Prawn Fishery By-catch and Discards: Fates and Consequences for a Marine Ecosystem

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Objectives

1) To determine which scavengers exploit material from prawn trawlers.
2) To determine the relative contribution of discards on the diet of scavenger species and the population level consequences.
3) To determine the population level consequences for prawn by-catch for the by-catch species themselves.
4) To quantify the rates and relative importance of nutrient regeneration by natural processes (wind and currents) and by prawn trawling activities in the Spencer Gulf
5) To integrate the information that has been collected from both this study and previous work to develop a conceptual model that describes the influence of prawn trawling in a coastal ecosystem.
6) To complete a comprehensive written assessment of the ecological impact of prawn trawling in the Spencer Gulf, consistent with the need to adopt principles of Ecological Sustainable Development.
7) To identify and promote environmental favourable work practices.

Outcomes Achieved

The outcome of this project is an ecological assessment of the Spencer Gulf prawn fishery. This involves a description of the food web and trophic relationship of commonly occurring species, an assessment of the trawled ecosystem, particularly the distribution, abundance and productivity of the trawled bottoms, an assessment of the fate of discarded by-catch, and an identification and quantification of the major scavenger groups and their consumption. This information is used to describe in energetic terms the contribution of discarded by-catch to the function of the ecosystem. A further outcome is an assessment of grain size distribution and sedimentation within the Spencer Gulf, and a test of how trawling activity affect re-suspension and sedimentation. In conjunction with project 98/208 ‘Habitat modification and its influence on prawn and crab fisheries’, this project will contribute significantly to the ecologically sustainable development of South Australian prawn fisheries. Together, the two projects provide a clear indication of the effects of prawn fishing on the ecosystem, and will allow industry and management to assess potential ways for reducing these effects.

Non Technical Summary

The ecological assessments are based on a series of investigations using a consistent rigorous statistical approach applied to data sampled during three seasons at five selected sites with a history of different trawling intensities and subsequently different discard load. The important findings are that the trawled sites are different habitat with a different biomass, species composition, abundance, and with a patchy distribution. Macro-faunal species diversity was relatively low but variable. Five functional groups could be identified in the food web with possibility of further subdivisions. The dietary composition of prawns, blue crabs and Degens leatherjacket, measured by stable isotope analyses, was found to be consistent among the five sites indicating independence of discard load. Probability values of obtaining by-catch by prawn trawling have been calculated for the five studied sites. The most important bottom scavengers were sealice, leatherjackets, blue crabs, Port Jackson sharks and larger stingrays. Consumption of by-catch species was variable between sites but not between season. Consumption rates in the field and laboratory have been estimated. Using these findings it was estimated that sealice have the capacity to consume more than 99% of the discarded by-catch that settles on the bottom at night. Blue crabs, leatherjackets, sharks and rays consumed the remaining 1%. No mid-water scavengers were observed. The most important surface scavengers were bottlenose dolphins and seagulls. The occurrence of these scavengers varied between sites and season but not by time of night. The mean number of dolphins feeding on discarded by-catch was found to be 1.3 dolphins per boat and observation and the mean number of seabirds observed to feed on discarded by-catch was found to be 1.2 seagull per boat and observation. An estimated 190 ton of discards can potentially be consumed by dolphins while seagulls may consume 1.6 ton of discards from the prawn fishery per year. The remaining 808 ton will sink to the bottom and be consumed by sealice at night and what little remains will be consumed particularly by leatherjackets but also blue crabs by day. A large unknown amount is likely to be consumer by Port Jackson sharks and stingrays. Variation in sealice occurrence will allow more to be left for the other consumers.

Keywords

Prawn fishery, scavengers, by-catch, discards, ecosystem effects, trophic relationships, stable isotopes, resuspension.

Acknowledgements

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Finally, I am grateful to the Fisheries Research and Development Cooperation and the South Australian Research and Development Institute who paid the lion’s share of the bill.

Background

The Spencer Gulf prawn fishery is the largest prawn fishery in South Australia with a production of about 2000 ton caught by 39 vessels. The fishery has been managed on a sustainable basis for more than 20 years by strict spatial and seasonal control. The Rio Declaration set down a number of principles that are substantially altering the framework within which fisheries are being required to operate. Among them, the concepts of Ecological Sustainable Development (ESD) and the Precautionary Approach are particularly prominent. The notion of precaution is now extending far beyond simple sustainable management of harvestable stocks. Effects of non-target species and the ecology of whole systems are also a focus of attention, with a widespread perception that fishing activity is causing damage to ecosystems. Prawn fisheries in particular have been highlighted reflecting the high levels of discarding in some fisheries. In response to this increasingly negative perceptions of commercial fishing, the South Australian prawn industry is keen to fully evaluate the environmental consequences of their activities and, if necessary, further adapt work practices to allay public concerns and retain or improve market share. This project has been developed in consultation with the industry to further this objective and has their strong support.

There has been relatively little research done on the ecosystem level consequences of commercial fishing, despite the perceptions of widespread damage. This gap is harmful because it leaves a fishery open to uninformed speculation or accusation about fishing impacts that cannot be adequately challenged. Without a sound scientific assessment, claims that current practices are not harmful are difficult to sustain against pressure from effective lobbyists.

The project seeks to examine the wider ecological consequences for the ecosystem of an important coastal fishery: the Spencer Gulf prawn fishery. Unlike most, this fishery is highly amenable to experimental evaluation of ecosystem effects and aspect of fishery impact study that previously has received little attention. When addressing the scientific issues considerations have to be taken in the context of the geographical size and heterogeneity of the Spencer Gulf and the dynamics of the fishery. When planning an investigation the problem of scale has to be considered: is the investigation to be at the scale of the fishery or are reductions required? Considering the available resources and what is practically possible within the given time, reductions in the scale of observation have to be made. This requires that the fishing area has to be subdivided and that only a small selection of sites can be sampled at only a few times. It also requires that results from small-scale sampling and experiments have to be used to explain what occurs at a larger scale. Furthermore, to maximise research efforts, sub-projects must be designed as honours-projects with the aim of attracting students. Accordingly, the main project is then for structural reasons subdivided into sub-projects with the purpose of specifying and identifying suitable student- and work projects.

Prawn fisheries, which use light otter trawls and occur predominantly in tropical waters, have drawn attention due to the composition of by-catch from coral reef environments. In Australian tropical prawn fisheries by-catch/prawn-catch ratio as high as 10:1 off shore and 6:1 inshore has been reported. Similar data from the fishery in the North Sea shows a ratio of 6:1 for ground fish and 10:1 for others. Trawling for the Norwegian lobster (*Nephrops norvegicus*) showed a by-catch/catch ratio of 8:1. The Spencer Gulf prawn fishery shows a by-catch/catch ratio of 1:2. Because the total recorded catch of prawns is about 1,650 – 2,600 ton, approximately 1,000 ton of by-catch are discarded annually. Although recently developed by-catch reduction devices can eliminate larger animals and reduce by-catch, there is little likelihood for further elimination. Little is known about the fate and consequences of by-catch and to what extend discards affect ecosystems. Three ecological effects of prawn fishery can be identified: 1) The effects of by-catch on trophic linkages and food web dynamics, 2) The effect of trawling on resuspension and nutrient regeneration, and 3) The direct effects of trawling on the benthic and pelagic assemblages. The research described here focus primarily on 1 & 2, while effect 3 has been presented in 98/208: "Habitat modification and its influence on prawn and crab fisheries" by Dr. J. Tanner.

The study has thus nine major components to it:

1. *Food Chains: Stable Isotope Analyses to Determine Trophic Relationships in the Spencer Gulf.* This study utilise stable isotopes to describe the trophic relationships of a large number of species collected in the Spencer Gulf.
2. *Quantitative Benthic Surveys of the Spencer Gulf: Biomass, Diversity and Production.* This study provides insight into the distribution and abundance of epibenthic and benthic organisms that potentially will be a part of the by-catch in the prawn fishery.
3. *Quantitative Benthic Surveys of the Spencer Gulf using Underwater Stereophotography to Determine Spatial Patterns of Distribution and Abundance.* This study is non-destructive and provides insight into the small-scale distribution and abundance and provide a photographical base-line for future studies on temporal variability.
4. *Consumption by Surface Scavengers in the Spencer Gulf Prawn Fishery.* This study utilise the prawn fishing fleet to estimate distribution and abundance of the surface scavengers, dolphins and seabirds.
5. *Occurrence and Consumption by Benthic Scavengers in The Spencer Gulf, South Australia: a UV-video analysis.* This study utilise under water video-techniques to characterise scavenger assemblages and to estimate their abundances and consumption of discarded by-catch.
6. *Occurrence and Consumption of Sealice in the Spencer Gulf, South Australia.* This study provides an assessment of the distribution and abundance of sealice and an estimate on their consumption in the field.
7. *Consumption by Degens Leatherjacket (Thamnacanus degeni), Blue Swimmer Crab (Portunus pelagicus) and Sealice (Natatolana woodjonesi) Under Laboratory Conditions.* This study provides a series of laboratory experiments to determine the consumption and feeding rates of the major by-catch consumers.
8. *Sediment resuspension and nutrient regeneration in the Spencer Gulf, South Australia.* This study provides an analysis of the sediment characteristics and distribution in the Spencer Gulf and an experimental assessment of the effect of trawling on sediment resuspension utilising vessels from the Spencer Gulf fishing fleet.
9. *On the Relationships between Prawn Trawling, By-catch and the Ecosystem of the Spencer Gulf.* This study finalise the entire project in a conceptual model integrating the information that has been collected from both this study and

previous work describing the fate of discarded by-catch and the ecological impacts of discarded by-catch on the Spencer Gulf ecosystem.

Need

Public perceptions

Commercial fisheries, in particular prawn fisheries, conjour negative perceptions of environmental impact by the general community. This stem as much from the negative imagery of the capture of species of intrinsic public concern e.g. dolphins, as it do from notions that commercial fishery irreversibly depletes stocks.

Adverse consumer response

Public perceptions have been shown to translate into adverse consumer response. In addition, domestic perception and political pressure threatens the actual conduct of fisheries rather than the market for the product. There is a clear need to better inform the Australian public on the environmental performance of commercial fisheries by identifying environmental impacts and promoting responsible work practices.

Improving promotion of commercial fishing

The proposal addresses a major need for more effective promotion of commercial fisheries linked to domestic perceptions and market opportunities.

The ecosystem effects of fishing need to be understood

Most of Australia's major fisheries are undertaken in near-shore habitats yet relatively little is known of the effects of fishing on coastal ecosystems. This project seeks to address this question for a major coastal fishery. The objectives of the project are consistent with the aims of modern fisheries management and have been identified as an information need by FRDC.

Objectives

1. To determine which scavengers exploit material from prawn trawlers.
2. To determine the relative contribution of discards on the diet of scavenger species and the population level consequences.
3. To determine the population level consequences for prawn by-catch for the by-catch species themselves.
4. To quantify the rates and relative importance of nutrient regeneration by natural processes (wind and currents) and by prawn trawling activities in the Spencer Gulf
5. To integrate the information that has been collected from both this study and previous work to develop a conceptual model that describes the influence of prawn trawling in a coastal ecosystem.
6. To complete a comprehensive written assessment of the ecological impact of prawn trawling in the Spencer Gulf, consistent with the need to adopt principles of Ecological Sustainable Development.
7. To identify and promote environmental favourable work practices.

The objectives stated above have been maintained as in the original application with two major exception. The concept of developing an “Ecopath Model” was replaced by “Conceptual Model” (Objective 5). This allows much more freedom of choice in the future development necessary to achieve the objectives and to generate coherence between the proposed objectives, methods and milestones. The reason for this has to be seen in the light of the required input (data) to an “Ecopath Model”, the resources available to obtain such data, and also the oceanographical characteristics of the Spencer Gulf. The input to an “Ecopath Model” are:

- Production/biomass ratio (P/B): equal to instantaneous rate of total mortality (Z) in steady-state systems.
- Diet composition (DC): for a given group of species (i), the diet composition is the fraction of each species (groups) it consumes, usually estimated from stomach contents.
- Annual fishery catch (or quantity killed by fishing and discarded): needed for all exploited species.
- Habitat area: use standardised area (Ecopath II)
- Ecotrophic efficiency (EE): expressing the fraction of total production consumed by predators or caught by a fishery.
- Primary production (PP, in g C m^{-2} $year^{-1}$).
- Detritus biomass (estimated from PP by regression)
- Food consumption per unit biomass (Q/P): the number of times per year a population (fish) consumes its own weight (difficult to estimate!)

To obtain data on production/biomass ratios (=instantaneous mortality rates) in the Spencer Gulf ecosystem, regular quantitative sampling of all important species during at least a two year period is required. This involves an intensive sampling program where also migration/immigration in an open system is considered. The methods originally suggested in the project dos not address sampling of data for an estimate of P/B ratios. Such a study, however desirable it my be, require considerable boat resources and manpower, and was not considered to be realistic within the available resources.

A change of objective 3 was proposed to FRDC and subsequently accepted. To determine population level consequences for prawn by-catch for the by-catch species themselves, the research presented in this report is to a large extent a prerequisite, particularly the characterisation and identification of scavengers. The objective requires population level studies on a wide range of species in a large open system characterising the Spencer Gulf and was considered premature and not possible within the available resources. This objective was to be met by theoretical studies of available data. Objective 7, however, needs to be addressed in cooperation with the prawn fishing industry. The objective is depending on this final report allowing management option to be discussed and implemented.

Chapter 1: On the Relationships between Prawn Trawling, By-catch and the Ecosystem of the Spencer Gulf.

Ib Svane

Abstract

The fraction of benthic biomass caught as by-catch in the Spencer Gulf prawn fishery has been estimated at five sites using mean biomass values obtained from benthic surveys and 12-year logbook data on fishery performance. Additionally, the relative probabilities of catching one unit of prawns per trawl hour using historical data, and the relative probabilities of catching one unit of by-catch per trawl hour (survey data) have been calculated for the five studied sites. The result showed that fraction of benthic biomass caught as by-catch varies between sites with the lowest values at the two northernmost sites. The site with the relatively highest fraction of benthic biomass caught as by-catch was Site 3 at Middle Bank where 94.1% of the total benthic biomass are caught as by-catch. At the two southernmost sites intermediate values were found. The relative probabilities of catching one unit of prawns per trawl hour was found to be relatively constant among sites while the relative probabilities of catching one unit by-catch per trawl hour varied with the highest values at the two northernmost sites, the lowest value at Site 3, and intermediate values at the southernmost sites. These results were proportional to the fraction of benthic biomass caught as by-catch. The reported patterns may be a result of trawling but there is some historical evidence suggesting that the bottom, particularly at Site 3, did not support large volumes of epifauna when the prawn fishery originally started.

Discarded by-catch was found to be quickly consumed by firstly dolphins and seagulls then secondly, when reaching the bottom, by sealice during night. During day leatherjackets, crabs and other minor consumers take what sealice are not consuming during night. An estimated 190.4 ton of discards can potentially be consumed by dolphins while seagulls can potentially consume 1591.2 kg discards from the prawn fishery per year. The remaining 808 ton will sink to the bottom and be consumed by benthic scavengers. A large unknown amount is likely to be consumer by Port Jackson sharks and stingrays. Sealice was found to have more than 99% of the capacity to consume carrion while the capacity of leatherjackets and blue crabs was found to be in the order of 0.2%. The capacity of Port Jackson sharks, skates and rays was not calculated but is likely to be substantial. It was concluded that the contribution of discarded by-catch to the benthic scavenger assemblages of the Spencer Gulf appear to be minor.

Introduction

The impact of trawling on benthic ecosystems has recently received considerable attention (Pilskaln *et al.* 1998, Schwinghamer *et al.* 1998, Engel & Kvitek 1998, Watling & Norse 1998). Prawn fisheries, which use light otter trawls and occur predominantly in tropical waters, have drawn attention due to the composition of by-catch from coral reef environments. Poiner *et al.* (1998) published an extensive study of the Great Barrier Reef prawn fishery. The results showed that the by-catch/prawn-catch ratio was 10:1 off shore and 6:1 inshore. Similar data from the fishery in the North Sea shows a ratio of 6:1 for ground fish and 10:1 for others. Trawling for the Norwegian lobster (*Nephrops norvegicus*) showed a by-catch/catch ratio of 8:1 (Garthe *et al.* 1996). The Spencer Gulf prawn fishery, however, shows a by-catch/catch ratio of 1:2. Although recently developed by-catch reduction devices can eliminate larger animals and reduce by-catch, there is little likelihood for further elimination (Eayrs *et al.* 1997). However, little is known about the fate and consequences of by-catch and to what extend discards affect ecosystems (Andrew & Pepperell 1992, Kennelly 1995).

Carrick (1997) investigated by-catch and discards in the Spencer Gulf prawn fishery. That study was performed with the purpose of describing by-catch of non-target species, which constitute 15 dominating species of finfish (97% of total by-catch sampled). Of mobile epibenthos of quantitative importance, the blue crab (*Portunus pelagicus*) was recorded (Table 1. I). The tooth flounder (*Pseudorhombus arsius*), reported by Carrick (1997) to be an important predator on prawns was not commonly occurring. Of sessile and semi-sessile invertebrates only sponges were recorded while other benthic invertebrates were disregarded. The results showed that sponge biomass increased with trawling depth and were more common in the two northern regions than in the two southern regions. In addition, sponge biomass was found to be negatively correlated to salinity. However, the composition of the recorded by-catch was found to be is highly variable in both space and time.

In prawn and shrimp trawling the proportion of non-target species (by-catch) can be high but with substantial variation between and within geographical regions (Alverson *et al.* 1994, Andrew & Pepperell 1992). By-catch is usually reported as a fraction of the targeted catch. In the Spencer Gulf Prawn fishery, a catch/by-catch ratio reported is 2:1 (Carrick & McShane 1999). In the tropical Queensland prawn fishery, the reported catch/by-catch ratio is 1:4.3 and is accordingly much higher (Poiner *et al.* 1998). A generalisation based on catch/by-catch volumes is a poor descriptor of by-catch in a fishery because spatial variation is disregarded. However, Carrick & McShane (1999) realised this and provided a spatial and temporal assessment but largely disregarded the benthic component of the by-catch.

Prawn fishing in the Spencer Gulf is undertaken using the demersal otter trawl equipped with a BRD (crab bag), which allows blue crabs to escape while prawns and by-catch flow to the cod end. The total recorded catch of prawns is about 1,650 – 2,600 ton, approximately 1,000 ton of by-catch are discarded annually of which a large fraction including blue crabs and sponges will probably survive when discarded.

Three ecological effects of prawn fishery can be identified: 1) The effects of by-catch on trophic linkages and food web dynamics, 2) The effect of trawling on resuspension and nutrient regeneration, and 3) The direct effects of trawling on the benthic and pelagic assemblages (see Drabsch *et al.* 2001). Tanner (2002) has contributed significantly to an understanding of the effects of prawn trawling on the benthic habitats of Gulf St Vincent and Fitzpatrick (Chapter 8) has described effects of trawling on resuspension and nutrient regeneration. Few attempts have been made to link by-catch from a prawn-trawling fishery to benthic assemblages or examined the possibility that enhancement of prawn populations occur through increased energy availability of discarded by-catch (Sheridan *et al.* (1984). The purpose of this study is to give a broad overview of the linkage between prawn fishery of the Spencer Gulf and ecosystem with a focus on the effects of discarded by-catch.

Methods

Scale of Observation and Selection of Study Areas

To conduct an investigation at the scale of the Spencer Gulf prawn fishery was not possible with the resources available and subsequently a smaller scale of observation was decided. The rationale behind the selection was based on the administrative fishing sectors, which has been established to subdivide the Spencer Gulf into areas from which catch and trawling hours are reported. The assumption was made that trawling hours is a better correlate to the volume of discarded by-catch rather than prawn catch. This assumption is likely to be a simplified view because the relationships between discarded by-catch and prawn catch have not been investigated. Trawl hour statistics from a period of 1987-98 was provided by SARDI Aquatic Sciences. For the purpose of managing the Spencer Gulf prawn fishery, the gulf is divided into “blocks” of various sizes from which fishery data are reported. The trawling hours reported from each fishing block that include a station, plus data from the neighbouring sectors were pooled and the annual mean and the 95% C.I. was calculated for each station (Fig. 1.1). Five stations were selected representing areas of different fishing intensity (Fig. 1.2 & Table 1. I). The depths recorded at the five stations were between 22-26 meters.

Table 1. I. Positions of the five stations selected for the study on discarded by-catch in the Spencer Gulf prawn fishery.

Stn 1: 33^{o} 11.1 S; 137^{o} 36.0 E (Western Shoal, sector 10)

Stn 2: 33^{o} 25.8 S; 137^{o} 29.6 E (Plank Pt, sector 23)

Stn 3: 33^{o} 36.3 S; 137^{o} 29.0 E (Middle Bank, sector 31)

Stn 4: 33^{o} 53.0 S; 137^{o} 28.8 E (Wallaroo, sector 43)

Stn 5: 34^{o} 06.5 S; 136^{o} 56.3 E (The Gutter, sector 54)

The generalised by-catch to catch ratio was obtained from Carrick & McShane (1999). The mean trawled area per hour was calculated as follows: When fishing, a vessel will travel at a speed of 3.2-3.6 knots depending on tides and weather. The otter boards will force each trawl to open about 80% of the maximum width of 8 fathoms. The total bottom cover of both trawls will then be 23.4 metres. Using an average vessel speed of 3.4 knots the area trawled per hour will be 23.4 x 6296.8 = 147,345 m^2 per hour.

Data on benthic biomass was obtained from the benthic surveys reported in Chapter 3.

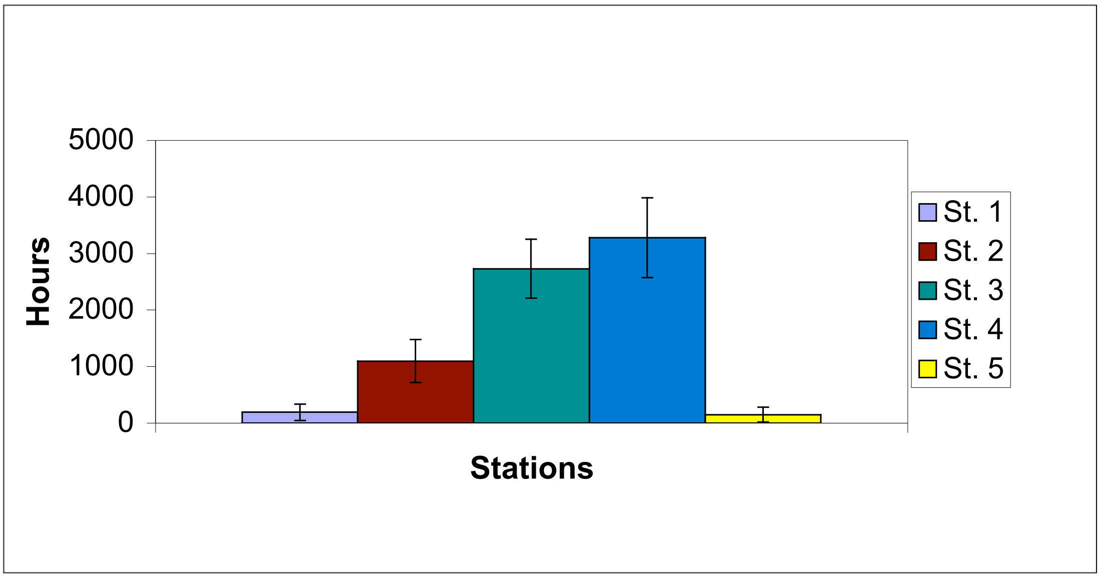


Fig. 1.1. The annual mean numbers of trawl hours reported at the five selected stations during the period of 1987-98. (Error bars show 95% C.I.)

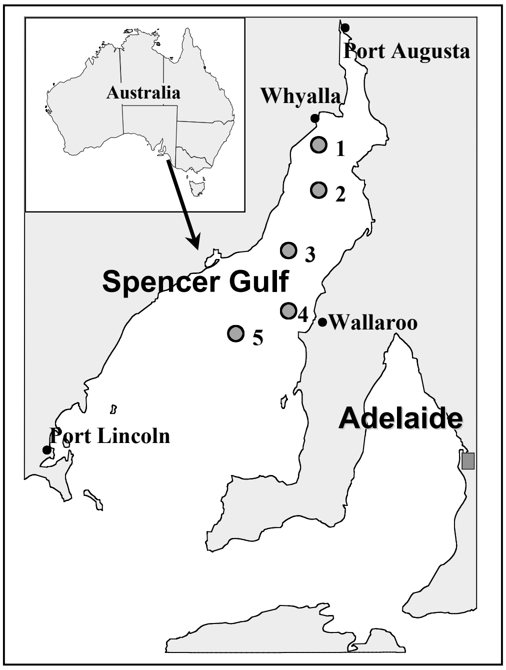


Fig. 1.2. Map showing the Spencer Gulf indication the positions of the five selected stations for this study.

Results

Relationships Between By-catch and Benthos

In order to estimate the fraction of the benthic biomass, which is caught as by-catch, an average estimate of by-catch to catch ratio of 1:2 is used (Carrick & McShane 1999). Table 1. II show the spatial variation in maximum catchable by-catch obtained from the benthic dredge surveys compared to by-catch volumes calculated from logbook data using the generalised catch/by-catch ratio. The mean (12 yr) prawn catch (2) and the mean (12 yr) number of trawl hours per year (3) are calculated using logbook data. The mean biomass values (4) are estimated from the benthic survey reported in Chapter 3 and the maximum by-catch (5) is calculated by multiplying the mean biomass per m^2 (4) with the mean area trawled per hour (147,345 m^2 per hour). The maximum catchable by-catch (6) is calculated by multiplying the mean number of trawl hours per year (3) with the maximum by-catch (kg per hour) (5). By subtracting the maximum by-catch calculated using the 1:2 ratio (7) from the maximum catchable by-catch (6), the fraction of benthic biomass caught as by-catch can be estimated (Table 1. II, right).

Table 1. II. Estimated maximal catch of benthic biomass by the Spencer Gulf prawn fishing fleet compared to reported by-catch as a fraction of prawn catch. Data from log book fishery statistics and data obtained from this study.

1 Site (block number)	2 Mean (12yr) prawn catch (kg)	3 Mean (12yr) number of trawl hours/yr	4 Mean Biomass (kg WW/ m^2)	5 Maximum by-catch (kg/h)	6 Maximum catchable by-catch (kg/yr)	7 Maximum by-catch (ratio 2:1)	8 Fraction caught (%)
1(10)	17,203	192.05	0.00313	461.2	88,574	8,602	9.7
2(23)	72,506	1097.01	0.00295	434.7	476,870	36,253	7.6
3(31)	196,924	2731.66	0.00026	38.3	104,623	98,462	94.1
4(43)	199,702	3280.07	0.00141	207.8	681,599	99,851	14.65
5(54)	9,200	149.22	0.00068	100.2	14,952	4,600	30.8

Using the approximations shown in Table 1. II, the largest amount of by-catch will be caught at Site 1 and 2 with approximately 435-462 kg/h. At the most fished sites (3,4 and 5) further south, the mean maximum by-catch rates are 100-200 kg/h (Table 1. II, column 5). With a generalised by-catch-catch ratio of 1:2, the fraction caught by the double trawl is estimated to be within the range of 7.6-94.1% of the possible catch depending on site (Table 1. II, column 8). However, these estimates are based averages excluding a substantial variation and shall be viewed as gross approximations only.

The result showed that fraction of benthic biomass caught as by-catch varies between sites with the lowest values at the two northernmost sites. The site with the relatively highest fraction of benthic biomass caught as by-catch was Site 3 at Middle Bank were 94.1% of the total benthic biomass are caught as by-catch. At the two southernmost sites intermediate values were found. However, the benthic biomass at Site 3 is low.

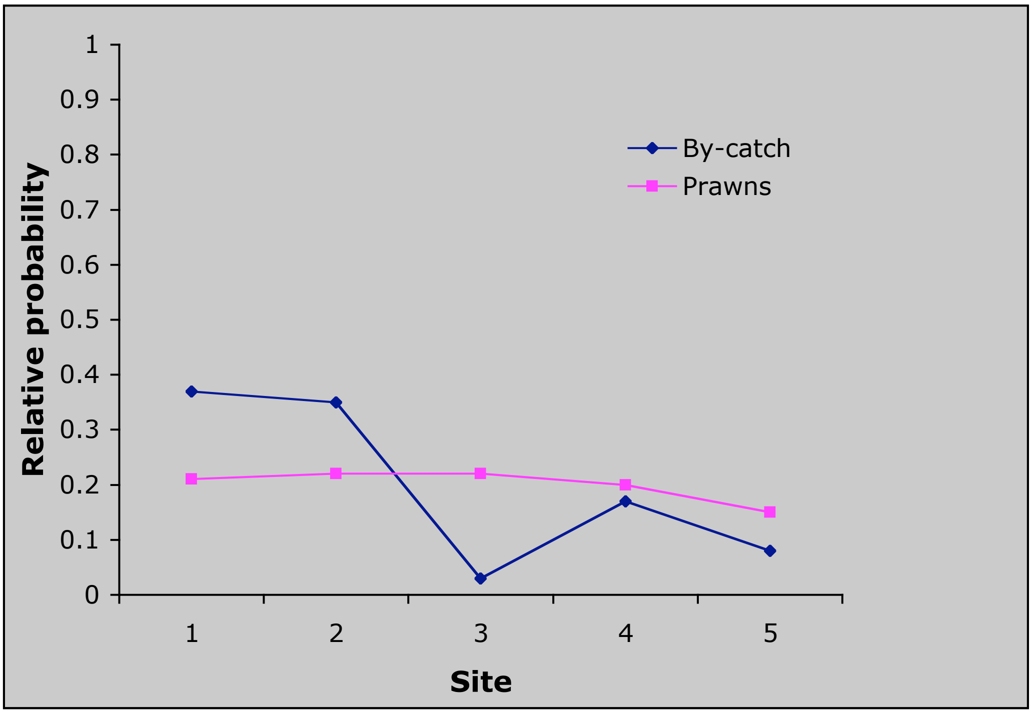


Fig. 1.3. The relative probabilities of catching one unit of prawns per trawl hour (historical data) and the probability of catching one unit of by-catch per trawl hour (survey data).

The probability of catching by-catch can be calculated by using the catch data from logbooks (12 year) and the mean abundance of benthic organisms from this study. Fig. 1.3 show the relative probability of catching one unit (kg) of prawns compared to one unit of by-catch (kg) from Site 1, 8 Nm south of Whyalla, to Site 5 in the Gutter. While the catch of prawns historically is fairly independent of site, by-catch is not. Lowest by-catch/catch ratios are obtained on the coarse sediment with high tidal currents along the Middle Bank (Site 3) and further south on the sandy plains of the Gutter (Site 5). The highest by-catch/catch ratios will be obtained at the two northern sites at Western Shoals and Plank Point (Site 1 & 2). What reflects the relative probabilities of by-catch is the variability in the mean abundance of benthos and demersal fish. These distribution patterns may be a consequence of the history of the sites, past trawling effort and other fishing activities. However, the physical and biological properties of the sites are different, which strongly add to the variability of the fished ecosystems of the Spencer Gulf.

Relationships Between Scavenger Biomass and Consumption

Data on biomass abundance of Degens leatherjackets and Blue crab from dredge studies (Chapter 2) and the potential consumption calculated by using the mean laboratory consumption rate of 9.0 mg/g/min and 0.05 g/g/h, respectively, (Chapter 6) for the five investigated sites in the Spencer Gulf is shown in (Table 1. III and IV). These estimates show shows that biomass abundance from the benthic surveys (Chapter 2) for Degens leatherjacket fit well with the pattern of occurrence at bait observed in the cafeteria experiments with the highest abundances, measured in biomass and leatherjacket occurrence observed at Site 4 and 5 (Chapter 5, Fig. 5.3 and Table 5. V).

Table 1. III. Biomass and consumption rates of Degens leatherjacket at five sites in the Spencer Gulf. (Biomass data from benthic survey and consumption rates, 9.0 mg/g/min, from laboratory estimates)

Site	1	2	3	4	5
Biomass (mg WW/m^2)	0.4117	0.2929	0.0398	1.6366	4.3491
95%CI	0.2597	0.2989	0.0780	0.8751	3.2842
Consumption (mg WW/h/m^2)	0.222	0.158	0.022	0.884	2.349

However, Blue crab occurrence at bait in the cafeteria experiments did not correlated well with the estimated abundances in the benthic dredge surveys (Chapter 3, Fig. 3.5 and Table 3. VI). Variation was high and occurrence at bait may be dependent on a number of factors such as moulting and reproductive stage, previous feeding history and the presence of other scavengers. In addition, a confounding factor is that blue crab consumption is limited by a 6-hour gut clearance. Blue crabs quickly fill their foregut and do not feed again before an approximately 6-hour digestion period (Chapter 6). The estimates are calculated for crabs of average size and weight from each size class. Thus, the above consumption estimates should be viewed conservatively and caution should be taken in generalising these results beyond the temporal and spatial scale of this study.

Table 1. IV. Consumption rates of blue crabs at five sites in the Spencer Gulf. (Biomass data from benthic survey and the consumption rate, 0.05 g/g/h, from laboratory estimates)

Site	1	2	3	4	5
Abundance (mg WW/m^2)	10.2257	28.0335	8.7848	40.0210	10.7040
95%CI	7.7257	22.1936	5.9791	18.5268	5.9294
Consumption (mg WW/h/m^2)	0.511	1.402	0.439	2.001	0.5351

Table 1. V. Consumption rates of sealice at five sites in the Spencer Gulf. (Abundances are estimates based on accumulation rates at bait after 4 minutes. Consumptions rates are estimates from field trapping, 4.86 mg/min/sealice, and laboratory, 0.44 mg/min/sealice, experiments. Numbers in brackets are consumption rates based on feeding rates observed in the field.

Site	1	2	3	4	5
Abundance (no/m^2)	13.67	27.58	86.03	105.17	48.92
95%CI	7.52	14.49	40.96	59.35	21.03
Consumption (mg WW/h/m^2)	360.89 (3,986.17)	728.11 (8,042.33)	2,271.19 (25,086.35)	2,776.49 (30,667.57)	1,291.49 (14,265.07)

Consumption by sealice calculated from field and from laboratory experiments is shown in Table 1. V. The values, based on field estimates of sealice consumption are given in parenthesis. The two feeding rates calculated from trap and laboratory experiments were an order of magnitude different to each other, with the feeding rate in the field using baited traps (4.86 mg/min/sealice) being ten-fold higher than that found under laboratory conditions (0.44 mg/min/sealice).

Table 1. VI summarise the consumption and the relative importance of the three major scavenger groups at the five studied sites. The results showed that scavengers have the capacity to consume between 361.63 to 2,779.37 mg WW/h/m^2 discarded by-catch depending on site. The values, based on field estimates of sealice consumption are given in parenthesis. However, this is a conservative estimate and is probably much higher when considering the difficulties in calculating sealice abundance.

Table 1. VI. Summary of consumption and the relative importance (%) of the three major scavenging groups at five sites in the Spencer Gulf. Consumption is mg WW/h/m^2. Numbers in brackets are consumption of sealice based on feeding rates observed in the field by trapping.

Site	1	2	3	4	5
Degens leatherjacket	0.222 *0.06%*	0.156 *0.02%*	0.024 *0.001%*	0.882 *0.03%*	2.346 *0.18%*
Blue crab	0.511 *0.14%*	1.402 *0.19%*	0.439 *0.02%*	2.001 *0.07%*	0.5351 *0.04%*
Sealice	360.89 (3,986.17) *99.80%*	728.11 (8,042.33) *99.79%*	2,271.19 (25,086.35) *99.98%*	2,776.49 (30,667.57) *99.90%*	1,291.49 (14,265.07) *99.78%*
Total consumption	361.62 (3,986.90)	729.67 (8,043.89)	2,271.65 (25,086.81)	2,779.37 (30,670.45)	1,294.37 (14,267.95)

Port Jackson sharks and rays have not been included because feeding rates could not be calculated in the laboratory due to size of animals. The results showed that sealice is far the most important scavenger group with more than 99% of the capacity to consume carrion.

The overall mean number of dolphins feeding on discarded by-catch was found to be 1.3 dolphins per boat and observation. Using a consumption rate of 6.26 kg per dolphin per day, disregarding any effects of food preference, then at 10 trawl-hauls per night 81.4 kg of discards can potentially be consumed per night and boat. When 39 trawlers are fishing then 3,174 kg discards will be consumed per night. When fishing 60 days a year an estimated 190.4 ton of discards is consumed by dolphins in the Spencer Gulf prawn fishery.

The overall mean number of seabirds observed to feed on discarded by-catch was 1.2 seagull per boat and observation. Using the estimates of Garthe *et al.* (1996) a seabird will on average consume 21.1 kg discarded by-catch, predominantly fish, per year. Because prawn fishery takes place about 60 days per year then a single seagull will consume 3.47 kg discards from that fishery. Considering that a seagull get a full feed at each trawl haul, which has to be digested before a second one can be consumed the following night. At 10 trawl hauls per night by 39 trawlers with 1.2 seagull per haul, this is equal to 468 seagulls. Using these approximations, seagulls will potentially consume 1591.2 kg discards from the prawn fishery per year (3.47 kg/seagull x 468 seagulls).

Discussion

During commercial fishing the ratio of by-catch to prawn catch constitutes 1:2. Because the total recorded catch of prawns is about 1,650 – 2,600 ton, approximately 1,000 ton of by-catch are discarded annually. About 3.7% of the total catch is blue crabs, which probably survive when discarded (Carrick pers. comm.) thereby reducing the amount of discarded material available to surface, mid-water and bottom scavengers. The discards thus constitute approximately 80 ton of carbon redistributed annually in the ecosystem (0.2 conversion ratio wet/dry weight, 40% C). A speculative approximation of the primary production of the Spencer Gulf has been done by Smith & Veeh (1989) who estimated that 2×10^5 ton C were produced annually. About 10% was estimated to be "new" production while 90% was cycled between respiration and production. Accordingly, the discards constitute about 0.04% of the carbon turnover in the Spencer Gulf ecosystem and probably play an insignificant role in the total energy flow. However, discards are not distributed evenly throughout the Gulf and may cause energy displacements locally affecting species composition and abundance.

The analyses of the spatial and temporal distribution of discarded by-catch in trawl fisheries constitute an important element when implementing Ecosystem Based-Management Principles (EBM) (see Ward *et al.* 2002) and a prerequisite to understand ecosystem effects. Sheridan *et al.* (1984) made an attempt to link by-catch from a prawn fishery to benthic assemblages of the Gulf of Mexico by constructing a simple trophic mass-balance model to summarise the patterns of energy flow through the system. In the area of the prawn fishery in the Gulf of Mexico, the major contribution of organic material is via discharge from a major waterway (the Mississippi River), which is quite large making the contribution of by-catch discards tenuous. Spencer Gulf, however, is an oligotrophic coastal ecosystem with low nutrient additions, primarily through point source discharges to the north (Smith & Veeh 1989). In the Spencer Gulf, seagrass, which are the dominant marine plants along the coastal margin covering about 3600 km^2 (Shepherd 1983), is believed to be the major source of energy. The seagrasses of the Spencer Gulf unlike most coastal ecosystems is likely to be the primary source of carbon (Smith & Veeh 1984). However, prawns and other detrivorous scavengers are thus likely at a large extend to be depending on seagrass productivity (Newell *et al.* 1995). Many species in the Spencer Gulf ecosystem are generalists and voracious scavengers likely to benefit from discarded by-catch as a source of high-nitrogen organic material.

The by-catch ratios for prawn trawling in the Spencer Gulf are among the lowest recorded for penaeid trawl fisheries and the mean by-catch biomass to prawn biomass of 1:2 is less than most recorded ratios (Alverson *et al.* 1994, Andrew & Pepperell, 1992). During the 90-ties, by-catch has become reduced in the Spencer Gulf prawn fishery as a consequence of spatially focussed effort on aggregations of prawn. The ratio of by-catch to catch is variable in both space and time and the 1:2 ratio used in this study was obtained as a mean of 219 trawl shots during an annual fishing period

(Carrick & McShane 1999). Clearly the ratio will increase during fishing as prawn biomass decreases providing that large fractions of the discarded by-catch survive (Carrick 1997). Blue crabs are likely to survive being discarded relatively fast and sponges most likely will also survive. In the most trawled areas many species of sponges are not attached to the substratum but developed into balls probably discarded several times. A comparison of benthic biomass sampled using a dredge is likely to be different to that of a prawn trawl but nevertheless represents what a trawl may catch. Carrick (1997) and Carrick & McShane (1999) reported that incidentally caught by-catch consist of 97% by weight of small finfish species. The distribution of by-catch ratios was found to be skewed because of occasional capture of large elasmobranch (*Myliobatis sp.*). The data presented in Table 4. I, are gross estimates likely to be indicative only. The estimates (Table 4. I, column 8), are nevertheless proportional to the probability estimates shown in Fig. 4. 3.

The Spencer Gulf prawn fishing grounds are fished ecosystem and the distribution and abundances of benthic organisms are likely to be affected by many years of trawling activities. However, due to spatial management arrangements (closures) and the targeting of prawn aggregations with specific size compositions, the area trawled has been successively reduced over time leaving large areas unaffected. The reported patterns of benthic biomass distribution and abundance may be a result of trawling but there is some non-published historical evidence suggesting that the bottom, particularly at Site 3, did not support large volumes of epifauna when the prawn fishery originally started and that the composition of by-catch remains the same for each area.

Carrick (1997) indicated that the approximate annual discard from Spencer Gulf prawn trawlers equates to 1000 tonnes. Since the approximate area of the fishing zones in the Spencer Gulf is 18700 km^2, then roughly 53.5 mg/ m^2 of discard would be available to scavengers if it was assumed that discard was evenly distributed. By-catch is furthermore not evenly distributed. From this study is clear that sealice are far the most important scavenger group with more than 99% of the capacity to consume carrion. Sealice are only active at night when also discarded by-catch is available. During day leatherjackets, crabs and other minor consumers take what sealice are not consuming during night. Because of the variability of occurrence in sealice activity, daytime scavengers are periodically and spatially more important than indicated above. Considering that sealice alone in a conservative estimate can consume more than 2,777 mg WW/h/m^2, the contribution of discarded by-catch to the benthic scavenger assemblages of the Spencer Gulf appear to be minor.

However, discarded by-catch is not distributed evenly in both space and time. Fishing is regulated by closures with periods of high trawler concentration, particular at Middle Bank and off Wallaroo, and takes place only 50-70 days per year. The first scavengers approaching discarded by-catch are dolphins and seagulls.

The mean number of dolphins feeding on discarded by-catch was found to be 1.3 dolphins per boat and observation and the mean number of seabirds observed to feed on discarded by-catch was found to be 1.2 seagull per boat and observation. If fishing takes place 60 days a year an estimated 190.4 ton of discards can potentially be consumed by dolphins while seagulls can potentially consume 1591.2 kg discards from the prawn fishery per year. The remaining 808 ton will sink to the bottom and be consumed by sealice at night and what remains will be consumed by leatherjackets and blue crabs by day. A large unknown amount is likely to be consumer by Port Jackson sharks and stingrays. These results are based on estimates involving several assumptions and likely to be associated with both observational and experimental errors.

References

Alverson, D.L., Freeberg, M.H., Pope, J.G. & S.A. Murawski 1994. A global assessment of fisheries by-catch and discards. FAO Fisheries Technical Paper, No. 339, 233 pp.

Andrew, N.l. & J.G. Pepperell 1992. The by-catch of shrimp trawl fisheries. Oceanogr. Mar. Bil. Ann. Rev. 30: 527-565.

Carrick N.A. 1997. A preliminary assessment of the by-catch from the Spencer Gulf prawn fishery. South Aus. Fish. Ass. Ser. 97/02

Carrick, N.A. & P.E. McShane 1999. Spatial analyses of by-catch in the Spencer Gulf prawn fishery, South Australia (in manuscript).

Drabsch S.L, Tanner, J.E. & S.D. Connell 2001. Limited infaunal response to experimental trawling in previously untrawled areas. ICES J. Mar. Sci. 58: 1261-1271.

Eayrs, S., Buxton, C., McDonald, B. & G. Day 1997. A guide to bycatch reduction in Australian prawn fishery. Australian Maratime College, Launceston 53 pp.

Engel J. & R. Kvitek 1998. Effects of otter trawling on a benthic community in Monterey Bay national marine sanctuary. Cons. Biol. 12: 1204-1214.

Garthe, S, Camphuysen, C.J. & R.W. Furness 1996. Amounts of discards by commercial fisheries and their significance as food for seabirds in the North Sea. *Mar. Ecol. Prog. Ser.* 136:1-11.

Kennelly, S.J. 1995. The issue of bycatch in Australia's demersal trawl fisheries. Rev. Fish. Biol. 5: 213-234.

McShane, P.E., Hall, S. & N.A. Carrick (in press). Trophic consequences of prawn trawling: linking by-catch to benthos. 14pp.

Newell, R.I.E., Marshall, N., Sasekumar, A. & V.C. Chong 1995. relative importance of benthic microalgae, phytoplankton, and mangroves as sources of nutrition for penaeid prawns and other coastal invertebrates from Malaysia. Mar. Biol. 123: 595-606.

Pilskaln, C.H., Churchill, J.H. & L.M. Mayer 1998. Resuspension of sediment by bottom trawling in the Gulf of Main and potential geochemical consequences. Cons. Biol. 12: 1223-1229.

Poiner, I., Glaister, J., Pitcher, R., Burridge, C., Wassenberg, T., Gribble, N., Hill, B., Blaber, S., Milton, D., Brewer, D. & N. Ellis 1998. Final report on effects of trawling in the far northern section of Great Barrier Reef: 1991-1996. CSIRO Division of Marine Research, Cleveland.

Schwinghamer, P. Gordon, D.C., Rowell, T.W., Prena, J., McKeown, D.L., Sonnichen, G. & J.Y. Guignes 1998. Effects of experimental otter trawling on surficial sediment properties of a sandy-bottom ecosystem on the Grand Banks of Newfoundland. Cons. Biol. 12: 1215-1222.

Shepherd, S. 1983. Benthic communities in the upper Spencer Gulf, South Australia. Trans R. Soc. S. Aust. 107: 69-86.

Sheridan, PF; Browder, JA; Powers, JE 1984. Ecological interactions between penaeid shrimp and bottomfish assemblages. In: Gulland, JA, Rothschild, BJ (eds). Penaeid shrimps – Their biology and management. Selected papers presented at the workshop on the scientific basis for the management of penaeid shrimp held at Key West, Florida, USA, Nov. 1984, pp. 235-254.

Smith, S.V. & H.H. Veeh 1989. Mass balance of biogeochemically active materials (C, N, P) in a hypersaline gulf. Estua. Coast. Shelf Sci. 29: 195-215.

Tanner, J.E. 2002. habitat modification and its influence on prawn and crab fisheries. FRDC and SARDI Aquatic Sciences, 213 pp.

Ward, T., D. Tarte, Hegerl, & K. Short 2002. Policy Proposals and Operational Guidance for Ecosystem-Based Management of Marine Capture Fisheries. WWF Australia, 80 pp. Andrew, N.L. & J.G. Pepperell 1992. The by-catch of shrimp trawl fisheries. Oceanogr. Mar. Biol. Annu. Rev. 30: 527-565.

Watling, L. & E.A. Norse 1998. Effects of mobile fishing gear on marine benthos. Cons. Biol. 12: 1178-1179.

Chapter 2: Food Chains: Stable Isotope Analyses to Determine Trophic Relationships in the Spencer Gulf.

Ib Svane

Abstract

A study of the food web in the Spencer Gulf using stable isotope (^{13}C and ^{15}N) analyses has been undertaken with the primary aim to identify effects of discarded by-catch from prawn trawling. A large variation within species was evident but the data points in a $\delta^{13}C$ and $\delta^{15}N$ correlation graph formed largely four clusters with overlap between groups indicating shared food resources. Replicated samples of prawn, blue crab and Degens leatherjacket were statistically analysed using separate ANOVA's for each isotope with species and site as the main effects. Both $\delta^{13}C$ and $\delta^{15}N$ showed a significant effect of species but no effect of site indicating that the trophic levels of the three species are different and that this difference is independent of site and can accordingly not be directly correlated to trawling intensity or discarded by-catch. The study showed that prawn and blue crab broadly share the same food source while the food source of Degens leatherjacket is different. The species effect observed was predominantly for $\delta^{13}C$ while the $\delta^{15}N$ pattern was inconsistent. Carbon isotopic compositions showed little change with trophic level while nitrogen isotopic distributions showed broadly three trophic levels with 3-4‰ increase per trophic level. A large degree of interconnectivity among the investigated species was evident indicating that these species are generalists with a broad diet covering more than one trophic level making non-trivial generalisations about feeding patterns difficult.

Introduction

A study of a marine food web usually involves gut content analysis of the dominant species in combination with direct observations of feeding. More refined methods of quantifying trophic pathways using radiotracer techniques are sometimes used. Unfortunately, all these methods are time consuming and may not separate or identify the components of the different trophic levels. The reason for this is usually that rates of digestion vary between organisms, food items are often difficult to identify from stomach contents, and dietary analyses only give a snapshot of consumption of an individuals immediate past. In contrast, the analysis of stable isotope ratios provides an alternative whereby an organism's trophic position (level) may be identified by a simple tissue sample, which provides an integrated signal of diet over a long period (Peterson & Fry 1987, Lajtha & Michener 1994).

The basis for using stable isotope ratios is founded on the observation of a regular and consistent pattern of isotopic enrichment with increasing trophic level. However, the isotopic composition of tissues between organisms and within an organism may vary, reflecting a change in diet or selective feeding (Peterson & Fry 1987, Boon & Bunn 1994). Many studies have been done along physical gradients and in estuaries with a high organic load and did not take into account spatial variability and variability within an organisms because of lack of replication. In this study we collected replicated samples of all species and furthermore replicated these samples at five sites along the Spencer Gulf with a history of different trawl intensity. The general purpose was to describe the food web structure in the Spencer Gulf where the prawn fishery operates, and to test whether the stable isotope composition of major consumers of discarded by-catch varies along a gradient of different trawl intensity and thus different by-catch exposure.

Material & Methods

Replicated samples (N=3, different individuals) were collected in the Spencer Gulf at the five selected sites form 8NM south of Whyalla to the Gutter in the south using a three meter wide beam trawl (see Chapter 3). Organisms were collected at a depth of 25-30 m where prawn trawling occurs. Plankton sampling was obtained by replicated hauls using a VP2 plankton net equipped with a 85 μm filter in the cod end. Larger plankton (jellyfish etc.) were decanted and kept separately. At each of the five stations three species were collected for spatial statistics, namely Degens leatherjacket, blue crab and prawn.

After collection, the samples were dissected and the muscle tissue immediately frozen. On return to the laboratory all samples were freeze-dried. POM samples were also frozen immediately after sampling, but were defrosted in the laboratory and centrifuged to reduce the water content before re-freezing and freeze-drying the supernatant. All samples were ground and subsequently analysed for ^{13}C and ^{15}N in addition to total C and N at Waikoto Stable Isotope Unit, Department of Biological Sciences, University of Waikato, Hamilton, New Zealand.

The results were calculated as delta values, which are expressed as deviation from standard reference material (stable isotope ratio) where
$\delta X = [(R_{sample}/R_{std})-1] \times 1000$;
$X = {}^{13}C$ and ${}^{15}N$;
$R = {}^{13}C/{}^{12}C$, ${}^{15}N/{}^{14}N$.
The standards used were Canyon Diablo Troilite limestone and nitrogen in air, respectively.

Stable isotope concentrations from species sampled at all five localities were statistically analysed using separate two-way ANOVA's with site and species as the main effects. The data were tested for homoegeneity of variances using the Fmax – test.

Table 2. I. Species collected for stable isotope analysis.

Invertebrates	Teleosts	Elasmobranchs
Ascidian *Polycarpa viridis*	Southern silverbelly *Parequela melbournensis*	Great White shark *Carcharodon carcharis*
Ascidian *Phallusia obesa*	Mosaic leatherjacket *Eubalichthys mosaicus*	Wobbegong *Orectolobus maculatus*
Scallop *Equichlamys bifrons*	Red mullet *Upeneichthys lineatus*	Stingray *Dasyatis brevcaudata*
Bearded mussel *Trichomya hirsutu*	Soldierfish *Gymnapistes marmoratus*	Elephant fish *Callorhinchus milii*
Plankton, small (P(s))	Snapper (juvenile) *Chrysophrys auratus*	Port Jackson shark *Heterodontus portusjacksoni*
Plankton, large (P(l))	Flounder *Ammotretis lituratus*	Angelshark *Squatina australi*
Sealice *Natatolana woodjonesi*	Flathead *Platycephalus bassensis*	
Seacucumber *Stichopus ludwigi*	Sand Trevally *Pseudocaranax wrighti*	
File shell *Lima lima*	Degens leatherjacket *Thamnoconus degeni*	
Strawberry prawn *Pandalidae sp.*	Spiny gunard *Lepidotrigla papilio*	
Morton Bug *Inacus alticrenatus*	Rough leatherjacket *Scobinichthys granulatus*	
Blue crab *Portunus pelagicus*	Porcupine fish *Diodon nicthemerus*	
Sponges	Pilchard *Sardinops neopilchardus*	
Prawn *Penaeus latisulcatus*	Striped Trumpeter *Pelates octolineatus*	

Results

The species that were analysed for the stable isotopes ^{13}C and ^{15}N are listed in Table 2. I. All samples were replicated three times using different individuals. The listed species represent different anticipated trophic levels constituting plankton, filter feeders (ascidians, bivalves), plankton feeders, deposit feeders, benthic crustaceans, teleosts and elasmobranchs with the great white shark represented by a single sample.

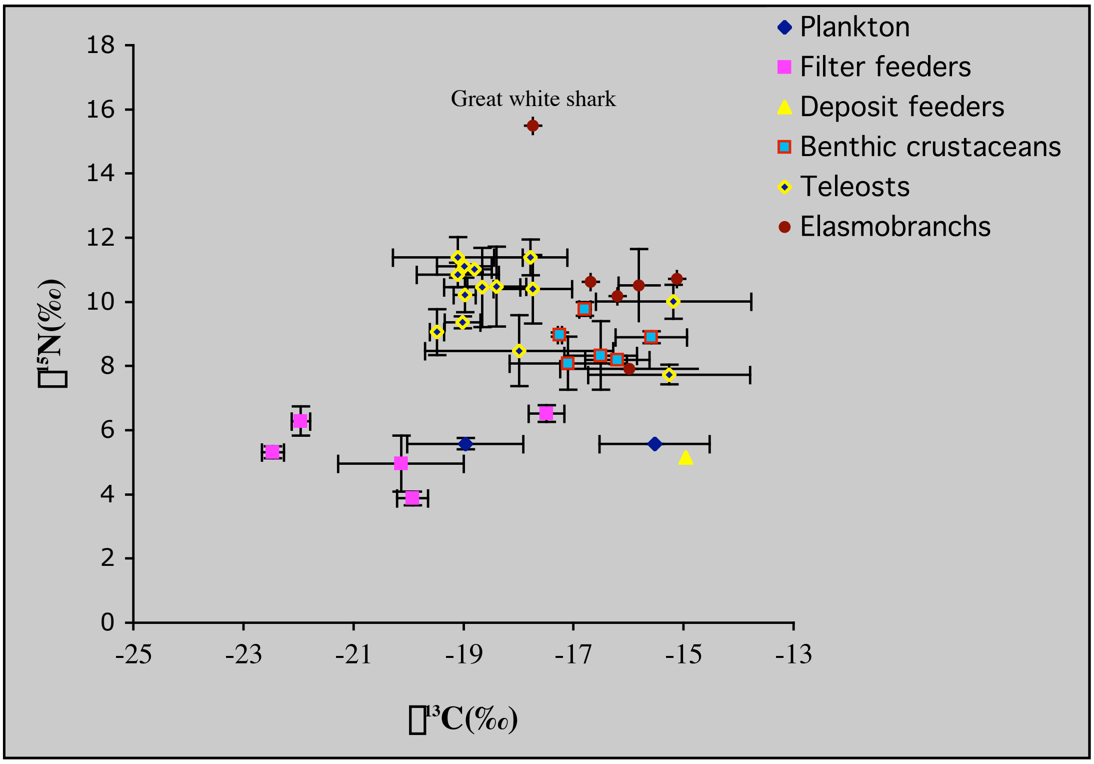


Fig. 2.1. Relationship of the stable isotopes ^{13}C and 1^{5}N of various species in the Spencer Gulf. N=3 but for White Pointer N = 1. Error bars are 95% CI.

The result of the overall analysis of stable isotopes is shown in Fig. 2.1, which display the relationship of the stable isotope ^{13}C and ^{15}N. A large variation within many species is evident but the data group into four clusters with the lowest values consisting of plankton and filter feeders and the highest elasmobranchs (sharks and rays). However, an overlap between the different groups indicates that many of the species share a common food source and most can be considered generalists. Not surprisingly, the great white shark was found to occupy the top of the food chain (N=1). Three species were collected at all five stations in order to test for spatial variability, these were Degens leatherjacket, blue crab and prawn. The result of a three way ANOVA on δ^{13}C and δ^{15}N is shown in Table 2. II. Both δ^{13}C and δ^{15}N showed a significant effect of species and no significant effect of site with significant interactions for δ^{15}N but not for δ^{13}C.

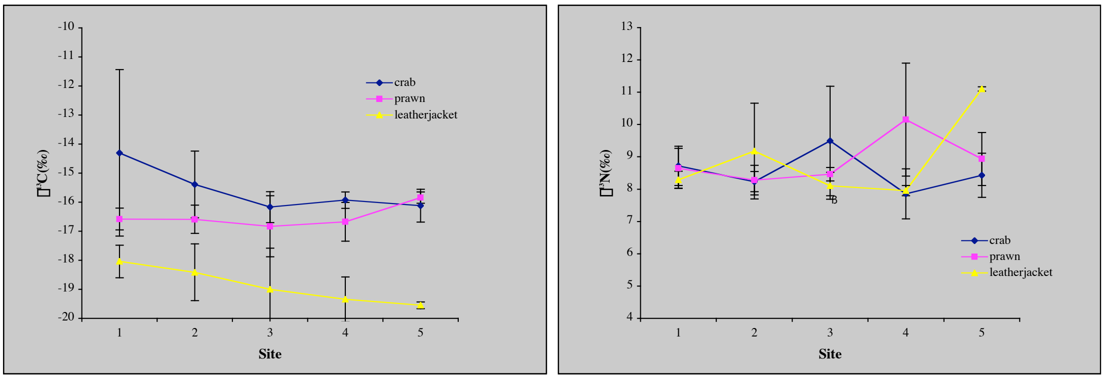


Fig. 2.2. Interaction graphs showing effects of species and site for δ^{13}C (left) and δ^{15}N (right), respectively. Error bars are 95% CI.

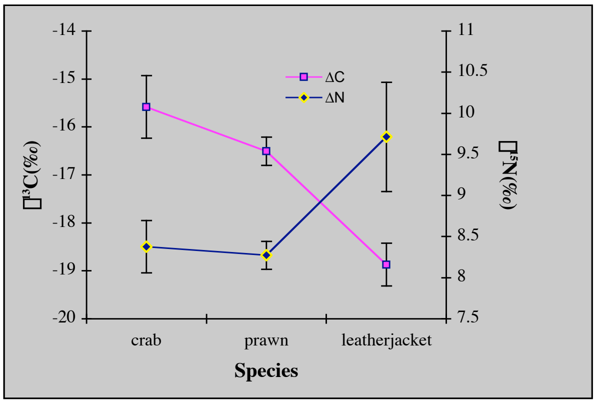


Fig. 2.3. Stable isotope (C, N) composition for blue crab, prawn and leatherjacket in the Spencer Gulf. Error bars are 95% confidence levels. Sample size N = 15.

Table 2. II. Result of a two-way ANOVA on the distribution of δ^{13}C (stable isotope ratio) with site and species as the main effects. * $P<0.05$, ns = not significant

Source	df	SS	MS	F	P
Species	2	86.305	43.152	51.659	0.001*
Site	4	6.851	1.713	2.050	0.1125 ns
Species * Station	8	7.006	0.876	1.048	0.4237 ns
Residual	30	25.060	0.835		

Result of a two-way ANOVA on the distribution of δ^{15}N (stable isotope ratio) with site and species as the main effects. * $P<0.05$, ns = not significant

Source	df	SS	MS	F	P
Species	2	19.365	9.683	16.545	0.0001*
Site	4	2.997	0.749	1.280	0.2977 ns
Species * Station	8	10.631	1.329	2.271	0.0496 *
Residual	30	17.556	0.585		

This indicates that trophic levels are different among the three investigated species but not affected by site of collection and can accordingly not be correlated to different trawling intensities or by-catch load. Fig. 2.2 shows the interaction graphs of the two variables, species and site for δ^{13}C and δ^{15}N, respectively. Blue crab has a consistent higher δ^{13}C than prawn and Degens leatherjacket. No significant differences between sites are evident. A significant effect of species was also found for δ^{15}N (Table 2. II. Fig. 2.2, right) but no effect of site is evident. However, interference between species concealed any patterns of difference for δ^{15}N giving significant interactions making the result inconclusive (Table 2. II).

The stable isotope signal clearly separate leatherjackets from blue crab and prawn, respectively (Fig. 2.3). Degens leatherjacket is an important daytime scavenger on discarded by-catch but also a generalist utilising numerous food sources high in proteins relative to carbohydrates giving the species a relatively high trophic position. Prawns on the other hand are not scavengers and feed primarily on meio-fauna found between sand grains of the bottom top sediment. As a consequence, prawns appeared to occupy a relatively low trophic position (Fig. 2.2 & 2.3). Surprisingly, blue crabs have a similar stable isotope pattern as prawn but with a slightly higher C content. SNK tests revealed that for δ^{13}C all species were significantly different while for δ^{15}N, leatherjackets was found to be significantly different from prawn and crab but crab and prawn were not significantly different. This indicates that by-catch only play a minor role in the diet of blue crabs and that crab and prawn differ only slightly in diet. Carbon isotopic compositions showed little change with trophic level, and an apparent diversity of phytoplankton carbon isotopic inputs at the base of the food web complicated the use of δ^{13}C to estimate trophic position (Fig. 2.4). Nitrogen isotopic distributions were, however, robust measures of tropic position and showed only three broad trophic levels estimated using a 3-4% increase per trophic level (Fry 1988). The Great White Shark and un-sampled large top carnivores represented the fourth and fifth trophic level. The trophic groups “filter feeders” and “teleosts” as shown in Fig. 2.4, right, are each probably two levels. These results show that the Spencer Gulf ecosystem have a complicated food web structure and accommodate a large number of generalist with a broad diet.

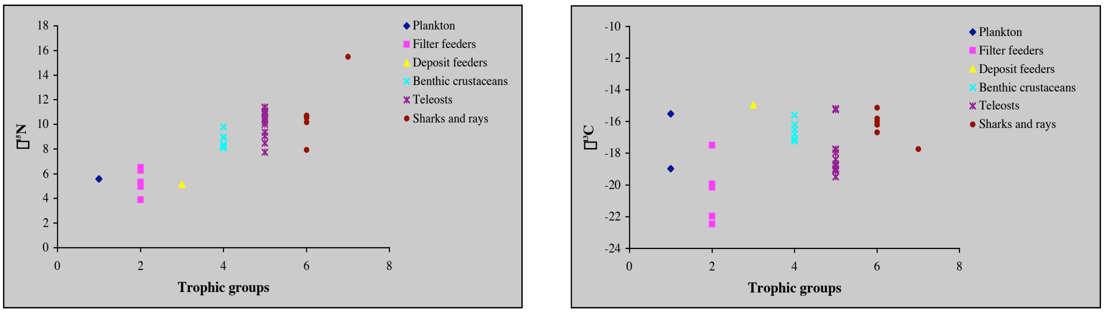


Fig. 2.4. Trophic level estimates for the Spencer Gulf using δ^{15}N and δ^{13}C. Points are mean values of species.

Discussion

Food web characterisation is an initial step in understanding an ecosystem by specifying the number of species interactions or links but their usefulness and validity can be questioned due to effects of spatial, temporal and taxonomic resolution (Hall & Raffaelli 1993, Link 2002). Particular marine food webs have shown to be inconsistent with the general theory and seem to be limited by weak interconnectivity and species interactions (Raffelli 2000). Recently, even the fundamental mechanistic view of defining natural habitats as closed and self-regulating ‘ecosystems’ has been challenged (Neill 2001). Ecosystems may be defined by functional groups rather than species list but are disequilibrial, hierarchical, spatial variable, open and affected by dispersal from outside. Ecosystems are consequently not stable and show a high degree of spatial and temporal dynamics with boundaries difficult to define.

The Spencer Gulf ecosystem is not an exception from the above difficulties and the results from this study indicated a high degree of interconnectivity among a large number of generalist species with a broad diet covering more than one trophic level. Only a relatively limited number of species are included in the analysis here but they represent a magnitude of sizes and trophic levels. Whether the interconnectivity in the system allows for larger stability is unclear (see Link 2000). It is difficult to measure stability and consequently sustainability of the Spencer Gulf ecosystem, including the fished ecosystem, with a model analysis of biomass fluxes because it is not possible to specify with any scientific rigor the anthropogenic effects, which may have altered the stability properties of the system.

The basis of using isotopic measurements to study trophic structure lies in documenting a regular and consistent pattern of isotopic enrichment with increasing trophic level. In this study, isotopic enrichment with increasing trophic level was evaluated by analysing a variety of fish and invertebrates of known trophic habits. For carbon δ^{13}C and nitrogen δ^{15}N heavy isotope enrichment occurs between animals and their foods. Heavy isotope ^{13}C enrichment is estimated at about 1‰ per tropic level for carbon and ^{15}N enrichment at 3-4‰ for nitrogen (Fry & Sherr 1984, Fry 1988, Jennings *et al.* 1997). However, such a generalisation does not seem to apply to more open systems and large within species variation may be evident (Boyce *et al.* 2001, Doucett *et al.* 1996).

In general most δ^{13}C increase occurs early in the food web making δ^{13}C and δ^{15}N poorly correlated (Fry 1988). An increase in δ^{13}C for primary consumers is believed to be 1‰, for secondary consumers 2‰ and for top predators 3‰ (Doucett *et al.* 1996). The results from this study showed that δ^{13}C enrichment was inconsistent across trophic levels while δ^{15}N enrichment increased consistently with trophic position (Fig. 2.4). The δ^{15}N values reported in the literature (reviewed by Thomas & Cahoon 1993) are for planktivores 10.2 to 11.2‰, opportunistic generalists 10.2 to 13.0‰, piscivores 11.2-15.2‰, and demersal fish 13.5-14.9‰. The Spencer Gulf fishes have δ^{15}N values within the range of 7.73-11.39‰ (striped trumpeter-sand trevally) indicating that a number of fishes are present that feed at lower levels of the food chain and possible seagrasses. Within each group a considerable overlap is evident calling for further investigations into these species role in the food chain.

Loneragan *et al.* (1997) found for the offshore prawns *Penaeus merguiensis*, *P. esculentus*, and *P. semisulcatus* (CL 25-35 mm) from the Gulf of Carpentaria that δ^{13}C ranged from –17 to 14‰, with a difference between season and size. The δ^{15}N values ranged from 5.2 and 10.0‰ without any marked trend with season and size-class. The δ^{13}C values found in offshore prawns are also consistent with the primary source being benthic microalgae, which are thought to be an important source for marine food webs (Newell *et al.* 1995). These results confirm that mangrove/terrestrial carbon makes a minor contribution to the food web supporting prawns in coastal waters. This study has shown that benthic crustaceans (prawn, blue crab, Moreton Bay Bug) broadly share the same food source and with a stable isotopic composition within the range found for tropical prawns by Loneragan *et al.* (1997).

In order to separate the various teleosts and elasmobranchs in a food web, sampling of all year classes associated with stomach content analyses is required in order to obtain information of the food source as well as assimilation. An obvious confounding element is that most species studied appear to be generalist indicated by the large within species variation (Fig. 2.1). This variation is not shown in Fig. 2.4, where each point represents the mean (N=3).

Thomas & Cahoon (1993) studied five reef-associated fish from the North Carolina continental shelf ecosystem with different positions within the food chain and found mean δ^{15}N values of 10.1 to 11.0‰, which is within the upper part of the range reported here for teleosts. This indicates that the Spencer Gulf fishes measured in this study have a broader diet than the one reported by Thomas & Cahoon (1993). The reef fishes studied represented one trophic level (secondary consumers) but the studied fish were classified as pelagic (zooplankton, pelagic prey) and benthic feeders. Only when using a third stable isotope δ^{34}S it was possible to separate the groups.

The Spencer Gulf ecosystem is an open system with a large temporal biomass flux, which makes it difficult to interpret large-scale studies of stable isotope distribution. Although a large number of papers on the application of stable isotope analyses to ecological research have been published, this field of research is still in its infancy (Hobson & Wassenaar 1999). Our results suggest that that it is difficult to make reliable and non-trivial generalisations about feeding patterns without spatial and temporal replication on a number of scales using several year classes in an experimental design.

References

Boon, P.I. & S.E. Buun 1994. Variations in the stable isotope composition of aquatic plants and their implications for food web analysis. Aquatic Bothany 48: 99-108.

Boyce, M.C., lavery, P., Bennett, I. & P. Horowitz 2001. Spatial variation in the δ^{13}C signature of *Ruppia megacarpa* (Mason) in coastal lagoons of southwestern Australia and its implication for isotopic studies. Aqua. Bot. 71: 83-92

Doucett, R.R., barton, D.R. Guiguer, K.R.A., Power, G. & R.J. Drimmie 1996. Comment: Critical examination of stable isotope analysis as a mean for tracing carbon pathways in stream ecosystems. Can. J. Fish. Aquat. Sci. 53: 1913-1915.

Fry, B. 1988. Food web structure in George's Bank from stable C, N and S isotopic compositions. Limnol. Oceanogr. 33: 1182-1190.

Fry, B. & E. Sherr 1984. Delta 13 C measurements as indicators of carbon flow in marine and freshwater ecosystems. Contrib. Mar. Sci. 27:13-47.

Hall, S.J. & D.G. Raffaelli 1993. Food webs: theory and reality. Adv. Ecol. Res. 24: 187-236.

Hobson, K.A. & L.I. Wassenaar 1999. Stable isotope ecology: an introduction. Oecologia 120: 312-313.

Jennings, S., Reñones, O., Morales-Nin, B., Polunin, N.V.C., Moranta, J. & J. Coll 1997. Spatial variation in the ^{15}N and ^{13}C stable isotope composition of plants, invertebrates and fishes on Mediterranean reefs: implications for the study of trophic pathways. Mar. Ecol. Prog. Ser. 146: 109-116.

Link, J. 2002. Does food web theory work for marine ecosystems? Mar. Ecol. Prog. Ser. 230: 1-9.

Loneragan, N,R., Brunn, S.E. & D.M. Kellaway 1997. Are mangroves and seagrasses sources of organic carbon for penaeid prawns in a tropical Australian estuary: A multiple stable isotope study. Mar. Biol. 130: 289-300.

Lajtha, K. & R,H, Michener 1994. Stable isotopes in ecology and environmental science. Blackwell Scientific Publications, London.

Newell, R.I.E, marshall, N. Sasekumar, A. & V.C. Chong 1955. Relative importance of benthic microalgae, phytoplankton and mangroves as source of nutrition for penaeid prawns and other coastal invertebrates from Malaysia. Mar. Biol. 123: 595-606.

Neill, R.V. 2001. Is it time to bury the ecosystem concept? (With full military honors, of course!). Ecology 82: 3275-3284.

Peterson, B.J. & B. Fry 1987. Stable isotopes in ecosystem studies. Ann. Rev. Ecol. Sys. 18: 293-320.

Raffaelli, D. 2000. Trends in research on shallow water food webs. J. Exp. Mar. Biol. Ecol. 250: 223-232.

Thomas, C.J. & L.B. Cahoon 1993. Stable isotope analyses differentiate between different trophic pathways supporting rocky-reef fishes. Mar. Ecol. Prog. Ser. 95:19-24.

Chapter 3: Quantitative Benthic Surveys of the Spencer Gulf: Biomass, Diversity and Production

Ib Svane

Abstract

A quantitative survey of the benthic assemblages of the Spencer Gulf using a 3.2-meter wide dredge has been undertaken in order to characterise the abundance and distribution of macro fauna in comparison with by-catch of prawn trawling. Sampling was undertaken at five sites, which can be characterised as "fished ecosystems" previous exposed to different trawling pressure. The selected sites were distributed from 8 nautical miles south of Whyalla to the central part of the gulf (the Gutter). The physical characteristics of the benthic environment are different between the studied sites dominated by sandy to coarse gravel bottoms that are exposed to relatively strong tidal currents. Biomass varied significantly between sites, season and fauna type where the fauna group "sessile benthos" showed the highest values followed by mobile epifauna. Pelagic and demersal fish constituted only a small fraction of the total biomass. A reduction in biomass from the two northern sites towards the Gutter is evident with the lowest levels in the high current environments off Middle Bank and in the Gutter. The lowest biomass values were found in March (late summer) and the highest in September (spring). A consistent pattern of seasonal growth of sessile benthos was evident with the highest value of 4.1 mg AFDW/m^2/yr at the northern site while negative growth was observed for pelagic and demersal fish at all sites from March through September. Mobile epifauna showed consistently negative growth at Site 3 and 5. The total mean benthic productivity showed that the most productive site is Site 1 (Western Shoal) 8 Nm south of Whyalla and Site 2 (Plank Pt.) with 4.14 and 3.18 mg AFDW/m^2/yr, respectively. Diversity at all sites was found to be relatively low varying between 12 and 27 species. Species diversity (Simpson Index of Diversity/Eveness) was fairly even among sites with the exception of Site 1 (Western Shoal), which was dominated by large patches of the bearded mussels (*Trichomya hirsutu*). A high degree of patchiness in species distribution in the Spencer Gulf is evident. It was concluded that distribution and abundance of sessile fauna was negatively correlated with historical trawling exposure. Only little significance can be attached to this correlation because the five sites are different environments with different physical and biological characteristics making it difficult to separate effects of trawling from natural variability.

Introduction

There is a large volume of literature on quantitative studies of marine soft sediment assemblages reporting decades of research primarily from the Northern Hemisphere (e.g. Gray 1974, Buchanan & Moore 1986, Frid *et al.* 1999, Currie & Parry 1996, Trush *et al.* (2001) while quantitative studies of marco-epifauna and flora on hard substrata including hard coarse sandy or gravel bottoms are relatively rare. The reason being that classic methodology using grab sampling on these types of bottoms is inefficient, due to the high levels of spatial heterogeneity in distribution and abundance, the physical nature of the substrata, and the lack of alternative methods (see Thouzeau *et al.* 1991).

The bottoms of the Spencer Gulf, South Australia, are sandy and in many places with strong tidal currents the sediments are coarse sand and gravel in ripples or patches. In many areas the coarser grains are covered with rhodoliths forming so-called “popcorn bottoms”. Dredging is probably the best quantitative sampling of macro fauna on these types of bottoms. However, this allows only for sampling of larger macro fauna leaving infauna and meiofauna un-sampled.

The use of dredges in fishery is in most cases within scallop and shrimp fishery (Eleftheriou & Robertson 1992). The sampling efficiency is high because a dredge scrape-off the top layer of sediment and retain close to 100% of the macro epifauna. It is a destructive practice and the impacts on benthic epifaunal assemblages are high (Caddy 1973). However, a prawn trawls are considerable lighter with less impact.

Dredging as a method is not strictly quantitative because of variation in the topography of the bottoms and variation in speed and length of tow and secondly, only large macro-fauna and flora are retained in a dredge while sediment living organisms are disregarded. The use of standard photography and video techniques has limitations because of difficulties in obtaining adequate taxonomic resolution and obtain estimates of biomass (see Cohen *et al.* 2000). However, these problems are not believed to be of fundamental importance for this study when combined with the method of diver-operated underwater stereophotography, which allows for a three-dimensional view of the bottom that substantially increases taxonomic resolution compared with two-dimensional photography (Lundälv 1971, Svane 1988). The study using stereophotography is reported in Chapter 3.

The purpose of this study was to estimate distribution, abundance and biomass of the macro benthic epifauna/epiflora at five trawled sites in the Spencer Gulf and compare the data quantitatively with the by-catch of the prawn fishery. Studies on the distribution and abundance of benthic organisms in the Spencer Gulf have not previously been undertaken so no comparative data are available. The selected sites can be defined as “fished ecosystems” previous exposed to different trawling pressure. Two of the sites (3 and 4) are high-energy environments with strong tidal currents and the bottoms are coarse sand and gravel. The remaining three sites are characterised by sandy sediments.

Material & Methods

Sampling

On three occasions (June 99, October 99, and March 00) dredging were performed during day at all five stations (see Chapter 1) in order to obtain estimates of benthic macro-fauna abundance and distribution, which are likely to constitute by-catch during prawn trawling. The dredge used was 3.2 meter wide and had a vertical opening of one meter. A net bag was fitted to the frame with a coarse diamond mesh size of 45 mm close to the frame while the cod end had a smaller mesh size due to constriction of the diamond mesh (Fig. 3.1). The dredge was on each side equipped with metal "skids" allowing the lower beam of the frame to scrape the bottom surface.

At each station and sampling event, three haphazardly selected transects were sampled. The distances sampled (towing distance) were calculated using differential GPS and varied between 700-1200 meters at a maximum speed of max 2 knots. The depth at all five stations varied between 21-33 meters.

Fig. 3.1. Dredge used for sampling benthic macro-fauna in the Spencer Gulf.

Biomass

The collected material was on deck separated to nearest taxonomical group, counted, measured and weighted before being bagged and frozen. Sponges were not identified and the cryptofauna was not extracted. Biomass and productivity values were expressed as ash-free dry weight (AFDW), the difference between animal (shell-free) dry weight (after drying to constant weight at 105 ^{O}C for 24 hours) and inorganic weight (ashed at 500 ^{O}C for 2 hours). In the laboratory, dry weight (DW) and AFDW for quantitatively important groups was estimated by length-weight regression calculated for each species using a subset of various sizes. DW and AFDW were estimated by drying and combustion but for minor groups with few individuals weight-to-weight conversion factors were used (Ricciardi & Bourget 1998).

The biomass data was separated according to three faunal groups: pelagic and demersal fishes, mobile epifauna, and sessile benthos.

Diversity

Species diversity was calculated as Simpson's Index of Diversity (1-D) and evenness (D/Dmax). Jacknife estimates were calculated of species richness for quadrant sampling in order to obtain 95% confidence intervals (Krebs (1989). The latter analysis was carried out for comparison because no rigorous test for diversity indices is available.

Production

Fauna group production for all five sites was estimated as the slope of the regression line calculated on biomass estimates using March 2000 values as day 55, June 1999 as day 166, and September 1999 as day 258. These values represent assemblage production as a function of time disregarding mortality, migration and immigration and were calculated for the purpose of comparison between sites.

Statistics

The sampling program was designed to be statistical analysed using a three-way ANOVA with station, season and faunal group (type) nested within site as the main effects. Homogeneity of variances was tested using the Fmax-test. To obtain homogeneity of variances the data were log (x+1) transformed prior analysis. Student-Newman-Keul Test was applied for multiple comparisons.

Results

Benthic Biomass

The result of a nested analysis of variance (ANOVA) on biomass with site, season and fauna type as the main effects is shown in Table 3. I.

Table 3. I. The results of a three-way ANOVA on biomass (AFDW mg/m^2). The table shows the main effects of site (5), season (3) and fauna type (3) nested within Site. Data were log(x+1) transformed prior analysis to obtain homogeneity of variances.

Source	df	SS	MS	F	P
Site	4	27.059	6.765	25.094	0.0001
Season	2	5.418	2.709	10.050	0.0001
Fauna type (Site)	10	38.444	3.844	14.261	0.0001
Site*Season	8	5.536	0.692	2.567	0.0132
Residual	110	29.653	0.270		

Effects of Site

The biomass distribution at the five studied sites in the Spencer Gulf was found to be significantly different (Fig. 3.2 A). The two most northern sites (Site 1: Western Shoal, Site 2: Plank Pt.) had the highest biomass with a mean of about 250 mg AFDW/m^2. Site 3 (Middle Bank) showed the lowest values while Site 4 (off Wallaroo) and 5 (The Gutter) had biomass values of 50-100 mg AFDW/m^2. An SNK-test confirmed this pattern showing that there is no significant difference between Site 1 and 2 and between Site 4 and 5 while Site 3 was uniquely different from all other sampled sites (Table 3. II, Fig. 3.2 A).

Effects of Season

The seasonal pattern of biomass distribution is shown in Fig. 3.2 B. A significant effect of season was found (Table 3. I). The lowest biomass values were observed in March (late summer) increasing through June (winter) and September (spring). The SNK-test showed significant differences between all seasons confirming the observed pattern of seasonal variation in production (Table 3. II).

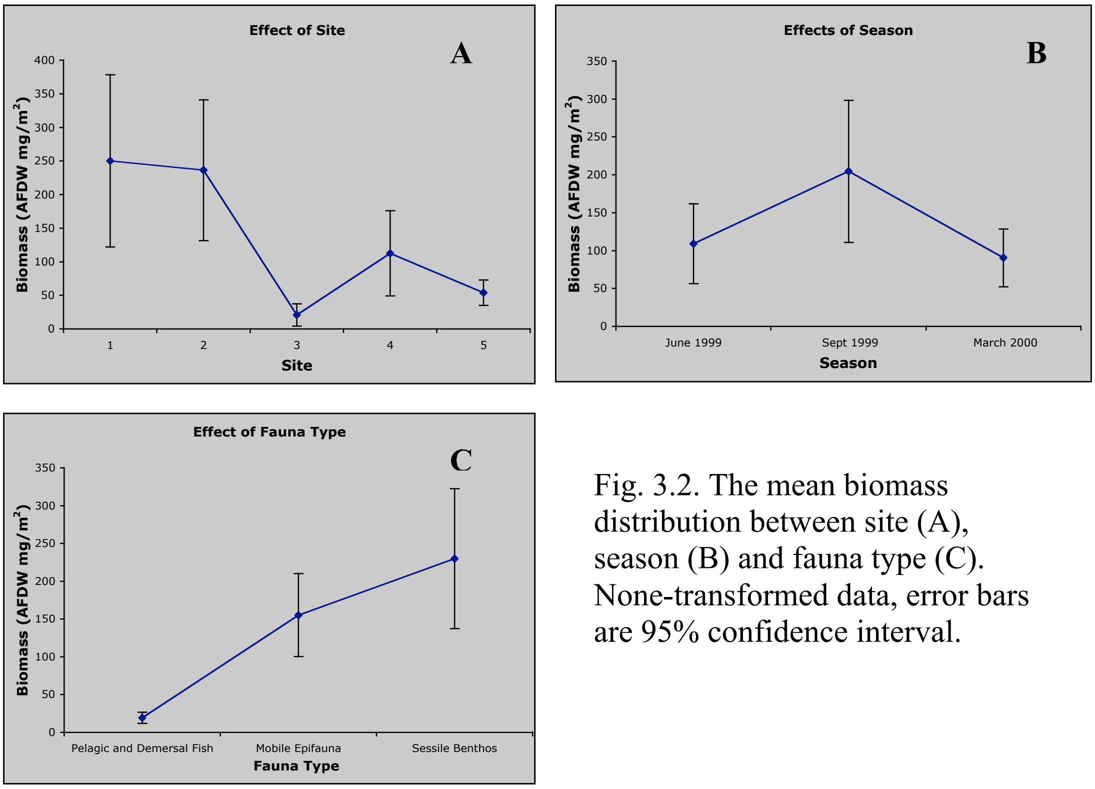


Fig. 3.2. The mean biomass distribution between site (A), season (B) and fauna type (C). None-transformed data, error bars are 95% confidence interval.

Table 3. II. Student-Newman-Keul Test (** = p<0.05) showing significance levels between sites and seasons. Biomass log (x+1) transformed data.

Effects of Site	Vs.	Diff.	Crit. Diff.	Significance
Site 1	Site 2	0.170	0.280	ns
	Site 3	1.129	0.370	**
	Site 4	0.247	0.280	ns
	Site 5	0.353	0.336	**
Site 2	Site 3	1.298	0.393	**
	Site 4	0.416	0.336	**
	Site 5	0.523	0.370	**
Site 3	Site 4	0.882	0.36	**
	Site 5	0.775	0.280	**
Site 4	Site 5	0.107	0.280	ns
Effects of Season				
June 99	March 00	0.244	0.217	**
	Oct 99	0.491	0.261	**
March 00	Oct 99	0.247	0.217	**

Effects of Fauna Type

The biomass distribution among fauna types is shown in Fig. 3.2 C. A significant effect of fauna type was found (Table 3. I). Pelagic and demersal fish constituted a small fraction of the total biomass (19 mg AFDW/m^2) while mobile epifauna and sessile benthos constituted 155 and 229 mg AFDW/m^2, respectively. An SNK-test showed significant differences between all three fauna groups (Table 3. II).

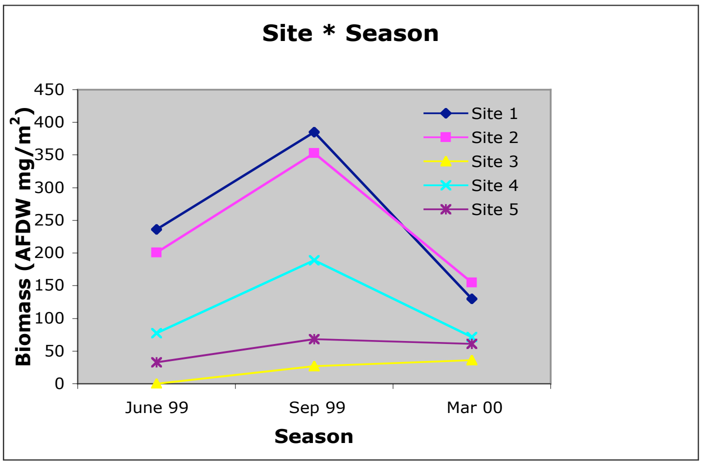
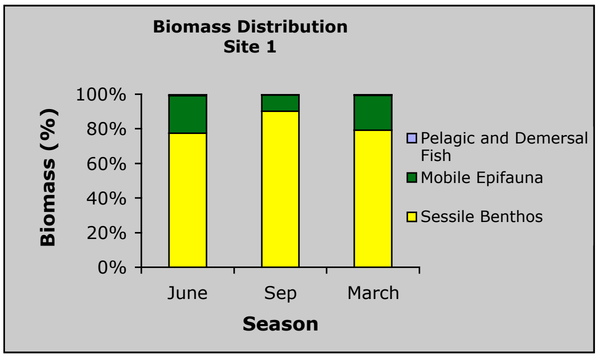
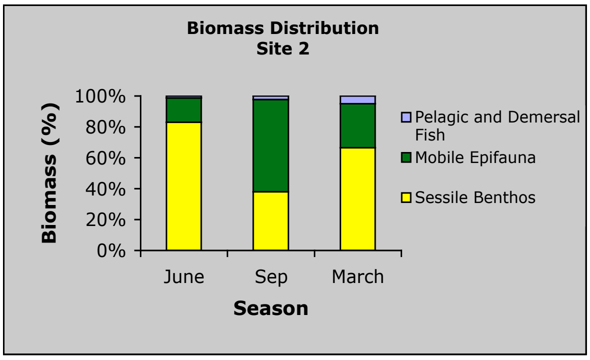


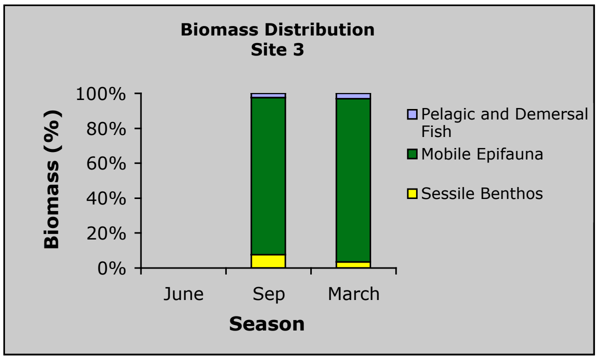
Fig. 3.3. Interaction graphs separating effects of site, season and fauna type.

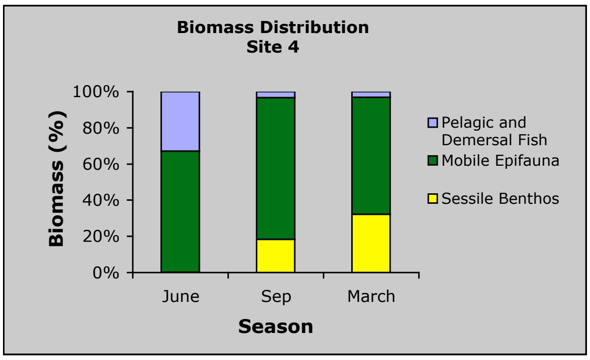
Variation and Interaction

A substantial variation in the data set was evident but log (x+1) transformation stabilised the variance allowing the use of a nested three-way ANOVA. The variance at the lowest statistical level (transect) was relatively high due to patchiness and significant levels of interactions among the major effects, Site and Season, was evident (Table 3. I). The interactions of Site *Season is shown in Fig. 3.3 are caused firstly by interference at Site 1 and 2, and secondly by the pattern of successive lower biomass values further south in the Gulf. The significant effect of season is clearly carried by the larger biomass values at Site 1 and 2. However, the significant interaction did not change the overall patterns and conclusions. Interactions between fauna type one hand and site and season on the other was not considered because fauna type is dependent on site and subsequently nested in the statistical analysis.









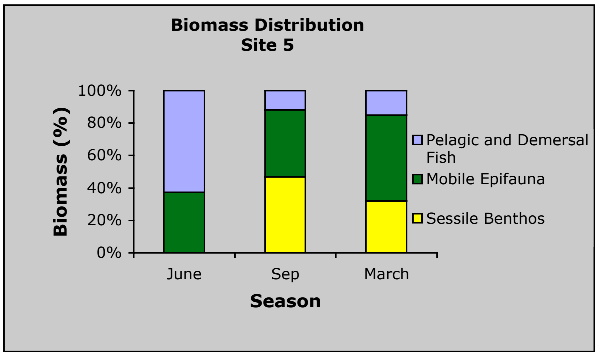


Fig. 3.4. The mean percentage distribution of fauna types at the five studied sites.

Biomass Distribution between Site and Season

Detailed patterns of the relative biomass distribution of fauna types among sites and seasons are shown in Fig. 3.4. These graphs show the percentage distribution of fauna types at the five studied sites substantiating the results of the ANOVA. Sessile benthos dominated the biomass at the two northern sites 1 (Western Shoal) and 2 (Plank Pt.) (Fig. 3.4). Towards Site 3 (Middle Bank) the biomass became successively dominated by mobile epifauna, which subsequently constituted more than 90% of the biomass at Site 3. Further south, the distribution of biomass among fauna type became more even. The pattern of relative distribution of fauna type biomass between seasons is consistent with sessile benthos as the major contributor followed by mobile epifauna while the biomass of pelagic and demersal fish is low at all seasons. Seasonal variation in biomass of sessile benthos and mobile epifauna is the major contribution to the significant effect of season (Table 3. II, Fig. 3.2, Fig. 3.4).

Detailed patterns of the total biomass distribution of fauna types among sites at the three studied seasons are shown in Fig. 3.5. The overall pattern of a reduction in biomass from north (Site 1 and 2) to south (Site 4 and 5) with the lowest values at

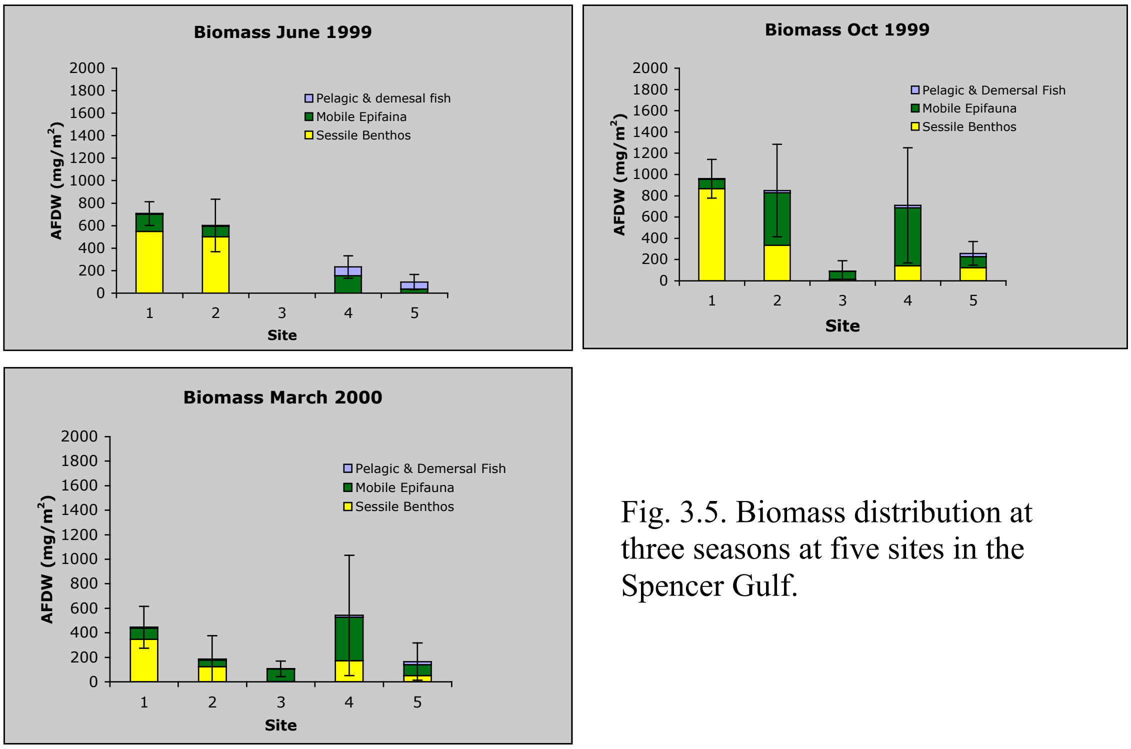


Fig. 3.5. Biomass distribution at three seasons at five sites in the Spencer Gulf.

Middle Bank (Site 3) is evident. Variations among fauna groups are primarily seasonal but a high degree of patchiness at each site (transect) induced natural variance.

Biomass Distribution among Fauna Types and Species

Sessile benthos comprised in general the overwhelming majority of the biomass at Site 1 and 2 with values of 60-80% (Table 3. IV). Sponges and clumps of the Mytelid *Trichomya hirsutu* (bearded mussel) dominated the samples of sessile benthos from these two northern sites. The remaining fauna component constituted primarily mobile epifauna dominated by the blue swimmer crab *Portunus pelagicus*. The bottoms at Site 1 and 2 were sandy with some silt. The turbidity of the water was generally high and had a whitish appearance especially during windy conditions.

At Site 3, west off Middle Bank, mobile epifauna consistently dominated the dredged macro fauna with 80-90% (Table 3. IV). The two major fauna component was the blue swimmer crab and prawns (*Melicertus latisulcatus*). Unfortunately, no data are available from June 1999 due to bad weather and destruction of the dredge. The bottom at Site 3 was coarse sand/gravel reflecting the strong tidal currents.

Further south off Wallaroo (Site 4) and The Gutter (Site 5), the biomass of mobile epifauna constituted between 40-70% and with the remaining biomass dominated by sessile benthos. However, at Site 5 pelagic and demersal fish constituted a significant part of the biomass consisting primarily of schooling leatherjackets, notably *Thamnoconus degeni* (Degens leatherjacket) (Table 3. IV). The bottom at Site 4 was mixed sand and gravel while Site 5 was sandy with little variability.

Table 3. III. Estimated mean annual density, biomass and productivity of pelagic and demersal fish, mobile epifauna and sessile benthic fauna at five sites in the Spencer Gulf.

Site	Faunal group	Density		Biomass		Productivity			
		(ind/m^2)		(mg AFDW/m^2)		(mg AFDW/m^2/yr)			
		Mean	%	Mean	%	Mean	%	Mean	%
Site 1	Pel. Dem. Fish	0.0013	0.4	4.922	0.2	-0.04	-0.5		
	Mobile Epi	0.0105	2.9	113.056	5.6	0.16	2.0		
	Sessile Ben	0.1761	49.1	632.661	31.3	4.01	51.0		
	Total							4.14	46.2
Site 2	Pel. Dem. Fish	0.0028	0.8	18.621	0.9	-0.06	-0.8		
	Mobile Epi	0.0079	2.2	285.949	14.1	2.73	34.7		
	Sessile Ben	0.0912	25.4	404.041	20.0	0.51	6.5		
	Total							3.18	35.5
Site 3	Pel. Dem. Fish	0.0005	0.1	1.783	0.1	-1.05	-13.4		
	Mobile Epi	0.0050	1.4	57.853	2.9	-0.15	-1.9		
	Sessile Ben	0.0078	2.2	3.325	0.2	0.01	0.1		
	Total							-1.18	-13.2
Site 4	Pel. Dem. Fish	0.0093	2.6	33.729	1.7	-0.08	-1.0		
	Mobile Epi	0.0055	1.5	246.026	12.2	1.67	21.2		
	Sessile Ben	0.0279	7.8	57.987	2.9	0.2	2.5		
	Total							1.78	19.9
Site 5	Pel. Dem. Fish	0.0106	2.9	37.755	1.9	-0.18	-2.3		
	Mobile Epi	0.0019	0.5	72.768	3.6	-0.07	-0.9		
	Sessile Ben	0.0006	0.2	51.524	2.5	0.2	2.5		
	Total							-0.04	-0.4
Total	Pel. Dem. Fish	0.0245	6.8	96.81	4.8	-1.41	-17.9		
	Mobile Epi	0.0308	8.6	775.65	38.4	4.34	55.2		
	Sessile Ben	0.3036	84.6	1149.54	56.8	4.93	62.7		
Grand Total		0.3589	100	2022.0	100	7.86	100		

Density, Biomass and Productivity

The mean densities, biomass and productivity are shown in Table 3. III. The largest density of individuals was found at Site 1 and 2 where sessile benthos constituted 49.1% and 25.4%, respectively (Table 3. III). At Site 4 and 5, a largest occurrence in terms of number of individuals of pelagic and demersal fish were sampled with 2.6% and 2.9%, respectively, of the total number of individuals (Table 3. III). In general, the mean density of individuals (ind/m^2) was low at all sites with the highest density at Site 1 of 0.18 ind/m^2. The area covered by any one transect varied between 2400 to 9000 m^2 influenced by weather and tides.

The spatial distribution of mean biomass values to a large extent reflects the mean density with the highest biomass values at Site 1 and 2 dominated by sessile benthos and mobile epifauna (Table 3. III). However, biomass values were generally low and the highest values were found at Site 1 and 2 with about 700 mg/m^2. Further south the biomass did not exceed 300 mg/m^2 and was as low as about 60 mg/m^2 at Site 3.

Productivity was calculated by linear regression of the biomass variation during the seasons March-June-September (Table 3. III). The linear fit at Site 1, 2 and 4 was statistically acceptable ($r > 0.70$, $n = 9$). The results show a consistent pattern of seasonal growth of sessile benthos with the highest value of 4.1 mg AFDW/m^2/yr at Site 1. Consistent negative growth was observed for pelagic and demersal fish at all sites indicating a trend towards reduced biomass from March through September of this fauna group. Mobile epifauna showed consistently negative growth at Site 3 and 5 following the pattern observed for pelagic and demersal fish (Table 3. III). The total mean benthic productivity including pelagic and demersal fish showed that the most productive site is Site 1 (Western Shoal) 8 Nm south of Whyalla and Site 2 (Plank Pt.) with 4.14 and 3.18 mg AFDW/m^2/yr, respectively.

Diversity

Species diversity at the five sites and three seasons is shown as Simpson's Index of Diversity (1-D) and Evenness (D/Dmax) (Fig. 3.6). Further comparison using Jackknife estimates of species richness to generate 95% CI are shown in Fig. 3.7. In general, the number of macro fauna species caught by the dredge was low and ranged between 12 and 27 (Fig. 3.6 A).

Species diversity (Simpson's Index of Diversity = the probability of sampling two species at random that are not the same) is fairly even among sites with the exception of Site 1 (Fig. 3.6 A). This is caused by the dominance of one species (Bearded mussel) at this site in particular. Variation in Simpson's Index of Diversity between seasons is large reflecting variation in seasonal occurrence with a general increase of diversity from June to March. (Fig. 3.6 B).

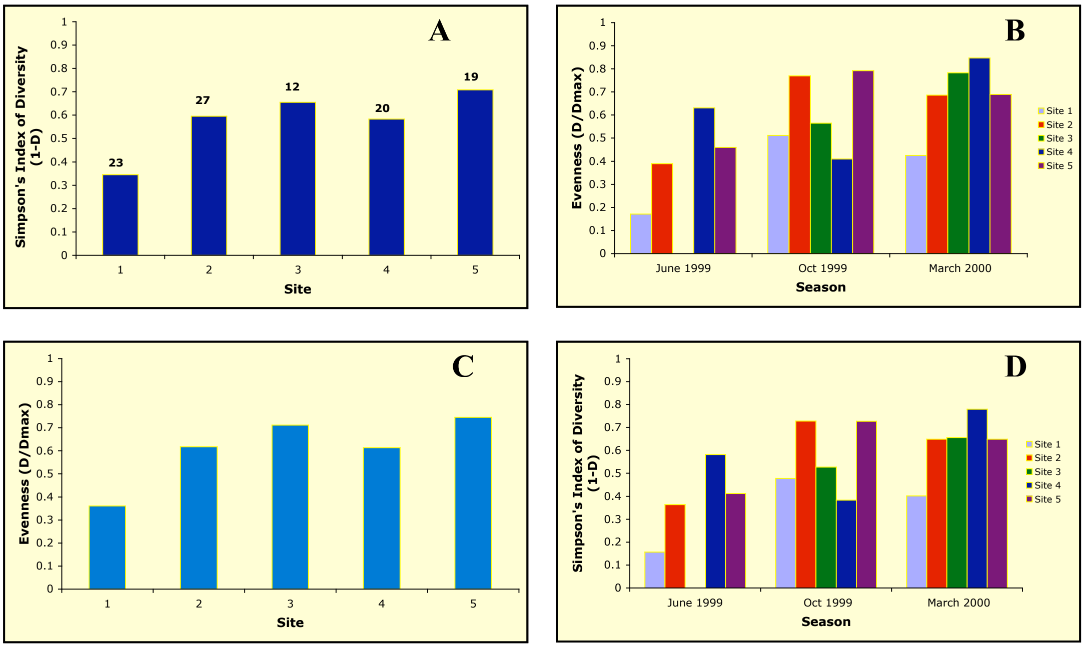


Fig. 3.6. Species diversity at the five sites and three seasons shown as Simpson's Index of Diversity (1-D)(A, B) and Evenness (D/Dmax)(C, D).

Evenness (D/Dmax) illustrates how even species are distributed among the total number of individuals (Fig. 3.6 C, D). The evenness index is the fraction of the value D (the probability of sampling two species at random that are the same) of D max, which is the value of D when all species in a sample is represented by same number of individuals. The observed pattern generally follow that of species diversity showing that at site 3 and 5, species are distributed more evenly among number of individuals than at Site 2 and 4, while Site 1 has the lowest evenness (Fig. 3.6 C). Seasonal patterns of evenness were quite variable with a general trend of increased evenness from June to March (Fig. 3.6 D).

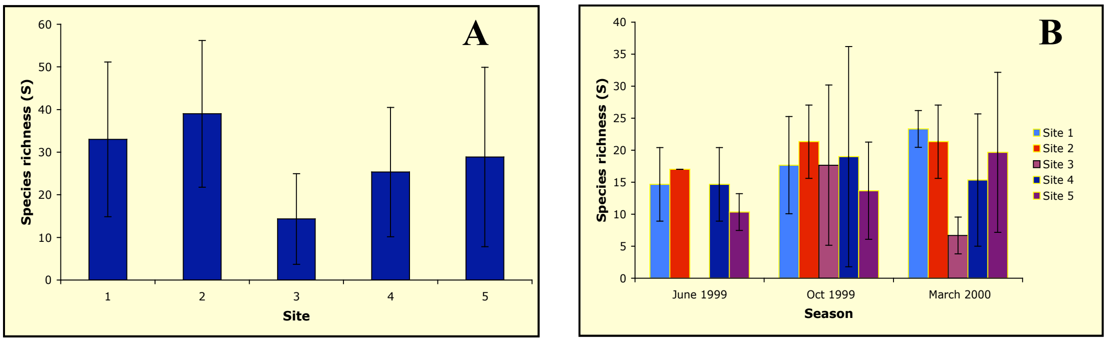


Fig. 3.7. Jackknife estimates of species richness at five sites (A) and during three seasons (B). Error bars are 95% confidence interval.

Species richness at the five sites is shown in Fig. 3.7 A. The richness index used take into consideration total number of species and the number of unique species (the number of species that occur only once) in relation to number of quadrants (dredge transects). This is done because species number in a sample is usually lower than the total species number for an area. The index thus reflects mean number of species and how evenly species are distributed among quadrants. By using the Jackknife method it is possible to calculate the 95% confidence interval. However, the variance is probably overestimated due to the relative small number of quadrants. The results showed a high degree of patchiness in species distribution within sites but with the significantly lowest species richness at Site 3 (Middle Bank)(Fig. 3.7 A). These values reflect total species numbers where at Site 3 only 12 species were sampled. The seasonal pattern of species richness was highly variable reflecting variation between both season and site (Fig. 3.7 B).

Discussion

Distribution and Abundance of Benthos

The habitat for the benthos of the Spencer Gulf is variable with sediment characteristics ranging from fine sand at Site 1 and 2 (Western Shoal, Plank Point), hard coarse sand and gravel at Site 3 (Middle Bank), mixed sand and patches of gravel at Site 4 (Wallaroo) and sandy plains at Site 5 (the Gutter). At Site 3 and 4 the coarse sediment grains are usually covered by rhodoliths. The physical characteristics of the environment are different in salinity, temperature and tidal currents. During the summer months, the two northern sites (1 & 2) experience slightly higher temperatures and salinity than further south (Bye 1981, Smith & Veeh 1989). Tidal currents are relatively stronger at Middle Bank and Wallaroo than elsewhere. Differences the distribution and abundance of benthos are therefore to be expected.

The distribution and abundance of sessile fauna (Fig. 3.2 A) appear to be negatively correlated with mean number of trawl hours shown in Chapter 1. However, there is a lack of baseline data on epifaunal assemblages of the Spencer Gulf in order to attach any significance to this observation although the cumulative long-term effects of trawling are likely to be pronounced. A major problem when considering this correlation is the fact that the five sites are very different environments with different physical and biological characteristics making it difficult to separate effects of trawling from natural variability.

The analysis of biomass distribution patterns at five sites in the Spencer Gulf showed a significant effect of site, season and fauna type indicating spatial and seasonal variability. The highest biomass values were found at Site 1 and 2 while Site 3, 4 and 5 had considerable lower values. These values can be correlated to sediment characteristics. Sponges were abundant at all sites with the exception of Site 3 while the blue swimmer crab, *Portunus pelagicus*, was abundant at all sites. Large patches of the mytelid bivalve, *Trichomya hirsutu*, as well as high abundance of dominated at Site 1 and 2 and contributed significantly to the biomass (see Table 3, IV). The contribution of pelagic and demersal fish to the overall biomass was low and Port Jackson sharks, skates and rays were able to escape capture of the dredge. It was only at Site 5 in June 1999 that relatively large quantities of Degens leatherjacket (*Thamnoconus degeni*) were caught in the dredge. Pelagic and demersal fish, however, showed no variation between seasons. Because the dredge sampling was done at day while trawling occurs at night, it is likely that the composition on mobile epifauna is somewhat different in the dredge samples compared to by-catch in prawn trawls. However, the major difference is likely to be in the abundance of prawns while the other fauna components are likely to be the same. The contribution of the biomass of prawns to the overall biomass of benthos is, however, relatively small. A number of species of sessile benthos showed expected seasonal variations such as ascidians and bearded mussels but a large component of the seasonal variability is likely to be caused by high spatial heterogeneity not accounted for, particularly at Site 4, which is currently the most active trawling site. Many of these sponges are not attached to the bottom and are likely to be caught and discarded many times. They are thus not sessile benthos but rather mobile epibenthos. However, in many cases it is difficult with certainty to establish whether a sponge caught by a dredge has been attached to the bottom or not.

The significant effect of fauna type indicates that the faunal composition is not homogeneous and varies throughout the Gulf. The highest biomass was recorded at the two most northern sites (Site 1 and 2, Western Shoal, Plank Point) with 700 mg AFDW/m^2. At Site 4 and 5 (Off Wallaroo, The Gutter) about 300 mg AFDW/m^2 were recorded while the lowest values were recorded at Site 3 (Middle Bank) with 60 mg AFDW/m^2. The faunal composition was divided into three groups, namely pelagic and demersal fishes, mobile epifauna and sessile benthos. The biomass values were highest for sessile benthos (mostly sponges) particularly at Site 1 and 2 with 60-80%. At Site 3 mobile epifauna dominated with 80-90% of the total biomass. Further south

(Site 5, The Gutter) the biomass of mobile epifauna constituted 40-70% where the remaining component was pelagic and demersal fish.

The biomass and density values are overall relative low (Table 3. III). In an epibenthic study of Port Philip Bay, Victoria, Cohen *et al.* (2000) found a total abundance of epifaunal species to be 9.3664-0.7795 ind/m^2 compared to only 0.3588 ind/m^2 for the Spencer Gulf. However, this estimate is probably too low because small crypto fauna living in sponges was not included. The biomass values reported by Cohen *et al.* (2000) were in the range of 1.37-0.27 mg AFDW/m^2 (conversion WW/AFDW factor 0.2) compared to 1149.54 mg AFDW/m^2 in Spencer Gulf. Clearly the organisms in the Spencer Gulf in this study are much larger than those in Port Philip Bay. However, there are several reasons for this difference. Firstly, the study in Port Phillip Bay did not report large volumes of sponges, which constitute up to 70% of the sessile benthos in the Spencer Gulf (Table 3. IV), and secondly, the sediment in Port Philip Bay was sand to mud while the sediments in the Spencer Gulf is sand to coarse sand/gravel, making a direct comparison difficult.

Productivity

To estimate secondary production for multi-species assemblages require estimates of metabolic rate-body size relationship of all species and the distribution of body sizes within populations. In diverse assemblages where sessile epifauna is a major component a number of constraints other than study resources restrict estimation of secondary production such as the existence continuous breeding species (ascidians, sponges) and their identification (sponges). Most production studies from which data may be used are from soft-sediment environments in the Northern hemisphere. The cohort data in these studies, which are of different species living under entirely different temperature regimes and environmental circumstances, cannot be used with any accuracy (see Edgar 1990). The approached used in this study is to compare biomass change over time (see Holme & McIntyre 1984) disregarding mortality (including fishing mortality), migration and immigration. It is nevertheless possible to compare these estimates of “ assemblage production” with other known environments. The biomass and productivity estimates of the sampled organisms represent benthic macrofauna assemblages that are likely to be by-catch in the prawn fishery. The bottom types at all five sites are coarse to sandy sediments with relatively little macro-infauna and can accordingly be viewed as hard substratum such as subtidal reefs. Especially at Site 3 and 4, which are strong current environments, the sediment is highly compacted. It is likely, however, that a major part of the total benthic production of sessile and semi-sessile fauna constitutes meio-fauna (<0.5mm), which is the primary food source for the prawns. Taylor (1998) estimated the production of four shallow subtidal rocky reef habitats dominated by alga to be form 100 to 115 g AFDW/m^2/yr, which is not surprisingly a magnitude higher than estimated for the five sites in this study (max 4.14 mg AFDW/m^2/yr). Taylor (1998) listed estimated annual productivity of a number of different habitats around the world reporting productivity values from 2-7000 g AFDW/m^2/yr. For environments with sandy sediments the production values of animals >0.5mm, ranged between 19 to 34 g AFDW/m^2/yr. The lowest value is from a coral reef lagoon habitat at the Great Barrier Reef and this probably the most comparable habitat. In this study, a seasonal pattern of productivity was evident at Site 1 and 2 with values of 4.14 and 3.18 AFDW/m^2/yr constituting 46.2 to 35.5% of the total production. At Site 3 production was negative and at Site 5 close to zero. At Site 4 (Off Wallaroo) production was measured to 1.78 AFDW/m^2/yr, which is 19.9% of the total production. The density of individuals was generally low. The highest value was at Site 1 with 0.18 ind/m^2. The production values are comparatively much lower that what has been reported for other habitats. However, the calculated values are gross production and should be cautiously interpreted.

Diversity

Diversity at all sites was found to be relatively low varying between 12 and 27 species. Species diversity (Simpson Index of Diversity/Eveness) was fairly even among sites with the exception of Site 1 (Western Shoal), which was dominated by large patches of the bearded mussels (*Trichomya hirsutu*). A high degree of patchiness in species distribution in the Spencer Gulf is evident. Species richness, however, was highly variable but evenly distributed among sites with the exception of Site 3 (Middlebank) where the lowest number of species was recorded. Diversity was likely to be considerable higher if the crypto fauna of sponges was included. In addition, if meiofauna had been included the diversity is probably extremely high. To measure accurately the diversity of the benthic assemblages in the Spencer Gulf considerable resources and time is required, which is outside the scope of this study. The diversity described in this study is for the purpose of comparing benthic macro fauna

References

Buchanan, J.B. & J.J. Moore 1986. A broad review of variability and persistence in Northumberland benthic fauna, 1971-1985. J. mar. biol Ass. UK. 66: 641-657.

Bye, J.A.T. 1981. Exchange processes for upper Spencer Gulf, South Australia. Trans. Royal Soc. South Aust. 105: 59-66.

Caddy, J.F. 1973. Underwater observations on tracks of dredges and trawls and some effects of dredging on a scallop ground. J. Fish. Res. Bd. Can. 30: 173-180.

Cohen, B.F., Currie, D.R. & M.A. McArthur 2000. Epibenthic community structure in Port Phillip Bay, Victoria, Australia. Mar. Freshwater Res. 51: 689-702.

Currie, D.R. & G.D. Parry 1996. Effects of scallop dredging on a soft sediment community – a large-scale experimental study. Mar. Ecol. Prog. Ser. 134: 131-150.

Edgar, G.J. 1990. The use of the size structure of benthic macrofaunal communities to estimate faunal biomass and secondary production. J. Exp. Mar. Biol. Ecol. 137: 195-214.

Eleftheriou, A. & M.R. Robertson 1992. The effects of experimental scallop dredging on the physical environment and fauna of a shallow sandy community. Neth. J. Res. 30:289-299.

Frid, C.L.J., Clark, R.A. & J.A. Hall 1999. Long-term changes in the benthos on a heavily fished ground off the NE coast of England. Mar. Ecol. Prog. Ser. 188: 13-20.

Gray, J.S. 1974. Animal-sediment relationships. Oceanogr. Mar. Biol. Ann. Rev. 12: 223-261.

Holme, N. A. & A.D. McIntyre 1984. Methods for the study of marine benthos, 2nd edn. Blackwell Scientific Press Publ., Oxford.

Lundälv, T. 1971. Quantitative studies on rocky-bottom biocoenoses by underwater photogrammetry. A methodological study. Thalassia Jugoslav. 7: 201-208.

Ricciardi, A. & E. Bourget 1998. Weight-to-weight conversion factors for marine benthic macroinvertebrates. Mar. Ecol. Prog. Ser. 163: 245-251.

Smith, S.V. & H.H. Veeh 1989. Mass balance of biogeochemically active materials (C, N, P) in a hypersaline gulf. Estua. Coast. Shelf Sci. 29: 195-215.

Svane, I. 1988. Recruitment and development of epibioses on artificial and cleared substrata at two sites in Gullmarsfjorded on the Swedish west coast. Ophelia 29: 25-41.

Taylor, R.B. 1998. Density, biomass and productivity of animals in four subtidal rocky reef habitats: the importance of small mobile invertebrates. Mar. Ecol. Prog. Ser. 172: 37-51.

Thouzeau, G. Robert, G. & R. Ugarte 1991. Faunal assemblages of benthic macroinvertebrates inhabiting sea scallop grounds from eastern Georges Bank, in relation to environmental factors. Mar. Ecol. Prog. Ser. 74: 61-82.

Thrush, S.F., Hewitt, J.E., Funnell, G.A., Cummings, V.J., Ellis, J., Schultz, D., Talley, D. & A. Norkko 2001. Fishing disturbance and marine biodiversity: Role of habitat structure in simple soft-sediment systems. Mar. Ecol. Prog. Ser. 221: 255-264.

Table 3. IV. Percentage biomass distribution among dominating species of the three fauna types, Pelagic and Demersal Fish, Mobile Epifauna, and Sessile Benthos at five sites sampled at three seasons in the Spencer Gulf. Site 3 was not sampled in June 99 due to equipment failure and bad weather.

	June 1999					September 1999					March 2000				
Species	Site 1	Site 2	Site 3	Site 4	Site 5	Site 1	Site 2	Site 3	Site 4	Site 5	Site 1	Site 2	Site 3	Site 4	Site 5
Pelagic and Demersal Fish	0.98	1.19		32.92	62.33	0.46	2.65	2.22	3.17	12.01	1.37	5.01	2.74	3.03	15.18
Thamnoconus degeni	0.56	0.78		7.02	52.65	0.29	-	0.50	1.68	7.88	0.13	0.20	-	-	2.21
Scobinichthys granulatus	0.08	0.27		1.27	-	0.13	1.05	1.72	0.45	-	-	1.10	2.74	2.75	0.95
Parequula melbournensis	-	-		0.44	3.98	-	0.03	-	0.17	1.53	0.10	0.04	-	-	6.11
Upeneichthys valmingii	0.24	-		0.83	1.62	-	0.90	-	0.21	0.99	0.08	0.31	-	-	1.38
Platycephalus bassensis	-	-		0.14	0.24	-	0.03	-	-	0.42	-	-	-	-	2.87
Gymnapistes marmoratus	0.10	0.09		22.26	0.54	-	-	-	-	-	-	-	-	-	-
Sepia apama	-	-		0.74	-	-	-	-	0.54	-	-	2.78	-	0.23	-
Others	-	0.05		0.22	3.30	0.04	0.37	-	0.12	1.19	1.06	0.58	-	0.05	1.66
Mobile Epifauna	20.86	15.78		66.88	37.67	9.37	59.56	80.30	76.95	40.02	21.45	28.15	93.57	64.85	53.11
Melicertus latisulcatus		2.87	2.42		2.82	8.62	3.98	1.41	2.65	1.14	1.95	0.22	2.92	40.15	1.83
Portunus pelagicus	17.21	9.24		64.06	29.05	-	56.34	69.07	51.66	38.07	17.26	14.15	53.42	48.57	49.07
Ibacus alticrenatus	0.64	-		-	-	1.32	-	3.96	-	-	1.38	-	-	-	-
Stichopus ludwigi	-	3.94		-	-	3.35	1.71	3.71	24.15	-	0.84	10.78	-	14.44	2.96
Goniocidaris tubaria	0.14	0.18		-	-	0.72	0.10	0.69	-	-	1.35	0.30	-	-	-
Others	-	-		-	-	-	-	0.22	-	-	0.40	-	-	0.01	1.08
Sessile Benthos	78.16	83.03		0.20	-	90.17	37.79	17.48	19.88	47.97	77.18	66.84	3.69	34.12	31.71
Trichomya hirsutu	19.65	24.42		-	-	13.99	1.06	-	-	-	13.79	3.85	-	0.29	-
Malleus meridianus	5.41	3.00		-	-	4.41	-	-	-	-	7.65	0.79	-	0.12	0.47
Equichlamys bifrons	-	-		-	-	0.03	-	0.69	-	-	0.18	0.06	-	0.07	-
Polycarpa viridis	-	0.40		-	-	0.91	0.20	2.95	4.93	-	2.01	2.29	1.79	0.42	-
Phalusia obesa	-	1.04		0.17	-	0.17	0.23	-	0.31	0.31	0.87	0.39	0.08	0.06	-
Sarcoptilus grandis	-	-				-	-	11.34	1.75	-	-	0.00	-	-	-
Sponges	53.10	53.41		0.03	-	70.58	36.30	2.38	12.45	47.66	52.54	59.41	1.82	31.03	30.98
Others	-	0.76		-	-	0.08	-	0.12	0.44	-	0.14	0.05		0.13	0.26

Chapter 4: Quantitative Benthic Surveys of the Spencer Gulf using Underwater Stereophotography to Determine Spatial Patterns of Distribution and Abundance

Ib Svane and Zoe Hammett

Abstract

Replicated stereophotographic transects of the bottom were sampled at five sites during three periods in the Spencer Gulf, South Australia. The five selected sites have been historically exposed to different prawn trawling activity likely to affect distribution and abundance of benthic organisms. The results showed that the five sites represented different ecosystems subjected to different physical factors. An analysis showed a statistical significant difference in percentage cover between sites, season and organism group. This result mainly caused by the relatively large difference between the southernmost site and the four more northern sites. The organism composition varied considerable between sites with Site 3 and 4 dominated by so called rhodoliths, which are incrusting algae covering popcorn-sized pebbles. The two northern sites are dominated by sandy bottoms with patches of sponges rich in crypotofauna, ascidians and large patches of the mytelid bivalve, *Trichomya hirsutu* (bearded mussel). At Site 5, the southernmost one, sandy bottoms dominated with only a few organisms. The distribution of organisms was found to be significantly contagious at all sites with the exception of Site 5. The obtained stereophotographic transects constitute a "base-line" against future investigations can be assessed. It was concluded that a casual negative relationship between mean trawling hours and the occurrence of erect sessile epifauna is evident but the five sites are exposed to different physical forces, have different sediment characteristics, and probably have a different biological history. The spatial distribution of organisms was heterogeneous, which may be a consequence of present and past trawling activity likely to cause fragmentation of assemblages and fundamentally change diversity, distribution and abundance.

Introduction

Quantitative studies of epifauna and flora on hard substrata including hard sandy bottoms are relatively rare because of lack of efficient methods (Thouzeau *et al.* 1991). The use of standard photography and video techniques have been widely used but is limited by the difficulties in obtaining adequate taxonomic resolution and obtain estimates of biomass (see Cohen *et al.* 2000). However, these problems can be overcome by using underwater stereophotography. This method is non-destructive and allows for a three-dimensional view of the bottom that substantially increases taxonomic resolution compared with two-dimensional photography (Lundälv 1971, Svane 1988). In addition, accurate measurement of length in three-dimensions can be obtained by using a so-called stereo-comparator (Torlegård & Lundälv 1974).

In marine environments such as subtidal hard substratum, a true representation of the seabed is best obtained by stereo-photographically recorded quadrants. To get an understanding of spatial distribution and heterogeneity, sampling of a large number of replicate quadrants is desirable. The number and size of the quadrants required for statistical purposes is depending on the mean size of the organisms (colonies), the spatial heterogeneity and the desired spatial scale under investigation (Kingsford & Battershill 1998, Svane 1999). By photographing haphazardly selected and replicated transects and estimate of distribution and abundance can be obtained.

The purpose of this investigation was to describe the spatial heterogeneity of trawled seabeds in The Spencer Gulf, South Australia, experiencing historically different trawling activity and to estimate abundance and distribution of macro-fauna/flora assemblages in the trawled areas of the Spencer Gulf.

Material and Methods

Selection of Transects

On three occasions (June 99, October 99, and March 00) stereo-photographically recorded transects were sampled at all five stations in order to obtain estimates of benthic macro-fauna/flora abundance and distribution, which are likely to constitute by-catch during prawn trawling. At each occasion and site, the research vessel was positioned at the site using GPS. Within about 100 meters of the research vessel divers on the bottom selected haphazardly three transects by stretching a 40-meter plastic measuring tape on the seabed in various directions. A diver took 18 stereo-pair photographs vertically along each transect (Fig. 4.1). Each photograph was taken with a distance of 2 meters and covered an area of 0.25 m^2. Site 4 and 5 were not sampled in October 99 due to equipment failure and Site 3 was not sampled in March 2000 due to bad weather.

Camera Equipment

The stereo-camera was constructed by using two NIKONOS V cameras equipped with 15 mm UW-Nikkor lenses. The two cameras had a stereo-base of 25 cm accurately mounted on an aluminium frame. The camera frame was attached to a 50x50x10cm double reference frame made of 10mm stainless steel tubing and painted with yellow-black markings for every 2 cm. The distance between the reference frame and the camera was 67.5 cm to obtain complete linear photographic covering by the two 15 mm UW-Nikkor lenses. Balanced lighting was provided electronically by using 4 DYFO UV-flash controlled through a master flash connected to an electronic/manual shutter release unit allowing exposure when both camera shutters synchronise. The stereo-photographs (35 mm Kodak E100) were viewed through two NIKON dissecting microscopes mounted parallel and using the right and left ocular tubes to obtain polarisation and a 3-dimensional image. In this way objects of a size down to 2 mm could be characterised and organisms within the frame identified. Measurement of size in three dimensions is possible by using a stereo-comparator but this technique was not applied in this study. For a description of the theory and application of underwater photogrammetry see Lundälv (1971), Rørslett *et al.* (1978), and Torlegård & Lundälv (1974).

Analysis

The photographs were analysed by using point-sampling techniques. A transparent acetate sheet with 100 regular spaced points framed to fit the exact size of the camera frame in the stereo-photographs was fitted on the left stereo-pair to be viewed in the 3-D image of the bottom (Svane 1988). Organisms beneath each point were recorded as "primary substratum" (attached or imbedded in the substratum), "secondary substratum" if secondary attached to another organism, and "canopy" if attachment was located beyond the point of observation. In this way an estimate of percentage cover could be obtained. The three classifications were pooled and could thus reach values above 100% depending of density.

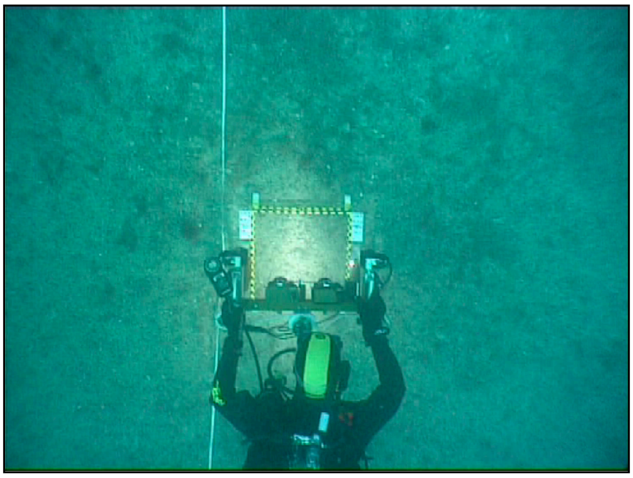


Fig. 4.1. UW-photograph showing a diver operating the stereo-camera.

Organisms were identified to species when possible or to nearest taxonomical level. Organisms down to a size of 2 mm can be identified in the stereophotographs depending on visibility and undisturbed view. For simplicity and statistical purposes, the observed organisms/substratum were sorted into 8 groups (bare substratum, foliaceous algae, Rhodoliths, sponges, Ascidiacea, Bivalvia, Echinoidea and others).

The purpose of the analyses was to describe spatial variation and patchiness. The data were therefore statistically compared using a three-way ANOVA with Site, Season and Group (nested within Site) as the main effects (Morrisey *et al.* 1992). The data were measured as percentages/proportions and thus Arcsin-transformed to obtain normality. To obtain homogeneity of variances the data were additionally log (x+1) transformed when required (Fmax-test). To test a posterior for differences SNK-test was applied. The group “bare substratum” was not included in the statistical test because the proportionality of bare space to organism cover made the variable irrelevant.

To further test for spatial heterogeneity, the variance mean ratio or “Index of Dispersion” (Elliott 1977) was calculated and evaluated against the χ^2-distribution.

Results

Effects of Site and Season

The results of a three-way ANOVA with season, site and group (nested within site) are shown in Table 4. I. Significant effects of Season, Site and Group is apparent with no Season*Site interactions. The interaction graph of Site * Season is shown in Fig. 4.2. A pattern of significant difference between seasons was observed. The statistical significant difference is between June 99 and October 99, and October 99 and March 00, while June 99 and March 00 was not significantly different (Fig. 4.2, Table 4. II; SNK-test, $p<0.05$). This result reflects the lowest abundance in June and March but the highest in October.

Table 4. I. The results of a three-way ANOVA on percentage cover of benthic macro organisms with the main effect season (3), site (5) and group (7) nested within sites. Data were arcsine and log (x+1) transformed prior analysis to obtain normality and homogeneity of variances.

Source	df	SS	MS	F	P
Site	4	5.118	1.280	17.838	0.0001
Season	2	1.182	0.591	8.237	0.0004
Organism group (Site)	30	35.559	1.185	16.524	0.0001
Site* Season	5	0.156	0.031	0.434	0.8244
Residual	203	14.561	0.072		

The significant effect of Site is predominantly an effect of the low abundance of organisms at Site 5 (The Gutter) and the relative high abundance at Site 4 (off Wallaroo). An SNK-test reveals that all sites were significantly different ($p<0.05$) with the exception of no difference between Site 1 and 2, Site 1 and 3, Site 2 and 3, respectively (Table 4. III). Accordingly, three site groupings could be identified, Site 1, 2, and 3 as the first, Site 4 as a the second, and Site 5 as the third, dividing the three northern sites (Western Shoals, Plank Pt., Middle Bank) from the site off Wallaroo, and from the southern site, The Gutter (Table 4. III, Fig. 4.2).

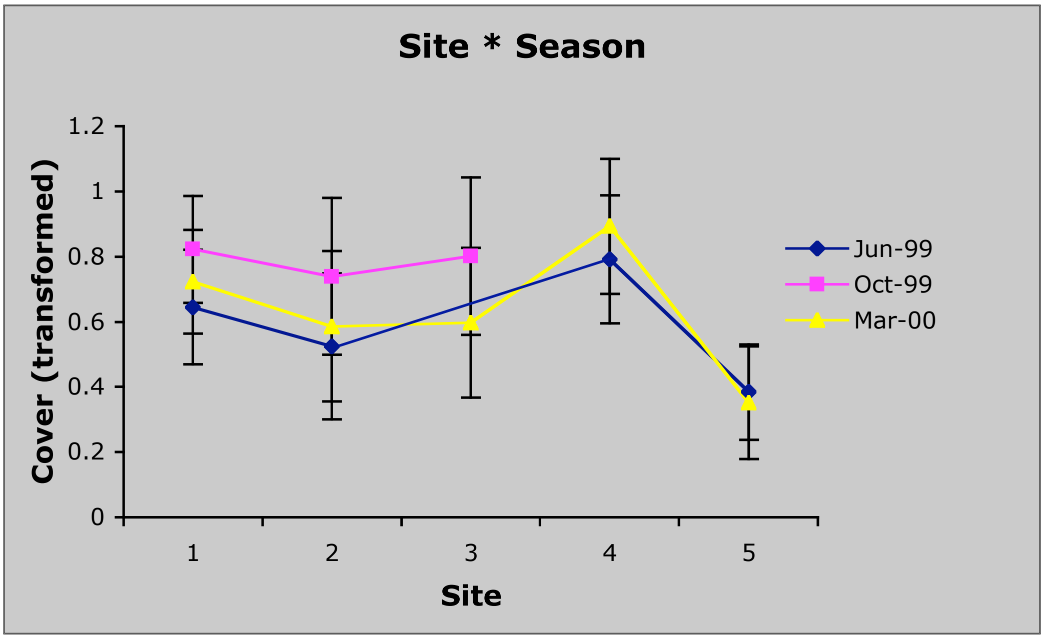


Fig. 4. 2. Interaction graphs showing the effects of Site * Season. Error bars are 95% confidence interval.

Table 4. II. Student-Newman-Keul Test (** = p<0.05) showing significance levels between sites and seasons. Point sampling; arcsine-transformed data.

Effect of Site

	Vs.	Diff.	Crit. Diff.	Significance
Site 1	Site 2	0.102	0.130	n.s.
	Site 3	0.031	0.108	n.s
	Site 4	0.112	0.108	**
Site 2	Site 3	0.071	0.108	n.s.
	Site 4	0.215	0.143	**
Site 3	Site 4	0.143	0.130	**
Site 5	Site 1	0.362	0.143	**
	Site 2	0.260	0.108	**
	Site 3	0.331	0.130	**
	Site 4	0.474	0.152	**
Effect of Season				
June 99	March 00	0.039	0.085	n.s
	Oct 99	0.196	0.101	**
March 00	Oct 99	0.157	0.085	**

Table 4. III. Index of Dispersion (I) of cover (point sampling %) of benthic organisms at three seasons at five stations in the Spencer Gulf. Upper and lower limits are the probability levels ($p<0.05$) of the χ^2-values separating a random distribution form contagious and regular distributions.

Season	Site	I	χ^2	Upper limit	Lower limit	Distribution
Jun-99	1	3.247	64.939	31.410	7.434	Contagious
Jun-99	2	1.835	23.854	22.362	3.565	Contagious
Jun-99	3	na	-	-	-	-
Jun-99	4	25.198	503.967	31.410	7.434	Contagious
Jun-99	5	1.086	21.726	31.410	7.434	Random
Oct-99	1	5.289	105.785	31.410	7.434	Contagious
Oct-99	2	25.215	504.296	31.410	7.434	Contagious
Oct-99	3	25.898	517.950	31.410	7.434	Contagious
Mar-00	1	6.605	132.105	31.410	7.434	Contagious
Mar-00	2	17.645	352.893	31.410	7.434	Contagious
Mar-00	3	31.689	633.784	31.410	7.434	Contagious
Mar-00	4	20.335	406.698	31.410	7.434	Contagious
Mar-00	5	1.445	28.893	31.410	7.434	Random

Heterogeneity

The distributions and abundance of organisms on the seabed were significantly contagious ($p<0.05$) at all sites with the exception of Site 5, which showed a significant random distribution (Table 4. III). However, considering the general low abundance at Site 5, these values have little importance. It is thus clear that the epifauna/flora is patchy and heterogeneously distributed on the bottom. The organisms were mainly found in aggregates. The highest Index of Dispersion (Table 4. III) was observed at Site 3 at Middle Bank (mean I = 28.8) followed by Site 4 off Wallaroo (mean I=22.8), Site 2 (mean I = 14.9), Site 1 (mean I=5.1) and finally Site 5 (mean I=1.3).

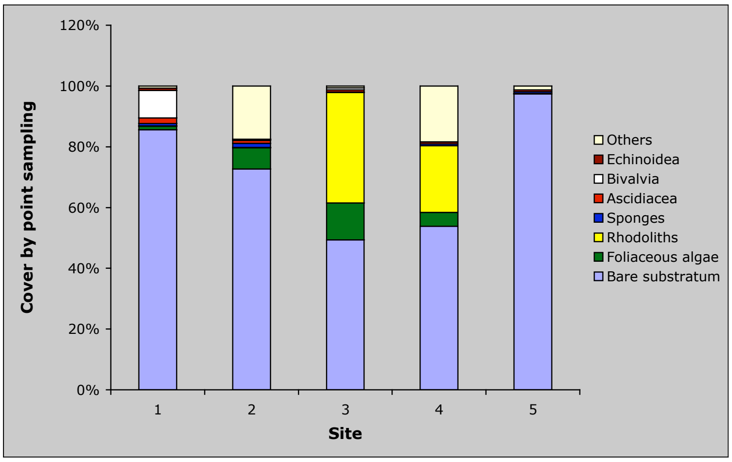


Fig. 4.3. Mean percentage of cover of the different organism groups and bare substratum summarised from three seasons at five sites in the Spencer Gulf.

Abundance and Distribution

The mean percentage of cover of the different organism groups and bare substratum at all five sites is shown in Fig. 4.3. The two groups that influence the overall pattern are “Bare substratum” and “Rhodoliths”. Rhodoliths are incrusting coralline algae covering popcorn-sized pebbles and form so-called “popcorn bottoms” characterising especially Site 3 and to some extend Site 4 as well. These bottoms are in a high flow regime and consist of hard gravel and coarse sand where large catches of prawns may be obtained. The bottoms at these two sites in additions to the Rhodoliths, were dominated by foliaceous algae and encrusting bryozoans (Others) of various species. If “Rhodoliths” were excluded from the statistical analysis, the cover of Site 3 will be considerable lower and significant different from all other sites. At Site 1 and 2 the assemblages were more diverse with sponges, ascidians and importantly the mytelid bivalve *Trichomya hirsutu* (bearded mussel). At Site 5, bare substratum (coarse to fine sand) dominated the seabed with little macro- fauna/flora.

Variations in the seasonal patterns were relatively small (Fig. 4.4) and mainly influenced by variation in foliaceous algae and somewhat by encrusting bryozoans.

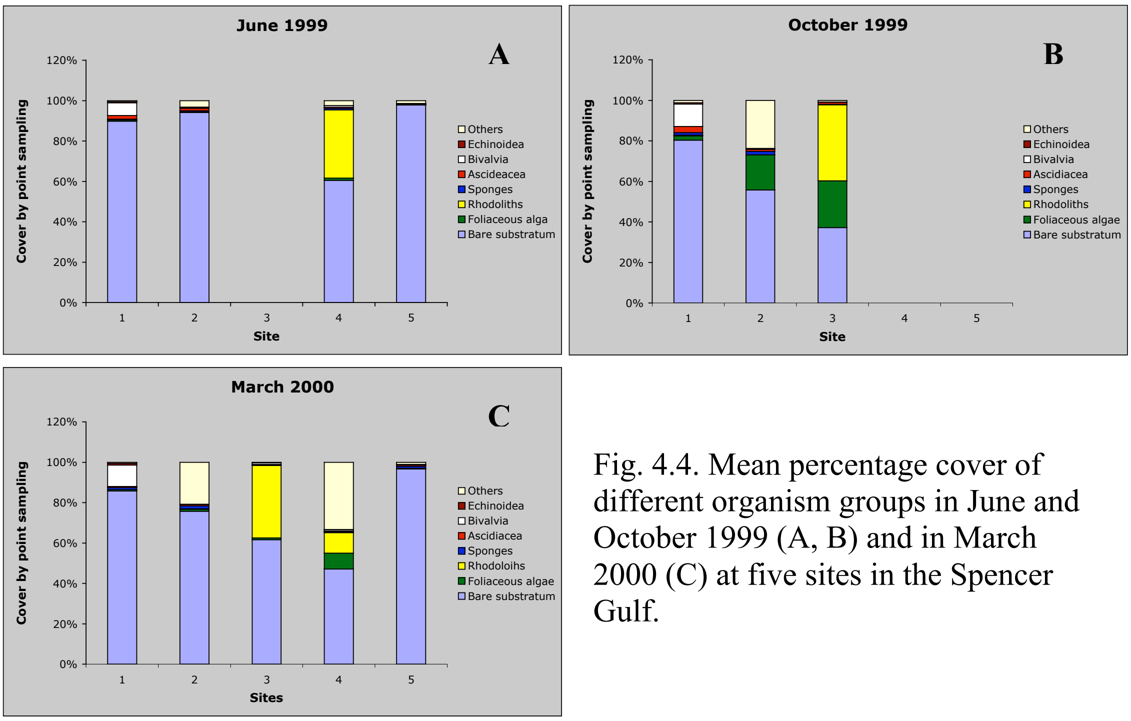


Fig. 4.4. Mean percentage cover of different organism groups in June and October 1999 (A, B) and in March 2000 (C) at five sites in the Spencer Gulf.

Discussion

The main advantages of the stereo-photographic method are that it is non-destructive and that the photographs constitute a “base-line” against which future investigation can be assessed. Each transects covered a length of about 18 meter (4.5 m^2) and is thus a powerful tool in analysing spatial and temporal patterns not possible by using remotely operated mechanical sampling equipment. The major problem in studying the five sites in the Spencer Gulf is the high degree of patchiness, which introduces large variances in the statistical data (see Fig. 4.2). Reduction in the variances can be obtained by increasing the sampling size (area) but this was not possible for financial and practical reasons. However, the sampled transect were adequate to statistically describe and substantiate the observed patterns.

The stereo-photographs of the bottoms of the five sites clearly show the difference between the environments (Fig. 4.5). Despite that the sites have different physical characteristics (currents, grain size), they were all dominated by filter feeders, primarily sponges, mussels, bryozoans and ascidians. The two northern sites were dominated by large populations of the mytelid *T. hirsutu* (bearded mussel) but also many sponges and ascidians. The ascidians were dominantly *Pyura momus* and *Ascidia obesa*. Among the sponges and bryozoan aggregates, the hammer-oyster *Malleus meridianus* was abundant. In the high current environments at Site 3 and 4, the smaller ascidian *Polycarpa viridis* was common among the Rhodoliths and occasionally *A. obesa*. Also at these two sites scallops were abundant, notably *Equichlamys bifrons*. Site 5 consisted of monotonous sandy bottoms with very few signs of infaunal activity. An occasional sponge aggregate can be found. The mean cover among sites was general uniform with the exception of Site 5, which had a low cover. Without considering Rhodoliths at Site 3, this site had a low cover of macro-epifauna.

The effect of trawling in gavel/sandy sediment habitats has attracted little attention. However Collie *et al.* (1997, 2000) studied photographically gravel bottoms at St. George Banks and found the bottom topography affected by trawl tracks. Their studies showed that there was a significantly greater cover of erect fauna (fan worms, hydroids etc.) at unfished sites and that more erects fauna was observed at deeper sites. Collie *et al.* (1997, 2000) concluded that gravel habitats are very sensitive to physical disturbance by bottom fishing and the primary impact is the removal of emergent epifauna taxa. A similar conclusion can be reached when comparing occurrence of sessile epifauna at the five studied sites in the Spencer Gulf. However, that a casual negative relationship exists between mean trawling hours (see Chapter 1) and the occurrence of erect sessile epifauna can be an erroneous conclusion when comparing bottom types at different depth and at different sites because they are exposed to different physical forces and probably have a different biological history. Site 3 and partly Site 4 are hard gravel bottoms with very little epifauna and also the sites exposed to intensive fishing. However, these sites are high current sites not necessary ecological comparable to Site 1 and 2 further north and Site 5 to the south. There is some historical evidence obtained by independent interviews with experienced and retired trawl skippers suggesting that the bottom, particularly at Site 3, did not support large volumes of epifauna when the prawn fishery originally started. During these interviews, the large beds of bearded mussels found at Site 1 and 2 were also identified as being present since the start of the fishery. However, the distribution of organism at the five sites was significantly heterogeneous, which may be a consequence of past and present trawling likely to cause fragmentation of assemblages that may fundamentally change diversity, distribution and abundance (Hovel & Lipcius 2002, Phillips 2001, Trautman *et al.* 2003). The results from the dredge study (Chapter 3) describe the cumulative samples in a 700-1200 meter long transects thus concealing any patterns of heterogeneity within that scale of observation. The results of the analyses of the stereo-photographical transects, however, describe patterns of heterogeneity at a scale of a 40-meter transect and with a better resolution because bottom topography does not prevent sampling as it may when using a dredge. However, the overall patterns observed in the stereophotographic transects by using point sampling are in accordance with the biomass estimates from the dredge sampling (Fig. 4.2 and Chapter 3). The major difference is at Site 3, where the point sampling method allows for the recording of rhodoliths, which is not sampled by the dredge. Similar, the observation “bare space” can naturally not be estimated by dredging.

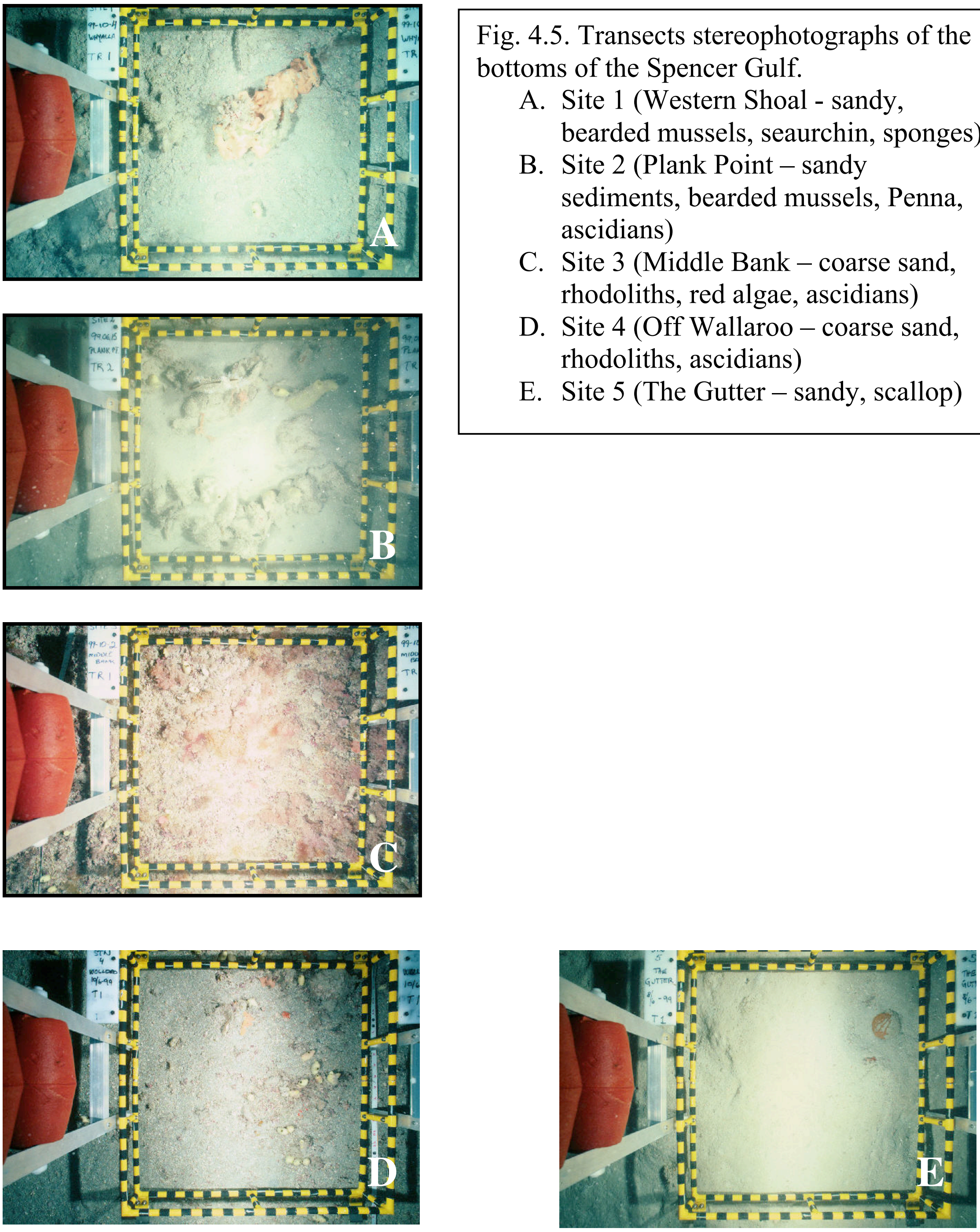


Fig. 4.5. Transects stereophotographs of the bottoms of the Spencer Gulf.

- A. Site 1 (Western Shoal - sandy, bearded mussels, seaurchin, sponges)
- B. Site 2 (Plank Point – sandy sediments, bearded mussels, Penna, ascidians)
- C. Site 3 (Middle Bank – coarse sand, rhodoliths, red algae, ascidians)
- D. Site 4 (Off Wallaroo – coarse sand, rhodoliths, ascidians)
- E. Site 5 (The Gutter – sandy, scallop)

References

Andrew, N.L. & J.G. Pepperell 1992. The by-catch of shrimp trawl fisheries. Oceanogr. Mar. Biol. Ann. Rev. 30: 527-565.

Buchanan, J.B. & J.J. Moore 1986. A broad review of variability and persistence in Northumberland benthic fauna, 1971-1985. J. mar. biol Ass. UK. 66: 641-657.

Caddy, J.F. 1973. Underwater observations on tracks of dredges and trawls and some effects of dredging on a scallop ground. J. Fish. Res. Bd. Can. 30: 173-180.

Carrick, N. 1997. A preliminary assessment of the by-catch from the Spencer Gulf prawn fishery. South Australian Fisheries Assessment Series 97/02.

Cohen, B.F., Currie, D.R. & M.A. McArthur 2000. Epibenthic community structure in Port Phillip Bay, Victoria, Australia. Mar. Freshwater Res. 51: 689-702.

Collie, J.S., Escanero, G.A. & P.C. Valentine 2000. Photographic evaluation of the impacts of bottom fishing on benthic epifauna. J. Mar. Sci. 57: 987-1001.

Collie, J.S., Escanero, G.A. & P.C. Valentine 1997. Effects of bottom fishing on the benthic megafauna at St. Georges Bank. Mar. Ecol. Prog. Ser. 155: 159-172.

Currie, D.R. & G.D. Parry 1996. Effects of scallop dredging on a soft sediment community – a large-scale experimental study. Mar. Ecol. Prog. Ser. 134: 131-150.

Edgar, G.J. 1990. The use of the size structure of benthic macrofaunal communities to estimate faunal biomass and secondary production. J. Exp. Mar. Biol. Ecol. 137: 195-214.

Elliott, J.M. 1977. Some methods for the statistical analysis of samples of benthic invertebrates. Freshwater Biol. Assoc. Sci. Publ. No. 25, 160 pp.

Frid, C.L.J., Clark, R.A. & J.A. Hall 1999. Long-term changes in the benthos on a heavily fished ground off the NE coast of England. Mar. Ecol. Prog. Ser. 188: 13-20.

Gray, J.S. 1974. Animal-sediment relationships. Oceanogr. Mar. Biol. Ann. Rev. 12: 223-261.

Holme, N. A. & A.D. McIntyre 1984. Methods for the study of marine benthos, 2nd edn. Blackwell Scientific Press Publ., Oxford.

Hovel, K.A & R.N. Lipcius 2002. Effects of seagrass habitat fragmentation on juvenile blue crab survival and abundance. J. Exp. Mar. Biol. Ecol. 271: 75-98.

Kingsford, M. & C. Battershill 1998. Studying temperate marine environments. Canterbury University Press, New Zealand, 335 pp.

Lundälv, T. 1971. Quantitative studies on rocky-bottom biocoenoses by underwater photogrammetry. A methodological study. Thalassia Jugoslav. 7: 201-208.

McShane, P.E., Hall, S. & N.A. Carrick (in press). Trophic consequences of prawn trawling: linking by-catch to benthos. 14pp.

Morrisey, D.J., Howitt, L., Underwood, A.J. & J.S. Stark 1992. Spatial variation in soft-sediment benthos. Mar. Ecol. Prog. Ser. 81: 197-204.

Phillips, J.A 2001. Marine macroalgal biodiversity hotspots: why is there high species richness and endemism in southern Australian marine benthic flora? Biodivers. Conserv. 10: 1555-1577.

Poiner, I., Glaister, J., Pitcher, R., Burridge, C., Wassenberg, T., Gribble, N., Hill, B., Blaber, S., Milton, D., Brewer, D. & N. Ellis 1998. Final report on effects of trawling in the far northern section of Great Barrier Reef: 1991-1996. CSIRO Division of Marine Research, Cleveland.

Ricciardi, A. & E. Bourget 1998. Weight-to-weight conversion factors for marine benthic macroinvertebrates. Mar. Ecol. Prog. Ser. 163: 245-251.

Rørslett, B., N.W. Green & K. Kvalvågnæs 1978. Stereophotography as a tool in aquatic biology. Aquatic Botany 4:73-81.

Svane, I. 1988. Recruitment and development of epibioses on artificial and cleared substrata at two sites in Gullmarsfjorded on the Swedish west coast. Ophelia 29: 25-41.

Svane, I. 1999. On some statistical problems in marine benthic ecology. - Phuket mar. biol. Cent. Spec. Publ. 19:119-127.

Taylor, R.B. 1998. Density, biomass and productivity of animals in four subtidal rocky reef habitats: the importance of small mobile invertebrates. Mar. Ecol. Prog. Ser. 172: 37-51.

Thouzeau, G. Robert, G. & R. Ugarte 1991. Faunal assemblages of benthic macroinvertebrates inhabiting sea scallop grounds from eastern Georges Bank, in relation to environmental factors. Mar. Ecol. Prog. Ser. 74: 61-82.

Thrush, S.F., Hewitt, J.E., Funnell, G.A., Cummings, V.J., Ellis, J., Schultz, D., Talley, D. & A. Norkko 2001. Fishing disturbance and marine biodiversity: Role of habitat structure in simple soft-sediment systems. Mar. Ecol. Prog. Ser. 221: 255-264.

Torlegård, K. & T. Lundälv 1974. Under-water analytical system. Photogramm. Eng. 40: 287-293.

Trautman, D. A, Hinde, R & M. A. Borowitzka 2003. The role of habitat in determining the distribution of a sponge-red alga symbiosis on a coral reef. J. Exp. Mar. Biol. Ecol., 283: 1-20.

Chapter 5: Consumption by Surface Scavengers in the Spencer Gulf Prawn Fishery

Ib Svane

Abstract

In the Spencer Gulf prawn fishery, which occurs at night, family groups of dolphins and seabirds feed on discarded by-catch. The dolphins follow the cod ends as they appear close to or on the surface. Here they pick or bite fish protruding through the cod end mesh or on what are lost from the net. Seabirds pick floating objects. Contrary to seabirds, dolphins appear to be selective in their choice of food. Certain species of fish is preferred, notably red mullet, whiting and squids, while blue crabs, elasmobranchs, leatherjackets and benthic invertebrates are largely ignored.

In order to quantify the importance of dolphins and seabirds as consumers of discarded by-catch, four series of statistical surveys were undertaken where prawn trawler captains recorded on three successive nights, each night on three occasions, after the first shot, at midnight and after the last shot of the night, the number of seabirds and dolphins feeding on discarded by-catch. A total of 24 vessels participated in the surveys. The mean number of dolphins per boat and observation varied between seasons with 0.5 to 1.3 dolphins/boat/observation. At the southerly Site 2-5, 0.5-0.8 dolphins were observed per boat and observation while at Site 1, 3.4 dolphins were recorded per boat and observation. No significant difference between observations at night was observed. The occurrence of seabirds varied between sites but not between season and time of night. The largest number of seabirds was observed at Site 1 and 4 with a mean of 2.2 and 2.8 seabirds per observation. It was concluded that an estimated 190.4 ton of discards are consumed per year by dolphins while seagulls potentially consume 1591.2 kg discards per year from the Spencer Gulf prawn fishery.

Introduction

In the Spencer Gulf prawn fishery, far the two most common groups of surface scavengers reported are dolphins and seabirds, notably bottlenose dolphin (*Tursinus truncatus*), Silver Gull (*Larus novaehollandiae*) and Pacific Gull (*Larus pacificus*).

Cetaceans in general are known to interact with trawls in a complex way, which may cause damage to gear as well as to the animals themselves. At a world wide scale 25 cetacean species have been observed to interact with trawls and 15 species have been reported to feed in association with trawling activities, which allow the animals to exploit a concentrated food source including discarded by-catch (Fertl & Leatherwood 1997).

Seabirds are also known to be important scavengers on offal and discarded by-catch. In the North Sea roughly 5.9 million seabirds consume more than 124,600 ton of discarded offal and by-catch annually (Garthe *et al.* 1996). No information is available on the scavenging activities of seabirds in Southern Australia but seabird abundance in the Spencer Gulf is considerable lower than the North Sea and their scavenging activity appear to be local (see also Skov & Durinck 2001).

A survey was undertaken to quantify the number of seagulls and dolphins actively feeding and assess their importance as consumers of discarded by-catch in the Spencer Gulf prawn fishery. The survey was based on observations made simultaneously by the captains of the trawling vessels during prawn fishing.

Material & Methods

In order to measure the occurrence of common surface scavengers in the Spencer Gulf prawn fishery and quantify their importance as consumers of discarded by-catch, four series of statistical surveys were undertaken. During four fishing periods (Nov, Dec, March and April/May), prawn trawler captains were asked to record the number of seabirds and dolphins feeding on the discarded by-catch. The observations were made on three successive nights, each night on three occasions, after the first shot, at midnight and after the last shot of the night. When the trawls were retrieved, the number of dolphins around the cod ends at both sides of the vessel was recorded and the number of seabirds over rear deck estimated. The positions of the vessels were recorded and grouped within the sections of five selected sites from 8 Nm south of Whyalla south to the Gutter (see Chapter 1). A form for recording of the observations was provided and collected after each survey. A total of 24 vessels participated in the surveys with some variation between seasons.

The data were analysed using a three-way ANOVA for dolphins and seagulls, respectively, with site, season and time as the main effects. Multiple comparisons were done using Student-Newman Keul test (SNK). Data were log (x+1) transformed to remove zeros and to obtain homogeneity of variances.

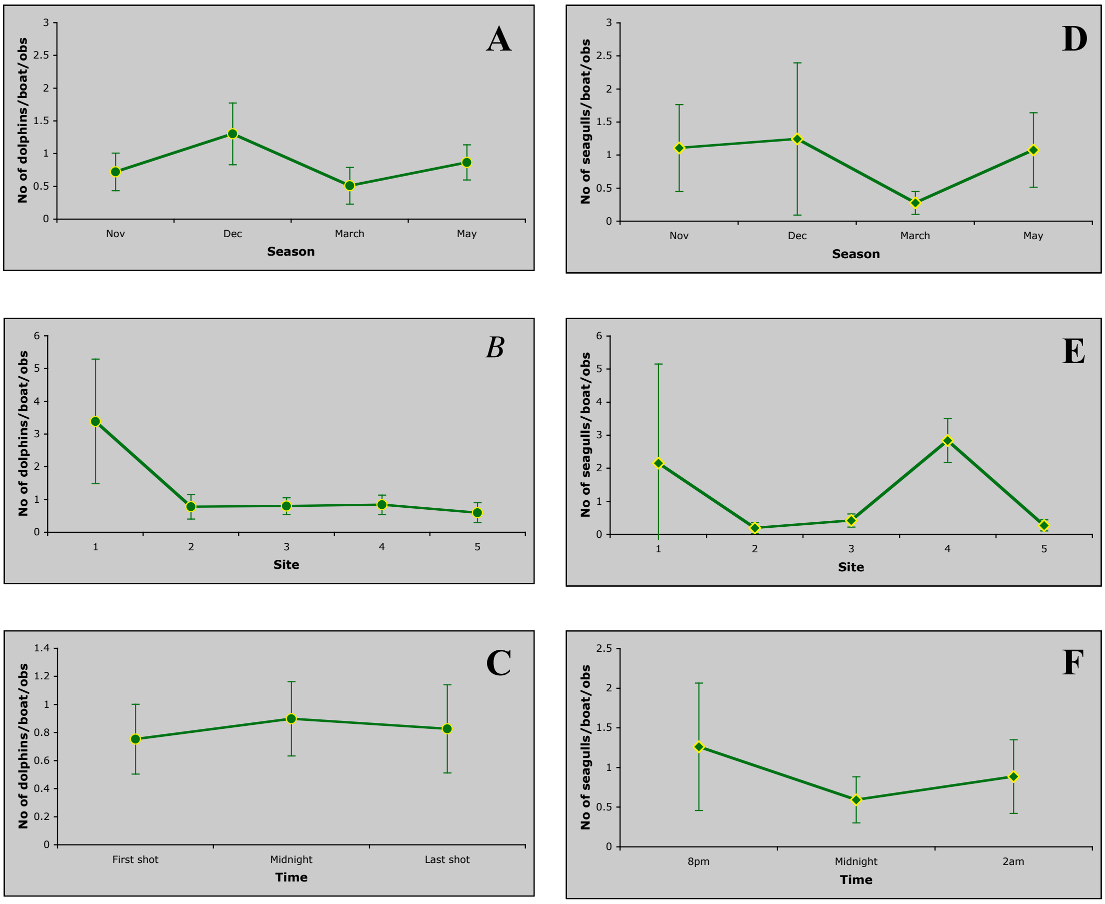


Fig. 5.1. Number of dolphins (A, B, C) and seabirds (D, E, F) observed feeding at prawn trawlers as a function of season (A, D), site (B, E) and time (C, F). Error bars are 95% confidence interval.

Results

General Observations

Seabirds appear sporadically and in relatively low numbers at fishing vessels in the Spencer Gulf and consumption of discarded by-catch appears to be of little importance. Dolphins, however, are common in the Spencer Gulf throughout the year usually found segregated in groups according to age and sex. The different groups are divided into female-calf pairs, sub-adults and adults and males and females and probably use varying home ranges and locations.

During prawn fishing, which occurs at night, family groups of dolphins and seabirds appear at the fishing vessel when the double trawl is retrieved. It is likely that dolphins respond to the sound of running winches, a noise that travel far under water. The dolphins follow the cod ends as they appear close to or on the surface as the vessel travels forward at a speed of about two to four knots. Individual animals pick or bite fish protruding through the cod end mesh or on what is lost from the net (see Broadhurst 1998). When sorting the catch, by-catch is discarded over the sides of the vessel, allowing seabirds and dolphins to feed. Feeding dolphins appear to be selective in their choice of food. Certain species of fish is preferred, notably red mullet, whiting and squids, while blue crabs, elasmobranch's, leatherjackets and benthic invertebrates are largely ignored. To quantify by observation what species various sizes of dolphins eat was not possible because prawn fishery takes place at night and that most feeding occurs below the surface.

The Occurrence of Dolphins as Scavengers

A significant effect of Season and Site was evident (Table 5. I). No significant effect of time and no significant interactions were evident. Due to the large unexplained variance the results have to be interpreted cautiously.

Effects of Season
The mean number of dolphins per boat and observation varied between seasons with means between 0.5 to 1.3 dolphins/boat/observation and is shown in Fig. 5.1. A. The observations in March were significantly lower that at other seasons. An SNK-test revealed that March was significant different from Nov and May but not different Dec (Table 5. II). However, these differences were minor and statistically affected by the relatively large variations.

Effects of Site
The mean number of dolphins/boat/observation was relatively constant at Site 2-5 with 0.5-0.8 dolphins observed per boat and observation (Fig. 5.1. B). At Site 1, however, a mean of 3.4 dolphins were recorded per boat and observation. An SNK test confirmed that Site 1 was significantly different from all other sites, while Site 2, 3, 4 and 5 were not significantly different.

Effects of Time
No significant effect of time was observed. The number of dolphins observed per boat and observation after the first shot, at midnight and after the last shot of the night was between 0.8-0.9 but with a large variation (Fig. 5.1 C). The SNK-test confirmed this pattern (Table 5. II).

The Occurrence of Seabirds as Scavengers

A significant effect of Site was observed but no significant effect of Season and Time was evident. No significant interactions were evident with the exception of Site x Season x Time caused by large within factor variation (Table 5. III). Due to the large unexplained variance the results have to be interpreted cautiously.

Effects of Season
The number of seabirds observed during the four seasons was from 0.3-1.2 per boat and observation (Fig. 5.1 D). March observations had the lowest number but no significant effect of season was observed due to the large variations. An SNK test revealed that March was significant different from December and May observations (Table 5. III), but no importance should be attached to this due to the non-significant overall effect.

Table 5. I. The results of a three-way ANOVA on number of dolphins observed during prawn trawling in the Spencer Gulf. The main effects are Season (4), Site (5) and Time (3). Data were log (x+1) transformed prior analysis to obtain homogeneity of variances. **=P<0.05.

Source	df	SS	MS	F	P
Site	4	1.378	0.345	5.099	0.0005**
Season	3	0.942	0.314	4.647	0.0033**
Time	2	0.247	0.123	1.826	0.1623
Site*Season	4	0.625	0.156	2.310	0.0571
Site*Time	8	0.778	0.097	1.440	0.1777
Season*Time	6	0.554	0.092	1.367	0.2266
Site*Season*Time	7	0.690	0.099	1.458	0.1806
Residual	428	28.922	0.068		

Table 5. II. Student-Newman-Keul Test (**=p<0.05) showing significance levels between sites, seasons and time on number of dolphins observed at prawn trawling. Data are log (x+1) transformed.

Effects of Season				
	Vs.	Diff.	Crit. Diff.	Significance
Dec	May	0.052	0.069	ns
	Nov	0.078	0.082	ns
May	Nov	0.026	0.069	ns
March	Nov	0.056	0.069	ns
	Dec	0.134	0.090	**
	May	0.082	0.082	**
Effects of Site				
S1	S2	0.322	0.145	**
	S3	0.320	0.132	**
	S4	0.307	0.110	**
	S5	0.376	0.154	**
S2	S3	0.002	0.110	ns
	S4	0.015	0.132	ns
	S5	0.055	0.110	ns
S3	S4	0.013	0.110	ns
	S5	0.056	0.132	ns
S4	S5	0.069	0.145	ns
Effects of Time				
Midnight	8pm	0.025	0.058	ns
	2am	0.028	0.069	ns
8pm	2am	0.003	0.058	ns

Table 5. III. The results of a three-way ANOVA on number of seagulls observed during prawn trawling in the Spencer Gulf. The main effects are Season (4), Site (5) and Time (3). Data were log (x+1) transformed prior analysis to obtain homogeneity of variances. **=P<0.05.

Source	df	SS	MS	F	P
Site	4	3.792	0.948	13.917	0.0001**
Season	3	0.165	0.055	0.809	0.4891
Time	2	0.042	0.021	0.310	0.7338
Site*Season	4	0.532	0.133	1.951	0.1012
Site*Time	8	0.392	0.049	0.720	0.6739
Season*Time	6	0.598	0.100	1.463	0.1893
Site*Season*Time	7	0.969	0.138	2.033	0.0498
Residual	428	29.157	0.068		

Table 5. IV. Student-Newman-Keul Test (**=p<0.05) showing significance levels between sites, seasons and time on number of seagulls observed at prawn trawling. Data are log (x+1) transformed.

Effects of Season				
	Vs.	Diff.	Crit. Diff.	Significance
Dec	May	0.013	0.069	ns
	Nov	0.017	0.082	ns
May	Nov	0.004	0.069	ns
March	Nov	0.088	0.090	ns
	Dec	0.071	0.069	**
	May	0.084	0.082	**
Effects of Site				
S1	S2	0.184	0.145	**
	S3	0.150	0.111	**
	S4	0.067	0.111	ns
	S5	0.173	0.133	**
S2	S3	0.034	0.133	ns
	S4	0.251	0.155	**
	S5	0.012	0.111	ns
S3	S4	0.217	0.133	**
	S5	0.023	0.111	ns
S4	S5	0.240	0.145	**
Effects of Time				
Midnight	8pm	0.012	0.058	ns
	2am	0.034	0.070	ns
8pm	2am	0.022	0.058	ns

Effects of Site

The number of seabirds varied significantly between sites (Table 5. III). The largest number of seabirds was observed at Site 1 and 4 with a mean of 2.2 and 2.8, respectively (Fig. 5.1. E). Low numbers were recorded at other sites. An SNK test revealed that Site 1 and 4 on one hand and Site 2, 3 and 5 on the other hand were not significantly different. However, the two groups were significantly different (Table 5. IV).

Effects of Time

The largest numbers of seabirds were observed at the first shot with a mean of 1.3 seabirds and the lowest numbers were observed at midnight with 0.6 and at the last shot with 0.9 seabirds per boat and observation (Fig. 5.1. F). However, no significant effect of time was evident (Table 5. III). An SNK test confirmed this (Table 5. IV).

Discussion

Methods of observation

To estimate the true number of a bottlenose dolphin population several methods are available. These include mark-recapture methods and photo-identification data (Wilson *et al.* 1999), aerial surveys (Belkovich & Zatevakhin 1994) or simultaneous counts by independent shore-based observers (Young & Peace 1999). However, these methods require an extensive program and substantial resources to obtain sufficient data. Furthermore, observations have to be done in daylight to obtain accuracy.

The subject of interest in this study is not to obtain a true estimate of the Spencer Gulf dolphin and seabird populations however desirable that may be but to estimate the amount of discarded by-catch consumed by these scavengers. In order to estimate the number of dolphins and seabirds feeding on discarded by-catch, a straightforward approach was chosen using time restricted observations from the trawler bridge and a statistical three-way ANOVA design, with site (5), season (4), and time of the night (3) as the main effects. Using the mean numbers of observed individuals, their standard feeding rates from the literature, the total time of feeding possibilities and the total amount of discarded by-catch, it is possible to estimate the fraction of by-catch eaten by surface scavengers. The observer, the number of observation, and seasonal and spatial variations in the Gulf, affects the errors of the estimates.

An observer stationed at a higher elevation above the sea level is likely to provide a good estimate of dolphin and seabird numbers within the light of the trawler. However, at the time of census not all animals are visible, diving or out of view hidden by the trawl bags. The true number of dolphins present and the total scavenging population estimated from this study is probably too low. Young & Peace (1999) have shown that observer estimates is likely to underestimate the true number of dolphins of about 30%. In addition, estimate differences between observers and multiple sightings during the night of fishing are likely to induce variance not accounted for.

Dolphin behaviour

Most dolphins show a daily behavioural pattern of feeding, travelling and socialising. The relative amount of time devoted to these three behaviours may vary with season and water temperatures. According to Braeger (1993), feeding occurs and in the late afternoon, while socialising increased as feeding decreases. Travelling was observed mostly in the late afternoon. However, during winter socialising and travelling decreases to the benefit of feeding as temperatures decrease. Feeding behaviours generally may occupy 40-80% of the daytime activities with socialising and travelling occupying equal parts of the remaining time. Balance (1992) reported that bottlenose dolphins observed close to the shores of the Gulf of California spend on average 62% feeding, 22% travelling and 16% socialising/resting. When observed off shore, travelling was a larger component of all behaviours. However, Scarpaci *et al.* (2000) found that in Port Philip Bay sightings of dolphins were greatest in January/February (summer) and least in October. The groups observed consisted of 2-5 individuals. Travelling constitutes here 51% of the behaviours, socialising 31% and feeding only 17%. This is in accordance with Hanson & Defran (1993) who found that coastal bottlenose dolphin behaviour constitutes 63% travelling, 19% feeding, 15% socialising and 3% rest. There is likely to be differences in behavioural patterns between groups of dolphins occupying different environments, however, no observation of behavioural patterns at night seems available.

Range of dolphins

The coastal range of bottlenose dolphins can be large. Balance (1992) reported several sightings of identified individuals within a rage of about 65 km in the Gulf of California. At the west coast of Florida, a range of 1,340 km of coastline has been reported (Scott *et al.* 1990). It is thus possible, that dolphins sighted in the Spencer Gulf are not locals but they are likely to be so. The result of a long-term population study on the west coast of Florida showed that a population of about 100 individuals were all-year residents within an area of approximately 85 km^2 and that migration and immigration was rare (Scott *et al.* 1990).

Dolphin feeding behaviour

Dolphins are considered catholic and opportunistic feeders. Corkeron *et al.* (1990) investigated feeding behaviour of bottlenose dolphins at prawn trawlers in Morton Bay, NSW, and found that acceptance of species of discarded by-catch varied greatly but preference was given to the putty-nose perch (*Polydactylus plebejus*) while crustaceans, predominantly blue crabs, and some fish species were never eaten. Our observations confirmed this but bottlenose dolphins in the Spencer Gulf exercised a clear preference for red mullet and squid and disregarded blue crabs entirely. Other fish species where observed to be eaten, such as whiting, but these occur in low quantities in the by-catch. Leatherjackets, which are very common in the by-catch, were largely ignored. Bottlenose dolphins have been observed to actively manipulate the cod-end, removing and consuming components of the catch thus demonstrating behavioural response to trawling activities (Broadhurst 1998).

The diet of coastal bottlenose dolphins is not likely to fundamentally change over longer time scales (yrs) but differences in the diet of coastal and offshore ecotypes are likely to be pronounced (Walker, Potter & Macko 1999). Braeger (1993), recorded that in the Gulf of Mexico fish constitute 68-82% of all studied stomach contents and Blanco *et al.* (2001) examined the stomach content of 16 bottlenose dolphins stranded on the Spanish Mediterranean coast and found that primarily fish (>90%) and secondarily cephalopods (both squids and octopus) constituted the main diet. Differences in diet between males, females and juveniles were found to be significant probably due to the long association between juveniles and lactating females, which occur closer to the shore.

Dolphin consumption

Barros & Odell (1995) found that bottlenose dolphins inhabiting the Indian River Lagoon in Florida consumed 1.98 ton (WW) of fish annually equivalent to a daily ration of 5.6 kg of fish per 100 kg adult. Shapunov (1973) estimated the relationship between daily ration and body weight of Black Sea bottlenose dolphins to be $y=1.56 + 0.047x$ at 23-28C degrees water temperature equivalent to 6.26 kg fish per 100 kg dolphin per day. Dolphins in captivity in Sea World, Orlando, Florida consumes 3.84% of their body weight per day (Barros, pers. com.).

The mean number of dolphins feeding on discarded by-catch is statistically independent of time but depending on season and site. The occurrence of dolphins was lowest in March and highest in December but these differences were generally small (Fig. 5.1 A). However, dolphin numbers were high at Site 1 with a mean of 3.4 dolphins per boat and observation but fairly similar numbers were observed at all other sites (0.8 at Site 2, 3, 4 and 0.6 at Site 5). The overall mean number of dolphins feeding on discarded by-catch was found to be 1.3 dolphins per boat and observation. Using a consumption rate of 6.26 kg per dolphin per day, disregarding any effects of food preference, then at 10 trawl-hauls per night 81.4 kg of discards can potentially be consumed per night and boat. When 39 trawlers are fishing then 3,174 kg discards will be consumed per night. When fishing 60 days a year an estimated 190.4 ton of discards are consumed per year by dolphins at the Spencer Gulf prawn fishery.

Seabird consumption

Seabird aggregation and scavenging at fishing vessels is commonly assumed to be a natural element in seabird ecology. However, there is little information on the relative importance of discarded by-catch as food and the natural availability of food sources. Skov & Durinck (2001) have shown that in the North Sea there is only a little overlap between the spatial distribution of fishing vessels and that of potentially scavenging seabirds. The authors furthermore showed that attraction of seabirds to a vessel is a local (<10km) process. The number of seabirds scavenging at the Spencer Gulf prawn fishery is low and certainly small in comparison with what have been reported from the North Sea (5.9 million birds consuming 124,600 ton of discarded offal and by-catch (Garthe *et al.* 1996)), the Norwegian Sea (11 million birds consuming 681,000 ton (Barrett *et al.* 2002)), off Heard Island, Antarctica (seabird consumption reported to be 36,660 to 84,166 ton by Green *et al.* (1998)).

The mean number of seabirds reported to feed at discarded by-catch in the Spencer Gulf at all sites and seasons were low and variable. No seasonal differences were found with the exception of the March observation, which were lower than at other seasons (Table 5. IV). However, a significant effect of Site was evident and the largest concentration of seabirds were observed at Site 1, 8 NM south of Whyalla with a mean of 2.2 seagulls per boat and observation, and at Site 4 off Wallaroo with a mean of 2.8 seagull per boat and observation. The overall mean number of seabirds observed to feed on discarded by-catch was 1.2 seagull per boat and observation. Using the estimates of Garthe *et al.* (1996) a seabird will on average consume 21.1 kg discarded by-catch, predominantly fish, per year. Because prawn fishery takes place about 60 days per year then a single seagull will consume 3.47 kg discards from that fishery. By assuming that a seagull get a full feed at each trawl haul, which has to be digested before a second feed can be consumed the following night, following estimates can be made. With 10 trawl hauls per night by 39 trawlers with 1.2 seagulls feeding per haul, this is equal to an observation of 468 seagulls feeding. Using these approximations, seagulls will potentially consume 1591.2 kg discards from the prawn fishery per year (3.47 kg/seagull x 468 seagulls).

References

Balance, L.T. 1992. Habitat use and ranges of the bottlenose dolphin in the Gulf of California, Mexico. Mar. *Mam. Sci.* 8: 262-274.

Barrett, R.T., Anker-Nilssen, T., Gabrielsen, G.W. & G. Chapdelaine 2002. Food consumption by seabirds in Norwegian waters. *J. Mar. Sci.* 59: 43-57.

Barros, N.B. & D.K. Odell. Bottlenose dolphin feeding and interactions with fisheries in the Indian River Lagoon system. *Bull. Mar. Sci.* 57: 278-285.

Belkovich, V.M. & I.I. Zatevakhin 1994. Methods of enumerating the bottlenose dolphin population. P. 75-76 in: S. Ozturk (ed.), Proc. 1st. Int. Symp. Mar. Mam. Black Sea.

Blanco, C., Salomon, O. & J.A. Raga 2001. Diet of the bottlenose dolphin (*Tursiops truncatus*) in the western Mediterranean Sea. *J. Mar. Biol. Ass. U.K.* 81: 1053-1058.

Braeger, S. 1993. Diurnal and seasonal behaviour patterns of bottlenose dolphins (*Tursiops truncatus*). *Mar. Mam. Sci.* 9: 434-438.

Broadhurst, M.K. 1998. Bottlenose dolphins, *Tursiops truncatus*, removing by-catch from prawn-trawl codends during fishing in New South Wales, Australia. Mar. Fish. Rev. 60: 9-14.

Corkeron, P.J., Bryden, M.M. & K.E. Hedstrom 1990. Feeding by bottlenose dolphins in association with trawling operations in Moreton Bay, Australia, P. 329-336 in: S. Leatherwood & R.R. Reeves (eds.), The Bottlenose Dolphin, Academic Press, N.Y., 653 pp.

Fertl, D. & S. Leatherwood 1997. Cetacean interactions with trawls: A preliminary review. *J. Northwest Atl. Fish. Sci.* 22: 219-248.

Garthe, S, Camphuysen, C.J. & R.W. Furness 1996. Amounts of discards by commercial fisheries and their significance as food for seabirds in the North Sea. *Mar. Ecol. Prog. Ser.* 136:1-11.

Green, K., Slip, D.J. & G.J. Moore 1998. The take of fish species by seabirds and marine mammals in the Australian Fisheries Zone around Heard Island: The potential for competition with a commercial fishery. *Pol. Biol.* 20: 273-280.

Hanson, M.T. & R.H. Defran 1993. The behaviour and feeding ecology of the Pacific coast bottlenose dolphin, *Tursiops truncatus*. *Aqua. Mam.* 19: 127-142.

Scarpaci, C. Bigger, S.W., Saville, T.A. & D. Nugegoda 2000. The bottlenose dolphin *Tursiops truncatus* in the Southern end of Port Phillip Bay; behavioural characteristics in spring and summer. *Vic. Nat.* 117: 4-9.

Scott, M.D., Wells, R.S. & A.B. Irvine 1990. A long-term study of bottlenose dolphins on the west coast of Florida. P. 235-244 in: S. Leatherwood & R. R. Reeves eds. The bottlenose dolphin. Academic Press, San Diego.

Shapunov, V.M. 1973. Food requirements and energy balance in the Black Sea bottlenose dolphin *Tursiops truncatus ponticus* Barbasch. P. 207-212 in K.K. Chapskii & V.E. Sokolov eds. Morphology and ecology of marine mammals: seals, dolphins, porpoises. J. Wiley, N.Y.

Skov, H. & J. Durinck 2001. Seabird attraction to fishing vessels is a local process. *Mar. Ecol. Prog. Ser.* 214: 289-298.

Walker, J.L., Potter, C.W. & S.A. Macko 1999. The diets of modern and historic bottlenose dolphin populations reflected through stable isotopes. *Mar. Mam. Sci.* 15: 335-350.

Wilson, B., Hammond, P.S. & P.M. Thompson 1999. Estimating size and assessing trends in a coastal bottlenose dolphin population. *Ecol. Appl.* 9: 288-300.

Young, R.F. & S. Peace 1999. Using simultaneous counts by independent observers to correct for observed variability and missed sightings in a shore-based survey of bottlenose dolphins, *Tursiops truncatus*. *J. Cetacean Res. Manage.* 1: 279-287.

Chapter 6: Occurrence and Consumption by Benthic Scavengers in The Spencer Gulf, South Australia: a UV-video analysis.

Ib Svane and Thor Saunders

Abstract

The purpose of this study was to identify the common scavengers feeding on by-catch in the Spencer Gulf prawn fishery, quantify their occurrence at bait (discard species) and estimate their consumption rates. Series of so-called “cafeteria experiments” were conducted at five representative selected sites during four periods using a feeding platform and an underwater video camera. The results showed that by-catch was not approached mid water but only when it reached the bottom. Far the most important scavengers were Degens leatherjacket during day, sealice during night, and blue crabs, which appeared to feed only during day. Port Jackson sharks were observed during both day and night while large stingrays during day. Degens leatherjackets and blue crabs were voracious daytime scavengers. A significant effect of site and time was found showing that these species only feed at day and that occurrence was dependent on site. Leatherjackets were dominating at the two southernmost sites while blue crab abundance decreased from north to south. Sealice were only observed during night dominating at Middle Bank and off Wallaroo with no seasonal effect. Within the time of observation, the dominating scavengers arrived at the bait at a constant rate. The number of leatherjackets and blue crabs that arrived at the bait at day at any site was not saturated during the 30 minutes period of observation but at night the saturation levels on blue crabs were reached after 12 minutes. Sealice reached their saturation levels after 12 minutes. The results showed that scavengers are randomly dispersed and that rate of occurrence is largely independent of resident population size. Bait consumption was variable with a significant effect of time and species. Bait consumption was found to be independent of site. Day and night consumption was found to be 150.9 and 178.9 g WW/hour, respectively. The mean consumption for all sites was 164.9 g WW/hour, which is eight times higher than reported elsewhere.

Introduction

Discarded by-catch constitutes increased feeding opportunities for benthic scavengers. Hall (1999) in his review suggested that a population response by the dominating species is possible but few data are available to test this hypothesis.

Many marine species are scavengers and feed opportunistically on carrion. Carrion is spatially and temporally an infrequent food resource and a single meal may sustain individuals for long periods (Britton & Morton 1994). Discarded by-catch constitutes a significant food source for benthic scavengers and can be divided into two categories: that which floats, and that which sinks. Wassenberg & Hill (1990) found that of the by-catch discarded from Moreton Bay prawn trawlers, only 3% floats while the rest sinks. The discarded by-catch that sink do so rapidly, spending only 5-10 minutes in the water column where they are susceptible to mid-water scavengers such as dolphins and sharks (Kennelly, 1995). However most of this sinking material ends up on the seabed where it becomes available as food for benthic scavengers (Wassenberg & Hill 1990, Britton & Morton 1994, Kennelly 1995, Moore & Wong 1995, Ramsay *et al.* 1997). In marine environments with many generalists, scavenging activities can be expected to be high (Laptikhovsky & Fetisov 1999). Few studies have examined the role of benthic scavengers in recycling the energy source from trawl discard (Ramsay *et al.* 1997). These studies have paid particular interest to sand crabs (family: Portunidae) (Wassenberg & Hill 1987; Kennelly 1995).

Discards that settle on the bottom attract a variety of scavenging benthic species depending on the type of environment and may constitute as much as 6-13% of the annual secondary production (Groenewold & Fonds 2000). Densities of scavenger species up to 200 times that of the background populations have been reported, and aggregation of some species may persist for up to three days (Veale *et al.* 2000). In the northwestern Mediterranean, Bozzano & Sarda (2002) reported that 48 to 64% of all fishery discards were consumed after 12 hours immersion and more than 90% after 24 hours. The mean rate of consumption was estimated to 23.8 ±5.7 g/hour on the shelf and 30.8±10.5 g/hour on the slope, indicating that depth influence consumption rates. Many animals inhabiting the deep sea floor are specialised as scavengers, such as the isopod *Natatolana borealis*, and rely on fall-outs from the surface because of lack of primary production (Collins & Bagley 1999, Johansen 2000).

In the Spencer Gulf, South Australia, the discarded by-catch from prawn trawling is variable both in space and time and constitutes about 1000 ton annually. The fished areas vary slightly in depth (20-40 m) but the benthic environments are highly variable. The Spencer Gulf is an oligotrophic environment with low levels of primary productivity and as such may resemble the deep sea with high levels of scavenger activity.

The purpose of this study was to identify the common scavengers feeding on by-catch in the Spencer Gulf prawn fishery, quantify their occurrence at bait (discard species) and estimate consumption rates. This was done in the field by conducting series of so-called "cafeteria experiments" using underwater video at five representative selected sites during four seasons, and through series of laboratory feeding experiments using the most common scavenging species (see Chapter 6).

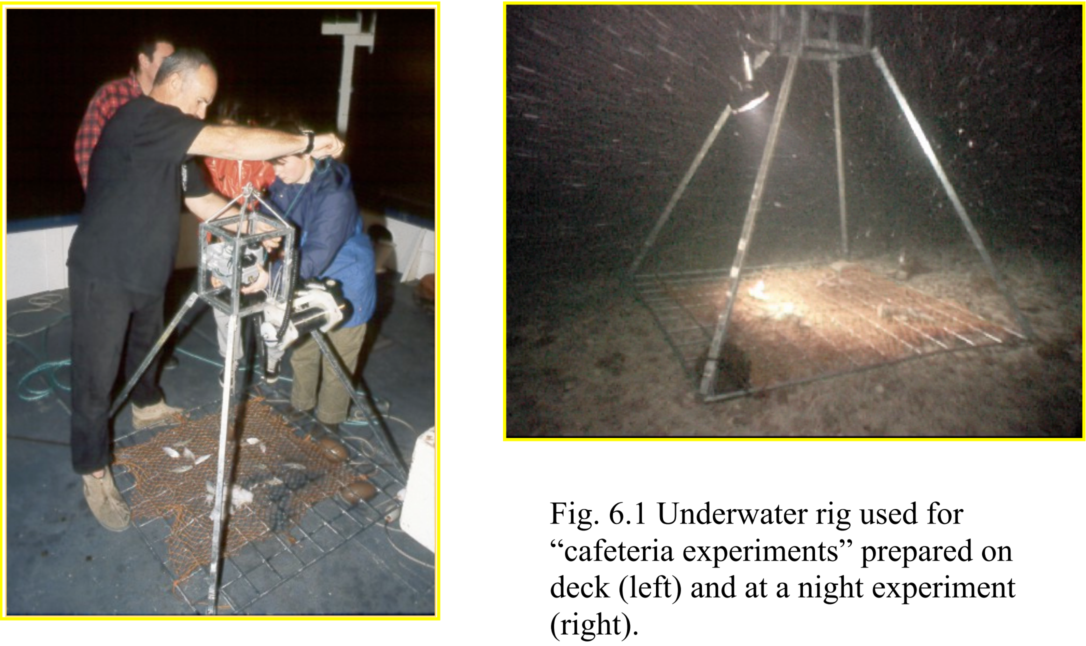


Fig. 6.1 Underwater rig used for "cafeteria experiments" prepared on deck (left) and at a night experiment (right).

Material & Methods

Equipment

A digital video camera Canon MV1 in an underwater housing was mounted vertically on a galvanised rig above a mesh grid measuring 1 x 1 meter. The distance from the focal plane to the grid base was 120 cm allowing a full photographic view using a wide-angle lens. During night, light was supplied by a 50-watt underwater daylight photographic lamp controlled by an adjustable timer set to 5 minutes intervals of light and darkness (Fig. 6.1).

Occurrence of Scavengers

Field experiments on scavenger occurrence were conducted during four seasons at five sites and in the Spencer Gulf. The selected sites are representative environments for the Gulf and with a different history of trawling intensity. At each site, four series of so-called "cafeteria experiments" were conducted. Each series consisted of three replicated experiments conducted during night and during day with the rig suspended mid-water and on the bottom. The depth at each site varied between 21-26 meters. Four batches of four different by-catch species were used as bait and attached to the grid base by 1 mm steel wire in each quarter section. The camera was activated and the rig lowered over the side of the research vessel and placed on the bottom for 30 minutes before being retrieved. A variety of bait species were used and whenever possible the same four by-catch species were used. These were red mullet, squid, leatherjacket and sand trevally.

The 30-minute video recordings of the grid were analysed by recording the species numbers present in each quarter of the grid/bait species at 2-minute intervals (14 observations). Night recordings were analysed by recording numbers present and species two times during each 5 minutes of light with a 2-minute intervals (6 observations). The data were analysed for each scavenger group sharks and rays, leatherjackets and sealice using three-way ANOVA's with season, site and time (nested within site) as the main effects. Bait preference could not be analysed because of difficulties in obtaining the same bait species for each experiment. All data set were tested for homogeneity of variances using the F-max test and subsequently log (x+1) transformed to obtain homogeneity.

Consumption Experiment

At one cruise, batches of four species of by-catch, namely Degens leatherjacket (*Thamnocanis degni*), Squid (*Sepioteuthis australis*), Bulls eye (*Parapriacanthus elongatus*) and Red mullet (*Upeneichthy vlamingii*), were pre-weighted in the laboratory, numbered and frozen. On board the bait was thawed before used for "cafeteria experiments". After up to 30-minute exposure to scavengers the rig was retrieved and the remaining bait packed and frozen in order to be re-weighted in the laboratory and the consumed weight subsequently calculated. This procedure was carried out because of the difficulties of weighting with any accuracy at sea.

Consumption was analysed using a three-way ANOVA with site, time nested within site and bait species nested within site as the main effects. All data set were tested for homogeneity of variances using the F-max test and subsequently log (x+1) transformed to obtain homogeneity.

Results

At all five sites mid-water cafeteria experiments (15 meters depth) were conducted by day and night. The results showed that during 30 minutes of immersion (n=15) no scavengers appeared in the video recordings and no bait was consumed. Accordingly, mid-water consumption of discarded by-catch was considered negligible and disregarded in further experiments.

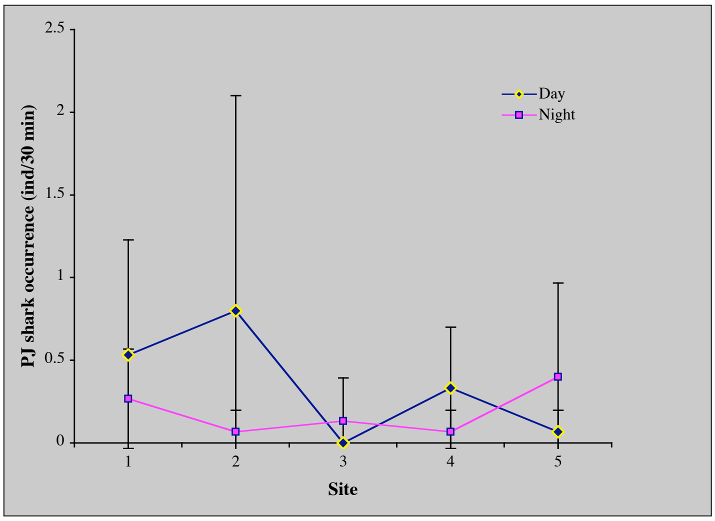


Fig. 6.2. The occurrence of Port Jackson sharks at bait at five sites in the Spencer Gulf. Error bars are 95% CI.

Occurrence of Scavengers

In particular, four species were observed as the dominating scavengers in cafeteria experiments; Degens leatherjacket during day, sealice during night, and blue crabs and Port Jackson sharks (*Heterodontus portusjacksoni*) during both day and night. However, blue crabs appeared to feed only during day. Other species were attracted to the cafeteria experiments but these were few in numbers and were not observed to feed. These were sand trevally (*P. wrighti*) and striped trumpeter (*Pelates octolineatus*) and wavy grubfish (*Parapercis haackei*). Occasionally prawns were observed in the video at night but did not feed on the bait or showed any attraction. Light and the general feeding activity probably attracted prawns.

Port Jackson Sharks and Stingrays

Large stingrays (*Dasyatis* sp.) (> one meter width) occurred during day at the cafeteria experiments but the stingrays had difficulties due to their size of assessing the grid but when successful they forcefully removed the bait. The number of stingrays recorded was 9 individuals at Site 2 and 2 individuals at Site 4.

Port Jackson sharks were commonly feeding on the bait offered in the cafeteria experiments irrespective of time and in an inconsistent pattern with large variations (Fig, 6.2). The result of the three-way ANOVA showed no effects of site ($p = 0.4066$) and time (time nested within site; $p=0.2247$) but a significant effect of season ($p=0.0275$). However, significant interactions were evident because effects of season were not consistent between sites and time. The result showed that Port Jackson sharks were uneven distributed among the five investigated sites both during day and night. The occurrence of Port Jackson varied with a mean of 0.2-0.4 individuals per experiment (n=3) at all sites and seasons. However, when Port Jackson sharks occurred, they usually cleared the tray.

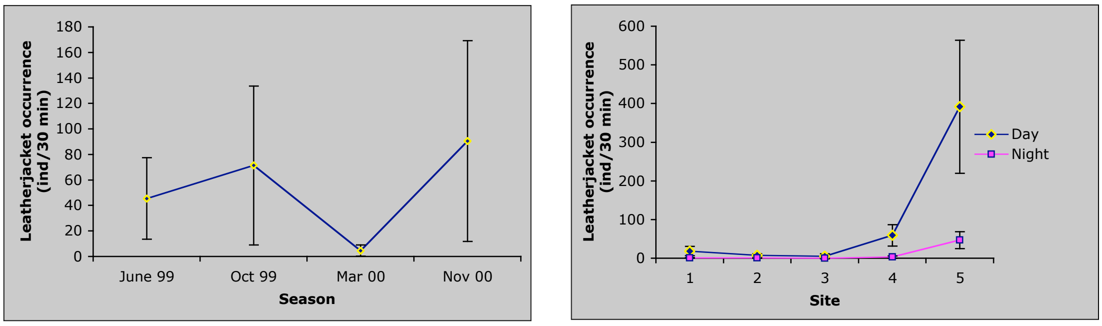


Fig. 6.3. The occurrence of Degens leatherjackets at bait (cafeteria experiments) during (left) four seasons and (right) at five sites in the Spencer Gulf during day and night. Error bars are 95% CI.

Degens leatherjacket

Degens leatherjackets were voracious scavengers attacking bait at day within a short time after the camera rig was established on the bottom. The result of a three-way ANOVA with season, site and time (nested within site) is shown in Table 6. I.
A significant effect of season, site and time was found. However, significant interactions of season were evident due to large variations between sites making effects of season non-conclusive. The occurrence of Degens leatherjackets as a

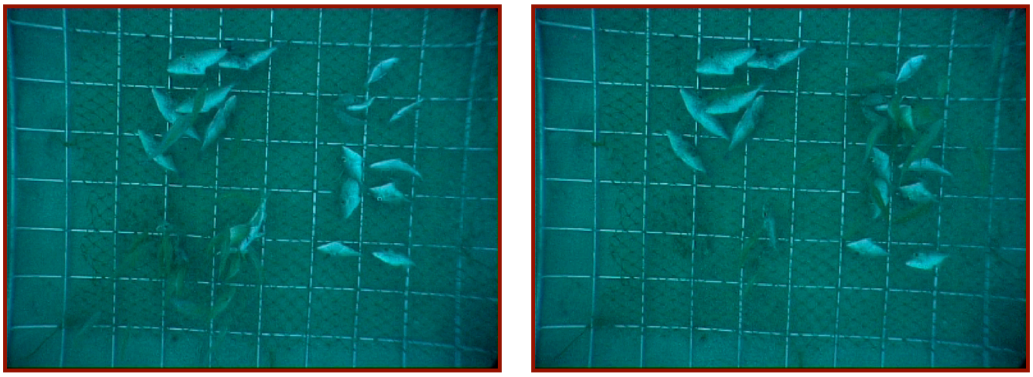


Fig. 6.4. Video clip showing the arrival of Degens leatherjacket at bait after 2 minutes of deployment of the rig (left). The leatherjackets immediately attack red mullet (soft-bodied) and proceed after 5-8 minutes to sand trevally (right) leaving the two other batches of Degens leatherjackets, males (top left) and females (bottom right) until last.

function of season and site (non-transformed data) is shown in Fig. 6.3. It is clear that the significant effects of season was caused by low occurrence in March 00 only. Nevertheless, the significant pattern of difference in occurrence between day and night is consistent with more Degens leatherjackets occurring at the baits during day rather than at night. Significantly more leatherjackets occur at Site 4 and 5 (Wallaroo and the Gutter) compared to the two northern sites. Site 3 (Middle Bank) had the lowest occurrence (Fig. 6.3). At Site 5 a mean of 391.7 leatherjackets per 30 minutes was observed at the bait during day. At night only 46.8 per 30 minutes were observed.

A test of bait (by-catch) preference was not statistically possible because of the difficulties in collecting the same species throughout the Gulf. Nevertheless, it is clear from the video recordings that Degens leatherjacket showed a preference for soft-bodied carrion (Fig. 6.4).

Table 6. I. Result of a three-way ANOVA on the occurrence of Degens leatherjackets with season, site and time (nested within site) as the main effects. Data log (x+1) transformed. * $p<0.05$

	df	SS	MS	F	P
Season	3	10.936	2.645	46.945	0.0001 *
Site	4	45.459	11.365	146.349	0.0001 *
Time (Site)	4	2.387	0.597	7.686	0.0001 *
Season * Site	12	5.976	0.498	6.414	0.0001 *
Time * Season	3	4.756	1.585	20.415	0.0001 *
Residual	92	7.144	0.078		

Blue crabs

Blue crabs occurred at the bait irrespective of day or night but most abundantly at day. At night crabs did not appear to feed because they spend comparatively less time at a bait at night than at day. However, crabs did tear up bait thus facilitating consumption by other scavengers. The result of a three-way ANOVA on log (x+1) transformed data on blue crab occurrence with season, site and time (nested within site) is shown in Table 6. II. A significant effect was found for all variables with a significant interaction of season * time. This pattern is caused entirely by inconsistency in seasonal patterns rendering the effect of season inclusive. However, the effects of site and time are significant and conclusive.

Table 6. II. Result of a three-way ANOVA on the occurrence of blue crabs with season, site and time (nested within site) as the main effects. Data log(x+1) transformed. * p<0.05; ns = not significant.

Source	df	SS	MS	F	P
Season	3	4.951	1.650	21.734	0.0001 *
Site	4	7.273	1.818	23.944	0.0001 *
Time (Site)	4	1.075	0.269	3.540	0.0098 *
Season * Site	12	5.882	0.490	6.455	0.0001 *
Time * Season	3	0.514	0.171	2.256	0.0871 ns
Residual	92	6.986	0.076		

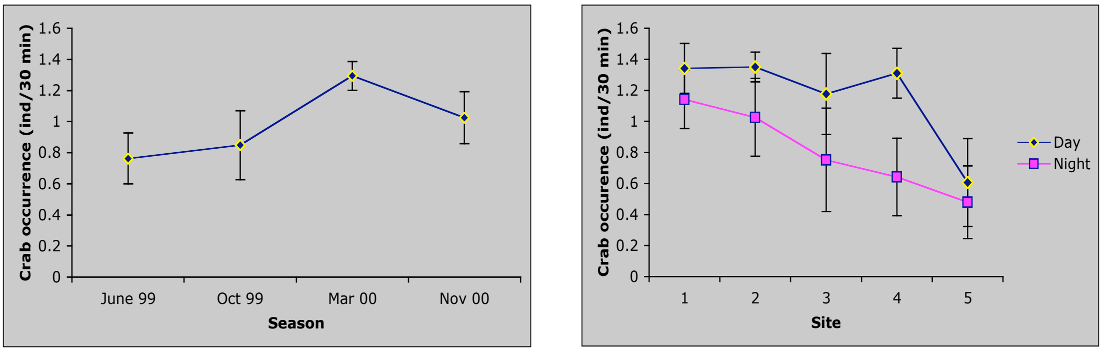


Fig. 6.5. The occurrence of blue crabs at bait (cafeteria experiments) during (left) four seasons and (right) at five sites in the Spencer Gulf during day and night. Error bars are 95% CI.

The occurrence of blue crabs at bait as a function of season, site and time can be seen in Fig. 6.5. Season effects can be disregarded due to season*site interactions. Crab occurrence at night declined from north to south of the Gulf with the lowest occurrence at Site 5 in the Gutter. This effect was not pronounced at day for Site 1, 2, 3, and 4 with the exception of Site 5, which generally had low crab occurrence. Crab occurrence was double as high at Site 1 (1.2-1.4 crab per 30 minutes) than at site 5 (0.5-0.6 crab per 30 min). The significant difference in crab occurrence between day and night is evident with more crabs appearing at bait during day than during night. Crabs did not appear to have any bait preference.

Table 6. III. Result of a three-way ANOVA on the occurrence of sealice with season and site as the main effects. Data log (x+1) transformed. * p<0.05; ns = not significant.

Source	df	SS	MS	F	P
Season	3	1.138	0.379	4.882	0.0055 *
Site	4	7.691	1.923	24.755	0.0001 *
Season * Site	12	6.508	0.542	6.983	0.0001 *
Residual	40	3.107	0.078		

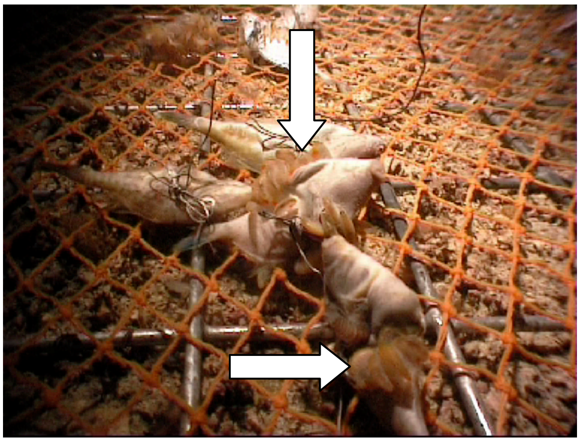


Fig. 6.6. Sealice feeding on leatherjackets (arrows). Blue crabs and tough skinned fish are attacked aggressively through the mouth, eyes, gills and anus and consumed from the inside.

Sealice

Sealice are extremely voracious scavengers but did not occur at bait during day. Sealice is a group of isopods and amphipods that aggressively attack carrion within minutes. The dominating species are the isopods *Natatolana woodjonesi* and *N. viridis*. The amphipod species have not been identified (Fig. 6.6).

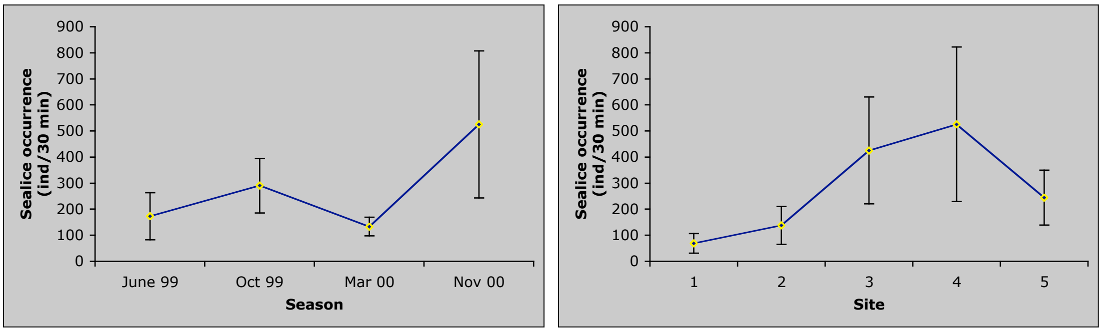


Fig. 6.7. The occurrence of sealice at bait (cafeteria experiments) during (left) four seasons and (right) at five sites in the Spencer Gulf during night. Error bars are 95% CI.

The result of the ANOVA showed a significant effect of season and site but also a significant interaction (Table 6. III). As with crabs this interaction is caused by interference by seasonal effects and site, which rendered this test inconclusive (Fig. 6.7 left). However, the effect of site is significantly consistent (Fig. 6.7 right). An SNK test revealed that Site 3 and 4 were significantly different from Site 1, 2 and 5. Sealice occurrence was highest at Site 3 (Middle Bank) and Site 4 (Wallaroo) with a mean of 425 and 526 individuals per 30 minutes, respectively. Sealice did not appear to show any bait preference.

Rate of occurrence

The rate of occurrence of the dominating scavengers is shown in Fig. 6.8. Accumulation of scavengers at bait was a linear function indicating arrival at a constant rate. Deviations from a straight line for all species can be attributed to sites with low occurrence. The number of blue crabs that arrived at the bait at day at any site was not saturated during the 30 minutes period of observation but at night the saturation levels were reached after 12 minutes. The saturation levels for Degens leatherjacket at day was similarly not reached within 30 minutes. At nigh, too few leatherjackets were observed at bait to calculate accumulation curves. Sealice reached their saturation levels after 12 minutes causing the accumulation rate to drop off. These results show that these scavengers are randomly dispersed when attracted to bait and that rate of occurrence is largely independent of resident population size.

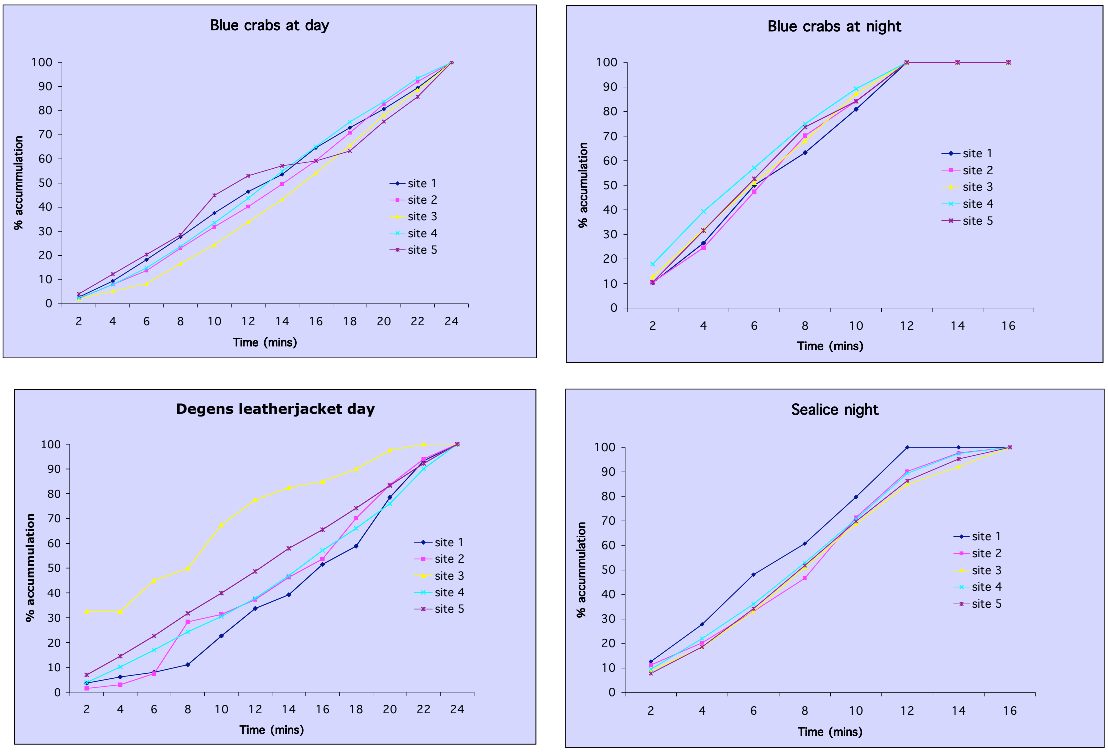


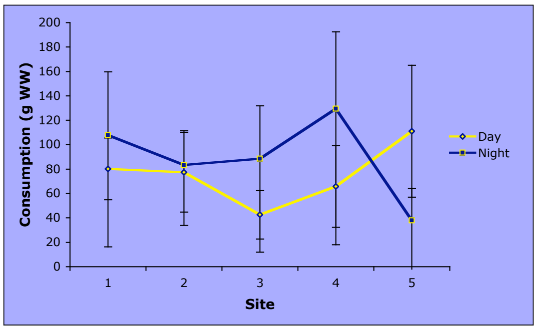
Fig. 6.8. Rate of occurrence of the dominating scavenging species at five sites in the Spencer Gulf.

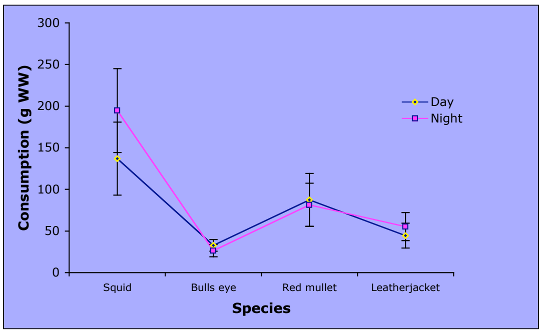
Consumption Experiments

Bait consumption was highly variable between all factors leading to a large unexplained variance making the results less conclusive (Table 6. IV). Nevertheless, the results showed a significant effect of time and species but no significant effect site. A significant interaction of time and species was evident.

Table 6. IV. A nested three-way ANOVA on bait consumption with site, time (site) and species (site) as the main effects. * p<0.05

	df	SS	MS	F	P
Site	4	17234.81	4308.70	2.370	0.0582 ns
Time (Site)	4	67895.28	16973.82	9.335	0.0001*
Species (Site)	12	41945.88	3495.49	1.922	0.0414*
Time * Species	3	20475.26	6825.09	3.754	0.0136*
Residual	92	167282.63	1818.29		





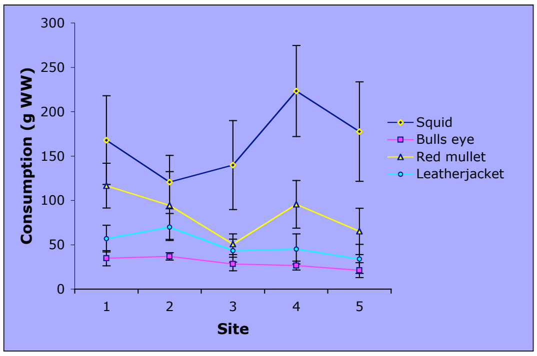


Fig. 6.9. Interaction graphs showing (top) effects of time nested within site (right), species nested within site (right), and (below) time * site on bait consumption at five sites in the Spencer Gulf. Error bars are 95% confidence interval.

Fig. 6.9 show the interaction graphs for time (sites), species (site) and time*species, respectively. The results for time (site) showed that consumption is generally higher at night than at day with the exception of Site 5 (Fig. 6.9 top left). This explains partly the significant interaction caused by interference. The different consumption pattern at Site 5 was caused by the high abundance of schooling Degens leatherjackets at the Gutter, which only feed during day. The night experiments showed higher consumption correlated with high abundance of scavenging sealice. The results for species (site) showed that squid was consumed in the highest quantities followed by red mullet with no statistical difference between sites with no interactions (Fig. 6.9 below). This pattern is consistent between day and night experiments explaining the remaining interaction as well (Fig. 6.9 top right). The overall consumption between day and night was not, however, significantly different (SNK-test $p>0.05$). Accordingly, the mean consumption for all sites was 164.9 g WW/hour ±12.0 SE and for day and night with 150.9 g WW/hour ±16.5 SE and 178.9 g WW/hour ±21.2 SE, respectively.

Discussion

In the Spencer Gulf, South Australia, the discarded by-catch from prawn trawling is variable both in space and time and constitutes about 1000 ton annually. The fished areas vary slightly in depth (20-40 m) but the benthic environments are highly variable. The most common scavengers observed were leatherjackets, notably Degens leatherjacket (*Thamnaconus degeni*), blue crabs (*Portunus pelagicus*) and sealice, a group of voracious scavengers on carrion composed of several species of isopods and amphipods dominated by *Natotalana woodjonesi* (Wassenberg & Hill 1987, 1990, Britton & Morton 1994, Moore & Wong 1995, Kennelly 1995, Ramsay *et al.* 1997). In addition, Port Jackson shark and stingray play an important role.

Juvenile Degens leatherjackets are inhabitants of shallow seagrass beds of Spencer Gulf while adults school deeper and relatively close to the bottom. Other species of leatherjackets join the schools such as mosaic leatherjacket (*Eubalichthys mosaicus*) and rough leatherjacket (*Scobinichthys granulatus*). The literature provides little information regarding the feeding ecology of leatherjackets in general and no studies seems to have been carried out on Degens leatherjacket. Leatherjackets are important consumers in seagrass assemblages and have been found to be generalists feeding on a variety of food items (Bell *et al.* 1978, Buchmore *et al.* 1984, Edgar & Shaw 1995, Last 1983).

The blue swimmer crab *Portunus pelagicus* is an important scavenger on discard in the Spencer Gulf ecosystem but it is also a dominant species in the prawn fishery by-catch (Carrick 1997). *P. pelagicus* is a member of the large family of sand crabs (Portunidae) and has several common names including the blue swimmer crab, blue crab, blue manna crab and sand crab (Dhawan *et al.* 1976, Potter *et al.* 1983, Wassenberg & Hill 1987, Potter *et al.* 1991). *P. pelagicus* has a wide geographical distribution, occurring throughout coastal waters of the Indo-West Pacific (Potter *et al.* 1983, Potter *et al.* 1991, Weng 1992). Many previous studies on the feeding ecology of *P. pelagicus* have indicated that it is an opportunistic carnivore, acting as either a predator or scavenger, depending on local availability of food items (Williams 1982, Wassenberg & Hill 1987, Edgar 1990, Sukumaran & Neelakantan 1997, Wu & Shin 1998). The natural predatory diet of *P. pelagicus* is a wide variety of sessile and slow moving invertebrates with small bivalves and ophiuroids (brittle stars) found to dominate its diet (Williams 1982, Sukumaran & Neelakantan 1997, Wu & Shin 1998. However, stomach content analyses have shown that *P. pelagicus* consume a wide variety of decaying flesh as well, indicating its scavenging tendencies (Sukumaran & Neelakantan 1997.

There is little information on the ecology of the Australian *Natatolana* species, and what is known has been interpolated from closely related species. Relatively large amounts of work have been carried out on *Natatolana borealis,* a deep-sea species of the northern hemisphere, a voracious scavenger that attacks carrion actively (Moore & Wong 1995). It has been reported that these isopods burrow in the sediment during the day, emerging primarily at dusk to travel up into the water column, only to return before dawn (Stepien & Brusca 1985). There are also reports of these sealice attacking living animals by entering the body cavity through the gills or anus and consuming the fish from the inside out (Hammer & Zimmerman 1979, Hammer 1981). The number of sealice observed in this study is probably underestimated because many enter the carrion and are otherwise difficult to observe in video recordings due to high swimming speed. Johansen (2000) estimated that *Natatolana borealis* was attracted to bait from a maximum distance of 190 m and swam at a speed of 4.5 to 18.7 cm/sec. The cafeteria experiments showed that the accumulation rate of *N. woodjonesi* was constant during a 30 minutes period. Because sealice responded to bait within 2 minutes the maximum distance travelled to bait, using the swimming speed reported for *N. borealis*, could be about 75-300 meters within the 30 minutes period of bait deployment.

This study shows that benthic scavengers play an important role in the Spencer Gulf ecosystem. Far the most important scavengers were Degens leatherjacket during day, sealice during night, and blue crabs, which appeared to feed only during day. Port Jackson sharks were observed during both day and night while large stingrays during day. By-catch was not approached mid water but only when it reached the bottom. Poiner *et al.* (1998) used a video camera to estimate scavenger abundance in the so-called Green Zone where prawn trawling occur north of Cape Grenville off the Queensland coast (far northern section of the Great Barrier Reef Marine Park) and found that in more than 50 camera deployments with 30 minutes deployment only between one and nine scavengers (mean 2.3 individual SD=2.49), mostly fish, were feeding on bait. In this study during a 30 minutes deployment at day, on average 0.2-0.4 Port Jackson sharks, up to 390 leatherjackets (Site 4 & 5) and 1.2-1.4 blue crab were feeding on bait. At night, blue crab occurrence was observed to be 0.4-1.2 per 30 minutes but in addition 100-500 sealice were furiously competing for the bait.

Consumption rates of carrion reported in the Catalan Sea (north-western Mediterranean) are 20-30 g/h (Bozzano & Sarda 2002). In this study consumption was found to be 164.6 g/hour, which is eight times higher. The mid water experiments did not reveal any scavengers, which is in accordance with the results of Wassenberg & Hill (1990) who found in a study on discards in the Moreton Bay prawn fishery that only 2 of 185 baits from 23 vertical set lines were eaten. The Spencer Gulf is an oligotroph environment with a large number of generalist predators and scavengers (see Chapter 1), especially teleosts and elasmobranchs (finfish, sharks and rays). These species appear to contribute significantly to the total biomass. The relative high consumption rates and the spatial and temporal variation in consumption and species increase the complexity of the ecosystem.

References

Bozzano, A. & F. Sarda 2002. Fishery discard consumption rate and scavenging activity in the northwestern Mediterranean Sea. *ICES J. Mar. Sci.* 59: 15-28.

Britton, J. C. and Morton, B. (1994). Marine carrion and scavengers. *Oceanogr. Mar. Biol. Ann. Rev.* 32: 369-434.

Bell, J.D., Burchmore, J.J. & D.A. Pollard 1978. Feeding ecology of three sympatric species of leatherjackets (Pisces: Monacanthidae) from a Posidonia seagrass habitat in New South Wales. *Aust. J. Mar. Freshw. Res.* 29: 631-643.

Buchmore, J.J., Pollard, D.A. & J.D. Bell 1984. Community structure and trophic relationships of the fish fauna of an estuarine *Posidonia australis* seagrass habitat in Port Hacking, New South Wales. *Aquatic Botany* 189: 71-87.

Carrick, N. A. (1997). A preliminary assessment of the by-catch from the Spencer Gulf Prawn Fishery. *South Australian Fisheries Assessment Series*. 97/02, 28 pp.

Collins, M. & P. Bagley 1999. Scavengers of the deep. *Biologist* 46: 54-56.

Dhawan, R. M, Dwivedi, S. N. and Rajamanickam, G. V. (1976). Ecology of the blue crab *Portunus pelagicus* (Linnaeus) and its potential fishery in Zuari estuary. *Ind. J. Fish.* 23: 57-64.

Edgar, G. J. (1990). Predator-prey interactions in seagrass beds. II. Distribution and diet of the blue manna crab Portunus pelagicus Linnaeus at Cliff Head, Western Australia. *J. Exp. Mar. Biol. Ecol.* 139: 23-32.

Edgar , G.J. & C. Shaw 1995. The production and trophic ecology of shallow-water fish assemblages in southern Australia. 2. Diets of fishes and trophic relationships between fishes and benthos at Western Point, Victoria. *J. Exp. Mar. Biol. Ecol.* 194: 83-106.

Groenewold, S. & M. Fonds 2000. Effects on benthic scavengers of discards and damaged benthos produced by the beam-trawl fishery in the southern North Sea. *ICES J. Mar. Sci.* 57: 1395-1406.

Hall. S.J. 1999. The effects of fishing on marine ecosystems and communities. Blackwell Scientific Press, 274 pp.

Hammer, R.M. 1981. Day-night differences in the emergence of demersal zooplankton from a sand substrate in a kelp forest. *Mar. Biol.* 62:275-280.

Hammer, R.M. & R.C. Zimmerman 1979. Species of demersal zooplankton inhabiting a kelp forest ecosystem off Santa Catalina Island, California. *Bull. South Calif. Acad. Sci.* 78:199-206.

Johansen, P.O. 2000. Bait attraction studies on the scavenging deepwater isopod *Natatolana borealis*. *Ophelia* 53: 27-35.

Kennelly, S. J. 1995. The issue of bycatch in Australia's demersal trawl fisheries. *Rev. Fish Biol. & Fish.* 5: 213-234.

Laptikhovsky, V. & A. Fetisov 1999. Scavenging by fish of discards from the Patagonian squid fishery. *Fish. Res.* 41:93-97.

Last, P.R. 1983. Notes on the feeding ecology of four sympatric leatherjackets (Pisces: Monocanthidae) from Tasmania. *Tasm. Fish. Res.* 25: 17-25.

Moore, P. J. & Wong, Y. M. 1995. *Orchomene nanus* (Kroyer) (Amphipoda: Lysianassoidea), a selective scavenger of dead crabs: feeding preferences in the field. *J. Exp. Mar. Biol. Ecol.* 192: 35-45.

Poiner, I., Glaister, J., Pitcher, R., Burridge, C., Wassenburg, T., Gribble, N., Hill, B., Blaber, S., Milton, D., Brewer, D. & N. Ellis 1989. Environmental effects of prawn trawling in the far northern section of the Great Barrier Reef: 1191-1996. *Final Report to Great Barrier Reef Marine Park Authority and Fisheries Research and Development Corporation vol. 1 & 2.*

Potter, I. C., Chrystal, P. J. & N.R. Longeragan 1983. The biology of the blue manna crab *Portunus pelagicus* in an Australian estuary. *Mar. Biol.* 78: 75-85.

Potter, M.A., Sumpton, W.D. & G.S. Smith 1991. Movement, fishing sector impact, and factors affecting the recapture rate of tagged sand crabs, *Portunus pelagicus* (L.), in Moreton Bay, Queensland. *Aust. J. Mar. Freshw. Res.* 42: 751-760.

Ramsay, K., Kaiser, M. J., Moore, P.G. & R.N. Hughes 1997. Consumption of fisheries discards by benthic scavengers: utilization of energy subsidies in different marine habitats. *J. Ani. Ecol.* 66: 884-896.

Stepien, C.A. & R.C. Brusca 1985. Nocturnal attacks on near shore fishes in southern California by crustacean zooplankton. *Mar. Ecol. Prog. Ser.* 25:91-105.

Sukumaran, K. K. & B. Neelakantan 1997. Food and feeding of *Portunus (Portunus) sanguinolentus* (Herbst) and *Portunus (Portunus) pelagicus* (Linnaeus) (Brachyura: Portunidae) along Karnataka coast. *Ind. J. Mar. Sci.* 26: 35-38.

Veale, L.O., Hill, A.S. & A.R. Brand 2000. An in situ study of predator aggregations on scallop (Pecten maximus (L.)) dredge discards using static time-lapse camera system. *J. Exp. Mar. Biol. Ecol.* 255: 111-129.

Wassenberg, T. J. & B.J. Hill 1987. Feeding by the sand crab *Portunus pelagicus* on material discarded from prawn trawlers in Moreton Bay, Australia. *Mar. Biol.* 95: 387-393.

Wassenberg, T. J. & B.J.Hill 1990. Partitioning of material discarded from prawn trawlers in Moreton Bay. *Aust. J. Mar. Freshw. Res*. 41: 27-36.

Weng, H. T. 1992. The sand crab (*Portunus pelagicus* (Linnaeus)) populations of two different environments in Queensland. *Fish. Res*. 13: 407-422.

Williams, M. J. 1982. Natural food and feeding in the commercial sand crab *Portunus pelagicus* Linnaeus, 1766 (Crustacea: Decapoda: Portunidae) in Moreton Bay, Queensland.). *J. Exp. Mar. Biol. Ecol.* 59: 165-176.

Wu, R. S. S. & P.K.S. Shin 1998. Food segregation in three species of portunid crabs. *Hydrobiologia*. 362: 107-113.

Chapter 7: Occurrence and Consumption of Sealice in the Spencer Gulf, South Australia.

Ib Svane & Kirsty Laube

Abstract

Sealice are commonly occurring in south Australian waters particularly the two isopod species, *Natatolana woodjonesi* and *N. viridis,* but also several amphipod species are found. Sealive are voracious scavengers active at night only. They are important consumers of discarded by-catch in the Spencer Gulf prawn fishery. The occurrence of sealice was measured at five sites in the Spencer Gulf know to have a history of different prawn trawling intensity. The occurrence and consumption of sealice was measured by using baited traps while a test on chemotaxis was done on observations by using underwater video. A significant effect of site and season on sealice number was found but also a significant interaction indicating inconsistency of the data particular differences between repeated sampling periods. Most sealice were trapped at Site 3 and 4 (Middle Bank and off Wallaroo). However, the high numbers were also caught at Site 1 but only during December. Sealice were observed to show chemotaxis and arrived at bait against an upstream tidal current of up to 2 knots. Sealice accumulated at bait at a constant rate independent of site. The observed patter was a logaritmic saturation curve indicating that sealice were evenly dispersed before they respond to bait. Of the five species used in bait preference trails, bait preferences were detected for Degens leatherjacket (DL) over sand trevally (TR) and rough leatherjacket (RL) over red mullet (RM). The observed pattern of preference was consistently independent on bait size. However, the results were not consistent in repeated experiments. The feeding rates of sealice in traps were found found to be 0.00486 g/min/sealice ± 0.00146 (95% CI).

Introduction

A group of marine scavengers composed of several isopod and amphipod crustaceans are collectively known as sealice. Bird (1981) described the group as being eminently carnivorous, active swimmers and voracious scavengers active at night where they aggregate at carrion in swarms (Hale 1976, Stepien & Brusca 1985). In the Spencer Gulf, South Australia, the dominating species are isopods of the genus Natatolona (Cirolanidae), notably *Natatolana woodjonesi* and *N. viridis*. Bruce (1986) lists 31 species of *Natatolona* that are known to inhabit Australian waters.

There is little information on the ecology of the Australian *Natatolana* species and most published work is on *Natatolana borealis,* a deep sea species occurring in the northern hemisphere (Bird, 1981, Johansen 1996, Moore & Wong 1995, Taylor & Moore 1995, Wong & Moore 1995). It has been reported that these isopods burrow in the sediment during the day, emerging primarily at dusk to feed and return before dawn (Stepien & Brusca, 1985). Sealice are voracious scavengers that feed on carrion and may attack living animals by entering the body cavity through the gills or anus and consuming their prey from the inside out (Hammer & Zimmerman, 1979; Hammer, 1981).

In South Australian waters, sealice are considered a pest in many fisheries because they rapidly consume bait and may attack animals that are caught, whether in nets, pots or hooked. Sealice are important scavengers on discarded by-catch in the Spencer Gulf prawn fishery. The purpose of this study was to describe the occurrence and consumption of sealice at five sites in the Spencer Gulf, which a subjected to different levels of trawling activity.

Material & Methods

Occurrence

Sampling was carried out during October and December 1999. The five sampling stations in the Spencer Gulf are described in Chapter 1. At each site four weighted baskets, each containing four baited traps with the same bait species (sand trevally) were used to determine the occurrence of sealice. The traps were made of a one-litre plastic container or similar size PVC tubing with a 10 mm hole drilled through the centre of the bottom and lid to allow sealice access. Additional 2 mm holes were drilled through the lid and bottom to ensure ventilation and release of odour (Fig. 1). All four baskets were lowered to the bottom at the same time and then retrieved at different time intervals. At station four, the traps were retrieved at 5-minute intervals (5, 10, 15, 20 minute basket submersion), at station three, at 3-minute intervals (3, 6, 9, 12 minute basket submersion) and at station two, at 4-minute intervals (4, 8, 12, 16 minute basket submersion). At all stations 4 traps were retrieved at 30 minutes.

Attraction to Bait

Attraction to bait was measured form video recordings in so-called cafeteria experiments where four bait species were distributed on a tray and the occurrence of number of sealice at fixed time intervals in relation to upstream and downstream directions were recorded (Chapter 6).

Bait Preference

By-catch bait species were obtained from trawling. Twelve traps were used, six baited with one species and six baited with a different species, and haphazardly placed in a waited basket and lowered to the bottom for 30 minute before being retrieved.

Data Recording

The initial and final weights of baitfish were recorded using a 'sea scale' electric balance to calculate consumption. The sealice collected from each trap were placed in numbered sample bags, frozen and taken to the laboratory for recording. Identification was carried out using classification tables provided in Bruce (1986). Sealice preference for bait was assumed to be consistent across all stations. One experiment was carried out during night and day at each station.

Fig. 7.1. Sealice-trap after being retrieved containing the sealice caught and remains of the bait.

Data Analyses

The total number of sealice caught in traps during 30 minutes bottom time at each station at two periods (October, November) was analysed using a two-way ANOVA. When Levene's test of homogeneity failed a square root transformation was carried out to obtain homogeneity of variances. The main factors were site and time. A Tukey posthoc test was used to determine differences between sites. Mann-Whitney U-tests were used to pair wise test for bait preferences with the null hypothesis of no difference between traps. The tests were carried out using number of sealice caught in traps as well as number of sealice per gram of bait weight at all stations at which an initial weight was recorded. This was performed so as to correct for the variation in size of baitfish used, and therefore to determine whether the size of bait contributed to the number of sealice caught in a trap.

Feeding rates were calculated using the bait species preference field data where an initial and final bait weight were recorded. Feeding rate was calculated by dividing the weight eaten with the number of sealice per 30 minutes bottom time to obtain a feeding rate in gram per minute per sealice.

The rate of occurrence was estimated using the cumulative number sealice caught per time unit converted to a percentage of the total sealice caught at that station. This transformation was used because of the variation in numbers of sealice occurring at different stations. A Student t-test on arcsine-transformed data was used to test the null-hypothesis of no difference between regression coefficients. Attraction to bait was analysed by using a G-test to test the null hypothesis of no difference between upstream and downstream occurrence.

Results

Occurrence

Figure 7.2 shows the mean number of sealice caught in traps during 30-minute on the bottom at each station in October and December cruises. The number of sealice caught in traps is variable. The highest numbers were caught at Site 3 and 4 with the exception of the large samples at Site 1 in December.

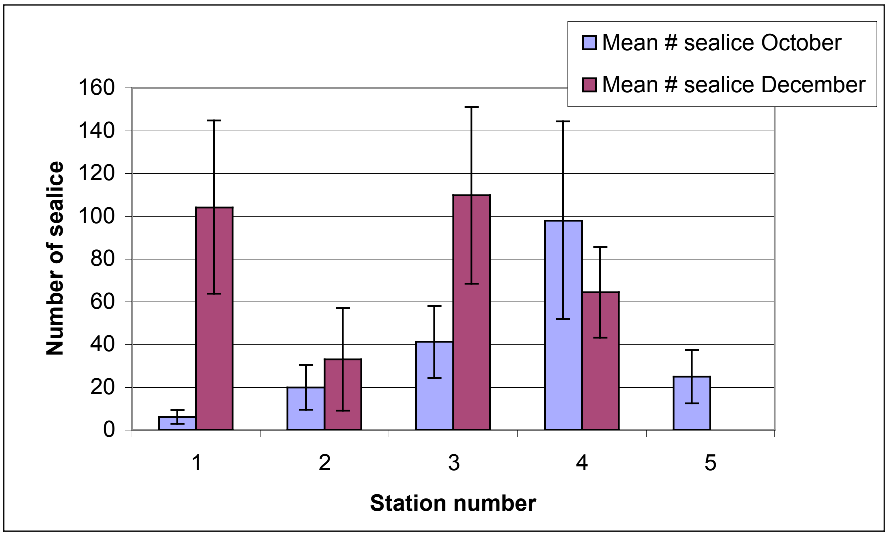


Fig. 7.2. Mean number of sealice caught in traps during field experiments at stations (1-5) during the field trips in October and December (± 95% confidence limits)

Table 7. I. Results of a post-hoc Turkey-test. * P<0.05

Site	Site	Sig.	Site	Site	Sig.
1.00	2.00	.300	3.00	1.00	.119
	3.00	.119		2.00	.000*
	4.00	.030*		4.00	.981
	5.00	.453		5.00	.004*
2.00	1.00	.300	4.00	1.00	.030*
	3.00	.000*		2.00	.000*
	4.00	.000*		3.00	.981
	5.00	1.000		5.00	.001*
			5.00	1.00	.453

A two-way ANOVA showed a significant effect of site and season on sealice number (season: $F = 22.535$, $P < 0.001$, site: $F = 8.061$, $P < 0.001$) was found but also a significant interaction (season x site: $F = 11.670$, $P < 0.001$) indicating inconsistency of the data. A post-hoc Tukey test confirmed the significance of Site 3 and 4 (Table 7. I) . However, the high numbers caught at Site 1 was only during December adding to the inconsistency between sampling periods.

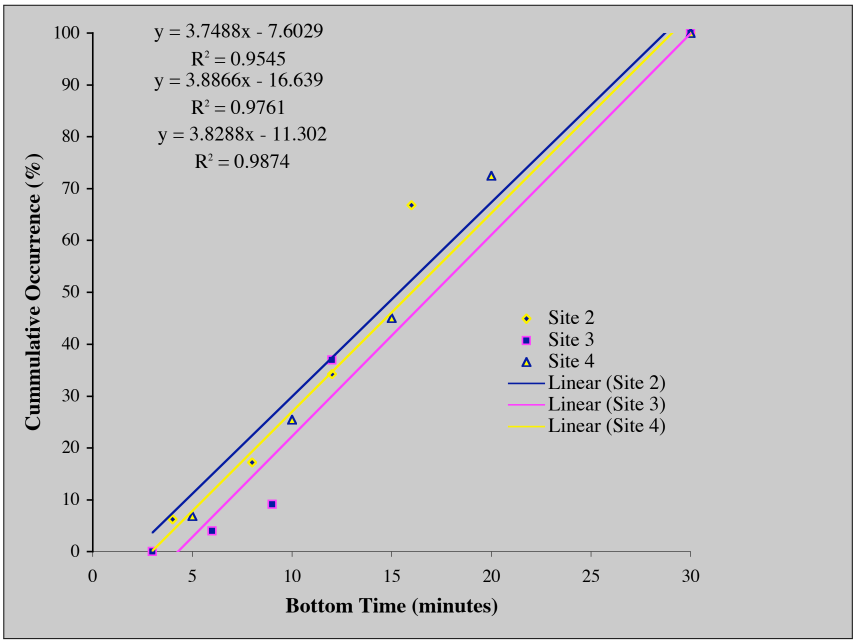
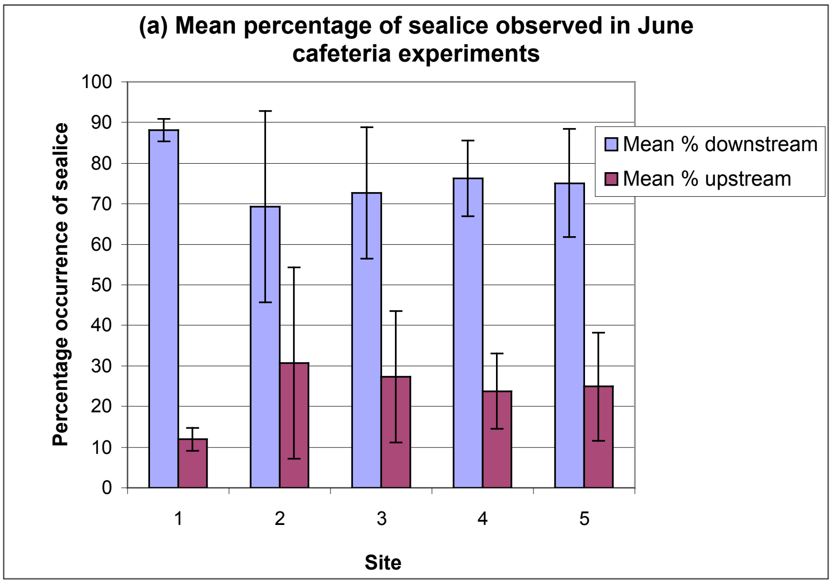


Fig. 7.3. Cumulative percentage occurrence of sealice at three sites caught in baited traps at different bottom time intervals. (±95% CI). Trend lines added.



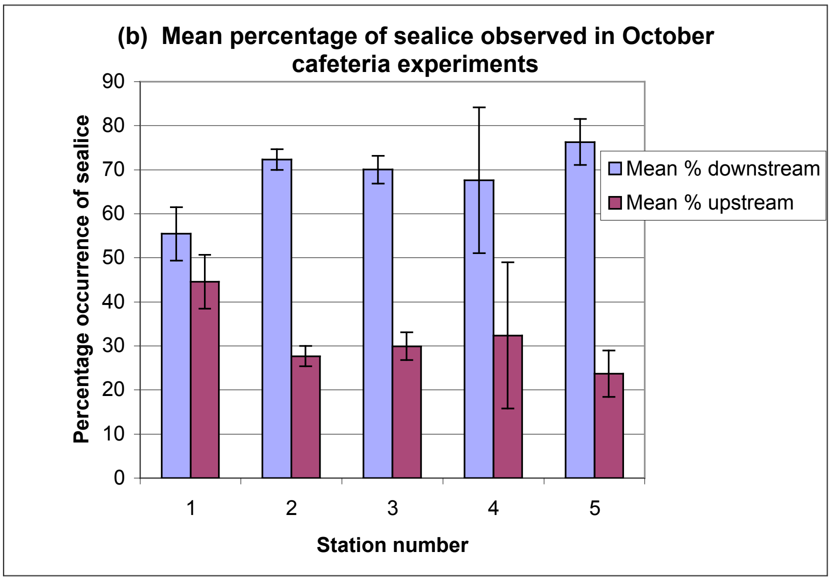


Figure 7.4. Mean percentage occurrence of sealice observed at upstream and downstream bait groups at each site (± 95% confidence limits) for (a) June cafeteria experiments and (b) October cafeteria experiments.

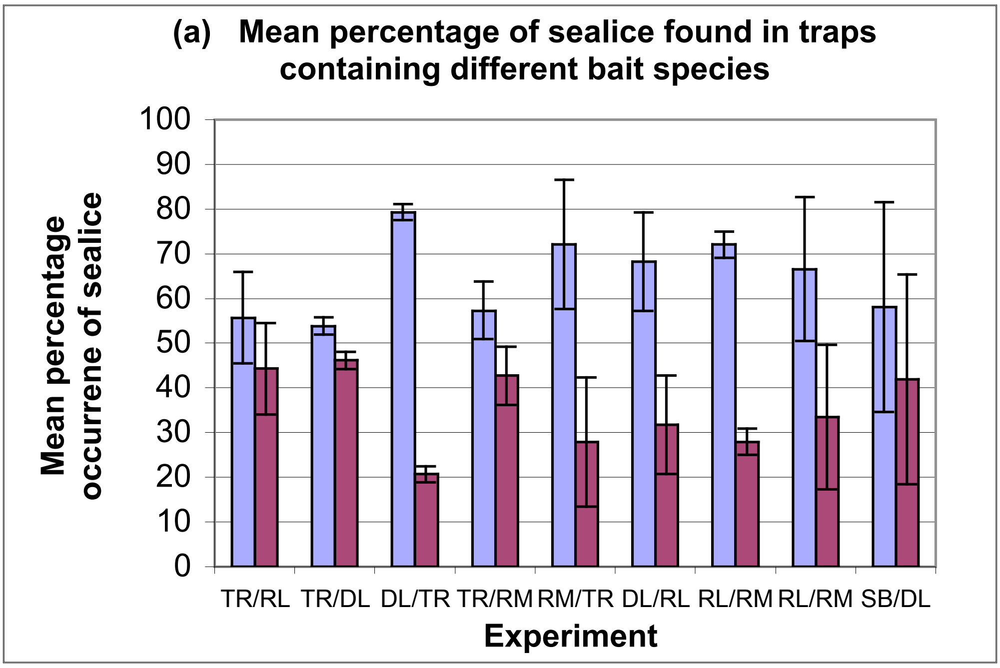
Attraction to Bait
Sealice showed well-developed chemotaxis behaviour when observed in nigh time video recordings. Sealice were observed to arrive at bait against an upstream tidal current of about 2 knots. Fig. 7.4 shows the mean percentage of sealice recorded at downstream and upstream bait groups (N=3) at each station for June (a) and October (b). A significant difference in the number of sealice found in upstream bait groups compared to downstream bait groups at all stations with a few exceptions. The null hypothesis that current direction has no effect on bait group on sealice number was rejected in all cases except June Site 2, October Site 1 and 4 (G-test, $p<0.05$).
Fig. 7.3 shows the cumulative percentage occurrence at a function of bottom time at three stations in December 1999 with the best linear fit for each site. Sealice accumulated at bait at a constant rate independent of site. The observed patter is a logaritmic saturation curve indicating that sealice are evenly dispersed before they respond to bait. The results of a student t-test on arcsine-transformed data accepted the null-hypothesis of no difference between regression coefficients ($P>0.05$).

Consumption
Fig. 7.4a, b shows the mean percentage (± 95% CI) of total number of sealice found in traps (a) and of the number of sealice per gram bait (b) containing various bait combinations. It should be noted that three bait pair experiments were repeated. These are sand trevally vs. Degens leatherjacket (TR/DL), sand trevally vs. red mullet (TR/RM) and rough leatherjacket vs. red mullet (RL/RM). The data were analysed pair wised using a Mann-Whitney U-test and the results are shown in Table 7. II. Bait preferences were detected for Degens leatherjacket (DL) over sand trevally (TR) and rough leatherjacket (RL) over red mullet (RM). The observed pattern of preference is consistently independent on bait size. However, the results were not consistent in repeated experiments.

Table 7. II. Summary of Mann-Whitney U-tests on sealice bait preference. + indicates the bait species on the x-axis being preferred, – indicates the bait species on the y-axis being preferred, * indicates a non-significant result.
(a) total number of sealice, (b) number of sealice per gram bait.

(a)	TR	RL	DL	RM	SB
TR			*	*	
RL	*			*	
DL	-	*			
RM	*	+			
SB			*		

(b)	TR	RL	DL	RM	SB
TR				*	
RL	*			*	
DL	-	*			
RM	*	+			
SB			*		



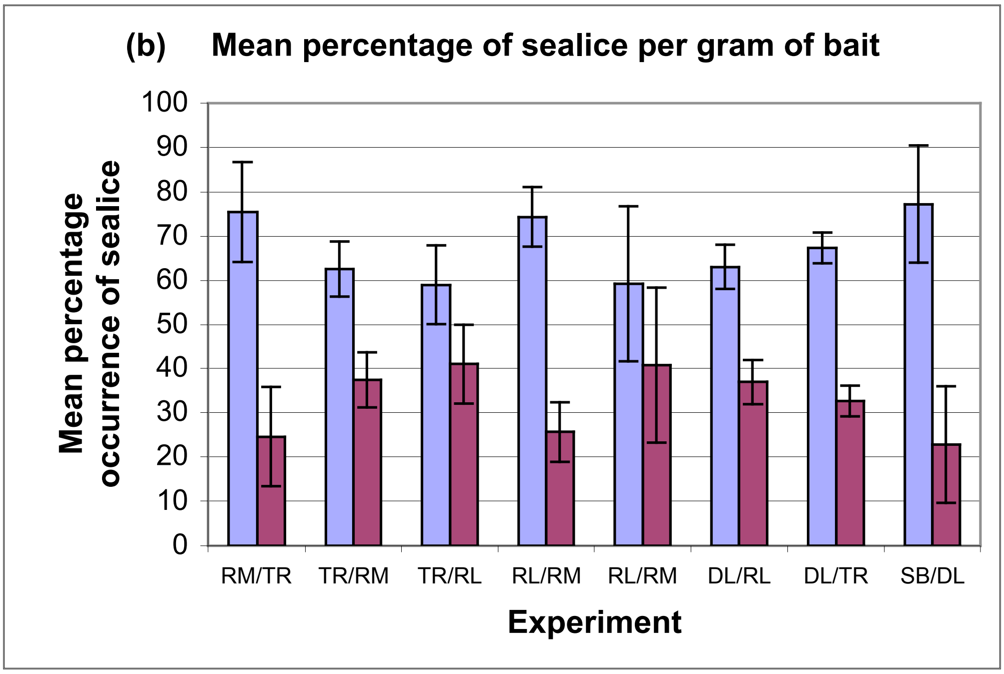


Fig. 7.4 (a) Mean percentage of total sealice caught in traps containing different combinations of baitfish (± 95% confidence limits). (b) Mean percentage of sealice per gram of bait weight caught in traps containing different combinations of baitfish (± 95% CL). TR=sand trevally, DL= Degens leatherjacket, RM=red mullet, SB=silverbelly, RL=rough leatherjacket.

The feeding rates of sealice in traps are summarised in Table 7. III. The mean feeding rate was found to be 0.00486 g/min/sealice ± 0.00146 (95% confidence limit).

Table 7. III. Estimated sealice feeding rates and the mean of all field experiments. Feeding rate units are g/min/sealice.

Consumed gram/min	Number of sealice	Time(min)	Feeding rate
8.000	50	30	0.00533
8.000	51	30	0.00523
6.000	67	30	0.00299
12.000	106	30	0.00377
10.000	107	30	0.00312
8.000	25	30	0.01067
10.000	93	30	0.00358
14.000	108	30	0.00432
2.000	25	30	0.00267
4.000	14	30	0.00952
18.000	179	30	0.00335
16.000	141	30	0.00378
Mean			0.00486
95% CI			0.00146

Discussion

The introduction of carrion through discards from trawl fishery is likely to affect the energy flow and the ecosystem food webs by subsidising consumer populations (Ramsay *et al.*, 1997). Walter and Becket (1997) observed an increase in seabird population as a consequence of fishery and showed that shrimp trawler discards in the Wadden Sea support 60,000 birds. The practice of discarding is likely to affect populations of benthic scavengers in a similar way to seabird populations (Ramsay *et al.*, 1997). In the Spencer Gulf prawn fishery approximately 1000 ton of by-catch is discarded annually. This discard is not distributed evenly but is likely to be a function of trawl hours at any given place. Presently, the most trawled areas are Site 3 and 4 and these areas also showed the highest sealice activity levels (see Chapter 1 and 6). However, this correlation may be incidental because the different areas are ecologically different with different assemblages and substratum.

Underwater video observations showed that current affect the direction of arrival of sealice. Non-significant results were only obtained when there were no current. This suggests that sealice are attracted to carrion by chemical signals, they presumably move upstream, attracted by a scent to reach carrion. Many crustaceans are known to have well-developed chemoreceptory abilities (Moore *et al.* 1991, Pearson & Olla 1977, Rittshcoff, 1992). Wong and Moore (1995) studied the feeding biology of *Natatolana borealis* and found that the response to food odour was kinetic and involved sensory organs situated on both pairs of antennae. The chemical signals to which the isopods react are thought to be simple molecules of universal occurrence (Wong & Moore, 1995). As *N. borealis* and the *Natatolona* species that occur in the Spencer Gulf are closely related, similar chemoreceptory abilities are to be expected.

The arrival of sealice to the bait was a logarithmic function and linear when shown as cumulative percentage (Fig. 7.3). This implies that when no carrion is available sealice are distributed evenly as any aggregation will give a non-linear function.

To record sealice feeding on carrion in underwater video is difficult because many sealice quickly enter the carrion body through gill opercula or the anus and are therefore out of view. A test on bait preference using vide recordings was therefore not carried out. The test of pair wise bait preferences using baited traps showed a significant preference in two cases. However when the bait combination was repeated this effect could not be demonstrated (Fig. 7.4 a, b, Table 7. II). Accordingly, the results are inclusive and the conclusion is that sealice do not show any preference for the bait species considered here.

Feeding rates were calculated from field data (this study) and from laboratory experiments (Chapter 8). The two feeding rates calculated were an order of magnitude different to each other, with the feeding rate in the field (0.00486 g/min/sealice) (Table 7. III), ten-fold higher than that found in the laboratory (0.00044 g/min/sealice). Sealice observed in the laboratory conditions is different from that in the field. When kept in aquaria, sealice may not exhibit voracious scavenging behaviour, spending most of the time burrowed in sediment. This could be a consequence of digestion time and disturbance by light even though animals were kept shaded. Wong and Moore (1995) found that "*N. borealis* processes food in the manner of a batch rectory. It bolts food rapidly and unselectively, stores it in its extensible anterior hindgut, and then takes a long time (weeks) to digest a single meal. It can survive long periods of time (months) without food". They concluded that sated sealice do not respond to food. Wong and Moore (1995) furthermore observed that sealice kept in laboratory conditions was that cannibalism of damaged or moulting individuals occurred.

Carrion is a spatially and temporally infrequent food resource in the sea, particularly the deep sea. In the absence of human interference, few marine animals die as a consequence of natural senescence, thereby becoming available as carrion for scavengers (Britton & Morton, 1994). The Spencer Gulf prawn fishery was closed from July to November and at the October field trip sealice would not have had the opportunity to feed to on discarded by-catch and showed no evidence of recent feeding. However, the anterior hindgut was full in a majority of the sealice collected in December, which may have affected the number of sealice occurring at the baits but likely not their relative occurrence as used in the bait preference test and the rate of occurrence.

References

Andrew, N.L. and Pepperell, J.G. (1992). The by-catch of shrimp trawl fisheries. *Oceanography and Marine Biology Annual Review* **30:**527-565.

Bergham, R. (1990). On the potential impacts of shrimping on trophic relationships in the Wadden Sea. *Trophic Relationships in the Marine Environment*, Proceedings of the 24th European Marine Biology Symposium, pp:130-140.

Bird, P.M. (1981). The occurrence of *Cirolana borealis* (Isopoda) in the hearts of sharks from Atlantic coastal waters of Florida. *Fishery Bulletin* **79**(2):376-383

Britton, J.C. and Morton, B. (1994). Marine Carrion and Scavengers. *Oceanography and Marine Biology: an Annual Review* **32:**369-434.

Bruce, N.L. (1986). Cirolanidae (Crustacea: Isopoda) of Australia. *Records of the Australian Museum: Supplement 6.*

Carrick, N.A. (1997). A preliminary assessment of the by-catch from the Spencer Gulf Prawn fishery. *South Australian Fisheries Assessment Series* **97/02**: 28pp.

Furness, R.W. (1984). Seabird-fisheries relationships in the northeast Atlantic and North Sea. *Marine Birds: Their Feeding Ecology and Commercial Fisheries Relationships* (eds Nettleship, D.N., Sanger, G.A. and Springer, P.F.) pp:162-169. Canadian Wildlife Service Special Publication, Dartmouth, Nova Scotia.

Furness, R.W., Hudson, A.V. and Ensor, K. (1988). Interactions between scavenging seabirds and commercial fisheries around the British Isles. *Seabirds and Other Marine Vertebrates: Competition, Predation and other Interactions* (ed Burger, J.) pp:240-268, Columbia University Press, Columbia.

Garcia, S.M. and Newton, C. (1997). Current situation, trends, and prospects in World Capture Fisheries. *American Fisheries Society Symposium* **2:**3-27.

Hale, H.M. (1976). The Crustaceans of South Australia. In: Handbook of the Flora and Fauna of South Australia parts 1 and 2, pp:1927-29.

Hammer, R.M. (1981). Day-night differences in the emergence of demersal zooplankton from a sand substrate in a kelp forest. *Marine Biology* **62:**275-280.

Hammer, R.M. and Zimmerman, R.C. (1979). Species of demersal zooplankton inhabiting a kelp forest ecosystem off Santa Catalina Island, California. *Bulletin of the South Californian Academy of Science* **78:**199-206.

Hudson, A.V. and Furness, R.W. (1988). Utilisation of discarded fish by scavenging seabirds behind whitefish trawlers in Shetland. *Journal of the Zoological Society of London* **215:**151-166.

Johansen, P. (1996). Reproduction and sexual maturation of the scavenging deepwater isopod *Natatolana borealis* (Lilljeborg) from western Norway. *Sarsia* **81:**297-306.

Kaiser, M.J. and Spencer, B.E. (1994). Fish scavenging behaviour in recently trawled areas. *Marine Ecology Progress Series* **112:**41-49.

McShane, P.E., Hall, S.J. and Carrick, N.A. (submitted). Trophic consequences of prawn trawling: linking by-catch to benthos.

Moore and Wong (1995). *Orchomene nanus* (Krøyer)(Amphipoda: Lysianassoidea), a selective scavenger of dead crabs: feeding preference in the field. *Journal of Experimental Marine Biology and Ecology* **192**:35-45.

Moore, DP.A., Scholz, N. and Atema, J. (1991). Chemical orientation of lobsters, *Homarus americanus*, in turbulent odor plumes. *Journal of Chemical Ecology* **17**(7):1293-1307

Pearson, W.H. and Olla, B.L. (1977). Chemoreception in the blue crab *Callinectes sapidus*. *Biological Bulletin* **153**:346-354

Pointer, I., Glaister, J., Pitcher, R., Burridge, C., Wassenburg, T., Gribble, N., Hill, B., Blaber, S., Milton, D., Brewer, D. and Ellis, N. (1989). Environmental effects of prawn trawling in the far northern section of the Great Barrier Reef: 1191-1996. *Final Report to Great Barrier Reef Marine Park Authority and Fisheries Research and Development Corporation,* Vol. 1 and 2.

Ramsay K., Kaiser, M.J. and Hughes, R.N. (1998). Responses of benthic scavengers to fishing disturbance by towed gears in different habitats. *Journal of Experimental Marine Biology and Ecology* **224:**73-89.

Ramsay, K., Kaiser, M.J., Moore, P.G. and Hughes, R.N. (1997). Consumption of fisheries discards by benthic scavengers: utilisation of energy subsidies in different marine habitats. *Journal of Animal Ecology* **66:**884-896.

Regehr H.M. and Montevecchi, W.A. (1997). Interactive effects of food shortage and predation on breeding failure of black-legged kittiwakes: indirect effects of fisheries activities and implications for indicator species. *Marine Ecology Progress Series* **155:**249-260.

Rittschoff, D. (1992). Chemosensation in the daily life of crabs. *American Zoologist* **32**:363-369.

Smith, S.V. and Veeh, H.H. (1989). Mass balance of biogeochemically active materials (C, N, P) in a hypersaline gulf. *Estuarine, Coastal and Shelf Science* **29**:196-215.

Stepien, C.A. and Brusca, R.C. (1985). Nocturnal attacks on near shore fishes in southern California by crustacean zooplankton. *Marine Ecology Progress Series* **25:**91-105.

Taylor, A.C. and Moore, P.G. (1995). The burrows and physiological adaptations to a burrowing lifestyle of *Natatolana borealis* (Isopoda: Cirolanidae). *Marine Biology* **123:**805-814.

Underwood, A.J. and Kennelly, S.J. (1990). Pilot studies for designs of surveys of human disturbance of intertidal New South Wales. *Australian Journal of Marine and Freshwater Research* **41:**65-73.

Walter, U. and Becker, P.H. (1997). Occurrence and consumption of seabirds scavenging on shrimp trawler discards in the Wadden Sea. *ICES Journal of Marine Science* **54:**684-694.

Wassenburg, T.J. and Hill, B.J. (1990). Partitioning of material discarded from prawn trawlers in Moreton Bay. *Australian Journal of Marine and Freshwater Research* **41:**181-196

Wong, Y.M. and Moore, P.G. (1995). Biology of feeding in the scavenging isopod *Natatolana borealis* (Isopoda: Cirolinidae). *Ophelia* **43**(3):181-196.

Chapter 8: Consumption by Degens Leatherjacket (*Thamnaconus degeni*), Blue Swimmer Crab (*Portunus pelagicus*) and Sealice (*Natatolana woodjonesi*) Under Laboratory Conditions

Ib Svane, Kirsty Laube, Shane Roberts & Thor Saunders

Abstract

Consumption of various species occurring as discarded by-catch in the Spencer Gulf prawn fishery by the most common scavengers, Degens leatherjacket, blue swimmer crab and sealice was measured in the laboratory. When kept individually *T. degeni* was found to consume little but when kept in groups feeding increased with no difference between genders. Squid was found to be consumed in larger quantities than red mullet (15.0 and 9.9 mg/g/min), which in turn was consumed more than sand trevally and leatherjacket (6.2 and 4.4 mg/g/min). Blue crabs consumed similar amounts of food after a 6-hour starvation period (0.060 ± 0.017 g/g crab) compared to that of the initial feeding period (0.054 ± 0.010 g/g crab). At 1.5 and 4 hours, crabs ate only half the amount of the initial feed indicating foregut fullness. Blue crabs consumed roughly the same amount at 6 hours than that of the initial consumption indicating that after 6 hours of digestion the foregut is empty. Consumption by the two larger size classes of blue crabs was significantly different, with medium sized crabs consuming more discards per gram body weight than the large size class. The small size class of crabs consumed more discard per gram of body weight than both medium and large size classes. A medium size crab of 100 mm will consume 27.6 mg/g crab during 8 minutes before the foregut will be full. The highest consumption rates was found for squid and blue crabs show preference for squid over flathead under laboratory conditions. Consumption of bait cubes by sealice varied significantly between experiments indicating that factors other than the presence of bait may regulate feeding. The mean feeding rate found in laboratory experiments was 0.00044 g/min/sealice ± 0.00028 (95% confidence limit). Sealice did not show any bait preference under laboratory conditions.

Introduction

In the Spencer Gulf the most common scavengers are leatherjackets, notably Degens leatherjacket (*Thamnaconus degeni*), blue crabs (*Portunus pelagicus*) and sealice, a group of voracious scavengers on carrion composed of several species of isopods and amphipods, notably *Natotalana woodjonesi.* The feeding ecology of the blue crab in general and in relation to discarded by-catch from the Moreton Bay prawn fishery has been previously studied. Blue crabs are found to be opportunistic carnivores, as either predators or scavengers. (e.g. Wassenberg & Hill 1990, Edgar 1990, Sukumaran & Neelakantan 1997, Wu & Shin 1998). However, little is know about the feeding ecology of leatherjackets and sealice. The purpose of this study was to estimate experimentally consumption rates for the most important consumers of discarded by-catch in the Spencer Gulf prawn fishery with the aim of characterising and quantifying the energy pathways. A necessary component of this study is to estimate consumption of the above-mentioned species by a series of laboratory experiments.

Materials and Methods

Collection of specimens

All *Portunus pelagicus* and by-catch material used in the experiments were collected on several occasions from both the Spencer Gulf and Gulf St. Vincent using trawl gear and commercial crab pots on board the RV Ngerin. In order to prevent crabs from damaging one another, healthy specimens had their claws carefully bound. They were then placed in a small holding tank filled with iced seawater to lower their metabolism. A total of 74 crabs were used in experiments with an exact 50:50 sex ratio. Additionally, 3 size classes were used (60-84, 85-109 and 110-140 mm carapace width) where the largest represented legal sized crabs of the blue crab fishery. Experiments with *P. pelagicus* were conducted at SARDI aquatic sciences laboratory at West Beach in Adelaide.

Degens leatherjackets (*Thamnaconus degeni*) were captured by using cylindrical mesh traps baited with sand trevally (*Pseudocaranx wrighti*) in Boston Bay, Port Lincoln. After capture the leatherjackets were transported within 30 minutes to Lincoln Marine Science Centre and allowed to acclimatise in the laboratory before use.

Sealice of the species *Natatolana woodjonesi* were captured in baited traps made of 30 cm lengths of 10 cm wide polypipe, capped with holes drilled in for lice access and ventilation. The sealice were transported to Lincoln Marine science Centre and kept in holding aquaria with 2 cm sandy sediment.

Consumption by Degens Leatherjackets

Consumption by Individual Degens Leatherjackets

Glass aquaria (25H x 20W x 40D cm) wrapped in black plastic and labelled 1-12 were set up with flow through seawater (54 L/hr) at 17°C. Individual leatherjacket's weight, sex and length were recorded before they were put in each aquarium. They were then allowed to acclimatise for 24 hrs. Portions of sand trevally collected by trawling were weighed and hooked onto a small piece of wire. These were then lowered into each tank. Baits from 4 tanks were reweighed at 0, 2.5, 6 and 9 hours, respectively. Tanks were randomly selected for the time period where the bait was reweighed. Individual leatherjackets from each tank were then removed and the above procedure was repeated with a new set of leatherjackets.

Consumption by Groups of Degens Leatherjackets

Leatherjackets were observed to eat more voraciously when kept in groups. Therefore, a series of consumption experiments were done using groups of leatherjackets. Four large (1.0H x 1.0L x 0.5D m) fibreglass aquaria with flow through seawater (54 L/hr) at 17°C were set up, each containing 17 pre-weighed leatherjackets. The leatherjackets were allowed to acclimatise for 24 hours before experiments were run. The experiments consisted of weighing a large amount of discard material (typically >110 gram of squid, red mullet, trevally and leatherjacket) and placing it in each of the four tanks. The bait was reweighed after 4, 8, 16 and 32 minutes respectively, and placed back into the tanks after each weigh period until the experiment was terminated at 32 minutes. The experiments were replicated four times. All weights in both experiments were corrected for weight change from immersion in water (estimated in separate experiments) and standardised by dividing by the weight of the leatherjacket(s) (g/g eaten).

Statistical Analysis

A single factor ANOVA was used to test for effects of time in the consumption experiments, while a two factor ANOVA was used to test for effects of time and species of by-catch during the consumption experiments. All data were tested for homogeneity using Levene's test and square root transformed to obtain homogeneity. Tukey's post hoc tests were performed for multiple comparisons.

Consumption by Blue Crabs

Foregut Clearance of Blue Crabs

To determine when a crab foregut is full and thus satiated, 11 clear plastic aquaria (44H x 66L x 38W cm each) wrapped in black plastic to reduce disturbance and direct light were set-up with flow through seawater (54 L/hr). A perforated (2 mm thick) plastic divider was inserted diagonally into each aquarium allowing a total of 22 crabs to be individually tested at any one time. The bottom of the aquaria had sterile shell grit of approximately 3-4 cm in depth for crabs to bury in.

A group of crabs was placed in the tanks and starved for 24 hours then fed a weighed amount of sand trevally. The food was re-weighed after 16 minutes to establish the amount consumed by each crab on an empty gut. This same procedure was repeated at $1^1/_2$, 4 and 6 hours respectively after the initial feed. All weights were corrected for autogenic change of trevally whilst immersed in water and standardised to gram eaten per gram of crab (g/g crab).

Consumption

The consumption experiments involved the estimate of food uptake (g/g crab) by blue crab over varying time intervals (4, 8, 16, 32 and 64 minutes) for seven discard species:

1. Squid – *Sepioteuthis australis*
2. Red mullet – *Upeneichthy vlamingii*
3. Flathead – *Platycephalis basensis*
4. Sand trevally – *Pseudocaranx wrighti*
5. Southern silverbelly – *Parequula melbournensis*
6. Rough leatherjacket – *Scobinichthys granulatus*
7. Degens leatherjacket – *Thamnaconus degeni*

Consumption was measured for 3 size classes of crabs (60-84, 85-109 and 110-140 mm) and both sexes. Three series of experiments, one for each size class of crabs with a sex ratio of 50:50, and two series of experiments, one for each sex were conducted. This ensured that each crab variable was tested for all discard species and all time periods.

Crabs that were needed for a series of experiments were tagged and placed in a holding tank for acclimatisation and subsequently selected randomly for the experiments. Tags were small (10 x 4 mm) plastic coded strips, attached posterior on the carapace using a spatula and a small drop of Selleys ‘Supa Glue’. When used for an experiment, the code for each crab was recorded along with its size, sex and the experimental tank in which it was tested.

Each experiment in a series consisted of 4 crabs per time interval (a total of 20 crabs), where pairs of crabs in the same tank were not tested for the same time. Thus, the 4 replicate consumption measures for each time interval were from different experimental units. All crabs were allowed to settle in their experimental tanks for at least 2 days before any testing began. They were starved for at least 6 hours between experiments, thus allowing two experiments to be carried out per day.

All consumption experiments followed the same protocol. A whole bait item (fish/squid) was blotted dry and weighed on a set of scales (accurate to 0.1 g). The weight was recorded and the bait was then skewered onto a thin piece of galvanised wire (1.25 mm diameter). Each wire skewer was labelled (with insulating and masking tape), numbered (with a water marker texta) and recorded along with the weight of the bait. The skewer generally passed through the gut of the bait animal, bent back and passed through the head. Bait numbers were randomly assigned a consumption time for which a crab was allowed to feed. They were then administered to the crabs randomly. The starting time of an experiment was when all baits had been administered.

For each of the five time periods (4, 8, 16, 32 and 64 minutes), baits were collected and the crab details recorded. Retrieval of baits often required the use of a small net. This was used to scoop liberated pieces of the bait that had been torn away by the ferocious feeding mannerisms of the crabs. Once the experiment was finished and the remains of baits had been collected, each was blotted dry and reweighed. All weights were corrected for autogenic change and standardised to g/g crab. Crabs that did not feed were disregarded for that experiment.

Food Preference

Food preference of blue crabs was tested between natural and by-catch items. The natural food items used were a combination of gastropods, bivalves, asteroids, holothuroids and ophiuroids collected from various beaches. These animals were encased in a cylinder made from black plastic mesh (2.5 mm). By-catch items included the species listed above, excluding silverbelly.

Both the cylinder of natural food items and the group of by-catch items were each attached to galvanised wire for administration to individual crabs. With plastic dividers taken out of each experimental tank, both food options (natural and by-catch) were placed at opposite ends of a tank using a single crab. The first bait attacked was recorded and the same method was repeated for the next tank being tested.
This method of choice experiments was repeated for testing between selected discard species. With time constraints preventing thorough testing of all species, only a few were chosen on the basis of observations from laboratory experiments.

Statistical analysis

A one way ANOVA was performed to test for differences between times in the foregut clearance experiment while a 2-way ANOVA was used to test for differences between times and sexes and a 3-way ANOVA was performed to test differences between times, size and species of by-catch. Levene's test was performed to test homogeneity of variance in all ANOVA's and a square root transformation was carried out on all data. Chi-square analysis was used on each of the food preference experiments.

Consumption by Sealice

Feeding Rates

A seawater table with a water depth of 30 cm and supplied with aerated flow-through seawater was used for consumption experiments carried out on *N. woodjonesi.*
The bottoms of twelve plastic sieves, with a diameter of 25 cm and a depth of 15 cm, were covered with black plastic. A layer of sand was added to the sieves to allow the sealice to burrow, and to replicate natural conditions.

The sieves were set on a platform to ensure that the water level was no higher than 1 cm below the top of each sieve to avoid sealice escaping and divided into four groups (3 replicates of each group) representing the different times the bait would be left in with the sealice. Fifteen sealice were held in each of the sieves and starved for one week. One cube of sand trevally was weighed and placed in each sieve simultaneously. The bait cube was removed from the different groups after 5, 15, 30 and 60 minutes and reweighed.

Food Preference

Two 40 x 20 cm aerated aquariums with flow-through seawater were used for food preference experiments. Small (1 cm^3) pieces of flesh from Degens leatherjacket, rough leatherjacket, sand trevally and red mullet were cut and weighed.
Three sealice were held in the middle of the aquarium by two dividers. One cube of bait was added to each end of the aquarium. This was repeated for each combination of bait species so that pair-wise comparisons were carried out for all bait species under investigation. Six replicates were completed of each pair. The sealice were left for 5 minutes and then their position was recorded.

Statistical analysis

A two-way ANOVA was performed to test for effects of time and night in the consumption rate experiments. The ANOVA was preceded by a Levene's homogeneity test. A Tukey post hoc test was carried out on both the bait weight eaten per night, and the bait weight eaten per time treatment for multiple comparisons. Wilcoxon's paired-sample was used to test for bait preference.

Results

Consumption by Degens Leatherjacket (*Thamnaconus degeni*)

Consumption by Individual Degens Leatherjackets

Individual *T. degeni* was found to take approximately nine hours before resume feeding after consuming a bait of sand trevally of a mean weight of 45 mg (Fig. 8.1). However, a large variation between individual leatherjackets was evident and no significant effect of feeding time could be detected ($p>0.05$) (Table 8. I). Post Hoc tests did not show any significant differences between treatments.

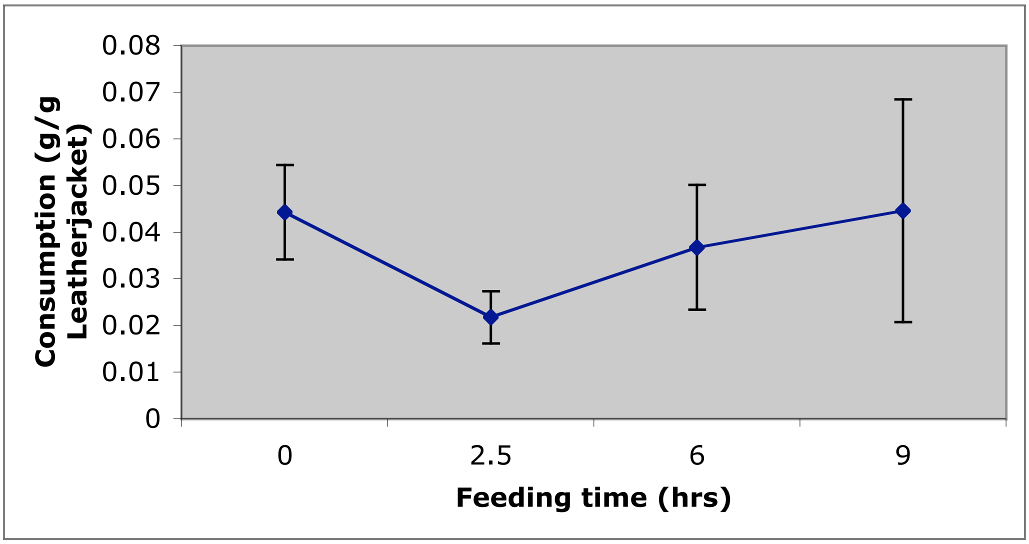


Figure 8.1. Weight of food consumed per gram of Degens leatherjacket (*Thamnaconus degeni*) after initial feeding at 0, 2.5, 6 and 9 hours (Error bars ± 95% CI).

Degens leatherjacket show sex dimorphism where males are much larger than females. A test of effects of size (sex) on consumption per gram consumer was performed. However, no difference in consumption between males and females (size) per unit weight was found (Fig. 8.2). Accordingly, males and female were not separated in the group experiments.

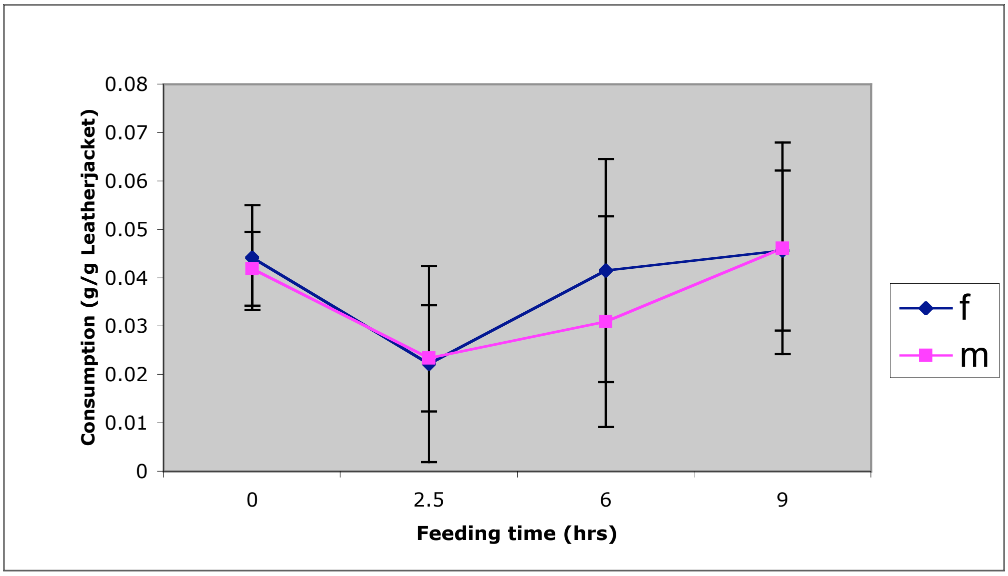


Fig. 8.2. Weight of bait consumed per gram of female (f) and male (m) Degens leatherjacket (*Thamnaconus degeni*) after initial feeding at 0, 2.5, 6 and 9 hours (Error bars ± 95% CI).

Table 8. I. Summary table of ANOVA's for consumption of sand trevally by Degens leatherjacket (*Thamnaconus degeni*). * P<0.05

Source of variation	df	F	P value
Time	3	2.403	NS
Time	3	22.109	*
Species	3	97.741	*
Time x Species	9	0.886	NS

Consumption by Groups of Leatherjackets

Leatherjackets kept individually in aquaria showed little interest in feeding. However, when several individuals were kept together feeding increased. Accordingly, experiments with several individuals in one aquarium were undertaken to determine consumption rates. Baits of four common by-catch species were used.

Consumption rate estimates of the four different species of by-catch all showed a strong logarithmic trend irrespective of bait type (Fig. 8.3). There was a significant difference between the amounts consumed of the different by-catch species (Table 8. I).

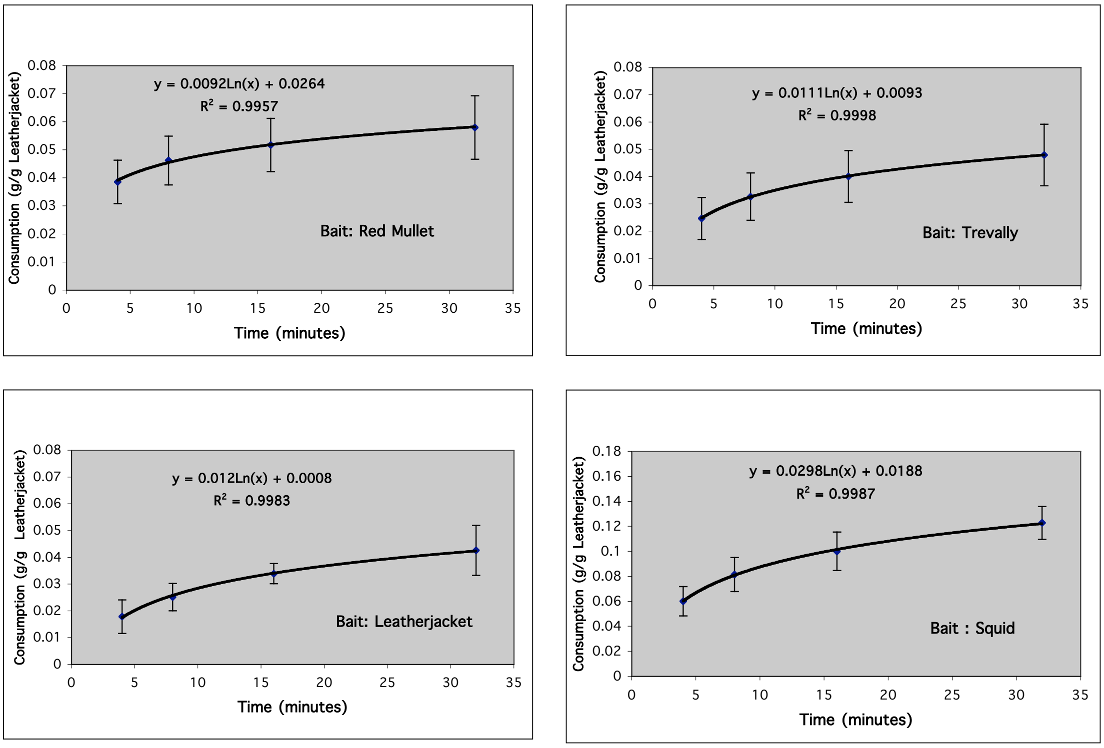


Fig. 8.3. Consumption by Degens leatherjacket (*Thamaconus degeni*) of four commonly occurring by-catch species. R^2 values and the best logarithmic fits are shown. Error bars ±95% CI.

Post hoc tests revealed squid was consumed in significantly larger quantities than red mullet, which in turn was consumed significantly more than sand trevally and leatherjacket, which were consumed in equal amounts. In all bait species experiments each successive time period had a significantly greater amount of bait consumed. However, the rate of consumption can be clearly seen to be higher between 4 and 8 minutes in all experiments (Fig. 8.3). The maximum consumption rate (0-4 minutes) is thus highest for squid (15.0 mg/g/min) followed by red mullet (9.9 mg/g/min) and trevally and leatherjackets (6.2 and 4.4 mg/g/min), respectively.

Consumption by the Blue Crab

Foregut Clearance

To determine the minimal time interval between experiments, blue crab consumption rates on sand trevally were measured as a function of starvation time. Fig. 8.4 displays the mean consumption by different groups of crabs (fed for 16 minutes) after varying starvation times.

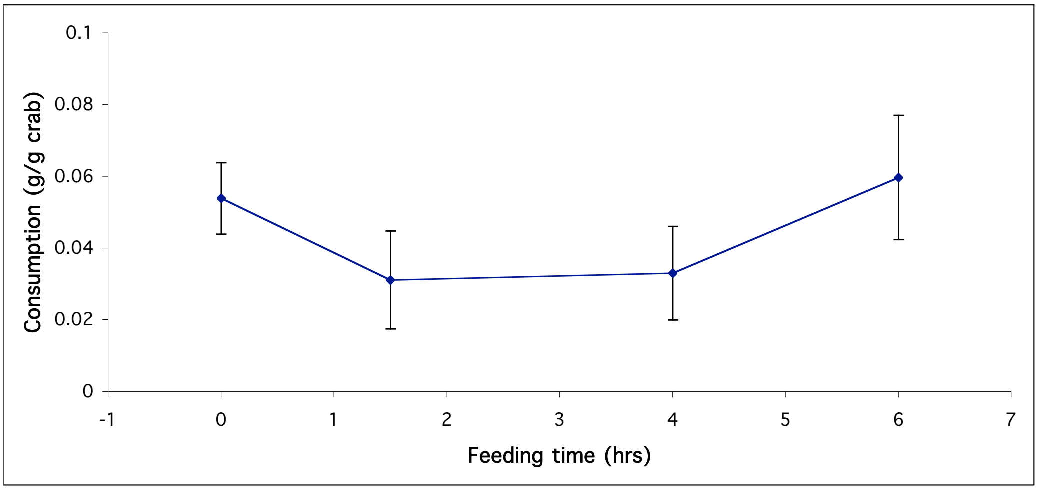


Fig. 8.4. Hunger levels in the blue crab (*Portunus pelagicus*) (mean ± 95% CI). Groups of crabs were fed sand trevally for 16 minutes at time 0 (initial) then again after 1.5, 4 and 6 hours for separate starved groups.

Table 8. II. Summary table of ANOVA on crab consumption (g/g crab).

Source of variation	df	P value	Power Effect
Time (hunger)	3	*	0.752
Sex	1	NS	0.385
Time	4	* * *	1.000
Sex*time	4	NS	0.286
Time	4	* * *	1.000
Size	1	* * *	0.966
Species	6	* * *	0.933
Size*time	4	NS	0.418
Species*time	24	*	0.970
Size*species	6	NS	0.570
Size*species*time	15	NS	0.324

The data indicates that crabs consumed similar amounts of food after a 6-hour starvation period (0.060 ± 0.017 g/g crab) compared to that of the initial feeding period (0.054 ± 0.010 g/g crab). At 1.5 and 4 hours, crabs ate only half the amount of the initial feed (0.031 ± 0.014 and 0.033 ± 0.013 g/g crab respectively) indicating foregut fullness. With the data set found to be homogeneous, a one-way ANOVA was performed to test the null hypothesis of no significant difference between feeding times. Results showed a significant difference between groups ($p<0.05$) (Table 8. II). However, a post hoc test did not statistically separate time periods, possibly due to uneven sample sizes. The power of the test was calculated at 0.752, which was slightly lower than the conventionally sufficient 0.8. Consequently the possibility of a type I error (rejecting a true null hypothesis) could not be excluded. Nevertheless, the results suggest that crabs consumed roughly the same amount at 6 hours than that of the initial consumption indicating that after 6 hours of digestion the foregut is empty. Furthermore, as crabs were starved for 24 hours prior to this experiment, it can be concluded that hunger level is similar between a 24-hour and a 6-hour starvation period.

Consumption of By-catch Species

Both male and female consumption estimates as separate factor levels are shown in Fig. 8.5. Consumptions were found to increase over time. However, consumption between sexes did not differ. Consumptions at 8 minutes were 0.022 ± 0.004 g/g crab for males and 0.023 ± 0.005 g/g crab for females. Assumptions of an ANOVA were met, so a two-way general model was used to test for effects of sex and time. The results indicated no effect of sex (p>0.05) (Table 8. II). However, the power of the test (0.385) was lower than the desirable level of 0.8. The effect of time was found to be a significant variable attributing to variations in consumption for all data pooled (P<0.001, power = 1.000). No interaction between sex and time was found to be significant.

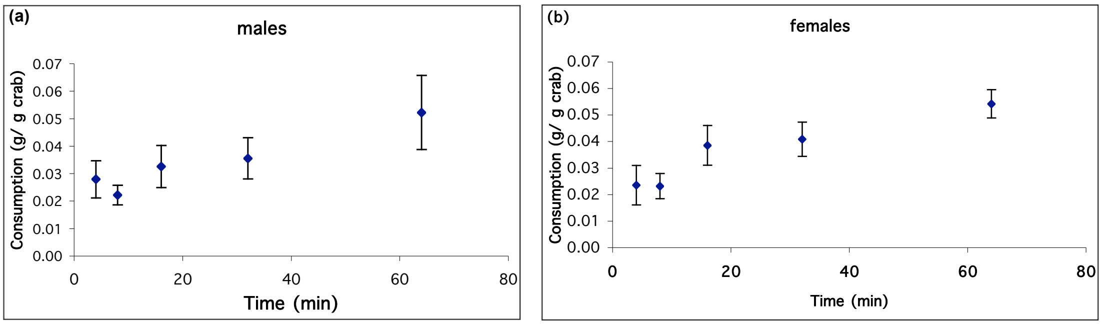


Figure 8.5. Consumption (g/g crab) of (a) male and (b) female blue crab (*Portunus pelagicus*). Data was pooled for discard species, and size. Error bars ± 95% CI).

Figure 8.6 show the consumption estimates for three size classes of blue crabs. The small size class showed a large variation. Consumption for all three size groups increased logarithmically over time. At 60 minutes the small size groups had consumed 0.06 g/g and the two larger groups 0.05 and 0.04 g/g, respectively. A trend of decreased consumption (g/g crab) with increased size class was evident. R^2 values and the logarithmic equations for the small, medium and large size classes respectively, are given in Table 8. IV.

Size as a factor of consumption showed a marked effect. In a three-way ANOVA with time, size and species as the main effects on square root transformed data consumption was found to be significantly different between medium and large size classes (p<0.001, Table 8. II). A significant effect of time on consumption was also found (p<0.001). As the power of both tests was large (0.966 and 1.000 respectively), the conclusions drawn can be viewed with confidence. The three-way ANOVA also indicated that there was no interaction between time and size (p>0.05).

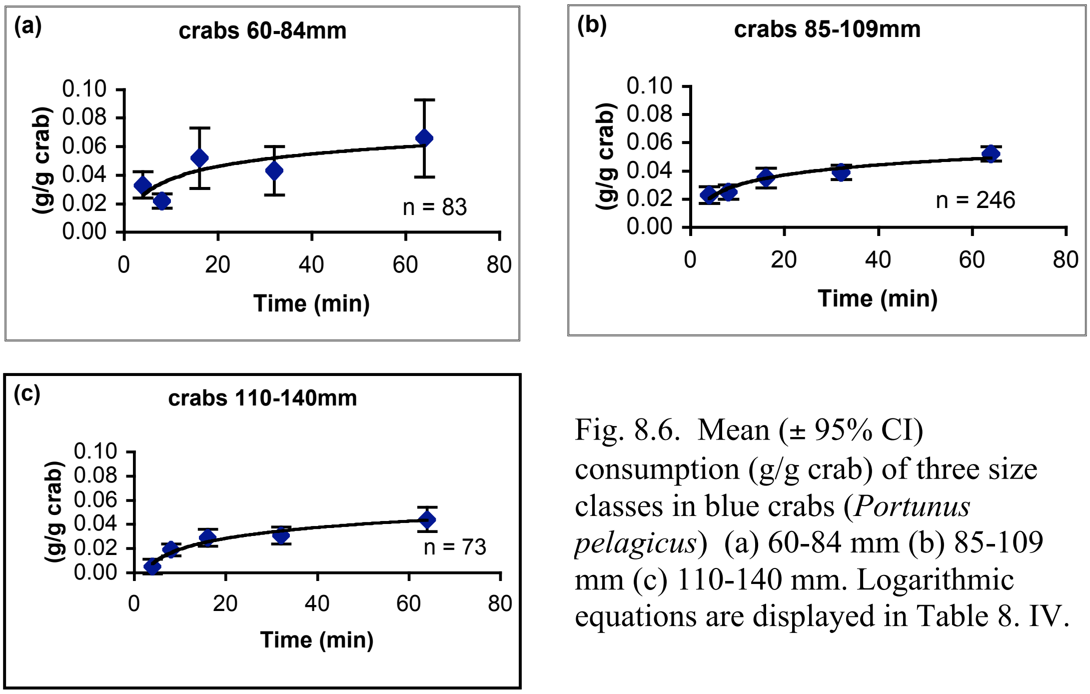


Fig. 8.6. Mean (± 95% CI) consumption (g/g crab) of three size classes in blue crabs (*Portunus pelagicus*) (a) 60-84 mm (b) 85-109 mm (c) 110-140 mm. Logarithmic equations are displayed in Table 8. IV.

Because consumption data of the small size class was not homogeneous, a Kruskal-Wallis non-parametric analysis was conducted separately for this group. A significant difference in consumption as a function of time was found (p<0.01, Table 8. III).

Table 8. III. Non-parametric test with consumption as a dependent variable for blue crabs 60-84mm in size. NS (not significant) P> 0.05; *P< 0.05; * *P< 0.01.

Variable	df	M-Whitney U	K-Wallis
Sex	1	NS	
Time	4		* *
Species	6		* *

In summary, consumption of the two larger size classes of blue crabs is significantly different, with medium sized crabs consuming more discards per gram body weight than the large size class. The small size class of crabs consumed more discard per gram of body weight than both medium and large size classes. Consumption increases logarithmically over time for all size classes tested. Difference in consumption between size classes and the logarithmic equations derived from each size class is shown in Table 8. IV). A medium size crab of 100 mm will thus consume 27.6 mg/g crab during 8 minutes and the foregut will be full. The total amount consumed by a 100 mm female (171.5 g) and male (154.2 g) will therefore be 4.7 g and 4.3 g, respectively.

Consumption estimates for blue crabs feeding on 7 common discard species were conducted in separate experiments. Estimates for each species are shown in Fig. 8.7. All 7 graphs show an increase in consumption over time. When logarithmic trend lines were fitted to each graph, all gave high R^2 values (from squid with $R^2 = 0.70$ to sand trevally with $R^2 = 0.959$). Red mullet (Fig 8.7 b) had its first time period (4 minutes) disregarded due to gross sex and size bias in the data. This enabled a more accurate logarithmic equation to be calculated. The confidence intervals were generally small with the exception of rough leatherjacket (Fig 8.7 d) exhibited quite large confidence intervals with its largest being at 64 minutes (0.046 ± 0.04 g/g crab) reflecting the difficulties of the crabs of cutting through the tough skin of the bait. Nevertheless, a logarithmic trend line fitted the data well ($R^2 = 0.908$). When comparing consumption of the different bait species, sand trevally and flathead in particular, were initially consumed less (0.016 ± 0.006 and 0.012 ± 0.006 g/g crab respectively) while all other species were consumed above 0.02 g/g crab. Both species had negative values for their equations' constant (-0.0013 and -0.0087, Table 8. IV).

Table 8. IV. Logarithmic equations of consumption of by-catch species by the blue crab (*Portunus pelagicus*). y= consumption (g/g crab); x= feeding time (min).

Variable	N	R^2	Equation
Blue crab size			
60 – 84 mm	83	0.658	$y = 0.0126\text{Ln}(x) + 0.0084$
85 – 109 mm	246	0.945	$y = 0.0104\text{Ln}(x) + 0.006$
110 – 140 mm	73	0.956	$y = 0.013\text{Ln}(x) - 0.0104$
Species consumed			
Squid	61	0.701	$y = 0.0103\text{Ln}(x) + 0.0167$
Red mullet	54	0.819	$y = 0.0086\text{Ln}(x) + 0.0003$
Flathead	63	0.823	$y = 0.0123\text{Ln}(x) - 0.0087$
Rough leatherjacket	51	0.908	$y = 0.0185\text{Ln}(x) - 0.006$
Trevally	61	0.959	$y = 0.012\text{Ln}(x) - 0.0013$
Degens leatherjacket	55	0.860	$y = 0.0111\text{Ln}(x) + 0.0028$
Silverbelly	49	0.905	$y = 0.0061\text{Ln}(x) + 0.0207$

The result of a three-way ANOVA with time, size and species as the main effects, on square root transformed data, showed a significant effect of time, size and bait species ($P<0.001$) (ANOVA statistics, Table 8. II). The power of the test was high (>0.8). However, a significant interaction between time and species was found to occur ($p<0.05$). The interaction is result of interference between factors indicating that consumption over time is not consistent among species. A Post hoc test (Turkey HSD) was performed for both time and discard species. Times 4 and 8 minutes, 16 and 32 minutes and 64 minutes were grouped into three separate subsets of data. This supporting the result showing increased consumption over time. Post hoc test's grouped the data for discard species into three separate subsets with overlap between each subset. Red mullet and flathead were found to be in different subsets to that of leatherjackets, silverbelly and squid. From graphical data also, the latter three species were consumed at a higher rate by the crabs with squid exhibiting the highest rate.

Consumption of discard species by blue crabs varies with time and with discard species consumed and increases logarithmically for all discard species. This indicates that when the asymptote is reached the foreguts of the crabs are full and feeding may be resumed after a period of up to six hours digestion. According to Fig. 8.7, crabs seem to be able to feed for at least an hour before being full. The consumption equations are shown in Table 8. IV.

Food Preference

The Chi-square statistic for the food preference experiments comparing by-catch/natural food items was not significant ($p>0.05$) with the exception for the combination flathead/squid ($p<0.05$). The numbers of feeding attempt were 6 and 16, in favour of squid. Accordingly blue crabs appear to have preference for squid over flathead under laboratory conditions (Table 8. V).

Table 8. V. Food preferences of the blue crab, *Portunus pelagicus*. Chi-square test: NS (not significant), * $P< 0.05$.

Food stimuli	No. feeding attempts	χ^2
bycatch	39	NS
natural	33	
Trevally	11	NS
Red mullet	11	
Flathead	1	NS
Degens L.J.	9	
Trevally	6	NS
Flathead	2	
Flathead	6	*
Squid	16	
Red mullet	4	NS
Squid	4	

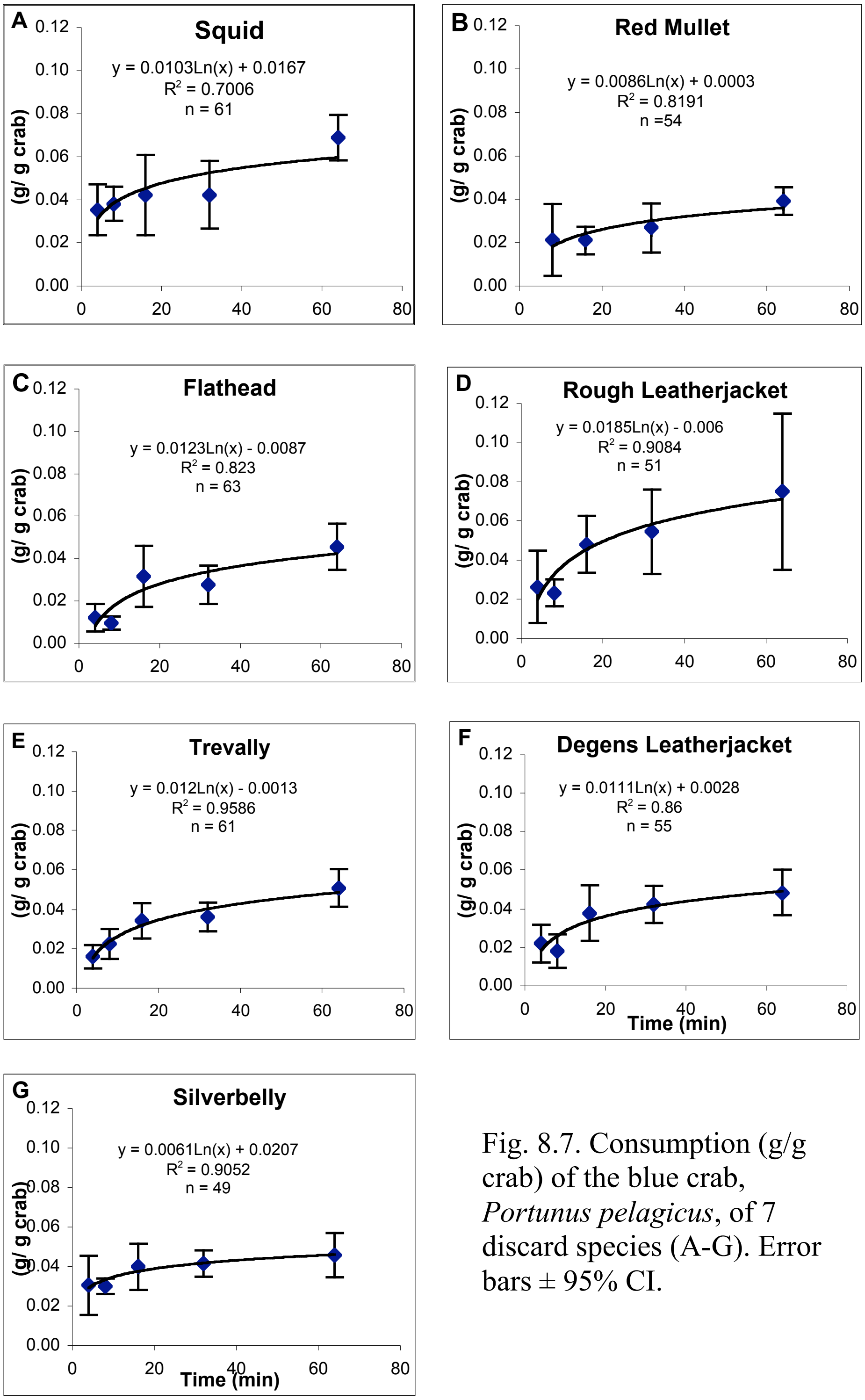


Fig. 8.7. Consumption (g/g crab) of the blue crab, *Portunus pelagicus*, of 7 discard species (A-G). Error bars ± 95% CI.

Consumption by Sealice

Sealice Consumption and Feeding Rates

Consumption of bait cubes by sealice varied significantly between experiments (F = 436.383, $p < 0.001$) and time (F = 1185.921, $p < 0.001$). A significant interaction (interference) is evident caused by the night three experiment (F = 293.818, $P < 0.001$) indicating that factors other than the presence of bait may regulate feeding (Fig. 8.8).

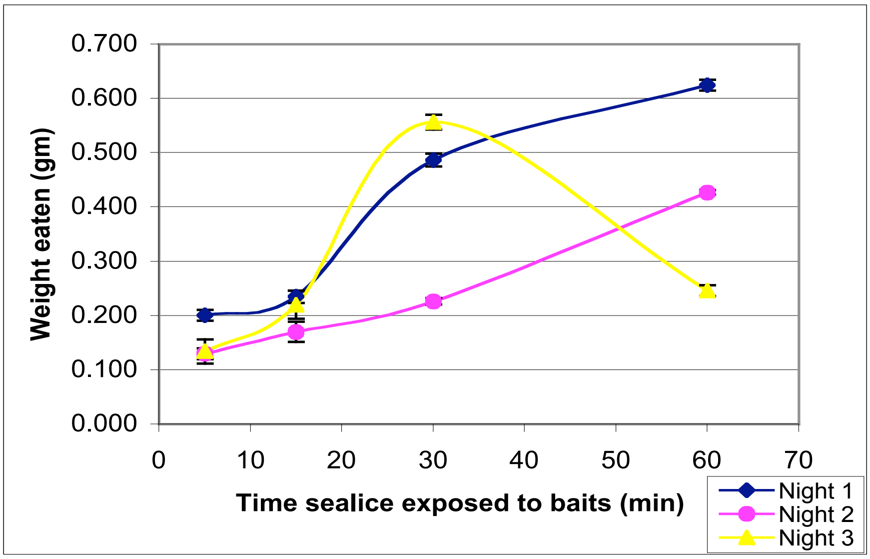


Fig. 8.8. Mean amount of bait (g) consumed by 15 sealice during 5, 15, 30 and 60 minutes at three separate night experiments. Error bars ± 95% CI.

Table 6. VI. Sealice feeding rates estimated by laboratory experiments. Feeding rate units are g/min/sealice.

Experiment	After t_1 (g)	Before t_2 (g)	Difference (g)	Time (min)	Sealice #	Feeding rate
Night $1_{5\text{-}15min}$	0.201	0.235	0.034	10	15	0.00023
Night $1_{15\text{-}30min}$	0.235	0.487	0.252	15	15	0.00112
Night $1_{30\text{-}60min}$	0.487	0.625	0.138	30	15	0.00031
Night $2_{5\text{-}15min}$	0.13	0.17	0.04	10	15	0.00027
Night $2_{15\text{-}30min}$	0.17	0.226	0.056	15	15	0.00025
Night $2_{30\text{-}60min}$	0.226	0.427	0.201	30	15	0.00045
Mean						0.00044
95% CL						0.00028

Laboratory feedings rates are summarised in Table 8. VI. The mean feeding rate found in laboratory experiments was 0.00044 g/min/sealice ± 0.00028 (95% confidence limit).

Bait Preference of Sealice

Fig. 8.9 shows the results of pair-wise tests comparing preference in bait fish. Wilcoxon's paired-sample test comparisons all conformed to the null hypothesis that there was no significant difference in the number of sealice at different bait cubes and consequently no preference was shown.

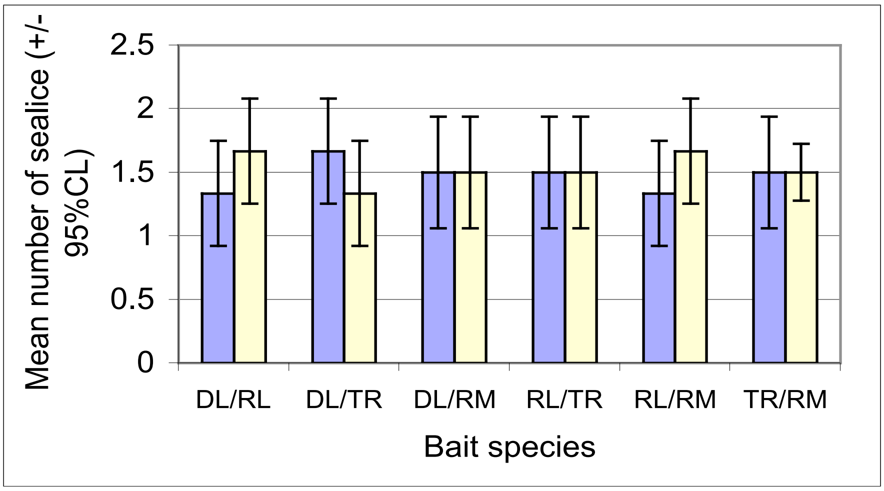


Fig. 8.9. Mean number of sealice that were found at bait cubes of different by-catch species for six different bait combinations (DL= Degens leatherjacket; RL= Rough leatherjacket; TR= Trevally; RM= Red mullet).

Discussion

Consumption by Degens Leatherjacket

After an initial feeding period of 12 minutes, where a single leatherjacket consumed a mean of 45 mg, a similar amount was consumed irrespective of time for consumption (Fig. 8.1). These experimental results showed no significant effect of time due to the large individual variation. The result showed that it took approximately 9 hours before feeding was resumed indicated by increased variation (Fig. 8.1). Most animals had large endoparasites feeding on their gut contents, which may have influenced the results. Our observations showed that leatherjackets kept individually are less interested in feeding that when two or more are together. Accordingly, in further experiments on feeding, leatherjackets were kept in experimental groups arbitrarily chosen to be 17 individuals per aquarium mimicking the densities observed around bait in the field.

The differences in the amount of bait consumed between the four by-catch species can be probably explained by differences in flesh structure (Fig. 8.3). Squid and red mullet have much softer flesh and so could be more easily consumed compared to trevally and leatherjackets. Leatherjacket group consumption rates were higher during the initial 4 to 8 minute period in all experiments and then gradually declined following broadly a logarithmic function reaching a plateau shortly after indicating gut fullness.

Schooling Degens leatherjackets feeding on discarded by-catch are between 60-120 mm long (females 60-90 mm, males 80-120 mm) and weight between 7-40 g WW (females 7-19g, males 12-40g). This implies that a median size Degens leatherjacket of 90 mm length and irrespective of sex will consume between 90-308 mg/minute by-catch depending on bait species. Given the information from the consumption experiment, the consumption rate over 8 minutes (time when consumption rate was highest) can be calculated for each species by dividing the amount consumed by the number of leatherjackets: Squid~ 2.3 g/8 min, red mullet~ 1.29 g/8 min, sand trevally~ 0.91 g/8 min, leatherjacket~ 0.70 g/8 min. These estimates can then be averaged to get the overall consumption rate for a single *T. degeni* of ~ 1.3 g/8 min or 162.5 mg/min at each feeding event. The mean consumption of the four by-catch species is 0.475 mg per mg leatherjacket per 8 min (feeding event).

It can be assumed that when Degens leatherjackets feed on discarded by-catch most will be consumed within 8 minutes. Because the consumption experiments utilised groups of leatherjackets rather than individuals, there could be no comparison between different sexes or size classes. However, given that this is the way Degens leatherjackets are observed to feed in the Spencer Gulf, it can be assumed that any variances in consumption rates between individuals is averaged out. The mean consumption rate for any by-catch species estimated in the laboratory is thus 9.0 mg/g/min.

Consumption by Blue Crab

Foregut Clearance

In order to determine the minimum time interval between consumption rate experiments, groups of blue crabs were fed sand trevally after varying starvation times. It was concluded that hunger level does not differ between a 24-hour and a 6-hour starvation period. For the two time periods under 6 hours ($1^1/_2$ and 4 hours), crabs consumed approximately 50% of their initial consumption. Similarly, Wassenberg and Hill (1987) found that *P. pelagicus* cleared 50% of its foregut after $1^1/_2$ hours and 95% cleared after 6 hours.

Effects of Sex

Variation in consumption between male and female portunid crabs is a contentious topic in the literature (Williams 1982, Choy 1986, Sumpton & Smith 1990, Kawamura *et al.* 1995, Sukumaran & Neelakantan 1997). Our studies showed that when consumption rates for both sexes were compared, no significant differences was found and both sexes consumed similar amounts of food at a similar rate of intake. This finding supports a majority of studies in the literature suggesting that no feeding differences occur between the sexes of portunid crabs (Williams 1982, Choy 1986, Sumpton & Smith 1990).

Effects of Time, Size and Species

Most studies on the feeding ecology of portunid crabs have focussed on variations in the diet composition between size classes (Williams 1982, Choy 1986, Cerda & Wolff 1993, Sukumaran & Neelakantan 1997). Consumption estimates for crabs feeding on 7 discard species indicated a significant difference in consumption rates between size classes, consumption times and bait species (Table 8. II). This implies that given the opportunity, a crab will feed on a bait for a far longer period than expected (from field observations) which supports the conclusion by Clark *et al.* (1999) that foraging decreases in the presence of other crabs. The large variation in consumption estimates for the small size class may have been a result of the limited number of crabs that could be caught. This resulted in repeated use of the same crabs. However, this can be seen as pseudo-replication but long time intervals with feeding were insured before any crab was tested again. Additionally, moulting may have been an extraneous variable that would have affected consumption estimates for the small size class in particular (Gannon 1990).

All three consumption rates for crab size increased logarithmically, with a high fit of the data for each (Table 8. IV). Subsequent logarithmic equations were calculated for each size class. These equations allow consumption rates (g/g crab) to be measured for varying time intervals (minutes) of feeding with sexes pooled. Thus, if the average size for each size class of crabs is used to calculate a consumption rate for 8 minutes (an average time of consumption observed in the field), it can then be multiplied by the weight for that size crab (using length/weight equations) to obtain an estimate of consumption (g) for individual crabs. An estimate of one-hour consumption of a medium sized crab is then 0.05 g/g/h.

Consumption estimates were found to significantly vary between the discard species being consumed. Red mullet and flathead were eaten at a significantly lower rate than rough leatherjackets, silverbelly and squid but a significant interaction between species and time occurred. This interaction was the result of statistical interference, indicating that consumption of different discard species was inconsistent in time probably affected by the moulting stage in crabs. However, consumption of all species increased logarithmically, with a high statistical fit of the data for each. According to Carrick (1997) the relative abundance of of the most important discard species caught in prawn trawls in the Spencer Gulf are sand trevally (10.5%), Degens leatherjacket (5.7%), rough leatherjacket (1.2%), silverbelly (1.2%) and squid or Southern calamari (0.9%). Squid has been observed to be a significant food item in the stomach content of *P. pelagicus* when feeding on by-catch (Williams 1982, Choy 1986). Similarly, laboratory results have indicated that the blue crab does elicit a preference for squid, more so than any other species tested (Rheinallt & Hughes 1985). Crabs may select for food that maximise their net rate of energy intake (Hughes 1979, Pyke 1984). The energy content of fish is approximately 5.073 kJ g^{-1} (Wassenberg & Hill 1990) while Atlantic squid is in the range of 5.9 – 6.9 kJ g^{-1} (Lawson *et al.* 1998). Rough leatherjacket, silverbelly and squid were all included in this test, and were consumed by blue crabs at a significantly higher rate than red mullet and flathead (species not as common in the discard) it can be suggested that conditioning may occur in blue crabs implying that crabs may be more accustomed to eating discard species, so exhibit a relative higher consumption than at a natural diet. Micheli (1995) reported size selective conditioning for bivalve prey in the blue crab *Callinectes sapidus* and suggested that crabs learn to choose prey that lower the associated cost of claw wear. Red mullet is a soft tissued fish, probably more so than silverbelly and squid, and the significance of any preference among by-catch species is unclear.

Ramsay *et al.* (1997) suggested that the impact of carrion on scavenger species may be affected by local natural food supply but no preference was exhibited between natural food and by-catch in the laboratory experiments. In the field, competition between individuals may be an over-riding factor, influencing food preferences exhibited under laboratory conditions.

Consumption by Sealice

Observations of sealice under laboratory conditions indicated that captivity significantly altered behaviour. Once in the laboratory, sealice may not exhibit voracious scavenging behaviour, spending most of the time burrowed in sediment. The effect of the relatively strong light compared with natural conditions and the small area the sealice were confined to is likely to affect feeding behaviour. Moore and Wong (1995) found that *Natatolana borealis* processes food in the 'manner of a batch rectory'. It bolts food rapidly and unselectively, stores it in its extensible anterior hindgut, and then takes a long time (weeks) to digest a single meal. It can survive long periods of time (months) without food'. The experimental sealice were fed a small amount regularly to maintain them before experiments were commenced, which may have been enough to keep them sated and at relatively high stocking cannibalism cannot be excluded. Thus, the one-week starvation period before commencing the feeding experiments may have been inadequate to ensure optimal feeding. Apart from the effects of laboratory confinement on the sealice, the estimated laboratory feeding rates may mimic natural conditions near the end of the prawn fishing season where carrion may be abundant. To accurately determine feeding rates repeated laboratory experiments would need to be carried out simultaneously with field experiments closely mimicking natural surroundings.

In the feeding experiments sealice were found to be attracted to bait cubes indicating that if sealice showed preference for any by-catch species it should be exhibited in laboratory experiments. The null hypothesis that was tested was that there was no preference for by-catch species. The null hypothesis was accepted for all experiments indicating that no preference for by-catch species is exhibited by sealice under laboratory conditions. The choice of by-catch species for use in laboratory experiments was limited due to dependence on trawl catches.

Consumption by sealice was additionally calculated in field experiments. The feeding rate calculated in the field using baited traps was 0.00486 g/min/sealice compared to the laboratory estimate of 0.00044 g/min/sealice (Table 8. VI). Sealice held in the laboratory may have been sated. The anterior hindgut was full in a majority of the sealice collected in December for the laboratory experiments because of the method of trapping. This would have kept them sated for weeks according to Moore and Wong (1995).

References

Carrick, N. A. 1997. A preliminary assessment of the by-catch from the Spencer Gulf Prawn Fishery. *South Australian Fisheries Assessment Series*. 97/02, 28 pp.

Cerda, G. & M. Wolff 1993. Feeding ecology of the crab *Cancer polyodon* in La Herradura Bay, northern Chile. II Food spectrum and prey consumption. *Mar. Ecol. Prog. Ser*. 100: 119-125.

Choy, S.C. 1986. Natural diet and feeding habits of the crabs *Liocarcinus puber* and *L. holsatus* (Decapoda, Brachyura, Portunidae). *Mar. Ecol. Prog. Ser*. 31: 87-99.

Clark, M.E., Wolcott, T.G., Wolcott, D.L. & A.H. Hines 1999. Foraging and agonistic activity co-occur in free-ranging blue crab (*Callinectes sapidus*): observation of animals by ultrasonic telemetry. *J. Exp. Mar. Biol. Ecol.* 233: 143-160.

Edgar, G. J. 1990. Predator-prey interactions in seagrass beds. II. Distribution and diet of the blue manna crab *Portunus pelagicus* Linnaeus at Cliff Head, Western Australia. *J. Exp. Mar. Biol. Ecol.* 139: 23-32.

Gannon, A. T. 1990. Distribution of *Octolasmis muelleri*, an ectocommensal gill barnacle, on the blue crab. *Bull. Mar. Sci*. 46: 55-61.

Hughes, R. N. 1979. Optimal diets under the energy maximization premise: the effects of recognition time and learning. *Am. Nat*. 113: 209-221.

Kawamura, G., Matsuoka, T., Tajiri, T., Nishida, M. & M. Hayashi 1995. Effectiveness of a sugarcane-fish combination as bait in trapping swimming crabs. *Fish. Res*. 22: 155-160.

Lawson, J. W., Magalhaes, A. M. & E.H. Miller 1998. Important prey species of marine vertebrate predators in the northwest Atlantic: proximate composition and energy density. *Mar. Ecol. Prog. Ser.* 164: 13-20.

Moore, P.J. & Y.M. Wong 1995. *Orchomene nanus* (Kroyer) (Amphipoda: Lysianassoidea), a selective scavenger of dead crabs: feeding preferences in the field. *J. Exp. Mar. Biol. Ecol.* 192: 35-45.

Micheli, F. (1995). Behavioural plasticity in prey-size selectivity of the blue crab *Callinectes sapidus* feeding on bivalve prey. *Journal of Animal Ecology*. 64: 63-74.

Pyke, G. H. 1984. Optimal foraging theory: a critical review. *Ann. Rev. Ecol. Systm.* 15: 523-575.

Ramsay, K., Kaiser, M. J., Moore, P.G. R.N. Hughes 1997. Consumption of fisheries discards by benthic scavengers: utilization of energy subsidies in different marine habitats. *J. Anim. Ecol.* 66: 884-896.

Rheinallt, T. & R.N. Hughes 1985. Handling methods used by the velvet swimming crab Liocarcinus puber when feeding on molluscs and shore crabs. *Mar. Ecol. Prog. Ser.* 25: 63-70.

Sukumaran, K. K. & B. Neelakantan 1997. Food and feeding of *Portunus (Portunus) sanguinolentus* (Herbst) and *Portunus (Portunus) pelagicus* (Linnaeus) (Brachyura: Portunidae) along Karnataka coast. *Ind. J. Mar. Sci*. 26: 35-38.

Sumpton, W. D. & G.S. Smith 1990. Effects of temperature on the emergence, activity and feeding of male and female sand crabs (*Portunus pelagicus*). *Aust. J. Mar. Freshw. Res*. 41: 545-550.

Wassenberg, T. J. & B.J. Hill 1990. Partitioning of material discarded from prawn trawlers in Moreton Bay. *Aust. J. Mar. Freshw. Res*. 41: 27-36.

Williams, M. J. 1982. Natural food and feeding in the commercial sand crab *Portunus pelagicus* Linnaeus, 1766 (Crustacea: Decapoda: Portunidae) in Moreton Bay, Queensland.). *J. Exp. Mar. Biol. Ecol.* 59: 165-176.

Wu, R.S.S. & P.K.S. Shin 1998. Food segregation in three species of portunid crabs. *Hydrobiologia*. 362: 107-113

Chapter 9: Sediment Re-suspension and Nutrient regeneration in the Spencer Gulf, South Australia.

Matt Fitzpatrick

Abstract

The sediment distribution patterns of the Spencer Gulf and the rate of sedimentation have been described. This study showed that the Gulf lack any depositional areas of fine sediment grains (<500 µm) with the exception of the far northern part of the Gulf where patches of fine mud and clay can be found. The reason for this is that the energy of the Gulf is sufficient to retain finer particles in near-permanent suspension. The bottom sediments are highly variable throughout the Gulf and the most fisher areas have grain sizes larger than 1 mm. The Spencer Gulf can be subdivided into two zones in term of kinetic energy of the system. The southern zone below Franklin Harbour has currents in excess of 2 m/sec whereas the northern part has slightly less. Sedimentation rates have been measured to about with inter-annual variation 4 g/day. The grain sizes collected were relatively large of up to 1000µm reflecting deposition in strong currents.

Experimental trawling activity with one trawler showed not surprisingly a significant increase in near-bed concentrations of sediment and elevated the sediment load of up to 11 g per litre. The developed plume lasted well over 80 minutes and dispersed over a large area. During fishing with 39 vessels trawling activity will dramatically increase the localised sediment load. The movement of this sediment is depending on the hydrodynamic regime at the particular time of trawling but a substantial part will most likely settle in other parts of the Gulf and provides a source of N and P, which may increase production.

Introduction

Sediment resuspension is a prime mechanism for benthos structuring and nutrient distribution within coastal environments, particularly semi-closed systems such as estuaries and gulfs. It is also important in distribution of mass, eutrophication and light attenuation within a marine system (Fanning *et al.*, 1982). It is well realised however, that the processes governing coastal hydrodynamics are complex, thus making sediment movement studies one of the more challenging aspects of coastal studies (Falconer and Owens, 1990).

Many studies have attempted to apply numerical models to predict the sediment resuspension in their area of study. However the sheer number of independently acting variables (e.g. waves, currents, bottom stresses, turbulence, sediment composition, biological reworking of the sediment) confound the widespread use of such models, and hence most developed models have been on a case-by-case study (Hawley and Lesht, 1992).

In the last two decades, the environmental impact of trawling activities has been a focus of intense scientific research and debate (e.g. Wassenberg and Hill, 1990; Currie and Parry, 1996; Pilskaln *et al.*, 1998). Recently, it has been shown that the sediment resuspension induced by trawling vessels may be a significant factor in the environmental and dynamical structure of a marine system (Churchill, 1989). Studies have thus begun focusing on determining empirically the sediment dynamics associated with trawling (e.g. Schoellhamer, 1996). However, few studies have attempted to both quantify in the field the sediment resuspension induced by a trawler, as well as contrasting this with numerical modelling results.

To accurately assess the results from complex numerical models, a thorough empirical assessment at the location must also be made. Thus, several studies have laid excellent groundwork for future work expanding into numerical modelling, yet never pursued this avenue. In light of these factors, the aim of this particular project was to conduct a full-scale empirical assessment of sedimentation and suspended sediment load, and to compare this with data obtained from model predictions. Spencer Gulf represents an ideal area of study due to it’s proximity to an established scientific infrastructure, established prawn trawling industry, ease of access and shallow water depth.

Methodology

Determining Sediment Distribution

Sediment samples were taken at 40 stations in Spencer Gulf (Figure 1) over a 10-day period in October 1998 on the *M.R.V. Ngerin*. The primary sampler was a gravity corer, with sampling tubes consisting of a 6cm diameter PVC tube with internally mounted backward pointing spikes to retain the integrity of the sediment sample during retrieval. The corer was allowed to free-fall from a depth of 5-6m above the seafloor, and typically penetrated to depths of 5-7cm.

In some areas, the sediment layer was impenetrable using the gravity corer, even when dropped from a greater height above the seafloor. In these instances, a bucketgrab corer was used to obtain samples, typically to a depth of 4-5cm. All samples were transferred to plastic zip-lock bags and frozen for analysis back in the laboratory.

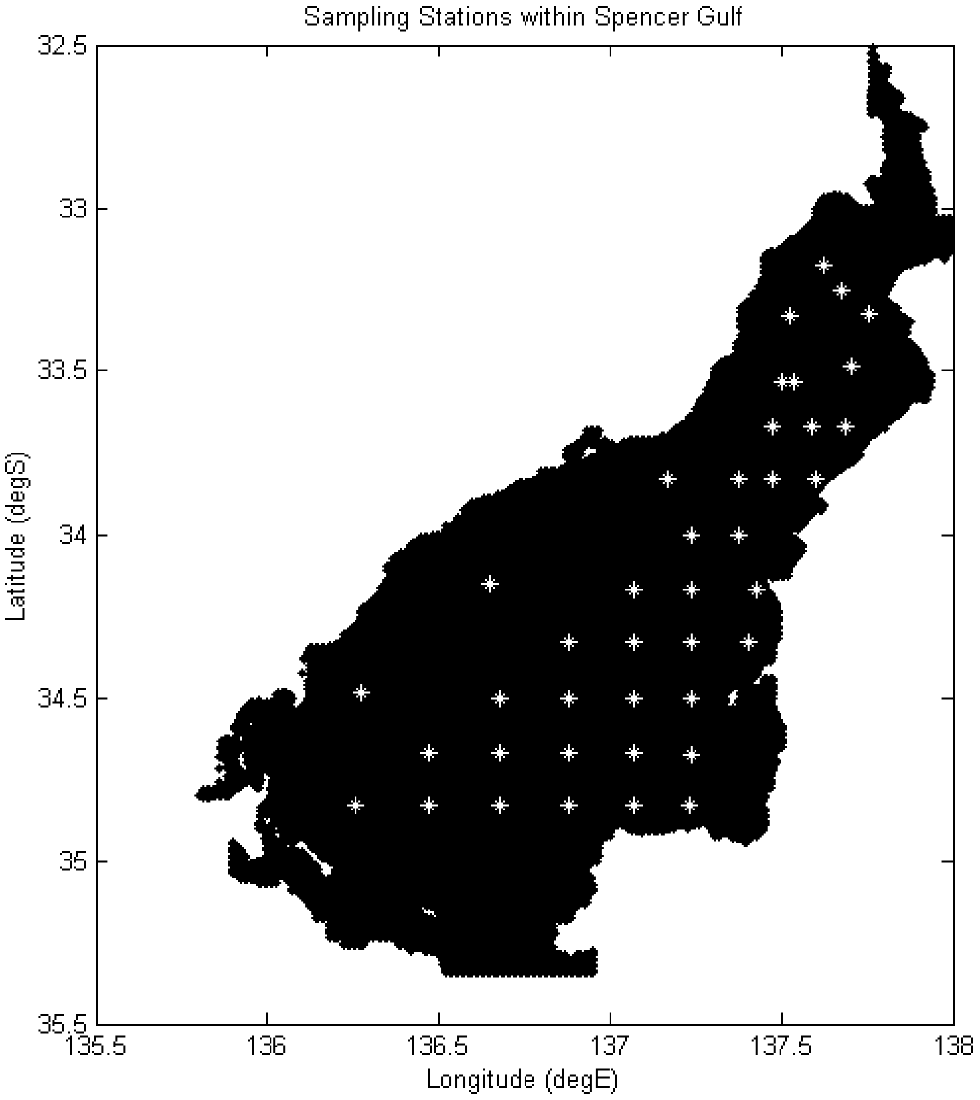


Figure 1: Stations within Spencer Gulf sampled for sediment characteristics

Sediment Sample Analysis

Laboratory Analysis:

Each sample was initially treated with concentrated hydrogen peroxide to remove organic matter. The samples were subsequently rinsed with fresh water and dried at 60°C for 48 hours.

Sediment Density:

Wet density was determined by filling a container of known volume and mass with sediment from an undisturbed sample and weighing.

Grain Size Distribution:
Each sample was dry sieved using a stack (1mm; 500um; 250um; 125um) of Endecotts™ sieves on a shaker for 5 minutes. Attempts were made to use a 63 um sieve in the stack, however this mesh size became clogged frequently during sieving and so was abandoned. Each portion was weighed, giving proportional grain size distribution for each site. These proportions were then added into the mapping program SURFER, and contour maps generated for each grain size fraction.

Field Measurements

Deployment

In order to evaluate the sedimentation rate in Spencer Gulf, it was decided to build several sediment traps and place them at certain positions within the gulf. These locations were to coincide with the five study positions used for the other elements of this project.

Initially, it was decided to conduct a quick pilot study to determine the approximate sedimentation rate, so that larger, more complex sediment traps can be designed. To fulfil this, several 9mm diameter PVC tubes were cut to length of 25cm. These were deployed (using concrete blocks as anchors) at Sites 1, 3, and 4, three replicates at each site. After three months, these were recovered, analysed, and based on the results five complex traps were built.

Each complex sediment trap (hereafter referred to simply as “traps”) consists of eight PVC tubes arranged in a circle approximately 60cm in diameter. Each tube is capped at the bottom (forming an open-topped container) and measures 9cm diameter and 40cm height. Positioned slightly above the tubes is a large disc with a hole cut into it slightly larger than the opening of one of the tubes. This allows the disc to cover all tube openings apart from one, permitting only one tube to be open to settling sediment at any one time. After a twelve day time period, this disc will rotate 45^o, covering the previously opened tube and uncovering a new “fresh” tube. The time frame of 12 days per tube is such that it gives approximately 100 days (12 days x 8 tubes) before each trap needs to be recovered, the tubes changed with fresh ones, and redeployed. Additionally, this design allowed for a temporal-based comparison of sedimentation to be made not only between sites, but also within a site. It is loosely based on a sediment trap design used in the Gulf of Maine for similar work (Pilskaln, pers. comm.).

Each trap was deployed approximately 1.5m above the seafloor, attached to a weight via 8mm chain. A subsurface float was also attached to the top of the instrument via a 2m length rope piece. The purpose of this float was to:

a) Keep the trap suspended up off the seafloor
b) Help retain the trap in an upright position in the event of strong tidal currents

A “test trap” was deployed in December 1999, with four more being deployed in March 2000 for a one-year period. Approximately every three months, the traps would be recovered from the seabed, the tubes replaced with a fresh set, and the trap redeployed. Once recovered from the deployment, each tube was frozen until analysis.

Tube Analysis

The primary problem with analysis was the fact that each tube contained approximately two litres of seawater that needed to be drained off to allow analysis of the remaining sediment sample. Several methods were trialled for this purpose.

Evaporation: Considered inadequate because of the resulting salt crystals.

Decantation: Also inadequate as the settled sediment fraction was resuspended by the water movement. This gave rise to the possibility of accidentally losing some of the sediment sample during the decanting process.

A combination of both the above methods (decanting as much of the water as possible without disturbing the sediment, and then evaporating the rest) still gave rise to a sufficiently large enough quantity of salt crystals for this method to also be considered ineffective.

Eventually, the following process of "flushing out" the saline water was developed: Each tube was thawed and allowed to stand undisturbed for two weeks to allow settling of any suspended sediment. Approximately 80% of the covering water in each tube was siphoned off carefully to avoid disturbing the settled sediment. The remaining "sludge" was then transferred into a 2l plastic container. This was filled with fresh, demineralised water.

After another 2 weeks waiting period (to again allow settling of disturbed sediments), 80% of this new water mixture was siphoned off carefully. The containers were refilled with more demineralised water, thus "flushing" the saline water from the sediment sample/water mixture. The results from a pilot trial of this method revealed that a total of three such "flushings" were sufficient to lower the salinity level of the water covering the sediment to approximately 0 psu.

Once the sediment samples had undergone a final settling phase, again approx. 80% of the fresh water layer was siphoned off, and the containers were placed in a drying oven at 60^{o}C to allow the remaining fresh water to evaporate.

The resulting, dried, sediment sample from each tube was then analysed according to the method described previously, with the exception of determining sediment density.

Empirical Trawler-Induced Resuspension

The sediment traps provide a long-term picture of the sediment loads and sedimentation rates in Spencer Gulf. This can be correlated with fishing activity and weather patterns in an attempt to determine if any significant relationships exist. However, field based determination of the sediment plume created by a trawler will provide a clearer picture of any impact prawn trawling activities may be having, whilst also providing an empirical foundation for the numerical modelling side of the study.

To accomplish this, it was necessary to obtain a SeaTech Transmissometer from CSIRO, a device that measures water clarity via light attenuation. While this instrument can be calibrated to provide a sediment concentration reading, there has been some discussion as to how accurate this is due to misinterpretation of organic load as sediment, and thus it was felt that a relative (percentage) determination of water clarity was most appropriate.

The method of determining a trawler-induced sediment plume was similar to that used by Pilskaln *et al.* (1998). A ship ("Ship A") positions itself directly behind an active trawler (Ship B) as close as possible without risking entanglement in the trawl nets. Vertical casts of the transmissometer are performed on Ship A, thus capturing the vertical extent of the plume created by Ship B before the resuspended sediment resettles or is flushed away by water movement.

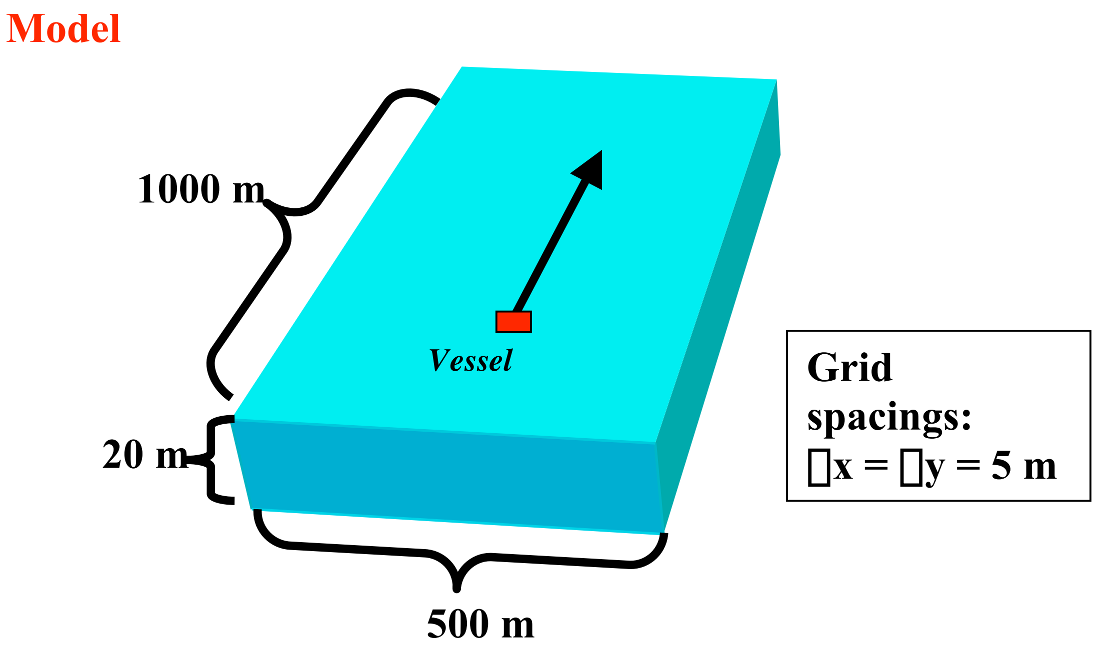


Figure 2: An illustration of the model boundary conditions and coordinate system used (Kaempf, 2001).

Model Predictions

The numerical model used in this study is one originally designed for use in describing sediment plumes in submarine canyons (Kaempf and Fohrmann, 2000). Essentially, it is a three dimensional, rotational model coupling hydrodynamic movement and sediment transport via critical erosion/deposition speeds for separate grain size fractions. Vertical grid spacing is independent of water depth, thus allowing high vertical resolution as opposed to the more common □-coordinate models. For a more detailed description, the reader is invited to examine Kaempf and Fohrmann (2000).

The above-mentioned model has been adapted for use in describing the sediment plume that arises from an active prawn trawler in a shallow marine system such as Spencer Gulf. The model's vertical and horizontal grid point spacing was aimed at providing a reasonable resolution in the x- and y- directions and, due to the shallow depth, a high resolution in the vertical direction. Thus, it was decided to prescribe a seabed section 1000m long (□x), 500m wide (□y) and 20m depth (□z). It is assumed the trawler is operating both nets and is moving at a constant speed of 1 ms^{-1} in the x-direction. The bottom sediment characteristics were divided up into three fractions: fine (<125□m), medium (125-500□m) and coarse grain sands (>500□m). Preliminary studies showed that the coarse grains are resuspended, but due to their weight settle back down to the seafloor within a matter of seconds to minutes, and so were disregarded. The finer grains were also disregarded as the energy in Spencer Gulf is such that they are almost permanently in suspension, and this study is primarily aimed at sediment resuspension and sedimentation. Consequently, the model assumes that the background concentration of the medium sized grains is 0, which is not the case. This assumption may be justified however, in taking the concentrations of suspended sediment calculated by the model not to be the total concentration, but rather an as an addition to the already present sediment load. The density of sediment on the seabed was taken as an average of the values determined from the sediment samples taken (see Section 2.1.1). A graphic illustration of the model conditions can be seen in Figure 2.

Results

Sediment Distribution

The results from the sediment core samples taken in Spencer Gulf are shown in Figures 3-7. The map showing proportions of grains 1mm or larger (Figure 3) indicates a relatively high concentration in the northern section, as well as the two apparent depositional points on each side of the southern end of the gulf. Maximum proportion reached is approximately 65% at one northern site and the coastal area in Hardwicke Bay.

The 500μm map (Figure 4) shows some anomalies, with point locations of high concentrations (45%), yet close by (i.e. the next station) there is a low proportion of grains this size (10-15%). However, a general trend appears to exist showing slightly higher proportions along the west coast and northern section, relative to the rest of the gulf.

The map showing proportions of grains in the size fraction 250μm - 499μm (Figure 5) also seems show two main depositional points, one in the centre of the mouth of the gulf, and one to the northeast approximately one-third the way up the gulf. Maximum proportion at these two locations approaches 50%, yet the remainder of the gulf exhibits lower proportions (~15-20%).

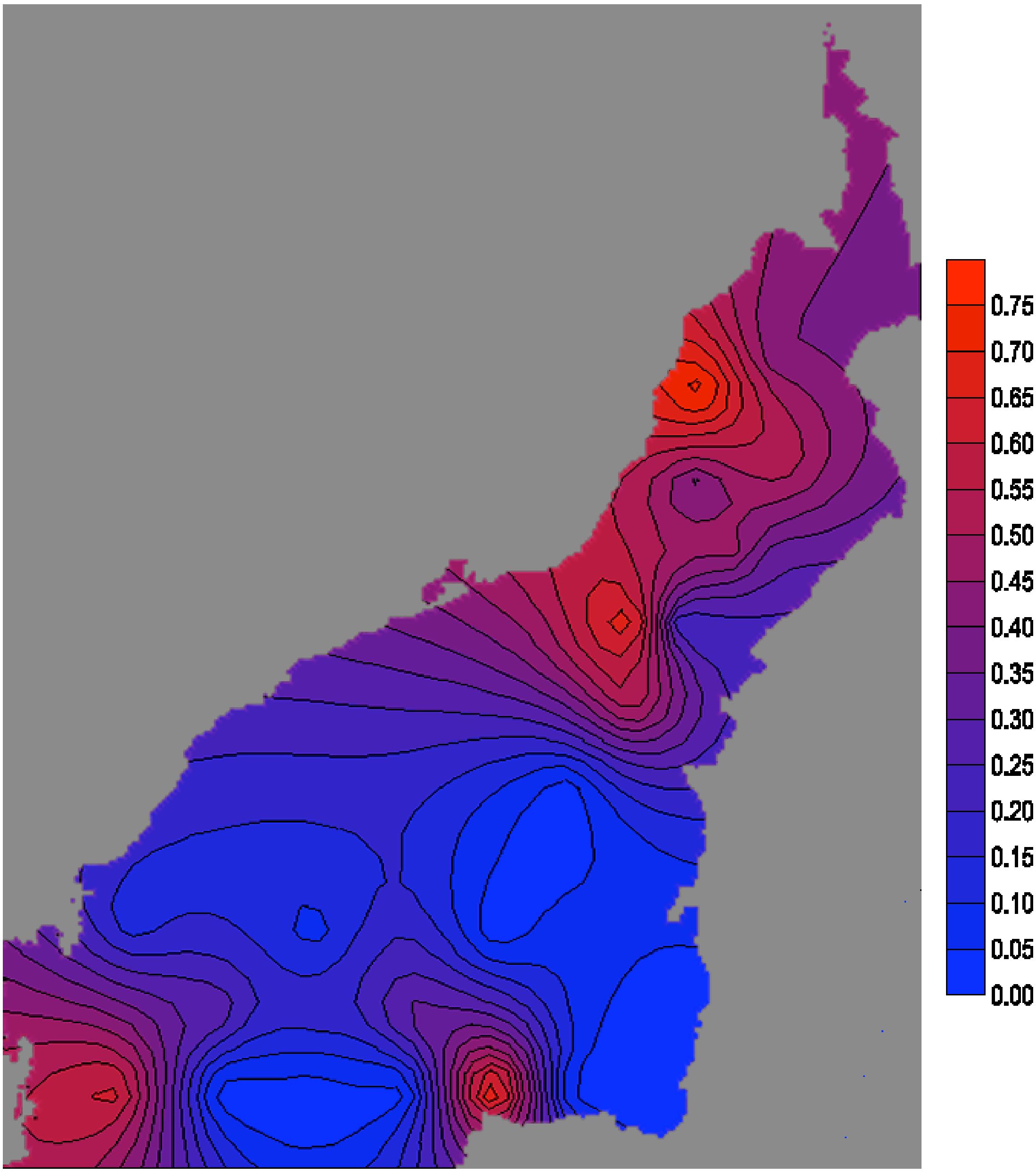


Figure 3: The proportionate composition of grain larger than 1mm to the bed sediment within Spencer Gulf.

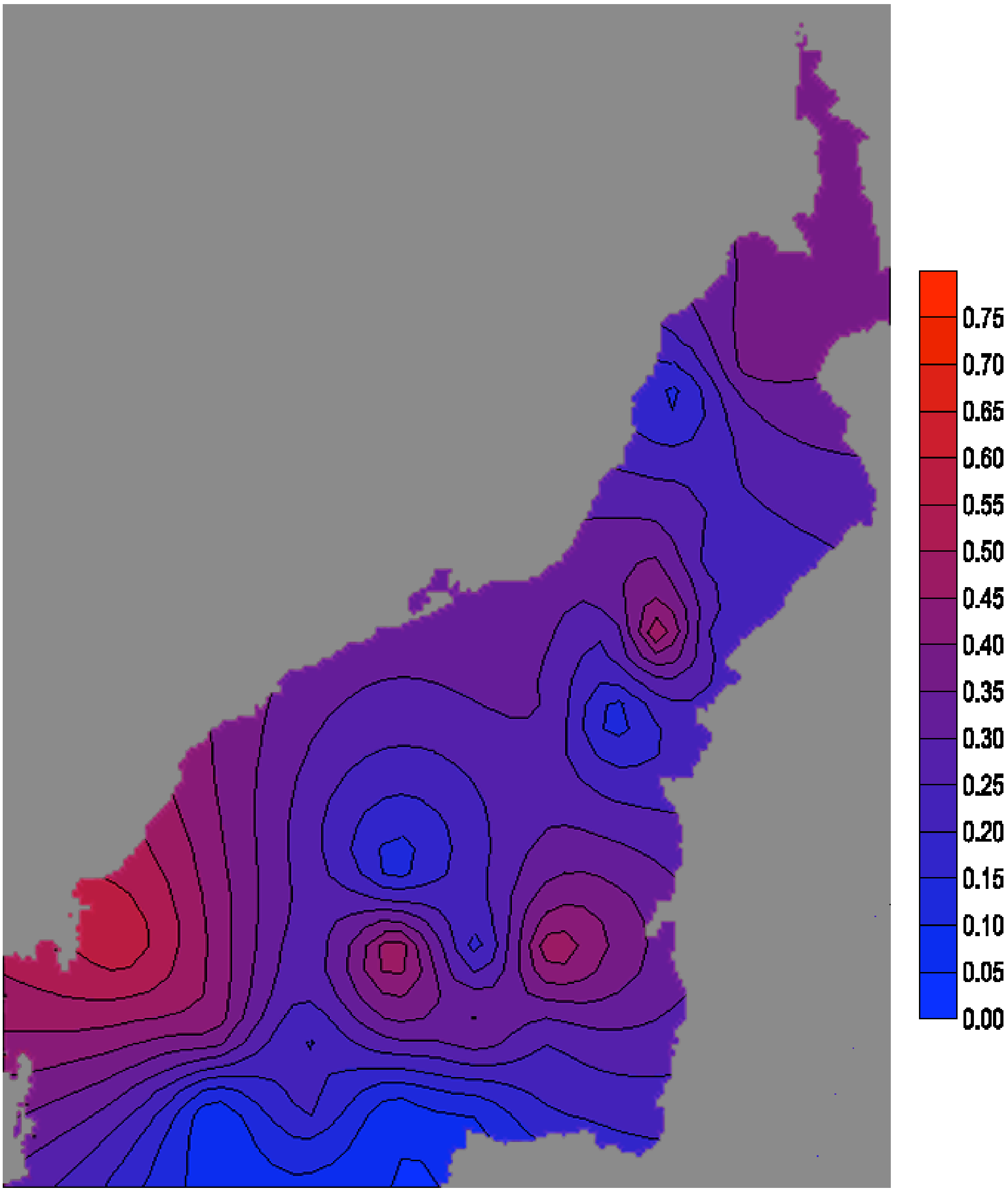


Figure 4: The proportionate composition of grains in the size range 500μm – 1mm to the bed sediment within Spencer Gulf.

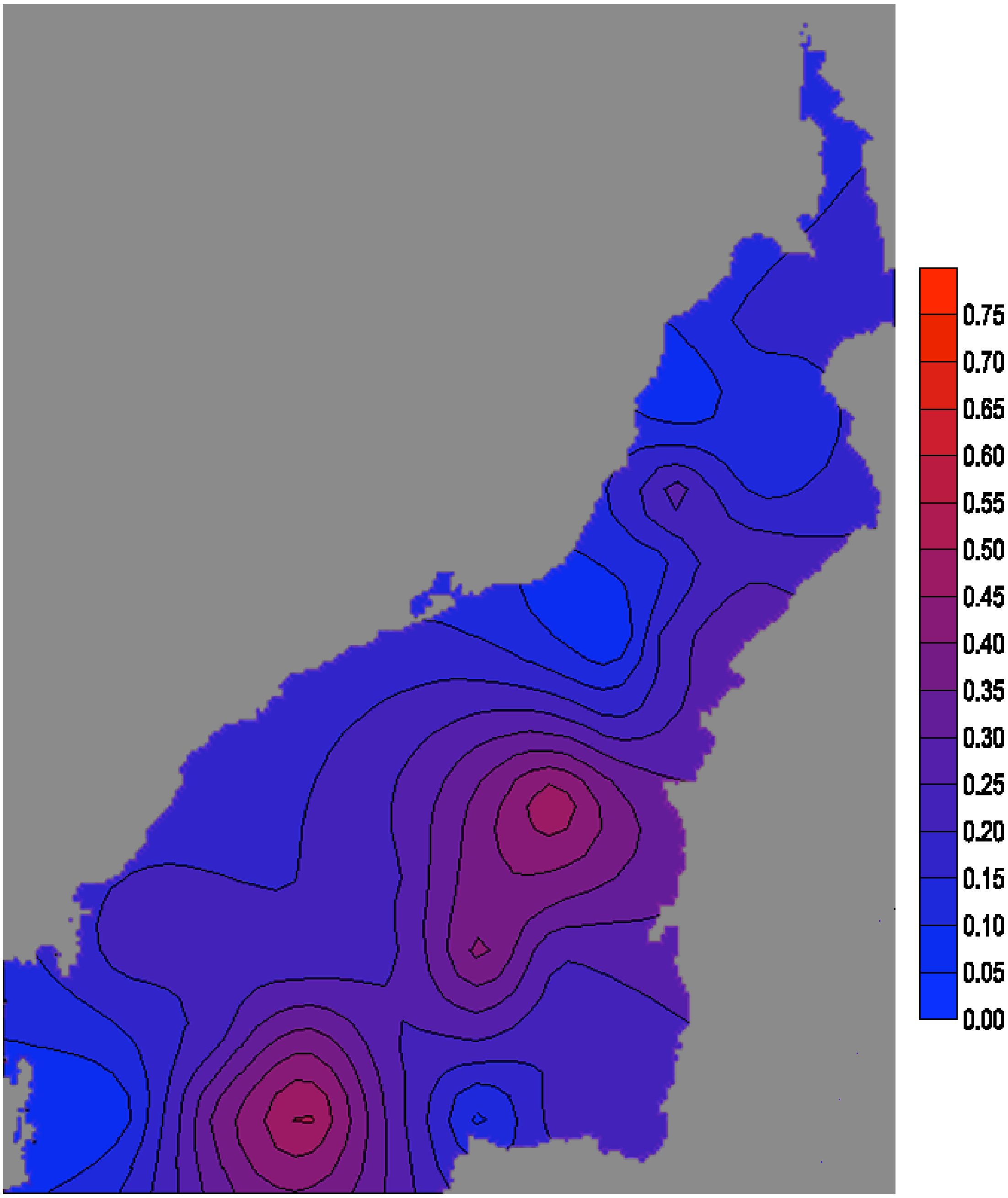


Figure 5: The proportionate composition of grains in the size range 250μm - 500μm to the bed sediment within Spencer Gulf.

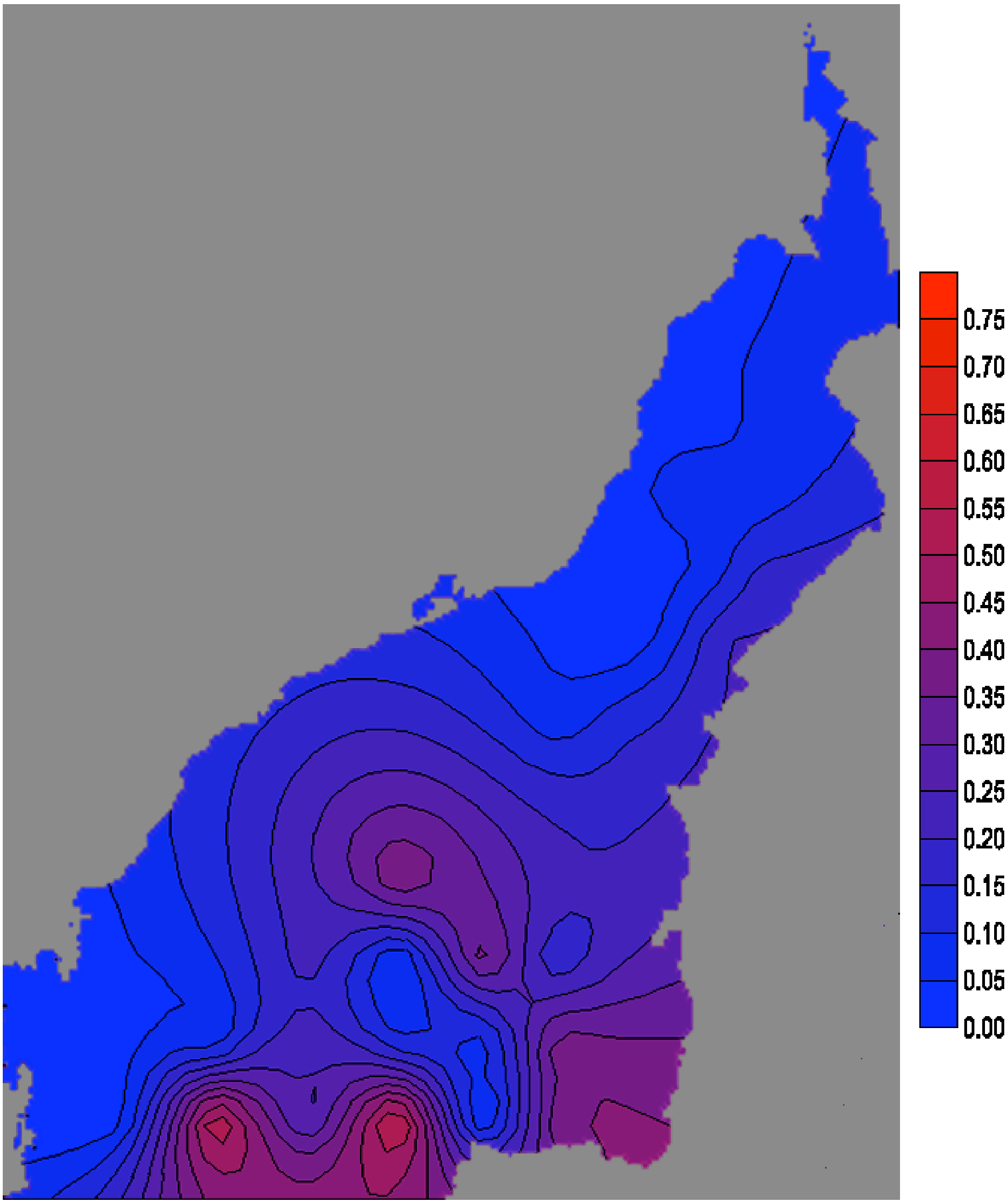


Figure 6: The proportionate composition of grains in the size range 125m - 250m to the bed sediment within Spencer Gulf.

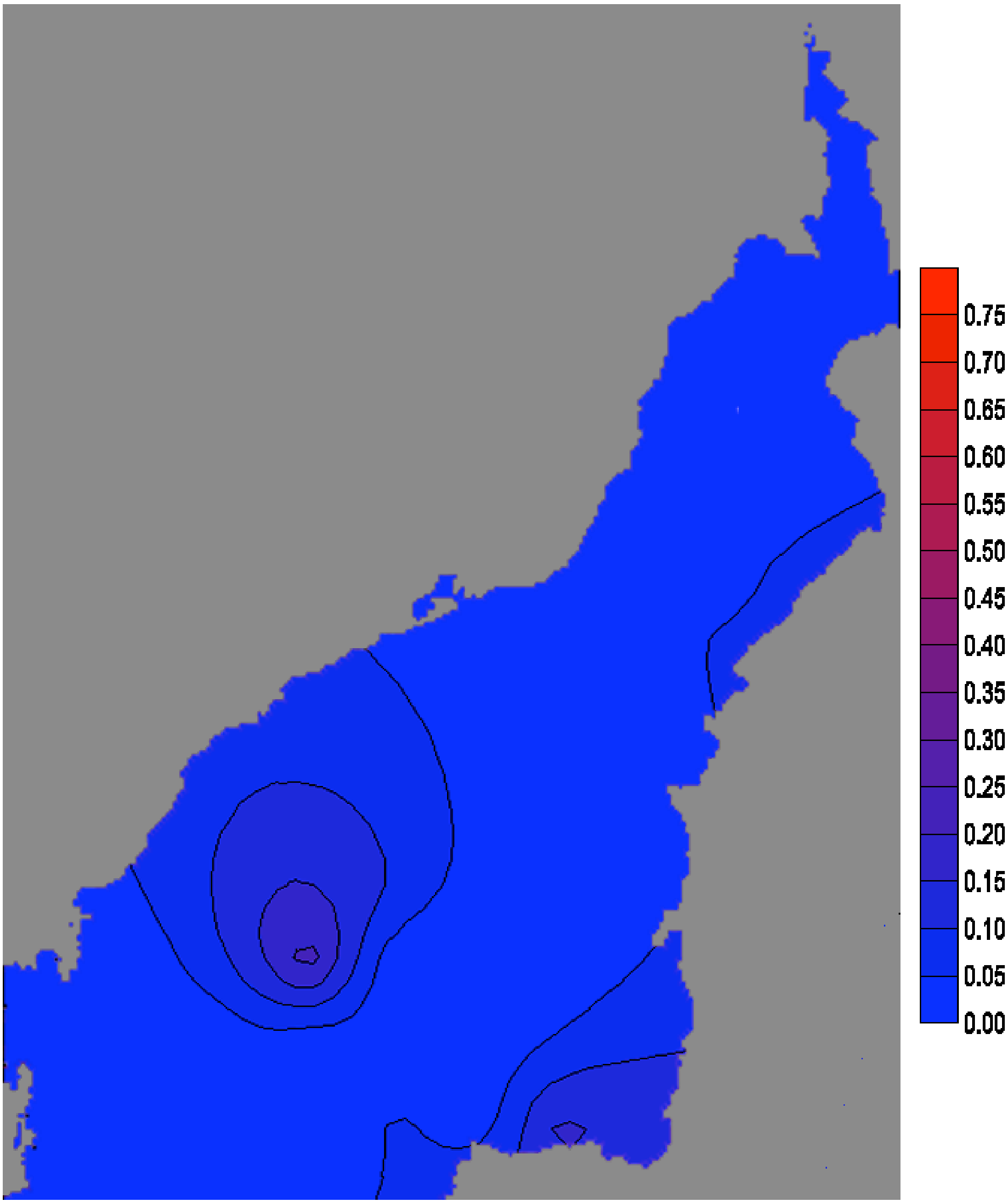


Figure 7: The proportionate composition of grains smaller than 125µm to the bed sediment within Spencer Gulf.

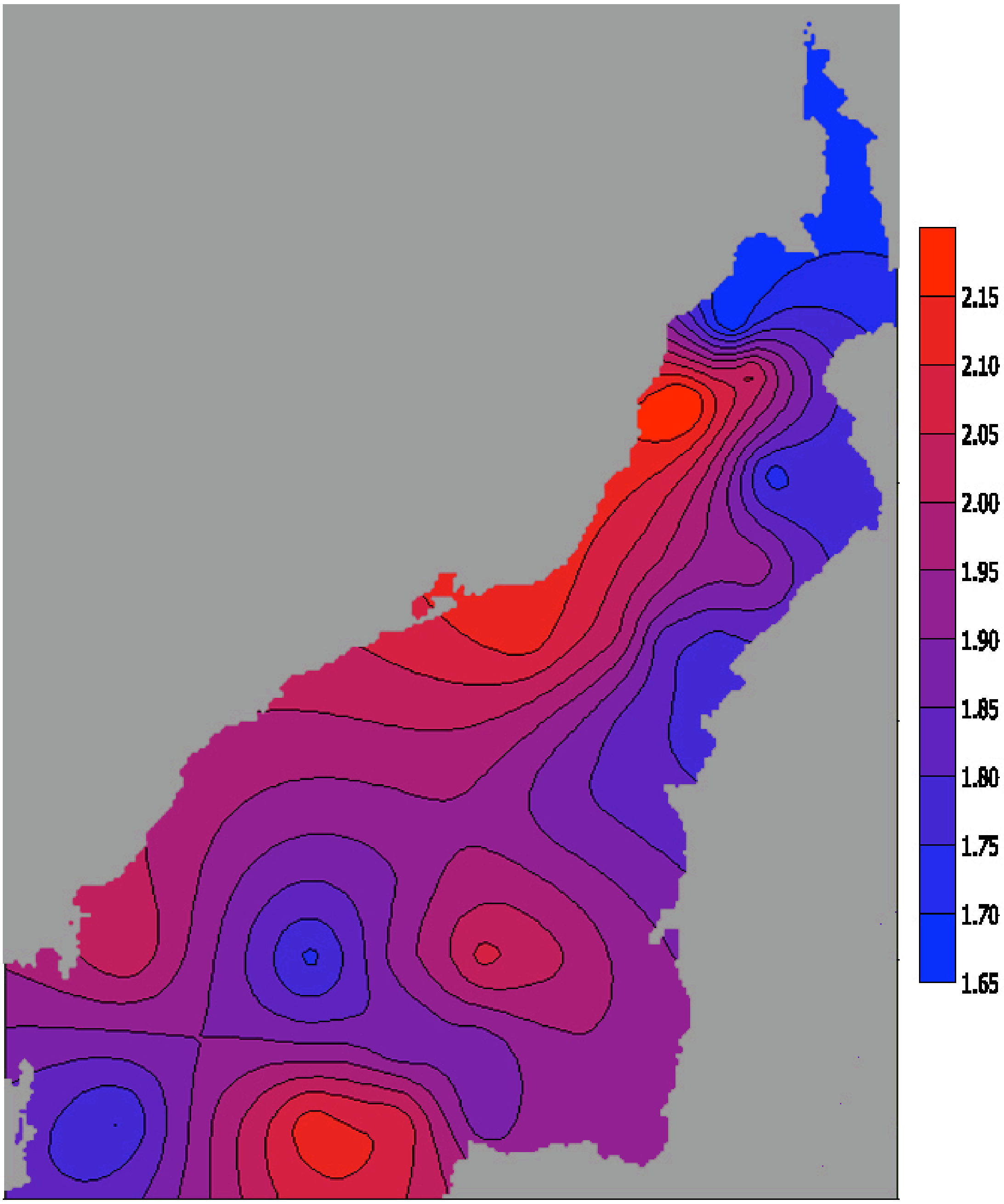


Figure 8: A contour map depicting sediment density in Spencer Gulf. The legend is values of density in g.cm^{-3}.

The contour map describing distribution of grain sizes in the class 125μm - 249μm (Figure 6) shows several apparent areas of high deposition rates in the central and southern areas of the gulf, while the rest of the gulf shows almost low proportions (0-10%). Maximum proportion of this grain size class reached is 75% in two locations along the mouth of the gulf, with slightly lower values at two other depositional areas (central gulf and Hardwicke Bay).

The final grain size fraction (<125μm – Figure 7) shows no real depositional areas within Spencer Gulf, with proportions rarely surpassing 15%, and most of the gulf showing 0%.

Figure 8 shows the sediment density determined as described in Section 2.1.1. Sediment density is found to be approximately 2g.cm^{-3}, which compares favourably with previous work (Cartwright, 1998), with elevated levels (2.15g.cm^{-3}) up the western coast, possibly related to the extremely limited trawling that occurs in that area. (Trawling disturbs bottom sediments, causing them to be less packed).

Sediment Traps

Unfortunately, several problems hampered the recovery effort of some of the traps (e.g. spillage due to rough weather, spillage in transit). Combined with the length of time required to develop and implement an analysis method, analysis of all the tubes is incomplete. Hence (as well as for brevity), a subset indicative of the results thus found is presented here.

Total Sediment Collected

Figure 9 shows the difference (in terms of weight) in sediment collected from each tube for each deployment. The x- axis (Tubes) is representative of time progression during the period of deployment.

There was a difference in suspended sediment load between the two deployments. From December 1999 – March 2000, total sediment per tube is approximately 15g until the time the trap failed (marked by red dot). Yet for the following deployment period, each tube collected in the region of 50g, with a spike in Tube 3 upto 70g.

Figures 10 and 11 show the sedimentation rate (g/day) of two consecutive deployments at Site 4. The average amount of sediment being deposited per day for the period December 1999 – March 2000 can be seen in Figure 10; a value in the range of 1 – 1.5 g/day. The red point indicates when the timed motor jammed due to excessive growth, and the resulting low sedimentation rates for tubes not exposed at all can be seen. It should be noted that this trap stopped functioning whilst Tube 7 was exposed, due to substantial colonisation on the trap by marine fauna. This growth prevented the motor from turning the top rotating disc – this was addressed in future deployments by coating the trap with antifoulant.

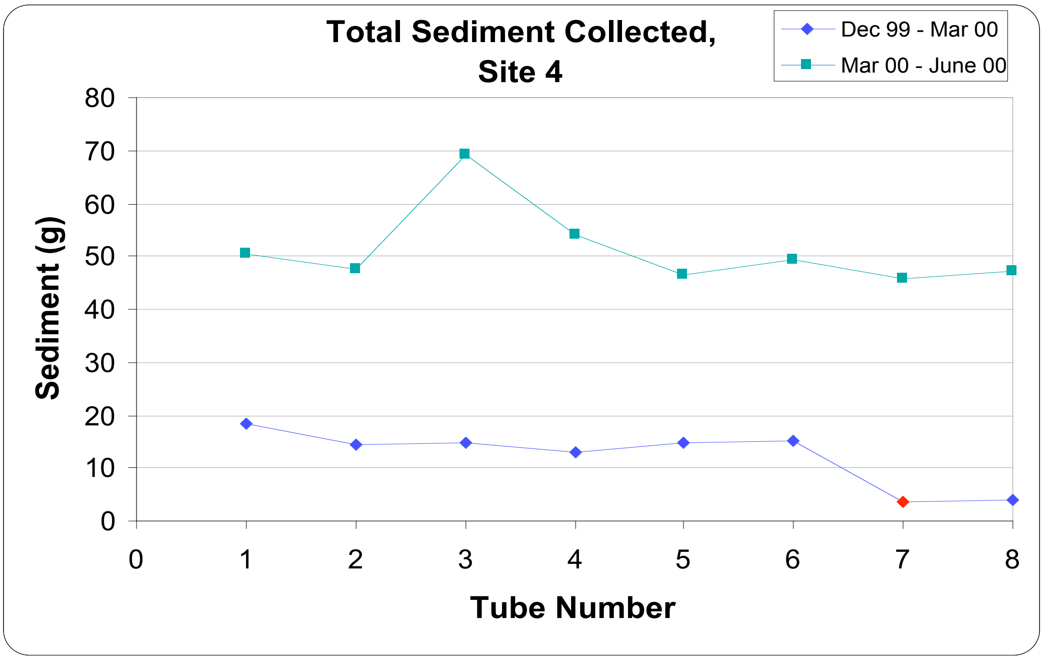


Figure 9: The amount of sediment retrieved from each tube in the period of December 1999 – June 2000. The red dot indicates when the trap ceased functioning during the first deployment.

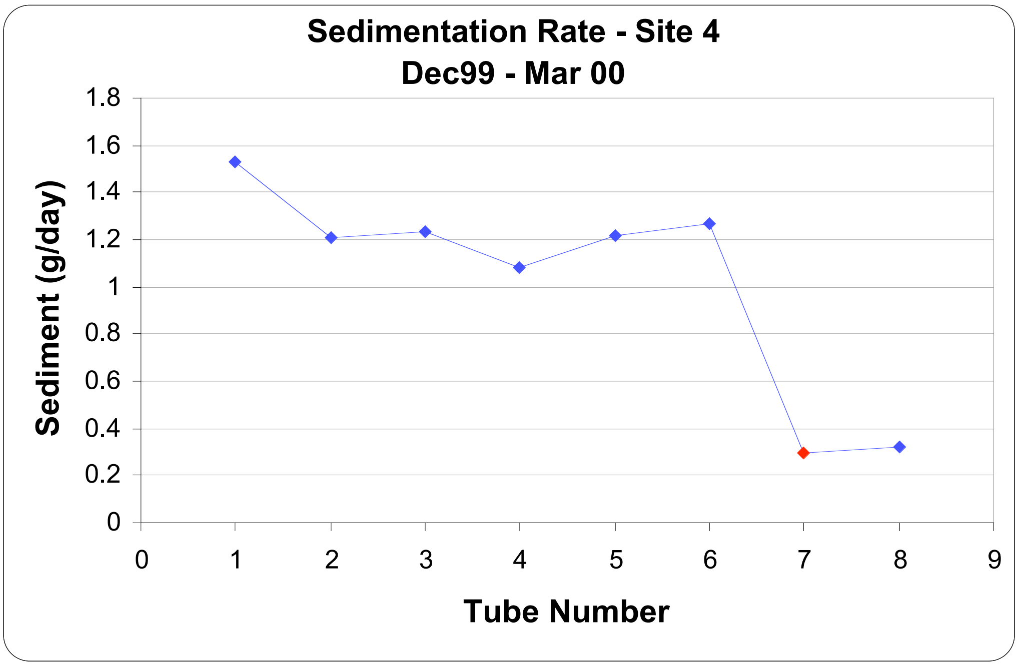


Figure 10: The average amount of sediment deposited per day for the period each tube was exposed, December 1999 – March 2000, with red indicating when trap stopped functioning. Sedimentation Rate

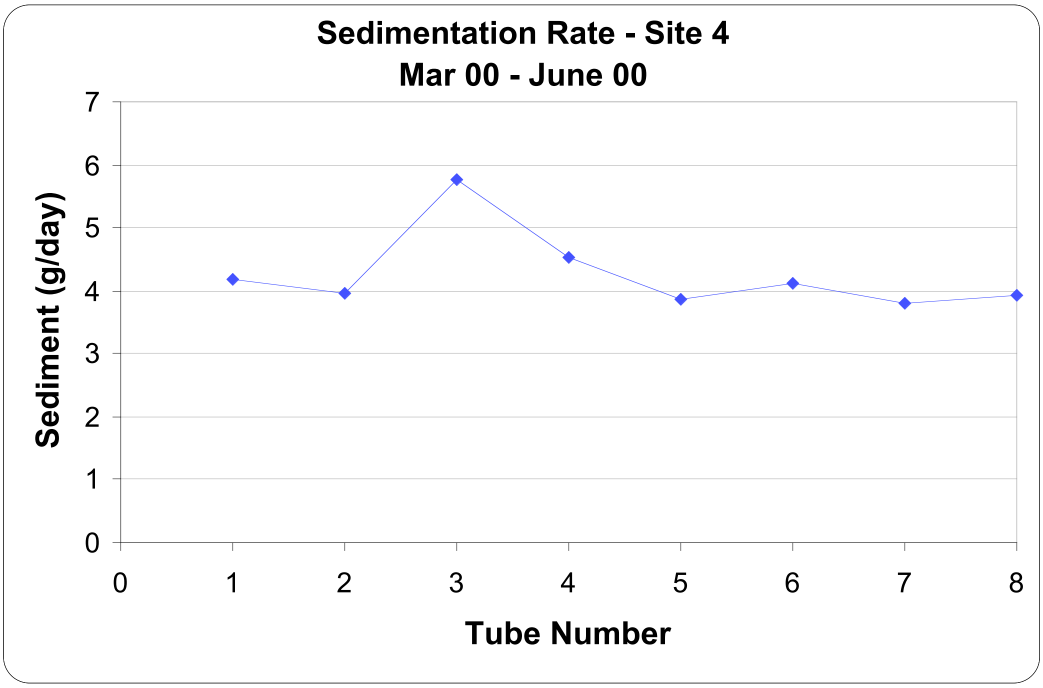


Figure 11: The average amount of sediment deposited per day for the period each tube was exposed, March 2000 – June 2000.

Figure 11 shows the sedimentation rate at Site 4 for the period of March 2000 – June 2000. Note the average is approximately 4g of sediment being deposited per day, however during the period Tube 2 was exposed, there is a spike of approximately 6g/day. Note the almost tripling of the sedimentation rate as compared to the previous deployment at the same location (Figure 10).

Grain Size Fractions

The proportionate grain size fractions in each tube were found to be highly variable both inter- and intra- deployment. This is despite that intra- deployment, each tube contained approximately the same amount of sediment (see Figure 9). Figures 12a and 12b show the proportions each grain size class comprised of the total sample from each tube. During the analysis procedure, it became apparent that the grain size fraction greater than 1mm was not present in any of the samples, thus it is excluded. Note in Figure 12a, initially the size fractions were approximately equal, followed by a rapid divergence in percentage composition. It can also be seen that the most variable size fraction for both deployments was that of 250-500µm, ranging from 20-50% in the first deployment, and 20-60% in the second. The 125-250µm fraction also exhibits some variation, showing a surge to 40% in the early stages of the first deployment before settling to a constant 20%. During the second deployment, this fraction shows a gradual change in composition from 50% initially down to a final value of approximately 30%. During both deployments, the 500-1000µm fraction is steady within the range 15-25% composition, and the <125µm class is persistently low.

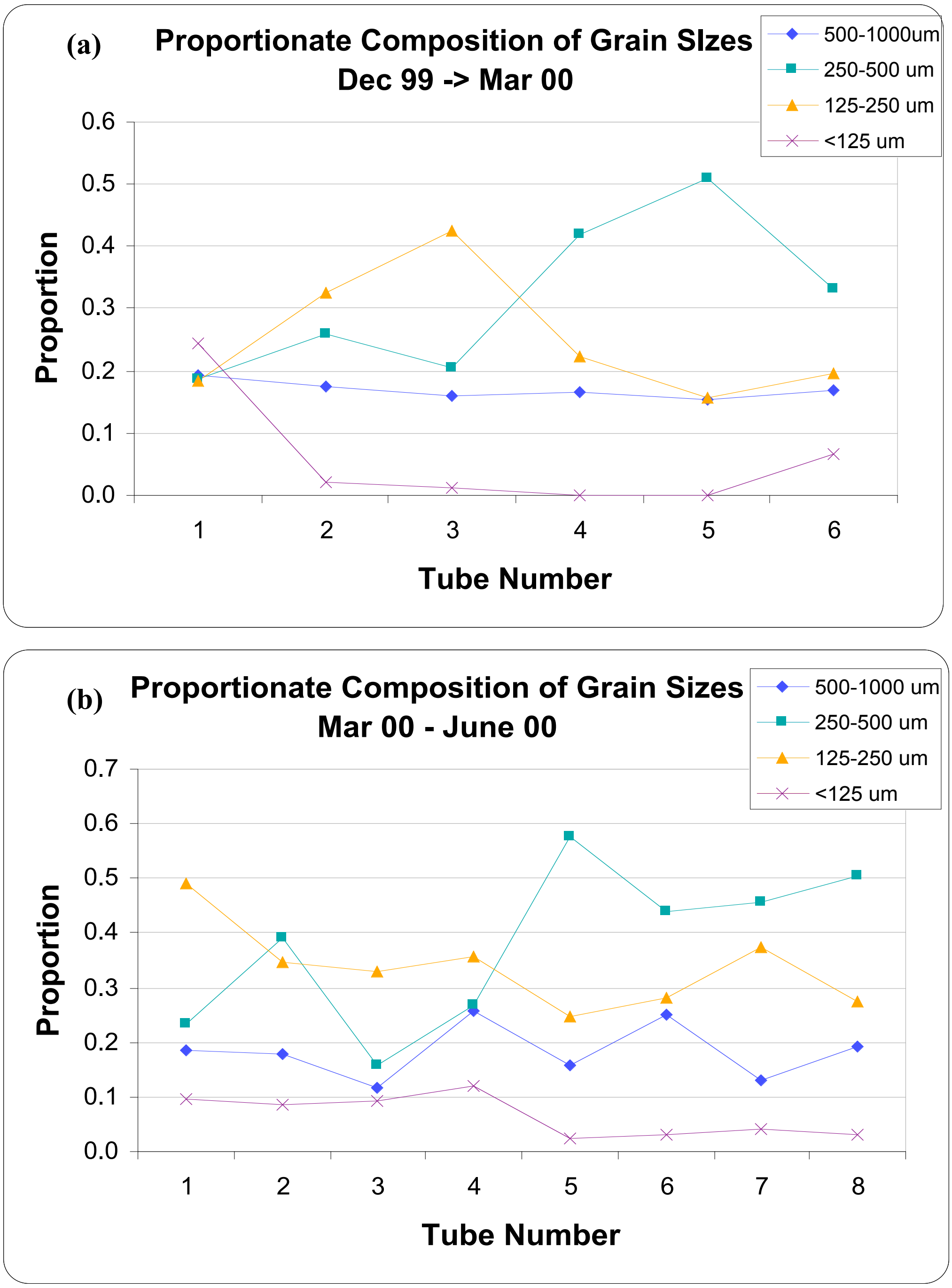


Figure 12: The proportionate fraction each grain size class contributes to the sediment sample retrieved from each tube in (a) December 1999 – March 2000 (Note only 6 tubes displayed), and (b) March 2000 – June 2000.

Trawler Induced Resuspension

The profiles obtained in this section quite clearly illustrate the vertical extent of the plume created immediately behind a prawn trawler. Figure 13a is a vertical profile taken before the trawler began operation (i.e. an unperturbed seabed and water column). It can be seen that the water column appears uniform in clarity (~30% attenuation of the light beam of the transmissometer) over the entire depth range.

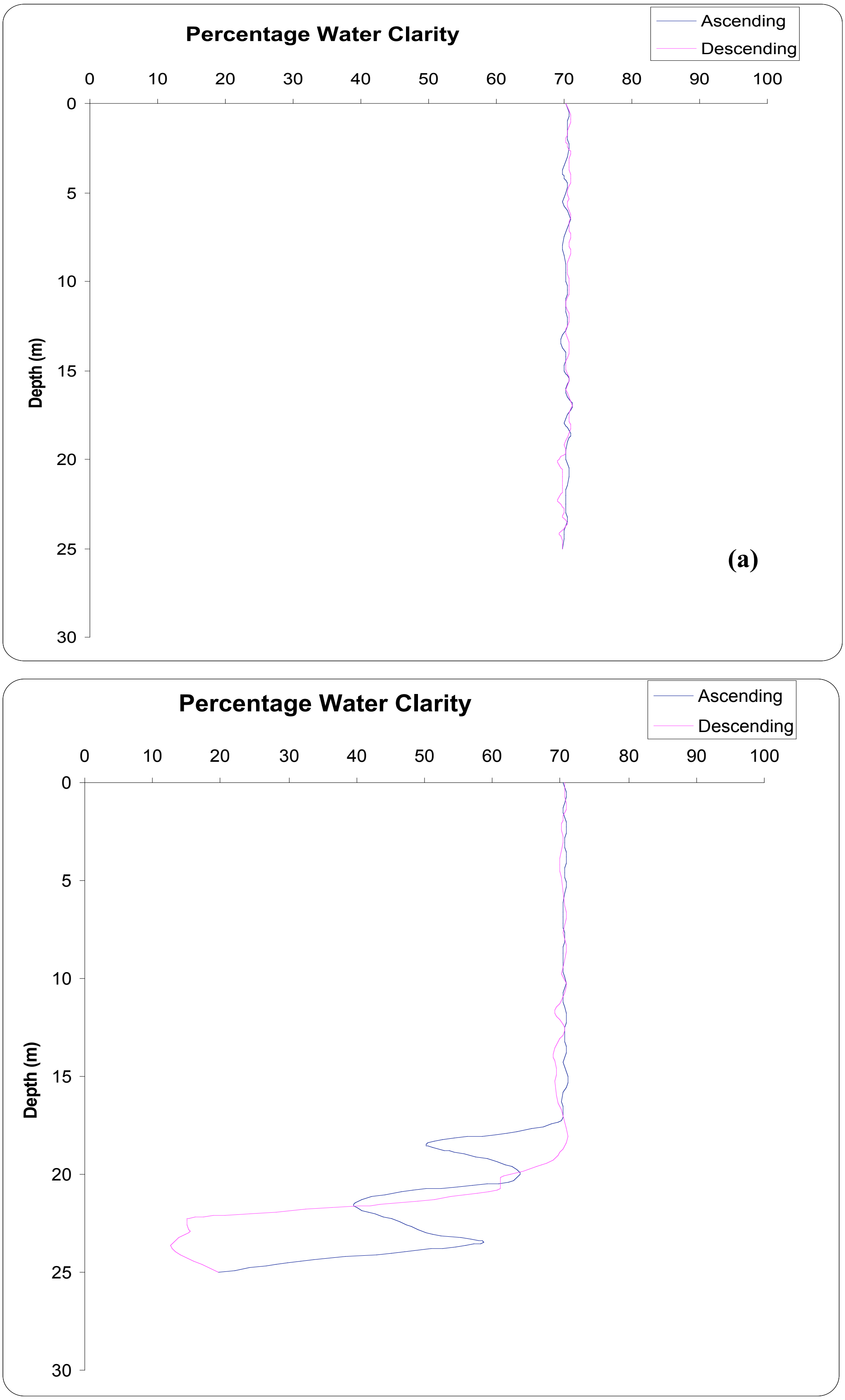


Figure 13: Transmissometer profiles at Site 4, Spencer Gulf before a trawler commenced operating (a), and immediately trailing a trawler (b).

However, immediately behind a trawler, a significant reduction in clarity over the bottom 8m of the water column is observed (Figure 13b). The large variations in clarity close to the bottom seen in Figure 13b presented themselves in approximately 30% of all the profiles taken, and are probably related to the mixing/flushing away of sediment by localised currents.

It should also be noted that the plume of sediment created by the trawler was visible using the echo sounder of the trailing boat (pers. obs.). The plume appeared as a thick suspended mass, extending approximately 7m up into the water column from the seafloor. Whilst this is not a quantitative measurement, it is of sufficient relevance to acknowledge that the *mass* of suspended sediment from *one* trawler is enough to appear distinctly on the echo sounder.

Model Results

The following two figures are a time-based series of outputs from the model (one "snapshot" of near-bed suspended sediment concentration every 10 minutes) as a single point source of resuspension (i.e. a trawler) passes through. The numbers in red at the above left and above right of each snapshot respectively indicate the maximum recorded suspended sediment concentration and the time since the trawler commenced.

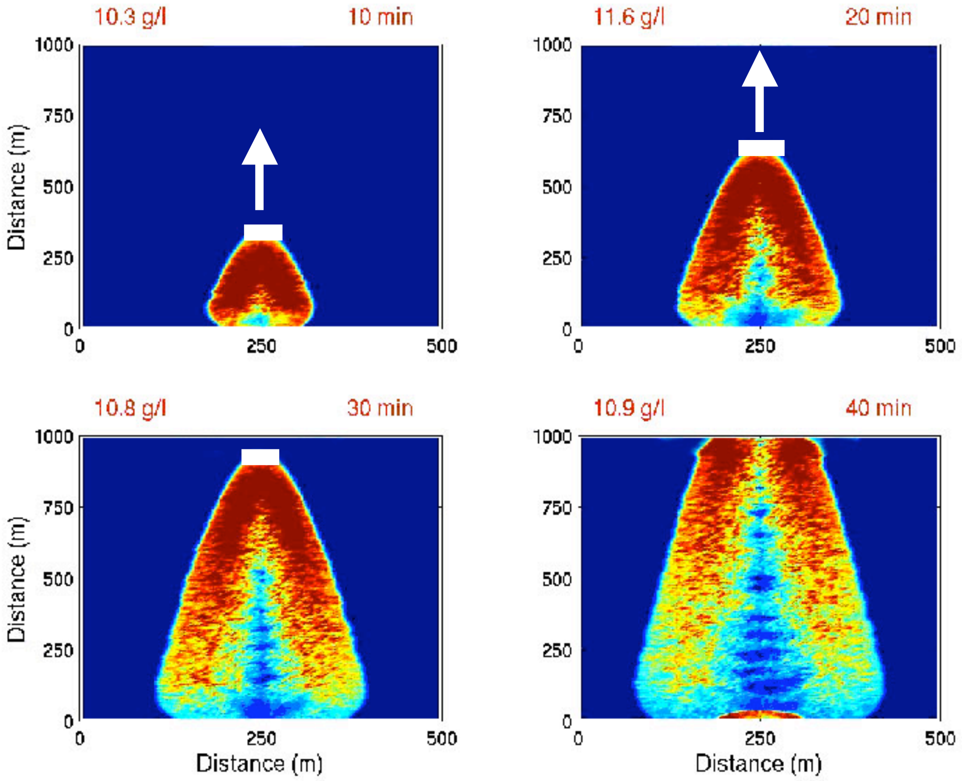


Figure 14: Snapshots of the suspended sediment concentration at ten-minute intervals as determined by the (modified) resuspension model of Kaempf and Fohrmann (2000). The time ranges is 0-40 mins from commencement of trawling activity.

Note in Figure 14 it can be seen that within the timeframe 10-15 minutes after commencement of the trawler, the plume starts to separate into two separate plumes in either direction along the x-axis. In between these two plumes is a region of surprisingly low suspended sediment concentration, i.e. approaching 0g/l.

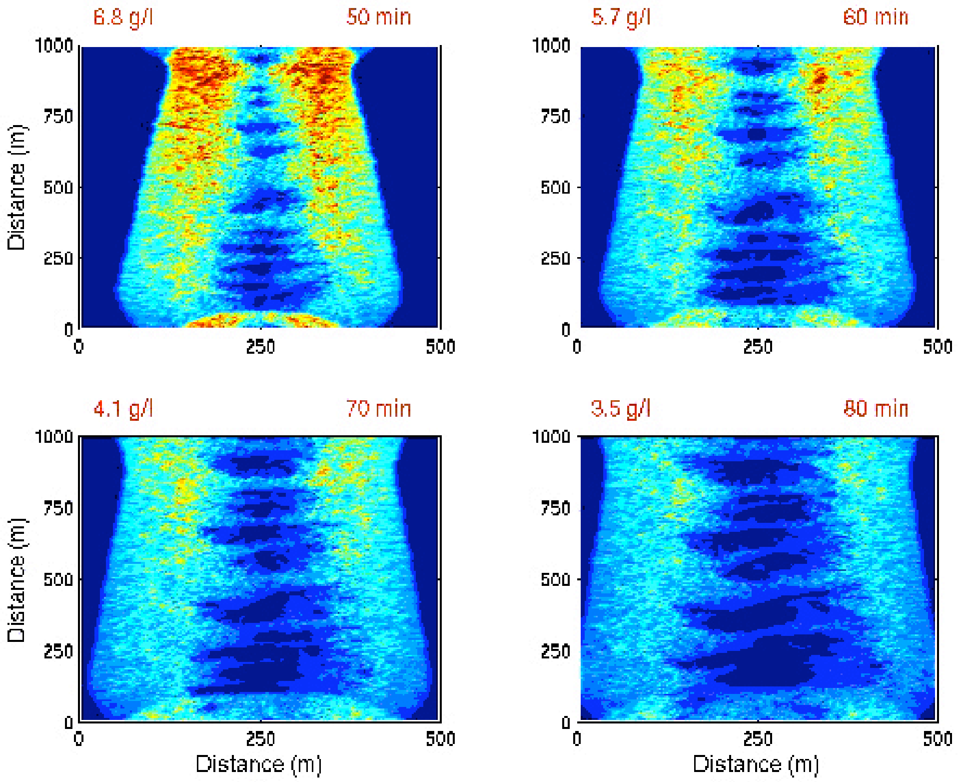


Figure 15: Snapshots of the suspended sediment concentration at ten-minute intervals as determined by the (modified) resuspension model of Kaempf and Fohrmann (2000). The time ranges is 50-80 mins from commencement of trawling activity.

Figure 15 illustrates the persistence of the plume under still water conditions, with low concentrations (~3.5g/l) of sediment remaining in suspension near the bed 80 mins after the trawler has passed. It is acknowledged that still water is rare occurrence during prawn trawling (although not unknown), and future work will include introducing a current in an attempt to approach a slightly more realistic result. Also to note is the presence of what appears to be a “bubble” of slightly elevated sediment concentrations at the bottom of each snapshot, from time t=40mins onwards. With time, this bubble slowly expands horizontally in the x-direction (and slightly in the y-direction), despite a gradual diminishing of the sediment concentration. This bubble is effectively a spillover from the top of each snapshot where it is present. The borders on the grid are not finite, and so the top/bottom edges of the grid may be considered joined, as are the left/right edges. This was done to allow a future development: the determination of how repeated trawling over the same area influences the suspended sediment concentration. (This approach was easier than constantly introducing new point sources at the origin, then having them “disappear” after reaching the top edge of the grid).

Figure 16 shows two vertical cross-sections of the water column; one 100m and another 250m behind the trawler. These particular cross-sections are taken at t=30mins (see Figure 14). It illustrates the vertical extent and concentration of the sediment plume, as well as the circulation pattern induced by the suspended sediment and moving trawler.

It can be seen the speed at which the plume rapidly sinks down to the lower layers of the water column. At 100m behind the vessel, the plume extends up to approximately 10-12m above the seafloor, yet at 250m behind the vessel it only reaches up to ~5m. At this point (250m) the plume has almost doubled in width compared to at 100m, and clearly evident also is the separation into two separate horizontal elements previously described.

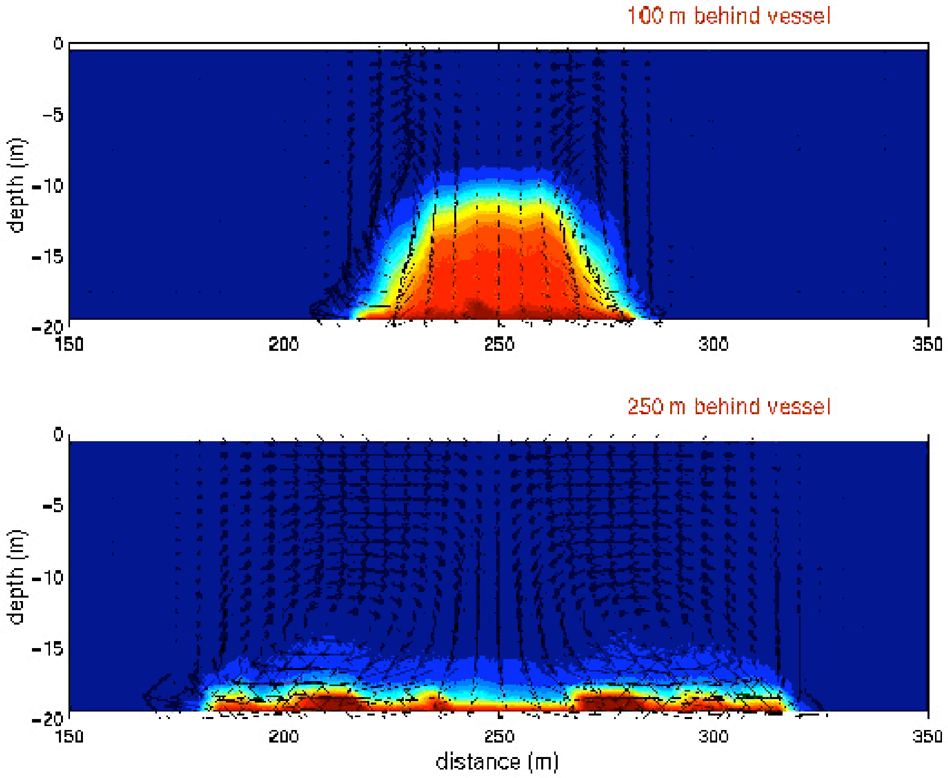


Figure 16: Vertical sections at two distances behind the trawler, indicating concentration and vertical height of the plume, and circulation patterns.

Discussion

The contour maps of grain size distribution clearly show the absence of any depositional areas of fine sediment grains. One possible reason for this, of course, is their absence from the system. This is not a viable answer though, as the far northern part of the gulf (above where my sample were taken) are primarily comprised of fine muds with the occasional patch of clay (Gostin *et al.*, 1984). Unfortunately, it was not possible to take samples in this area as it is primarily a military exclusion zone; however it is well acknowledged (Gostin *et al.*, 1984; Fuller *et al.*, 1994) to serve as a source of fine grains for the rest of Spencer Gulf. The reason a depositional point does not appear is the energy in Spencer Gulf is sufficient to retain these finer particles in near-permanent suspension, or until they are flushed from the gulf onto the shelf zone. This is borne out by the near absence of any fine grains collected by the sediment traps (see Figure 12).

Some of the areas that have high proportions of the larger grains (e.g. the southern areas for 1mm grains, and the southwestern zone for 500μm grains) are due to sole sampling points, as opposed to being a general trend observed over several sampling stations. This could be due to a number of reasons. Firstly, local anomalies in the seabed; the bulk of the sampling stations are ~10-15km apart, which in a gulf experiencing high water movement (Hemer and Bye, 1999), can easily hide localised irregularities. Secondly, erosion from a nearby exposed bed surface can act as a source of larger grains, however if the energy in the system is not sufficient to retain these larger particles in suspension for extended periods, they will quickly resettle out, causing a "localised anomaly" described above. The other areas containing a high proportion of larger grains are the northern parts of the gulf. This is not unexpected, as Spencer Gulf may well be considered divided into two zones in terms of kinetic energy of the system (Bullock, 1975; Nunes and Lennon, 1986). The southern zone below Franklin Harbour can experience tidally induced currents in excess of 2m.s^{-1} (pers. obs.), whereas the northern zone experiences slightly lower energies. It is in this lower energy area that the larger particles cannot be kept in suspension, and thus settle out. The sediment density determinations also match well with known values for areas of Spencer Gulf. Cartwright (1998) found values approaching 2g.cm^{-3} in the southwestern and western regions of Spencer Gulf.

The sediment trap data shows remarkable differences in sedimentation rate, even at the same location in consecutive three-month periods. Initially it appears there is no intermediate period between the low sedimentation rate in December – March and the higher rate during March – June. However, this transition period was probably not recorded due to the trap failure in the last 3 weeks of the first deployment period. Unfortunately, the set of tubes at Site 4 following these two deployments are yet to be analysed, as they may provide some clue. This higher rate of sedimentation during the second deployment period could be caused by several factors (or a combination thereof) such as:

1. The onset of winter manifesting itself by stronger weather patterns. While the water at Site 4 is deep enough to prevent any direct significant resuspension due to elevated wave/wind action, the overall increase in energy in the Gulf may lead to elevated resuspension (and thus settling out rates).

2. The activity of trawlers in the area, yet this seems unlikely as the prawn fleet would not have operated continuously for three whole months. They may, however, be responsible for the spike seen in Tube 3.
3. Dredging activity in the nearby coastal town of Wallaroo. While the instrument was deployed a substantial distance offshore (several kms), it is feasible that dredging in the Wallaroo area elevated the local sediment load. Although this scenario too is unlikely, as it is doubtful as to whether the dredging would occur for a three-month period.

The presence of larger grain sizes in the tubes was also not unexpected, due to the nearby presence of areas of high concentrations of these grain sizes (see Figures 3 and 4). The reason behind the variability of the 250-500μm grain size fraction is as of yet unknown. For both deployments, initially (the first 3-4 tubes) it comprises approximately 30% of the collected sediment sample, consistent with what is found locally on the bed (see Figure 5). Yet, at Tube 5, the proportion it comprises of the collected sediment sample spikes to 50%, for both deployments. Possibly, at this point during the deployment, the growth of organisms (such as tunicates) on the instrument reaches a level that somehow influences local current flow, causing these medium grains to settle out in a higher proportions. Hopefully this will be made clearer once the analysis of all tube sets is complete.

The model results of the plume behind a trawler compare well with the transmissometer profiles; both show a significant increase in the near-bed concentrations of sediment. The persistence of the plume as predicted by the model was surprising, lasting well over 80 minutes. It is acknowledged that *in situ*, the plume would be dispersed over a much larger area due to the actions of currents, removing any persistence of "shape" of the plume. This is observed with the transmissometer, insofar as it was impossible to track the plume after the trawler had passed due to currents diffusing the sediment, resettlement of the larger particles and wind/wave action acting on the boat's position.

However, it is interesting to note that one single trawler significantly elevated levels of sediment load (up to an approx. value of 11g/l – see Figure 14). During an active trawling period, there are approximately 40 boats all operating within a small section of the gulf. It can be inferred that the activity of this fleet would dramatically increase the localised sediment load of the trawled area. The movement of this sediment is dependent on the location of the fleet, and the hydrodynamic movement at the particular time, but it is probable that a substantial portion would be carried to other sections of the gulf and deposited. To investigate this possibility, we are currently adapting the model to determine the approximate distance the plumes could be carried when a current is applied.

In conclusion, it can be seen that trawling activity appreciably alters the sediment load of the water column, possibly influencing a much larger section of the gulf than the areas trawling is limited to. Consideration should be given to the consequences this increased sediment load may have on benthic environments where it potentially deposits (these locations can be roughly determined by examining Figures 3-7), and the areas it passes through whilst in suspension. An increased sediment load elevates light attenuation, thus diminishing the availability of light to benthic flora and fauna (e.g. the extensive seagrass beds located throughout the Gulf). Conversely, resuspension of interstitial pore water provides a source of nitrogen and phosphorus based nutrients to the surrounding oligotrophic environment (Cartwright, 1998). The importance of the effect of anthropomorphic-induced sediment resuspension can not be adequately evaluated more work is carried out to better quantify this phenomena.

References

Bullock, D. A. (1975). The general water circulation of Spencer Gulf, South Australia, in the period February to May. *Transactions of the Royal Society of South Australia* **99**(1): 43-53.

Cartwright, N. (1998). The measurement and modelling of differences in the marine benthic environment. *Honours Thesis, The Flinders University of South Australia.*

Churchill, J. H. (1989). The effect of commercial trawling on sediment resuspension and transport over the Middle Atlantic Bight continental shelf. *Continental Shelf Research* **9**(9): 841-864.

Currie, D. R. and Parry, G. D. (1996). Effects of scallop dredging on a soft sediment community: a large scale experimental study. *Marine Ecology Progress Series* **134**: 131-150.

Falconer, R. A. and Owens, P. H. (1990). Numerical modelling of suspended sediment fluxes in estuarine waters. *Estuarine Coastal and Shelf Science* **31**: 745-762.

Fanning, K. A., Carder, K. L. and Betzer, P. R. (1982). Sediment resuspension by coastal waters: a potential mechanism for nutrient recycling on the ocean's margins. *Deep-Sea Research* **29**(8A): 953-965

Fuller, M. K., Bone, Y., Gostin, V. A. and Von Der Borch, C. C. (1994). Holocene cool-water carbonate and terrigenous sediments from southern Spencer Gulf, South Australia. *Australian Journal of Earth Sciences* **41**: 353-363.

Gostin, V. A., Hails, J. R. and Belperio, A. P. (1984). The Sedimentary Framework of Northern Spencer Gulf, South Australia. *Marine Geology* **61**: 111-138.

Hawley, N. and Lesht, B. M. (1992). Sediment resuspension in Lake St. Clair. *Limnology and Oceanography* **37**(8): 1720-1737.

Hemer, M. A. and Bye, J. A. T. (1999). The swell climate of the South Australian sea. *Transactions of the Royal Society of South Australia* **123**: 107-113.

Nunes, R. A. and Lennon, G. W. (1986). Physical property distributions and seasonal trends in Spencer Gulf, South Australia: an inverse estuary. *Australian Journal of Marine and Freshwater Research* **37**: 39-53.

Pilskaln, C. H., Churchill, J. H. and Mayer, L. M. (1998). Resuspension of sediment by bottom trawling in the Gulf of Maine and potential geochemical consequences. *Conservation Biology* **12**(6): 1223-1229.

Schoellhamer, D. H. (1996). Anthropogenic sediment resuspension mechanisms in a ashallow microtidal estuary. *Estuarine Coastal and Shelf Science* **43**: 533-548.

Wassenberg, T. J. and Hill, B. J. (1990). Partitioning of material discarded from prawn trawlers in Moreton Bay. *Australian Journal of Marine and Freshwater Research* **41**: 27-36.

Benefits

The main beneficiary of this research is the South Australian prawn fishery because the study provides an empirical examination of ecosystem level effect of prawn fishery required to implement ecosystem-based management and to substantiate ecological sustainable development. A prerequisite for EBM is an understanding of the ecosystem as a whole and not just the fished stocks. This study provides an understanding of the distribution and abundance of benthic organisms, which are likely to constitute a part of the by-catch. It also determines the fate of the discarded by-catch, identifies by-catch consumers and their consumption. Furthermore, the study gives an account of the Spencer Gulf food chain. A conceptual model is provided, which describes quantitatively the fate of the discarded by-catch in relation to the fished environment. Additionally, a description of the sediment characteristics of the Spencer Gulf is provided and an experimental test of the impact of trawling on resuspension. An understanding of all these elements will allow the prawn fishing industry to implement fishing strategies taking into consideration the ecosystem as a whole. The benefits are thus not to the prawn fishing industry alone but also the community by provide knowledge that will encourage environmentally friendly fishing practices.

The study provides an opportunity for promotion of the prawn fishery to enhance public awareness of the actual ecological effects. The wider benefits to the general community are the ecological assessment that may contribute to the management of the coastal zone. For the scientific community, including those with an interest in prawn fisheries, the study provides a tractable experimental examination of trophodynamics that is difficult to achieve elsewhere.

Further Development

Ecosystem-Based management (EBM) and the concept of Ecological Sustainable Development (ESD) are important for fishery management to implement precautionary fishing thereby protecting the fisher resources and the environment. An important part of this work is to incorporate by-catch in fishery management models and operational practices. This requires that knowledge be obtained on how fishing affects ecosystem structure and function. The marine environment is dynamical and ecological assessments are therefore a continuous process to be conducted alongside stock assessments. The management model and the operational practises used in the Spencer Gulf prawn fishery is at an international level more technically advanced than most fisheries allowing for the utilisation of complex ecological data to be incorporated, particular data on by-catch species importance, distribution and abundance. Unlike most, the Spencer Gulf prawn fishery is highly amenable to experimental evaluation of ecosystem effects, an aspect of fisheries impact study that has received relatively little practical attention. A further development is to maintain the momentum of focus on ESD and EBM incorporating the obtained results into wider ecological management plans and ensure proactively dissemination to other fisheries.

Conclusions

Objective 1: To determine which scavengers exploit material from prawn trawlers.

Surface scavengers on by-catch discarded in the Spencer Gulf are primarily bottlenose dolphins and the seabirds, silver gull and pacific gull. Groups of dolphins appear when trawls are retrieved and selectively feed on discarded by-catch or directly from the cod end. Seagulls feed primarily on floating by-catch. The occurrence of dolphins was affected significantly by site and season but not by time during night. Most dolphins occurred at Site 1 (Whyalla) with a mean of 3.5 per boat and observation while the other sites had a mean occurrence of 1 per boat and observation. Seasonal effects were small. Seagulls on the other hand were more common at Site 1 (Whyalla) and 4 (off Wallaroo) relatively to the other sites. An estimate of bottlenose dolphin consumption per night is 3,174 kg or 190.4 ton of discards per year. Seabird occurrence was generally low with a mean of 2.2-2.8 seagull per boat and observation. Seagulls can consume 1.6 ton discarded by-catch per year. No occurrence of midwater scavengers at all sites and seasons, and during day or night was observed. The occurrence of benthic scavengers observed by underwater video using various bait types showed no seasonal differences but was found to be different between sites and day and night. The dominating species recorded were Degens leatherjacket during day, sealice during night and blue crab and Port Jackson shark at both day and night. However, blue crab appeared to feed only during day. Other species were attracted to the bait were few in numbers and were not observed to feed with the exception of larger stingrays. The occurrence of leatherjackets was largely confined to Site 4 and 5 with no seasonal effect. The rate of occurrence of leatherjackets was not saturated within 30 min. Blue crab occurred at day at all sites with a mean of 1.4 crab per 30 min with the exception of Site 5, where the occurrence was 0.5 per 30 min. Port Jackson shark occurred variably at all sites and during day or night with a mean of 0.3-0.4 individuals per 30 min. The rate of occurrence of blue crab was not saturated after 30 min at day but at nigh a saturation level was reached at 12 min. Sealice occurred only at night and were extremely voracious scavengers. Bait consumption was found to be highly variable with no significant effect of site but significant effect of time and species. Significantly higher consumption occured at night than at day. The overall mean consumption for all sites was estimated to be 150.9 g WW/hour at day and 178.9 g WW/hour at night.

Objective 2: To determine the relative contribution of discards on the diet of scavenger species and the population level consequences.

In the context of energy flow the variables of interest are the abundance and distribution of scavenger species and how much discard carbon is distributed further up the food chain. However, the food web in the Spencer Gulf is highly complicated where most species are generalist that are likely to change their diet according to food availability of the day. It was possible to separate at least five trophic levels subdivided into functional groups. Within each functional group a subdivision is possible if gut content analyses are performed. If discarded by-catch affect the diet of scavengers it is likely that the isotopic composition will show spatial variation. A test of spatial variation was conducted using prawn, blue crab, and leatherjacket where the two latter species were found to be important scavengers. No spatial variation in the isotopic composition was found. However, the results showed that the dietary difference between blue crabs and prawns are small and most likely share the same food resource. Blue-crab feed on discarded by-catch but prawns do not. The isotopic composition of Degens leatherjacket is significantly different from blue crab and prawn.

The benthos, epibenthos and demersal fishes constitute the major component of discarded by-catch. An analysis of biomass distribution patterns at five sites in the Spencer Gulf showed a significant effect of site, season and fauna type indicating spatial and seasonal variability. The significant effect of fauna type indicates that the faunal composition is not homogeneous and varies throughout the Gulf. The biomass values were highest for sessile benthos (mostly sponges) particularly at Site 1 and 2 with 60-80%. At Site 3 mobile epifauna dominated with 80-90% of the total biomass. Further south (Site 5, The Gutter) the biomass of mobile epifauna constituted 40-70% where the remaining component was pelagic and demersal fish. A seasonal pattern of productivity was evident at Site 1 and 2 with values of 4.14 and 3.18 AFDW/m^2/yr constituting 46.2 to 35.5% of the total production. At Site 3 production was negative and at Site 5 close to zero. At Site 4 (Off Wallaroo) production was measured to 1.78 AFDW/m^2/yr, which is 19.9% of the total production. The density of individuals was generally low. The production values are comparatively much lower that what has been reported for other habitats. An analysis in dispersion (Index of Dispersion) showed that benthic organisms in the Spencer Gulf are contagious distributed. The group that influence the overall pattern was so-called Rhodoliths (incrusting coralline algae consisting of popcorn sized pebbles), which is associated with the highest abundance of prawns.

Objective 3: To determine the population level consequences for prawn by-catch for the by-catch species themselves.

To determine population level consequences for prawn by-catch for the by-catch species themselves, the research presented in this report is to a large extent a prerequisite, particularly the characterisation and identification of scavengers. This objective was meet for the scavengers, which are also by-catch. Discarded by-catch was found to be quickly consumed by firstly dolphins and seagulls then secondly, when reaching the bottom, by sealice during night. During day leatherjackets, crabs and other minor consumers take what sealice are not consuming during night. An estimated 190.4 ton of discards can potentially be consumed by dolphins while seagulls can potentially consume 1591.2 kg discards from the prawn fishery per year. The remaining 808 ton will sink to the bottom and be consumed by benthic scavengers. A large unknown amount is likely to be consumer by Port Jackson sharks and stingrays. Sealice was found to have more than 99% of the capacity to consume carrion while the capacity of leatherjackets and blue crabs was found to be in the order of 0.2%. The capacity of Port Jackson sharks, skates and rays was not calculated but is likely to be substantial. Contribution of discarded by-catch to the benthic scavenger assemblages of the Spencer Gulf appears to be minor.

Objective 4: To quantify the rates and relative importance of nutrient regeneration by natural processes (wind and currents) and by prawn trawling activities in the Spencer Gulf

This study showed that the Spencer Gulf lack any depositional areas of fine sediment grains (<500 µm) with the exception of the far northern part of the Gulf where patches of fine mud and clay can be found. The bottom sediments are highly variable throughout the Gulf and the most fisher areas have grain sizes larger than 1 mm. The Spencer Gulf can be subdivided into two zones in term of kinetic energy of the system. Experimental trawling activity with one trawler showed a significant increase in near-bed concentrations of sediment and elevated the sediment load of up to 11 g per litre. The developed plume lasted well over 80 minutes and dispersed over a large area. During fishing with 39 vessels trawling activity will dramatically increase the localised sediment load. The movement of this sediment is depending on the hydrodynamic regime at the particular time of trawling but a substantial part will most likely settle in other parts of the Gulf and provides a source of N and P, which may increase production.

Objective 5: To integrate the information that has been collected from both this study and previous work to develop a conceptual model that describes the influence of prawn trawling in a coastal ecosystem.

The fraction of benthic biomass caught as by-catch in the Spencer Gulf prawn fishery has been estimated at five sites using mean biomass values obtained from benthic surveys and 12-year logbook data on fishery performance. Additionally, the relative probabilities of catching one unit of prawns per trawl hour using historical data, and the relative probabilities of catching one unit of by-catch per trawl hour (survey data) have been calculated for the five studied sites. The result showed that fraction of benthic biomass caught as by-catch varies between sites with the lowest values at the two northernmost sites. The site with the relatively highest fraction of benthic biomass caught as by-catch was Site 3 at Middle Bank where 94.1% of the total benthic biomass are caught as by-catch. At the two southernmost sites intermediate values were found. The relative probabilities of catching one unit of prawns per trawl hour was found to be relatively constant among sites while the relative probabilities of catching one unit by-catch per trawl hour varied with the highest values at the two northernmost sites, the lowest value at Site 3, and intermediate values at the southernmost sites. These results were proportional to the fraction of benthic biomass caught as by-catch. The reported patterns may be a result of trawling but there is some historical evidence suggesting that the bottom, particularly at Site 3, did not support large volumes of epifauna when the prawn fishery originally started. If by-catch is evenly distributed throughout the fished area then 53.5 mg WW/ m^2/yr by-catch will be available for scavengers. This is of course not the case but it is clear that the discarded amount is most likely not enough to sustain the food need for scavenging populations throughout the year. Assuming that discarded by-catch do not survive then of 1000 ton of by-catch discarded at night an estimated 190.4 ton will be consumed by bottlenose dolphins and 1.6 ton by seabirds at the surface. Nothing will be consumed mid-water and 806.4 ton will quickly be consumed by sealice, which have the capacity to remove 99.78-99.80%. The remaining 1.6 ton will be shared by other species but primarily Port Jackson sharks. This consumption will be depending on site due to variability in scavenger abundance. What is not consumed at night is likely to be taken during day with site depending consumption shared between blue crab, leatherjacket, sharks and rays. The scavengers in Spencer Gulf have the capacity of consume far more than is available of discards.

Objective 6 & 7: To complete a comprehensive written assessment of the ecological impact of prawn trawling in the Spencer Gulf, consistent with the need to adopt principles of Ecological Sustainable Development.

These objectives need to be addressed in cooperation with the prawn fishing industry. The objectives are depending on this final report allowing management option to be discussed and implemented.

Appendix 1

Intellectual Property

The FRDC’s share of intellectual property, based on inputs, is 48.34%.

Appendix 2

Project Staff

The staff of this project consisted of following:

Principal Investigator (s):

1998-1999:	Dr. Paul McShane
1999-2000:	Dr. Howel Williams (SARDI)
2000-2002:	Dr. John Johnson (SARDI)
2003-:	Dr. Ib Svane (SARDI

Research scientist:
Dr. Ib Svane SARDI/Flinders University

PhD stipend:
Matt Fitzpatrick

Technical Officers (s)
1999-2002: Zoe Hammett (50%)
2001-2002: Thor Saunders (50%)

Technical Officers (casual)
Daniel Casement
Neil Chigwidden
Brian Davis
Brian Fourier
Nelli Horrigan
Alan Jones
Dave Kerr
Ralf Putz
Kate Rodda
Chris Small

Students (Flinders University)
Kirsty Laube
Shane Roberts