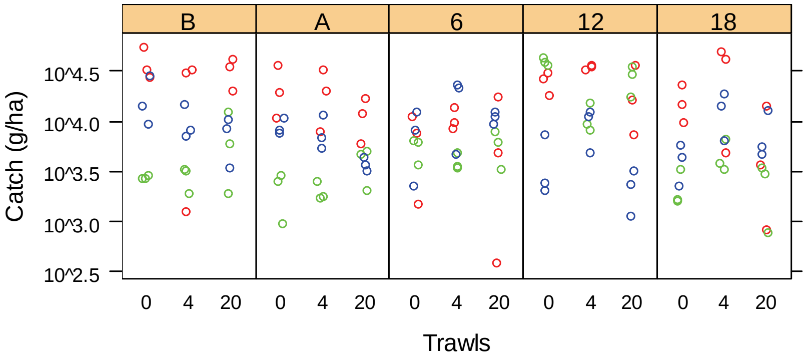


Figure 7-13: LME model for time and treatment effects for Gymnolaemata in the eastern region: (a) catch by time, treatment and location (colours); (b) catch by time and treatment; and (c) fixed effects estimates for time and treatment within time. In (a) and (b), zero catches are plotted as half the smallest non-zero catch. In (c) the error bars indicate 95% confidence intervals. The time effect for time B and the treatment within time effects for 0 trawls are constrained to be zero. B=Before trawling, A=After trawling, 6=6 months after, 12=12 months after and 18=18 months after.

(a)



(b)

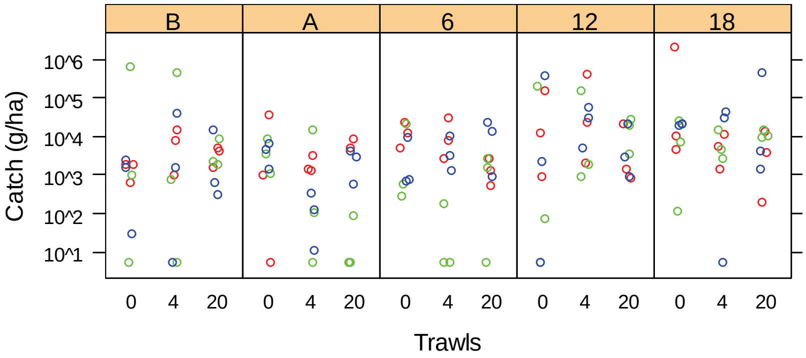


Figure 7-14: Catch by time, treatment and location for (a) seagrasses and (b) sponges. Zero catches have been plotted as half the smallest non-zero catch.

7.4 Discussion

Benthic communities in shallow tropical areas are not in equilibrium, they are undergoing constant change – seasonal, natural disturbances and successional. Our ability to detect anthropogenic impacts such as those due to trawling and subsequent recovery from these impacts is dependent upon the relative magnitude and frequency of the natural changes. In our experiment the natural variation was substantial, with the total biomass on all the control lanes increasing from 21 kg/ha to 56 kg/ha over 18 months. There was also considerable variation within the period of the experiment and it was not consistent across the two regions. The species assemblage analyses indicated that seasonal changes dominated the dynamics of the benthos, especially in the west. Seasonal changes were evident in the east, but they were not as significant or as clear-cut. It is possible that cyclone Craig affected the eastern sites more than those in the west since Craig passed well to the east of Mornington Island (Figure 7-15).

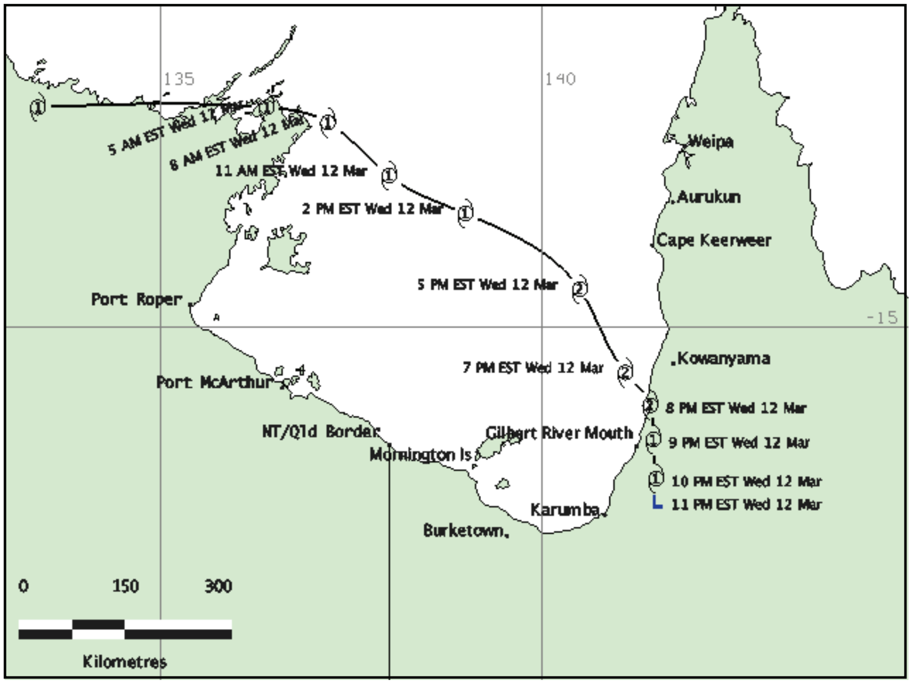


Figure 7-15: Track of tropical cyclone Craig during March 2003. Image provided by the Bureau of Meteorology.

In contrast to the MDS and ANOSIM analyses, the abundance/biomass curves in the west gave some indication of an impact of trawling in that the *w* values decreased and the abundance and biomass curves converged immediately following the trawling on the 4 and 20 trawl lanes, but not on the control lanes. The level of impact matches that exhibited by a “moderately disturbed” community as suggested by Warwick (1986). After 6 months, the *w* values had risen and the curves had diverged again and remained so until 18 months after when the curves crossed over on all treatments, suggesting some unknown natural disturbance to the benthic community. It is possible that this was the result of a massive recruitment event, although there is not any evidence of this from the plots of change in length of the 26 most abundant taxa (Appendix I).

The fact that the multivariate analyses indicated no impact/recovery signal whereas the impact was evident in the biomass abundant curves suggests that perhaps nature of the impact was to reduce the biomass diversity of the benthos rather than to alter its composition significantly. This impact appears to have been relatively short lived given that it was not evident 6 months after the trawling.

The abundance/biomass curves for the east Mornington sites appear to show the affect of the cyclone in addition to any impact generated by the trawling as the curves for the benthos immediately after trawling converge on the control sites as well as the other treatments. The curves for the 20 trawl sites appear to suggest no recovery until 18 months after the trawling; however, they indicated the community was in a disturbed state before the trawling began, unlike those at the control and 4 trawl sites where the curves were well separated.

Analysis of individual taxa indicated clear depletion and recovery only for a number of immobile or slow-moving taxa such as Gymnolaemata, Hydrozoa, Echinoidea and Phaeophyta. All appeared to have recovered within 6–12 months of trawling. Note that our estimates of recovery times were conservative because we inferred recovery when we were no longer able to detect any remaining depletion rather than by directly measuring recovery. A more statistically powerful experiment might detect depletion effects for a longer time after trawling. We might then change our definition of recovery time from ‘time to no statistically significant remaining depletion’ to ‘time to no biologically significant remaining depletion', which would of course require us to define biologically significant depletion e.g. in terms of the percentage difference in biomass between trawled and untrawled sites.

In general it appeared that recovery signals were probably quite rapid and masked by significant natural variation in the benthic communities. Many studies have suggested that recovery from impacts is more rapid in areas having loosely consolidated substrates (e.g. sand) and in shallow areas because the flora and fauna in these types of environments are well adapted to disturbance (Dernie et al. 2003.

Our experiment was a small scale pulse impact which does not mimic the spatial and temporal scale of the fishery. Many of the taxa found on our trawl plots in the present study were mobile. This combined with the fact that our plots were only about 50 m wide and were located in an area that had not been trawled for at least 8 years meant that it is likely that much of the dynamics observed for the mobile taxa in our plots was the result of movement into and out of the plots rather than recruitment. Twenty-five percent of the benthos in the west and 16% (by weight) in the east could be regarded as mobile c.f. sessile. Rapid recovery of these taxa may be dominated by immigration.

It is inevitable that recovery rates of biota in the fishing grounds will be slower than we have observed in this experiment because the fishing grounds are much larger than the area impacted in this study (Collie et al. 2000). However, it is possible that the highly fragmented patterns of trawling may facilitate rapid recovery/recolonisation by movement rather than recruitment for mobile taxa. Fragmented nature of trawling patterns may also help recruitment of immobile taxa because no place is completely isolated; there are often "islands" of untrawled ground which may act as sources of recruits for the surrounding trawled areas.

It is important to note that although we are attempting to estimate recovery rates for fairly broad taxonomic categories, at finer levels of taxonomic resolution, there may be synergistic effects. For example, some of the habitat forming taxa such as sponges and bryozoans may have commensal species which live on them e.g. ophiuroids, polychaetes and crustaceans. For these cases the rate of recovery of the commensals will be limited to that of the habitat forming taxa.

7.5 References

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CHAPTER 8. MODELING THE EFFECTS OF TRAWLING

Nick Ellis, Andrzej Welna, Burke Hill

Summary

- We revisited the trawl modelling around Groote Eylandt with the revised depletion rates and assessed the sensitivity of various indicators to these rates.
- We applied the trawl model to the area around Mornington Island with separate rates for the East and West regions under four management scenarios.
- The trawl model now incorporates effort creep through the swept area rate.
- The spatial effort distribution is computed at 1-nautical mile resolution by combining VMS and logbook data.
- We define the overall vulnerability of a taxon as the ratio of depletion rate to recovery rate.
- The overall impact is proportional to the amount of trawling effort and the vulnerability of the taxon.

8.1 Introduction

In a previous report (Ellis et al. 2002), we pointed out that the condition of the seabed biota in an area subject to trawling is the result of several factors. These include the original or pre-trawled condition, the rate at which the biota is removed by trawling and the rate at which it recovers from trawling. Each of these factors can vary considerably between different areas. The seabed composition may include hard substrates that support an attached sessile fauna or it may consist of soft muddy sediments or coarse sandy sediments. In turn these sediments may be stable or may be subject to disturbance from waves and currents. The rate at which components of the fauna are removed by a trawl can vary. Poiner et al. (1998) found rates between near zero and 20% in the Great Barrier Reef region. Finally the rate at which different components of the fauna recover from a trawl impact is very different between taxa. It is generally slower for sessile animals such as sponges that have to grow back but rapid for mobile animals like crabs that can simply migrate into the trawled area from adjacent areas. Even within these broad groupings there is substantial variation. Pitcher et al. (2004) measured regrowth of sessile megabenthos on the seabed following an experimental trawl impact. Recovery rates were higher than expected: 29% per annum for Porifera; 35% for Alcyonacea; 68% for Scleractinia and 124% for Echinogorgia (gorgonian).

CSIRO has developed a trawl impact model for the Queensland East Coast trawl fishery (Ellis et al. in prep). This model estimates the impact of repeated trawling on marine epibenthos in terms of percentage removed biomass per vulnerability class on a 6 × 6 nautical mile grid given the level of fishing effort in that grid. The model integrates information on the amount of benthos removed by a trawl, the rate of recovery of benthos from trawl impact and the number of times a trawl passes over the seabed. An output of the model is advice to managers on the probable effect of changes in trawl effort on the seabed fauna.

Ellis et al. (2002) applied the East Coast model to the NPF using data on removal and recovery rates derived from the Great Barrier Reef region. They found a large difference in the composition of the seabed biota between the GBR and the NPF and recommended that the application of the model to the NPF be revisited when information on the removal and recovery rates was available for the NPF seabed fauna.

In the current project we have calculated removal rates for the biota in two areas of the southern Gulf of Carpentaria. The original model assumed a constant swept area rate (net spread × trawling speed), however, recently it has been shown that swept area rate has been increasing steadily since the 1970’s

(Sterling and Bishop in: Dichmont et al. 2003), so we have incorporated a time-varying swept area rate. We present here the application of this new information to the model

8.2 Methods

The structure of the trawl impact model is shown in Figure 8.2-1.

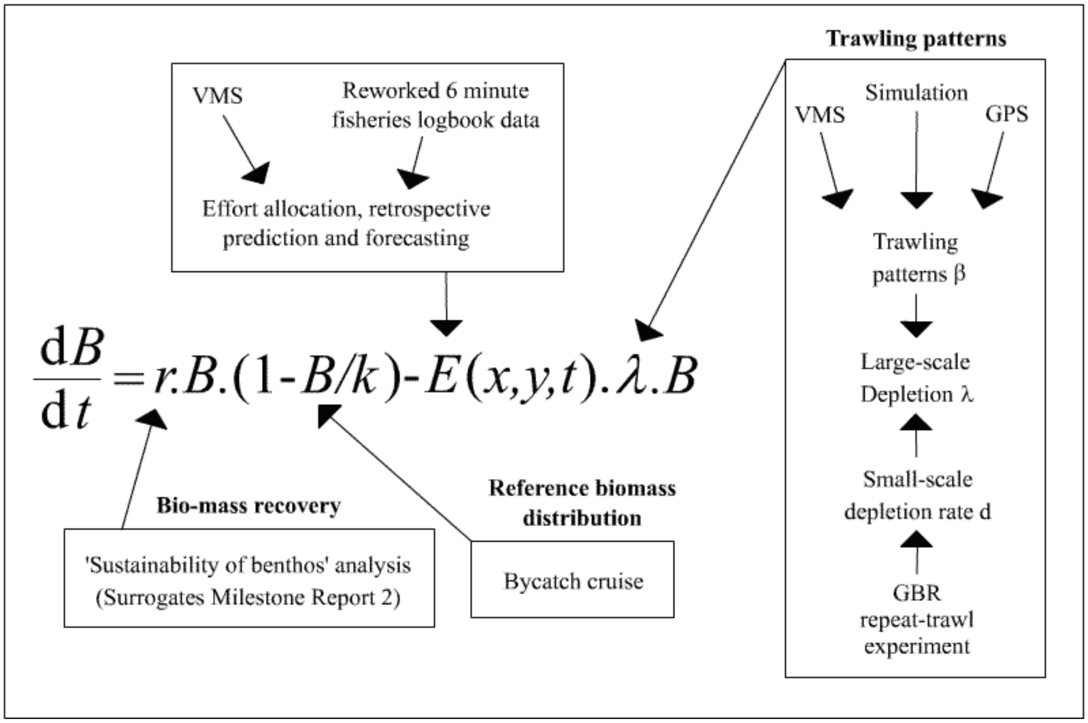

Figure 8.2-1: Operational model for the scenario modeling – from Ellis et al. (2002).

As pointed out by Ellis et al. (2002), the four main input parameters of depletion rate, recovery rate, level of trawl aggregation and the total effort expended are critical. The following section describes the source of the data and the way we have used the information in applying the East Coast model to the NPF.

8.2.1 Depletion rate

As noted in Chapter 6.2 the depletion rates of various groups of benthos in the path of a prawn trawl is quite variable. In this study we estimated the depletion rates for a variety of taxonomic Classes of fauna that were found at our study sites east and west of Mornington Island. We carried out repeated trawls in 6 lanes and collected, identified and weighed all of the catch from each trawl. Although the lanes were trawled 20 times, there was significant non-coincidence of trawls and most of the area of the lanes was trawled less than 10 times. The depletion rates calculated from the experiment are shown in

Table 8.2-1. We have estimated an overall rate for all sites, but because of the considerable differences in the composition of the benthos in east and west Mornington, where possible, we have also estimated depletion rates for east and west separately.

Table 8.2-1: Depletion rates for the various taxa caught in prawn trawls both in the Great Barrier Reef (D_{GBR}; Burridge et al. 2002) and east (D_{east}) and west (D_{west}) of Mornington Island and east and west combined (D_{GoC}). The depletion rate (π) can be converted to a percentage depletion by multiplying the π value by 100.

Taxon	Alternate name	D_{GBR}	D_{GoC}	D_{west}	D_{east}
Desmospongiae	Sponges	0.12	0.123		0.103
Ophiuroidea	Ophiuroids	0.09	0.033		0.033
Holothuroidea	Holothuroids	0.11	0.164	0.160	0.242
Asteroidea	Asteroids	0.10	0.109	0.017	0.120
Crinoidea	Crinoids	0.08	0.105	0.136	0.111
Echinoidea	Echinoids	0.14	0.031		0.031
Gymnolaemata	Bryozoans	0.09	0.213	0.136	
Alcyonacea	Alcyonarians	0.09	0.136	0.136	
Hydrozoa	Hydrozoans	0.08	0.198	0.180	0.196
Crustacea	Crustaceans	0.13	0.158	0.183	0.130
Gorgonacea	Gorgonians	0.15	0.136	0.136	
Gastropoda	Gastropods	0.20	0.200	0.200	0.200
Bivalvia	Bivalves	0.09	0.122		0.122
Ascidiacea	Ascideans	0.11	0.120	0.120	
Phaeophyta	Brown algae		0.373		0.373

8.2.2 Recovery rate

Although several studies have examined the rate at which benthos is removed by trawling, there is little information on the rate at which benthos recovers from impacts. There is some information for benthos on the GBR which were monitored for 5 years following a trawl depletion experiment (Pitcher et al, in preparation). However, this project only examined a relatively narrow group of sessile taxa, many of which are not found in the soft sediments characteristic of our NPF study. We attempted to measure recovery directly, but as described in Chapter 7, this proved to be very difficult because of the high degree of natural variability in the abundance of almost all groups of seabed biota. In an earlier study (FRDC 2000/160) we carried out an evaluation of the vulnerability and recovery of the NPF benthos to trawling as part of the estimation of the sustainability of the benthos. In that evaluation, we scored the sustainability of each benthic group on a scale of 1 to 3 on the basis of a number of biological attributes (fragility, regenerative capacity, reproductive pattern and the effect of damage induced by trawling on reproduction [A score of 3 for an attribute indicated a high recovery rate with respect to that attribute; Table 8.2-2]). The scores were averaged to give an index of recoverability for each group. We have used the additional information on recovery of seabed biota obtained in this project to modify the scores assigned in FRDC 2000/160. As in the previous project, the scores were then converted into a scale of recovery time τ; the time taken for a group of organisms to recover from 50% biomass to 95% biomass. We assigned a recovery time of 1 year for animals with a recovery index of 3, 5 years for a recovery index of 2 and 10 years for a recovery index of 1, but note that this may be a major underestimate for some species. Actual conversions were made using the relationship,

$$\tau = 14.33 - 4.5\, i,$$

where i is the mean recovery index and τ is in years. The trawl depletion model assumes that, in the absence of depletion, the biomass of an organism will follow the sigmoidal curve,

$$\mathrm{B}(t) = \mathrm{B}_{\max}\exp(r_s t)/(1+\exp(r_s t)),$$

with recovery rate parameter r_s. The conversion from recovery time to recovery rate is:

$$r_s = 3/\tau.$$

The recovery rates used in this study are shown in Table 8.2-3.

Table 8.2-2: Recovery attributes used in assessing the susceptibility of biota to trawling (Source: Hill et al. 2002)

Criterion	Scoring
Fragility with respect to trawl	1 = very fragile 2 = damage from trawls is probably not lethal 3 = very robust
Ability to regenerate	1 = Regeneration limited to minor wound repair, likely to be killed by trawl impact 2 = Can replace appendages but not recover from major damage 3 = Well developed regeneration ability
Reproductive strategy	1 = No or short-lived larval dispersal stage 3 = Pelagic larval stage
Effect of trawl damage on reproduction	1 = eggs vulnerable to trawl damage or are broadcast spawners 3 = trawl damage limited to juvenile or adult stage

Table 8.2-3: Recovery rates for the benthic taxa for which trawl management scenarios were run.

Taxon	Alternate name	Recovery Rate r_s (year^{-1})
Desmospongiae	Sponges	0.71
Ophiuroidea	Ophiuroids	0.63
Holothuroidea	Holothuroids	0.56
Asteroidea	Asteroids	0.97
Crinoidea	Crinoids	0.56
Echinoidea	Echinoids	0.40
Gymnolaemata	Bryozoans	0.40
Alcyonacea	Alcyonarians	0.40
Hydrozoa	Hydrozoans	0.56
Crustacea	Crustaceans	0.52
Gorgonacea	Gorgonians	0.71
Gastropoda	Gastropods	0.41
Bivalvia	Bivalves	0.52
Ascidiacea	Ascideans	0.40
Phaeophyta	Brown algae	0.92

The biological part of the trawl model can be summarized in the depletion-recovery diagram, Figure 8.2-2. This diagram allows one to assess the overall vulnerability of the taxa, which is the ratio of depletion rate and recovery rate. Vulnerability increases with the angle from the horizontal. The most vulnerable taxa are Bryozoans, Gastropods, Phaeophyta and Holothuroids in the East. Phaeophyta are rapidly depleted by trawling but recover relatively quickly. Bryozoans on the other hand recover less quickly but also have a correspondingly lower depletion rate. All these taxa would be driven to extinction (locally) by long-term trawling at a rate of 3 times a year. At the other extreme Ophiuroids, Echinoids and Asteroids in the West are relatively invulnerable to trawling. They would survive long-term trawling at a rate of 10 times a year, albeit at reduced abundances. We expect taxa with the same ratio of depletion rate to recovery rate to respond similarly to trawling.

8.2.3 Trawl effort and aggregation

As was done by Ellis et al. (2002), we have partitioned the fishery into two main components – a banana fishery and a tiger fishery. Each of these targets more than one species of prawn but the difference between them relates to the main method of trawling. Banana fishing targets schools and generally the trawl shots are of short duration with little seabed contact. Tiger fishing by comparison involves long duration (generally 3 hour) trawls that are in contact with the seabed the whole time. It is this fishery that we consider is likely to have the greater impact on the seabed fauna. Trawler skippers are required to record catches on a 6 × 6 nautical mile grid. In the original application of this model, on the east coast prawn fishery, we modelled the within 6 × 6 nautical mile grid aggregation of trawling effort using a statistical model based on a sample of trawler tracks recorded by fisher's GPS plotters. Ellis et al. (2002) used VMS data to allocate effort within the grids. However, only four months data were available. We now have five years (1999 to 2004; see Chapter 4) of VMS data and in the present project we have used all of this data to allocate the within 6 nautical mile grid effort, giving a much more reliable picture of fine-scale effort patterns than previously available.

In the projection phase of the simulations we generated effort by randomly sampling from the spatial effort in the historical period and scaling the effort up to the desired total as specified in the scenario. This was the same as was done for the earlier Groote study.

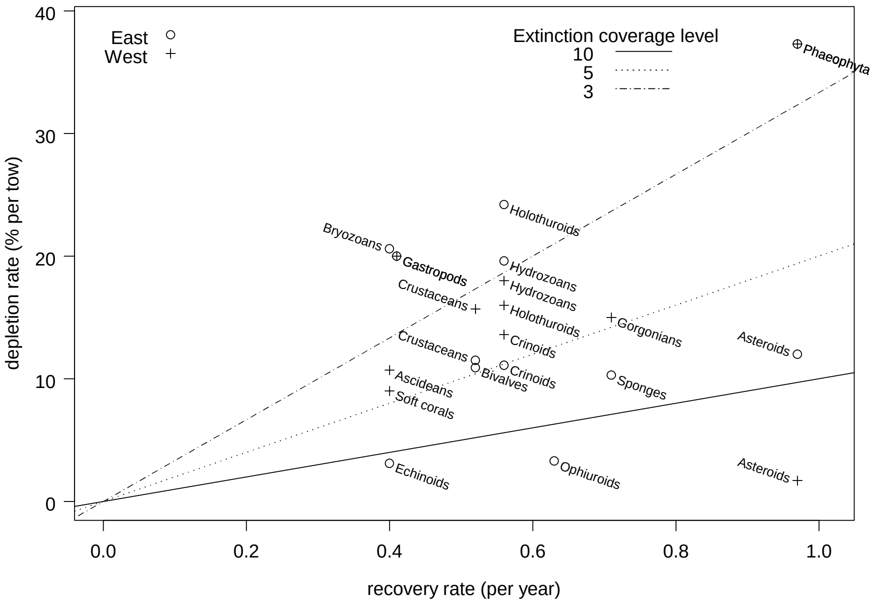

Figure 8.2-2: Depletion rates and recovery rates for the taxa modelled in the Mornington Island region. Taxa found in the west are denoted by a cross and those in the east by a circle. Bryozoans, Echinoids, Ophiuroids and Sponges are modelled only in the east, and Ascideans, Soft Corals and Gorgonians only in the west. For Gastropods and Phaeophyta the same rates are used in the east and west, otherwise they differ. The sloping lines denote border of extinction at a various levels of effort. For instance, all species above the solid line would go extinct in a grid cell whose entire area was trawled 10 times per year.

A refinement of the trawl model has been to incorporate time-varying swept area rates as calculated by Sterling and Bishop in Dichmont et al. (2003). This work shows that the average swept area rate, which is the product of spread and trawl speed, has been steadily increasing since 1970, except for a downward step in 1987 when gear cuts were introduced (Figure 8.2-3). The earlier version of the trawl model used a constant spread of 25m and trawl speed of 3 knots, amounting to a swept area rate of about 39 m^2s^{-1}, as shown by the dashed line in Figure 8.2-3. This refinement should more accurately model the effects of trawling and result in larger impacts from more recent times. The model assumes that the NPF-wide swept area rate applies in the Mornington region. For the rerunning of the Groote study, we used the original effort model, in order to focus on the effect of updating the depletion rates.

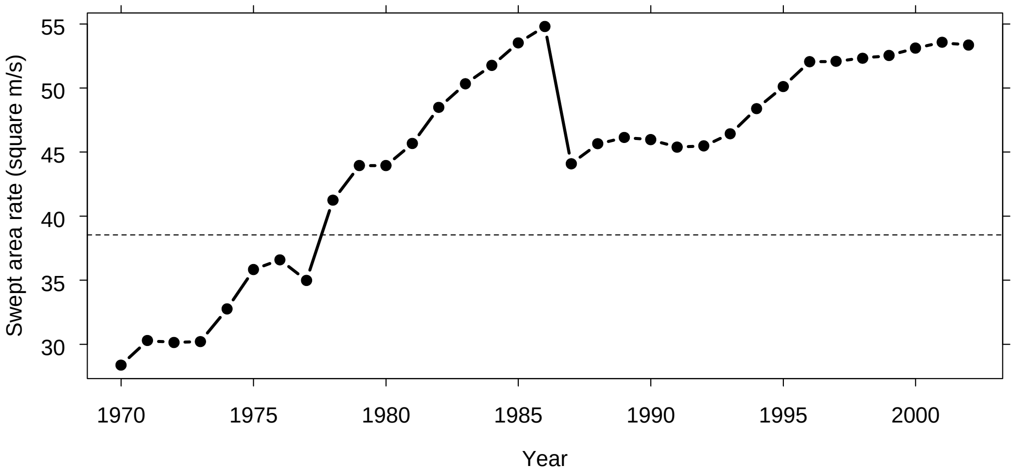

Figure 8.2-3: Average swept area rate for a vessel targeting tiger prawns in the NPF fleet (source: Objective 3.2 in Dichmont et al. (2003)). The dashed line shows the swept area rate of a vessel trawling at 3 knots with spread 25m.

8.2.4 Scenarios

We ran a range of scenarios with the model in two different regions within the Gulf of Carpentaria. Firstly, we re-ran the scenarios used in a previous study (Ellis et al. 2002) in which we had used depletion rates estimated from GBR benthos. The scenarios were:

1. Status quo: no management intervention
2. Instantaneous reduction of effort of 25%
3. Reduction of effort by 25%, phased in over 5 years
4. Reduction of effort by 25%, phased in over 10 years

These scenarios were run for the fishing grounds north and south of Groote Eylandt. We then compared the results for the new depletion rates with the original results using the GBR depletion rates.

Given that we had collected our data around Mornington Island we felt that it would be sensible to run some scenarios in this region. However, the fishing effort (and catch) in the Mornington Island region dropped dramatically in 1999 to approximately 40% (medium levels) of what it had been during the previous eight years (high levels; see Figure 8.2-3). Since that time and during the life of this project, effort continued to decline up until 2004 (low levels). This limited our choice of potential scenarios; we couldn’t invoke a cut in fishing effort as it was close to zero anyway. One possible explanation for the continued to decline in effort in the region after 2001 is because the mid-year closure was extended to include August for the period 2002 to 2004. If this explanation is correct then it is possible that from 2005 on, when August is once again open to fishing, effort levels in the area may increase to be similar to 1999 to 2001 levels.

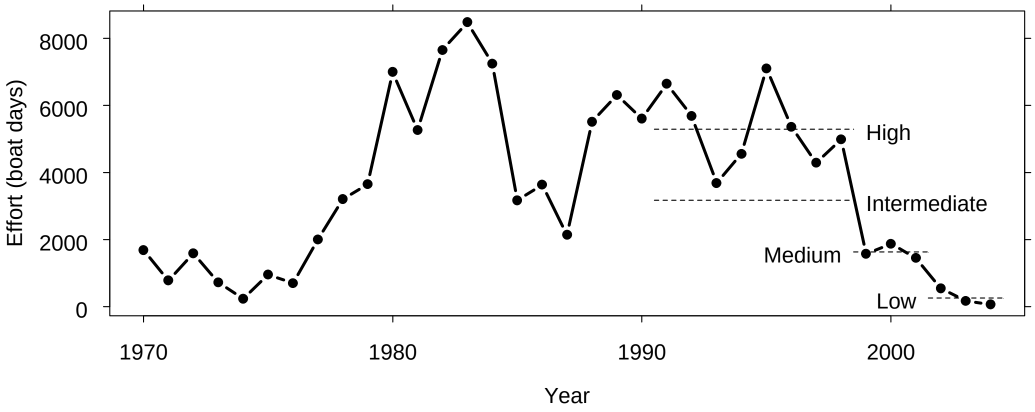

Figure 8.2-4: Total tiger prawn effort in the region around Mornington Island for each year since 1970. Dashed lines indicate the level over effort in the projection period for the Low, Medium, Intermediate and High scenarios. The Intermediate level is 60% of the High level.

With these factors in mind, we decided on the following scenarios:

1. To maintain effort at the very low levels of 2003 and 2004 to determine how long it would take the benthos in the area to recover from its present state. This is the *Low* scenario.
2. To assume that by opening August to the fishery, more effort will be directed there and to set effort at something approximating the levels prior to the August closure. This is the *Medium* scenario.
3. The *Intermediate* scenario simulates the highest feasible effort in the management era after 1998 when reductions of 25% and 20% were applied. Here the effort is at 60% the level of the *High* scenario.
4. The *High* scenario examines the effects of fishing in the hypothetical case where levels are similar to those in the period 1991–1998, before effort reductions were applied.

Figure 8.2-5 shows the average effort over the projection period (2005–2020) for the four Mornington scenarios.

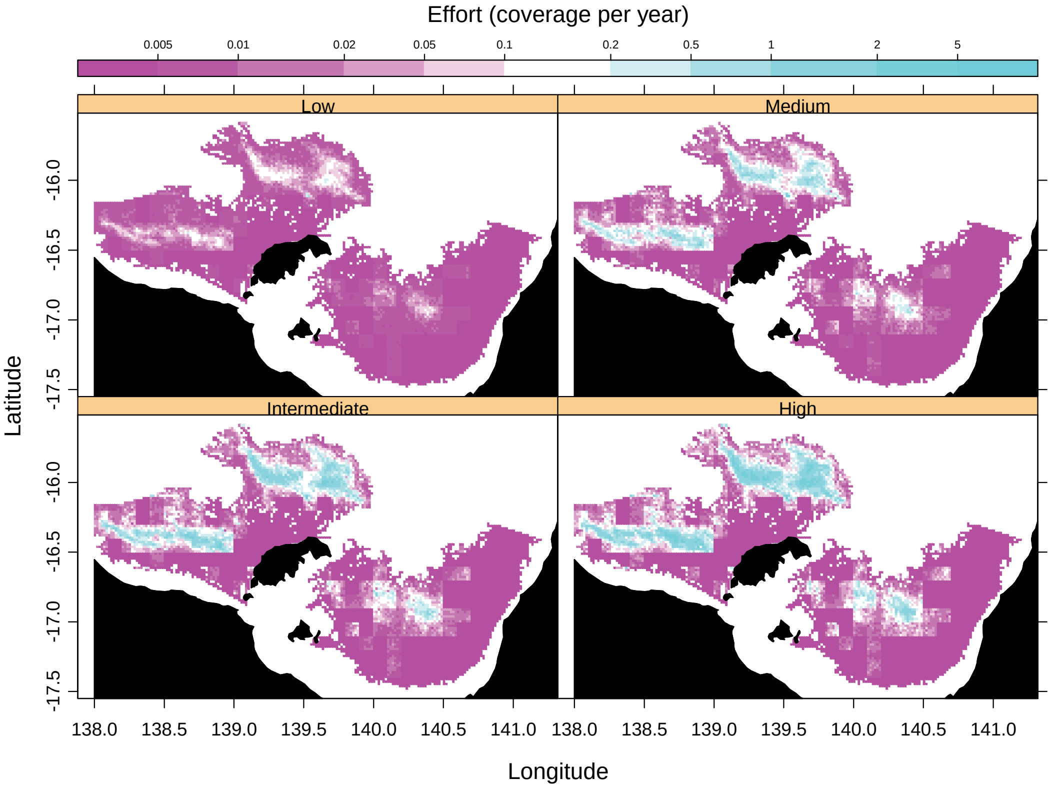

Figure 8.2-5: Average effort at 1-nautical mile resolution over the projection period 2005–2020 for the 3 scenarios. Effort is in units of coverage. A 10-hour day for a vessel with a swept area rate of 50 m^2s^{-1} is equivalent to a coverage of 0.52 for a 1-nautical mile grid.

8.3 Results

8.3.1 Groote study

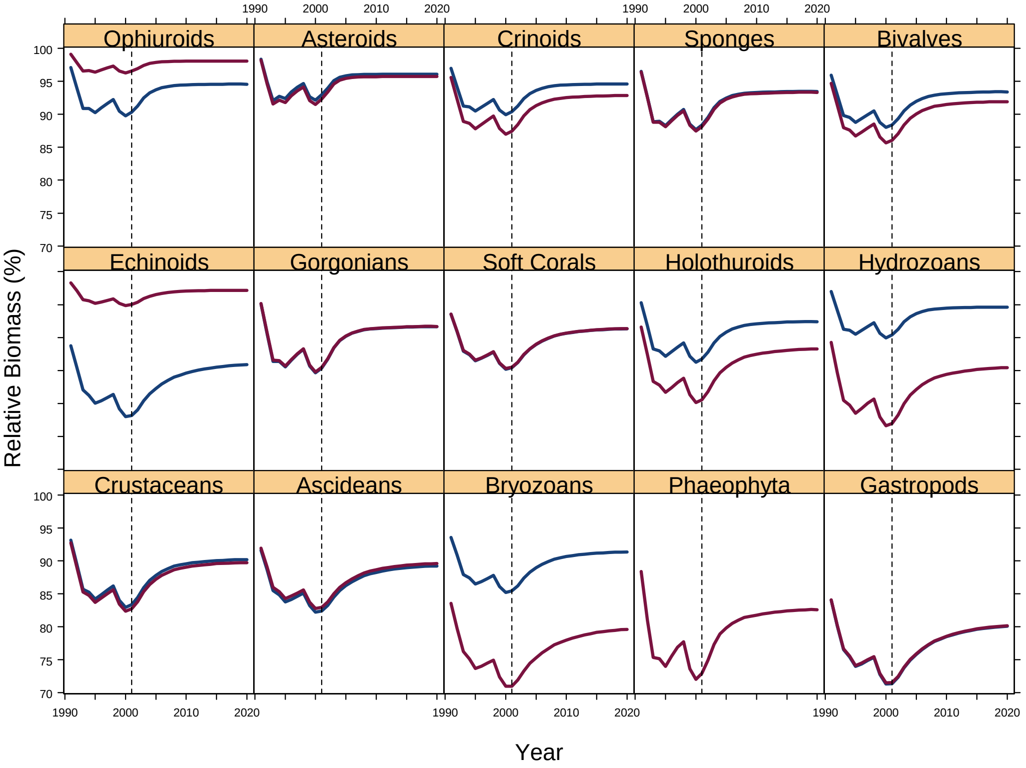

Figure 8.3-1: Relative biomass history 1991-2020 for the scenario 'Instantaneous reduction of effort of 25%', under the Green Zone depletion rates (blue) and the Mornington depletion rates (red). The onset of the projection period in 2001 is marked by a dashed line.

The effect of the new depletion estimates relative to the GBR rates can be seen in Figure 8.3-1 for the instantaneous 25% effort reduction scenario. For several taxa the estimates are quite similar leading to very similar time histories. The shape of the curves is due to the shape of the effort history over time. Generally the different taxa have similarly shaped curves with overall level scaled up or down depending on their vulnerability. High biomass implies low vulnerability, and vice versa. The most vulnerable taxa (according to the Mornington values), Bryozoans, Phaeophyta and Gastropods, have very similar histories, as expected. The effect of the Mornington rates is to revise our assessment of the vulnerability of various taxa, making Bryozoans, Holothuroids and Hydrozoans more vulnerable and Echinoids less vulnerable.

One of the important products of this kind of analysis is a decision table based on how certain indicators change under the different scenarios relative to a baseline scenario. In the earlier study, we used the status quo scenario as the baseline. This is a scenario where effort remains at recent historical levels. The indicators we looked at were the mean relative biomass, the median relative biomass and the percentage of grids reduced to 20% initial biomass in 2020, the final projection year. By comparing the relative change of the indicator we can assess the relative merits of the management scenarios. The purpose of using relative changes is to reduce the sensitivity to errors in the model, since those errors would be common to all scenarios. One type of error is misspecification of the depletion rate. We test this in Figure 8.3-2 by showing relative change of the indicators for five taxa using both the GBR and the Mornington depletion rates. Since all scenarios are effort reductions relative to the status quo, all the indicator changes are positive, meaning the biomass is increased. We see that the effect of changing the depletion rate (Mornington *vs.* Green Zone) is generally larger than the relative effects of the scenarios themselves. For instance, suppose we arbitrarily say that a 5% relative change is a significant effect. Then, for Hydrozoans, using the Mornington depletion rates would change an insignificant effect into a significant effect for all three scenarios on two of the indicators. We can make similar remarks for Holothuroids and, in the reverse direction, Echinoids. The results also show that the mean relative biomass indicator is more sensitive than the other two. Also, as reported in the earlier study, the two 25% reduction scenarios have practically identical effects by 2020.

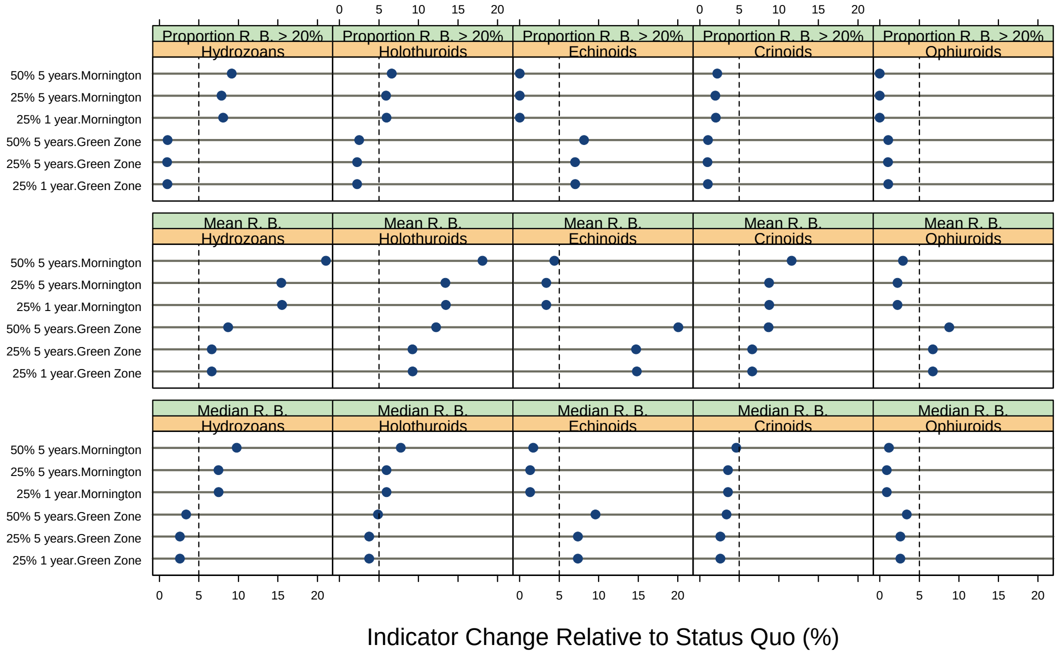

Figure 8.3-2: Percentage change in three indicators relative to status quo for the three alternative scenarios under the GBR and Mornington depletion rates. Each row corresponds to a different indicator and each column to a different taxon. Within each panel the top three lines correspond to Mornington and the bottom three to the GBR. Within each set of three, the topmost is the 50% reduction and the other two are the 25% reductions. Only those taxa with sizeable differences in depletion rate are shown. The dashed line marks the 5% relative change point.

We see from Table 8.2-1 that the estimate of Echinoid depletion rate for Mornington (3%) is much less than that in the GBR Green Zone (14%). The spatial effect of this is shown in Figure 8.3-3. The overall level of depletion is reduced and the region of high depletion has shrunk. However for Bryozoans, Holothuroids and Hydrozoans we would reach the opposite conclusion and the maps would look similar to the Figure with the left and right panels swapped.

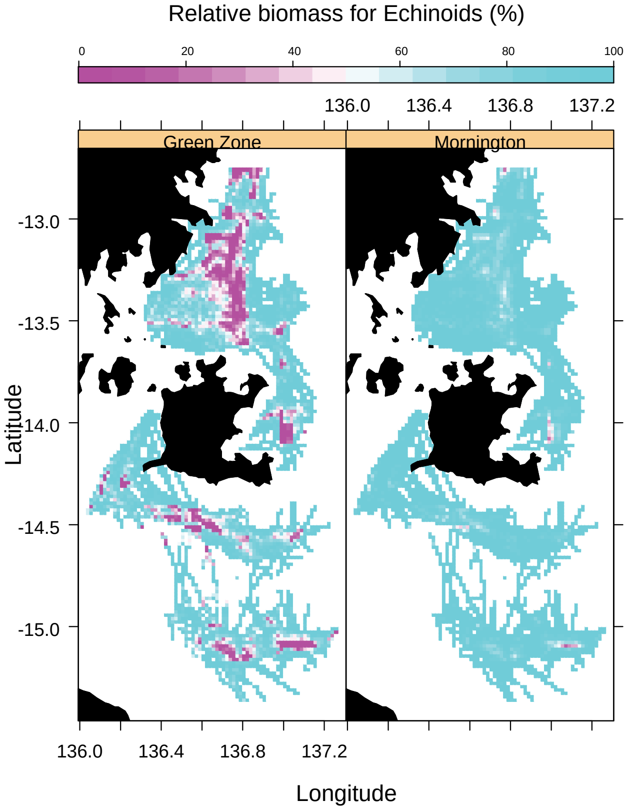

Figure 8.3-3: Relative biomass for Echinoids (*left*) using Green Zone depletion rates and (*right*) Mornington depletion rates.

8.3.2 Mornington study

The Mornington study differs somewhat from the Groote study because the fleet situation has been very dynamic over the previous ten years. Of the four scenarios it is not clear which can be referred to as the 'baseline' scenario. Therefore, rather than pick one as a baseline we present all four separately and show the raw indicator rather than a relative change. We replace the median relative biomass indicator with the 1st quartile relative biomass. This indicator is more sensitive to biomass changes in the highly depleted grids. All the indicators are measured in 2020 and they are based on fished grids only. We show the results for West Mornington in Figure 8.3-4 and East Mornington in Figure 8.3-5. The indicators, and the taxa with each indicator group, are displayed in order of decreasing sensitivity with respect to scenarios. A value of 100% denotes full recovery. Most taxa reach close to 100% for the Low scenario. For the unrealistic High scenario the taxa respond differently according to their vulnerability with Gastropods being the most vulnerable and Asteroids and Ophiuroids the least vulnerable. For instance, under the High scenario, Gastropods would be depleted to below 60% initial biomass in 25% of all fished grids in West Mornington (**Error! Reference source not found.**, top left panel). The dependence of the indicators on the more realistic Intermediate and Medium scenarios is some where between the two extremes, and in fact in most cases the variation is almost linear and certainly monotonic (i.e. increasing from High to Low).

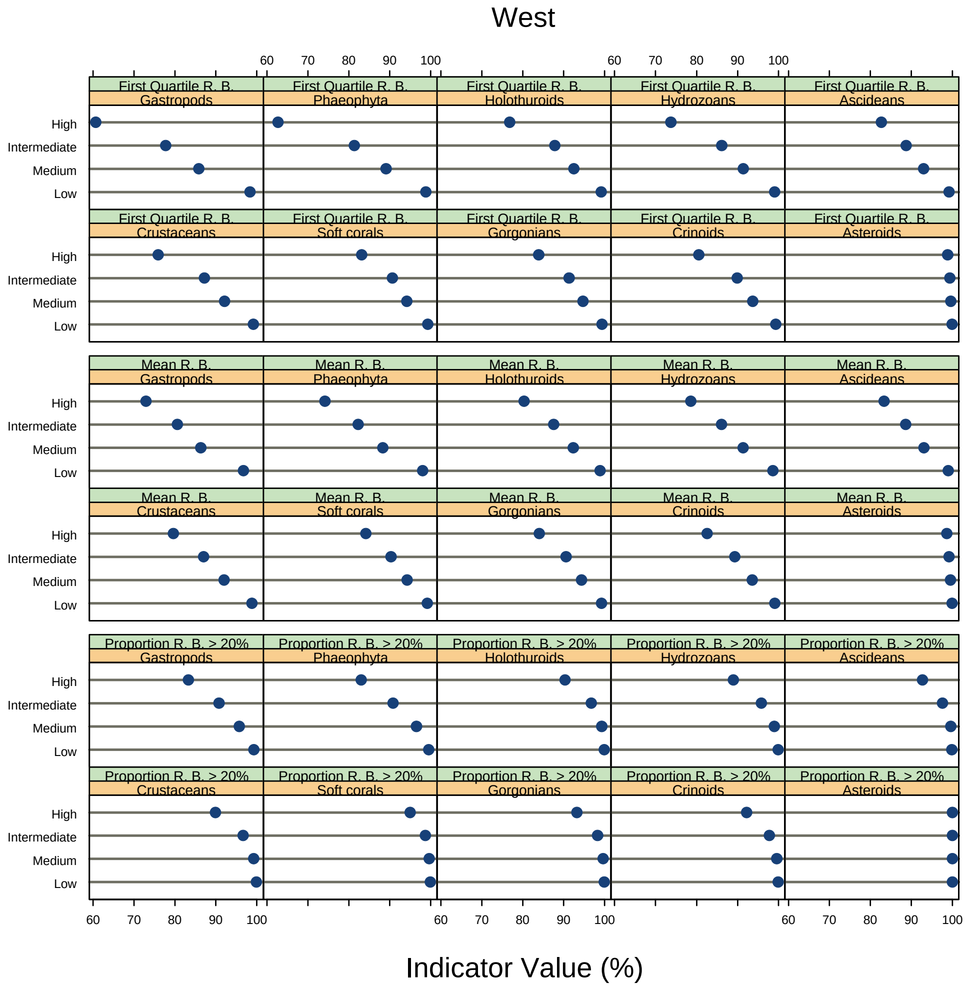

Figure 8.3-4: Decision table for three performance indicators in the West Mornington region. The indicators are (*top*) 1st quartile relative biomass (R. B.) (*middle*) mean relative biomass, and (*bottom*) percentage of grids exceeding 20% initial biomass, all measured in 2020. The taxa are sorted in decreasing order of vulnerability to trawling. Each panel compares the four scenarios: High, Intermediate, Medium and Low.

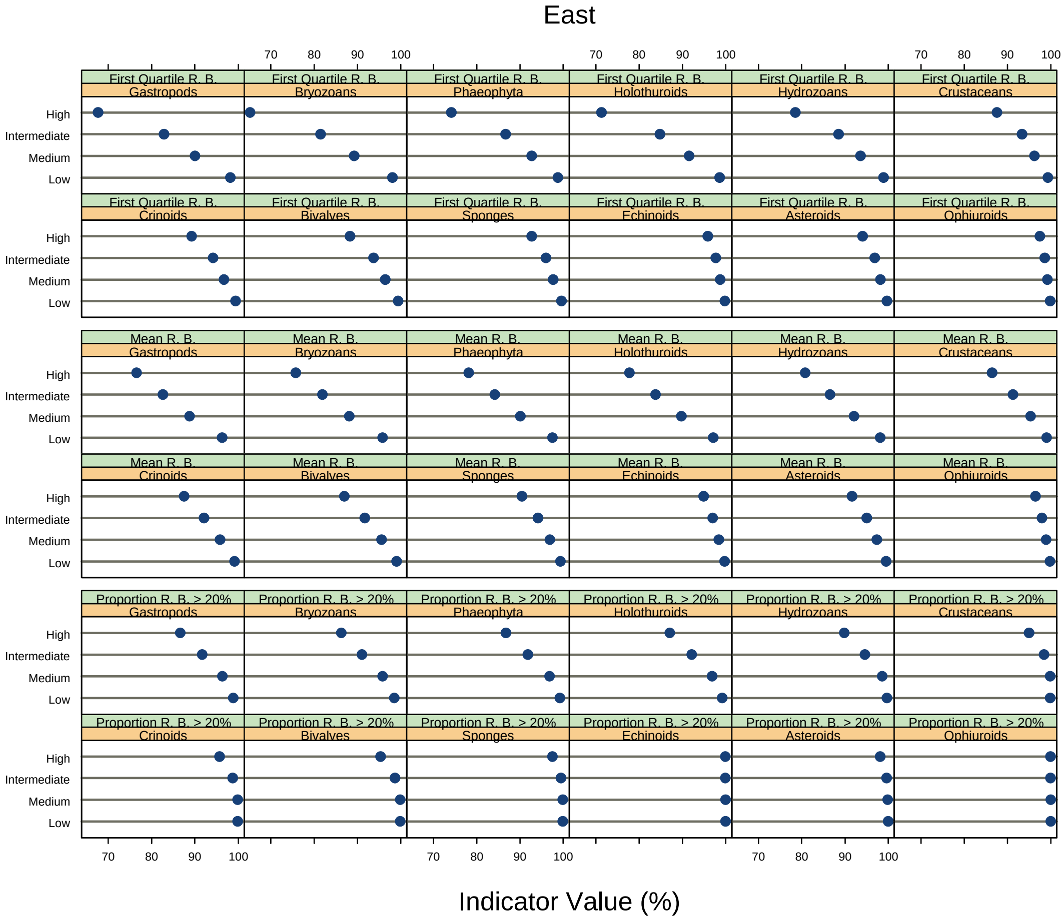

Figure 8.3-5: Decision table for three performance indicators in the East Mornington region. The indicators are (*top*) 1st quartile relative biomass (R. B.) (*middle*) mean relative biomass, and (*bottom*) percentage of grids exceeding 20% initial biomass, all measured in 2020. The taxa are sorted in decreasing order of vulnerability to trawling. Each panel compares the four scenarios: High, Intermediate, Medium and Low.

The mean relative biomass histories of taxa in East Mornington are shown in Figure 8.3-6 in decreasing order of vulnerability. All taxa declined in the high-effort period 1975–1985, then roughly stabilized in the period until 2000. Since 2000, biomass levels recovered somewhat. After 2005 it can be seen how the different scenarios affect the biomass. In particular the High scenario would return levels to those of the pre-2000 period. Note that Holothuroids and Phaeophyta have very similar end values (as they have almost identical vulnerability) but Phaeophyta varies more rapidly because the depletion and recovery rates are higher. The end values in 2020 are the same as the values in the middle row of indicators in Figure 8.3-5.

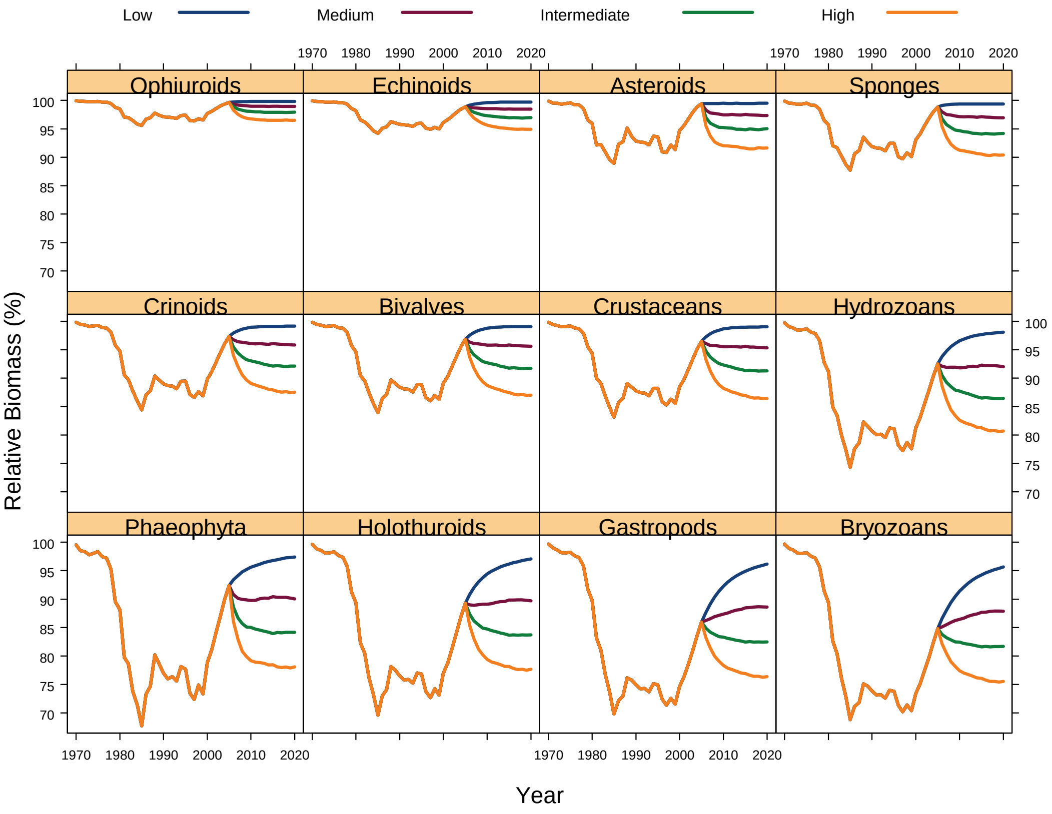

Figure 8.3-6: Relative biomass history 1970-2020 for the 12 taxa in East Mornington using the East Mornington depletion rates. The four scenarios come into force in the projection period 2005–2020.

Although the mean relative biomass may seem fairly high for all the taxa there are nevertheless many grids in which some taxa are depleted to nearly zero. Figure 8.3-7 shows how the relative biomass depends on the average effort in the grid over the projection period. There is a roughly linear decline with effort down to a maximum effort level after which the biomass remains at close to zero. The slope of the linear descent is proportional to the vulnerability, with Gastropods being depleted at lower effort levels than Echinoids. The shapes of the distributions would be the same for all scenarios; it is just that there are more high effort grids for the High scenario.

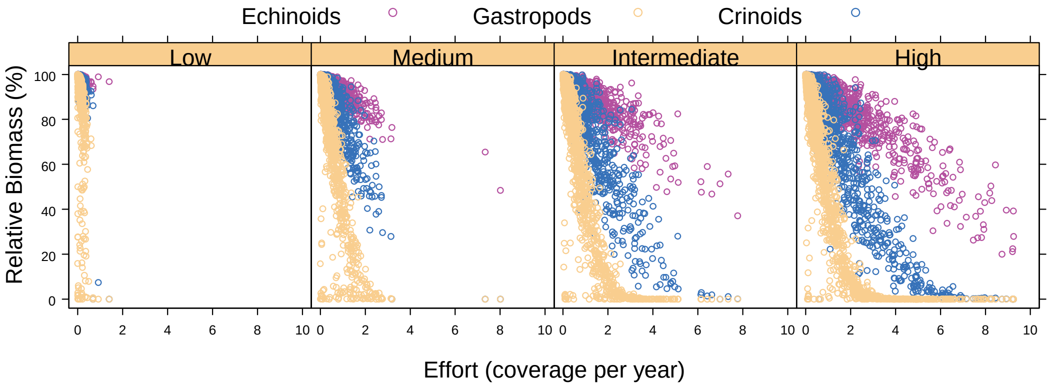

Figure 8.3-7: Relative biomass vs effort for Echinoids, Crinoids and Gastropods in 2020.

Finally we show spatial distributions of some taxa for the projection year 2020 under the Intermediate scenario (Figure 8.3-8). Echinoids and Bivalves were not caught in the West, and Gorgonians were not caught in the East. We have therefore not shown these taxa in those regions. Also roughly half of the grids displayed were not fished at all in the projection period. These grids were excluded for calculating indicators. We see that for the Echinoids the relative biomass remains above 50% everywhere. On the other hand, Gastropods are depleted to below 10% in the highly fished areas north of Mornington Island. This is despite the mean relative biomass being about 80%.

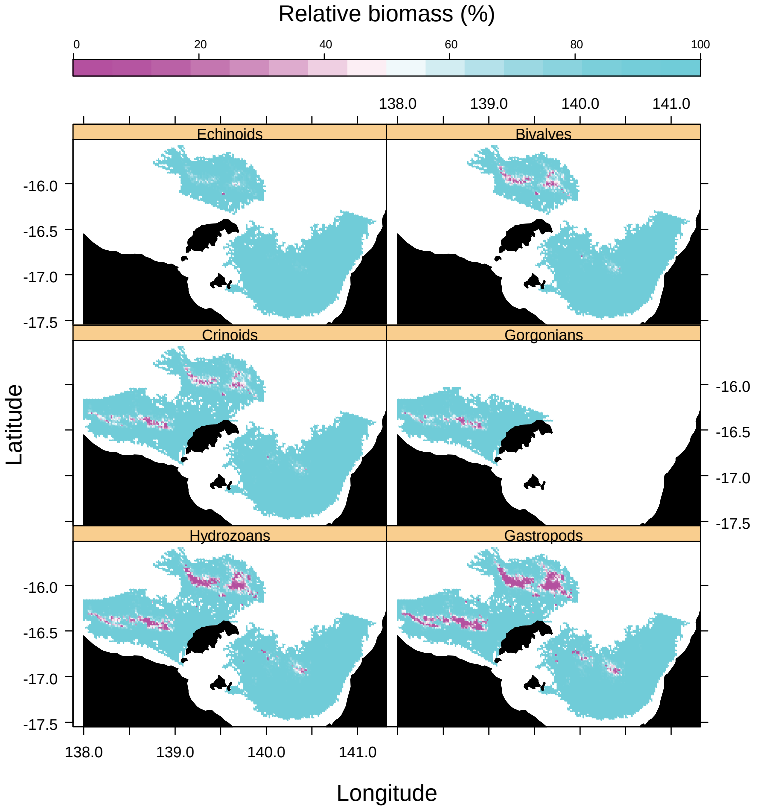

Figure 8.3-8: Relative biomass maps for Bivalves, Crinoids, Echinoids, Hydrozoans, Gorgonians and Gastropods using the appropriate depletion rate in each region under the Intermediate scenario.

8.4 Discussion

Much of the methodology used in this study was first developed in the study by the Hill et al. (2002) in which the trawl impact model was applied to the region around Groote Eylandt. In this study, the two innovations have been the application of depletion rates appropriate to the area, as calculated in Chapter 6 and the refinement of the model to include swept area rates. Also, the VMS data set was more extensive. This was used to provide an accurate picture of effort in the data period for which VMS was available, and in the projection period, which is based on sampling from the recent historical period.

We have also been able to revisit the Groote study to obtain more reliable indicators based on the overall depletion rates of seabed biota from the Mornington Island region. We believe that these rates are more representative of the depletion rates for Groote, because as we demonstrated in a previous study (Hill et al. 2002), the composition of the benthos of the GBR is very different to that from any of the regions sampled in the NPF. This study has demonstrated how sensitive the model is to estimated depletion rates; the effect of using the updated depletion rates for the Mornington area was generally larger than the effects generated by the differing scenarios.

The scenarios here have been necessarily more speculative, because of the recent changeable effort patterns in Mornington. Our scenarios have been simple projections of constant effort at various levels ranging from the current very low to probably unfeasibly high.

The response to the scenarios has been fairly straightforward. Basically, the more vulnerable taxa are impacted more, and the impact is higher for all taxa in areas with higher effort. We have shown a variety of ways of looking at the results including raw indicators, indicator changes, time histories and maps. Indicators are a good way to assess the overall impact (or relative impact) of a scenario, however they may not reveal important local effects whereas more detailed summaries (such as maps) can alert one to impacts in a particular area.

8.5 References

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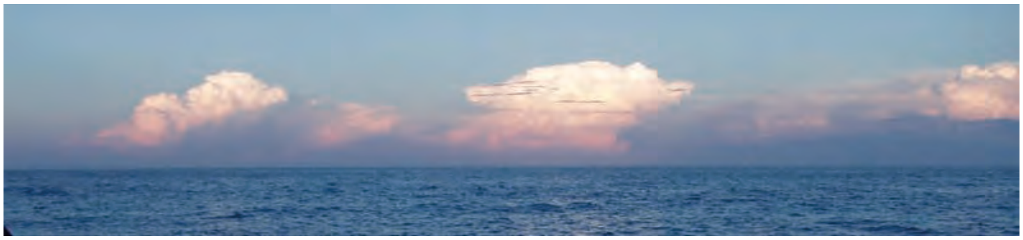

CHAPTER 9. DISCUSSION

Mick Haywood, Wayne Rochester and Burke Hill

Trawling has come under considerable criticism in recent years. It has been compared with clear felling of forests. Accounts of sponges, corals and gorgonians being destroyed by trawls all contribute to a negative image of this major fishing activity. Prawn trawling has the dubious distinction of having the highest ratio of bycatch to catch of any fishing method – in the western NPF for example ratios of 2:1 to 21:1 were recorded by Pender et al. (1992) whereas Stobutzki et al. (2000) reported a ratio of 9:1 on commercial trawlers in the tiger prawn fishery in the Gulf of Carpentaria. Worldwide prawn trawling is estimated to produce a third of all discards (Alverson et al. 1994). Considerable research effort has been directed towards assessing the sustainability of bycatch species in the NPF (Stobutzki et al. 2000 and 2001) and especially reducing the catch of large animals such as turtles (Brewer et al. 1998). These studies have been directed at what arrives on deck of a trawler, there has not been the same effort directed at the effect a trawl has on the biota on the seabed. Apart from general surveys of the seabed biota (e.g. Long and Poiner, 1994) we have no information on this other important aspect of trawling. In contrast, on the Queensland east coast, there has been a major effort to assess the effect of trawling on seabed biota (see Poiner et al. 1998 and Pitcher et al. 2004). The present study arose from an initiative by the NORMAC Research Committee and seed funding provided by the NPF through NORMAC. The study aimed to assess the impact of prawn trawling on the seabed biota and the recovery of the biota from the impact. The study would be limited to the invertebrates since fish have previously been the subject of a large impact study by Stobutzki et al. (2000). This information would be combined with information on the distribution of fishing effort in a model that would attempt to predict the likely long term effect of trawling on the biota and how this would be affected by changes in effort. The study would require an experimental approach of simulating a trawl impact as well as obtaining more detailed information on the distribution of trawl effort at a finer resolution than currently available.

Commercial logbook data shows that the prawn trawl fishery in the NPF is concentrated in only part of the managed area. The resolution of this data is coarse – six nautical miles – and does not lend itself to an understanding of the real distribution of trawl effort. Is it for example evenly spread across each 6-n-mile grid cell or is it concentrated? In the present study we have used VMS data to increase the resolution of the effort data to one nautical mile – a 36 fold improvement. As shown in Chapter 4, the greater resolution reveals that effort is not evenly spread across the 6-n-mile grid cell but is even more concentrated than expected. This data coupled with plotter data from individual fishers has shown a picture of highly concentrated trawling in which trawls are towed repeatedly over small areas of seabed. There are three important consequences of this fishing behaviour. The first is that trawling takes place in a small percentage of the NPF, most of the area is not trawled at all. The second is that a relatively small proportion of the NPF is yielding most of the prawn catch. The third is that small areas in the NPF are being subjected to intensive trawling disturbance.

We found that only 17% (130,000 km^2) of the 1-n-mile grid cells in the NPF had any trawling recorded in them in any year from 1999 to 2004. We refer to this area as the *fished area* of the NPF. In any given year the trawling intensity in the majority of grid cells in the fished area was less than 1 h/n mile^2. A trawling intensity of 1 h/n mile^2 equates to a swept area of about 6% of the seabed. This is an interesting contrast to the National Park in the Wadden Sea of Schleswig-Holstein in which ‘Every square metre of the sea bottom in the sublittoral zone of the National Park is fished several times a year by shrimp trawls.’ (Berghan and Vorberg, 1998).

A small proportion of the fished area was trawled quite intensively. In this report we defined hotspots as areas with at least 6 hours of trawling per 1-nautical-mile grid cell in a year. In the period 1999 to 2004, 37% of the fished area was classified as hotspot in one or more years. The hotspots were not constant: only around half of the hotspot grid cells in a given year were the same as those in the previous year. This year to year shift resulted in only 12% of the fished area being classified as hotspot in at least 50% of years and only 3% as a hotspot in every year. We can conclude from this that the hotspots make up a very small proportion (6%) of the managed area of the NPF and although an area may be trawled intensively in one year, it is unlikely to be trawled intensively every year.

Despite their small size, hotspots are extremely important to the fishery. Between 1999 and 2004, the hotspots contributed an average of 91% of the total tiger fishery catch (Chapter 4). Knowing what happens on hotspots is therefore vital for the fishery managers. Do hotspots change from year to year because prawn populations are negatively affected by intensive trawling or is it simply that the prawns are reacting to other environmental factors? Importantly also, does intensive trawling affect the habitat in some way that may impact on the fishery?

Assessment of the impact of trawling ideally requires that we are able to compare the pre- and post-trawling conditions on the seabed – the biota as well as the environment. The post-trawl condition is determined by the composition of the seabed biota, the rate at which the biota is removed or altered by trawling and the rate at which the biota recovers from trawling. We set out to measure these three parameters.

The benthic biota in the Gulf of Carpentaria study area is extremely rich. Long et al. (1995) recorded 840 species of megabenthos from the Gulf of Carpentaria. In the present study we recorded 950 taxa and caught a total of 43,778 individuals. This figure excludes fish caught in the prawn trawl so the overall number is much higher. The high level of biodiversity of tropical continental shelf benthic faunas relative to temperate regions is well known (Allongi, 1990). Drabsch et al. (2001) for example recorded only 67 taxa from the Gulf St Vincent in South Australia. The richness of the Gulf of Carpentaria biota complicates the assessment of the impact of trawling. Firstly the numbers of the different taxa vary widely. Table 5.3-10 for example shows that catch rates for the major taxa varied by more than three orders of magnitude. Secondly most of the biota is patchily distributed on the seabed (see Figure 5.3-11 for examples). If a particular animal is present in low numbers and is not caught in samples after trawling, does this mean it has been depleted by the trawl or simply that it does not occur in the area being sampled?

The effect of trawling on such a broad spectrum of biota is affected by the rate at which they are caught by trawls. Prawn trawls do not catch all taxa with the same efficiency - see Table 5.3-10. It is very efficient at catching crustaceans but very inefficient at catching bivalves and most echinoderms. Burridge et al. (2003) measured the rate of depletion of benthic fauna by a prawn trawl in the northern Great Barrier Reef region. They also showed significant differences in depletion rates between various groups. We obtained our measurements of the efficiency of the trawl by comparing the catch of a trawl with that made by the epi-benthic sled in the same area. Because of its design, the sled we used for sampling is a very efficient device (Figure 5.3-1) and we have assumed that it catches 100% of the biota in its path. This is unlikely to be correct and so our estimates of efficiency are probably too high at least for some taxa. The comparison confirmed that prawn trawls are selective and except for crustaceans are not an efficient device for collecting seabed biota. The efficiency for asteroids, cephalopods, crinoids, sponges and holothuroids was between 10 and 25% but for the remaining taxa the efficiency was below 10%. This means that a trawl has a much greater impact in terms of removal on crustaceans than on other groups. Our estimates of removal by the trawl were derived from our experiments in which we replicated hotspot trawling by trawling lanes up to 20 times. This technique has been used in other studies (e.g. Burridge et al. 2003; De Biasi, Anna Maria, 2004; Drabsch et al. 2001). We experienced considerable difficulty in carrying out these experiments. Despite using skippers experienced in line trawling and accurate navigation equipment, it proved impractical to keep the trawler on the same straight line 20 times because of the effects of wind and currents. In addition our tracking devices on the nets showed that the path of the net was not exactly the same as the trawler – although some earlier studies have assumed that it is. This non-coincidence of trawls made analysis of our experiments more complicated but it also gave us an insight into interpreting what happens in a commercial hotspot. Although a trawler may attempt to trawl over the same line, in practice the path wanders. This is well illustrated by Fig 1.4 in Chapter 4 which shows that only a very small part of the hotspot is really trawled repeatedly.

Calculation of the rates of depletion from our experiments had to take coincidence of trawls into account. If a trawl does not follow exactly the path of the previous trawl, it will probably catch biota that have not been exposed to trawling and this will give a higher catch rate than if the tracks had been coincident. Burridge et al. (2003) carried out a repeat trawl experiment in the Great Barrier Reef region. They recognised that the tracks were not coincident and used a modelling approach to deal with the problem. Using data on the track of the trawler – there was no information on the track of the trawl – they estimated the bias in depletion rates from non-coincidence. They found that depletion rates of between 10 and 20% were probably reasonably accurate but were biased outside this range. In our experiments we had information on the track of the trawl. We also had information on the seabed biota from sled samples. Statistical analysis of the data showed that non-coincidence has a very large effect on estimated depletion rates. On average they were twice as high when non-coincidence was taken into account. The overall average depletion for all biota combined was 11% when non-coincidence was not taken into account and increased to 22% when it was. The estimate of biomass on the seabed was similarly affected, halving when non-coincidence was taken into account.

This finding is of major importance to effects of fishing studies because it implies that the depletion rates estimated in many earlier studies have been too low. The higher depletion rate we have estimated indicates a greater impact by trawls than previously thought. It would take only 6 trawls to remove approximately 50% of the biota by weight. This trawl intensity is quite achievable given the intensity of trawling on hotspots. The impact is not evenly spread across all taxa. For example, animals that tend to bury will be less affected than those that are on the surface. However, even buried animals can be damaged by trawl doors (Gilkinson et al. 1998). Trawl doors however, have a narrow path compared to the trawl net and so the total impact on the seabed biota from this source may be minor. Prawn trawls are rigged so the foot rope is off the bottom – although it may touch when it encounters irregularities in the seabed. This is completely different to some types of bottom fishing gear. The 12-m beam trawls used in the North Sea for example are estimated to penetrate 6 cm into the substrate (Bergman and van Santbrink, 2000). Dredges are designed to dig out animals living in the upper layers of the seabed and they are fitted with tines to assist in this. Collie et al. (2000b) reviewed the literature on the effects of trawling. Their analysis shows that inter-tidal dredging and scallop dredging have the greatest initial effects on benthic biota, while trawling has less effect. Drabsch et al. (2001) could not detect an effect of prawn trawling on infauna and suggested this was due to high spatial and temporal variability coupled with the use of light trawling gear. We can fairly safely generalise that the greater the physical impact of the fishing gear on the seabed, the greater the ecological impact.

Measurement of the rate at which the seabed biota recovers from trawling was a major part of the study. We did this by monitoring the trawled and control lanes at six-month intervals for 18 months taking three sled samples from each site on each occasion – a total of 54 samples from each area. We subjected the data to non-metric multidimensional scaling (MDS) ordination plots, ANOSIM (Clarke and Warwick 2001) analyses and species dominance curves. The considerable natural variability in the seabed biota made it difficult to detect a trawl impact signal – the total biomass on all the control lanes increased from 21 kg/ha to 56 kg/ha over 18 months. The MDS plots showed that seasonal effects were more important in determining the species assemblage than were the effects of trawling. This finding was confirmed by the ANOSIM analysis which showed that differences between samples taken before and after trawling were generally not statistically significant whereas those taken at different times of the year were. We also analysed size data collected from the biota using abundance biomass curves. Unexploited populations tend to have a greater proportion of large individuals than exploited populations and these in turn tend to have higher numbers of individuals. The curves showed an apparent trawl effect immediately after the experimental trawling. West of Mornington, the curves had returned to their pre-trawl condition six months later. The picture was not as clear to the east of Mornington where it appeared to take 12 months for the trawled plots to recover. The fact that the multivariate analyses indicated no impact/recovery signal whereas the impact was evident in the biomass abundant curves suggests that perhaps the nature of the impact was to reduce the biomass diversity of the benthos rather than to alter its composition significantly. Overall we concluded that the trawl impact was relatively short lived given that it was not evident 6 to 12 months after the trawling. This agrees with the conclusions of Collie et al. (2000b) after a major review of the literature that most mobile species recover in 100 to 500 days. Although this represents a rapid recovery, on a commercial trawl ground where the trawl impact is repeated regularly, this time frame for recovery would mean that the ground is permanently in a state of disturbance. There is not sufficient time for the biota to recover to its pre-trawl condition before it is impacted again.

Recovery times for sessile organisms tend to be longer than for the mobile species. Pitcher et al. (2004) used video and sled samples to monitor recovery of megabenthos (mainly sponges and gorgonians) on experimentally trawled tracks in the northern Great Barrier Reef. Their experiment ran for five years. They found a wide variation in recovery rates for different species but concluded that most large epifauna – sponges and gorgonians – required five years to recover from a trawl impact. Collie et al. (1997) estimated that epi-benthic megafauna on Georges Bank off Canada recovered in 5 to 10 years. This data means that mobile and sessile species will not fully recover on trawl grounds that are fished regularly.

The most important process of recovery for sessile animals must be through recruitment. Once larvae/spores have settled from the plankton, some of the sessile taxa are capable of rapid growth. In the present study, the biomass of Gymnolaemata (a class of Bryozoa) rose from around 100 g/ha in one sampling period to 5 kg/ha in the following sampling. This is a fifty fold increase in six months and was clearly obvious in photographs of the seabed. Even temperate bryozoans can grow quite rapidly. Hermansen et al. (2001) transplanted a temperate bryozoan (*Electra pilosa*, from the Menai Strait) into the laboratory and measured growth under a range of food concentrations. They found growth rates ranging from ~0.04 to 0.12 day^{-1} specific growth rate and doubling times (in area) ranging from 6.30 to 13.86 days. The maximum specific growth rate for hydroid colonies (*Clytia gracilis*) was 0.24 day^{-1} (specific growth rate = $\ln[N_t/N_0]/t$) which equates to increasing the number of polyps by a factor of 5 every week (Bollens et al. 2000). Brown algae often exhibit distinct seasonal changes in growth; but during the period of peak growth rates, growth of 4.6% per day has been recorded for *Sargassum horneri* (Fuclaes, Phaeophyta; Gao and Hua 1997). The results reported by Pitcher et al. (2004), indicate slower growth for sponges and gorgonians.

Slow rates of recovery coupled with trawl impacts that recur annually will keep slow growing species in a permanently repressed state. There are side effects of this situation. Emergent colonial epifauna provide a complex habitat for shrimp, polychaetes, brittle stars and small fish at undisturbed sites. Bottom fishing removes this epifauna, thereby reducing the complexity and species diversity of the benthic community (Collie et al, 2000b). The trawl grounds in our study had very little of this emergent fauna. Although there was a high biomass of sponges, in fact there were extremely few – only a mean of 31.5 per ha in the eastern study area.

Depending upon the frequency of trawling and the recovery rates of the benthic biota, it is possible that intensively fished areas may be maintained in a permanently altered state, inhabited by fauna adapted to frequent physical disturbance. Epifaunal organisms for example are much less common in areas that have been subjected to intensive trawling (Collie et al. 1997; Sainsbury et al. 1997; Thrush et al. 1998). Trawling can cause a reduction in large sessile epifauna (sponges, bryozoans, alcyonarians etc.) and a general homogenisation of the sediment and loss of fine-scale topography caused by feeding activities of rays, and holothurians, burrowing (e.g. pits and mounds made by bivalves, polychaetes, thalassinids, holothurians etc.), and sediment features such as sand waves. All of this results in a reduction in habitat complexity which has important consequences for fish communities and the biodiversity of the benthos in general (e.g. Sainsbury et al. 1997, Thrush et al. 2001). Our current understanding of the functional role of many of the larger-bodied long-lived species (e.g. as habitat features, bioturbators etc.) is limited but will have to be addressed to predict the outcome of permitting chronic fishing disturbance in areas where these animals occur. Studies have shown that even low-density features creating small-scale structure on the seabed (e.g. sponges <2, hydroids <1 individuals per 0.3 m^2) can significantly influence biodiversity on the 100 to 1000s of metres scale (Thrush et al. 2001). Our finding of unattached sponges in our trawled lanes suggested that at least some species can live permanently in this form. A recent paper by Mercurio et al., (2006) reports finding sessile and non-sessile specimens of a Desmospongiae in two areas in the Mediterranean. Unattached sponges have also been reported in a Scottish loch. It now appears that this may be widespread condition. Mercurio et al., (2006) found that free living sponges were more common on soft substrates and could be moved by currents. They tended to have a spherical shape which is similar to many of the sponges that we caught (Fig 9-1). We do not know if these free-living sponges can survive being trawled and dumped back into the sea but if they can it means that at least some sponges are tolerant of trawling to an extent not previously recognised.

Fig 9-1. Example of a rounded-off near spherical sponge collected by trawl in study area

There is considerable evidence in the literature suggesting that repeated and intense bottom-fishing can cause a shift from benthic communities dominated by relatively high-biomass species towards dominance by a high abundance of small-biomass organisms (e.g. Kaiser et al. 2000 a, b; Sainsbury et al. 1997). In low energy habitats, intensive trawling disturbance may also destabilize benthic system chemical fluxes, and have the potential to propagate more widely through the marine ecosystem (Kaiser et al. 2002). In the North Sea there have been significant changes in the composition of the seabed biota that are thought to be due to trawling (Rumohr and Kujawski 2000). These include a reduction in the numbers of bivalves and an increase in numbers of predatory gastropods and asteroids – possibly due to the availability of discards and damaged benthos. The composition of the seabed biota in a areas subject to trawling is the result of several dynamic processes. These are the composition before trawling, the rate at which various components are removed, damaged or killed by trawling and the rate at which the biota can recover through immigration, recruitment, regrowth and damage repair.

There is a belief by many fishers in the NPF that trawling enhances the production of prawns perhaps by increasing the amount of available food through discarded bycatch. This idea is supported by some studies. Rijsdorp et al. (1991) reported that the growth rates of sole and plaice increased in the North Sea reputedly as a result of a greater food supply in the form of small opportunistic species which were abundant in heavily trawled areas. It is likely that an abundant supply of discards may benefit a range of scavengers on trawl grounds but at this stage we do not have evidence for enhancement of prawns. Prawns have not been observed to feed directly on discards in studies in northern Australia so any discard effect would be indirect (Hill and Wassenberg, 1990). However, other studies have indicated that productivity is actually lowered as fishing intensity increases and the high biomass species are removed (Jennings et al. 2001, Kaiser et al. 2002). Sainsbury (1988) found that trawling can affect stock abundances of fish indirectly by affecting structures and organisms that serve as habitat and food. Given that such a high proportion of the NPF tiger fishery catch comes from such a small area it is vital that we identify what makes these areas so productive so that we can ensure their sustainability.

Apart from the direct impact of trawls on the biota, trawling may have indirect effects. The most commonly cited disturbance is the suspension of fine sediments. A study by Hiddink et al. (in press) shows that the impacts of trawling were greatest in areas with low levels of natural disturbance, while the impact of trawling was small in areas with high rates of natural disturbance. The Gulf of Carpentaria has a high incidence of cyclones – around three per annum. In the shallow waters of the Gulf, these major natural events represent a significant disturbance. In the present study for example we found that sponges had been moved around by a cyclone. The seabed biota of the Gulf presumably is adapted to coping with this disturbance and this would also offer some degree of preadaptation to anthropogenic impacts such as trawling.

In this study we focused on the effects of trawling on epifauna and epiflora; however, trawling may also impact infauna. Infauna are important because they may act as food for commercially important species such as prawns and their burrowing activities can affect substrate characteristics such as water and oxygen content, fine-scale topography and the microbial assemblages. They may help to increase resistance to erosion, decrease sediment compaction and alter the grain size (Hall, 1994). The effects of trawling on infauna are likely to be complex as many of them are too small to be directly retained by trawl gear and they are more likely to be resuspended into the water column rather than be killed by the trawl gear. Benthic trawls result in significant amounts of sediment and dissolved nutrients being mixed into the water column (Durrieu de Madron et al. 2005) which can increase the quality and bioavailability of organic carbon to consumers, modifying the trophic state of benthic systems (Pusceddu et al. 2005). However, several studies on the effects of trawling on infauna have not been able to identify any significant impacts on the abundance or community structure of epifauna (Lampadariou et al. 2005).

We used the data collected in this study in a model that could be used to predict the effect of changes in trawl effort on the seabed biota. Ellis et al. (2002) modelled the effect of trawling on the seabed biota around Groote Eylandt in the western Gulf of Carpentaria. As pointed out by Ellis et al. (2002), the four main input parameters of depletion rate, recovery rate, level of trawl aggregation and the total effort expended are critical in such a model. The depletion rates used in their model were derived from a study on the Queensland East Coast because there was no data for the NPF. In addition, the trawl aggregation data was based on only four months of VMS data. In the present study it was possible to use depletion rates measured on the seabed biota in the southern Gulf of Carpentaria and also to use five years of VMS data. We also incorporated data on swept area which allows for effort creep in the fishery. Running the model using the depletion rates measured in the present study showed definite changes – for example we found that bryozoans, holothuroids and hydrozoans were more vulnerable and echinoids less vulnerable than had been found using Queensland East coast data. These differences vindicated the decision to measure the rates in the Gulf of Carpentaria as recommended by Ellis et al. (2002). The modelling showed that, following reductions in effort it would take around ten years for the seabed biota to stabilise to a new level. It also showed that some groups are particularly vulnerable to trawling and populations are likely to be reduced to very low levels under current trawling regimes. Even under a moderate trawl effort scenario, gastropods will be reduced to 10% of original levels. Other groups – such as asteroids and echinoids – would increase under the same trawl effort scenario. These differences highlight the complexity of the seabed biota responses to trawling.

This study has shown that for most of the managed area of the NPF, prawn trawling has no direct impact. Over 80% of the area is not trawled at all and vulnerable areas of seagrass are closed to trawling. In addition, the NPF has seen large reductions in effort in recent decades. A fleet of over 250 trawlers has been reduced to less than a hundred and the activity of the remaining vessels has been restricted to less than six months of the year instead of year round fishing. Overall we are dealing with a system in which trawl impacts are limited spatially and reducing. Nevertheless, trawling does take place over a significant area. The results of the present study and those in other areas, especially the Queensland east coast, show that trawling has an impact on the seabed biota. The nature of this impact is complex because it varies between species. In general, slow growing organisms that are vulnerable to trawling – sponges for example – are most impacted. Rapid growing species and those with a low catchability are likely to be least impacted or can rapidly recover from an impact. We suspect that indirect effects such as suspension of sediments are of low importance because of the relatively frequent and major disturbance caused in shallow water by cyclones. We consider that the major impact of trawling in the NPF is to hold the community in trawled areas in a steady state which favours the fast growing or ‘weedy’ species over the slow growing ones. Thus trawled areas still have a rich biota, but it is not the same as the original ‘prefishing’ one. Our study has shown that this is not a steady state but a highly dynamic one in which the seabed biota is changing in response to factors other than trawling. Many of the major species showed significant increases in biomass on our control plots through the course of the experiment. These are natural changes that are not occurring in response to trawling.

Although trawling occurs in only a minor proportion of the NPF, it is possible that the trawl grounds represent a special environment. In this case, trawling may be taking place in a very large proportion of some unique habitat. It is important to bear in mind however, that these quite limited areas are extremely important to the fishery and it is in the interests of the industry to ensure that they are not altered in such a way that they are no longer productive for prawns as well as for other biota.

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