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Development of biodiversity and habitat monitoring systems for key trawl fisheries in Western Australia

Final FRDC Report – Project 2002/038

M.I. Kangas, S. Morrison, P. Unsworth, E. Lai, I. Wright and A. Thomson

Fisheries Research Division
Western Australian Fisheries and Marine Research Laboratories
PO Box 20 NORTH BEACH
Western Australia 6920

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Enquiries:

WA Fisheries and Marine Research Laboratories, PO Box 20, North Beach, WA 6920
Tel: +61 8 9203 0111
Email: library@fish.wa.gov.au
Website: http://www.fish.wa.gov.au
ABN: 55 689 794 771

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Development of biodiversity and habitat monitoring systems for key trawl fisheries in Western Australia

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PRINCIPAL INVESTIGATOR:	Dr Mervi Kangas
ADDRESS:	WA Fisheries and Marine Research Laboratories PO Box 20 North Beach WA 6920 Telephone: 08 9203 0164 Fax: 08 9203 0199 Email: mervi.kangas@fish.wa.gov.au
CO-INVESTIGATOR:	Sue Morrison (WA Museum)
STEERING COMMITTEE:	Penn J, Joll L (Department of Fisheries) Stewart G (Shark Bay Prawn Trawler Operators Association) Hood S (MG Kailis Group) Ch'ng H (West Coast Trawl Association) Dunlop N (Conservation Council of WA) Wells F (WA Museum/Department of Fisheries)

Objectives

1) To develop and compare biodiversity measures of trawled and untrawled areas in Shark Bay and Exmouth Gulf
2) To examine seasonal and annual variation
3) To examine the rate of depletion of selected species to ensure bycatch CPUE is related to actual abundance
4) To assess age composition and size structure of indicator species
5) To develop criteria for selection of reference sites/times for future monitoring.

NON-TECHNICAL SUMMARY

OUTCOMES ACHIEVED

- The project has demonstrated that bycatch species on trawl grounds are also found in areas closed to trawling, during the season and between years. In the current study, no statistical significance was found for pooled data between trawled and untrawled sites in Shark Bay, Exmouth Gulf and Onslow Area 1, with respect to fish and invertebrate abundance, species richness, evenness or diversity. Areas that are closed to trawling provide protection to most species more vulnerable to trawling.

- The project has determined that the primary strategy to monitor trawl impacts will be by annual monitoring of the extent of trawling within each fishery, however, the project has also recommended longer term sampling strategies to determine trends in faunal assemblages, abundance levels and diversity measures to ensure that the management of bycatch species is sustainable in the future.

- The project identified that the 10-20 most common species of fish and invertebrates could be used as indicator species (for trends in abundance and diversity measures) in Shark Bay, Exmouth Gulf and Onslow Area 1. A few vulnerable species were also identified that could be monitored to ensure there are no conservation issues with respect to these species. No threatened or protected species were considered to be vulnerable.

- No major detrimental ecological impacts were identified during the project although there was some evidence that high trawl effort sites had lower faunal abundance in Exmouth Gulf. This was not noted in Shark Bay. It is suggested however, that several small areas that are currently within the trawl grounds in both Shark Bay and Exmouth Gulf, which contain sensitive habitats and are not currently trawled, be clearly identified and boundaries set. These areas would then be closed to trawling by industry agreement.

The need for this project was identified through the ESD Risk Assessment workshops held for the Shark Bay and Exmouth Gulf trawl fisheries in May and October 2001. Bycatch issues in the Shark Bay and Exmouth fisheries were identified as a moderate risk through an Ecological Risk Assessment workshop. A better understanding of the faunal composition and habitat preferences of bycatch species in both trawled and untrawled areas has assisted in determining the level of risk to bycatch species. The project provided baseline data on biodiversity and variability of trawl bycatch on and off the trawl grounds in Shark Bay and Exmouth Gulf in order to set up potential reference sites for long-term monitoring. The study examined seasonal and annual variation in abundance and diversity measures and trawl efficiency in capture of bycatch species. This information will enable the Department of Fisheries and industry to effectively respond to information required by Department of Environment and Water Resources in order to continue to provide top quality, highly valued seafood to both export and local markets. It also provides a basis to answer queries from conservation and community groups on the effects of fishing on the bycatch. A summary of the key results for each objective is as follows:

1) To develop and compare biodiversity measures of trawled and untrawled areas in Shark Bay and Exmouth Gulf

Prawn trawls are only selective for a certain suite of species with particular size ranges, behaviour and position in the water column, therefore, the results of this study reflect the bycatch from prawn fishing and do not represent the total biodiversity within these regions.

The biodiversity measures used and determined to be practical were; species abundance (number per nautical mile), species richness, evenness and diversity. The number of individuals sampled (or a sub-sample if very high catches encountered) is relatively easy to achieve. The abundance of species is an important measure to use in conjunction with species richness, evenness and diversity. In this study, weight of species was not measured but this would serve as a useful measure if attempting to obtain biomass estimates.

Species richness is a useful measure of biodiversity, even if the suite of species changes. A change in the number of species in an area is an important indicator of ecological change. Generally a stable number or an increase in the number of species indicates a healthy, self-sustaining ecosystem, whereas a decrease in species number is likely to indicate an imbalance or potential problem in the ecosystem. Evenness and diversity measures provide more insight into the overall distribution of all the species present including dominance of a few species or rarity of many species.

The most abundant 10 to 20 species of fish and invertebrates for the majority of survey sites in Shark Bay, Exmouth Gulf and Onslow represented around 90% of the total catch. These abundant species can, therefore, be used to characterise the faunal assemblage of most sites. Since most abundant species occur in large numbers, with the majority being widespread, it would be anticipated that these core groups of species are dominant in the various regions from year to year. The trends in the cluster relationships between sites may be used to determine changes in any major 'region' within each fishery that may in turn provide for an indication of ecosystem change.

Although the 20 most abundant species of fish and invertebrates may be used to characterise a site or sites, there is a danger of over-simplification of the ecosystem if the less common species are totally ignored. Some of these less abundant species may be key indicators of the health of an ecosystem, and naturally only occur in low numbers, for example elasmobranchs.

In the current study, no statistical significance was found for pooled data between trawled and untrawled sites in Shark Bay, Exmouth Gulf and Onslow Area 1, with respect to fish and invertebrate abundance, species richness, evenness or diversity. Spatial differences in assemblages were seen, and in Shark Bay fish assemblages were correlated with depth and temperature, and invertebrate assemblages were correlated with salinity and temperature. In Exmouth Gulf, where there are less pronounced environmental gradients, there was low correlation between faunal assemblages and depth, temperature and salinity.

2) To examine seasonal and annual variation

The study highlighted that Shark Bay, Exmouth Gulf and Onslow Area 1 are highly complex marine faunal assemblages with the dominant species patterns dictating the overall seasonal and annual patterns in abundance, which were also variable between years. Consequently caution must be used when comparing faunal abundances and species richness from different seasons and different years. Additionally, inconsistent seasonal and annual variation in species richness, evenness and diversity was observed between trawled and untrawled areas.

In Shark Bay there was a significant seasonal decline in bycatch fish abundance at the selected sites, attributed to reductions of five very abundant species *Lethrinus genivittatus*, *Paramonacanthus choirocephalus*, *Pelates quadrilineatus*, *Torquigener pallimaculatus* and *Upeneus asymmetricus*. For invertebrate species abundance in Shark Bay in 2003, trends indicated an initial reduction between the start and mid season but no further decline towards the end of the season. For Exmouth Gulf there was no significant seasonal decline for fish species abundance although there was a seasonal decline in fish species richness whereas all the other diversity measures were similar throughout the year. For invertebrate species in Exmouth Gulf there was a significant seasonal decline in abundance between start, mid and end of the season in 2004 for both trawled and untrawled sites.

High natural annual variability of species abundance may mask trawl impacts. Annual differences were observed in Shark Bay for species abundance and richness at three fixed sites sampled over five periods spanning the end of 2002 to the start of 2004, however these differences were not consistent for species or between sites. For the start of 2004 high variability was seen at the three sites sampled due to high variability of fish species *Pelates quadrilineatus*, *Pentapodus vitta*, *Paracentropogon vespa*, *Upeneus tragula*, *Repomucenus sublaevis*, *Gerres subfasciatus* and *Leiognathus leuciscus* and the scallop species *Annachlamys flabellata* and *Amusium balloti*. The overall abundance was significantly higher for some species in the start of 2004 compared to the start of 2003 indicating annual recruitment variability. Environmental factors such as depth, temperature and salinity are important factors affecting species distributions. This was more pronounced in Shark Bay than Exmouth Gulf as the variation of these environmental variables is greater in Shark Bay.

3) To examine the rate of depletion of selected species to ensure bycatch CPUE is related to actual abundance

The depletion experiments carried out in Shark Bay indicated that, demersal prawn trawling has variable impacts on species on trawl grounds and can differ for a single species between different time periods. Very few species that were truly sedentary were caught in sufficient numbers for analysis. The rest of the results need to be interpreted with the mobility and behaviour of the species, or species groups taken into account. For a few fish species, it was obvious that movement into the experimental area occurred during the experiment with significant increases in abundance over consecutive days, instead of an expected decline. For several invertebrate species their abundance also increased, possibly due to the trawl disturbance making them more catchable.

The results indicate that some fish and invertebrate species are relatively vulnerable to trawl gear. These had depletion rates of greater than 50% over the four nights of the experiments. The highly ‘catchable’ fish were: *Pelates sexlineatus*, *Parupeneus chrysopleuron*, *Lethrinus genivittatus*, *Synodus sageneus*, *Pentapodus vitta*, *Choerodon cephalotes* and *Sillago robusta*. The highly ‘catchable’ invertebrate species were: *Luidia maculata* and the sponges. Of the highly ‘catchable’ species the majority occurred in both trawled and untrawled areas with only three species in less than 70% of sites sampled. The least common were sponges that were found in 50% of sites overall and these could not all be identified to species. There was however, no significant difference between the abundance of ‘sponges’ between trawled and untrawled areas. Therefore although some localised depletion may occur in areas of intensive fishing, other areas with no or very little trawling also have these species. Movement and potential for recruitment from unaffected sites would be likely to re-populate depleted areas. With current knowledge of species distributions, no other species is restricted to these regions, giving them robustness from trawl impacts; particularly since both fishing areas have a significant proportion (>60%) of areas not trawled.

As prawn trawling is selective in capturing species, fish trawl gear was deployed over one night at six sites in Shark Bay to compare the fish faunal composition of the two gear types. More than 50% of species sampled were common to both types of gear. The main differences between the two gear types were that the prawn gear caught bottom dwelling species such as flounders and flatheads which the fish trawl gear did not catch. The fish trawl caught a few species that had not been caught by the prawn trawls anywhere in Shark Bay and caught a few individuals of faster more mobile fish such as the blue mackerel that were not caught in prawn trawls.

4) To assess age composition and size structure of indicator species

A significantly higher proportion of smaller individuals of prawns were observed at the start of the season for all sites pooled, indicating that this is the main recruitment period for king and tiger prawns in Shark Bay and Exmouth Gulf. For scallops in Shark Bay a significantly smaller mean size was observed at the end of the season indicating recruitment at this time of year. However, in the closed area in Denham Sound a significantly smaller mean size was observed at the start of the season. Due to the short-term nature of the sampling program (only four time periods from October 2002 to October 2003) no firm conclusions can be made if this annual variation in recruitment at this localised site is a true timing difference in southern Denham Sound compared to the rest of Shark Bay.

The total length frequencies of four fish species were assessed in Shark Bay and three species in Exmouth Gulf. Two to four cohorts (possible annual or multiple recruitment events) were observed for pooled site data indicating that at least two or three year classes were present, with none of the species for which length frequencies were recorded with more than four or possibly five cohorts. This may be either evidence of a relatively short-lived species or selectivity in the prawn nets for certain sized individuals. Twenty four species of fish in Shark Bay and 38 species of fish in Exmouth Gulf that were sampled can attain a size greater than 50cm but these were generally rarely caught nor were they seen at the higher end of their size ranges indicating, either gear selectivity differences for larger animals or potential trawl impacts on numbers of larger and longer-lived species.

Examination of a selection of otoliths from common species of fish in both Shark Bay and Exmouth Gulf were primarily unsuccessful in determining ages of the fish sampled. Most of the otoliths of the common species were difficult to interpret with only two or three species being suitable for otolith analysis. However, the scope of this project did not allow sufficient sampling of these species to determine firm conclusions about fish ages. Generally however it appeared that the species examined were in the age range of 1-5 years. None of the species for which length frequencies were recorded appeared to have more than three size cohorts, either indicating a relatively short-lived species or selectivity in the prawn nets for certain sized individuals. The size range of fish measured in our sampling was generally less than 25 cm except for *Saurida undosquamis*, which was measured up to 63cm in the northern part of Shark Bay.

A general observation can be made that many common species and the target species are short-lived and highly productive.

5) *To develop criteria for selection of reference sites/times for future monitoring*

One of the main objectives of this study was to compare the faunal composition between trawled and untrawled areas and if the faunal composition was similar, then it was highly likely that closed areas act as refuges for the majority of those species impacted by trawling. Faunal composition was similar in trawled and untrawled areas in general and therefore it is sufficient that the principal form of monitoring the effects of fishing on the bycatch in the Shark Bay and Exmouth Gulf fisheries is the extent of the trawled areas. The percentage of area trawled should not exceed that observed in recent years (20-40% of area of the fishery).

However if there is a requirement to monitor changes in biodiversity of trawl bycatch in future years and to detect trends (be it due to fishing, environmental or some other factor), limited long-term monitoring of trawl bycatch may be necessary. Sites should be selected from the divisive cluster groupings, taking into account the various levels of fishing effort. The sites sampled in Shark Bay provided an observed power for 5% significance test of only 40% to detect differences. However there was a significant difference observed with trawl effort and it will be necessary to maintain a similar number of sampling sites in Shark Bay in order to not reduce power even further. The sites would remain fixed sites for comparison with four additional random sites, incorporated to provide additional information of site variability. In Exmouth Gulf and Onslow Area 1 there was more than sufficient observed power (well over 90% for 5% significance test) in the number of sites sampled to detect differences. Fixed sites would be selected from the assemblage groups with two additional random sites to be sampled. This combination of fixed and random sites is recommended for future monitoring. Continued use of fixed sites facilitates the estimation of trends, while the use of random sites protect against problems of unusability of the some of the fixed sites.

There are significant differences between assemblages and overall abundance between seasons, with the highest abundance overall observed at the start of the season for most groups with a decline in abundance by mid season. It may therefore be appropriate to sample at both the start and mid year (i.e. February/March and June/July). If costs only allow one sampling period, then the start of the season is recommended. Species which have a moderate to high catchability (>30%) and those that are generally widespread (occur in > 70% of sites sampled) are good candidate indicator species for trend analyses.

KEYWORDS: Biodiversity, sustainability, trawl effort, Shark Bay, Exmouth Gulf, Onslow, impacts of trawling, risk assessment, bycatch monitoring

1.0 INTRODUCTION

M. Kangas

1.1 BACKGROUND

1.1.1 Biodiversity and bycatch issues

There are good descriptions of biodiversity and fishing impacts in tropical trawl fisheries in Australia (FRDC Effects of trawling subprogram: FRDC 88/108, Poiner et al. 1998, FRDC 96/257, FRDC 2000/132, FRDC 2000/160). Further work is now required to adapt this generic understanding of biodiversity and trawl impacts to the needs of long-term ESD management. For this purpose, cost effective monitoring systems are now required for specific fisheries, which take into account their spatial impact relative to habitat types and related species assemblages captured in the trawls.

Two basic approaches can be taken to address biodiversity issues associated with trawl-based fisheries. One is where trawling can potentially occur over a relatively high percentage (>50%) of the trawlable habitats in a bioregion unless there is evidence to restrict it. This method requires the assessment (and ongoing monitoring) of the level of impact that trawling is causing to the communities in the bioregion (infauna, epifauna, benthic or pelagic bycatch) and was the approach taken in the GBRMPA experiment (Poiner et al. 1998). Such a strategy requires a high level of information on the biodiversity of the trawled regions and experimental assessments of the relative impact of trawling on each of these communities. The statistical analysis of this information often suffers from low power given the high levels of sampling variability against a background of high natural variability and differential susceptibility and temporal responses of the species involved. It can also suffer from the inherent difficulty of trying to “prove a negative”. Moreover, determining what is an “unacceptable level of impact” is not well defined even if data are available. Using this approach as the basis of management would require comprehensive information on the patterns of trawling along with detailed experiments and sampling of all elements of the communities in the region to be monitored at regular intervals to ascertain if changes were occurring requiring additional management to be instigated (eg Queensland Prawn Trawl changes). Consequently, the costs would be substantial. Moreover, the outcomes of such programs are often inconclusive and problematic for management purposes.

The alternative approach, which is the one adopted by the Department of Fisheries in WA, is to clearly acknowledge that trawling may have a level of impact on the abundance of species and therefore limit the area where trawling can occur to an acceptable percentage of the trawlable habitat (less than 50%). Most areas of the west coast are closed to prawn and scallop trawling except those areas specifically identified. The areas available for trawling have sub-areas that are permanently closed or closed for part of the year. Those fisheries have been limited-entry since inception so the number of boats are generally the minimum required to achieve the catch available. Such limits on trawling ensure that sufficient refuge areas are available within the bioregion for the species & communities potentially affected by trawling not to be put at risk by these fishing activities. Ongoing management only requires that the areas trawled be maintained within the defined boundaries - this is now a simple task to monitor using VMS.

The main assumption that needs to be tested for this spatially based approach is that the species caught by the trawls are also present in areas where trawling is not allowed. It is this assumption that will be tested by the current proposal. Thus the project seeks to sample in trawlable regions open to fishing and closed to fishing to assess whether the basic species composition in each of these areas is sufficiently similar to support this assumption and hence the management approach. The project also undertakes an assessment of fishing on these species in the fished area and compares this with the variation that is occurring in the non-fished control sites.

The key WA trawl fisheries requiring these monitoring systems include the temperate and sub-tropical Shark Bay prawn and scallop fisheries and the Exmouth, Nickol Bay and Onslow prawn fisheries. These have been operating in WA for almost 40 years. They have always been limited entry and their development and areas of fishing are tightly controlled. The overall area of trawling is limited by area, seasonal and moon closures. In Shark Bay, geological surveys were conducted prior to the commencement of fishing (Logan and Cebulski 1970) and some documentation is available on early impacts of trawling on some grounds within Shark Bay (i.e. expansion of fishing grounds during the early years of the fishery (Slack-Smith 1978) and loss of soft coral and sponge beds in one region (Penn pers.comm.). However, detailed information on the faunal and floral composition in Shark Bay or the other key trawl regions prior to trawling is generally lacking.

With the move towards a more holistic approach to fisheries management and the requirement of export fisheries to demonstrate that they are fishing sustainably under the amendments to the *Wildlife Protection (Regulations of Exports and Imports) Act 1982*, now the *Environment Protection and Biodiversity Conservation Act 1999*, the description and quantification (where appropriate) of the biodiversity (primarily faunal composition) in currently trawled and untrawled areas is highly desirable. Some of these untrawled areas have never been trawled whereas other areas were trawled during the early history of the fishery providing a comparison between levels of trawling. Within the trawl grounds themselves, there have been and are different levels of trawl activity, which can be verified through logbooks and Vessel Monitoring System (VMS) plots allowing for comparisons between trawled areas at various trawl densities. The impacts of trawling will vary between bycatch species and animal groups and the distribution of species both on and off the trawl grounds will be an important factor in their overall vulnerability. Similar habitats within and outside trawl grounds will be sampled during this study.

The export value of these fisheries is around $90 million (ABARE, 2000) with 80% of product being exported with the rest being sold on the local or interstate markets. With a more environmentally conscious consumer group, addressing the ecological sustainability of not only the target species but also byproduct and bycatch species is paramount. A report on the biodiversity of fish and elasmobranchs in trawled areas has been prepared for the Northern Prawn Fishery (NPF) (Stobutzki et al. 2000) and this study will incorporate those methodologies (Stobutzki et al. 2001a) which are appropriate for the WA fisheries. It will provide a comparison between temperate and semi-tropical trawl fisheries to a tropical prawn trawl fishery. The invertebrate data collected during this NPF study is currently being analysed as part of an additional study of biodiversity (FRDC 2000/160) and therefore comparisons between geographical regions for invertebrate taxa can also be made.

Trawl gear is non-selective and the amount of unwanted bycatch can vary between locations and fisheries. An observer program as part of a FRDC project 2000/189 on the implementation of bycatch reduction devices (BRDs) into Shark Bay and Exmouth Gulf trawl fisheries, showed bycatch to catch ratios between 2:1 and 8:1 in the prawn fisheries and 0.5:1 in the Shark Bay scallop fishery. This is relatively low compared to some trawl fisheries. However, it is still considered that the effect of fishing on bycatch should be evaluated and minimised.

The Environment Protection and Biodiversity Conservation Act 1999 also imposes requirements for trawl fisheries that may capture threatened species such as loggerhead turtles. Incorporation of turtle exclusion devices (grids) is required for all the key prawn and scallop trawl fisheries in WA as turtle captures, although low, have been recorded. Full implementation of grids in the Shark Bay prawn and scallop and Exmouth Gulf prawn fisheries occurred during the 2002 fishing season. Grids became compulsory in the other prawn trawl fisheries in WA during 2003. Grids were shown to exclude nearly all (95-100%) large animals including sharks, rays and turtles (Kangas and Thomson 2004). Secondary devices such as square mesh panels were also trialled from 2000 and are now compulsory in the Shark Bay and Exmouth Gulf prawn fisheries and are being trialled in the smaller prawn fisheries in WA. Incorporation of square mesh panels can result in a reduction of smaller fish species between 20-75% with some individuals being reduced by over 90% (Kangas and Thomson 2004, Broadhurst et al. 2002).

Another mechanism to reduce trawl impacts that is voluntarily being used by some boats is the ‘hopper’, in-water sorting systems which can increase the quality of prawns and the survival of some bycatch species. More sophisticated area and spatial closures targeting only optimal sized product and reduction in overall fishing days (effort) and the number of boats operating (fleet rationalisation) are also being implemented.

1.1.2 Shark Bay prawn fishery

The Shark Bay Prawn fishery (Figure 1.1) is the largest prawn fishery in Western Australia and targets western king prawns *Penaeus latisulcatus*, brown tiger prawns *Penaeus esculentus* and a variety of smaller prawn species including coral prawns *Metapenaeopsis* species and endeavour prawns *Metapenaeus endeavouri* and is valued at around $AU 20-40 million. The fishery has operated under a detailed and sophisticated limited-entry management regime since its inception in 1962 with catches over the last 30 years maintained within a range of 1000-2300 tonnes per year using a comprehensive set of regulations that include limits on vessel numbers, gear, zoning, closed seasons and extensive closed areas, along with a variety of biological controls. Each of these has been refined through time, and is subject to regular reviews to achieve the overall aim of successful management.

Figure 1.1 Location of the Shark Bay prawn and scallop fisheries.

In summary these arrangements include:

- limited entry with a small numbers of vessels (27) and with the potential for further reductions
- Fixed seasonal closures (November – March)
- Real time monitoring of fleet dynamics and operations by departmental staff to determine catch rate thresholds
- Variable temporal closures of spawning and recruitment grounds (areas closed or opened depending upon catch rates and sizes of prawns, See Figure 1.2)
- Permanent area closures to preserve sensitive habitats that are essential nursery areas for prawns and other species
- Time closures- this now includes full moon closures and due to prawn's nocturnal behaviour, restricts fishing to night hours
- Input controls on gear and vessel equipment (currently, the regulations allow the vessels in this fishery to tow two 8-fathom otter trawl nets and one otter trawl try-net but some operators have permits for the trial use of quad gear).

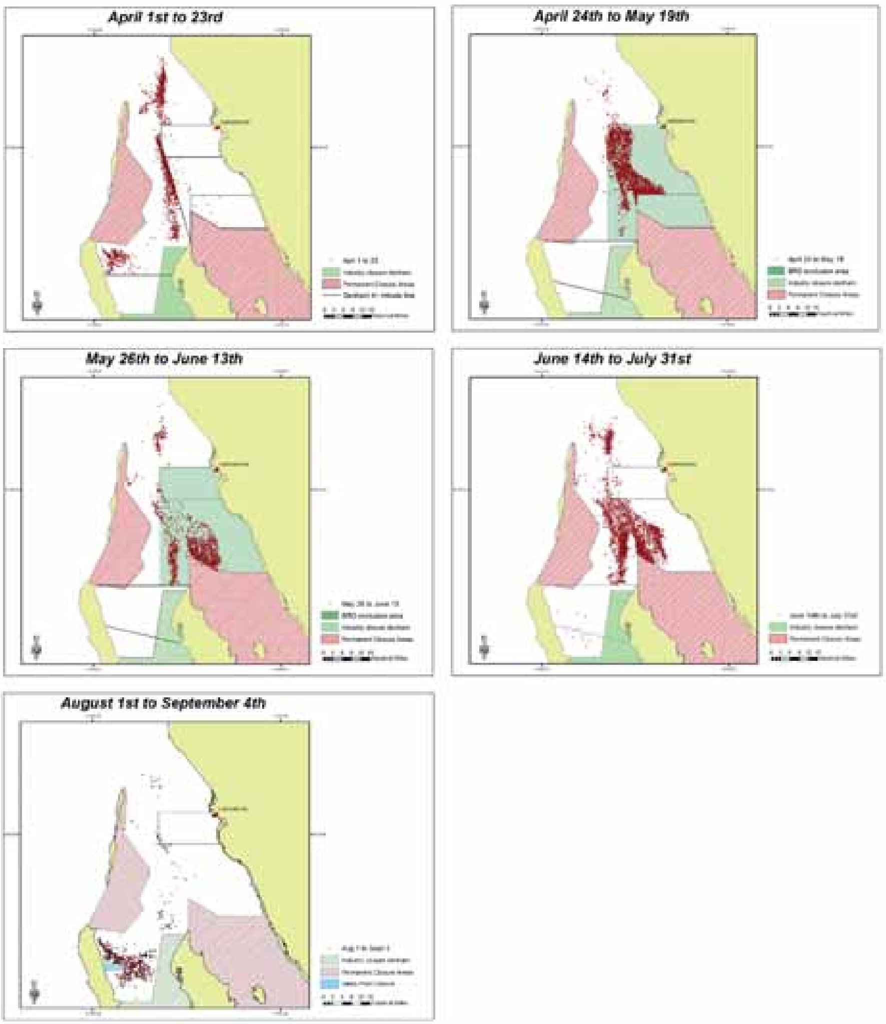

Figure 1.2 Sequence of openings and closings in the Shark Bay prawn fishery in part of the 2003 season, illustrating the dynamic nature of prawn fishing within the Bay. a) 1 to 23 April b) 24 April to 19 May c) May 26 to June 13 d) 14 June to 31 July e) 1 August to 4 September. (Note: There are missing days in between are moon breaks when no fishing takes place).

1.1.3 Shark Bay scallop fishery

The Shark Bay Scallop fishery also exists within the waters of Shark Bay. The fishery is based on the take of the saucer scallop *Amusium balloti* and the catch is taken by otter trawl. Currently, the scallop fishery consists of two types of licences, Class A and B. Class A license holders (currently 14) can take only scallops while Class B license holders (currently 27), can take scallops and prawns (in the Shark Bay Prawn fishery).

For the last 18 years, annual catches are typically highly variable and have ranged from 605 to 22,070 tonnes whole weight, depending primarily on the naturally variable strength of recruitment flowing from the breeding season of the previous year. Consequently, the fishery's value has also fluctuated on an annual basis, ranging from $2 - $58 million. Despite the highly variable annual catches, the Shark Bay Scallop Fishery is WA's most significant scallop fishery, although in some years large catches have been taken in other scallop fisheries (Kangas and Sporer 2001).

The Shark Bay scallop fishery is restricted to the western waters of the Bay due to the natural distribution pattern of scallops primarily in these areas (Figure 1.3) and in the last few years catch rate limits have been used to close areas of the fishery. There is an overlap of the spatial distribution of fishing effort for the prawn and scallop fleets and this overlap varies between years depending on the settlement pattern of scallops. Generally this overlap occurs in the northern and central part of Shark Bay and in parts of Denham Sound (refer to Figure 2.1).

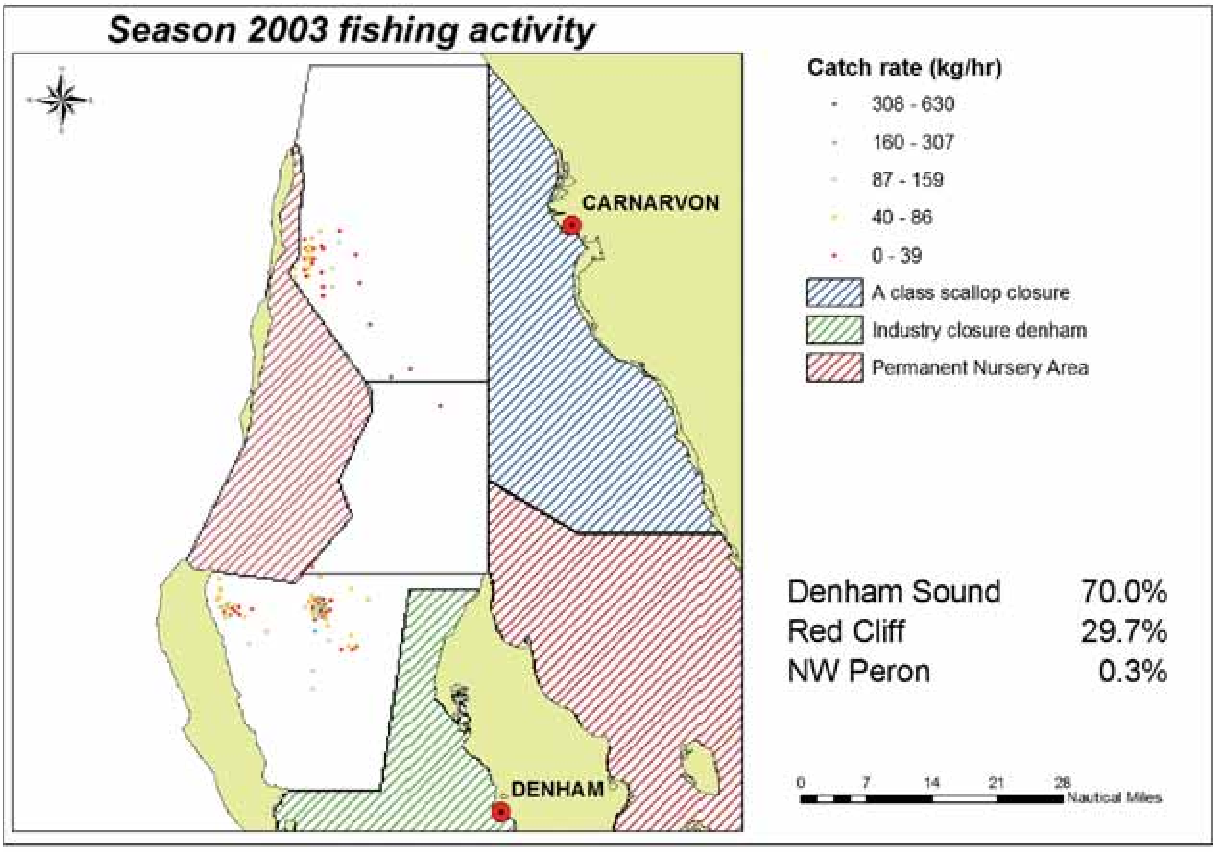

Figure 1.3 The boundary of the Shark Bay scallop fishery with the fishing activity for 2003 season. Note: Low scallop abundance in Shark Bay in 2003 resulted in very low levels of trawl activity by scallop boats.

1.1.4 Exmouth Gulf prawn fishery

The Exmouth Gulf prawn fishery is located in the relatively sheltered waters in and to the north of Exmouth Gulf (Figure 1.4).

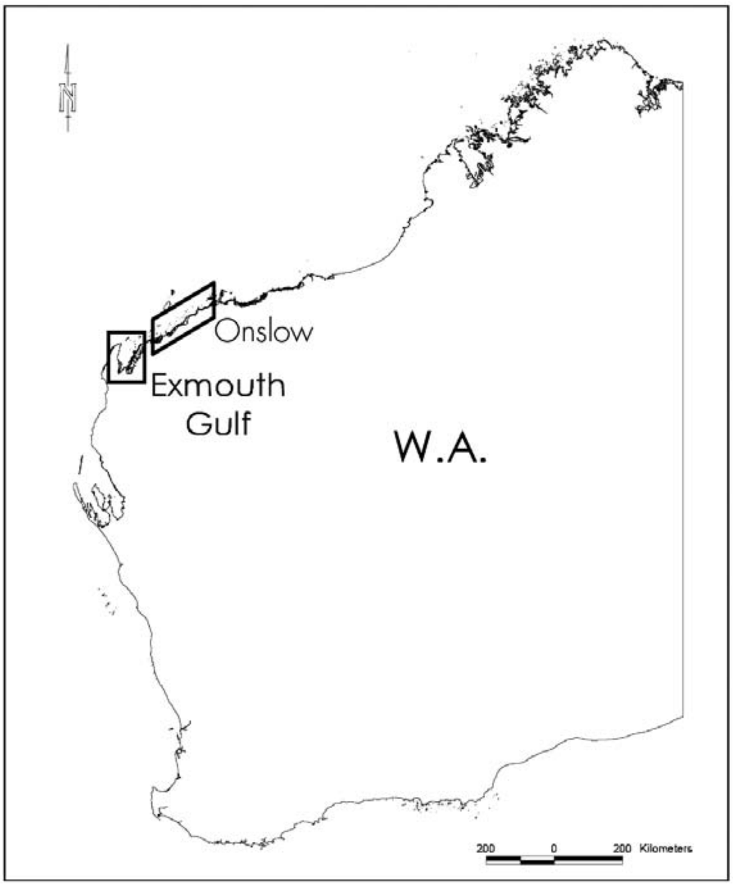

Figure 1.4 The location of the Exmouth Gulf and Onslow Prawn Fisheries.

The Exmouth Gulf prawn fishery began in 1963 initially targeting banana prawns *Penaeus merguiensis.* As the fishery expanded in the following years the initial target species changed as *P. esculentus* became increasingly more important. Now, the two main target species of this fishery are the *P. esculentus* and *P. latisulcatus*, with *P. latisulcatus* contributing an average of 505t of the total catch each year. The catch in 1999/2000 was 1467t (king prawns 471t, tiger prawns 451t, endeavour prawns 543t, banana prawns 2t) and valued at $AU 19.4 million. As a result, the Exmouth Gulf prawn fishery is the second largest prawn fishery in WA (Kangas and Sporer 2001).

Management of the Exmouth Gulf prawn fishery is an "input controlled fishery" that has a complex series of management restrictions, including limited entry (16 licences), boat size and gear controls and seasonal spatial and temporal closures. These management restrictions (in particular the spatial and temporal closures) help to sustain all of the prawn species while minimising the impact on the environment and maximising the value of the prawns at capture by protecting small prawns. In reality, the fishery is managed under a "constant escapement policy", which is designed to leave a minimum level of tiger prawn spawning stock during their breeding season that is capable of producing good recruitment levels the following year (Kangas et al. 2006).

As with the Shark Bay prawn fishery, the fishery openings and closings are dynamic with fishing targeting optimum sized prawns and protection of spawning stock (Figure 1.5). A catch rate limit is used for brown tiger prawns and a total closure of key spawning grounds is implemented for the spawning period between August and October each year.

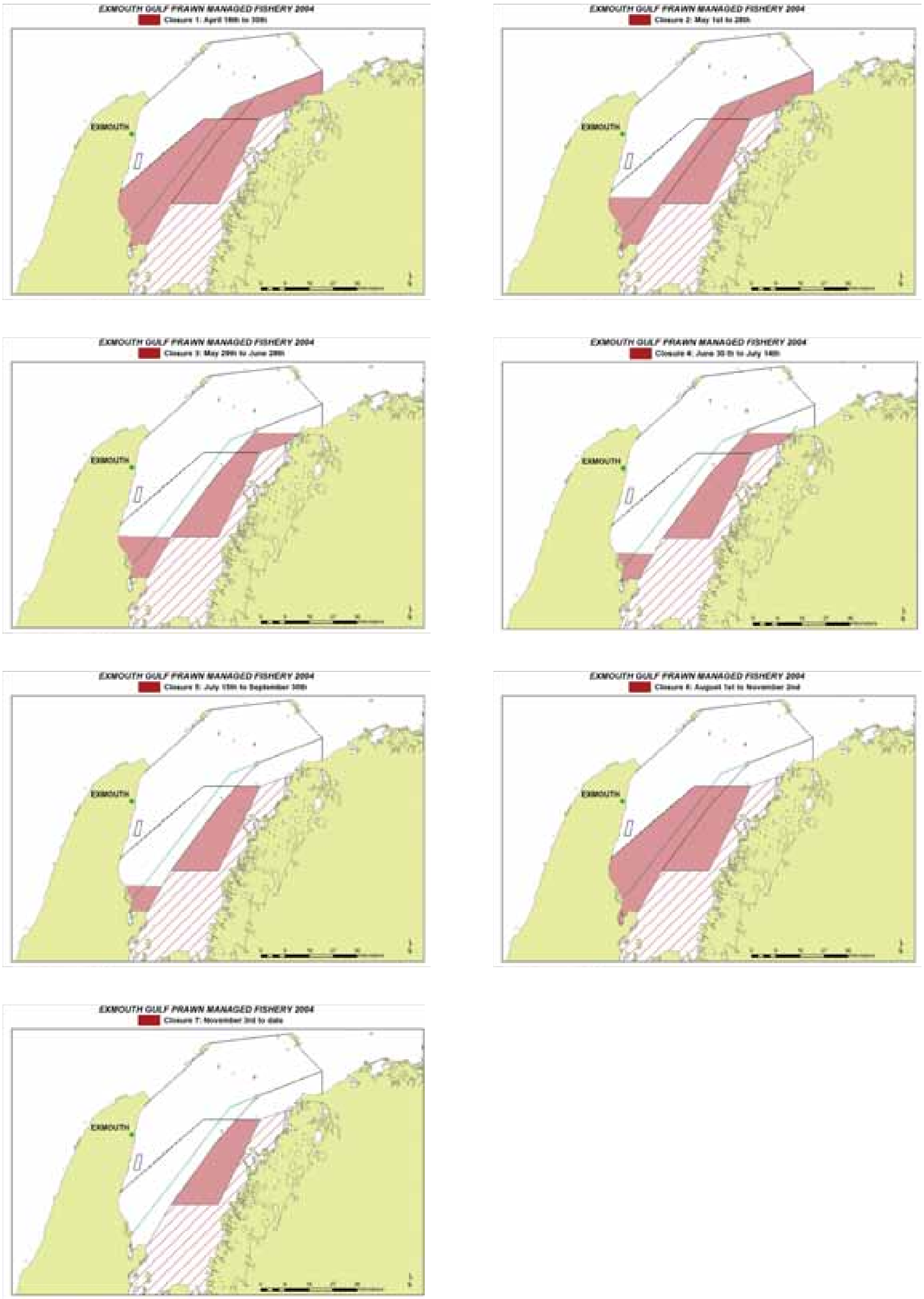

Figure 1.5 2004 Season area closures in the Exmouth Gulf prawn fishery. Hatched area is permanently closed to trawling.

1.1.5 Onslow prawn fishery

The Onslow prawn fishery operates along the western part of the North West Shelf (Figure 1.4) and the fishery targets *P. latisulcatus, P. esculentus, M. endeavouri* and *P. merguiensis.* Different areas within the fishery have different season dates, which allow access to target species, usually tiger and banana prawns, at appropriate times. The five-year average landed values for the Onslow prawn fishery is $AUD 1.3 million.

This fishery has been operating under a detailed and sophisticated management regime since 1991 using a comprehensive set of regulations that include limits on vessel numbers, gear, zoning, seasonal and spatial closures. Each of these has been refined through time, and is subject to regular reviews to achieve the overall aim of sustainable management of the stocks.

This fishery has a total of 31 licencees. Not all licensees are permitted to fish the entire range of this fishery. Each licence is endorsed with a class according to the area or areas of the fishery for which it is issued. In Area 1, that is adjacent to Exmouth Gulf and the focus of this study, only four boats are licensed to fish and it is open to fishing from April/May until November.

1.2 NEED

The need for this project was identified through the ESD/DEWR Risk Assessment workshops held for the Shark Bay and Exmouth Gulf trawl fisheries in May and October 2001. Research is required to provide baseline data on biodiversity on and off the trawl grounds in Shark Bay and Exmouth Gulf in order to set up reference sites for long-term monitoring of the environmental impact of trawling. The study will examine seasonal variation in biodiversity and efficiency in capture of bycatch species to provide a rigorous scientific basis for determining references sites in other fisheries. Understanding seasonal variability will allow the selection of the appropriate timing of long-term monitoring. Depletion experiments will ensure that bycatch catch per unit effort is related to actual abundance. The sampling undertaken in Shark Bay will cover both prawn and scallop ESD requirements to enable similar reference sites to be established in all WA trawl fisheries. Bycatch issues in the Shark Bay and Exmouth fisheries were identified as a moderate risk through an Ecological Risk Assessment workshop. There is a need for a better understanding of the faunal composition and distribution of bycatch species in both trawled and untrawled areas that will aid in determining the most appropriate level of risk to bycatch species. This may allow management strategies to be developed to ameliorate any detrimental impacts on those species that are found to be highly vulnerable to trawl impacts. This information will also enable the Department of Fisheries and industry to effectively respond to information required by Department of Environment and Heritage on the risk level, objectives, performance indicators and management responses for each issue in order to continue to provide quality and highly valued seafood to both export and local markets. It will also provide a basis to answer queries from conservation and community groups.

1.3 OBJECTIVES

1) To develop and compare biodiversity measures of trawled and untrawled areas in Shark Bay and Exmouth Gulf.

2) To examine seasonal and annual variation.

3) To examine the rate of depletion of selected species to ensure bycatch CPUE is related to actual abundance.

4) To assess age composition and size structure of indicator species.

5) To develop criteria for selection of reference sites/times for future monitoring.

2.0 GENERAL METHODS

S. Morrison, M. Kangas and P. Unsworth

Methods for objectives 1, 2 and 4

2.1 SITE SELECTION

Commercial voluntary logbooks are currently completed by 100% of skippers in the Shark Bay, Exmouth Gulf prawn fisheries and by Onslow Area 1 fishers. This provides daily shot by shot spatial information of fishing activity. This daily logbook information was used for the 2000 and 2001 fishing seasons for Shark Bay and Exmouth Gulf to map trawled and untrawled areas. Sites were then selected from both prawn and scallop grounds (spatially separate in parts of Shark Bay and overlapping in others) that represented varying levels of effort (no, low, medium and high) and adjacent areas that were closed or untrawled were also selected. The selected areas were then shown to operators in each fishery for confirmation.

All boats which operate in Shark Bay, Exmouth Gulf and Onslow fisheries are equipped with a 'Vessel Monitoring System' (VMS). This logs the position of each vessel continuously and relays the information back to a Department of Fisheries (DOF) base on shore. It is therefore possible to see where each boat is fishing and over what time period, at any time of day. This valuable information can be used to complement the daily logbook information and to verify vessel positions.

For Shark Bay, 26 sites were selected in total, representing 4 trawled areas for the scallop fishery, 13 trawled areas for the prawn fishery and six areas that are permanently closed to trawling (three since the late 1960's and three since 1990) and three sites very lightly or untrawled in the last 10 years (Figure 2.1). These sites are considered to effectively cover the sandy habitats over the major environmental gradients (salinity) that exist in Shark Bay (see Appendix 1 – Desktop Study).

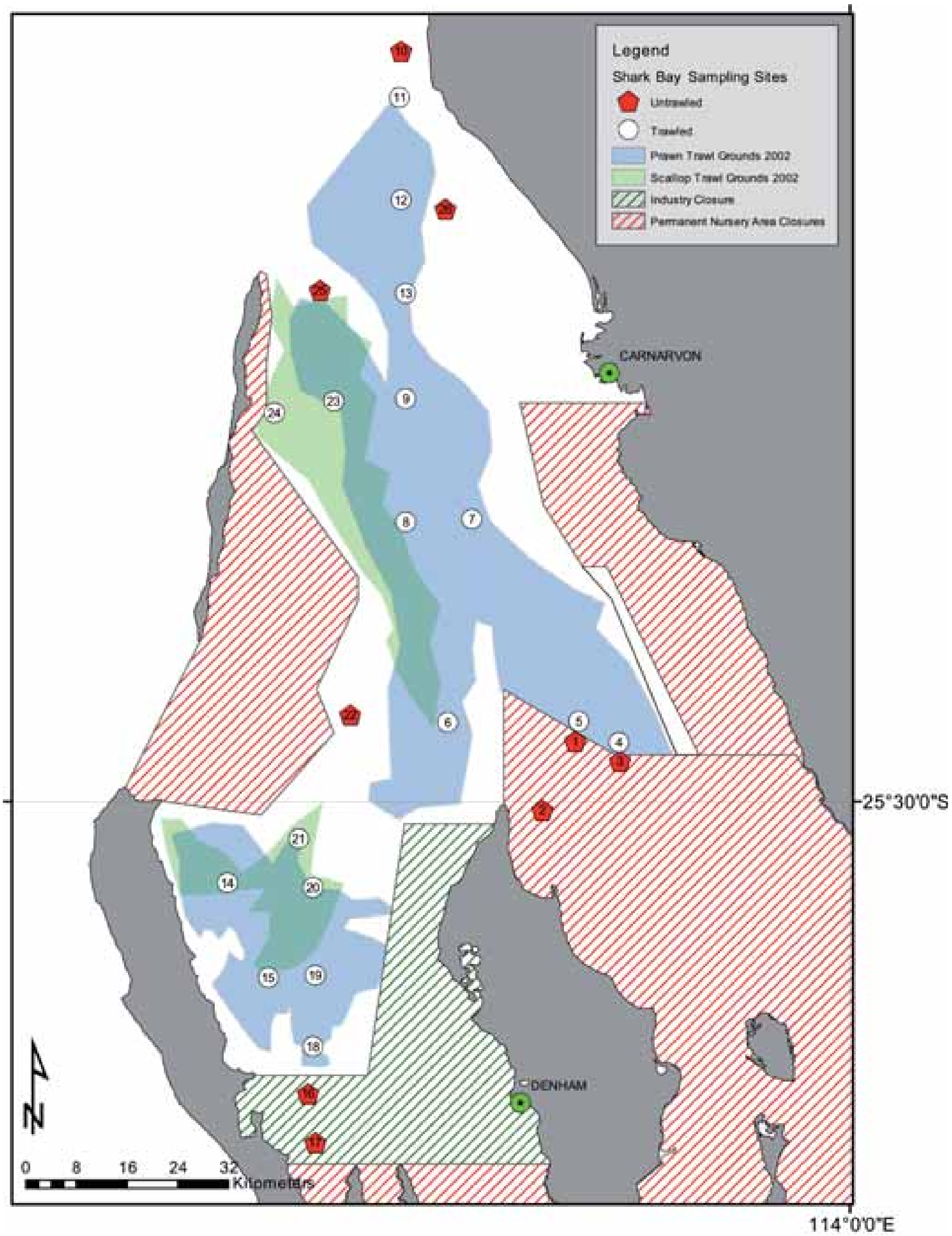

Figure 2.1 Sampling sites in Shark Bay, based on trawl activity during 2000 and 2001 fishing seasons, latitudinal position and salinity profiles.

In Exmouth and Onslow, scallops do not occur and therefore the sites were selected to represent both the king and tiger prawn fishing grounds and adjacent closed or untrawled areas. Daily logbook information for 2000 and 2001 was used to determine trawling activity within Exmouth Gulf and seventeen sites were selected in Exmouth Gulf to represent, king (5 sites) and tiger (6 sites) prawn trawl grounds and adjacent closed areas (6 sites) (Figure 2.2). Less pronounced salinity gradients were observed in Exmouth Gulf compared with Shark Bay and sites were selected throughout the fishery from the inner gulf to the outer regions.

In the Onslow fishery, polling data from the Vessel 2003 Monitoring System was used to determine general areas of trawling and a skipper, who is actively fishing in Onslow, provided locations of their trawl sites and historical trawl sites that currently have very little to no trawl activity. Seven sites (four trawled and 2 untrawled) were selected within 'Area 1', one of three main fishing areas in the Onslow prawn fishery (Figure 2.2). It was not possible to extensively sample all the Onslow fishery and only Area 1 could was covered during this project. However, Area 1 is the most productive part of this fishery (in terms of target species catches) and generally has the most trawl activity in any one year.

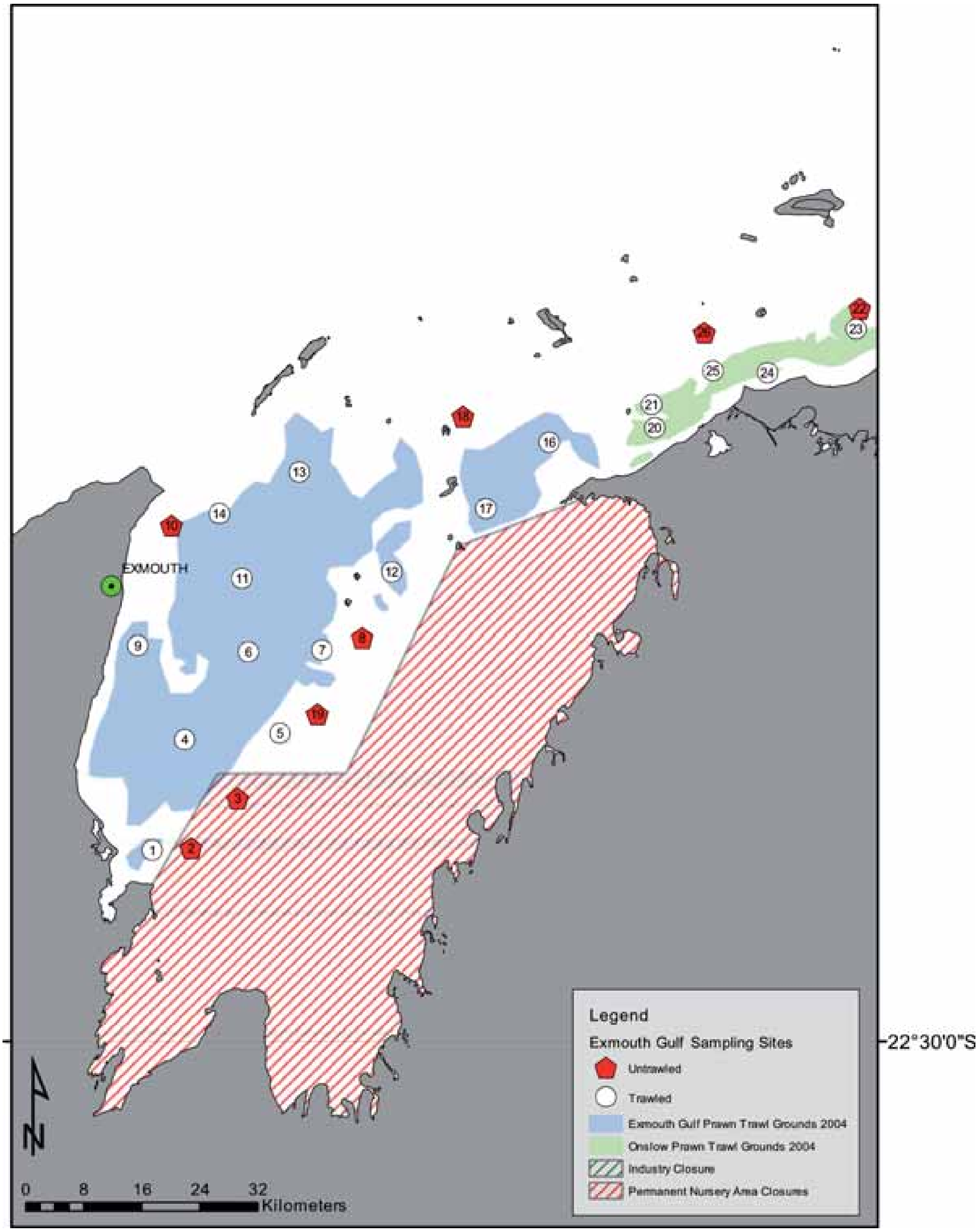

Figure 2.2 Sampling sites selected in Exmouth Gulf using daily logbook data for 2002 and 2003 fishing effort and for Onslow Area 1 using 2003 Vessel Monitoring (VMS) data and fisher information.

The hours trawled around sampling sites were verified using logbook information for the actual years of sampling (end 2002 and 2003 for Shark Bay and 2004 for Exmouth and Onslow). All commercial fishers in Onslow Area 1 completed voluntary daily logbooks in 2004, greatly assisting the project in effort estimations at sampling sites (see Chapter 4).

2.2 TRAWL SAMPLING

All the trawl surveys were carried out from the FRV Naturaliste. It required 5 crew and 4 to 5 research scientists and volunteers to run the program. The crew handled the nets and other trawling gear. Two teams of both crew and scientists were set up, one to work on fish and the other to work on invertebrates.

For each survey site in Shark Bay, Exmouth Gulf and Onslow it was attempted to carry out three 10 minute trawls (shots) conducted parallel to each other 0.1 nautical miles apart. On average this trawl time covered a distance of approximately 0.5 nautical mile. In Shark Bay, the nets were twin rig demersal otter trawl nets with a 6-fathom (7.7 m) headrope length. The net mesh size was 50 mm with 45 mm diamond mesh cod ends. New nets were required to be manufactured after the Shark Bay sampling had been completed and therefore in Exmouth Gulf, twin 6-fathom (7.7 m) headrope semi-flyers were used with the same mesh size. The port and starboard nets were adjusted so that they fished in a similar manner. These nets are similar to commercial prawn trawl nets, except that prawn boats in Shark Bay towed two 8-fathom (10.3 m) nets in 2002/2003 and Exmouth Gulf trawlers are currently trialling quad-gear with either 4.5, (5.8 m) 5 (6.4 m) or 5.5 (7.1 m) fathom nets. Onslow Area 1 commercial fishers use twin or quad gear to a maximum total headrope length of 16 fathoms (20.6 m).

No bycatch reduction devices were used during the sampling so that the total bycatch abundance could be assessed as would have occurred prior to the introduction of BRDs which was taking place during the lifetime of this project.

For the majority of sites, three shots were completed, but occasionally only one or two shots could be done at a site (Table 2.1a and b). This was due to either inclement weather, making it dangerous to continue (such as cyclonic conditions in Shark Bay in March 2003), or problems at certain sites due to huge quantities of bycatch (i.e. large schools of ponyfish or jellyfish), seagrass or rubble, making the sorting time too long to finish the work in the given time period.

Table 2.1 a) Number of samples taken per site in Shark Bay, October 2002 to October 2003.

Site	Oct 02	Feb 03	Jun 03	Oct 03
1	3	3	2	3
2	3	3	3	3
3	3	3	2	3
4	3	3	2	3
5	3	2	3	3
6	3	3	3	3
7	3	3	3	3
8	3	2	3	2
9	3	3	3	3
10	3	3	3	3
11	3	3	3	3
12	3	3	3	3
13	3	3	3	3
14	3	2	3	3
15	3	2	3	3
16	3	3	3	3
17	3	3	3	3
18	3	3	3	3
19	3	3	2	3
20	3	2	3	3
21	3	3	3	2
22	2	1	1	1
23	2	3	2	3
24	3	3	3	3
25	3	3	3	2
26	3	3	3	3

Table 2.1 b) Number of samples taken per site in Exmouth Gulf in 2004.

Site	Feb 04	June 04	Oct 04
1	3	3	3
2	3	3	3
3	3	3	3
4	3	3	3
5	3	3	3
6	3	3	3
7	3	3	3
8	3	3	3
9	3	3	3
10	2	2	2
11	3	3	3
12	3	3	3
13	3	3	3
14	3	3	3
16	3	3	3
17	2	3	3
18	3	3	3
19	2	3	3
20	3	3	3
21	3	3	3
22	3	3	3
23	3	3	3
24	3	3	3
25	3	3	3
26	3	3	3

The sampling was carried out at night (except the day-time trawl trials), starting around 1830 hrs in winter and 1930 hrs in summer, working through until between 0130 hrs and 0500 hrs the next day. The timing of sampling was used to simulate commercial prawn trawling activities. This is because one of the target species (primarily *P. latisulcatus*) is generally only active, and therefore only caught in viable quantities, at night. However it should be noted that scallop trawling can operate 24 hours when the season is open, though generally boats only fish approximately 10-12 hours primarily between 1700 and 0900 hrs. Scallop boats also use nets with a larger mesh size of 100mm (cf. 50 mm prawn nets) and bycatch is much reduced. Therefore these larger mesh size nets were not used during this study.

Catches varied greatly in both total volume and number of species. Some trawl shots took over an hour to sort whereas a few took only 15 minutes. It was usually possible to complete three to four sites (9-12 shots) per night. The number of sites completed per night was also limited by the distance and time taken to travel between sites.

For each trawl shot the starboard and port catches were kept separate but were combined for analysis. The haul from each net was emptied onto a central sorting table, divided along the middle to keep the two sides separate. A rough sort of fish and invertebrates into baskets was done on the table, with three to four people per side. The fish and invertebrate teams then further refined their sorting, identified all the species present and counted them. Weight was not recorded. All species of target catch and bycatch were recorded on waterproof data sheets. Selected fish, prawn and scallop species that were abundant were also measured. Specimens were retained for verification of identity, and as voucher specimens for the Western Australian Museum Aquatic Zoology reference collection. The majority of specimens were frozen, but some required preserving immediately. Sponges were photographed and small portions cut and retained (frozen) for identification purposes. All protected and large specimens (such as turtles, large sharks and rays) that were not feasible to keep were photographed and returned to the water alive as quickly as possible.

2.2.1 Seasonal and annual sampling

During all sampling cruises, at each site, the depth and surface water temperature and salinity measurements were recorded using a WTW Cond 315i conductivity meter with a WTW Tetracon® 325 conductivity cell. The conductivity cell had a built-in temperature probe (thermistor). Video footage of the bottom type was taken at sites 16, 17, 18, 21 and 22 in Shark Bay and at sites 4, 6, 9, 10, 11, 12, 13, 14 and 16 in Exmouth Gulf and sites 21 and 26 in Onslow. Due to poor visibility in many sites, reasonable quality footage is only available for a selection of sites in each region. These were recorded onto CD and will be catalogued in the Western Australian Fisheries and Marine Laboratories library for future reference. No quantitative analyses were made using the video footage.

2.2.1.1 Shark Bay

To examine seasonal and annual variation in Shark Bay prawn and scallop trawling bycatch, sampling trips were carried out at different times during the trawl season. These were done at the end of trawl season in October/November 2002, and during the start (February/March), middle (June/July) and end (October/November) of season in 2003. All 26 sites were surveyed on each of the above trips. During March 2004, 3 sites (15, 16 and 21 Figure, 2.1) were re-sampled (prior to the start of the Exmouth Gulf survey). The commercial prawn season generally commences in mid March and is closed October/November and includes monthly moon breaks (5-9 days and in 2006 up to 12 days around the full moon) when no fishing takes place. In recent years approximately 170 fishing nights has been permitted for the 27 boats in the fleet. The scallop season is highly variable depending on the amount of settlement in any one year. The length and timing of season is determined by results of a pre-season survey (conducted in Oct/Nov) which allows the prediction of the following season's catch. In recent years with relatively low catches available, the scallop season has commenced between March to May and has only lasted between three and six weeks.

2.2.1.2 Exmouth Gulf

Only seasonal variation was studied in Exmouth Gulf and Onslow. A similar sampling regime to Shark Bay was carried out to examine seasonal variation in Exmouth Gulf prawn bycatch (no scallop fishery exists in Exmouth Gulf). Trips were carried out at the start (March), middle (June/July) and end (November) of season in 2004. The Exmouth Gulf prawn fishery generally commences around mid April and continues until November with a maximum of 200 nights fishing. Four to six day moon breaks are taken around the full moon each month. Sixteen licences are allowed to operate in the fishery but in 2004 only 13 boats fished as all boats converted from twin to quad gear. In Onslow, Area 1 the area generally opens between March and June each year with only four boats licensed to fish the area.

2.2.2 Fish and invertebrate processing

Voucher specimens of all vertebrate and invertebrate bycatch species were collected, excluding most reptiles and large species of fish and invertebrates. Photographic records of the large, uncollected species were taken, where possible. The majority of retained specimens were frozen on board the boat immediately after sorting. Some specimens required different preservation procedures, including crinoids, brittlestars, ascidians and certain cephalopods, as detailed below. All specimens were labelled with field identification names and collection location details, and sealed in individual plastic bags. The specimens were stored in polystyrene foam boxes, which could later be transported by freezer truck back to Perth and processed at the WA Museum.

2.2.3 Identification of specimens

Taxonomic specialists at the Western Australian Museum identified the fish (Sue Morrison, Dr Barry Hutchins, Glenn Moore), echinoderms (Loisette Marsh), molluscs (Shirley Slack-Smith, Corey Whisson), crustaceans (Melissa Titelius, Diana Jones), cnidaria and sponges (Dr Jane Fromont) from the bycatch. Ascidians were identified by Dr Patricia Mather (QLD Museum), and soft corals by Dr Phil Alderslade (NT Museum).

Fish: Fishes were identified using FAO (Food and Agriculture Organization of the United nations) species identification keys, and specialist keys in reviewed scientific papers and books. The large WA Museum collection of preserved fish specimens was used as a reference to check identifications. A small number of specimens that could not be identified to species level were sent to specialists in the relevant family at other institutions. Specimens were thawed out in the laboratory and examined with the use of a microscope. Characters commonly used in species identification are body colour and patterns, body proportions, number of fin spines and rays, and number of scales in the lateral line. However, many families and/or species have a unique set of additional characters that are also used.

Taxonomic problems were occasionally encountered. Some specimens were in such poor condition after trawling, that identification to species was not possible, and even the generic status was not clear. Sometimes there was insufficient material to find other specimens in better condition. Another problem was distinguishing between pairs of similar species in the field. Sometimes it was not possible to separate species until they had been viewed under a microscope in the laboratory. For example the zig-zag ponyfish *(Leiognathus moretoniensis)* and the whipfin ponyfish *(Leiognathus leuciscus)* are separated on the basis of the presence or absence (respectively) of tiny scales on the cheek. Even under a microscope these are difficult to view. It was not possible to bring all these specimens back to the WA Museum, since they occurred in huge numbers at some locations. When possible, sub-samples of the ponyfish catch were retained for complete identification. The proportions of the different species were then used to extrapolate the numbers for the whole ponyfish catch. It wasn't until near the end of the fieldwork that a character visible only in fresh specimens was observed by a Murdoch PhD student volunteer (Michael Travers) that could be used to separate the two species. These issues have been marked accordingly in the Appendix 3.

Invertebrates: Many invertebrate species do not have comprehensive taxonomic keys, and some (particularly sponges) are still undescribed. Consequently, some invertebrate identifications rely completely on the expertise and experience of scientists doing the research. Where possible, taxonomic keys were used in identification. Specific methods apply to certain phyla, as follows:

Sponges: Colony shape and live colouration can be useful for preliminary identification, but these are often extremely variable depending on the ecology, depth and exposure of the habitat. Examination of histological sections of the skeleton and internal spicule preparations are necessary for complete identification. The preparation of sponge tissue for sectioning involves embedding small samples of the specimen in wax. These samples are then cut into fine sections with a microtome and placed onto glass slides. The fine structure of the sponge skeleton can then be examined under the microscope. Spicule preparation involves digesting all the sponge tissue, except for the spicules with acid. The spicules are thoroughly washed, then dried onto a glass slide which can then be examined under the microscope. These preparations can be stored permanently for future reference. Temporary 'bleach' preparations can also be prepared for quick comparison with identified material.

Cnidaria:
Octocorals: Live colony shape, texture, hardness and colouration are important in preliminary identification. Microscopic examination of internal sclerites is usually required for identification to genus and species. However, sclerites can vary in shape considerably in a single genus, and also between different locations within an individual colony. For complete identification a range of characters therefore need to be used.

Hard corals: Live colony shape, texture and colour are important in identification. Microscopic examination of the cleaned skeleton is usually required for identification to species.

Crustacea: Body shape and live coloration are useful in identification. The structure of the mouthparts, and ornamentation of the carapace and telson are particularly important in many families. Examination of internal male reproductive organs is necessary for identification to species in certain families, which evidently poses a problem if only female specimens have been collected.

Molluscs:
Bivalves: Valve shape, surface relief and colour are important in identification. Examination of the hinge structure and muscle 'scars' on the inside of the valves of most species is required for complete identification.

Shelled Gastropods: Shell shape, surface relief and colour, colour of operculum (if present) and body colour can all be important in identification. Microscopic examination of the protoconch (first few whorls of the shell) is essential in some species.

Opistobranchs: Live colour pattern and morphology are very important for identification. Once preserved, most of the colour is lost. Microscopic examination of the radula (teeth) is often necessary to identify to species.

Cephalopods: The external features of most cephalopods cannot be used to identify the animal. For cuttlefish, examination of the structure of the internal 'bone' is essential to identify to species. For octopus and squid, examination of the tentacles and fine details of suckers is usually required. For octopus, the structure of the hectocotylised (reproductive) arm of the male is essential to identify to species.

Echinoderms: Body shape, colour, texture and number of arms (when present) are important in identification. Microscopic examination of the calcified plates is necessary for some species. Holothurians require microscopic examination of spicules in the skin.

Ascidians: Microscopic examination of internal structures is required for identification to species. Most species cannot be identified from external features.

2.2.4 Preservation of specimens

Fish (in laboratory): After identification, a photographic record of the fresh colouration was made, then the specimen fixed in 10% formalin. After fixation the specimens were briefly soaked in water, then transferred to 75% ethanol for permanent storage. Smaller specimens were stored in glass jars, and larger specimens (over 20 cm in length) in 20 or 60 litre polydrums.

Invertebrates: Different phyla require different methods of fixation. The preferred method for the majority of molluscs, brittlestars and ascidians is to immediately relax the specimens in magnesium chloride in seawater, followed by fixation in 10% formalin. Specimens are then briefly soaked in water and permanently stored in 75% ethanol. Holothurians also need to be relaxed, but are fixed in 75% ethanol. After freezing, sponges, crustacea, and echinoderms other than holothurians are fixed directly in 75% ethanol. Hard corals are bleached in household bleach, then dried leaving a clean, white skeleton. Some other specimens are dried after fixation including large seastars, echinoids and crinoids.

2.2.5 Collection storage

All specimens were registered with the Western Australian Museum, recorded on a database and stored in the Museum Aquatic Zoology collections. Each phylum is stored separately, and is managed by different sections of the Aquatic Zoology department of the Museum. These collections will be kept permanently with the WA Museum and can be accessed in the future for further reference and research. All specimen labels include a reference to the relevant trawl trip, and are therefore easy to find on the database and also locate within the collections.

2.3 EXMOUTH GULF SEDIMENT SAMPLING

Sediments were sampled from a total of 17 sites in Exmouth Gulf and Onslow (Figure 2.2), covering trawled, lightly trawled and untrawled sites as listed below:

Level of trawling	Site numbers Exmouth Gulf	Site numbers Onslow	Total
Trawled	1,4,6,7,9,11,13,14	20,23,24,25	12
Lightly trawled	5,12,16,17	21	5
Untrawled	2,3,8,10,18,19	22,26	8

Sediments were collected using a Van Veen grab. The grab was deployed from a steel cable at the stern of the boat when stationary. Once the grab hit the seabed it automatically released, sampling 0.1 m^2 of the sediment. It was immediately raised, and a sub-sample of approximately 500 cm^3 taken. This was transferred to a plastic whirlpack and frozen.

Sediment samples were sorted into grain sizes between 63 and 4,000 microns, using sieves. Three samples were processed from each sub-sample to ensure the results were consistent. Sieve sizes used were 63, 125, 250, 500, 1,000, 2,000 and 4,000 microns.

3.0 OBJECTIVE 1

S. Morrison, M. Kangas, E. Lai, I. Wright and A. Thomson

Objective 1. To develop biodiversity measures of trawled and untrawled habitats in Shark Bay and Exmouth Gulf

3.1 INTRODUCTION

Prawn and to a lesser extent scallop trawling is known to incidentally capture significant quantities of bycatch (Poiner et al. 1998, Ramm et al. 1990, Stobutzki et al. 2001a, Wassenberg and Hill 1990). The effects of trawling on bycatch and the whole ecosystem they are collected from has become of major concern in recent years, as commercial marine food stocks have become increasingly depleted in many parts of the world. Community expectations are that commercial fishing should only be carried out if it can be shown to be sustainable, not only for the target species, but also for the bycatch species and the habitat they come from. In order to demonstrate sustainability some measures of the impacts of trawling needs to be established to ensure the ability to monitor and document changes within the systems that include trawl fisheries. During this study the aim was to develop biodiversity measures in trawled and untrawled sandy habitats.

Major advances have been made in Western Australia with the introduction of several types of bycatch reduction devices (BRDs) to the commercial prawn and scallop boats in Shark Bay and Exmouth Gulf between 2000 and 2002. It is now mandatory for all trawl boats in these regions to have exclusion grids and secondary BRDs such as square mesh panels. Exclusion grids or turtle exclusion devices (TEDs) are sturdy metal grids positioned halfway down the throat of the net, with an escape flap in the net above it. This excludes larger animals such as turtles, sharks, large rays and large teleosts. It is documented to exclude 95-100% turtles, 80-90% sharks and rays, with a 40% reduction in sea snake capture (Kangas and Thomson 2004). Square mesh panels are additional escape openings that consist of larger mesh located in the net beyond the TED. This allows some of the stronger swimming fish such as lizardfish, whiting and butterfish to escape. Preliminary results indicate a 47% reduction in fish bycatch and a 33% reduction in total bycatch, with very little difference in prawn catch. Hoppers are large, water-filled tanks that receive the catch directly from the nets, thereby reducing the time the catch spends out of water. It results in a better quality product of prawns and also makes for more efficient sorting, and consequently bycatch is returned to the sea more quickly (Oceanwatch 2004).

In addition to these physical alterations to trawl gear the Department of Fisheries has used area and time closures in significant parts of each fishery to limit trawl impacts and large portions of the Western Australian coastline have no trawling undertaken at all.

The Department of Fisheries and commercial fishers in Shark Bay and Exmouth Gulf have developed an excellent working relationship and have a very high level of liaison. This has resulted in good records being kept of all trawl activity in Shark Bay and Exmouth Gulf since the commencement of the fishery in the early 1960's, and detailed daily shot by shot information on catch and fishing location since 1998. All skippers log details of every shot carried out and pass the information on to Fisheries Research Division for analysis, which provides fine spatial data of all catches and effort. These measures facilitate management of the trawl fisheries that aim to optimise catches and target an optimum prawn size, while maintaining spawning stock levels. Also all commercial trawlers have a 'vessel monitoring system' (VMS) that continuously records their location accurately.

Despite such pro-active measures, comprehensive information is still lacking on the biology and sustainability of many of the bycatch species. The major part of this project was, therefore, designed to assess the variation in biodiversity (species richness, diversity and evenness) and abundance (number of individuals) of species between trawled and untrawled sandy habitats in Shark Bay, Exmouth Gulf and part of the Onslow prawn fishery. The aim was to determine whether there is a significant difference in the abundance of all vertebrate and invertebrate species captured by trawling, between trawled and untrawled sites in these regions.

The amount of bycatch can vary depending on the type of fishing gear utilised, the location of the trawl sites, time of trawling and season, physical oceanographic parameters and biological factors. Nets similar to those used by commercial prawn trawlers were used for the duration of the study. However bycatch reduction devices were not used in order to assess total bycatch abundance and species richness as at the commencement of this study, the BRD implementation project was still underway. Trawling was carried out at night (except for day night trials), between March to November encompassing the annual fishing season. Sites were selected to cover as many sites (both trawled and untrawled) within the regions as possible, while some video recording of the seabed was carried out to confirm habitat type which was primarily expected to be soft sediments.

3.2 METHODS

The general methods of sampling, sorting and species identification are described in Chapter 2.

3.2.1 Data analysis

3.2.1.1 Factor Analysis

Factor analysis (Statistica) of the fish species abundances in Shark Bay and Exmouth Gulf and Onslow was undertaken to determine the differences between the sites sampled within each fish assemblage group. Fish species were grouped into Families to reduce the data set and those Families that had abundance at less than 2.5 individuals per nautical mile of trawling were removed from the data set. Thus, 32 fish Families in Shark Bay and 36 Families in Exmouth Gulf and Onslow were used in the factor analyses using normalised Variamax and two factors in both Shark Bay and Exmouth Gulf have been used to explain the main trends in the samples.

3.2.1.2 Permanovas

Considering fish and invertebrate data for Shark Bay and Exmouth and Onslow separately, permutation tests for multivariate analysis of variance (permanova) (Anderson 2001) was used to analyse the Bray Curtis similarity index for each sample taken at each site. Factors considered in the permanova were site, season (‘start’, Jan – April; ‘mid’, May – August; and ‘end’, September – December) and their two-way interaction. The fourth root transformation was applied to the sample data before calculating the associated Bray Curtis index. Type 3 sum of squares have been presented due to the sampling being unbalanced (unequal number of observations per treatment).

With each treatment having a small number of replicates it was not possible to test for normality or homogeneity of variance with any power (i.e. we would not be able to reject that each treatment is normally distributed with equal variance). We have therefore assumed normality and homogeneity of variance throughout.

3.2.1.3 Cluster analysis

Divisive clustering analysis was undertaken to examine variation in the fish and invertebrate assemblages at Shark Bay and Exmouth Gulf. For each pair of samples, a simplified Morisita's index of similarity (Horn 1966) was calculated using the catch rates of individual species (number per nautical mile trawled). The complement of this index was used as a measure of dissimilarity for the cluster analysis. Catch rates were square-root transformed before similarity values were calculated to reduce the variance. The fish and invertebrates were examined separately and then combined. Species that occurred at one site only were removed. Results from the analysis were presented in dendrograms and in non-metric multi-dimensional scaling (MDS) ordinations. The statistical software, S-Plus (version 7, Insightful Corp.), was used to perform the analysis. MDS ordinations were done using Plymouth Routine in Multivariate Ecological Research (Primer6) software (Clarke and Warwick 2001).

3.2.1.4 Environmental data analysis

Analyses were conducted with Primer6 software. The procedure BEST (Clarke and Ainsworth 1993) in Primer6 was used to find a set of environmental variables which was the best in explaining the species assemblage pattern. The BIO-ENV procedure amalgamated in BEST was chosen to carry out a full search of all possible combinations of the environmental variables. The environmental data was first averaged (for all sampling periods) for each site. The data was standardised and normalised before analysis. The resemblance matrix obtained for the species assemblage from clustering analysis was used by BEST to compare with the resemblance matrix, which was calculated using Euclidean distance, for the environmental data resulting in Spearman rank correlation values.

3.2.1.5 Richness, Evenness & Diversity

The Margalef's richness index (Margalef 1958) was used to examine fish and invertebrate species richness. The richness index (d) incorporates the total number of individuals (N) and is a measure of the total number of species (S) present for a given number of individuals: $d = (S-1)/\log N$.

A Margalef's richness index was calculated for each sample for each site for all sampling periods and analysis of variance applied to check for significant differences.

The Pielou's evenness index (Pielou 1975) was used to examine the equitability – how evenly the individuals are distributed among the different species: $J = H / \log S$, where H is the Shannon diversity index and S is the total number of species.

Diversity indices take into account of the species richness and evenness. Two common diversity indices were calculated. The Shannon (or Shannon-Wiener) diversity index: $H = -\sum_i p_i \ln (p_i)$ where p_i is the proportion of the total count arising from the ith species and the Simpson's index (Simpson 1949): $1 - \lambda' = 1 - \{ \sum_i N_i(N_i - 1)\} / \{ N(N - 1)\}$, where N_i is the number of individuals of species i. It represents the probability of two randomly chosen individuals being different species. It ranges from 0 (low diversity) to almost 1 (high diversity).

With cluster groups identified from the earlier clustering analysis of fish and invertebrate species abundances, ANOVA tests were carried out to test if there were differences in the diversity measures among the cluster groups and if any environmental variables had significant effect. Margalef's richness, Pielou's evenness, Shannon's diversity and Simpson's diversity indices were calculated using Primer6. Analysis of variance (ANOVA) tests were carried out in S-plus, Type 3 sum of squares have been presented due to the sampling being unbalanced (unequal number of observations per treatment). Diversity measures were modelled using environmental variables as co-variates as well as factors; site, season, Group and whether a site was trawled or untrawled. The resulting least squares means with 95% confidence interval was presented graphically. Least-squares means are what the arithmetic means are expected to be if the experimental design was balanced.

3.3 RESULTS

3.3.1 Shark Bay

A total of 241 fish and 360 invertebrate species were recorded from all the trawl surveys in Shark Bay during 2002, 2003 and 2004 (Appendix 3.1). These surveys included the standard night-time trawls at the 26 selected sites, plus depletion trawls and daytime trawls at a small number of sites.

3.3.1.1 Factor Analysis

Shark Bay Fish Families

The two factors explained 59% of the variation. Factor 1 explained 38% of the variance and Factor 2 explained a further 21% of the variance. Rotation of the axes showed that Factor 1 was a contribution of 12 Families and four further families for Factor 2 (Table 3.1). Factor 1 is most likely related to the abundance of fish species in Families and Factor 2 are species that separate Group 1 from Groups 2 and 3.

Table 3.1 Factor analysis for fish families in Shark Bay showing the families with the highest scores on each factor.

Factor 1	Factor 2
Narcinidae	Clupeidae
Platycephalidae	Pegasidae
Nemipteridae	Pinguipedidae
Lethrinidae	Callionymidae
Mullidae	
Pomacentridae	
Sphyraenidae	
Labridae	
Siganidae	
Soleidae	
Monacanthidae	
Ostraciidae	

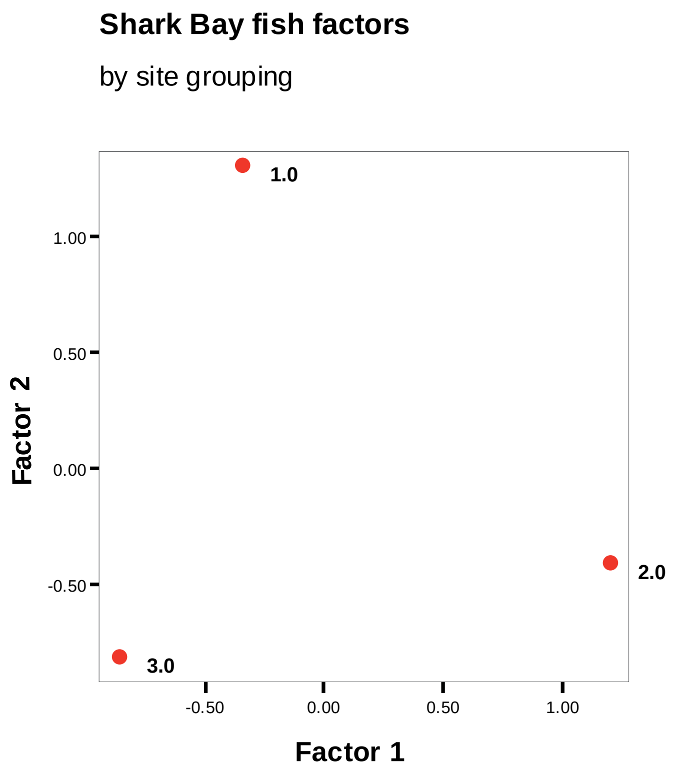

Figure 3.1 Factor analysis of mean abundance of fish families by site groupings in Shark Bay.

3.3.1.2 Permanova – fish species abundance

Site, season and their interaction was significant for fish species abundance in Shark Bay (Table 3.2).

Table 3.2 Permanova results for fish species in Shark Bay biodiversity trawls (R^2 = 0.91). Only observations for 2003 were included in this analysis. Type 3 sum of squares have been presented.

Source	df	SS	MS	Pseudo-F	P (perm)
Site	25	282390	11296	39.841	< 0.01
Season	2	21608	10804	38.105	< 0.01
Site x Season	50	93944	1878.9	6.6269	< 0.01
Residuals	137	38843	283.52		

3.3.1.3 Shark Bay fish divisive cluster and MDS analysis and correlation with environmental variables

Data from the end of season survey in 2002 (October), and start (February/March), middle (June/July) and end of season (September/October) surveys for 2003 were included. However, fish species from the depletion trawls (see Chapter 5), daytime trawls and those that were extremely rare (i.e. single individuals in one site) were excluded, reducing the total number of fish species to 215.

Divisive clustering analysis of the abundance of fish species indicates three main groupings of sites in Shark Bay (Figure 3.2). Each grouping has a mixture of trawled and untrawled sites. MDS ordination of fish species abundances at the 26 sites indicate similar groupings to that observed with cluster analysis (Figure 3.3).

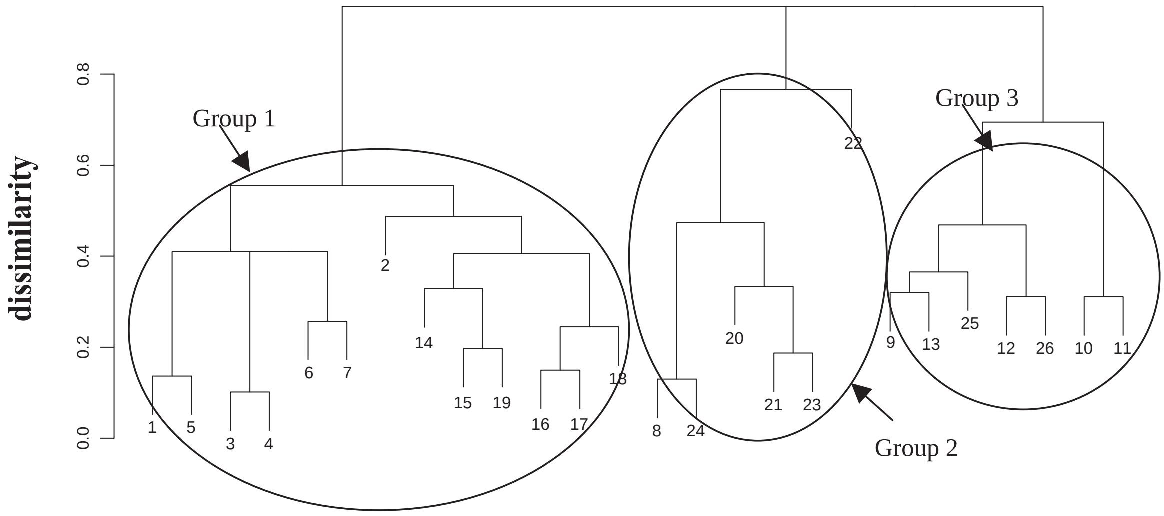

Figure 3.2 Divisive cluster analysis of Shark Bay fish abundance data based on four surveys (October 2002 to October 2003).

Group 1 encompasses the largest number of sites (13) in the southern reaches of Shark Bay, including Denham Sound and the Eastern Gulf, including one site (7) in the central prawn trawl grounds.

Group 2 includes six sites along the western reaches of Shark Bay located on or near the scallop trawl grounds. This covers a long, thin area extending from just east of Bernier Island to the northern end of Denham Sound. Site 22 can be regarded as distinct from Group 2.

Group 3 consists of seven sites centred around the northern prawn trawl grounds of Shark Bay, extending between Carnarvon and Point Quobba (Figure 3.4).

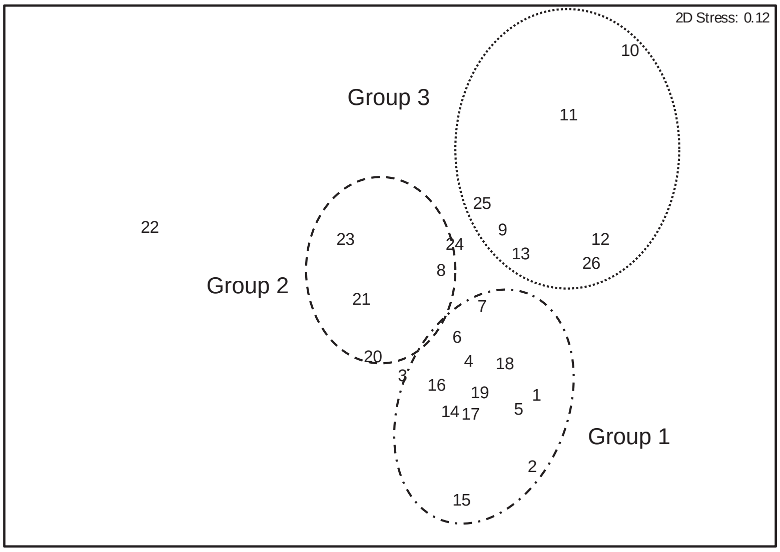

Figure 3.3 MDS plots of fish species assemblages in Shark Bay (dashed lines indicate groupings defined by cluster analysis).

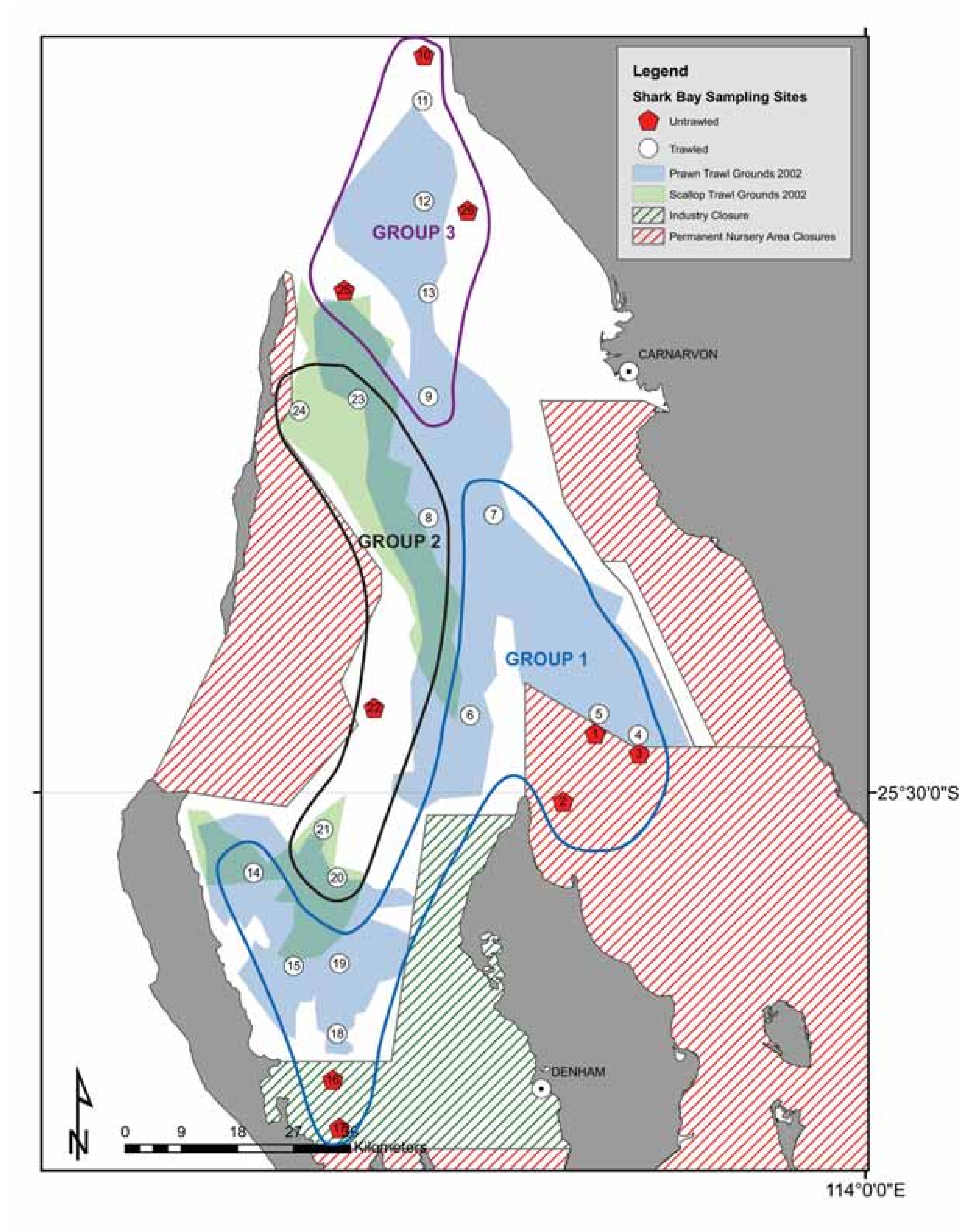

Figure 3.4 Shark Bay site groupings for cluster analysis of fish abundance data.

3.3.1.4 Linking abundance data to environmental measures

The BEST procedure showed similarities for sites with environmental variables depth (Figure 3.5) and temperature (Figure 3.6) for fish abundance. Group sites 1 are shallower with cooler water temperatures whereas Group 3 sites are deeper with warmer water temperatures.

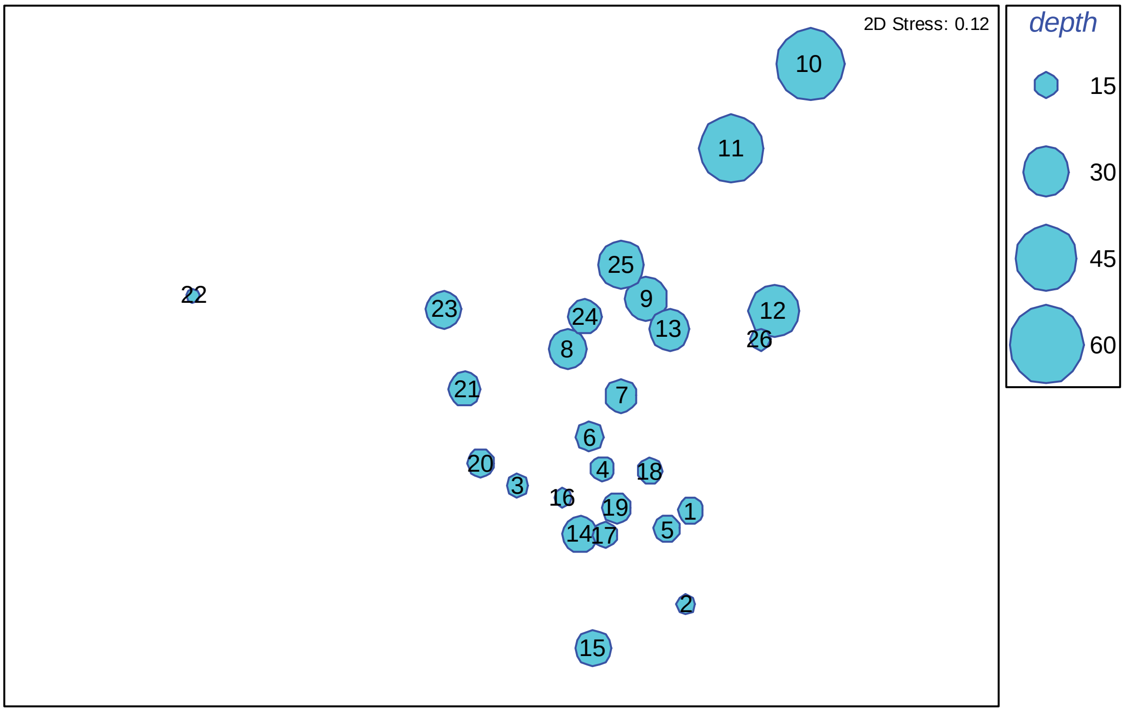

Figure 3.5 MDS of fish species abundance as the 26 sites superimposed with depth (m).

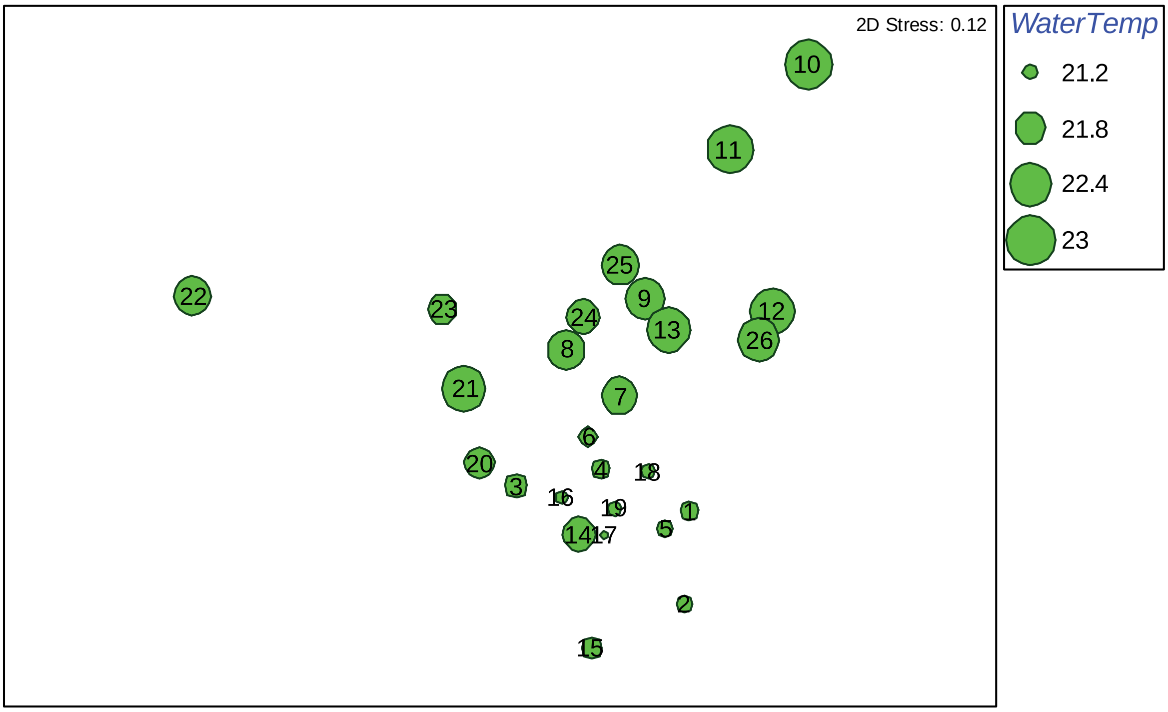

Figure 3.6 MDS of fish species abundance as the 26 sites superimposed with mean surface water temperature (°C) measurements (for all sampling periods).

The Spearman rank correlation between water depth and temperature matrix and the fish abundance matrix was 0.67 indicating only a moderate correlation for fish species.

3.3.1.5 Fish species richness, evenness and diversity

There were significant differences in the Margalef's richness, Pielou's evenness, Shannon's diversity and Simpson's diversity indices of the three groups ($p < 0.01$) (Figure 3.7 a-d). For richness all three groups were significantly different to each other, for evenness only Groups 1 and 3 were similar and for diversity, Group 1 was different to Groups 2 and 3. Season was found to a significant factor for the species richness ($p < 0.01$) whereas salinity was found to be a significant co-variate for species evenness (p=0.035).

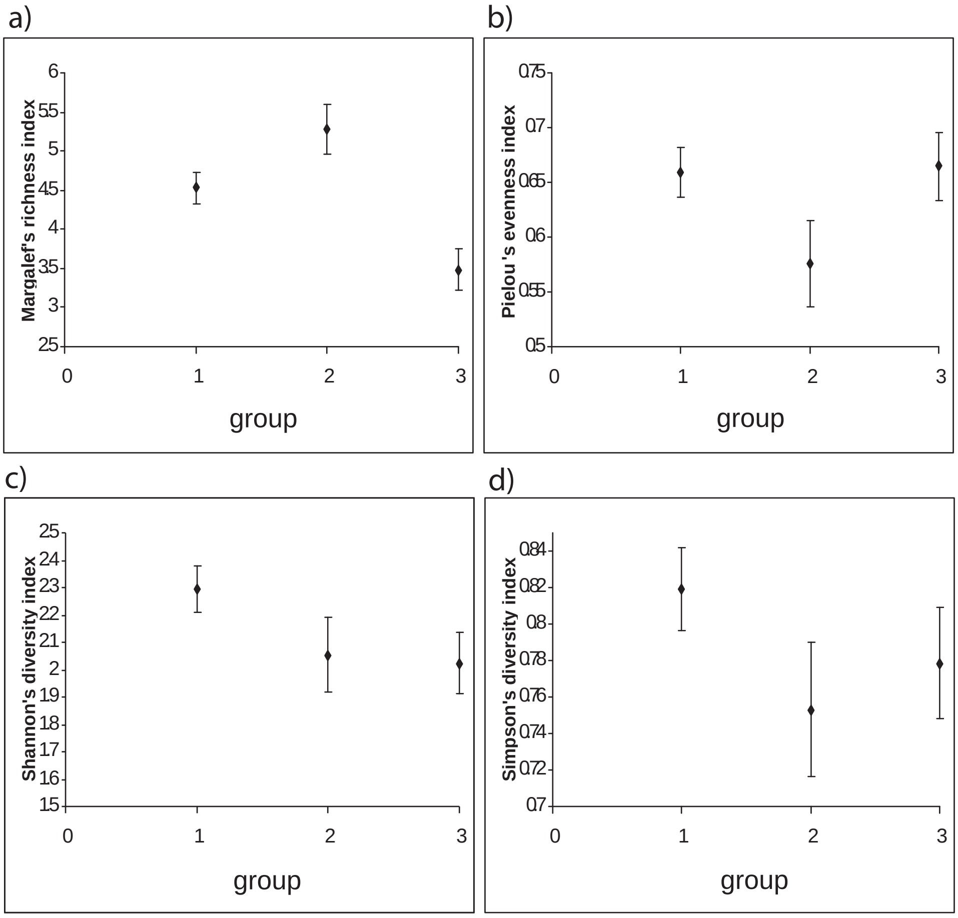

Figure 3.7 Least squares means of indices with 95% confidence interval calculated for sites within groups identified from the fish abundances in Shark Bay. a) Margalef's richness index b) Pielou's evenness index c) Shannon's diversity index d) Simpson's diversity index.

Restricting analysis to each of the three groups separately, the effect of trawling and no trawling was tested. For the fish assemblages, the results indicated that there were significant differences in the species evenness ($p < 0.01$), the Shannon's diversity index ($p < 0.01$) and Simpson's diversity index ($p < 0.01$) for the trawled and untrawled sites within Group 1. These were higher in the untrawled sites. Significant differences were also seen in the species richness ($p < 0.01$) and the Shannon's diversity index (p=0.013) for the trawled and untrawled sites within Group 3 but the values were higher in the trawled sites (Figure 3.8 a-d). There were too few untrawled samples in Group 2 for analysis.

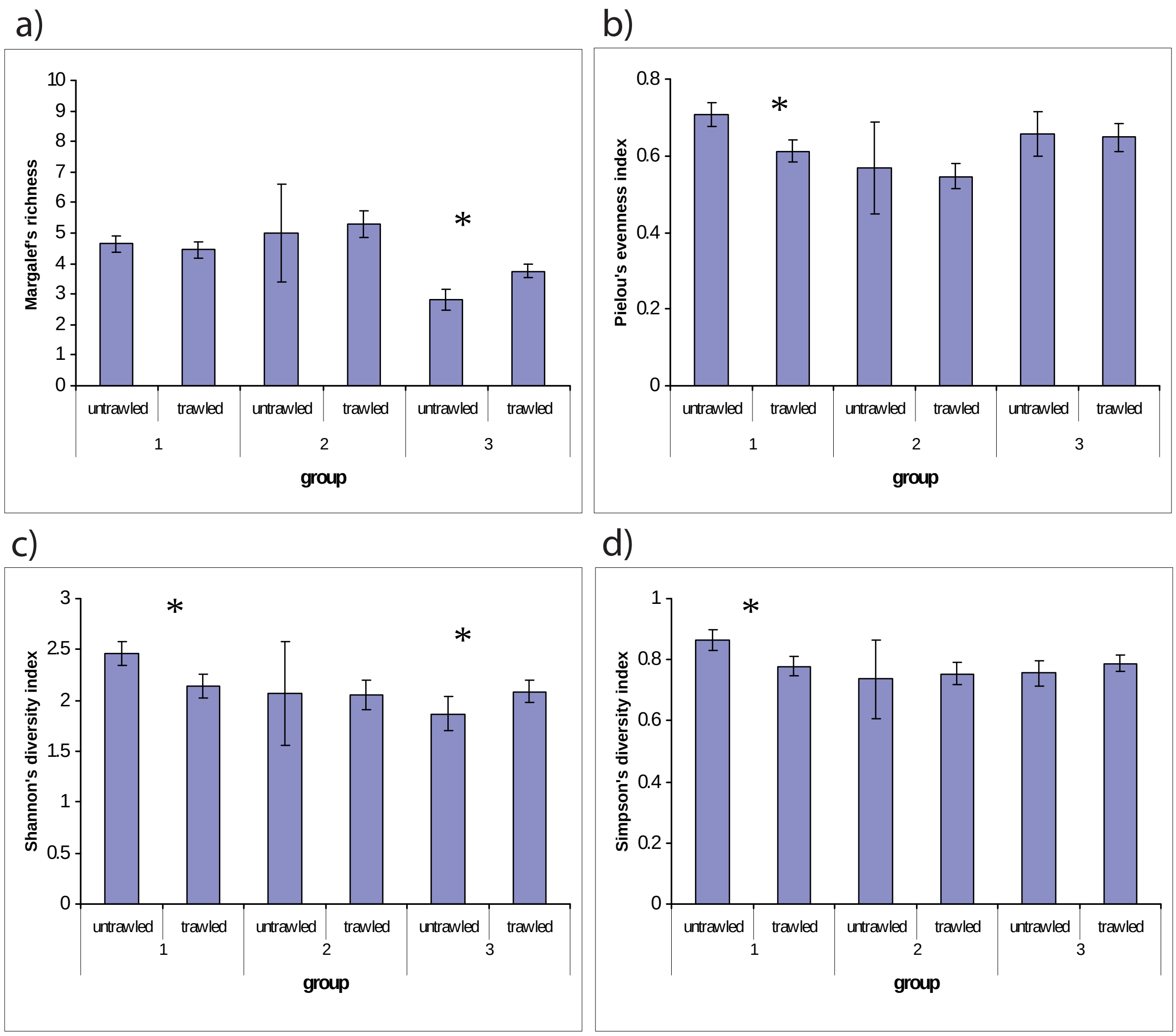

Figure 3.8 Least squares means of indices with 95% confidence interval calculated for trawled and untrawled sites within groups identified from the fish abundances in Shark Bay. a) Margalef's richness index b) Pielou's evenness index c) Shannon's diversity index d) Simpson's diversity index. * indicates significant differences between trawled and untrawled sites within the grouping.

Description of fish groupings

The levels of abundance and species richness for fish and invertebrates, as described below, are categorised as low, medium and high. These are subjective levels used to give an idea of relative number and diversity of fish and invertebrates at the various survey sites. Individual richness values for each sample for a site for each sampling period are illustrated in Figure 3.9. Different scales were used for fish and invertebrates (Table 3.2) because the overall abundance and species levels were disparate for the two groups. Fish abundance was almost double that of invertebrates in many cases due to the lower catchability of some invertebrate species to trawl gear, and the mean number of fish species ranged from 25 to 73 species per site, whereas mean number of invertebrate species were 12 to 40 species per site.

Table 3.2 Range levels used for fish and invertebrate abundance and species richness in Shark Bay.

Category	Abundance (no: /nautical mile)		Species Richness (no: species/site)	
	Fish	Invertebrates	Fish	Invertebrates
Low	0-700	0-400	<40	<20
Medium	700 - 1,200	400 - 800	40 - 60	20 - 30
High	>1,200	>800	>60	>30

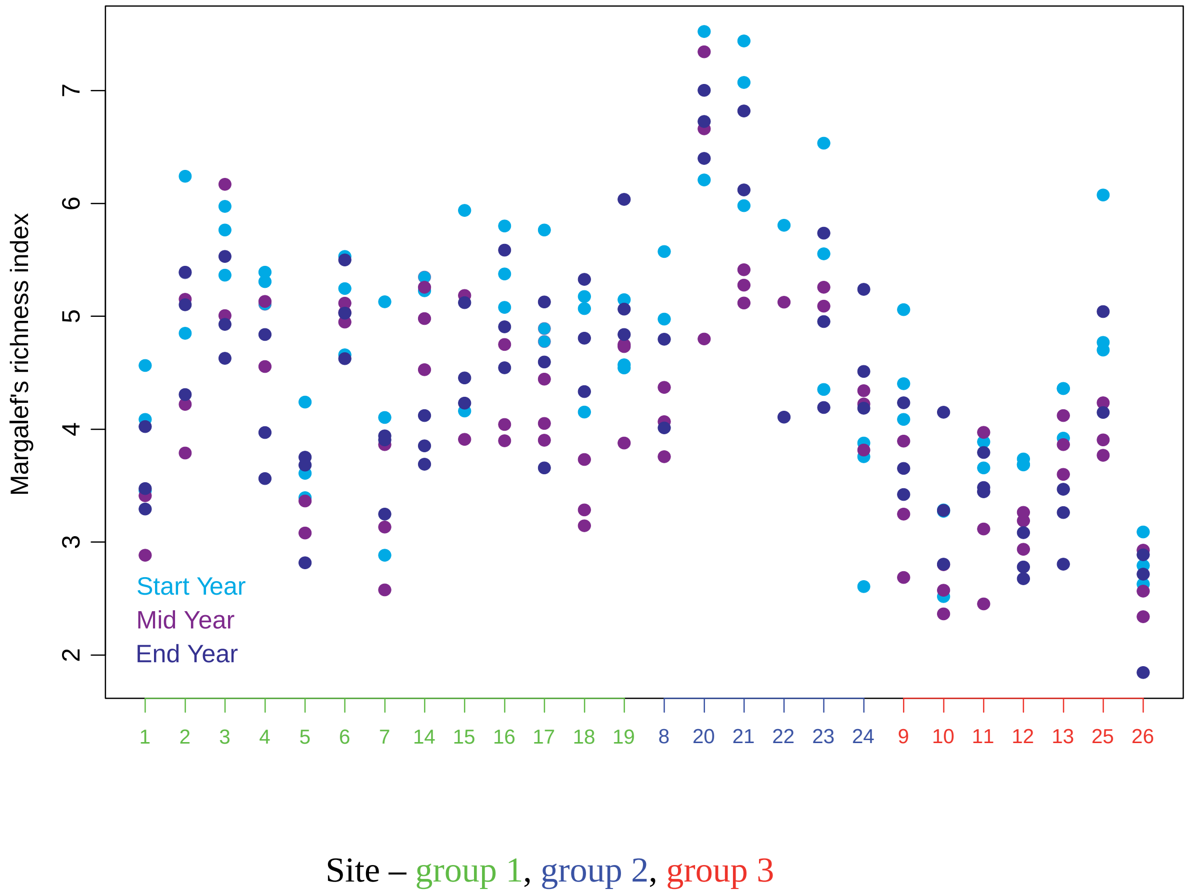

Figure 3.9 Fish species richness for individual samples at each site per season in Shark Bay.

Group 1 – Sites 1, 5, 3, 4, 6, 7, 2, 14, 15, 19, 16, 17, 18

The 13 sites in Group 1 include some with low abundance (approximately 500 to 650 fish caught per nautical mile - average of four seasons) at sites 1, 2, 3, 4, and 5 in the eastern gulf, and sites 16, 17, and 18 in the western gulf (Figure 3.10). These sites verge on the metahaline waters (salinity 40‰ to 56‰) of Freycinet Reach in the southwestern arm of Shark Bay, and Hopeless Reach in the southeastern part of Shark Bay. Remaining sites 6 and 7 in the central prawn trawl grounds, and sites 14 and 19 in the Denham Sound prawn and scallop grounds had fish in moderate abundance (between 920 and 1,100 fish caught per nautical mile). Site 15 in the western gulf had slightly greater abundance with about 1,370 fish per nautical mile.

For all sites, the five most abundant fish species at each site comprise between 46% and 75% of the total abundance, and the 10 most abundant species comprise between 69% and 86% of the total abundance.

Species richness in the Group 1 sites was low to medium, ranging from 33 to 50 fish species per site. Only sites 1 and 5 had low species richness (33-37 species per site, Figure 3.10) and the remaining sites has medium species richness of 41-50 species per site.

The cluster analysis (Figure 3.2) indicates a further split in the Group 1 sites, in which sites 1, 5, 3, 4, 6, and 7 differ slightly from the rest. Four species were common to, and dominated the abundance in variable proportions at these sites, which were the bullrout *(Paracentropogon vespa)*, hair-finned leatherjacket *(Paramonacanthus choirocephalus)*, goodlad's stinkfish *(Pseudocalliurichthys goodladi)* and the asymmetrical goatfish *(Upeneus asymmetricus)*. They accounted for between 47% and 67% of the total fish abundance at each site. Sites 1, 5, 3 and 4 are in the lower eastern arm of Shark Bay and sites 6 and 7 are in the central prawn trawl grounds. Only sites 1 and 3 are untrawled in this group. These four species were present in lower abundance (10% to 42% of the total fish bycatch) at the other sites in this group.

Sites 2, 14, 15, 19, 16, 17 and 18 were more variable in which species dominated the abundance levels. These species include the roach *(Gerres subfasciatus)*, whipfin ponyfish *(Leiognathus leuciscus)*, four-lined trumpeter *(Pelates quadrilineatus)*, orange-spotted toadfish *(Torquigener pallimaculatus)*, trumpeter whiting *(Sillago burrus)*, robust whiting *(Sillago robusta)* and the western butterfish *(Pentapodus vitta)*. Sites 2, 16, 17 and 18 are untrawled in this group.

Apart from site 2 in the eastern gulf clustering with the sites in Denham Sound, the groupings tend to follow geographical location, rather than trawled/untrawled distinctions. In the eastern gulf and central prawn trawl grounds, depths ranged between 13.9 and 19 metres, salinity varied between 35.4 and 39ppt, and temperature ranged from 18.5 to 26.3°C throughout the year. In Denham Sound, depth ranged from 12.6 - 21.4 m and salinity 34.6 - 37.0 ppt and temperature 18.7 - 25.1°C.

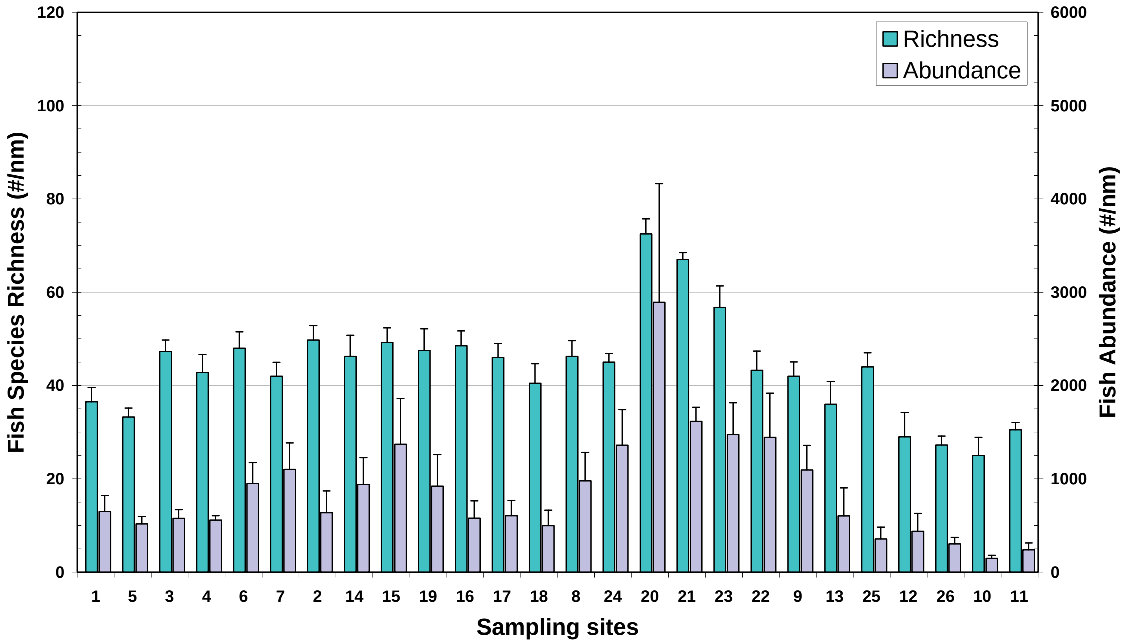

Figure 3.10 Mean fish species abundance and mean fish species richness (+ SE) (for four sampling trips) at each survey site. Sites are ordered according to the cluster groupings (Group 1: 1 to 18, Group 2: 8 to 22, Group 3: 9 to 11).

Group 2 – Sites 8, 24, 20, 21, 23, 22

Within this group, five of the six sites (sites 20, 23, 24, 21, 22) had the greatest abundance of fish (ranging from about 1,360 to 2,890 fish per nautical mile – average of four seasons) in the whole of Shark Bay, with two of the sites (20 and 21) having the greatest species richness (Figure 3.10) with between 57 and 73 species per site. The remaining sites (8, 22, 24) had between 43 and 46 species per site.

For all six sites, the five most abundant fish species constituted 72% to 82%, and the 10 most abundant fish species made up 79% to 90% of the bycatch at each site. These species are therefore likely to largely determine the similarity/dissimilarity between the sites. Site 20 had the greatest abundance of fish in Shark Bay, largely due to huge schools of *Pelates quadrilineatus* at the start of 2003. Three fish species constituted a large proportion (between 32% and 68%) of the fish bycatch at five of the six sites. These were *P. choirocephalus*, *U. asymmetricus* and threadfin emperor *(L. genivittatus)*. However, at site 22 these species only accounted for 17.8% of the abundance. Interestingly, other species from the same families accounted for 55% of the abundance at this site, including Paxman's leatherjacket *(Colurodontis paxmani)*, the fan-bellied leatherjacket *(Monacanthus chinensis)* and the blue-spotted emperor *(Lethrinus punctulatus)*. All these species feed on a wide range of benthic invertebrates found in sand and weed areas, such as worms, crabs, prawns, molluscs and echinoderms, and small fishes. Leatherjackets also ingest significant quantities of seagrass and epiphytic algae. Evidently soft-sediment trawl grounds with patches of seagrass, such as occur in the western reaches of Shark Bay are favourable habitats for these species. Other species abundant at 4 of the 6 sites were *T. pallimaculatus and P. vitta*.

Site 22 is the only untrawled site in this group and is separated from the others in the cluster analysis. This untrawled site is the most shallow (12.3 metres deep) and has large, dense meadows of seagrass between 21-40% seagrass cover (Department of Fisheries 1995), predominantly wireweed *Amphibolis antarctica* (Figure 3.11). Trawled sites 23, 24, 8, 21, and 20 are in or on the perimeter of the scallop trawl grounds. These sites have little or no seagrass and are largely bare, soft sediment. These bare habitats are slightly deeper (16.8 – 22.3 metres) and consequently have lower light levels. Wireweed is unlikely to form such dense beds under these conditions (Kirkman 1997). This difference in habitats is likely to account for the separation of site 22 from the others due to the abundance and composition of species although the fish species richness is similar (Figure 3.10). The main difference in fish abundance was the large proportion of *C. paxmani* that made up 42% of the catch at site 22, but was in very low abundance (0.09-1.27%) at the other sites.

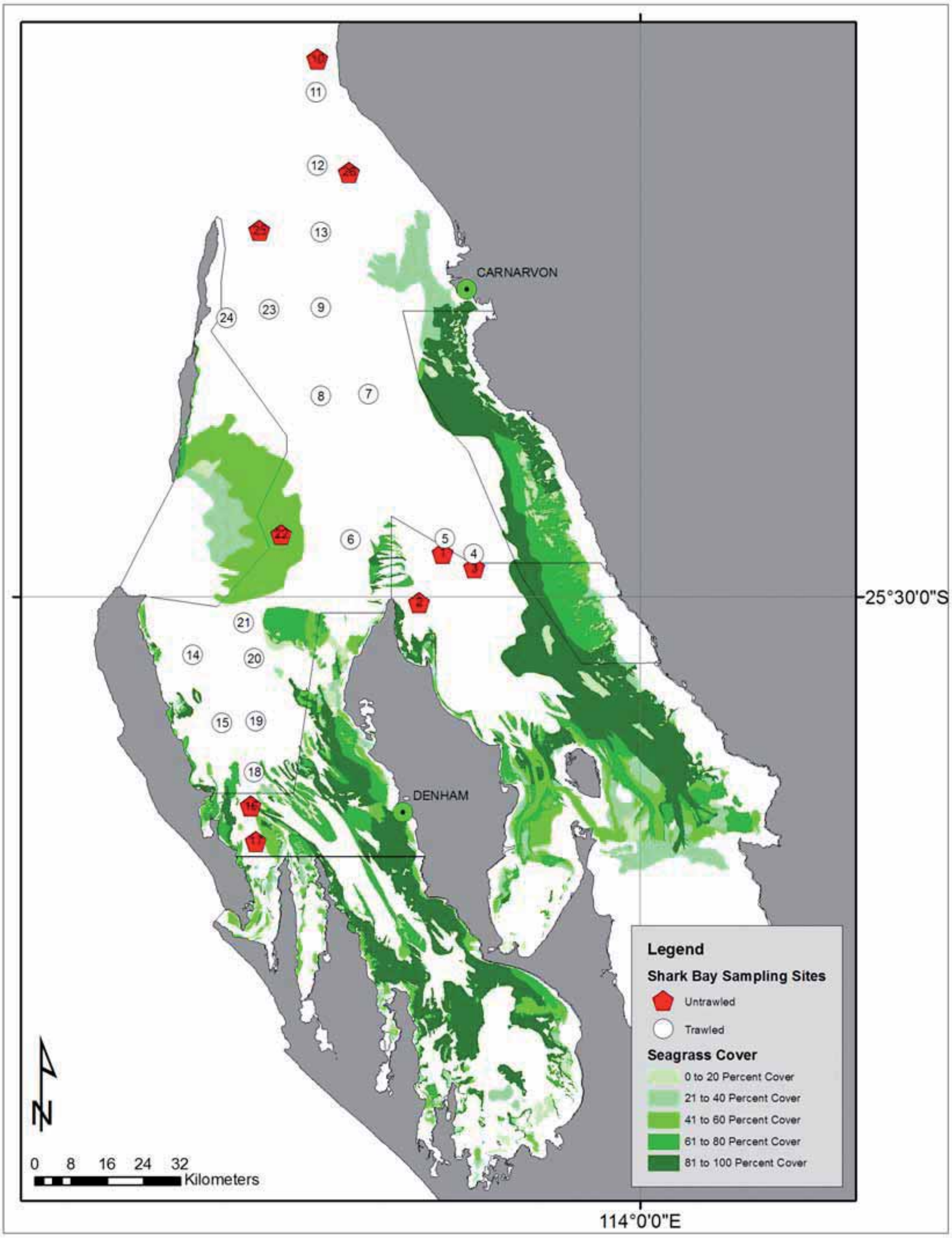

Figure 3.11 Distribution of seagrasses in Shark Bay and sampling sites (seagrass data prepared by Eleanor Bruce for PhD thesis).

Group 3 – Sites 9, 13, 25, 12, 26, 10, 11

Of the seven sites in this group, five sites (10, 11, 12, 25 and 26) had the lowest abundance of fish (between approximately 150 and 440 fish per nautical mile) in the whole of Shark Bay, plus five of these sites (sites 10, 11, 12, 13 and 26) had among the lowest species richness in Shark Bay (25 - 36 species per site). Site 26 had consistently low species richness (Figure 3.10). The remaining two sites (site 9 and 13) had a moderate abundance of fish (approximately 600 to 1,095 fish per nautical mile) and sites 9 and 25 had moderate species richness (between 42 and 44 species per site).

For all sites the five most abundant fish species comprised between 52% and 78% of the total fish bycatch abundance, and the 10 most abundant fish species comprised between 70% and 88% of the total fish bycatch abundance.

As in Groups 1 and 2, *P. choirocephalus* and *U. asymmetricus* were among the top 10 most abundant species at sites 9, 13, 25, 12 and 26, constituting between 19% and 40% of the abundance at each site. Also among the most abundant in variable proportions at these sites were *L. leuciscus, M. chinensis*, *S. robusta*, spiny-headed flounder *(Engyprosopon grandisquama)*, large-scaled lizardfish *(Saurida undosquamis)* and *T. pallimaculatus.*

Site 11 only had the asymmetrical goatfish *(U. asymmetricus)* in the most abundant 10 species (22% of the bycatch) and very few *P. choirocephalus*, while at site 10 these 2 species only represented 1.68% of the total catch. Sites 10 and 11 were dominated in abundance by the long-finned waspfish *(Apistus carinatus)*, deep-bodied flounder *(Pseudorhombus elevatus)* and the long-finned gurnard *(Lepidotrigla sp.)*.

Similar to the Group 2 region, this area is heavily influenced by oceanic water from Geographe Passage. The salinity range was between 34.6 and 35.9 ppt and the water temperature was between 20.4 and 26.1°C over the year. The major environmental differences that could contribute to the separate clustering of sites 10 and 11 within this group are depth and location. Sites 10 and 11 are between 48 and 52 metres deep, while the remaining sites are from 13 to 33 metres deep. Sites 10 and 11 are also further out in the oceanic conditions, being the furthest north of the group.

Sites 10 and 26 are the only untrawled sites in this group. Site 26 had *S. robusta*, as the most abundant species (36% of bycatch), as did the trawled site 12 (30% of bycatch). Site 10 had moderately abundant *L. argus* (12% of bycatch), but is otherwise fairly similar in bycatch proportions to site 11. Cluster analysis does not indicate any difference between trawled and untrawled sites in this group.

Distribution of most abundant fish species

Eight of the 20 most abundant species (Table 3.3) had an extremely widespread distribution in Shark Bay, and were found in 92% to 100% of sites (in bold). Seven species were fairly widespread being found at 81% to 88% of sites (in italic). The remaining 5 species were found in 73% to 77% of sites.

Table 3.3 Twenty most abundant fish species in Shark Bay in 2002 and 2003.

	Scientific name	Common name	Av no:/nm
1	*Paramonacanthus choirocephalus*	Hair-finned Leatherjacket	447
2	*Upeneus asymmetricus*	Asymmetrical Goatfish	438
3	*Pelates quadrilineatus*	Trumpeter	392
4	*Lethrinus genivittatus*	Threadfin Emperor	303
5	*Torquigener pallimaculatus*	Orange-spotted Toadfish	152
6	*Paracentropogon vespa*	Bullrout	146
7	*Pseudocalliurichthys goodladi*	Goodlad's Stinkfish	136
8	*Colurodontis paxmani*	Paxman's Leatherjacket	106
9	*Pentapodus vitta*	Western Butterfish	105
10	*Sillago robusta*	Robust Whiting	101
11	*Leiognathus leuciscus*	Whipfin Ponyfish	93
12	*Saurida undosquamis*	Large-scaled Lizardfish	83
13	*Engyprosopon grandisquama*	Spiny-headed Flounder	78
14	*Apistus carinatus*	Long-finned Waspfish	51
15	*Gerres subfasciatus*	Roach	50
16	*Lethrinus punctulatus*	Blue-spotted Emperor	48
17	*Monacanthus chinensis*	Fan-bellied Leatherjacket	47
18	*Upeneus tragula*	Bar-tailed Goatfish	45
19	*Sillago burrus*	Trumpeter Whiting	42
20	*Parapercis nebulosa*	Red-barred Grubfish	31

3.3.1.6 Permanova – invertebrate species abundance

Site, season and their interaction was significant for invertebrate species abundance in Shark Bay (Table 3.4).

Table 3.4 Permanova results for invertebrate species in Shark Bay biodiversity trawls (R^2 = 0.89). Only observations for 2003 were included in this analysis. Type 3 sum of squares have been presented.

Source	df	SS	MS	Pseudo-F	P(perm)
Site	25	295060	11802	28.621	< 0.01
Season	2	52053	26027	63.116	< 0.01
Site x Season	50	119250	2384.9	5.7836	< 0.01
Residuals	137	56494	412.36		

3.3.1.7 *Shark Bay invertebrate cluster and MDS analysis and correlation with environmental variables*

For this analysis, abundance data from the end of season survey in 2002, and the start, middle and end of season surveys for 2003 were included. The number of invertebrate species used for the analysis was reduced from 360 to 288 due to the exclusion of species only found in the depletion trawls, daytime trawls and those that were extremely rare (found at one site only).

Divisive clustering analysis of the abundance of invertebrate species indicates four main groupings of sites in Shark Bay (Figure 3.12). MDS principal component analysis confirms four main invertebrate species groupings for sites (Figure 3.13).

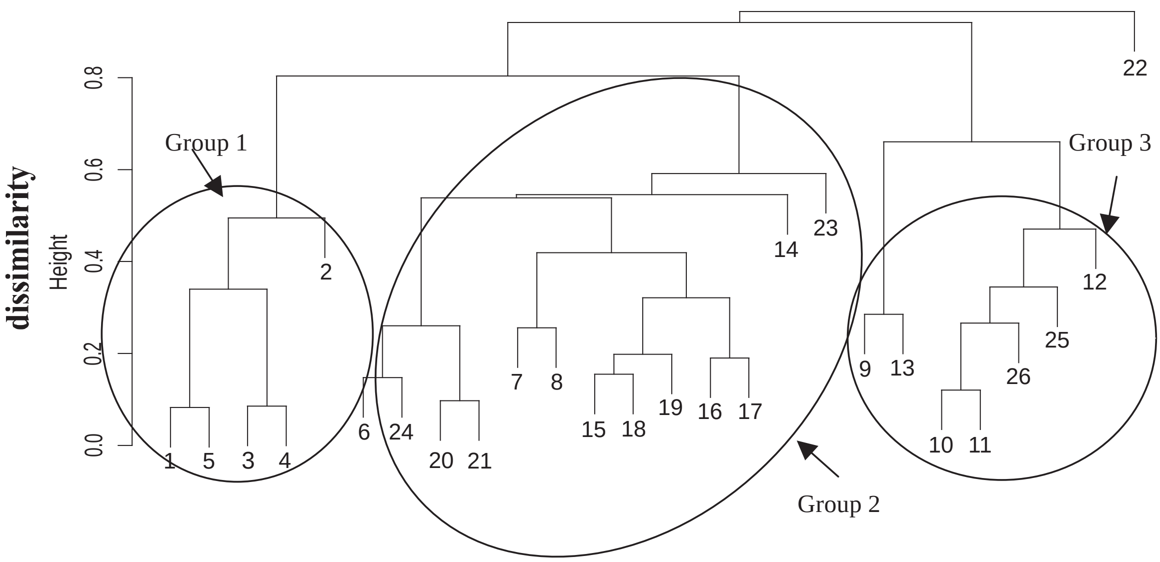

Figure 3.12 Divisive cluster analysis of Shark Bay invertebrate abundance data based on four surveys (October 2002 to October 2003).

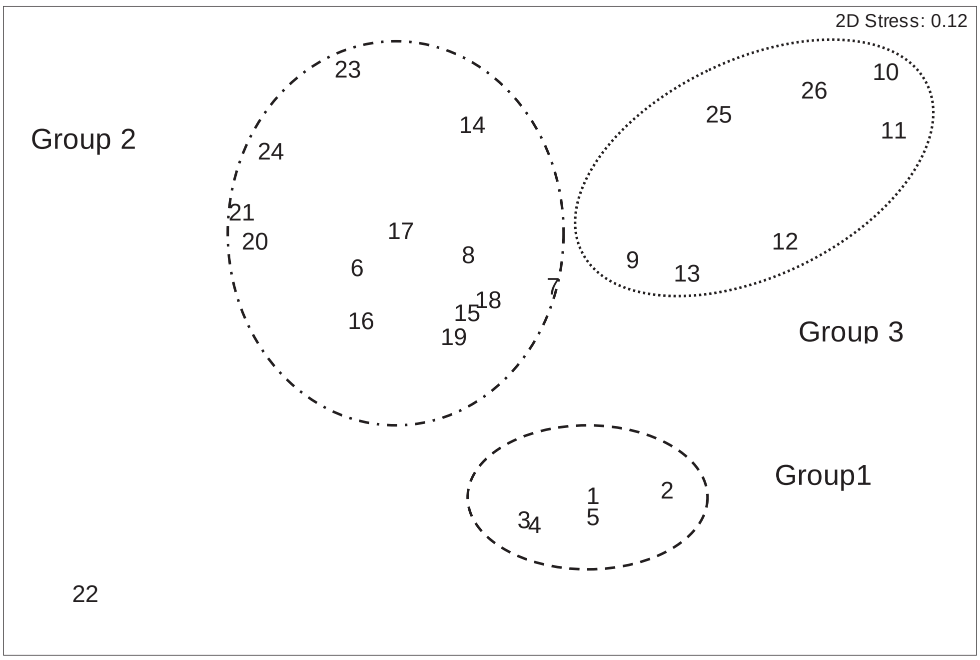

Figure 3.13 MDS plots of invertebrate species assemblages in Shark Bay (dashed lines indicate groupings defined by cluster analysis).

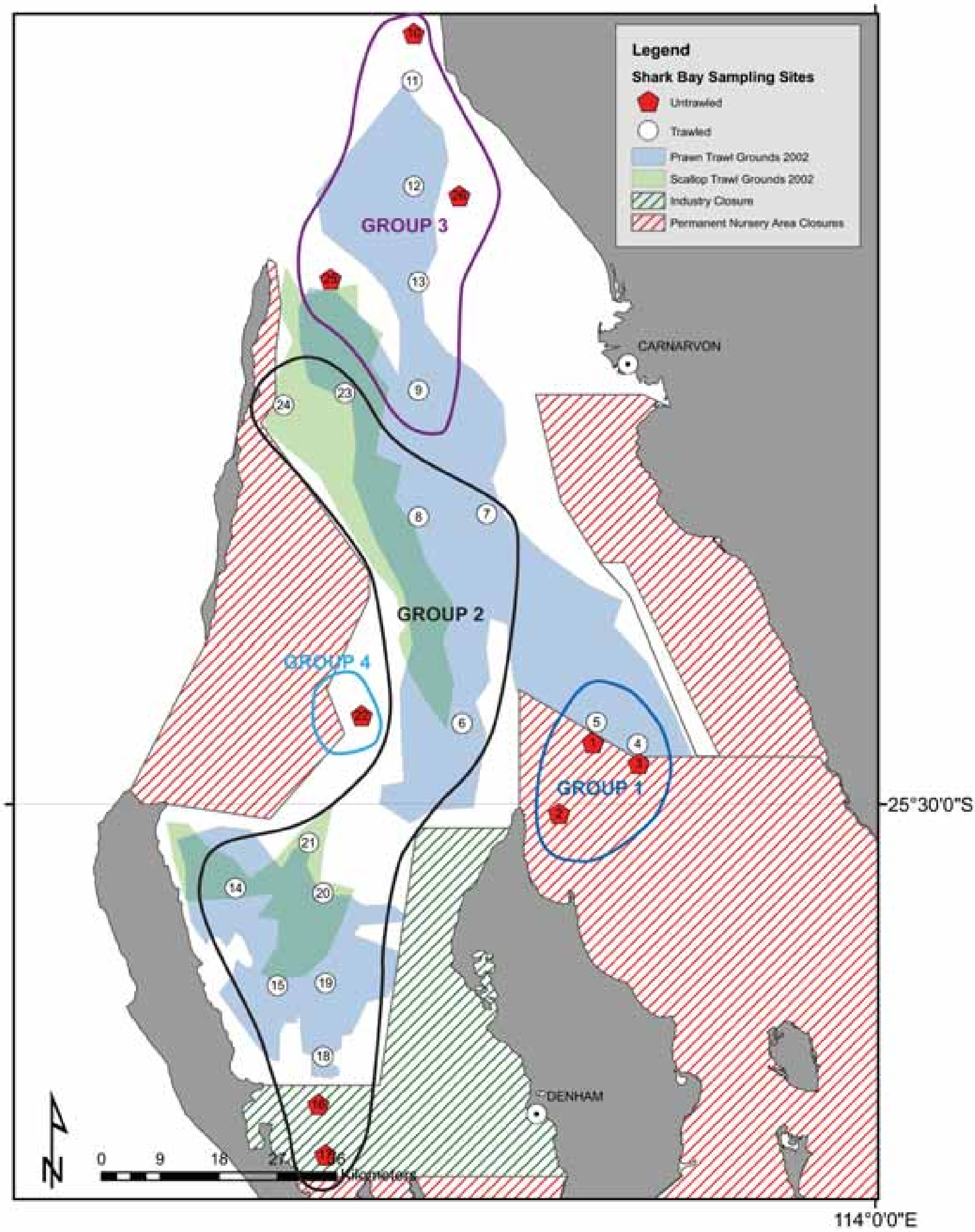

Figure 3.14 Site groupings for cluster analysis of invertebrate abundance data in Shark Bay.

3.3.1.8 Linking abundance data to environmental measures

For invertebrate assemblages the BEST procedure showed similarities between the environmental variables of salinity (Figure 3.15) and water temperature (Figure 3.16). Sites in Group 1, had higher salinities and cooler water temperatures whereas Groups 2 and 3 were similar except for sites 16 and 17 in southern Denham Sound with higher salinities.

The Spearman rank correlation between salinity and temperature matrix and the invertebrate abundance matrix was 0.51 indicating only a moderate correlation for invertebrate species.

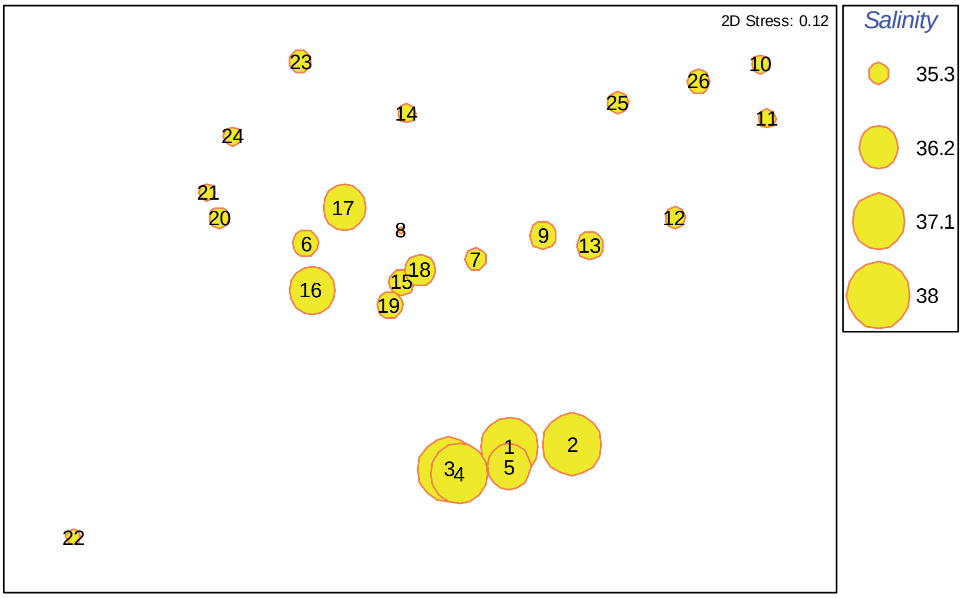

Figure 3.15 MDS of invertebrate species abundance as the 26 sites superimposed with salinity (ppt).

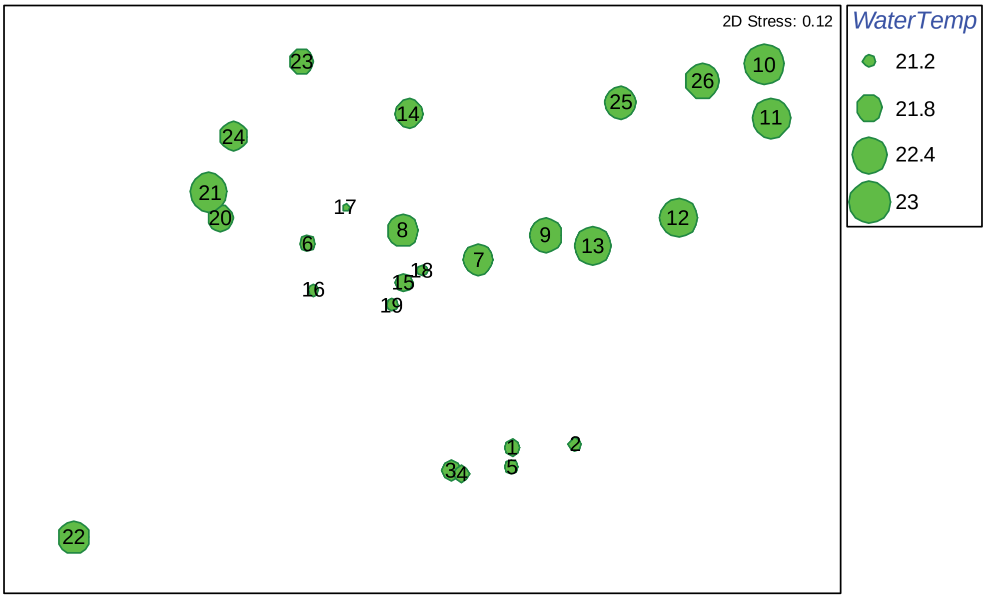

Figure 3.16 MDS of invertebrate species abundance as the 26 sites superimposed with temperature (ºC).

3.3.1.9 Shark Bay Invertebrate Species Richness, Evenness and Diversity

There were significant differences in the Margalef's richness, Pielou's evenness, Shannon's diversity and Simpson's diversity indices of the three Groups ($p < 0.01$) (Figure 3.17). Season was found to be a significant factor for the species richness ($p < 0.01$). Salinity and water depth were found to have significant effect on the Shannon's diversity index ($p < 0.01$, $p < 0.01$) and the Simpson's diversity index ($p < 0.01$, $p < 0.01$). Water depth was found to have significant contribution to the variations in species evenness ($p < 0.01$). Due to the significant difference in habitat type (i.e. abundant seagrass) and distinct invertebrate assemblage at site 22, it was excluded from the diversity tests.

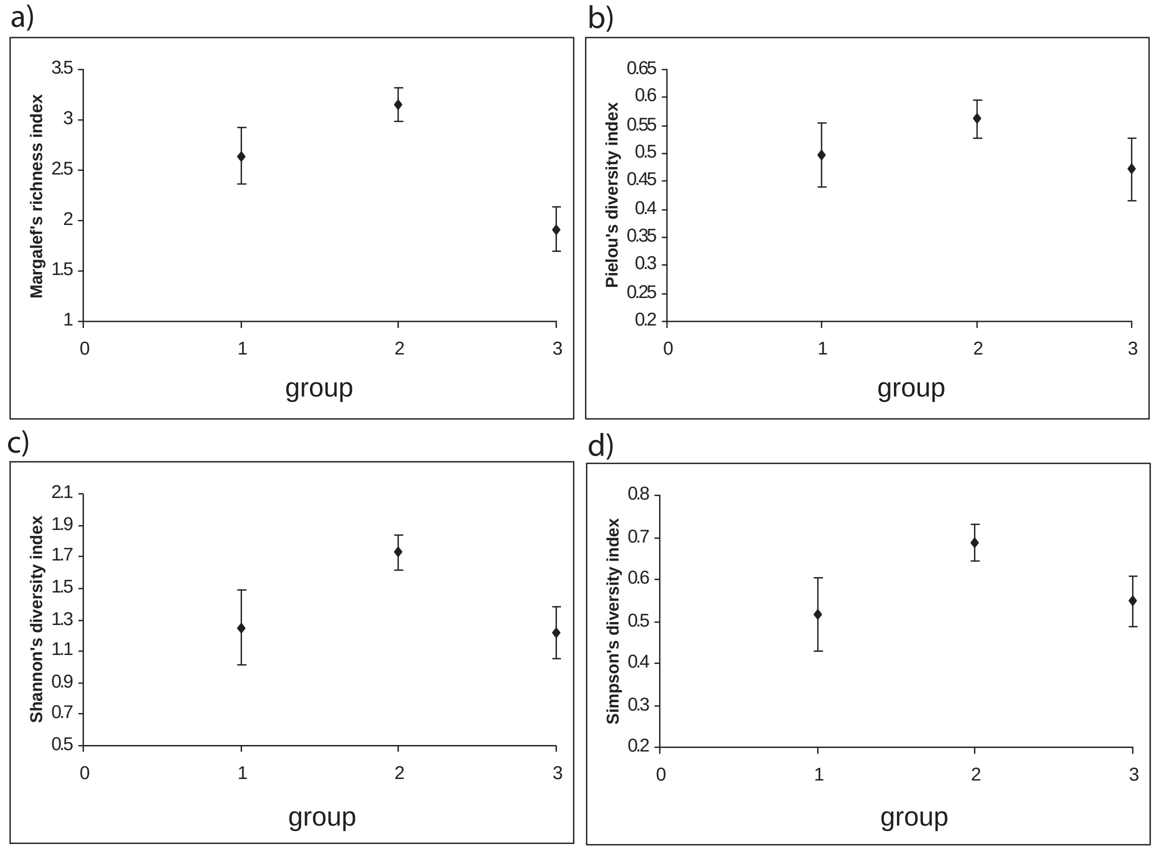

Figure 3.17 Least squares means with 95% confidence interval for the 3 groups identified from the invertebrate assemblage in Shark Bay for a) Margalef's richness index b) the Pielou's evenness index c) the Shannon's diversity index d) the Simpson's diversity index.

For any of the invertebrate assemblages, test results indicated that there were no significant differences in the diversity measures for the trawled and untrawled sites within Groups 1 and 2 (Figure 3.18). However there were significant differences in the species richness ($p < 0.01$), the Shannon's diversity index ($p < 0.01$) and Simpson's diversity index ($p < 0.01$) for the trawled and untrawled sites within Group 3 with trawled sites having higher indices. Water depth was found to have significant effect on these three diversity measures ($p < 0.01$).

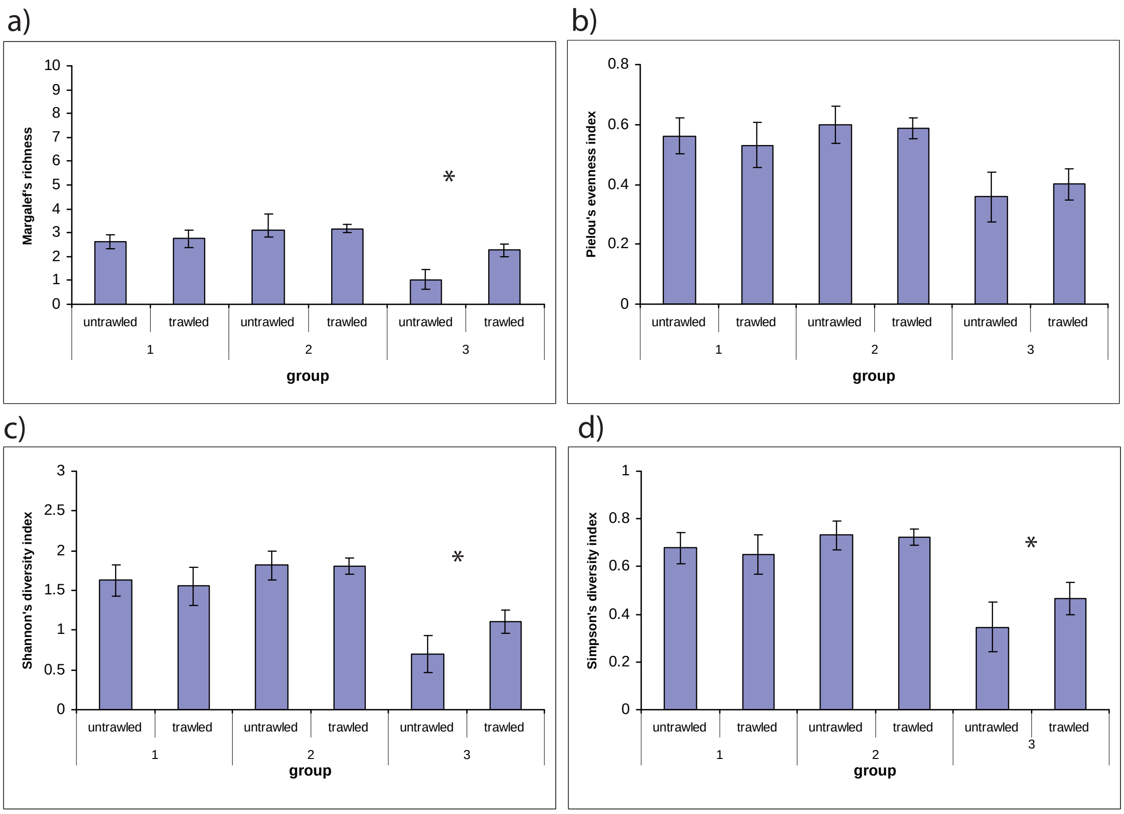

Figure 3.18 Least squares means for untrawled / trawled sites within a group identified from the invertebrate abundances with 95% confidence interval in Shark Bay of; a) Margalef's richness index, b) evenness index c) Shannon's diversity index and d) Simpson's diversity index. *Indicates significant differences between trawled and untrawled sites.

Description of invertebrate groupings

Group 1 – Sites 1, 2, 3, 4, 5

The five sites in Group 1 had a low abundance at sites 3 and 4 (365 to 375 invertebrates per nautical mile), and a moderate abundance at sites 1, 2 and 5 (470 to 520 invertebrates per nautical mile) (Figure 3.19). These sites verge on the metahaline waters (salinity 40 to 56‰) of Hopeless Reach in the southeastern part of Shark Bay. Individual richness values for each sample at each site for each time period is illustrated in Figure 3.20.

For all sites the five most abundant species at each site comprised between 73% and 83% of the total abundance, and the 10 most abundant species comprised between 83% and 90% of the total abundance.

The five sites in Group 1 had moderate species richness, with between 23 and 29 species per site. The lowest was site 2 (23 species) with consistently low species richness (Figure 3.20) and the highest were sites 3 and 4 (29 species). These five sites were dominated by crustaceans. All sites had the blue swimmer crab *(Portunus pelagicus)* and brown tiger prawns *(Penaeus esculentus)* among the top five most abundant species. A small commercial blue swimmer crab trap fishery exists in this part of Shark Bay. Site 2 differed slightly from the others in the cluster analysis. Sites 1, 3, 4 and 5 had the western king prawn *(Penaeus latisulcatus)* among the five most abundant species (11% to 21% of the catch), whereas it only represented under 3% of the abundance at site 2. The endeavour prawn *(Metapenaeus endeavouri)* and a sea slug (*Philine* species) were among the most five abundant species in three of these sites, but were much less abundant at site 2. Site 2 is further distinguished by the presence of abundant heart urchins *(Echinocardium cordatum)* not present at the other sites, and coral prawns *(Metapenaeopsis species)* and a small swimmer crab *(Portunus hastatoides)* that were less common at the other sites.

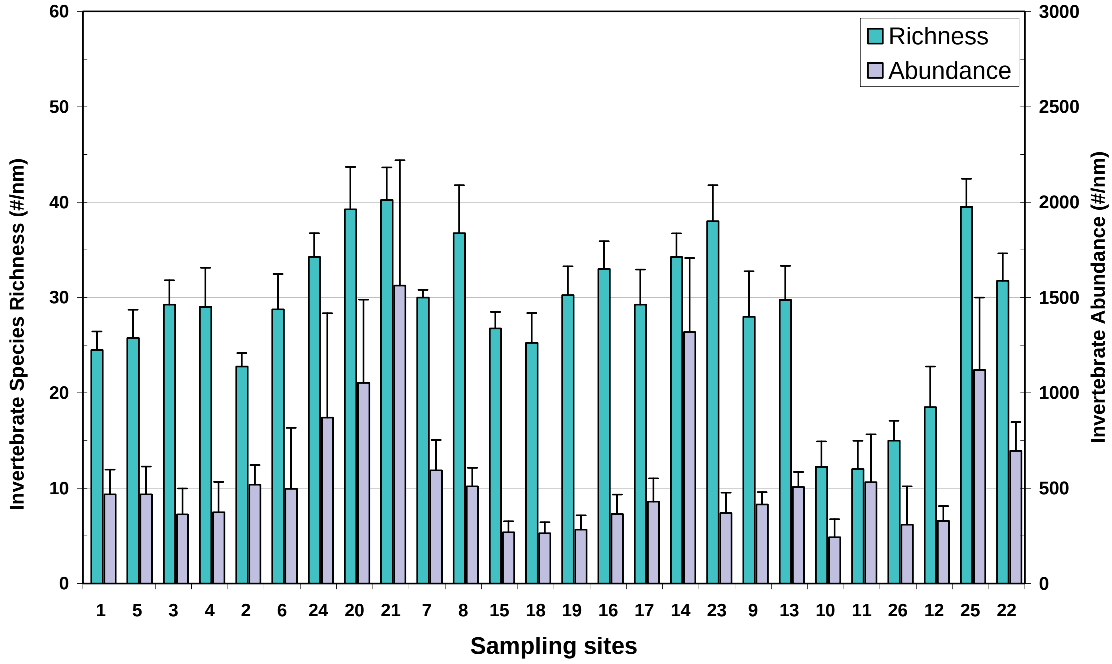

Figure 3.19 Shark Bay invertebrate species richness (mean ± SE of four trips) and abundance (mean ± SE of four trips) at each survey site. Sites ordered according to cluster groupings. (Group 1: 1 to 2, Group 2: 6 to 23, Group 3: 9 to 25, Group 4: 22 only).

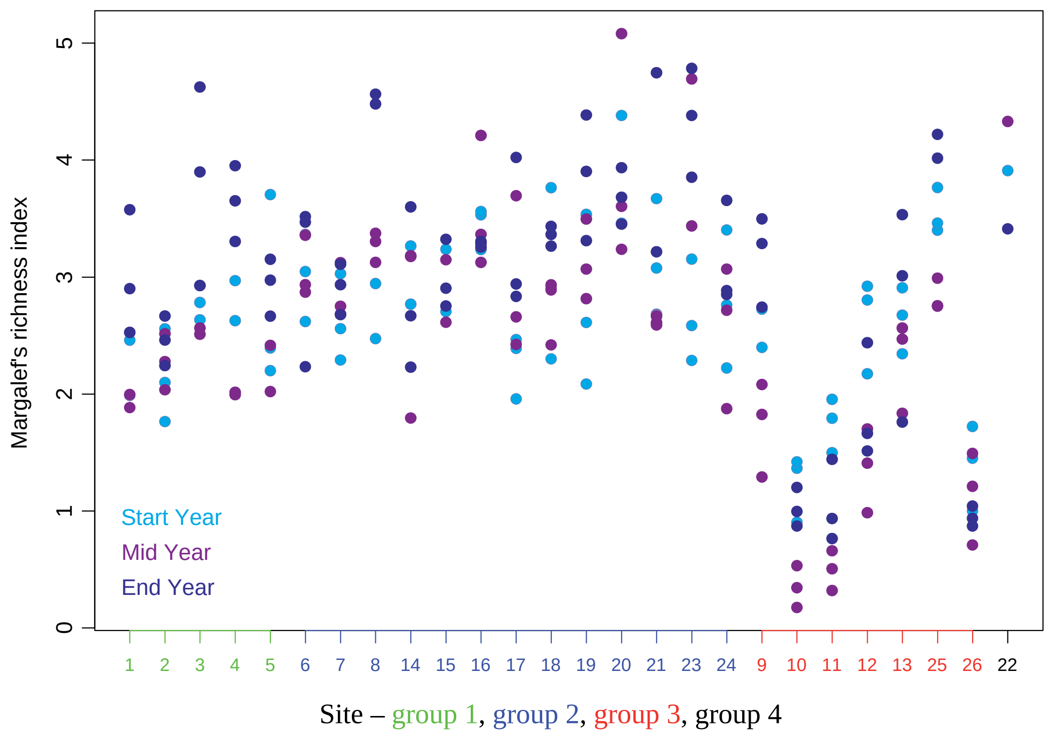

Figure 3.20 Invertebrate species richness indices for individual samples at each site per season in Shark Bay.

Group 2 – Sites 6, 24, 20, 21, 7, 8, 15, 18, 19, 16, 17, 14, 23

The 13 sites in Group 2 cover a wide latitudinal range in Shark Bay. Out of this group, sites 15, 16, 17, 18 and 19 had the least abundance of invertebrates (264 to 430 individual per nautical mile). These sites form a small sub-group within the main cluster. As with the sites in Group 1, they are in close proximity to the metahaline waters of Freycinet Reach in the south western parts of Shark Bay. Sites 6, 7 and 8 had a moderate abundance (500 to 595 individuals per nautical mile) and are in the central trawl grounds. Sites 14, 20 and 21 in Denham Passage, and site 24 close to the eastern shores of Bernier Island, had a very high abundance of individuals (870 to 1565 individuals per nautical mile).

For all sites, the five most abundant species comprised between 56% and 89% of the total abundance, and the 10 most abundant species comprised between 73% and 94% of the total abundance.

Sites in Group 2 had medium to high species richness. The greatest numbers of invertebrate species (33 to 40 species per site) were found at sites 8, 23, 24, 14, 16, 20 and 21. These sites were in the northern and southern sections of scallop trawl grounds, plus site 16 that is further south in the untrawled section of Denham Sound. Moderate species numbers (25 to 30 species per site) were recorded from sites 6, 7, 15, 19, 18 and 17. Sites 6 and 7 are in the central prawn trawl grounds and the rest are in the southern reaches of Denham Sound.

This large group is split into 4 sub-groups. Sites 14 and 23 are different from all the rest and distinct from each other. Sites 6, 24, 20 and 21 cluster separately from all the remaining sites.

Sites 6, 24, 20 and 21 all had large quantities of the saucer scallop *Amusium balloti* (41% to 75% of the total abundance) that reflects their location in the commercial scallop trawl grounds. These sites had abundant *A. balloti* and *P. latisulcatus* in common with sub-group sites 15, 18, 19, 16 and 17, but differed in having abundant ascidians (unidentified species), small urchins (*Temnotrema elegans*), slipper lobsters (*Eduarctus martensi*), turban shells (*Turbo haynesi*) and cuttlefish (*Sepia species*) among the 10 most abundant species.

Sites 15, 18, 19, 16 and 17 had *P. latisulcatus*, *A. balloti*, a fan scallop (*Annachlamys flabellata*), and all except site 19 had *Metapenaeopsis* species among the five most abundant species. These sites are in the southern reaches of Denham Sound. Although sites 16, 17 and 18 are untrawled, they cluster closely with the trawled sites 15 and 19, with a similar suite of prawns, crabs, scallops and some seas slugs dominating the abundant species. Sites 7 and 8 differed slightly from the above sites, and had *P. latisulcatus* and *Metapenaeopsis* species, and site 8 had *A. balloti* in common with this sub-group of sites. These two sites are located in the central prawn trawl grounds.

Sites 14 and 23 had moderate species richness with 71 and 78 species per site respectively. Site 14 was distinguished by huge quantities of ascidians (*Herdmania pallida*) that constituted 21%, and unidentified ascidians that made up a further 9%, of the total abundance at the site. There were abundant *P. latisulcatus*, *Metapenaeopsis* species, scallops and small crustaceans in common with the majority of other sites in Group 2. Site 23 differed in having moderate quantities of coral crabs (*Charybdis feriata*) (10%) and *E. martensii* (6%), besides abundant *Metapenaeopsis* species, scallops, small crustaceans and *Sepia* species.

Group 3 – Sites 9, 13, 10, 11, 26, 12, 25

Three of the seven sites in this group (10, 12 and 26) had extremely low invertebrate abundance (245 to 330 individuals per nautical mile), 3 sites (9,11 and 13) had moderate abundance (415 to 530 individuals per nautical mile) and site 25 had very high abundance (1,120 individuals per nautical mile). These sites are in the northern part of Shark Bay centred around Geographe Passage.

For all sites the five most abundant species comprised between 80% and 94% of the total abundance, and the 10 most abundant species comprised between 88% and 98% of the total abundance.

These sites ranged from low species richness at sites 10, 11, 12 and 26 (12 to 19 species per site) to moderate to high species richness at sites 9, 13 and 25 (28 to 40 species per site). Sites 10, 11 and 26 in the northern most part of Shark Bay had consistently low species richness (Figure 3.20).

All sites in Group 3 had *Metapenaeopsis* species as the most abundant species comprising between 27 % and 79% of the total abundance. Also common to all sites were *P. latisulcatus,* but these comprised between only 2% and 17% of the total abundance.

Sites 9 and 13 differed slightly from the rest with their abundant species dominated by coral prawns (*Metapenaeopsis* species and *Metapenaeopsis crassissima*), *P. latisulcatus, P. esculentus, P. pelagicus* and western school prawns (*Metapenaeus dalli*). These two sites are in the northern prawn trawl grounds.

The remaining five sites (10, 11, 26, 12 and 25) only had coral prawns and *P. latisulcatus* in common. Other abundant species at some of these sites were the coral prawn (*M. crassissima*), southern rough prawn (*Trachypenaeus curvirostris*), *P. latisulcatus, P. pelagicus,* small swimmer crabs, moon jellies (*Aurelia* species), brittle stars (*Ophiothrix viridialba*) and moon crabs (*Matuta granulosa).* Sites 10 and 26 are untrawled but are not clearly distinct from the other sites. Among the 10 most abundant species only found at these two sites were ascidians, hermit crabs, mantis shrimps (*Oratosquilla oratoria*), squid (*Photololigo* species) and southern dumpling squid (*Euprymna tasmanica*).

Group 4 – Site 22

Site 22 is clearly different from all other sites in Shark Bay. It had low abundance (310 individuals per nautical mile), and high species richness (32 species). It is located in the central west side of the gulf adjacent to Naturaliste passage and has reasonably dense stands of seagrass.

Instead of the abundant species being dominated by crustaceans, they comprised 35% holothurians (*Colochirus quadrangularis* and *C. crassus*), 20% ascidians (unidentified species), 10% heart urchins (*Breynia desorii*), 10% swimmer crabs (*Thalamita sima, Portunus pubescens, P. rubromarginatus*), 3% urchins (*T. elegans*), 2% masked burrowing crab (*Gomeza bicornis*) and 2% hermit crabs.

Distribution of most abundant invertebrate species

Six of the 20 most abundant invertebrate species (Table 3.5) were found at the majority of sites (92% to 100%) in Shark Bay (in bold). Nine species occurred in 81% to 88% of sites (in italic). All the remaining species except for *Herdmania pallida* were recorded from 62% to 77% of sites. The ascidian *H. pallida* was only found at 4% of sites, but is included in this list because it was extremely abundant at site 14.

Table 3.5 Twenty most abundant invertebrate species in Shark Bay in 2002 and 2003.

	Scientific name	Common name	Av no:/nm
1	*Metapenaeopsis* species	Coral prawn	441
2	*Amusium balloti*	Ballot's Saucer Scallop	403
3	*Penaeus latisulcatus*	Western King Prawn	231
4	*Annachlamys flabellata*	Fan Scallop	159
5	*Portunus pelagicus*	Blue Swimmer Crab	139
6	*Penaeus esculentus*	Brown Tiger Prawn	90
7	*Portunus rubromarginatus*	Crab	87
8	*Portunus tenuipes*	Crab	61
9	*Metapenaeopsis crassissima*	Coral Prawn	53
10	*Ascidiacea*	Ascidians, unidentified	49
11	*Herdmania pallida*	Ascidian	42
12	*Philine species*	Sea slug	40
13	*Metapenaeus dalli*	Western School Prawn	38
14	*Metapenaeus endeavouri*	Endeavour Prawn	36
15	*Colochirus quadrangularis*	Holothurian	34
16	*Eduarctus martensi*	Slipper Lobster	33
17	*Thalamita sima*	Crab	19
18	*Colochirus crassus*	Holothurian	19
19	*Portunus hastatoides*	Crab	18
20	*Charybdis feriata*	Coral Crab	12

3.3.1.10 Shark Bay fish and invertebrates

Divisive clustering analysis of the combined fish and invertebrate abundance and richness data results in five main groups with some sub-grouping (Figure 3.21). These are most closely allied with the fish groupings. Group 1 consists of five sites in the south east arm of Shark Bay. Group 2 encompasses six sites in Denham Sound. Group 3 includes seven sites in the central west region covering the scallop trawl grounds and central prawn trawl grounds. Group 4 includes seven sites in the northern part of Shark Bay, and Group 5 is site 22 alone in the central west (Figure 3.22).

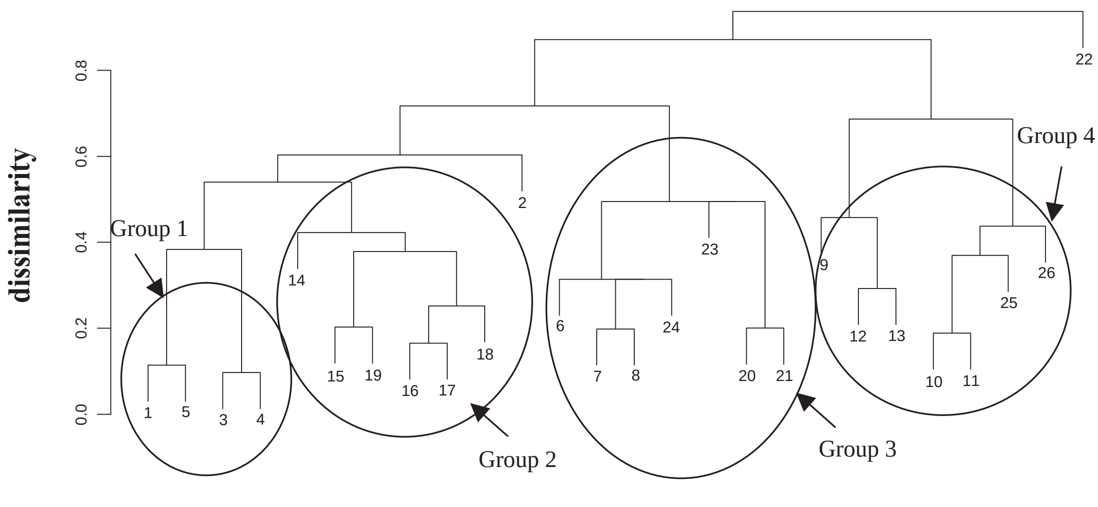

Figure 3.21 Divisive clustering of sites in Shark Bay for fish and invertebrates combined.

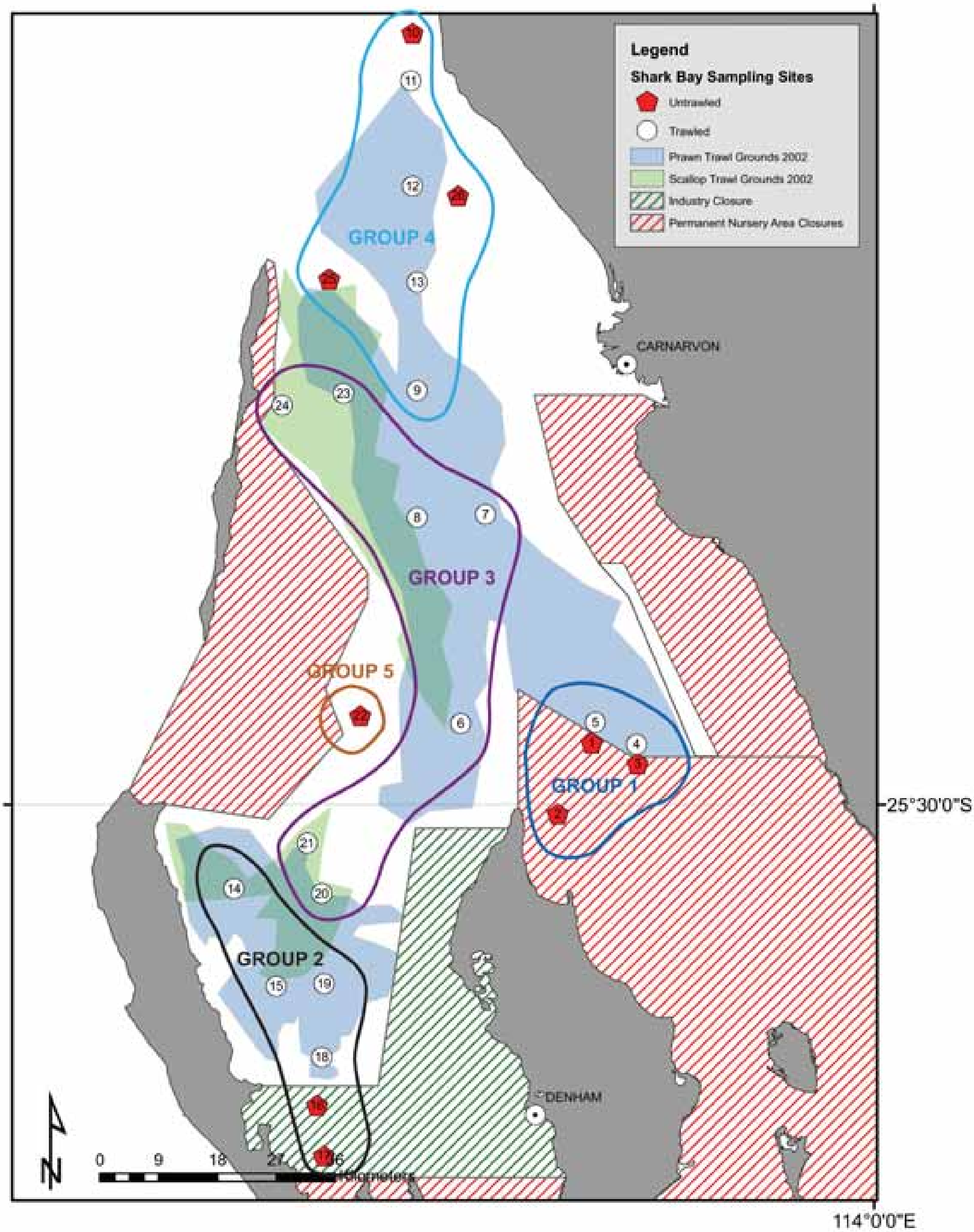

Figure 3.22 Grouping of sites in Shark Bay for fish and invertebrates combined.

Groups 1, 2 and 4 have a mixture of trawled and untrawled sites, while group 3 are all trawled sites, and the group 5 site is untrawled. Group 1 has 2 distinct sub-groups. Sites 1 and 3 (untrawled), and sites 4 and 5 (trawled) are tightly clustered together, whereas site 2 (untrawled) is quite separate from them, despite being in the same locality in the south east. All these sites had a low to moderate abundance of fish and invertebrates and low to moderate species richness (30 to 38 species per site). As indicated in the separate analyses, site 2 had a different assemblage of both fish and invertebrates from sites 1, 3, 4 and 5 even though depth, salinity and water temperature were similar in all these groups.

Group 2 contains the six sites in Denham Sound. These sites generally had a low to moderate abundance of fish and invertebrates, except that site 15 had a high abundance of fish and site 14 a very high abundance of invertebrates. The sites ranged from low to high species richness, with site 18 being low (33 species per site), sites 15, 17 and 19 medium species richness (38-39 species per site) and sites 14 and 16 having high species richness (40-41 species per site).

Group 3 sites 6, 7 and 8 had moderate abundance of fish and invertebrates and sites 20, 21, 23 and 24 had the highest abundance of fish and invertebrates in the whole of Shark Bay (except for low invertebrate abundance at site 23). Sites 6, 7 and 8 are subject to heavy prawn trawl impacts, which are likely to result in moderate abundance. Sites 20, 21, 23 and 24 however, despite being in the scallop trawl grounds are influenced by oceanic waters that are a likely source of new recruits and additional species. Fish and invertebrate species richness was medium to high with sites 6 and 7 having medium species richness (36-39 species per site) and the remaining sites having high species richness (40-56 species per site).

Group 4 sites all had low to moderate abundance, except for a high abundance of invertebrates at site 25. There is a general reduction in abundance and species richness as sites get deeper further north. Species richness at the more northerly sites (10, 11, 12, 13 and 26 was very low (19-33 species per site) with sites 9 and 25 having moderate species richness (35-42 species per site).

Group 5 is site 22 that is quite distinct from all other sites in Shark Bay, with respect to both fish and invertebrate assemblages. This is a shallow site in Shark Bay where wireweed proliferates and forms a different habitat from all other sites sampled. Species richness was moderate for both fish and invertebrates (38 species per site), while abundance of fish was high and invertebrates was low.

3.3.1.11 Shark Bay reptiles

Since bycatch reduction devices were not employed for this study, marine reptiles were occasionally caught in the nets. Only a small number of turtles and sea snakes were caught over the five sampling trips to Shark Bay.

A total of three loggerhead turtles (*Caretta caretta*) were caught in Shark Bay, two at the end of season in October 2002 at site 18 in Denham Sound and site 11 near Quobba, and one at the start of trawl season in February 2003 at site 15 in Denham Sound.

A total of six individuals of two species of sea snakes were caught in Shark Bay. Single specimens of the Bar-bellied sea snake (*Hydrophis elegans*) were recorded from site 11 in October 2002, site 16 in February 2003, site 13 in July 2003, and sites 16 and 21 in March 2004. One specimen of the Shark Bay sea snake (*Aipysurus pooleorum*) was caught in the northern prawn trawl grounds in March 2003.

All turtles were in good condition and returned to the water as quickly as possible. Three sea snakes were damaged when trapped in the mesh of the net, but those inside the net were usually in good condition and were returned to the water alive.

3.3.1.12 Shark Bay threatened species

Some of the marine fish species caught as bycatch in Shark Bay are included in the 'Australian Threatened and Potentially Threatened Marine and Estuarine Fishes' list developed by the NSW Fisheries Research Institute and Fish Section of the Australian Museum (Pogonoski et al. 2002) (Table 3.6).

Table 3.6 Shark Bay bycatch species listed under the Australian Threatened Marine and Estuarine Fishes list (Pogonoski et al. 2002). LR (nt) = Lower Risk (near threatened), LR (lc) = Lower Risk (least concern).

Common name	Scientific name	No: caught	IUCN status
Dusky Whaler Shark	*Carcharhinus obscurus*	1	LR (nt)
Sandbar Shark	*Carcharhinus plumbeus*	1	LR (nt)
White-spotted Shovelnose Ray	*Rhychobatus australiae*	10	LR (lc)
White-spotted Eagle Ray	*Aetobatus narinari*	1	LR (lc)
Western Spiny Seahorse	*Hippocampus angustus*	17	LR (lc)
False-eyed Seahorse	*Hippocampus biocellatus*	29	LR (nt)
Flat-face Seahorse	*Hippocampus planifrons*	4	LR (lc)
Alligator Pipefish	*Syngnathoides biaculeatus*	1	LR (lc)

The sharks and rays were identified as soon as they were brought up and returned to the water as quickly as possible. They appeared to be in good condition. A small number of the Syngnathids were kept for formal identification, and the rest were returned to the water quickly. These species also appeared to be fairly resilient to trawling, however, their fate on return to the water was unknown.

3.3.1.13 Shark Bay fish diet types

For the 241 species of fish recorded from the 26 survey sites in Shark Bay, the diets were determined from published literature. In some cases it was difficult to find sufficient information, but an informed estimate of diet was made (Appendix 3.1). These diet categories are not definitive, because many fish are opportunistic and will eat a wide array of available food items of the appropriate size. It was considered diet preferences may provide insight into fish species assemblages.

The majority of fish species in Shark Bay are carnivores (around 77%), with much smaller proportions of omnivores (10%) and planktivores (11%), and very few herbivores (2%) (Figure 3.23). These proportions are fairly typical of many marine assemblages according to Bone et al. (1995), who reports that out of 600 marine fish species examined (location not specified) that 85% are carnivorous and 6% are herbivorous. Helfman et al. (1997) also state that herbivory is rare in marine fish assemblages, with 5 to 15% herbivorous fish in temperate marine communities, but up to 30 to 50% in coral reef communities. It is not surprising that there are small numbers of herbivores in trawled and adjacent areas, since algae and seagrasses are limited in these habitats. Omnivores would be expected to comprise a significant proportion of the assemblage in trawl habitats because there is plenty of animal matter and usually a lesser quantity of plant material to scavenge from bycatch discard, plus abundant detritus from the disturbed seabed.

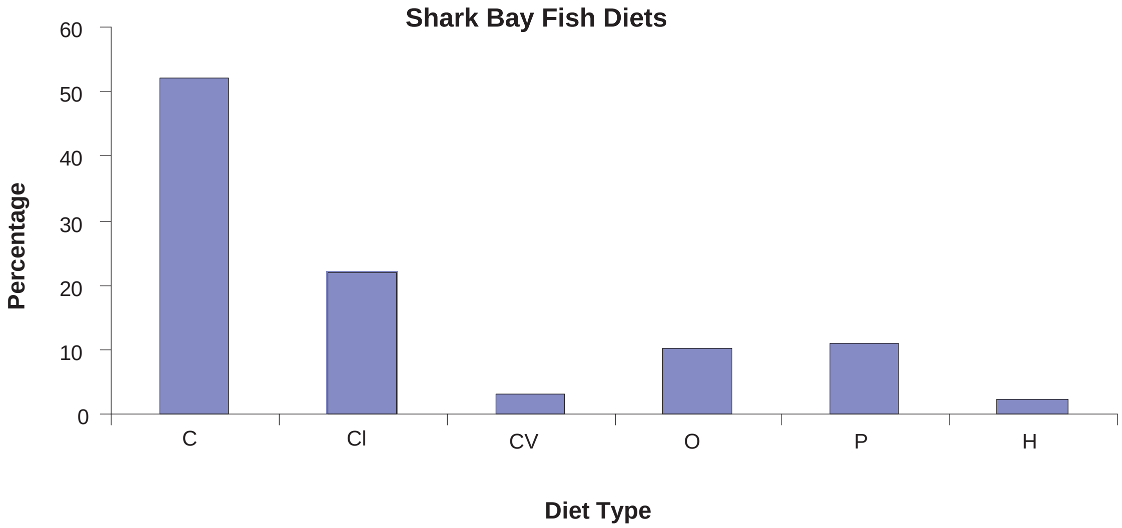

Figure 3.23 Shark Bay fish diets. C = general carnivore, CI = carnivore of invertebrates, CV = carnivore of vertebrates, O = omnivore, P = planktivore, H = herbivore.

3.3.1.14 Shark Bay fish tropical/subtropical/temperate species

According to Hutchins (1994), tropical species are defined as those species that occur mostly to the north of the Tropic of Capricorn (23.5°S), although many species have small numbers of individuals that occur further south. Many of these species are widespread throughout the Indo-West Pacific region. Subtropical species are found on the west coast, mainly between 23.5°S and 34°S. Many of these species are endemic to Western Australia. Warm temperate species are found in the south west of the state, with some species ranging eastwards along the southern coast. They generally range between 34°S and 45°S.

Of the 241 fish species recorded from Shark Bay trawls, 79% are tropical, 13% subtropical, 7% warm temperate, and 1% wide ranging between warm-temperate and tropical regions. Of these, approximately 10% (23 species) are endemic to Western Australia. This differs slightly from the Shark Bay reef fish fauna of South Passage, Dirk Hartog Island, Boat Haven Loop, Wilds Islands, Denham and Monkey Mia surveyed by Hutchins (1994). In these surveys 309 species were recorded of which 81% were tropical, 8% subtropical and 7% warm-temperate species. The main difference being that the trawl grounds had around 5% more sub-tropical species compared with the reef habitats.

3.3.2 Exmouth Gulf and Onslow

A total of 298 fish and 365 invertebrate species (see Appendix 3.2) were recorded from all three trawl surveys (at the start, middle and end of season) in Exmouth Gulf and Onslow during 2004. These were standard night time trawls at 25 selected sites (18 in Exmouth Gulf and 7 in Onslow).

3.3.2.1 Exmouth Gulf and Onslow fish factor analysis

Factor analysis for fish abundance indicates two groups of fish families account for 53% of the variability in the data. The first group of eight families represent 38% of the variance and the second group with 2 families represent 15% of the variance (Table 3.7). For the grouping of sites, the factor analysis indicates a declining trend between time periods and the factor analysis separates each site grouping (Figure 3.24).

Table 3.7 Factor analysis of fish families in Exmouth Gulf and Onslow showing the families with the highest scores on each factor.

Factor 1	Factor 2
Bothidae	Carangidae
Dactylopidae	Tetraodontidae
Lethrinidae	
Monacanthidae	
Pegasidae	
Pinguipedidae	
Platycephalidae	
Pomacentridae	

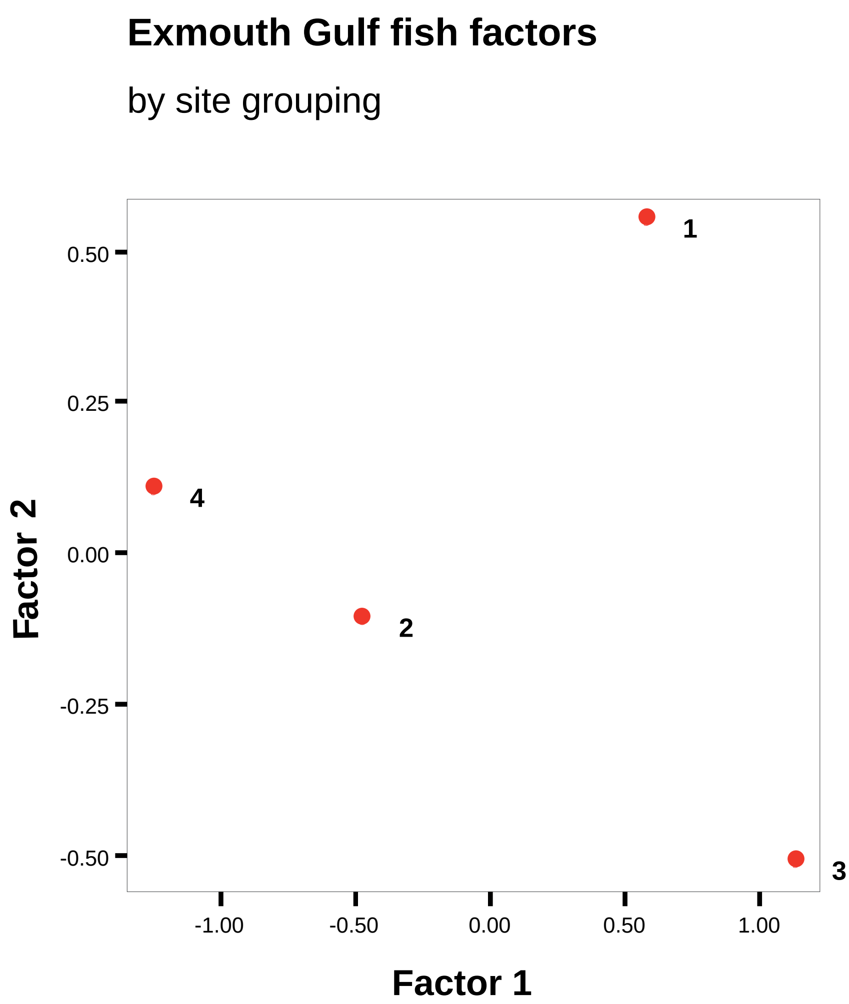

Figure 3.24 Factor analysis of mean abundance of fish Families by site groupings in Exmouth Gulf and Onslow.

3.3.2.2 Permanova – fish species abundance

Site, season and their interaction was significant for fish species abundance in Exmouth Gulf and Onslow (Table 3.8).

Table 3.8 Permanova results for fish species in Exmouth biodiversity trawls (R^2 = 0.85). Type 3 sum of squares have been presented.

Source	df	SS	MS	Pseudo-F	P(perm)
Site	24	273330	11389	23.874	< 0.01
Season	2	32387	16194	33.946	< 0.01
Site x Season	48	91670	1909.8	4.0034	< 0.01
Residuals	143	68216	477.04		

3.3.2.3 *Exmouth Gulf and Onslow fish divisive cluster and MDS analysis and correlation with environmental variables*

The total number of species was reduced from 298 to 289 when those species that were extremely rare (i.e. single individual in one site) were excluded.

Divisive clustering analysis of the abundance of fish species in Exmouth Gulf and Onslow indicates four main groupings of sites (Figure 3.25). Each grouping has a mixture of trawled and untrawled sites. MDS principal component analysis tends to indicate sites in the cluster Groups 1 and 2 are similar (Figure 3.26).

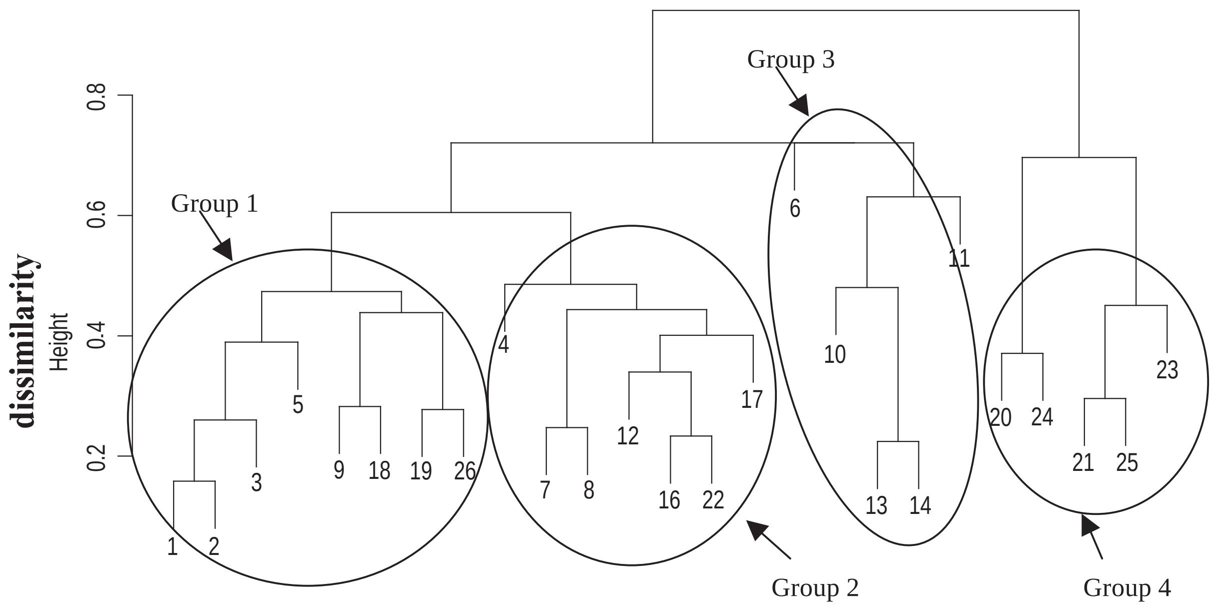

Figure 3.25 Divisive cluster analysis of Exmouth Gulf and Onslow fish abundance data based on all three surveys.

Group 1 contains 8 sites, 5 of which are in the southern part of Exmouth Gulf, along with one site close to Exmouth townsite, and two sites in the offshore northeast region towards Onslow.

Group 2 encompasses 7 sites that sit in a narrow band stretching from the central part of Exmouth Gulf in a north-east direction as far as Onslow.

Group 3 encompasses 5 sites in the north-western part of Exmouth Gulf.

Group 4 is a cluster of 5 sites close inshore just south of Onslow (Figure 3.27).

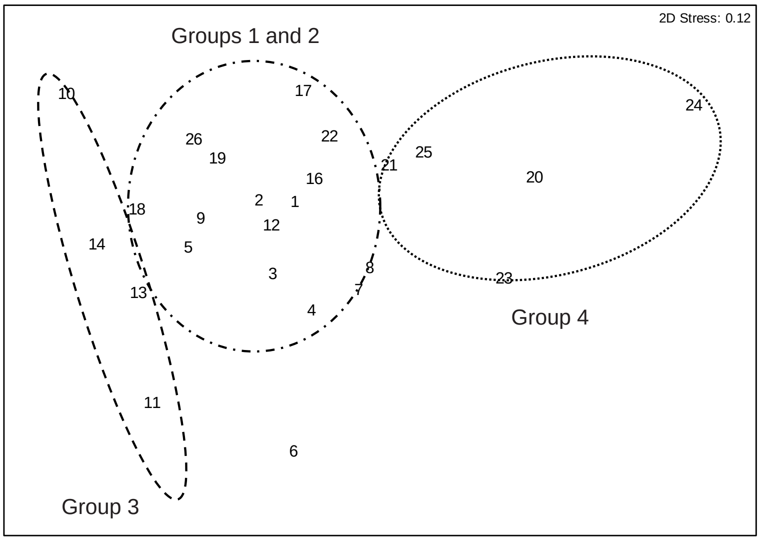

Figure 3.26 MDS plots of fish species assemblages in Exmouth Gulf and Onslow (dashed lines indicate groupings defined by cluster analysis).

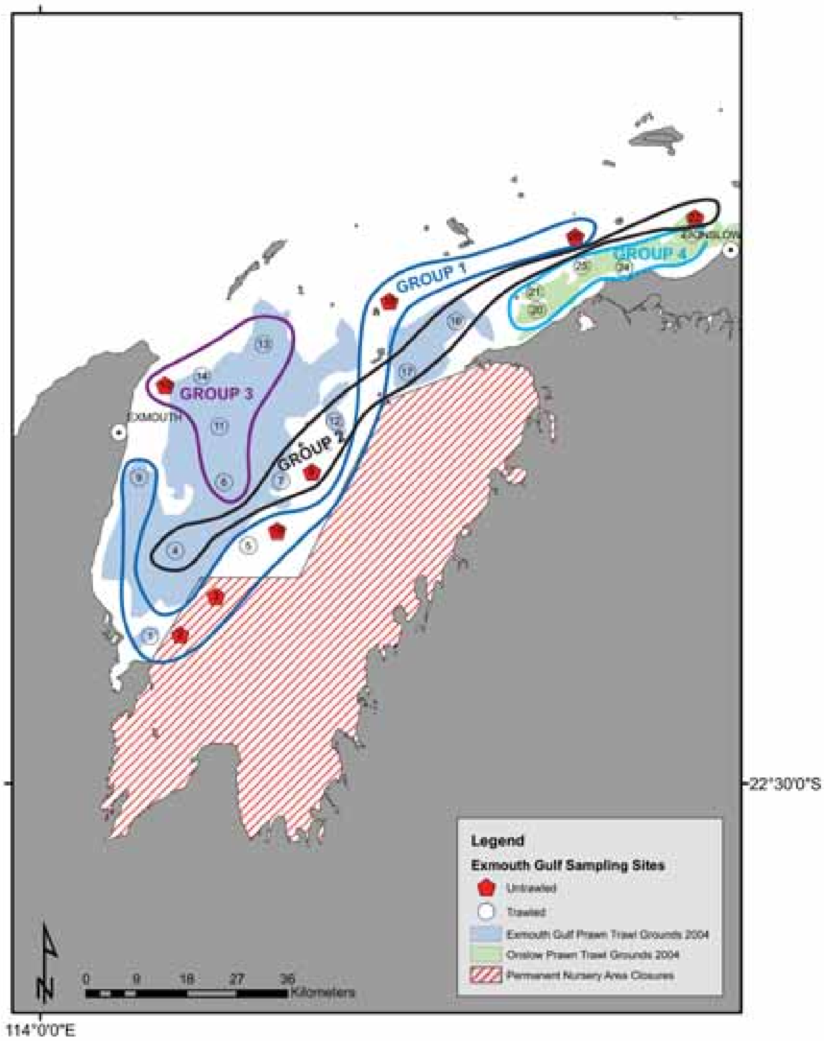

Figure 3.27 Exmouth Gulf and Onslow site groupings from cluster analysis for fish abundance data from all three survey trips.

3.3.2.4 Linking abundance data to environmental measures

The BEST procedure showed similarities for sites with the environmental variable of temperature (Figure 3.28) for fish abundance. The Spearman rank correlation between water temperature matrix and the fish abundance matrix was 0.50 indicating only a moderate correlation for fish species.

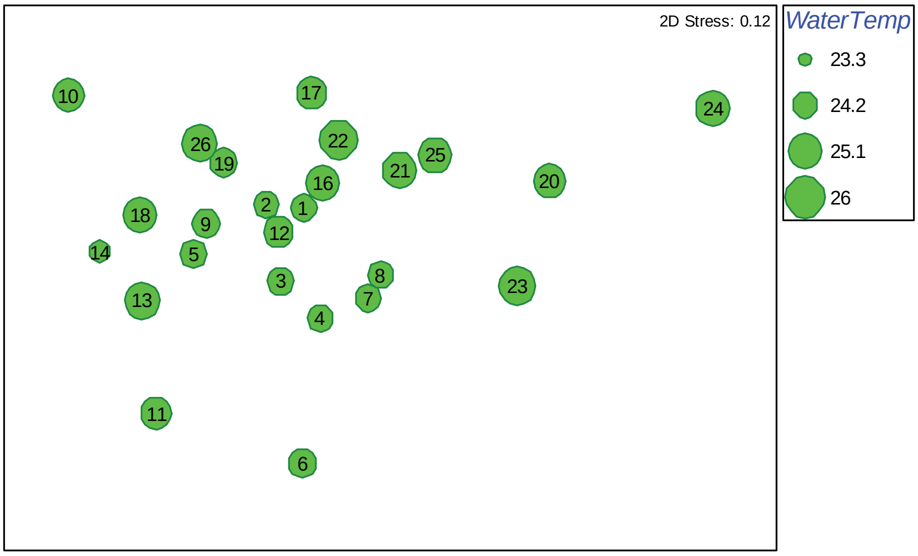

Figure 3.28 MDS of fish species abundance as the 25 sites in Exmouth Gulf superimposed with mean surface water temperature (ºC) measurements (for all sampling periods).

3.3.2.5 Fish species richness, evenness and diversity

Using least square means of the diversity measures there were significant differences in the Margalef's richness, Pielou's evenness, Shannon's diversity and Simpson's diversity indices of the four Groups ($p < 0.001$) (Figure 3.29). Water temperature was a significant co-variate on the Shannon's diversity index (p=0.006). Salinity and season were found to have significant effect on the species richness (p=0.003, p=0.0001, respectively). Salinity was a significant co-variate for species evenness (p=0.035).

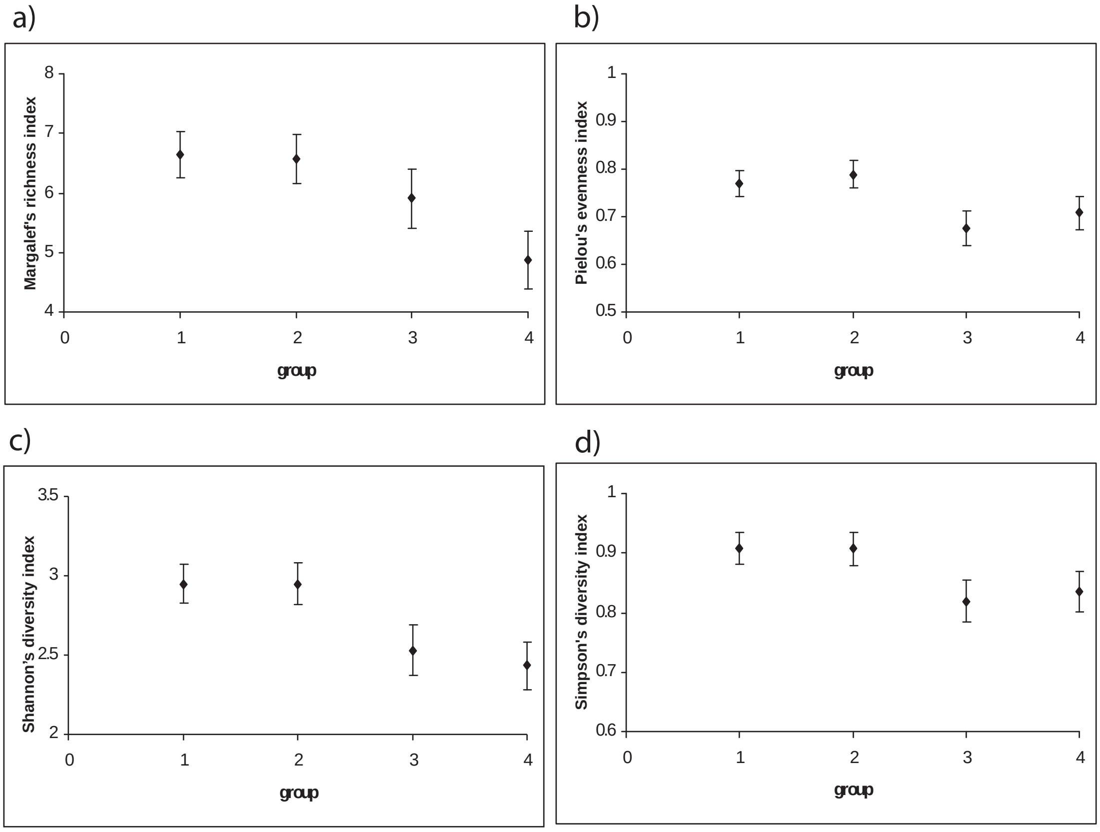

Figure 3.29 Least squares means with 95% confidence interval for the 4 groups identified from the fish assemblage in Exmouth Gulf of: a) Margalef's richness index. b) Pielou's evenness index with 95% confidence interval, c) Shannon's diversity index with 95% confidence interval d) Simpson's diversity index with 95% confidence interval.

Tests on trawled and untrawled sites within a Group indicated significant differences in the species richness (p=0.003) (Figure 3.30), the Shannon's diversity index (p=0.031) and Simpson's diversity index (p=0.042) for the trawled and untrawled sites within Group 1. Richness and diversity was higher in the trawled sites (Figure 3.30). Salinity was a significant contributor to the variance in species richness (p=0.032) and depth a significant contributor to the variance in the Simpson's diversity index (p=0.021).

A significant difference in the species richness ($p < 0.001$) and the Shannon's diversity index (p=0.003) was seen for the trawled and untrawled sites within Group 3, however, the richness and diversity was higher in untrawled sites. Salinity was a significant contributor to the variance in species richness ($p < 0.001$). No significant differences in the diversity measures were seen for the trawled and untrawled sites within Group 2. Lack of untrawled sites in Group 4 prevented any analyses being undertaken for this group.

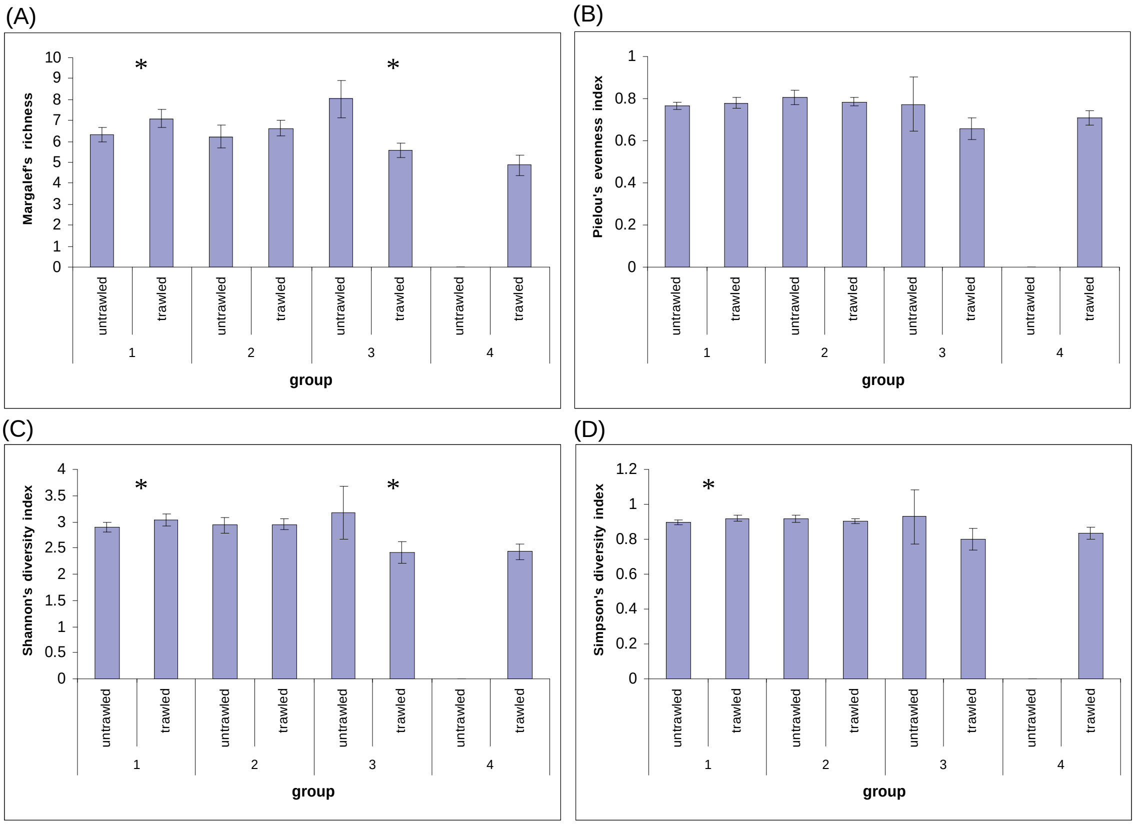

Figure 3.30 Least squares means with 95% confidence intervals for untrawled/trawled sites within a group identified from the fish abundances in Exmouth Gulf and Onslow of; a) Margalef's richness index, b) evenness index c) Shannon's diversity index and d) Simpson's diversity index. * indicates significant differences between trawled and untrawled sites within the grouping.

Description of fish groupings

As in Shark Bay the abundance and species richness levels used were subjective (Table 3.9). The ranges for fish and invertebrates in Exmouth Gulf, however, were much closer than those for Shark Bay. Individual richness values for each sample at a site for each sampling period is illustrated in Figure 3.31.

Table 3.9 Range used for fish and invertebrate abundance and species richness in Exmouth Gulf and Onslow.

Category	Abundance (no:/nautical mile)		Species Richness (no: species/site)	
	Fish	Invertebrates	Fish	Invertebrates
Low	0 - 410	0 - 400	<50	<35
Medium	410 - 700	400 - 700	50 - 70	35 - 55
High	>700	>700	>70	>55

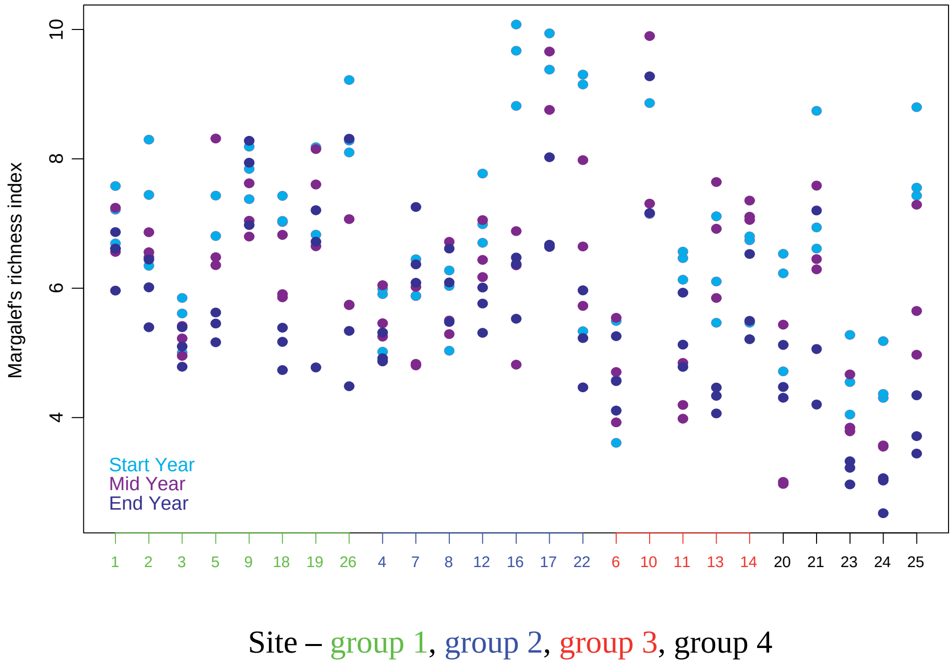

Figure 3.31 Fish species richness for individual samples at each site for each time period in Exmouth Gulf and Onslow.

Group 1 – Sites 1, 2, 3, 5, 9, 18, 19, 26

The eight sites in Group 1 include some with a moderate abundance of fish (approximately 440 to 580 fish per nautical mile – average of three seasons) at sites 1, 2, 3 and 19 in the southern and south east parts of Exmouth Gulf, and others with a high abundance of fish (approximately 730 to 890 fish per nautical mile) at sites 5, 9, 18 and 26 that are scattered between the central and northern parts of Exmouth Gulf and off Onslow (Figure 3.32).

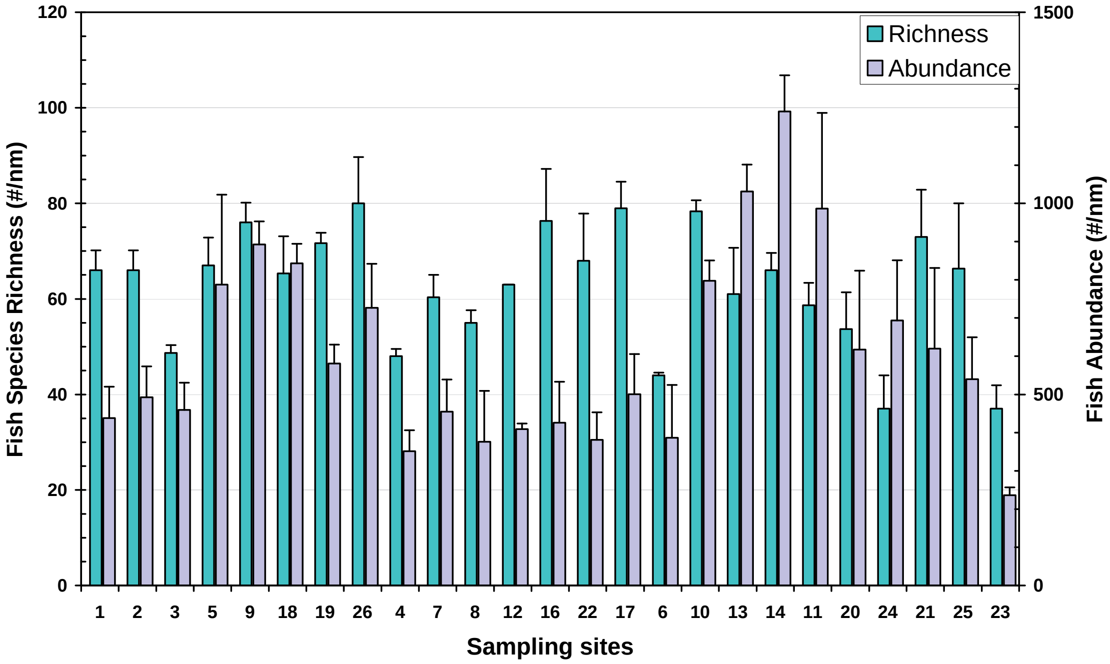

Figure 3.32 Mean fish species richness and abundance (± SE) (for three trips) at each survey site. Sites are ordered according to cluster groupings. (Group 1: sites 1 to 26, Group 2: sites 4 to 17, Group 3: sites 6 to 11 and Group 4: sites 20 to 23).

For all eight sites, the 10 most abundant fish species constituted 45% to 69%, and the 20 most abundant fish species constituted 64% to 82% of the bycatch at each site.

These eight sites clearly spilt into 2 further sub-groups according to the cluster analysis, with sites 1, 2, 3 and 5 being slightly different from the others. Sites 1, 2, 3 and 5 are physically close together in the southern part of Exmouth Gulf. Sites 2 and 3 are untrawled, and 1 and 5 are lightly trawled. Of the 10 most abundant species recorded, there are six common to all these sites, which are *L. leuciscus*, *U. asymmetricus*, rusty flathead (*Inegocia japonica*), banded trumpeter (*Terapon theraps*), *S. burrus* and *P. vitta*. These species comprised between 37% and 51% of the total fish abundance at sites 1, 2 and 3, but only 27% at site 5 due to a large school of striped catfish (*Plotosus lineatus*) that made up almost a quarter of the catch at this site.

Species richness was lowest at site 3, despite being untrawled, with 88 fish species recorded for the site in 2004, whereas sites 1, 2 and 5 had between 103 and 106 species per site. All these sites are all in shallow water from 8 to 13 metres depth.

Sites 9, 18, 19 and 26 are a geographically disparate group with site 9 in the prawn trawl grounds in the central west part of Exmouth Gulf, site 19 is in the south eastern part, and sites 18 and 26 are further offshore in the north eastern parts of the region. Site 9 is trawled and the rest untrawled. Of the 15 most abundant species at these sites, only *U. asymmetricus* and *I. japonica* were common to all sites, comprising 3.4% to 9.8%, and 2.1% to 4.7% of the total abundance respectively. Other species abundant at these sites in variable proportions were *E. grandisquama*, *L. genivittatus*, *P. choirocephalus*, Gross's stinkfish (*Calliurichthys grossi*), *P. vitta*, slender seamoth (*Pegasus volitans*) and *Apistus carinatus.*

Species richness was moderate at sites 9, 18 and 19 with between 106 and 109 species per site.

Group 2 – Sites 4, 7, 8, 12, 16, 22, 17

Group 2 sites had a low abundance of fish at sites 4, 8, 12 and 22 (between 350 and 410 fish per nautical mile), and moderate abundance at sites 7, 16 and 17 (between 425 and 500 fish per nautical mile). These seven sites are widely spread in a narrow band between the central part of Exmouth Gulf and Onslow.

For all seven sites, the 10 most abundant fish species constituted 41% to 55%, and the 20 most abundant fish species constituted 57% to 74% of the bycatch at each site.

Among the 20 most abundant species, four were common to all seven sites. These are *C. grossi*, *I. japonica*, *S. undosquamis* and redspot monocle bream (*Scolopsis taenioptera*). These species constituted between 8% and 25% of the total abundance at these sites. Also abundant at several of these sites were the ochre-banded goatfish (*Upeneus sundaicus*), *S. burrus*, multifilament stinkfish (*Repomucenus sublaevis*), *P. choirocephalus*, and the notched threadfin bream (*Nemipterus peronii*).

Site 4 (trawled) differed slightly from all the other sites in this group, due to a large abundance (11% of bycatch) of common silverbiddy (*Gerres oyena*), that were not recorded among the 20 most abundant species at the remaining sites. This site has consistently low species richness (Figure 3.31). Sites 7 (trawled) and 8 (untrawled) cluster tightly together since they had the same three most abundant species in common. These are the zig-zag ponyfish (*Leiognathus moretoniensis*), sunrise goatfish (*Upeneus sulphureus*) and *S. burrus*. Of the remaining sites 16 and 17 are heavily trawled, 12 is lightly trawled and site 22 is untrawled. The latter 4 sites cluster fairly closely together.

Species richness showed a gradual increasing trend from 48 species at site 4 in central Exmouth Gulf, 55 to 63 species at sites 7, 8, and 12 in eastern Exmouth Gulf, to high species richness of 76 and 79 species at sites 17 and 16 in the north east, and a slight decline to 68 species at site 22 offshore from Onslow.

Group 3 – Sites 6, 10, 13, 14, 11

Four of the sites (10, 13, 14, 11) in Group 3 are among those with the greatest abundance of fish in Exmouth Gulf, with between 800 and 1240 fish per nautical mile per site. Site 6 had low abundance (390 fish per nautical mile) and is well separated from the rest by cluster and MDS analysis. These sites are geographically close together in the north west section of Exmouth Gulf. All sites are trawled except for site 10 which showed consistently high species richness (Figure 3.31).

For all five sites, the 10 most abundant fish species constituted 55% to 78%, and the 20 most abundant fish species constituted 71% to 87% of the bycatch at each site.

Of the 20 most abundant species, five were common to all sites in Group 3, which are *P. vespa*, *C. grossi*, *I. japonica*, red-barred grubfish (*Parapercis nebulosa*) and *P. choirocephalus.*

The sites in this cluster are only loosely clustered except for sites 13 and 14. The latter two sites were both dominated in abundance by *P. vespa*, *U. asymmetricus*, *C. grossi*, and *I. japonica*. Site 11 is separated due to 52% of the bycatch being represented by *P. vespa*. Site 6 differs in having a large proportion of *P. lineatus* (37% of the bycatch) and also many *R. sublaevis* (14% of the bycatch) that only occurred in low numbers at the other sites.

Species richness was low at site 6 with 45 species, moderate at sites 11, 13 and 14 with 58 to 66 species per site, and high at site 10 with 78 species per site. These sites are in the deepest part of Exmouth Gulf, with depths ranging between 18 and 23 metres.

Group 4 – Sites 20, 24, 21, 25, 23

Group 4 sites had a low abundance of fish at site 23 with 235 fish per nautical mile, and moderate abundance at sites 20, 24, 21 and 25 with 540 to 690 fish per nautical mile per site. These five sites are located close inshore to Onslow. All sites are trawled except sites 21 and 23 that are lightly trawled.

For all five sites, the 10 most abundant fish species constituted 48% to 84%, and the 20 most abundant fish species constituted 67% to 92% of the bycatch at each site.

There were only three species common to all five sites among the 20 most abundant species, which were *U. sulphureus*, pearly-finned cardinalfish (*Apogon poecilopterus*) and the giant salmon catfish (*Arius thalassinus*). Abundant at four of the 5 sites were *S. undosquamis*, *I. japonica*, *U. sundaicus* and the blotched javelinfish (*Pomadasys maculatus*). *Leiognathus moretoniensis*, *L. leuciscus*, little jewfish (*Johnius borneensis*), mud whiting (*Sillago lutea*), *N. peronii* and the saddle-tailed seaperch (*Lutjanus malabaricus*) were among the five most abundant species at one or two sites.

Species richness ranged from low to high, with low richness at sites 23 and 24 (38 species each), moderate richness for sites 20 and 25 (54-67 species per site), and high richness for site 21 (73 species).

Distribution of the most abundant fish species

Fifteen of the 20 most abundant species (bold in Table 3.8) were also extremely widespread (i.e. occur in 92 to 100% of the sites sampled). Three species, *P. maculatus*, *L. genivittatus* and the six-lined trumpeter (*Pelates sexlineatus*) were fairly widespread and occurred at 84% of sites. *Upeneus sulphureus* was found at 64% of sites, while *P. lineatus* was only found in 20% of sites. The latter species often occurs in large schools, hence its patchy distribution.

Table 3.10 Twenty most abundant fish species in Exmouth Gulf and Onslow.

	Scientific name	Common name	Av no: /nm
1	*Paracentropogon vespa*	Bullrout	130
2	*Leiognathus moretoniensis*	Zig-Zag Ponyfish	98
3	*Upeneus asymmetricus*	Asymmetrical Goatfish	95
4	*Inegocia japonica*	Rusty Flathead	79
5	*Calliurichthys grossi*	Gross's Stinkfish	78
6	*Paramonacanthus choirocephalus*	Hair-finned Leatherjacket	60
7	*Pomadasys maculatus*	Blotched Javelinfish	56
8	*Engyprosopon grandisquama*	Spiny-headed Flounder	53
9	*Pentapodus vitta*	Western Butterfish	46
10	*Terapon theraps*	Banded Grunter	45
11	*Sillago burrus*	Trumpeter Whiting	43
12	*Plotosus lineatus*	Striped Catfish	41
13	*Repomucenus sublaevis*	Multifilament Stinkfish	39
14	*Lethrinus genivittatus*	Threadfin Emperor	36
15	*Upeneus sulphureus*	Sunrise Goatfish	35
16	*Saurida undosquamis*	Large-scaled Lizardfish	31
17	*Monacanthus chinensis*	Fan-bellied Leatherjacket	30
18	*Sillago lutea*	Mud Whiting	30
19	*Parapercis nebulosa*	Red-barred Grubfish	29
20	*Pelates sexlineatus*	Six-lined Trumpeter	28

3.3.2.6 Permanova – invertebrate species abundance

Site, season and their interaction was significant for invertebrate species abundance in Exmouth Gulf and Onslow (Table 3.11).

Table 3.11 Permanova results for invertebrate species in Exmouth biodiversity trawls (R^2 = 0.83). Type 3 sum of squares have been presented.

Source	df	SS	MS	Pseudo-F	P(perm)
Site	24	224380	9349	15.47	< 0.01
Season	2	74209	37105	61.397	< 0.01
Site x Season	48	136350	2840.6	4.7003	< 0.01
Residuals	143	86420	604.34		

3.3.2.7 *Exmouth Gulf and Onslow invertebrate cluster and MDS analysis and correlation with environmental measures*

The total number of species analysed was reduced from 365 to 332 when rare species (only found at one sites) were excluded.

Divisive clustering analysis of the abundance of invertebrate species in Exmouth Gulf indicates five groupings of sites (with site 19 being unique) that generally run from the south-west to north-east direction (Figure 3.33). The MDS plots support the divisive cluster analysis (Figure 3.34).

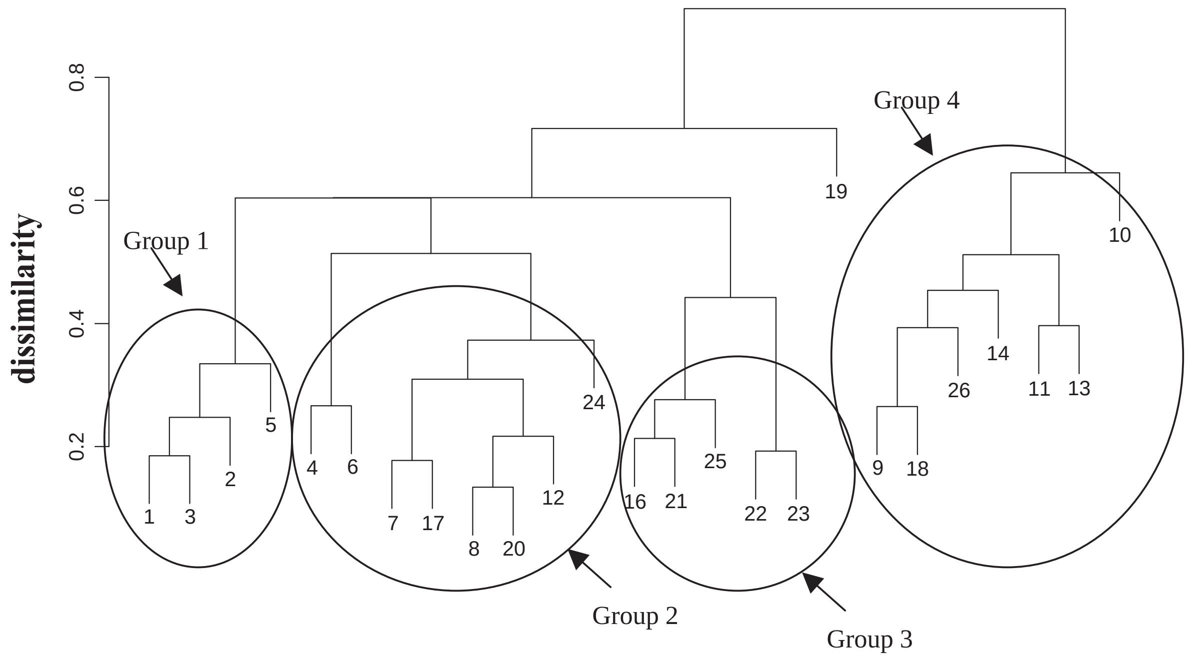

Figure 3.33 Divisive cluster analysis of Exmouth Gulf and Onslow invertebrate abundance data based on all three surveys.

Group 1 contains four sites in the southern part of Exmouth Gulf.

Group 2 contains eight sites in a narrow band between central Exmouth Gulf region running in a north east direction to the inshore area of Onslow.

Group 3 encompasses five sites just offshore from Onslow, running parallel to the shore in a south-west/north-east direction.

Group 4 contains the sites in the north west section of Exmouth Gulf, along with two offshore sites in the north east region.

Group 5 consists of a single site in the south east of Exmouth Gulf (Figure 3.35). This was due to high abundance of the sea urchin *P. bispinosa*.

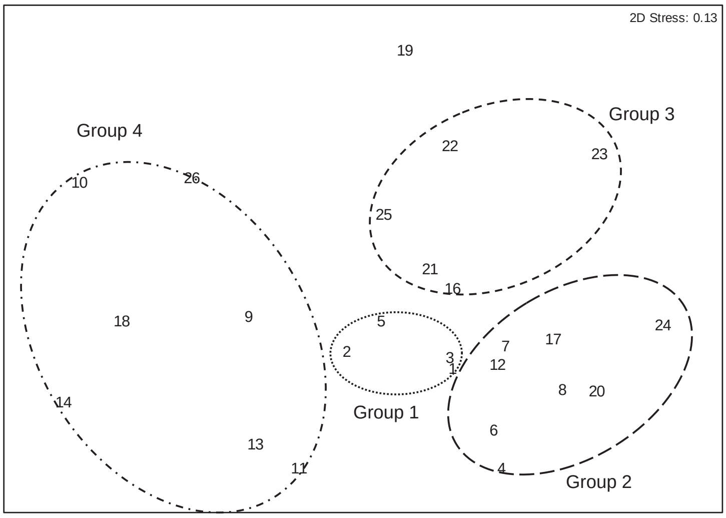

Figure 3.34 MDS plots of invertebrate species assemblages in Exmouth Gulf and Onslow (dashed lines indicate grouping defined by cluster analysis).

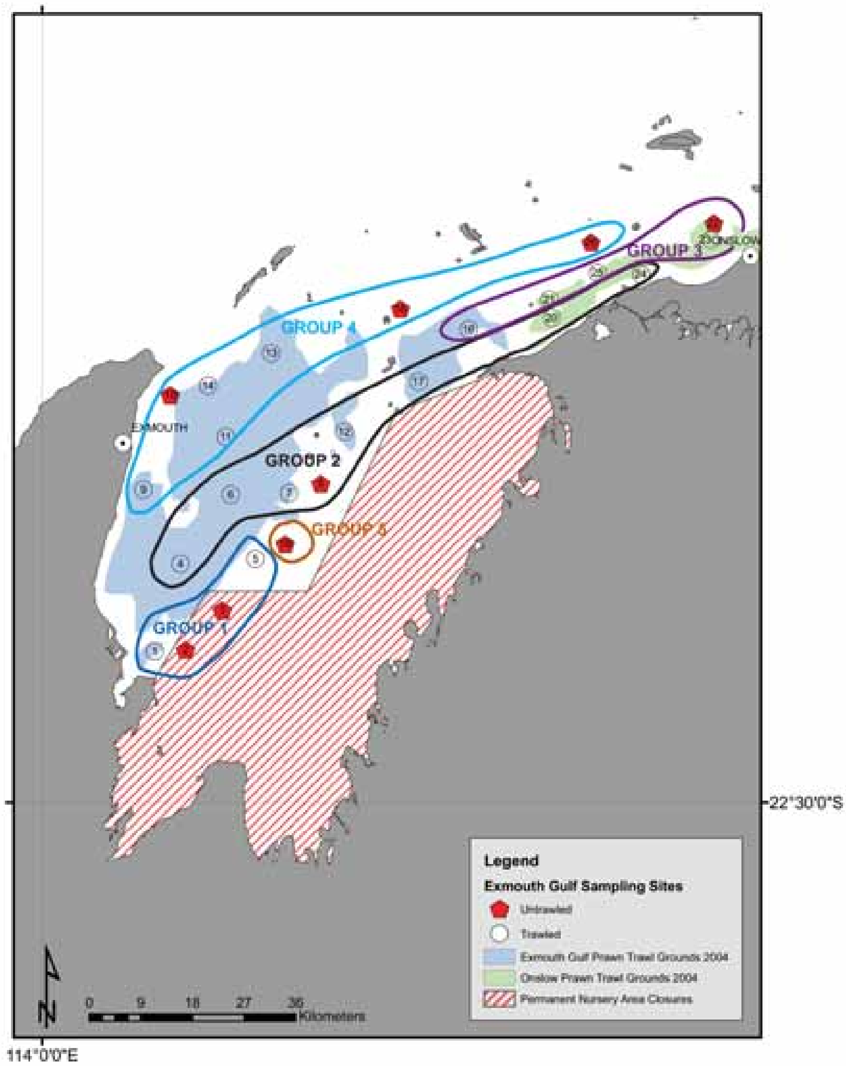

Figure 3.35 Site groupings from cluster analysis for Exmouth Gulf and Onslow for invertebrate data from all three survey trips.

3.3.2.8 Linking abundance data to environmental measures

The BEST procedure showed relatively poor similarities for invertebrate species abundance for sites with all of the environmental variables with a Spearman rank correlation of only 0.35.

3.3.2.9 Exmouth Gulf and Onslow invertebrate species richness, evenness and diversity

The results indicated that there were significant differences in the Margalef's richness, Pielou's evenness, Shannon's diversity and Simpson's diversity indices of the four groups ($p < 0.001$) (Figure 3.36). Site 19 was excluded from the tests. Season was found to be significant for species richness ($p < 0.001$). It was also a significant factor for Simpson's diversity index ($p < 0.001$) and species evenness ($p < 0.001$).

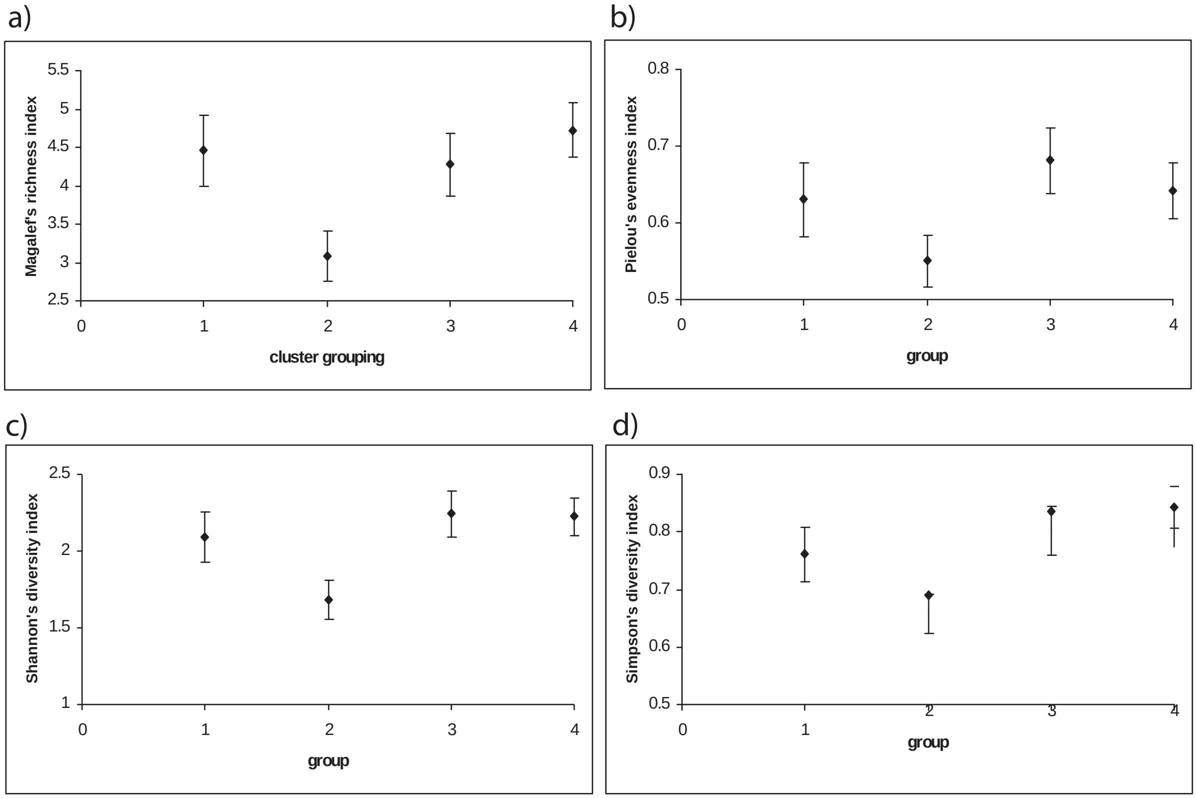

Figure 3.36 Least squares means with 95% confidence interval for the 4 groups identified from the invertebrate assemblage in Exmouth Gulf of: a) Margalef's richness index b) Pielou's evenness index, c) Shannon's diversity index d) Simpson's diversity index.

For the invertebrate assemblage, there were significant differences in the species richness (p=0.001), species evenness ($p < 0.001$) the Shannon's diversity index (p=0.0003) and Simpson's diversity index (p=0.0001) for the trawled and untrawled sites within group 4 (Figure 3.37).

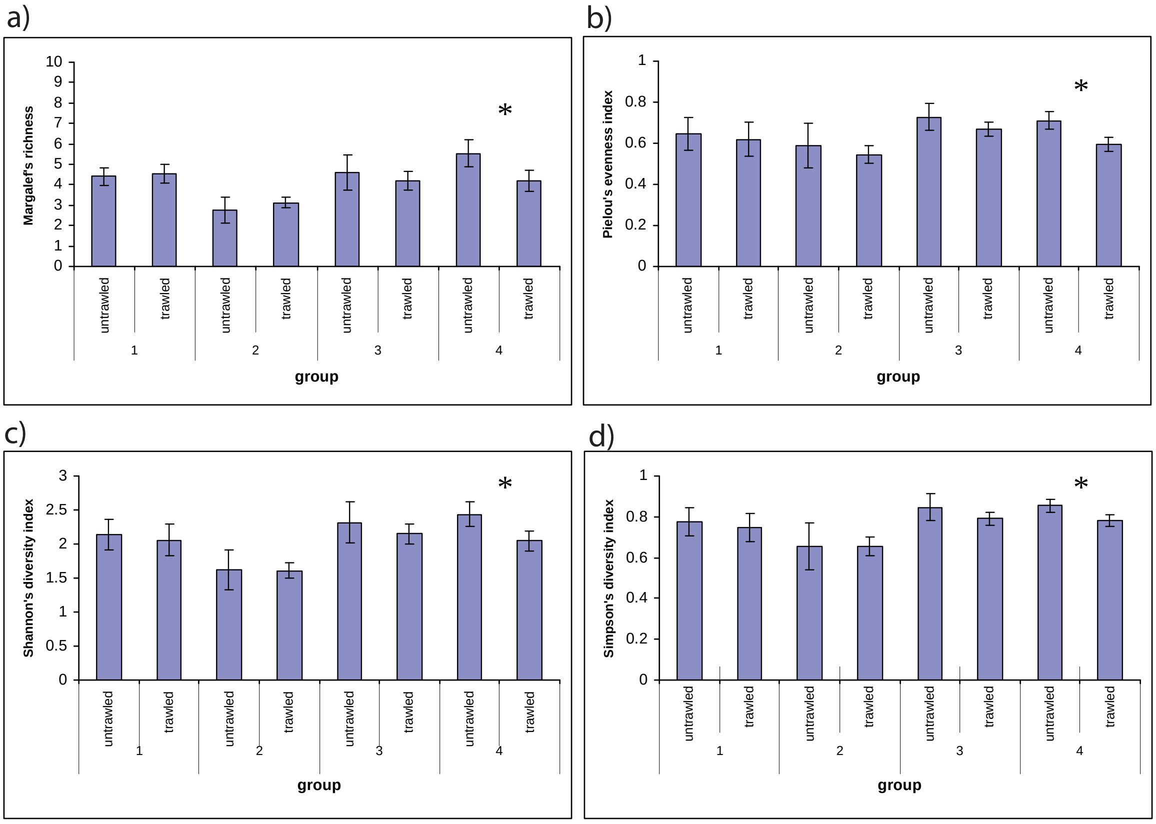

Figure 3.37 Least squares means with 95% confidence interval for untrawled/trawled sites within a group identified from the invertebrate abundances in Exmouth Gulf and Onslow of; a) Margalef's richness index, b) evenness index c) Shannon's diversity index and d) Simpson's diversity index. * indicates significant differences between trawled and untrawled sites within the grouping.

Description of invertebrate groupings

Group 1 Sites 1, 3, 2 and 5

The four sites in Group 1 had low abundance of invertebrates at site 3 (370 invertebrates per nautical mile), to moderate abundance of species at sites 1, 2 and 5 (510 to 670 invertebrates per nautical mile) (Figure 3.38). These sites are in close physical proximity at the southern end of Exmouth Gulf. Sites 2 and 3 are untrawled, and sites 1 and 5 are lightly trawled.

For all four sites the 10 most abundant invertebrate species constituted 69% to 76% of the bycatch, and the 20 most abundant species constituted 80% to 86% of the bycatch. These sites all had abundant commercial prawn species, *P. esculentus*, *P. latisulcatus* and *M. endeavouri*, plus other crustaceans including *P. tenuipes*, in abundance.

Species richness was moderate at sites 1, 2 and 3 with between 42 and 60 species per site, and high at site 5 with 55 species per site.

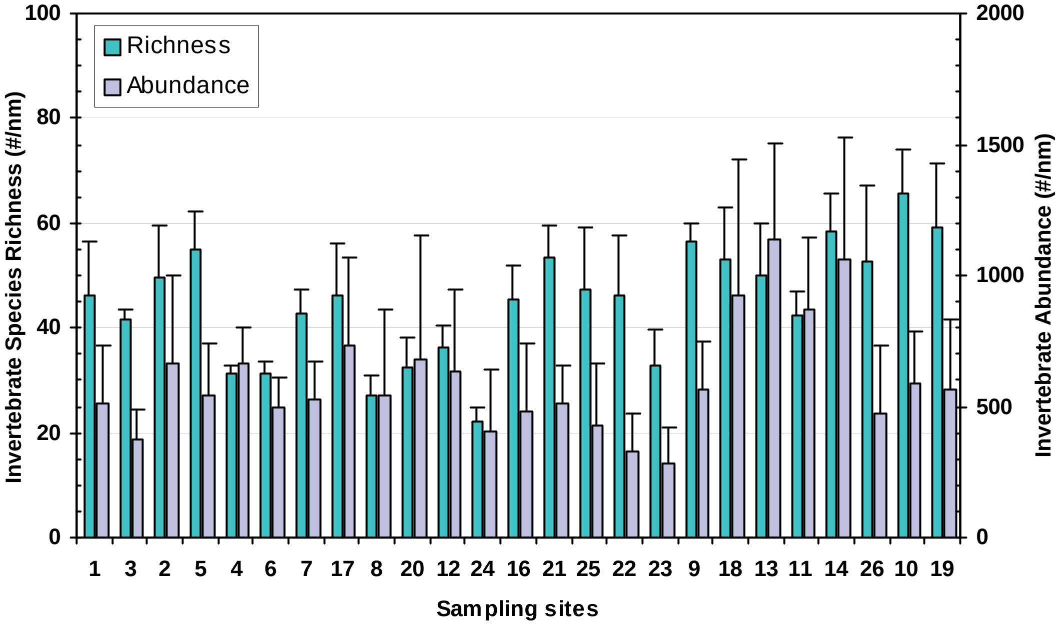

Figure 3.38 Mean species richness and abundance (± SE) (for three sampling periods) at each survey site. Sites are ordered according to cluster groupings. (Group 1: sites 1 to 5, Group 2: sites 4 to 24, Group 3: sites 16 to 23, Group 4: sites 9 to 10 and Group 5; site 19 only).

Group 2 – Sites 4, 6, 7, 17, 8, 20, 12, 24

The eight sites in Group 2 had a moderate abundance of invertebrates at most sites (405 to 685 invertebrates per nautical mile), with high abundance at site 17 (735 invertebrates per nautical mile). This group covers a wide geographical range from central Exmouth Gulf in a north-east direction to the inshore region of Onslow. Sites 4, 6, 17, 20 and 24 are trawled, site 7 is lightly trawled and site 8 is untrawled.

The 10 most abundant species accounted for 82% to 90%, and the 20 most abundant species accounted for 89% to 95% of the invertebrate bycatch at each site. The most abundant species at all eight sites in Group 2 was *P. esculentus*, and *M. endeavouri* was the second most abundant species at six of the eight sites. The main difference from Group 1 was that *P. latisulcatus* was much less abundant at all these sites, except for site 12. Also abundant at several of the Group 2 sites were *P. pelagicus*, northern rough prawn (*Trachypenaeus anchoralis*) and *T. curvirostris.*

Sites 4, 6, 8, 20 and 24 had low species richness (22 to 33 species per site), and sites 7, 12 and 17 had moderate species richness with 37-45 species per site. This group had the lowest invertebrate richness for all sites, especially site 24, the site adjacent to Ashburton River (Figure 3.39).

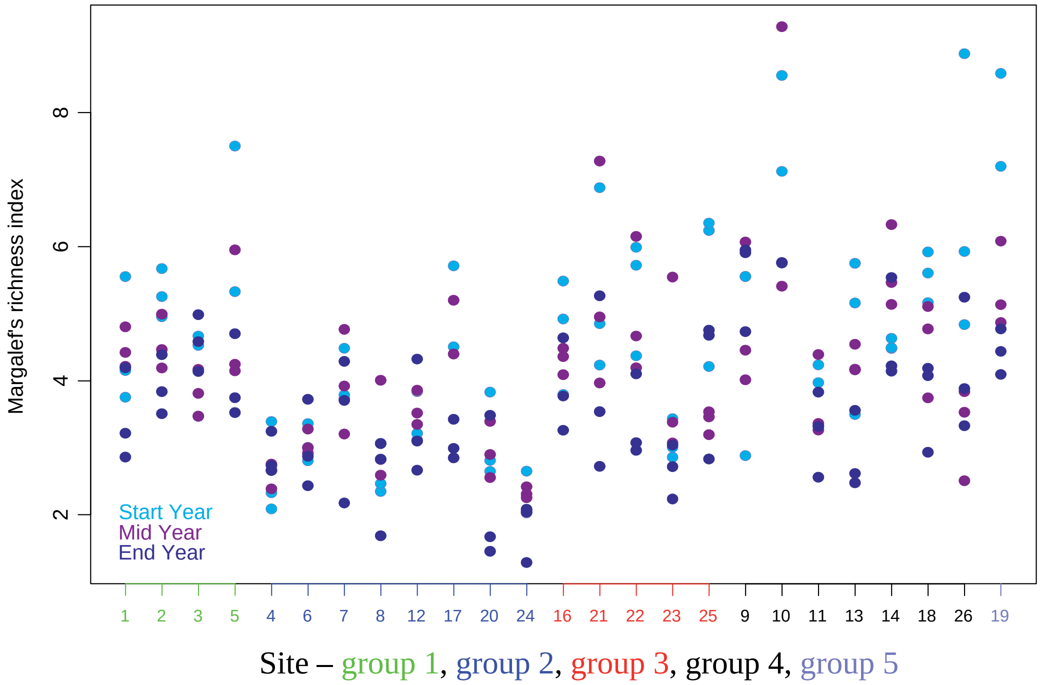

Figure 3.39 Invertebrate species richness index for each sample taken at each site for each sampling period in Exmouth Gulf and Onslow for assemblage groupings.

Group 3 – Sites 16, 21, 25, 22, 23

The five sites in Group 3 had low abundance at sites 22 and 23 (280 to 330 invertebrates per nautical mile), and moderate abundance at sites 16, 21 and 25 (430 to 510 invertebrates per nautical mile). This group is restricted to a narrow band in the north east of the region, offshore from Onslow. Sites 16 and 25 are trawled, sites 23 and 21 are lightly trawled and site 22 is untrawled.

For all sites the 10 most abundant species accounted for 64% to 80%, and the 20 most abundant species accounted for 78% to 89% of the total abundance. These sites have the following more abundant species in common: *P. esculentus*, *P. pelagicus*, *M. endeavouri*, *P. rubromarginatus* and *T. curvirostris*. These sites were dominated in abundance by crabs and prawns.

Species richness was low at site 23 (33 species) and moderate at the remaining sites (46 to 54 species per site).

Group 4 – Sites 9, 18, 13, 11, 14, 26, 10

Four of the seven sites in Group 4 had the highest abundance for the whole of Exmouth Gulf. These are sites 18, 13, 11 and 14 that had between 870 and 1140 invertebrates per nautical mile. Sites 26 and 9 had moderate abundance with 470 to 565 invertebrates per nautical mile. The sites in this group are widely spread between the northeast region of Exmouth Gulf and offshore from Onslow. Sites 18, 26 and 10 are untrawled and the rest are trawled.

For all sites the 10 most abundant species accounted for between 62% and 89%, and the 20 most abundant species accounted for between 77% and 93% of the total bycatch abundance.

The sites in Group 4 were the least tightly clustered of all the invertebrate groupings. As in groups 1, 2 and 3 they were dominated in abundance by crabs and prawns, but there was more variability in species between sites. Abundant species common to most sites were

P. latisulcatus, P. rubromarginatus, P. tenuipes and *M. endeavouri*. Sites 9 and 18 cluster closely together, partly due to having *B. desorii* in common, which was not abundant at the other sites. Site 14 is separate because of an abundance (17%) of *A. flabellata*, site 26 stands out due to the presence of *T. elegans*, Papuan cuttlefish (*Sepia papuensis*) and the mushroom coral (*Cycloseris cyclolites*) among the more abundant species, and site 10 is well separated from all other sites because of scallops (*Mimachlamys australis*) that made up 11% of the abundance, plus abundant ascidians, *S. papuensis* and crinoids.

Species richness was moderate at sites 18, 13, 11 and 26 (43 to 53 species per site), and high at sites 14 and 10 (57 to 67 species per site). The latter sites had among the greatest species richness in invertebrates for the whole Exmouth Gulf region with site 10 being untrawled and 14 being trawled.

Group 5 – Site 19

Site 19 had a moderate abundance of invertebrates with 565 individuals per nautical mile. It is located on the eastern central side of Exmouth Gulf. The 10 most abundant invertebrate species represented 61%, and the 20 most abundant species represented 71%, of the bycatch.

This site was separated from all other sites in Exmouth Gulf and Onslow, due to a dominance of sea urchins: *Salmacis sphaeroides* (16%) and *Prionocidaris bispinosa* (16%). *Penaeus esculentus, M. endeavouri* and *P. pelagicus* featured among the more abundant species. Species richness was high with 60 species recorded for this site.

Distribution of the most abundant invertebrate species

Of the 20 most abundant species (total of all three trips in 2004), 11 species (in bold, Table 3.12) were widespread in the region, and occurred at 92 to 100% of the sites. Of the remaining species, all except *B. desorii, A. flabellata* and red spot king prawn (*Penaeus longistylis*) were found at 72 to 88% of all sites. *Annachlamys flabellata* occurred at 40% of sites and the *M. longistylis* at 56% of sites. *Breynia desorii* was found at only 12% of sites. This species is included in the list of abundant species only because a large catch was made at site 18 at the start of the season when the nets were set slightly ‘heavy’. For the reminder of the survey heart urchins were only caught in small numbers.

Table 3.12 Twenty most abundant invertebrate species in Exmouth Gulf and Onslow.

	Scientific name	Common name	Av no:/nm
1	*Penaeus esculentus*	Brown tiger prawn	461
2	*Penaeus latisulcatus*	Western king prawn	153
3	*Metapenaeus endeavouri*	Endeavour Prawn	150
4	*Metapenaeopsis rosea*	Rosy Prawn	110
5	*Portunus tenuipes*	Swimmer Crab	110
6	*Portunus rubromarginatus*	Swimmer Crab	59
7	*Portunus pelagicus*	Blue Swimmer Crab	52
8	*Trachypenaeus anchoralis*	Northern Rough Prawn	51
9	*Trachypenaeus curvirostris*	Southern Rough Prawn	46
10	*Charybdis truncata*	Crab	38
11	*Metapenaeopsis crassissima*	Coral prawn	29
12	*Eduarctus martensi*	Slipper lobster	23
13	*Annachlamys flabellata*	Fan Scallop	22
14	*Portunus hastatoides*	Swimmer Crab	19
15	*Comatula solaris*	Crinoid	18
16	*Prionocidaris bispinosa*	Pencil urchin	16
17	*Breynia desorii*	Heart urchin	16
18	*Penaeus longistylus*	Red spot king prawn	15
19	*Portunus curvipenis*	Swimmer Crab	15
20	*Sepia papuensis*	Papuan Cuttlefish	12

3.3.2.10 Exmouth Gulf and Onslow fish and invertebrates

Both the combined and separate analyses of fish and invertebrate abundance and species richness, indicate that the similarities and dissimilarities between sites could depend more on the geographical location and environmental parameters in Exmouth Gulf and Onslow than the level of trawling.

The results are observations made over a single year (2004) and considering the large number of physical and biological variables that interplay and influence species abundance and richness, there could be significant differences from year to year as was observed in Shark Bay. Also within these regions, catastrophic events such as strong cyclones occur every 10-20 years and have a dramatic effect on flora and fauna. It can take a considerable time for populations and a natural balance to recover from such events. The last major cyclone events were in 1999/2000.

Divisive clustering analysis of the combined fish and invertebrate data results in clustering into approximately three main groups (Figure 3.40). Group 1 encompasses nine sites in the southern and eastern parts of Exmouth Gulf, excluding sites 5 and 19. Group 2 includes seven sites inshore in the Onslow region. Group 3 covers nine sites, seven of which are in the north west of Exmouth Gulf and in a north easterly direction towards the offshore reaches of Onslow, plus two sites on the central eastern shores of Exmouth Gulf (Figure 3.41).

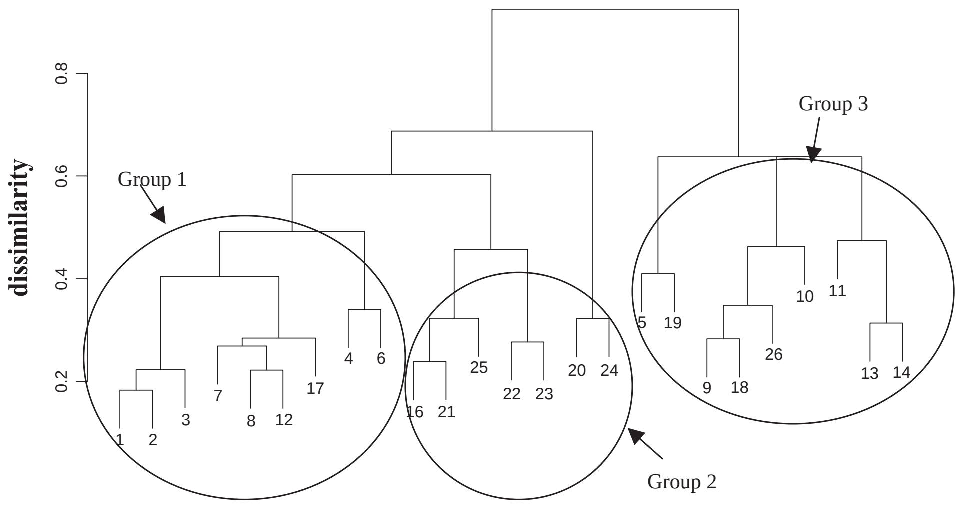

Figure 3.40 Divisive clustering of sites in Exmouth Gulf and Onslow for fish and invertebrates combined.

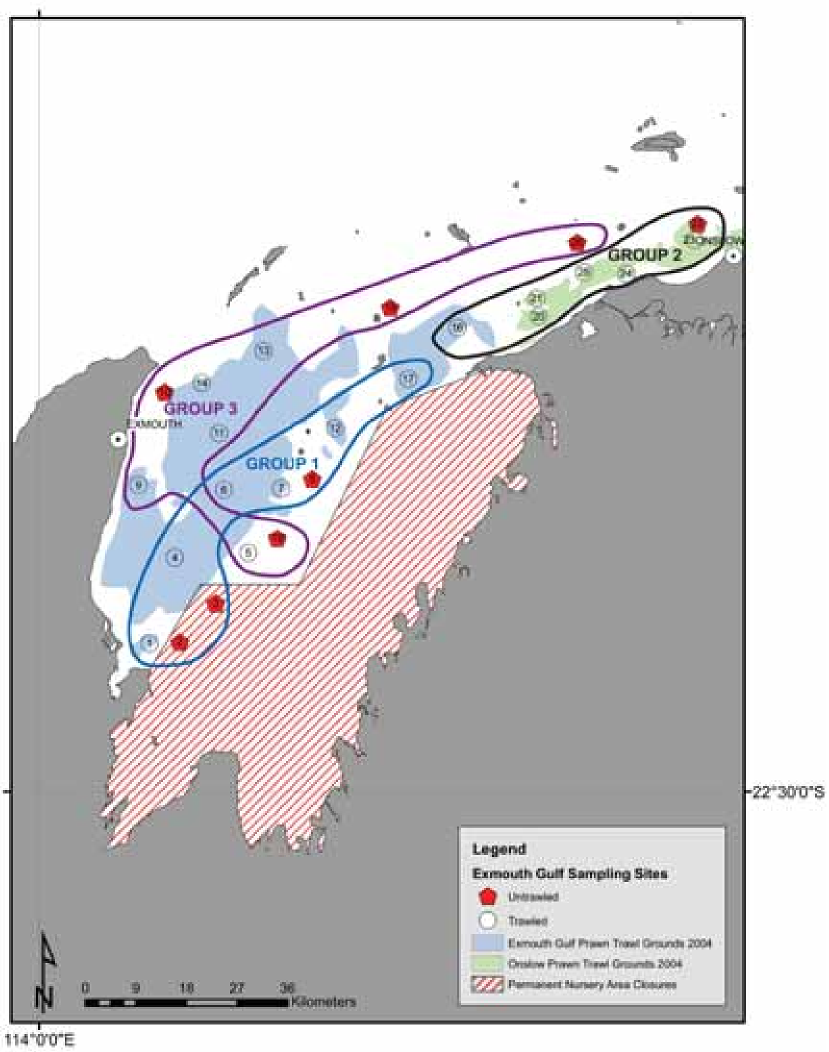

Figure 3.41 Grouping of sites from cluster analysis in Exmouth Gulf and Onslow for fish and invertebrates combined for all three surveys.

Each group contains a mixture of trawled, lightly trawled and untrawled sites. Both fish and invertebrates show similar general trends in the extremes of abundance and species richness throughout the region, but with some variation in the intermediate levels.

Group 2 sites had a low to moderate abundance of fish and invertebrates. Species richness also ranged from the lowest in the region at trawled sites 23 and 24 close inshore (30 to 35 species per site), to high species richness at sites 16 and 21 further offshore (61 to 63 species per site). It is likely that the low abundance and low species richness at sites closest to shore (sites 20, 23, 24) were due to the extreme seasonal fluctuations in salinity, temperature and turbidity, as mentioned above. Further offshore, (sites 16, 21, 25, 22) these factors are slightly moderated. This appears to have little effect on the abundance, but there is a trend towards an increase in species richness, the further away the sites are from the Ashburton River mouth.

Group 1 sites also had a low to moderate abundance of fish and invertebrates. The overall abundance of fish was slightly less than that of the invertebrates. Trawled sites 4, 6 and untrawled sites 3 and 8 had the lowest species richness in this group (38 to 46 species per site). The temperature and salinity fluctuations were less extreme than in the Onslow region, and depth was slightly greater (12 to 16 metres), and consequently these factors may have had less influence on abundance and species richness in this part of Exmouth Gulf. Sites 4 and 6 are in heavily trawled grounds, and the low abundance and species richness may be a result of trawl activity.

The sites in the most southern part of Exmouth Gulf (1 and 2) and those in the central eastern part of Exmouth Gulf (7, 12) had moderate species richness (50 to 58 species per site). Similar to other sites in Group 1, the fluctuations in salinity and water temperature were moderate. Depths ranged from 8 to 18 metres. Site 17 in the north eastern part of Exmouth Gulf had a moderate abundance, but high species richness (63 species). This is possibly because site 17 is in close proximity to an area rich in soft coral and sponge gardens. Small numbers of additional fish and invertebrate species could easily move from these areas to site 17.

Group 3 contains sites that had the greatest abundance and species richness in the whole region. However, maximum species richness and abundance did not necessarily occur together at the same sites. Sites 9, 11, 13, 14 and 18 had the greatest abundances of fish and invertebrates, but sites 11, 13 and 18 only had moderate species richness (51 to 59 species per site). Sites 9 and 14 had high species richness (62-66 species per site). All these sites except for 18 are trawled, which could explain the great abundance of species that prefer trawl habitats, but the presence of fewer species than at untrawled sites close by. It is unclear why site 18 is similar to trawled sites. Possibly the habitat or currents at this site are unsuitable for a wide variety of species to settle, resulting in only moderate species richness.

Conversely sites 10 and 26 had the greatest overall species richness (67 to 72 species per site), but only moderate abundance of individuals. These latter two sites are untrawled, with site 10 adjacent to the protected Bundegi Reef, and site 26 in proximity to rich marine communities further offshore in the West Pilbara region (Hutchins 2001), which is likely to account for the high species richness at these sites.

Cluster analysis shows that sites 5 and 19 are slightly different from the others in Group 3. Both show moderate abundance, and high species richness (61-66 species).

3.3.2.11 Sediment Analysis

ANOVA of mean particle size indicated significant differences between sites ($p < 0.001$). Sites 3, 10, 14 and 21 had higher proportion of coarser material in the samples compared to other sites. These four sites are a mixture of untrawled, lightly trawled and trawled sites and also are sites in different fish and invertebrate species assemblage groups (Figures 3.42 to 3.45). It was considered more likely that sediment type may influence the distribution of invertebrate species that are less mobile than fish species. Those sites representing invertebrate species assemblage Group 2 had a narrow range of particle sizes at the 50% cumulative percent of weight of the samples whereas Groups 1 and 4 had a moderate range and Group 3 showed high variability at 50% cumulative percent. The sites in Group 2 contained untrawled, lightly trawled and trawled sites indicating a lack of correlation with trawl effort and particle size.

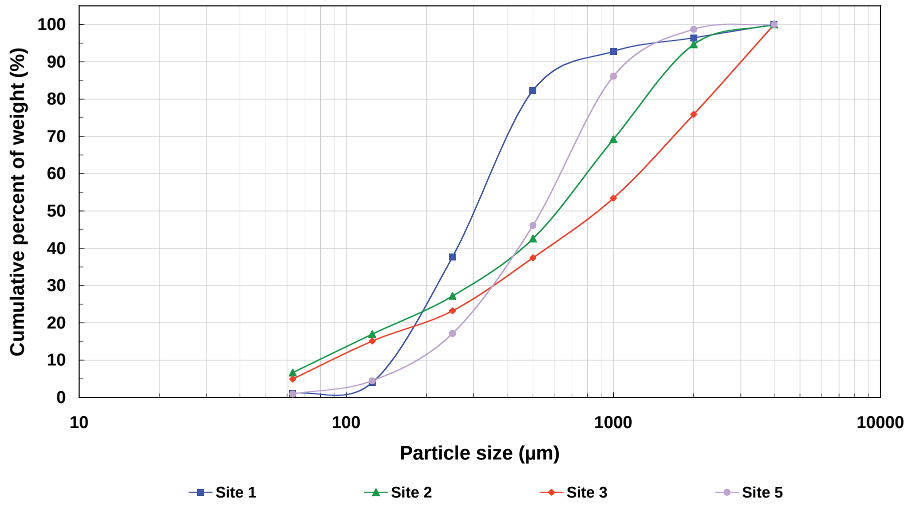

Figure 3.42 Particle size of sites in invertebrate assemblage Group 1 for Exmouth Gulf and Onslow.

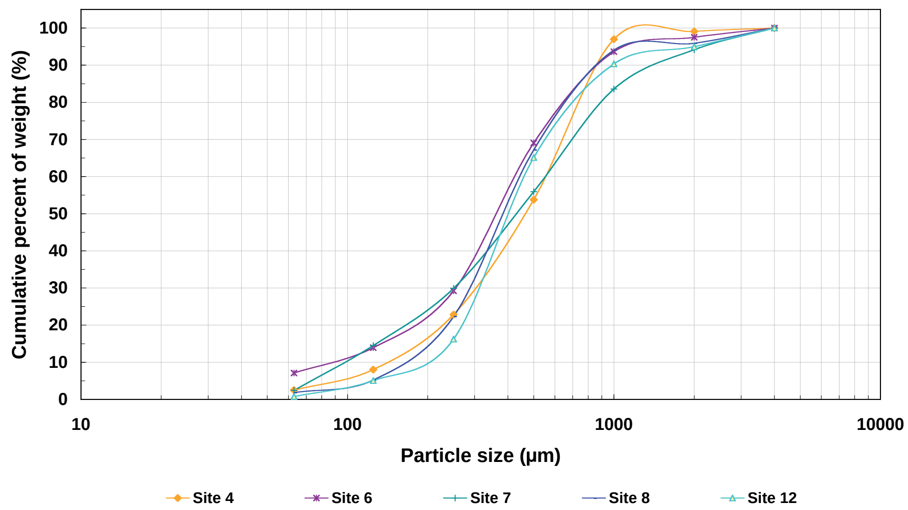

Figure 3.43 Particle size of sites in invertebrate assemblage Group 2 for Exmouth Gulf and Onslow.

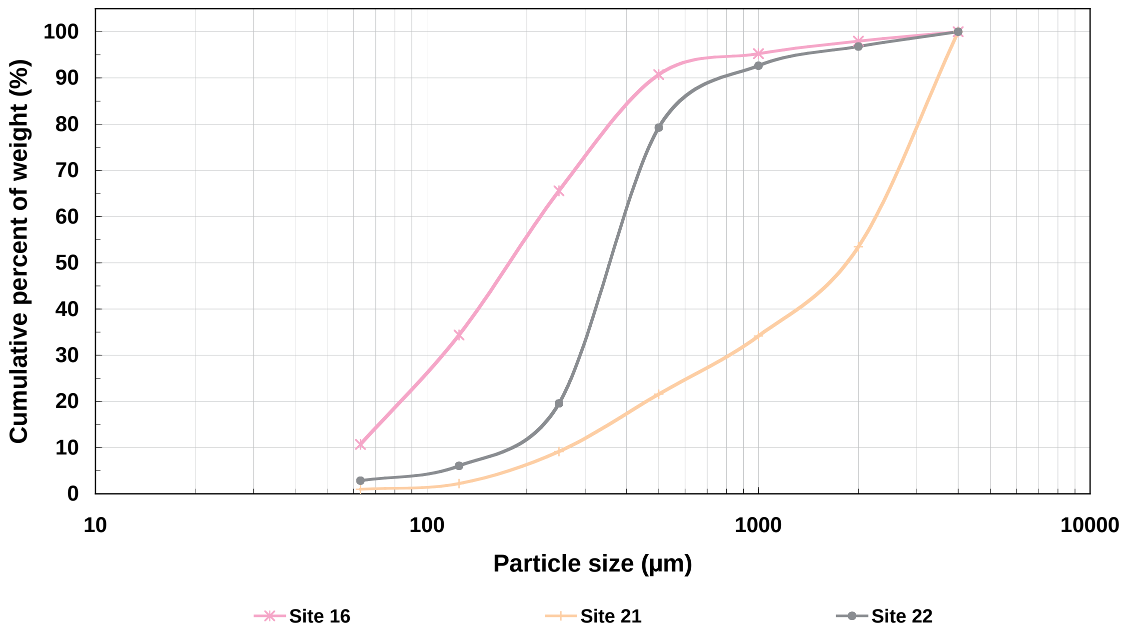

Figure 3.44 Particle size of sites in invertebrate assemblage Group 3 for Exmouth Gulf and Onslow.

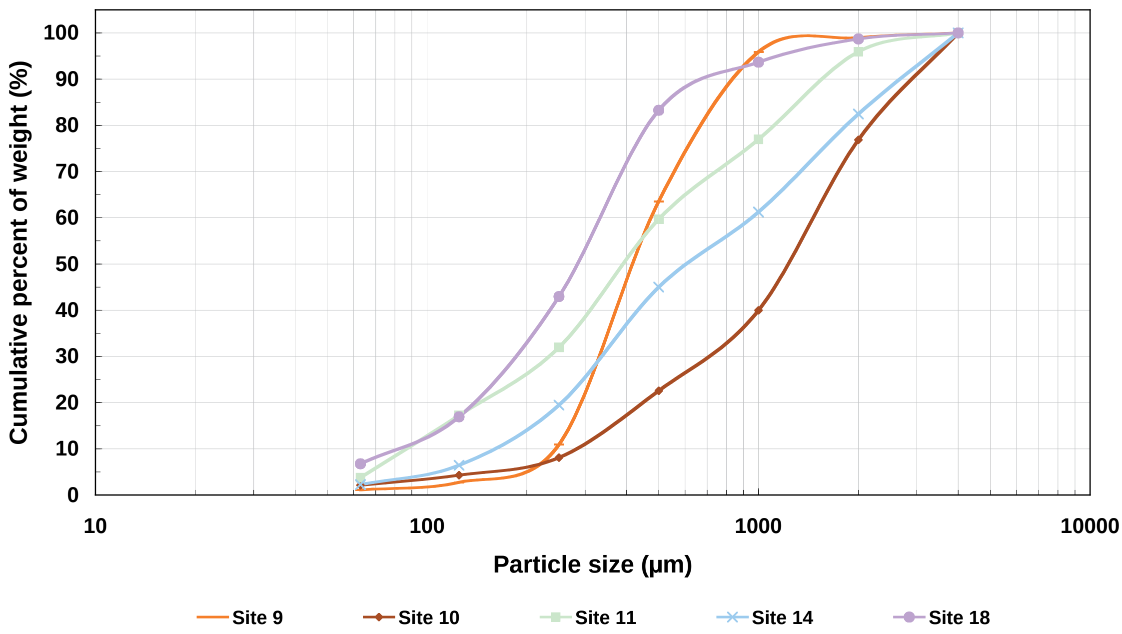

Figure 3.45 Particle size of sites in invertebrate assemblage Group 4 for Exmouth Gulf and Onslow.

3.3.2.12 Exmouth Gulf and Onslow reptiles

A slightly greater number of reptiles were caught in Exmouth Gulf and Onslow compared with Shark Bay, but the numbers were still low (Table 3.13).

Table 3.13 Reptiles caught in Exmouth Gulf and Onslow.

Date	Site	No:	Scientific name	Common name
Turtles				
18/3/04	8	1	*Natator depressus*	Flatback Turtle
18/3/04	8	1	*Chelonia mydas*	Green Turtle
06/7/04	23	1	*Chelonia mydas*	Green Turtle
3/11/04	16	1	*Caretta caretta*	Loggerhead Turtle
3/11/04	20	1	*Natator depressus*	Flatback Turtle
4/11/04	24	1	*Natator depressus*	Flatback Turtle
4/11/04	24	1	*Natator depressus*	Flatback Turtle
Sea snakes				
10/3/04	4	1	*Aipysurus duboisii*	Dubois'Sea Snake
10/3/04	4	1	*Aipysurus duboisii*	Dubois'Sea Snake
10/3/04	5	3	*Aipysurus duboisii*	Dubois'Sea Snake
10/3/04	5	3	*Aipysurus duboisii*	Dubois'Sea Snake
10/3/04	19	1	*Aipysurus laevis*	Golden Sea Snake
11/3/04	2	1	*Aipysurus laevis*	Golden Sea Snake
11/3/04	2	1	*Aipysurus duboisii*	Dubois'Sea Snake
12/3/04	11	1	*Aipysurus apraefrontalis*	Short-nosed Sea Snake
18/3/04	6	1	*Disteira major*	Olive-headed Sea Snake
9/7/04	4	1	*Disteira stokesii*	Stoke's Sea Snake
1/11/04	4	1	*Aipysurus duboisii*	Dubois'Sea Snake
2/11/04	19	1	*Aipysurus duboisii*	Dubois'Sea Snake
6/11/04	12	1	*Aipysurus duboisii*	Dubois'Sea Snake

3.3.2.13 Exmouth Gulf and Onslow threatened species

Some of the marine fish species caught as bycatch in Exmouth Gulf and Onslow are included in the 'Australian Threatened and Potentially Threatened Marine and Estuarine Fishes' list developed by the NSW Fisheries Research Institute and Fish Section of the Australian Museum (Pogonoski et al. 2002) (Table 3.14).

Table 3.14 Exmouth Gulf and Onslow bycatch species listed under the Australian Threatened Marine and Estuarine Fishes list (Pogonoski et al. 2002). LR (nt) = Lower Risk (near threatened), LR (lc) = Lower Risk (least concern).

Common name	Scientific name	No: caught	IUCN status
White-spotted Shovelnose Ray	*Rhychobatus australiae*	5	LR (lc)
Winged Seahorse	*Hippocampus alatus*	2	LR (lc)
Western Spiny Seahorse	*Hippocampus angustus*	11	LR (lc)
Flat-face Seahorse	*Hippocampus planifrons*	5	LR (lc)
Zebra Seahorse	*Hippocampus zebra*	1	LR (lc)

3.3.2.14 Exmouth Gulf and Onslow fish diet types

Of the 298 fish species recorded from the 25 survey sites in Exmouth Gulf and Onslow, the proportions of the various diet types are similar to those for Shark Bay. Carnivores make up 81% of fish species, made up of 54% general carnivores, 24% carnivores of invertebrates and 3% carnivores of vertebrates. Planktivores constitute 10%, omnivores 7% and herbivores 2% (Figure 3.46).

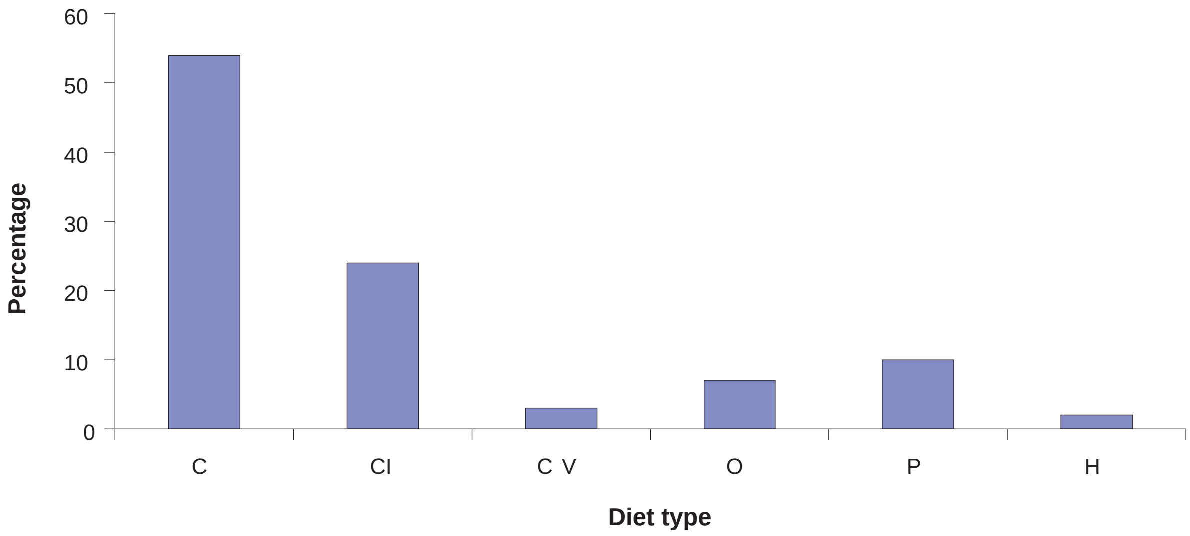

Figure 3.46 Exmouth Gulf fish diets. C = general carnivore, CI = carnivore of invertebrates, CV = carnivore of vertebrates, O = omnivore, P = planktivore, H = herbivore.

3.3.2.15 Exmouth Gulf and Onslow fish tropical/subtropical/temperate species

A greater number of fish species (298) were recorded from Exmouth Gulf trawls compared with Shark Bay trawls. Of these there was a higher percentage of tropical species (91%), and fewer subtropical (6%) and warm-temperate species (1.3%). Only around 1.7% were wide-ranging warm-temperate to tropical species. Of the 298 species only 5.8% are endemic to Western Australia. There is a higher degree of endemism among the sub-tropical species than the tropical species.

A comparison of the Shark Bay and Exmouth Gulf species shows that there are 160 species common to both regions, which accounts for 66.4% of the Shark Bay species and 53.7% of the Exmouth Gulf species. The majority of these (87%) are tropical, 9% are subtropical, 2.7% are warm-temperate and 1.3% are widespread. Out of these 8% are endemic to Western Australia.

3.4 DISCUSSION

3.4.1 Shark Bay fish

Comparison of trawled and untrawled sites

Cluster and MDS analysis of abundance indicates that there is no clear distinction between fish assemblages from trawled and untrawled sites in Shark Bay. Depth and water temperature had a moderate correlation with fish assemblages. Differences between species richness, evenness and diversity were observed between assemblage groups. Within fish assemblage groups, differences were observed between trawled and untrawled sites but these were not consistent between assemblage groups.

Abundance

Maximum abundance of fish in Shark Bay is recorded from trawled sites 15, 24, 20, 21 and 23, in addition to untrawled site 22. Sites 15, 20 and 21 are at the southern end of the scallop trawl grounds. The greatly elevated numbers at site 20 are due to large schools of *P. quadrilineatus*, also present at site 15 but not in such large numbers. At site 21 *L. genivittatus* dominates abundance, followed by *U. asymmetricus* and *P. choirocephalus*. These three species are also numerous at site 20, but not at site 15. Sites 23 and 24 are at the opposite (northern) end of the scallop trawl grounds. The pattern of dominant species is most similar to that at sites 20 and 21, with abundant *U. asymmetricus* and *P. choirocephalus*, but *L. genivittatus* dominating site 23, and *T. pallimaculatus* being abundant at site 24. Site 22 stands alone, being the only site in Shark Bay with large numbers of *C. paxmani*, but it also has many *L. genivittatus* and *Lethrinus punctulatus*. The different suite of fish species at this site is likely to be due to the extensive meadows of wireweed (*A. antarctica*) in this area, not found in such densities in other sites sampled.

Moderate abundance of fish was found at trawled sites 6, 7, 8, 9, 14 and 19, but not at any untrawled sites. These sites are in the middle of trawl grounds in the centre of Shark Bay and in Denham Sound. Five species were highly abundant at most of these sites, which were *P. choirocephalus, U. asymmetricus* and *P. goodladi, T. pallimaculatus* and *P. vespa*. Additionally, *P. quadrilineatus* was abundant at sites 9, 14 and 19, *L. genivittatus* at site 8 and *L. leuciscus* at sites 9 and 19. All these fish species thrive in trawl habitats and appear to be able to maintain reasonable-sized populations in trawl grounds. They are likely to have reached a balance between fish removed by trawl activity and re-population of the sites by breeding and/or migration from adjacent areas.

A low abundance of fish was found in many trawled sites (5, 4, 11, 12, 13, 25) and untrawled sites (1, 2, 3, 10, 16, 17, 18, 26). These sites are at the extreme northern and southern limits of Shark Bay. Sites 10, 11, 12, 13, 25 and 26 are in the north of Shark Bay, and the six sites appear to pair up with respect to similarity in dominant species. Most dominant at sites 13 and 25 were *U. asymmetricus* and *P. choirocephalus*. Sites 12 and 26 were both dominated by *S. robustus* and *U. asymmetricus*. Sites 10 and 11 are more variable, but both had *A. carinatus* and *P. elevatus* among the top three most abundant species. Sites 1, 2, 3, 4 and 5 are in the south east, just east of Cape Peron North. All except site 2 had *P. choirocephalus* and *P. vespa* among the three most abundant species, whereas site 2 had *G. subfasciatus* and *L. leuciscus*. Sites 16, 17 and 18 are in the south of Denham Sound and had *U. asymmetricus, T. pallimaculatus, S. robusta, S. burrus, P. vitta, P. goodladi* and *P. quadrilineatus* among the three most abundant species. Many of the species that dominate abundance in the central trawl grounds are also present among the most abundant species, but in lower numbers, at the perimeters of Shark Bay. It is possible that environmental conditions are not so suitable for breeding at the edges of Shark Bay, and consequently the populations are smaller. Alternatively a proportion of these populations could migrate towards the central trawl grounds, thereby decreasing numbers in the outer regions.

Species richness, evenness and diversity

High, medium and low fish species richness was found in both trawled and untrawled sites throughout Shark Bay, indicating a lack of correlation between species richness and level of trawling. Richness was significantly different between the three fish assemblage groups and within assemblage groups, species richness was significantly higher in the trawled sites in Group 3.

High species richness occurred in trawled sites as well as untrawled sites, and appears to depend more on latitudinal location within Shark Bay rather than trawling activity. The highest species richness in Shark Bay was found at trawled sites 20, 21 and 23 (57 to 73 species per site) that also had a high abundance of fish. These sites are at the northern and southern limits of the scallop trawl grounds.

Seventeen sites had moderate species richness (41 to 50 species per site), 12 of which are trawled and 5 untrawled (sites 2, 3, 16, 17 and 22). These are in a range of locations in the central prawn trawl grounds and northern scallop trawl grounds, just east of Cape Peron North, and the west side of Denham Sound. The trawled sites have moderate oceanic influence that could be a source of new species, keeping the richness up to moderate levels. Sites 2 and 3 in Hopeless Reach and sites 17, 18 and 19 in south Denham Sound are close to metahaline waters and substantial water temperature fluctuations that may not be suitable habitats for a many species.

Low species richness was recorded from trawled sites 5, 11 and 12 and untrawled sites 1, 10, and 26. Minimum species richness occurred at the northern sites 10, 11, 12 and 26 (25 to 35 species per site). Possibly the deeper waters, oceanic conditions and slight difference in substrate in this region are less suitable for species that thrive in the shallower regions of Shark Bay. Sites 1 and 5 (33 to 37 species per site) are in the eastern Gulf adjacent to metahaline waters and extremes in water temperature fluctuations during the year – factors that are likely to limit the number of species that can inhabit this area.

No consistent patterns were observed with species evenness and diversity indices. Species evenness was lower for fish assemblage Group 2 and was significantly higher in the untrawled sites compared to trawled sites in Group 1. For species diversity Group 1 had higher diversity in untrawled sites whereas for Group 3 trawled sites had higher diversity. For evenness untrawled sites in Group 1 had a significantly higher value.

3.4.2 Shark Bay invertebrates

Comparison of trawled and untrawled sites

Cluster and MDS analysis did not reveal any clear distinctions between trawled and untrawled sites with respect to invertebrate abundance in Shark Bay. Salinity and temperature had a moderate correlation with invertebrate assemblages. Differences between richness, evenness and diversity was observed between invertebrate species assemblages.

Abundance

Invertebrates only occurred in high abundance (870 to 1565 invertebrates per nautical mile) at trawled sites 14, 20 and 21 in Denham Passage, and sites 24 and 25 at the northern end of the scallop trawl grounds east of Bernier Island. Sites 20 and 21 were dominated by *A. balloti* and *A. flabellata* that made up 64% and 78% of the catches respectively, while site 24 had 75% *A. balloti* alone. Site 14 had high numbers of *H. pallida* that made up 21% of the catch, plus many *P. latisulcatus* and *Metapenaeopsis* species. Coral prawns constituted 73% of the invertebrates sampled in Site 25.

A moderate abundance of invertebrates (415 to 595 invertebrates per nautical mile) was found at trawled sites 5, 6, 7, 8, 9, 11 and 13 in the central Shark Bay region and up to the northern end of Shark Bay. These trawled sites were dominated by different species depending on their location in Shark Bay. Site 5 in the south eastern section had abundant *P. pelagicus, Philine* species and *P. latisulcatus*, with a smaller number of *P. esculentus*. Sites 6 and 8 in the central region had significant quantities of *A. balloti*, *Metapenaeopsis* species and *P. latisulcatus*, while site 7 further east had few scallops, but more *Metapenaeopsis* species, *P. latisulcatus*, *M. dalli* and *P. pelagicus*. Sites 9, 11 and 13 in the northern part of Shark Bay had predominantly *Metapenaeopsis* species and *P. latisulcatus* with a smaller number of *P. esculentus*, plus *P. pelagicus* at site 13.

A low abundance of invertebrates was found at trawled sites 4, 15, 19, 23 and 12. These sites are scattered throughout Shark Bay from the north to the eastern and western Gulfs in the south.

None of the untrawled sites had a high abundance of invertebrates. A moderate abundance of invertebrates is found at untrawled sites 1, 2 and 17 in the southern extremes of Shark Bay in Freycinet Reach and Hopeless Reach. Sites 1 and 2 in the south east had abundant *P. pelagicus*, but site 1 has many *P. latisulcatus* while site 2 closer to Cape Peron North had many *P. esculentus*. Brown tiger prawns migrate north around the tip of Cape Peron North into Denham Passage, staying close to the Point and evidently not many spread east as far as site 1. Site 17 had a different suite of abundant species including *A. flabellata*, *A. balloti*, *Metapenaeopsis* species, *P. latisulcatus* and *P. tenuipes*. The environmental fluctuations in salinity and temperature could restrict large numbers of invertebrates surviving in these areas.

A low abundance of invertebrates was found at untrawled sites 3, 16, 10, 18, 26 and 22. Site 3 had many *P. pelagicus*, *M. endeavouri*, *P. latisulcatus* and *P. esculentus*, similar to other sites (1, 4, 5) in this area. Sites 16, 17 and 18 were similar in having abundant *A. flabellata*, *A. balloti* and *P. latisulcatus*. Sites 10 and 26 in the northern part of Shark Bay were dominated by *Metapenaeopsis* species and *P. latisulcatus*. Site 22 in the central western part of Shark Bay is different from all other sites in Shark Bay in that it had no abundant crustacean species. Instead the site was dominated by small *C. quadrangularis* and *C. crassus*, ascidians (unidentified species) and *B. desorii*.

Invertebrate abundance appeared to be greater in trawled sites compared with untrawled sites. It could be that the untrawled sites are in regions of Shark Bay where abundance is naturally low, in the southern extremes where salinity and temperature fluctuate most throughout the year, in the north where abundance declines with increasing depth, and one site in the west where there is abundant seagrass. Alternatively, higher abundance of invertebrates in trawled areas could be because these habitats have been altered by trawling in such a way as to favour feeding and breeding of certain species, particularly the commercial prawn and scallop species. The overall abundance is likely to be a combination of these two factors, plus subtle additional variation due to other physical and biological impacts.

Species richness, evenness and diversity

High, medium and low invertebrate species richness was found in both trawled and untrawled sites throughout Shark Bay, indicating a lack of correlation between species richness and level of trawling. Richness was significantly different between the three invertebrate assemblage groups and within assemblage groups species richness was significantly higher for trawled sites in Group 3.

The maximum invertebrate species richness in Shark Bay was recorded from trawled sites 21, 20, 25, 24, 8, 23 and 14 (34 to 40 species per site), and untrawled sites 16 and 22 (32 to 33 species per site). The trawled sites are at the northern and southern extremes of the scallop trawl grounds. Five of these sites (14, 21, 20, 24, 25) also had the maximum abundance of invertebrates in Shark Bay. These trawled sites all have limited salinity and temperature fluctuations during the year, plus they are subject to oceanic influence which is a possible source of additional species. Site 22 has dense seagrass meadows which may provide additional structure and habitat for a diverse invertebrate assemblage.

Moderate invertebrate species richness was recorded from trawled sites 4, 5, 6, 7, 9, 13, 15, 18 and 19 and untrawled sites 1, 2, 3 and 17. Sites 6, 7, 9, and 13 are in the central prawn trawl grounds, sites 15 and 17 in Denham Sound, and 1, 2, 3, 4 and 5 in the south eastern extreme. Evidently some sites in the southern parts of Shark Bay can support moderate invertebrate species richness, despite metahaline waters and large temperature fluctuations. The central trawl grounds have a range of habitats surrounding them that can possibly re-populate these sites.

Low invertebrate species richness in Shark Bay was found at trawled sites 11 and 12, (12 to 19 species per site) and untrawled site 26 (12 to 15 species per site). Sites 10, 11, 12 and 26 are all at the northern limit of the region which is also low in abundance of individuals. Possibly the deeper waters, oceanic conditions and slight difference in substrate in this region are less suitable for species that thrive in the shallower regions of Shark Bay.

For invertebrate assemblage groups, Group 2 had higher richness, evenness and diversity and within assemblage groups only diversity was significantly higher in trawled sites in Group 3.

3.4.3 Exmouth Gulf and Onslow fish

Comparison of trawled and untrawled sites

As with fish in Shark Bay, the fish abundance from trawled and untrawled sites in Exmouth Gulf and Onslow are not clearly distinguished by cluster or MDS analysis. Water tempertaure had a moderate correlation with fish species assemblages.

Abundance

The abundance of fish in Exmouth Gulf were highest in heavily trawled sites 9, 13, 14 and 11 (890 to 1240 fish per nautical mile). The most abundant species at these four sites were *U. asymmetricus, P. vespa, P. goodladi, L. moretoniensis, E. grandisquama, I. japonica, P. volitans, M. chinensis* and *G. subfasciatus.* These are all benthic- or epibenthic-dwelling species that are carnivores of small fish and/or invertebrates, except for the leatherjacket, which is an omnivore. The soft sediments of the trawl grounds evidently harbour sufficient prey items and are suitable habitats for these species to thrive in large numbers. These sites are in a deeper part (15 to 23 metres) of Exmouth Gulf that has minimal fluctuations in environmental factors such as salinity and water temperature, compared with other sites in the region. It is likely that the populations of these species are self-sustaining within Exmouth Gulf, with some possible recruitment from deeper water soft-bottom habitats offshore to the north east of Exmouth Gulf and Onslow. To the north west is the North West Cape and Muiron Islands that are very rich in reef dwelling species, less suited to inhabiting trawl grounds. Only minimal recruitment is therefore likely from the north west.

Conversely, two other heavily trawled sites (4 and 6) showed a low abundance of fish (350 to 390 fish per nautical mile). *Paracentropogon vespa, P. grossi, L. moretoniensis* and *I. japonica* are among the most abundant species at these sites as well, but also common are a different suite of species, including *G. oyena, S. undosquamis, P. lineatus, R. sublaevis, U. sulphureus, A. poecilopterus, N. peronii* and *L. malbaricus.* These are all carnivores of small fish and/or invertebrates, and majority are benthic and epibenthic species, except for *G. oyena* and *L. malabaricus* that are benthopelagic. These species are also well suited to soft sediment trawled habitats. Low abundance at heavily trawled sites 4 and 6 in central Exmouth Gulf could be because there is a lack of recruitment of additional fish from surrounding areas, since much of it is also trawled.

Other heavily trawled sites (17, 20, 24 and 25) displayed a moderate abundance of fish (500 to 695 fish per nautical mile). Most abundant at these sites were *U. sulphureus, T. theraps, S. lutea, J. vogleri, L. moretoniensis*, plus *P. maculatus* at site 7. The low to moderate abundances at sites 20, 24 and 25 are likely to be due to the effects of the Ashburton River which flows heavily in summer after cyclonic rains. The salinity at these sites was extremely low at the start of the trawling season in March 2004, ranging between 30.3 and 34.3 ppt. The lowest salinity of 30.3 ‰ was at site 24, which is at the river mouth. Besides low salinity, the river carries copious quantities of silt into the coastal waters. Many species cannot tolerate such conditions. Water temperature also fluctuates widely in these sites largely due to the shallowness of the sites (7.6 to 10.4 metres depth), with the lowest winter temperature dropping to 17.9° C at site 23, and the highest summer temperature reaching 30.4 °C at sites 22 and 23.

Lightly trawled sites had a low abundance of fish at site 23 (235 fish per nautical mile), moderate abundance at sites 1, 7, 12, and 21 (410 to 620 fish per nautical mile), but high abundance at site 5 (787 fish per nautical mile). Site 23 was dominated by *U. sulphureus* and *A. poecilopterus*, sites 1, 12 and 21 are dominated by abundant *U. asymmetricus, U. sundaicus, I. japonica, L. leuciscus* and *P. sexlineatus*, site 7 has abundant *L. moretoniensis* and *S. burrus*, and site 5 has abundant *P. lineatus, U. asymmetricus* and *P. choirocephalus.* There is little similarity in the fish communities between these sites.

The untrawled sites displayed low abundance of fish at sites 8 and 22, moderate abundance at sites 2, 3 and 19, and high abundance at sites 18, 26 and 10.

Species richness, evenness and diversity

Heavily trawled sites had between 38 and 76 fish species, lightly trawled 38 to 79 species and untrawled 48 to 80 species per site. There are clearly many other factors besides level of trawling that affect species richness at the various sites.

High species richness (72 to 80 species per site) was recorded from untrawled sites 10, 19, and 26, lightly trawled sites 16, 17 and 21, and heavily trawled site 9. Sites 10 and 9 are close to Bundegi Reef and North West Cape, which are likely to be sources of additional species at these sites. The remaining sites are located in the north east of Exmouth Gulf and offshore from Onslow. Since these areas are reasonably close to the Mackerel Islands offshore from Onslow that have rich fish populations (Hutchins 2001), it is possible that these islands are sources of additional species that move into suitable habitats in Exmouth Gulf.

Moderate species richness (55 to 68 species per site) was found at untrawled sites 2, 8, 18, and 22, lightly trawled sites 1, 5, and 12, and heavily trawled sites 11, 13, 14, 20 and 25. The untrawled and lightly trawled sites are located in a band from the southern end of Exmouth Gulf as far as the central eastern side of Exmouth Gulf, plus site 18 further north offshore from Tubridgi Point and site 22 offshore from Onslow For species richness and diversity, significant differences were observed in fish assemblage Groups 1 and 3 with higher richness in trawled sites in Group 1 and higher richness in untrawled sites in Group 3. The heavily trawled sites are in the north west part of Exmouth Gulf, plus site 20 close to shore just northeast of Tubridgi Point. These sites occupy regions in Exmouth Gulf that are not regularly subject to environmental extremes, and are somewhat distant from areas with more diverse fish faunas. Consequently the above sites display moderate species richness.

The lowest species richness in the region was recorded for heavily trawled sites 4 and 6 and untawled site 3 in central Exmouth Gulf (44 and 48 species per site), and sites 23 (lightly trawled) and 24 (heavily trawled) close to shore in the Onslow fishery (38 species per site). Sites 4 and 6 are likely to have the number of species reduced by trawling, and in addition to this, the location in central Exmouth Gulf minimises recruitment from other richer areas. Some of the other heavily trawled sites are closer to more varied habitats that are likely to be inhabited by a greater number of species, that could possibly re-populate areas after trawling. Sites 23 and 24 are also heavily influenced by large salinity and temperature fluctuations, and silt loading resulting from summer cyclones. Such conditions can only be tolerated by a limited number of species, or by species that are quick to re-colonise an area after cyclones have passed.

Differences between richness, evenness and diversity were observed between the four fish assemblage groups with Groups 3 and 4 having lower values for all indices and species richness in Group 4 which were the inshore sites in Onslow being particularly low. Differences between trawled and untrawled sites were observed for Groups 1 and 3 with higher diversity in trawled sites in Group 1 and untrawled sites in Group 3.

3.4.4 Exmouth Gulf and Onslow invertebrates

Comparison of trawled and untrawled sites

Trawled and untrawled sites were not separated through cluster or MDS analysis with all invertebrate species assemblage groups having both trawled and untrawled sites. No strong correlation was observed for any of the environmental measures.

Abundance

The abundance of invertebrates in Exmouth Gulf was highest in heavily trawled sites 13, 14 and 11 (870 to 1140 invertebrates per nautical mile), all in the north west region of Exmouth Gulf. The most abundant species at some of these sites were *P. latisulcatus*, rosy prawn (*Metapenaeopsis rosea*), *P. esculentus, M. endeavouri, T. anchoralis, M. crassissima, P. tenuipes*, plus *A. flabellata* at site 14. Many species of prawns and the fan scallop appear to thrive in trawled habitats, but populations can fluctuate from year to year. Monitoring of the commercial fishery, and fishery independent surveys of Exmouth and Onslow indicated that the numbers of *P. esculentus* were high and extensively distributed in Exmouth Gulf and Onslow for both 2003 and 2004. In 2005, however, the numbers dropped back to average levels and therefore if the project had continued into 2005 the dominance of *P. esculentus* may have been less.

Heavily trawled site 24 displayed a minimal abundance of invertebrates (405 invertebrates per nautical mile). Among the most abundant species at this site were *P. esculentus, T. curvirostris, C. truncata*, and the mantis shrimp (*Carinosquilla australiensis*). This site is in the Onslow area that is subject to large fluctuations in salinity, temperature and silt levels that could possibly limit abundance. Heavily trawled site 17 in the north east of Exmouth Gulf had a high abundance of invertebrates (735 individuals per nautical mile). The bulk of the abundance at site 17 is due to *P. esculentus* that made up 70% of the catch. This site is also close to an area to the north west that is rich in sedentary invertebrates, that is likely to be a source of new recruits.

A moderate abundance of invertebrates was found at heavily trawled sites 4, 6, 9, 16, 20 and 25 (430 to 685 invertebrates per nautical mile). Sites 4, 6, and 9 are in the central Exmouth

Gulf region and site 16 is in the north east of Exmouth Gulf. Sites 4, 6 and 16 are dominated in abundance by *P. esculentus* and *M. endeavouri,* but site 9 is distinctly different being dominated by *P. latisulcatus* and *M. endeavouri.* Site 9 is a sandier habitat which is preferred by *P. latisulcatus* compared with *P. esculentus.* Depth, temperature and salinity were similar in the central and northern areas yet the commercial species of prawns are less abundant at these sites than in the trawled north west part of Exmouth Gulf. It is possible that many biological reasons, such as differences in level of competition for space, food, or recruitment of individuals from adjacent areas influences abundance levels. Sites 20 and 25 are in the southern part of the Onslow Fishery, and have abundant *P. esculentus* and *P. pelagicus*, whilst *P. latisulcatus* occur in abundance at site 25 only. Site 25 has a much lower abundance than site 20 (430 compared with 685 individuals per nautical mile), which indicates that abundance increases with distance from the mouth of the Ashburton River (site 25 is closer to the river mouth).

Lightly trawled sites displayed a moderate abundance at sites 1, 5, 7, 12, 16, 21 (485 to 630 individuals per nautical mile). These sites had *P. esculentus* as the most abundant species, along with abundant *M. endeavouri*. *Portunus pelagicus* were abundant at the northern site 21.

Untrawled site 18 had a high abundance of invertebrates (925 per nautical mile), sites 2, 8, 10, 19, 26 had a moderate abundance (470 to 670 individuals per nautical mile), and sites 3 and 22 had a low abundance (330 to 370 invertebrates per nautical mile). Site 18, like site 17, is close to the habitat with rich sedentary invertebrates, a possible source of recruits. The most abundant species here were *P. tenuipes, M. rosea, P. latisulcatus* and *B. desorii*. Sites 2, 8, 10, 19, and 26 were varied in the range of abundant species. Sites 2 and 8 had abundant *P. esculentus, M. endeavouri, P. pelagicus* and, *P. tenuipes*, site 26 has abundant *P. rubromarginatus, P. tenuipes* and *P. latisulcatus,* site 10 had abundant *P. tenuipes, M. endeavouri* and *M. australis*, and site 19 was completely different being dominated by abundant *S. sphaeroides* and *P. bispinosa*, along with *P. esculentus.* Sites 3 was dominated by abundant *P. esculentus, M. endeavouri* and *P. latisulcatus*, whereas site 22 is dominated by *T. curvirostris, C. truncata, P. rubromarginatus* and *P. esculentus.* It is unclear why site 3 had low abundance since adjacent sites all have moderate abundance. Site 22 is likely to be affected by the Ashburton River runoff.

Species richness, evenness and divesity

For the invertebrate abundance assemblage groups, Group 2 was consistently lower in richness, evenness and diversity. This group includes inshore sites 20 and 24 near the Ashburton River, inshore sites 7, 8, 12 and 17 in Eastern Exmouth Gulf and heavily trawled sites 4 and 6.

Heavily trawled sites had between 22 and 59 species, lightly trawled 34 to 55 species, and untrawled sites 27 to 67 species per site.

The highest species richness for the region was recorded from untrawled sites 10 and 19, lightly trawled site 5, heavily trawled sites 9 and 14 (55 to 67 species per site). Sites 9, 10 and 14 are adjacent to Bundegi reef which is likely to be a source of additional species. Sites 5 and 19 are on the central eastern side of Exmouth Gulf, with no obvious source of different species.

Moderate species richness (37 to 54 species per site) was found at heavily trawled sites 7, 11, 13, and 25, lightly trawled sites 1, 12, 16, 17 and 21, and untrawled sites 2, 3, 22 and 26. All sites, except for Onslow sites 21, 22, and 25, are in areas of relatively stable environmental conditions that may enable good survival rates for a variety of species, and average recruitment from adjacent areas. Although sites 21, 22 and 25 have greater fluctuations in environmental conditions, the sites could possibly have a steady influx of species from the richer offshore regions in stable environmental periods.

The lowest species richness in the region was recorded from lightly trawled site 23 and heavily trawled sites 20 and 24 close inshore to Onslow (22 to 34 species per site), and heavily trawled sites 4, 6, and untrawled site 8 in central Exmouth Gulf region (27 to 32 species per site). The Onslow sites, as previously mentioned, are likely to have reduced species richness due to effects of the Ashburton River, besides the impact of trawling. The central Exmouth Gulf region possibly has reduced species richness because of minimal recruitment from surrounding areas.

Significant differences were observed between diversity indices of richness, evenness and diversity with assemblage Group 2 having a lower value than the other groups for all indices. Group 2 sites had the narrowest range of particle sizes in the sediments. Comparison of trawled and untrawled sites only indicated significantly higher indices for evenness and diversity for untrawled sites in Group 4.

3.5 GENERAL DISCUSSION

Shark Bay and Exmouth Gulf

This survey of prawn trawl bycatch species indicates assemblages of great complexity in Shark Bay and Exmouth Gulf. There was no clear distinction between faunal assemblages in trawled and untrawled sites in either of these regions.

Comparison of trawled and untrawled sites within faunal assemblage groups did indicate significant differences between sites but these differences were not consistent as both trawled and untrawled sites had higher richness, evenness and diversity on occasion. Variability between species abundance and richness within samples within a site for a sampling period was observed, reducing the power to detect differences.

Shark Bay is an unusual embayment with limited freshwater run-off from the mainland, extensive shallow areas and inshore areas in the southern gulfs that have limited exchange with oceanic waters (Logan and Cebulski 1970). These geographical conditions result in hypersalinity in the southern gulfs, and large fluctuations in water temperature in shallow areas throughout the year. Additionally, depth and currents vary considerably between the survey sites. Depth and water temperature had a moderate correlation with fish species assemblages in Shark Bay whilst salinity had a moderate correlation for invertebrate assemblages. This may be due to their more limited mobility.

Exmouth Gulf and Onslow have a different climate from Shark Bay with a higher rainfall (largely from summer cyclones), and seasonal freshwater river runoff particularly from the Ashburton River near Onslow. Like Shark Bay, it is a semi-enclosed embayment in which there is restricted exchange of water with the southern (inner) reaches of Exmouth Gulf, and depth and current varies between sites. However, the elevated salinities observed in Shark Bay were not encountered in the sites sampled in Exmouth Gulf. This may be why there was only a moderate correlation with temperature for fish and a poor correlation for all measures for invertebrates.

Although divisive clustering and MDS analysis implies little impact from trawl activity on faunal assemblages, there are many interacting factors that can mask these effects. One main factor is the mobility of many species of fish and invertebrates. Some species can travel large distances between trawled and untrawled areas and vice versa. For example, once an area has been trawled and many individuals removed, there is an opening for opportunistic species to move in and find adequate food with less competition from other individuals. Another factor is that different species can react in very different ways to the effect of trawling. Some species such as *S. undosquamis, U. asymmetricus, P. choirocephalus*, commercial prawn species and portunid crabs prefer the disturbed, low-relief, soft sediment habitats modified by trawling. These are species that benefit when the structural complexity of a habitat is reduced. They appear to thrive and many are likely to be self-sustaining in such systems. An interesting phenomenon termed the 'intermediate disturbance hypothesis' (Connell, 1978) suggests that the highest diversity of species is maintained at intermediate scales of disturbance. In other words, a moderate level of trawling disturbance does not necessarily result in a decrease in species richness. This hypothesis could, at least partially, explain high species richness and also greater abundance of fish and invertebrates in some of the trawled sites, particularly the scallop grounds in Shark Bay and prawn trawl grounds in the northern regions of Exmouth Gulf.

The increasing abundance of one species may balance the decrease in abundance of another when all data is analysed together. Additionally, it has been previously observed that natural environmental variability is often greater than fishing-induced changes (Jones 2000), further masking the effects of trawl activity. Such large variability in species richness and abundance between species indicates that interpretation of the analyses must be made with caution.

Commercial trawling has been ongoing in Shark Bay and Exmouth Gulf from 1963, to the present day. We lack sufficient baseline data to measure the spatial and temporal variability of faunal assemblages in the regions prior to the commencement of commercial trawling. It was difficult to find equal numbers of non-trawled sites for the survey, because many of the areas had been trawled in the past, or were unsuitable to trawl. It has been observed elsewhere that high levels of trawling may not only decrease the complexity of the habitat and biodiversity of the fauna, but also enhance the abundance of opportunistic species including prey species that are important in the diet of some commercial species (Engel and Kvitek, 1998). It is likely that the faunal assemblages, biodiversity and habitats in the trawled areas of Shark Bay and Exmouth Gulf and Onslow have changed significantly since trawling began, but have now reached a new 'balance' compatible with trawling. Comparsions of biodiversity and abundance measures are difficult to make since there are no equivalent soft sediment untrawled regions similar to Shark Bay or Exmouth Gulf in Western Australia. However, comprehensive surveys of nearshore reef fish species have been carried out in many WA locations (Hutchins, 1994). Although reef habitats are physically more complex than soft sediments and consequently provide niches for a wider suite of species, comparison of species richness between areas does give an indication of level of biodiversity. At the Houtman Abrolhos, for example, a total of 249 reef fish species were recorded, in contrast to 309 for Shark Bay (surveys carried out around reefs and islands) (Hutchins, 1994); whereas the total for trawled (soft sediment) species in Shark Bay is 241 fish species. Further north at Coral Bay, 307 reef fish species were recorded by Hutchins (1994). Although comparing different habitats, these figures indicate that species richness in the trawled regions of Shark Bay is not depauperate. The composition of the fish communities in these contrasting habitats are, however, likely to be very different and the two studies are not directly comparable. A previous study by the WA Museum in 1995 (Hutchins et al. 2005 unpublished report) recorded 636 invertebrate species but this did not include crustaceans or many of the minor invertebrate groups indicating high invertebrate species diversity in the region. This survey recorded a total of 360 invertebrate species for soft sediments of Shark Bay.

A total of 298 fish species were recorded from Exmouth Gulf and Onslow survey sites. The nearest surveys to this region are those of Hutchins (1994) in which he recorded 482 fish species for the

Muiron Islands and the west coast of North-West Cape. These latter regions have a high physical complexity, diversity of habitats and variable levels of exposure, and, therefore, species richness would be expected to be much greater than in a soft sediment locality such as Exmouth Gulf and Onslow. The species richness for Exmouth Gulf and Onslow survey sites appears to be relatively 'healthy'. Again, the fish assemblages in the different types of habitats are likely to be dissimilar. Comparison of invertebrate species richness is problematic, because of different sampling techniques and different phyla were examined at finer levels during a 1995 survey of the Muiron Islands (W.A. Museum unpublished report, Hutchins et al. 1996). Invertebrates recorded from this work totalled approximately 920 species. The total number of invertebrate species from our study was approximately 365 (see bullet points p. 97) which only includes those species captured by a prawn trawl net.

This study was conducted over a relatively brief period (1 year in Shark Bay and 10 months in Exmouth Gulf) for fixed sites with up to three samples within a site. There can also be large fluctuations in the catches of target species from year to year, and it is likely that bycatch species abundance is equally variable (see Chapter 4). In considering useful measures of biodiversity in these two embayments, these factors must be kept in mind.

Species richness, evenness and divesity are useful measures of biodiversity in these areas, even if the suite of species changes. This is because a change in the number of species in an area is an important indicator of ecological change, for good or bad. Generally a stable number or an increase in the number of species indicates a healthy, self-sustaining ecosystem, whereas a decrease in species number is likely to indicate an imbalance or problem in the ecosystem.

Abundance of species is an important measure to use in conjunction with species richness. The most abundant 10 to 20 species of fish and invertebrates for the majority of survey sites in Shark Bay and Exmouth Gulf represent around 90% of the total catch. These abundant species can, therefore, be used to characterise the faunal assemblage of most sites. Since many abundant species occur in such large numbers, with the majority being widespread within the embayments, it would be anticipated that these core groups of species are dominant in the various regions from year to year. The most likely factors to change this dominance rapidly are naturally occurring extremes of weather such as cyclones, or accidental anthropogenic causes such as oil spills or introduction of exotic marine species. Although the 20 most abundant species of fish and invertebrates may be used to characterise a site or sites, there is a danger of over-simplification of the ecosystem if less abundant species are ignored. Some of the less abundant species can be key indicators of the health of an ecosystem, and naturally only occur in low numbers. Elasmobranchs are prime examples of such indicator species and the limited data available on the impact of prawn trawling on them suggests that many species are very susceptible to capture and mortality from trawling (Stobutzki et al. 2002). Many elasmobranchs are top predators that normally occur in very low numbers. Once these predators are removed from an ecosystem, their prey species may multiply dramatically. If these prey species are one of the more abundant species in trawl habitats and used to characterise an area, their increase could be mis-interpreted as improvement in the health of an area. It is important, therefore, to identify all fish and invertebrate species in bycatch to fully understand the health of an ecosystem and to determine whether biodiversity is being sustained.

In conclusion, despite faunal assemblages being extremely variable in the different regions within Shark Bay and Exmouth Gulf, the biodiversity measures of species richness, evenness, diversity and abundance are still useful tools to assess the health and sustainability of these marine communities, so long as they are interpreted with caution.

3.6 SUMMARY

The results of this survey can be summarised as follows:

3.6.1 Shark Bay

- No clear differences between faunal assemblages in trawled and untrawled survey sites in Shark Bay were observed.
- Regional differences between faunal assemblages exist in Shark Bay. The four main groups being to the north-east of Cape Peron North, Denham Sound, central and western regions, and the northern section. A fifth separate site in the central west of Shark Bay stands alone.
- The regional clusters of sites appear to be moderately correlated with some environmental parameters; salinity, water temperature and depth.
- Mean species richness, recorded over four survey trips, range from 12 to 40 species per site for invertebrates, and from 25 to 73 species per site for fish. The maximum species richness is found in the northern and southern extremes of the scallop trawl grounds, and the minimum is found at the northern limits of Shark Bay.
- A total of 360 invertebrate, 241 fish, one turtle and two seasnake species were recorded from five trips to Shark Bay between October 2002 and February 2004.
- The 10 most abundant fish species at each site account for 69% to 90% of the total abundance per site.
- The 10 most abundant invertebrate species at each site account for 73% to 98% of the total abundance per site.
- A small number of threatened and CITES-listed species (Elasmobranchs, Syngnathids, turtles and seasnakes) were captured. The majority of the large species would have been excluded if exclusion devices (eg grids) had been used.
- Species richness and abundance of the 20 most abundant species were determined to be a useful measure of biodiversity in trawled and untrawled areas of Shark Bay.

3.6.2 Exmouth Gulf and Onslow

- No clear differences between faunal assemblages in trawled and untrawled survey sites in Exmouth Gulf and Onslow were observed.
- Regional differences between faunal assemblages exist in Exmouth Gulf and Onslow. There are three main groups that cluster in the (i) south, central and eastern areas of Exmouth Gulf as far north as Tubridgi Point, (ii) inshore regions north of Tubridgi Point as far as Onslow, and (iii) between the north west of Exmouth Gulf and offshore from Onslow, with two separate sites (5 and 19) in the central eastern part of Exmouth Gulf.
- Mean species richness, recorded over three survey trips, ranges from 22 to 66 species per site for invertebrates, and from 37 to 80 species per site for fish. Maximum species richness occurs in the north-west of Exmouth Gulf adjacent to Bundegi Reef, offshore in the Onslow fishery and in the north-east of Exmouth Gulf. Minimum species richness occurs close inshore to Onslow adjacent to the Ashburton River, and in the central Exmouth Gulf area.

- A total of 365 invertebrate, 298 fish, three turtle and five seasnake species were recorded from three trips to Exmouth Gulf and Onslow between March 2004 and November 2004.
- The 10 most abundant fish species at each site account for 40% to 84% of the total abundance per site.
- The 10 most abundant invertebrate species at each site account for 63% to 90% of the total abundance per site.
- A small number of threatened and CITES-listed species (Elasmobranchs, Syngnathids, turtles and seasnakes) were captured. The majority of the large species would have been excluded if exclusion devices (eg grids) had been used.
- Species richness and abundance of the 20 most abundant species were determined to be a useful measure of biodiversity in trawled and untrawled areas of Exmouth Gulf and Onslow.

3.7 APPENDICES

Appendix 3.1 Shark Bay fish species recorded from four survey trips in 2002 and 2003

Key:

Habitat: B = benthic, EB = epibenthic, BP = benthopelagic, M = mid-water, P = pelagic, S = surface waters

Diet: C = general carnivore, CI = carnivore of invertebrates, CV = carnivore of vertebrates, O = omnivore, P = planktivore, H = herbivore

Shark Bay total number of species for all trips = 241

CAAB Fam no	Family	Scientific name	Common name*	Oct-02 Trip 1	Feb-03 Trip 2	Jun-03 Trip 3	Sep-03 Trip 4	Habitat	Diet
013.2	Hemiscylliidae	*Chiloscyllium punctatum*	Catshark, Brown-banded	1			4	B	C
015	Scyliorhinidae	*Halaelurus boesemani*	Catshark, Speckled	1				B	C
017	Triakidae	*Mustelus sp. A*	Shark, Grey Gummy		2	3	4	B	C
018.1	Carcharhinidae	*Carcharhinus cautus*	Shark, Nervous	1				P	C
018.1	Carcharhinidae	*Carcharhinus melanopterus*	Shark, Blacktip Reef	1				BP	C
018.1	Carcharhinidae	*Carcharhinus obscurus*	Shark, Dusky Whaler	1				BP	C
018.1	Carcharhinidae	*Carcharhinus plumbeus*	Shark, Thickskin/Sandbar	1				BP	C
018.1	Carcharhinidae	*Rhizoprionodon acutus*	Shark, Milk	1				BP	C
018.2	Hemigaleidae	*Hemigaleus australiensis*	Shark, Weasel		2			BP	C
026	Rhynchobatidae	*Rhina ancylostoma*	Shark Ray		2			B	CI
026	Rhynchobatidae	*Rhynchobatus australiae*	Shovelnose Ray, White-spotted		2	3	4	B	C
027	Rhinobatidae	*Aptychotrema vincentiana*	Shovelnose Ray, Western	1	2		4	B	CI
28.2	Narcinidae	*Narcine westraliensis*	Numbfish, Banded	1	2	3	4	B	CI
28.3	Hypnidae	*Hypnos monopterygium*	Numbfish	1				B	C
035	Dasyatididae	*Dasyatis kuhlii*	Stingray, Blue-spotted	1		3	4	B	C
035	Dasyatididae	*Dasyatis leylandi*	Stingray, Brown Reticulated	1	2	3	4	B	C
035	Dasyatididae	*Himantura* sp. *(toshi?)*	Stingray, Coachwhip	1				B	C
035	Dasyatididae	*Himantura toshi*	Whipray, Black-spotted		2		4	B	C
035	Dasyatididae	*Himantura uarnak*	Whipray, Reticulate		2		4	B	C
035	Dasyatididae	*Taeniura meyeni*	Stingray, Black-blotched		2			B	C
037	Gymnuridae	*Gymnura australis*	Ray, Rat-tailed/Butterfly	1	2	3	4	B	C
038	Urolophidae	*Trygonoptera ovalis*	Stingaree, Striped			3	4	B	C
039	Myliobatididae	*Aetobatus narinari*	Ray, White-spotted Eagle		2			BP	CI
060	Muraenidae	*Gymnothorax woodwardi*	Eel, Woodwards Reef	1				B	C
063	Muraenesocidae	*Oxyconger leptognathus*	Eel, Shorttail Pike		2		4	B	C
067	Congridae	*Ariosoma* sp.	Conger Eel				4	B	C
067	Congridae	*Gnathophis longicaudus*	Eel, Silver Conger		2	3		B	CI
067	Congridae	*Gnathophis* sp.	Conger Eel				4	B	CI
067	Congridae	*Uroconger lepturus*	Eel, Longtail Conger		2			B	C
085	Clupeidae	*Herklotsichthys lippa*	Herring, Australian Spotted	1	2	3	4	P	P
085	Clupeidae	*Sardinella gibbosa*	Sardine, Gold-striped	1	2	3	4	P	P

CAAB Fam no	Family	Scientific name	Common name*	Oct-02 Trip 1	Feb-03 Trip 2	Jun-03 Trip 3	Sep-03 Trip 4	Habitat	Diet
085	Clupeidae	*Sardinella lemuru*	Sardine, Scaly Mackerel	1	2	3	4	P	P
085	Clupeidae	*Sardinella sp.*	Sardine		2			P	P
085	Clupeidae	*Spratelloides robustus?*	Sprat		2			P	P
086	Engraulidae	*Engraulis australis*	Australian Anchovy				4	P	P
118.1	Bathysauridae	*Saurida undosquamis*	Lizardfish, Large-scaled Grinner	1	2	3	4	B	C
118.2	Synodontidae	*Synodus dermatogenys*	Lizardfish, Banded		2			B	C
118.2	Synodontidae	*Synodus doaki*	Lizardfish, Doak's/ Arrowtooth				4	B	C
118.2	Synodontidae	*Synodus tectus*	Lizardfish, Black-shouldered			3		B	C
118.2	Synodontidae	*Synodus sageneus*	Lizardfish, Netted	1	2	3	4	B	C
118.2	Synodontidae	*Trachinocephalus myops*	Lizardfish, Painted Grinner	1	2	3	4	B	C
141	Gonorynchidae	*Gonorynchus greyi*	Salmon, Beaked	1	2	3		B	C
192	Plotosidae	*Euristhmus microceps*	Catfish, Small-headed		2	3	4	B	C
192	Plotosidae	*Paraplotosus albilabris*	Catfish, White-lipped				4	B	C
192	Plotosidae	*Paraplotosus sp.*	Catfish, Eel-tailed	1	2	3	4	B	C
192	Plotosidae	*Plotosus lineatus*	Catfish, Striped	1			4	B	C
205	Batrachiodidae	*Halophryne ocellatus*	Frogfish, Ocellated		2		4	B	C
210	Antennariidae	*Antennarius striatus*	Anglerfish, Striated	1	2		4	B	CV
210	Antennariidae	*Tathicarpus butleri*	Anglerfish, Butler’s	1	2	3	4	B	CV
225	Bregmacerotidae	*Bregmaceros* sp.	Codlet				4	P	P
233	Exocoetidae	*Cheilopogon* sp.	Flying fish, West Australian				4	S	P
234	Hemiramphidae	*Euleptorhamphus viridis*	Garfish, Long-finned				4	S	O
234	Hemiramphidae	*Hemiramphus robustus*	Garfish, Robust	1	2		4	S	O
235	Belonidae	*Ablennes hians*	Longtom, Barred		2			S	CV
269	Veliferidae	*Metavelifer multiradiatus*	Veilfin		2			BP	P
269	Veliferidae	*Velifer hypselopterus*	Veilfin, High-finned		2			BP	P
278	Fistulariidae	*Fistularia commersonii*	Flutemouth, Smooth		2	3		P	C
282	Syngnathidae	*Filicampus tigris*	Pipefish, Tiger	1	2	3	4	B	P
282	Syngnathidae	*Haliichthys taeniophorus*	Pipefish, Ribboned		2	3	4	B	P
282	Syngnathidae	*Hippocampus angustus*	Seahorse, Western Spiny	1	2	3	4	B	P
282	Syngnathidae	*Hippocampus biocellatus*	Seahorse, False-eyed	1	2	3	4	B	P
282	Syngnathidae	*Hippocampus planifrons*	Seahorse, Flat-face		2			B	P
282	Syngnathidae	*Stigmatopora argus*	Pipefish, Spotted				4	B	P
282	Syngnathidae	*Syngnathoides biaculeatus*	Pipefish, Alligator		2			B	P
282	Syngnathidae	*Trachyrhamphus bicoarctatus*	Pipefish, Short-tailed	1	2		4	B	P
287	Scorpaenidae	*Apistus carinatus*	Scorpionfish, Long-finned Waspfish	1	2	3	4	B	C
287	Scorpaenidae	*Dendrochirus brachypterus*	Scorpionfish, Dwarf Lionfish	1	2	3		EB	C
287	Scorpaenidae	*Inimicus sinensis*	Stinger, Spotted	1	2	3	4	B	C
287	Scorpaenidae	*Minous versicolor*	Scorpionfish, Plumb-striped Stingfish	1	2	3	4	B	C

CAAB Fam no	Family	Scientific name	Common name*	Oct-02 Trip 1	Feb-03 Trip 2	Jun-03 Trip 3	Sep-03 Trip 4	Habitat	Diet
287	Scorpaenidae	*Paracentropogon vespa*	Scorpionfish, Bullrout	1	2	3	4	B	C
287	Scorpaenidae	*Pterois volitans*	Scorpionfish, Red Firefish		2	3		EB	C
287	Scorpaenidae	*Scorpaena gasta*	Scorpionfish, Ghostly	1	2	3	4	B	C
287	Scorpaenidae	*Synanceia horrida*	Stonefish, Estuarine	1	2			B	C
288	Triglidae	*Lepidotrigla sp.*	Gurnard, Long-finned	1	2	3	4	B	C
290	Aploactinidae	*Aploactis aspera*	Velvetfish, Dusky	1	2	3	4	B	CI
290	Aploactinidae	*Kanekonica queenslandica*	Velvetfish, Queensland	1		3	4	B	CI
290	Aploactinidae	*Paraploactis intonsa*	Velvetfish, Bearded	1	2	3	4	B	CI
290	Aploactinidae	*Peristrominous dolosus*	Velvetfish, Cod	1	2	3	4	B	CI
296.1	Platycephalidae	*Papilloculiceps bosschei*	Flathead, Bossch's	1	2	3	4	B	C
296.1	Platycephalidae	*Papilloculiceps nematophthalmus*	Flathead, Fringe-eyed	1	2	3	4	B	C
296.1	Platycephalidae	*Inegocia japonica*	Flathead, Rusty	1	2	3	4	B	C
296.1	Platycephalidae	*Onigocia spinosa*	Flathead, Spiny	1	2	3	4	B	C
296.1	Platycephalidae	*Platycephalus arenarius*	Flathead, Northen Sand	1	2	3	4	B	C
296.1	Platycephalidae	*Platycephalus endrachtensis*	Flathead, Bar-tailed	1	2	3	4	B	C
296.1	Platycephalidae	*Platycephalus longispinis*	Flathead, Long-spined	1	2	3	4	B	C
296.1	Platycephalidae	*Sorsogona tuberculata*	Flathead, Heart-headed	1	2	3	4	B	C
296.1	Platycephalidae	*Thysanophrys cirronasa*	Flathead, Tassel-snouted	1		3		B	C
308	Dactylopteridae	*Dactyloptena orientalis*	Searobin, Oriental	1			4	B	C
308	Dactylopteridae	*Dactyloptena papilio*	Searobin, Sharp-eared		2	3	4	B	C
309	Pegasidae	*Pegasus volitans*	Seamoth, Slender	1	2	3	4	B	C
310.2	Centropomidae	*Hypopterus macropterus*	Spiky Bass	1	2	3	4	BP	C
310.2	Centropomidae	*Psammoperca waigiensis*	Sand Bass		2	3	4	BP	C
311.1	Serranidae	*Caesioscorpis theagenes*	Sweep, Fusilier			3		P	P
311.1	Serranidae	*Centrogenys vaigiensis*	Rockcod, False Scorpionfish	1	2	3	4	EB	C
311.1	Serranidae	*Epinephelus rivulatus*	Rockcod, Chinaman			3		BP	C
313	Pseudochromidae	*Assiculus punctatus*	Dottyback, Longfin	1				EB	C
321	Terapontidae	*Pelates quadrilineatus*	Trumpeter, Four-lined	1	2	3	4	BP	C
321	Terapontidae	*Pelates sexlineatus*	Trumpeter, Striped/Six-lined	1	2	3	4	BP	C
321	Terapontidae	*Terapon puta*	Trumpeter, Three-lined	1				BP	C
321	Terapontidae	*Terapon theraps*	Trumpeter, Banded	1	2	3	4	BP	C
326	Priacanthidae	*Priacanthus macracanthus*	Bigeye, Red	1	2	3		EB	C
326	Priacanthidae	*Priacanthus tayenus*	Bigeye, Threadfin				4	EB	C
327.1	Apogonidae	*Apogon brevicaudatus*	Cardinalfish, Many-banded	1	2	3	4	EB	CI
327.1	Apogonidae	*Apogon cavitiensis*	Cardinalfish, Cavite	1	2	3	4	EB	CI
327.1	Apogonidae	*Apogon monospilus*	Cardinalfish, Moluccan		2	3	4	EB	CI
327.1	Apogonidae	*Apogon nigripinnis*	Cardinalfish, Two-eyed	1	2	3	4	EB	CI
327.1	Apogonidae	*Apogon poecilopterus*	Cardinalfish, Pearly-finned	1	2	3		EB	CI

CAAB Fam no	Family	Scientific name	Common name*	Oct-02 Trip 1	Feb-03 Trip 2	Jun-03 Trip 3	Sep-03 Trip 4	Habitat	Diet
327.1	Apogonidae	*Apogon quadrifasciatus*	Cardinalfish, Broad-banded	1	2	3	4	EB	CI
327.1	Apogonidae	*Apogon rueppellii*	Cardinalfish-Gobbleguts	1	2	3	4	EB	CI
327.1	Apogonidae	*Apogon semilineatus*	Cardinalfish, Black-tipped	1	2	3	4	EB	CI
327.1	Apogonidae	*Apogon victoriae*	Cardinalfish, Victorian		2	3	4	EB	CI
327.1	Apogonidae	*Foa brachygramma*	Cardinalfish, Weed			3	4	EB	CI
327.1	Apogonidae	*Siphamia roseigaster*	Cardinalfish, Pink-breasted Siphonfish		2	3	4	EB	CI
330	Sillaginidae	*Sillago burrus*	Whiting, Trumpeter	1	2	3	4	B	C
330	Sillaginidae	*Sillago robusta*	Whiting, Robust	1	2	3	4	B	C
330	Sillaginidae	*Sillago schomburgkii*	Whiting, Yellowfin	1	2	3	4	B	C
334	Pomatomidae	*Pomatomus saltatrix*	Tailor	1	2	3		P	C
336	Echeneidae	*Echeneis naucrates*	Suckerfish, Slender		2		4	P	CI
337	Carangidae	*Alepes apercna*	Trevally, Small Mouth Scad	1	2			P	CI
337	Carangidae	*Alepes* **cf.** *djedaba*	Trevally, Shrimp Scad			3		P	CI
337	Carangidae	*Carangoides chrysophrys*	Trevally, Club-nosed		2	3		P	C
337	Carangidae	*Carangoides hedlandensis*	Trevally, Bump-nosed		2			P	C
337	Carangidae	*Carangoides malabaricus*	Trevally, Malabar		2	3		P	C
337	Carangidae	*Carangoides talamparoides*	Trevally, White-tongued	1	2			P	C
337	Carangidae	*Decapterus russelli*	Trevally, Russell's Mackerel Scad		2	3		P	P
337	Carangidae	*Gnathanodon speciosus*	Trevally, Golden	1	2			BP	C
337	Carangidae	*Parastromateus niger*	Pomfret, Black		2			BP	P
337	Carangidae	*Pseudocaranx dinjerra*	Trevally, Western	1	2	3	4	BP	C
337	Carangidae	*Selar boops*	Trevally, Oxeye Scad		2			P	CI
337	Carangidae	*Selaroides leptolepis*	Trevally, Smooth-tailed	1	2	3	4	BP	C
337	Carangidae	*Seriolina nigrofasciata*	Trevally, Black-banded Kingfish	1		3		P	C
337	Carangidae	*Trachurus novaezelandiae*	Trevally, Yellowtail	1	2	3	4	P	P
341	Leiognathidae	*Gazza minuta*	Ponyfish, Toothpony		2		4	EB	C
341	Leiognathidae	*Leiognathus bindus*	Ponyfish, Orangefin		2	3	4	EB	C
341	Leiognathidae	*Leiognathus leuciscus*	Ponyfish, Whipfin	1	2	3	4	EB	CI
341	Leiognathidae	*Leiognathus moretoniensis*	Ponyfish, Zig-Zag	1?	2?	3	4?	EB	C
341	Leiognathidae	*Secutor insidiator*	Ponyfish, Pugnose		2	3	4	EB	O
346.1	Lutjanidae	*Lutjanus carponotatus*	Seaperch, Stripey		2			BP	C
346.1	Lutjanidae	*Lutjanus malabaricus*	Seaperch, Saddle-tailed		2	3		BP	C
347	Nemipteridae	*Nemipterus celebicus*	Threadfin Bream, 5-lined	1		3	4	EB	CI
347	Nemipteridae	*Nemipterus furcosus*	Threadfin Bream, Rosy	1	2	3	4	EB	C
347	Nemipteridae	*Nemipterus peronii*	Threadfin Bream, Notched	1				EB	C
347	Nemipteridae	*Pentapodus porosus*	Monocle bream, False Whiptail	1	2	3	4	EB	C

CAAB Fam no	Family	Scientific name	Common name*	Oct-02 Trip 1	Feb-03 Trip 2	Jun-03 Trip 3	Sep-03 Trip 4	Habitat	Diet
347	Nemipteridae	*Pentapodus vitta*	Monocle Bream, Western Butterfish	1	2	3	4	EB	C
347	Nemipteridae	*Scaevius milii*	Monocle Bream, Coral		2			EB	C
349	Gerreidae	*Gerres subfasciatus*	Roach/Banded Silver Biddy	1	2	3	4	BP	CI
350	Haemulidae	*Diagramma labiosum*	Sweetlip, Painted	1				BP	CI
350	Haemulidae	*Pomadasys kaakan*	Javelinfish, Spotted		2	3		BP	CI
351	Lethrinidae	*Lethrinus genivittatus*	Emperor, Threadfin	1	2	3	4	BP	C
351	Lethrinidae	*Lethrinus punctulatus*	Emperor, Blue-Spotted	1	2	3	4	BP	C
351	Lethrinidae	*Lethrinus laticaudis*	Emperor, Grass/Black Snapper		2	3		BP	C
353	Sparidae	*Argyrops spinifer*	Snapper, Long-spined	1	2	3	4	BP	CI
353	Sparidae	*Pagrus auratus*	Snapper, Pink	1	2	3	4	BP	C
353	Sparidae	*Rhabdosargus sarba*	Tarwhine	1	2	3		BP	CI
354	Sciaenidae	*Argyrosomus hololepidotus*	Mulloway				4	BP	C
355	Mullidae	*Parupeneus barberinoides*	Goatfish, Swarthy-headed	1				B	C
355	Mullidae	*Parupeneus chrysopleuron*	Goatfish, Yellow-striped	1	2	3	4	B	C
355	Mullidae	*Parupeneus spilurus*	Goatfish, Black-spot	1	2	3	4	B	C
355	Mullidae	*Upeneichthys stotti*	Goatfish, Stott's		2	3		B	C
355	Mullidae	*Upeneus asymmetricus*	Goatfish, Asymmetrical	1	2	3	4	B	C
355	Mullidae	*Upeneus sulphureus*	Goatfish, Sunrise				4	B	C
355	Mullidae	*Upeneus tragula*	Goatfish, Bar-tailed	1	2	3	4	B	C
357	Pempherididae	*Parapriacanthus ransonneti*	Bullseye, Slender	1	2			BP	CI
357	Pempherididae	*Pempheris ypsilychnus*	Bullseye, Ypsilon	1	2	3		BP	CI
361.2	Kyphosidae	*Microcanthus strigatus*	Stripey		2			BP	O
362	Ephippidae	*Platax batavianus*	Batfish, Hump-headed		2			P	CI
362	Ephippidae	*Zabidius novemaculeatus*	Batfish, Short-finned		2			P	CI
365.1	Chaetodontidae	*Chaetodon assarius*	Butterflyfish, Western		2	3	4	BP	CI
365.1	Chaetodontidae	*Parachaetodon ocellatus*	Coralfish, Ocellate		2	3		BP	CI
372	Pomacentridae	*Amphiprion clarkii*	Anemonefish, Clark's		2	3	4	BP	P
372	Pomacentridae	*Chromis fumea*	Damsel, Smoky Chromis				4	P	P
372	Pomacentridae	*Pristotis obtusirostris*	Damsel, Gulf	1	2	3	4	P	O
377	Cheilodactylidae	*Cheilodactylus gibbosus*	Morwong, Crested	1				B	CI
382	Sphyraenidae	*Sphyraena obtusata*	Seapike, Striped	1	2	3	4	P	C
384	Labridae	*Choerodon cauteroma*	Tuskfish, Blue Spotted	1	2	3		BP	C
384	Labridae	*Choerodon cephalotes*	Tuskfish, Purple	1	2	3	4	BP	CI
384	Labridae	*Pteragogus enneacanthus*	Wrasse, Flagfin	1	2	3	4	BP	C
384	Labridae	*Suezichthys soelae*	Wrasse, Spotted-tail	1				BP	C
385	Odacidae	*Odax acroptilus*	Rainbow Cale				4	BP	CI
386	Scaridae	*Leptoscarus vaigiensis*	Parrotfish, Blue-spotted	1	2	3	4	BP	O
386	Scaridae	*Scarus* sp.	Parrotfish		2	3		BP	O
390	Pinguipedidae	*Parapercis nebulosa*	Grubfish, Red-barred	1	2		4	B	C
400	Uranoscopidae	*Ichthyscopus insperatus*	Stargazer, Double-banded		2			B	CV
400	Uranoscopidae	*Uranoscopus bicinctus*	Stargazer, Marbled	1	2	3	4	B	CV

CAAB Fam no	Family	Scientific name	Common name*	Oct-02 Trip 1	Feb-03 Trip 2	Jun-03 Trip 3	Sep-03 Trip 4	Habitat	Diet
400	Uranoscopidae	*Uranoscopus cognatus*	Stargazer, Yellowtail	1				B	CV
408	Blenniidae	*Petroscirtes breviceps*	Blenny, Short-headed Sabretooth	1	2	3	4	B	C
411	Congrogadidae	*Congrogadus subducens*	Eel-Blenny, Carpet	1				B	C
416	Clinidae	*Heteroclinus roseus*	Weedfish, Rosy			3		B	CI
427.1	Callionymidae	*Calliurichthys grossi*	Stinkfish, Gross's	1	2	3	4	B	CI
427.1	Callionymidae	*Dactylopus dactylopus*	Dragonet, Fingered	1	2	3	4	B	CI
427.1	Callionymidae	*Pseudocalliurichthys goodladi*	Stinkfish, Goodlad's	1	2	3	4	B	CI
427.1	Callionymidae	*Repomucenus calcaratus*	Stinkfish, Spotted	1		3	4	B	CI
427.1	Callionymidae	*Repomucenus sublaevis*	Stinkfish, Multifilament	1	2	3	4	B	CI
427.1	Callionymidae	*Orbonymus rameus*	Dragonet, High-finned	1	2	3	4	B	CI
428	Gobiidae	*Amblyeleotris* sp.?	Goby, Shrimp	1				B	CI
428	Gobiidae	*Cryptocentrus* sp.	Shrimpgoby		2			B	CI
428	Gobiidae	*Oplopomus caninoides*	Goby, Robust		2			B	CI
428	Gobiidae	*Priolepis semidoliatus*	Goby, Head-barred		2		4	B	CI
428	Gobiidae	*Yongeichthys nebulosus*	Goby, Shadow	1	2	3	4	B	CI
438	Siganidae	*Siganus nebulosus*	Spinefoot, Black	1	2	3	4	BP	H
441	Scombridae	*Scomberomorus queenslandicus*	Mackerel, Queensland School		2			P	C
460.1	Bothidae	*Asterorhombus intermedius*	Flounder, Intermediate	1	2	3	4	B	C
460.1	Bothidae	*Crossorhombus azureus*	Flounder, Blue-spotted	1	2	3	4	B	C
460.1	Bothidae	*Engyprosopon grandisquama*	Flounder, Spiny-headed	1	2	3	4	B	C
460.1	Bothidae	*Engyprosopon* sp. 1?	Flounder	1		3		B	C
460.1	Bothidae	*Grammotobothus pennatus*	Flounder, Pennant			3	4	B	C
460.2	Paralichthyidae	*Pseudorhombus argus*	Flounder, Peacock		2	3	4	B	C
460.2	Paralichthyidae	*Pseudorhombus arsius*	Flounder, Large-toothed	1	2	3	4	B	C
460.2	Paralichthyidae	*Pseudorhombus elevatus*	Flounder, Deep-bodied	1	2	3	4	B	C
460.2	Paralichthyidae	*Pseudorhombus jenynsii*	Flounder, Small-toothed	1	2	3	4	B	C
460.2	Paralichthyidae	*Pseudorhombus spinosus*	Flounder, Spiny	1	2	3	4	B	C
462	Soleidae	*Aesopia cornuta*	Sole, DarkThick-rayed	1	2	3	4	B	C
462	Soleidae	*Aseraggodes melanospilos*	Sole, Dark-Spotted	1	2	3	4	B	C
462	Soleidae	*Phyllichthys* sp.	Sole		2	3		B	C
462	Soleidae	*Zebrias cancellatus*	Sole, Harrowed	1	2	3	4	B	C
462	Soleidae	*Zebrias craticulus*	Sole, Wickerwork		2	3	4	B	C
463	Cynoglossidae	*Cynoglossus maccullochi*	Sole, MacCulloch's Tongue	1	2	3	4	B	C
463	Cynoglossidae	*Paraplagusia bilineata*	Sole, Patterned Tongue	1	2	3	4	B	C
465.1	Balistidae	*Abalistes stellatus*	Triggerfish, Starry				4	BP	C
465.2	Monacanthidae	*Anacanthus barbatus*	Leatherjacket, Bearded	1	2	3	4	BP	O
465.2	Monacanthidae	*Cantheschenia longipinnis*	Leatherjacket, Smoothspine		2			BP	O
465.2	Monacanthidae	*Chaetodermis penicilligera*	Leatherjacket, Prickly	1	2	3	4	BP	O

CAAB Fam no	Family	Scientific name	Common name*	Oct-02 Trip 1	Feb-03 Trip 2	Jun-03 Trip 3	Sep-03 Trip 4	Habitat	Diet
465.2	Monacanthidae	*Colurodontis paxmani*	Leatherjacket, Paxman's	1	2	3	4	BP	O
465.2	Monacanthidae	*Eubalichthys caeruleoguttatus*	Leatherjacket, Blue-spotted	1	2	3		BP	O
465.2	Monacanthidae	*Monacanthus chinensis*	Leatherjacket, Fan-bellied	1	2	3	4	BP	O
465.2	Monacanthidae	*Paramonacanthus choirocephalus*	Leatherjacket, Hair-finned	1	2	3	4	BP	O
465.2	Monacanthidae	*Pseudomonacanthus peroni*	Leatherjacket, Pot-bellied	1	2	3	4	BP	O
465.2	Monacanthidae	*Scobinichthys granulatus*	Leatherjacket, Rough	1	2	3	4	BP	O
465.2	Monacanthidae	*Stephanolepis* sp.	Leatherjacket, Brown Blotched	1	2	3	4	BP	O
466	Ostraciidae	*Lactoria diaphana*	Cowfish, Roundbelly		2		4	B	CI
466	Ostraciidae	*Rhynchostracion nasus*	Boxfish, Small-nosed	1	2	3	4	B	CI
466	Ostraciidae	*Tetrosomus reipublicae*	Turretfish, Small spined	1	2	3	4	B	CI
467	Tetraodontidae	*Arothron hispidus*	Toadfish, Stars and Stripes	1	2	3	4	BP	O
467	Tetraodontidae	*Arothron stellatus*	Toadfish, Starry				4	BP	O
467	Tetraodontidae	*Lagocephalus lunaris*	Toadfish, Rough Golden		2			P?	O
467	Tetraodontidae	*Lagocephalus sceleratus*	Toadfish, Silver/NW Blowie	1		3	4	P	O
467	Tetraodontidae	*Polyspina piosae*	Toadfish, Orange-barred Pufferfish	1			4	EB	O
467	Tetraodontidae	*Torquigener pallimaculatus*	Toadfish, Orange-spotted	1	2	3	4	EB	O
467	Tetraodontidae	*Torquigener pleurogramma*	Toadfish, Banded	1	2	3	4	EB	O
467	Tetraodontidae	*Torquigener whitleyi*	Toadfish, Whitley's	1	2	3	4	EB	O
469	Diodontidaae	*Tragulichthys jaculiferus*	Porcupinefish, Long-spined	1	2	3	4	EB	CI
			Total number of species/trip	**154**	**185**	**158**	**160**		

* Common names are now recognised as those listed in the following publication: Yearsley, G.K., Last, P.R. and Hoese, D.F. (2006)

Appendix 3.2 Exmouth Gulf and Onslow fish species recorded from three survey trips in 2004

Key:

Habitat: B = benthic, EB = epibenthic, BP = benthopelagic, M = mid-water, P = pelagic, S = surface waters

Diet: C = general carnivore, CI = carnivore of invertebrates, CV = carnivore of vertebrates, O = omnivore, P = planktivore, H = herbivore

Exmouth Gulf total number of species for all trips = 298

CAAB Fam no	Family	Scientific name	Common name*	Mar-04 Trip 1	Jul-04 Trip 2	Nov-04 Trip 3	Habitat	Diet
013	Hemiscylliidae	*Chiloscyllium punctatum*	Catshark, Brown-banded	1	2	3	B	C
013.5	Orectolobidae	*Eucrossorhinus dasypogon*	Wobbegong, Tasselled			3	B	C
015	Scyliorhinidae	*Atelomycterus* sp. A *(fasciatus?)*	Catshark, Banded	1	2	3	B	C
018.1	Carcharhinidae	*Rhizoprionodon acutus*	Shark, Milk	1		3	BP	C
018.2	Hemigaleidae	*Hemigaleus australiensis*	Shark, Sicklefin Weasel	1	2		BP	C
026	Rhynchobatidae	*Rhynchobatus australiae*	Ray, White-spotted Shovelnose	1		3	B	C
027	Rhinobatidae	*Rhinobatos typus*	Ray, Giant Shovelnose	1			B	C
035	Dasyatididae	*Dasyatis kuhlii*	Ray, Blue-spotted Stingray		2		B	C
035	Dasyatididae	*Dasyatis leylandi*	Ray, Brown Reticulated Stingray	1	2	3	B	C
035	Dasyatididae	*Himantura toshi*	Ray, Black-spotted Whipray	1	2	3	B	C
037	Gymnuridae	*Gymnura australis*	Ray, Butterfly/Rat-tailed	1	2	3	B	C
039	Myliobatididae	*Aetomylaeus vespertilio*	Ray, Ornate Eagle Ray	1			BP	C
039	Myliobatididae	*Aetomylaeus nichofii*	Ray, Banded Eagle Ray			3	BP	C
054	Megalopidae	*Megalops cyprinoides*	Herring, Oxeye/Tarpon		2		P	C
060	Muraenidae	*Gymnothorax cribroris*	Moray Eel, Sieve-patterned	1	2	3	B	C
060	Muraenidae	*Gymnothorax pseudothyrsoideus*	Moray Eel, Highfin		2		B	C
060	Muraenidae	*Gymnothorax undulatus*	Moray Eel, Mottled/ Undulate	1			B	C
063	Muraenesocidae	*Muraenesox bagio*	Eel, Common Pike		2		B	C
065	Nettastomatidae	*Saurenchelys* sp.	Eel, Duckbill			3	B	C
067	Congridae	*Ariosoma* sp.	Conger Eel	1		3	B	C
067	Congridae	*Conger cinereus*	Conger Eel, Black-edged	1	2		B	C
067	Congridae	*Uroconger lepturus*	Conger Eel, Longtail/ Slender	1		3	B	C
085	Clupeidae	*Escualsoa thoracata*	Sardine, White			3	P	P
085	Clupeidae	*Herklotsichthys blackburni*	Herring, Blackburn's	1		3	P	P
085	Clupeidae	*Herklotsichthys collettei*	Herring, Collette's	1			P	P
085	Clupeidae	*Herklotsichthys koningsbergeri*	Herring, Koningsberger's		2		P	P
085	Clupeidae	*Herklotsichthys lippa*	Herring, Australian Spotted	1	2	3	P	P
085	Pristigasteridae	*Pellona ditchela*	Ditchelee		2	3	P	P
085	Clupeidae	*Sardinella gibbosa*	Sardine, Gold-striped	1	2	3	P	P
085	Clupeidae	*Sardinella lemuru*	Sardine, Scaly Mackerel	1		3	P	P
086	Engraulidae	*Stolephorus indicus*	Anchovy, Indian	1	2	3	P	P
086	Engraulidae	*Thryssa hamiltoni*	Anchovy, Hamilton's	1	2	3	P	P

CAAB Fam no	Family	Scientific name	Common name*	Mar-04 Trip 1	Jul-04 Trip 2	Nov-04 Trip 3	Habitat	Diet
086	Engraulidae	*Thryssa setirostris*	Anchovy, Longjaw	1	2	3	P	P
086	Engraulidae	*Thryssa* cf. *spinidens*	Anchovy, Bengal	1			P	P
087	Chirocentride	*Chirocentrus dorab*	Herring, Wolf	1	2		P	CV
118.1	Bathysauridae	*Saurida argentea*	Lizardfish, Short-finned	1	2	3	B	C
118.1	Bathysauridae	*Saurida nebulosa*	Lizardfish, Clouded	1	2	3	B	C
118.1	Bathysauridae	*Saurida undosquamis*	Lizardfish, Large-scaled	1	2	3	B	C
118.2	Synodontidae	*Synodus dermatogenys*	Lizardfish, Banded		2		B	C
118.2	Synodontidae	*Synodus doaki*	Lizardfish, Doak's/ Arrowtooth	1		3	B	C
118.2	Synodontidae	*Synodus hoshinonsis*	Lizardfish, Black-shouldered	1	2	3	B	C
118.2	Synodontidae	*Synodus sageneus*	Lizardfish, Netted	1	2	3	B	C
118.2	Synodontidae	*Trachinocephalus myops*	Lizardfish, Painted	1	2	3	B	C
188	Ariidae	*Arius thalassinus*	Catfish, Giant Salmon	1	2	3	B	O
192	Plotosidae	*Euristhmus nudiceps*	Catfish, Naked-headed	1	2	3	B	C
192	Plotosidae	*Paraplotosus* sp.	Catfish, Eel-tailed	1	2	3	B	C
192	Plotosidae	*Plotosus lineatus*	Catfish, Striped	1	2	3	B	C
205	Batrachoididae	*Batrachomoeus dahli*	Frogfish, Dahl's			3	B	C
205	Batrachoididae	*Batrachomoeus* n.sp.	Frogfish new species	1	2	3	B	C
205	Batrachoididae	*Halophryne ocellatus*	Frogfish, Ocellated	1		3	B	C
210	Antennariidae	*Antennarius pictus*	Anglerfish, Painted	1			B	CV
210	Antennariidae	*Antennarius striatus*	Anglerfish, Striated	1	2	3	B	CV
210	Antennariidae	*Histrio histrio*	Anglerfish, Sargassum Fish	1			P	CV
210	Antennariidae	*Tathicarpus butleri*	Anglerfish, Butler’s	1	2	3	B	CV
210	Antennariidae	*Tetrabrachium* sp.	Anglerfish, Humpback	1	2		B	CV
212	Ogcocephalidae	*Halieutaea* cf. *indica*	Goosefish/Seabat/Indian Handfish			3	B	C
228	Ophidiidae	*Monothrix* cf. *mizolepis*	Cuskeel, Smalleye		2		B	CI
228	Ophidiidae	*Ophidion muraenolepis*	Cuskeel, Black-edged		2		B	CI
233	Exocoetidae	*Cheilopogon* sp.	Flyingfish, West Australian	1			S	P
233	Exocoetidae	*Cypselurus* sp.	Flyingfish	1			S	P
233	Exocoetidae	*Parexocoetus mento?*	Flyingfish, African Sailfin	1		3	S	P
234	Hemiramphidae	*Hemiramphus robustus*	Garfish, Robust	1		3	S	O
234	Hemiramphidae	*Hyporhamphus affinis*	Garfish, Tropical	1		3	S	O
235	Belonidae	*Ablennes hians*	Longtom, Barred	1			S	CV
235	Belonidae	*Strongylura leiura*	Longtom, Slender	1			S	CV
246	Atherinidae	*Atherinomorus vaigiensis*	Hardyhead, Ogilby's	1	2	3	S	O
246	Atherinidae	*Hypoatherina temminckii*	Hardyhead, Samoan		2		S	O
259	Monocentrididae	*Monocentris japonica*	Pineapplefish, Japanese		2		EB	CI
269	Veliferidae	*Velifer hypselopterus*	Veilfin, High-finned	1	2	3	BP	P
278	Fistulariidae	*Fistularia commersonii*	Flutemouth, Smooth	1	2	3	P	C
280	Centriscidae	*Centriscus scutatus*	Razorfish, Grooved	1	2	3	EB	CI
282	Syngnathidae	*Halicampus grayi*	Pipefish, Gray's/Mud		2	3	B	P
282	Syngnathidae	*Haliichthys taeniophorus*	Pipefish, Ribboned	1			B	P
282	Syngnathidae	*Hippocampus alatus*	Seahorse, Winged	1			B	P
282	Syngnathidae	*Hippocampus angustus*	Seahorse, Western Spiny	1	2	3	B	P
282	Syngnathidae	*Hippocampus planifrons*	Seahorse, Flat-face		2		B	P
282	Syngnathidae	*Hippocampus zebra*	Seahorse, Zebra	1			B	P

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282	Syngnathidae	*Trachyrhamphus bicoarctatus*	Pipefish, Short-tailed	1	2		B	P
287	Scorpaenidae	*Apistops caloundra*	Scorpionfish, Short-finned Waspfish	1	2	3	B	C
287	Scorpaenidae	*Apistus carinatus*	Scorpionfish, Long-finned Waspfish	1	2	3	B	C
287	Scorpaenidae	*Cottapistus cottoides*	Scorpionfish, Marbled Stingfish			3	B	C
287	Scorpaenidae	*Dendrochirus brachypterus*	Scorpionfish, Dwarf Lionfish	1		3	EB	C
287	Scorpaneidae	*Inimicus sinensis*	Stinger, Spotted	1	2	3	B	C
287	Scorpaenidae	*Minous versicolor*	Scorpionfish, Plumb-striped	1	2	3	B	C
287	Scorpaenidae	*Paracentropogon vespa*	Scorpionfish, Bullrout	1	2	3	B	C
287	Scorpaenidae	*Parascorpaena mossambica*	Scorpionfish, Mozambique	1			B	C
287	Scorpaenidae	*Parascorpaena picta*	Scorpionfish, Northern/ Painted		2	3	B	C
287	Scorpaenidae	*Pterois russelii*	Scorpionfish, Spotless Firefish			3	EB	C
287	Scorpaenidae	*Pterios volitans*	Scorpionfish, Red Firefish	1	2	3	BP	C
287	Scorpaenidae	*Richardsonichthys leucogaster*	Scorpionfish, White-bellied Rougefish	1			B	C
287	Scorpaenidae	*Scorpaenodes smithi*	Scorpionfish, Little	1			B	C
287	Scorpaenidae	*Scorpaenopsis neglecta*	Scorpionfish, Yellowfin		2		B	C
287	Scorpaenidae	*Synanceia horrida*	Scorpionfish, Estuarine Stonefish	1			B	CV
288	Triglidae	*Lepidotrigla* sp**.**	Gurnard, Long-finned	1	2	3	B	C
290	Aploactinidae	*Adventor elongatus*	Velvetfish, Sandpaper	1	2	3	B	CI
290	Aploactinidae	*Aploactis aspera*	Velvetfish, Dusky,	1			B	CI
290	Aploactinidae	*Kanekonica queenslandica*	Velvetfish, Queensland	1	2	3	B	CI
290	Aploactinidae	*Paraploactis intonsa*	Velvetfish, Bearded	1		3	B	CI
290	Aploactinidae	*Peristrominous dolosus*	Velvetfish, Cod		2	3	B	CI
296	Platycephalidae	*Papilloculiceps bosschei*	Flathead, Bossch's		2	3	B	C
296	Platycephalidae	*Papilloculiceps nematophthalmus*	Flathead, Fringe-eyed	1	2	3	B	C
296	Platycephalidae	*Inegocia japonica*	Flathead, Rusty	1	2	3	B	C
296	Platycephalidae	*Onigocia spinosa*	Flathead, Spiny	1	2	3	B	C
296	Platycephalidae	*Platycephalus arenarius*	Flathead, Northern Sand	1	2	3	B	C
296	Platycephalidae	*Platycephalus endrachtensis*	Flathead, Bar-tailed	1	2	3	B	C
296	Platycephalidae	*Platycephalus indicus*	Flathead, Indian	1			B	C
296	Platycephalidae	*Rogadius patriciae*	Flathead, Blackbanded		2		B	C
296	Platycephalidae	*Sorsogona tuberculata*	Flathead, Heart-headed	1	2	3	B	C
296	Platycephalidae	*Suggrundus macracanthus*	Flathead, Large-spined	1	2	3	B	C
308	Dactylopteridae	*Dactyloptena orientalis*	Searobin, Oriental	1	2	3	B	C
308	Dactylopteridae	*Dactyloptena papilio*	Searobin, Sharp-eared	1	2	3	B	C
309	Pegasidae	*Eurypegasus draconis*	Seamoth, Short	1	2		B	C
309	Pegasidae	*Pegasus volitans*	Seamoth, Slender	1	2	3	B	C
310	Centropomidae	*Hypopterus macropterus*	Bass, Spiky	1	2	3	BP	C
310	Centropomidae	*Psammoperca waigiensis*	Bass, Sand	1	2	3	BP	C

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311	Serranidae	*Centrogenys vaigiensis*	Scorpionfish, False	1	2	3	BP	C
311	Serranidae	*Cephalopholis boenak*	Rockcod, Brown-banded		2		BP	C
311	Serranidae	*Epinephelus amblycephalus*	Rockcod, Blunt-headed	1			BP	C
311	Serranidae	*Epinephelus areolatus*	Rockcod, Yellow-spotted	1		3	BP	C
311	Serranidae	*Epinephelus multinotatus*	Rockcod, Rankin's	1		3	BP	C
311	Serranidae	*Epinephelus quoyanus*	Rockcod, Long-finned	1	2		BP	C
311	Serranidae	*Epinephelus rivulatus*	Rockcod, Chinaman			3	BP	C
311	Serranidae	*Epinephelus sexfasciatus*	Rockcod, Six-banded	1	2	3	BP	C
313	Pseudochromidae	*Assiculus punctatus*	Dottyback, Longfin/ Bluespotted	1	2		B	C
313	Pseudochromidae	*Cypho* cf. *purprascens*	Dottyback, Oblique-lined	1			B	C
313	Pseudochromidae	*Pseudochromis quinquedentatus*	Dottyback, Spotted	1	2		B	C
320	Glaucosomatidae	*Glaucosoma magnificum*	Pearl-perch, Threadfin	1			BP	CI
321	Terapontidae	*Pelates quadrilineatus*	Trumpeter, 4-lined	1	2	3	BP	C
321	Terapontidae	*Pelates sexlineatus*	Trumpeter, 6-lined	1	2	3	BP	C
321	Terapontidae	*Terapon jarbua*	Trumpeter, Crescent perch	1			BP	C
321	Terapontidae	*Terapon puta*	Trumpeter, 3-lined	1	2	3	BP	C
321	Terapontidae	*Terapon theraps*	Trumpeter, Banded	1	2	3	BP	C
326	Priacanthidae	*Priacanthus macracanthus*	Bigeye, Red	1	2	3	EB	C
326	Priacanthidae	*Priacanthus tayenus*	Bigeye, Threadfin	1	2	3	EB	C
327	Apogonidae	*Apogon brevicaudatus*	Cardinalfish, Many-banded	1	2	3	EB	CI
327	Apogonidae	*Apogon cavitiensis*	Cardinalfish, Cavite	1	2	3	EB	CI
327	Apogonidae	*Apogon fuscomaculatus*	Cardinalfish, Brown-spotted	1	2	3	EB	CI
327	Apogonidae	*Apogon monospilus*	Cardinalfish, Moluccan		2	3	EB	CI
327	Apogonidae	*Apogon nigripinnis*	Cardinalfish, Two-eyed	1	2	3	EB	CI
327	Apogonidae	*Apogon poecilopterus*	Cardinalfish, Pearly-Finned	1	2	3	EB	CI
327	Apogonidae	*Apogon quadrifasciatus*	Cardinalfish, Broad-banded	1	2	3	EB	CI
327	Apogonidae	*Apogon rueppellii*	Cardinalfish, Gobbleguts	1	2	3	EB	CI
327	Apogonidae	*Apogon truncatus*	Cardinalfish, Flagfin	1	2	3	EB	CI
327	Apogonidae	*Apogon victoriae*	Cardinalfish, Victorian	1			EB	CI
327	Apogonidae	*Archamia fucata*	Cardinalfish, Narrow-lined	1			EB	CI
327	Apogonidae	*Archamia biguttata*	Cardinalfish, Blackspot		2	3	EB	CI
330	Sillaginidae	*Sillago burrus*	Whiting, Trumpeter	1	2	3	B	C
330	Sillaginidae	*Sillago lutea*	Whiting, Mud	1	2	3	B	C
330	Sillaginidae	*Sillago vittata*	Whiting, Western School	1	2	3	B	C
335	Rachycentridae	*Rachycentron canadum*	Cobia	1			P	C
336	Echeneidae	*Echeneis naucrates*	Suckerfish, Slender			3	P	C
336	Echeneidae	*Remora remora*	Remora	1			P	CI
337	Carangidae	*Alectis indica*	Trevally, Diamond	1	2	3	P	C
337	Carangidae	*Alepes apercna*	Trevally, Small Mouth Scad		2	3	P	CI
337	Carangidae	*Carangoides chrysophrys*	Trevally, Club-nosed	1			P	C
337	Carangidae	*Carangoides hedlandensis*	Trevally, Bump-nosed	1	2	3	P	C
337	Carangidae	*Carangoides talamparoides*	Trevally, White-tongued	1	2	3	P	C
337	Carangidae	*Caranx bucculentus*	Trevally, Blue-spotted	1		3	P	C
337	Carangidae	*Decapterus russelli*	Trevally, Russell's Mackerel Scad		2		P	P

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337	Carangidae	*Parastromateus niger*	Pomfret	1	2	3	BP	P
337	Carangidae	*Scomberoides commersonnianus*	Queenfish, Giant/Talang		2		P	C
337	Carangidae	*Selar boops*	Trevally, Oxeye Scad		2	3	P	CI
337	Carangidae	*Selaroides leptolepis*	Trevally, Smooth-tailed	1	2	3	BP	C
337	Carangidae	*Seriolina nigrofasciata*	Kingfish, Black-banded	1	2	3	P	C
341	Leiognathidae	*Gazza minuta*	Ponyfish, Tooth Pony	1	2	3	EB	C
341	Leiognathidae	*Leiognathus decorus*	Ponyfish, Yellowfinned	1			EB	C
341	Leiognathidae	*Leiognathus equulus*	Ponyfish, Common	1			EB	C
341	Leiognathidae	*Leiognathus fasciatus*	Ponyfish, Striped	1	2	3	EB	C
341	Leiognathidae	*Leiognathus leuciscus*	Ponyfish, Whipfin	1	2	3	EB	CI
341	Leiognathidae	*Leiognathus longispinis*	Ponyfish, Smithurst's	1			EB	CI
341	Leiognathidae	*Leiognathus moretoniensis*	Ponyfish, Zig-zag	1	2	3	EB	C
341	Leiognathidae	*Secutor insidiator*	Ponyfish, Pugnose	1	2	3	EB	O
346	Lutjanidae	*Lutjanus carponotatus*	Seaperch, Stripey	1	2	3	BP	C
346	Lutjanidae	*Lutjanus fulviflamma*	Seaperch, Black-spot	1	2		BP	C
346	Lutjanidae	*Lutjanus lutjanus*	Seaperch, Bigeye		2		BP	C
346	Lutjanidae	*Lutjanus malabaricus*	Seaperch, Saddle-tailed	1	2	3	BP	C
346	Lutjanidae	*Lutjanus russelii*	Seaperch, Moses	1		3	BP	C
346	Lutjanidae	*Lutjanus vitta*	Seaperch, Striped	1	2	3	BP	C
347	Nemipteridae	*Nemipterus celebicus*	Threadfin Bream, Five-lined	1			EB	CI
347	Nemipteridae	*Nemipterus furcosus*	Threadfin Bream, Rosy	1	2	3	EB	C
347	Nemipteridae	*Nemipterus peronii*	Threadfin Bream, Notched	1	2	3	EB	C
347	Nemipteridae	*Pentapodus porosus*	Monocle Bream, False Whiptail	1	2	3	EB	C
347	Nemipteridae	*Pentapodus vitta*	Monocle Bream, W. Butterfish	1	2	3	EB	C
347	Nemipteridae	*Scaevius milii*	Monocle Bream, Coral	1	2	3	EB	C
347	Nemipteridae	*Scolopsis taenioptera*	Monocle Bream, Red-Spot	1	2	3	EB	C
349	Gerreidae	*Gerres filamentosus*	Silver Biddy, Whipfin	1			BP	CI
349	Gerreidae	*Gerres oyena*	Silver Biddy, Common	1	2		BP	CI
349	Gerreidae	*Gerres subfasciatus*	Roach/Banded Silver-biddy	1	2	3	BP	CI
349	Gerreidae	*Pentaprion longimanus*	Silver Biddy, Long-Finned	1	2	3	BP	CI
350	Haemulidae	*Diagramma labiosum*	Sweetlips, Painted	1	2	3	BP	CI
350	Haemulidae	*Pomadasys kaakan*	Javelinfish, Spotted	1			BP	CI
350	Haemulidae	*Pomadasys maculatus*	Javelinfish, Blotched	1	2	3	BP	CI
351	Lethrinidae	*Gymnocranius elongatus*	Seabream, Swallowtail		2	3	BP	CI
351	Lethrinidae	*Lethrinus genivittatus*	Emperor, Threadfin	1	2	3	BP	C
351	Lethrinidae	*Lethrinus punctulatus*	Emperor, Blue-spotted		2	3	BP	C
351	Lethrinidae	*Lethrinus laticaudis*	Snapper, Black	1	2	3	BP	C
353	Sparidae	*Argyrops spinifer*	Snapper, Long-spined	1			BP	CI
353	Sparidae	*Pagrus auratus*	Snapper, Pink			3	BP	C
353	Sparidae	*Rhabdosargus sarba*	Tarwhine	1			BP	CI
354	Sciaenidae	*Johnius borneensis*	Croaker, Little Jewfish	1	2	3	BP	C
355	Mullidae	*Parupeneus chrysopleuron*	Goatfish, Yellow-striped	1	2	3	B	C
355	Mullidae	*Upeneus asymmetricus*	Goatfish, Asymmetrical	1	2	3	B	C
355	Mullidae	*Upeneus moluccensis*	Goatfish, Gold-band	1			B	C

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355	Mullidae	*Upeneus sulphureus*	Goatfish, Sunrise	1	2	3	B	C
355	Mullidae	*Upeneus sundaicus*	Goatfish, Ochre-banded	1	2	3	B	C
355	Mullidae	*Upeneus tragula*	Goatfish, Bar-tailed	1	2	3	B	C
355	Pempherididae	*Parapriacanthus ransonneti*	Bullseye, Slender	1			BP	CI
357	Pempherididae	*Pempheris ypsilychnus*	Bullseye, Ypsilon	1	2	3	BP	CI
362	Ephippidae	*Drepane punctata*	Sicklefish	1	2	3	BP	CI
362	Ephippidae	*Platax batavianus*	Batfish, Humphead	1		3	P	CI
362	Ephippidae	*Platax teira*	Batfish, Teira/Roundface	1	2		P	O
362	Ephippidae	*Zabidius novemaculeatus*	Batfish, Short-finned	1			P	CI
365	Pomacanthidae	*Chaetodontoplus duboulayi*	Angelfish, Scribbled	1		3	BP	CI
365	Chaetodontidae	*Chaetodon assarius*	Butterflyfish, Western	1	2		BP	CI
365	Chaetodontidae	*Chelmon marginalis*	Coralfish, Margined	1	2	3	BP	CI
365	Chaetodontidae	*Coradion chrysozonus*	Coralfish, Orange-banded		2		BP	CI
365	Chaetodontidae	*Parachaetodon ocellatus*	Coralfish, Ocellate	1	2	3	BP	CI
372	Pomacentridae	*Chromis fumea*	Damsel, Smoky Chromis	1	2	3	P	P
372	Pomacentridae	*Neopomacentrus cyanomos*	Damsel, Regal		2		P	P
372	Pomacentridae	*Neopomacentrus filamentosus*	Damsel, Brown Demoiselle	1	2	3	P	P
372	Pomacentridae	*Pristotis obtusirostris*	Damsel, Gulf	1	2	3	P	O
380	Cepolidae	*Acanthocepola abbreviata*	Bandfish	1	2	3	B	CI
382	Sphyraenidae	*Sphyraena obtusata*	Seapike, Striped	1	2	3	P	C
383	Polynemidae	*Polydactylus multiradiatus*	Threadfin, Gunther's	1	2	3	B	CI
383	Polynemidae	*Polydactylus nigripinnis?*	Threadfin, Black-finned	1			B	CI
384	Labridae	*Choerodon cauteroma*	Tuskfish, Blue-spotted	1	2	3	BP	C
384	Labridae	*Choerodon cephalotes*	Tuskfish, Purple	1	2	3	BP	CI
384	Labridae	*Choerodon vitta*	Tuskfish, Redstripe	1	2		BP	C
384	Labridae	*Pteragogus enneacanthus*	Wrasse, Flagfin	1	2	3	BP	C
386	Scariidae	*Calotomus spinidens*	Parrotfish, Spinytooth			3	P	O
388	Opistognathidae	*Opistognathus latitabundus*	Jawfish, Blotched	1	2		B	CI
390	Pinguipedidae	*Parapercis diplospilus*	Grubfish, Doublespot	1	2	3	B	C
390	Pinguipedidae	*Parapercis nebulosa*	Grubfish, Red-Barred	1	2	3	B	C
408	Blenniidae	*Meiacanthus luteus*	Blenny, Yellow Fang	1	2	3	B	C
408	Blenniidae	*Petroscirtes breviceps*	Blenny, Short-headed Sabretooth	1			B	C
408	Blenniidae	*Xiphasia setifer*	Blenny, Hair-tail	1			B	C
411	Congrogadidae	*Congrogadus spinifer*	Eel-Blenny, Spiny	1	2	3	B	CI
427	Callionymidae	*Calliurichthys grossi*	Stinkfish, Gross's	1	2	3	B	CI
427	Callionymidae	*Dactylopus dactylopus*	Dragonet, Fingered	1	2	3	B	CI
427	Callionymidae	*Pseudocalliurichthys goodladi*	Stinkfish, Goodlad's	1	2	3	B	CI
427	Callionymidae	*Repomucenus meridionalis*	Stinkfish, Highfin			3	B	CI
427	Callionymidae	*Repomucenus sublaevis*	Stinkfish, Multifilament	1	2	3	B	CI
427	Callionymidae	*Orbonymus rameus*	Dragonet, High-finned	1	2	3	B	CI
428	Gobiidae	*Oplopomus caninoides*	Goby, Robust	1	2	3	B	CI
428	Gobiidae	*Parachaeturichthys polynema*	Goby, Taileyed		2	3	B	CI
428	Gobiidae	*Priolepis semidoliatus*	Goby, Head-barred	1	2		B	CI

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428	Gobiidae	*Yongeichthys nebulosus*	Goby, Shadow	1	2		B	CI
438	Siganidae	*Siganus nebulosus*	Spinefoot, Black	1	2	3	BP	H
438	Siganidae	*Siganus spinus*	Spinefoot, Spiny/Scribbled			3	BP	H
440	Trichiuridae	*Trichiurus lepturus*	Hairtail, Largehead	1			P	C
441	Scombridae	*Rastrelliger kanagurta*	Mackerel, Long-jawed	1			P	P
457	Psettodidae	*Psettodes erumei*	Halibut, Queensland	1	2	3	B	CV
460.1	Bothidae	*Arnoglossus* sp.	Flounder, Lefteye		2	3	B	C
460.1	Bothidae	*Arnoglossus aspilos*	Flounder, Spotless Lefteye	1	2	3	B	C
460.1	Bothidae	*Asterorhombus intermedius*	Flounder, Intermediate	1	2	3	B	C
460.1	Bothidae	*Crossorhombus azureus*	Flounder, Blue-spotted	1	2	3	B	C
460.1	Bothidae	*Engyprosopon grandisquama*	Flounder, Spiny-headed	1	2	3	B	C
460.1	Bothidae	*Engyprosopon maldivensis*	Flounder, Olive Wide-eye	1			B	C
460.1	Bothidae	*Grammatobothus pennatus*	Flounder, Pennant			3	B	C
460.1	Bothidae	*Grammatobothus polyophthalmus*	Flounder, 3-spot	1	2	3	B	C
460.2	Paralichthyidae	*Pseudorhombus argus*	Flounder, Peacock	1	2	3	B	C
460.2	Paralichthyidae	*Pseudorhombus arsius*	Flounder, Large-toothed	1	2	3	B	C
460.2	Paralichthyidae	*Pseudorhombus diplospilus*	Flounder, Twin-spot	1	2	3	B	C
460.2	Paralichthyidae	*Pseudorhombus elevatus*	Flounder, Deep-bodied		2	3	B	C
460.2	Paralichthyidae	*Pseudorhombus jenynsii*	Flounder, Small-toothed	1	2	3	B	C
460.2	Paralichthyidae	*Pseudorhombus spinosus*	Flounder, Spiny	1	2	3	B	C
461	Rhombosoleidae	*Psammodiscus ocellatus*	Flounder, Freckled	1	2	3	B	C
462	Soleidae	*Aesopia cornuta*	Sole, Dark Thick-rayed	1	2	3	B	CI
462	Soleidae	*Aseraggodes melanospilos*	Sole, Dark-spotted	1		3	B	CI
462	Soleidae	*Dexillus muelleri*	Sole, Tufted	1	2	3	B	C
462	Soleidae	*Zebrias cancellatus*	Sole, Harrowed	1	2	3	B	C
462	Soleidae	*Zebrias craticulus*	Sole, Wickerwork	1	2	3	B	C
462	Soleidae	*Zebrias quagga*	Sole, Zebra	1			B	C
463	Cynoglossidae	*Cynoglossus maculipinnis*	Sole, Spotfin Tongue	1	2	3	B	CI
463	Cynoglossidae	*Paraplagusia bilineata*	Sole, Patterned Tongue	1	2		B	C
464	Triacanthidae	*Tripodichthys angustifrons*	Tripodfish, Black Flag	1	2	3	B	CI
465.1	Balistidae	*Abalistes stellatus*	Triggerfish, Starry	1	2		BP	C
465.1	Monacanthidae	*Aluterus scriptus*	Leatherjacket, Scribbled	1			BP	O
465.2	Monacanthidae	*Anacanthus barbatus*	Leatherjacket, Bearded	1	2	3	BP	O
465.2	Monacanthidae	*Chaetodermis penicilligera*	Leatherjacket, Prickly	1	2	3	BP	O
465.2	Monacanthidae	*Eubalichthys caeruleoguttatus*	Leatherjacket, Blue-spotted			3	BP	O
465.2	Monacanthidae	*Monacanthus chinensis*	Leatherjacket, Fan-bellied	1	2	3	BP	O
465.2	Monacanthidae	*Paramonacanthus choirocephalus*	Leatherjacket, Hair-finned	1	2	3	BP	O
465.2	Monacanthidae	*Pseudomonacanthus peroni*	Leatherjacket, Pot-bellied	1	2	3	BP	O
466	Ostraciidae	*Lactoria cornuta*	Cowfish, Long-horned	1	2	3	B	CI
466	Ostraciidae	*Lactoria diaphana*	Cowfish, Round-belly	1	2	3	B	CI
466	Ostraciidae	*RhynchRhynchostracion nasus*	Boxfish, Small-nosed	1	2	3	B	CI
466	Ostraciidae	*Tetrosomus reipublicae*	Turretfish, Small-spined	1	2	3	B	CI
467	Tetraodontidae	*Anchisomus multistriatus*	Toadfish, Many-striped	1	2		EB	O

CAAB Fam no	Family	Scientific name	Common name*	Mar-04 Trip 1	Jul-04 Trip 2	Nov-04 Trip 3	Habitat	Diet
467	Tetraodontidae	*Arothron stellatus*	Toadfish, Starry	1	2	3	BP	O
467	Tetraodontidae	*Canthigaster coronata*	Toadfish, Three-barred			3	EB	O
467	Tetraodontidae	*Canthigaster rivulata*	Toadfish, Brown-lined	1		3	EB	O
467	Tetraodontidae	*Lagocephalus lunaris*	Toadfish, Rough Golden	1	2		P?	O
467	Tetraodontidae	*Lagocepahalus sceleratus*	Toadfish, Silver	1	2	3	P	O
467	Tetraodontidae	*Torquigener pallimaculatus*	Toadfish, Orange Spotted	1	2	3	EB	O
467	Tetraodontidae	*Torquigener whitleyi*	Toadfish, Whitley's	1	2	3	EB	O
469	Diodontidae	*Cyclichthys orbicularis*	Porcupinefish, Short-spined	1	2	3	EB	CI
469	Diodontidae	*Tragulichthys jaculiferus*	Porcupinefish, Long-spined	1	2	3	EB	CI
			Total number of species/trip	**248**	**212**	**209**		

* Common names are now recognised as those listed in the following publication: Yearsley, G.K., Last, P.R. and Hoese, D.F. (2006)

Appendix 3.3.1 Shark Bay sponge species recorded from four survey trips in 2002 and 2003

Key:

Habitat: I = infauna, SE = sessile, B = benthic, EB = epibenthic, BP = benthopelagic, P = pelagic, S = surface waters

Diet: C = general carnivore, CI = carnivore of invertebrates, CV = carnivore of vertebrates, O= omnivore, P = planktivore, H = herbivore, F = filter feeder, S = suspension feeder, SC = scavenger, DE = deposit feeder

Shark Bay total sponge species = 64

Family	Scientific name	Habitat	Diet
Ancorinidae	*Stelletta* sp.1	B	F
Ancorinidae	*Stelletta* sp.2	B	F
Axinellidae	*Axinella* cf. *aruensis*	B	F
Axinellidae	*Reniochalina stalagmites*	B	F
Axinellidae	*Reniochalina* cf. Qld sp.1642	B	F
Axinellidae	*Stylotella* sp.?	B	F
Calcarea	*Calcarea* sp.1	B	F
Callyspongidae	*Callyspongia* sp.1	B	F
Callyspongidae	*Callyspongia* sp.2	B	F
Callyspongidae	*Callyspongia* sp.3	B	F
Callyspongidae	*Callyspongia* sp.4	B	F
Callyspongidae	*Callyspongia* sp.5	B	F
Callyspongidae	*Callyspongia* sp.6	B	F
Callyspongidae	*Callyspongia* sp.7	B	F
Callyspongidae	*Callyspongia* sp.8	B	F
Callyspongidae	*Callyspongia* sp.9	B	F
Chalinidae	*Haliclona* (*Haliclona*) sp.1	B	F
Chondropsidae	*Chondropsis* sp.1	B	F
Chondropsidae	*Chondropsis* sp.2	B	F
Chondropsidae	*Strongylacidion* sp.1	B	F
Dictyodendrillidae	*Dictyodendrilla* sp.1	B	F
Dictyodendrillidae	*Igernella* sp.1	B	F
Dysideidae	*Dysidea* sp.1	B	F
Halichondriidae	*Amorphinopsis* sp.1	B	F
Halichondriidae	*Amorphinopsis* sp.1 cf. JNA 1785	B	F
Halichondriidae	*Epipolosis* sp.1	B	F
Iotrochotidae	*Iotrochota baculifera*	B	F
Ircinidae	*Ircinia* sp.1	B	F
Ircinidae	*Ircinia* sp.2	B	F
Ircinidae	*Psammocinia* sp.1	B	F
Ircinidae	*Psammocinia* sp.2	B	F
Ircinidae	*Psammocinia* sp.3	B	F
Ircinidae	*Psammocinia* sp.4	B	F
Ircinidae	*Psammocinia* sp.5	B	F
Ircinidae	*Psammocinia* sp.6	B	F
Ircinidae	*Psammocinia* sp.7	B	F
Microcionidae	*Acainus* sp.	B	F
Microcionidae	Microcionid (trip 1)	B	F

Family	Scientific name	Habitat	Diet
Mycalidae	*Mycale* (*Arenochalina*) *mirabilis*	B	F
Mycalidae	*Mycale* sp.1	B	F
Mycalidae	*Mycale* sp.2	B	F
Mycalidae	*Mycale* sp.3	B	F
Raspailidae	*Echinodictyum clathroides*	B	F
Raspailidae	*Echinodictyum mesenterinum*	B	F
Raspailidae	*Echinodictyum nidilus*	B	F
Raspailidae	*Ectyoplasia tabula*	B	F
Spirastrellidae	*Spirastrella* sp.1	B	F
Spongiidae	*Hippospongia* sp.1	B	F
Spongiidae	*Hippospongia* sp.2	B	F
Spongiidae	*Hippospongia* sp.3	B	F
Spongiidae	*Spongia* (*Australospongia*) sp.1	B	F
Spongiidae	*Spongia* (*Heterofibria*) sp.1	B	F
Spongiidae	*Spongia* (*Heterofibria*) sp.2	B	F
Suberitidae	*Caulospongia perfoliata*	B	F
Tedaniidae	*Hemitedania* sp.1	B	F
Tedaniidae	*Tedania* (*Tedania*) sp.1	B	F
Tedaniidae	*Tedania* (*Tedania*) sp.2	B	F
Tedaniidae	*Tedania* (*Tedania*) sp.3	B	F
Thorectidae	*Cacospongia* sp.1	B	F
Thorectidae	*Cacospongia* sp.2	B	F
Thorectidae	*Fasciospongia* sp.1	B	F
Thorectidae	*Fenestraspongia* sp.1	B	F
Thorectidae	*Lendenfeldia* sp.1	B	F
Verongidae	Verongid sponge	B	F

Appendix 3.3.2 Shark Bay octocoral species recorded from four survey trips in 2002 and 2003

Key:
Habitat: I = infauna, SE = sessile, B = benthic, EB = epibenthic, BP = benthopelagic, P = pelagic, S = surface waters
Diet: C = general carnivore, CI = carnivore of invertebrates, CV = carnivore of vertebrates, O= omnivore, P = planktivore, H = herbivore, F = filter feeder, S = suspension feeder, SC = scavenger, DE = deposit feeder

Shark Bay total octocoral species = 19

Family	Scientific name	Common name	Habitat	Diet
Ellisellidae	*Dichotella* sp A	Gorgonian		
Fasciculariidae	*Studeriotes* sp B	Soft coral		
Nephtheidae	*Dendronephthya* cf sp C	Soft coral		
Nephtheidae	*Dendronephthya* sp C	Soft coral		
Nephtheidae	*Dendronephthya* sp G	Soft coral		
Nephtheidae	*Denronephthya* spF	Soft coral		
Nephtheidae	Nephtheidae	Soft coral		
Nephtheidae	*Umbellulifera* sp A	Soft coral		
Plexauridae	*Euplexaura* sp A	Gorgonian		
Plexauridae	*Menella* sp C	Gorgonian		
Pteroeididae	*Pteroeides* sp.	Seapen		
Pteroeididae	*Pteroeides* sp A	Seapen		
Pteroeididae	*Pteroeides* sp B	Seapen		
Pteroeididae	*Pteroeides* sp D	Seapen		
Pteroeididae	*Pteroeides* sp F	Seapen		
Veretillidae	*Lituaria* sp A	Seapen		
Veretillidae	*Veretillum australis*	Seapen		
Veretillidae	*Veretillum* sp A	Seapen		
Veretillidae	*Veretillum* sp C	Seapen		

Appendix 3.3.3 Shark Bay crustacean species recorded from four survey trips in 2002 and 2003

Key:

Habitat: B = benthic, EB = epibenthic, BP = benthopelagic, M = mid water, P = pelagic, S = surface waters
B/SP = benthic, inside sponge, B/B = benthic, inside burrow

Diet: C = general carnivore, CI = carnivore of invertebrates, CV = carnivore of vertebrates, O= omnivore, P = planktivore, H = herbivore, F = filter feeder, S = suspension feeder, SC = scavenger, DE = deposit feeder

Shark Bay total crustacean species = 76

Order	Family	Species	Common name	Habitat	Diet
Stomatopoda	Squillidae	*Alimopsoides* sp.1	Mantis shrimp	B	C
	Squillidae	*Oratosquilla oratoria*	Mantis shrimp	B	C
	Squillidae	*Odontodactylus latirostris*	Mantis shrimp	B	C
	Squillidae	*Carinosquilla australiensis*	Mantis shrimp	B	C
	Eurysquillidae	*Manningia notialis*	Mantis shrimp	B	C
Isopoda	Isopoda	Isopoda	Isopod - parasitic	B	C
Decapoda	Hippolytidae	*Tozeuma pavoninum*	Hump-backed prawn	B	O
	Palaemonidae	*Palaemon serenus*	Palaemonid shrimp	B	O
	Penaeidae	*Penaeus latisulcatus*	King prawn	B	O
	Penaeidae	*Penaeus longistylus*	Red spot king prawn	B	O
	Penaeidae	*Metapenaeus dalli*	Western school prawn	B	O
	Penaeidae	*Metapenaeus endeavouri*	Endeavour prawn	B	O
	Penaeidae	*Metapenaeus* sp.	Prawn	B	O
	Penaeidae	*Metapenaeopsis lamellata*	Rooster prawn	B	O
	Penaeidae	*Metapenaeopsis novaeguineae*	Northern velvet prawn	B	O
	Penaeidae	*Metapenaeopsis palmensis*	Southern velvet prawn	B	O
	Penaeidae	*Metapenaeopsis crassissima*	Coral prawns	B	O
	Penaeidae	*Metapenaeopsis wellsi*	Coral prawns	B	O
	Penaeidae	*Metapenaeopsis* sp.	Coral prawns	B	O
	Penaeidae	*Penaeus esculentus*	Tiger prawn	B	O
	Sicyoniidae	*Sicyonia lancifera*	Ridgeback rock shrimp	B	O
	Sicyoniidae	*Trachypenaeus curvirostris*	Southern rough prawn	B	O
	Solenoceridae	*Solenocera pectinulata*	Solenocerid prawn	B	O
	Alpheidae	Alpheid	Snapping shrimp	B	C
	Panuliridae	*Panulirus cygnus*	Western rock lobster	B	O
	Scyllaridae	*Eduarctus martensii*	Slipper lobster	B	O
	Scyllaridae	*Thenus orientalis*	Slipper lobster	B	O
Infraorder Anomura	Diogenidae	Diogenid	Hermit crabs	B	O
	Porcellanidae	*Porcellanella* sp.	Porcelain crab	B	F
	Galatheidae	Galatheid	Squat lobster	B	C
Infraorder Brachyura	Calappidae	*Calappa philargius*	Red spotted box crab	B	O
	Corystidae	*Gomeza bicornis*	Masked burrowing crab	B/B	O
	Dorippidae	*Dorippe quadridens*	Crab	B	O
	Dorippidae	*Paradorippe australiensis*	Crab	B	O
	Dromiidae	Dromiid	Sponge crab	B	O
	Gonoplacidae	*Eucrate crenata*	Crab	B	O
	Leucosiidae	*Leucosia haswelli*	Pebble crab	B	O
	Leucosiidae	*Myra mammillaris*	Pebble crab	B	O

Order	Family	Species	Common name	Habitat	Diet
	Leucosiidae	*Myra* cf. *mammillaris*	Pebble crab	B	O
	Majidae	*Hyastenus diacanthus*	Spider crab	B	O
	Majidae	*Hyastenus spinosus*	Spider crab	B	O
	Majidae	*Micippa* sp.	Spider crab	B	O
	Majidae	*Paranaxia serpulifera*	Spider crab	B	O
	Majidae	*Schizophrys damae*	Spider crab	B	O
	Majidae	Majid	Spider crab	B	O
	Matutuidae	*Ashtoret granulosa*	Moon crab	B	O
	Matutuidae	*Matutua planipes*	Reticulated surf crab	B	O
	Ocypodidae	*Macrophthalmus* sp.1	Ghost crab	B	O
	Parthenopidae	*Cryptopodia spatulifrons*	Long-armed crab?	B	O
	Parthenopidae	*Parthenope nodosus?*	Long-armed crab?	B	O
	Parthenopidae	*Parthenope* sp.	Long-armed crab?	B	O
	Parthenopidae	*Pseudolambrus harpax*	Long-armed crab?	B	O
	Pilumnidae	*Bathypilumnus pugilator*	Hairy crab	B	O
	Pilumnidae	*Pilumnus semilanatus*	Hairy crab	B/SP	O
	Pilumnidae	*Pilumnus* sp.1	Hairy crab	B/SP	O
	Portunidae	*Charybdis feriata*	Coral crab	B	O
	Portunidae	*Charybdis granulata*	Swimmer crab	B	O
	Portunidae	*Charybdis jaubertensis*	Swimmer crab	B	O
	Portunidae	*Charybdis natator*	Hairyback crab	B	O
	Portunidae	*Charybdis* sp.	Swimmer crab	B	O
	Portunidae	*Nectocarcinus integrifrons*	Rough rock crab	B	O
	Portunidae	*Portunus gladiator*	Swimmer crab	B	O
	Portunidae	*Portunus hastatoides*	Swimmer crab	B	O
	Portunidae	*Portunus pelagicus*	Blue manna crab	B	O
	Portunidae	*Portunus haanii*	Swimmer crab	B	O
	Portunidae	*Portunus pubescens*	Swimmer crab	B	O
	Portunidae	*Portunus rubromarginatus*	Swimmer crab	B	O
	Portunidae	*Portunus sanguinolentus*	Three spot crab	B	O
	Portunidae	*Portunus tenuipes*	Swimmer crab	B	O
	Portunidae	*Portunus* sp.1	Swimmer crab	B	O
	Portunidae	*Portunus* sp.2	Swimmer crab	B	O
	Portunidae	*Thalamita admete*	Swimmer crab	B	O
	Portunidae	*Thalamita sima*	Four-lobed swimmer crab	B	O
	Portunidae	*Thalamita* sp.	Swimmer crab	B	O
	Xanthidae	*Actea savignyi*	Black-clawed crab	B	O
	Xanthidae	*Neoxanthops rotundus*	Black-clawed crab	B	O

Appendix 3.3.4 Shark Bay mollusc species recorded from four survey trips in 2002 and 2003

Key:

Habitat: B = benthic, EB = epibenthic, BP = benthopelagic, M = mid water, P = pelagic, S = surface waters
I = infauna
B/SP = inside sponge, B/B = benthic inside burrows

Diet: C = general carnivore, CI = carnivore of invertebrates, CV = carnivore of vertebrates, O= omnivore, P = planktivore, H = herbivore, F = filter feeder, S = suspension feeder, SC = scavenger, DE = deposit feeder

Shark Bay total crustacean species = 97

Order	Family	Scientific name	Common name	Habitat	Diet
Polyplacophora					
	Chitonidae	Chiton sp.	Chiton	B	O
Bivalvia					
	Arcidae	*Anadara crebicostata*	Arc shell	B	F
	Arcidae	*Trisidos semitorta*	Arc shell	B	F
	Cardiidae	*Fragum hemicardium*	Heart cockle	I	F
	Cardiidae	*Fragum retusum*	Heart cockle	I	F
	Cardiidae	*Fulvia australe*	Heart cockle	I	F
	Cardiidae	*Fulvia* sp.	Heart cockle	I	F
	Hiatellidae	*Hiatella australis*	boring bivalve	B/SP	F
	Malleidae	*Vulsella vulsella*	Sponge finger	B/SP	F
	Mactricidae	*Lutraria rhynchaena*	Trough clam	I	F
	Mytilidae	*Modiolus proclivis*	Mussel	B	F
	Ostreidae	*Dendostrea folium*	Oyster	B	F
	Ostreidae	*Ostrea* sp.	Oyster	B	F
	Pectinidae	*Amusium balloti*	Saucer scallop	B	F
	Pectinidae	*Annachlamys flabellata*	Fan scallop	B	F
	Pectinidae	*Mimachlamys asperrima*	Doughboy scallop	B	F
	Pectinidae	*Mimachlamys australis*	Scallop	B	F
	Pectinidae	*Mimachlamys crassicostata*	Scallop	B	F
	Pectinidae	*Mimachlamys scabricostata*	Scallop	B	F
	Pectinidae	*Pecten fumatus*	King scallop	B	F
	Pharidae	*Ensiculus cultellus*	Bivalve	B	F
	Pinnidae	*Pinna bicolor*	Razor clam	I	F
	Pteriidae	*Pinctada albina*	S. Bay Pearl oyster	B	F
	Pteriidae	*Pinctada radiata*	Pearl oyster	B	F
	Pteriidae	*Pinctada sp.*	Pearl oyster	B	F
	Trapeziidae	*Trapezium* sp.	Bivalve	B	F
	Veneridae	*Antigona lamellaris*	Venus shell	I	F
	Veneridae	*Callista planatella*	Venus shell	I	F
	Veneridae	*Circe rivularis*	Venus shell	I	F
	Veneridae	*Circe sulcata*	Venus shell	I	F
	Veneridae	*Paphia crassisulca*	Venus shell	I	F
	Veneridae	*Paphia semirugata*	Venus shell	I	F
	Veneridae	*Pitar nancyae*	Venus shell - dead	I	F
Gastropoda	Buccinidae	*Cantharus erythrostomus*	Whelk shell	B	CI
	Bullidae	*Bulla ampulla*	Bubble shell	B	H

Order	Family	Scientific name	Common name	Habitat	Diet
	Bullidae	*Bulla quoyi*	Bubble shell	B	H
	Cassidae	*Semicassis paucirugis*	Helmet shell	B	CI
	Columbellidae	*Pyrene bidentata*	Dove shell	B	O
	Cypraeidae	*Cypraea* sp.	Cowrie	B	CI
	Ficidae	*Ficus eospila*	Fig shell	B	CI
	Fissurellidae	*Diodora occidua*	Keyhole limpet	B	H
	Fissurellidae	*Scutus antipodes*	Keyhole limpet	B	H
	Fissurellidae	*Scutus unguis*	Keyhole limpet	B	H
	Hydatinidae	*Hydatina albocincta*	Rose petal bubble shell	B	CI
	Muricidae	*Cronia avellana*	Oyster drill	B	CI
	Muricidiae	*Morula* sp.	Murex shell	B	CI
	Nassaridae	*Nassarius glans*	Dog whelk	B	CI
	Naticidae	*Natica? stellata*	Moon snail	B	CI
	Naticidae	*Natica vitellus*	Moon snail	B	CI
	Olividae	*Ancillista cingulata*	Ancillid	B	CI
	Ranellidae	*Cymatium caudatum*	Triton shell	B	CI
	Ranellidae	*Cymatium oblitum*	Triton shell	B	CI
	Ranellidae	*Cymatium parthenopeum*	Triton shell	B	CI
	Ranellidae	*Cymatium vespaceum*	Triton shell	B	CI
	Ranellidae	*Cymatium* sp.	Triton shell	B	CI
	Ranellidae	*Septa* sp.	Triton shell	B	CI
	Strombidae	*Strombus campbelli*	Stromb shell	B	H
	Strombidae	*Strombus vomer*	Stromb shell	B	H
	Tonnidae	*Tonna chinensis*	Tun shell	B	CI
	Tonnidae	*Tonna variegata*	Tun shell	B	CI
	Trochidae	*Calthalotia mundula*	Top shell	B	H
	Trochidae	*Tallorbis roseolus*	Top shell	B	H
	Trochidae	*Thalotia* sp.	Top shell	B	H
	Turbinidae	*Phasianella solida*	Turban shell	B	H
	Turbinidae	*Phasianella variegata*	Turban shell	B	H
	Turbinidae	*Turbo haynesi*	Turban shell	B	H
	Velutinidae	*Lamellaria* sp.	Velutinid	B	CI
	Volutidae	*Melo amphora*	Bailer shell	B	CI
	Volutidae	*Melo miltonis*	Southern bailer shell	B	CI
	Fasciolariidae ?	Egg-Case	Tulip shell	B	CI
Opistobranchia					
O. Anaspidea	Akeridae	*Akera soluta*	Akerid	B	H/DE
O. Anaspidea	Aplysiidae	*Aplysia* sp.	Sea hare	B	H
O. Cephalaspidea	Philinidae	*Philine* sp.	Philinid	I	CI
O. Nudibranchia	Arminidae	*Armina* sp.	Arminid	B	CI
O. Nudibranchia	Dorididae	*Platydoris* sp.	Nudibranch	B	CI
O. Nudibranchia	Dendrodorididae	*Dendrodoris denisoni*	Nudibranch	B	CI
O. Notaspidea	Pleurobranchidae	*Euselenops luniceps*	Side-gilled slug	B	CI
O. Notaspidea	Pleurobranchidae	*Euselenops* sp.	Side-gilled slug	B	CI
O. Notaspidea	Pleurobranchidae	*Pleurobranchus* sp.	Side-gilled slug	B	CI
Cephalopoda					
	Loliginidae	*Photololigo* sp.	Squid	BP	C

Order	Family	Scientific name	Common name	Habitat	Diet
	Loliginidae	*Photololigo* sp.2	Squid	BP	C
	Loliginidae	*Sepioteuthis australis*	Southern calamari	BP	C
	Loliginidae	*Sepioteuthis ‘lessoniana”*	Northern calamari	BP	C
	Octopodidae	*Hapalochlaena* sp.	Blue-ringed octopus	B	C
	Octopodidae	*Octopus* sp. cf. *O.tetricus*	Gloomy octopus	B	C
	Octopodidae	*Octopus* sp. cf. *O. kaurna*	Southern sand octopus	B	C
	Octopodidae	*Octopus* sp. cf. *O. mototi*	Poison ocellate octopus	B	C
	Sepiadariidae	*Sepiadarium* sp.	Bottletail squid	B	CI
	Sepiadariidae	*Sepiadarium austrinum*	Southern bottletail squid	B	CI
	Sepaidariidae	*Sepiadarium kochii*	Bottletail squid	B	CI
	Sepiadariidae	*Sepioloidea lineolata*	Pyjama bottletail squid	B	CI
	Sepiidae	*Metasepia pfefferi*	Flamboyant cuttlefish	EB	C
	Sepiidae	*Sepia apama*	Giant cuttlefish	EB	C
	Sepiidae	*Sepia papuensis*	Papuan cuttlefish	EB	C
	Sepiidae	*Sepia pharaonis*	Pharaoh’s cuttlefish	EB	C
	Sepiidae	*Sepia smithi*	Smith’s cuttlefish	EB	C
	Sepiidae	*Sepia sp. (Eggs)*	Cuttlefish	B	
	Sepiolidae	*Euprymna tasmanica*	Southern dumpling squid	B	CI

Appendix 3.3.5 Shark Bay echinoderm species recorded from four survey trips in 2002 and 2003

Key:

Habitat: B = benthic, EB = epibenthic, BP = benthopelagic, M = mid water, P = pelagic, S = surface waters
Diet: C = general carnivore, CI = carnivore of invertebrates, CV = carnivore of vertebrates, O= omnivore, P = planktivore, H = herbivore, F = filter feeder, S = suspension feeder, SC = scavenger, DE = deposit feeder

Shark Bay total echinoderm species = 67

Class	Family	Species	Common name	Habitat	Diet
Crinoidea	Antedonidae	*Dorometra parvicirra*	Crinoid	B	S
	Comasteridae	*Comatula purpurea*	Crinoid	B	S
	Comasteridae	*Comatula rotalaria*	Crinoid	B	S
	Comasteridae	*Comatula solaris*	Crinoid	B	S
	Tropiometridae	*Tropiometra afra*	Crinoid	B	S
	Zygometridae	*Zygometra comata*	Crinoid	B	S
	Zygometridae	*Zygometra microdiscus*	Crinoid	B	S
Asteroidea	Archasteridae	*Archaster angulatus*	Seastar	B	DE
	Asterinidae	*Nepanthia crassa*	Seastar	B	O
	Astropectinidae	*Astropecten monacanthus*	Seastar	B	CI
	Astropectinidae	*Astropecten preissi*	Seastar	B	CI
	Astropectinidae	*Astropecten zebra*	Seastar	B	CI
	Astropectinidae	*Astropecten* sp.	Seastar	B	CI
	Echinasteridae	*Metrodira subulata*	Seastar	B	O
	Goniasteridae	*Stellaster equestris*	Seastar	B	DE
	Goniasteridae	*Stellaster inspinosus*	Seastar	B	DE
	Luidiidae	*Luidia hardwicki*	Seastar	B	CI
	Luidiidae	*Luidia maculata*	Seastar	B	CI
	Ophidiasteridae	*Leiaster coriaceus*	Seastar	B	DE
	Oreasteridae	*Anthenea conjungens*	Seastar	B	O
	Oreasteridae	*Anthenea* sp.	Seastar	B	O
	Oreasteridae	*Pentaceraster gracilis*	Seastar	B	O
	Oreasteridae	*Protoreaster nodulosus*	Seastar	B	O
	Pterasteridae	*Eurataster insignis*	Seastar	B	CI
Ophiuroidea	Ophiactidae	*Ophiactis savignyi*	Brittle star	B	S
	Ophiactidae	*Ophiactis* sp.	Brittle star	B	S
	Ophiotrichidae	*Macrophiothrix megapoma*	Brittle star	B	S
	Ophiotrichidae	*Macrophiothrix paucispina*	Brittle star	B	S
	Ophiotrichidae	*Ophiothrix (Acanthophiothrix) viridialba*	Brittle star	B	S
	Ophiotrichidae	*Ophiothrix (Keystonea) martensi*	Brittle star	B	S
	Ophiotrichidae	*Ophiothrix (Ophiothrix) ciliaris*	Brittle star	B	S
	Ophiotrichidae	*Ophiothrix* sp.	Brittle star	B	S
	Ophiuridae	*Dictenophiura stellata*	Brittle star	B	S
Echinoidea	Cidaridae	*Prionocidaris bispinosa*	Sea urchin	B	CI
	Laganidae	*Peronella lesueuri*	Sea urchin	B	DE
	Loveniidae	*Breynia desorii*	Sea urchin	B	DE
	Loveniidae	*Echinocardium cordatum*	Sea urchin	B	DE
	Temnopleuridae	*Temnopleurus alexandri*	Sea urchin	B	O
	Temnopleuridae	*Temnopleurus michaelseni*	Sea urchin	B	H

Class	Family	Species	Common name	Habitat	Diet
	Temnopleuridae	*Temnotrema elegans*	Sea urchin	B	O
	Toxopneustidae	*Nudechinus darnleyensis*	Sea urchin	B	DE
	Toxopneustidae	*Tripneustes gratilla*	Sea urchin	B	O
Holothuroidea					
Or. Aspidochirotida	Holothuriidae	*Holothuria (Metriatyla)* cf. *albiventer*	Sea cucumber	B	DE
	Holothuriidae	*Holothuria (Stauropora)* aff. *pervicax*	Sea cucumber	B	DE
	Holothuriidae	*Holothuria (Theelothuria) michaelseni*	Sea cucumber	B	DE
	Holothuriidae	*Holothuria (Thymiosycia) impatiens*	Sea cucumber	B	DE
	Stichopodidae	*Stichopus* cf. *chloronotus*	Sea cucumber	B	DE
	Stichopodidae	*Stichopus* cf. *hermanni*	Sea cucumber	B	DE
	Stichopodidae	*Stichopus* sp.	Sea cucumber	B	DE
Or. Dendrochirotida	Cucumariidae	*Actinocucumis typica*	Sea cucumber	B	S
	Cucumariidae	*Cercodemas anceps*	Sea cucumber	B	S
	Cucumariidae	*Colochirus crassus*	Sea cucumber	B	S
	Cucumariidae	*Colochirus quadrangularis*	Sea cucumber	B	S
	Cucumariidae	*Loisettea amphictena*	Sea cucumber	B	S
	Cucumariidae	*Mensamaria intercedens*	Sea cucumber	B	S
	Cucumariidae	*Plesiocolochirus challengeri*	Sea cucumber	B	S
	Cucumariidae	*Staurothyrone rosacea*	Sea cucumber	B	S
	Phyllophoridae	*Havelockia versicolor*	Sea cucumber	B	S
	Phyllophoridae	*Phyllophorus (Urodemella) brocki*	Sea cucumber	B	S
	Phyllophoridae	cf. *Phyllophorus* sp.	Sea cucumber	B	S
	Phyllophoridae	*Phyrella trapeza*	Sea cucumber	B	S
	Phyllophoridae	*Stolus buccalis*	Sea cucumber	B	S
	Phyllophoridae	*Thyone* cf. *okeni*	Sea cucumber	B	S
	Phyllophoridae	*Thyone* sp.	Sea cucumber	B	S
Or. Molpadiida	Caudinidae	*Paracaudina chilensis*	Sea cucumber	B	DE
Or. Apodidae	Synaptidae	*Synaptula recta*	Sea cucumber	B	DE
	Synaptidae	*Synaptula reticulata*	Sea cucumber	B	DE

Appendix 3.3.6 Shark Bay ascidian species recorded from four survey trips in 2002 and 2003

Key:

Habitat: I = infauna, SE = sessile, B = benthic, EB = epibenthic, BP = benthopelagic, P = pelagic, S = surface waters

Diet: C = general carnivore, CI = carnivore of invertebrates, CV = carnivore of vertebrates, O= omnivore, P = planktivore, H = herbivore, F = filter feeder, S = suspension feeder, SC = scavenger, DE = deposit feeder

Shark Bay total ascidian species = 15 (not all identified)

Family	Scientific name	Common name	Habitat	Diet
Clavelinidae	*Clavelina meridionalis*	Solitary ascidian	B	F
Holozoidae	*Sigillina australis*	Colonial ascidian	B	F
Polyclinidae	*Polyclinum vasculosum*	Solitary ascidian	B	F
Didemnidae	*Didemnum membranaceum*	Solitary ascidian	B	F
Didemnidae	*Leptoclinides kingi*	Colonial ascidian	B	F
Ascidiidae	*Ascidia latesiphonica*	Solitary ascidian	B	F
Ascidiidae	*Phallusia millari*	Solitary ascidian	B	F
Plurellidae	*Microgastra granosa*	Solitary ascidian	B	F
Styelidae	*Polycarpa olitoria*	Solitary ascidian	B	F
Styelidae	*Polycarpa aurata*	Solitary ascidian	B	F
Styelidae	*Botrylloides perspicuus*	Colonial ascidian	B	F
Pyuridae	*Herdmania pallida*	Solitary ascidian	B	F
Pyuridae	*Herdmania mentula*	Solitary ascidian	B	F
Pyuridae	*Microcosmus exasperatus*	Solitary ascidian	B	F
Molgulidae	*Molgula ficus*	Solitary ascidian	B	F

Appendix 3.4.1 Exmouth Gulf and Onslow sponge species recorded from survey trip 1 in March 2004

Key:

Habitat: B = benthic, EB = epibenthic, BP = benthopelagic, M = mid-water, P = pelagic, S = surface waters

Diet: C = general carnivore, CI = carnivore of invertebrates, CV = carnivore of vertebrates, O= omnivore, P = planktivore, H = herbivore, F = filter feeder, S = suspension feeder, SC = scavenger, DE = deposit feeder

Exmouth Gulf and Onslow total sponge species = 59

Family	Scientific name	Habitat	Diet
Axinellidae	*Reniochalina stalagmitis*	B	F
Axinellidae	sp. EG 1	B	F
Axinellidae	sp. EG 2	B	F
C. Calcarea	Calcarea	B	F
Callyspongiidae	*Callyspongia* sp. EG 1	B	F
Callyspongiidae	*Callyspongia* sp. EG 2	B	F
Callyspongiidae	*Callyspongia* sp. EG 3	B	F
Callyspongiidae	*Callyspongia* sp. EG 4	B	F
Callyspongiidae	*Callyspongia* sp. EG 5	B	F
Chalinidae	sp. EG 1	B	F
Chondropsidae	*Chondropsis* sp. EG 1	B	F
Darwinellidae	sp. EG 1	B	F
Desmacellidae	sp. EG 1	B	F
Desmoxyidae	*Higginsia* sp. EG 1	B	F
Dictyodendrillidae	sp. Eg 1	B	F
Halichondriidae	*Amorphinopsis* sp. EG 1	B	F
Halichondriidae	sp. EG 1	B	F
Halichondriidae	sp. EG 2	B	F
Hemiasterellidae	*Axos flabelliformis*	B	F
Ianthellidae	*Ianthella basta*	B	F
Ianthellidae	*Ianthella flabelliformis*	B	F
Ianthellidae	*Ianthella quadrangulata*	B	F
Irciniidae	sp. EG 1	B	F
Irciniidae	sp. EG 2	B	F
Irciniidae	sp. EG 3	B	F
Irciniidae	sp. EG 4	B	F
Irciniidae	sp. EG 5	B	F
Irciniidae	sp. EG 6	B	F
Irciniidae	sp. EG 7	B	F
Microcionidae	*Clathria (Thalysias) abietina*	B	F
Microcionidae	*Clathria (Thalysias) cactiformis*	B	F
Microcionidae	sp. EG 1	B	F
Microcionidae	sp. EG 2	B	F
Microcionidae	sp. EG 3	B	F
Mycalidae	*Mycale* sp. EG 1	B	F
Mycalidae	*Mycale* sp. EG 2	B	F
Myxillidae	*Iotrochota* sp.EG 1	B	F
Myxillidae	*Iotrochota* sp.EG 2	B	F
Niphatidae	*Amphimedon paraviridis*	B	F

Family	Scientific name	Habitat	Diet
O. Verongida	sp. EG 1	B	F
Raspailiidae	*Echinodictyum cancellatum*	B	F
Raspailiidae	*Echinodictyum clathrioides*	B	F
Raspailiidae	*Echinodictyum mesenterinum*	B	F
Raspailiidae	*Echinodictyum* sp. EG 1	B	F
Raspailiidae	*Ectyoplasia tabula*	B	F
Spirastrellidae	*Spirastrella* sp. EG 1	B	F
Spongiidae	*Hippospongia* sp.EG 1	B	F
Spongiidae	*Hippospongia* sp.EG 2	B	F
Spongiidae	*Spongia* sp.EG 1	B	F
Spongiidae	*Spongia* sp.EG 2	B	F
Spongiidae	*Spongia* sp.EG 3	B	F
Suberitidae	*Caulospongia perfoliata*	B	F
Tedaniidae	*Tedania* sp. EG 1	B	F
Tedaniidae	*Tedania* sp. EG 2	B	F
Tethyidae	*Tethya* sp. EG 1	B	F
Thorectidae	sp. EG 1	B	F
Thorectidae	sp. EG 2	B	F
Thorectidae	sp. EG 3	B	F
Thorectidae	sp. EG 4	B	F

Appendix 3.4.2 Exmouth Gulf and Onslow octocoral species recorded from three survey trips in 2004

Key:

Habitat: B = benthic, EB = epibenthic, BP = benthopelagic, M = mid-water, P = pelagic, S = surface waters

Diet: C = general carnivore, CI = carnivore of invertebrates, CV = carnivore of vertebrates, O= omnivore, P = planktivore, H = herbivore, F = filter feeder, S = suspension feeder, SC = scavenger, DE = deposit feeder

Exmouth Gulf and Onslow total octocoral species = 34

Family	Scientific name	Common name	Habitat	Diet
Anthothelidae	*Alertigorgia orientalis* (Ridley, 1884)	Soft coral	B	S
Anthothelidae	*Semperina brunnea* (Nutting, 1911)	Soft coral	B	S
Anthothelidae	*Solenocaulon* sp A	Soft coral	B	S
Anthothelidae	*Solenocaulon* sp B	Soft coral	B	S
Clavulariidae	*Carijoa* cf *multiflora* (Laackmann, 1909)	Soft coral	B	S
Fasciculariidae	*Studeriotes* sp B	Soft coral	B	S
Melithaeidae	*Melithaea* sp A	Gorgonian	B	S
Melithaeidae	*Melithaea squamata* (Nutting, 1910)	Gorgonian	B	S
Melithaeidae	*Mopsella* sp A	Gorgonian	B	S
Nephtheidae	*Dendronephthya* sp A	Soft coral	B	S
Nephtheidae	*Dendronephthya* sp B	Soft coral	B	S
Nephtheidae	*Dendronephthya* sp C	Soft coral	B	S
Nephtheidae	*Dendronephthya* cf sp C	Soft coral	B	S
Nephtheidae	*Dendronephthya* sp D	Soft coral	B	S
Nephtheidae	*Dendronephthya* sp E	Soft coral	B	S
Nephtheidae	*Dendronephthya* sp H	Soft coral	B	S
Nephtheidae	*Stereonephthya* spA	Soft coral	B	S
Nephtheidae	Dendronephtheid	Soft coral	B	S
Nidallidae	*Nephthyigorgia* sp A	Soft coral	B	S
Nidallidae	*Nephthyigorgia* sp B	Soft coral	B	S
Plexauridae	*Astrogorgia* sp A	Soft coral	B	S
Plexauridae	*Astrogorgia* sp B or possible new genus	Gorgonian	B	S
Plexauridae	*Echinogorgia* sp A	Gorgonian	B	S
Plexauridae	*Echinogorgia* sp B	Gorgonian	B	S
Plexauridae	*Menella* sp A	Soft coral	B	S
Plexauridae	*Menella* sp B	Whip coral	B	S
Plexauridae	*Menella* sp C	Soft coral	B	S
Plexauridae	*Paraplexaura* sp A	Soft coral	B	S
Pteroeididae	*Pteroeides* sp ?	Seapen	B	S
Pteroeididae	*Pteroeides* sp C	Seapen	B	S
Pteroeididae	*Pteroeides* sp F	Seapen	B	S
Veretillidae	*Veretillum australis* (Gray, 1870)	Seapen	B	S
Virgulariidae	*Virgularia* sp A	Soft coral	B	S
Virgulariidae	*Virgularia* sp B	Seapen	B	S

Appendix 3.4.3 Exmouth Gulf and Onslow crustacean species recorded from three survey trips in 2004

Key:

Habitat: B = benthic, EB = epibenthic, BP = benthopelagic, M = mid-water, P = pelagic, S = surface waters
B/B = benthic, in burrows, B/SP = benthic, in sponge

Diet: C = general carnivore, CI = carnivore of invertebrates, CV = carnivore of vertebrates, O= omnivore, P = planktivore, H = herbivore, F = filter feeder, S = suspension feeder, SC = scavenger, DE = deposit feeder

Exmouth Gulf and Onslow total crustacean species = 82

Order	Family	Scientific name	Common name	Habitat	Diet
Stomatopoda	Gonodactylidae	*Gonodactylaceus graphurus*	Mantis Shrimps	B/B	C
	Odontodactylidae	*Odontodactylus cultrifer*	Mantis Shrimps	B/B	C
	Odontodactylidae	*Odontodactylus latirostris*	Mantis Shrimps	B/B	C
	Squillidae	*Anchisquilla fasciata*	Mantis Shrimps	B/B	C
	Squillidae	*Carinosquilla australiensis*	Mantis Shrimps	B/B	C
	Squillidae	*Harpiosquilla melanoura*	Mantis Shrimps	B/B	C
	Squillidae	*Oratosquillina interrupta*	Mantis Shrimps	B/B	C
	Squillidae	*Oratosquillina quinquedentata*	Mantis Shrimps	B/B	C
	Squillidae	*Oratosquillina* sp.	Mantis Shrimps	B/B	C
Isopoda	Isopoda	Isopod	Isopods - from sponges	B/SP	H/DE?
	Isopoda	Isopod	Isopods - parastic	BP	C
Decapoda	Penaeidae	*Penaeus latisulcatus*	King prawn	B	O
	Penaeidae	*Penaeus longistylus*	Red spot king prawn	B	O
	Penaeidae	*Metapenaeopsis crassissima*	Coral prawn	B	O
	Penaeidae	*Metapenaeopsis lamellata*	Rooster prawn	B	O
	Penaeidae	*Metapenaeopsis novaeguineae*	Northenr velvet prawn	B	O
	Penaeidae	*Metapenaeopsis palmensis*	Southern velvet prawn	B	O
	Penaeidae	*Metapenaeopsis rosea*	Rosy prawn	B	O
	Penaeidae	*Metapenaeopsis wellsi*	Coral prawn	B	O
	Penaeidae	*Metapenaeus dalli*	Western school prawn	B	O
	Penaeidae	*Metapenaeus endeavouri*	Endeavour prawn	B	O
	Penaeidae	*Metapenaeus ensis*	Red endeavour prawn	B	O
	Penaeidae	*Parapenaeopsis cornuta*	Coral prawn	B	O
	Penaeidae	*Penaeus esculentus*	Tiger prawn	B	O
	Penaeidae	*Penaeus merguiensis*	Banana Prawn	B	O
	Penaeidae	*Penaeus monodon*	Black tiger prawn	B	O
	Sicyoniidae	*Sicyona lancifera*	Ridgeback rock prawn	B	O
	Sicyoniidae	*Trachypenaeus anchoralis*	Northen rough prawn	B	O
	Sicyoniidae	*Trachypenaeus granulosus*	Hardback prawn	B	O
	Sicyoniidae	*Trachypenaeus curvirostris*	Southern rough prawn	B	O
	Alpheidae	Alpheid	Snapping shrimps	B	C
	Stenopodidae	*Stenopus hispidus*	Banded Coral Shrimp	B	C
	Panuliridae	*Panulirus ornatus*	Tropical Rock Lobster	B	O
	Scyllaridae	*Thenus orientalis*	Slipper lobster	B	O
	Scyllaridae	*Eduarctus martensii*	Slipper lobster	B	O
Infraorder Anomura	Diogenidae	Diogenid	Hermit crabs	B	O
	Porcellanidae	Porcellanid	Porcelain Crabs	B	F

Order	Family	Scientific name	Common name	Habitat	Diet
	Galatheidae	Galatheid	Squat lobster	B	C
Infraorder Brachyura	Dromiidae	Dromiid	Sponge crab	B	O
	Calappidae	*Calappa clypeata*	Shame-faced crab	B	O
	Corystidae	*Gomeza bicornis*	Masked burrowing crab	B/B	O
	Dorippidae	*Dorippe quadridens*	Dorippe sp	B	O
	Goneplacidae	*Eucrate* sp.	Crab	B	O
	Leucosiidae	*Leucosia haswelli*	Pebble crabs	B	O
	Leucosiidae	*Leucosia ocellata*	Pebble crabs	B	O
	Leucosiidae	*Ixa acuta*	Pebble crabs	B	O
	Majidae	*Phalangipus longipes*	Decorator Crabs/Spider Crab	B	O
	Majidae	Majid	Decorator Crabs/Spider Crab	B	H/O
	Matutidae	*Ashtoret granulosa*	Moon crab	B	O
	Parthenopidae	*Cryptopodia dorsalis*	Long-armed crab	B	O
	Parthenopidae	*Pseudolambrus harpax*	Long-armed crab	B	O
	Parthenopidae	*Rhinolambrus* sp.	Long-armed crab	B	O
	Parthenopidae	*Rhinolambrus contrarius*	Long-armed crab	B	O
	Portunidae	*Charybdis anisodon*	Swimmer crab	B	O
	Portunidae	*Charybdis feriata*	Coral crab	B	O
	Portunidae	*Charybdis jaubertensis*	Swimmer crab	B	O
	Portunidae	*Charybdis truncata*	Swimmer crab	B	O
	Portunidae	*Lupocyclus* sp.	Swimmer crab	B	O
	Portunidae	*Podophthalmus vigil*	Sentinel crab	B	O
	Portunidae	*Portunus curvipenis*	Swimmer crab	B	O
	Portunidae	*Portunus granulatus*	Swimmer crab	B	O
	Portunidae	*Portunus haanii*	Swimmer crab	B	O
	Portunidae	*Portunus hastatoides*	Swimmer crab	B	O
	Portunidae	*Portunus pelagicus*	Blue swimmer crab	B	O
	Portunidae	*Portunus rubromarginatus*	Swimmer crab	B	O
	Portunidae	*Portunus rugosus*	Swimmer crab	B	O
	Portunidae	*Portunus samoensis?*	Swimmer crab	B	O
	Portunidae	*Portunus sanguinolentus*	Three-spot swimmer crab	B	O
	Portunidae	*Portunus tenuipes*	Swimmer crab	B	O
	Portunidae	*Portunus* sp.2	Swimmer crab	B	O
	Portunidae	*Thalamita intermedia*	Swimmer crab	B	O
	Portunidae	*Thalamita picta*	Swimmer crab	B	O
	Portunidae	*Thalamita sima*	Four-lobed swimmer crab	B	O
	Xanthidae	*Actaea jacquelinae*	Black-clawed crab	B	O
	Xanthidae	*Liomera semigranosa*	Black-clawed crab	B	O
	Xanthidae	*Lophozozymus pictor*	Black-clawed crab	B	O
	Pilumnidae	*Actumnus* sp.	Hairy crab	B	O
	Pilumnidae	*Bathypilumnus pugilator*	Hairy crab	B	O
	Pilumnidae	*Ceratoplax* sp.	Hairy crab	B	O
	Pilumnidae	*Halimede ochtrodes*	Hairy crab	B	O
	Pilumnidae	*Pilumnus semilanatus*	Hairy crab	B/SP	O
	Pilumnidae	*Pilumnus* sp.	Hairy crab	B/SP	O

Appendix 3.4.4 Exmouth Gulf and Onslow mollusc species recorded from three survey trips in 2004

Key:

Habitat: B = benthic, EB = epibenthic, BP = benthopelagic, M = mid-water, P = pelagic, S = surface waters B/B = benthic, in burrows, B/SP = benthic, in sponge, I = infauna

Diet: C = general carnivore, CI = carnivore of invertebrates, CV = carnivore of vertebrates, O= omnivore, P = planktivore, H = herbivore, F = filter feeder, S = suspension feeder, SC = scavenger, DE = deposit feeder

Exmouth Gulf and Onslow total mollusc species = 89

Order	Family	Scientific name	Common name	Habitat	Diet
Bivalvia	Pectinidae	*Amusium balloti*	Saucer scallop	B	F
	Pectinidae	*Annachlamys flabellata*	Crinkly scallop	B	F
	Pectinidae	*Cryptopecten nux*	Scallop	B	F
	Pectinidae	*Mimachlamys australis*	Scallop	B	F
	Pectinidae	*Mimachlamys asperrima*	Doughboy scallop	B	F
	Pectinidae	*Scaeochlamys livida*	Scallop	B	F
	Spondylidae	*Spondylus victoriae*	Thorny oyster	B	F
	Veneridae	*Paphia (Protapes) gallus*	Venus shell	I	F
	Veneridae	*Paphia crassisulca*	Venus shell	I	F
	Veneridae	*Paphia semirugata*	Venus shell	I	F
	Veneridae	*Paphia (Paphia)* cf. *undulata*	Venus shell	I	F
	Veneridae	*Sunetta perexcavata*	Venus shell	I	F
	Arcidae	*Arca (Arca) navicularis*	Arc shell	B	F
	Arcidae	*Trisidos semitorta*	Arc shell	I	F
	Cucullaeidae	*Cucullaea labiata*	Bivalve	I	F
	Malleidae	*Malleus* sp.	Hammer oyster	B	F
	Glycymerididae	*Melaxinaea vitrea*	Dog cockle	I	F
	Gryphaeidae	*Hyotissa ? hyotis*	Oyster	B	F
	Hiatellidae	*Hiatella australis*	Out of sponge	B/SP	F
	Limidae	*Lima lima vulgaris*	File shell	B	F
	Ostreidae	*Dendostrea folium*	Oyster	B	F
	Chamidae	*Chama lazarus*	Jewel box shell	B	F
	Pteriidae	*Pinctada albina*	S. Bay pearl oyster	B	F
	Pteriidae	*Pteria* sp.	Pearl oyster	B	F
	Solenidae	*Solen aureomaculatus*	Razor shell	I	F
Gastropoda	Buccinidae	*Buccinidae*	Whelk	B	CI
	Buccinidae	*Cantharus erythrostomus*	Whelk	B	CI
	Buccinidae	*Cantharus* sp.	Whelk	B	CI
	Buccinidae	*Fusinus colus*	Whelk	B	CI
	Bursidae	*Bursa* sp.	Frog shell	B	CI
	Calliostomatidae	*Calliostoma similarae*	Trochid shell	B	CI?
	Capulidae	*Capulus sycophanta*	Cap limpet on *A. flabellata*	B	D
Gastropoda	Cassidae	*Phalium bandatum*	Helmet shell	B	CI
	Conidae	*Conus trigonus*	Cone shell	B	C
	Conidae	*Conus tropicensis*	Cone shell	B	C
	Cypraeidae	*Cypraea subviridis*	Cowrie shell	B	CI
	Epitoniidae	*Eglisia tricarinata*	Wentletrap	B	CI
	Eulimidae	*Thyca* sp.	Parasitic on *Anthenea* sp.	B	CI

Order	Family	Scientific name	Common name	Habitat	Diet
	Fissurellidae	*Scutus granulatus*	Keyhole limpet	B	H
	Fissurellidae	*Scutus unguis*	Keyhole limpet	B	H
	Hipponicidae	*Hipponix* sp.?	On A. flabellata	B	D
	Muricidae	*Chicoreus cornucervi*	Murex shell	B	CI
	Muricidae	*Haustellum multiplicatus*	Murex shell	B	CI
	Muricidae	*Murex acanthostephes*	Murex shell	B	CI
	Muricidae	*Murex brevispina macgillivrayi*	Murex shell	B	CI
	Muricidae	*Pterynotus acanthopterus*	Murex shell	B	CI
	Muricidae	*Thais echinata*	Murex shell	B	CI
	Olividae	*Ancillista cingulata*	Olive shell	B	CI
	Ovulidae	*Volva volva*	Egg cowrie	B	CI
	Personidae	*Distorsio reticulata*	Personid shell	B	CI
	Ranellidae	*Cymatium* sp.	Triton shell	B	CI
	Ranellidae	*Cymatium caudatum*	Triton shell	B	CI
	Ranellidae	*Cymatium vespaceum*	Triton shell	B	CI
	Ranellidae	*Gyrineum lacunatum*	Triton shell	B	CI
	Strombidae	*Strombus dilatatus*	Stromb shell	B	H
	Trochidae	*Herpetopoma atrata*	Trochus shell	B	H
	Turbinellidae	*Syrinx aruanus*	Giant Conch	B	CI
	Turbinellidae	*Tudivasum inermis*	Conch shell	B	CI
	Turridae	*Turris crispa*	Turrid shell	B	CI
	Turritellidae	*Archimediella fastigiata*	Screw shell	B/I	S
	Volutidae	*Amoria damonii damonii*	Volute	B	CI
	Volutidae	*Amoria grayi*	Volute	B	CI
	Volutidae	*Cymbiola oblita*	Volute	B	CI
	Volutidae	*Melo amphora*	Bailer shell	B	CI
	Volutidae	*Melo* sp.	Bailer shell	B	CI
	Xenophoridae	*Xenophora indica*	Carrier shell	B	D/H
	Xenophoridae	*Xenophora pallida*	Carrier shell	B	D/H
Opisthobranchia					
O. Notaspidea	Umbraculidae	*Umbraculum sinicum*	Umbrella shell	B	CI
O. Notaspidea	Pleurobranchidae	*Pleurobranchus hilli*	Purple ophistobranch	B	CI
O. Cephalaspidea	Bullidae	*Bulla ampulla*	Bubble shell	B	H
O. Cephalaspidea	Philinidae	*Philine* sp.	Philinid	I	CI
O. Anaspidea	Aplysiidae	*Aplysia* sp.	Sea hare	B	H
O. Nudibranchia	Dorididae	*Aphelodoris karpa*	Nudibranch	B	CI
O. Nudibranchia	Dorididae	*Aphelodoris* sp.	Nudibranch	B	CI
O. Nudibranchia	Dorididae	*Platydoris ellioti*	Nudibranch	B	CI
O. Nudibranchia	Chromodorididae	*Ceratosoma tenue*	Nudibranch	B	CI
O. Nudibranchia	Dendrodorididae	*Dendrodoris* sp.	Nudibranch	B	CI
O. Nudibranchia	Tritoniidae	*Tritoniopsis elegans*	Nudibranch	B	CI
Cephalopoda					
	Loliginidae	*Loligo sp*	Squid/Calamari	BP	C
	Loliginidae	*Photololigo* sp.	Squid/Calamari	BP	C
	Sepiolidae	*Euprymna tasmanica*	Southern Dumpling Squid	B	CI
	Sepiadariidae	*Sepiadarium sp.*	Bottletails Squids	B	CI
	Octopodidae	*Octopus* sp.	Octopus with white spots	B	C

Order	Family	Scientific name	Common name	Habitat	Diet
	Octopodidae	*Octopus* sp.	Octopus with brown lines	B	C
	Sepiidae	*Metasepia pfefferi*	Flamboyant Cuttlefish	EB	C
	Sepiidae	*Sepia elliptica*	Oval Bone Cuttlefish	EB	C
	Sepiidae	*Sepia papuensis*	Papuan Cuttlefish	EB	C
	Sepiidae	*Sepia pharaonis*	Pharaoh’s Cuttlefish	EB	C
	Sepiidae	*Sepia smithi*	Smith’s Cuttlefish	EB	C

Appendix 3.4.5 Exmouth Gulf and Onslow echinoderm species recorded from three survey trips in 2004

Key:

Habitat: B = benthic, EB = epibenthic, BP = benthopelagic, M = mid-water, P = pelagic, S = surface waters

Diet: C = general carnivore, CI = carnivore of invertebrates, CV = carnivore of vertebrates, O= omnivore, P = planktivore, H = herbivore, F = filter feeder, S = suspension feeder, SC = scavenger, DE = deposit feeder

Exmouth Gulf and Onslow total echinoderm species = 73

Order	Family	Scientific name	Common name	Habitat	Diet
Holothuroidea					
Aspidochirotida	Holothuriidae	*Bohadschia marmorata*	Holothurian	B	DE
	Holothuriidae	*Holothuria modesta*	Holothurian	B	DE
	Holothuriidae	*Holothuria ocellata*	Holothurian	B	DE
	Stichopodidae	*Stichopus monotuberculatus*	Holothurian	B	DE
	Stichopodidae	*Stichopus* sp.	Holothurian	B	DE
Dendrochirotida	Cucumariidae	*Actinocucumis typica*	Holothurian	B	S
	Cucumariidae	*Cercodemas anceps*	Holothurian	B	S
	Cucumariidae	*Colochirus crassus*	Holothurian	B	S
	Cucumariidae	*Loisettea amphictena*	Holothurian	B	S
	Cucumariidae	*Mensamaria intercedens*	Holothurian	B	S
	Cucumariidae	*Plesiocolochirus challengeri*	Holothurian	B	S
	Cucumariidae	*Pseudocolochirus violaceus*	Holothurian	B	S
	Phyllophoridae	*Stolus buccalis*	Holothurian	B	S
Molpadida	Caudinidae	*Acaudina leucoprocta*	Holothurian	B	DE
Apodida	Synaptidae	*Synaptula recta*	Holothurian	B	DE
	Synaptidae	*Synaptula* cf *reticulata*	Holothurian	B	DE
Asteroidea					
	Archasteridae	*Archaster angulatus*	Seastar	B	DE
	Asterinidae	*Anseropoda rosacea*	Seastar	B	CI
	Asterinidae	*Nepanthia belcheri*	Seastar	B	O
	Asterodiscidae	*Asterodiscides macroplax*	Seastar	B	?
	Asterodiscidae	*Asterodiscides* sp.	Seastar	B	?
	Astropectinidae	*Astropecten granulatus*	Seastar	B	CI
	Astropectinidae	*Astropecten preissi*	Seastar	B	CI
	Astropectinidae	*Astropecten vappa*	Seastar	B	CI
	Astropectinidae	*Astropecten zebra*	Seastar	B	CI
	Astropectinidae	*Astropecten* sp.	Seastar	B	CI
	Echinasteridae	*Echinaster superbus*	Seastar	B	O
	Echinasteridae	*Echinaster varicolor*	Seastar	B	O
	Echinasteridae	*Metrodira subulata*	Seastar	B	O
	Goniasteridae	*Stellaster equestris*	Seastar	B	DE
	Goniasteridae	*Stellaster inspinosus*	Seastar	B	DE
	Goniasteridae	*Stellaster princeps*	Seastar	B	DE
	Luidiidae	*Luidia hardwicki*	Seastar	B	CI
	Luidiidae	*Luidia maculata*	Seastar	B	CI
	Ophidiasteridae	*Tamaria tumescens*	Seastar	B	O
	Ophidiasteridae	*Tamaria* sp.	Seastar	B	O
	Oreasteridae	*Anthenea* cf. *elegans*	Seastar	B	O

Order	Family	Scientific name	Common name	Habitat	Diet
	Oreasteridae	*Anthenea conjungens*	Seastar	B	O
	Oreasteridae	*Anthenea pentagonula*	Seastar	B	O
	Oreasteridae	*Anthenea sibogae*	Seastar	B	O
	Oreasteridae	*Anthenea* sp.	Seastar	B	O
	Oreasteridae	*Goniodiscaster acanthodes*	Seastar	B	O
	Oreasteridae	*Goniodiscaster australiae*	Seastar	B	O
	Oreasteridae	*Gymnanthenea globigera*	Seastar	B	O
	Oreasteridae	*Pentaceraster gracilis*	Seastar	B	O
	Oreasteridae	*Protoreaster* cf. *linckii juv*	Seastar	B	O
	Oreasteridae	*Protoreaster nodulosus*	Seastar	B	O
	Pterasteridae	*Eurataster insignis*	Seastar	B	CI
Echinoidea					
	Cidaridae	*Prionocidaris baculosa*	Pencil urchin	B	CI
	Cidaridae	*Prionocidaris bispinosa*	Pencil urchin	B	CI
	Clypeasteridae	*Clypeaster latissimus*	Sand Dollar	B	DE
	Laganidae	*Peronella lesueuri*	Sand Dollar	B	DE
	Loveniidae	*Breynia desorii*	Heart urchin	B	DE
	Temnopleuridae	*Salmacis sphaeroides*	Urchin	B	O
	Temnopleuridae	*Temnopleurus alexandri*	Urchin	B	O
	Toxopneustidae	*Tripneustes gratilla*	Urchin	B	O
Ophiuroidea					
	Euryalidae	*Euryale asperum*	Basket star	B	CI
	Ophiactidae	*Ophiactis luteomaculata*	Brittle star	B	S
	Ophiodermatidae	*Ophiopsammus yoldii*	Brittle star	B	CI
	Ophiotrichidae	*Macrophiothrix lineocaerulea*	Brittle star	B	S
	Ophiotrichidae	*Macrophiothrix megapoma*	Brittle star	B	S
	Ophiotrichidae	*Macrophiothrix melanosticta*	Brittle star	B	S
	Ophiotrichidae	*Ophiomaza cacaotica*	Brittle star	B	S
	Ophiotrichidae	*Ophiothrix ciliaris*	Brittle star	B	S
	Ophiuridae	*Ophiolepis unicolor*	Brittle star	B	S
Crinoidea					
	Comasteridae	*Clarkcomanthus littoralis*	Crinoid	B	S
	Comasteridae	*Comaster multifidus*	Crinoid	B	S
	Comasteridae	*Comatula pectinata*	Crinoid	B	S
	Comasteridae	*Comatula solaris*	Crinoid	B	S
	Comasteridae	*Comatula rotalaria*	Crinoid	B	S
	Himerometridae	*Heterometra crenulata*	Crinoid	B	S
	Zygometridae	*Zygometra elegans*	Crinoid	B	S
	Zygometridae	*Zygometra microdiscus*	Crinoid	B	S

4.0 OBJECTIVE 2

M. Kangas, S. Morrison, P. Unsworth, G. Parry, I. Wright and E. Lai

Objective 2. ***To examing seasonal (to select timing of monitoring) and annual variation of biodiversity at representative sites in Shark Bay***

4.1 INTRODUCTION

High variability in abundance in natural populations is common particularly in species that are relatively short lived. Sampling at different times during the year can provide a representative picture of the mean abundance for a region (Stewart-Oaten et al. 1986, Underwood 1993). In order to understand changes in biodiversity of trawl bycatch in trawled and untrawled areas, some understanding of seasonal and annual variability in distribution and abundance of species is required. Also, in order to determine long term monitoring strategies, the timing of monitoring needs to be optimal. Some understanding of the seasonal cycles of species is required so that these can be considered when interpreting results. Diurnal, seasonal and annual variation was studied in Shark Bay whilst in Exmouth Gulf and Onslow, seasonal variability only was studied during this project.

Some sites were sampled during day and night to determine the differences in abundance and species composition of daytime and night-time trawls, recognising that the majority of trawling within Shark Bay and Exmouth Gulf occur at night. The sampling was undertaken to highlight those species less susceptible to trawling if they are much more prevalent at daytime.

4.2 METHODS

4.2.1 General (see Chapter 2)

4.2.2 Day-night trawling

On 24 February 2003 sampling was undertaken at sites 3 and 4 in the Eastern Gulf and for sites 11 and 12 in the Northern part of Shark Bay on 5 March 2003 during both night and day (Figure 2.1). Daytime sampling was carried out between 1300 and 1600 hours and night-time sampling between 1800 and 2400 hours.

Three 10-minute trawls were undertaken at each site during each time period and all the fish and invertebrates were sorted and counted keeping the port and starboard nets separate.

4.2.3 Trawling effort

The daily logbook information provides shot by shot details of location, time of trawl and catch details but only provides the start location of each trawl. Trawl paths are variable and often not in a straight line i.e. turns or U-turns are completed during a run, therefore the precise track of each trawl is not known. Most trawls in Shark Bay are 60-80 minutes and during that time a distance of 3-4 nautical miles may be traveled and a variable amount of area covered (examples refer to Figure 4.1).

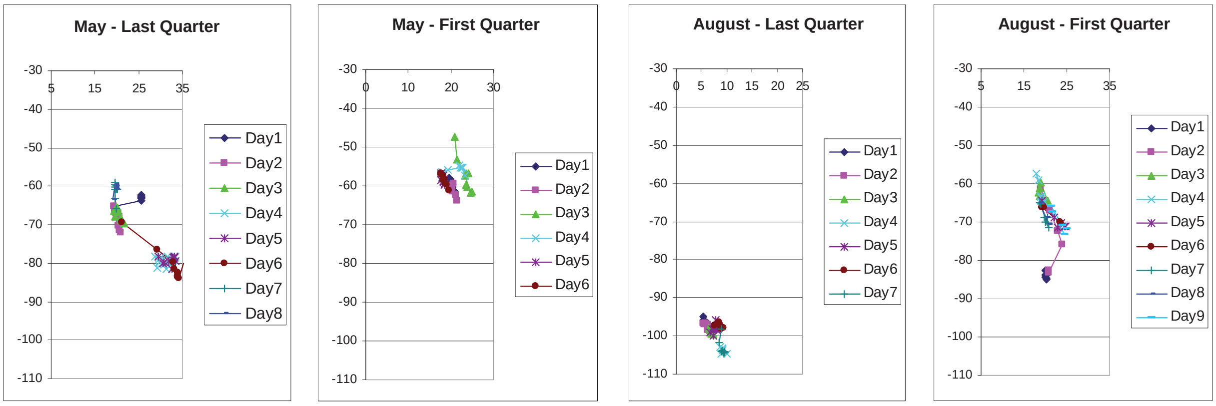

Figure 4.1 Examples of a boat's trawl patterns in the Shark Bay prawn fishery using daily logbook data.

In Exmouth Gulf and Onslow, trawls are usually 60 to 180 minutes duration and as in Shark Bay, they rarely occur in a straight line with turns common and the overall area covered can be variable. Using daily logbook information on trawl shot details, for two months prior to each sampling period, the amount of effort was determined around a 1 nautical mile radius of each sampling site (Tables 4.1 and 4.2). This was used as the approximate amount of effort that may have occurred at the site prior to a sampling. The overall effort during all sampling periods (October 2002 to October 2003 in Shark Bay and February 2004 to October 2004 for Exmouth Gulf and Onslow) was then used to determine how much effort was at each site (Figures 4.2 and 4.3). Trawl effort was categorized into four levels, 0: no trawling, 1: 1-50 hours, 2: 51-200 hours and 3: >200 hours.

Table 4.1 Hours of trawl effort per season per site and trawl effort category for the Shark Bay prawn and scallop fisheries for end of season 2002 to end of season 2003.

Site	End 02	St 03	Mid 03	End 03	Total	Category
1	0.0	0.0	0.0	0.0	0.0	0
2	0.0	0.0	0.0	0.0	0.0	0
3	0.0	0.0	0.0	0.0	0.0	0
4	0.0	0.0	7.3	0.0	7.3	1
5	0.0	0.0	189.8	14.0	203.8	3
6	60.9	0.0	67.3	105.8	234.0	3
7	2.0	0.0	110.8	0.0	112.8	2
8	9.7	0.0	267.6	39.9	317.2	3
9	0.0	0.0	107.9	1.0	108.9	2
10	0.0	0.0	0.0	0.0	0.0	0
11	0.0	0.0	5.1	0.0	5.1	1
12	0.0	0.0	317.0	0.0	317.0	3
13	0.0	0.0	81.9	110.6	192.5	2
14	13.1	0.0	22.1	34.8	70.0	2
15	106.4	0.0	0.0	202.4	308.8	3
16	0.0	0.0	0.0	0.0	0.0	0
17	0.0	0.0	0.0	0.0	0.0	0
18	82.3	0.0	0.0	0.3	82.7	2
19	260.5	0.0	0.0	133.8	394.3	3
20	3.7	0.0	4.2	23.2	31.0	1
21	1.3	0.0	179.4	0.0	180.8	2
22	0.0	0.0	0.0	0.0	0.0	0
23	0.0	0.0	5.3	0.0	5.3	1
24	0.0	0.0	98.9	19.5	118.4	2
25	0.0	0.0	29.4	0.0	29.4	1
26	0.0	0.0	0.0	0.0	0.0	0

Table 4.2 Hours of trawl effort and trawl effort category in the Exmouth Gulf and Onslow (Area 1) trawl fisheries for 2004 season.

Site	Start 04	Mid 04	End 04	Total	Category
1	0.0	13.5	0.0	13.5	1
2	0.0	0.0	0.0	0.0	0
3	0.0	0.0	0.0	0.0	0
4	0.0	155.9	45.2	201.1	3
5	0.0	18.2	8.6	26.8	1
6	0.0	153.9	47.4	201.3	3
7	0.0	12.8	0.0	12.8	1
8	0.0	0.0	0.0	0.0	0
9	0.0	34.7	61.2	95.8	2
10	0.0	0.0	0.0	0.0	0
11	0.0	197.2	731.6	928.8	3
12	0.0	6.0	1.5	7.5	1
13	0.0	103.2	779.2	882.3	3
14	0.0	3.5	52.5	56.0	2
16	0.0	77.3	44.8	122.1	2
17	0.0	0.0	44.8	44.8	1
18	0.0	0.0	0.0	0.0	0
19	0.0	0.0	0.0	0.0	0
20	0.0	112.7	40.9	153.6	2
21	0.0	6.0	0.0	6.0	1
22	0.0	0.0	0.0	0.0	0
23	0.0	6.0	5.8	11.8	1
24	0.0	12.8	10.5	23.3	1
25	0.0	43.1	30.4	73.5	2
26	0.0	0.0	0.0	0.0	0

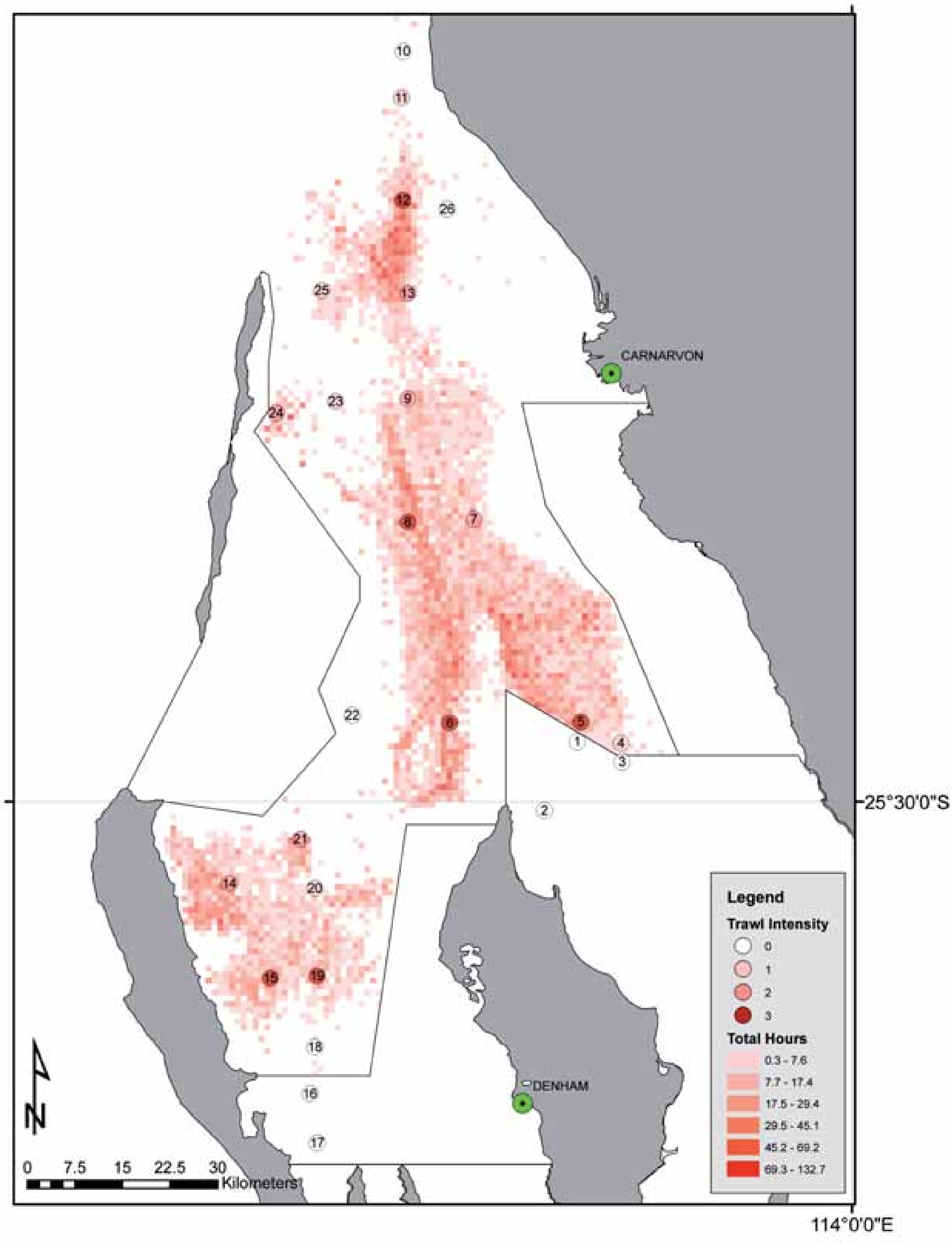

Figure 4.2 Actual effort in the Shark Bay prawn and scallop fishery as reported in daily logbooks extracted to 0.5nm grids for the period September 2002 to October 2003.

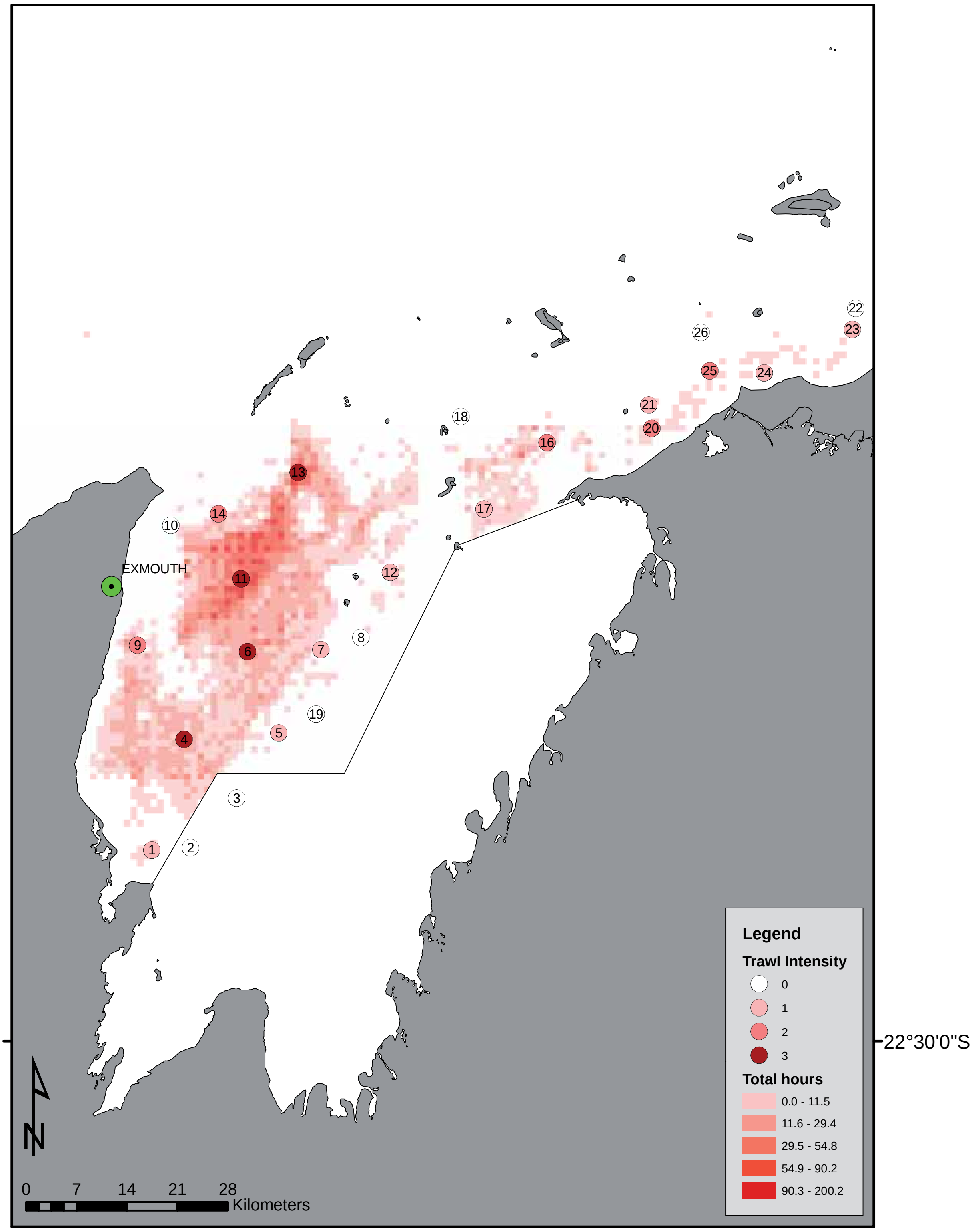

Figure 4.3 Actual effort in the Exmouth Gulf and Onslow prawn fishery as reported in daily logbooks extracted to 0.5nm grids for the period March 2004 to November 2004.

4.2.4 Statistical Methods

Permanovas

Considering fish and invertebrate data for Shark Bay and Exmouth separately, permutation tests for multivariate analysis of variance (permanova) (Anderson 2001) was used to analyse the Bray Curtis similarity index for each sample taken at trawled and untrawled sites. Factors considered in the permanova were trawl/non-trawl, season ('start', Jan – April; 'mid', May – August; and 'end', September – December) and their two-way interaction. The fourth root transformation was applied to the sample data before calculating the associated Bray Curtis index. Type 3 sum of squares have been presented due to the data being unbalanced (unequal number of observations per treatment).

Richness, Evenness & Diversity

Richness, evenness and diversity measures were determined as described in Chapter 2. With groups of untrawled and trawled sites for Shark Bay and Exmouth Gulf, ANOVA tests were carried out for trawled and untrawled sites to test if there were differences with season and between end of season 2002 and end of season 2003 in Shark Bay.

Annual variation at three sites in Shark Bay

A total of 41 samples were collected from the end of year 2002 to the start of year 2004 in sites 15, 16 and 21, with 2 or 3 samples in each of season. Site 16 was an untrawled site while sites 15 and 21 were heavily trawled location.

ANOVA tests were conducted to test if the number of species and the number of individuals caught in those three sites were significantly different and if season was a significant factor. Log-transformation of the number of individuals was undertaken first.

Relative fish species abundance related to trawl effort

To determine the power to detect differences with fish abundance and trawl effort, ANOVA (Statistica) was conducted using the square root of the 'relative' catch rates of fish Families for combined sites for four trawl effort categories (Tables 4.1 and 4.2) in Shark Bay and Exmouth Gulf. The relative catch rates were derived using a mean catch rate for sampling periods. Post hoc tests (Student-Newman-Keuls) were conducted to determine which levels of effort were significant.

Diurnal Variation in Shark Bay

Two sites in northern Shark Bay and two sites in the eastern gulf were sampled during both night and day. For the paired sites (sites 3 and 4, sites 11 and 12) ANOVA tests were carried out for mean abundance and number of species to test if there were differences with night and day.

4.3 RESULTS

4.3.1 Seasonal variation in abundance and diversity measures in Shark Bay

Seasonal abundance trends were seen in Shark Bay for both fish and invertebrate abundance. Permanovas indicated significant differences between trawled and untrawled sites between seasons (Tables 4.3a and 4.3b) but not for their interaction. The R^2 value is low indicating that site differences observed in previous analyses (Chapter 3) are likely to be more important that trawled/untrawled differences. Differences are observed between trawled and untrawled sites at start2003 and end2003. Mobility of fish species makes interpretation between sites difficult and high site variability may account for this significance.

Table 4.3a Permanova results for fish species in Shark Bay biodiversity trawls (R^2 = 0.10). Only observations for 2003 were included in this analysis. Type 3 sum of squares have been presented.

Source	df	SS	MS	Pseudo-F	P(perm)
Trawled	1	17093	17093	9.0395	< 0.01
Season	2	21591	10795	5.7089	< 0.01
Trawled x Season	2	5584	2792	1.4765	0.07
Residuals	209	3.95E+05	1890.9		

Table 4.3b Permanova results for invertebrate species in Shark Bay biodiversity trawls (R^2 = 0.11). Only observations for 2003 were included in this analysis. Type 3 sum of squares have been presented.

Source	df	SS	MS	Pseudo-F	P(perm)
Trawled	1	8556.4	8556.4	3.8849	< 0.01
Season	2	43803	21902	9.944	< 0.01
Trawled x Season	2	6338.9	3169.5	1.439	0.12
Residuals	209	4.60E+05	2202.5		

A significant increase is observed between end2002 and start2003 for both trawled and untrawled sites. For trawled sites a significant reduction in abundance is observed between start2003 and mid2003 with a small but insignificant decline by end2003. For untrawled sites no significant decline is observed between start2003 and mid2003 but there is a significant decline by end2003 (Figure 4.4).

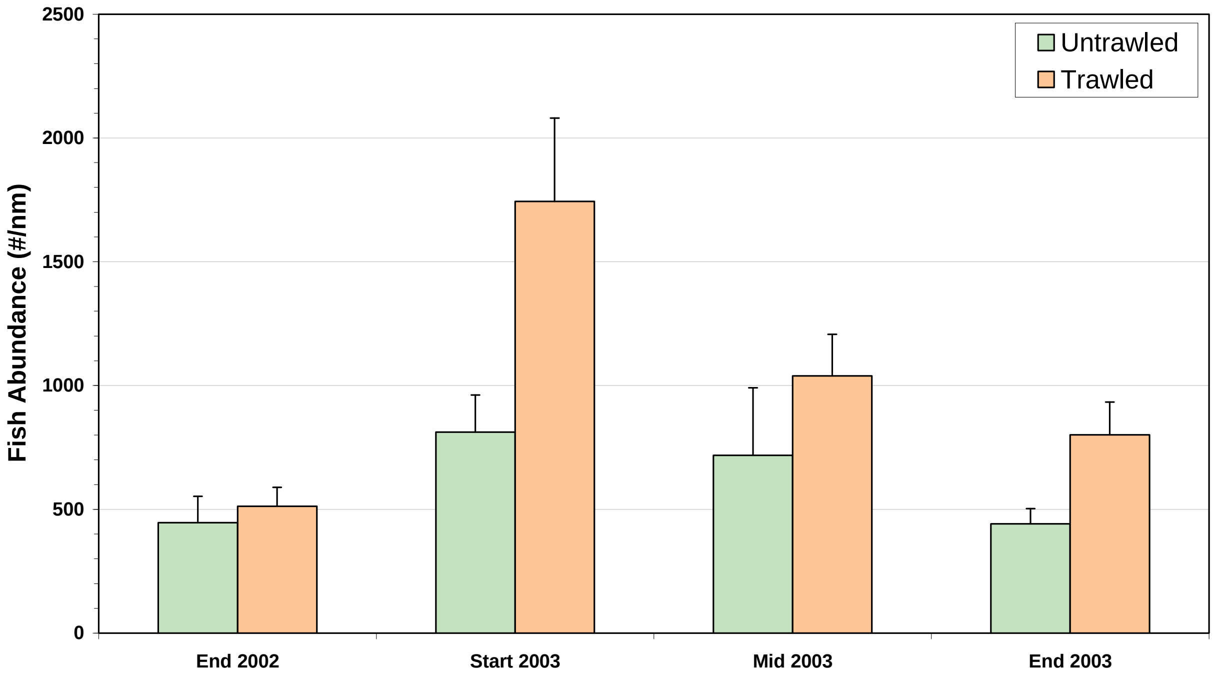

Figure 4.4 Fish abundance (+SE) in trawled and untrawled sites in Shark Bay over four seasons between 2002 and 2003.

There was a significant difference in fish abundance between the trawled and untrawled sites at start 2003 (February/March) with trawled sites having a mean abundance of around 1,743 fish per nautical mile, and the untrawled sites only 812 fish per nautical mile. Five fish species; *L. genivittatus*, *P. choirocephalus*, *P. quadrilineatus*, *T. pallimaculatus* and *U. asymmetricus* were the key species contributing to the high abundance seen on trawled sites particularly for site 20 (Figure 4.5). By mid-season (June/July) the mean abundance dropped in the trawled sites to 1039 fish per nautical mile, but only decreased slightly in the untrawled sites to 718 fish per nautical mile. At the end of the season (September/October) the trawled sites abundance dropped to 801 fish per nautical mile, and the untrawled sites to 441 fish per nautical mile. The abundance approximately halved in both the trawled and untrawled sites by the end of the trawl season. Also at the start and end of 2003 season there was a significantly higher abundance for trawled sites while no significant difference was observed for the end of 2002 nor mid 2003.

High variation in fish abundance between sites and seasons was observed (Figure 4.5). Ten sites (2, 5, 7, 8, 13, 14, 19, 20, 23, 26) show an incremental decline over the trawl season, six sites (1, 3, 4, 9, 15, 22) show a maximum abundance in the middle of the year with an overall decline by the end of the year, nine sites (6, 10, 11, 12,16, 17, 18, 24, 25) have a minimal abundance in the middle of the year with an increase at the end but not to the levels at the start of the season, and one site (21) shows a steady increase in abundance over the season. These changes would be as a result of movement between sites, responses to trawl activity, or lack of trawling and life history characteristics (see section 4.3.2).

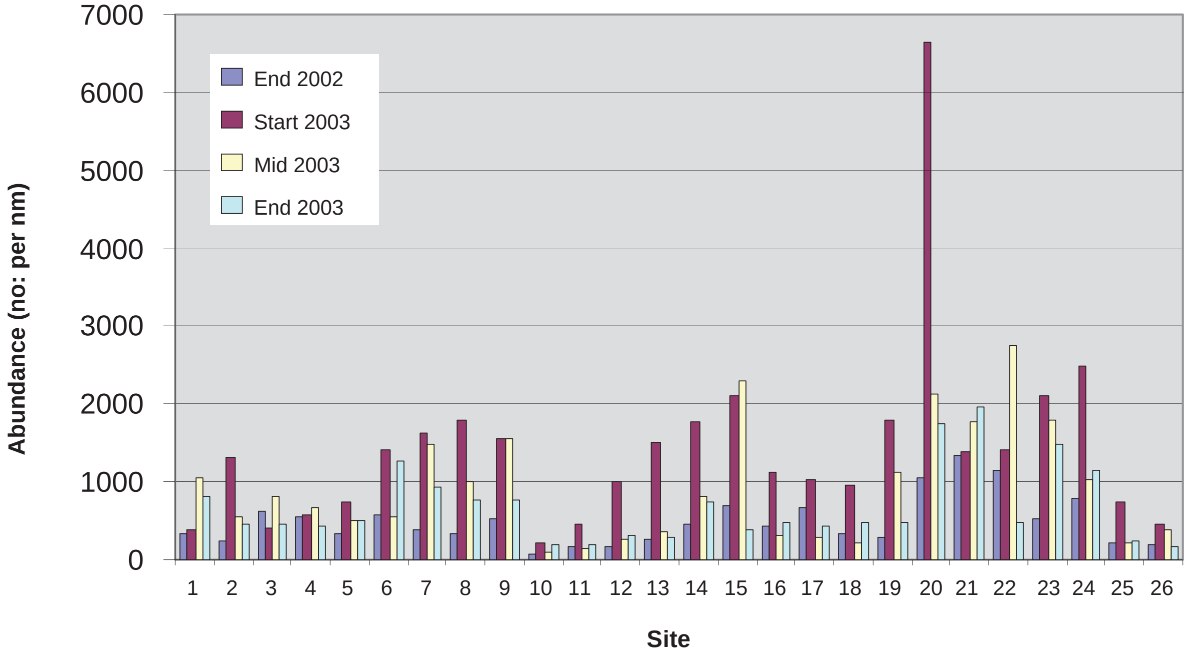

Figure 4.5 Mean fish abundance at each site in Shark Bay over four seasons in 2002 and 2003.

There was no significant seasonal difference nor year differences between end of 2002 and end of 2003 for any of the diversity measures for fish species in Shark Bay in the untrawled sites whereas there was a significant difference in the species richness ($p < 0.01$) and evenness ($p < 0.01$) for the trawled sites between the end of 2002 and start of 2003 (Figure 4.6).

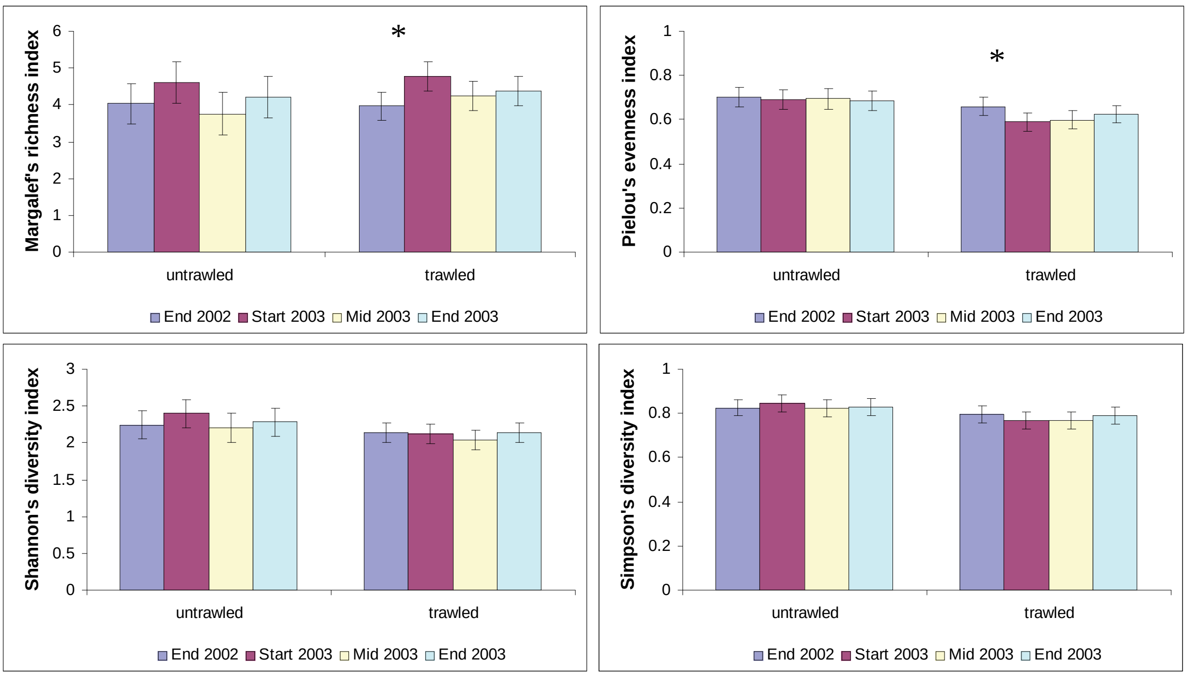

Figure 4.6 Least squares means with 95% confidence intervals for untrawled and trawled sites for each season from the fish abundances in Shark Bay; a) Margalef's richness index, b) Pielou's evenness index, c) Shannon's diversity index and d) Simpson's diversity index. * indicates a significant differences between seasons with the trawled or untrawled site groupings.

Permanovas indicated significant differences between trawled and untrawled sites between seasons (Table 4.4) but not for their interaction. The R^2 value is low indicating that site differences observed in previous analyses (Chapter 3) are likely to be more important that trawled/untrawled differences. A significant increase was observed in invertebrate abundance between end2002 and start2003 for both trawled and untrawled sites. A significant decline in abundance was then observed between start2003 and mid2003 with no further decline observed by end2003. Abundances were similar in untrawled sites between end2002 and end2003 whereas trawled sites showed higher abundance at end2003.

Table 4.4 Permanova results for invertebrate species in Shark Bay biodiversity trawls (R^2 = 0.11). Only observations for 2003 were included in this analysis. Type 3 sum of squares have been presented.

Source	df	SS	MS	Pseudo-F	P(perm)
Trawled	1	8556.4	8556.4	3.8849	< 0.01
Season	2	43803	21902	9.944	< 0.01
Trawled x Season	2	6338.9	3169.5	1.439	0.12
Residuals	209	4.60E+05	2202.5		

At the start of season, trawled sites had around 1,196 invertebrates per nautical mile and untrawled sites 552 invertebrates per nautical mile (Figure 4.7). The high abundance on trawled sites was attributed to high abundances of *A. balloti, P. latisulcatus, P. rubromarginatus* and *H. pallida*. By mid-season the abundance at the trawled sites has more than halved to 532 invertebrates per nautical mile, and the untrawled site has declined by 30% to 387 invertebrates per nautical mile. In contrast to the fish, however, these levels elevate slightly towards the end of the season to 570 in the trawled sites and 401 in the untrawled sites. The abundance at the end of season has approximately halved in the trawled sites, but reduced by only 27% in the untrawled sites.

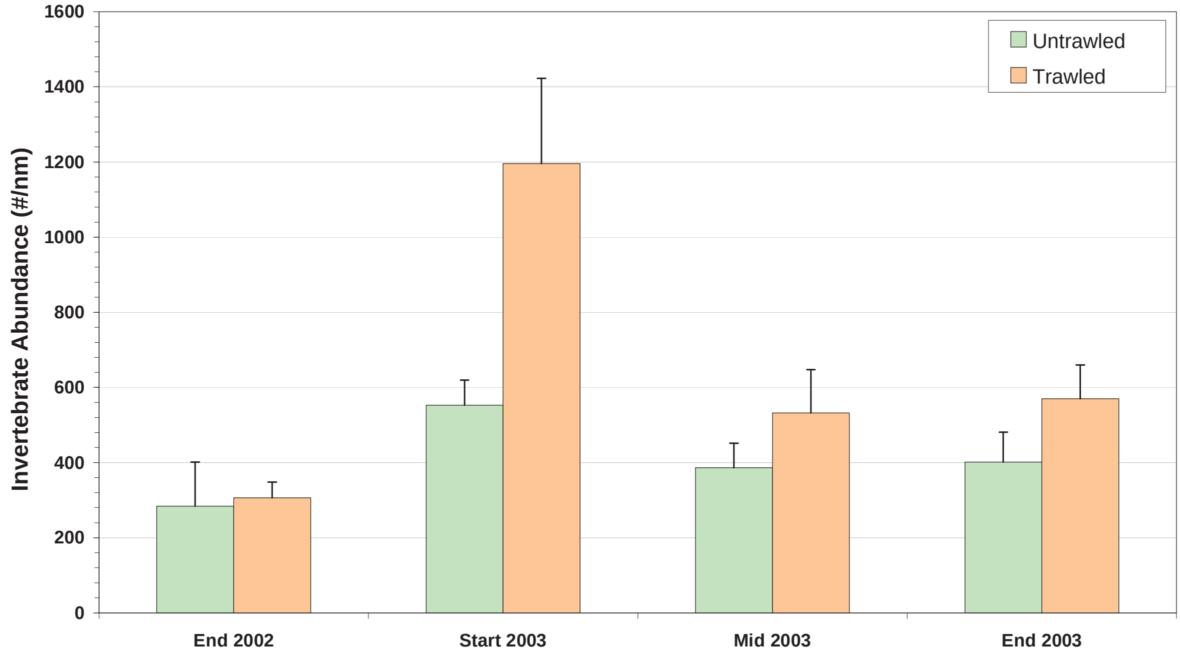

Figure 4.7 Invertebrate abundance (+S.E.) in trawled and untrawled sites in Shark Bay over four seasons in 2002 and 2003.

High variability is also observed for invertebrate abundances at different sites (Figure 4.8). An incremental seasonal decline in abundance occurs in only five sites (3, 4, 6, 7, 26), a maximum abundance in the middle of the year was recorded at three sites (1, 19, 25), eleven sites (8, 10, 11, 12, 13, 14, 18, 20, 21, 23, 24) had a have a minimal abundance in the middle of the year with an increase at the end but not to the levels at the start of the season, two sites (2, 5) showed a gradual increase in abundance with a maximum at the end of the year, and five sites (9, 15, 16, 17, 22) showed a decrease in the middle of the year, followed by an overall increase by the end of the season.

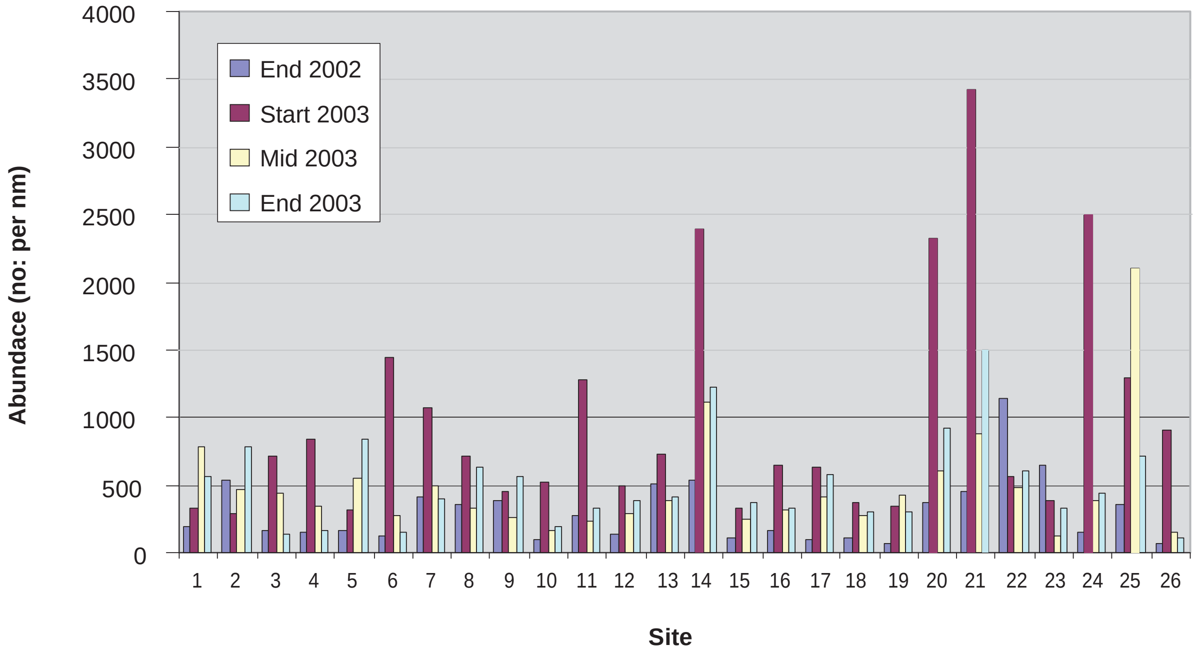

Figure 4.8 Mean invertebrate abundance at each site in Shark Bay over four seasons in 2002 and 2003.

For invertebrate species, there was a significant seasonal difference (p = 0.05) for species evenness in the untrawled sites in Shark Bay with higher richness at end2002 whereas there was a significant difference in the species richness (p < 0.01) for the trawled sites (Figure 4.9) with higher richness at end2003.

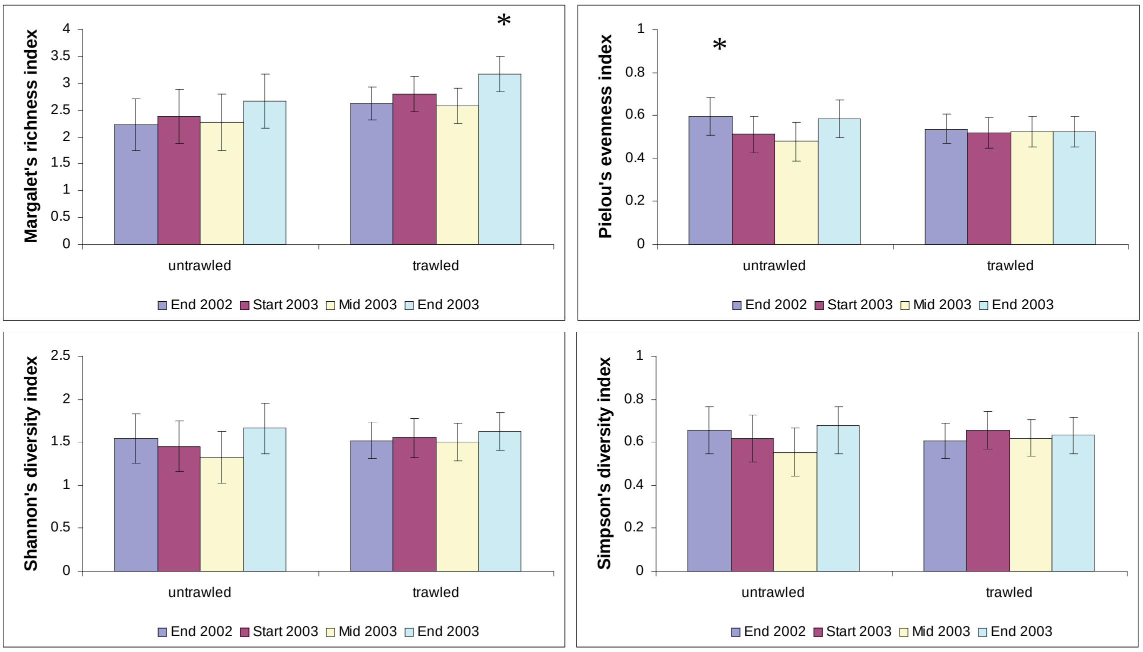

Figure 4.9 Least squares means with 95% confidence intervals for untrawled and trawled sites for each season from the fish abundances in Shark Bay; a) Margalef's richness index, b) Pielou's evenness index, c) Shannon's diversity index and d) Simpson's diversity index. * indicates a significant differences between seasons with the trawled or untrawled site groupings.

4.3.2 Spatial and temporal variation of some species in Shark Bay

The spatial distribution and abundance of a selection of some of the more abundant fish and invertebrate species caught as bycatch in Shark Bay were looked at in detail. The selected species illustrate the variability in seasonal abundance and distribution. The nine fish and 12 invertebrate species are as follows:

Hair-finned Leatherjacket (Paramonacanthus choirocephalus) (Figure 4.10)

Paramonacanthus choirocephalus was the most abundant species of fish in Shark Bay and was found at all survey sites. It was abundant at all sites except for the deep sites 10 and 11 (48 to 52 metres depth) near Quobba, and site 22 rich in *A. antarctica* in the central west region. At site 22 *C. paxmani* has replaced *P. choirocephalus* as the most abundant species. *Paramonacanthus choirocephalus* was more abundant in the central northern sites, where it was most numerous at the start of the season, and it declines in abundance towards the end of the season. In the southwest and southeastern sites it was generally most abundant in the middle of the year. This may indicate southerly movement of individuals from the northern sites and/or depletion at the northern sites particularly in the first part of the season.

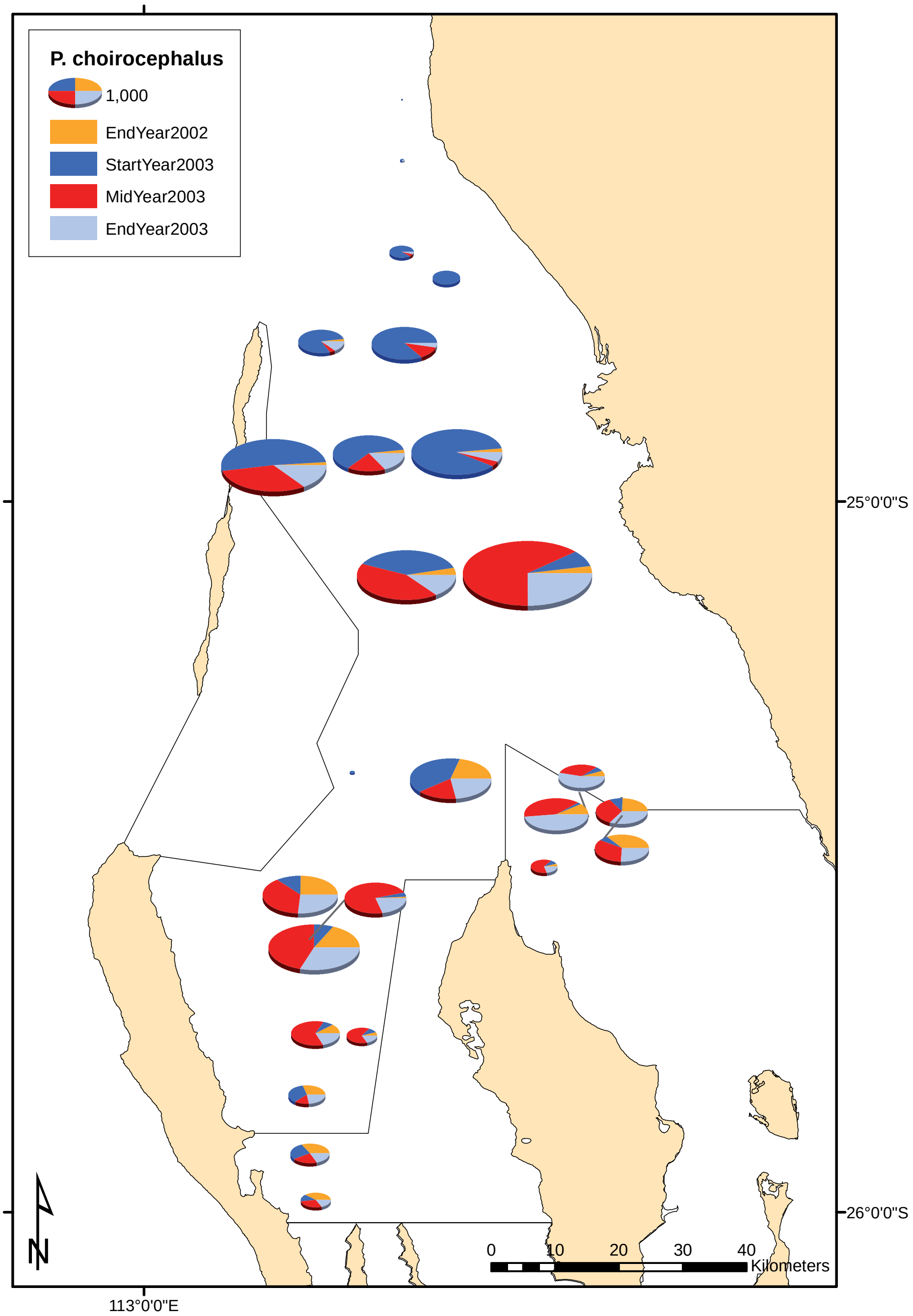

Figure 4.10 Seasonal and spatial distribution of *Paramonacanthus choirocephalus* in Shark Bay during end of 2002 and 2003 sampling periods.

Asymmetrical goatfish (Upeneus asymmetricus) (Figure 4.11)

Upeneus asymmetricus was the second most abundant species of fish, and was also found at all survey sites in Shark Bay. It occurs in reasonable abundance at all sites except for the deep site 10 in the extreme north. In the northern prawn trawl grounds the numbers decline through the year, but at most other sites the abundance remains fairly even and at some sites numbers increase towards the end of the season. Such steady abundance indicates that this species thrives in this trawled habitat and is likely to have a self-sustaining population within Shark Bay.

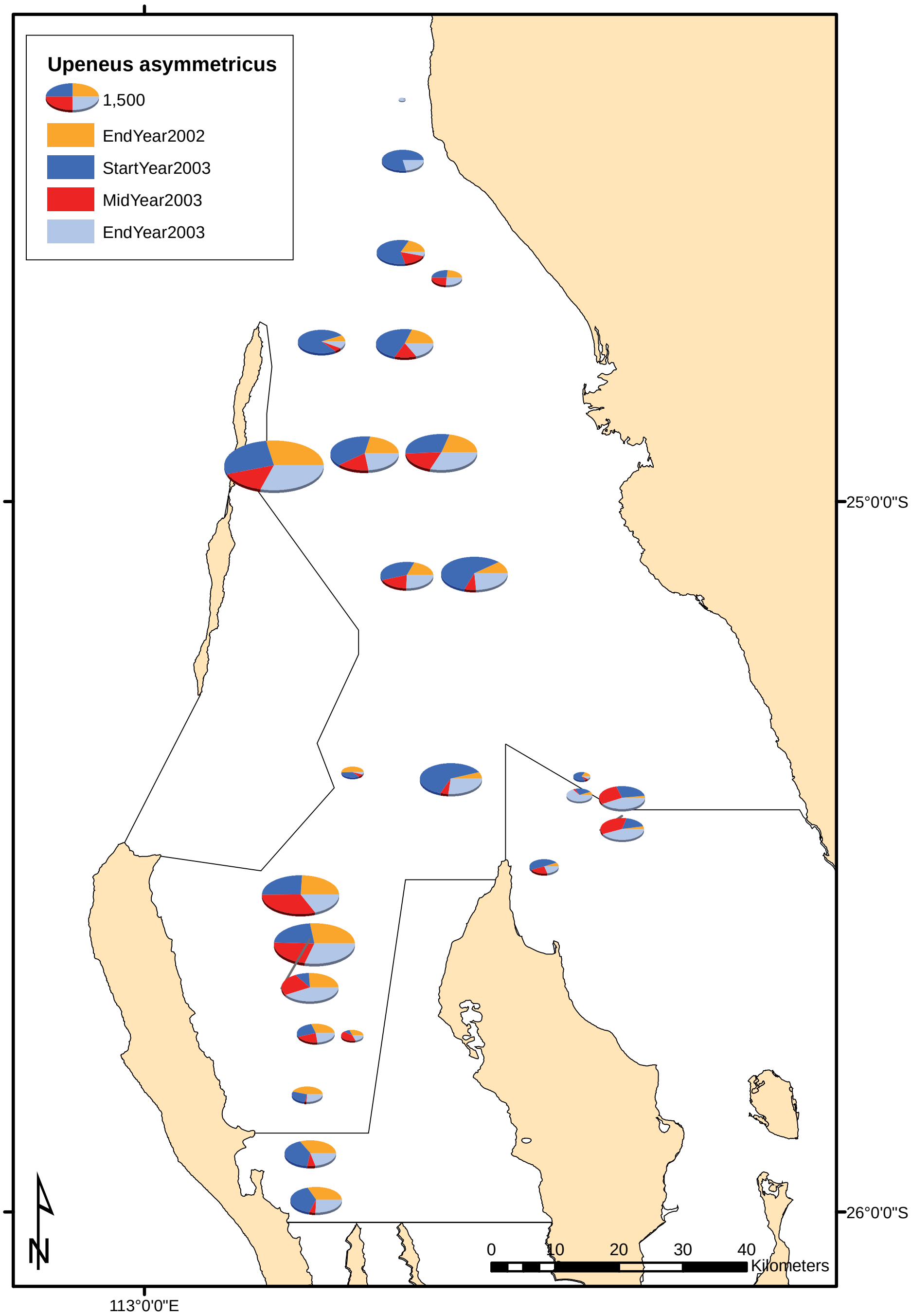

Figure 4.11 Seasonal and spatial distribution of *Upeneus asymmetricus* in Shark Bay during end of 2002 and 2003 sampling periods.

Large-scaled lizardfish (Saurida undosquamis) (Figure 4.12)

Saurida undosquamis was the twelfth most abundant species of fish in Shark Bay, and was abundant at all sites except for site 22 where dense *A. antarctica* occurs. Generally there was a decline in abundance at all sites throughout the season. Similar to *U. asymmetricus*, *S. undosquamis* was likely to have a self-sustaining population within Shark Bay.

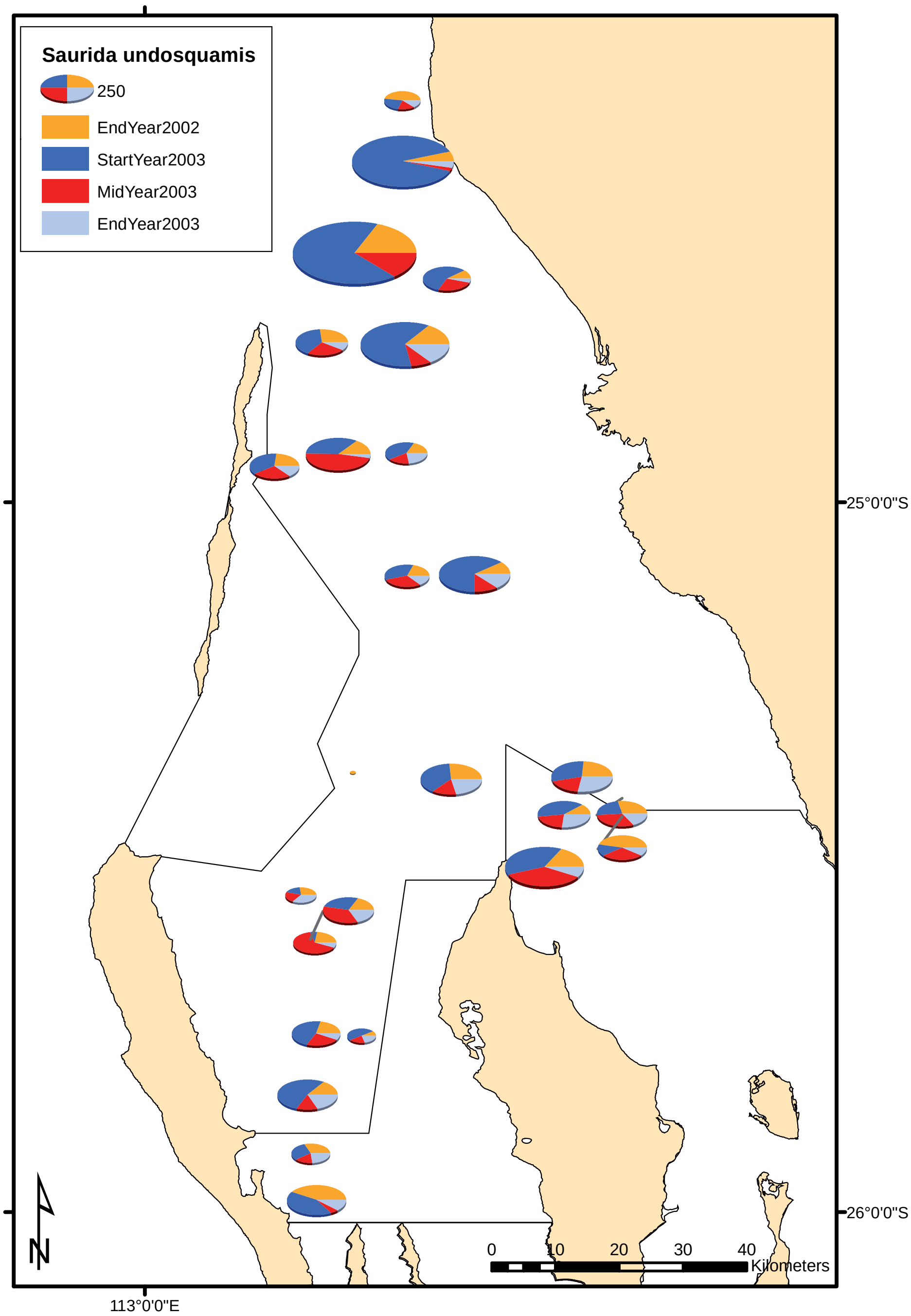

Figure 4.12 Seasonal and spatial distribution of *Saurida undosquamis* in Shark Bay during end of 2002 and 2003 sampling periods.

Bullrout (Paracentropogon vespa) (Figure 4.13)

Paracentropogon vespa was the sixth most abundant fish species in Shark Bay, but was not found in any of the northern sites (10, 11, 12, 25, 26). Abundance at the remaining sites was variable with the greatest abundance in the southern Gulfs, particularly the eastern Gulf . Large annual differences at the end of season were observed.

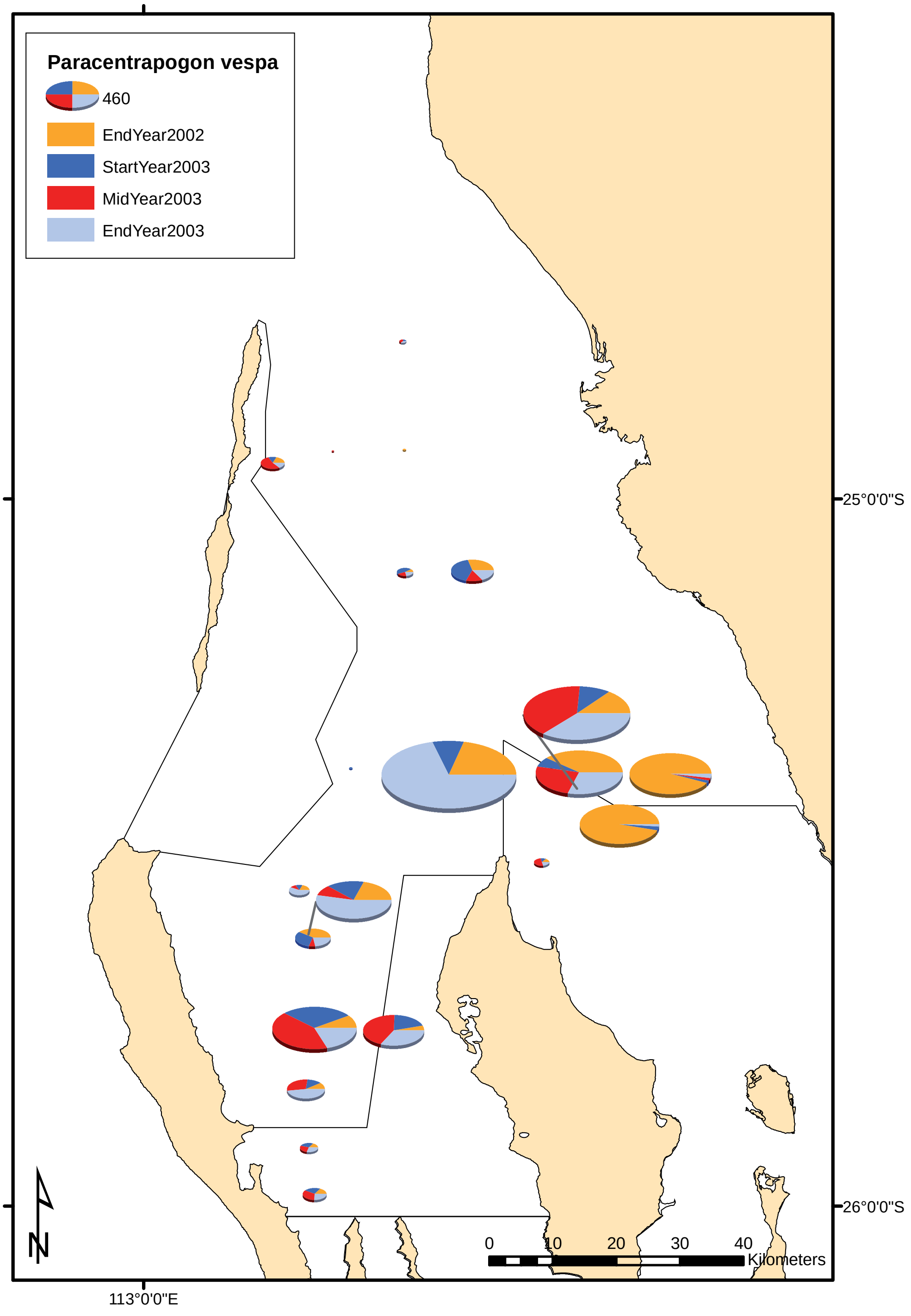

Figure 4.13 Seasonal and spatial distribution of *Paracentropogon vespa* in Shark Bay during end of 2002 and 2003 sampling periods.

Trumpeter (Pelates quadrilineatus) (Figure 4.14)

Pelates quadrilineatus was the third most abundant fish species in Shark Bay, and although it was found at all survey sites, it was only abundant in trawl sites in Denham Sound, one site (9) in the central prawn trawl grounds and in moderate abundance in the eastern Gulf. In the southern reaches of Shark Bay it was extremely abundant at the start of the season, then abundance declined at most sites by mid-year. At site 9 it was only abundant in the middle of the year.

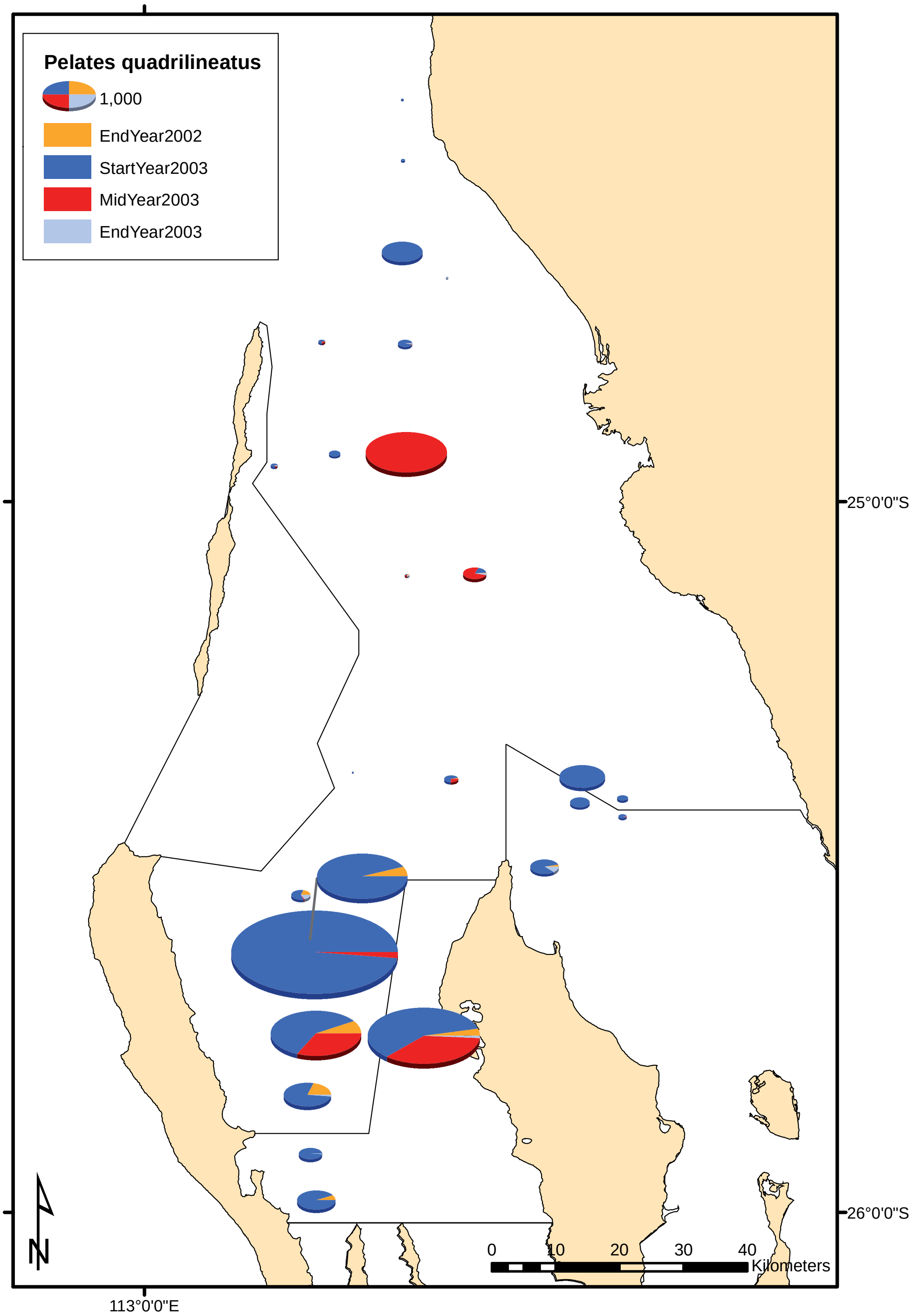

Figure 4.14 Seasonal and spatial distribution of *Pelates quadrilineatus* in Shark Bay during end of 2002 and 2003 sampling periods.

Western Australian butterfish (Pentapodus vitta) (Figure 4.15)

Pentapodus vitta was the ninth most abundant trawl bycatch fish species in Shark Bay. It is the third most frequently caught recreational species in Shark Bay (Mant 2000). It was found at all sites except for the six most northerly sites. It was most abundant in Denham Sound where there was a marked decline in abundance in the southern sampling sites during the season. At the eastern gulf sites there was an increase in abundance in the middle of the season.

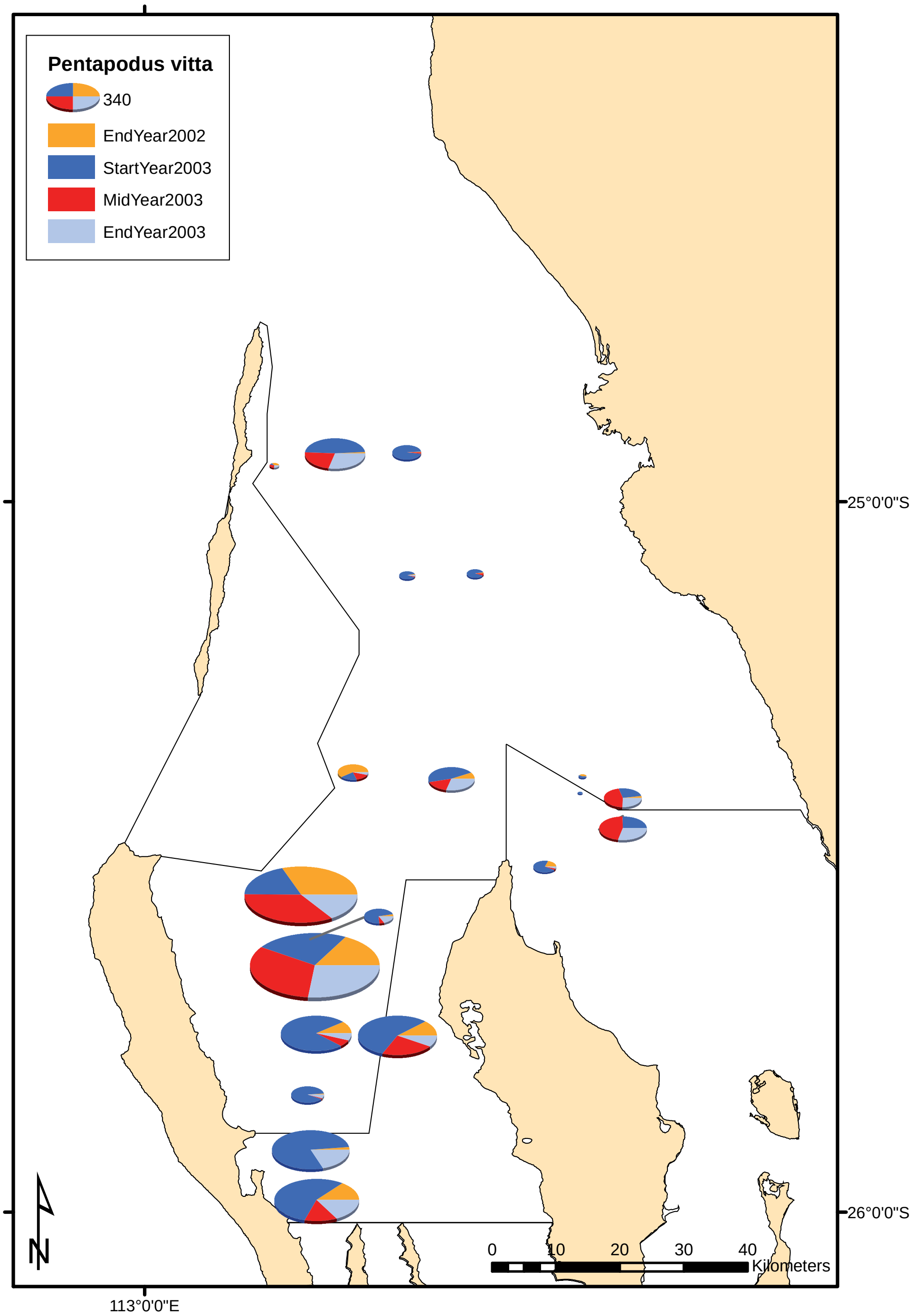

Figure 4.15 Seasonal and spatial distribution of *Pentapodus vitta* in Shark Bay during end of 2002 and 2003 sampling periods.

Threadfin emperor (Lethrinus genivittatus) (Figure 4.16)

Lethrinus genivittatus was the fourth most abundant fish species in Shark Bay, but was absent from site 10 in the north of the region, and sites 1, 2 and 5 in the eastern Gulf. It has a very uneven distribution of abundance with extremely high abundance in the northern and southern parts of the scallop trawl grounds in the central and western regions, but low abundance at all other sites. The abundance shows a slight decline during the year, with maximum numbers in the middle of the year. High annual variation was evident with very low abundance in end of season 2002 compared to 2003.

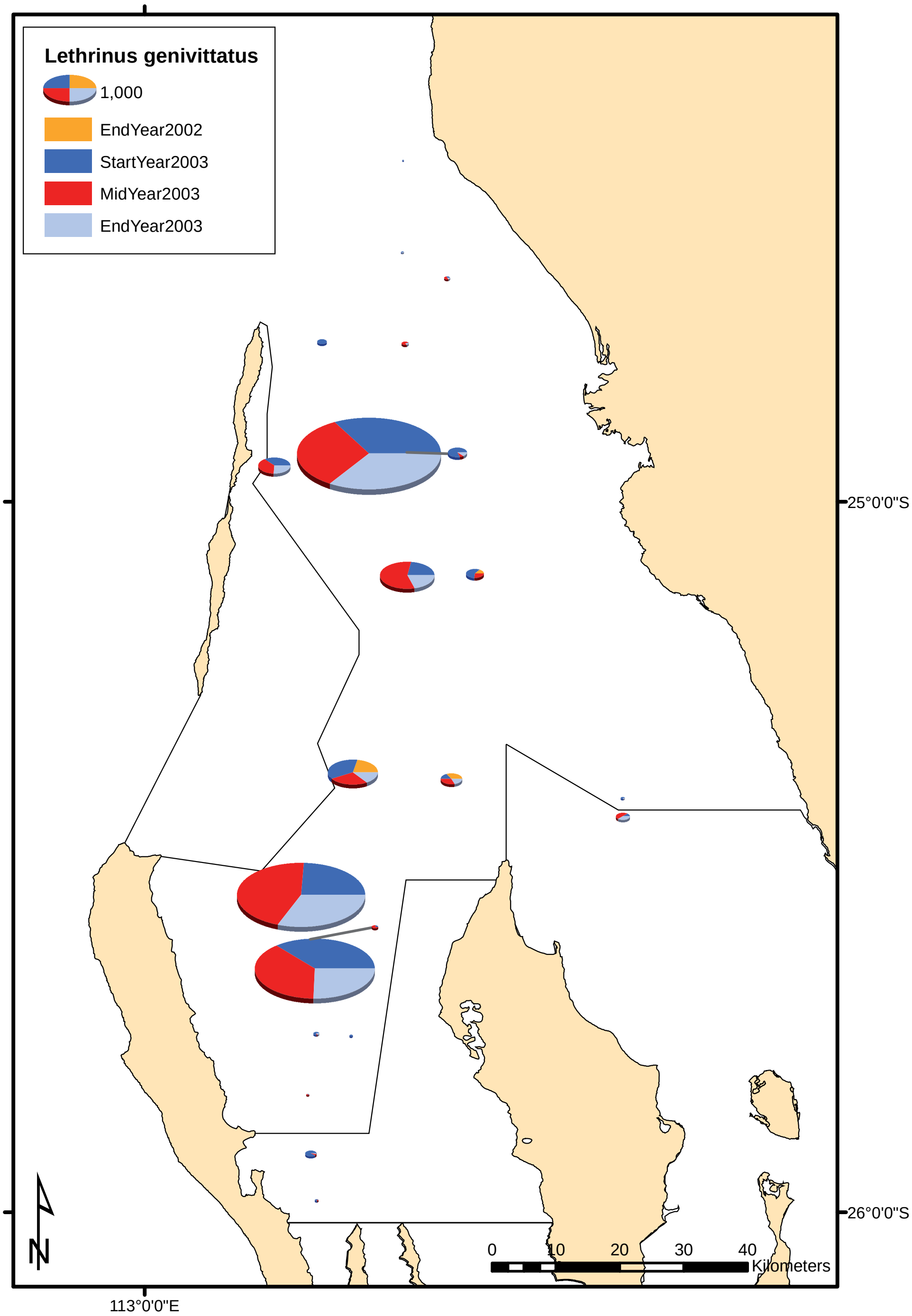

Figure 4.16 Seasonal and spatial distribution of *Lethrinus genivittatus* in Shark Bay during end of 2002 and 2003 sampling periods.

Purple tuskfish (Choerodon cephalotes) (Figure 4.17)

Choerodon cephalotes was not among the 20 most abundant fish species in Shark Bay, but was widespread, occurring at all sites except the seven most northerly sites. It has maximum abundance in Denham Sound, east of Bernier Island, and moderate abundance in the eastern Gulf. It shows a marked decline in abundance during the trawl season. It also shows a variable distribution pattern between years.

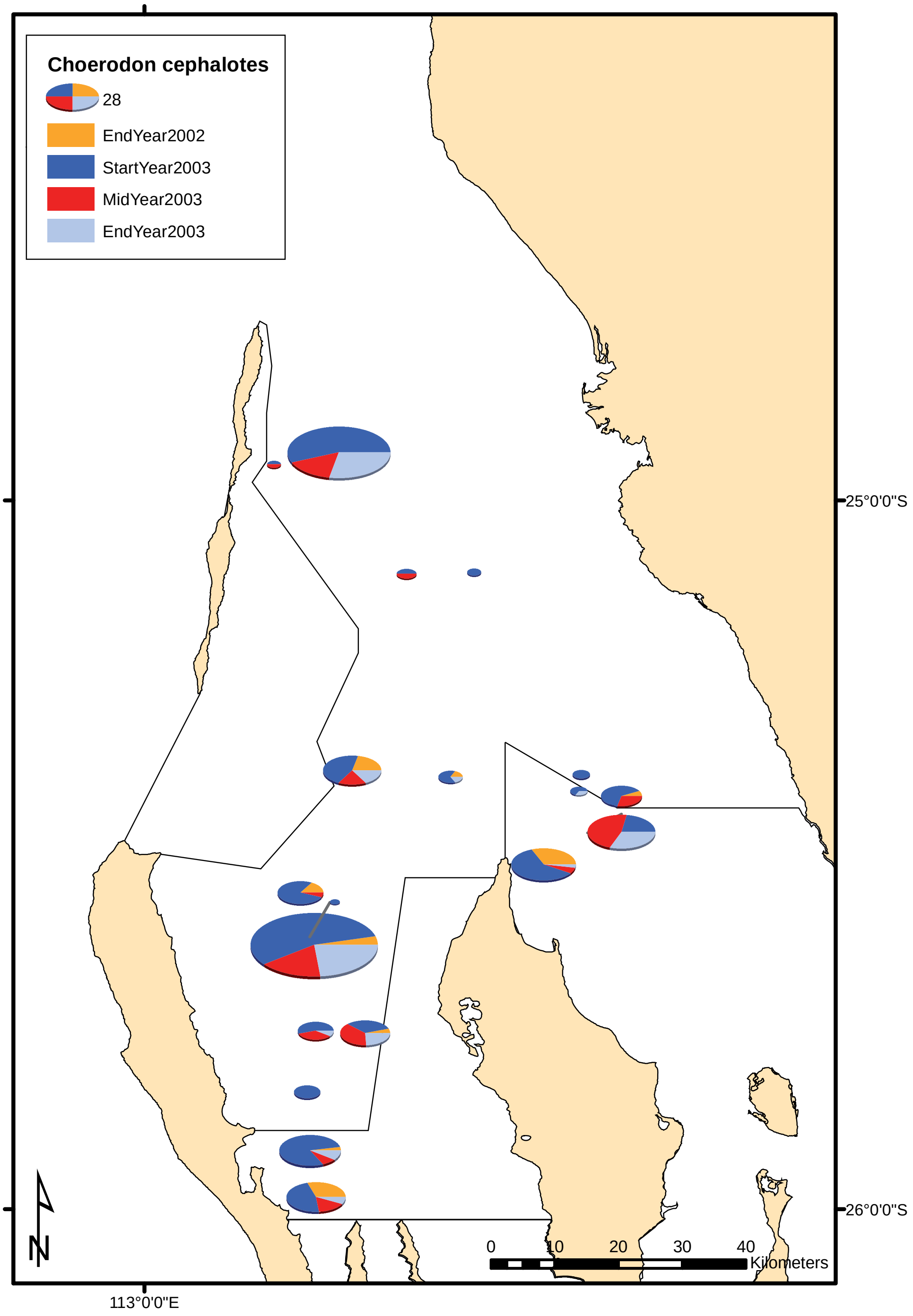

Figure 4.17 Seasonal and spatial distribution of *Choerodon cephalotes* in Shark Bay during end of 2002 and 2003 sampling periods.

Yellow-striped goatfish (Parupeneus chrysopleuron) (Figure 4.18)

Like *C. cephalotes*, *P. chrysopleuron* was not among the 20 most abundant fish species in Shark Bay, but was relatively widespread. It was absent from all sites in the eastern Gulf and three sites in Denham Sound. It has maximum abundance in northern Denham Sound and east of Bernier Island which are primarily scallop trawl grounds. The seasonal pattern of abundance varies in different regions.

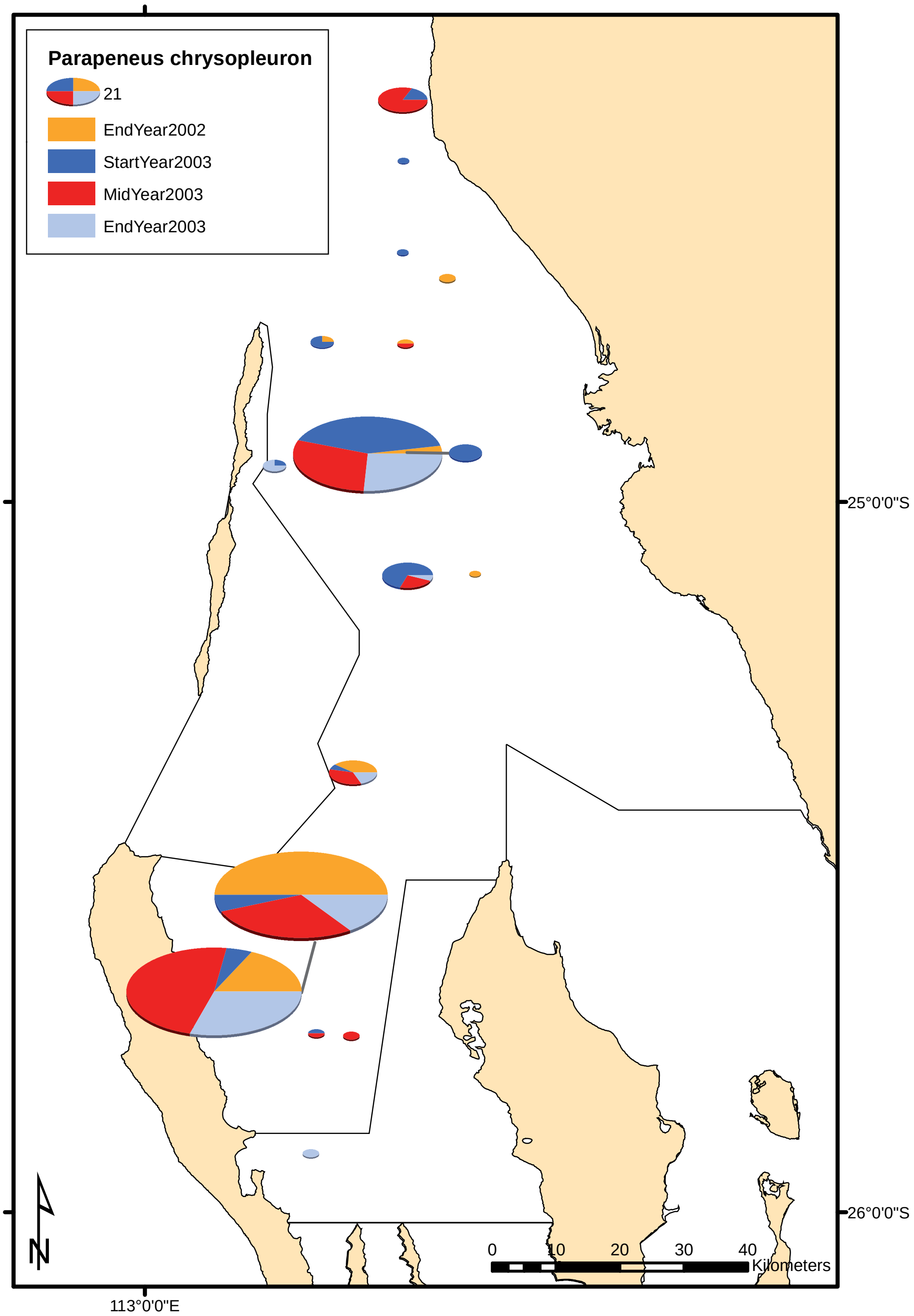

Figure 4.18 Seasonal and spatial distribution of *Parupeneus chrysopleuron* in Shark Bay during end of 2002 and 2003 sampling periods.

Coral prawn (Metapenaeopsis species) (Figure 4.19)

Coral prawns include several species, but as a group they were the most abundant genus of invertebrates in Shark Bay, and were found at all survey sites. They were highly abundant in the northern regions of Shark Bay, and less abundant in the southern and eastern Gulfs. At three northern sites (10, 11, 26) the abundance declines throughout the year, at sites 12 and 13 there was a gradual increase during the year, at the remaining northern sites there was an increase in the middle of the year with an overall decline by the end of the year. In Denham Sound there was an increase in abundance by the end of the year. At some sites in central Shark Bay coral prawns catches were not made for all seasons.

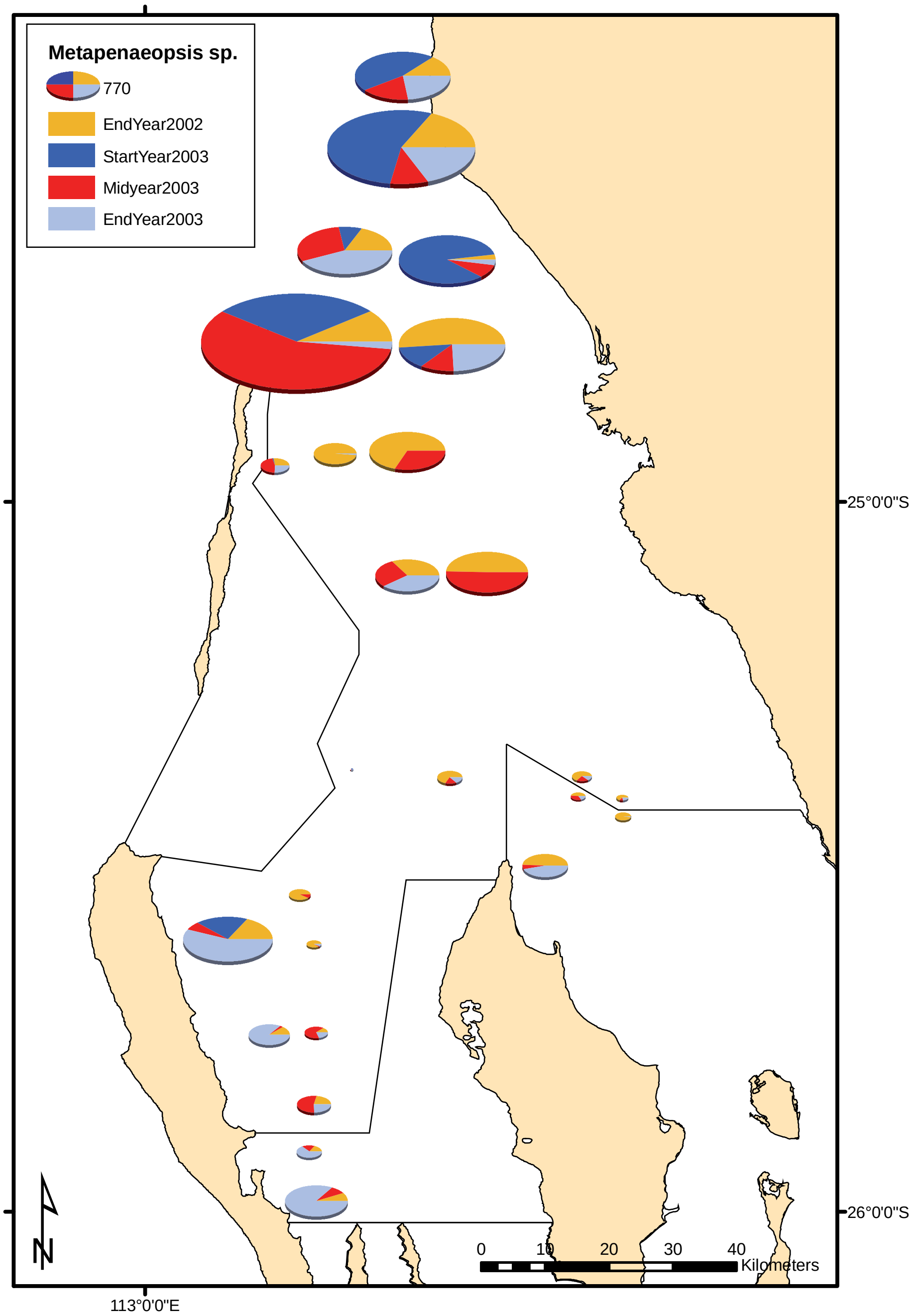

Figure 4.19 Seasonal and spatial distribution of *Metapenaeopsis* species in Shark Bay during end of 2002 and 2003 sampling periods.

Western king prawn (Penaeus latisulcatus) (Figure 4.20)

Penaeus latisulcatus was the third most abundant invertebrate species in Shark Bay, and was abundant at all sites, except for sites 22 and 23. There was generally a higher abundance at the start of the season, with a decline during the year due to trawling (and capture and retention of prawns by fishers) and migration. There was a continuous migration of recruits out of the eastern gulf and Denham Sound, which maintains a relatively high abundance in the middle of the year in these areas, but with a subsequent decline at the end of the season. Some annual variability was seen in abundances with abundances slightly higher at the end of 2002 compared to 2003.

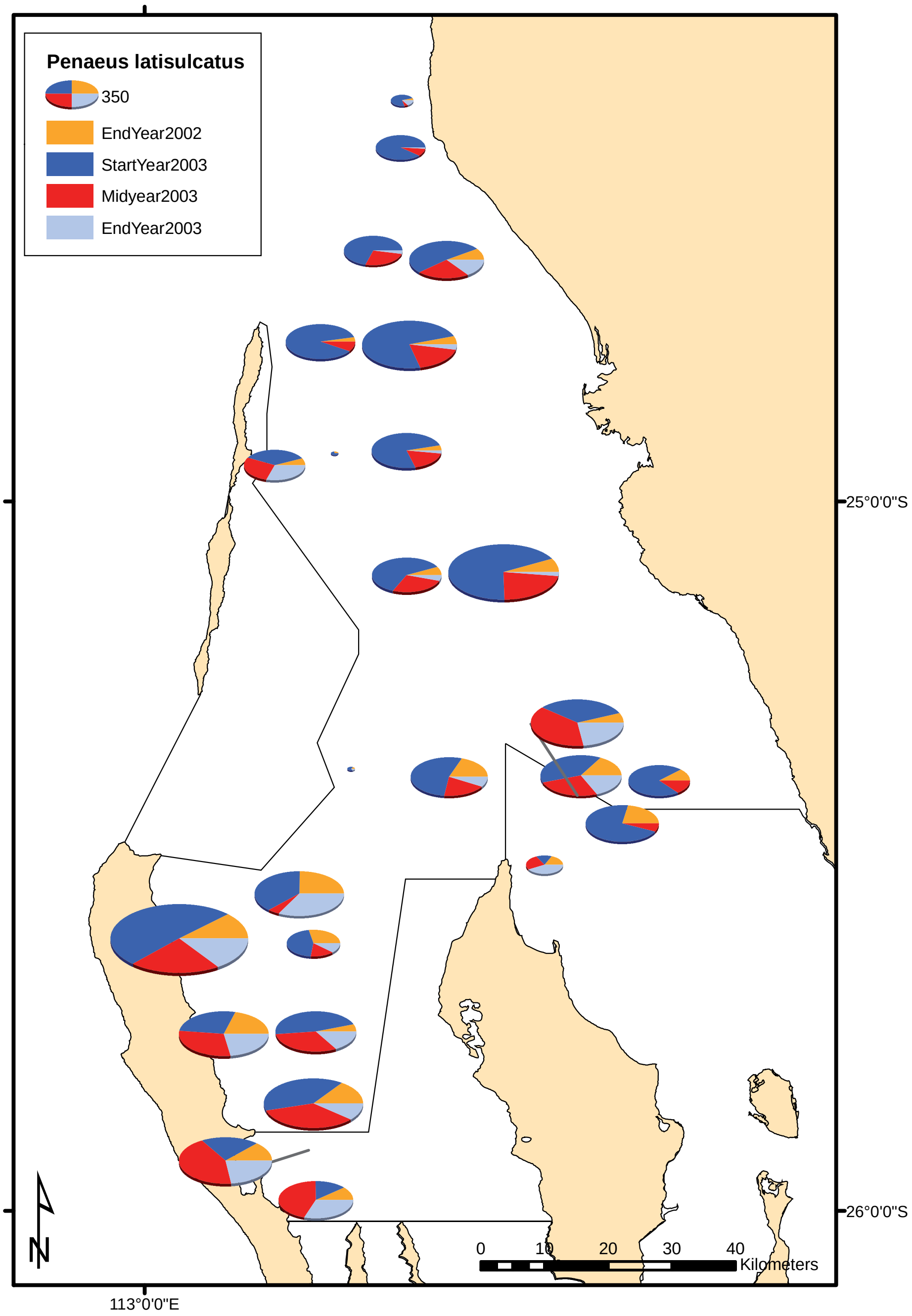

Figure 4.20 Seasonal and spatial distribution of *Penaeus latisulcatus* in Shark Bay during end of 2002 and 2003 sampling periods.

Brown tiger prawn (Penaeus esculentus) (Figure 4.21)

Penaeus esculentus was the sixth most abundant invertebrate species in Shark Bay, and was found at all sites except for two sites east of Bernier Island, and site 22 in the central west. It was most abundant in the northern part of Shark Bay, eastern Gulf and moderately abundant in Denham Sound. In the northern sites, central Denham Sound and sites 3 and 4 in the eastern Gulf the abundance declines markedly during the year. The remaining eastern Gulf sites show an increase in abundance by the end of the year. Site 2 has particularly high abundance but Fisheries survey records show that prawn abundances can be highly variable between years. Brown tiger prawns as well as king prawns are known to migrate north into the central grounds during the year (Penn 1980).

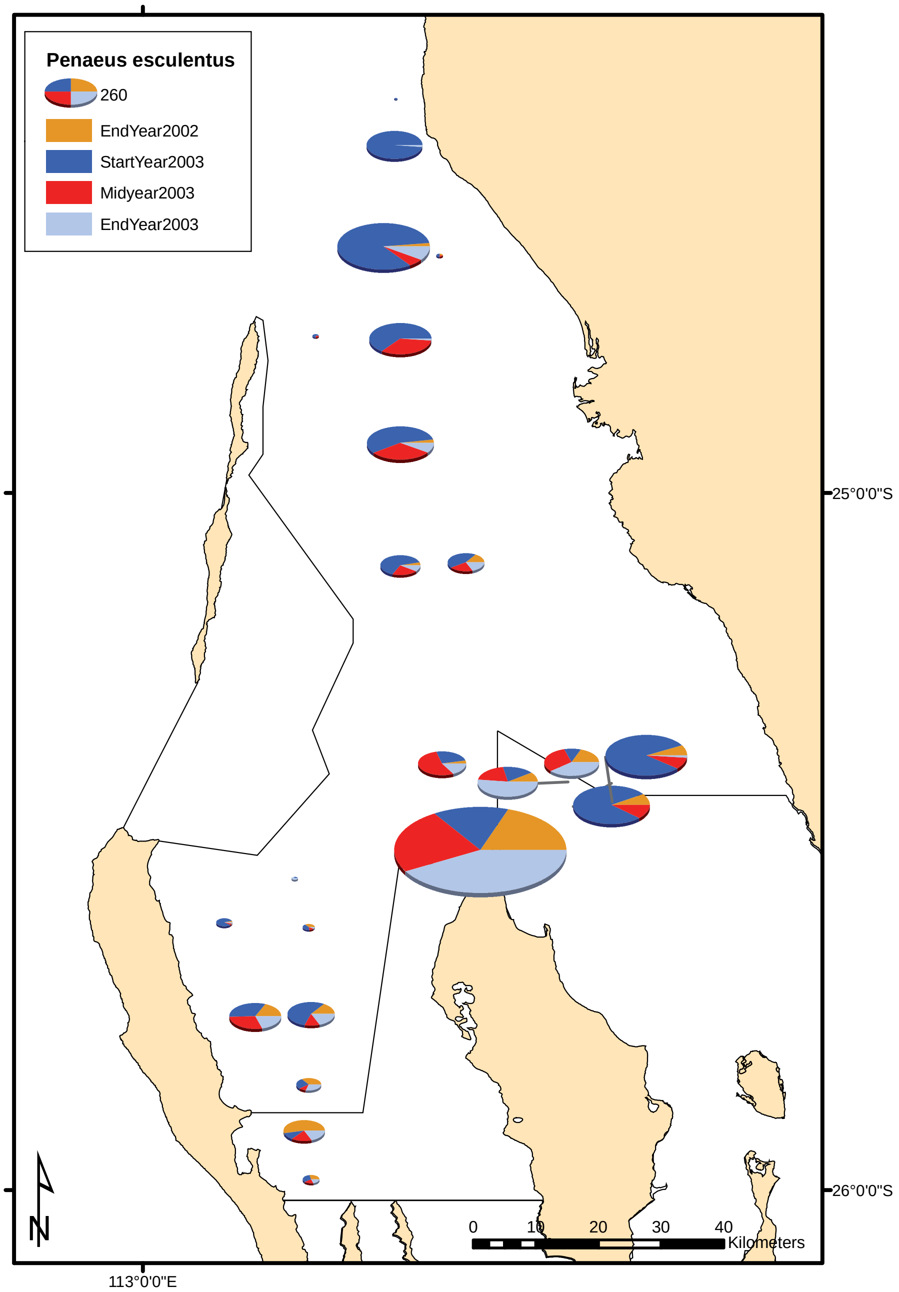

Figure 4.21 Seasonal and spatial distribution of *Penaeus esculentus* in Shark Bay during end of 2002 and 2003 sampling periods.

Blue swimmer crab (Portunus pelagicus) (Figure 4.22)

Portunus pelagicus is targeted by commercial crab pot fishers in Shark Bay as well as being a recreationally important species and incidentally caught (and some retained) by scallop and prawn trawlers. *Portunus pelagicus* was the fifth most abundant invertebrate species in Shark Bay, and was found at all sites. It was most abundant in the central and eastern parts of Shark Bay. In the central regions it was most abundant at the start of the year and declined markedly by end 2003, but in the eastern gulf it was generally most abundant in the middle of the year with an overall decline by the end of the year.

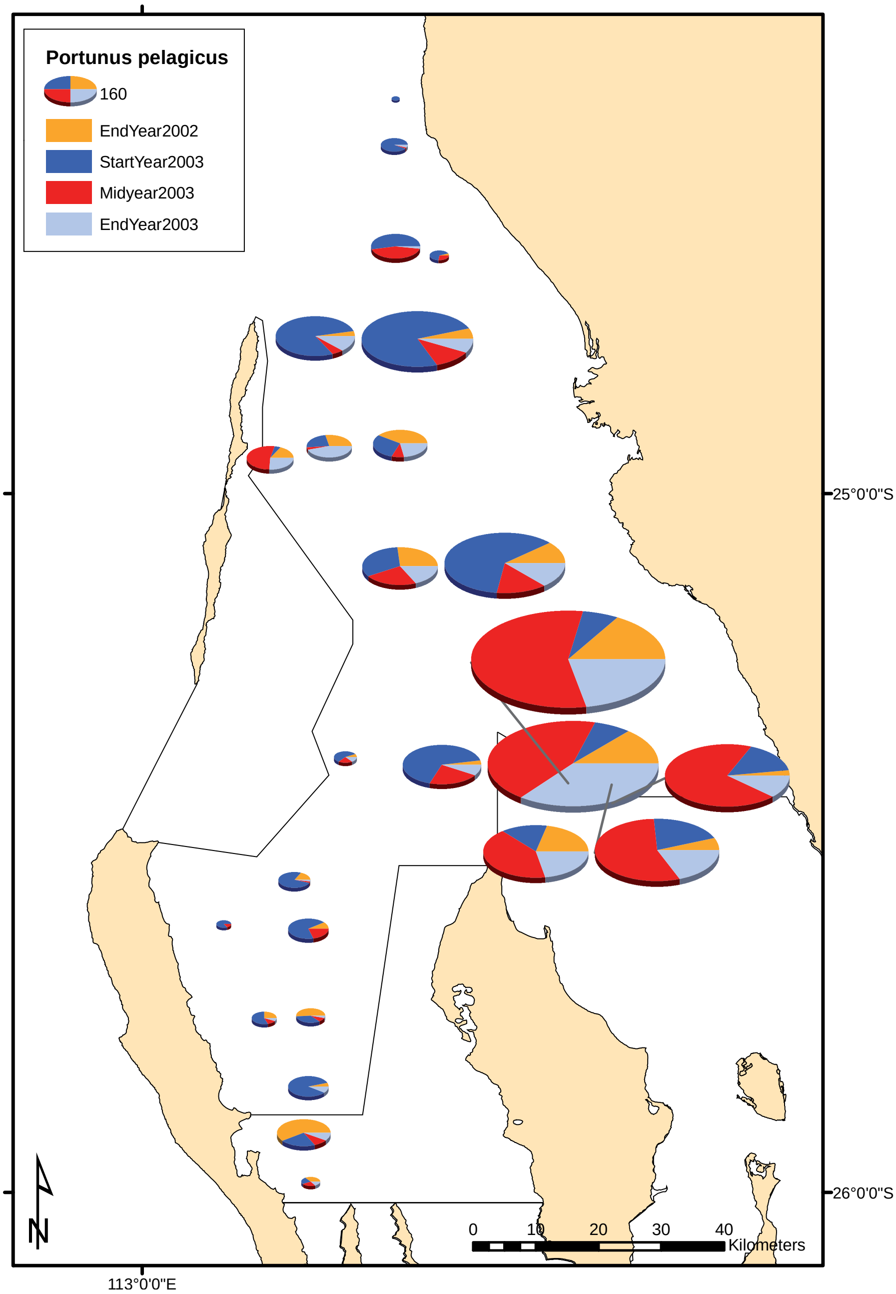

Figure 4.22 Seasonal and spatial distribution of *Portunus pelagicus* in Shark Bay during end of 2002 and 2003 sampling periods.

Saucer scallop (Amusium balloti) (Figure 4.23)

Amusium balloti was the second most abundant invertebrate species in Shark Bay, and was found at all sites except for four in the eastern Gulf and four in the most northern regions. It was particularly abundant in the western reaches of Shark Bay and in Denham Sound which are traditional scallop trawl grounds. Abundance was high at the start of the season at all sites with a marked decline throughout the year. This species experiences high annual variation in recruitment due to environmental factors (Joll and Caputi 1995) which is in turn, reflected in highly variable fishing effort between years.

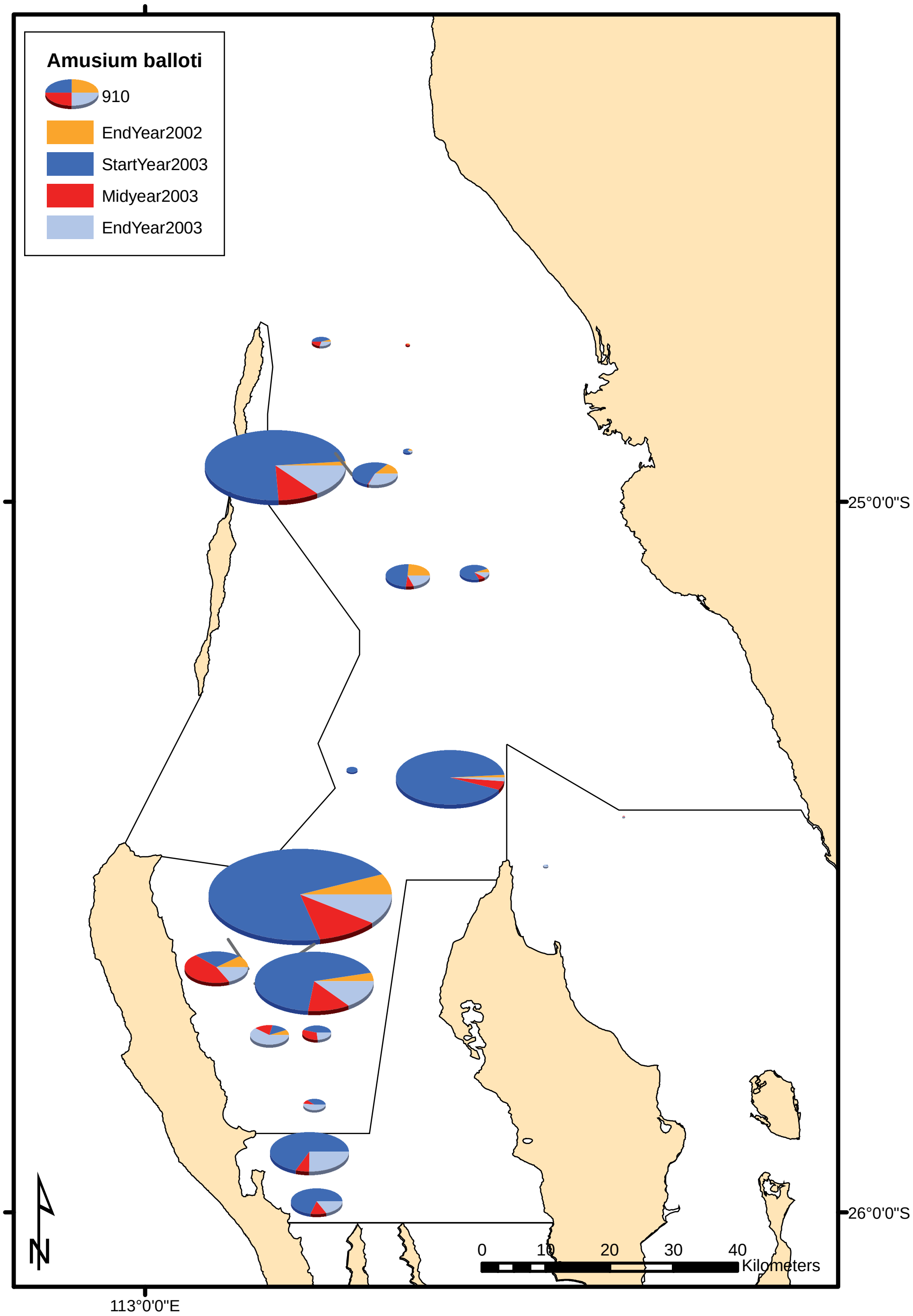

Figure 4.23 Seasonal and spatial distribution of *Amusium balloti* in Shark Bay during end of 2002 and 2003 sampling periods.

Fan scallop (Annachlamys flabellata) (Figure 4.24)

Annachlamys flabellata was the fourth most abundant invertebrate species in Shark Bay, and was found at all sites except for one site in the eastern Gulf and two sites at the north end of Shark Bay. The greatest abundance was in Denham Sound with very low abundance at all other sites. Most sites show a decline by mid-year, but with some showing an overall increase by the end of the year.

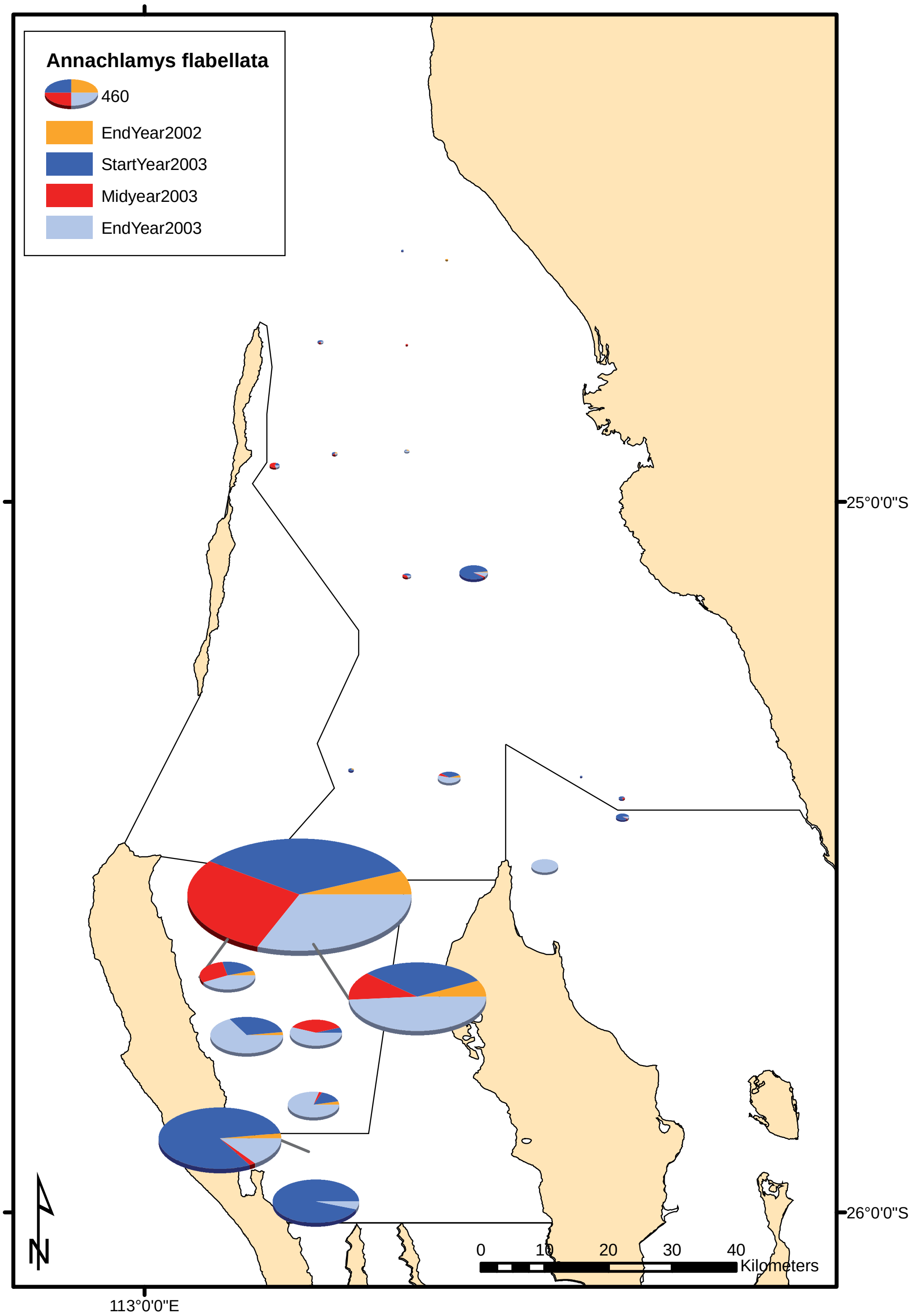

Figure 4.24 Seasonal and spatial distribution of *Annachlamys flabellata* in Shark Bay during end of 2002 and 2003 sampling periods.

Sea slug (Philine species) (Figure 4.25)

Philine species was the twelfth most abundant invertebrate species in Shark Bay, and was found at all sites except for one in the central prawn trawl grounds, and four at the northern end of Shark Bay. It was most abundant in the eastern Gulf with moderate abundance in Denham Sound, but very low abundance at all other sites. The species was most abundant at sites at the end of 2003 and indicated high annual variability.

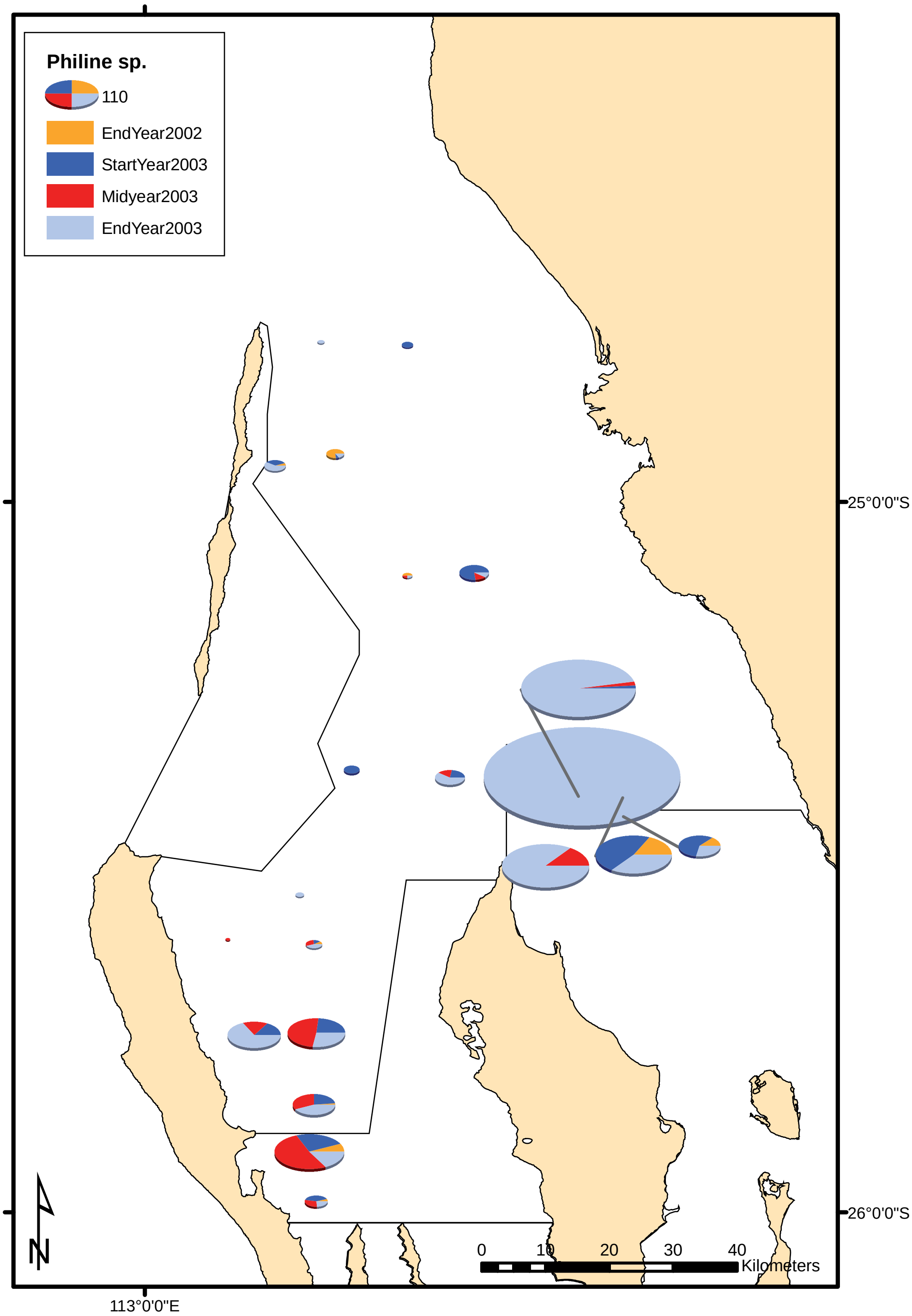

Figure 4.25 Seasonal and spatial distribution of *Philine* species in Shark Bay during end of 2002 and 2003 sampling periods.

Squid (Photololigo species) (Figure 4.26)

Photololigo species was not among the 20 most abundant species of invertebrates in Shark Bay, but was widespread, occurring at all sites. It was highly abundant in the northern sites at the start of 2003 only, moderately abundant in the eastern Gulf and in low abundance at all other sites. This was possibly because this is a highly mobile species and consequently the low catches or lack of catches during the middle and end of year could be because they have migrated elsewhere.

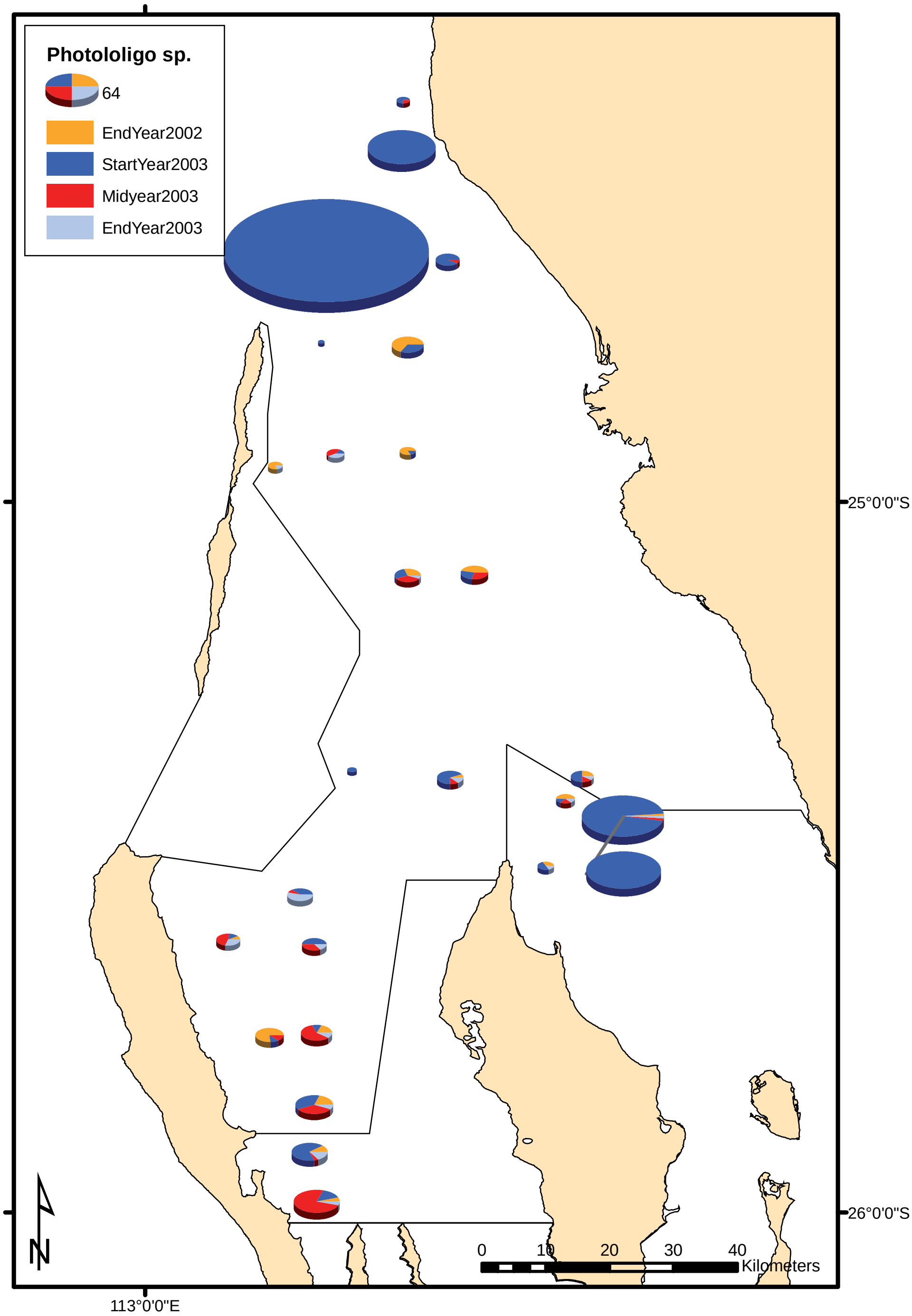

Figure 4.26 Seasonal and spatial distribution of *Photololigo* species in Shark Bay during end of 2002 and 2003 sampling periods.

Holothurian (Colochirus quadrangularis) (Figure 4.27)

Colochirus quadrangularis was the fifteenth most abundant invertebrate species in Shark Bay, but has an extremely patchy distribution and abundance pattern. It was present at 18 sites, but was absent from two sites in Denham Sound, two sites east of Bernier Island, and four sites at the northern end of Shark Bay. It was only highly abundant at one untrawled site (22) in the central west, which was site with dense meadows of *A. antarctica* on which it was attached. At this site high annual variation was observed.

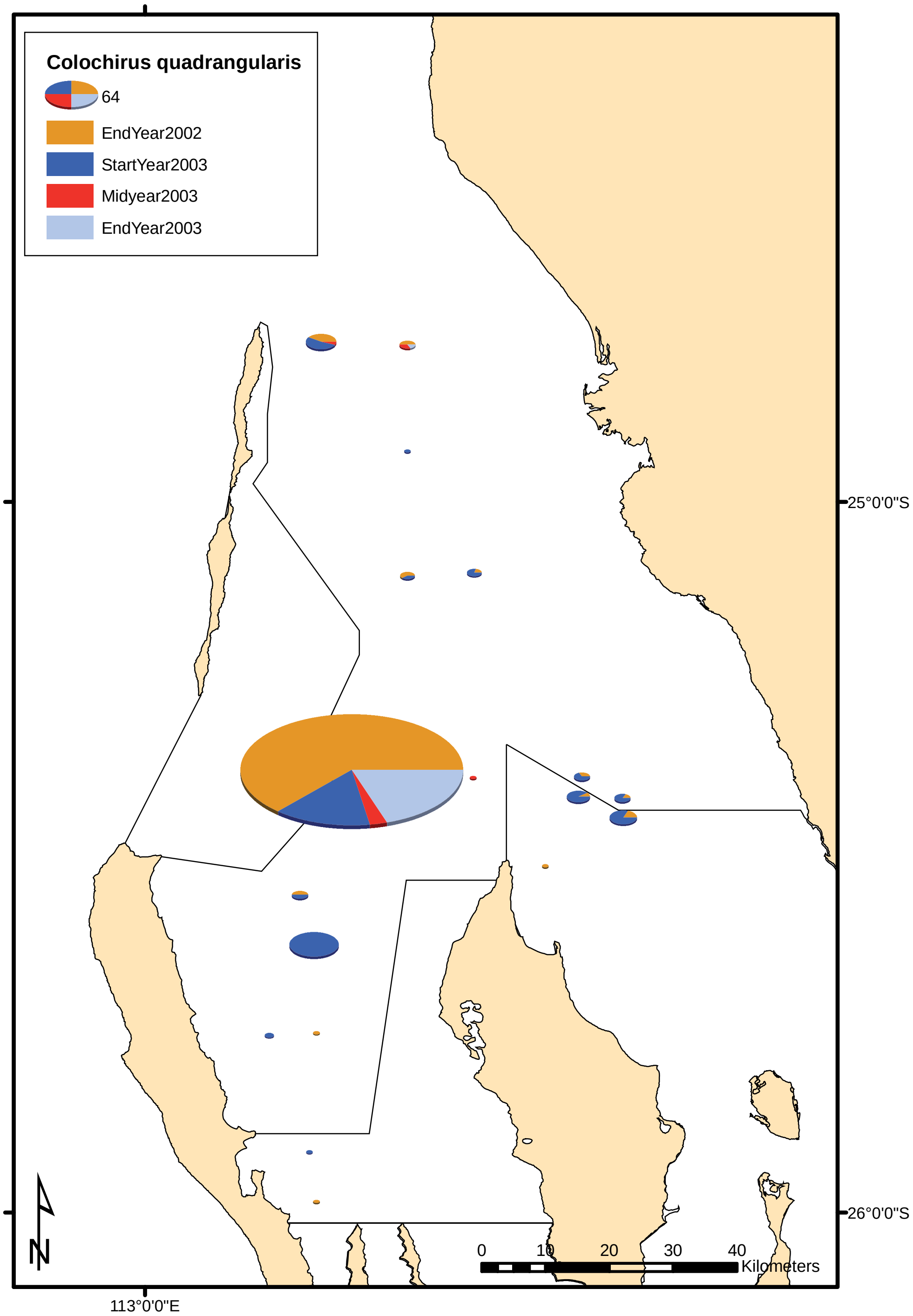

Figure 4.27 Seasonal and spatial distribution of *Colochirus quadrangularis* in Shark Bay during end of 2002 and 2003 sampling periods.

Holothurian (Colochirus crassus) (Figure 4.28)

Colochirus crassus was the eighteenth most abundant invertebrate species in Shark Bay, and was extremely widespread, being found at all sites. Unlike *C. quadrangularis*, this species was moderately abundant at most sites. It was highly abundant at site 22 but was only found in high numbers at the end of 2002. The general trend at most other sites was an overall increase in abundance by the end of the year.

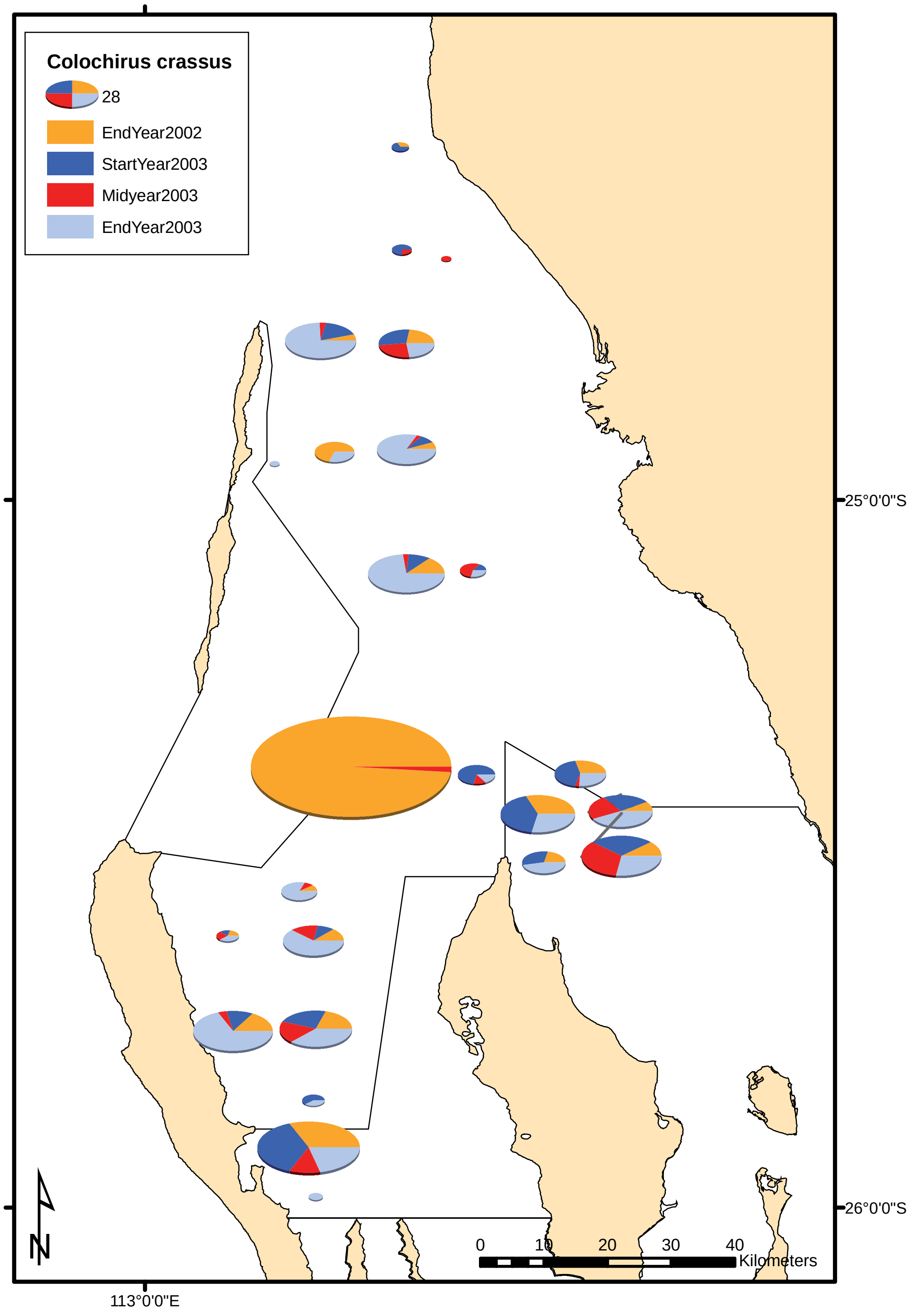

Figure 4.28 Seasonal and spatial distribution of *Colochirus crassus* in Shark Bay during end of 2002 and 2003 sampling periods.

Sea star (Luidia maculata) (Figure 4.29)

This sea star was not among the 20 most abundant species of invertebrates in Shark Bay, and only occurs at 16 of the survey sites. It was absent from the northern and most central parts of Shark Bay. Abundance was relatively low, but it was abundant at site 2 east of Cape Peron North.

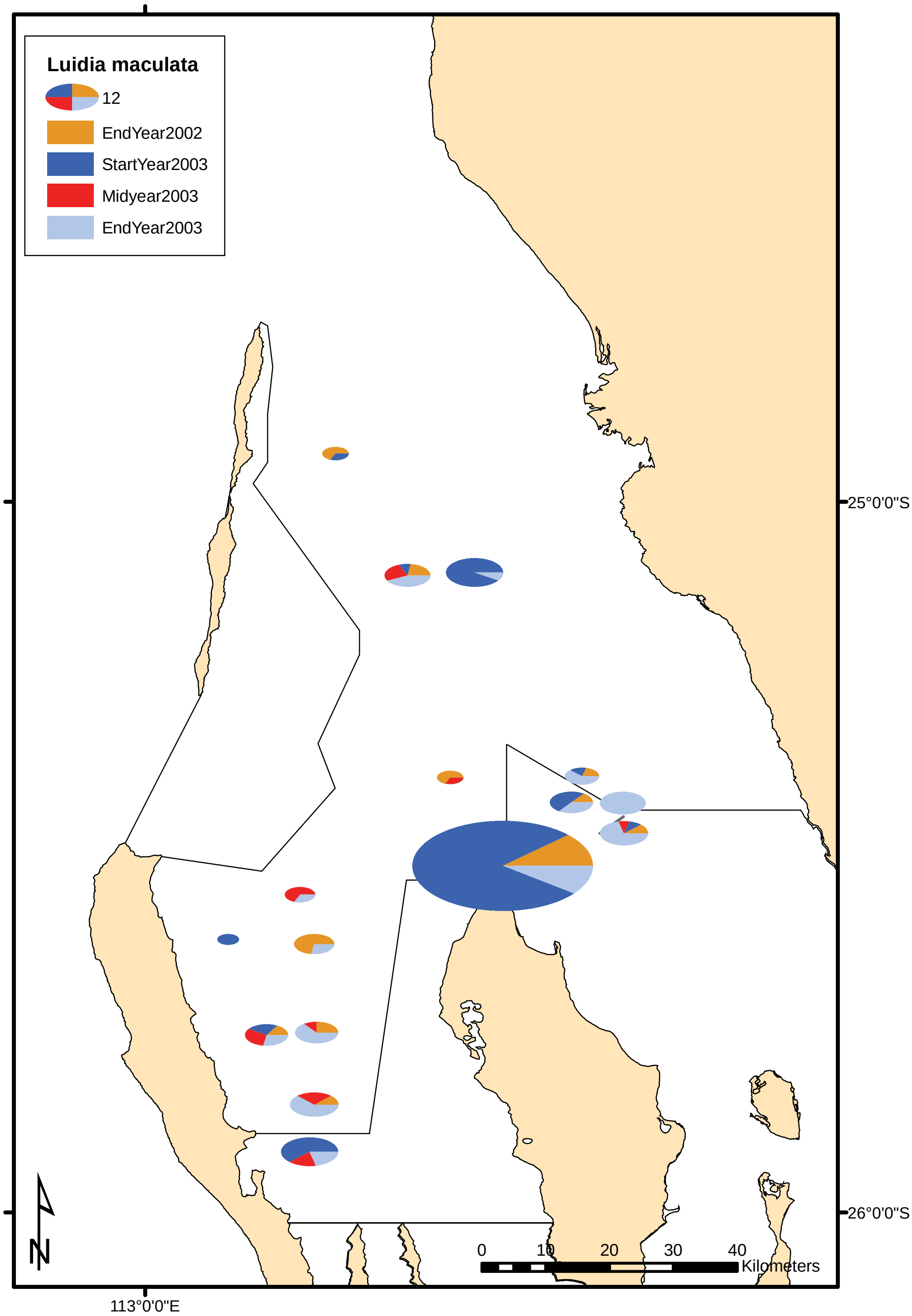

Figure 4.29 Seasonal and spatial distribution of *Luidia maculata* in Shark Bay during end of 2002 and 2003 sampling periods.

Ascidians (Ascidiacea) (Figure 4.30)

Ascidians were the tenth most abundant group of invertebrates in Shark Bay, but this includes several species in the phylum, not a single species as in other examples. These were found at all sites in Shark Bay except for two sites in the north and two sites in Denham Sound. They were most abundant in the central west and northern part of Denham Sound.

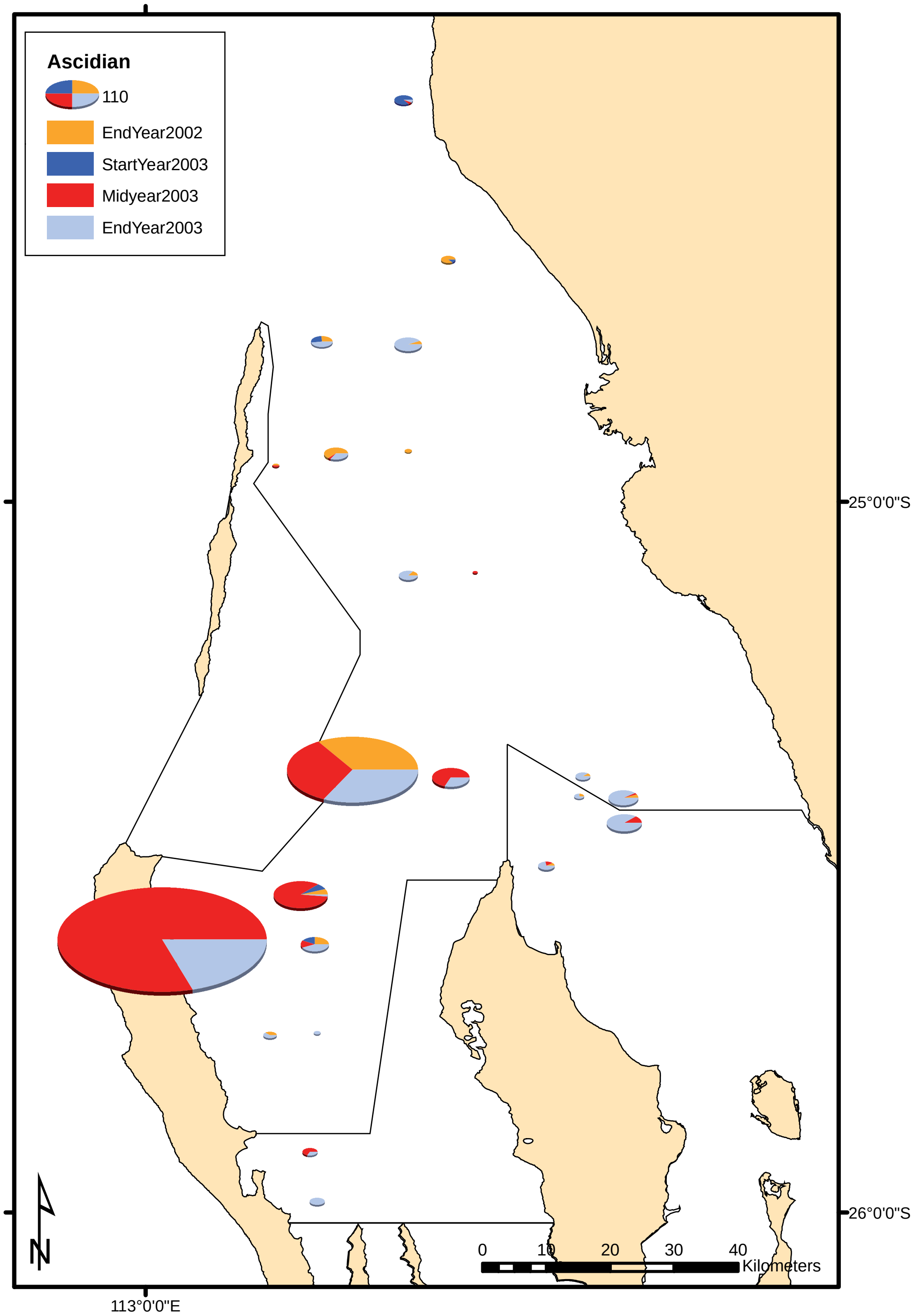

Figure 4.30 Seasonal and spatial distribution of Ascidiacea in Shark Bay during end of 2002 and 2003 sampling periods.

4.3.3 Annual variation at three sites in Shark Bay

Annual differences were observed in the abundance of fish and invertebrates between sites during the 2002 and 2003 surveys. Three sites were opportunistically sampled in February 2004 providing additional information on annual differences for sites 15, 16 and 21 in Denham Sound (Figure 4.2).

For fish species, there was a significant seasonal difference and site differences for both the number of species (richness) and fish abundance ($p < 0.01$) (Figure 4.31). However consistent trends between sites were not observed. Using one-way ANOVA for a season between years, there was no significant difference in the number of species (richness) between end2002 and end2003 ($p = 0.8$) or start2003 and start2004 ($p = 0.4$). For fish abundance, a significant difference was observed between start2003 and start2004 ($p = 0.04$). This difference was largely due to high abundance of *P. quadrilineatus* and *P. vitta* at sites 15 and 16 in 2004.

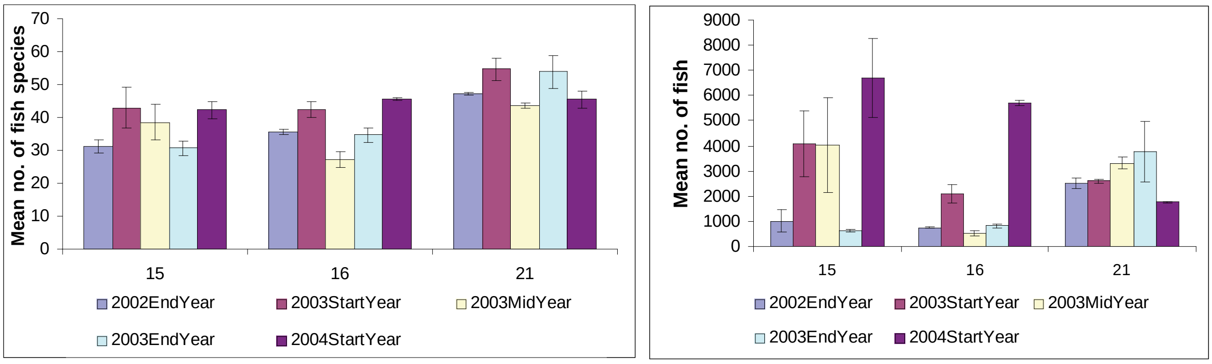

Figure 4.31 Mean and SE for fish species at sites 15, 16 and 21 in Denham Sound, Shark Bay between end 2002 and start 2004; a) mean number of species (richness) ± SE, b) mean abundance (number of fish per nm) ± SE.

For invertebrates, there was a significant difference in the number and abundance of species caught ($p < 0.01$) amongst sites and seasons (Figure 4.32). Using one-way ANOVA for a season between years, there was a significant difference between the number of species ($p = 0.03$) and the abundance of species ($p = 0.05$) between end2002 and end2003. The high variability in abundance in the start of 2003 and 2004 at site 21 was primarily attributed to the scallops *A. balloti* and *A. flabellata* reflecting the highly variable and patchy nature of scallop settlement and abundance.

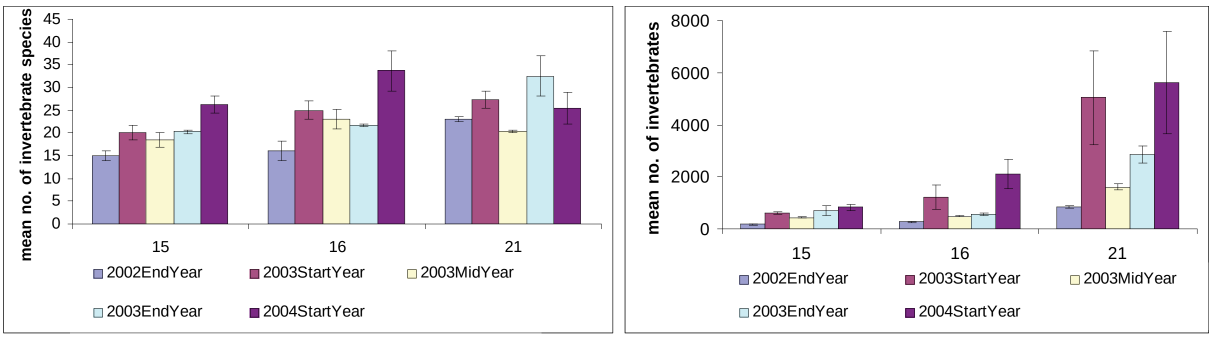

Figure 4.32 Mean and ±SE for invertebrate species at sites 15, 16 and 21 in Denham Sound, Shark Bay between end 2002 and start 2004; a) mean number of species (richness), b) mean abundance (number of fish per nm).

4.3.4 Faunal abundance and levels of trawl effort in Shark Bay

4.3.4.1 Power Analysis for fish abundance

Analysis of variance of overall Shark Bay fish family catch rates (square root transformed) indicated a significant effect from previous trawl effort, $F_{3,460} = 4.50$, p=0.004. For this observed F value the observed power of the ANOVA test at 5%, was 40% and at 10% was 47%. This indicates that increasing sample size would improve the power of the tests in Shark Bay. Post-hoc tests for trawl effort indicated that low trawl effort (Trawl Effort Category 1) had significantly higher catch rates than the other levels of trawl effort.

4.3.4.2 Seasonal abundance of selected species with trawl effort

When individual species are considered most of the abundant species were widespread and occurred at most sites and shared no trend with trawl effort. Only *P. choirocephalus* and *P. longispinis* were more abundant on trawl grounds but no seasonal effects were evident. (Figure 4.33).

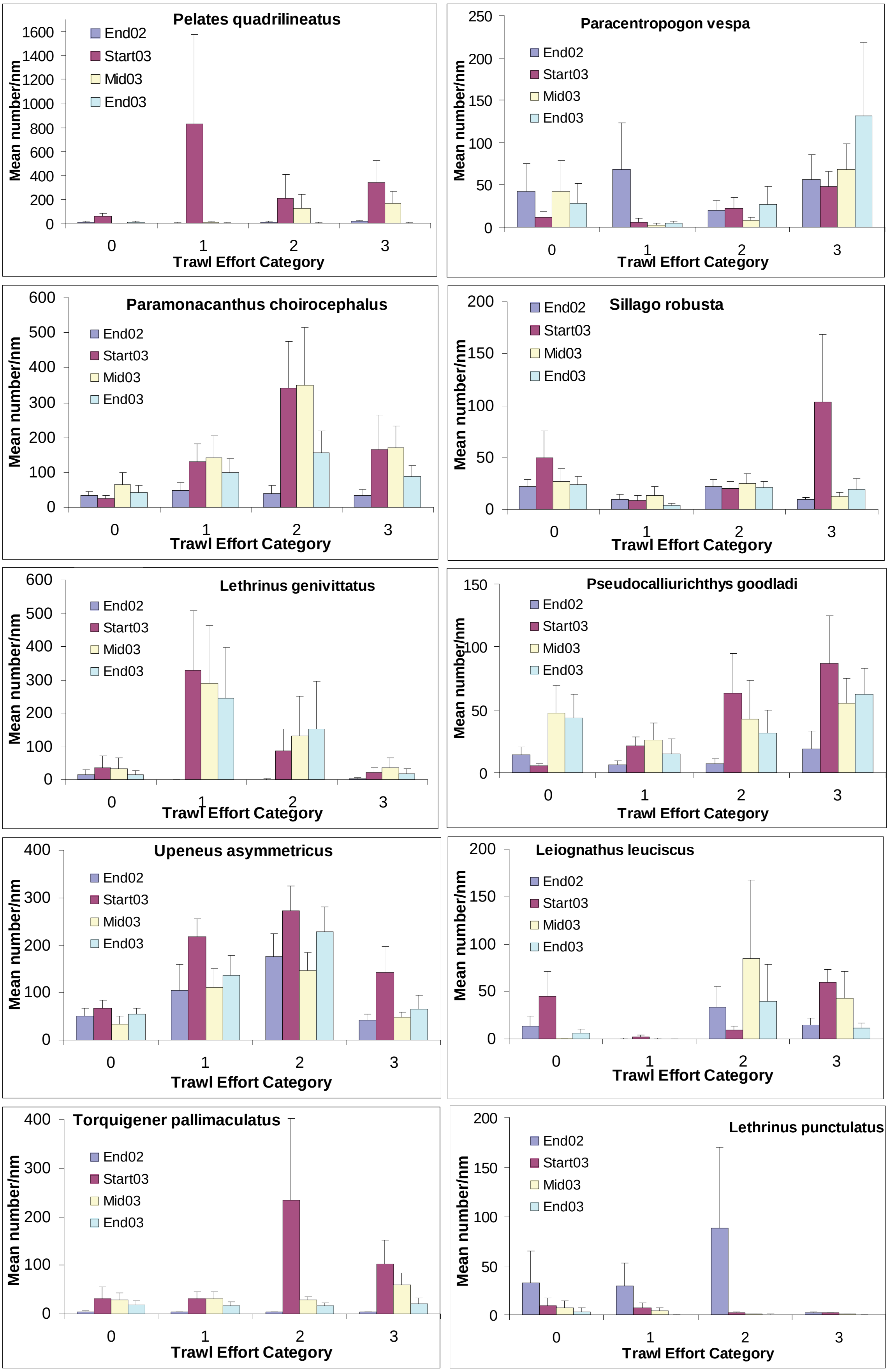

Figure 4.33 Mean abundance (±SE) of main fish species in Shark Bay between October 2002 and October 2003 for sites for levels of trawl effort.

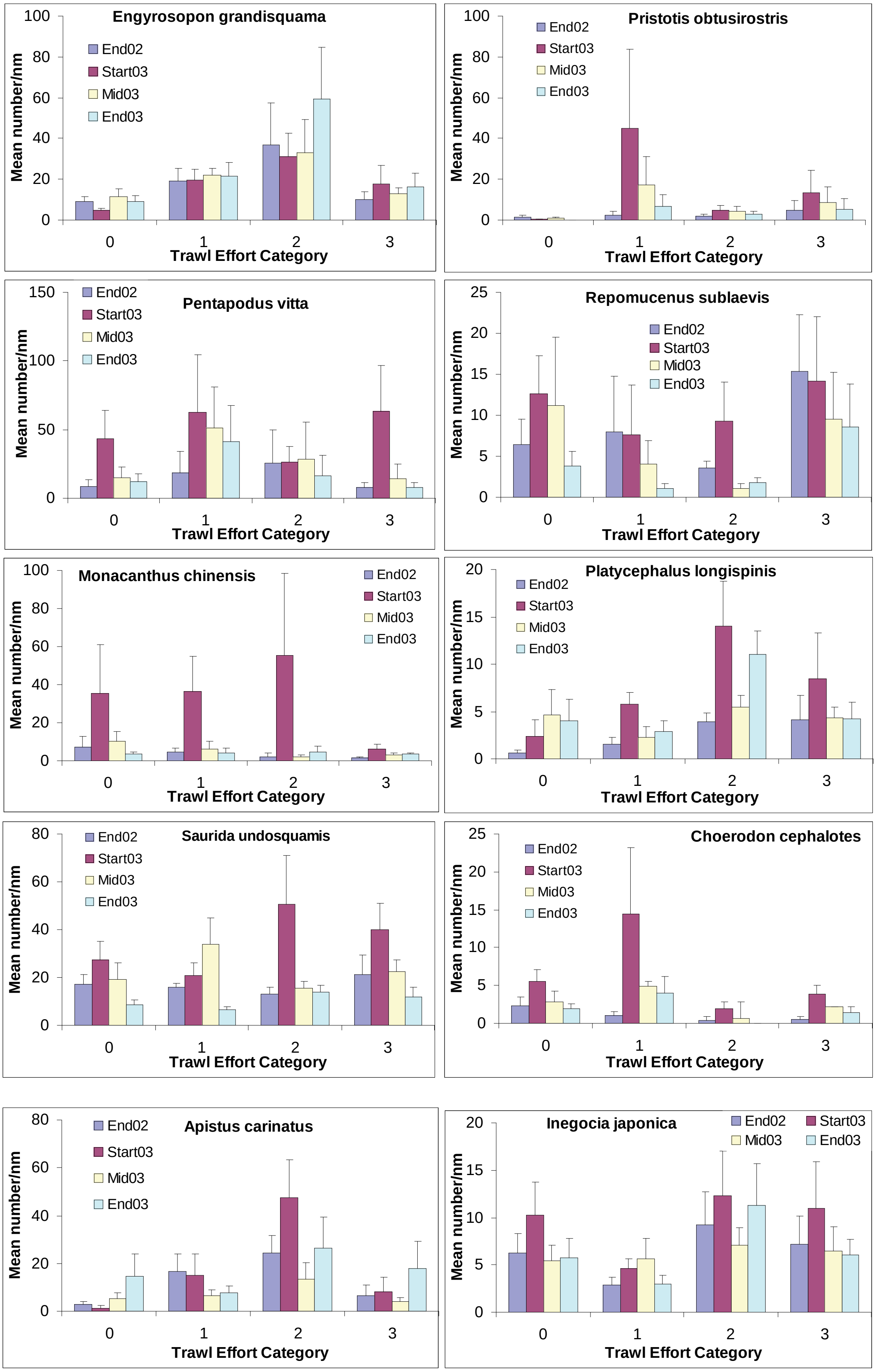

Figure 4.33 cont. Mean abundance (±SE) of main fish species in Shark Bay between October 2002 and October 2003 for sites for levels of trawl effort.

Similarly for invertebrates, most were widespread and found at sites for all trawl categories (Figure 4.34) except for bugs and sedentary fauna (ascidians, soft coral and anemones) which were significantly lower abundance in the untrawled sites. As a majority of the untrawled sites were hypersaline areas this maybe less suitable for sedentary species (other than sponges). Only holothurians were found in higher abundance in the untrawled sites. This was primarily attributed to high abundance at site 22.

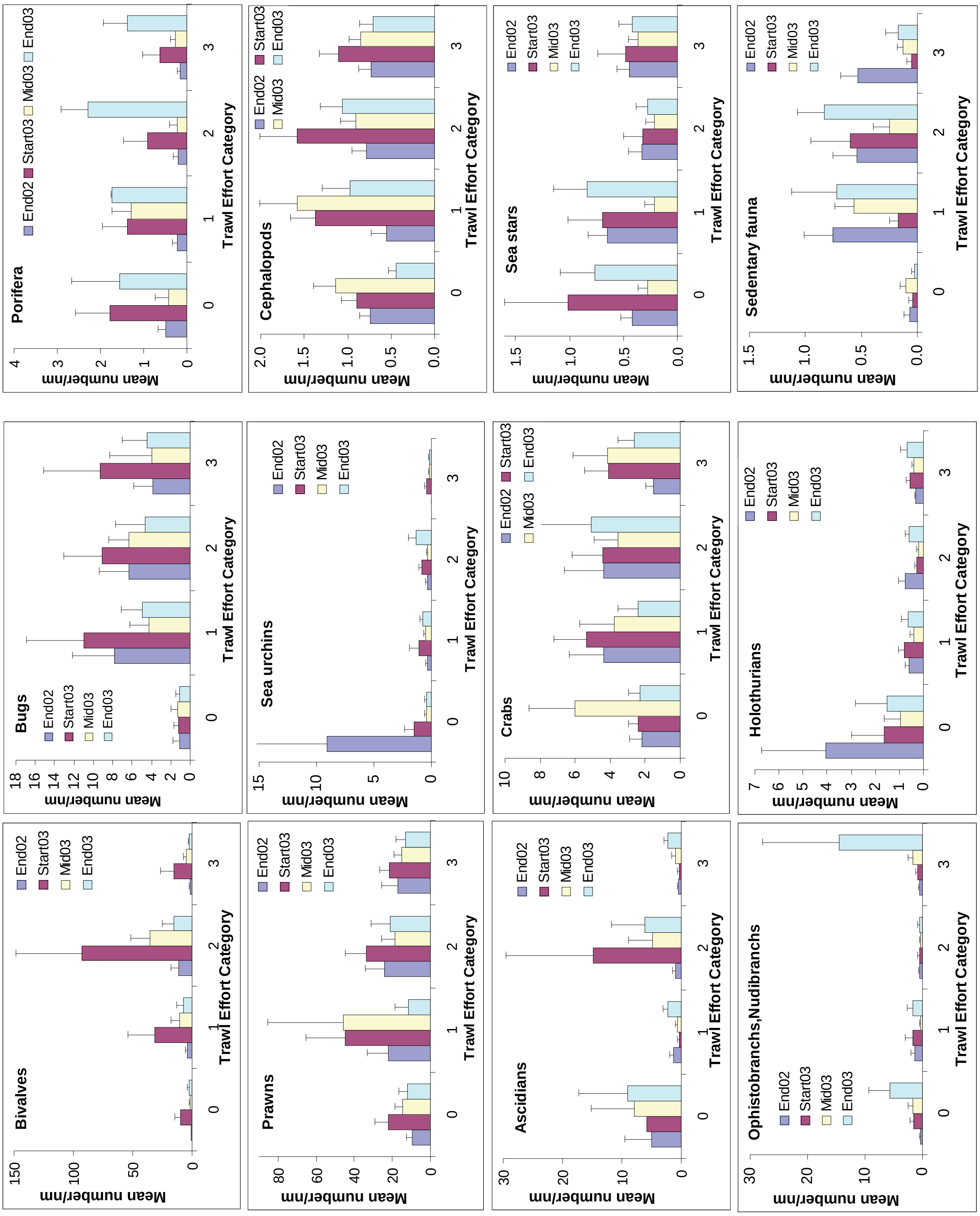

Figure 4.34 Mean abundance (±SE) of main invertebrate groups in Shark Bay between October 2002 and October 2003 for sites for levels of trawl effort.

4.3.5 Diurnal Variation in Shark Bay

A total of 98 species of fish and 72 species of invertebrates (family or 'group' if not identified to species) was sampled during the day-night trials. For invertebrates, sedentary species such as Porifera and soft corals are listed but were not considered as they were not expected to vary in their diurnal behaviour and catchability. There was a significantly higher mean abundance and number of fish and invertebrate species during night-time trawls compared to daytime trawls for sites 3 and 4 (Tables 4.3 and 4.4) (ANOVA $p < 0.01$) as well as sites 11 and 12 for invertebrates. However, for fish species, at the northern sites (11 and 12) very large numbers of orange-fin ponyfish (*Leiognathus bindus*) at day time reversed the trend at these sites (Table 4.4).

Table 4.3 The mean number of species (±SE) and mean abundance (±SE) of fish caught in Shark Bay Day-Night trials.

Site	Daytime				Night-time			
	Number of species	S.E.	Mean no./nm	S.E.	Number of species	S.E.	Mean no./nm	S.E.
3	18	5.0	3.17	0.91	38	1.0	9.18	0.23
4	19	0.3	11.97	3.76	38	1.0	13.56	0.44
11	27	2.7	75.36	8.20	27	1.3	33.19	1.35
12	21	1.5	55.40	21.01	27	1.3	14.16	1.27

For invertebrate species, the abundance was also significantly higher ($p < 0.01$) in night-time trawls for site 11. The high night time abundance is mainly attributed to the Penaeidae. For site 12 the abundance was similar during the daytime which was attributed to very high catches of the squid *Photololigo* species during daytime.

Table 4.4 Mean number of species (±SE) and mean abundance (±SE) of invertebrates caught in Shark Bay Day-Night trials.

Site	Daytime				Night-time			
	Numbers	S.E.	Mean no./nm	S.E.	Numbers	S.E.	Mean no./nm	S.E.
3	11	1.3	9.20	0.39	20	0.3	26.08	0.11
4	11	25	8.15	0.61	20	1.8	28.40	0.96
11	9	1.2	7.68	0.75	15	1.5	35.19	4.21
12	9	0.9	18.28	0.29	17	0.6	22.22	0.18

The main species of fish which showed higher abundance at day were in the families Carangidae, Leiognathidae, Harpodontidae and Terapontidae (Figure 4.35).

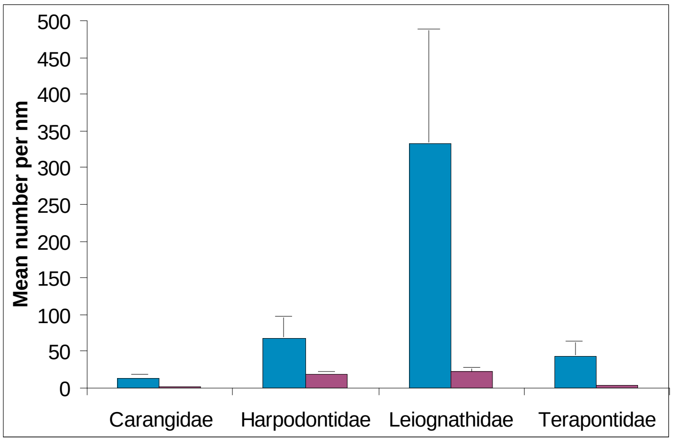

Figure 4.35 Fish families that were more abundant in daytime trawls (blue – daytime).

The main species of fish which showed higher abundance at night were in the families Monacanthidae, Mullidae, Sillaginadae and Triglidae (Figure 4.36).

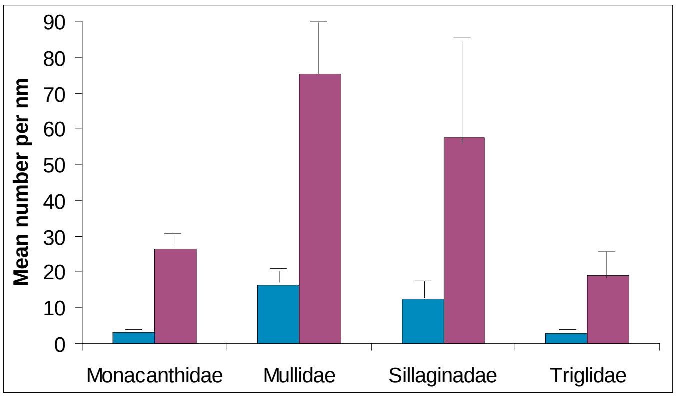

Figure 4.36 Fish families that were more abundance in night trawls (blue - daytime).

Some species only occur at night and some only at daytime (Table 4.5) whereas other species can occur during both day and night but their abundance may be higher in one or the other. *Saurida undosquamis, S. robusta*, and *P. quadrilineatus* all occur during day and night but have significantly higher numbers during daytime trawls whereas *P. choirocephalus* and *U. asymmetricus* have significantly higher numbers at night even though they are also sampled during the day. A few species were common throughout the areas sampled at both day and night in similar numbers. These included *E. grandisquama, R. sublaevis L. leuciscus, Lethrinus species, I. japonica, S. burrus, T. pallimaculatus* and *T. whitleyi.*

Geographic differences in distribution of invertebrates was evident (Table 4.6). Only 15 species of the 72 species sampled occurred in both northern and southern sites at night and/or day. These included; *A. flabellata,* the coral crab, *C. feriata*, other portunid crabs *P. pelagicus, P. rubromarginatus* and *T. sima*, spider crabs (Majidae), prawns *P. latisulcatus* and *P. esculentus*, the seastar *Luidia hardwicki*, the cephalopods *Photololigo* species and *Sepia smithi*. Most of the more abundant species sampled both day and night occurred in higher abundances at night. However, *Photololigo* species was the only species occurring in one site in very high numbers during the day.

Table 4.5 Fish species found in Northern (sites 11 and 12) and Southern (sites 3 and 4) areas of Shark Bay at either at night or day.

Sites 3 and 4 Daytime		Sites 3 and 4 Night Time	
Centropomidae	*Hypopterus macropterus*	Callionymidae	*Dactylopus dactylopus*
Eceneidae	*Echeneis naucrates*	Cynoglossidae	*Cynoglossus maculipinnis*
Gymnuridae	*Gymnura australis*	Ephippidae	*Zabidius novemaculeatus*
Rhynchobatidae	*Rhina ancylostoma*	Gobiidae	*Priolepis semidoliatus*
Sphyraenidae	*Sphyraena obtusata*	Hemiramphidae	*Hemiramphus robustus*
Syngnathidae	*Hippocampus biocellatus*	Hypinidae	*Narcine westraliensis*
Syngnathidae	*Hippocampus planifrons*	Lethrinidae	*Lethrinus laticaudis*
		Lutjanidae	*Lutjanus carponotatus*
		Ostraciidae	*Rhynchostracion nasus*
		Rhynchobatidae	*Rhynchobatus australiae*
		Syngnathidae	*Filicampus tigris*
Total	7	Total	11

Sites 11 and 12 Daytime		Sites 11 and 12 Night Time	
Carangidae	*Alepes apercna*	Apogonidae	*Siphamia roseigaster*
Carangidae	*Carangoides chrysophrys*	Labridae	*Choerodon cauteroma*
Carangidae	*Carangoides hedlandensis*	Ostraciidae	*Tetrosomus reipublicae*
Carangidae	*Carangoides talamparoides*	Scorpaenidae	*Minous versicolor*
Carangidae	*Decapterus russelli*	Serranidae	*Centrogenys vaigiensis*
Carangidae	*Parastromateus niger*	Triakidae	*Mustelus sp. A*
Carangidae	*Selar boops*	Scorpaenidae	*Apistus carinatus*
Carangidae	*Trachurus novaezelandiae*		
Haemulidae	*Pomadasys kaakan*		
Leiognathidae	*Gazza minuta*		
Pomacentridae	*Pristotis obtusirostris*		
Scombridae	*Scomberomorus queenslandicus*		
Sparidae	*Pagrus auratus*		
Number	6		10
Total	13		21

Sites 3 and 4 Both Night and Day		Sites 3, 4, 11 and 12 Daytime only	
Bothidae	*Pseudorhombus jenynsii*	Clupeidae	*Sardinella lemuru*
Callionymidae	*Callionymus goodladi*	Sparidae	*Rhabdosargus sarba*
Carangidae	*Selaroides leptolepis*		2
Centropomidae	*Psammoperca waigiensis*	At sites 3, 4 and 11 and 12 Night Time only	
Dasyatididae	*Dasyatis leylandi*		
Diodontidae	*Tragulichthys jaculiferus*	Cynoglossidae	*Paraplagusia bilineata*
Labridae	*Choerodon cephalotes*	Monacanthidae	*Pseudomonacanthus peroni*
Monacanthidae	*Anacanthus barbatus*	Platycephalidae	*Sorsogona tuberculata*
Monacanthidae	*Monacanthus chinensis*		3
Mullidae	*Upeneus tragula*	Sites 3, 4, 11 and 12 Both Night and Day	
Nemipteridae	*Pentapodus vitta*		
Pegasidae	*Pegasus volitans*	Apogonidae	*Apogon nigripinnis*
Pinguipedidae	*Parapercis nebulosa*		
Platycephalidae	*Papilloculiceps nematophthalmus*	Bothidae	*Asterorhombus intermedius*
		Bothidae	*Engyprosopon grandisquama*
Siganidae	*Siganus canaliculatus*	Bothidae	*Pseudorhombus arsius*
Sillaginidae	*Sillago vittata*	Callionymidae	*Repomucenus sublaevis*
Synodontidae	*Synodus sageneus*	Gerreidae	*Gerres subfasciatus*
Terapontidae	*Pelates sexlineatus*	Harpodontidae	*Saurida undosquamis*
Total	18	Leiognathidae	*Leiognathus leuciscus*
Sites 11 and 12 Both Night and Day		Lethrinidae	*Lethrinus genivittatus*
		Lethrinidae	*Lethrinus* species
Apogonidae	*Apogon quadrifasciatus*	Monacanthidae	*Paramonacanthus choirocephalus*
Aulostomidae	*Fistularia commersonii*		
Bothidae	*Pseudorhombus elevatus*	Mullidae	*Upeneus asymmetricus*
Bothidae	*Pseudorhombus spinosus*	Platycephalidae	*Inegocia japonica*
Carangidae	*Pseudocaranx dinjerra*	Platycephalidae	*Platycephalus arenarius*
Clupeidae	*Sardinella gibbosa*	Platycephalidae	*Platycephalus longispinis*
Leiognathidae	*Leiognathus bindus*	Sillaginidae	*Sillago burrus*
Leiognathidae	*Secutor insidiator*	Sillaginidae	*Sillago robusta*
Lutjanidae	*Lutjanus malabaricus*	Soleidae	*Aseraggodes melanospilos*
Monacanthidae	*Stephanolepis sp.*	Terapontidae	*Pelates quadrilineatus*
Mullidae	*Parupeneus chrysopleuron*	Tetraodontidae	*Torquigener pallimaculatus*
Nemipteridae	*Nemipterus furcosus*	Tetraodontidae	*Torquigener whitleyi*
Pomatomidae	*Pomatomus saltatrix*		
Priacanthidae	*Priacanthus macracanthus*		
Scorpaenidae	*Apistus carinatus*		
Scorpaenidae	*Paracentropogon vespa*		
Sparidae	*Argyrops spinifer*		
Terapontidae	*Terapon theraps*		
Tetraodontidae	*Lagocephalus lunaris*		
Triglidae	*Lepidotrigla sp.*		23
Number	19		27
Total	37	Overall Total species	98

Table 4.6 Invertebrate species found in Northern (sites 11 and 12) and Southern (sites 3 and 4) areas of Shark Bay at either at night or day.

Sites 3 and 4 Daytime		**Sites 3 and 4 Night Time**	
Actinaria	Actinaria	Corystidae	*Gomeza bicornis*
Arcidae	*Anadara secticostata*	Cucumariidae	*Mensamaria intercedens*
Clavelinidae	*Clavelina meridionalis*	Didemnidae	*Leptoclinides kingi*
Dromiidae	*Dromiidae*	Leucosiidae	*Leucosia haswelli*
Echinasteridae	*Metrodira subulata*	Leusosiidae	*Myra mammillaris*
Fissurellidae	*Scutus unguis*	Malleidae	*Vulsella vulsella*
Holozoidae	*Sigillina australis*	Neptheiidae	*Neptheid sp.*
Isopoda	Isopoda	Parthenopidae	*Parthenope nodosus*
Pectinidae	*Mimachlamys asperrima*	Penaeidae	*Metapenaeus dalli*
Polyclinidae	*Polyclinum vasculosum*	Penaeidae	*Metapenaeus endeavouri*
		Penaeidae	*Metapenaeopsis sp.*
		Plurellidae	*Microgastra granosa*
		Sepiadariidae	*Sepiadarium kochii*
		Sepiadariidae	*Sepioloidea lineolata*
		Sepiidae	*Metasepia pfefferi*
		Sepiidae	*Sepia papuensis*
		Squillidae	*Alimopsoides sp.*
		Volutidae	*Melo sp.*
Total number of species (or group)	10	Total	18
Sites 3 and 4 Both Night and Day		**Sites 3, 4 and 11 and 12 Both Night and Day**	
Ascidiidae	*Phallusia millari*	Cucumariidae	*Colochirus crassus*
Cucumariidae	*Actinocucumis typica*	Loliginidae	*Photololigo sp.*
Cucumariidae	*Colochirus quadrangularis*	Luidiidae	*Luidia hardwicki*
Dorippidae	*Dorippe frascone*	Majidae	*Majidae*
Molgulidae	*Molgula ficus*	Pectinidae	*Annachlamys flabellata*
Nudibranchia	*Nudibranchia*	Penaeidae	*Penaeus latisulcatus*
Philinidae	*Philine sp.*	Penaeidae	*Penaeus esculentus*
Pteroidea	*Pteroides sp.*	Porifera	*Porifera*
Scyllaridae	*Eduarctus martensii*	Portunidae	*Portunus rubromarginatus*
Veneridae	*Callista planatella*	Portunidae	*Portunus pelagicus*
		Portunidae	*Thalamita sima*
		Pteroeididae	*Pteroeides sp.*
		Sepiidae	*Sepia smithi*
		Sites 3, 4 and 11 and 12 Night Only	
		Portunidae	*Charybdis feriata*
Total	10	Total	14

Sites 11 and 12 Daytime		**Sites 11 and 12 Night Time**	
Astropectinidae	*Astropecten preissi*	Diogenidae	*Diogenidae*
Comasteridae	*Comatula solaris*	Pleurobranchidae	*Euselenops luniceps*
Ophiuridae	*Dictenophiura stellata*	Naticidae	*Natica stellata*
Penaeidae	*Metapenaeopsis palmensis*	Opiotrichidae	*Ophiothrix viridialba*
Ostreidae	*Ostrea sp.*	Squillidae	*Oratosquilla oratoria*
Portunidae	*Portunus pubescens*	Portunidae	*Portunus haanii*
		Scyllaridae	*Thenus orientalis*
		Toxopneustidae	*Tripneustes gratilla*
		Plurellidae	*Microgastra granosa*
		Phyllophoridae	*Phyllophorus brocki*
Number	6		10

Sites 11 and 12 Both Night and Day			
Scyphozoa	*Aurelia sp.*		
Portunidae	*Portunus hastatoides*		
Portunidae	*Portunus sanguinolentus*		
Goniasteridae	*Stellaster inspinosus*		
	4		14

4.3.6 Seasonal Variation in abundance and diversity measures in Exmouth Gulf and Onslow Area 1

Fish abundance records for 2004 cover three sampling trips to Exmouth Gulf and Onslow.

Permanovas indicated significant differences in fish species abundance between trawled and untrawled sites between seasons (Table 4.7a and 4.7b) but not for their interaction. The R^2 value is low indicating that site differences observed in previous analyses (Chapter 3) are likely to be more important that trawled/untrawled differences. Differences are observed between trawled and untrawled sites at start2004 and end2004 (Figure 4.37).

Table 4.7a Permanova results for fish species in Exmouth Gulf and Onslow biodiversity trawls (R^2 = 0.11). Type 3 sum of squares have been presented.

Source	df	SS	MS	Pseudo-F	P(perm)
Trawled	1	18627	18627	9.6221	< 0.01
Season	2	27936	13968	7.2154	< 0.01
Trawled x Season	2	4645.1	2322.5	1.1997	0.21
Residuals	212	4.10E+05	1935.8		

Table 4.7b Permanova results for invertebrate species in Shark Bay biodiversity trawls (R^2 = 0.11). Only observations for 2003 were included in this analysis. Type 3 sum of squares have been presented.

Source	df	SS	MS	Pseudo-F	P(perm)
Trawled	1	8556.4	8556.4	3.8849	< 0.01
Season	2	43803	21902	9.944	< 0.01
Trawled x Season	2	6338.9	3169.5	1.439	0.12
Residuals	209	4.60E+05	2202.5		

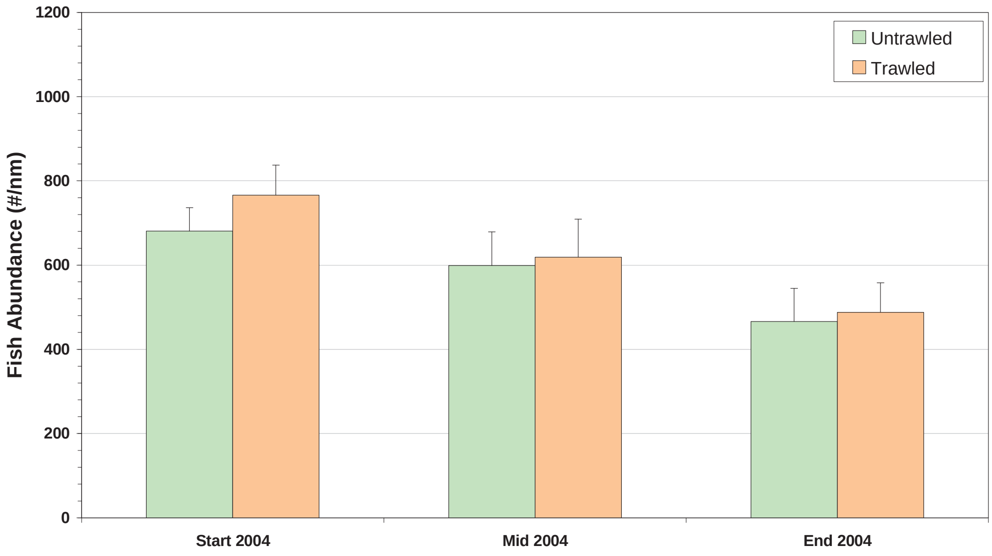

Figure 4.37 Fish abundance (+ S.E.) in trawled and untrawled sites in Exmouth Gulf and Onslow in 2004.

Trawled sites have a slightly elevated abundance of fish in all seasons compared with untrawled sites. This difference was greatest at the start of the season with trawled sites having a mean abundance of around 766 fish per nautical mile, and untrawled sites having 681 fish per nautical mile. Both trawled and untrawled sites show a gradual decline (but not significant) in abundance throughout the year. By mid-year there was little difference between trawled and untrawled sites, which have 619 and 599 fish per nautical mile respectively. At the end of the year trawled sites have dropped by 36% since the start of the year to 488 fish per nautical mile, and untrawled sites have declined by 32% to 466 fish per nautical mile.

The majority of sites show a steady decline in fish abundance throughout the year; these were 1, 2, 3, 8, 12, 13, 16, 17, 18, 20, 21, 22, 23, 25 and 26 (Figure 4.38). These sites include untrawled, lightly trawled and heavily trawled sites. Sites 5 and 11 show an increase in abundance in the middle of the year, but there was an overall decrease by the end of the year. Six sites (4, 6, 7, 14, 19 and 24) have a decrease in abundance in the middle of the year followed by a moderate increase at the end of the year. Only two sites (9 and 10) show an overall increase in abundance by the end of the year.

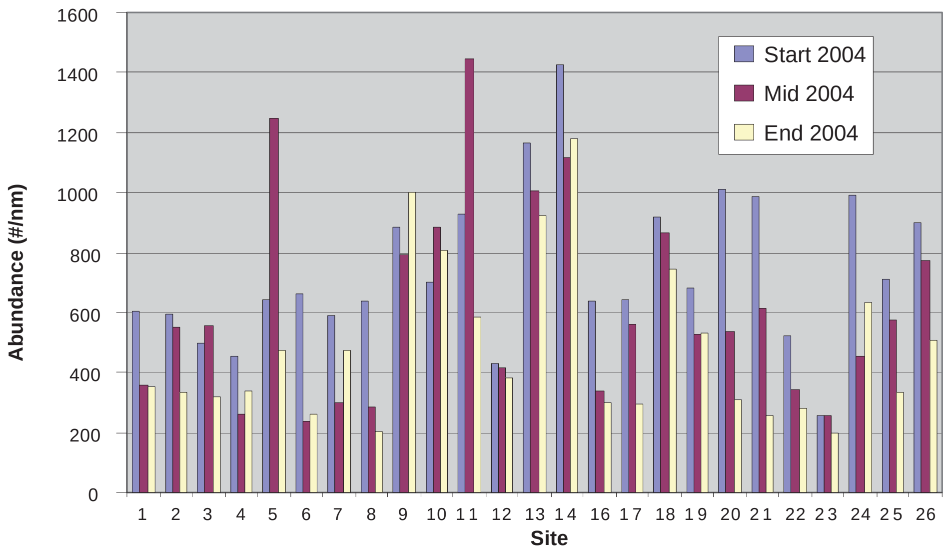

Figure 4.38 Mean seasonal fish abundance at each site in Exmouth Gulf and Onslow in 2004.

For the diversity measures for fish species there was a significant difference ($p < 0.01$) in species richness in both trawled and untrawled sites with a seasonal decline being evident (Figure 4.39). All other measures were similar throughout the year.

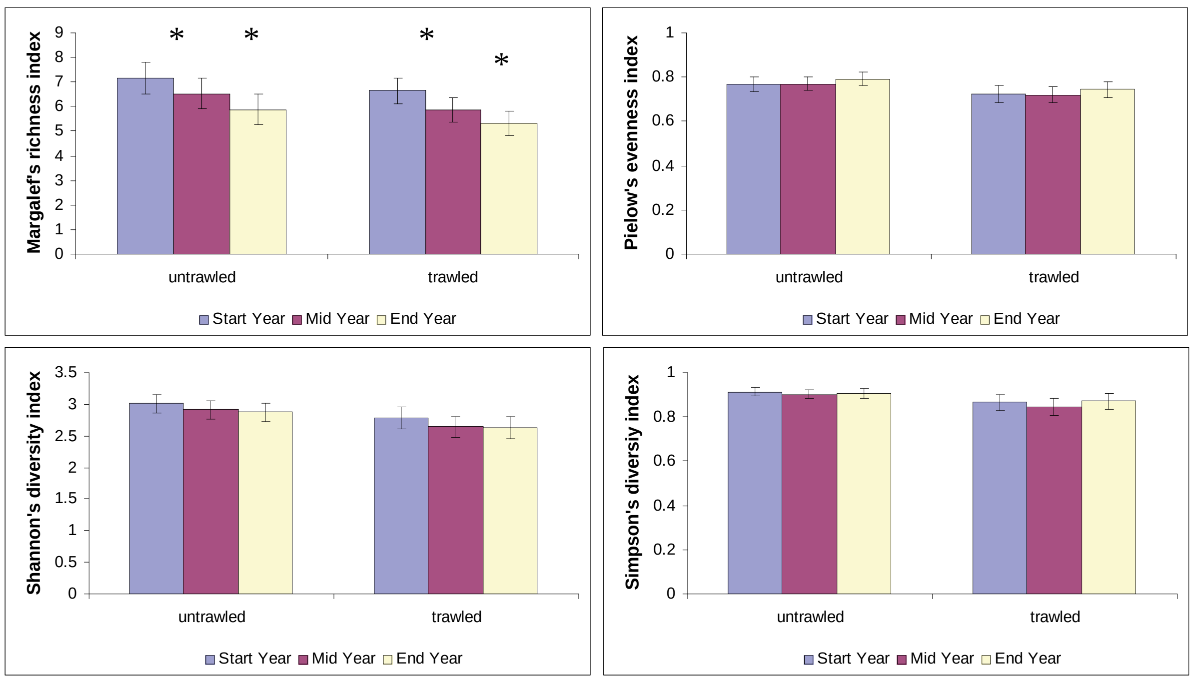

Figure 4.39 Least squares means with 95% confidence intervals for untrawled and trawled sites for each season from the fish abundances in Exmouth Gulf and Onslow; a) Margalef's richness index, b) Pielou's evenness index, c) Shannon's diversity index and d) Simpson's diversity index. * indicates a significant differences between seasons with the trawled or untrawled site groupings.

The invertebrates from Exmouth Gulf and Onslow show a different pattern of abundance change from fish (Figure 4.40).

Permanovas indicated significant differences in invertebrate species abundance between trawled and untrawled sites between seasons (Table 4.8a and 4.8b) as well as their interaction. The R^2 value is low indicating that site differences observed in previous analyses (Chapter 3) are likely to be more important that trawled/untrawled differences. Significant differences are observed between trawled and untrawled sites between each season whilst only at the end of year are the trawled sites significantly higher than untrawled sites (Figure 4.40).

Table 4.8a Permanova results for invertebrate species in Exmouth biodiversity trawls (R^2 = 0.17). Type 3 sum of squares have been presented.

Source	df	SS	MS	Pseudo-F	P(perm)
Trawled	1	14644	14644	7.2963	< 0.01
Season	2	68843	34422	17.15	< 0.01
Trawled x Season	2	6382.4	3191.2	1.59	0.03
Residuals	212	4.26E+05	2007.1		

Table 4.8b Permanova results for invertebrate species in Shark Bay biodiversity trawls (R^2 = 0.11). Only observations for 2003 were included in this analysis. Type 3 sum of squares have been presented.

Source	df	SS	MS	Pseudo-F	P(perm)
Trawled	1	8556.4	8556.4	3.8849	< 0.01
Season	2	43803	21902	9.944	< 0.01
Trawled x Season	2	6338.9	3169.5	1.439	0.12
Residuals	209	4.60E+05	2202.5		

At the start of the year invertebrate abundances were greater than those of the fish, but these numbers drop through the year until invertebrates were much less abundant than fish by the end of the season. At the start of the season there was no difference between invertebrate abundance at trawled and untrawled sites, which have 1,046 and 1,041 invertebrates per nautical mile respectively. By mid-year these numbers have approximately halved to 576 invertebrates per nautical mile in trawled sites and 483 invertebrates per nautical mile in untrawled sites. By the end of the year they have declined even further by 77% since the start of the year to 236 invertebrates per nautical mile in trawled sites, and by 86% to 147 invertebrates per nautical mile in untrawled sites. The trawled sites indicate a large depletion of invertebrates mainly due to a decline in prawn abundances. The untrawled sites, however, also show a higher depletion rate than trawled areas. This could be because mobile invertebrates such as prawns move from untrawled to trawled sites as part of the annual migration pattern.

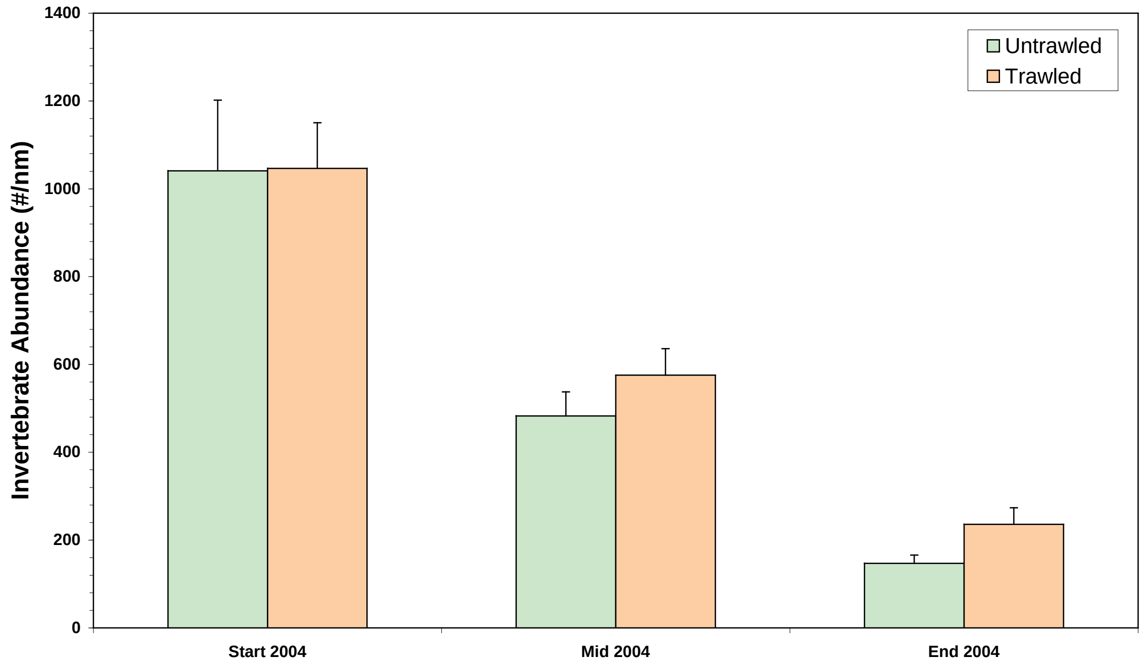

Figure 4.40 Mean Invertebrate species abundance (+ S.E.) in trawled and untrawled sites in Exmouth Gulf and Onslow in 2004.

All except two sites have an incremental decline in abundance over the year (Figure 4.41). Only sites 3 and 4 show an increase in abundance in the middle of the year, but there was an overall decrease by the end of the year.

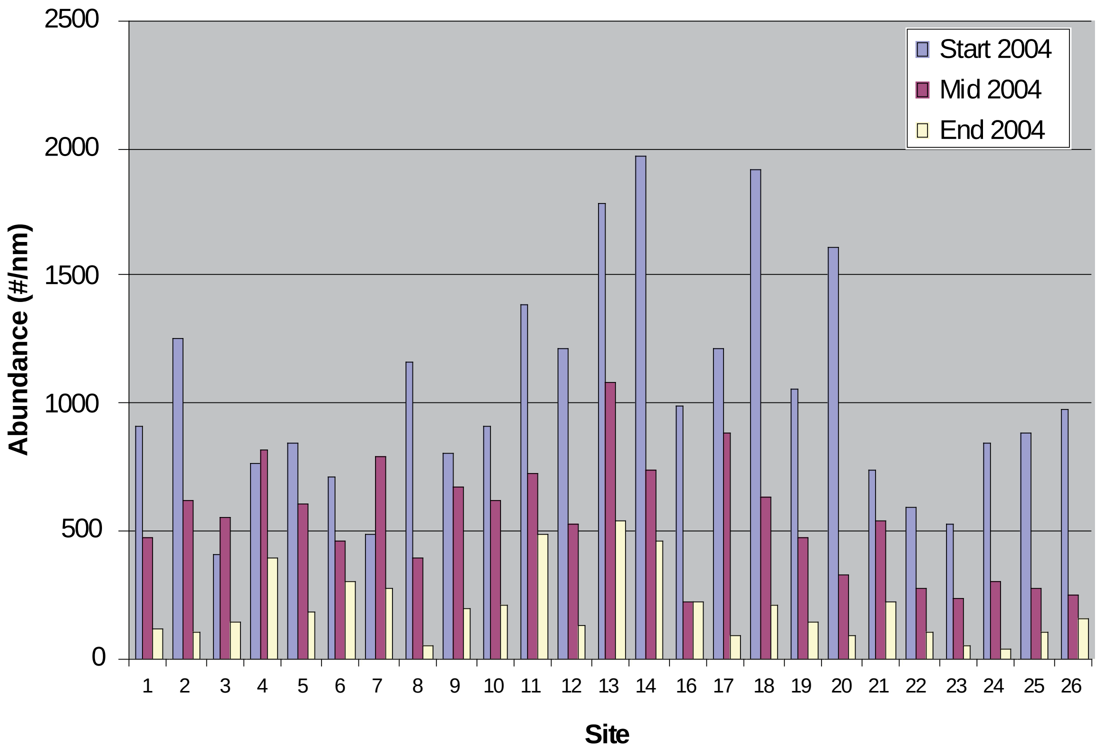

Figure 4.41 Seasonal invertebrate abundance at each site in Exmouth Gulf and Onslow in 2004.

For the diversity measures for invertebrate species there was a significant difference in all the diversity measures ($p < 0.01$) in both trawled and untrawled sites. All four measures were higher in the untrawled sites (Figure 4.42). For the Margalef's species richness, there was a seasonal decline evident whilst the other measures increased during the season.

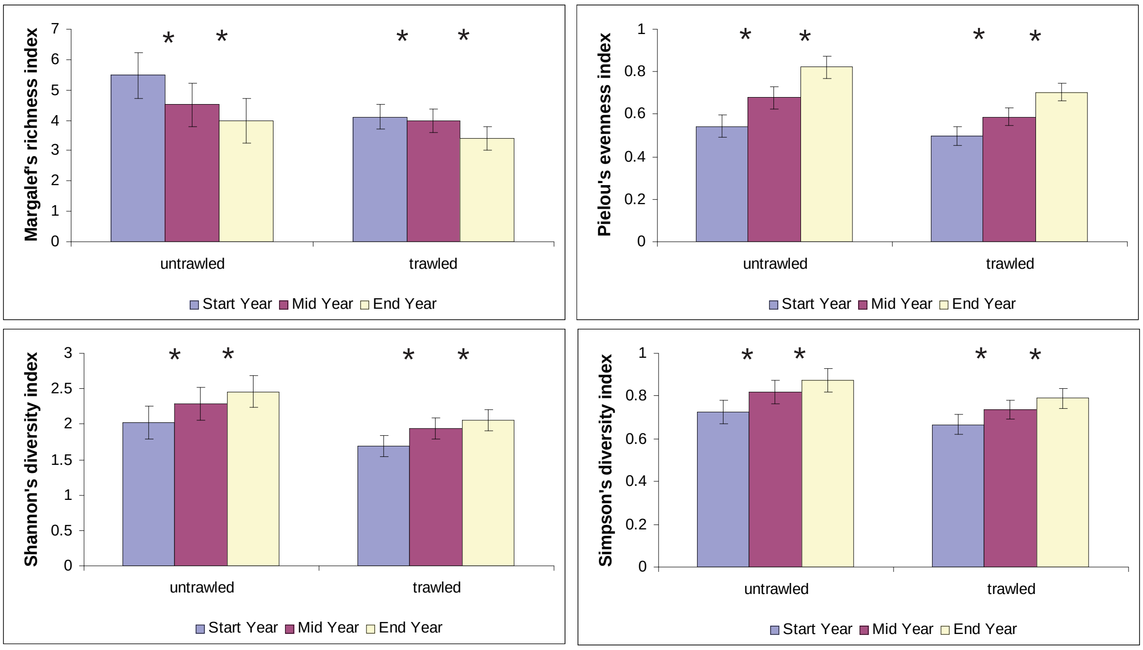

Figure 4.42 Least squares means with 95% confidence intervals for untrawled and trawled sites for each season from the invertebrate abundances in Exmouth Gulf and Onslow; a) Margalef's richness index, b) Pielou's evenness index, c) Shannon's diversity index and d) Simpson's diversity index. * indicates a significant differences between seasons with the trawled or untrawled site groupings.

4.3.7 Spatial and temporal variation of some species in Exmouth Gulf and Onslow

The spatial distribution and abundance of a selection of some of the more abundant fish and invertebrate species for Exmouth Gulf and Onslow were looked at in detail. The selected species illustrate the variability in seasonal abundance and distribution. The nine fish and nine invertebrate species are as follows:

Bullrout (Paracentropogon vespa) (Figure 4.43)

The bullrout was the most abundant fish species in Exmouth Gulf and Onslow, and was found at all survey sites. Its abundance, however, was highly variable with a huge abundance in the north west of Shark Bay, but limited elsewhere. The abundance was high at the start and middle of the season, with a decline towards the end of the year.

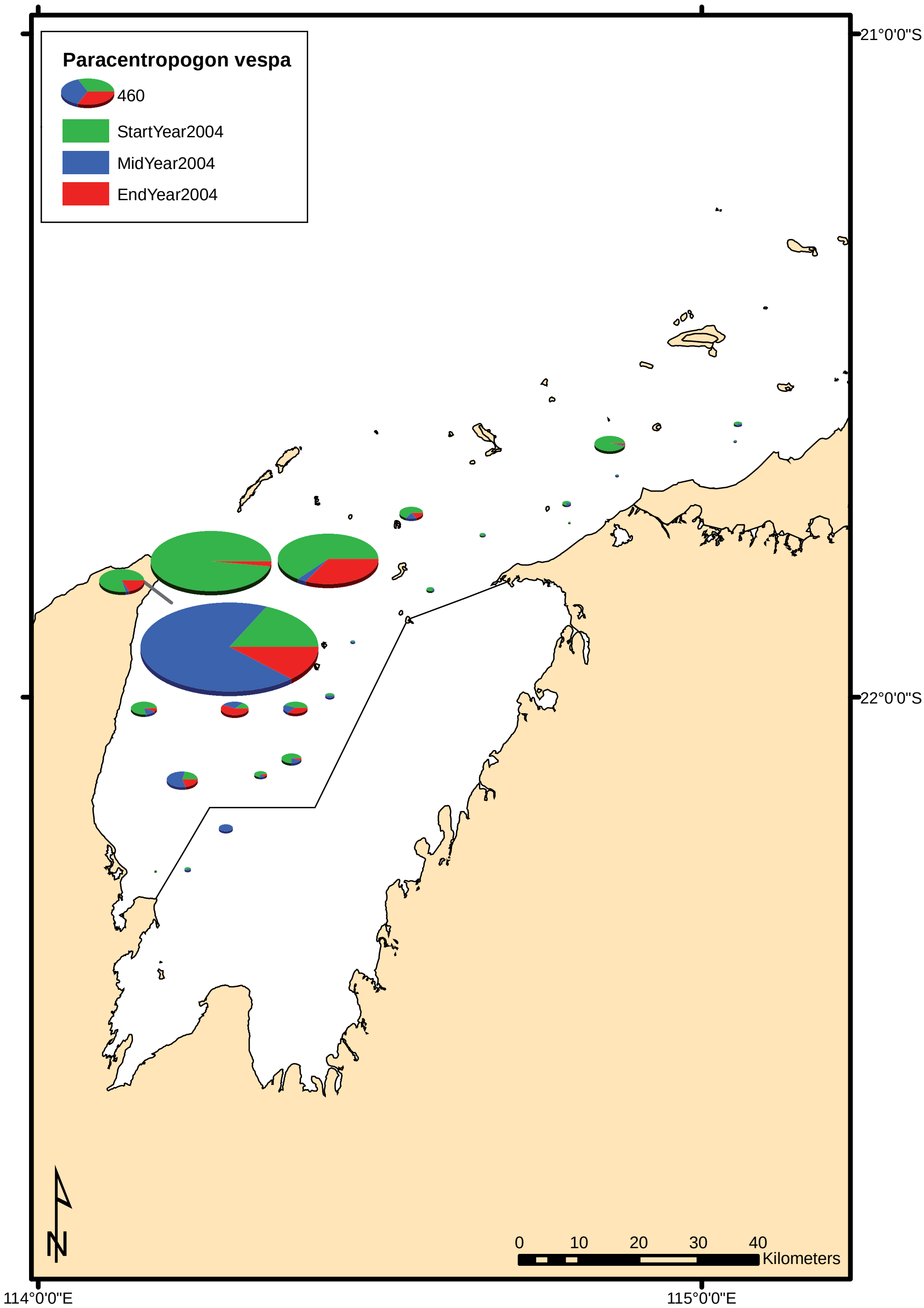

Figure 4.43 Seasonal and spatial distribution of *Paracentropogon vespa* in Exmouth Gulf and Onslow during 2004 sampling periods.

Asymmetrical goatfish (Upeneus asymmetricus) (Figure 4.44)

The asymmetrical goatfish was the third most abundant fish species in Exmouth Gulf and Onslow and occurs at all sites. It was most abundant in the north west of Exmouth Gulf, and was moderately abundant in the central Gulf and offshore from Onslow. In all areas except the northwest, the general pattern was for an increase in abundance in the middle of the year, followed by a decline towards the end of the year. In the northwest there was an increase in abundance by the end of the year.

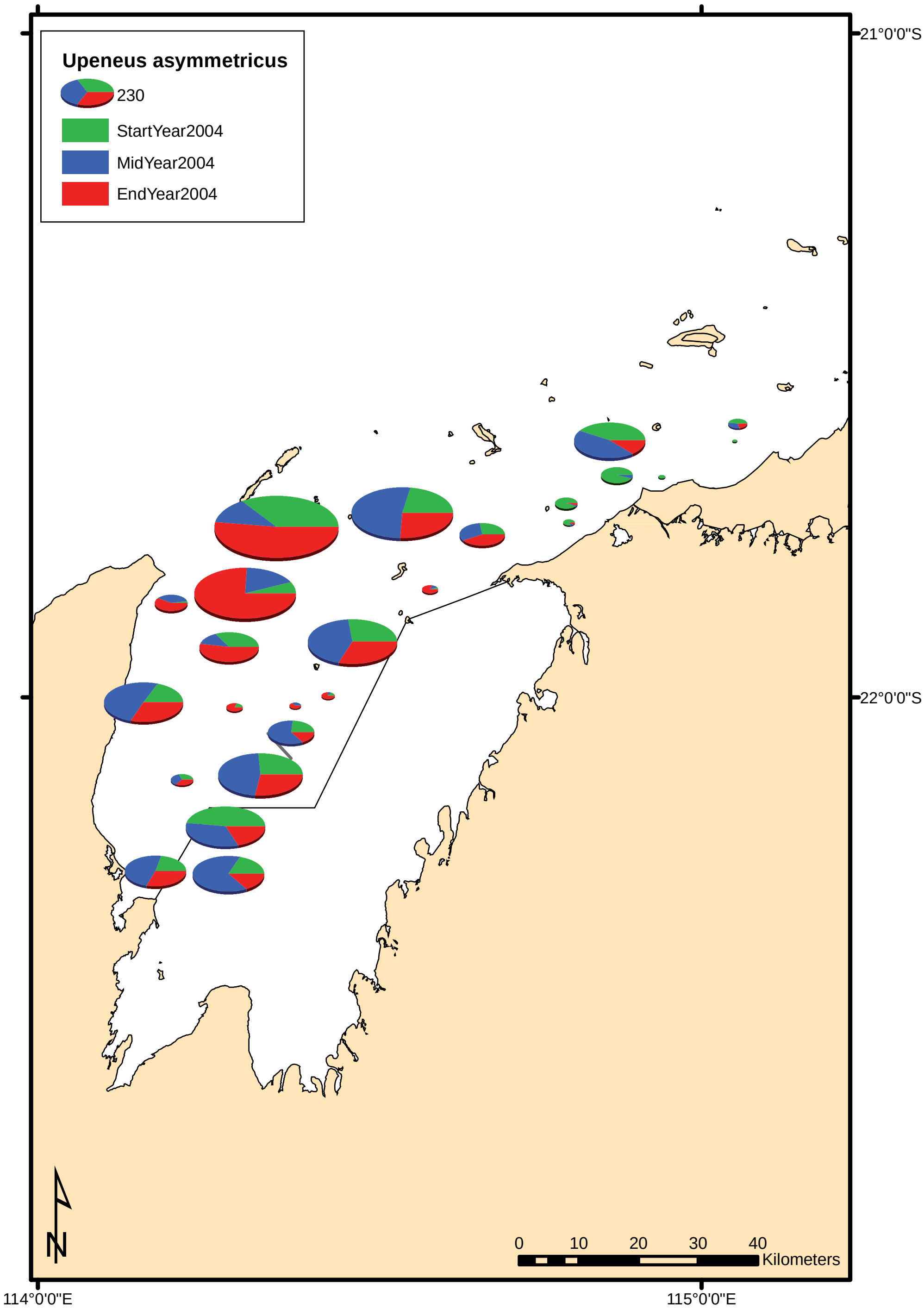

Figure 4.44 Seasonal and spatial distribution of *Upeneus asymmetricus* in Exmouth Gulf and Onslow during 2004 sampling periods.

Rusty flathead (Inegocia japonica) (Figure 4.45)

The rusty flathead was the fourth most abundant fish species in Exmouth Gulf and Onslow and occurs at all sites. Its abundance appears to be relatively evenly spread across the region. At the majority of sites it shows a steady decline in abundance through the year, but in the north west and central Gulf there was a marked increase in abundance by the end of the year.

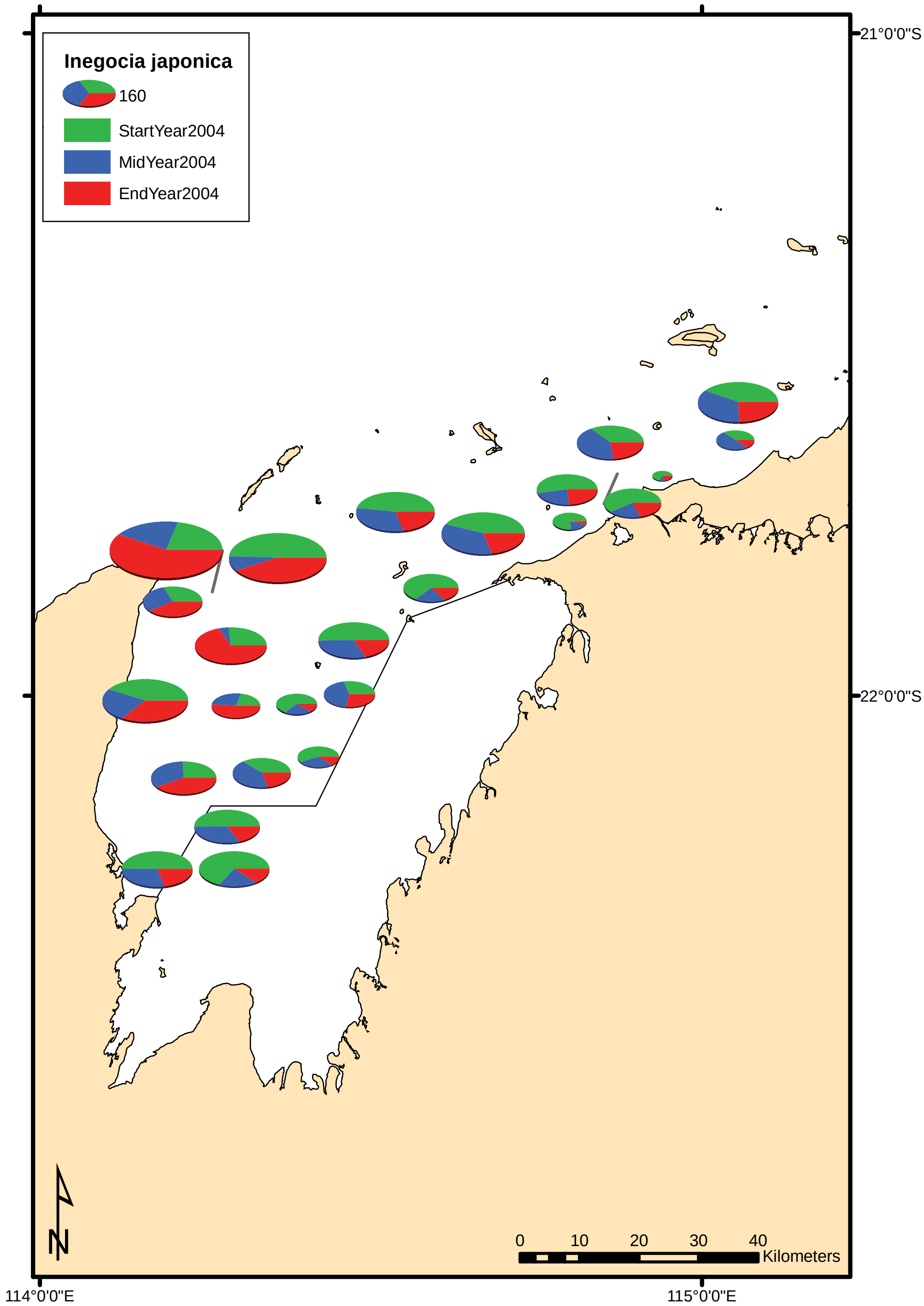

Figure 4.45 Seasonal and spatial distribution of *Inegocia japonica* in Exmouth Gulf and Onslow during 2004 sampling periods.

Gross's stinkfish (Calliurichthys grossi) (Figure 4.46)

Gross's stinkfish was the fifth most abundant fish species in Exmouth Gulf and Onslow and occurs at all sites. It was most abundant in the north west of Exmouth Gulf. The patterns of abundance were variable, but generally the sites along the eastern half of Exmouth Gulf and in Onslow show a trend towards increasing abundance in the middle of the year, followed by a decrease at the end of the year. In the central Gulf and northwest, however, there was a large increase in abundance at the end of the year.

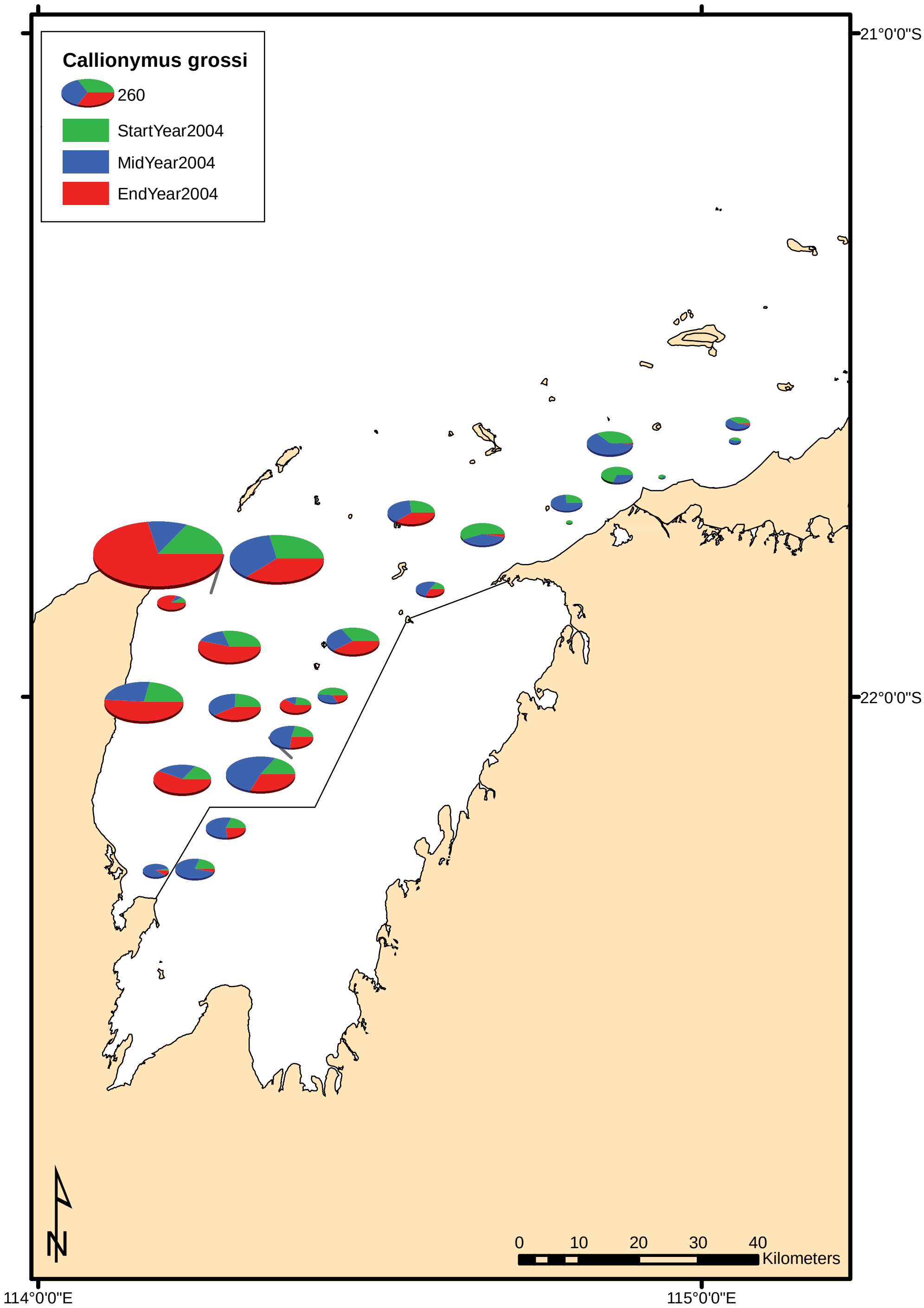

Figure 4.46 Seasonal and spatial distribution of *Calliurichthys grossi* in Exmouth Gulf and Onslow during 2004 sampling periods.

Hair-finned leatherjacket (Paramonacanthus choirocephalus) (Figure 4.47)

The hair-finned leatherjacket was the sixth most abundant species of fish in Exmouth Gulf and Onslow and was found at all survey sites. Its abundance was fairly evenly spread with most abundant sites in the northwest, southeast and offshore from Onslow. Sites along the eastern half of Exmouth Gulf and in Onslow show little decline in abundance in the middle of the year, but greater decline by the end of the year. In the northwest sites there was an increase in abundance in the middle of the year.

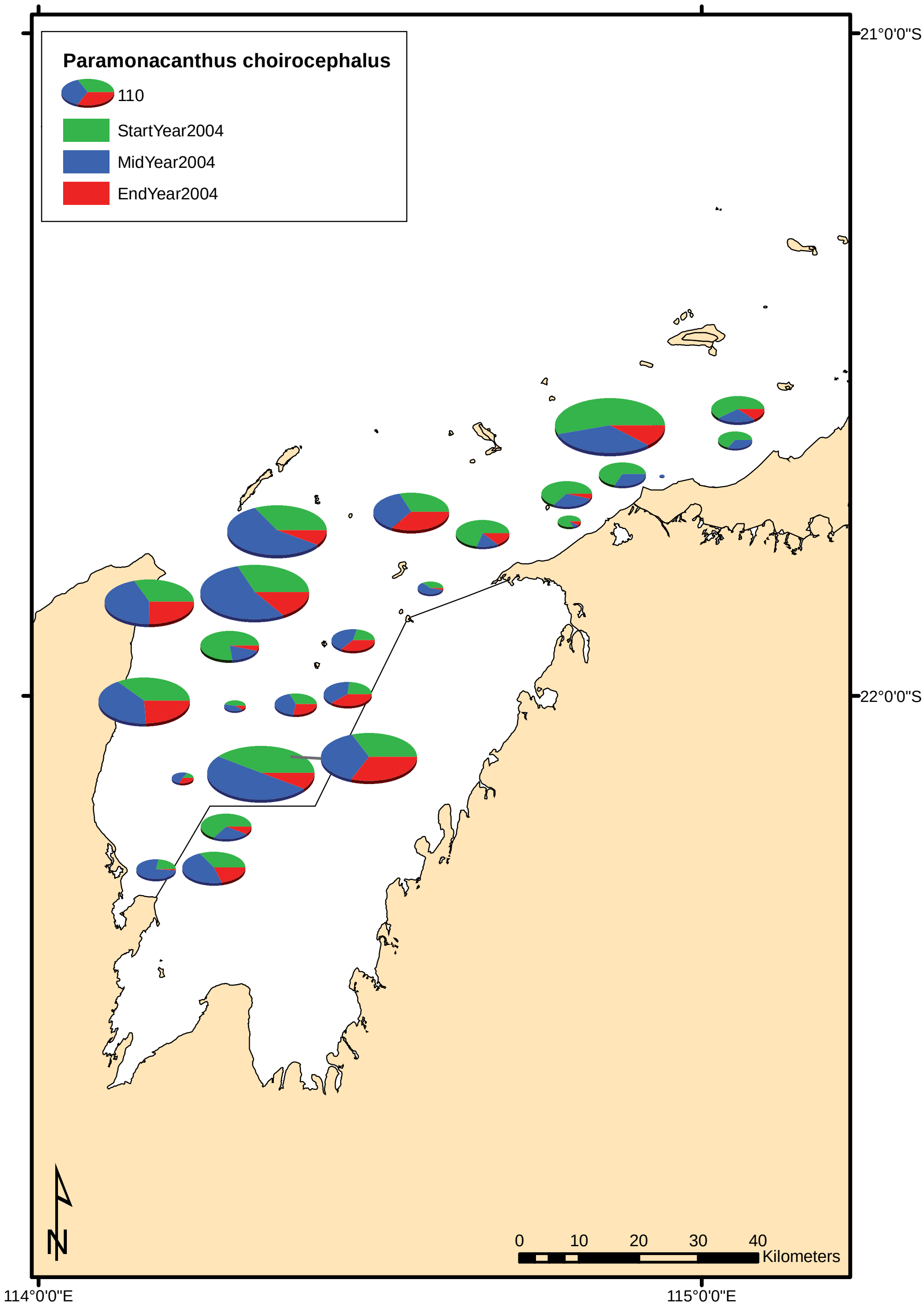

Figure 4.47 Seasonal and spatial distribution of *Paramonacanthus choirocephalus* in Exmouth Gulf and Onslow during 2004 sampling periods.

Western butterfish (Pentapodus vitta) (Figure 4.48)

The western butterfish was the ninth most abundant species of fish in Exmouth Gulf and Onslow and was found at all survey sites with little change in abundance through the year.

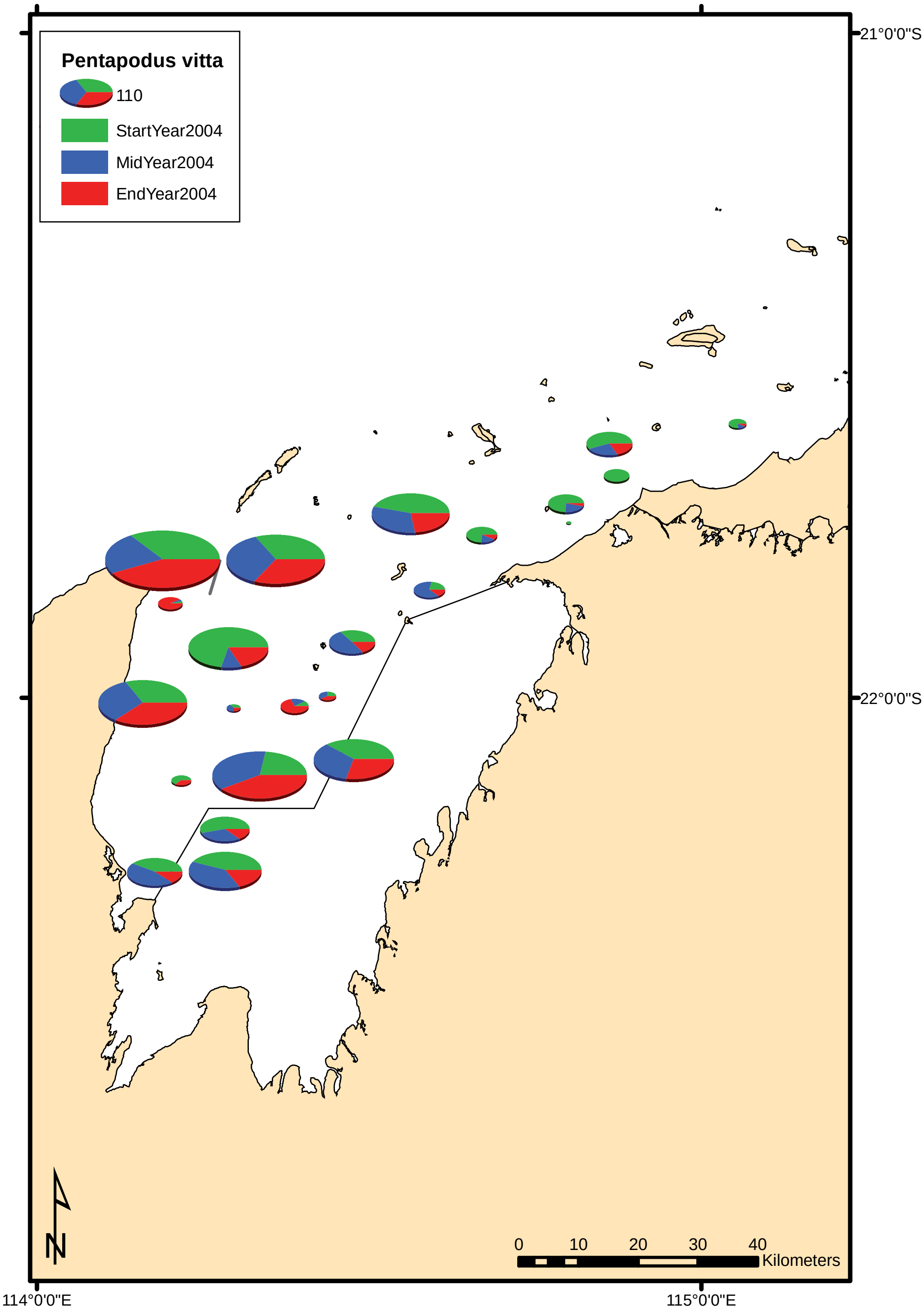

Figure 4.48 Seasonal and spatial distribution of Pentapodus vitta in Exmouth Gulf and Onslow during 2004 sampling periods.

Large-scaled lizardfish (Saurida undosquamis) (Figure 4.49)

The large-scaled lizardfish was the sixteenth most abundant species of fish in Exmouth Gulf and Onslow and was found at all survey sites. Its abundance was relatively evenly spread throughout the region. Abundance increases in the central trawl grounds areas in mid to end of the year.

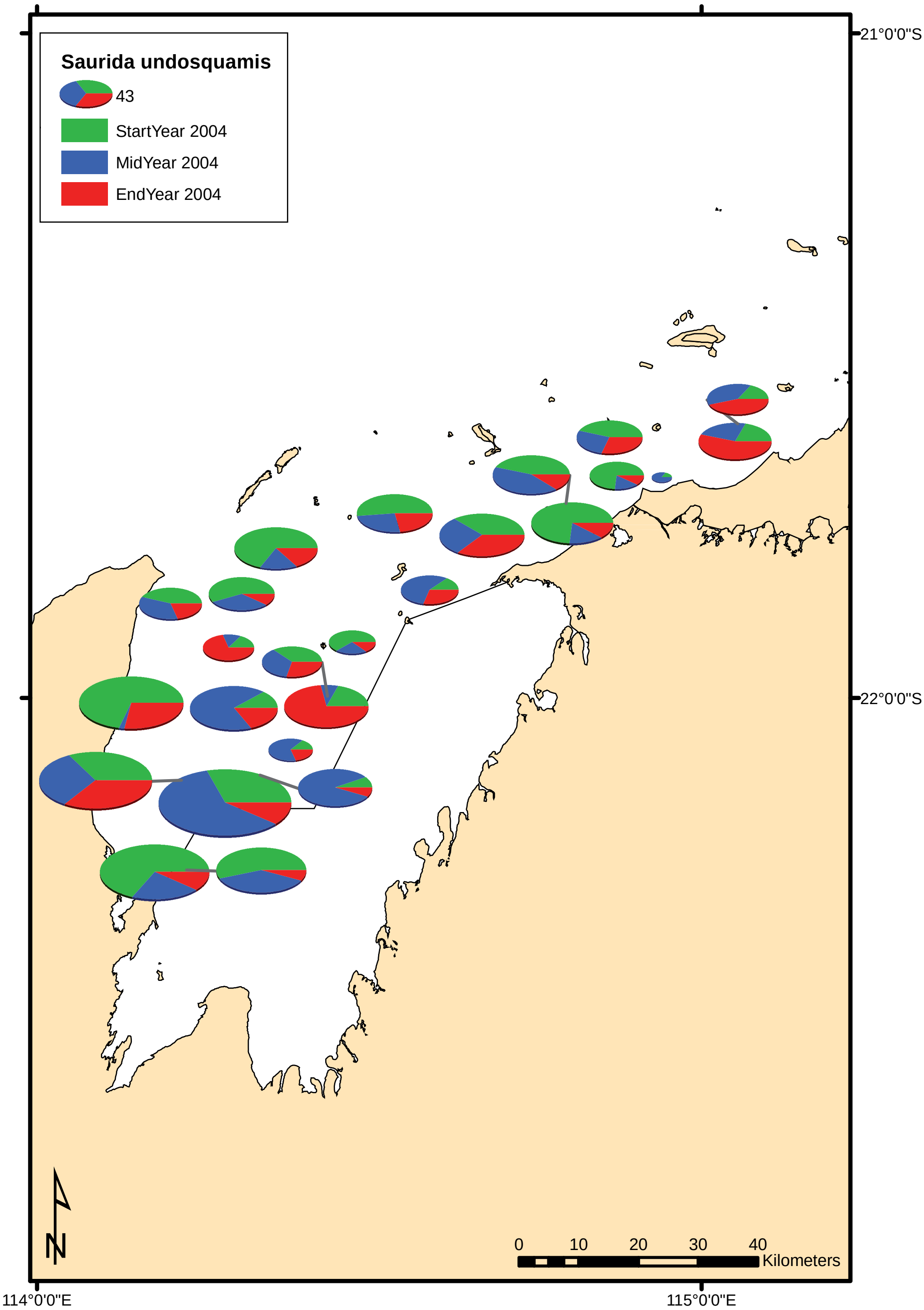

Figure 4.49 Seasonal and spatial distribution of *Saurida undosquamis* in Exmouth Gulf and Onslow during 2004 sampling periods.

Threadfin emperor (Lethrinus genivittatus) (Figure 4.50)

The threadfin emperor was the fourteenth most abundant species of fish in Exmouth Gulf and Onslow. It was found at all sites except for one in the central Gulf and three sites at Onslow. It was relatively abundant at sites 10, 19 and 26, and in low abundance elsewhere. A seasonal decline in abundance was observed for some sites whilst others indicated an increase during the mid-season.

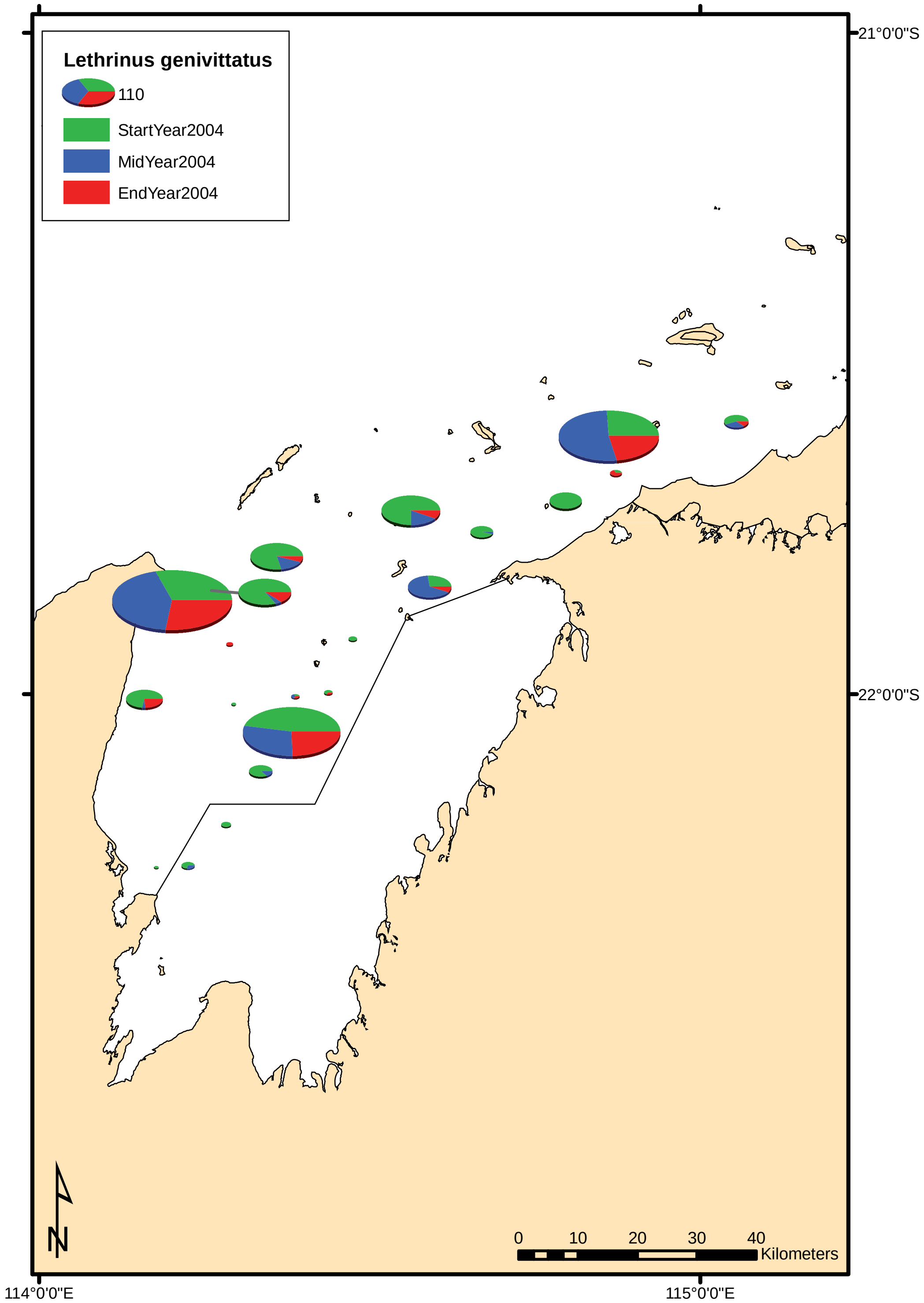

Figure 4.50 Seasonal and spatial distribution of *Lethrinus genivittatus* in Exmouth Gulf and Onslow during 2004 sampling periods.

Trumpeter (Pelates quadrilineatus) (Figure 4.51)

The trumpeter was not among the 20 most abundant species in the region. It was widespread throughout Exmouth Gulf, but was absent from three sites near Onslow and one site in the northwest. Its abundance varied between sites and seasons. This species tends to form large schools, and these varied patterns may indicate migration of schools.

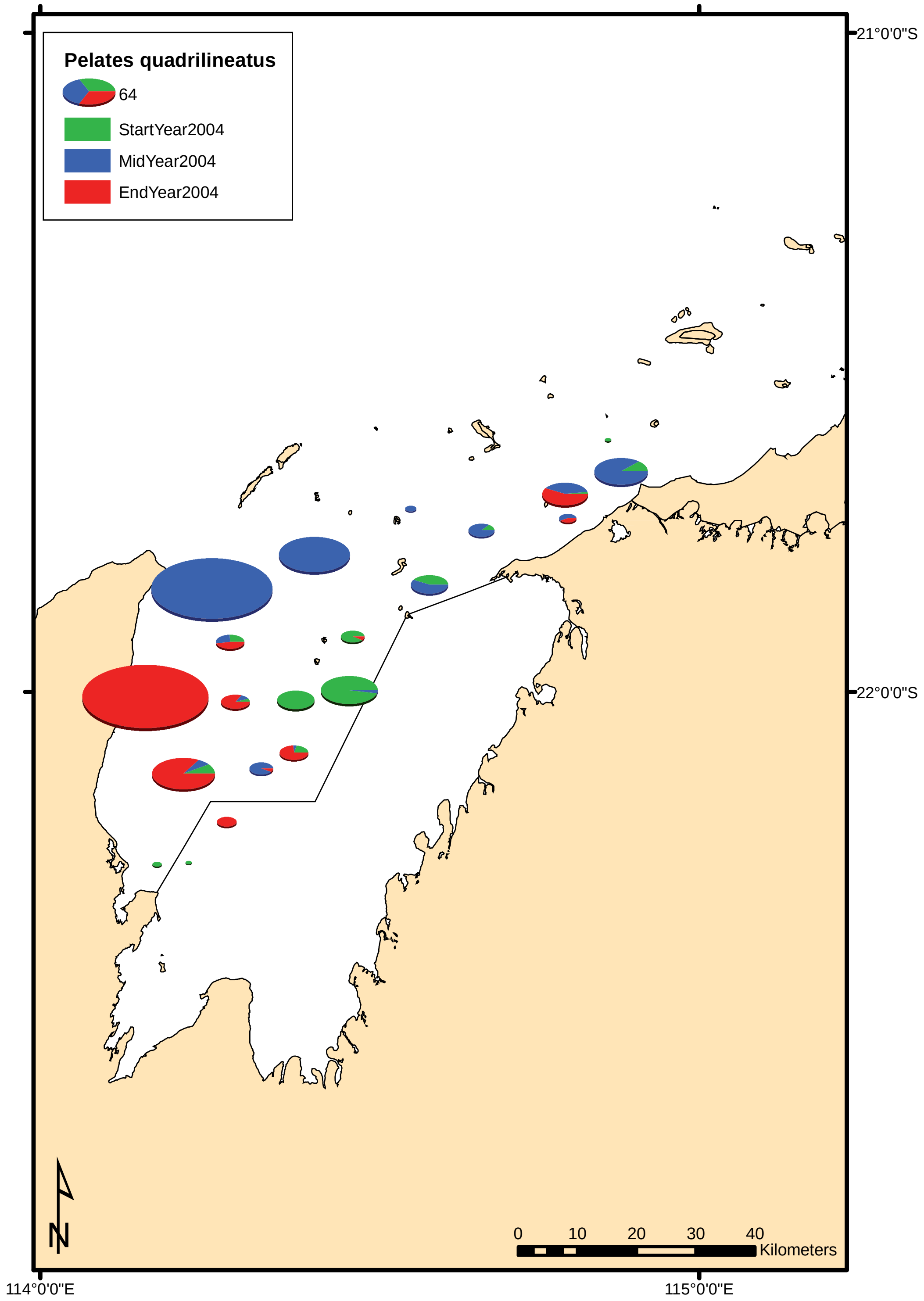

Figure 4.51 Seasonal and spatial distribution of *Pelates quadrilineatus* in Exmouth Gulf and Onslow during 2004 sampling periods.

Brown tiger prawn (Penaeus esculentus) (Figure 4.52)

The brown tiger prawn was the most abundant invertebrate species in Exmouth Gulf and Onslow. The abundance of brown tiger prawns in 2004 was higher than average and their distribution was widespread, being abundant in all sites except for a small number of sites in the north west of Exmouth Gulf. In the majority of sites in the south and eastern parts of Exmouth Gulf and in the northeast, abundance was particularly high at the start of the season, and then declines markedly over the year. At two sites near Onslow and some sites in the central Gulf there was an increase in abundance in the middle of the year, followed by a further increase at the end of the year, especially in the north west of Exmouth Gulf.

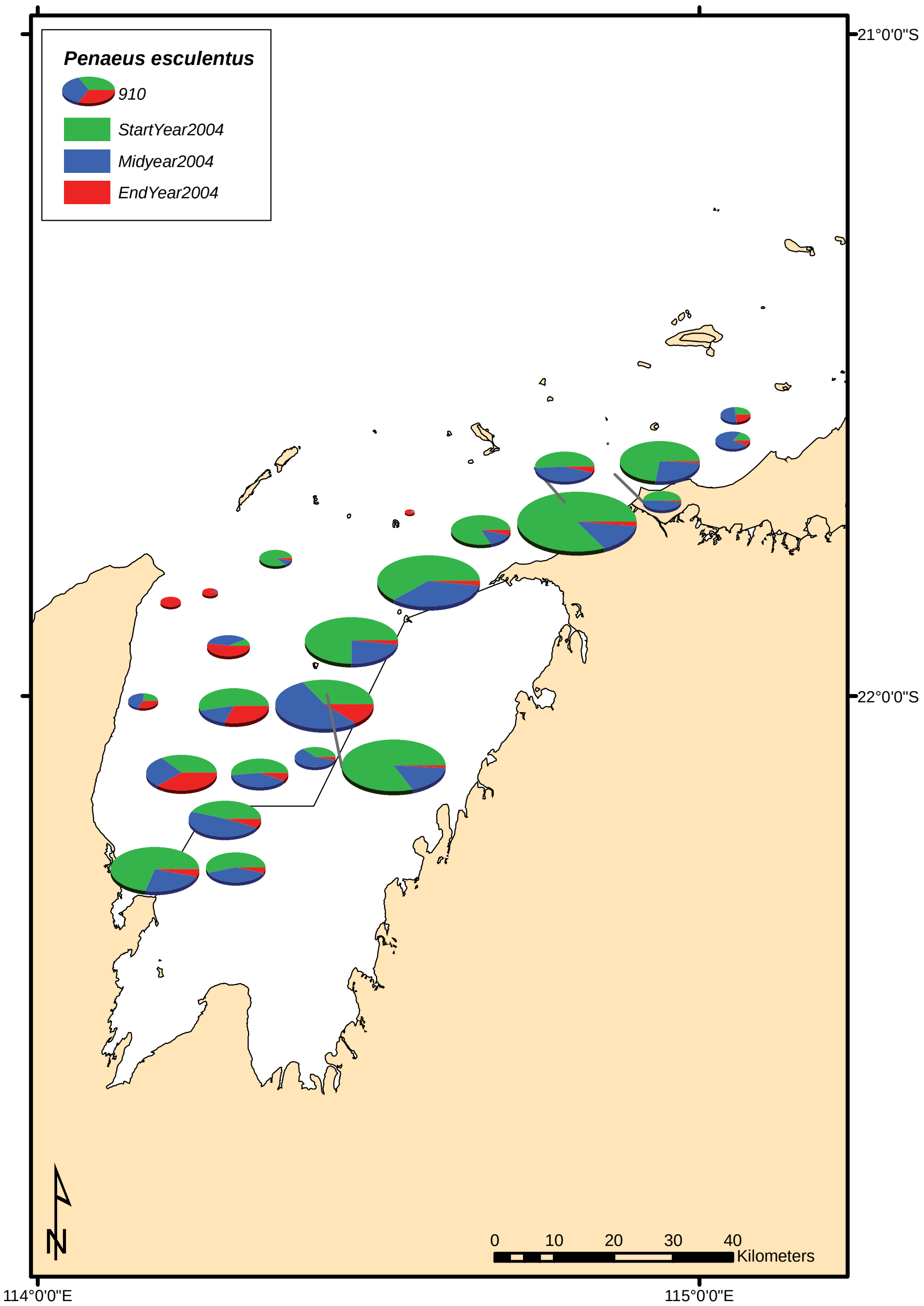

Figure 4.52 Seasonal and spatial distribution of *Penaeus esculentus* in Exmouth Gulf and Onslow during 2004 sampling periods.

Western king prawn (Penaeus latisulcatus) (Figure 4.53)

The western king prawn was the second most abundant invertebrate species in Exmouth Gulf and Onslow, and was found at all sites. This prawn was more abundant at the more northerly sites, which are known to be its preferred habitat. In Onslow and the north east of Exmouth Gulf they were most abundant at the start of the year, then decline markedly towards the middle of the year, with none left by the end of the year. In the southern and central parts of Exmouth Gulf there was maximum abundance in the middle of the year, followed by a clear decline. The northwest was the only region that has a reasonable abundance at the end of the year.

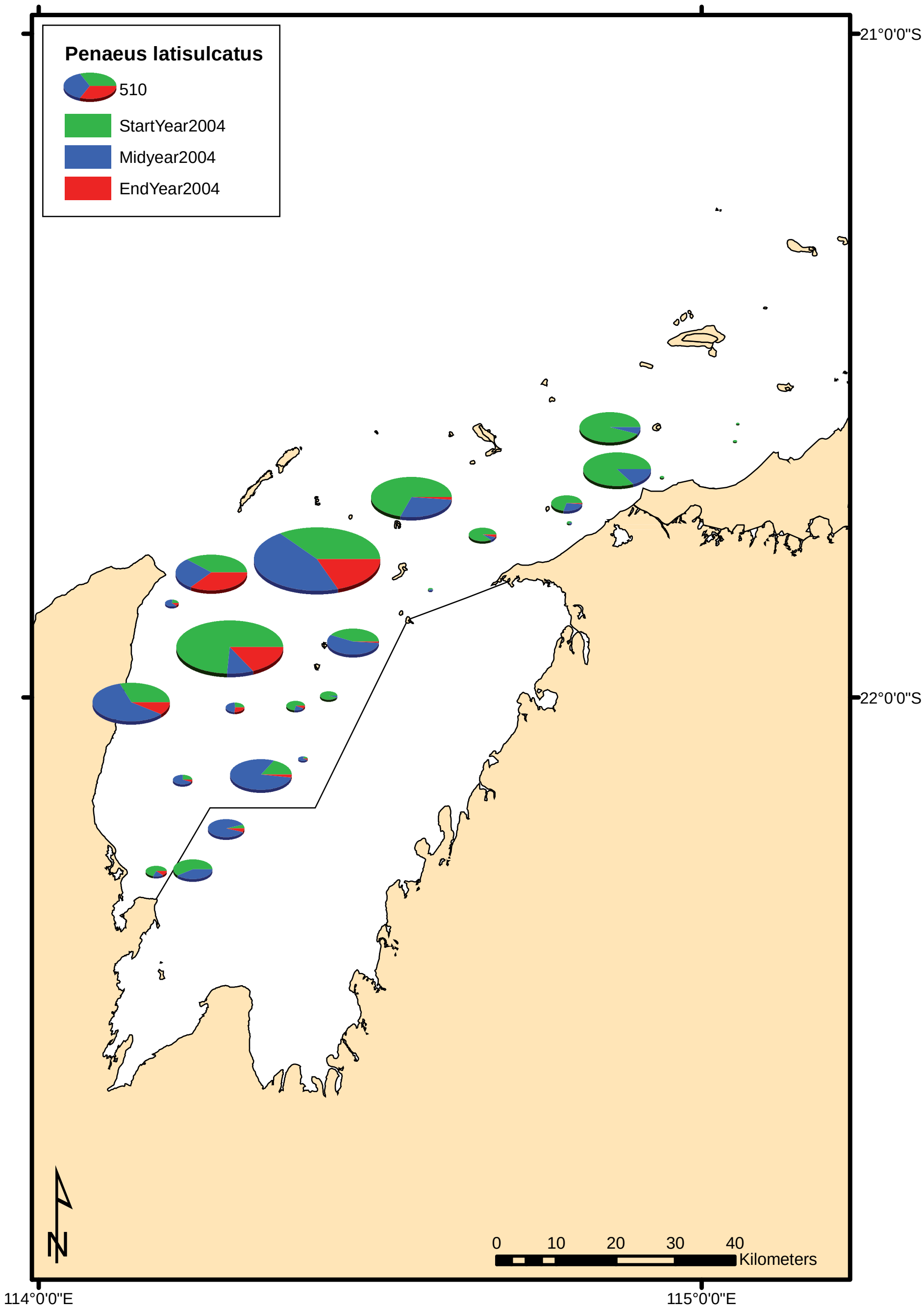

Figure 4.53 Seasonal and spatial distribution of *Penaeus latisulcatus* in Exmouth Gulf and Onslow during 2004 sampling periods.

Endeavour prawn (Metapenaeus endeavouri) (Figure 4.54)

The endeavour prawn was the third most abundant invertebrate species in Exmouth Gulf and Onslow, and was found at all sites. Abundance tapers off towards the northwest and Onslow sites. They were most abundant at the start of the year in the Onslow region and the southern and eastern parts of Exmouth Gulf; abundance then declines during the rest of the year. In the central and northwest Gulf regions abundance was greatest in the middle of the year at some sites and end of the year at other sites.

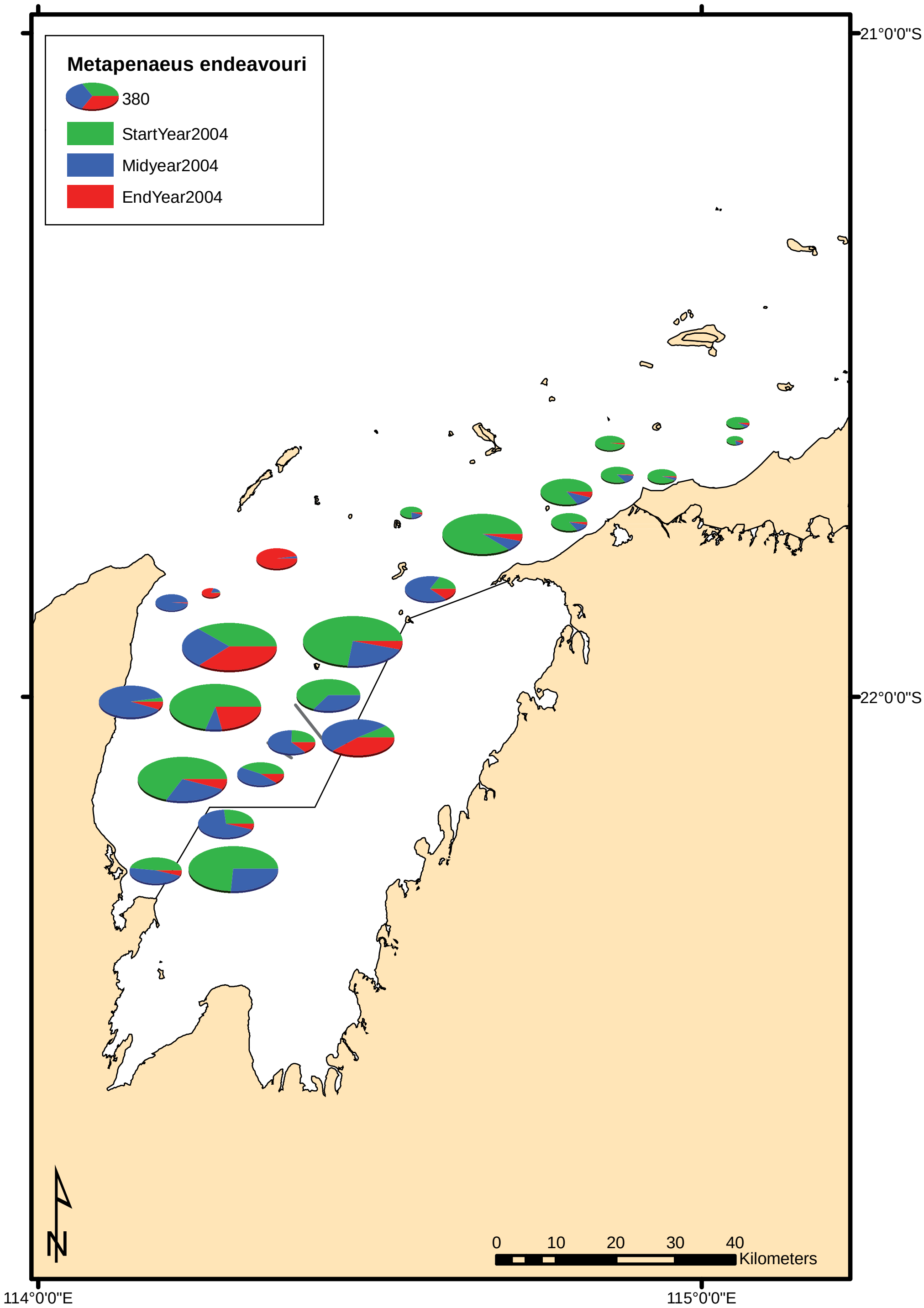

Figure 4.54 Seasonal and spatial distribution of *Metapenaeus endeavouri* in Exmouth Gulf and Onslow during 2004 sampling periods.

Swimmer crab (Portunus tenuipes) (Figure 4.55)

The swimmer crab *Portunus tenuipes* was the fifth most abundant invertebrate species in Exmouth Gulf and Onslow. It was widespread, but absent from two sites in the eastern side of Exmouth Gulf and three sites at Onslow. It was most abundant in the northern and western sites. In the majority of sites it was very abundant at the start of the season, then numbers drop rapidly towards the middle and end of the year.

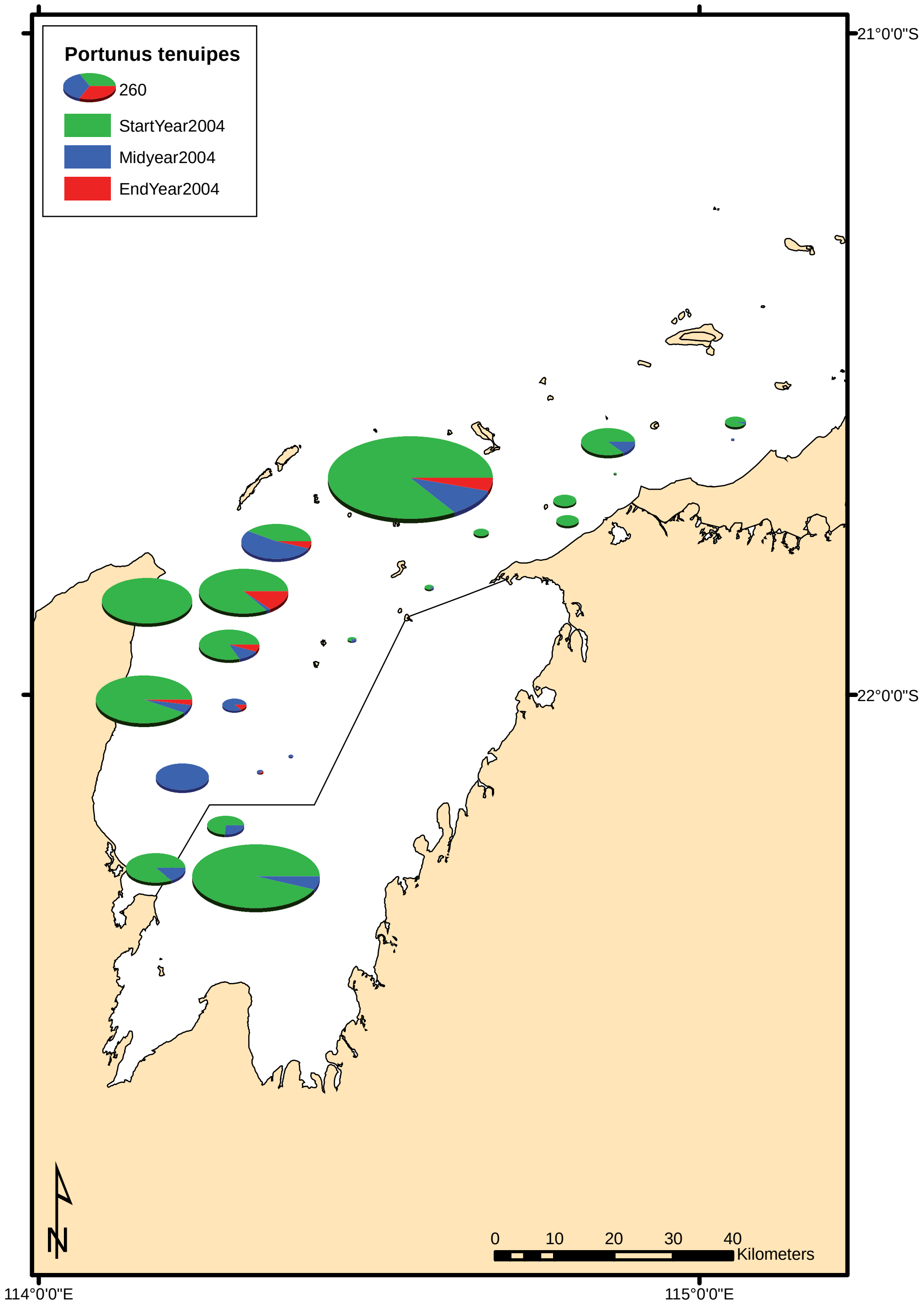

Figure 4.55 Seasonal and spatial distribution of *Portunus tenuipes* in Exmouth Gulf and Onslow during 2004 sampling periods.

Blue swimmer crab (Portunus pelagicus) (Figure 4.56)

The blue swimmer crab was the seventh most abundant invertebrate species in Exmouth Gulf and Onslow, and was found at all sites. It was fairly evenly abundant at most sites in the region, with maximum abundance in the north east of Exmouth Gulf and western Onslow fishery. It was most abundant at the start of the season, with a marked decline by mid-year followed by a further decline at the end of the year.

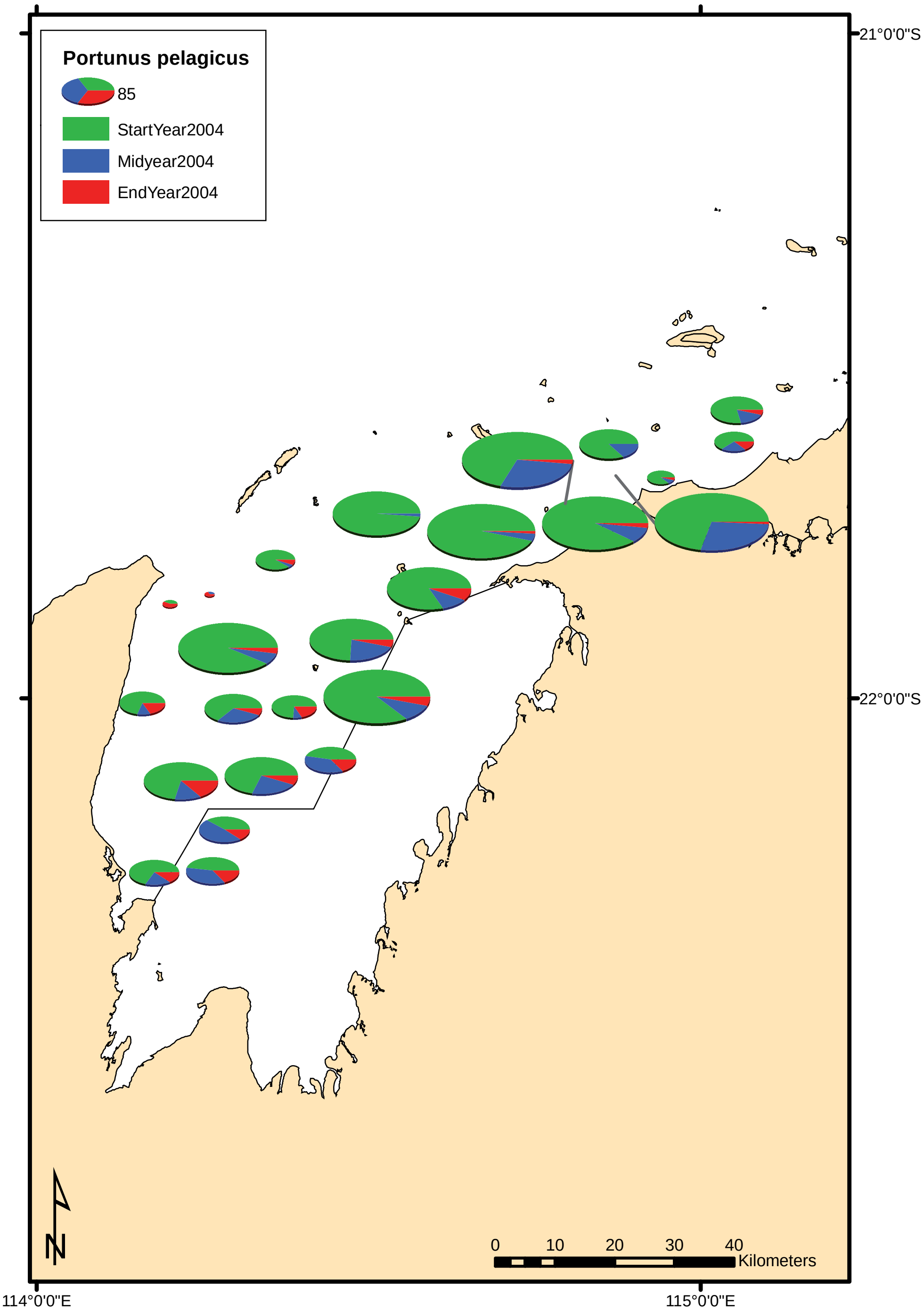

Figure 4.56 Seasonal and spatial distribution of *Portunus pelagicus* in Exmouth Gulf and Onslow during 2004 sampling periods.

Ascidians (Ascidiacea) (Figure 4.57)

Ascidians were the twenty-first most abundant group of invertebrates in Exmouth Gulf and Onslow, but this includes several species in the phylum, not a single species as in other examples. It was present at all sites except for one in Onslow, with fairly low abundance overall, but reaching a maximum in the north west of the Gulf and south west of Onslow. In the Onslow region and the south of the Gulf the abundance declines markedly throughout the year, but in parts of the central and north west Gulf the abundance remains relatively high at the end of the year.

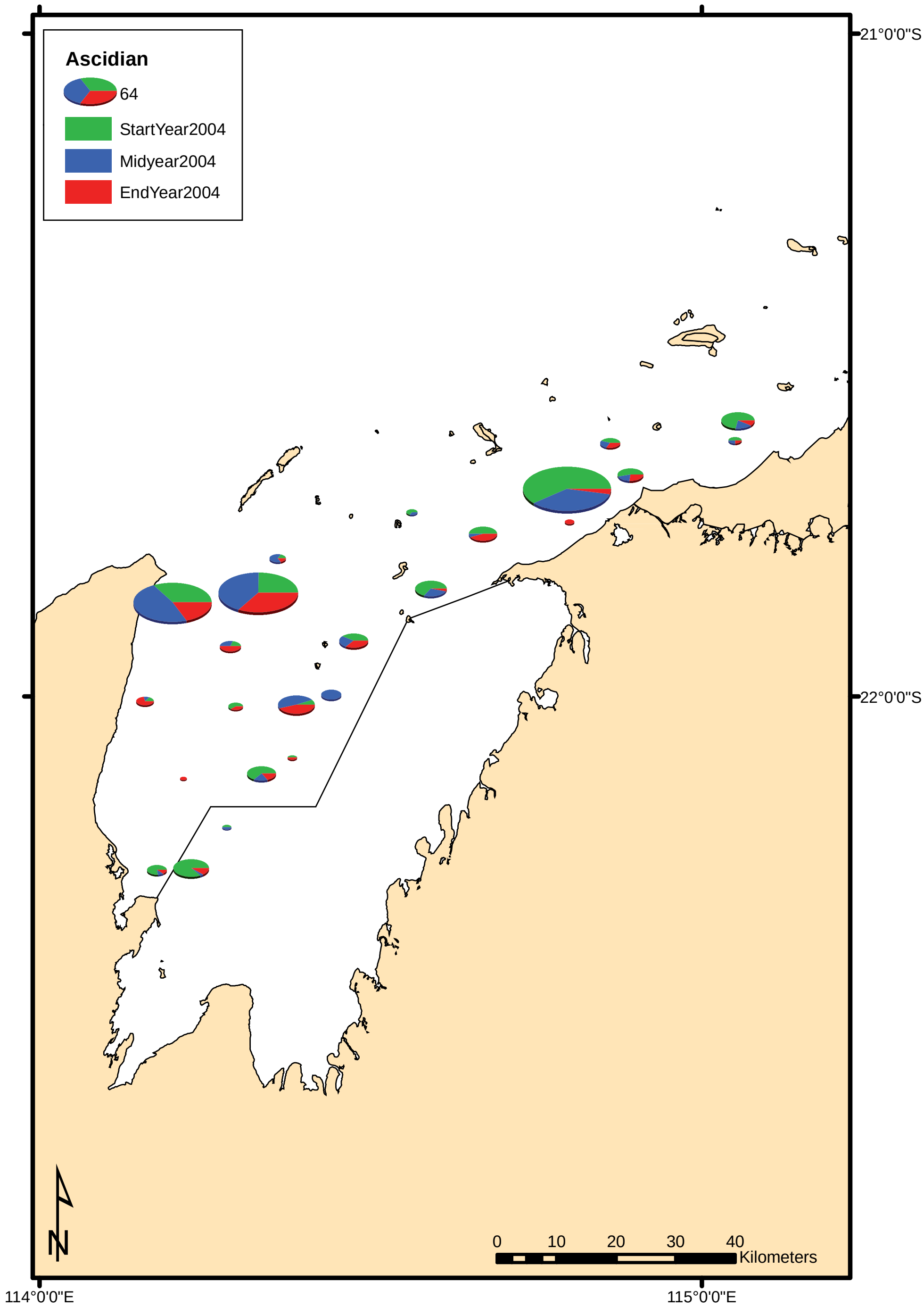

Figure 4.57 Seasonal and spatial distribution of Ascidiacea in Exmouth Gulf and Onslow during 2004 sampling periods.

Fan scallop (Annachlamys flabellata) (Figure 4.58)

The fan scallop was the thirteenth most abundant invertebrate species in Exmouth Gulf and Onslow, but has a restricted distribution, only occurring at ten sites. Of these sites, it was extremely abundant only at site 14 in the north west of the Gulf. At site 14 it was abundant at the start of the season, then numbers decline markedly towards the end of the year.

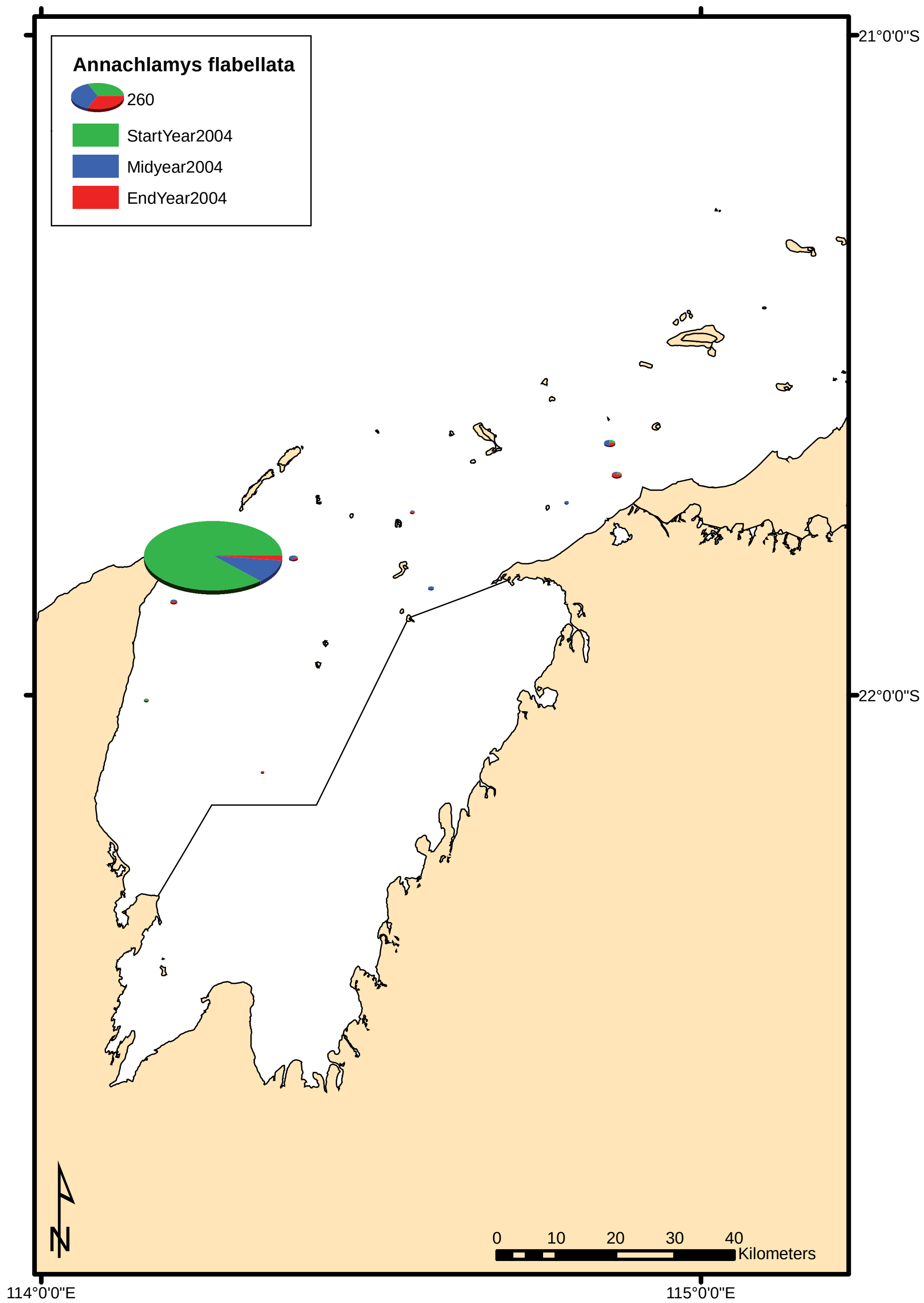

Figure 4.58 Seasonal and spatial distribution of *Annachlamys flabellata* in Exmouth Gulf and Onslow during 2004 sampling periods.

Pencil urchin (Prionocidaris bispinosa) (Figure 4.59)

The pencil urchin is the sixteenth most abundant invertebrate species in Exmouth Gulf and Onslow. It only occurs at 17 sites, being absent form three sites in the central Gulf and four sites in the northern region. The distribution of abundance was very patchy, only showing high abundance at one site in the northwest and two in the east. It occurs in large numbers at sites 5 and 19 in the eastern Gulf at the start of the year, then numbers decline rapidly, with very few by the end of the year. This pattern could be due to a heavier trawl gear setting being used for these two sites in the first trip at the start of the season. The gear configuration was modified after this and therefore this period may not be indicative of actual abundance during normal trawl operations for this species. In the northwest it occurs in high abundance in both the middle and end of the year.

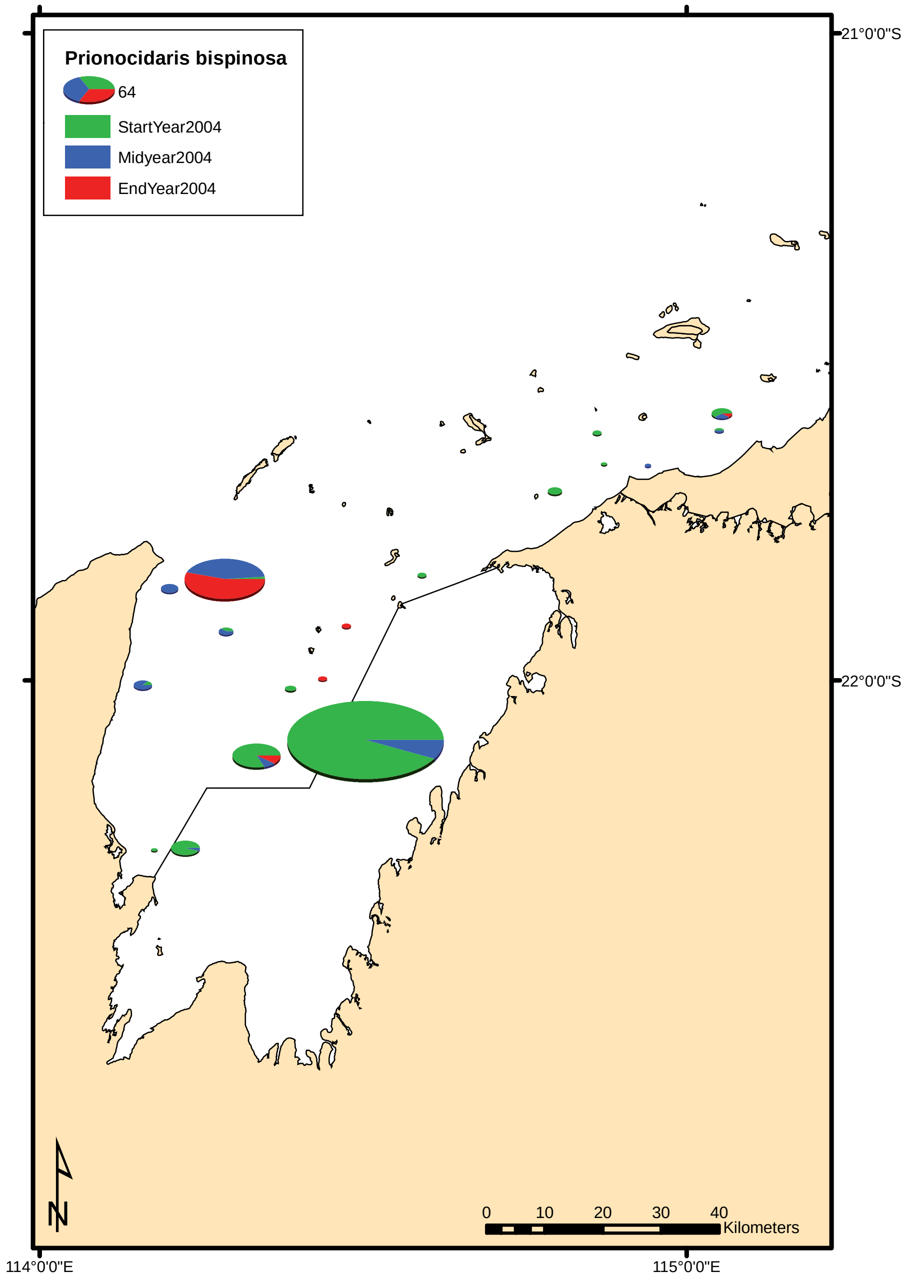

Figure 4.59 Seasonal and spatial distribution of *Prionocidaris bispinosa* in Exmouth Gulf and Onslow during 2004 sampling periods.

4.3.8 Faunal abundance and levels of trawl effort in Exmouth Gulf

4.3.8.1 Power analysis of fish abundance

Analysis of variance of overall Exmouth Gulf fish family catch rates (square root transformed) indicated a highly significant effect from previous trawl effort, $F_{3,568} = 19.51$, p=0.000. For this observed F value the observed power of the ANOVA test at 5%, was 98% and at 10% was 97%. This indicates that sample size was sufficient in Exmouth to detect differences. Post-hoc tests for trawl effort indicated that high trawl effort (Trawl Effort Category 3) had significantly lower catch rates than the other levels of trawl effort, but the highest catch rates were associated with both moderate trawl effort (Category 2) and no trawl effort which were inseparable.

4.3.8.2 Seasonal abundance of selected species with trawled effort

For the invertebrates, all groups were widespread between trawled and untrawled areas (Figure 4.61). The Porifera, were the only group to be in higher abundance in the untrawled areas of Exmouth Gulf and Onslow but only at the start of the season.

Most common fish species occurred on both trawled and untrawled sites and most showed no obvious trend with trawl effort. Only *P. vespa* and *C. grossi* had significantly high numbers at sites with high trawl effort (Figure 4.60). *P. vespa* did not show any seasonal trend although *C. grossi* abundance was high at the end of the season. The only species that had significantly high abundance in Exmouth Gulf untrawled grounds was *L. genivittatus* and *E. grandisquama,* however these species had high variability on the untrawled sites.

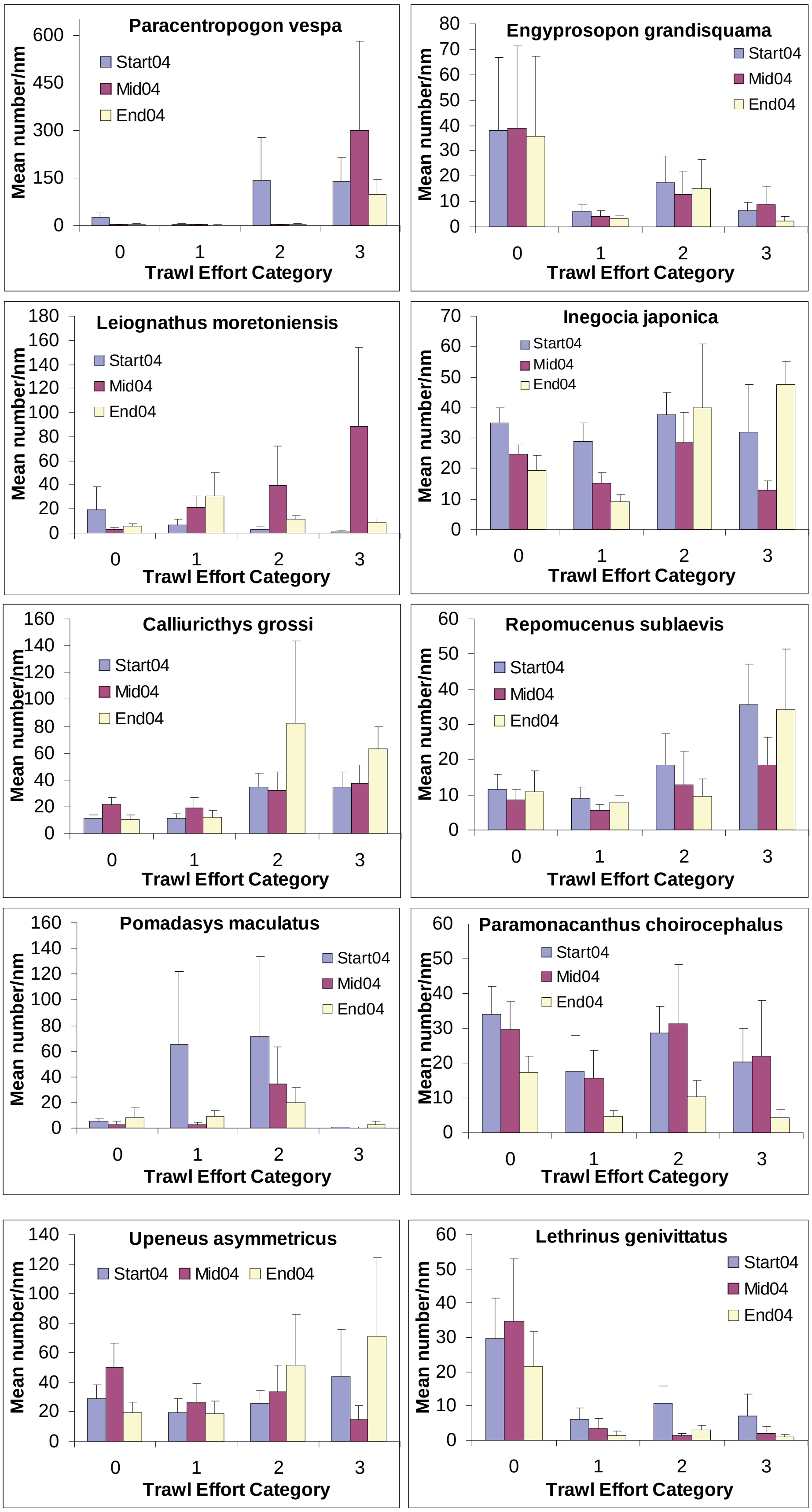

Figure 4.60 Mean abundance (+ S.E.) of main fish species in Exmouth Gulf and Onslow during 2004 for sites for levels of trawl effort.

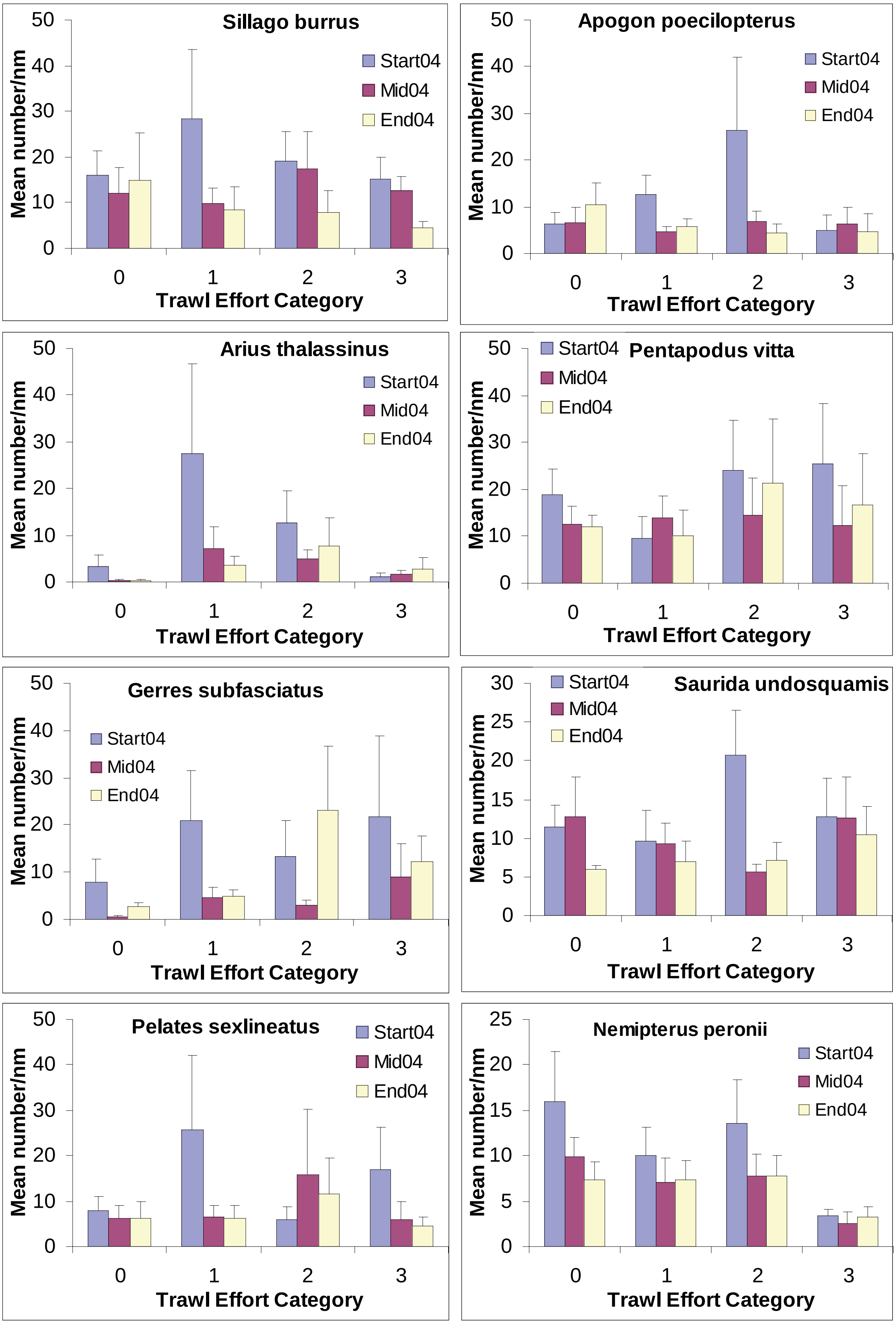

Figure 4.60 cont. Mean abundance (+ S.E.) of main fish species in Exmouth Gulf and Onslow during 2004 for site for levels of trawl effort.

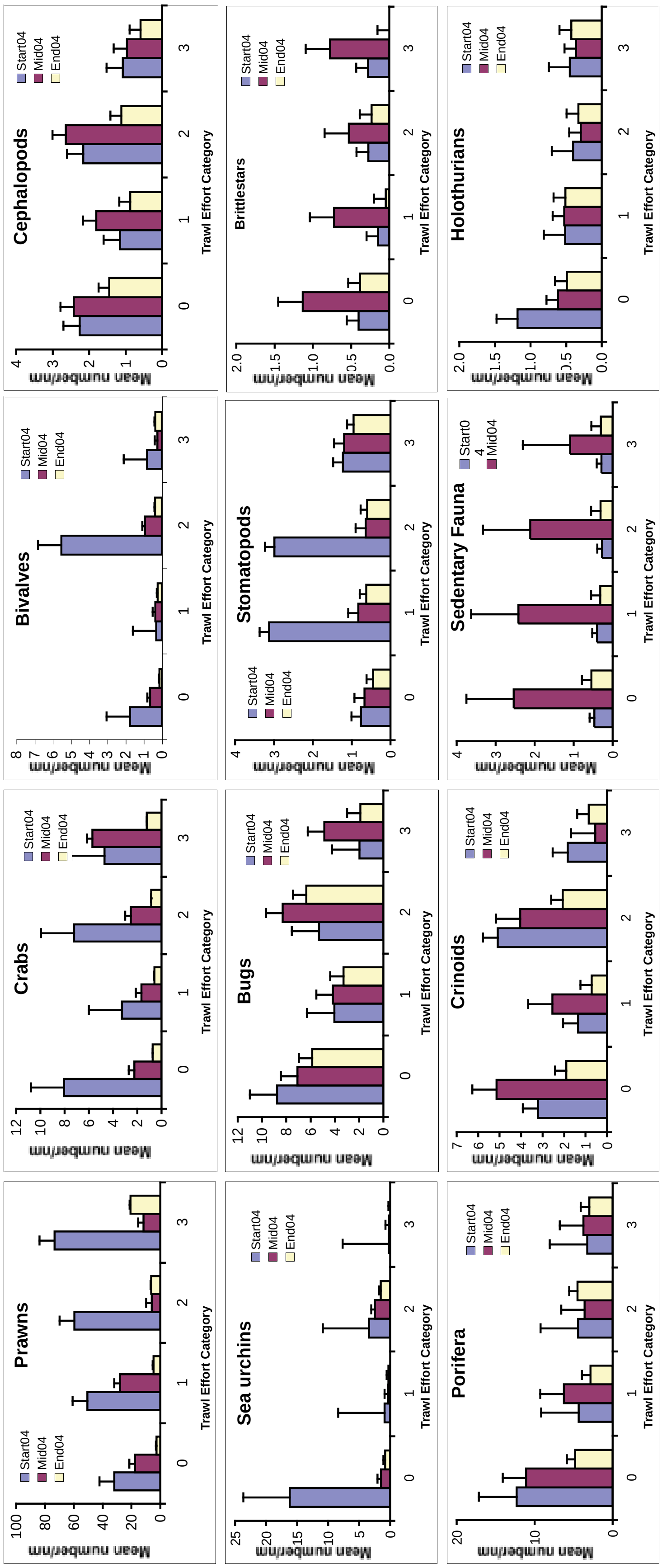

Figure 4.61 Mean abundance (+ S.E.) of invertebrate groups in Exmouth Gulf and Onslow during 2004 for sites fpr levels of trawl effort.

4.4 DISCUSSION

To address seasonal and annual variation in abundance and diversity measures, sampling in Shark Bay was undertaken over four time periods representing the end of 2002, and the start, mid and end of the 2003 fishing season. In addition, three sites were sampled in early 2004 to allow for further assessment of annual variability at sites. Day-night sampling was also undertaken at four sites (two trawled and two untrawled/lightly trawled) to examine diurnal variation in faunal assemblages and abundance. For Exmouth Gulf and Onslow, three sampling periods were undertaken in 2004 representing pre-, mid and end of season. This sampling has provided some understanding of the dynamics and high variability within trawl bycatch species spatially, seasonally and annually.

In Shark Bay there was a seasonal decline in fish abundance which was primarily attributed to reductions of five very abundant species *L. genivittatus, P. choirocephalus, P. quadrilineatus, T. pallimaculatus* and *U. asymmetricus.* There was only a significant difference in fish abundance between trawled and untrawled sites for the start of 2003 with much higher abundance in trawled sites. This period also showed high variability in abundance which was mostly due to very high numbers of the schooling species *P. quadrilineatus.* For Exmouth Gulf, although a small seasonal decline was observed, fish abundance was not significantly different between seasons for either trawled or untrawled sites but a significant decline was evident between the start of 2004 and the end of 2004.

For fish species in Shark Bay, the species richness and evenness showed seasonal variation in the untrawled sites whilst there was only a significant difference in richness and evenness for the end of 2002 and the start of 2003 for trawled sites. In Exmouth Gulf for fish species, there was a significant difference in species richness in both trawled and untrawled sites with a seasonal decline being evident whereas all other diversity measures were similar throughout the year.

For invertebrate species abundance in Shark Bay in 2003, trends indicated an initial reduction between the start and mid season but no further decline was observed at the end of the season. At the start of the 2003 season, a significantly higher abundance was observed in the trawled sites but during other times the differences between trawled and untrawled sites were not significant. The high abundance and high variability at the start of the season was attributed to the very abundant species *A. balloti*, *P. latisulcatus*, *P. rubromarginatus* and *H. pallida*. *A. balloti* and *P. latisulcatus* are both targeted commercially especially between the start and mid season. The decline in abundance occurs at both trawled and untrawled sites and in trawled sites was likely attributed to depletion by trawling, natural mortality and migration. For the untrawled sites only the latter two are occurring. In Exmouth Gulf, there was a significant seasonal decline between start, mid and end of 2004 for both trawled and untrawled sites. There was no significant difference between trawled and untrawled sites for start and mid 2004 but a significantly higher abundance in trawled sites in the end of 2004. The decline between start and mid 2004 can be mainly attributed to the large decline observed in prawn abundances due to fishing during the season and migration out of inshore areas into the central trawl grounds during this period.

For the diversity measures for invertebrates in Shark Bay the species evenness showed seasonal variation for the untrawled sites whereas only species richness was higher at the end of 2003 for trawled sites. In Exmouth Gulf there was a significant difference in all the diversity measures in both trawled and untrawled sites. All four measures were higher in the untrawled sites.

For species richness, there was a seasonal decline whilst the other measures increased during the season.

Spatial and temporal variation was evident from those species of fish and invertebrates considered in detail. Most species were widespread and occurred at most sites sampled but the temporal patterns of abundance varied between species and for a species from site to site. Some species showed restricted distributions such as; *P. vespa* and *P. vitta* which was found primarily in the southern part of Shark Bay, *L. genivittatus* which was sampled primarily on the scallop trawl grounds in central Shark Bay, *Metapenaeopsis* spp. and *Photololigo* sp. which was found in much higher abundance in the deeper and oceanic waters of northern parts of Shark Bay, *P. vespa* which was found at much higher abundance only in the sites in NW Exmouth Gulf and *A. flabellata* which was only found in significant abundance at site 10 in NW Exmouth Gulf. Most of the species were sampled over all sampling periods with some exceptions such as *Lethrinus punctulatus*, which was quite widespread and abundant in Shark Bay at the end of 2002 but was only sampled in very low numbers at a few sites in 2003. These are a schooling species and strongly migratory.

Annual differences were observed in Shark Bay for species abundance and richness over five sampling periods spanning the end of 2002 to the start of 2004 however these differences were not consistent for species nor between sites and for the start of 2004 high variability was seen at the three sites sampled due to high variability of fish species *P. quadrilineatus, P. vitta, P. vespa, U. tragula, R. sublaevis, G. subfasciatus* and *L. leuciscus* and the scallop species *A. flabellata* and *A. balloti*. The overall abundance was significantly higher for some species in the start of 2004 compared to the start of 2003 indicating annual recruitment variability. This was particularly evident at site 21 which had a high abundance of *A. balloti*, a species that is renowned for its high variability (Joll and Caputi 1995). High natural annual variability of species abundance may mask any trawl impacts.

Diurnal differences were observed at the sites sampled and also spatial differences were observed for species distribution between the northern and southern sites selected in Shark Bay for the day-night trials. The key species that showed differences in diurnal catchability were fish families; Carangidae, Harpodontidae, Leiognathidae and Terapontidae which were significantly more abundant during the daytime where as Callionymidae, Monacanthidae, Mullidae and Sillaginadae were more abundant at night. These species would be more vulnerable to trawl impacts as most trawling occurs at night. However, all these families were also sampled in lower numbers during both day and night. Of the 121 species of fish caught during day/night trials in the Great Barrier Reef (Poiner et al. 1998), 17 species (families Apogonidae, Scorpaenidae and Sauridae) were caught in higher abundance at night.

Diel differences in the catchability of fish probably reflect changes in their vertical distribution (Hobson 1972, 1974) or behaviour. Many of the leiognathids and some carangids move up into the water column at night and thus are not caught by a demersal prawn trawl. The leiognathids such as *L. bindus* are thought to follow the zooplankton as it spreads out through the water column at night (Blaber et al. 1990). The carangid *Caranx bucculentus* feeds on benthic crustaceans and fish during the day (Brewer et al. 1989), but was not caught in bottom waters at night. The Leiognathidae were the most numerous in the daytime time trawls in Shark Bay.

For invertebrates, the most abundant family, the Penaeidae were caught in significantly higher numbers at night whilst the cephalopods particularly the species *Photololigo* sp. was found in high abundance (at one site) during the day.

Significant differences were observed for faunal abundance and levels of trawl effort. In Shark Bay a significant result was observed even though the power to detect a difference was fairly low. In Exmouth Gulf the sampling provided sufficient power to detect differences. In Shark Bay highest fish abundance was observed in low trawl effort sites whilst in Exmouth there was evidence to indicate lower abundance at high trawl effort sites (category 3) even though no trawl and moderate trawl sites shared similar abundances. Most species are widespread and occur at most sites. For Porifera in Exmouth Gulf there was some evidence of higher abundance (but low abundance overall) in areas of no trawling. However this was not the case for sponges in Shark Bay.

Seasonal, annual, spatial and diurnal variability in species abundance and diversity measures in both Shark Bay and Exmouth Gulf requires that consideration of this variability be made when planning a sampling strategy. Highest abundance and diversity measures are generally observed (except for fish in Exmouth) at the start of the season but the relative abundance at the start of the season can be highly variable between years. In light of this, two sampling times in a year should be incorporated, one at the start and one during mid season. This will provide information of declines in relative abundance during the year, irrespective of initial abundance. Those highly aggregating, schooling or migratory species cannot be used as an indicators of change due to their high natural variability both temporally and spatially.

Obvious diurnal differences were apparent and have also been documented in other by catch studies (Stobutzki et al. 2000) so ideally sampling should be undertaken at night-time only. Also although not tested in this study, strong lunar effects have been documented for some by catch species and prawns (Render et al. 1987, Watson et al. 1990) and sampling should be avoided during full moon periods.

For Shark Bay, the observed power to detect differences for 5% significance test was relatively low (40%) indicating that more sampling sites would increase power. However, a significant difference in fish abundance was still observed for low trawl. In Exmouth Gulf, the observed power for 5% significance test was sufficient to detect differences. For the two areas; Shark Bay had highest abundance at sites with low trawl effort with all other sites being similar. Conversely in Exmouth Gulf high trawl effort had significantly lower abundance where as all other sites were similar. These inconsistent trends point that other factors in addition to fishing effort are important in faunal abundances and diversity measures.

5.0 OBJECTIVE 3

M. Kangas

Objective 3: To examine the rate of depletion of selected bycatch species (indicator species) to ensure bycatch CPUE is related to actual abundance

5.1 INTRODUCTION

Prawn trawling is a non-selective form of fishing however, prawn/scallop trawl nets are designed and set so that they are generally more efficient at catching the target species than bycatch as in most cases these species require significant sorting and handling and are discarded overboard. Using demersal trawling as a sampling method has its limitations in describing the overall biodiversity of a region because of what the nets sample effectively. This study should not be considered as a project describing overall biodiversity in the areas sampled but the biodiversity of fauna caught in prawn trawl nets. Limited sampling with fish trawl gear was undertaken at a few sites on one occasion to determine selectivity characteristics of the prawn net compared to a fish trawl net but these trials were not comprehensive.

This component of the project was undertaken to get a better understanding of the effectiveness of prawn/scallop nets on capturing both target and bycatch species and the relative impact of trawling on different groups of fish and invertebrate species, which due to their different mobility, life habits and habitat preferences may be differentially sampled by prawn nets. Those species that are poorly sampled (low catchability) or highly mobile might not be suitable candidates as indicator species as trawling may not provide any true indication of that particular species abundance. Species with low trawl catchability are also unlikely to be greatly affected by trawling. The efficiency of the trawl gear may also vary seasonally on bycatch species as it does on the target species whose catchability is influenced by water temperature, lunar cycles and other environmental factors (winds, tides). Prawn trawl nets, similar in design to those used by local commercial fishers, were used in this study. It was not attempted to try many different sampling methods (i.e. extensive fish trawls, dredges and grabs) in this study for comparison but both Stobutzki et al. (2000) and Poiner et al. (1998) noted substantial differences in faunal composition between different gear types.

The use of repeated trawling over the same area has been undertaken by several researchers (Joll and Penn 1990, McKeown & Gordon 1997, Gordon et al. 1997, Poiner et al. 1998) to describe the depletion effects on target species (Joll and Penn 1990) or both target and bycatch species (Poiner et al. 1998). The availability of Differential Global Positioning Systems (DGPS) with an accuracy of a few metres combined with plotter techniques has made accurate position fixing possible even though it is still difficult to ensure that the trawl is following the desired path due to the prevailing weather and current conditions at the time of sampling.

5.2 METHODS

5.2.1 Depletion Experiments

Two depletion experiments were conducted in the Denham Sound area of the Shark Bay prawn fishery between 28 February and 3 March, and between 25 and 28 June 2003 (Figure 5.1).

The water depth ranged between 16.8 and 17.2 m in February and 17.0 and 17.5 m in June over areas with primarily sand substrate. These two experiments were undertaken to provide information on depletion rates for different seasons. However, the location of the experimental site was moved between February and June 2003 because the first trawl undertaken in the same site in June (as in February) yielded only a handful of individuals of a few species and it would not have been possible to get any meaningful depletion estimates at this site with such low numbers. The low numbers were considered to be due to seasonal effects rather than the effect of trawling in the area in February. An area close by was selected for running the second experiment where overall fish and invertebrate species abundances were higher.

On both occasions the experiment was conducted over four nights at the specified site. In February the area was bounded by 25°49.700' and 25°50.450' S and 113°14.600' and 113°14.719' E and in June by 25°44.500' and 25°45.250' S and 113°14.000' and 113°14.119' E . The area trawled was 1000 m x 200 m and consisted of completing 16 parallel steering lines (sweeps) using twin 7-fathom (12.8 m) prawn nets with 50 mm stretched mesh and 45 mm in the cod-end. The seabed contact of the trawls was provided by a 10 mm ground chain positioned slightly ahead (two links) of the ground rope. The opening of each net under normal operational conditions has been estimated to be 60% of the headrope length and the total width swept by each trawl net (taking into account the two otter boards and short leg ropes) was estimated to be 8m. The separation of the two inside otter boards during trawling was estimated to be 8 m (Joll and Penn 1990).

5.2.2 Shark Bay Fish Trawling

During October 2003, a single fish trawl net (100 mm mesh size in the wings and 45mm cod-end) was used to compare fish catches with those caught in twin prawn trawl (50 mm mesh size in the wings and 45 mm cod-end) nets at the same sites. The single net had a headrope length of 14 m compared with the two 6-fathom (11 m) prawn nets, was deployed from the stern of the FRV Naturaliste and was a standard full bottom trawl net as used by commercial fishers in the Pilbara Fish trawl.

Two twenty-minute shots were made with the fish trawl at each of six sites in Shark Bay, covering the northern, central and western reaches of Shark Bay. Sites 7, 9 and 12 were sampled on 3/10/2003, and sites 17,19 and 21 on the 4/10/2003 (Figure 2.1). The prawn trawls were conducted as part of the standard sampling regime and were completed between 27/09/03 and 1/10/03. As the size of the two gears was different and the trawl duration longer for the fish trawl only the presence or absence of species is considered in this part of the study as no comparison of catch rates could be made.

The total catch of fish from each shot was sorted, identified and counted. Voucher specimens were collected and frozen. The small number of invertebrate species were noted, but not counted.

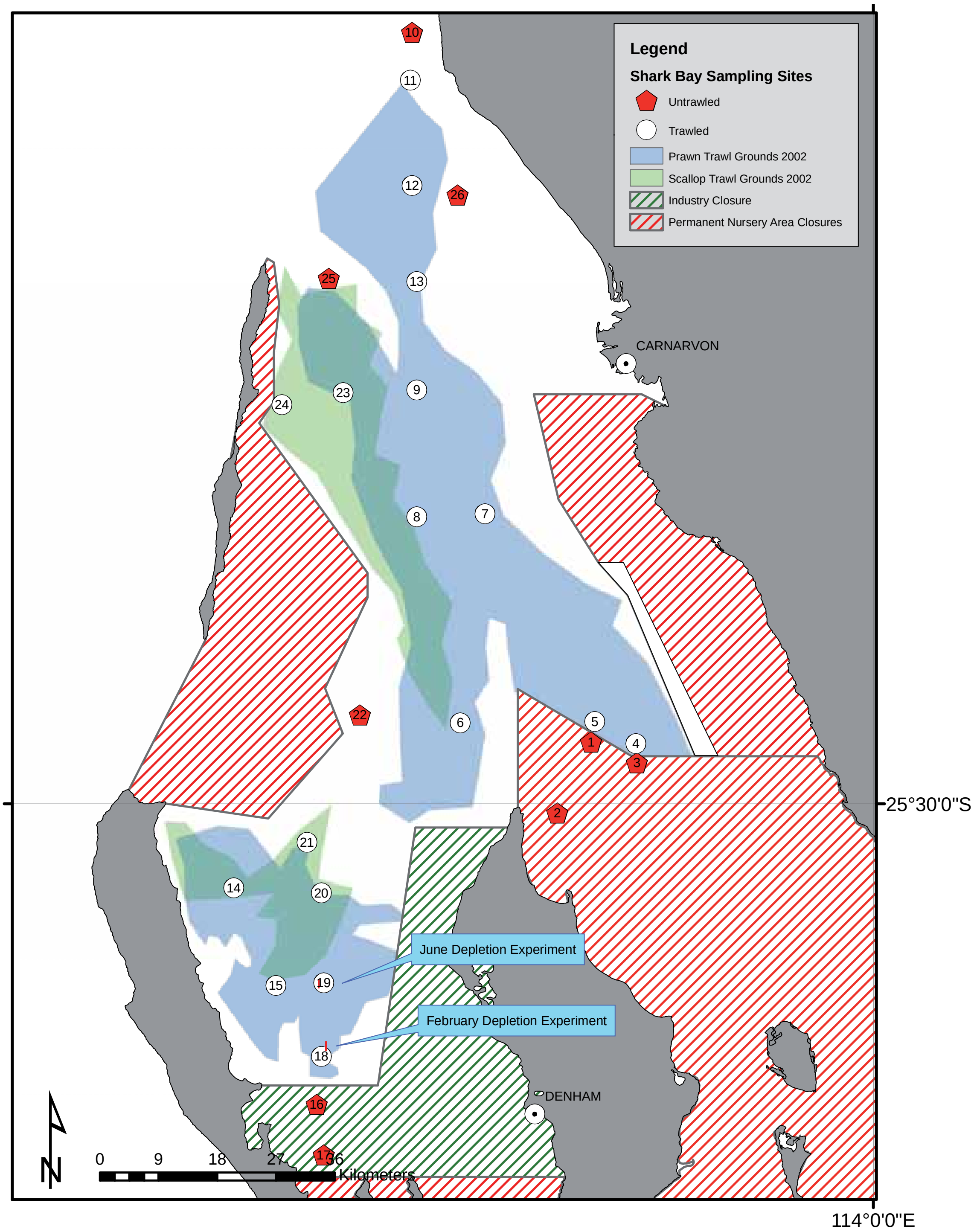

Figure 5.1 Shark Bay and the location of the two sites for depletion experiments conducted in February and June 2003.

The FRV Naturaliste was fitted with differential GPS (position accuracy of 2-5 m) so that it could as accurately as possible trawl the required path (Figure 5.2). The area delineated, was covered by the boat trawling north, then south with the gear overlapping the centre of the previous track so that all the area was covered. This was repeated until all 16 sweeps were completed to cover the full delineated area. The gear was deployed and retrieved just outside the delineated area so that it was completely covered. Each sweep was 10 minutes (approximately 13 minutes for deployment and retrieval) in duration and all the fish (except fish in families Scorpaenidae, Plotosidae and Siganidae) and invertebrates were sorted after every second sweep (i.e. 2 sweeps sorted at a time) to even out any effects of trawling in different directions. At the completion of the two sweeps, the entire catch was retained on board until the boat had moved out of the experimental area a sufficient distance so when the catch was disposed it would not be carried back by tidal currents into the study area to be caught again.

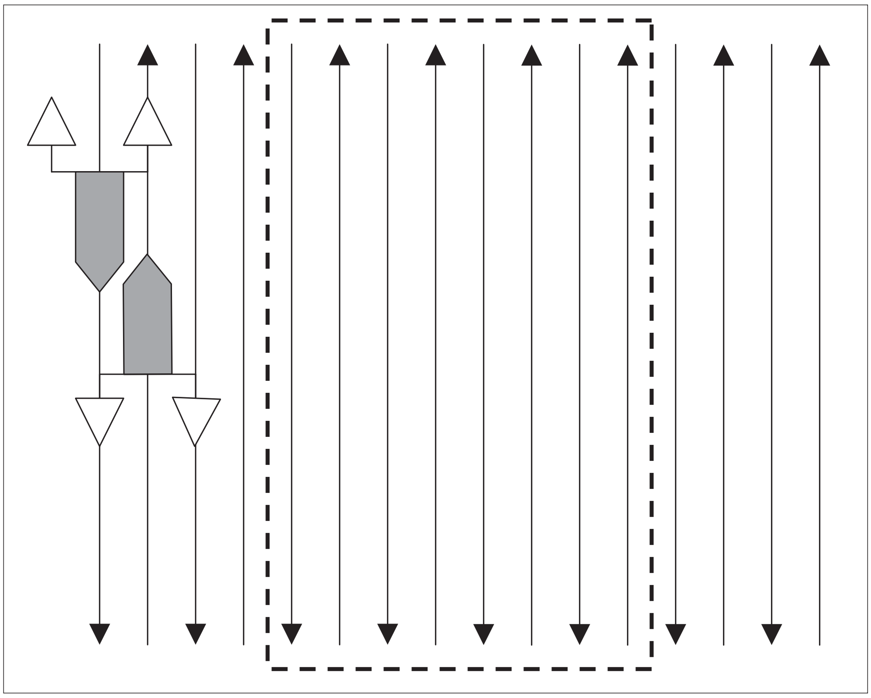

Figure 5.2 Schematic diagram of the sampling design with the boat (shaded) travelling north and south and covering the area in the boundary. To minimise immigration and emigration from the area, only the mid 8 tows are used in the analysis.

Data analysis

The catch can be described by the well-known model associated with the Leslie-Davis method (Leslie and Davis 1939, DeLury 1947, Hilborn & Walters 1992) of estimating populations from depletion studies. The basic model is as follows: $C_i = q_i\ (N_o - K_{i-1})$ where C_i is the biomass caught in the $_i$th trawl; q_i is the proportion of the available benthos caught in the $_i$th trawl; N_o is the total benthos present before trawling begins; and K_{i-1} is the total amount caught before the ith trawl begins.

The total number of all species, which were caught in each pair of sweeps were recorded. Because equal units of effort were used in each of the eight pairs of sweeps over the experimental area, the data were analysed with the cumulative catch being plotted against the total catch for the four mid pairs of trawl sweeps for each night. A regression line was then fitted to the data for groups of species or one species. The relationship developed between catch and cumulative catch should be linear with the slope equivalent to the catchability (or efficiency of the trawl gear) and the intercept on the cumulative catch axis corresponding to the original size of population in the experimental areas.

Due to the mobility of species, the outer four pairs of sweeps on the eastern and western edges were not included in the analysis so that immigration and emigration were minimised for most species.

5.3 RESULTS

Environmental conditions

The water temperatures of the time of sampling were 24.9-25.1° C at site A in February 2003 and 19.0-19.5°C at site B in June. The reduction in water temperatures may affect activity and hence catchability of some species.

Depletion experiment February 2003

The depletion analysis indicated variable depletion rates for groups of species. For all fish species combined the depletion rate in the experimental area was 21%, for all invertebrates it was 10%. For fish and invertebrates combined the depletion rate was 17% (Figure 5.3).

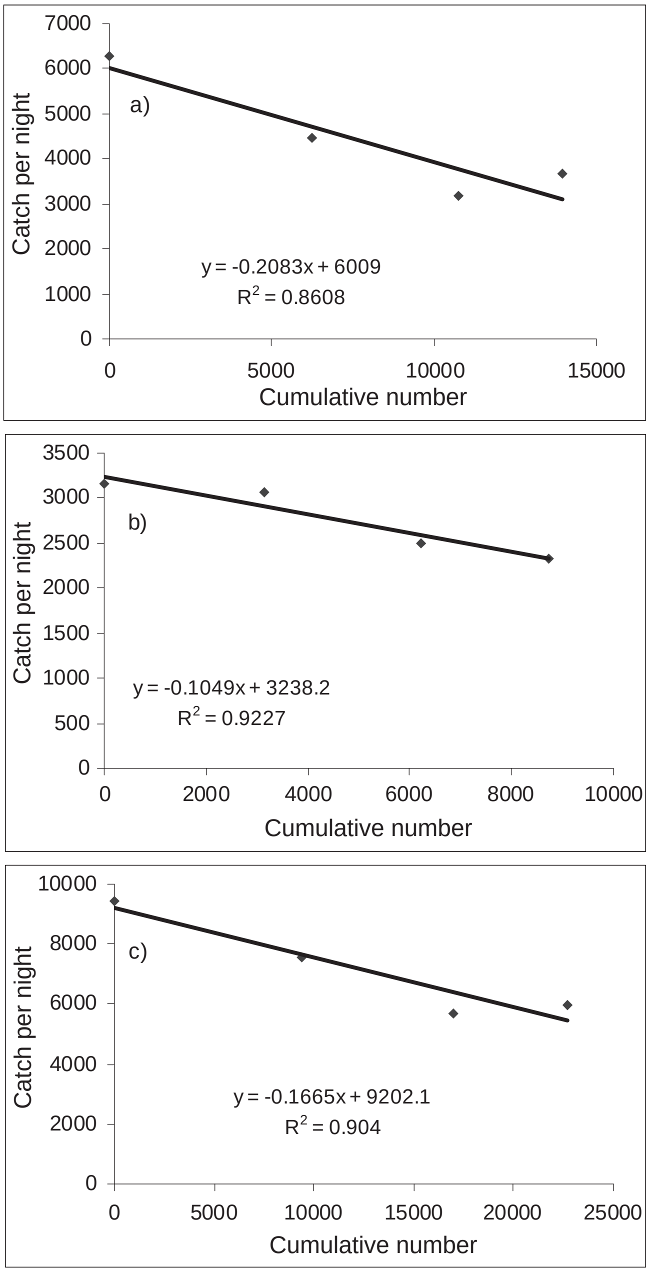

Figure 5.3 Catch per night from 8 mid-sweeps during the depletion experiment against the cumulative number of individuals per night in February 2003 in Denham Sound. a) all fish species, b) all invertebrate species, c) all bycatch.

When fish were grouped into similar types (Figure 5.4) depletion rates were as high as 37% for the fish species group including the monocle bream (nemipterids), trumpeters (terapontids), whiting (sillaginids) and snapper (sparids). Flathead (platycephalids) and flounders (bothids and paralichthyids) had a depletion rate of 21% and goatfish (mullids) 13%. For the goatfish species, the numbers increased on the fourth night possibly indicating movement into the experimental area and therefore the depletion rate may be an underestimate for these species. If the first three nights are analysed, the depletion rate for goatfish was 27%. The toadfish (teraodontids) and leatherjackets (monacanthids) had no significant trend in numbers over the four nights. For *S. undosquamis*, a decline in numbers was evident for the first three nights (30%) of the experiment however, on the fourth night, large numbers of small individuals of this species were caught in the area indicating a movement of small individuals into the area, possibly as a result of the removal of larger individuals or due to the disturbance of trawling during the previous 3 nights attracting them to the area. Ponyfish (leiognathids) abundance increased on the fourth night with no clear trend or explanation other than that they are a schooling species and most likely quite mobile in and out of the experimental area.

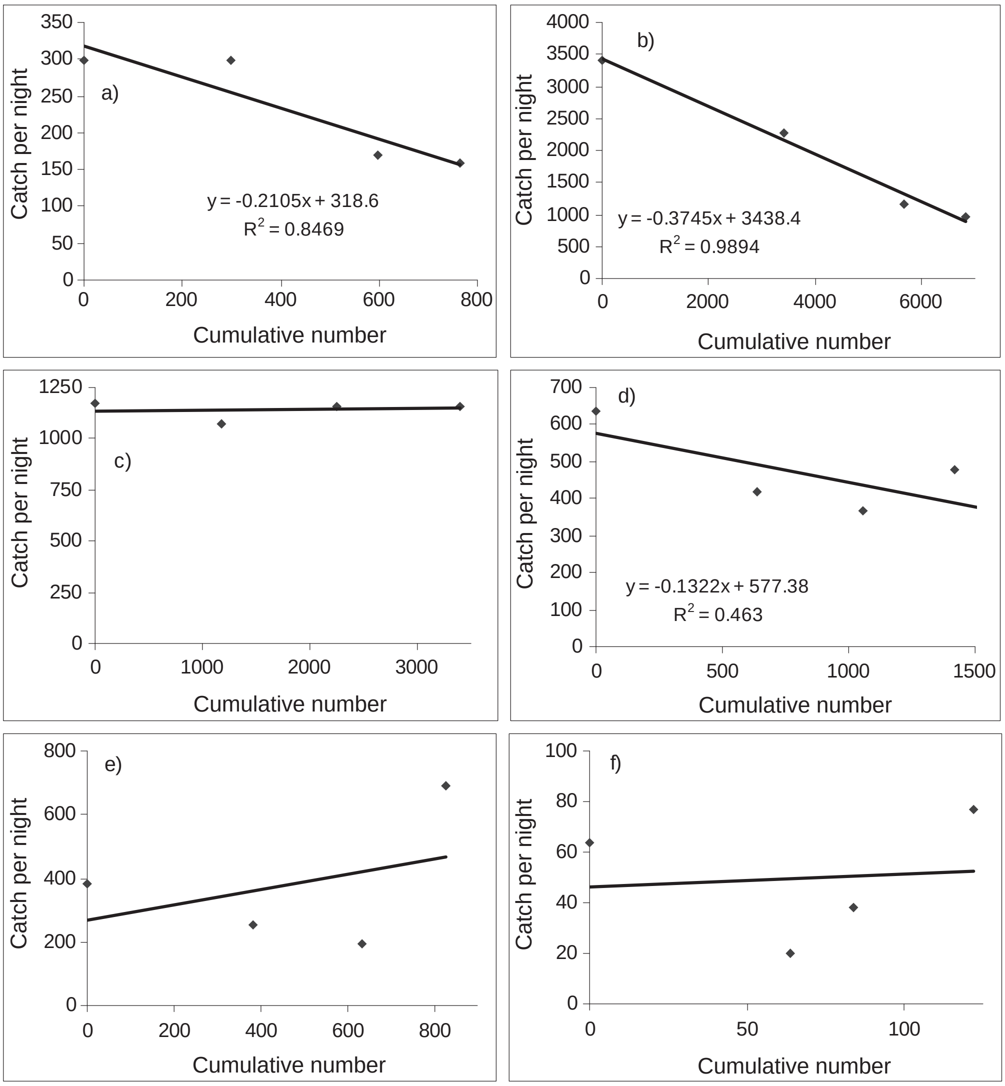

Figure 5.4 Catch per night using 8 mid sweeps against cumulative nightly catch during February 2003 in Denham Sound for fish species groups. a) Flathead and Flounders, b) Monocle bream, Trumpeters, Whiting and Snapper, c) Toadfish and Leatherjackets, d) Goatfish, e) Lizardfish and f) Ponyfish.

For the invertebrate groups there was a 20% decline for cephalopods (Figure 5.5), 13% for all scallop, 9% decline for all prawn and 10% decline for all crab species. For the target species of scallop, *A. balloti* the decline in abundance over the four nights was 42% (Figure 5.6). Only one sponge was caught during this experiment so no determination of trawl impacts on sponges could be made in February.

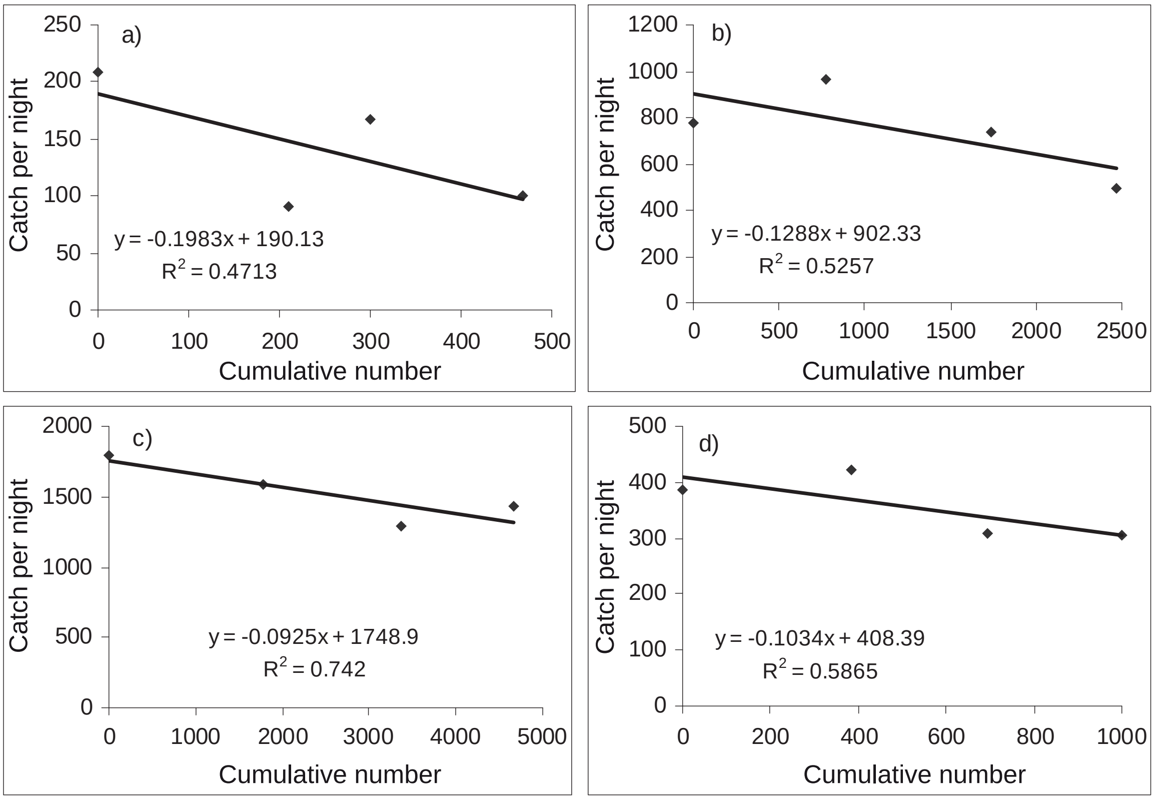

Figure 5.5 Catch per night using 8 mid-sweeps against cumulative nightly catch during February 2003 in Denham Sound for invertebrate species groups or individual species. a) Cephalopods, b) Scallops, c) Prawns and d) Crabs.

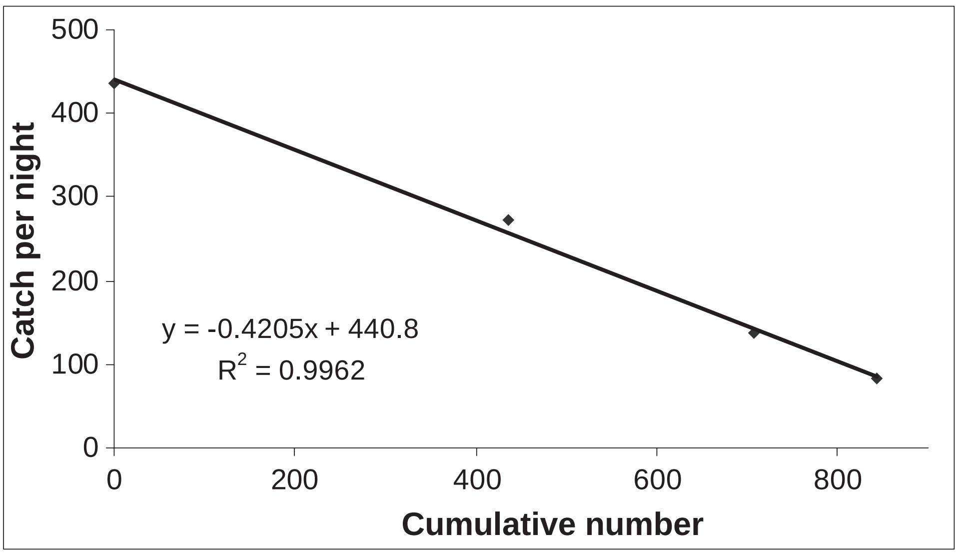

Figure 5.6 Catch per night using 8 mid-sweeps against cumulative nightly catch during February 2003 in Denham Sound for the saucer scallop *Amusium balloti.*

Depletion experiment June 2003

A larger suite of fish and invertebrate species were sampled in the June experimental area (Tables 5.1 and 5.2). However, in June the depletion rates between all fish and invertebrates overall was less than what was observed in February. For all fish species combined the depletion rate in the experimental area was 6%, for all invertebrates there was no decline evident and for fish and invertebrates combined the depletion rate was 3% (Figure 5.7). For fish, when individual species groups were compared, many fish group depletion rates in June were similar to those seen in February 2003 (Table 5.1). The exception was for the toadfish (teraodontids) and leatherjacket (monocanthids) groups and lizardfish (synodontidae), which did not show any declining trend (Figure 5.8 g and h). The most abundant species *P. choirocephalus* increased during the experiment and affected the overall results for all fish combined. Similarly for the invertebrates, two species, *P. hastatoides* and *A. flabellata* occur in high numbers in the experimental area and these increased in abundance during the experiment. As these were the most numerous invertebrate species caught in the area they influenced the overall results.

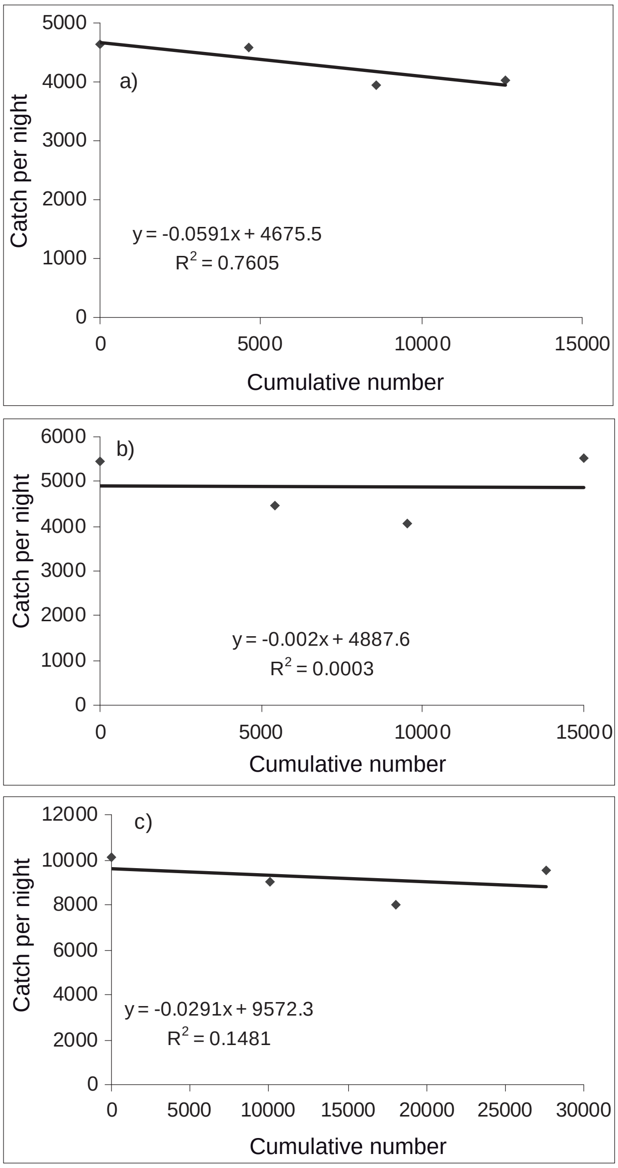

Figure 5.7 Catch per night from 8 mid-sweeps during the depletion experiment against the cumulative number of individuals per night in June 2003 in Denham Sound. a) All fish species, b) all invertebrate species, c) all bycatch.

Depletion rates were as high as 72% for the purple tuskfish *Choerodon cephalotes*, 55% for the fish species group including the monocle bream (nemipterids), trumpeters (terapontids), whiting (sillaginids) and snapper (sparids) and 38% for the goatfish (mullids). Flathead (platycephalids) and flounders (bothids and paralichthyids) had a depletion rate of 24% and stinkfish 18%. Ponyfish (leiognathids) also declined by 19% during this experiment showing high variability in results for this species between the two time periods. The toadfish (teraodontids), leatherjackets (monacanthids) and lizardfish (synodontids) did not show much decline during this experiment with only a depletion rate of less than 1% to 2%, however no influx of smaller individuals of large-scale lizardfish were observed at this area as was observed in February. One species not found in sufficient number for any analysis in February but were in sufficient numbers in June was the brown reticulated ray *Dasyatis leylandi*. This species did not show any significant decline with a <1% decrease in abundance during the four nights (Figure 5.8).

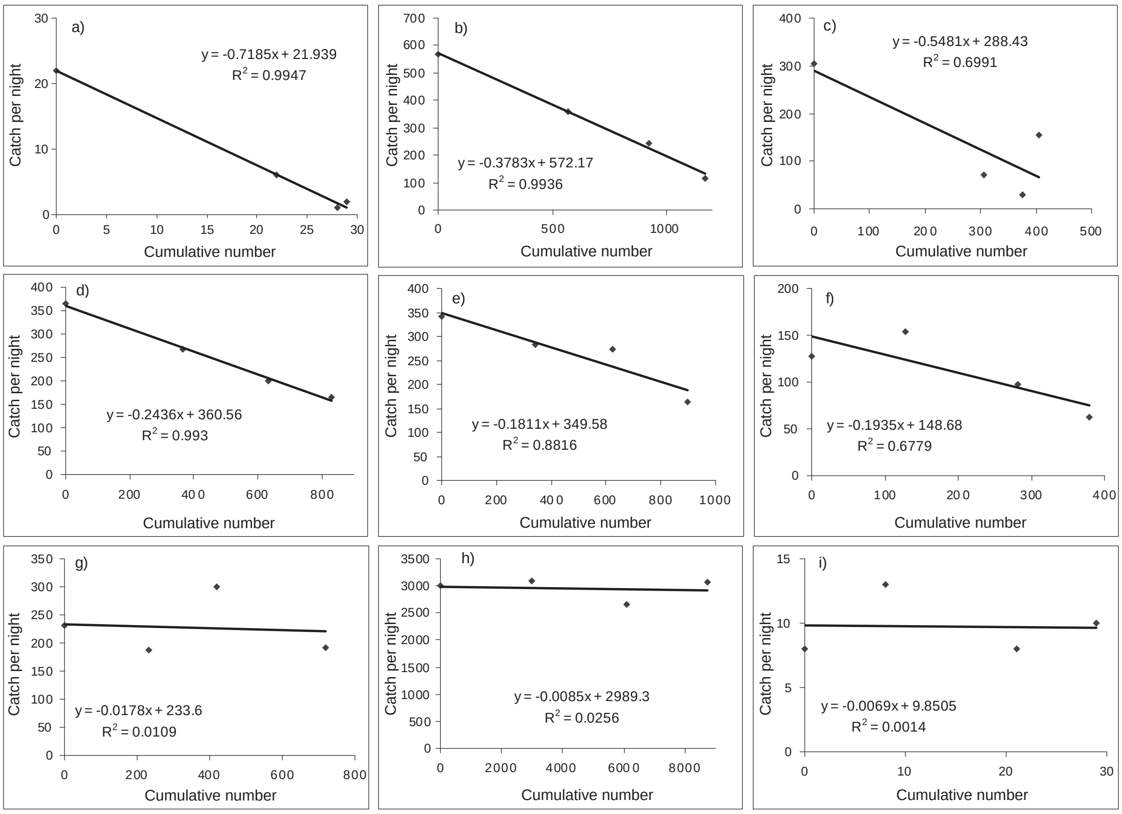

Figure 5.8 Catch per night using 8 mid-sweeps against cumulative nightly catch during June 2003 in Denham Sound for fish species groups. a) *C. cephalotes* b) Goatfish, c) Monocle bream, Trumpeters, Whiting and Snapper, d) Flathead and Flounders, e) Stinkfish, f) Ponyfish, g) Lizardfish, h) Toadfish and Leatherjackets and i) *D. leylandi.*

Nine sponges were sampled on the first night of the experiment and by night four, no sponges were collected. The decline in abundance was 54%. For the other invertebrates there was a 48% decline in the ophistobranch *Philine* species, a 41% decline in echinoderms, 29% decline in stomatopoda, 22% decline in the slipper lobster *Eduarctus martensii*, a 11% decline in cephalopods, 7% decline for crabs and a 3% decline for prawns (Figure 5.9). For all scallop species combined the abundance of scallops increased over the four nights due to the increase in numbers of one species, *A. flabellata*. This species is a small scallop species and probably becomes more catchable once trawling has taken place and they become more exposed. When *A. balloti* was analysed separately, its depletion rate was 40% (Figure 5.10).

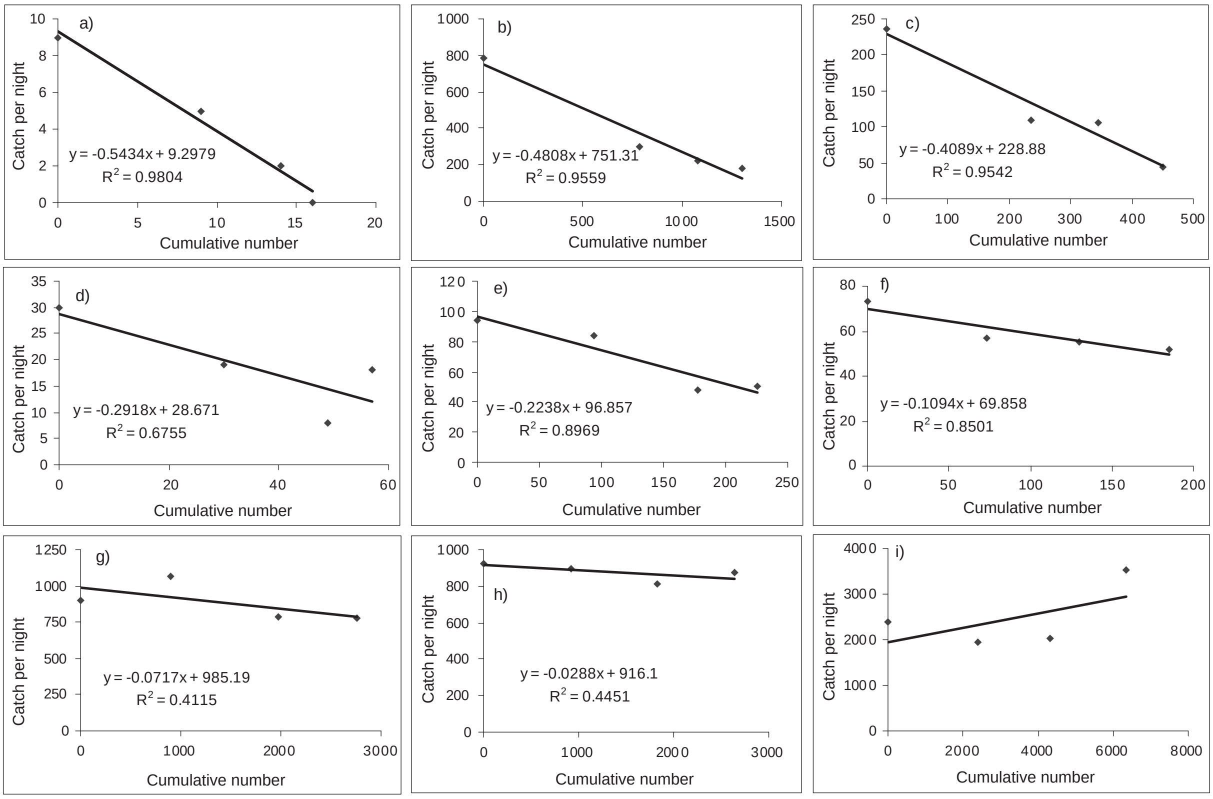

Figure 5.9 Catch per night using 8 mid-sweeps against cumulative nightly catch during June 2003 in Denham Sound for invertebrate species groups or individual species. a) Sponges b) *Philine* sp., c) Echinoderms, d) Scallops (all species), e) Crabs, f) Slipper lobster g) Stomatopods, h) Prawns and i) Cephalopods.

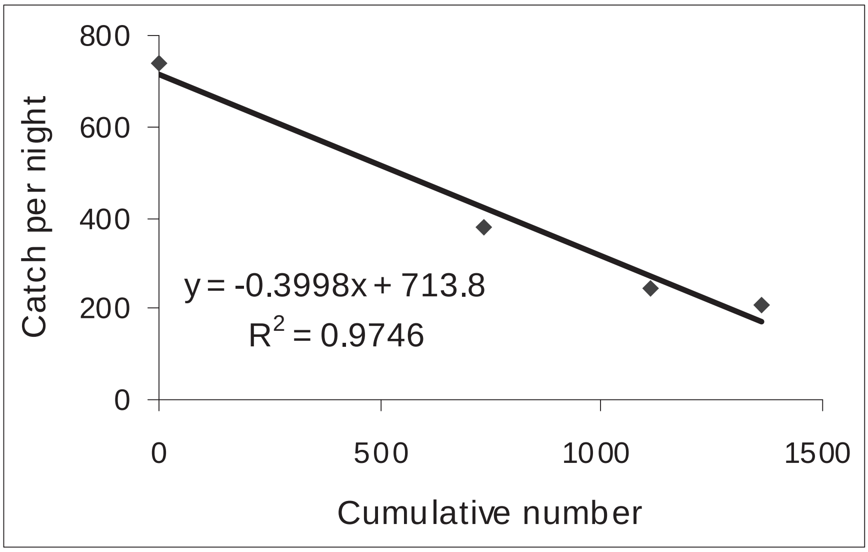

Figure 5.10 Catch per night using 8 mid-sweeps against cumulative nightly catch during June 2003 in Denham Sound for the southern saucer scallop *A. balloti.*

Individual species depletion rates for fish are shown in Table 5.1 and 5.2. The catchability of each species, taking into consideration the depletion analysis results is also provided using a subjective scale of <20% decline - low catchability, 21-50% decline – medium catchability and >50% decline – high catchability.

Table 5.1 Depletion rates for consecutive fishing nights during February and June 2003 and a scale of catchability for each species. N – insufficient numbers for analysis, L – low (<20% depletion), M – medium (21-50 % depletion), H - > 50% depletion rates, V – variable. + indicates numbers increased during experiment.

Teleosts & Elasmobranchs	% Change		Category
	February	June	
Cardinal fish – Many Banded *Apogon brevicaudatus*	None caught	<10 individuals	N
Cardinal fish – Two Eyed *Apogon nigripinnis*	None caught	<10 individuals	N
Flathead- Bar Tailed *Platycephalus endrachtensis*	None caught	<10 individuals	N
Flathead – Bosschs *Papilloculiceps bosschei*	None caught	<10 individuals	N
Flathead – Fringe-eyed *Papilloculiceps nematophtalmus*	None caught	<10 individuals	N
Flathead – Spiny *Onigocia spinosa*	None caught	<10 individuals	N
Flathead – Northern Sand *Platycephalus arenarius*	None caught	<10 individuals	N
Flathead – Longspined *Platycephalus longispinus*	None caught	<10 individuals	N
Flounder – Peacock *Pseudorhombus argus*	None caught	<10 individuals	N
Stinkfish – spotted *Repomucenus calcaratus*	None caught	<10 individuals	N
Turretfish *Tetrosomus reipublicae*	None caught	<10 individuals	N
Flathead-Heart-headed *Sorsogona tuberculata*	14	+	L
Brown Reticulated Ray *Dasyatis leylandi*	None caught	<1	L
Dragonet – Fingered *Dactylopus dactylopus*	None caught	14	L
Flounder-Large-toothed *Pseudorhombus arsius*	13	<10 individuals	L
Stinkfish – Gross *Calliurichthys grossi*	None caught	4	L
Gold Striped Sardine *Sardinella gibbosa*	None caught	3	L
Seamoth *Pegasus volitans*	None caught	+	L
Whiting-W. School *Sillago vittata*	+	None	L
Whiting-Trumpeter *Sillago burrus*	14	<10 individuals	L
Flounder-Small-toothed *Pseudorhombus jenynsii*	18	<10 individuals	L
Stinkfish – Goodlads *Callionymus goodladi*	None caught	18	L
Ponyfish, Whipfin *Leiognathus leuciscus*	+	19	L
Lizardfish-Large-scaled *Saurida undosquamis*	+	+	L
Flathead-Rusty *Inegocia japonica*	24	31	M
Grubfish – Reb-Barred *Parapercis nebulosa*	None caught	33	M
Longfinned Gurnard *Lepidotrigla sp.*	None caught	29	M
Snapper-Pink *Pagrus auratus*	31	None caught	M
Flounder-Spiny-headed *Engyprosopon grandisquama*	36	35	M
Goatfish-Asymmetrical *Upeneus asymmetricus*	14	35	M
Stinkfish – Multifilament *Repomucenus sublaevis*	None caught	38	M
Leatherjacket-Fan-bellied *Monacanthus chinensis*	20	42	M
Toadfish, Whitley's *Torquigener whitleyi*	8	37	M
Flounder, Intermediate *Asterorhombus intermedius*	27	8	M
Trumpeter, Six-lined *Pelates sexlineatus*	59	<10 individuals	H
Goatfish – Yellow striped *Parupeneus chrysopleuron*	None caught	62	H
Threadfin Emperor *Lethrinus genivittatus*	None caught	52	H
Lizardfish-Netted *Synodus sageneus*	53	54	H
Monocle Bream, W. Butterfish *Pentapodus vitta*	56	79	H
Tuskfish – Purple *Choerodon cephalotes*	None caught	72	H
Whiting, Robust *Sillago robusta*	73	63	H
Goatfish-Bar-tailed *Upeneus tragula*	13	62	V
Leatherjacket-Hair-finned *Paramonacanthus choirocephalus*	34	+	V
Trumpeter *Pelates quadrilineatus*	30	+	V
Toadfish-Orange-spotted *Torquigener pallimaculatus*	0	68	V

Table 5.2 Depletion of numbers of individuals for invertebrate species over four consecutive fishing nights during February and June 2003 and a scale of catchability for each species. N – insufficient numbers for analysis, L – low (<20% depletion), M – medium (21-50 % depletion), H - > 50% depletion rates, V – variable. + indicates numbers increased during experiment.

Invertebrates	% Depletion		Category
	February	June	
Rooster prawn *Metapenaeopsis lamellata*	None caught	<10 individuals	N
Coral crab *Charybdis feriata*	None caught	<10 individuals	N
Moreton Bay Bug *Thenus orientalis*	None caught	<10 individuals	N
Dumpling squid *Euprymna tasmanica*	None caught	<10 individuals	N
Octopus *Octopus sp.*	<10 individuals	<10 individuals	N
Blue-ringed octopus	None caught	<10 individuals	N
Echinoid – *Temnopleurus alexandrii*	None caught	<10 individuals	N
Blue Swimmer crab *Portunus pelagicus*	6	<10 individuals	L
King prawn *Penaeus latisulcatus*	1	<1	L
Southern Calamari *Sepioteuthis lessoniana*	+	+	L
Swimmer crab *Portunus hastatoides*	None caught	+	L
Fan scallop *Annachlamys flabellata*	+	+	L
Endeavour prawn *Metapenaues endeavouri*	23	<10 individuals	M
Stomatopods Fam. Squillidae	None caught	29	M
Swimmer crab *Portunus rubromarginatus*	12	28	M
Swimmer crab *Portunus tenuipes*	None caught	28	M
Coral prawn *Metapenaeus crassissima*	22	10	M
Slipper lobster *Eduarctus martensii*	None caught	22	M
Crinoidea	None caught	28	M
Southern saucer scallop *Amusium balloti*	42	40	M
Cuttlefish	39	31	M
Holothurian *Colochirus crassus*	None caught	41	M
Tiger prawn *Penaeus esculentus*	41	12	M
Philine species	9	48	M
Sea star *Luidia maculata*	<10 individuals	75	H
Porifera	None caught	54	H

The spatial distribution of the species that have high catchability indicate that most of them occur throughout Shark Bay (examples, Figures 4.11 and 4.16) with the exception of *C. cephalotes* (Figure 4.17) and yellow striped goatfish *Parupeneus chrysopleuron* (Figure 4.18). All highly catchable invertebrate groups are widely distributed (example Figures 4.21).

Fish Trawl and Prawn Trawl Comparisons

From the limited sampling using the two methods of trawling slight differences in the fish fauna were observed at the sites sampled. However for both fish and prawn trawls more than 50% of the fish caught were the most abundant species for both sampling types (Figures 5.11 and 5.12). Five fish species were more prevalent in prawn trawls whilst five were similar in the two trawls (Figure 5.13). Nine species of fish were caught by the prawn trawl and not by fish trawls and there were mainly the more bottom dwelling species such as the flatheads and flounders (Table 5.1). Ten species were caught by the fish trawls that were not caught by the prawn trawls and these had a mixture of behavioural characteristics and were not just confined to the more demersal species.

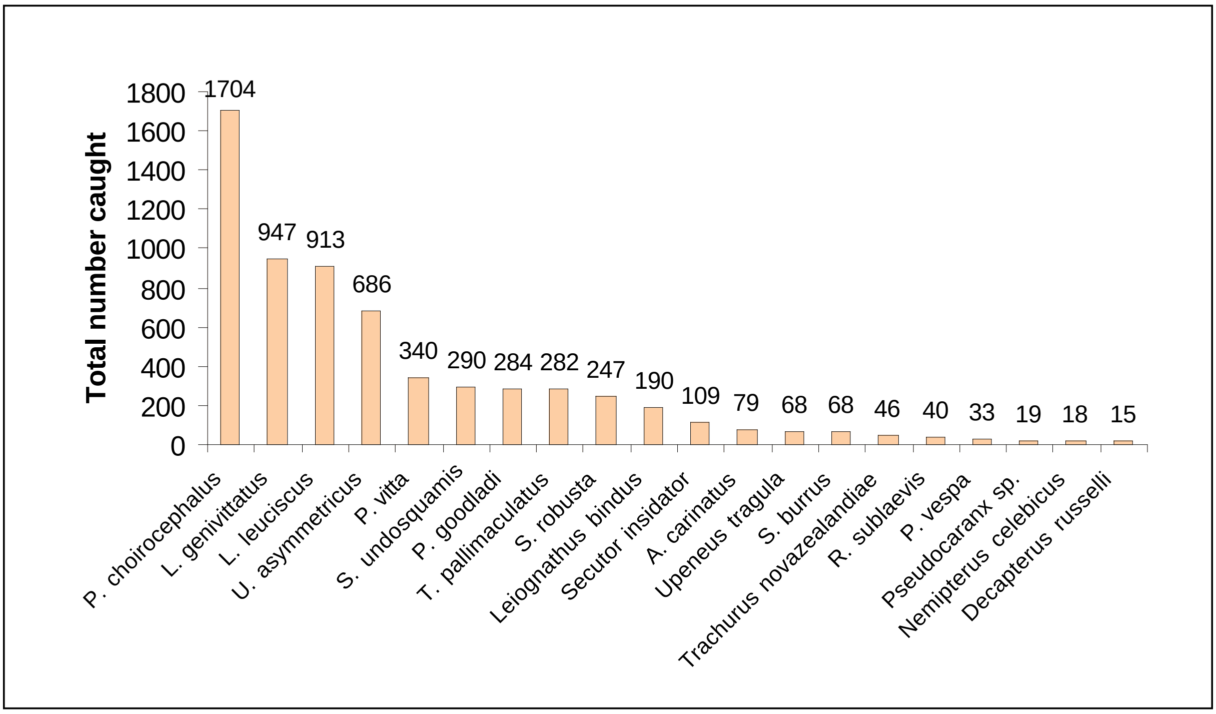

Figure 5.11 Abundance and species of fish caught in fish trawls in Shark Bay.

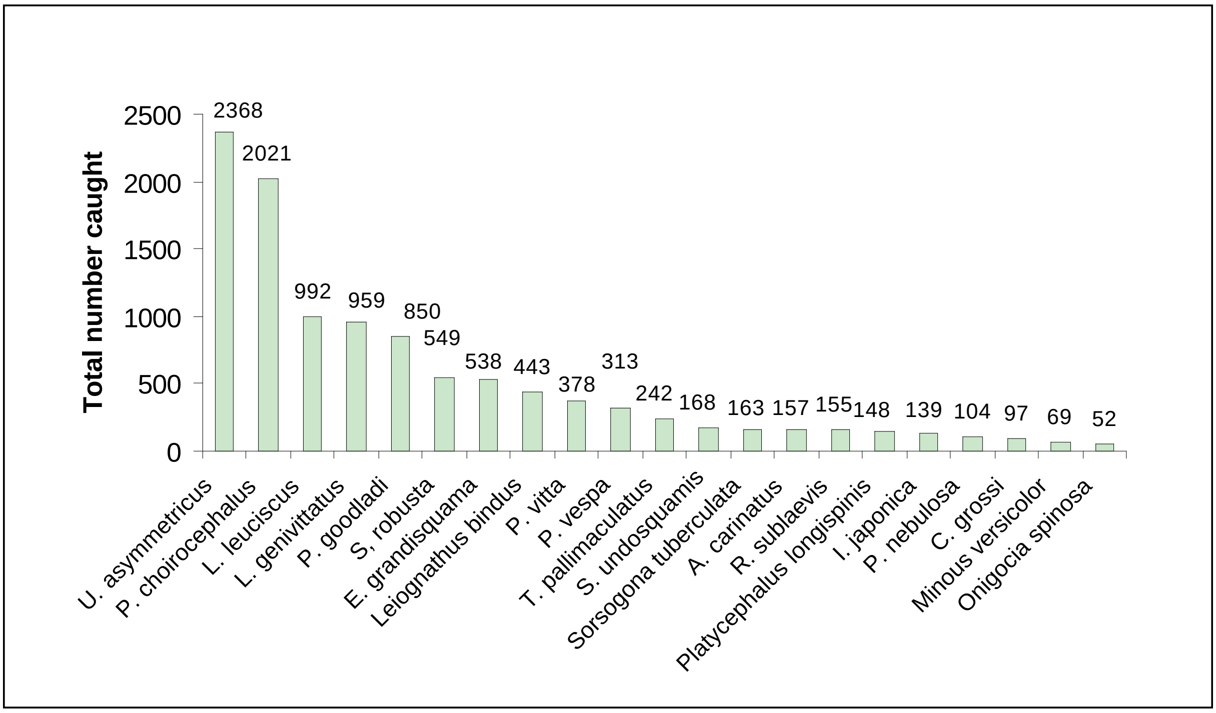

Figure 5.12 Abundance and species of fish caught in prawn trawls in Shark Bay.

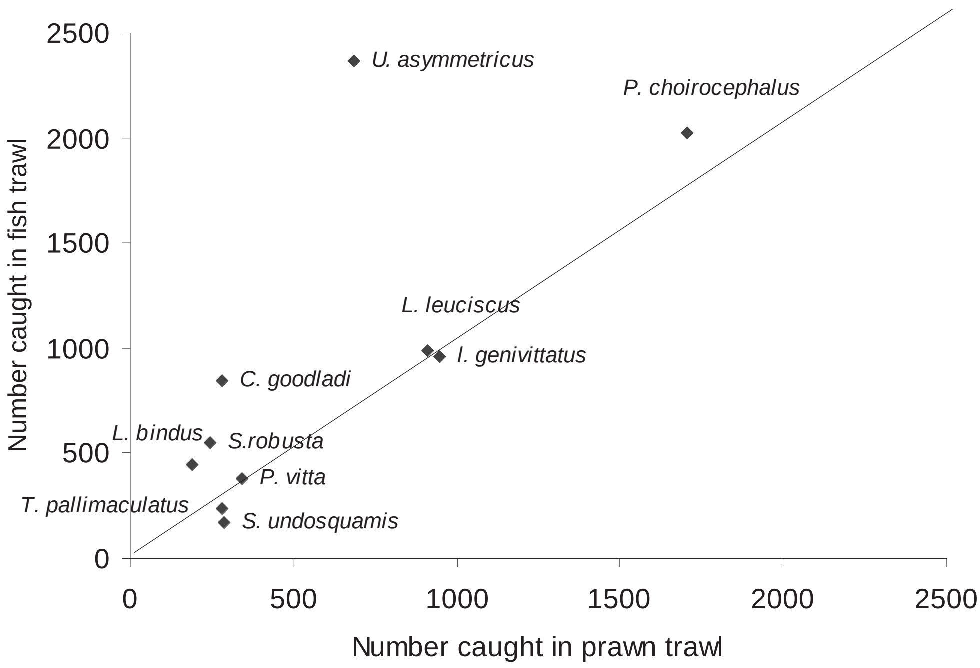

Figure 5.13 Comparison of fish species catch in prawn and fish trawls for those species caught by both methods (line indicates 1:1).

Table 4.5 Fish species caught by each trawl type in Shark Bay.

Both fish and prawn trawl	Fish trawl only	Prawn trawl only
U. asymmetricus	*Secutor insidator*	*E. grandisquama*
P. choirocephalus	*Upeneus tragula*	*S. tuberculata*
L. leuciscus	*S. burrus*	*P. longispinis*
L. genivittatus	*Trachurus novaezelandiae*	*I. japonica*
P. goodladi	*Pseudocaranx* new species	*R. sublaevis*
Leiognathus bindus	*Decapterus russelli*	*C. grossi*
P. vitta	*Nemipterus celebicus*	*Onigocia spinosa*
P. vespa	*Scomber australasicus*	*Minous versicolor*
T. pallimaculatus	*Cheilodonicthys kumu*	*P. nebulosa*
S. undosquamis	*Upeneus sulphureus*	
A. carinatus	*Chilomycterus reticulatus*	

A few species were only caught by the fish trawl and were species that had not been sampled prior to the fish trawling. They were only caught as individuals to up to three and were the blue mackerel *Scomber australasicus*, red gurnard *Cheiloodonichthys kumu*, sunrise goatfish *Upeneus sulphureus* and the spotfin porcupinefish *Chilomycterus reticulatus.*

5.4 DISCUSSION

The depletion experiments indicated demersal prawn trawling deplete various species found on trawl grounds in different ways. The catchability is highly variable between species and can differ for a single species with time. High variability was also observed by Poiner et al. (1998) where they found that the regression analysis was negative (i.e. depletion) for 46 out of 54 cases of sessile benthos, for 57 out of 60 cases for mobile benthos and for 42 out of 54 cases for fish guilds. However, within these cases there was considerable variation as was observed in this study. They suggested that there were possible causes for this, which may also be relevant for Shark Bay. The first was that since the trawl did not follow exactly the same track, it is likely that a later trawl in a series might have encountered a patch that was both rich and unfished giving a high catch value for that track. The second cause could be the result of cumulative impacts. Poiner et al. (1998) showed by using video footage from a camera attached to the net during the repeated trawling experiment that many small or flexible organisms such as seawhips and gorgonians are not caught by the net and many remained on the bottom after 13 trawls even though the regression analysis indicated that they were heavily depleted. Many sessile organisms may simply bend underneath the trawl on the first trawl impact. Successive impacts however loosen them up and eventually they are dislodged and either caught or rolled under the net. In addition they considered other factors such as time of night, tidal movements and with direction of tow that could influence differences.

In some instances the catch may increase as more trawls were carried out, resulting in the depletion rate not being able to be estimated using this method. This is most likely due to fish (and possibly some more mobile invertebrate species) moving into the trawled area.

The primary assumption made when undertaking depletion analysis is that there is no movement in or out of the experimental area except that which is removed by trawling. This is really only the case for sedentary animals or those species with very limited mobility. Similarly the level of movement either in or out of the experimental area of mobile species is variable. There are two factors independent of depletion that could affect the numbers of animals caught in successive trawls. Firstly it is possible that some mobile species move away from the disturbance and secondly, some species may be attracted by the disturbance (Poiner et al. 1998).

In these experiments very few species that were truly sedentary were caught in sufficient numbers for comparison. The rest of the results need to be interpreted with the mobility and habit of the species or species groups involved taken into consideration. There were a few fish species for which it was obvious that movement into the trawl grounds occurred with significant increases in abundance over consecutive days instead of a decline. For several invertebrate species their abundance also increased due to the trawl disturbance probably making them more catchable on subsequent nights.

As prawn trawling is selective in capturing species, fish trawl gear was also deployed over one night at six sites to compare the fish faunal composition of the two gear types. More than 50% of species sampled were common to both types of gear. The main differences between the two gear types were that the prawn gear caught bottom dwelling species such as flounders and flatheads which the fish trawl gear did not catch. The fish trawl caught a few species that had not been caught by the prawn trawls anywhere in Shark Bay and caught a few individuals of faster more mobile fish such as the blue mackerel that were not caught in prawn trawls. However, this sampling was limited to one time only at six sites and therefore was not comprehensive. Poiner et al. (1998) found that a prawn trawl catches only a subset of the fish population. This subset is composed of the smaller benthic species. The fish trawl catches show that a prawn trawl misses the larger more active species and also the more pelagic component. Hill et al. (2002) compared fish trawl and dredge samples and similarly found that there were differences between the two sampling methods.

Thus the fish trawl catch of a prawn trawl is not an accurate representation of the total fish fauna. This selectivity of the prawn trawl means that prawn trawling has a differential impact on species within the fish community, some are impacted and others are not (Poiner et al. 1998). They considered that this may lead to a change in species composition in heavily trawled areas. Because prawn trawls are only selective for a certain suite of species with particular size ranges, behaviour and position in the water column the results of this study do not represent the total biodiversity within a region.

For both experiments in Denham Sound in Shark Bay there was an overall depletion of numbers of animals caught over four nights of trawling over the same area. In February 2003 the depletion rate overall was 20% however in June it was only 3%. Therefore the impacts of trawling can be variable because of seasonal effects and the suite of species being trawled.

The overall depletion of fish was 21% in February 2003 and only 6% in June 2003. This was primarily due to the fish group containing the monocle bream, trumpeters, whiting and snappers being the most abundant group in February and they were a group with moderate depletion rate (37%) whereas in June, the most abundant group was the toadfish and leatherjackets and they had no declining trend in abundance over the four nights. Temperature was lower in June compared to February, however depletion rates between February and June were not consistent from group to group and temperature is unlikely to be the main factor in the differences between depletion rates between these two time periods.

For both time periods, several fish groups showed a clear declining trend in abundance over the four nights and these included goatfish, monocle bream, trumpeters, whiting, snapper, flathead and flounders. Carrick (1997) found a large significant impact of trawling on small-toothed flounder *Pseudorhombus jenynsii* with the fleet having capacity to reduce local populations by at least 60% over 14 days of intensive fishing. In Spencer Gulf, South Australia, flounder densities in unfished or closed areas showed little change but a large reduction occurred in the fished area. Generally regions more intensively fished had fewer larger individuals than those not fished (Carrick 1997). In our study, *P. jenynsii* was depleted by 18% in February but was not found in sufficient numbers in June for analysis indicating trawls are likely to have a relatively low impact on this species.

Other groups such as the toadfish and leatherjackets did not show any trends in abundance and were likely moving in and out of the experimental trawl area. In February, *S. undosquamis* initially decreased in abundance but then on the fourth night large numbers of small individuals of the species were found on the experimental area. These appeared to be attracted to the trawled area either by the disturbance or availability of more food or the decline in abundance of larger individuals. Poiner et al. (1998) also observed increases of some fish species on trawled areas, with numbers of both *Pentapodus paradiseus* and *Nemipterus furcosus* increasing over the course of their experiment. The increase was very large in the case of *P. paradiseus,* going on the second day from around 50 animals per trawl at the start of the second day to around 200 per trawl after 9 to 10 trawls. These two species were not encountered in our study as they are tropical species but we did observe increased abundances for *S. tuberculata, P. volitans, L. leuciscus, S. undosquamis, P. choirocephalus* and *P. quadrilineatus* during at least one experimental period. This indicates high mobility and movement in these species.

In February 2003, there was decline for most groups of invertebrates with cephalopods, scallops, prawns and crabs all having a depletion rate of between 9 and 20%. However in June, although a decline in abundance was seen for prawns, crabs and scallops, cephalopods increased due to high abundance of *S. lessoniana* which increased in abundance on the last night. The depletion estimates for highly mobile species such as squid is questionable.

Two other invertebrate species that showed a consistent increase in abundance on the experimental areas in February and June 2003 were *P. hastatoides* and *A. flabellata*. *Portunus hastatoides* may have been attracted to the trawled areas. Similar increases in abundance was observed for the hermit crab *Pagurus bernhardus* which was found in higher densities in trawl tracks than in adjacent areas (Ramsay et al. 1996). Crabs have been observed to move into areas disturbed by trawls and feed on animals damaged by the trawls and on discards (Wassenberg and Hill 1987), whereas it is likely the fan scallop became more catchable after surface sediments were disturbed after one of two nights of trawling.

In February 2003 no sponges were sampled in the experimental area, however in June 2003, 9 sponges were sampled on the first night of the experiment, these sponges tended to be mound-like and would have been easily caught by prawn trawl nets. On the second night, 5 sponges were sampled, with 2 on the third night and none on the fourth night. It appears that sponges with this kind of morphology were caught by trawl nets and quite vulnerable. It may be that other more flexible or lower growing sponge species, were less impacted by trawling but this cannot be verified for these experiments as no video footage was attempted during the experiment. Sainsbury et al. (1992) used a video camera to assess the impact on sponges by a fish trawl on the North West (NW) Shelf of Australia. Because many sponges passed under the net, they were unsure of the fate of the sponges passing under the trawl. However, where the fate of the impact was known, only 10% of sponges remained attached, the remaining 90% were detached from the seabed. This was a very high level of impact and this study is often quoted with respect to the effects of trawling. Moran and Stephenson (2000) conducted a fish trawl survey in the NW Shelf and found that their nets removed approximately 15.5% of the macrobenthos on a single pass. The majority of the macrobenthos was sponges (Moran, pers. comm.). Similarly, Pitcher et al. (2000) found a similar level of impact on sponges and gorgonians in the Great Barrier Reef using prawn trawls. However, Poiner et al. (1998) found that in the Great Barrier Reef, the overall impact on sponges by prawn trawls was around 10%. They found that certain groups, especially tall sponges, are more vulnerable, but there was a large proportion that is more resistant. Because of this differential vulnerability, they considered the real effect of multiple trawls is complex.

Apart from sponges, the only other sedentary invertebrates or ones with limited movement in sufficient number for analysis were the scallops, crinoids and the holothurian *C. crassus.* For the commercially caught *A. balloti* depletion rates of 42 and 40% were recorded for February and June respectively. This indicates that the prawn gear is a relatively good sampling/catching device for this species. Higher depletion rates (60 and 64% over three nights) was reported for this species by Joll and Penn (1990) in two experiments conducted on the scallop trawl grounds in central Shark Bay. These differences may be attributed to the specific habitats where the sampling took place and differences in the gear settings that were used for the experiment. However, due to the high natural variability of recruitment, this species would not be a good indicator species. The other common scallop species caught was *A. flabellata* and it increased in abundance on both occasions. This species is a fairly small scallop species and is generally buried in the sandy sediment. With consecutive trawls over the same area, they may have been more exposed and become more available for capture by the prawn gear.

Crinoids and the holothurian *C. crassus* appeared to have moderate catchability to the trawl gear with a depletion rate of 28% and 41% respectively over the four nights. The crinoids are fairly flexible and can be mobile and *C. crassus* is a relatively small species of sea cucumber usually being between 5 and 10 cm in length and it is unclear whether they would have been fully sampled by the trawl gear.

This project used the numbers of individuals per distance trawled as a proxy for the catch rate instead of weight of species per distance trawled. Highly aggregating species and those with high mobility are unlikely to be useful species when trying to assess trends in abundance and diversity measures. Species which have a moderate to high catchability (> 30%) and those that are generally widespread (occur in > 70% of sites sampled) are good candidate indicator species for trend analyses. For Shark Bay this could include the fish species *I. japonica, P. nebulosa. E. grandisquama, M. chinensis, S. sageneus, P. vitta, C. cephalotes, S. robusta, P. sexlineatus* and *L. genivittatus.* These ten species represented, on average 19.6 % (SE 2.3) of the total fish abundance. Species with low catchability or high mobility are less reliable as indicators as catch rates will not represent actual abundance. For invertebrate species, the only suitable indicator species are the group Porifera and the seastar *L. maculata* as all the other invertebrate species that displayed medium to high catchability are commercially targeted species (or secondary species) or schooling, mobile species such as the cephalopods. However both Porifera and *L. maculata* are a fairly small component of the invertebrate bycatch in Shark Bay and the morphology of sponges makes some individual species less catchable than others.

6.0 OBJECTIVE 4

M. Kangas, S. Morrison, B. Rome and M. Hammond

Objective 4: ***To assess size structure of indicator species and utilise the size composition proxy for age to assess basic productivity of species groups***

6.1 INTRODUCTION

Collection and use of length frequency information is a common tool used in stock assessment. Size composition information of individuals of species within areas and within season can give a picture of timing and strength of recruitment, patterns of spatial variability in size within a region and may provide information on movement of individuals. Analysis of mean length may also provide insight on changes in size composition over time, which may be as a result of fishing pressure. However, in relatively short-lived species with only one to three cohorts, mean size may be less useful. In this study, the length of selected (widespread and relatively abundant) species of both fish and invertebrates were measured during each sampling period in Shark Bay, Exmouth Gulf and Onslow to determine if any trends in recruitment patterns or size composition could be detected between sites and time periods.

Ageing of fish requires either, the removal and interpretation of scales and/or otoliths or using length frequency as a surrogate. In this study, several common species were selected to be assessed whether they could be aged using otoliths. Invertebrate species cannot be aged in this manner and therefore their age is interpreted from length frequencies using cohort analysis and known life history characteristics. This requires some biological knowledge of the species in order to make correct inferences about modal patterns.

Productivity in this study will be regarded as an increase in biomass through either recruitment or growth and how this may be variable between the indicator species (selected widespread and common species) and if any differences can be perceived over the timeframe of the project undertaken in Shark Bay and Exmouth Gulf. The size structure (possible age or cohort identification) and specific ageing of some species will be used as true biomass calculations could not be made with the current sampling program. Difficulties in achieving this component of the objective may be encountered due to the short timeframe of the sampling program and lack of multiple years of sampling without a full understanding of differences in annual variation in productivity for any one species or group of species.

6.2 METHODS

6.2.1 Length frequencies

In Shark Bay, Exmouth and Onslow, at most sites, samples of fish and invertebrate species were retained (Table 6.1) and these were measured to the nearest centimetre for fish (total length (TL)) and crabs (carapace width (CW)) whereas prawns (carapace length (CL)) and scallops (shell height) were measured to the nearest millimetre.

Table 6.1 Species of fish and invertebrates measured in Shark Bay and Exmouth Gulf and Onslow.

Shark Bay	Exmouth Gulf and Onslow
Asymmetrical Goatfish *Upeneus asymmetricus*	Asymmetrical Goatfish *Upeneus asymmetricus*
Red-barred Grubfish *Parapercis nebulosa*	Red-barred Grubfish *Parapercis nebulosa*
Large-scaled Lizardfish *Saurida undosquamis*	Large-scaled Lizardfish *Saurida undosquamis*
Hair-finned Leatherjacket *Paramonacanthus choirocephalus*	
WA Butterfish *Pentapodus vitta*	
Blue swimmer crab *Portunus pelagicus*	
Saucer scallop *Amusium balloti*	
Brown tiger prawn *Penaeus esculentus*	Brown tiger prawn *Penaeus esculentus*
Western king prawn *Penaeus latisulcatus*	Western king prawn *Penaeus latisulcatus*

Mean size (±SE) was determined for each site and time period when a measurement had been made. Cumulative length frequencies were calculated for some individual sites or pooled sites (to increase sample size) for fish and invertebrate species in both Shark Bay and Exmouth Gulf / Onslow. Differences in frequency distributions were assessed using non-parametric Kolmogorov-Smirnov tests.

6.2.2 Age determination of selected fish species

A total of 11 of the more abundant bycatch fish species were collected from the Shark Bay trawl surveys for age determination studies using otoliths (Table 6.2).

Table 6.2 Species of fish collected for otolith analysis from Shark Bay.

Family	Common name	Scientific name
Bathysauridae	Large-scaled Lizardfish	*Saurida undosquamis*
Terapontidae	Four-lined Trumpeter	*Pelates quadrilineatus*
Terapontidae	Six-lined Trumpeter	*Pelates sexlineatus*
Sillaginidae	Trumpeter Whiting	*Sillago burrus*
Sillaginidae	Robust Whiting	*Sillago robusta*
Sillaginidae	Western School Whiting	*Sillago vittata*
Nemipteridae	Western Butterfish	*Pentapodus vitta*
Gerreidae	Roach	*Gerres subfasciatus*
Mullidae	Asymmetrical Goatfish	*Upeneus asymmetricus*
Pinguipedidae	Red-barred Grubfish	*Parapercis nebulosa*
Paralichthyidae	Large-toothed Flounder	*Pseudorhombus arsius*

A preliminary study was carried out on the suitability of the otoliths from the above species for age determination. After extracting the otoliths, they were embedded in epoxy-resin and sectioned using an Isomet Low Speed Saw. Three sections were cut from each otolith at 270 microns thickness. The sections were permanently mounted on glass slides with casting resin.

To identify the growth rings in each otolith, two different methods were used. Larger otoliths such as those from whiting, were examined using a dissecting microscope with a standard light source pointing down onto to the slide. For smaller otoliths, such as those from the Large-scaled Lizardfish, Roach and Red-barred Grubfish, an ultra-violet projection screen was used.

A total of 13 species were collected for otolith studies from Exmouth Gulf during July and November 2004 (Table 6.3). The length and weight of each fish were also measured.

Table 6.3 Species of fish collected for otolith analysis from Exmouth Gulf.

Family	Common name	Scientific name
Bathysauridae	Large-scaled Lizardfish	*Saurida undosquamis*
Platycephalidae	Rusty Flathead	*Inegocia japonica*
Terapontidae	Banded trumpeter	*Terapon theraps*
Sillaginidae	Trumpeter Whiting	*Sillago burrus*
Sillaginidae	Mud Whiting	*Sillago lutea*
Sillaginidae	Western School Whiting	*Sillago vittata*
Nemipteridae	Notched Threadfin Bream	*Nemipterus peronii*
Nemipteridae	Red-spot Monocle bream	*Scolopsis taenioptera*
Haemulidae	Blotched Javelinfish	*Pomadasys maculatus*
Mullidae	Asymmetrical Goatfish	*Upeneus asymmetricus*
Pinguipedidae	Red-barred Grubfish	*Parapercis nebulosa*
Paralichthyidae	Large-toothed Flounder	*Pseudorhombus arsius*
Monacanthidae	Hair-finned Leatherjacket	*Paramonacanthus choirocephalus*

Due to time restrictions during the life of this project, only two species of fish, *N. peronii* and *U. asymmetricus* from Exmouth Gulf were used in otolith studies. Five additional species had been assessed from Shark Bay. A complementary project (FRDC 2004/042) is currently being completed which focussed on developing proxies for age (i.e. otolith weight, length, weight).

Age determination of Nemipterus peronii

Otoliths of *N. peronii* were removed, cleaned, dried and the otolith weight was recorded. Initially a sub sample of 50 otoliths were selected for assessment of the ageing of whole *N. peronii* otoliths. Each otolith was placed in glycerol and then examined with a microscope with reflective light under a black background. In previous studies whole otoliths have been used for age analysis (Sainsbury and Whitelaw 1984). Examination of whole otoliths during this study however, proved to be problematic due to poorly defined annual growth increments. From this sample 90 % of the otoliths were found to be unreadable. An attempt was then made to use sectioned otoliths for ageing.

Age determination of Upeneus asymmetricus

Attempts were made to age the otoliths whole by immersing them in water and glycerol. Preliminary examination of whole otoliths showed that they could not be used for age analysis as no clear opaque and translucent zones were visible. Otoliths of *U. asymmetricus* were then sectioned and read with a compound microscope under reflective light. After several attempts to age the otoliths the decision was made to cease any further sectioning. The majority of the otoliths that were sectioned were uninterpretable due to the presence of a dense opaque primordium. Under reflective light this area appeared white or opaque and caused several problems when trying to identify the first growth ring. Identification of the annuli in areas external to the nucleus was also difficult as the dark opaque bands were quite thick and were only separated by a very thin translucent zone. It was often hard to distinguish between each individual growth annuli.

Size at Maturity

Gonad size and condition was assessed for all the *N. peronii* and *U. asymmetricus.* Gonads were extracted from each fish and then weighed to the nearest gram. Once the gonads had been weighed they were then staged macroscopically.

6.3 RESULTS

6.3.1 Length frequencies and mean length at sites, Shark Bay

Invertebrates

Prawns

The size range of *P. esculentus* was between 27 mm and 47 mm carapace length. Insufficient numbers of *P. esculentus* were sampled in most areas for length frequency analysis, however at Site 2 (closed) (Figure 6.1) in the south eastern part of Shark Bay, no significant size differences were observed throughout the year at this site (Table 6.1). Comparing individual sites as well as pooling size frequencies in Denham Sound for adjacent closed (Sites 16 and 17) and open sites (Sites 18, 19 and 20) for End02 indicated no significant differences in size composition (Kolmogorov-Smirnov (KS) test, significance at the 95% level).

Table 6.1 Mean carapace length (CL) and SE for sampling periods for sites where sufficient number of *P. esculentus* were caught for measurement for a site for at least two time periods.

Males									Females								
Site	E02	SE	S03	SE	M03	SE	E03	SE	Site	E02	SE	S03	SE	M03	SE	E03	SE
2			30.3	5.15	28.1	4.51	29.4	5.24	2			35.2	4.66	32.5	4.39	35.1	4.42
6					31.8	4.22			6					37.5	4.11		
17	32.7	12.34							17	38.2	10.24						
16	30.6	4.60							16	32.5	4.05						
18	31.6	6.90							18	36.9	6.92						
19	35.3	5.97					33.3	7.71	19	39.9	5.79					40.7	6.05
20	34.0	0.00							20	41.8	8.33						

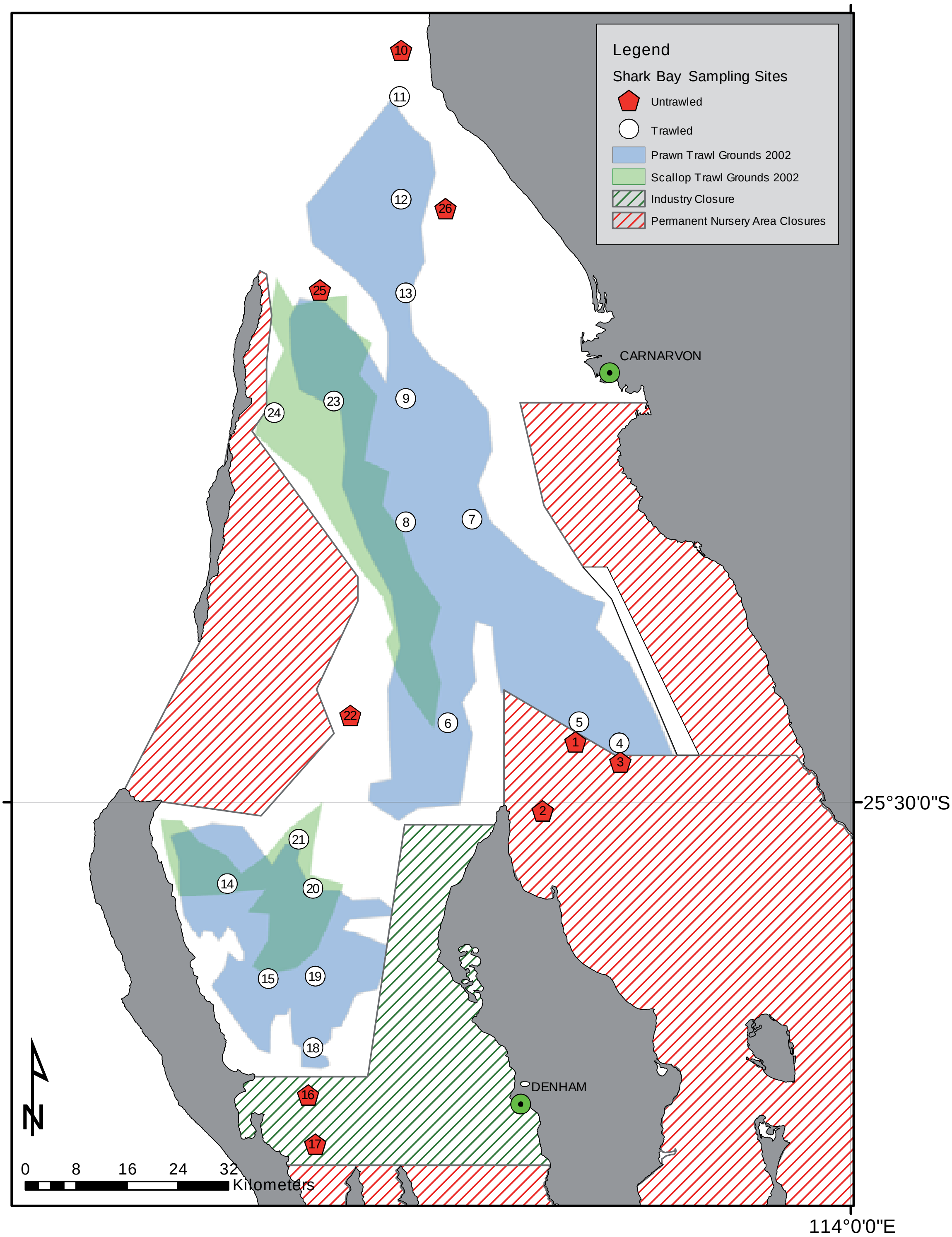

Figure 6.1 Sampling sites in Shark Bay during October 2002 and October 2003.

The size range of *P. latisulcatus* was between 19 mm and 50 mm carapace length. For *P. latisulcatus* only sites in Denham Sound had sufficient numbers for length frequency analysis. Kolmogorov-Smirnov tests and comparison of mean lengths for males and females indicated that the closed areas (sites 16 and 17) had significantly smaller prawns compared to the open sites (18, 19 and 14) for the same time period. The open sites are situated north of the closed areas (Figure 6.2, Table 6.2).

Table 6.2 Mean carapace length and SE for sampling periods for sites where sufficient number of *P. latisulcatus* were caught for measurement for a site for at least two time periods. Highlighting indicates significant differences in mean size.

Males									Females								
Site	E02	SE	S03	SE	M03	SE	E03	SE	Site	E02	SE	S03	SE	M03	SE	E03	SE
17	25.5	5.42			31.2	4.25	28.1	4.38	17	29.0	4.8			34.6	4.56	30.7	4.49
16	26.9	4.48			33.0	5.01	30.5	4.64	16	33.2	4.37			38.4	5.29	34.2	5.09
18	33.1	4.50	24.4	5.80	32.1	4.73	31.6	5.98	18	36.2	4.28	25.3	4.62	37.1	4.71	35.8	5.95
19	33.7	7.58	27.0	4.30			33.3	5.80	19	37.7	6.53	30.0	4.59			39.2	5.88
14	36.3	3.01	30.3	3.43	35.6	5.03	35.3	4.96	14	42.5	3.43	32.8	3.14	40.2	4.80	41.6	5.10

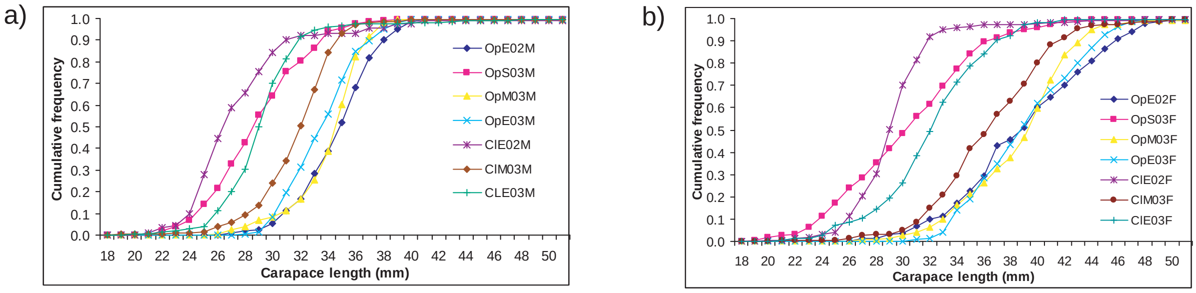

Figure 6.2 Cumulative frequencies of a) male and b) female *P. latisulcatus* for closed (sites 16 and 17) and open (sites 18, 19 and 14) areas in Denham Sound at End02.

All time periods were sampled at sites 18 and 14 and only Start03 was significantly smaller (KS test and mean sizes) for both male and female prawns compared to other time periods (Figure 6.3).

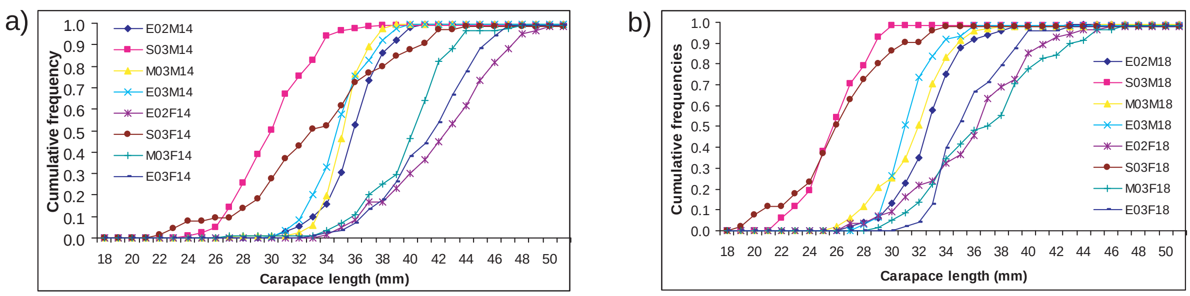

Figure 6.3 Cumulative frequencies for male and female *P. latisulcatus* for, a) site 14 and b) site 18 in Denham Sound for each sampling period.

Growth (increase in mean size) between Start03 and Mid03 was evident at sites 18 and 14 for both males and female prawns although Kolmogorov-Smirnov tests only showed that the size differences were only significant for males at site 14. There was however, no further increase in mean size in End03. There were no differences between in mean size of males and females for any of the five sites sampled in Denham Sound between End02 and End03 (Table 6.2, Figures 6.2 and 6.3).

Scallops

Sufficient numbers of scallops were only sampled at site 24 (open) in the north western part of Shark Bay and at sites 17 (closed) and 20 (open) in Denham Sound to compare mean size (Table 6.3). These regions are historically known as the main scallop trawl grounds in Shark Bay. The size range of scallops was between 22 mm and 104 mm shell height. An increase in mean size was observed between Start03 and Mid03 with mean size significantly higher in Mid03 compared to Start03 (Table 6.3, Figure 6.4) for site 17.

Table 6.3 Mean shell height (SE) for sampling periods for sites where sufficient number of *A. balloti* were caught for measurement for a site for at least two time periods. Highlighting indicates significant differences in mean size.

Site	S03	SE	M03	SE	E03	SE
17	63.2	6.50	84.5	5.74	89.2	6.21
20	89.6	5.74	95.8	6.36	92.5	5.55
24	78.1	6.21	87.8	7.69	67.9	5.86

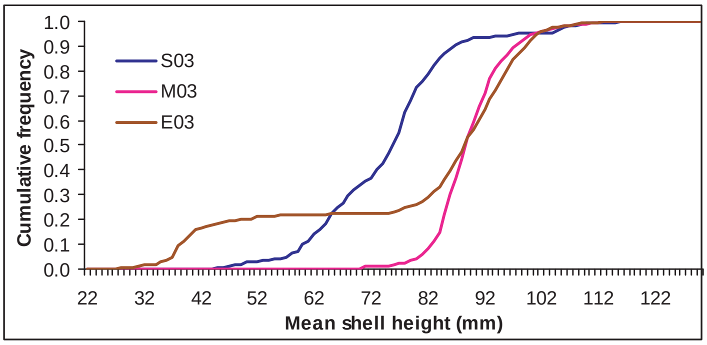

Figure 6.4 Cumulative frequencies for *A. balloti* at site 17 in Denham Sound for each sampling period.

A significantly smaller mean size was observed at site 17 in Start03 compared to sites 20 and 24 in Start03 (Figure 6.5).

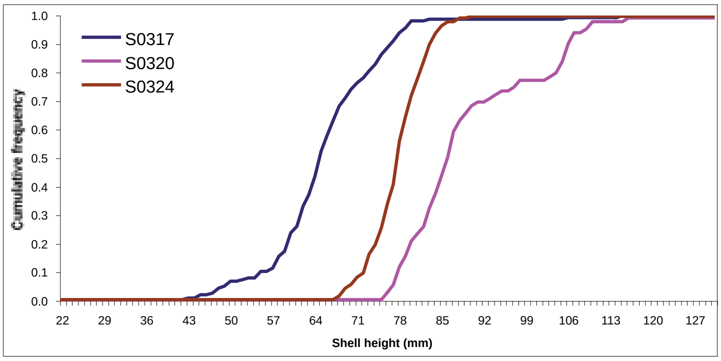

Figure 6.5 Cumulative frequencies for *A. balloti* at sites 17 and 20 in Denham Sound and site 24 in northern Shark Bay for Start03.

The lower mean size at site 17 in Start03 indicates a recruitment event in southern Denham Sound that was not observed in northern Denham Sound (site 20) or in northern Shark Bay (site 24) (Figure 6.6). These size differences were confirmed by Kolmogorov-Smirnov comparisons of size distributions.

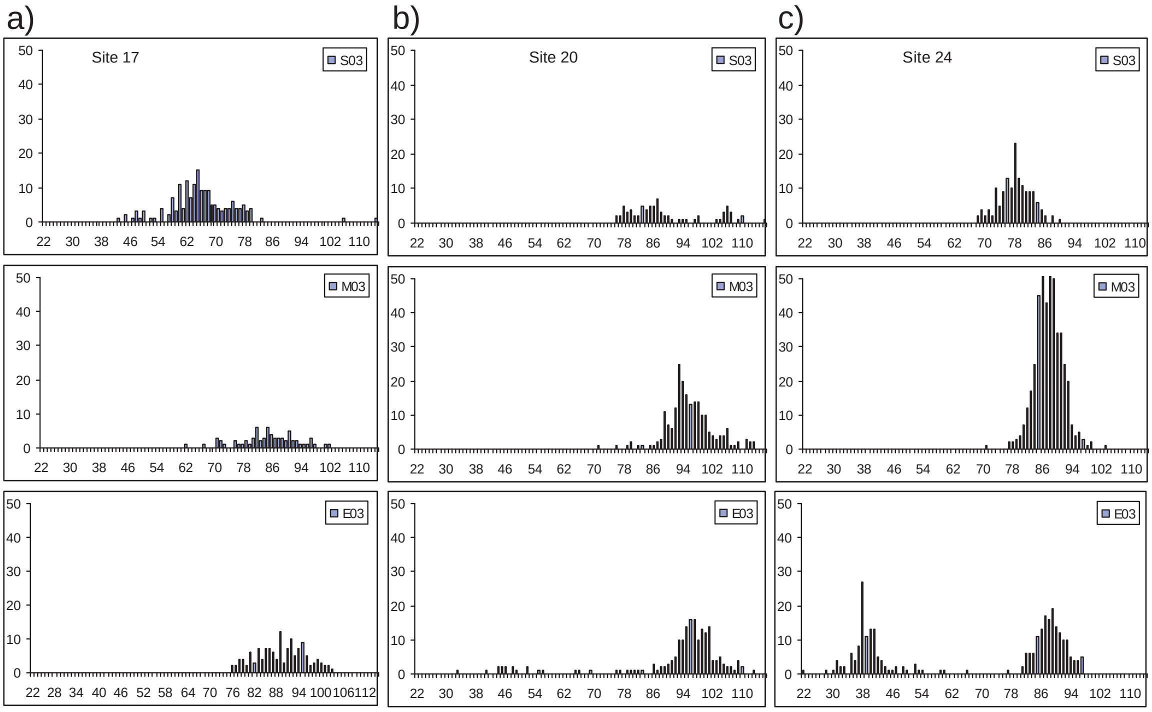

Figure 6.6 Size composition (mm shell height) of scallops at a) site 17 and b) site 20 and c) site 24 in Shark Bay between Start03 and End03.

A decrease in mean size was observed between Mid03 and End03 for sites 20 and 24 with the difference being significant at site 24 and this was attributed to recruitment into the area (Figure 6.6) between these time periods. This was not apparent at site 17 (Figure 6.6 and 6.7).

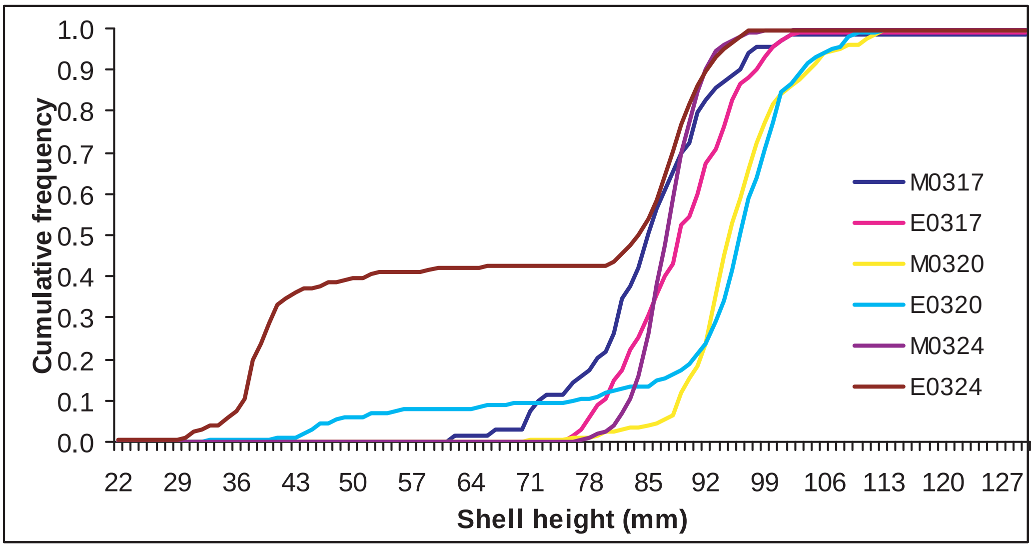

Figure 6.7 Cumulative frequencies for *A. balloti* at sites 17 and 20 in Denham Sound and site 24 in northern Shark Bay for Mid03 and End03.

Blue swimmer crabs

Sufficient numbers of *P. pelagicus* for size comparison were only sampled in sites 1 (closed) and 4 (open) in the eastern gulf of Shark Bay. The size range of crabs sampled was 5-16 cm carapace width (CW). For males, a general increase in mean size was observed between Start03, Mid03 and End03 for both sites 1 and 4 but differences were only significant between Start03 and End03 (KS test, significant at the 95% level). For female crabs an increase in mean size was observed at site 4 but not site 1, but this was not significant. Mean size of males and females were similar for all time periods for a site (Table 6.4).

Table 6.4 Mean carapace width (SE) for sampling periods for sites where sufficient number of *P. pelagicus* were caught for measurement for at least two sites for two time periods.

	Males						Females					
Site	**S03**	**SE**	**M03**	**SE**	**E03**	**SE**	**S03**	**SE**	**M03**	**SE**	**E03**	**SE**
1	93.0	13.69	94.9	17.69	105.7	18.43	100.3	14.50	95.9	18.30	103.9	20.27
4	90.6	17.59	115.5	23.23	130.9	27.67	92.0	19.00	112.6	27.20	128.0	35.90

Fish species

Western butterfish Pentapodus vitta

This species is a recreationally important fish species and was only caught in sufficient numbers at one site (site 6) in Shark Bay. The size range of individuals sampled was between 7 cm and 17 cm and there was a difference in mean total length at these sites between End02 (mean 9.5 SE 1.7) and End03 (mean 13.5 SE 3.4) (Figure 6.8).

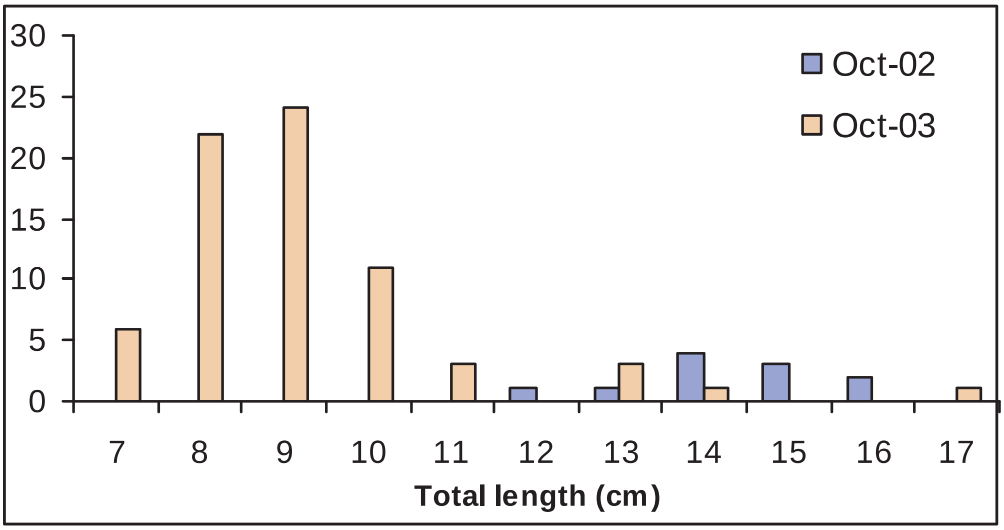

Figure 6.8 Size composition (cm total length) of the western butterfish *P. vitta* in site 6 in Shark Bay during October 2002 and 2003.

Snapper Pagrus auratus

This species is a highly popular recreational fish species. Only low numbers of snapper were caught during the sampling periods. The size range of those sampled was between 11cm and 15cm (Figure 6.9).

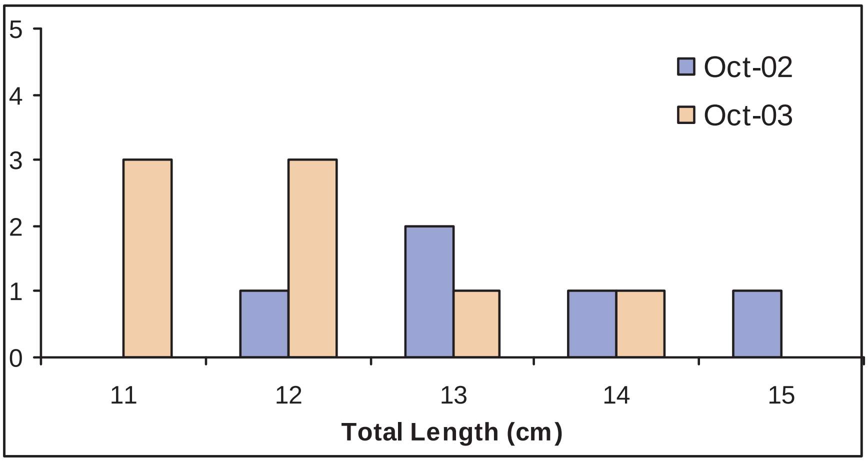

Figure 6.9 Size composition (cm total length) of snapper *P. auratus* in October 2002 and 2003.

Asymmetrical goatfish Upeneus asymmetricus

Upeneus asymmetricus was common throughout Shark Bay and samples from sites where sufficient numbers were used for length frequency analysis (Table 6.5). The size range of fish sampled was 3 cm to 21 cm. Pooling measurements for all sites (Figure 6.10), revealed two size cohorts. Higher numbers of smaller individuals were sampled (Figure 6.11) in Start03 with the size composition being significantly different (KS test, significant at 95% level) between Start03 and Mid03 and End03. Small individuals were not observed for the other time periods.

Table 6.5 Mean total length (SE) for sampling periods for sites where sufficient number of *U. asymmetricus* were caught for measurement for at least two sites for two time periods. Highlighting indicates a significant difference. Pink indicates significantly higher mean size.

Site	E02	SE	S03	SE	M03	SE	E03	SE
3	12.0	0.58	11.9	0.95	12.2	0.65	11.7	0.66
4			13.1	0.61	11.4	0.51		
8	12.2	0.59	11.9	0.62	11.5	0.59	11.8	0.64
6	11.3	0.61	12.3	0.78			9.7	0.64
17			12.4	0.39			10.3	0.40
16	11.5	0.48	13.6	0.42				
18	10.1	0.47					11.4	0.35
19	12.5	0.43	12.0	0.67				
20	12.9	0.56	11.4	1.32	11.2	0.74		
22	11.8	0.74					9.7	0.63
24	12.2	0.56			14.6	0.61		
26	14.0	0.46					11.9	0.39

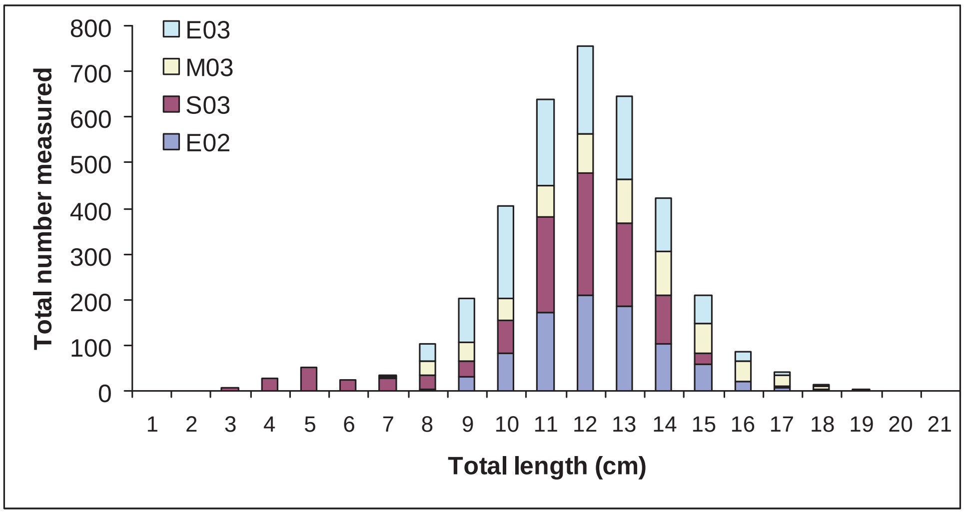

Figure 6.10 Length frequency distribution of *U. asymmetricus* pooled for all sites for sampling periods End02 to End03.

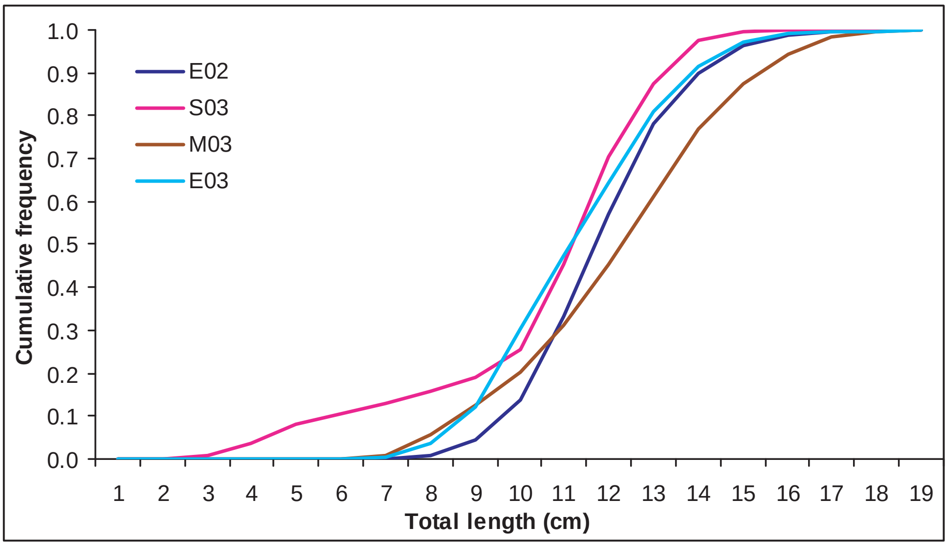

Figure 6.11 Cumulative frequencies for *U. asymmetricus* for pooled sites in Shark Bay for sampling periods End02 to End03.

Samples from all time periods were only measured at sites 3 and 8, and there were no significant differences between any time periods for a site. A larger mean size was observed at site 26 and site 24 in northern Shark Bay in End02 and Mid03 respectively.

Red-barred grubfish Parapercis nebulosa

The size range of fish sampled was between 9 cm and 23 cm. Nine sites had sufficient numbers for length frequency analysis. Pooled measurements from all sites provided evidence of three size classes at around 12 cm, 16 cm and 20 cm (Figure 6.12).

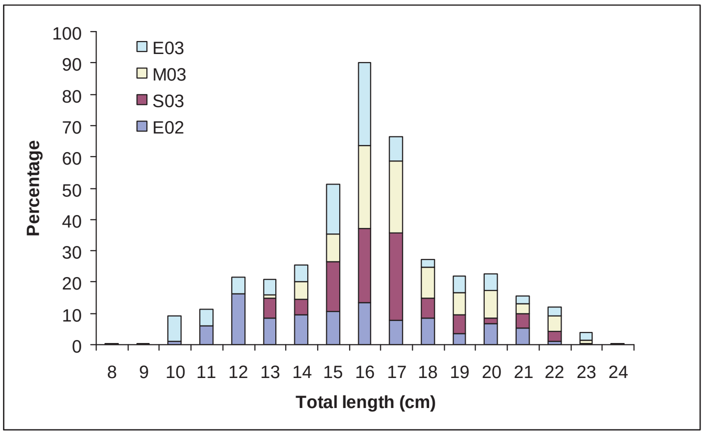

Figure 6.12 Size composition of *P. nebulosa* in Shark Bay for all sampling sites and periods combined.

For individual sites there was no significant differences in mean total length for any time period (Table 6.6). However, when all sites are pooled it is observed that larger numbers of smaller individuals are sampled at the end of the year (Figure 6.12 and 6.13) with End02 being significantly larger than Start03 and Mid03 (KS test, significant at the 95% level).

Table 6.6 Mean total length (SE) for sampling periods for sites where sufficient number of *P. nebulosa* were caught for measurement for at least two sites for two time periods.

Site	E02	SE	S03	SE	M03	SE	E03	SE
2			17.4	0.72	17.3	0.63		
8	14.9	0.83					16.5	0.98
6	14.8	1.25	16.2	1.25				
17	16.9	0.80						
16	18.3	1.12						
18	14.3	0.77	14.8	0.75				
19	17.7	0.65	15.9	0.65				
14	13.7	0.72			16.4	0.68		
20	18.6	0.93			18.3	0.80		

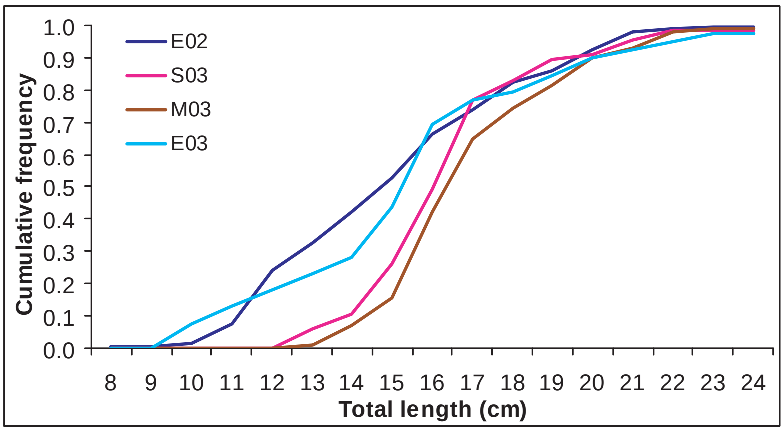

Figure 6.13 Cumulative frequencies of *P. nebulosa* for all sampling sites combined in Shark Bay between End02 and End03.

Hair-finned leatherjacket Paramonacanthus choirocephalus

The size range of fish sampled was 5 cm to 14 cm. Six sites had sufficient numbers of fish for length frequency analysis. For the sites measured, no significant differences were observed between sites for any single time period. A significantly smaller mean size was observed during Start03 compared to End02 for sites 6, 8 in Shark Bay and site 19 in Denham Sound (Table 6.8, Figure 6.14). When all sites were pooled for each sampling period, the pooled size compositions were significantly different for every comparison (KS test, significant at the 95% level).

Table 6.8 Mean total length (SE) for sampling periods for sites where sufficient number of *P. choirocephalus* were caught for measurement. Highlighting indicates significant differences.

Site	E02	SE	S03	SE	M03	SE	E03	SE
8	9.5	0.44	7.9	0.47			9.3	0.42
6	10.0	0.44	7.9	0.60				
7					7.6	0.31	8.7	0.33
16	11.1	0.52			10.2	0.48		
19	10.1	0.41	7.2	0.43				
20	10.6	0.45			10.5	0.38		

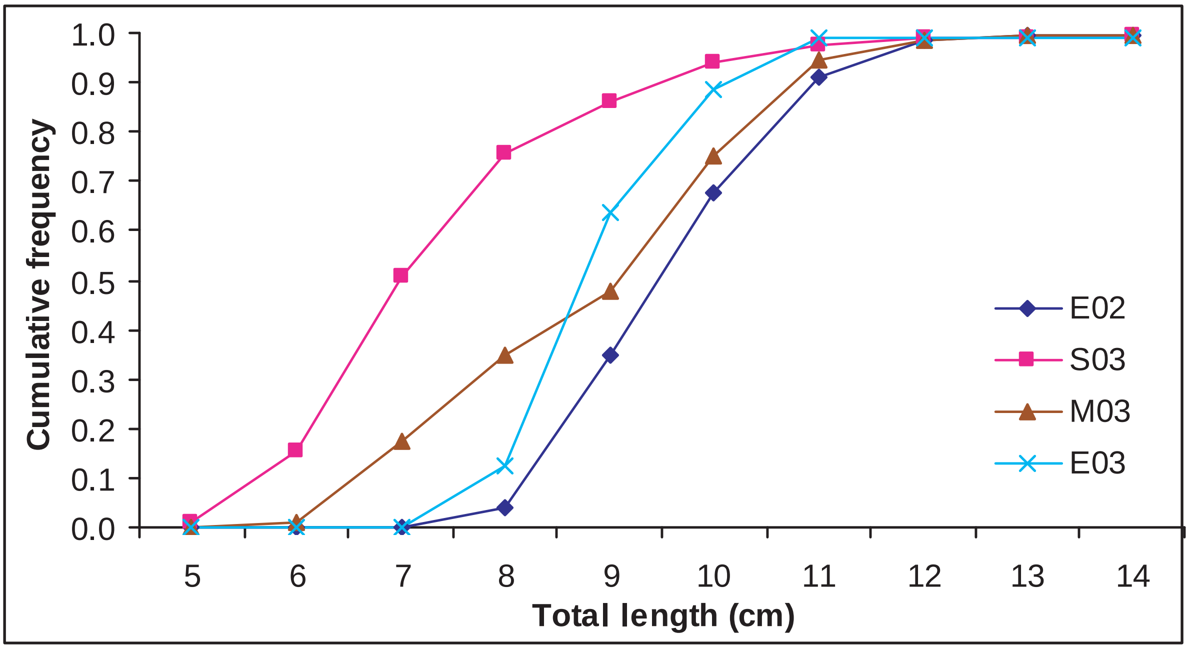

Figure 6.14 2 Cumulative frequencies of *P. choirocephalus* for all sampling sites combined in Shark Bay between End02 and End03.

Large-scaled lizardfish Saurida undosquamis

The sizes of fish sampled were between 11 cm and 59 cm. Significant mean size differences were observed between some sites (Table 6.7).

Table 6.7 Mean total length (SE) for sampling periods for sites where sufficient number of *S. undosquamis* were caught for measurement. Highlighting indicates significant differences.

Site	E02	SE	S03	SE	M03	SE	E03	SE
2			20.7	0.88	19.5	0.71		
3	27.3	1.16			24.9	0.98		
4			27.0	1.04	24.0	1.02		
5	23.1	1.51						
6	27.0	0.71	22.0	1.18				
8	32.0	1.56	23.8	1.88	24.6	1.88		
17	21.1	0.53	23.3	0.69				
16	27.1	0.69			23.5	1.18		
18	20.8	0.61	20.3	0.96				
19	23.4	0.62	20.7	0.91				
14	24.4	0.91			20.9	1.18		
20	30.8	0.40			27.8	0.97		
22	41.1	1.05					24.6	0.88
24	24.6	1.70			36.9	1.21		
25	34.1	2.19			36.6	1.85	36.3	4.06
11	36.9	1.76					26.7	2.38
12	37.7	0.91			23.3	1.80		

The length frequency for all sites pooled over time periods show a higher proportion of smaller individuals and possibly four size cohorts and very low numbers of fish over 50cm (Figure 6.15).

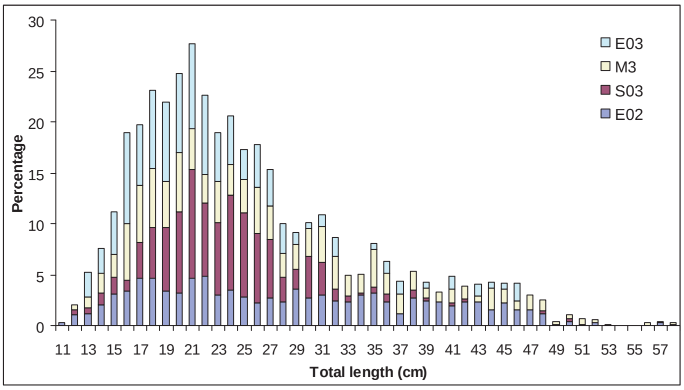

Figure 6.15 Size composition of *S. undosquamis* in Shark Bay for all sampling sites and periods combined.

Sites were then pooled into broad regions; eastern side (E) of Shark Bay (sites 2,3,4 and 5), Denham Sound (DS) (sites 17, 16, 18, 19 and 20), central Shark Bay (C) (sites 6, 8 and 22) and northern Shark Bay (N) (sites 24, 25, 11 and 12) for length frequency analysis (Figures 6.16 and 6.17).

Comparison of regions for sampling periods, the eastern and central sites and eastern sites and Denham Sound were significant only at the 90% level (KS test) whereas all the other combinations were significantly different at the 95% level (KS test) for End02. No significant differences were observed for the eastern, central sites or Denham Sound during Start03 (no sampling in northern sites during this time period). For Mid03 all site combinations were significantly different for size composition (KS test, significant at the 95% level) (Figure 6.16). Noticeably, the mid size *S. undosquamis* was not observed in the northern sites in End02 or Mid03.

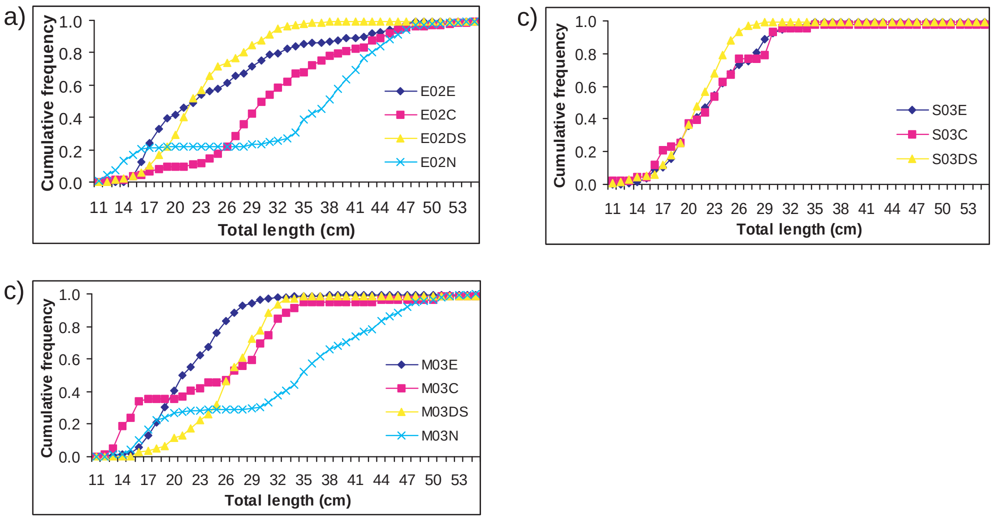

Figure 6.16 Cumulative frequencies of S. undosquamis at pooled sites in Shark Bay. E – eastern gulf, C – central gulf, DS – Denham Sound, N – northern Shark Bay. a) End02, b) Start03, c) Mid03. Only the northern area was measured in E03 and is not shown.

When comparing the cumulative size frequency of a group of sites between sampling periods, no significant differences were observed for the eastern or Denham Sound sites, for the central sites only End02 and Start03 were significantly different (KS test, significant at the 95% level) and for the northern sites End02 was significantly different to Mid03 and End03 (KS test, significant at the 95% level).

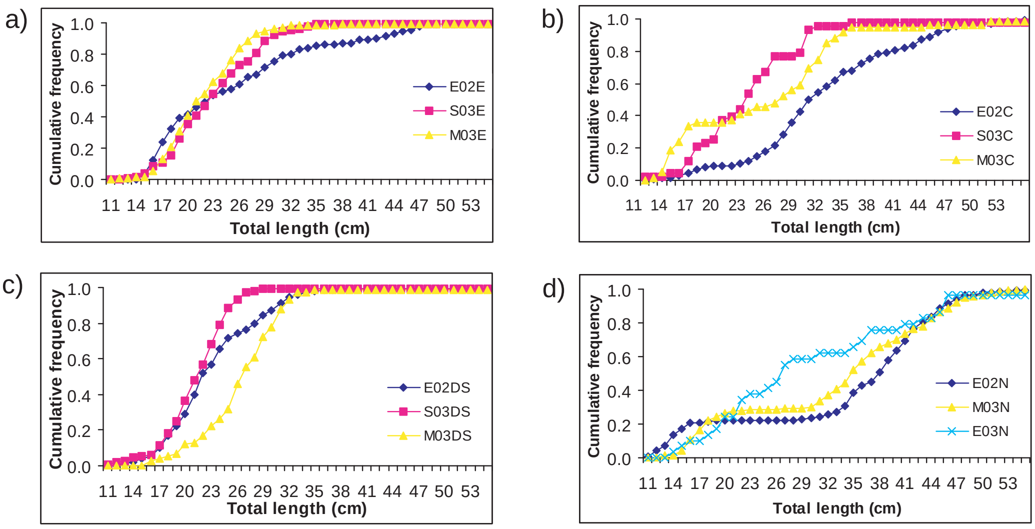

Figure 6.17 Cumulative frequencies of *S. undosquamis* at pooled sites in Shark Bay for each time period. a) E – eastern gulf, b) C – central gulf, c) DS – Denham Sound, d) N – northern Shark Bay.

6.3.2 Length Frequencies and mean length at sites, Exmouth Gulf and Onslow Area 1

Invertebrates

Prawns

The size range of *P. esculentus* was between 18 mm and 51 mm carapace length. Eight sites (Figure 6.18) had sufficient numbers of tiger prawns for length frequency analysis for Start and Mid04 whereas only two sites were measured in End04 (Table 6.8).

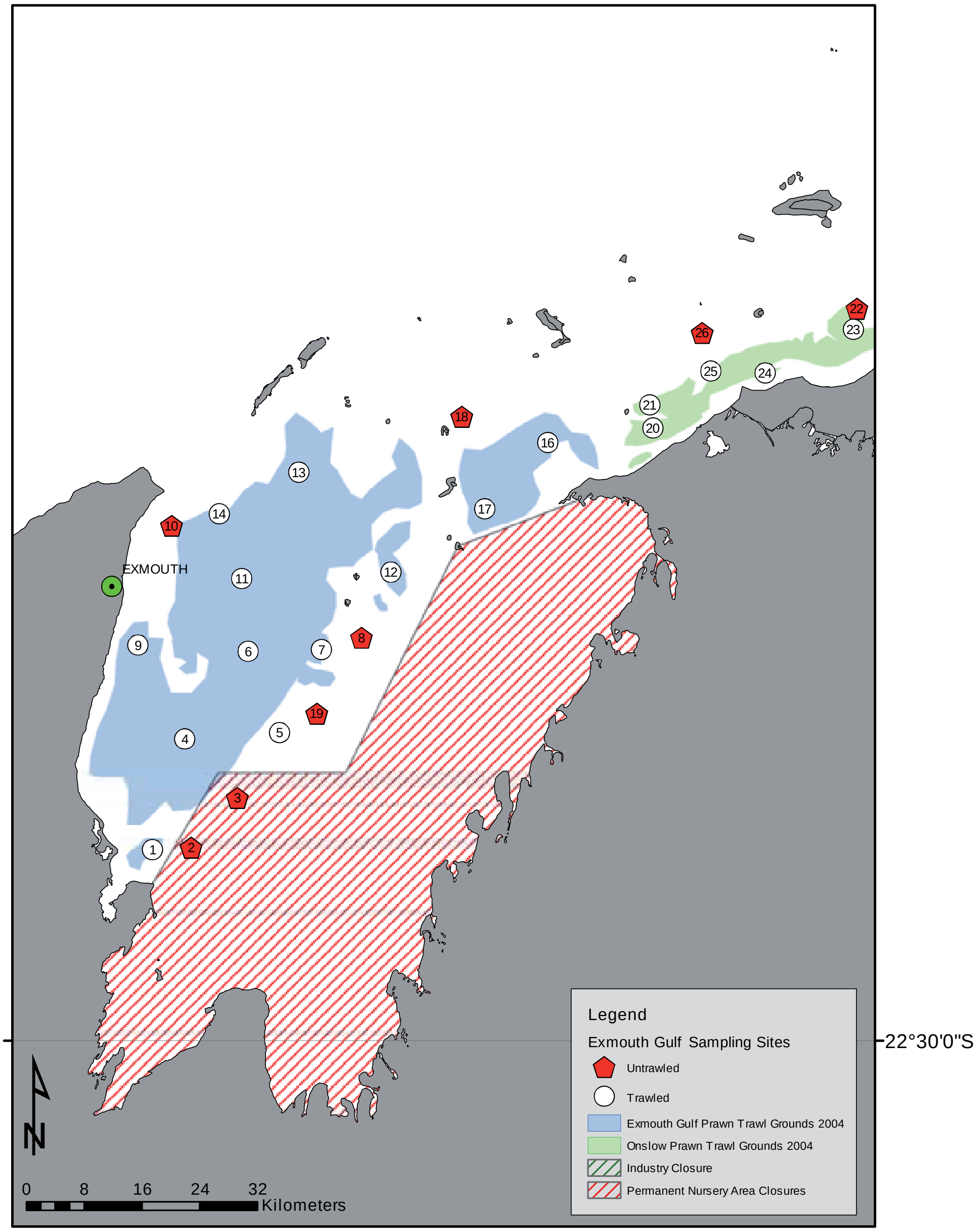

Figure 6.18 Exmouth Gulf and Onslow sampling sites during Start04 to End04.

Table 6.8 Mean carapace length (CL) and SE for sampling periods for sites where sufficient number of *P. esculentus* were caught for measurement for a site for at least two time periods in Exmouth Gulf and Onslow between Start04 and End04.

Males							Females						
Site	Start04	SE	Mid04	SE	End04	SE	Site	Start04	SE	Mid04	SE	End04	SE
4	26.1	4.04	30.1	6.43	29.6	6.89	4	26.9	3.65	33.0	5.81	33.8	5.98
5	28.0	3.02	33.9	7.47			5	28.2	3.23	38.4	6.20		
19	28.5	2.75	29.4	5.47			19	30.0	4.23	33.9	5.54		
6	26.4	3.61	28.6	6.73			6	27.8	3.36	33.5	5.15		
7	28.1	3.41	28.1	6.73			7	30.6	3.36	32.4	5.15		
8	24.2	3.67	27.7	4.33			8	24.7	4.09	31.3	4.28		
12	23.6	3.77	28.5	6.72			12	23.5	3.48	31.7	4.83		
17	25.8	4.12	28.5	6.29	31.6	4.57	17	27.7	3.73	33.0	6.40	30.0	5.41

When pooling all size frequencies for all sites for Start04 and Mid04 there is a significant difference (KS test, significant at the 95% level) between cumulative frequencies for male and female prawns (Figure 6.19).

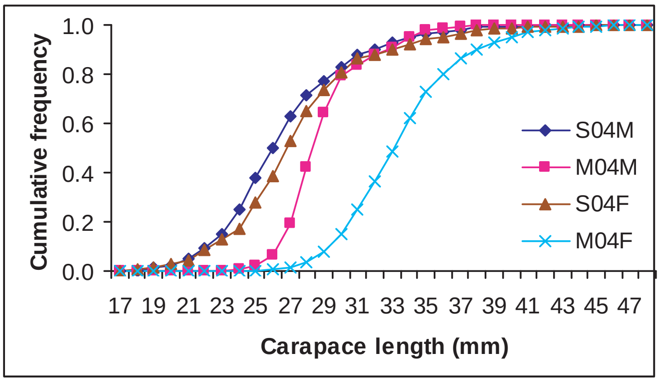

Figure 6.19 Cumulative frequencies of male (M) and female (F) *P. esculentus* for pooled sites in Exmouth Gulf for Start04 and Mid04.

Combining the two sites where all time periods were measured comparison of cumulative frequencies between time periods indicated significant differences (KS test, significant at the 95% level) between Start04 and Mid04 and Start04 and End04 for both male and female prawns. An increase in size is observed between Start04 and End04 for both male and female *P. esculentus* with the largest increase occurring between Start04 and Mid04 (Figure 6.20).

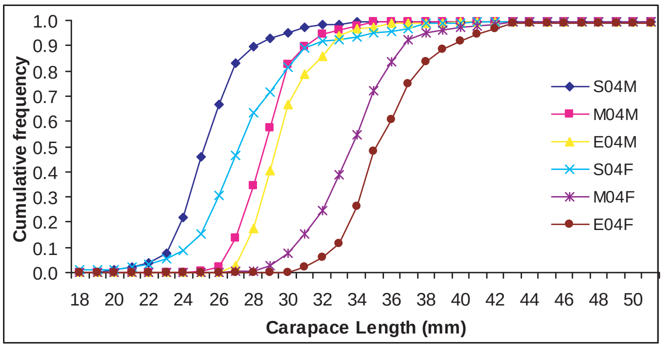

Figure 6.20 Cumulative frequencies of male (M) and female (F) *P. esculentus* for pooled length frequencies for site 4 and site 17 in Exmouth Gulf for Start04, Mid04 and End04.

The size range of *P. latisulcatus* sampled was between 20 mm and 50 mm carapace length. Only four sites had sufficient numbers of prawns for length frequency analysis. A smaller mean size of both male and female *P. latisulcatus* is observed in Start04 compared to Mid04 (Table 6.9). Little difference in the mean size of prawns is observed between Mid04 and End04 at sites 13 and 14 in northern Exmouth Gulf with similar length frequency distributions observed for these time periods (Figure 6.21).

Table 6.9 Mean carapace length (CL) and SE for sampling periods for sites where sufficient number of *P. latisulcatus* were caught for measurement for a site for at least two time periods in Exmouth Gulf and Onslow.

Males							Females						
Site	**Start04**	**SE**	**Mid04**	**SE**	**End04**	**SE**	**Site**	**Start04**	**SE**	**Mid04**	**SE**	**End04**	**SE**
16	29.0	3.56					16	31.1	5.12				
18	29.9	8.19	34.8	7.31			18	33.9	4.65	41.5	7.80		
13	28.8	7.45	35.1	7.67	34.0	7.18	13	31.7	5.96	40.3	9.04	41.0	6.10
14	31.0	7.97	32.3	6.30	31.5	6.70	14	31.9	6.20	44.6	10.48	42.4	7.81

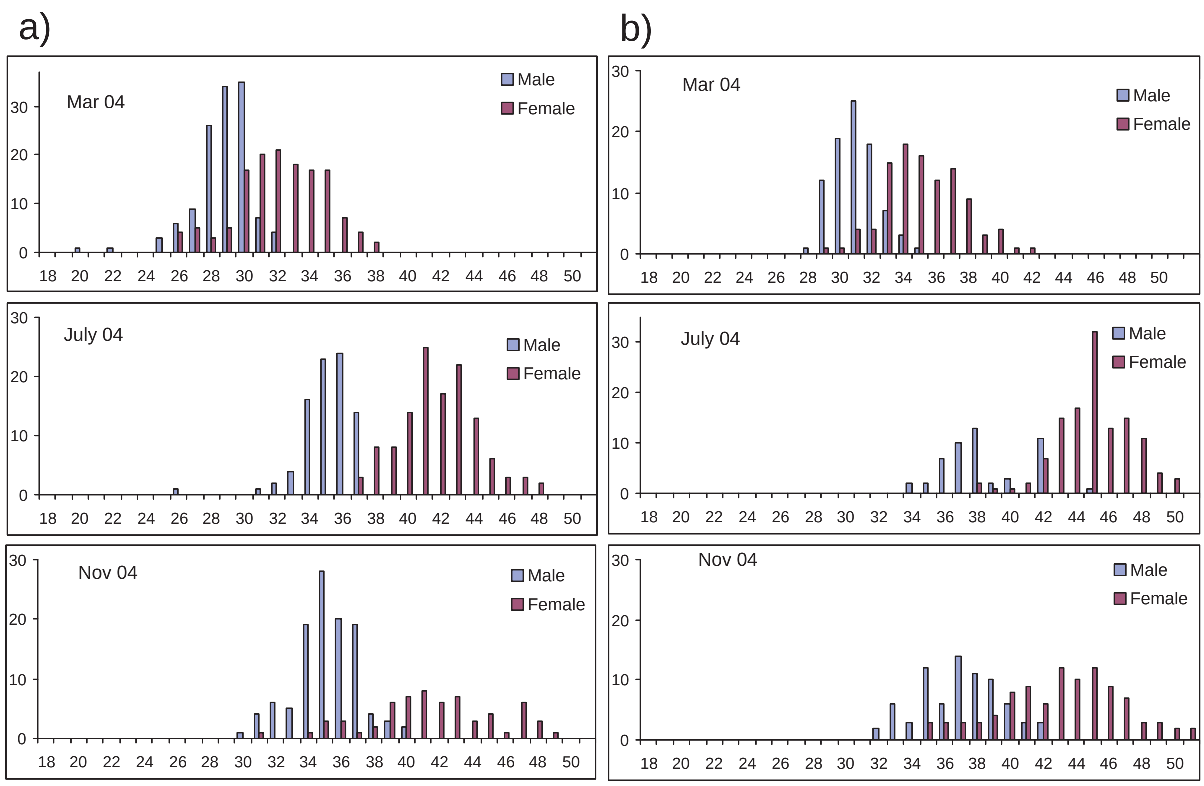

Figure 6.21 Length frequency distributions (mm CL) of male and female *P. latisulcatus* at a) site 13 and b) site 14 in northern Exmouth Gulf during Start04, Mid04 and End04.

Combining the two sites where all time periods were measured, a comparison of cumulative frequencies between time periods indicated significant differences (KS test, significance at the 95% level) between Start04 and Mid04 for males and female prawns and Start04 and End04 for male prawns. An increase in size is observed between Start04 and Mid04 for both male and female *P. latisulcatus* with no significant difference observed between Mid04 and End04 (Figure 6.22).

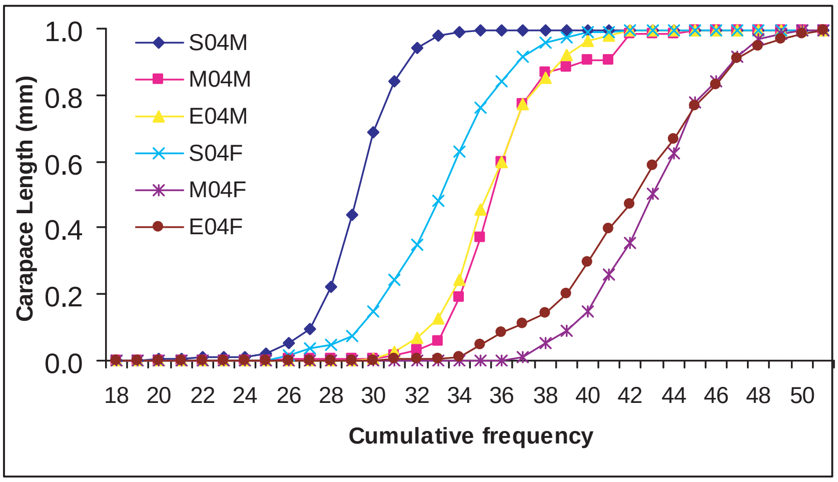

Figure 6.22 Cumulative frequencies of male (M) and female (F) *P. latisulcatus* for pooled length frequencies for site 13 and site 14 in northern Exmouth Gulf for Start04, Mid04 and End04.

Exmouth Gulf and Onslow Fish species

Asymmetrical goatfish Upeneus asymmetricus

The size range of fish sampled was between 4 cm and 18 cm (Figure 6.23). *Upeneus asymmetricus* is common throughout Exmouth Gulf and Onslow Area 1 and fourteen sites had sufficient numbers of *U. asymmetricus* for length frequency analysis (Table 6.10).

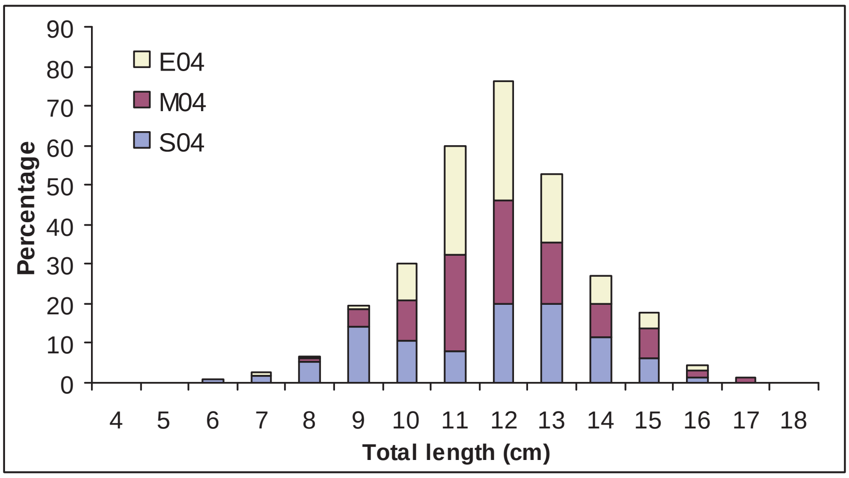

Figure 6.23 Length frequency distribution of *U. asymmetricus* pooled for all sites for sampling periods Start04 to End04.

For those sites where measurements were available for all time periods (Figure 6.24) all showed significantly different cumulative size frequencies between Start04 and Mid04 (KS test, significant at the 95% level). Sites 3 and 26 also showed a significant size difference between Mid04 and End04 at the 95% level with site 12 showing significance at the 90% level between these two time periods. Site 16 also had significant size differences for Start04 and End04.

Table 6.10 Mean total length (cm) and SE for sampling periods for sites where sufficient number of *U. asymmetricus* were caught for measurement for a site for at least two time periods in Exmouth Gulf and Onslow. Highlighting indicates significantly different mean size.

Site	March	SE	July	SE	Nov	SE
1			11.5	0.51	11.7	0.40
2	11.6	0.85	11.6	0.41	12.1	0.41
3	12.3	0.65	11.6	0.28	12.1	0.38
5			11.0	0.29	11.4	0.37
19			12.8	0.43		
12	12.5	0.50	12.6	0.67	11.7	0.37
9					12.1	0.36
10			14.6	0.76		
14	13.0	0.52	14.6	0.35	13.6	0.39
13	12.4	0.21	12.8	0.31	12.4	0.37
11			12.8	0.31	12.4	0.37
16	8.7	0.66	10.8	0.51	12.1	0.47
25	9.4	0.30				
26	9.6	0.50	10.2	0.27	9.5	0.60

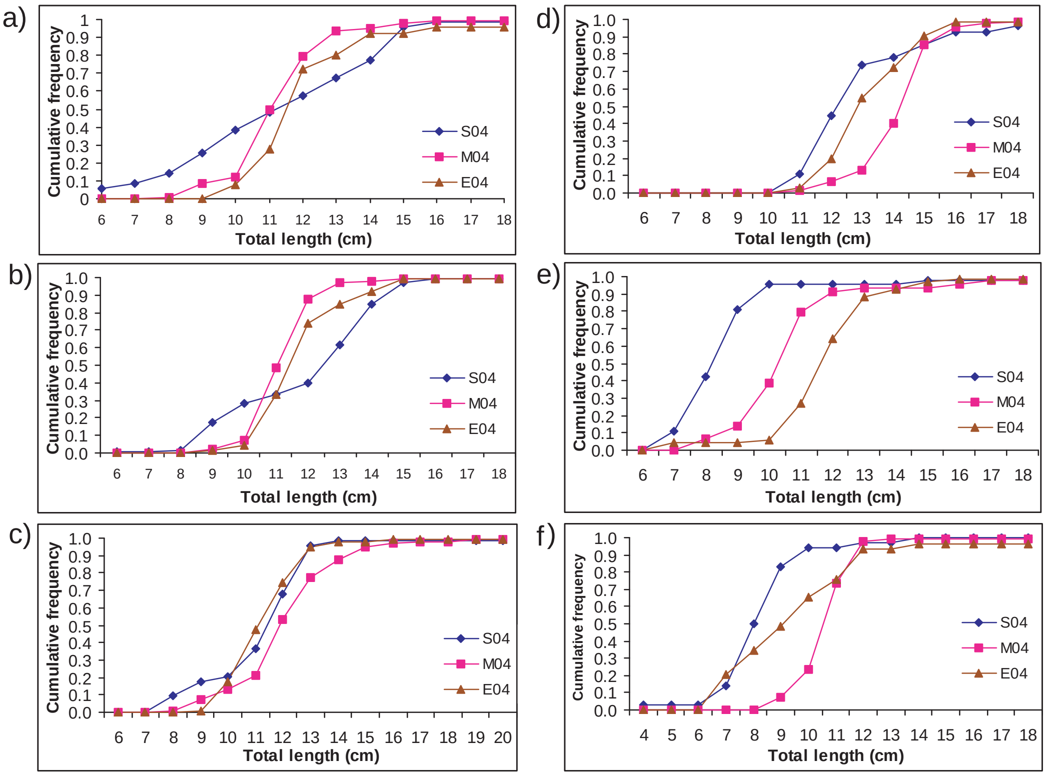

Figure 6.24 Cumulative frequencies of *U. asymmetricus* for those sites where measurements were made for all time periods in Exmouth Gulf or Onslow between Start04 and End04. a) site 2, b) site 3 in southern Exmouth Gulf, c) site 12 in central Exmouth Gulf, d) site14 in northern Exmouth Gulf, e) site 16 and f) site 26 in Onslow.

Smaller fish were observed in Start04 for sites 2, 3 and 16 whilst a clear absence of smaller fish with a larger mean size was evident at site 14 in northern Exmouth Gulf (Figure 6.24 d).

Red-barred grubfish Parapercis nebulosa

The size range of fish sampled was between 7 and 29 cm with majority of individuals between 11 and 19 cm total length (Figure 6.25).

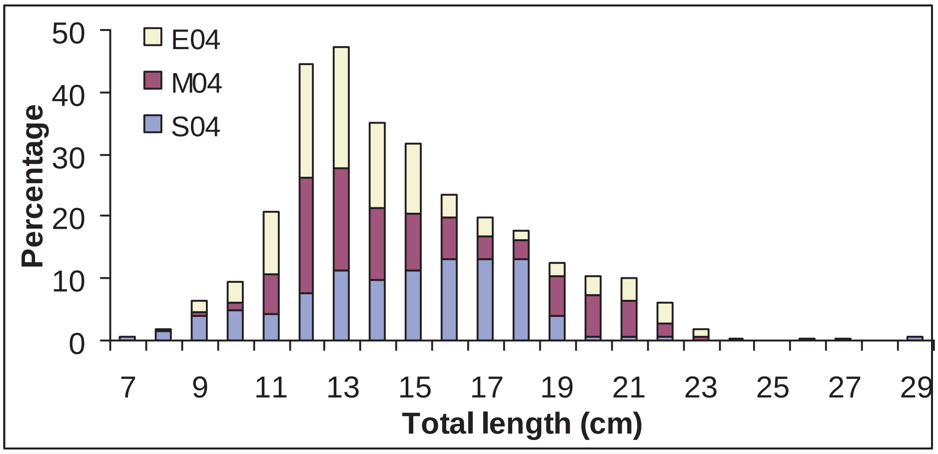

Figure 6.25 Size composition of *P. nebulosa* in Exmouth Gulf and Onslow Area 1 for all sampling sites and periods combined.

Parapercis nebulosa is common throughout Exmouth Gulf and Onslow Area 1 and fourteen sites had sufficient numbers of *P. nebulosa* for length frequency analysis (Table 6.11). Some individual sites showed significantly different mean size between Start04 and Mid04 or Mid04 and End04 but there were no consistent trends (Table 6.11).

Table 6.11 Mean total length (cm) and SE for sampling periods for sites where sufficient number of *P. nebulosa* were caught for measurement for a site for at least two time periods in Exmouth Gulf and Onslow. Highlighting indicates significantly different mean size.

Site	March	SE	July	SE	Nov	SE
1			15.2	1.63	12.6	0.52
2	13.4	0.96	14.9	1.00	9.4	0.67
3	17.1	1.11	14.4	1.50	13.3	2.28
6	14.6	1.00			14.2	1.12
5			16.6	0.96	13.2	0.72
19			14.5	1.05	13.9	1.09
8	12.8	0.76	13.8	0.94	13.5	1.09
9	15.6	0.76	16.5	0.94	16.9	1.14
10			15.7	1.01	15.1	0.98
11					15.3	1.14
12					13.2	0.64
14	15.2	0.74	16.1	0.93	15.0	0.98
16	13.3	0.90	16.4	1.17		
25			13.0	1.08	13.6	0.84
26			13.6	0.80	11.3	0.70

Pooling those sites that measurements were taken for all sampling periods to represent inner Exmouth Gulf (sites 1, 2 and 3), central Exmouth Gulf (sites 5, 19, 8 and 9) and northern

Exmouth Gulf (site 14 only) indicated significant differences in cumulative frequencies for Start04 and End04 and Mid04 and End04 for the southern sites and for Start04 and End04 for the central sites. No significant differences between time periods were observed for the northern site (Figure 6.26).

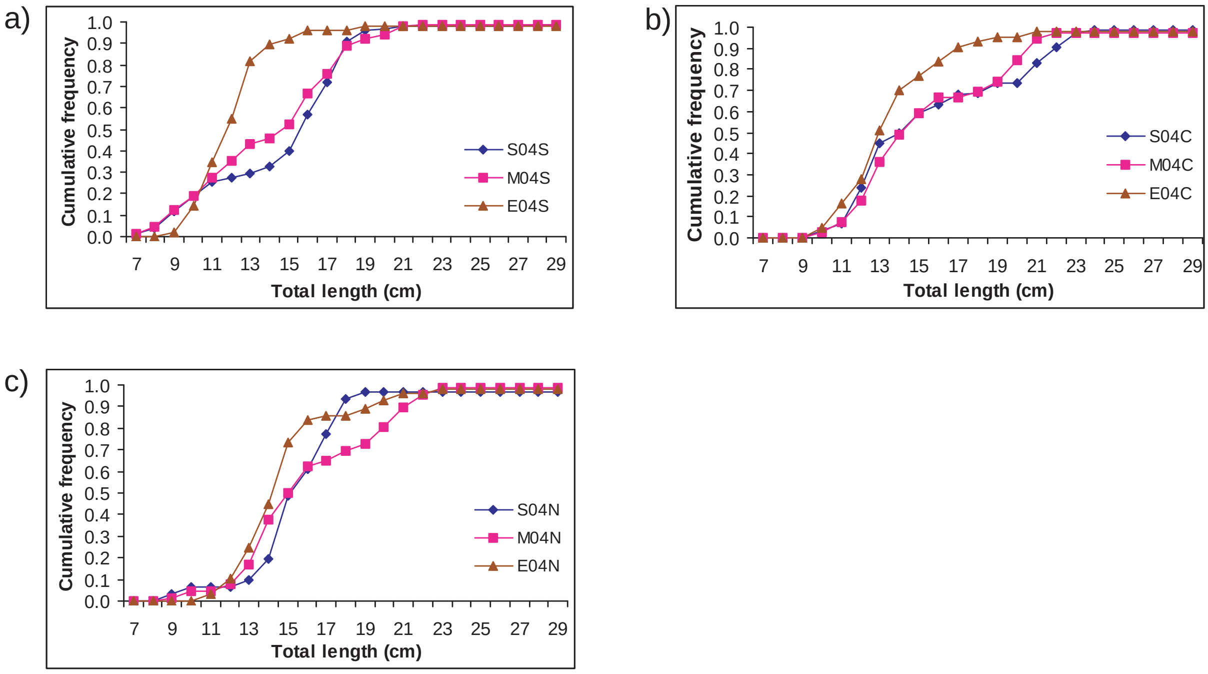

Figure 6.26 Cumulative frequencies of *P. nebulosa* for pooled sites where measurements were made for all time periods in Exmouth Gulf or Onslow between Start04 and End04. a) southern Exmouth Gulf, sites 1, 2 and 3, b) central Exmouth Gulf, sites 5, 19, 8 and 9 and c) site 14 in northern Exmouth Gulf between Start04 and End04.

Large-scaled lizardfish Saurida undosquamis

The size range sampled was 6 cm to 42 cm total length. Smaller individuals were more prominent at End04 and the may appear to at least three size cohorts (Figure 6.27).

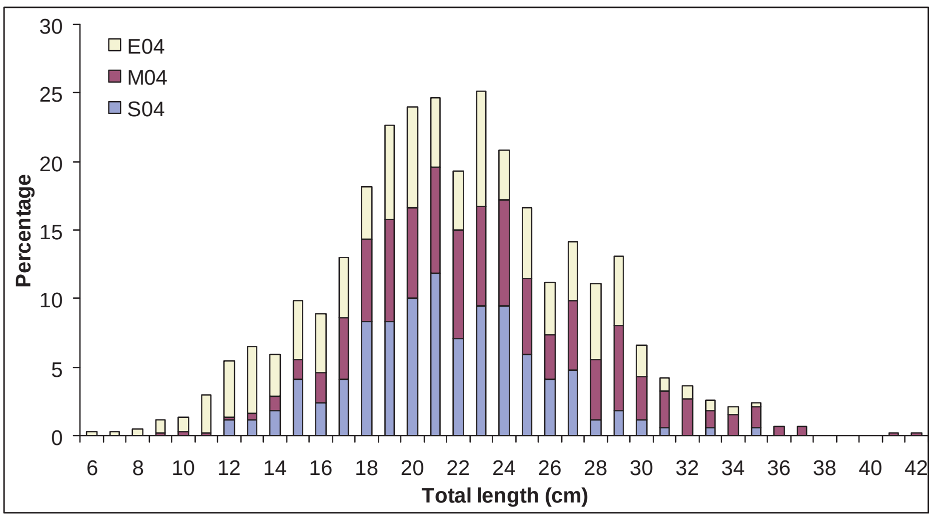

Figure 6.27 Size composition of *S. undosquamis* in Exmouth Gulf and Onslow Area 1 for all sampling sites and periods combined.

Saurida undosquamis was common in most areas of Exmouth Gulf and Onslow Area 1 and was found to be in sufficient numbers for measurement in fourteen sites (Table 6.12). However, there were only three sites (site 4 in southern Exmouth Gulf, site 5 in central Exmouth Gulf and site 14 in northern Exmouth Gulf) where all time periods were sampled. For these three sites significantly different cumulative size frequencies (KS test, significant at the 95% level) were evident for Mid04 and End04 for site 4, Start04 and both Mid04 and End04 for site 5 and Start04 and Mid04 for site 13 whilst Start04 and End04 was only significant at the 90% level for site 13 (Figure 6.28).

Table 6.12 Mean total length (cm) and SE for sampling periods for sites where sufficient number of *S. undosquamis* were caught for measurement for a site for at least two time periods in Exmouth Gulf and Onslow. Highlighting indicates significantly different mean size.

Site	March	SE	July	SE	Nov	SE
1			24.5	1.42	22.2	2.36
2			27.6	1.05	22.7	1.82
4	21.7	1.18	20.0	0.96	24.0	0.96
5	22.9	0.82	18.5	0.91	18.0	4.76
9					28.6	0.76
11					21.8	0.89
12					26.0	2.92
19			25.5	2.01	20.7	2.89
13	19.4	0.78	25.0	1.31	23.2	1.03
16	20.7	1.24	23.2	1.39		
22			23.2	1.09	20.0	1.08
23			21.5	1.17	16.5	1.00
25			27.0	1.67	18.5	2.10
26			27.3	1.36	15.7	1.05

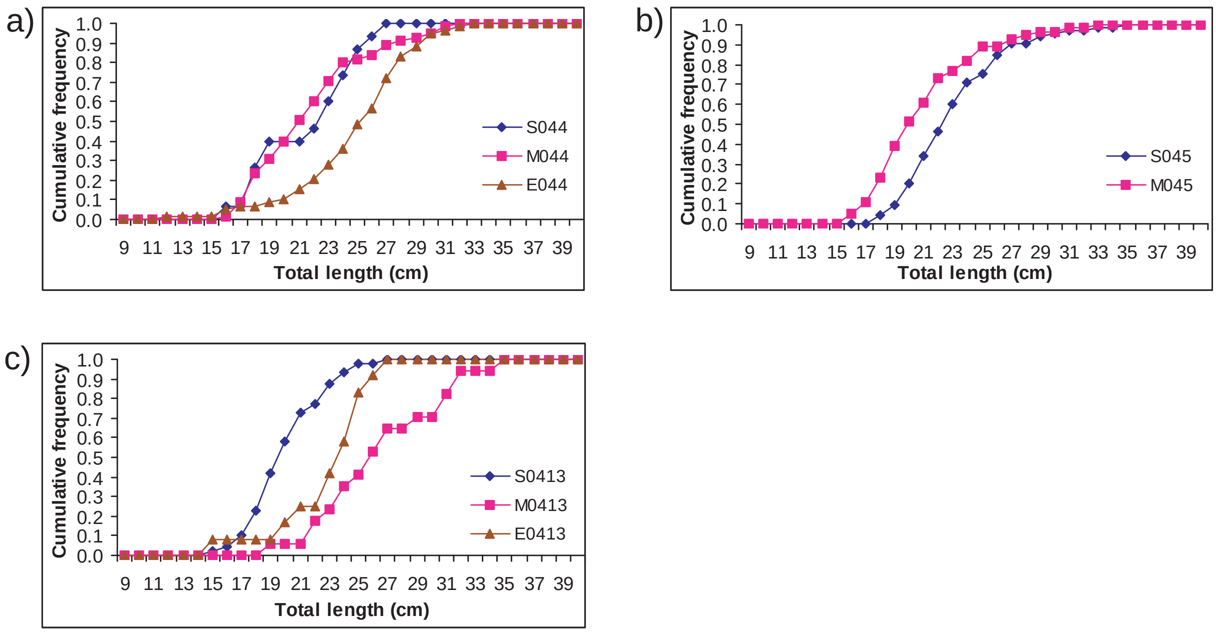

Figure 6.28 Cumulative frequencies of *S. undosquamis* for, a) site 4, b) site 5 and c) site 13 for all sampling periods in Exmouth Gulf between Start04 and End04.

To increase sample size for regions, sites were pooled to represent inner Exmouth Gulf (sites 1, 2 and 4), central Exmouth Gulf (sites 5, 19, and 12), northern Exmouth Gulf (site 11 and 13) and Onslow Area 1 (sites 22, 23, 25 and 26). There were no significant differences in cumulative frequencies (KS test, 95% significance level) for any of the regions or time periods (Figure 6.29).

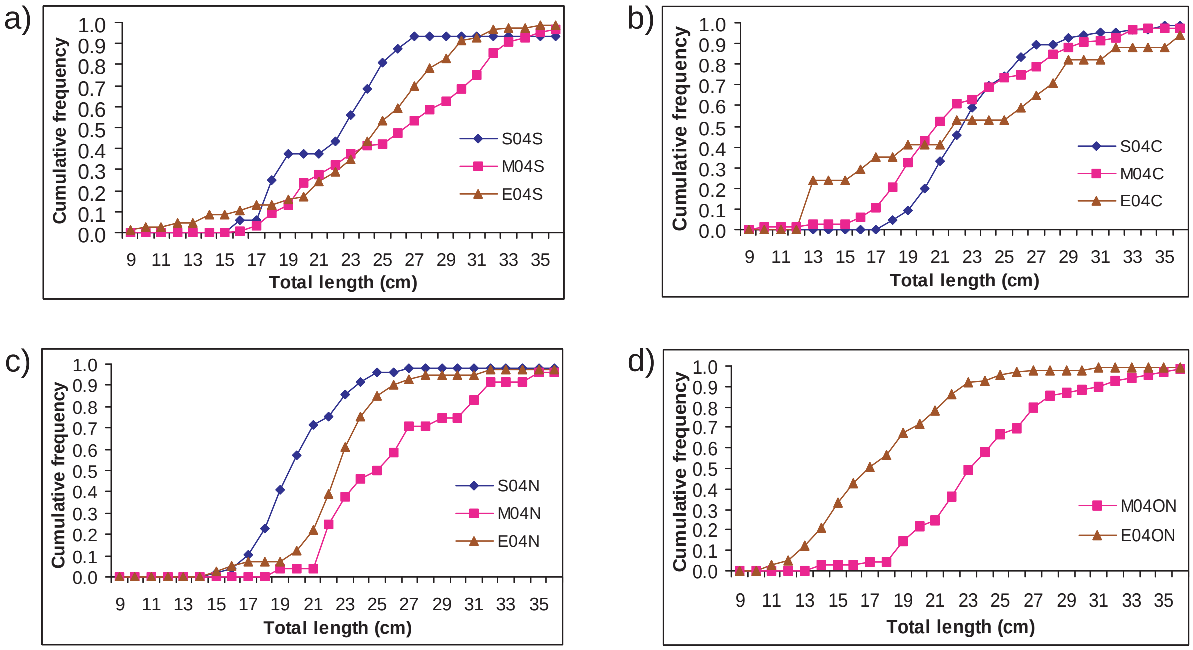

Figure 6.29 Cumulative frequencies of *S. undosquamis* for pooled sites, a) southern Exmouth Gulf (sites 1, 2 an 4, b) central Exmouth Gulf (sites 5, 19 and 12) c) northern Exmouth Gulf (sites 13 and 11) and d) Onslow (sites 22, 23, 25 and 26) for each sampling period. Note in Onslow d) Start04 is not included due to very low numbers of individuals.

6.3.3 Age determination of a selection of Shark Bay fish species

Overall, the species that had the most distinct growth rings in their otoliths were *P. arsius*, *P. quadrilineatus*, *P. sexlineatus* and *G. subfasciatus*. *Pentapodus vitta* is also likely to be suitable to age from its otoliths. Comments on the ability to use otoliths for aging for a selection of species are:

Large-scaled lizardfish (Saurida undosquamis)

Otoliths were sectioned from 17 individuals between 96 mm and 230 mm in length. The centre of most otoliths was very dark and opaque, which made which made it difficult to distinguish the growth rings. In some of the larger specimens, distinct growth rings could be seen, and indicated that these individuals were between 2 to 3 years old. Overall this was a difficult species to age from otoliths.

Large-toothed flounder (Pseudorhombus arsius)

Otoliths from 11 individuals were examined. The otoliths from smaller individuals were most difficult to read due to the section being too thin and translucent. Some of the larger fish had distinct growth rings, indicating that this species may be one of the easier ones to age from otoliths.

Roach (Gerres subfasciatus)

Otoliths from 12 individuals between 85 mm and 133 mm were examined. Most otoliths had very indistinct growth rings, but these were slightly clearer in larger individuals but no age determination could be made.

Red-barred grubfish (Parapercis nebulosa)

Otoliths from 8 individuals were examined and all had very indistinct growth rings. This species proved to be the most difficult to age.

Four-lined trumpeter (Pelates quadrilineatus)

Out of 20 individuals examined, some had clear growth rings, while others did not. The small size of the otoliths in this species made precise sectioning in the correct plane difficult. Those that had indistinct rings are likely to be those that were not sectioned precisely through the sulcus of the otolith.

Six-lined trumpeter (Pelates sexlineatus)

The otoliths of this species are similar to those of *P. quadrilineatus*, and therefore this species could be aged effectively from its otoliths.

Whiting (Sillago robusta, Sillago vittata and Sillago burrus)

Most otoliths had several hundred small rings, making it difficult to distinguish between a daily growth ring and an annual growth ring. Annual growth rings could be seen most easily by using overhead light. Sectioned otoliths had very indistinct growth rings.

Asymmetrical goatfish (Upeneus asymmetricus)

The otoliths from this species were extremely brittle. Whole otoliths were examined using an ultra-violet light projection screen, but insufficient detail could be seen.

Western butterfish (Pentapodus vitta)

This species has been examined previously (Mant 2000), and was reported to be easy to age using otoliths.

6.3.4 Age Determination of a selection of Exmouth Gulf fish species

Interpretation of the growth annuli for *N. peronii* from sectioned otoliths was difficult as translucent and opaque zones were not easily visible. Of the 229 otoliths that were sectioned approximately 40% of the otoliths were used for ageing. The majority of the otoliths were considered uninterpretable and were excluded from the age analysis. The sections were hard to age was due to the presence of a large white opaque central nucleus in the middle of each section. This opaque primordium reduced the accurate identification of the first annulus (Figure 6.30). Secondly in several sections there was a large degree of sub annual banding between each growth ring (Figure 6.31). This made the identification of each annuli difficult.

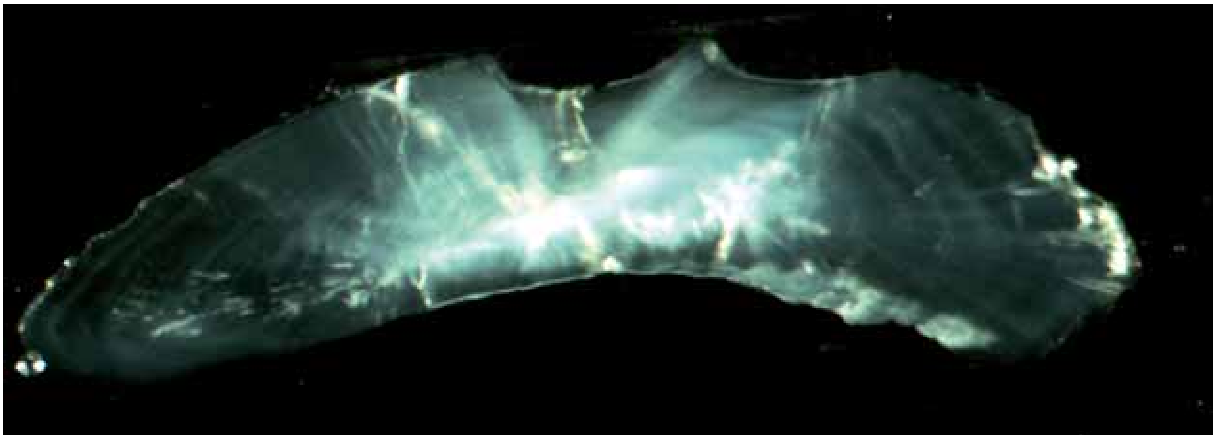

Figure 6.30 Section view of a *N. peronii* otolith with large degree of sub annual banding and no clear distinct growth annuli.

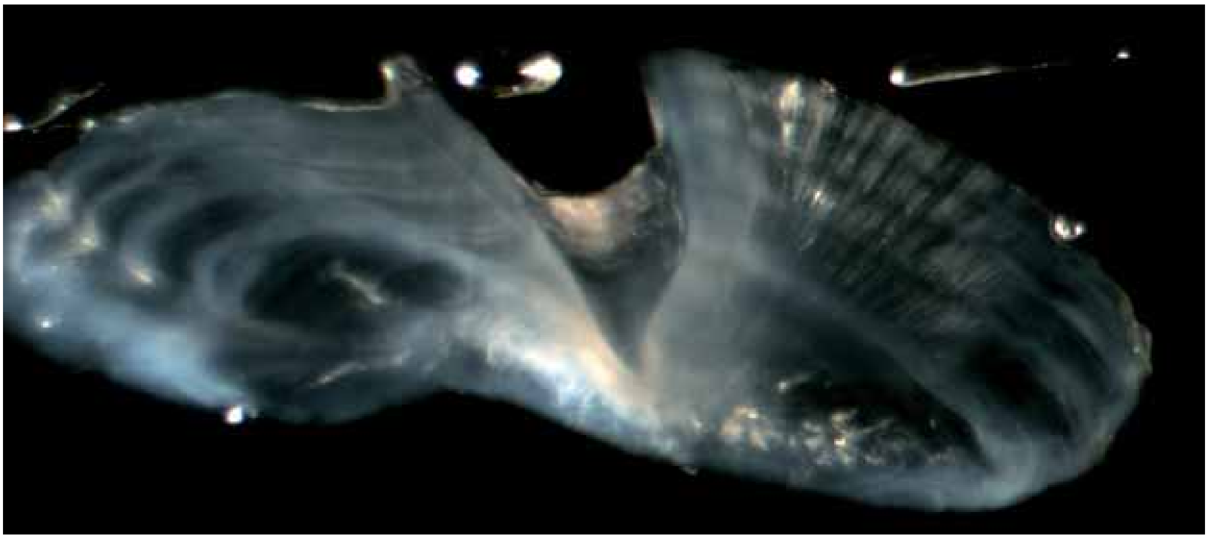

Figure 6.31 Section view of *N. peronii* otolith with distinct growth annuli on both the dorsal and ventral regions of the otolith.

No age determination from otoliths could be made for *U. asymmetricus.*

Size

Approximately 70% of the fish caught in the sample of *N. peronii* were between the 10 to 13 cm fork length size category (Figure 6.32). Previous records have indicated that the maximum size of *N.peronii* is 35 cm fork length. During this study the largest fish recorded had a total length of 23.3 cm indicating either that the gear selectivity is less for larger size classes or that they were not present on the trawl grounds.

A total of 749 specimens of *U. asymmetricus* were collected with sizes ranging from 6 to 16 cm fork length (Figure 6.33). Previous records have shown that the maximum size for *U.asymmetricus* is 30 cm total length. In this particular study the largest fish caught had a total length of 16.7 cm. This size distribution is very similar to that seen in *N. peronii*. Like *N. peronii,* the majority of the samples caught (i.e 65%) were in between the size range of 10-13 cm fork length.

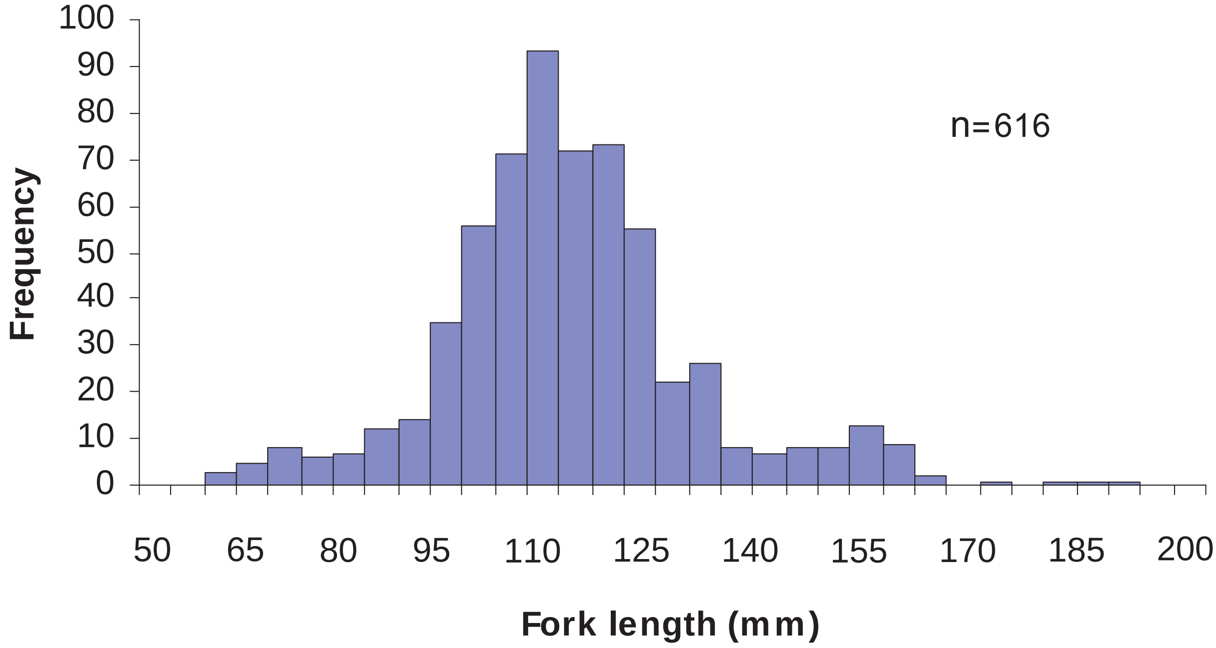

Figure 6.32 Size frequency distribution (mm fork length) of *N. peronii* from samples collected in Exmouth Gulf.

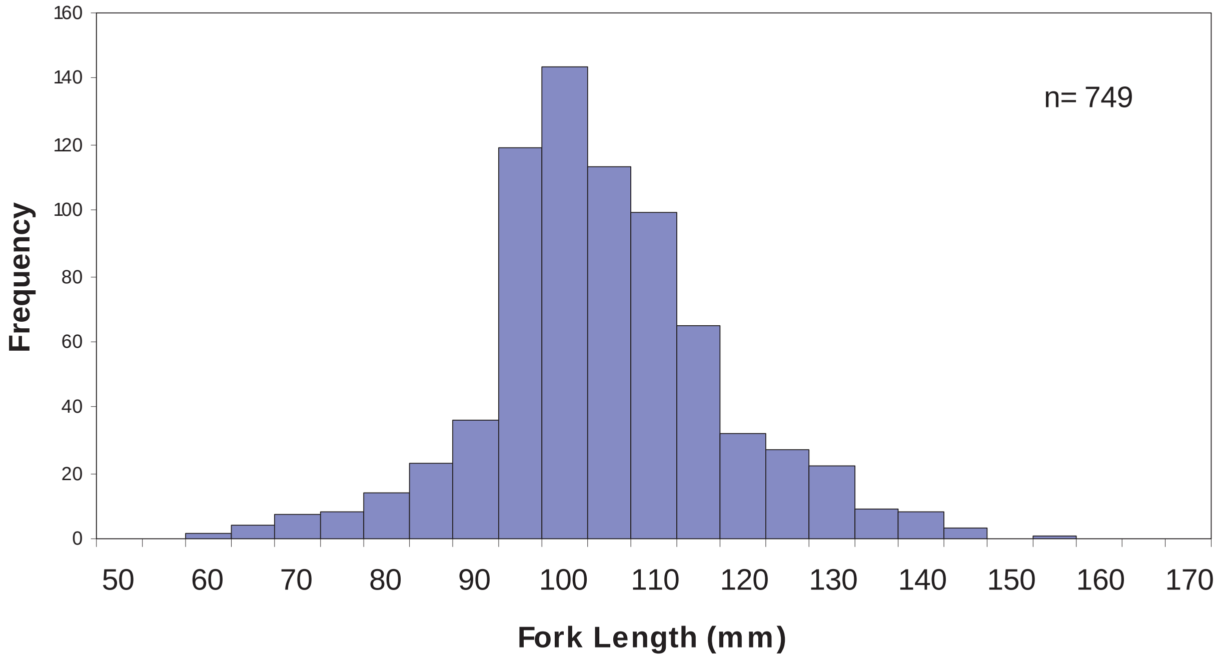

Figure 6.33 Size frequency distribution (mm fork length) of *U. asymmetricus* from samples collected in Exmouth gulf.

There is a strong power relationship between the length and weight of *N. peronii* (Figure 6.34) and *U. asymmetricus* (Figure 6.35).

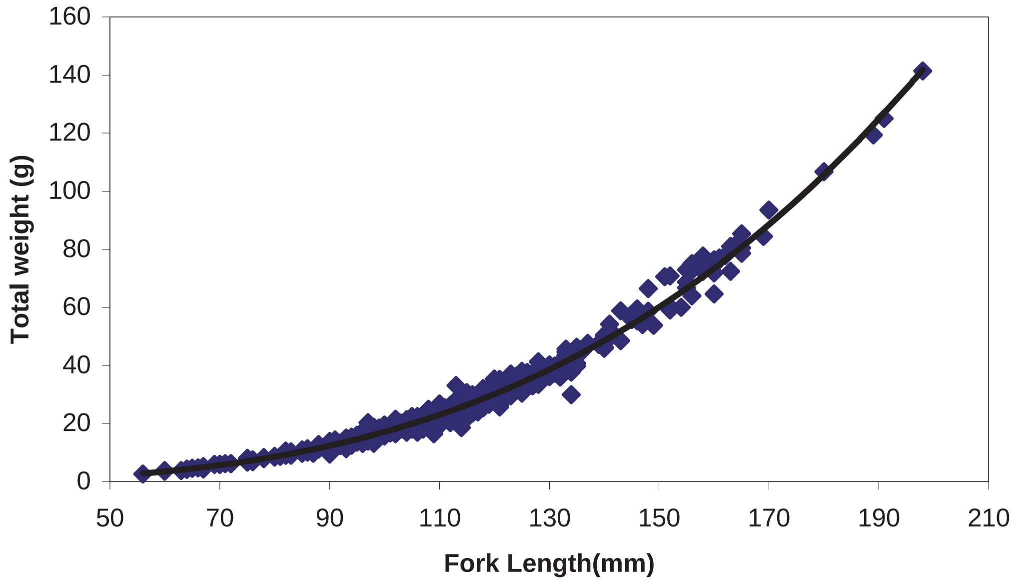

Figure 6.34 Relationship between fork length (mm) and total weight (g) for *N. peronii.*

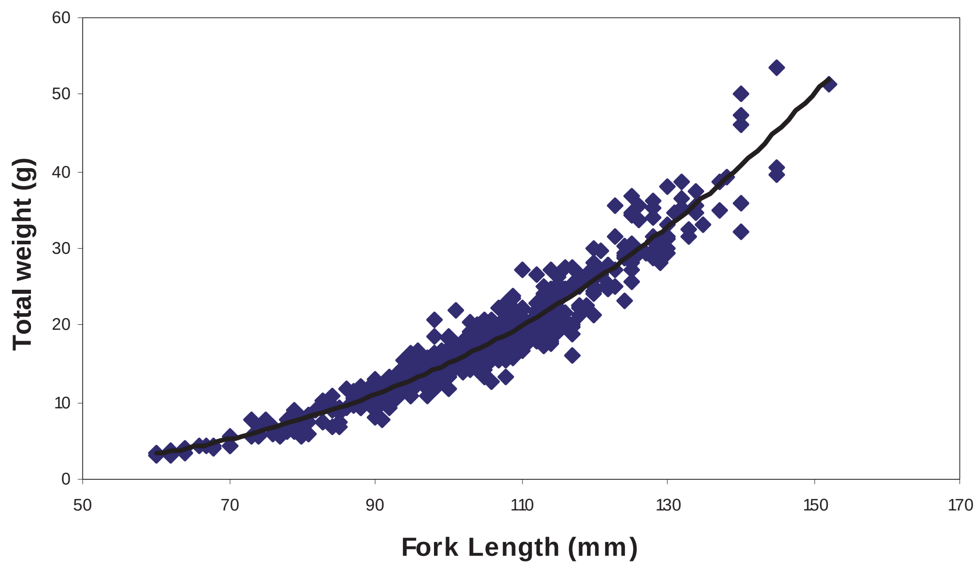

Figure 6.35 Relationship between fork length (mm) and total weight (g) for U. asymmetricus.

Size at maturity

None of the gonads that were examined for *N. peronii* from the November sample were found to contain mature gonads. All of the gonads were found to be either immature or in their resting stage. The relationship between gonad weight and fish weight was also examined (Figure 6.36).

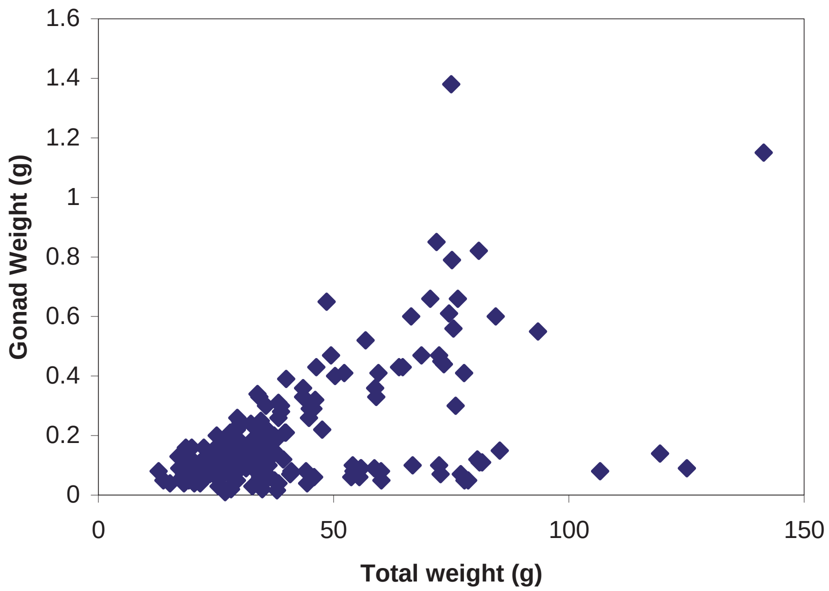

Figure 6.36 Relationship between gonad weight (g) and total weight (g) in *N. peronii.*

For *U. asymmetricus*, a large proportion of the gonads were in their resting stage (i.e. stage 2). However there was some evidence to suggest that the spawning in this species may occur during the warmer summer months. Several individual *U. asymmetricus* were found to contain gonads with ripe eggs in the samples collected during November. None of the other fish collected previously in July contained gonads with hydrated eggs. In order to calculate the length at which 50 % of the *U. asymmetricus* attain maturity further, samples would need to be collected during the peak spawning period. The relationship between gonad weight and fish weight was also examined (Figure 6.32)

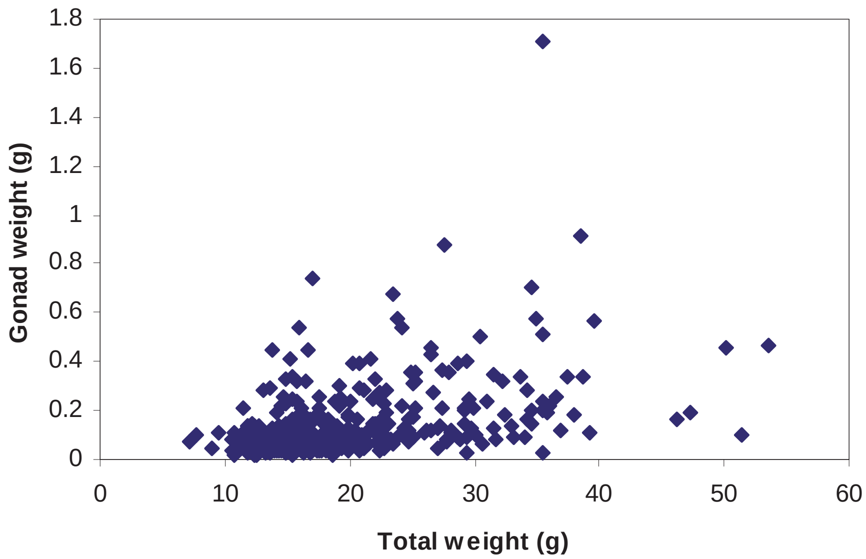

Figure 6.37 Relationship between gonad weight (g) and total weight (g) for *U. asymmetricus.*

6.4 DISCUSSION

In Shark Bay, the invertebrates *P. esculentus, P. latisulcatus, A. balloti* and *P. pelagicus* were numerous enough at some sites for length frequency analysis although only two sites had sufficient crab numbers limiting the ability to draw any inferences on overall size distribution for this species.

For *P. esculentus* a fairly small size range (27 mm to 42 mm CL) of individuals was observed during the project. This may be due to juvenile (and small adult) brown tiger prawns preferring structured habitats such as seagrass and algal beds during their early life stages (Loneragan et al. 1998, 2001) and also because these habitats were not sampled extensively in Shark Bay as part of this project as they are not features of active trawl grounds nor of the adjacent untrawled areas. In contrast the size range of *P. latisulcatus* (19 mm to 50 mm CL) was broader, as king prawns are more closely associated with sand or mud/sand habitats, even as juveniles (Kangas and Jackson 1998) and these were the habitats sampled during this study. A significantly higher proportion of smaller individuals were observed at the start of the season for all sites pooled, indicating that this is the main recruitment period for king prawns in Shark Bay. A smaller mean size of *P. latisulcatus* was observed in Denham Sound, in those areas closed to trawling, which are south of the open sites sampled in Denham Sound indicating these areas are important nursery and juvenile habitats. Migration of individuals once they attain a larger size occurs from these areas to the northern sites in Denham Sound during the year (Penn 1988).

Only three sites had sufficient numbers of scallops for length frequency analysis but these sites encompassed southern (closed) and central Denham Sound and in northern Shark Bay and were areas that are traditional scallop trawl grounds. For the sites sampled in areas open to fishing, a significantly smaller mean size was observed at the end of the season indicating recruitment at this time of year. However, in the closed area in Denham Sound a significantly smaller mean size was observed at the start of season. Due to the short term nature of the sampling program (only four time periods from October 2002 to October 2003) no firm conclusions can be made if this annual variation in recruitment occurs at a localised site or if it is a true recruitment timing difference in southern Denham Sound.

The total length frequencies for four fish species were assessed in Shark Bay; *U. asymmetricus*, *P. nebulosa*, *P. choirocephalus* and *S. undosquamis*. Two to four cohorts (possible annual or multiple recruitment events) were observed for pooled site data. *U. asymmetricus* and *P. choirocephalus* had significantly smaller mean size at the start of the season whereas *P. nebulosa* and *S. undosquamis* had a significantly smaller mean size at the end of the season indicating differences in timing of recruitment into Shark Bay for these species. For *P. choirocephalus* and *P. nebulosa* no significant differences were observed between any of the sites sampled that had sufficient numbers for analysis. Larger *U. asymmetricus* and *S. undosquamis* (>50 cm total length) were sampled in northern Shark Bay compared to more southern sites and for *S. undosquamis* there was an absence of the mid sized individuals in the northern site.

In Exmouth Gulf and Onslow Area 1 the size range of *P. esculentus* was much broader than that observed in Shark Bay. This is due to the relatively smaller overall area of Exmouth Gulf and wider extent of inner Exmouth Gulf sampled as well as the high abundance and extensive distribution of *P. esculentus* during 2004. Commercial catches (catch of 655 tonnes) of brown tiger prawns far exceeded the 10-year average for this fishery of 350 to 550 tonnes in 2004 (Sporer and Kangas 2005). The size range of king prawns was similar to that observed in Shark Bay. For both species a significantly smaller mean size was observed at the start of the season indicating that this is the recruitment period for these prawn species. An increase in mean size was observed between Start04 and Mid04 for both male and female prawns but no continued increase was observed between Mid04 and End04. No more than three cohorts were observed for prawn species. No other larger invertebrates were sampled in sufficient numbers for length analysis in Exmouth Gulf/ Onslow Area 1.

Three fish species were compared in Exmouth Gulf and Onslow Area 1, *U. asymmetricus*, *P. nebulosa* and *S. undosquamis*. They also showed two to four cohorts (annual or recruitment events) for pooled site data similar to the size composition in Shark Bay. Significantly smaller *U. asymmetricus* were seen at the start of the season in Exmouth Gulf indicating a similar recruitment pattern as in Shark Bay for this species. *P. nebulosa* and *S. undosquamis* had significantly smaller individuals at the end of the season, similar to trends seen in Shark Bay. Larger individuals of *P. nebulosa* were observed in Exmouth Gulf compared to Shark Bay whilst a smaller size range of *S. undosquamis* was sampled in Exmouth Gulf. This is possibly due to depth differences (Sainsbury and Whitelaw 1984) between the two areas as the larger individuals of *S. undosquamis* were only observed in northern Shark Bay in deeper waters than those encountered in the shallower waters of Exmouth Gulf and Onslow Area 1.

Examination of a selection of otoliths from common species of fish in both Shark Bay and Exmouth Gulf were primarily unsuccessful in determining ages of the fish sampled. Most of the otoliths of the common species were difficult to interpret with only three species that appeared suitable for otolith analysis. However, the scope of this project did not allow sufficient sampling of these species to determine firm conclusions about fish ages. Generally however it appeared that the species examined were in the age range of 1-5 years. A complementary FRDC project examining proxies for age (i.e. otolith weight, total fish weight and length) used the western butterfish and notched threadfin bream from Exmouth Gulf and estimated them to be 6 and 9 years maximum age, respectively (Craine pers. comm.). This indicates that in general, many of the common and most abundant fish species could be relatively short lived with the large long-lived species being very uncommon or rare. Very low numbers of large fish (including elasmobranchs) were caught during this project.

Two to three cohorts were observed for many of the fish species caught, indicating that at least two or three year classes were present. None of the species for which length frequencies were recorded had more than four or possibly five cohorts. This may be either evidence of relatively short lived species or selectivity in the prawn nets for certain sized individuals. Size selectivity in trawl nets is well known (Efanov et al. 1987, Watson 1988, Wakefield et al. 2007). Wakefield et al. (2007) found that in Shark Bay, the size of fish caught in prawn trawls were generally between 3 and 20 cm fork length (FL). Similarly, Poiner et al. (1998) noted that 92% of the fish caught in their study were small (< 30 cm) and generally they were mature individuals of small species and not juveniles of larger species. The size range of fish measured in our sampling was generally less than 25 cm except for *S. undosquamis* which was measured at up to 59 cm total length in the northern part of Shark Bay. Twenty four species of fish in Shark Bay and 38 species of fish in Exmouth Gulf that were sampled can attain a size greater than 50 cm but these were generally rarely caught nor were they seen at the higher end of their size ranges indicating either gear selectivity differences for larger animals or potential trawl impacts on numbers of larger and possibly longer-lived species.

Detailed studies of *P. vitta* and *P. auratus*, two species which are important recreationally (Sumner et al. 2002), have been previously undertaken by, Travers and Potter (2002), Jackson et al. (2007), Mant et al. (2006), and Wakefield et al. (2007) in Shark Bay. For *P. vitta* it was clear that the fish caught as bycatch in prawn nets were mature fish and the species was not considered to be vulnerable to trawling (Mant et al. 2006, Wakefield et al. 2007). *Pentapodus vitta* was fairly common in the southern parts of Shark Bay during this study whilst relatively few were caught in Exmouth Gulf. The size range sampled in Shark Bay was between 7 cm and 17 cm, within the size range described by the former studies for this species.

Wakefield et al. (2007) found for *P. auratus* that it was caught at a size range of 3-18 cm FL and they were susceptible to trawling for less than one year of their life from the ages of approximately 9 to 17 months. Therefore, although catchable, they considered trawling not to be a major component of mortality during the life of a pink snapper. During this project low numbers of *P. auratus* were caught over a size range of 11 cm to 15 cm total length, within the normal size range caught by prawn trawl gear (Moran and Kangas 2003, Wakefield et al. 2007).

Very few large, long-lived fish species were sampled during these research surveys even though on occasions they are caught in trawls for both scallop and prawn fisheries. Anecdotal information suggest these larger fish may have occurred in higher numbers early in the development of these fisheries as well as prior to high levels of recreational fishing activity (particularly in Shark Bay). There is however, no data to verify these early observations. It is unlikely that these larger, faster moving fish are sampled effectively by prawn trawl nets due the low speed of trawling. In addition, recent introduction of bycatch reduction devices such as grids, larger animals are now excluded from prawn trawls and are released whilst in the water through an escape opening reducing incidental catch and therefore observations of large individuals.

The productivity within Shark Bay and Exmouth Gulf appears to be reasonably high. The majority of common species are relatively short lived with ages less than 10 yeas and many under five years. Short-lived species usually have R type life history traits with high fecundity and high productivity with high input into reproduction during their relatively short life spans. The species measured fit this type of category and fall into similar life history categories as the target species of prawns and scallops. Differences in timing of recruitment for prawns and scallops is also reflected in differences of timing of recruitment in some fish species. These species all appear to be characterised by annual variation in recruitment levels and are likely to be influenced by environmental fluctuations.

The short duration of this project did not allow continued monitoring of species for several years to provide further insight into annual variability or to follow cohorts through any more than one year and therefore it was not possible to compare relative production (abundance and cohort structure) over time and between years. Some general observations can be made that many common species and the target species are short lived and highly productive. This however does not dismiss the likelihood that long-lived species have contributed to the food webs and productivity within these regions in the past, but are now in lower numbers and consequently play a lesser role.

7.0 OBJECTIVE 5

M. Kangas and S. Morrison

Objective 5: To develop reference sites/times for future monitoring

7.1 INTRODUCTION

When attempting to assess trawl impacts, reference sites need to include areas that are trawled and those not trawled in similar trawlable habitats. Detailed spatial information of prawn and scallop trawl effort distribution in Shark Bay, Exmouth Gulf and Onslow over the last ten years from logbook and VMS data allowed an accurate determination of both trawled and untrawled areas. The sites that were selected to be sampled during this study were trawled areas and adjacent closed or untrawled habitats and only reflect trawlable habitats and not the variety of habitats types that may be present in the full area of Shark Bay, Exmouth Gulf or Onslow Area I.

The high species diversity in prawn trawl bycatch is a challenge to monitoring and management (Stobutzki et al. 2000). There are a large number of taxa to identify, particularly in tropical and sub-tropical environments. Only a few species occurring in abundance with the majority of species being uncommon and thereby providing very little biological information. The practicality of evaluating the sustainability of each bycatch species using traditional stock assessment methods is low or not possible. For nearly all prawn fisheries around Australia, the use of BRDs is mandatory which aims to reduce the amount of incidental catch. However, BRDs are often aimed at reducing the catch of endangered or vulnerable species (Hall 1999) or of species important in other fisheries (Broadhurst et al. 1997) but their fate after encountering the BRD and being released is generally unknown. Efforts to reduce the overall bycatch is more difficult particularly with a diverse bycatch where the species are generally about the same size as the prawns. In these circumstances it is unrealistic to expect that bycatch could be eliminated entirely. Consequently it is essential to determine and monitor which species can or cannot sustain the impact of fishing (Stobutzki et al. 2000).

The requirements of future monitoring (frequency, number of sites etc.) can be moderated by the use of other management tools aimed at reducing the overall impact of trawling. These include permanent closures, specific and variable area and time closures, targeted harvesting strategies to optimise expenditure of effort, a reduction of overall fishing effort (reduction of boats or time and/or area) to optimise economic yield and use of mechanical or other devices such as BRDs and hoppers to reduce the landing of non-target species and increasing the survival of bycatch. These management tools have been used extensively in the prawn and scallop fisheries in Western Australia to reduce the time and cost of fishing as well as minimising the area of fishing by having extensive permanently closed areas and areas that are opened and closed for part of the season according to prawn/scallop size and catch rates.

The faunal assemblages studied during this project are likely to be different to that of these areas forty to fifty years ago before any major impacts including, fishing both recreational and commercial, coastal development and associated industries, climate change, tourism and pollution in these areas occurred. It is the aim of this study to provide a baseline of the current situation and makes recommendations to maintain long-term datasets on trawl bycatch composition and abundance but any changes detected may not be attributable to trawling.

7.2 METHODS

Twenty six sites were sampled in Shark Bay, 17 sites in Exmouth Gulf and eight sites in Onslow in order to provide baseline information of seasonal and spatial fish and invertebrate species abundance and distribution. Permanent area closures allowed untrawled areas to be clearly defined and other untrawled areas were chosen within 'open' trawl grounds that were not fished. Other trawled sites were selected and the amount of effort actually applied within 0.5nm of the sampling site was assessed using daily logbooks to determine overall effort at the site for the sampling year. This enabled an assessment of whether the site is subject to none, light, moderate or heavy levels of fishing during the year.

The sampling design was based on selecting a range of sites that encompassed the spatial extent of the Shark Bay and Exmouth Gulf fishery including Onslow Area 1 that had varying levels of fishing effort (0, 1 - low, 2 - medium and 3 - high). The sites were 'fixed' and sampled during each sampling period. This approach was taken, recognising that the focus was on soft bottom trawlable habitats and although latitudinal gradients were incorporated it was not intended to sample habitats that are not trawlable areas (i.e. highly structured areas such as seagrass and sponge garden habitats). Using fixed sites instead of a randomised sampling design has some limitations but these are addressed by the analyses conducted. Although the sites were fixed, original selection of sites was made using prior knowledge of the areas and the fishing effort information available from logbooks and from wide experience over many years of monitoring these fisheries it is considered that the sites selected do represent the broad characteristics of soft-bottom habitats in Shark Bay and Exmouth Gulf. Precise locations were determined on board the FRV Naturaliste during the first cruise in an area based on whether the area was 'trawlable' for sampling purposes.

The scope of the project (including boat time) only allowed a limited number of sites to be sampled within each region as well as a limit on how many samples at each site could be taken for any sampling period. It was considered that three samples should be adequate to incorporate sampling and site variability, however on some occasions due to technical difficulties, less than three samples were taken. Variability between samples from a site was observed but these were not consistent. This variability was address by transforming the data prior to analysis and conducting appropriate analyses (such as permanovas with Type 3 sums of squares).

Faunal assemblages were analysed using divisive clustering and MDS analyses for fish and invertebrates in Shark Bay and Exmouth Gulf/Onslow Area 1. For each set of samples, a simplified Morisita's index of similarity (Horn 1966) was calculated using the catch rates of individual species (number per nautical mile trawled). The complement of this index was used as a measure of dissimilarity for the cluster analysis. Catch rates were square-root transformed before similarity indices were calculated to reduce the variance due to the skewness of the catch rate distributions and obtain more robust indices. Richness, evenness and diversity indices were calculated for the sites within the assemblages identified. Whether the environmental parameters of depth, temperature and salinity influenced the assemblage groups identified were analysed using the BEST procedure in Primer.

To determine the power to detect differences with species abundance for different levels of trawl effort, ANOVA was conducted using the square root of the 'relative' catch rates of fish families for combined sites for four trawl effort categories in Shark Bay and Exmouth Gulf/ Onslow Area 1. The relative catch rates were derived using a mean catch rate for sampling periods. Post hoc tests (Student-Newman-Keuls) were conducted to determine which levels of effort were significant. Seasonal variation in species abundance, and species richness, evenness and diversity indices were compared using ANOVAs. Log-transformation of the number of individuals was undertaken first.

These analyses provided information on within site, between site and seasonal variability in faunal assemblages as well as determination as to whether trawl impacts could be detected in these regions.

7.3 RESULTS

The key results outlined in Chapters 3 and 4 are:

- There was no clear distinction between fish and invertebrate bycatch assemblages from trawled and untrawled sites in Shark Bay or Exmouth Gulf/Onslow Area 1.
- In general, divisive cluster analysis and MDS plots indicated grouping of sites that were not separated by trawl effort. For each bycatch assemblage group identified both trawled and untrawled areas occurred except in fish species Group 2 in Shark Bay and fish species Group 4 in Exmouth/Onslow Area 1where only trawled sites were grouped.
- In Shark Bay, depth and temperature had a Spearman rank correlation of 0.67 with the fish species assemblage groups whilst salinity and temperature had a Spearman rank correlation of 0.51 with the invertebrate species assemblage groups. There was only a weak correlation with fish or invertebrate assemblage groups for the environmental variables in Exmouth Gulf.
- Spatial (sites) and annual differences in richness, evenness and diversity were observed for sites and for groups of sites within assemblage groups. However these differences were not consistent and were not attributable to whether a site was trawled or not. For example in Shark Bay, fish diversity was higher in the untrawled sites in assemblage Group 1 whereas it was higher in trawled sites for Group 3. For invertebrates, no diversity measures were significantly different for any site in Groups 1 and 2 whilst higher diversity was observed in trawled sites for Group 3. This indicates that many other factors in addition to trawl impacts are important in species, richness, diversity and evenness. Some of these factors were environmental where for Shark Bay invertebrates, season was a significant factor for species richness and salinity and depth was significant for invertebrate species diversity.
- Positive and negative correlations for fish abundance with trawl effort were observed. For Shark Bay, the fish and invertebrate species were most abundant at sites with low trawl effort whereas in Exmouth Gulf, sites with high trawl effort has lower faunal abundance.
- In Shark Bay there was a significant seasonal decline in fish abundance whilst for invertebrates the decline was only significant between start of the season in 2003 and the middle of the season. For Exmouth Gulf there was no significant seasonal decline for fish species abundance although there was a seasonal decline in fish species richness. A highly significant reduction for invertebrate species abundance was observed and was a pattern observed at all trawled and untrawled sites sampled.
- High annual variability at a site was observed for some species. This implies that some species are not good indicator species due to their; schooling behaviour, high annual variability and for some species, their rarity.

- Common, widespread species are considered to be the best candidates for indicator species and constitute about 10-20 species of fish and invertebrates.
- The power to detect differences was fairly low in Shark Bay, however there was still a significant effect on fish abundance observed for low trawl effort where higher abundances were seen. Sampling more sites would have increased power but due to the limitations in time for this project this was not possible. In Exmouth Gulf the power to detect differences in fish abundance was 97% and additional sampling sites are not warranted.

7.4 DISCUSSION AND RECOMMENDATIONS

One of the main objectives of this study was to compare the faunal composition between trawled and untrawled areas and if the faunal composition was similar, then it was highly likely that closed areas act as refuges for those species impacted by trawling. Faunal composition was similar in trawled and untrawled areas in general and therefore it is sufficient that the principal form of monitoring in these fisheries on an annual basis is the extent of the trawled areas. The percentage of area trawled should not exceed that observed in recent years (20-40%). In fact, due to the market forces operating in these fisheries currently and the need to optimise harvesting, the overall area trawled (as well as hours) is reducing.

However if there is a requirement to monitor changes in biodiversity of trawl bycatch in future years and to detect trends (be it due to fishing, environmental or some other factor), limited long-term monitoring of trawl bycatch may be necessary. It is essential to survey both trawled and untrawled sites in future monitoring, as there are likely to be subtle differences between trawled and untrawled sites that may become more discernible during repeated sampling. Again, caution must be used when comparing faunal biodiversity from different surveys, as this study demonstrates how variable species presence/absence, abundance and diversity measures can be different between seasons and years.

This study indicates that for Shark Bay, Exmouth Gulf and Onslow, the major factors influencing the distribution of fish and invertebrate species are complex but there is some evidence, particularly in Exmouth Gulf that the level of trawl effort can influence faunal assemblages. Therefore selecting sites from the divisive cluster groupings and encompassing various levels of fishing effort is recommended for long-term monitoring. Species richness, evenness and diversity were variable between fish and invertebrate assemblage groupings with higher levels for trawled sites in some groups and lower levels in others. Therefore both trawled and untrawled sites should be sampled and compared over the long-term from a selection of assemblage groups.

Estimated depletion rates indicated that some species or species groups are more vulnerable to trawling compared to others. Some species are less vulnerable due to their lower selectivity by prawn trawl gear, or to their behaviour, or location in the water column. These include highly mobile species, aggregating species and the known short-lived species with high natural annual variability. Species that appear to be more vulnerable (or catchable) to trawling are good candidates as indicator species when considering prawn trawl bycatch comparisons. In this study, the main fish species we suggest to use as indicator species are: *S. robusta*, *C. cephalotes*, *P. vitta*, *S. sageneus*, *M. chinensis*, *E. grandisquama*, *I. japonica*, *P. nebulosa*, *P. sexlineatus* and *L. genivittatus*. These species are widespread in their distribution in both trawled and untrawled areas and are likely to be sampled at any reference sites selected. For invertebrates, most are highly variable and many are likely to be poorly sampled by trawl gear, however, *L. maculata* and Porifera could be monitored.

The sites sampled in Shark Bay provided only 40% power to detect a difference at the 0.05 significance level however there was a significant difference observed with trawl effort and therefore it may be necessary to maintain a similar number of sampling sites in Shark Bay in order to not reduce power even further. If possible new untrawled sites should be incorporated to provide a more balanced sampling design overall. The previously selected sites would remain fixed sites for comparison with four additional random sites incorporated to provide additional information of site variability. In Exmouth Gulf and Onslow Area 1 there was sufficient power in the number of sites sampled to detect differences. As in Shark Bay, a series of fixed sampling sites would be selected from the assemblage groups and additional two random sites to be sampled. This combination of fixed and random sites is recommended for future monitoring. Continued use of fixed sites facilitates the estimation of trends, while the use of random sites protect against problems of unusability of the fixed sites. This may be because the amount of fishing effort at a site changes considerably or ceases and or there may be pollution or development initiatives impacting the area.

There are significant differences between assemblages and overall abundance between seasons, with the highest abundance overall observed at the start of the season for most groups with a decline in abundance by mid season. It may therefore be appropriate to sample at both the start and mid year (i.e. February/March and June/July). If costs only allow one sampling period, then the start of the season is recommended. Studies that attempt to describe the situation at any 'one time' may not reflect the state at any other time due to the high seasonal variability observed for most species. Sampling should also be undertaken over a similar period of the lunar cycle, noting the variation in catchability for some species due to the lunar cycle (Stobutzki et al. 2001b, Poiner et al. 1998). Other environmental factors (eg. cyclones, sea surface temperature) before and during sampling should be noted as they are likely to affect abundances.

Annual differences in individual and total species abundance were evident in this study to the level of >50% difference in overall abundance at the start of a season for two out of three sites sampled in Shark Bay on five occasions. Both of these were untrawled sites. This level of change could be due to natural variation and no other factor. Therefore if the sampling can detect a greater than 50% level of change then the sampling would need to be repeated the following year in order to confirm a trend of continued decline not just natural variability.

Stobutzki et al. (2000) found that if they sampled 10% of catch it generally represented about 50% of what was caught in a trawl because of high numbers of fairly rare or uncommon species in trawl bycatch. Therefore, a larger proportion of the total catch i.e. half of the catch would represent the majority of species caught. If, for example, the port and starboard sides of the trawl gear is noted to be fishing equally, one side could be used as being representative of the catch to reduce sorting time.

It is recommended that all species be identified to the lowest taxonomic level possible in order to get some information on the more uncommon species as well as the 10-20 species of fish and invertebrates that represent the majority of the catch. The level of monitoring suggested above is expected to be able to record, in the longer term, trends in abundance and species distribution of representative sites within each fishery in a fairly cost efficient manner. This requires the use of a dedicated research vessel and scientific personnel to process the catches and continued collaborative links with the Western Australian Museum with taxonomic expertise.

8.0 DISCUSSION

This project was successful in addressing the five objectives:

1) To develop and compare biodiversity measures of trawled and untrawled areas in Shark Bay and Exmouth Gulf

This study has produced a reliable database of faunal biodiversity at fixed sites using standard prawn trawls in the trawl grounds and adjacent closed areas of Shark Bay, Exmouth Gulf and Onslow Area 1. It will be an invaluable resource for future monitoring of biodiversity of trawl bycatch in these regions. The major source of variability in species abundance was found between sites. Within site variability was evident between samples taken at a site at one time period and was addressed through data transformation and use of appropriate analyses. The observed power for 5% significance test was 40% for the sites sampled in Shark Bay and this was sufficient to detect a significant difference in faunal abundance between low trawl effort sites (with higher abundance) and other sites. In Exmouth Gulf and Onslow Area 1 however, the number of sites sampled provided more than sufficient observed power, well over 90% for 5% significance test. Sites of high trawl effort had significantly lower fish abundance compared to other sites but sites with, no trawling, low and moderate trawling were similar.

Prawn trawls are only selective for a certain suite of species with particular size ranges, behaviour and position in the water column therefore, the results of this study reflect the bycatch from prawn fishing and do not represent the total biodiversity within these regions. The sampling during this study was undertaken using demersal prawn trawl gear without bycatch reduction devices (BRDs). BRDs (both grids and fish exclusion devices) have been introduced into these fisheries during the course of this project and therefore the bycatch now retained by trawl nets (particularly larger species such as turtles and elasmobranchs) is significantly reduced. There are no equivalent previous studies of bycatch biodiversity in these areas to compare the results of these surveys directly.

The biodiversity measures used and determined to be practical were: species abundance (number per nautical mile) and species richness, evenness and diversity. The number of individuals sampled (or a sub-sample if very high catches encountered) is relatively easy to achieve. The abundance of species is an important measure to use in conjunction with species richness, evenness and diversity. In this study, weight of species was not measured but this would serve as a useful measure if attempting to obtain biomass estimates.

Species richness is a useful measure of biodiversity, even if the suite of species changes. A change in the number of species in an area is an important indicator of ecological change. Generally a stable number or an increase in the number of species indicates a healthy, self-sustaining ecosystem, whereas a decrease in species number is likely to indicate an imbalance or potential problem in the ecosystem. Evenness and diversity measures provide more insight into the overall distribution of all the species present including dominance of a few species or rarity of many species.

A total of 360 invertebrate, 241 fish, one turtle and two seasnake species were recorded from five trips to Shark Bay between October 2002 and February 2004. Species richness, recorded over four survey trips, ranges from 27 to 89 species per site for invertebrates, and from 46 to 102 species per site for fish. High species richness occurred in trawled sites as well as untrawled sites. The maximum fish and invertebrate species richness was found in the northern and southern extremes of the scallop trawl grounds, and the minimum was found at the northern limits of Shark Bay. No consistent patterns were observed with species evenness and diversity indices when comparing trawled and untrawled sites. Spatial (sites) and annual differences in richness, evenness and diversity were observed for sites and for sites within assemblage groups. However these differences were not consistent and were not attributable to whether a site was trawled or not. For example, in Shark Bay, fish diversity was higher in the untrawled sites in assemblage Group 1 whereas it was higher in trawled sites for Group 3, and for invertebrates, no diversity measures were significantly different for any site in Groups 1 and 2 whilst higher diversity was observed in trawled sites for Group 3. This indicates that many other factors in addition to trawl impacts are important in species, richness, diversity and evenness. For Shark Bay invertebrates, for example, season was a significant factor for species richness, whereas the environmental factors, salinity and depth were significant for invertebrate species diversity.

A total of 365 invertebrate, 298 fish, three turtle and five seasnake species were recorded from three trips to Exmouth Gulf and Onslow Area 1 between March 2004 and November 2004. Species richness, recorded over three survey trips, ranges from 44 to 119 species per site for invertebrates, and from 68 to 126 species per site for fish. Maximum species richness occurs in the northwest of Exmouth Gulf adjacent to Bundegi Reef, offshore in the Onslow fishery and in the northeast of Exmouth Gulf. Minimum species richness, evenness and diversity occurred close inshore to Onslow adjacent to the Ashburton River, and in the central Exmouth Gulf area.

A small number of threatened and CITES-listed species (elasmobranchs, syngnathids, turtles and seasnakes) were captured in Shark Bay, Exmouth Gulf and Onslow Area 1. The majority of the large species would have been excluded if exclusion devices (eg grids) had been used. It is recognised that the fate of the animals excluded is unknown but their survival is likely to be improved compared to being brought out of the water onto a sorting table and further handled.

The most abundant 10 to 20 species of fish and invertebrates for the majority of survey sites in Shark Bay, Exmouth Gulf and Onslow Area 1 represent around 90% of the total catch. These abundant species can, therefore, be used to characterise the faunal assemblage of most sites. Since most abundant species occur in large numbers, with the majority being widespread, it would be anticipated that these core groups of species are dominant in the various regions from year to year. The trends in the cluster relationships between sites may be used to determine changes in any major ‘region’ within each fishery that may in turn provide for an indication of ecosystem change.

Other studies of trawl bycatch biodiversity on trawled areas in the Northern Prawn Fishery (NPF) (Blaber et al. 1994, Stobutzki et al. 2001b, Hill et al. 2002) and the Great Barrier Reef (Poiner et al. 1998) found similar results. Although Stobutzki et al. (2001b) used 83 fish species in their analyses, which accounted for 66% of bycatch weight. The bycatch was highly diverse (over 350 species of teleosts and elasmobranchs) in which the majority of species were not widespread (75% of species occurred in <10% of trawls) and in low abundance (<10 nm). In many fisheries, a few species contribute most of the weight of the catch (Andrew and Pepperell 1992). This dominance of the fauna by a few species is a widespread phenomenon in marine ecosystems (Hill et al. 2002). The low abundance of most species in the bycatch may reflect their natural rarity with the ecosystem or may reflect the poor efficiency of trawls to capture them. Differences in catchability of various species are well recognized (Wassenberg et al. 1997). Some of the species that are rare in the bycatch may be caught at rates that are negligible from the point of view of the population. In the Gulf of Carpentaria, Blaber et al. (1994) found that for the fish fauna, 25 of the 300 species made up 75% of the biomass of the day trawl catches and 70% of the night trawl catches whilst there were a large number of species or taxa that are rarely caught. The 10 most abundant fish species in Shark Bay accounted for 80% of the total abundance and in Exmouth Gulf and Onslow the 10 most abundant fish species accounted for 68% of the total abundance.

In this study prawns and crabs were the major component of invertebrate catch and they were the top 10 species caught in Shark Bay, Exmouth Gulf and Onslow Area 1 with the exception of ascidians being the tenth most abundant group in Shark Bay. The 10 most abundant invertebrate species in Shark Bay accounted for 85% of the total abundance and in Exmouth Gulf and Onslow the 10 most abundant invertebrate species accounted for 87% of the overall abundance. For invertebrates in the NPF half of the bycatch consisted of only six taxa of which two were echinoids and three were crabs. Crustaceans were the largest single group in the invertebrate bycatch making up 20% by weight, echinoderms made up 14% by weight and Porifera 12% (Hill et al. 2002). Most (94%) of the Crustacea were decapods, of which 76% were crabs and 24% noncommercial penaeid prawns. Portunid crabs made up 77% of the weight of crabs.

Although the 20 most abundant species of fish and invertebrates may be used to characterise a site or sites, there is a danger of over-simplification of the ecosystem if the less common species are totally ignored. Some of these less abundant species may be key indicators of the health of an ecosystem, despite only occurring in low numbers. Elasmobranchs are prime examples of such indicator species and the limited data available on the impact of prawn trawling on them suggests that many species are very susceptible to capture and mortality from trawling (Stobutzki et al. 2002). Stobutzki et al. (2002) found that 66% of elasmobranchs died in nets and these were more often the smaller species. In Laurenson et al. (1993) trials to keep elasmobranchs for seven days after trawling indicated that about 50% died from impacts of trawling even though most appear to be alive when discarded. The use of grids in the WA trawl fisheries eliminates the capture of larger elasmobranchs, but smaller species which are more prevalent in the Exmouth Gulf and Onslow prawn fisheries are still caught as they pass through the bar spacings. Large, long-lived fish species such as mulloway and slimy cod may also fit this category and anecdotal comments suggest these species were more commonly caught in the early phases of trawl fisheries and these species should also be monitored during any sampling project. Twenty-four species of fish in Shark Bay and 38 species of fish in Exmouth Gulf that were sampled can attain a size greater than 50 cm. These species were rarely caught and if caught, were only smaller individuals usually less than 50 cm in length. This indicates either gear selectivity differences for larger animals or deleterious trawl impacts on the numbers of some larger longer-lived species.

In the current study, no statistical significance was found for pooled data between trawled and untrawled sites in Shark Bay, Exmouth Gulf and Onslow Area 1, with respect to fish and invertebrate abundance, species richness, evenness or diversity. Spatial differences in assemblages were seen, and additionally, in Shark Bay fish assemblages were correlated with depth and temperature, and invertebrate assemblages were correlated with salinity and temperature. In Exmouth Gulf, where there are less pronounced environmental gradients, there was low correlation between faunal assemblages and depth, temperature and salinity.

The complexities of the faunal community dynamics may mask effects on individual species or separate families and result in the lack of consistency in results. For fish, there was a mixed response for the top 10 species with respect to abundance, with some species being; more abundant on trawl grounds, others in similar abundance between trawled and untrawled areas and one or two species being in higher abundance in untrawled areas. For example, in Shark Bay, *C. paxmani* was only found at Site 22, an untrawled site with abundant seagrass and which was a habitat distinctly different from the other sites. In Exmouth Gulf and Onslow *E. grandisquama* and *L. moretoniensis* were more abundant in untrawled areas.

Some differences between trawled and untrawled sites were consistently detected for invertebrate species. The most obvious being the domination in abundance of invertebrate species that evidently thrive in trawled areas. In Shark Bay these were primarily the scallops *A. balloti* and *A. flabellata* and crabs *P. pelagicus* and *P. rubromarginatus.* However, in Exmouth Gulf and Onslow all of the top ten species were in higher abundance on the trawl grounds. These were all either prawn or crab species. These abundant species are those that thrive in the disturbed soft sediment of trawl grounds. These species are likely to out-compete species that might have moved in from adjacent non-trawled, more complex habitats such as sponge and soft coral gardens, rubble and reef habitats. It is well known that mobile fishing gear alters the physical structure of benthic habitats (Auster et al. 1996). Complexity is reduced by direct removal of biogenic (sponges, hydroids, bryozoans, amphipod tubes, shell aggregates) and sedimentary structures (sand waves, depressions).

The composition and distribution of suites of fish bycatch species appear to be more determined by environmental gradients than whether an area is trawled or untrawled. Invertebrate abundance appeared to be greater in trawled sites compared with untrawled sites mainly attributed to the scallop, prawn and crab species present. These habitats may have been altered by trawling in such a way as to favour feeding and breeding of certain species, particularly the commercial prawn and scallop species. Some of the untrawled sites are in regions of Shark Bay where abundance is naturally low, notably the southern extremes where salinity and temperature fluctuate the most throughout the year, and in the north of Shark Bay where abundance declines with increasing depth. The mobility of fish species could contribute to the general lack of difference between trawled and untrawled sites.

Species that occurred more frequently in untrawled sites were generally not in the most abundant category. There were approximately 10 species of fish in Shark Bay, Exmouth Gulf and Onslow Area 1 that consistently occurred in higher abundance in untrawled areas whilst there were six species of invertebrates that showed a similar trend. The invertebrates included several species of sea urchin, sea star and a holothurian, which are considered to be more 'vulnerable' to trawling. However, sedentary fauna were in lower abundance in the untrawled sites in Shark Bay. This may be due to the higher salinity and temperature fluctuations in these mainly southern areas of Shark Bay, which may not be optimal for these species. These environmental conditions could override any trawl impact effects. Hill et al. (2002) considered the sustainability of invertebrate species using similar criteria to that used for fish species by Stobutzki et al. (2001a). They concluded that there were examples of taxa with either high or low sustainability scores in nearly all phyla. For example, sea urchins have a low sustainability as they are more catchable and are more easily damaged whereas sea stars and sea cucumbers have high sustainability, as they are less catchable and more robust. Delicate crustaceans such as crangonids, carids and parthenopid crabs have low sustainability while hermit crabs, portunid crabs and bugs have high sustainability. Amongst the molluscs, bivalves have high sustainability while cephalopods have low sustainability. These results show that we cannot generalise about the impact of trawling on the various groups. They also indicate that one of the impacts of trawling will be to shift the species composition of the benthic fauna towards the species that have high sustainability.

Individuals that live off the trawl grounds are not exposed directly to trawling and they can also provide larval recruits to fished areas (Hill et al. 2002). Thus although some sedentary invertebrates on trawl grounds may have low sustainability, their widespread distribution ensures that they are unlikely to be threatened by trawling over the whole area. However, sponge larvae are not planktonic and their dispersal is limited. The management of trawl areas using permanent and seasonal closures within Shark Bay, Exmouth Gulf and Onslow ensure that those species more vulnerable are protected, as the majority of species occur in both trawled and untrawled areas. The patchy nature of trawling also results in areas within trawl grounds that are rarely trawled so the level of impacts on species on trawl grounds can also be variable.

In heavily trawled sites the most abundant fish species were primarily benthic- or epibenthic-dwelling species that are carnivores of small fish and/or invertebrates, except for most leatherjackets, which are generally omnivores. The soft sediments of the trawl grounds evidently harbour sufficient prey items and are suitable habitats for these species to thrive in large numbers. Species that feed on prawns may be attracted to the commercial fishing grounds increasing their susceptibility to capture. Those that feed on demersal organisms are assumed to be more susceptible than those that feed higher in the water column (Stobutzki et al. 2002).

2) To examine seasonal and annual variation

This study highlighted that Shark Bay, Exmouth Gulf and Onslow Area 1 have highly complex marine faunal assemblages, with the dominant species patterns dictating the overall seasonal and annual patterns in abundance, which were also variable. Consequently caution must be used when comparing faunal abundances and species richness from different seasons and different years. Additionally, inconsistent seasonal and annual variation in species richness, evenness and diversity was observed between trawled and untrawled areas.

In Shark Bay there was a significant seasonal decline in bycatch fish abundance at the selected sites, attributed to reductions of five very abundant species *L. genivittatus, P. choirocephalus, P. quadrilineatus, T. pallimaculatus* and *U. asymmetricus.* There was only a significant difference in fish abundance between trawled and untrawled sites for the start of the 2003 season with much higher abundance in trawled sites. This period also showed high variability in abundance that was mostly due to very high numbers of the schooling fish species *P. quadrilineatus.* For invertebrate species abundance in Shark Bay in 2003, trends indicated an initial reduction between the start and mid season but no further decline towards the end of the season. At the start of the 2003 season, a significantly higher abundance was observed in the trawled sites but during other times the differences between trawled and untrawled sites were not significant. The high abundance of invertebrates and high variability at the start of the season was attributed to the very abundant species *A. balloti*, *P. latisulcatus*, *P. rubromarginatus* and *H. pallida*. For Exmouth Gulf there was no significant seasonal decline for fish species abundance although there was a seasonal decline in fish species richness whereas all the other diversity measures were similar throughout the year. No significant differences were observed in abundance between trawled and untrawled sites. In Exmouth gulf, invertebrate species abundance indicated no significant difference between trawled and untrawled sites for start of season and mid season in 2004 but a significantly higher abundance in trawled sites in the end of season in 2004. There was a significant seasonal decline in abundance between start, mid and end of the season in 2004 for both trawled and untrawled sites.

Variability in responses for the diversity measures were observed, for example; in Shark Bay, the fish species richness and evenness showed seasonal variation in the untrawled sites.

However, there was no significant seasonal difference or year differences between the end of season in 2002 and end of season in 2003 for any of the diversity measures, whereas there was a significant difference in the species richness and evenness for the trawled sites between the end of season in 2002 and start of season in 2003. In Exmouth Gulf for fish species, there was a significant difference in species richness in both trawled and untrawled sites with a seasonal decline being evident whereas all other diversity measures were similar throughout the year.

Annual differences were observed in Shark Bay for species abundance and richness at three fixed sites sampled over five periods spanning the end of 2002 to the start of 2004, however these differences were not consistent for species or between sites. For the start of 2004 high variability was seen at the three sites sampled due to high variability of fish species *P. quadrilineatus*, *P. vitta*, *P. vespa*, *U. tragula*, *R. sublaevis*, *G. subfasciatus* and *L. leuciscus* and the scallop species *A. flabellata* and *A. balloti*. The overall abundance was significantly higher for some species in the start of 2004 compared to the start of 2003 indicating annual recruitment variability. This was particularly evident at site 21 which had a high abundance of *A. balloti*, a species that is renowned for its high variability (Joll and Caputi 1995). High natural annual variability of species abundance may mask trawl impacts.

When comparing species abundance and diversity measures in Shark Bay and Exmouth Gulf the seasonal, annual and spatial variability must be taken into account. Those highly aggregating, schooling or migratory species cannot be used as an indicator of change due to their high natural variability. Generally (except for fish in Exmouth Gulf) because a seasonal decline in abundance is observed, more than one sampling time period should be adopted.

Site, season and diurnal variability in abundance was observed in this study and as in other studies, this variability could not be attributed completely to trawling (Stobutzki et al. 2001b, Poiner et al. 1998, Laurenson et al. 1993). Lunar variability is also a factor for some species (Stobutzki et al. 2000). High annual variability was observed for some species in those sites sampled over five time-periods in Shark Bay. The seasonal decline was evident with an increase in abundance at the start of both seasons. This indicates that many of the species caught by prawn trawl gear have similar life-history traits to target prawn species with the main recruitment occurring early in the year providing high abundance prior to the fishing season. Length frequency analysis of selected fish and invertebrate species showed some species had a higher proportion of smaller individuals at the beginning of the season indicating recruitment events. However, conversely, some of the other fish species measured had a significantly smaller mean size towards the end of the season indicating differences in reproductive cycles for some species that closely reflect the seasonal life-history pattern of *A. balloti*.

Environmental factors such as depth, temperature and salinity are important factors affecting species distributions. This was more pronounced in Shark Bay than Exmouth Gulf. Spatial variation in species distributions was evident in Shark Bay with many species being widespread throughout the year and between years whilst others have a more restricted distribution to certain parts of Shark Bay. Species, which occur in higher abundance in the northern more deeper and oceanic waters of Shark Bay were the coral prawns *Metapenaeopsis* species and the squid *Photololigo* species. Many species appear to be in higher abundance throughout the central and southern parts of Shark Bay such as the fish *P. vespa*, *P. quadrilineatus*, *P. vitta*, scallops *A. balloti* and *A. flabellata* and the sea star *L. maculata*. Stobutzki et al. (2001b) found that spatial variation (habitat and environmental factors) had greater impact on faunal distributions than the variation due season. This was also seen in the GBR study (Poiner et al. 1998).

In Exmouth Gulf and Onslow Area 1 there was a more even distribution of most species, possibly due the lack of strong environmental gradients compared to Shark Bay. Many fish species were widespread including *U. asymmetricus*, *I. japonica*, *P. choirocephalus*, *S. undosquamis*, *P. vitta* as well as the blue swimmer crab *P. pelagicus*. However, some species showed more restricted spatial patterns such as the fish *L. genivittatus*, *P. quadrilineatus* and ascidians and the fish *P. vespa* and *C. grossi*, which showed a high abundance in the northwestern part of Exmouth Gulf.

Diurnal differences were observed at the few sites sampled both night and day and also spatial differences were observed for species distribution between the northern and southern sites selected in Shark Bay for the day-night trials. The key species that showed differences in diurnal catchability were fish from the families of Carangidae, Harpodontidae, Leiognathidae and Terapontidae, which were significantly more abundant during the daytime, where as Callionymidae, Monacanthidae, Mullidae and Sillaginidae were more abundant at night. The latter species would be more vulnerable to trawl impacts as most trawling occurs at night. However, all these families were sampled during both day and night. Of the 121 species of fish caught during day/night trials in the Great Barrier Reef (Poiner et al. 1998), 17 species (families Apogonidae, Scorpaenidae and Sauridae (now known as Synodontidae)) were caught in higher abundance at night.

Diel differences in the catchability of fish probably reflect changes in their vertical distribution (Hobson 1972, 1974, Harris and Poiner 1991) or behaviour. Many of the leiognathids and some carangids move up into the water column at night and thus are not caught by a demersal prawn trawl. The leiognathids such as *L. bindus* are thought to follow the zooplankton as it spreads out through the water column at night (Blaber et al. 1990). The carangid *Caranx bucculentus* feeds on benthic crustaceans and fish during the day (Brewer et al. 1989), but was not caught in bottom waters at night. The Leiognathidae were the most numerous in the daytime time trawls in Shark Bay.

For invertebrates, the most abundant family, the Penaeidae were caught in significantly higher numbers at night whilst the cephalopods particularly *Photololigo* sp. was found in high abundance (at one site) during the day.

Since prawn trawling generally takes place at night those species that were more active or catchable during the day were less vulnerable to trawling. Scallop trawling can take place over 24 hours but the level of bycatch from scallop trawlers is minimal due to a larger mesh size. Also, in the last few years, some portions of the scallop fishing grounds are only opened during daylight hours to reduce interaction with prawn species targeted by the prawn fleet.

Positive and negative correlations between faunal abundance and trawl effort were observed. In Shark Bay the effect of trawling on fish abundance was most evident in areas with low trawl effort that had higher abundance than in other trawl categories (which were similar), whereas in Exmouth Gulf a significantly lower abundance of fish was observed in areas of high trawl effort. Mean abundance in all the other trawl categories were similar to each other. These mixed results may be due to confounding effects of mobility of fish species and the high abundance of some species in both trawled and untrawled areas, and migration from these areas during the season. Also, as a result of the management strategies in place in these fisheries (i.e. limits on total nights fished, variable area closures and openings, full moon closures), the overall level of trawl effort in most areas is relatively low compared to some other trawl fisheries and so trawl impacts may be difficult to detect.

3) To examine the rate of depletion of selected species to ensure bycatch CPUE is related to actual abundance

The depletion experiments carried out in Shark Bay indicated that demersal prawn trawling has variable impacts on different species on trawl grounds. Catchability is highly variable between species and can differ for a single species between time periods. High variability in catchability was observed for bycatch species in the GBR (Poiner et al. 1998) with regression analyses indicating a negative response (i.e. depletion) for 46 out of 54 cases of sessile benthos, for 57 out of 60 cases for mobile benthos and for 42 out of 54 cases for fish guilds. There was considerable variation between species as was observed in this study. Many fish species showed no trend over the four nights of trawling and many occurred in such low numbers that trends could not be detected.

Very few species that were truly sedentary were caught in sufficient numbers for analysis. The rest of the results need to be interpreted with the mobility and behaviour of the species, or species groups taken into account. For a few fish species, it was obvious that movement into the experimental area occurred during the experiment with significant increases in abundance over consecutive days, instead of an expected decline. For several invertebrate species their abundance also increased, possibly due to the trawl disturbance making them more catchable.

The overall depletion of fish species over four nights was 21% in February 2003 and 6% in June 2003. The difference was primarily due to changes in the composition of the most abundant fish groups between the two time periods. In February, monocle bream (nemipterids), trumpeters (terapontids), whiting (sillaginids) and snappers (sparids) were abundant and they had a moderate depletion rate (37%) whereas in June, the most abundant groups were the toadfish (teraodontids) and leatherjackets (monacanthids) with no declining trend in abundance over the four nights. Temperature was lower in June compared to February, however depletion rates between February and June were not consistent between fish species groups and temperature is unlikely to be the main factor in the difference between the depletion rate between these two time periods. For invertebrate groups in February there was a 20% decline for cephalopods, 13% for all scallop species combined, 9% for all prawn species combined and a 10% decline for all crab species over the four nights. For the commercially caught, *A. balloti* the decline in abundance was 42%. In June 2003 there was no decline evident for all invertebrates combined and when fish and invertebrate groups were combined the depletion rate was only 3%. For individual invertebrate groups there was an 11% decline for cephalopods, 3% decline for all prawn species and 7% decline for all crab species. For all scallop species combined the abundance increased over the four nights due to an increase in *A. flabellata*. This is a small species and probably became more catchable once trawling had taken place and they became more exposed. When the commercially caught *A. balloti* was analysed separately the depletion rate was 40% over the four nights.

For both time periods, several fish groups showed a clear declining trend in abundance over the four nights and these included goatfish (mullids), monocle bream (nemipterids), trumpeters (terapontids), whiting (sillaginids), snapper (sparids), flathead (platycephalids) and flounder (bothids and paralichthyids). Carrick (1997) found a significant impact of trawling on small-toothed flounder *P. jenynsii* with the Spencer Gulf prawn fleet (39 boats) having the capacity to reduce local populations by at least 60% over 14 days of intensive fishing. Generally regions more intensively fished had fewer larger individuals than those not fished. The impact on species found in other fisheries may not be directly comparable to Shark Bay and Exmouth Gulf fisheries due to their locality and intensity of trawling. In this study, *P. jenynsii* was depleted by 18% indicating trawling had relatively low impact on this species in Shark Bay.

The results indicate that for both the fish and invertebrate species, there appear to be some species that are relatively vulnerable to the trawl gear. These had depletion rates of greater than 50%. The highly 'catchable' fish were: *P. sexlineatus*, *P. chrysopleuron*, *L. genivittatus*, *S. sageneus*, *P. vitta*, *C. cephalotes* and *S. robusta*. The highly 'catchable' invertebrate species were: *L. maculata* and Porifera.

Of the highly 'catchable' species, three occurred in less than 70% of sites sampled during the biodiversity study. The least common were Porifera that were found in 50% of sites overall. There was however, no significant difference between sponge abundances between trawled and untrawled areas. *Luidia maculata* and *P. chrysopleuron* were found in 62% of sites sampled but all were found on both trawled and untrawled sites and there was no significant difference between the abundance of either species between trawled and untrawled areas.

All the other fish and invertebrate species occurred in relatively high abundance on more than 70% of the sites sampled (both trawled and untrawled) during the sampling project. Therefore although some localised depletion may occur in areas of intensive fishing, other areas with none or very little trawling also have these species. Movement and potential for recruitment from unaffected sites would be likely to re-populate depleted areas.

In February 2003 no sponges were sampled in the experimental area, however in June 2003, nine sponges were sampled on the first night of the experiment, these sponges tended to be mound-like and would have been easily caught by prawn trawl nets. On the second night, five sponges were sampled, with two on the third night and none on the fourth night. It appears that sponges with this kind of morphology were caught by trawl nets and quite vulnerable. It may be that other more flexible, or low profile sponge species were less impacted by trawling but this cannot be verified from our experiment as no video footage was attempted during the experiment. Sainsbury et al. (1992) used a video camera to assess the impact on sponges by a fish trawl on the North West (NW) Shelf of Australia. Because many sponges passed under the net, they were unsure of the fate of the sponges passing under the trawl. However, where the fate of the impact was known, only 10% of sponges remained attached, the remaining 90% were detached from the seabed. This was a very high level of impact and this study is often quoted with respect to the effects of trawling. Moran and Stephenson (2000) conducted a fish trawl survey in the NW Shelf and found that their nets removed approximately 15.5% of the macrobenthos on a single pass. The majority of the macrobenthos were sponges (Moran, pers. comm.). Similarly, Pitcher et al. (2000) found a similar level of impact on sponges and gorgonians in the GBR using prawn trawls. However, Poiner et al. (1998) found that in the GBR, the overall impact on sponges by prawn trawls was around 10%. They found that certain groups, especially tall sponges, are more vulnerable, but there was a large proportion that is more resistant. Because of this differential vulnerability, they considered the real effect of cumulative trawls is complex.

Apart from sponges, the only other sedentary invertebrates or ones with limited movement in sufficient number for analysis were the scallops, crinoids and the holothurian *C. crassus*. For the commercially caught *A. balloti* depletion rates of 42% and 40% per trawl were recorded for February and June respectively. This indicates that the prawn gear is a relatively good sampling/catching device for this species. Higher depletion rates, of 60 and 64% per trawl were reported for this species by Joll and Penn (1990) in two experiments conducted on the scallop trawl grounds in central Shark Bay. These differences may be attributed to the specific habitats where the sampling took place and differences in the gear settings that were used for the experiment. The other common scallop species caught was *A. flabellata*, which increased in abundance on both occasions. This species is a fairly small scallop species and is generally buried in the sandy sediment. With multiple trawls over the same area, they may have been more exposed and become more vulnerable for capture by the prawn gear. Poiner et al. (1998) found that the prawn trawl is relatively good at catching crustaceans (40% efficiency relative to a dredge) but relatively poor (0-10% efficiency relative to a dredge) at catching most other benthic organisms, whether sessile or mobile. However data from prawn trawl catches do not show which organisms are completely unaffected by trawling, or which organisms are fatally damaged but not removed.

Crinoids and the holothurian *C. crassus* appeared to have moderate catchability by the trawl gear with a depletion rate of 28% and 41% respectively over the four nights. The crinoids are fairly flexible and can be mobile and *C. crassus* is a relatively small species of sea cucumber usually being between 5 and 10 cm in length and it is unclear whether they would have been fully sampled by the trawl gear.

Due to the variable impact of a prawn trawl on fauna, the amount of fauna removed each year is related to the resilience of the fauna and the intensity of trawling. In lightly trawled areas, the annual removal may be only a few percent, but in the most intensively trawled areas, a much higher proportion will be removed. While a single trawl has little detectable impact on the benthic communities, repeated trawling will gradually remove the animals and plants that are attached to the bottom as well as reduce the fauna associated with them (Poiner et al. 1998). Because of differential vulnerability, community composition will be substantially altered in most areas (Poiner et al. 1998). If fauna have no capacity for recovery, then eventually, all trawled seabed areas could become completely denuded of fauna. However, with capacity for recovery, then all faunal vulnerability types have the potential for sustaining a population level in balance with the amount removed by trawling, to a limit that is highly dependent on the intensity of trawling (Poiner et al. 1998).

Poiner et al. (1998) considered that it was possible for the most vulnerable fauna to become ‘extinct’ in areas with >2,000–3,000 hrs of effort and although 50-70% of trawled grids have been trawled only lightly (<700–1000 hrs) each year, they suggested that over the last 20 years the cumulative effect of this has been, that vulnerable types of fauna (i.e. those easily removed and/or slow to recover) have been severely depleted, causing change in the composition of the faunal community. In the year of sampling in Shark Bay no site had more than 400 hours of trawling overall whilst in Exmouth Gulf only two sites (Sites 11 and 13) had approximately 900 hours of trawling with the remainder of sites having less than 200 hours of trawling. Therefore relatively low trawl effort is expended overall even though cumulative impacts may well apply.

Even though some species are highly catchable, some are more resilient than others and may survive trawling when discarded. Fish in general are thought to have low resilience and generally most are thought to die as a result of trawling (Wassenberg and Hill 1989, Hill and Wassenberg 1990). Laurenson et al. (1993) documented that small prawns suffered 100% mortality. Cephalopods are thought to have 100% mortality. Most crabs are fairly resilient to trawling with approximately 14% mortality and for all other crustaceans about 50%. Scallops are quite robust and have about 5% mortality (Joll pers. comm.). Similarly, the type of gear towed will have variable impacts. In Shark Bay, the prawn and scallop boats tow nets with different mesh sizes. Laurenson et al. (1993) compared the two commercial mesh sizes used in trawl fisheries in WA during sampling in Geographe Bay. The total numbers of species caught for the 45 mm nets was always greater than for the 100 mm mesh size nets. Some of the species caught in the 45 mm mesh were completely absent in the larger mesh. The tendency of the 45 mm net was for smaller animals to be caught than the 100 mm mesh.

As prawn trawling is selective in capturing species, fish trawl gear was deployed over one night at six sites in Shark Bay to compare the fish faunal composition of the two gear types. More than 50% of species sampled were common to both types of gear. The main differences between the two gear types were that the prawn gear caught bottom dwelling species such as flounders and flatheads which the fish trawl gear did not catch. The fish trawl caught a few species that had not been caught by the prawn trawls anywhere in Shark Bay and caught a few individuals of faster more mobile fish such as the blue mackerel that were not caught in prawn trawls. However, this sampling was limited to one time only at six sites and therefore is not comprehensive. Poiner et al. (1998) found that a prawn trawl catches only a subset of the fish population. This subset is composed of the smaller benthic species. The fish trawl catches show that a prawn trawl misses the larger more active species and also the more pelagic component. Thus the fish trawl catch of a prawn trawl is not an accurate representation of the fish fauna. This selectivity of the prawn trawl means that prawn trawling has a differential impact on species within the fish community, some are impacted and others are not (Poiner et al. 1998). They considered that this might lead to a change in species composition in heavily trawled areas.

Most of the fish species caught in the trawls have a wide distribution. In the NPF study some of the least sustainable species have a very wide distribution. This indicates that despite their vulnerability to trawling, they are probably not threatened by trawling (Hill et al. 2002). Few of the fish species caught in Shark Bay (10%) and Exmouth Gulf (6%) are endemic to WA, however they are not specific to only Shark Bay or Exmouth Gulf and Onslow and are represented along a vast coastline. One species of seasnake, *Aipysurus pooleorum* is endemic to Shark Bay or it has not been recorded elsewhere to date. However it is quite common in trawled and untrawled areas and is usually returned to the sea alive by trawlers. With current knowledge of species distributions, no other species is restricted to these regions, giving them robustness from trawl impacts; particularly since both fishing areas have a significant proportion (>60%) of areas not trawled.

4) To assess age composition and size structure of indicator species

A significantly higher proportion of smaller individuals of prawns were observed at the start of the season for all sites pooled, indicating that this is the main recruitment period for king and tiger prawns in Shark Bay and Exmouth Gulf.

For scallops in Shark Bay a significantly smaller mean size was observed at the end of the season indicating recruitment at this time of year. However, in the closed area in Denham Sound a significantly smaller mean size was observed at the start of the season. Due to the short-term nature of the sampling program (only four time periods from October 2002 to October 2003) no firm conclusions can be made if this annual variation in recruitment at this localised site is a true timing difference in southern Denham Sound compared to the rest of Shark Bay.

The total length frequencies of four fish species were assessed in Shark Bay and three species in Exmouth Gulf. Two to four cohorts (possible annual or multiple recruitment events) were observed for pooled site data. *U. asymmetricus* and *P. choirocephalus* had significantly smaller mean size at the start of the season whereas *P. nebulosa* and *S. undosquamis* had a significantly smaller mean size at the end of the season indicating differences in timing of recruitment into Shark Bay and Exmouth Gulf for these species. In Shark Bay larger *U. asymmetricus* and *S. undosquamis* (>50 cm total length) were sampled in northern Shark Bay in deeper waters compared to more southern sites and for *S. undosquamis* there was an absence of the mid-sized individuals in the northern sites. In Exmouth Gulf the size range of *S. undosquamis* was less with no larger individuals. This may be because the depth range sampled was less.

Examination of a selection of otoliths from common species of fish in both Shark Bay and Exmouth Gulf were primarily unsuccessful in determining ages of the fish sampled. Most of the otoliths of the common species were difficult to interpret with only two or three species, being suitable for otolith analysis. However, the scope of this project did not allow sufficient sampling of these species to determine firm conclusions about fish ages. Generally however it appeared that the species examined were in the age range of 1-5 years. None of the species for which length frequencies were recorded appeared to have more than three size cohorts, either indicating a relatively short-lived species or selectivity in the prawn nets for certain sized individuals. The size range of fish measured in our sampling was generally less than 25 cm except for *S. undosquamis*, which was measured up to 63 cm in the northern part of Shark Bay. This northern site was the deepest site sampled. Water depth could also be another contributing factor, affecting the size range of fish caught (Sainsbury and Whitelaw 1984). Poiner et al. (1998) also found that most species of fish captured in prawn trawls in the GBR were less than 30 cm.

Two recreationally important fish species that are captured by prawn trawls in Shark Bay are the western butterfish *P. vitta* and snapper *P. auratus.* All the *P. vitta* caught in prawn nets were mature fish and the species was not considered to be vulnerable to trawling (Mant et al. 2006) and *P. auratus* was caught at a size range of 3-18 cm TL which makes them susceptible to trawling for less than one year of their life from the ages of approximately 9 to 17 months (Wakefield et al. 2007). Therefore although catchable, trawling was not considered to be a major component of mortality during the life of *P. auratus* from these earlier studies.

Two to three cohorts were often observed for the fish species indicating that at least two or three year classes were present with none of the species for which length frequencies were recorded with more than four or possibly five cohorts. This may be either evidence of a relatively short-lived species or selectivity in the prawn nets for certain sized individuals. Size selectivity in trawl nets is well known (Efanov et al. 1987, Watson 1988, Wakefield et al. 2007). Wakefield et al. (2007) found that in Shark Bay, the size of fish caught in prawn trawls were generally between 3 and 20 cm fork length (FL). Similarly, Poiner et al. (1998) noted that 92% of the fish caught in their study were small (< 30 cm) and generally they were mature individuals of small species and not juveniles of larger species. The size range of fish measured in our sampling was generally less than 25 cm except for *S. undosquamis* which was measured at up to 63 cm total length in the northern part of Shark Bay. Twenty four species of fish in Shark Bay and 38 species of fish in Exmouth Gulf that were sampled can attain a size greater than 50 cm but these were generally rarely caught nor were they seen at the higher end of their size ranges indicating either gear selectivity differences for larger animals or potential trawl impacts on numbers of larger and longer-lived species.

For many of the fish and invertebrate species sampled there is insufficient biological information to determine their longevity and overall vulnerability to trawling. Larger, long-lived fish species, such as large rays and sharks, were infrequently sampled during these research surveys and on occasions they were caught in trawls for both scallop and prawn fisheries. Anecdotal information suggest these larger fish may have occurred in higher numbers early in the development of these fisheries as well as prior to occurrence of high levels of recreational fishing activity (particularly in Shark Bay). There is however, no data to verify these early observations. It is unlikely that these larger, faster moving fish are sampled effectively by prawn trawl nets due the low speed of trawling. In addition, introduction of bycatch reduction devices in 2002, larger animals are now excluded from prawn trawls and escape whilst in the water through an escape opening, reducing the incidental catch of large individuals significantly.

The productivity within Shark Bay and Exmouth Gulf appears to be reasonably high. The majority of common species are relatively short lived with ages less than 10 years and many under five years. Short-lived species usually have R type life history traits with high fecundity and high productivity with high input into reproduction during their relatively short life spans. The species measured fit this type of category and fall into similar life history categories as the target species of prawns and scallops. Differences in the timing of recruitment in prawns and scallops are also reflected in differences of timing of recruitment in some fish species. These species all appear to be characterised by annual variation in recruitment variability and likely to be influenced by environmental fluctuations.

The short duration of this project did not allow continued monitoring of species for several years to provide further insight into annual variability or to follow cohorts through any more than one year and therefore it was not possible to compare relative production (abundance and cohort structure) over time and between years. Some general observations can be made that many common species and the target species are short-lived and highly productive. This however does not dismiss that long-lived species have contributed to the food webs and productivity within these regions but are now in low numbers.

5) To develop criteria for selection of reference sites/times for future monitoring.

One of the main objectives of this study was to compare the faunal composition between trawled and untrawled areas and if the faunal composition was similar, then it was highly likely that closed areas act as refuges for the majority of those species impacted by trawling. Faunal composition was similar in trawled and untrawled areas in general and therefore it is sufficient that the principal form of monitoring in the Shark Bay and Exmouth Gulf fisheries is of the annual extent of the trawled areas. The percentage of area trawled should not exceed that observed in recent years (20-40% of area of the fishery). In fact, due to the market forces operating in these fisheries currently with the need to optimise value of catch and reduce the cost of fishing, the overall area trawled (as well as trawl hours) is being reduced.

However if there is a requirement to monitor changes in biodiversity of trawl bycatch in future years and to detect trends (be it due to fishing, environmental or some other factor), limited long-term monitoring of trawl bycatch may be necessary. Trawled and untrawled sites should be sampled during any future monitoring program, as there are likely to be subtle differences between trawled and untrawled sites that may become more discernible during repeated sampling over a longer period. Again, caution must be used when comparing faunal biodiversity from different surveys, as this study demonstrates how variable species presence/absence, abundance and diversity measures can be different between seasons and years.

This study indicates that for Shark Bay, Exmouth Gulf and Onslow, the major factors influencing the distribution of fish and invertebrate species are complex but there is some evidence, particularly in Exmouth Gulf that the level of trawl effort can influence faunal assemblages. Therefore selecting sites from the divisive cluster groupings, taking into account the various levels of fishing effort is recommended for long-term monitoring. Species richness, evenness and diversity were variable between fish and invertebrate assemblage groupings with higher levels for trawled sites in some groups and lower levels in others. Therefore both trawled and untrawled sites should be sampled and compared over the long-term from a selection of assemblage groups.

The sites sampled in Shark Bay provided an observed power for 5% significance test of only 40% to detect differences. However there was a significant difference observed with trawl effort and it is necessary to maintain a similar number of sampling sites in Shark Bay in order to not reduce power even further. If possible new untrawled sites should be incorporated to provide a more balanced sampling design overall. The sites would remain fixed sites for comparison with four additional random sites, incorporated to provide additional information of site variability. In Exmouth Gulf and Onslow Area1 there was more than sufficient observed power (well over 90% for 5% significance test) in the number of sites sampled to detect differences. As in Shark Bay, a series of fixed sampling should be sites selected from the assemblage groups and two random sites to be sampled. This combination of fixed and random sites is recommended for future monitoring. Continued use of fixed sites facilitates the estimation of trends, while the use of random sites protect against problems of unusability of the fixed sites. This may be because the amount of fishing effort at a site changes considerably or ceases and or there may be pollution or development initiatives impacting the area.

There are significant differences between assemblages and overall abundance between seasons, with the highest abundance overall observed at the start of the season for most groups with a decline in abundance by mid season. It may therefore be appropriate to sample at both the start and mid year (i.e. February/March and June/July). If costs only allow one sampling period, then the start of the season is recommended. Studies that attempt to describe the situation at any 'one time' may not reflect the state at any other time due to the high seasonal variability observed for most species. Sampling should also be undertaken over a similar period of the lunar cycle, noting the variation in catchability for some species due to the lunar cycle (Stobutzki et al. 2001b, Poiner et al. 1998). Other environmental factors (eg. cyclones, sea surface temperature) before and during sampling should be noted, as they are likely to affect abundances.

Annual differences in individual and total species abundance were evident in this study to the level of >50% difference in overall abundance at the start of a season for two out of three sites sampled on five occasions. Both of these were untrawled sites. This level of change could be due to natural variation and no other factor. Therefore if the sampling can detect a greater than 50% level of change then the sampling would need to be repeated the following year in order to confirm if a trend indicates a true decline and not just natural variability.

Estimated depletion rates indicated that some species or species groups are more vulnerable to trawling compared to others. This project used the numbers of individuals per distance trawled as a proxy for the catch rate instead of weight of species per distance trawled. Highly aggregating species and those with high mobility are unlikely to be useful species when trying to assess trends in abundance and diversity measures. Species which have a moderate to high catchability (>30%) and those that are generally widespread (occur in > 70% of sites sampled) are good candidate indicator species for trend analyses. For Shark Bay this could include the fish species *I. japonica*, *P. nebulosa*. *E. grandisquama*, *M. chinensis*, *S. sageneus*, *P. vitta*, *C. cephalotes*, *S. robusta*, *P. sexlineatus* and *L. genivittatus.* These ten species represented, on average 19.6% (SE 2.3) of the total fish abundance. Species with low catchability or high mobility are less reliable as indicators as catch rates will not represent actual abundance. For invertebrate species, the only suitable indicator species are the group Porifera and the seastar *L. maculata* as all the other invertebrate species that displayed medium to high catchability are commercially targeted species (or secondary species) or schooling, mobile species such as the cephalopods. However both Porifera and *L. maculata* are a fairly small component of the invertebrate bycatch in Shark Bay and the morphology of sponges makes some individual species less catchable than others.

Stobutzki et al. (2000) found that if they sampled 10% of catch it generally represented about 50% of what was caught in a trawl because of high numbers of fairly rare or uncommon species in trawl bycatch. Therefore, a larger proportion of the total catch i.e. half of the catch would represent the majority of species caught. If, for example the port and starboard sides of the trawl gear is noted to be fishing equally, one side could be used as being representative of the catch to reduce sorting time.

It is recommended that all species be identified to the lowest taxonomic level possible in order to get some information on the more uncommon species as well as the 10-20 species of fish and invertebrates that represent the majority of the catch. The level of monitoring suggested above is expected to be able to record, in the longer term, trends in abundance and species distribution of representative sites within each fishery in a fairly cost efficient manner. This requires the use of a dedicated research vessel and scientific personnel to process the catches and continued collaborative links with the Western Australian Museum with taxonomic expertise.

9.0 CHANGES FROM THE ORIGINAL PROPOSAL

The project has had several extensions to the duration of project. No other changes were made from the original proposal.

10.0 BENEFITS

The outcomes of this project have benefits to the commercial prawn and scallop industries, fisheries researchers and managers, marine taxonomists, other stakeholders and the general community. Details of the objectives and methodology of the project were outlined at a public forum held in Carnarvon in late October 2004 and at the National Prawn Conference and research workshop held in Cairns in November 2004. This provided the opportunity to highlight aspects of the project to the public, industry members and other researchers. A poster outlining the objectives of the project and preliminary results was presented at the Seafood Directions conference in Fremantle in September 2003 and the National Coastal Conference in Geraldton in November 2003. Public information seminars have been held at the WA Museum in August 2004, a research forum on Exmouth Gulf in September 2006 and a Research Division research seminar in October 2006. An outline of the project was published in the WA Museum 'Tracks' magazine in early 2003 and a summary of preliminary results was published in the *Western Fisheries* in December 2005.

The information gathered during this project will enable the Department of Fisheries and industry to effectively respond to information required by Department of Environment and Water Resources (DEWR) in order to continue to provide top quality, highly valued seafood to both export and local markets. It also provides a basis to answer queries from conservation and community groups.

The baseline information on trawl bycatch provides a current inventory of the species caught by prawn trawls in Shark Bay, Exmouth Gulf and Onslow Area 1 which can be used by both industry and researchers working in these regions. The spatial, seasonal and annual components of the sampling provide a useful insight into the high diversity of both fish and invertebrate species in these regions and the highly variable nature of faunal assemblages.

Being able to confidently define areas that are trawled and those closed to trawling and demonstrating little difference between these areas provides support for the use of the suite of management tools that are currently used in these fisheries to ensure sustainable fishing. Other trawl fisheries can consider the appropriateness of these tools if they are not currently being employed.

11.0 FURTHER DEVELOPMENTS

The outcomes of this project has been and will be further discussed at the Joint Trawl Management Advisory Committee (JTMAC) for the Shark Bay prawn, Exmouth Gulf prawn and Shark Bay Scallop fisheries and the implication of these results in any improvements to the current management strategies. During the course of this project preliminary results and project progress was presented to the JTMAC during regular meetings and to the prawn and scallop licensees at regular industry association meetings. These are held three to four times a year. Pre-season skippers meetings are also held each year in March/April and key results have been disseminated during these meetings.

The final results will be discussed at the annual general meetings for the other minor trawl (8 fisheries) fisheries in WA. These meetings are generally held during in January/February each year. In particular, the applicability and expansion of the use of some of the management tools used in Shark Bay and Exmouth Gulf will be considered for the minor trawl fisheries.

The results of this project will assist in those areas identified as requiring further information for the DEWR review of ESD Risk Assessment applications due in 2008/09.

12.0 PLANNED OUTCOMES

1. Assessment of the bycatch species in sufficient number of closed areas and times to ensure that the management of these species is undertaken sustainably.
2. Determination of representative sites and appropriate sampling strategies which can be used for long-term monitoring of changes in biodiversity to ensure that the management of theses species is sustainable in the future.
3. Identification of bycatch indicator species and highly vulnerable species in Shark Bay and Exmouth Gulf to ensure there are no conservation issues with respect to these species.
4. Development and adoption of codes of conduct by industry to ameliorate any detrimental impacts identified.

13.0 CONCLUSION

Optimum ecological sustainability and economic return may be achieved by careful control of trawl effort and by selective use of area closures. This is being achieved in Shark Bay and Exmouth Gulf fisheries and more recently implemented in the Onslow Prawn Managed Fishery. One of the main objectives of this study was to compare the faunal composition between trawled and untrawled areas and if the faunal composition was similar, then it was highly likely that closed areas act as refuges for the majority of those species impacted by trawling. Faunal composition was similar in trawled and untrawled areas in general and therefore it is sufficient that the principal form of monitoring in the Shark Bay and Exmouth Gulf fisheries is of the extent of the trawled areas. This is possible through the use of daily shot-by-shot logbook records and VMS.

Commercial trawling has been undertaken in part of Shark Bay from 1962, and Exmouth Gulf from 1963, to the present day. We lack sufficient data to know the habitat complexity, or the richness of faunal assemblages in the trawled regions prior to the commencement of commercial trawling so this study provides data for the current situation from selected sites with soft bottom substrates in areas open and closed to trawling. This study demonstrated variability in faunal abundance and diversity measures within and between sites but these could not be attributed to trawling. Seasonal and annual variability within and between sites was also evident. Generally (except for fish species in Exmouth Gulf) abundance declined during the year, in both trawled and untrawled sites.

It has been observed elsewhere that high levels of trawling may not only decrease the complexity of the habitat and biodiversity of the fauna, but also enhance the abundance of opportunistic species including prey species that are important in the diet of some commercial species (Engel and Kvitek, 1998, Auster et al. 1996). It is highly likely that the faunal communities, diversity and habitat structure in the trawled areas of Shark Bay and Exmouth Gulf and Onslow have changed since trawling began, but have now reached a new 'balance' compatible with trawling. Even so, major differences in abundance or diversity measures are not discernible between those sites that have been closed to trawling for decades and those sites fished although some significant differences were observed in fish abundance when sites of differing trawl effort are compared. These results were not consistent between Shark Bay and Exmouth Gulf, with low trawl effort sites having a higher abundance in Shark Bay compared to no trawl effort sites, whereas high trawl effort sites had lower abundance in Exmouth Gulf where all the other trawl effort category sites were similar. Additionally, it has been previously observed that natural environmental variability is often greater than fishing-induced changes (Jones et al. 2000), further masking the effects of trawl activity. This was observed for some species, at the three fixed sites sampled in Shark Bay over five time periods where high variability in abundance and distribution was observed between years.

Even such an extensive survey as this does not provide sufficient information to understand what is happening in bycatch populations from year to year. As long as the limitations of this study are cautiously considered, the data from this work will provide an invaluable baseline on which to build on any future monitoring. Future data will further refine the database and will lead to a more detailed understanding of abundance and diversity of fish and invertebrate species in trawlable areas of Shark Bay and Exmouth Gulf.

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16.0 APPENDICES

16.1 Appendix 1 – Intellectual property

Not applicable

16.2 Appendix 2 – Staff

Principal Investigator:	Mervi Kangas
Co-Investigator:	Sue Morrison
Technical staff:	Phil Unsworth
	Gareth Parry
Research Vessel Crew:	Theo Berden
	Mark Baxter
	Tim Shepherd
	Kim Hillier
	Shaun O'Hara
Statisticians:	Eva Lai
	Ian Wright
	Adrian Thomson

16.3 Appendix 3 – Data sheets

BIODIVERSITY SURVEY WHEELHOUSE LOG

VESSEL: ....

SKIPPER: ....

LFB No.: .... DATE: .... TRAWL No: ....

	START	FINISH
TIME (24hr)	.... hrs	.... hrs
DEPTH	.... m	.... m
LATITUDE	° ‘ S	° ‘ S
LONGITUDE	° ‘ E	° ‘ E

DURATION: .... min DISTANCE TRAWLED: nm

WATER TEMP: .... °C CLOUD COVER: %

MOON (please tick): UP ☐ DOWN ☐ GEAR FISHING ☐ NOT FISHING ☐

QUARTER (please tick): LAST ☐ NEW ☐ FIRST ☐ FULL ☐

WIND - STRENGTH: .... kts DIRECTION:

SEA STATE (please tick): calm ☐ slight ☐ moderate ☐ rough ☐

REMARKS: ....

....

....

....

FRDC BIODIVERSITY PROJECT (Shark Bay) Date:__________ Port:__________ S'board________

Site No:____________ Shot No:______________ Time:______________ Master Sheet No:____________

Species	No:	No:	No:	Species	No:	No:	No:
Numbfish, Banded				Monocle Brm, False Whip			
Stingray, Brown reticulated				Monocle Brm, W. Butter			
Boxfish, Small-nosed				Pipefish, Short-tailed			
Cardinalfish, Black-tipped				Pipefish, Tiger			
Cardinalfish, Broad-banded				Ponyfish, Whipfin			
Cardinalfish-Many-banded				Roach			
Cardinalfish-Two-eyed				Rockcod-False Scorpion			
Damsel, Gulf				Sardine-Scaly Mackerel			
Dragonet-Fingered				Sardine, Gold-striped			
Dragonet-High-finned				Scorpion-Long-finned W			
Emperor, Blue-spotted				Scorpion-Plumb-striped S			
Emperor-Threadfin				Scorpion-Bullrout/Spotfin			
Flathead-Bar-tailed				Scorpion-W. Red			
Flathead-Bossch's				Seahorse, False-eyed			
Flathead-Fringe-eyed				Seahorse, W. Spiny			
Flathead-Heart-headed				Seamoth-Slender			
Flathead-Long-spined				Snapper, Long-spined			
Flathead-Northen Sand				Snapper-Pink			
Flathead-Rusty				Sole-Dark-Spotted			
Flathead-Spiny				Sole, Dark Thick-rayed			
Flathead, Tassel-snouted				Sole-Harrowed			
Flounder, Blue-spotted				Sole, McCulloch's Tongu			
Flounder, Deep-bodied				Sole-Patterned Tongue			
Flounder, Intermediate				Spinefoot-Black			
Flounder-Large-toothed				Stinger, Spotted			
Flounder-Small-toothed				Stinkfish, Goodlad's			
Flounder-Spiny				Stinkfish, Gross's			
Flounder-Spiny-headed				Stinkfish, Rough-headed			
Goatfish-Asymmetrical				Toadfish-Orange-spotted			
Goatfish-Bar-tailed				Toadfish, Whitley's			
Grubfish-Red-barred				Trevally, Western			
Gurnard-Flying				Trevally-Smooth-tailed			
Gurnard-Long-finned				Trevally, Yellowtail			
Herring, Australian spotted				Trumpeter, Six-lined			
Leatherjacket-Brn Bltchd				Trumpeter			
Leatherjacket-Fan-bellied				Turretfish			
Leatherjacket-Hair-finned				Whiting, Robust			
Leatherjacket, Paxman's				Whiting-Trumpeter			
Leatherjacket, Pot-bellied				Whiting-W. School			
Leatherjacket, Prickly							
Lizardfish-Large-scaled							
Lizardfish-Netted							
Lizardfish-Painted Grin							

FRDC BIODIVERSITY PROJECT (Exmouth) Date:______________ Side:____________________

Site No:____________________ Shot No:________________________ Location:_________________________

Species				Species			
Anglerfish, Butler’s				Leatherjacket, Pot-bellied			
Bigeye, Threadfin				Lizardfish, Large-scaled			
Boxfish, Small-nosed				Lizardfish, Netted			
Cardinalfish, Brown-spotted				Lizardfish, Painted			
Cardinalfish, Cavite				Monocle Bream, False Whip			
Cardinalfish, Flagfin				Monocle Bream, Red-Spot			
Cardinalfish, Gobbleguts				Monocle Bream, W. Butter			
Cardinalfish, Many-banded				Ponyfish, Pugnose			
Cardinalfish, Pearly-Finned				Ponyfish, Tooth Pony			
Catfish, Long-tailed				Ponyfish, Zig-zag			
Catfish, Giant				Ponyfish, Whipfin			
Croaker, Little Jewfish				Roach			
Damsel, Gulf				Sardine, Gold-striped			
Dragonet, Fingered				Scorpionfish, Bullrout			
Emperor, Threadfin				Scorpionfish, False			
Flathead, Bar-tailed				Scorpionfish, Long-fin Was			
Flathead, Fringe-eyed				Seamoth, Slender			
Flathead, Heart-headed				Seaperch, Saddle-tailed			
Flathead, Rusty				Searobin,			
Flathead, Spiny				Silver Biddy, Common			
Flounder, Blue-spotted				Silver Biddy, Long-Finned			
Flounder, Freckled				Stinger, Spotted			
Flounder, Intermediate				Stinkfish, Gross’s			
Flounder, Large-toothed				Stinkfish, Multifilament			
Flounder, Peacock				Sweetlips, Painted			
Flounder, Small-toothed				Threadfin Bream, Notched			
Flounder, Spiny				Toadfish, Golden			
Flounder, Spiny-headed				Toadfish, Orange Spotted			
Flounder, Twin-spot				Toadfish, Silver			
Flutemouth, Smooth				Toadfish, Whitley’s			
Goatfish, Asymmetrical				Trevally, Smooth-tailed			
Goatfish, Bar-tailed				Trevally, White-tongued			
Goatfish, Ochre-banded				Tripodfish, Black Flag			
Goatfish, Sunrise				Trumpeter, Banded			
Goby, Shadow				Trumpeter, 4-lined			
Grooved Razorfish				Trumpeter, 6-lined			
Grubfish, Red-Barred				Tuskfish, Purple			
Gunther’s Threadfin				Veilfin, High-finned			
Javelinfish, Blotched				Velvetfish Sandpaper			
Leatherjacket, Bearded				Whiting, Mud			
Leatherjacket, Fan-bellied				Whiting, Trumpeter			
Leatherjacket, Hair-finned							

FRDC BIODIVERSITY PROJECT (Shark Bay) Date:__________ Port:__________ S'board________

Site No:____________ Shot No:______________ Time:______________ Master Sheet No:_____________

Species:	No:	No:	No:	Species:	No:	No:	No:
Crustaceans				Molluscs			
Tiger prawn							
W King prawn							
Endeavour prawn							
Red spot prawn							
				S. Calamari squid			
				S. Dumpling squid			
				Pyjama squid			
				Bobtail squid			
Portunus pelagicus							
Portunus sanguinolentus				Echinoderms			
Portunus rubromarginatus							
Portunus pseudoargentatus							
Portunus pubescens							
Charybdis feriatus							
Charybdis natator							
Thalamita sima							
Decorator crab							
Hermit crab							
Alimopsoides sp.							
Carinosquilla australiensis							
Oratosquilla oratoria							
Scyllus martensii							
Thenus orientalis				14			
				15 Coelenterates			
Ascidians				Sponges			
Polychaetes							

FRDC BIODIVERSITY PROJECT (Exmouth) Date:______________ Side:____________________

Site No:____________________ Shot No:________________________ Location:_________________________

Crustaceans	**No:**	**No:**	**No:**	**Molluscs**	**No:**	**No:**	**No:**
Tiger prawn				Amusium balloti			
W King prawn							
Endeavour prawn							
Metapenaeopsis rosea				Cuttlefish			
M.crassisima				S. Calamari squid			
Trachypenaeus anchoralis				S. Dumpling squid			
Trachypenaeus curvirostris							
Parapenaeopsis cornuta							
M.novaeguinea				Echinoderms			
Metapenaeus dalli				H.fuscocinerea			
M.lamellata				Stichopus sp.			
Portunus pelagicus				Astropecten preissi			
Portunus sanguinolentus				Stellaster equestris			
Portunus rubromarginatus				Stellaster inspinosus			
Portunus cf rubro - spines				Pentaceraster gracilis			
Portunus curvipenis							
Portunus hastatoides							
Charybdis anisodon							
Thalamita sima				Temnopleurus alexandri			
				Temnopleurus elegans			
				Tripleneustes gracilia			
Spider crab				Prionocidaris bispinosa			
Decorator crab				Prionocidaris baculosa			
Hermit crab							
Alimopsoides sp.							
Carinosquilla australiensis				Peronella lesueuri			
Oratosquilla oratoria				Euryale asperum			
Scyllus martensii							
Thenus orientalis				Comatula solaris			
				Comatula rotalaria			
Ascidiacea – P. millari				Zygometra microdiscus			
				Soft Coral/Hydrozoa			
Sponges							

Sediment Analysis Exmouth Gulf – Biodiversity project

Sample Number	Bag + wet sample (g)	Tray + wet sample (g)	Tray + dry sample (g)	Tray (g)	Water Content	Bag Weight (g)	Sample weight
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
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20							
21							
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24							
25							
26							
27							
28							
29							
30							

16.4 Appendix 4 – Publications and presentations

Publications

'Trawling for science and sustainable fisheries'. Western Fisheries, December 2005.

'Fishing for Answers '. Tracks Western Australian Museum Magazine January 2003

Presentations/Posters

"Biodiversity in trawled and untrawled areas of Exmouth Gulf". Exmouth Gulf Scientific Forum, Murdoch University, September 2006.

"Biodiversity in trawled and untrawled areas in Shark Bay and Exmouth Gulf". Western Australian Fisheries and Marine Research Laboratories Research Seminar Series, Hillarys, August 2006.

"Biodiversity in trawled and untrawled areas of Shark Bay and Exmouth Gulf" WA FRAB Stakeholder Research Planning Workshop, Hillarys, March 2006.

"Research and Management of Prawn and Scallop Fisheries in Western Australia" Public seminar, Port Erin Marine Laboratories, Isle of Man, August 2005.

"Managing for environmental win-win solutions in a World Heritage Area - Shark Bay, Western Australia". National Prawn Conference, Cairns, November 2004.

"Trawl Fisheries Research in the Gascoyne" Public Forum, Carnarvon, October 2004.

"Prawn Tales" Museum at Work monthly public talk, Perth. August 2004.

"Biodiversity and habitat monitoring systems for trawl fisheries in Western Australia". National Coastal Conference, Geraldton, November 2003.

"Biodiversity and habitat monitoring systems for trawl fisheries in Western Australia". Seafood Directions Conference, Fremantle, September 2003

16.5 Appendix 5 – Species identification CD

A CD of the most abundant fish and invertebrate species in Shark Bay, Exmouth Gulf and Onslow Area 1 can be provided by the authors on request.

16.6 Appendix 6 – A review of the biodiversity of Western Australian soft-bottom habitats in Shark Bay and Exmouth Gulf and the impact of demersal trawl fisheries on benthic communities in Australia

A review of the biodiversity of Western Australian soft-bottom habitats in Shark Bay and Exmouth Gulf and the impact of demersal trawl fisheries on benthic communities in Australia

S. Morrison, P. Unsworth, M. Kangas

FEBRUARY 2003

Contents

1.0 INTRODUCTION

Demersal trawling commenced in Shark Bay and Exmouth during the early 1960's and has continued to the present. Since the early days of commercial trawling limited entry, temporal and spatial effort and gear restrictions have been imposed to manage the prawn and scallop fisheries. The prawn and scallop stocks are "fully exploited" for both the Shark Bay and Exmouth Gulf trawl fisheries (Fisheries WA, 2000). The export value of these fisheries is around $90 million (ABARE, 2000) with 80% of product being exported with the rest being sold on the local or interstate markets.

Fisheries management has focussed on the sustainability of target species and has included the protection of habitats crucial to particular life-history stages of the target species (juveniles, recruits and breeding stocks) and therefore these management measures have also provided protection to other species not targeted as well as their habitats. With a more environmentally conscious community, addressing the ecological sustainability of not only the target species but also by-product and bycatch species is paramount. The move towards a more holistic approach to fisheries management and the requirement of export fisheries to demonstrate that they are fishing sustainably under the amendments to the *Wildlife Protection (Regulations of Exports and Imports) Act 1982* the description and quantification (where appropriate) of the biodiversity (primarily faunal composition) in currently trawled and untrawled areas is desirable. This desktop study describes the state of knowledge to date.

2.0 SHARK BAY

2.1 Location

Shark Bay is located on the central Western Australian coastline between approximately 24°45'S and 26°36'S. It is a shallow marine embayment open to the north. It is bounded on the western side by Edel Land Peninsula which is connected to the mainland, and to the north of that by Dirk Hartog, Dorre and Bernier Islands. The southern part of the Bay is divided into eastern and western sections by the Peron Peninsula. Shark Bay covers an area of almost 13,000 km^2 (Logan and Cebulski 1970) (Figure 1).

Figure 1. Shark Bay locality map.

2.2 Conservation value

Shark Bay has been a World Heritage Property since 1991, the only area of this status in Western Australia. This encompasses the Shark Bay Marine Park and Hamelin Pool Marine Nature Reserve. It is an area of major conservation value since Shark Bay contains one of only seven marine parks in Western Australia and one marine nature reserve.

The significant marine features that have resulted in this level of protection are; the presence of the most extensive and diverse seagrass meadows in the world; one of the largest populations of dugongs in the world; substantial populations of dolphins and marine turtles; and a permanent hypersaline environment in Hamelin Pool that has facilitated the growth of stromatolites (one of only two marine locations world wide where living stromatolites exist), and the build up of large banks of *Fragum erugatum* shell deposits. The seagrass meadows play a fundamental role in the evolution of ecosystems and formation of Shark Bay, as they modify the physical, chemical, biological and in turn, the geological environments.

2.3 Geomorphology

Logan and Cebulski (1970), Logan *et al*. (1974) and Playford (1990) provide a comprehensive description of the geomorphology of Shark Bay. The peninsulas and islands consist of Pleistocene and Holocene dune deposits, overlying Tertiary limestone and sandstone. The Edel Land Peninsula and islands to the north are underlain by Tamala Limestone whereas; mainly red Peron Sandstone underlies the Peron Peninsula. Longitudinal north-south dune ridges present on the eastern side of Edel Land Peninsula and the Peron Peninsula formed in parallel due to the extremely strong prevailing southerly winds of the period. The Shark Bay shallow embayment formed about 6,000 years ago when sea levels rose and the dune area flooded, resulting in the gulfs with numerous small inlets that are partially cut off from the Indian Ocean. The inlets on the eastern coasts of the peninsulas have sandy beaches with rocky platforms and headlands.

The eastern coast of Shark Bay between Hamelin Pool and Carnarvon is mainly covered by Cretaceous chalk with some overlying Tertiary sandstone and calcarenite. This land consists of a gently sloping coastal plain of red alluvial sediments, clay pans and channel-fill sands. Two rivers, the Gascoyne and the Wooramel, drain across this plain into Shark Bay, but only carry sediment intermittently after summer cyclones or winter storms. There are wide supratidal samphire flats in this region, and a fringe of mangroves between Carnarvon and Long Point (Davies 1970, CALM 1994).

The region to the southeast of Shark Bay consists of Cretaceous and Tertiary limestone, and has limestone plateaus, rocky outcrops and small clay pans. The plain slopes gently to the west and there is a small limestone scarp along the coast around the south end of Hamelin Pool.

Two unique features that developed in the Holocene period are the Hamelin Coquina (a vast accumulation of tiny shells of the bivalve *Fragum erugatum*) and numerous stromatolites, that occur in the southern reaches of the eastern arm of Shark Bay (Logan *et al*. 1974a, Playford 1990).

2.4 Physical structure of the bay

Logan and Cebulski (1970) divide Shark Bay into three zones; intertidal to supratidal platform, sublittoral platform, and the embayment plain. The intertidal-supratidal platform varies in width from a few metres on rocky headlands to several kilometres on the flats. The sublittoral platform slopes gently down from the intertidal zone with an abrupt steep slope just before the embayment plain. The platform is narrower (100–800 metres) on the north and east-facing shores, with the steep section between 1.5–4.5 metres. On the south and southwest facing shores the sublittoral platform is wider (1.6–8 km), with the steep section at 4.5–7 metres. The embayment plain is flat and featureless and ranges from 7.5–9 metres in the southern part of Shark Bay to around 37 metres at the northern entrance to the Bay at Geographe Passage. There are several basins, notably Hamelin Pool Basin, Lharidon Basin and Freycinet Basin, within Shark Bay that are separated by submerged banks (sills) and shoals (Figure 2). Sills and shoals such as the Faure Sill and the Wooramel Bank have developed as seagrass meadows trap and bind sediments and moderate water flow. The Wooramel Bank, covering 1,030 km^2 is the largest known body of carbonate sediment formed by an organic baffle.

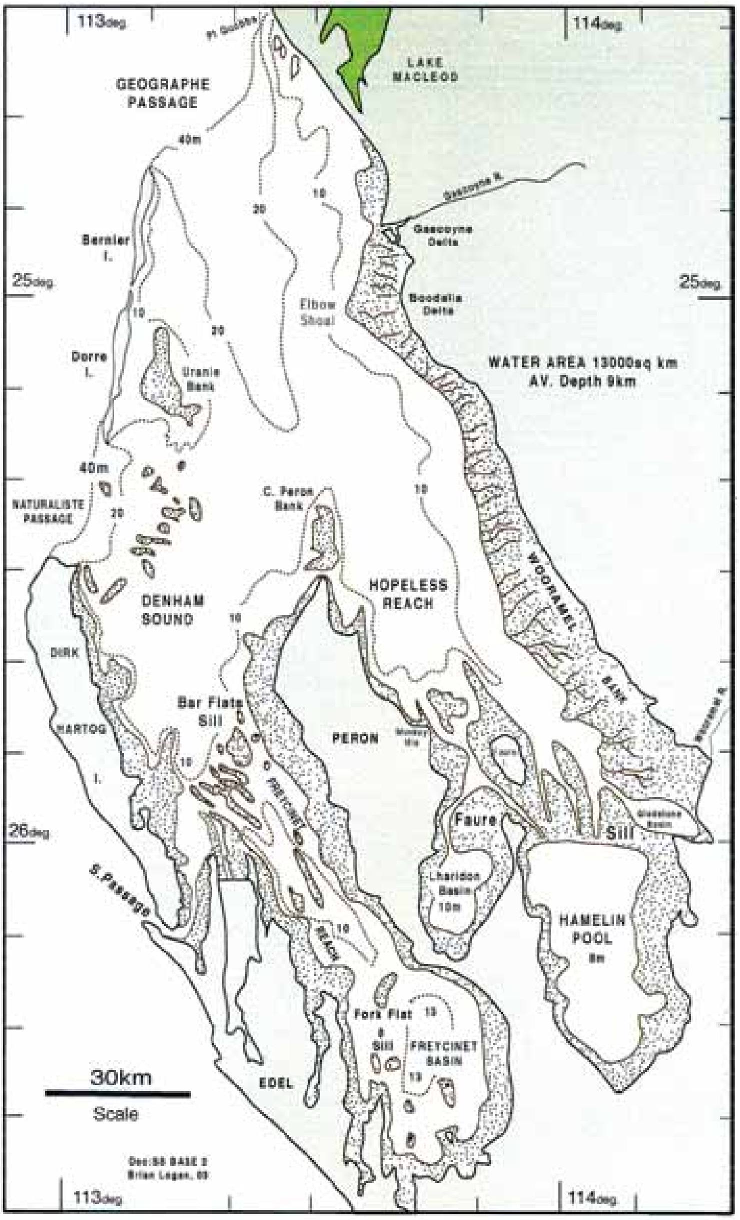

Figure 2. Shark Bay indicating basins and shoals.

2.5 Climate

Shark Bay is in a hot, arid to semi-arid zone. Combining data from the Carnarvon and Hamelin Pool weather stations, the mean minimum and maximum daily temperatures range from 16–37ºC in summer (November to March), and from 9–22ºC in winter (May to August) (Bureau of Meteorology, 2002).

Rainfall is low, with annual averages of 213 mm at Hamelin Pool and 233 mm at Carnarvon, with annual means of 38 and 41 days of rain respectively (Bureau of Meteorology, 2002). Maximum rainfall occurs in winter (May to August); with monthly means between 19 and 48 mm. Rainfall is minimal in spring/early summer (September to December) when monthly means are 2–8 mm. However, summer rainfall means (8–21 mm) are often increased due to occasional heavy cyclonic rains that occur mainly between January and March (Logan and Cebulski, 1970). A maximum rainfall of 135 mm is recorded for a day in Hamelin Pool in March.

Shark Bay is in the southeast tradewind belt, and prevailing winds are southerly. This wind pattern is affected by strong sea breezes during summer and depressions over the Southern Ocean during winter. In summer the mean monthly wind speeds range between 16–30 km/hr and tend to be south to southeast in the morning, and south to southwest in the afternoon and night. Strong winds are sometimes sustained for several days in summer, with gusts up to 115–178 km/hr recorded. The majority of tropical summer cyclones cross the northwest coast occur north of Exmouth Gulf. These cyclone events sometimes result in heavy rain and flooding in the Gascoyne and Wooramel basins, with runoff into Shark Bay. Occasionally cyclones pass closer to Shark Bay causing high winds and heavy rainfall directly over the Bay. In winter the winds are slightly moderated, with mean monthly windspeeds of 13–23 km/hr, with gusts of up to 84–93 km/hr (Bureau of Meteorology 2002). Frequent periods of calm occur in winter, but occasionally strong northerly winds develop when there are intense depressions in the Southern Ocean. These climatic conditions cause high evaporation rates between 2,000 and 3,000 mm that exceed the annual rainfall.

2.6 Oceanography

Salinity levels in Shark Bay have been well documented by Logan and Cebulski (1970), and Logan et al. (1974b). Shark Bay has a negative salinity gradient from oceanic salinity at the seaward openings (Geographe Passage, Naturaliste Passage and South Passage) to hypersaline conditions in the southern reaches of the two gulfs. This gradient has developed due to restricted water movement caused by the seagrass meadows and sills, combined with low rainfall and a high evaporation rate. The major salinoclines in the bay have been divided into three categories; oceanic (35–40‰) in the northern embayment of Shark Bay, metahaline (40–56‰) in Hopeless Reach, Denham Sound and Freycinet Basin, and hypersaline (56–70‰) in Hamelin Pool, Lharidon Bight, and small pockets the southern ends of Edel Land inlets (Figure 3). The spacing of these salinity bodies throughout the Bay is irregular and is affected by shallow shoals or water movements, the latter changing seasonally. There is intermittent freshwater input from the Gascoyne and Wooramel Rivers into Shark Bay, particularly after heavy rainfall from summer cyclones or in winter. These rainstorms only cause localised dilution of the intertidal environment and the overall salinity stays relatively constant for years. Consequently the stability of the salinoclines mainly depends on evaporation, and amount of tidal mixing with oceanic water.

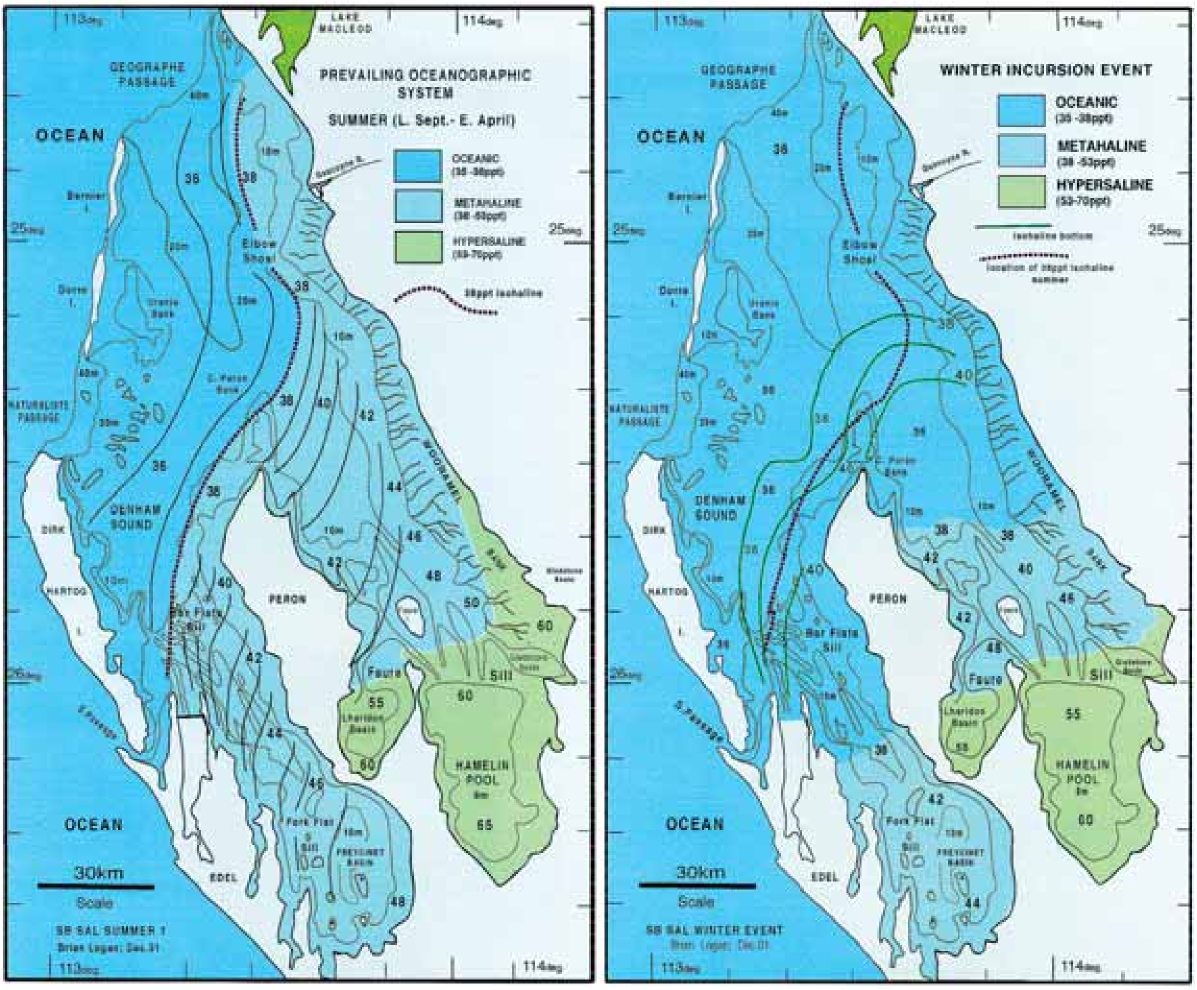

Figure 3. Salinity profiles of Shark Bay during a) summer and b) winter.

Tides in Shark Bay are mixed diurnal with a mean tidal range of 0.6 metres on a neap tide to a high of 1.7 metres on a spring tide at Carnarvon and 1.2 m at Denham. Tidal currents can be strong with 0.49–0.55 m/sec around Cape Peron, and 0.18–0.30 m/sec in Uranie Straits and Hopeless Reach. Southerly winds generate substantial seas that mainly affect the southeast or southwest facing coasts. Wave size is limited however by the relatively short fetch across the Bay. Sediments on the sublittoral platforms are frequently mixed by wave action, but sediments in the deeper embayment plain are rarely disturbed, under average conditions (Logan and Cebulski 1970). The pattern of water circulation in Shark Bay is complex, due to the imbalance of flood and ebb tides, plus restrictions on water movement due to physical barriers of shallow banks, and different salinities (with a range of densities).

The net circulation of water in Shark Bay tends to be an influx of low-salinity oceanic water along east-facing shores, and a discharge of high-salinity water along west-facing shores (Logan and Cebulski, 1970) the transitions between which constitute density fronts (Logan and Cebulski, 1970, Smith and Atkinson 1983, Burling et al. 1999). The two primary fronts, a semi-circular intrusion around Naturaliste Channel, and a transition funning southwest to northeast from Denham Sound to Carnarvon, effectively divide Shark Bay into its deeper, northern, and shallower, southern sections. The system has remained stable for more than three decades (Nahas et al., in press).

There are time lags in the tides, with tides in the southern sections up to nine hours behind those in the north of the bay. The tides are attenuated by sills and combined with the effects of prevailing southerly winds, there is little tidal exchange in the southern parts of the gulfs. Additionally, there is limited exchange of oceanic shelf waters with Shark Bay water. The greatest exchange occurs in winter when the Leeuwin Current is stronger and nearer to the coast, and northerly winds help to direct water into Geographe Passage. During the rest of the year the prevailing southerly winds enable some oceanic water to enter the gulf via Naturaliste Passage and exit via Geographe Passage.

Water temperatures are more extreme in the southern, shallower reaches of the Bay, where minimum winter temperatures range from 15 to 18ºC and maximum summer temperatures between 26 to 30ºC. In the northern reaches of the Bay water temperature is more influenced by the oceanic waters. In autumn (March to May) when the warm, south-flowing Leeuwin current is close to the coast, temperatures reach a maximum of 24 to 25ºC. The coolest period is in August when maximum temperatures fall to 21ºC.

2.7 Biological environment

There are three biogeographical inshore regions recognised in Western Australia;

1. The tropical north west coast extending northeast from North West Cape, dominated by tropical species.
2. The temperate south coast south and east from Cape Leeuwin, dominated by temperate species.
3. The lower west coast overlap zone in between North West Cape and Cape Leeuwin, where there is a combination of tropical and temperate species with a gradual change of dominance from tropical species in the north to temperate species in the south.

The flora and fauna of Shark Bay are nearer the northern end of the west coast overlap zone and are predominantly tropical, with a small number of temperate species, plus some species endemic to Western Australia. Many of the species found in Shark Bay are at the southern limits of their geographical range. Additionally, the unusual salinity regime of Shark Bay provides suitable habitats for proliferation of some species, such as and stromatolite-building microbes and *Fragum erugatum* that can survive in extreme hypersaline conditions.

The flora and fauna of Shark Bay will be discussed within the following major habitats:

1. Seagrasses and sediment areas.
2. Hypersaline environments.
3. Rocky shores and coral reefs.
4. Sandflats and mangroves
5. Soft sediments.
6. Open water.

The habitat types 1 to 4 described are generally not trawled and permanently closed to trawling activity.

2.7.1 Seagrasses and sediment areas

Of all the marine biota, seagrasses have had the greatest impact on the evolution and biodiversity in Shark Bay. Shark Bay has the largest and richest area of seagrass meadows known in the world, with twelve species covering 4,000 km^2 or approximately 30% of the Bay (Walker *et al.* 1988, Walker 1990). Most of these are southern temperate species at the northern limit of their range, notably the most widespread species in Shark Bay *Amphibolis antarctica* and *Posidonia australis.* However some species of tropical distribution are also found there, including *Syringodium isoetifolium*, *Halodule uninervis,* and *Cymodocea angustata*, which is endemic to northwest Australia. *Amphibolus antarctica* covers around 85% of the total seagrass area, and can live in a variety of sediment types and currents. It is found from below the intertidal zone down to the deepest regions of the Bay, but dense stands are uncommon beyond 13 m depth. *Posidonia australis* is mainly confined to channels, and *Halodule uninervis* is only found at the mouth of the Wooramel delta. Smaller species of seagrasses, such as *Halophila ovalis*, *H. ovata*, *H. uninervis*, *C. angustata* and *S. isoetifolium* colonise the shallow intertidal sand flats, sand patches in meadows, edges of banks and around islands (Walker 1990).

With increasing salinity towards the southern regions of Shark Bay, seagrass meadows become less dense, with very little present in Hamelin Pool. Different species can tolerate different levels of hypersalinity; *P. australis* rarely survives above 50‰, *A. antarctica* is found up to 60‰, and *H. uninervis* up to 62‰. *Amphibolus antarctica* has maximum biomass and productivity in slightly hypersaline conditions of 40–50‰ (Walker 1985), which are also correlated with maximum light intensities (Walker and McComb 1988). The productivity of *P. australis* is approximately half that of *A. antarctica.*

These extensive seagrass meadows have an important influence on current flow, deposition of sediments and nutrient levels in Shark Bay. Dense stands of seagrass can slow the rate of water flow over the substrate (Walker 1990) and reduce the height of waves (Logan and Cebulski 1970). Sediments accumulate more rapidly in the Shark Bay seagrass meadows than in those around coral reefs. This is due to the rapid rate of leaf turnover and also because of the large quantities of epiphytes associated with these leaves. Sedimentary banks, such as Faure Sill and Wooramel Bank, developed in this manner, and subsequently affected water circulation and mixing. This eventually resulted in the increases in salinity in the southern parts of the Bay. Phosphorus is depleted in Shark Bay due to reduced mixing of waters in the Bay with oceanic water, but seagrasses are an important alternative source of phosphorus. This is mainly via breakdown products in the detritus, but to a small extent to fauna that feed directly on them including dugongs, turtles, some crustaceans and some fish.

Evidently, seagrasses have a profound effect on the geological, chemical and biological aspects of Shark Bay and, over the long-term, have modified the whole system (Walker 1990).

Despite the dominance of seagrasses in Shark Bay, marine algae are an important part of the ecosystem, with 153 species recorded from this region (Huisman *et al.* 1990). Macroalgae are found on the extensive sandflats in the shallows, subtidal rock platforms, as epiphytes on other algae, seagrasses and mangroves, and as drift algae. Species richness decreases in the hypersaline regions. Tropical algal species are dominant in the Bay, with around 67% red algae, 18% green algae and 15% brown algae. Red algae are small, mainly epiphytic species, and green algae are most abundant comprising mainly of *Penicillus nodulosus* and *Polyphysa peniculus.* In high salinity areas the brown algae *Hormophysa cuneiformis* and *Dictyota furcellata* are common, along with the green algae *Polyphysa peniculus.*

Both *Amphibolis* and *Posidonia* beds have diverse and abundant invertebrate benthic fauna (115 and 97 species respectively) consisting mainly of crustaceans, molluscs and polychaetes (Wells *et al.* 1985). There is little difference between the communities inhabiting the two types of seagrass. Both are dominated by epifaunal and epibiotic species, with only a small component of infauna. Small gastropods, especially *Clypeomorus* species, dominate the seagrass habitats (Black *et al.* 1990). Black *et al.* (1990) also recorded small numbers of holothurians, ascidians and echinoids in these habitats.

Surveys of the fish fauna in seagrass meadows in South Passage and Blind Strait, Freycinet Reach and Freycinet Harbour, and four sites around the Peron Peninsula by Hutchins in 1990, recorded only 56 species. This is markedly less diverse than the 323 species recorded from Bernier and Dorre Islands. However, seagrass meadows provide important cover and nutrients for many fish species. Black *et al.* (1990) recorded 50 fish species from Monkey Mia, and found diversity slightly greater in seagrass beds than over bare sand.

Seagrass and soft sediment habitats are key nursery habitats for prawns, particularly brown tiger prawns for which the juvenile phases are closely associated with seagrass, and/or algal beds. The western king prawn has a preference for sandy/muddy sediments in inshore sheltered waters. Scallop grounds are not associated with seagrass beds.

2.7.2 Hypersaline environments

The permanent hypersaline conditions and the associated biota in the southern reaches of Shark Bay are one of the major factors used in nominating the region for World Heritage Property status. Numerous stromatolites, algal mats and flourishing populations of *Fragum erugatum* have developed in and around Hamelin Pool due to the extreme hypersaline conditions that have arisen there. These species can easily tolerate the elevated salinities, but neither their predators not their competitors can.

Surprisingly, a small number of other marine species can withstand such elevated salinities. Few seagrasses can survive in Hamelin Pool, but *Amphibolus antarctica* can survive in salinities up to 60‰ and *Halodule uninervis* up to 62‰. Some brown and green algae can also survive in these conditions. Some small crustaceans such as copepods are found in the hypersaline habitats. A relatively large number of molluscs have been recorded from hypersaline waters. Slack-Smith (1990), observed bivalve distribution patterns that show an apparent link with salinity gradients. Out of 204 species of bivalves within Shark Bay, 184 species were from oceanic salinities, 134 from the Cape Peron salinocline, 129 from metahaline waters, 53 from the Faure salinocline and 9 from hypersaline regions. Fish diversity is very low in hypersaline waters. Lenanton (1977) recorded only six fish species in Hamelin Pool.

2.7.3 Rocky shores and coral reefs

The western margins of Dirk Hartog, Bernier and Dorre Islands, and the Zuytdorp Cliffs are largely rocky limestone shores with shallow intertidal platform reefs. The eastern shores of the islands and the southern edges of south passage have more varied habitat with narrow patches of limestone reef and intertidal platform reef, interspersed with sandy areas, plus seagrass patches close into shore. There are also small patches of rocky reef on the Peron Peninsula and Heirisson Prong.

These rocky substrates are the sites of hard coral communities, with the most prolific and diverse in South Passage, with decreasing diversity on the east coasts of Bernier and Dorre Islands, and very few species on Dirk Hartog Island and the north end of the Peron Peninsula. The coral fauna on the east coasts of the three islands is more diverse and more extensive than that on the west coasts, possibly because the west coasts are more exposed.

Around 126 species of hard corals have been recorded for Shark Bay (Veron and Marsh 1988, Marsh 1990, Marsh 1995), which is depauperate compared with that of Ningaloo Reef (214 species) and the Houtman Abrolhos Islands (201 species). Of the Shark Bay species, 120 are hermatypic and 6 are non-hermatypic. The hermatypic corals are mainly tropical species and are largely restricted to regions with oceanic salinity, but some are found in the metahaline zone in Freycinet Reach. Environmental conditions in Shark Bay are not suitable for the development of extensive coral reefs.

Other invertebrate phyla, including crustaceans, molluscs and echinoderms, are found associated with these hard substrate habitats, attracted by their structural complexity.

Decapod crustaceans are diverse in Shark Bay with some species in large numbers. Approximately 232 decapod crustacean species have been recorded in these habitats for the region. Barnacle diversity and abundance is greatest around the east coasts of Bernier and Dorre Islands. The total number of barnacle species recorded from Shark Bay is 40 (Jones 1995).

A survey by Slack-Smith and Bryce (1995) found that the molluscan fauna of Bernier and Dorre Islands is diverse and abundant. Of the 425 species recorded, 7 were chitons, 275 gastropods and 143 were bivalves. The greatest diversity is along the eastern coast of Bernier Island, but Dorre Island has a slightly higher overall diversity. However, the molluscan diversity is less than that found at both Ningaloo Reef and the Houtman Abrolhos.

Approximately 135 species of echinoderms have been found in Shark Bay, of which 82 species have been recorded from Dorre and Bernier Islands (Marsh 1995). The echinoderm diversity was slightly greater on the eastern coasts than the western coasts of these islands. Most echinoderms from Shark Bay are confined to oceanic or near oceanic salinities, with very few found south of the Cape Peron salinocline. Overall, Shark Bay has a rich echinoderm fauna that is zoogeographically intermediate between Ningaloo and the Houtman Abrolhos.

A rich fish fauna is attracted to the complex habitats on these rocky substrates, with a total of 323 species recorded for South Passage and 300 species for Bernier and Dorre Islands (Hutchins 1995). The fish fauna was richer on the eastern coasts than the western coasts and the fauna of Bernier Island was slightly more diverse than at Dorre Island. The richest areas were reefs with high coral diversity. The composition of the fish fauna of Bernier and Dorre Islands is similar to that of Point Quobba and South Passage. The most diverse families being the wrasses, gobies, damselfish, blennies, rock cods, butterfly fish, cardinal fish, trevallies and parrotfish. There is a reduction in the number of tropical species, and an increase in the number of temperate species from Point Quobba to South Passage. South Passage appears to be the most southerly mainland region that supports a rich diversity of tropical fish species.

Surveys of the rocky habitats however, are incomplete and many major phyla, including sponges, worms and ascidians have not been studied. A summary of species numbers and affinities of the phyla of Bernier and Dorre Islands surveyed by the Western Australian Museum in 1995 are given in Table 1 (Hutchins *et al.* 1995). These data demonstrate that the faunal groups are dominated by tropical species (70–89%), with small proportions of temperate (4–25%), and endemic species (5–18%).

Table 1. Species collected at Bernier and Dorre Islands (from Hutchins et al. 1995).

Phylum	Total No: species	Tropical species	Temperate species	Endemic species
Decapod crustaceans	232	86%	7%	7%
Barnacles	40	70%	25%	5%
Molluscs	374	83%	7%	10%
Echinoderms	76	74%	8%	18%
Fish S. Passage	323	83%	11%	6%
Fish Bernier & Dorre	300	89%	4%	7%

2.7.4 Sandflats and mangroves

Intertidal sandflats and beaches are extensive in Shark Bay. The upper reaches of the intertidal zone is an extremely exposed and harsh habitat, being subject to very hot temperatures and strong winds much of the time, and is dry for lengthy periods, and consequently is depauperate in all phyla. The lower reaches of the intertidal zone however, have a diverse collection of invertebrates, especially molluscs.

There are thick stands of mangroves between the Gascoyne River and Long Point, but further south the density declines as salinity increases. Small pockets of mangroves occur on the Peron Peninsula, Faure Island and south shore of South Passage. There are distinct zones, with mudflats on the seaward edge, a central monospecific band of mangroves (*Avicennia marina*) and landward saltflats mostly covered with dense samphire. The fauna of Shark Bay mangroves has not been extensively studied, but it is likely to be similar to other mangroves with abundant and diverse invertebrates especially molluscs and crustaceans. The diversity, biomass and abundance of invertebrates generally decreases with zones further away from the water. It has been suggested that the diversity of invertebrates in Shark Bay mangroves is less than in Exmouth Gulf (Johnstone 1990).

Intertidal sandy beaches provide important nesting sites for the two species of turtle commonly seen in Shark Bay, the green turtle, *Chelonia mydas*, and the loggerhead, *Caretta caretta*. Loggerhead turtles nest on the northern tip of Dirk Hartog Island (in the summer months), which is thought to be the major nesting area for this species in Western Australia. Small numbers of green turtles nest on Bernier and Dorre Islands, and on Peron Peninsula.

2.7.5 Soft sediments

The subtidal seabed in the central northern and western regions of Shark Bay embayment consists of soft silty sands (DEP and URS 2001). This substrate is populated by a diverse array of sponges, octocorals and associated invertebrates, plus infaunal species. However, this habitat has not been well studied.

Observations from field notes taken by Marsh (1975) indicate that the central northern regions of the Bay approximately 28 km WSW of Carnarvon were populated by numerous, very large sponge colonies in 1975.

Soft sediments are unsuitable habitats for most hard corals, although a small number of coral patches and bommies are scattered irregularly throughout this zone, and also some solitary fungiids, *Cycloseris cyclolites* and *Diaseris fragilis*, and small colonies of the ahermatypic *Cyphastrea* and *Turbinaria* species (Marsh 1990, Marsh 1995).

Many crustaceans prefer soft sediments, especially prawns, shrimps and crabs including the commercially important prawn species, the tiger prawn *Penaeus esculentus*, king prawn *Penaeus latisulcatus,* endeavour prawn *Metapenaeus endeavouri*, coral prawn *Metapenaeus crassissima,* and some portunid crabs including the blue swimmer *Portunus pelagicus* and coral crab *Charybdis feriata,* parthenopids, pebble crabs, slipper lobsters and grotesque crabs.

Some mollusc species, such as the commercially important saucer scallop *Amusium balloti*, live on the surface of soft sediments; others are semi-infaunal including some bivalves and gastropods (Slack-Smith and Bryce 1995). The infaunal habitat is dominated by diverse and numerous bivalve species.

The soft sediments are populated by certain echinoderm species, including brittle stars in the family Amphiuridae, echinoids in the families Temnopleuridae, Laganidae, Astriclypeidae and Loveniidae, and the holothurians *Cercodemas anceps*, *Colochirus crassus* and *Colochirus quadrangularis.* Field notes taken by Marsh (1975) record several species of crinoids, asteroids, ophiuroids, holothurians and echinoids from the central northern regions of Shark Bay approximately 28 km WSW of Carnarvon. Most echinoderms prefer oceanic salinities, but the heart urchin *Breynia desorii* is found in the metahaline waters of Freycinet Harbour.

Few fish species have been found to live permanently in the soft, sandy substrates of Shark Bay. From brief surveys around Denham it was found that the diversity of fish fauna was very poor in the inner regions of the Bay compared with South Passage (Hutchins 1990). Unfortunately, no surveys have thoroughly examined the embayment regions of Shark Bay where commercial trawling is most active.

2.7.6 Open water

Kimmerer *et al.* (1985) is the only comprehensive survey of the distribution of plankton across the salinity gradients found in Shark Bay. They found that the total diversity of plankton species decreases from oceanic salinities to intermediate salinities, and drops to very low levels in the most hypersaline southern reaches of the Bay. The phytoplankton communities are distinct, with high diversity in the outer oceanic areas, reducing to communities dominated by diatoms in the intermediate salinities, and in Hamelin Pool mainly dinoflagellates. Zooplankton have an unusual pattern of abundance, with a greater abundance in intermediate salinities than in oceanic waters, but a dramatic decrease in the most hypersaline regions. The abundance of some species is limited by intolerance to high salinities, but scarcity of nutrients in the most hypersaline waters is also thought to be a major limiting factor.

The abundant marine megafauna in Shark Bay is another factor used in the nomination for World Heritage Property. Megafauna are generally found in open water and are not associated with any one habitat.

The large number of the dugong, *Dugong dugon*, in Shark Bay is of world-wide significance, with the population being estimated to exceed 10,000 (Preen *et al.* 1997).

The dugong is widespread in the Bay and relies on seagrasses for its most of its diet. It is thought that the seasonal movement of the dugongs in the Bay from the cooler, shallow waters of the Faure Sill and southern parts of the Bay in summer, to warmer deeper waters further north and west in winter, is to avoid waters cooler than 18°C.

Seven species of marine mammals besides the dugong have been recorded from Shark Bay (Baynes 1990, Preen *et al.* 1997). The most common species being the bottlenose dolphin, *Tursiops truncatus*, is frequently encountered on the beach at Monkey Mia. A population of 2,000 to 3,000 dolphins has been estimated for Shark Bay (Preen *et al.* 1997). The humpback whale, *Megaptera novaeangliae*, was hunted from 1912 to 1962 between Point Cloates and Carnarvon. The population was reduced to around 800, but they are now making a steady recovery (Preen *et al.* 1997). Southern Right Whales, *Eubalaena australis*, are occasionally sighted within the Bay. Other whales recorded from the Bay include the killer whale *Orcinus orca*, the pygmy sperm whale *Kogia breviceps*, a beaked whale Ziphiidae, and a pilot whale *Globicephala* sp.

Seven species of sea snake have been recorded for Shark Bay (Storr *et al.* 2002). Two species, the bar-bellied sea snake *Hydrophis elegans* and the olive-headed sea snake *Disteira major*, are very common throughout the Bay, and the Shark Bay sea snake *Aipysurus pooleorum* is endemic to Shark Bay, where it is common. Occasionally individuals of the golden sea snake *Aipysurus laevis*, the spotted sea snake *Hydrophis ocellatus*, the southern mud snake *Ephalophis greyae*, and the yellow-bellied sea snake *Pelamis platura* are found in Shark Bay. Sea snakes feed almost entirely on fish.

Only two species of marine turtle are regularly seen in Shark Bay, the green turtle, *Chelonia mydas*, and the loggerhead, *Caretta caretta*. Green turtles are the most common species with a population exceeding 8,400 in winter 1994 (Preen *et al.* 1997). These turtle species generally avoid water that is cooler than 18°C.

2.8 Shark Bay prawn and scallop managed fisheries

The fishery lies between 23° 34'S and 26° 30'S adjacent to the Western Australian coast (Figure 1) and the fishery extends to waters to a depth of 200m although both prawn and scallop fishing fleets operate within the bay only.

The Shark Bay prawn managed fishery (SBPMF) is the largest prawn fishery in Western Australia with an annual value around $35 million. The Shark Bay scallop managed fishery (SBSMF), due to highly variable recruitment between years has, during its history been the most productive fishery in the state. Both fisheries contribute substantially to the regional and state economy through provision of employment directly in fishing activities and down stream processing and services both in Carnarvon and Fremantle.

2.8.1 History

The first report of commercial quantities of prawns in Shark Bay was made by C.F. Gale, the Chief Inspector of Fisheries to both Houses of Parliament in the State's first fisheries resource survey (Gale, 1905). Gale was reporting on part of the survey carried out by the Rip the previous year when six tows were conducted east of Bernier Island during early June. W.C. Oxley wrote in the report:

> "Fairly large quantities of prawns were brought up with the trawl, which being of a large mesh, was thoroughly unsuitable for catching prawns, many therefore escaping. With a properly constructed net, I have every reason to believe that paying quantities could be obtained."

Although Oxley ordered the construction of a set of prawning gear for one of the fishing vessels operating in Shark Bay, nothing came of the venture.

It was not until May 1960 that commercial trawling commenced in Shark Bay when the Australian Pearling Company, in an attempt to recoup pearl shell losses, diversified into trawling for prawns with three converted pearl luggers and a Queensland prawn trawler. In the early days of the fishery, prawns were landed at Monkey Mia on the eastern side of Peron Peninsula (Fry 1988). The commercial trawl fleet grew to 35 prawn vessels by 1975. Trawlers first started fishing specifically for scallops in 1969 (Joll 1989). By 1983 the number of scallop trawlers had grown to 26. The implementation of management measures has reduced effort by decreasing the scallop fleet to 14 vessels in 1984. Similarly, the prawn fleet, which takes scallops as a secondary target species, was reduced to 27 vessels in 1990.

Inclusively from 1993 to 1997, the total annual effort has averaged 56,969 hours and 21,754 hours for the prawn and scallop fleets respectively.

2.8.2 Operational aspects and trawl gear

The Shark Bay Prawn Managed Fishery and the Shark Bay Scallop Managed Fishery are two discrete yet closely related fisheries. The scallop fleet is divided into two groups - dedicated scallop boats and prawn trawlers who also have a licence to catch scallops (*Amusium balloti*). The prawn fishery in Shark Bay is a nocturnal fishery restricted to fishing between 1700 and 0800 hours. Trawling ceases around the period of the full moon for 3 to 7 days when prawns tend to bury themselves in sediment making trawling uneconomical. The scallop trawlers (Class A) have no moon period or daily restrictions on fishing times and generally fishing takes place over 24 hours.

The boats trawl in the bay from approximately April until November, with the opening dates for each fishery set each year to optimise catch value. Scallop-only boats (Class A) use a codend minimum mesh size of no less than 100mm to limit their catch to scallops. Class B boats (prawn and scallop) use codend mesh not more than 60mm. The prawn and scallop trawlers tow twin 14.75m and 12.9m headrope flat nets respectively. Scallop boats have a maximum of two otter board of dimensions no greater than 2.29m long by 0.91m high whilst prawn boats have a maximum of two otter board of dimensions no greater than 2.44m long by 0.91m high. All trawlers are allowed a maximum of one ground chain per net with a maximum link size of 10mm. Tickler chains are not permitted.

2.8.3 Catch and value of the fishery

Catches of prawns have averaged 1,900 tonnes and scallops 600 tonnes over the last five years. This represents an average catch value from both fleets of approximately $45 million per annum and is a significant input to the local economy of Shark Bay, and to Western Australia in general. With maximum crewing levels set at 13 for each scallop trawler, six for each prawn trawler, and in combination with staff involved in processing and fleet maintenance work, the trawl fishing industry of Shark Bay makes an important contribution to employment opportunities within the Gascoyne Region.

2.8.4 Management and closure system

Management of the SBPMF is based on the maintenance of breeding stocks, particularly those of the more vulnerable tiger prawns which have been shown to be susceptible to overfishing (Penn *et al*. 1997). A series of seasonal and spatial closures exist within the fishery. The closures have a number of purposes including protection of important nursery areas, to allow for fishing of prawns as they reach optimal marketable size, and to protect breeding stocks. There are several areas permanently closed to trawling (Figure 4). These are the permanent nursery areas (3) designated in the Management Plan, as well as the Sanctuary Zones and some of the Special Purposes Zones of the Marine Park. In addition, industry has incorporated a voluntary closure area in Denham Sound (Figure 4). Approximately 9,300km² of the Bay, comprising recreational fishing, reef observation and permanent nursery areas are closed to all trawling.

Two main areas that have seasonal openings for the prawn fishery are; i) Denham Sound which is open to fishing between early March and mid April (above the Torbay line only), this fishing period allows the harvest of mainly residual prawns from the previous season from this area. This area closes mid April until around 1 August when the area re-opens (including area south of the Torbay Line) until the end of the fishing season which is normally around end of October/early November. During this period, newly recruited prawns are harvested. ii) Carnarvon-Peron Line and Extended Nursery Area (ENA) on the eastern side of Shark Bay remains closed until mid-April to provide protection to recruiting prawns from the southern portions of the eastern gulf. This area is then opened between mid-April to 1 August to allow the harvesting of newly recruited prawns. This area provides the peak catches of prawns for the fishery. Both king and tiger prawns are harvested during this period. In the northern portion of the Carnarvon-Peron Line is the main tiger prawn spawning areas (Figure 4). These areas are closed to fishing when a threshold catch rate is reached, usually sometime in June/July.

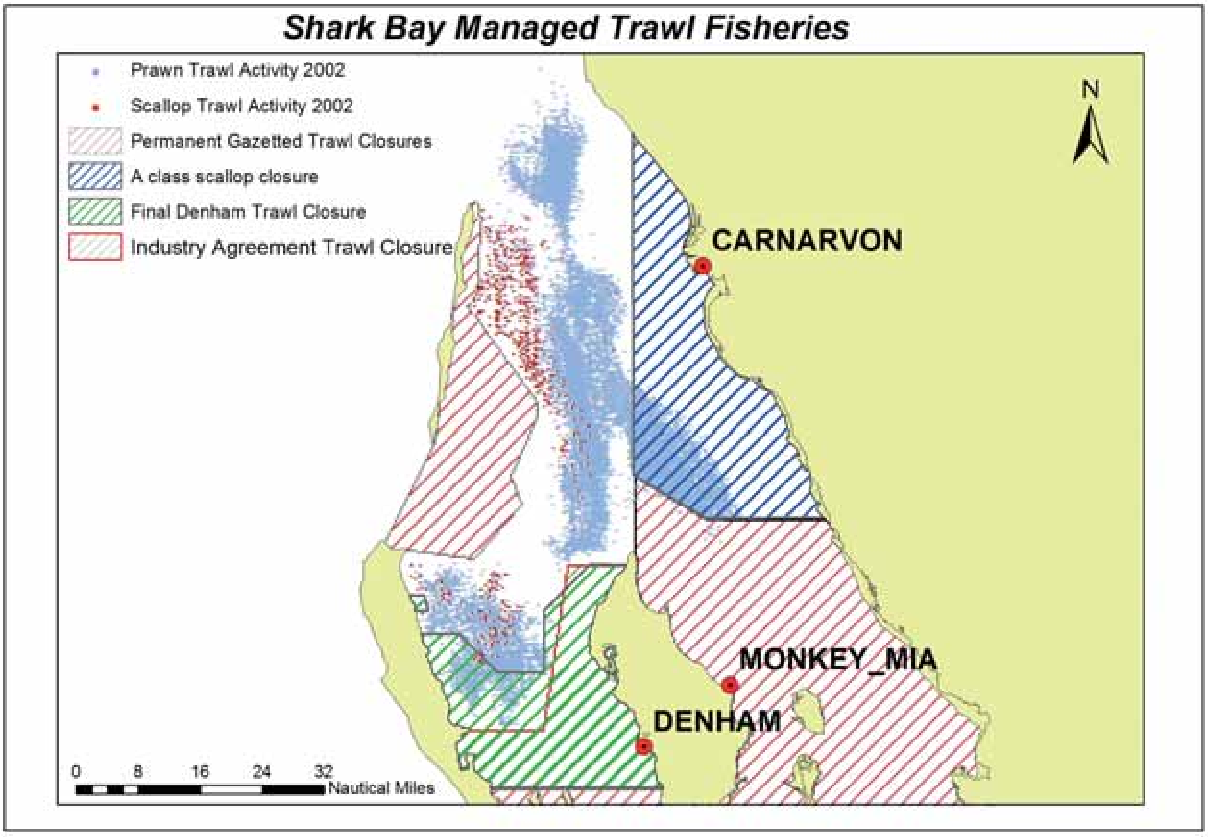

Figure 4. Shark Bay showing closure areas for the prawn and scallop trawl fisheries and areas of trawl activity in 2002. Scallop trawlers cannot fish east of the line running directly north from North West Peron (-).

For the SBSMF, although a spawning stock recruitment relationship has not been shown for the saucer scallop, management is still aimed at optimising catch whilst maintaining sufficient spawning stock to ensure subsequent recruitment under normal environmental conditions. In Shark Bay, the period of fishing coincides with the spawning period and the timing of the fishery (start of the season) is therefore determined through an annual pre-season survey that provides an index of recruitment and residual stock. The commencement date is based on the balance between stock abundance and scallop size which results in some spawning taking place prior to fishing commencing (Harris *et al*.1990).

Fishing can take place west of a line running directly north Peron Peninsula in all areas not permanently closed to trawling. During the last three years, the Denham Sound area has also been fished by the scallop fleet for between 3 and 10 days each year (in May). The scallop boats have been restricted to fishing north of the Torbay Line and scallop boats also maintain the voluntary industry closure on the eastern side of Denham Sound (Figure 4).

For both the prawn and scallop boats, in addition to seasonal and spatial closures, the implementation of bycatch reduction gear (grids for both scallop and prawn boats and secondary devices for prawn boats) reduce bycatch retention.

2.8.5 Overall swept area and spatial pattern of effort

Approximately 2,150km^2 or 40% of about 5,300km^2 available for trawling in the World Heritage area of the bay are trawled (Figure 4). The average trawl speed for the prawn fleet is estimated at about 4 knots and for the scallop fleet it is approximately 3 knots. From nominal effort data and an estimated width of the swept path the annual average swept area for the prawn fleet is 7,300km^2 and for the scallop fleet is 1,860km^2. However, effort tends to be concentrated in certain areas of the bay, and it must be emphasised that due to the amount of overlapping of trawl activity, the actual area of the bay subjected to trawling would be much smaller with some areas being swept over numerous times whilst others relatively less.

3.0 EXMOUTH GULF

3.1 Location

Exmouth Gulf is located in the northwest of Western Australia, immediately east of the Cape Range Peninsula (Figure 5) approximately 1100 km north of Perth. The Gulf is a marine embayment open to the north covering approximately 2,200 km^2 (White 1975) extending approximately 40km east west and 80km north south. The Cape Range Peninsula on the western margin, with a maximum elevation of 300 m, offers limited protection from westerly winds. The southern and eastern land margins are lower-lying and slope gently down towards the Gulf. North and South Muiron Islands are located approximately 17 km off the northeast tip of North West Cape at the head of the Gulf.

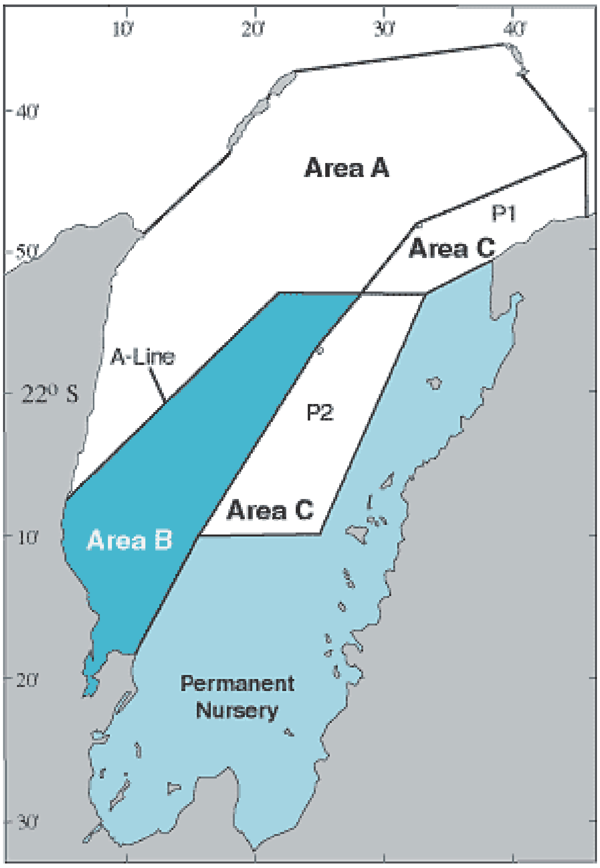

Figure 5. Exmouth Gulf Prawn Fishery area.

3.2 Geomorphology

Exmouth Gulf is in the Carnarvon Basin geological province (Playford *et al.* 1975). The Miocene and Pleistocene limestone that make up the Cape Range Peninsula were derived from marine sediments. The soft limestone has subsequently been eroded by weathering, resulting in numerous caves containing stygofauna along the Range, and a large coastal plain around the Peninsula. Consequently the western shores of the Gulf are predominantly sandy beaches and sandy shallow subtidal regions, overlying limestone pavement, with a few small rocky outcrops. There are narrow bands of coral reef at the northern end (Bundegi Reef to just south of Exmouth) and near the southern end (Point Lefroy and Roberts Island) of the western shores. In contrast, extensive muddy salt flats up to 10 km wide border the southern and eastern shores of the Gulf and are intersected by numerous tidal channels (McCook *et al.* 1995). The intertidal mudflats are lined with dense stands of mangroves, mainly *Avicennia* and *Rhizophora* species that make up one of the largest mangals in Western Australia (Wilson 1994). Small areas of beach rock are present, especially on the western sides of the larger islands and Tubridgi Point (Hutchins *et al.* 1996). The smaller islands in the northern section of the Gulf are mostly sandcays overlying limestone pavement, except for the Muiron Islands (an extension of the North West Cape) and Serrurier Island, which are composed of limestone overlain with some dunes and more recent sediments. The majority of these islands are surrounded by coral reefs.

Limited information is available on the composition of the seabed in the deeper subtidal regions of the Gulf. White (1975) took a small number of dredge samples in the Gulf. He found that the floor of the Gulf has red, terrigenous sediments that were probably transported there by wind and flooding events. The northern part of the Gulf past Y Island has coarser sediments, and the fine silt from it has become suspended in the Gulf waters giving them their characteristic cloudy appearance. Environmental studies conducted on behalf of oil exploration work (LeProvost *et al.* 1988), have found that sites in the northwest region of the Gulf between 22 and 23 metres deep have coarse-grained sand with a lesser amount of sediment, and some loosely packed calcareous gravel on top.

3.3 Climate

Exmouth Gulf lies in a hot, sub-tropical, semi-arid region. The summer (November to March) mean daily air temperature range is from 18 – 38°C, while the winter (May to August) range is from 11 – 28°C (Bureau of Meteorology 2002).

Rainfall is extremely low with an annual average for Exmouth of 270.7 mm and a mean number of 26.5 days of rainfall per annum (Bureau of Meteorology 2002). The rainfall is also highly variable with most occurring in the earlier months (February-March) of the ‘wet’ season (January-July), with a summer mean maximum of 45.6 mm for the month of February. The mean monthly maximum is only 2.1 mm for September and October. The heaviest falls are associated with thunderstorms or cyclones, which are common between February and March (Logan *et al.* 1976), and usually cause flooding, particularly in the low-lying salt flats.

The prevailing winds are southerly, generally with south to southeast winds in the mornings and, in the summer, south to southwest sea breezes in the afternoons. Mean wind speeds range between 18 – 25.3 km/hr in summer, and 10.7 – 18.3 km/hr in winter (Bureau of Meteorology 2002). Additionally, tropical cyclones occur in Exmouth Gulf in some years with winds tending to be strong north to north-easterly, with wind speeds up to 75 – 110 km/hr, gusting up to 180 km/hr (White 1975). The strongest cyclone to hit Exmouth Gulf was cyclone Vance in March 1999. Record Australian mainland wind speed gusts of up to 267 km/hr were recorded at Learmonth weather station 35 km south of Exmouth (Bureau of Meteorology 2002). Evidently, in some years, extensive storm damage can occur in the Gulf, with very high seas and tides that cause severe erosion of sediments and seagrass/algal beds.

3.4 Oceanography

Water depth ranges from around 5 m along the gradually sloping southern and eastern shores to around 20 m towards the northern and western regions of the Gulf. There are usually two tides per day in Exmouth Gulf with a mean tidal range of 1.5 – 2.1 m (Harris 2000). The range increases towards the head of the Gulf, with a maximum range of 2.5 metres. Tides can be strong, with currents between 0.5 – 0.65 m/s recorded for deep water during spring tides, and 0.5 – 0.1 m/s recorded for shallow regions (LeProvost *et al.* 1988). The channel between North West Cape and South Muiron Island has had currents up to 2.0 m/s during spring tides (Apache Energy 1988).

The north and north eastern part of the Gulf can be affected by swells from the Indian Ocean. The main body of the Gulf, however, is dominated by local wind action. The prevailing southerly winds generally only result in small waves of less than 2 m in height, with a short period of 1 – 10 secs (Apache Energy 1988).

The warm Leeuwin Current flows strongly southward during the winter months, and is clearly delineated at the Muiron Islands (Hatcher 1991). It can therefore affect the offshore waters of the Gulf in this period. This warm current maintains elevated water temperatures, depressed levels of dissolved nutrients and particle concentrations, and inhibits the growth of macroalgae (Hatcher 1991). Consequently fisheries production in such waters relies on nutrient sources from benthic habitats in near-shore waters, rather than from oceanic ecosystems (Lenanton *et al.* 1991).

There is a band of hypersaline water (35 – 55‰) around the eastern and south eastern sublittoral zone, which is up to 3km in width on the eastern shores (Harris 2000). The rest of the Gulf is of oceanic salinity (35‰). There is little freshwater run-off, or river flow into the Gulf during the dry winter months. However, during summer when severe tropical cyclones occur, the heavy rainfall results in freshwater runoff that reduces salinity and increases turbidity in the Gulf. The Ashburton River to the northeast of the Gulf discharges large volumes of water during flooding and may affect the Gulf temporarily (Wilson 1994). Strong winds associated with cyclonic weather also increase wave action that mixes water and further increases turbidity in the Gulf. Low pressures can cause local flooding from tidal surges (Penn and Caputi 1986).

3.5 Biological environment

Exmouth Gulf is at the southern end of a zoogeographic region known as the Northern Australian region (Wilson and Allen 1987). The majority of the flora and fauna is tropical, but some subtropical and temperate species are present in the Gulf (Hutchins 1994).

Few studies have been carried out on the marine fauna of Exmouth Gulf besides those species commercially fished. Wells (1983) investigated the mangrove molluscs at the head of the Gulf, Hutchins (1994) studied the reef fish fauna of the Muiron Islands, and the Western Australian Museum (Hutchins *et al.* 1996) surveyed some of the major phyla of the Muiron Islands and the eastern shores of the Gulf.

The flora and fauna of Exmouth Gulf will be discussed within the following major habitats:

1. Seagrasses, marine algae and sediment areas.
2. Hypersaline environments, mudflats and mangroves.
3. Rocky shores and coral reefs.
4. Soft sediments.
5. Open water.

3.5.1 Seagrasses, marine algae and sediment areas

Only two surveys on the seagrasses of Exmouth Gulf have been published to date (Walker and Prince 1987; McCook *et al.* 1995). In contrast to Shark Bay, seagrasses in Exmouth Gulf are in very low abundance. Seagrasses where present, rarely exceeded 5% cover, and are rare or absent below 5 metres (McCook *et al.* 1995). The shallows, especially in the southern regions of the Gulf, have very little vegetation and some areas are completely bare and consist only of sand or gravel (sometimes with a thin layer of cyanobacteria on the surface).

McCook *et al.* (1995) found sparse beds of *Cymodoce serrulata* and *C. angustata* with some *Halophila ovalis*, *H. spinulosa*, *Syringodium isoetifolium* and *Halodule* sp. in the central eastern shallows, with cover increasing to over 5% at the northern end of Tent Island. Small quantities of algae such as *Caulerpa*, *Halimeda*, *Udotea* and *Penicillus* also occur mixed in with these seagrass beds. Slightly more extensive beds of *Halodule* sp. with mean cover of 21%, are found in the same area, but were quite limited in their extent. Additionally, large quantities of algae are frequently found attached to, or tangled up with the seagrasses. These include filamentous turfs, ephemeral epiphytes such as *Hydroclathrus*, *Padina*, *Sporochnus*, *Dictyota*, *Asparagopsis*, and perennial macrophytes such as *Sargassum* spp. In some places, particularly the central eastern coast, the cover and biomass of these algae exceed that of the seagrasses. Large amounts of drift algae are also common throughout the Gulf.

On the west coast there is a more patchy distribution of seagrasses, including *Halophila* spp., *Cymodocea* spp. and *Thalassodendron ciliatum*, with none occurring below 8 m. Some brown algae such as *Sargassum* spp., are present down to 10 m.

The shallows in the southern end of the Gulf are largely bare sandy substrate with very sparse patches of seagrass (*Cymodocea* and *Halophila*) and small quantities of *Sargassum* where hard substrates occur.

The surveys by McCook *et al.* (1995) indicate that seagrasses are restricted to the shallow areas of the Gulf with very little deeper than 10 m. Some of the northern areas of the Gulf are unsurveyed and possibly have greater cover of seagrasses. They postulate that the low abundance of seagrasses in Exmouth Gulf is due to a lack of suitable substrate, as much of it is either hard substrate or extremely mobile, coarse sediments. It is unlikely that salinity is a limiting factor because many seagrasses can tolerate the elevated salinities recorded in the Gulf, and low nutrient levels are unlikely to be a limiting factor because seagrasses do not require abundant nutrients. Additionally, trawling cannot be the cause as trawling is restricted from these areas.

Between 1999 and 2001, CSIRO as part of a FRDC funded project on stock enhancement in Exmouth Gulf (FRDC 1998/222), undertook surveys or seagrass and algal communities in the gulf. The initial survey in 1999 took place after Cyclone Vance passed through the middle of the gulf. The final report is currently in preparation but the surveys indicated very low seagrass/algal abundance in any area after the cyclone and subsequent recovery of seagrass beds to 60-80% cover by 2001. A succession process was evident with high abundance of colonising seagrass/algal species and low abundance of more mature species. Continued monitoring of seagrass recovery will be undertaken by Department of Fisheries and industry in 2002/03. The seagrass abundances and extent of distribution recorded by CSIRO appear to be higher and more widely distributed than those documented by McCook *et al.* 1995.

Seagrass and algal habitats are key nursery areas for the brown tiger prawn (*Penaeus esculentus).* The loss of seagrass/algal habitat when Cyclone Vance passed through the gulf resulted in early 1999 in a recruitment failure of tiger prawns in the following year (2000) highlighting the dependence of tiger prawns on structured nursery habitats.

3.5.2 Hypersaline environments, mudflats and mangroves

Hypersaline conditions that occur in the eastern and south eastern sublittoral zones of Exmouth Gulf are markedly different from those in Shark Bay in three respects. Firstly, the salinity is not so extreme, reaching a maximum of around 55‰, compared with 70‰ in Shark Bay, secondly hypersalinity is not permanent because the shores are flooded with fresh water run-off during summer cyclones, and thirdly the area affected by hypersaline water is not so extensive as in Shark Bay, only covering a narrow sublittoral band that has a maximum width of approximately 3km in Exmouth Gulf.

The Western Australian Museum survey (Hutchins *et al.* 1996) found that intertidal and subtidal regions on the eastern shores of Exmouth Gulf (i.e. mainly the environments seasonally subject to hypersaline conditions, and adjacent to mudflats and mangroves) were less diverse in the faunal groups studied, namely octocorals, crustaceans, molluscs, echinoderms and fish. Octocorals and echinoderms were the most depauperate of the groups on the eastern shores, with less than 10% (9 to 10 species) of the diversity found at the Muiron Islands. Crustaceans and fish had 33 – 36% (12 and 114 species respectively) species diversity, compared with the Muiron Islands. Molluscs however, were the most diverse group with 62% (308 species) species diversity on the eastern shores. Although some species were common to both the Muiron Islands and the eastern shores of the Gulf, many species were different and the communities in the two regions were distinct, for example molluscs along the eastern shores are predominantly filter feeding bivalves, characteristic of fringing mangroves and mud flats. Other major phyla including sponges, hard corals and annelids were not studied in this survey. Sponges and hard corals are likely to follow similar distribution trends to the groups studied by Hutchins *et al.* (1996) but annelids could be more diverse along the eastern shores than around the Muiron Islands, since they are often abundant and diverse in soft sediments. The eastern shores of Exmouth Gulf have much in common with inshore regions of the Dampier Archipelago and the Kimberley further north, that have inter-tidal mudflats, mangrove communities, soft sediments and turbid waters. The overall lower diversity along the eastern shores of the Gulf is thought to be due to fewer habitat types available.

The mangrove stands are most extensive along the eastern shores of Exmouth Gulf, with some on the southern shores of Giralia Bay and Gales Bay, and a narrow, low zone on the western shore near Learmonth (Johnstone 1990). These areas are dominated by *Avicennia marina*, with *Rhizophora stylosa* in more sheltered locations, and a few low thickets of *Ceroiops* sp. and *Bruguiera* sp. (Johnstone 1990, Wyrwoll *et al.* 1993).

3.5.3 Rocky shores and coral reefs

Hard corals occur in a range of locations in Exmouth Gulf, including turbid inshore limestone pavement, fringing reefs around sand cays and offshore reefs in clear waters (Apache Energy 1998).

The most extensive inshore coral reefs occur at Bundegi Reef, just south of Point Murat on the northern end of western shores of the Gulf, where there is an extensive intertidal platform covered with silty sand. Subtidally there is a rich growth of hard corals, but only 28 species are recorded for the area (Veron and Marsh 1988). Less extensive inshore coral reef occurs at Point Lefroy between the Bay of rest and Gales Bay at the southern end of the western shores.

Many of the islands in the northern regions of the Gulf north of Tent Island have coral reefs around them. There are also patch reefs on the eastern side of the Gulf, but none of these reef systems have been thoroughly surveyed.

The clearer waters around the Muiron Islands however, support rich hard coral communities (Apache Energy 1998). Corals are more diverse on the protected eastern coasts than on the higher energy western coasts, and have distinct zones of faviids, *Acropora* and *Porites* species with increasing depth.

Associated with these coral reefs and rocky substrates of the Muiron Islands are diverse communities of fish and invertebrates. A survey by the Western Australian Museum (Hutchins *et al.* 1996) found a greater diversity of marine species at the Muiron Islands compared with the eastern regions of Exmouth Gulf, both intertidally and subtidally (Table 2). This applied to all groups studied; octocorals, barnacles, trapeziid crabs, molluscs, echinoderms and fish. The Muiron Islands have an ecosystem similar to that of Ningaloo Reef, with fauna that are found in clear waters with diverse coral reefs. A summary of the species numbers is given in the table below.

Table 2. Species collected at Muiron Islands and Eastern Shore of Exmouth Gulf (Hutchins et al. 1996).

Phylum	No: species at Muiron Islands	No: species on eastern shores	No: species common to both
Octocorals	112	10	4
Crustacea, barnacles	33	12	6
Crustacea, commensal crabs	12	0	0
Molluscs	495	308	150
Echinoderms	92	9	5
Fish	348	114	69

The majority of the species recorded in the Museum survey have tropical affinities, some are cosmopolitan, and only one temperate species (of fish) was found.

The diversity of molluscs from the Muiron Islands (495 species) is greater than that found around Bernier and Dorre Islands in Shark Bay (418 species), but is less than at the Montebello Islands (624 species). However, if species for all of Exmouth Gulf are compared (648 species), then diversity slightly exceeds that at the Monte Bellos (Slack-Smith *et al.* 1996).

The reef fish fauna of the Muiron Islands is also comparable in diversity with nearby regions, including the Monte Bello Islands, Ningaloo Reef, Coral Bay and Quobba, and Bernier and Dorre Islands (Hutchins 1995, Hutchins 2002). Hutchins (2002) combined species numbers for the Muiron Islands with other offshore West Pilbara Islands between North West Cape and Barrow Island, and found that this region has the most diverse reef fish fauna in coastal waters off Western Australia. However, such comparisons must be regarded with caution, since different survey techniques and amount of sampling effort varied.

3.5.4 Soft sediments

Limited information is available on the extent and type of soft sediment that covers a large part of the central seabed in Exmouth Gulf, or its associated fauna. Additionally, no published surveys have covered the benthic regions where commercial trawling is carried out. Apache Energy (1998) report that soft sediment regions above 20 m depth outside commercial trawl areas have extensive invertebrate communities, of which the most abundant are echinoderms including sand dollars, *Diadema* urchins, heart urchins and crinoids, plus some areas have abundant solitary corals. The channel between the Muiron Islands and North West Cape has only a thin veneer of coarse sediment overlying limestone pavement. This area is rich in gorgonians, sea whips, bryozoans, some hard corals, crinoids, ascidians and hydroids, but few fish species were recorded (Apache Energy 1998).

A Fisheries Research and Development Corporation project (2000/132) currently underway is describing the distribution and abundance of fish species caught by trawling during commercial operations and from survey sampling in closed nursery areas in Exmouth Gulf.

3.5.5 Open water

Large vertebrates including turtles, sea snakes, and marine mammals are found in the open waters of Exmouth Gulf.

Five species of marine turtles, the green (*Chelonia mydas*), flatback, (*Natator depressus*), loggerhead (*Caretta caretta*), hawksbill (*Eretmochelys imbricata*) and the leatherback (*Dermochelys coriacea*), are found in Exmouth Gulf (Storr and Hanlon 1980; Apache Energy 1998). The turtle population for Exmouth Gulf has been estimated to be between 3,200 and 4,500 (Preen *et al.* 1997). Important nesting sites for loggerhead, green and hawksbill turtles are found on the Muiron Islands. It is the main breeding site for loggerhead turtles, listed as endangered.

Ten species of seasnake occur in Exmouth Gulf: the short-nosed (*Aipysurus apraefrontalis*), Dubois's (*Aipysurus duboisii*), Eydoux's (*A. eydouxii*), golden (*A. laevis*), olive headed (*Disteira major*), Stoke's (*D. stokesii*), southern mud (*Ephalophis greyae*), bar-bellied (*Hydrophis elegans*), spotted (*H. ocellatus*) and the yellow-bellied (*Pelamis platura*) (Storr *et al.* 2002). Seasnakes are found throughout the Gulf, but are more common in the shallows of the eastern shores.

Fourteen species of marine mammal are found in the Exmouth Gulf region; dugong, four species of dolphin and nine species of whale (Preen *et al.* 1997). The dugong (*Dugong dugon*) population for Exmouth Gulf and Ningaloo Reef is estimated to be around 2,000, of which approximately half are in Exmouth Gulf. It is thought that dugongs move freely between Exmouth Gulf and Ningaloo Reef. They are usually found in proximity to seagrass beds, their main food source, in the northern reaches of the Gulf. It is thought that they may feed in different regions, depending on the water temperature, preferring to avoid the cooler waters below 18°C.

The humpback whale (*Megaptera novaeangliae*) is the only whale species commonly observed in the Gulf. It migrates to northern waters in winter to breed, then returns south in spring.

Two dolphin species, the bottle-nosed (*Tursiops truncatus*) and Indo-Pacific dolphin (*Sousa chinensis*) are often seen in the Gulf. Occasionally four other dolphin species, the common (*Delphinus delphis*), Risso's (*Grampus griseus*), spotted (*Stella attenuata*) and rough-toothed dolphin (*Steno bredanensis*) are also observed. The estimated total population of dolphins for Exmouth Gulf is between 300 and 500 (Preen *et al.* 1997).

Plankton make up an important part of the biota in open water. Few studies have been carried out on plankton in the north west of WA, including Exmouth Gulf. Tranter (1962) studied zooplankton biomass in Australian waters and found it to be low in comparison with other regions. However, plankton biomass reaches a maximum on the North West Shelf. Kimmerer *et al.* (1985) examined the abundance of coastal plankton in Shark Bay. It was not until 1996 that the Exmouth Gulf zooplankton were studied by McKinnon and Ayukai. They found that the greatest copepod egg production rates, concentrations of chlorophyll a, particulate carbon and nitrogen, and protozooplankton occurred in the southeast region of the Gulf. Since the Gulf is limited in nutrient supply, it indicates that the shallow coastal areas and fringing mangroves are likely to be important nutrient reservoirs, responsible for sustaining this zooplankton production.

3.6 Exmouth Gulf prawn managed fishery

Exmouth Gulf has the second largest prawn fishery in Western Australia (Sporer and Kangas, 2001) with an annual value between $7 and $12 million over the last five years.

3.6.1 History

Prawn trawling, with 12 converted rock lobster boats commenced in 1963 targeting schooling banana prawns (*Penaeus merguiensis*) during daylight hours (Penn *et al.* 1997). As the catch of banana prawns declined over the ensuing four years the trawl fleet transferred effort to night-time fishing on king (*Penaeus latisulcatus*), tiger (*Penaeus esculentus*) and endeavour prawns (*Metapenaeus endeavouri).* Annual nominal effort in the fishery gradually increased to about 50,000 hours trawled in the late 1970’s to the early 1980’s when a maximum of 23 trawlers operated in the fishery. In 1985 the number of trawlers was reduced to 17, to 16 in 1990, another boat was removed in 1998 and in 2000 two more were removed to 13 when boats changed to quad (four 4.5 fathom nets) gear. These 13 boats tow an equivalent headrope length (less 3 fathoms) to the previous 15 boats towing twin rig 7.5-fathom nets. The nominal effort in the fishery since 1980 has decreased from 52,710 hours to 30,773 hours in 2001.

3.6.2 Operational aspects and trawl gear

The Exmouth Gulf Prawn Managed Fishery (EGPMF) is a limited entry fishery (15 licenses) with currently 13 boats operating in the fishery. The fishery is closed seasonally between November and April to allow prawn recruits to grow. During the open season, trawling is only permitted between 1700 hours and 0800 hours except when banana prawns are available and daylight trawling can occur during this time. Trawl duration in this fishery is generally between one and three hours. Trawling ceases for 3 to 5 days around the period of the full moon each month when prawns tend to bury themselves in sediment making trawling less economical. Most boats are ‘wet’ boats with boats returning to port each day to unload their catch fresh. One boat is a freezer boat, snap freezing the prawns on board, either green or cooked. At least three boats (five in 2003) use a water-well system (hopper) to keep product alive prior to sorting and all unwanted catch goes back into the water along a conveyor belt. Pilot studies in Queensland and South Australia indicate these hopper systems are both beneficial in improved prawn quality and improved survival of some bycatch species (N. Gribble and N Carrick pers. comm.). Implementation of bycatch reduction devices (grids and secondary devices) into the fishery in 2002/03 will reduce the amount of bycatch retained by prawn boats.

Currently, trawling is undertaken using quad nets of 4.5-fathom headrope length for each net with two otter boards and a central skid between the two nets on each side. The mesh size of nets is approximately 45mm. The otter boards for each net have maximum dimension of 2.29m long by 0.91m high. A maximum of one ground chain and one tickler chain is permitted for each net with a maximum link size of 10mm.

3.6.3 Catch and value of the fishery

The five-year mean catch for Exmouth Gulf prawn trawl fishery from 1994 to 1999 (inclusive) is 1,027 tonnes (Kangas and Sporer 2001). The fishery has a value of about $13 million a year dependent upon species mix and catch level (Sporer and Kangas 2000). The fishery provides employment for the local Exmouth region and provides substantially to the local economy.

3.6.4 Management and closure system

Management of the EGPMF is based on the maintenance of breeding stocks, particularly those of the more vulnerable tiger prawns which have been shown to be susceptible to overfishing (Penn *et al.* 1997). Trawling is prohibited in a designated nursery area in southern and eastern areas of the gulf (Figure 5). The nursery area covers 344nm² of the marine habitat and represents 28% of the area of Exmouth Gulf.

Management of the fishery is achieved through a series of areal controls based on catch rate and size of prawns aimed at maximising the economic return from the fishery on a sustainable basis. The EGPMF is divided into a series of areas (Figure 5) that are opened and closed to trawling as the season progresses to optimise the catch of prawns for marketable size and value. Areas B and C (Figure 5) are also closed either at a time when the breeding stock reaches a threshold catch rate level or on 1 August. This closure remains in place until the end of the season to protect tiger prawn breeding stocks to ensure sufficient recruitment to the fishery the following year. In recent years, after surveys of the spawning areas, these areas have been briefly reopened to fishing to take excess prawns required to maintain breeding stock levels.

3.6.5 Overall swept area and spatial pattern of effort

The average trawl speed is 3.5 to 4 knots and trawl duration varies between one to 3.5 hours. Annual estimates of the accumulated swept area for boats fishing in Exmouth Gulf (using standard headline length, average speed of boats and the total number of hours trawled) between 1989 and 1999 ranges between 1240nm² and 1341nm² with an average of 1279nm². It is important to note however, that the actual area swept by trawl nets will be less because of spatial overlapping of trawl activity. Analysis of spatial effort distribution of the Exmouth Gulf prawn boats in 1998 shows that from a total allowable trawl area of 884 nm², only 424 nm² was actually trawled (48%). This represents 35% of the total area of Exmouth Gulf. The accumulated swept area in 1998 was estimated to be 1266 nm². Since this effort is concentrated into 424 nm², random points selected on the seabed in the trawled area would be expected to be swept over by a trawl net an average of three times during the course of one season.

4.0 REVIEW OF AUSTRALIAN STUDIES ON THE EFFECTS OF DEMERSAL TRAWLING ON SOFT BOTTOM HABITATS

4.1 Introduction

Five relevant studies have been undertaken in Australia on the effects of demersal trawling on soft bottom habitats and two studies were recently published on trawl effects on elasmobranchs and seasnakes, which are incidentally caught by demersal trawling. Numerous other studies have been conducted in the northern hemisphere and for other trawl methods such as fish trawling and dredging and these are not discussed in this review. Several other studies describing the components of bycatch and the fate of discards have been undertaken and a review of these can be found in Craik *et al.* (1990).

4.2 Summary findings of Australian studies

- Gibbs, P.J., Collins, A.J. and Collett, L.C. (1980) 'Effect of otter prawn trawling on the macrobenthos of a sandy substratum in a New South Wales estuary' Aust. J. Mar. Freshwater Res., 31: 509-16.

From analysis of quantitative grab samples and underwater observations, changes in epifaunal and infaunal macrobenthos were not detected using cluster analysis between pre and post trawling samples from a sandy seabed. The experiment was conducted one week prior to the start of the prawn season using an otter trawl without either tickler or ground chains. Underwater video comparisons between pre and post trawl season indicated no detectable changes to the macrobenthos from otter trawls.

- Wassenburg, T.J. and Hill, B.J. (1987) 'Feeding of the sand crab *Portunus pelagicus* on material discarded from prawn trawlers in Moreton Bay, Australia'. Mar. Biol. 95: 387-93.

Analysis of the foregut contents of the blue swimmer crab (*Portunus pelagicus*) from the trawl grounds in Moreton Bay showed that animals discarded from the trawl catches constitute about 33% of the diet of the crab. The finding suggested that trawler discards at periods of high food demand in summer may allow an increased population of *P. pelagicus* to occur on the trawl grounds than otherwise would be the case.

- Laurenson , L.J.B., Unsworth, P., Penn, J.W. & Lenanton, R.C.J., (1993) The impact of trawling for saucer scallops and western king prawns on the benthic communities in coastal waters off south western Australia. Fish. Res. Rep. Fish. Dept. West. Aust. 100: 1-93.

The South-West Managed Trawl Fishery is a low effort intensity trawl fishery operating between Moore River and Cape Naturaliste. The fishery covers a total area of about 18,000km^2 but approximately only 1.4% of the area, in six small discrete areas, was actively trawled at the time of the study by eight trawlers out of the 13 licences. Sampling and underwater observations before and after depletion trawling (area was completely swept by the trawl gear on four successive occasions during a single night, with one sweep over the area consisting of four trawls) in Geographe Bay, Western Australia failed to detect any impact on the benthic communities of existing trawl grounds (Laurenson, 1993). Cluster analysis comparing fish communities in trawled and similar untrawled sites between Fremantle and Cape Naturaliste did not show any appreciable differences. It was only possible to obtain an approximation of the effort and total swept area for the active trawlers.

- Stobutzki I., Blaber S., Brewer D., Fry G., Heales D., Miller M., Milton D., Salini J., Van der Velde T., Wassenberg T. (2000) Ecological Sustainability of Bycatch and Biodiversity, in Prawn Trawl Fisheries. FRDC Project NO. 96/257: Cleveland, Qld: CSIRO Marine Research, xvi, 512 pp.

Impacts of prawn trawling on vertebrate biodiversity was investigated by comparing trawled sites and sites closed to trawling. The investigation sampled areas closed to trawling, adjoining areas open to trawling and deeper waters further offshore open to trawling. The study found that depth and seafloor characteristics influenced the abundance of many but not all individual species between areas closed to trawling and deeper waters further offshore open to trawling. There was little observed difference in the species composition and abundance from sample catches between adjoining areas that had been closed and open to trawling.

- Poiner I., Glaister J., Pitcher R., Burridge C., Wassenberg T., Gribble N., Hill B., Blaber S., Milton D., Brewer D., and Ellis N. (1998) Final report on effects of trawling in the Far Northern Section of the Great Barrier Reef: 1991 – 1996. CSIRO Division of Marine Research, Cleveland.

An investigation of the impact of prawn trawling in a northern section of the Great Barrier Reef was made by comparing species abundance and composition in areas opened and closed to trawling between 1991 and 1996. No clear effect of trawling was demonstrated. Some individual species showed significant differences in abundance or biomass between areas, some species were more abundant in closed areas whereas other species were more abundant in trawled areas. Notably lizard fishes are regarded, as a group that appears to benefit from trawling were more abundant on the trawl grounds.

4.3 Discussion

No clear detrimental effects of trawling have been demonstrated in the any of the studies described. All have had some limitations such as;

- A lack of sufficient statistical power to discriminate between trawled and untrawled areas caused by inherent variability in the study areas.
- A lack of detailed and precise knowledge about the spatial distribution of commercial trawl effort.
- Illegal trawling in closed areas.
- Difficulty in finding untrawled areas close to areas that are trawled.

Trawl effort in the Northern Prawn (NPF) and Queensland East Coast Prawn Trawl Fisheries (QECPTF) were reported as trawl days within 6nm by 6nm grids and 30nm latitudinal zones respectively. A lack of detailed spatial resolution for the distribution of trawl effort within grids and zones confounds analysis when comparing the benthos of trawl grounds and areas closed to trawling. Recently Vessel Monitoring Systems trialed by the Queensland Fisheries Management Authority and in use in Shark Bay, by the Department of Fisheries Western Australia has shown that the distribution of prawn trawl effort is highly targeted and patchy in its distribution (unpublished data). Without precise detailed knowledge of the distribution and amount of trawl effort occurring it is difficult to reliably quantify the impact of trawling from a comparison of the sample catches from trawled and untrawled areas.

Approximately 10% of species or groups showed a statistically significant difference in bycatch (p:0.05) between areas open and closed to trawling in the QECPTF. Sponges were numerically 1.6 times more abundant and eight times more abundant by weight in closed areas. However, some groups, for example lizard fish (*Saurida* and *Synodus* spp) were more abundant on the QECPTF trawl grounds than in closed areas. Overall there was an equal division of species with a significant difference between open and closed areas with some being more abundant in closed areas and some more abundant in open areas. The study found that there was little evidence showing any impact of trawling. Furthermore, it was suggested that natural variation was responsible for most of the observed variation in the distributions of species. Confounding this finding repeat trawl experiments showed that the average prawn trawl removes about 10% of epibenthos.

Investigations into the impact of trawling in the NPF near Groote Eylandt showed a significant difference in abundance for up to 24% of species in a region during one period between combined closed and adjacent open areas and deeper adjacent offshore areas. However, there was little detectable difference between closed and adjacent areas open to trawling. Generally the number of species showing an increase in trawl areas was greater than the number showing a decrease in trawl areas. In a comparison of the mean size of individual species, there was no difference between adjacent areas open to and closed to trawling. Species showing a significantly larger mean size mainly occurred in deeper offshore areas.

Both investigations from the NPF and QECPTF emphasised that the equivocal results from both studies did not mean that there is no impact from demersal trawling on benthic fauna. As stated above both the studies were disadvantaged by a lack of detailed information regarding the quantity and distribution of trawl effort. Differences between trawled and untrawled areas are more likely to be discriminated where trawl effort is intensely focused on a small area. The QECPTF records trawl effort in 30' latitudinal bands. There are over 800 vessels licensed in the otter trawl fishery working about 90,000 days annually between Cape York and the NSW border (Queensland trawl fishery: proposed management arrangements (East coast – Moreton Bay) 1998 – 2005).

The proposed study in Western Australia has several advantages in determining trawled and untrawled area as;

- Detailed information is available using voluntary logbook data (and since 2001, VMS data) on trawl positions.
- Some areas have been permanently closed to trawling for over 20 years.
- Some areas have been closed to trawling in the last 10 years.
- Some areas are seasonally opened with varying levels of effort.
- There is spatial delineation (with some overlap in a small area) between scallop and prawn fleet activity.

These enable the comparison of faunal composition; not only by ‘open’ and ‘closed’ areas but also by fishing intensity and we are able to compare open and closed areas in the same habitat type because of the extensive areas that are closed to trawling.

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