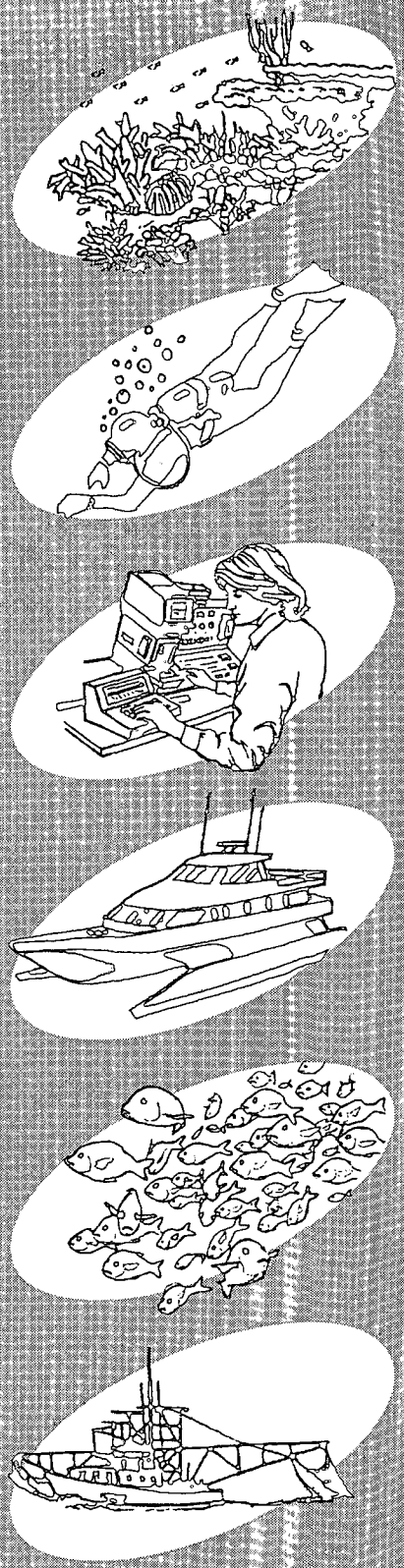
NO. 5

CRC REEF RESEARCH

TECHNICAL REPORT



Impact of tourist pontoons on fish assemblages on the Great Barrier Reef

Hugh Sweatman

Department of Marine Biology,
James Cook University of North Queensland

Project Funded by the CRC Reef Research Centre

This project is part sponsored by the Environmental Management Charge (EMC) paid by operators in the Great Barrier Reef Marine Park

CRC REEF RESEARCH TECHNICAL REPORT

IMPACT OF TOURIST PONTOONS ON FISH ASSEMBLAGES ON THE GREAT BARRIER REEF

Hugh Sweatman
Department of Marine Biology
James Cook University of North Queensland
4811

A report funded by the CRC Reef Research Centre

The CRC Reef Research Centre was established under the Australian Government's Cooperative Research Centres Program.

The Centre, established in 1993, undertakes an integrated program of applied research and development, training and education, aimed at increasing opportunities for ecologically sustainable development of the Great Barrier Reef and providing an improved scientific basis for reef management and regulatory decision making.

CRC Reef Research Centre
c/- James Cook University
TOWNSVILLE QLD 4811
Phone: (077) 81 4976
Fax: (077) 81 4099
Email: crc.reef@jcu.edu.au

National Library of Australia Cataloguing-in-Publication entry

Sweatman, Hugh P.A.
Impact of tourist pontoons on fish assemblages on the Great Barrier Reef

Bibliography.
Includes index.
ISBN 1 876054 04 2

1. Pontoons - Environmental aspects - Queensland - Great Barrier Reef. 2. Fishes - Behaviour - Queensland - Great Barrier Reef. 3. Fishes - Queensland - Great Barrier Reef - Habitat. 4. Fish populations - Queensland - Great Barrier Reef. 5. Tourist trade - Environmental aspects - Queensland - Great Barrier Reef. 6. Fishes - Behaviour - Australia. I. Cooperative Research Centre for the Ecologically Sustainable Development of the Great Barrier Reef. II. Title. (Series: CRC Reef Research technical report; 5).

597.09943

This publication should be cited as:
Sweatman, Hugh P.A. (1996). *Impact of tourist pontoons on fish assemblages on the Great Barrier Reef.*
CRC Reef Research Centre
Technical Report No. 5.
Townsville; CRC Reef Research Centre, 54 pp.

Published by the Cooperative Research Centre for Ecologically Sustainable development of the Great Barrier Reef.

Further copies may be obtained from CRC Reef Research Centre, c/- James Cook .University Post Office, Townsville, QLD 4811.

Printed by James Cook University.

TABLE OF CONTENTS

LIST OF FIGURES:

LIST OF FIGURES: (cont...)

LIST OF TABLES:

1. EXECUTIVE SUMMARY

This project by Dr Hugh Sweatman of James Cook University* studying two carnivorous fish species, provides further insight into the impacts of fish feeding at tourist pontoons on the Great Barrier Reef and the requirements for management. Both fish species, the spangled emperor, *Lethrinus nebulosus* and the red bass, *Litjanus bohar*, commonly aggregate around tourist pontoons and vessels in response to feeding. While behaviour of the two species varies, feeding reinforces spatially located aggregating behaviour around the actual tourist pontoons. Fish feeding for both species is observed to be the primary cause of formation of aggregations and, as such, feeding must be a key component to any management regime required around tourist pontoons.

For many tourists, observing schools of fish is an important part of the day's visit, whether it be watching the fish naturally in the water while snorkelling or diving or controlled feeding activity from the boat or pontoon. Many Reef managers have been concerned about the impacts this feeding might have on the natural regime of reefs. Concerns include possible depletion of aggregating species from other sections of the Reef and a concentration of feeding activity (and thus impact on other species) around tourist pontoons. Monitoring programs for tourist pontoons have been put in place by Reef managers based on the assumption that one or both of these impacts were occurring. For example, monitoring programs often require that fish census be taken at pontoon sites with aggregations and at control sites without aggregations.

The project has shown however that such a monitoring system based on 'presumed change' may be inappropriate. Both these species, and many others that are found in aggregations around pontoons, naturally form aggregations at particular sites on reefs or at least spend the day time within a restricted area.

Regarding the second assumed impact of increased predatory effort around the tourist pontoons, the project has, through observation of fish behaviour and analysis of densities of likely prey, determined that this impact is minimal, probably of no consequence. Certainly for red bass, predation on natural prey is very limited. A comparatively significant but still very small subset of the spangled emperor aggregations did feed on their natural prey. The impacts of this predation are not readily detectable within the bounds of the methods available.

So, in summary, what are the management requirements of aggregations around tourist pontoons? From this project it appears the only area of management activity might need to be the quantity and quality of the feed itself. Fairly obviously, from a fish health perspective, it can be assumed, based on experiences with feeding terrestrial wildlife, that the closer fish food mimics the fishes' natural diet, the better.

Regarding the quantity of food provided, time and logistic constraints meant that it was not feasible to determine just what proportion of their daily ration the fishes in the aggregations obtained from the fish feeding events. If the natural daily ration is augmented significantly in this way, two kinds of impacts can be foreseen. Increased food intakes could lead to increased survival rates and hence higher local population levels. Alternatively the additional food intake may lead to increased reproductive output. Since natural prey are available and given the intense physical competition among members of the aggregation for the extra food, the second alternative is more likely. The aggregations represent only a small proportion of the population on a reef and considering the likely dispersal trajectories of planktonic larvae, any such increase in reproduction is likely to be diluted over regions rather than reefs and so will be vanishingly small.

The findings of this project suggest that the quantities of food currently provided, while certainly sufficient to ensure aggregation, are having at most a very limited impact on the populations of fishes or their prey. Managers may need to set limits on total quantity of food and specify food quality as the only monitoring requirements for fish aggregations at tourist pontoons.

Colin Creighton
Regional Manager, Resource Management
Queensland Department of Primary Industries

* Dr Hugh Sweatman is now working on long-term Reef monitoring programs at the Australian Institute of Marine Science.

2. TECHNICAL REPORT

2.1 *General Introduction*

The most common way for tourists to experience the Great Barrier Reef is to make a day trip to one of the increasing number of pontoons situated along the coast of Queensland. There are currently at least nine tourist pontoons along the Queensland coast, all of which can accommodate more than 100 persons at a time. Some are routinely visited by more than 400 in a day. A typical day's outing involves 1.5-2.5 h journey from the coast by boat followed by 3-4 h at the pontoon. Activities include snorkelling (including optional guided tours), SCUBA diving (mainly 'resort' diving where completely inexperienced divers are taken diving under close supervision), glass-bottom boat or semi-submersible tours, in some cases fishing trips, as well as a large buffet lunch.

Aggregations of fishes are frequently associated with these pontoons. The species involved range from bait fishes through larger planktivorous species to herbivores and large carnivores. As well as the pontoon providing shade and, in the case of herbivores and carnivores, concentrations of natural food, many operators actively feed the fishes making them tame and unafraid of snorkellers so that swimming close to relatively large fish may be part of the reef experience.

The Marine Park Authority requires the operators of pontoons to support monitoring of various aspects of the local biota, particularly corals and fishes. Part of the monitoring effort at pontoons has been to make general fish counts next to the pontoons and at a number of control sites nearby. Predictable changes associated with the installation of a pontoon include a loss of hard corals immediately below the pontoon (presumably due to shading), an increase in certain fish species and possibly a decrease in others. Potential impacts of fish aggregation of concern to the Authority mainly involve larger carnivorous species:

1. Aggregations of carnivores may have a deleterious effect on local populations of smaller fishes and invertebrates that are their prey.

2. Aggregations near pontoons may deplete the population of the aggregating species over the adjacent reef. This is of particular concern in edible species since aggregations may be targeted by fishermen.

3. Feeding fishes supplementary food may adversely affect their condition through inappropriate food and through wounds sustained in the competition to eat it. This source of impact has been addressed by the Authority by restricting fish feeding allowed by the permits granted to tourist operators.

There have been few studies of any kind to examine the mechanisms producing local changes in the biota associated with pontoons. An exception is an intensive study (Cohen, 1990) which examined the distribution of infauna in general around established pontoons at Agincourt Reef. Considerable changes were measured at each site when a pontoon was moved from one location to another. Small scale experiments suggested that the general decrease found under the pontoons was mainly due to shading, though caging to exclude fishes of all sizes also increased densities of some groups.

While no two pontoons attract identical aggregations of fishes, it is clear from Appendix 1 that Spangled Emperor, *Lethrinus nebulosus*, and Red Bass, *Lutjanus bohar*, form a considerable component of many of the aggregations associated with pontoons in the northern half of the Great Barrier Reef. I chose to concentrate on these species for that reason. For reasons of access and safe working conditions, I chose to work at the two pontoons operated by Quicksilver Connections at Agincourt Reef off Port Douglas and the pontoon at Kelso Reef near Townsville operated by Pure Pleasure Cruises.

This study concentrated on the first of the potential impacts listed above. This involved a quantitative assessment of feeding activity by aggregating predatory species on natural prey. Where such feeding was evident, the populations of natural prey at the pontoon site were compared with control sites without resident aggregations. These subjects are addressed in Sections 2.2 to 2.4. A substantial study of the second impact proved to be beyond the resources of the task. Some studies of movement were attempted with little success. These are recorded, along with an assessment of the evidence for such impacts in Section 2.5.

2.2 *Behaviour of fishes at the pontoons: (1) Lethrinus nebulosus at Kelso Reef*

2.2.1 Summary

1. The spangled emperors that make up most of the aggregation at Kelso Reef pontoon are not present for most of the day. They arrive at the pontoon when the tourist boat comes

and depart shortly after the boat does. This means that they are not particularly vulnerable to fishermen when the tourists are not there.

2. The size of the aggregation varies from week to week and the fish are reportedly occasionally absent. This is unlikely to be due to fishing at the pontoon as sometimes suggested.

3. Fish at the pontoon do feed on animals in the sand as well as taking food at the operator's fish feeding event. Estimated feeding rates are about 1.5 bites per square metre per day for an average aggregation of 100 fish.

2.2.2 Introduction

Concern has been expressed that the aggregation of carnivorous fishes around tourist pontoons may lead to increased local predation pressure on prey organisms. In this section and the one that follows I report on the behaviour of two carnivorous species that aggregate at pontoons. This section concerns the Spangled Emperor, *Lethrinus nebulosus*, which is present at a number of pontoons and tourist facilities on the GBR (Appendix 1). At the Kelso Reef pontoon, *L. nebulosus* make up the majority of the aggregation (Sinclair Knight 1993, pers. obs.). Pure Pleasure Cruises have operated a day trip to Kelso Reef since mid 1990. Initially the catamaran was simply moored at a site in the lagoon and was then used as a base for the normal range of activities including feeding fishes. In December 1990 a 10 x 30 m steel pontoon was moored permanently close to the original mooring. Day trips run five days a week for most of the year and seven days a week in holiday seasons.

I studied the aggregation at Kelso Reef. My initial approach was to observe the behaviour of the fishes at the pontoon to try to determine the potential for an impact on prey species. A secondary concern, expressed by staff at Pure Pleasure Cruises and by the reviewer of the initial proposal for this project, was that aggregating at the pontoon would make fish vulnerable to unscrupulous fishermen when the tourist boat was not present. I also considered this possibility.

2.2.3 Methods

The Kelso reef pontoon was visited seven times on day trips on the Pure Pleasure Cruises catamaran: 8, 16, 17 March, 13 April, 7 May, 18 June and 27 July. In addition I made one three day trip 1-3 June on a charter vessel.

Counts: Fishes in the aggregation were counted by divers using SCUBA and hand tally counters. The accuracy of the count depended heavily on the way the animals arranged themselves: if the aggregation streamed past the observer in an orderly fashion then it was easy to be confident of the count; if the aggregation doubled back on itself then it was likely that individuals would be counted more than once. Such counts were discarded. A simple mean of all counts taken would not be the most accurate estimate of size of the aggregation. The cohesion of the aggregation varied and at times the fish were dispersed in multiple directions. Counts were made opportunistically at each visit, but the initial visits were mainly concerned with the numbers in the aggregation and the numbers feeding.

Feeding: To estimate the feeding activity of *L. nebulosus*, divers swam a transect under the pontoon and boat and counted the *L. nebulosus* that were in feeding pose: hovering <1 m above the bottom with their heads inclined slightly down or actually in the process of taking bites from the sand. Sixty-six counts were made during the visits in March and April. These figures were

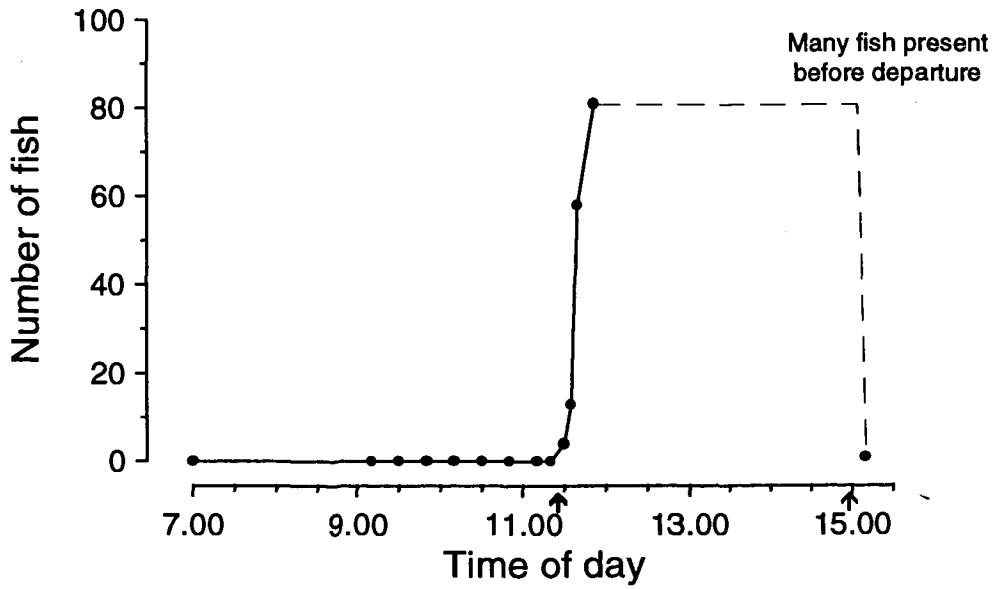


Figure 2.2.1: Numbers of *L. nebulosus* at the pontoon at various times of day, 2 June 1994.

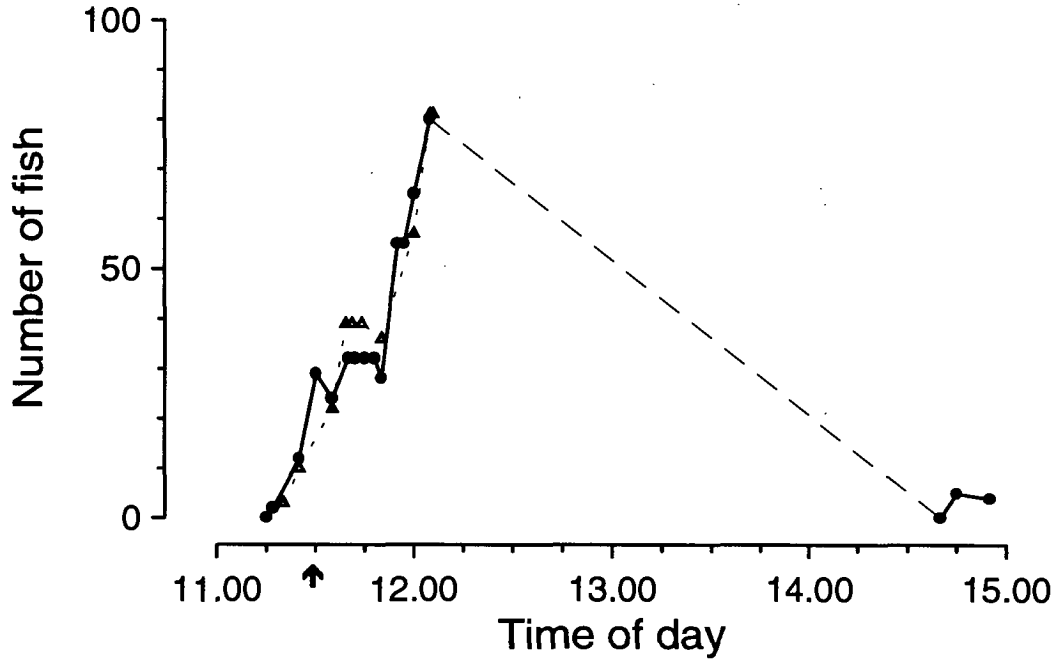


Figure 2.2.2: Numbers of *L. nebulosus* seen at the Kelso Reef pontoon 1 June 1994, when boat was scheduled but did not run. Triangles and circles denote different observers. Arrow indicates the normal arrival time of the catamaran.

converted to proportions of the aggregation using total counts (see above) that were closest in time because the size of the aggregation changed over the period the boat was alongside. The counts of the aggregation showed some sudden decreases (see below) when the fish pursued small boats leaving the pontoon; such deviant values were not used to calculate proportions, rather the next closest count was used.

The feeding rate of animals in feeding pose was estimated by following individuals and recording their behaviour, particularly bite rates, on slates. Forty-one observations lasting from one to 22 minutes were made during visits in all months.

Diet: Collection of *L. nebulosus* for gut analyses was inappropriate at Kelso Reef, so information on the diet of *L. nebulosus* depended heavily on the literature (Jones et al. 1991, Walker 1978). Faeces were collected from the sand under the rear of the boat, where the members of the aggregation spent most of their time. Mollusc and echinoderm remains were identified and the size of prey was estimated.

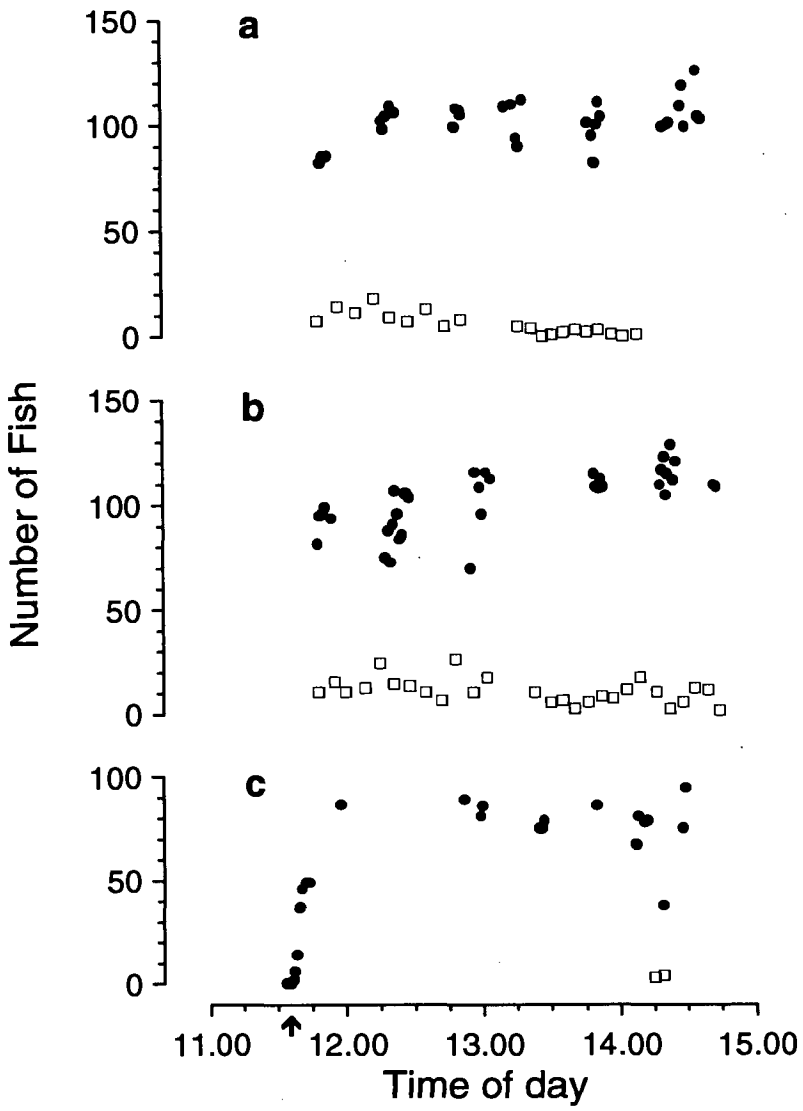


Figure 2.2.3: Patterns of counts of *L. nebulosus* in aggregation at the pontoon on three separate days: **a** = 16/3/94, **b** = 17/3/94, **c** = 18/6/94. Filled circles = counts of the aggregation, open squares = counts of fish feeding over the sand, arrow denotes time of arrival of the catamaran.

2.2.4 Results

Numbers of fishes in the aggregation: Observations from before the tourist boat arrived until after the boat left suggest that the spangled emperor are only at the Kelso Reef pontoon in any numbers while the boat is there (Fig. 2.2.1). The cues that draw fishes to the pontoon are not clear: on 1 June 1994 the daytrip was cancelled but a number of fish came to the pontoon about the time the boat was due (Fig. 2.2.2). On 3 June 1994 counts were made around arrival time (11:30 - 11:47). This was a Friday when the boat was not scheduled to come. No fish were seen.

In the time the boat is alongside the pontoon, the numbers build up rapidly to begin with and then increase more slowly towards the time of feeding and subsequent departure (Fig. 2.2.3). At 15:00 when all tourists are back on board the boat and the pontoon facilities are being packed away, fresh pilchards are thrown one at a time off the port side of the boat, bringing the whole aggregation thrashing to the surface in attempts to get the food. During their time at the pontoon, the *L. nebulosus* paid attention to small boats leaving and arriving at the pontoon; they would swim close behind the boat near the surface. Sudden drops and rapid recoveries in numbers correlated with such events. The daily activities include fishing trips away from the pontoon. Presumably the fishing party sometimes disposed of old bait or fish scraps.

On the basis of wounds and distinctive patterns of fin damage it was clear that some of the same individuals were present on several successive days. The maximum counts of *L. nebulosus* at the Kelso pontoon varied over a period of months (Fig. 2.2.4).

Identity of prey: Faeces were found to contain broken remains of spatangoids (burrowing sea urchins; sea potatoes), bivalves, particularly *Tellina robusta* and the gastropod *Umbonium guamensis*. One anecdotal observation gave an indication of the upper size limit for bivalve prey: on 18 June a live individual of the robust bivalve *Codakia paytenorum*, 37 mm long, was on the surface of the sand under the pontoon. While observing feeding I saw at least 25 *L.*

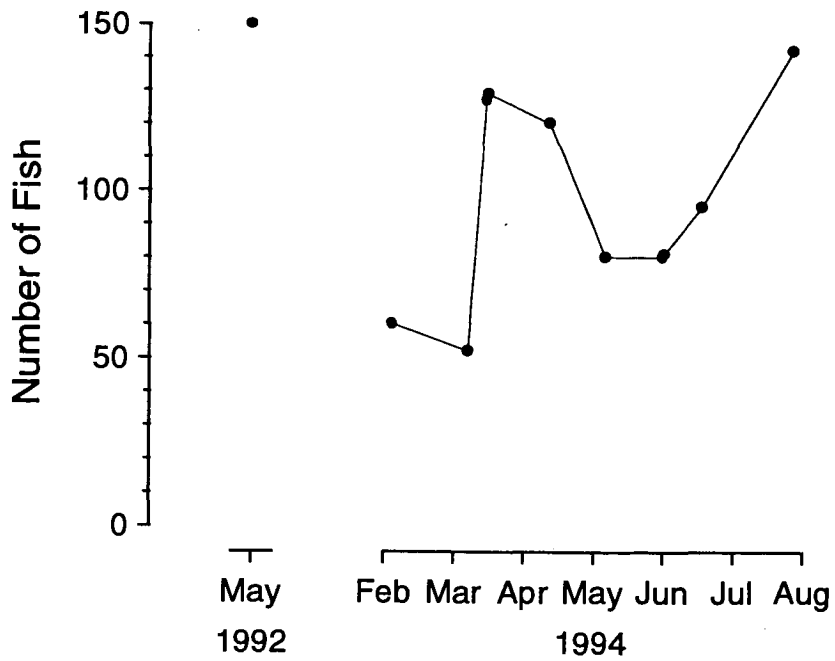


Figure 2.2.4: Number of *L. nebulosus* in the aggregation at Kelso reef pontoon over time. 1994 figures are maximum numbers seen on a day. 1992 figures from Sinclair Knight (1993).

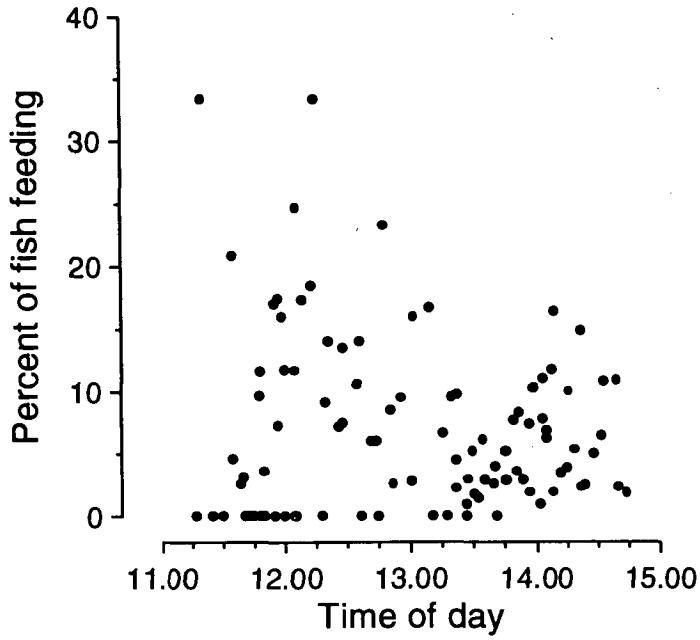


Figure 2.2.5: The proportion of *L. nebulosus* in the aggregation that were in feeding pose as a function of time of day. Observations from all visits combined.

nebulosus take the clam into their mouths, hold it for a few seconds, then reject it. Finally one large individual did manage to crack it with its pharyngeal teeth.

Feeding activity at the pontoon: A relatively small proportion of the members of the aggregation was in feeding pose at any instant (Fig 2.2.3). This proportion did not change obviously over the time the tourist boat was along side (Fig 2.2.5) though some of the large proportions are due to a few feeding individuals constituting a large fraction of the fish present. Bite rates of fish in the feeding pose were also variable (Fig 2.2.6). Nearly all feeding was observed to occur either under the pontoon or under the moored boat.

In order to estimate feeding activity and avoid the problem of propagation of errors from multiplying several estimates (Size of aggregation, proportion feeding, bite rate - each with associated confidence intervals) I used a simulation model. I divided the period that the boat was alongside the pontoon (and the aggregation was present) into 200 minutes and I assumed that the aggregation comprised 100 fish. For each minute, I drew a value for the proportion of the aggregation that were in feeding pose at random (with replacement) from the set of 92 observed values. This figure was converted to a number of individuals that were feeding. For each feeding individual, a number of bites for that minute was taken from a Poisson distribution with a mean drawn at random (with replacement) from the 41 observed bite rates. The total number of bites for all fish in all 200 minutes were summed.

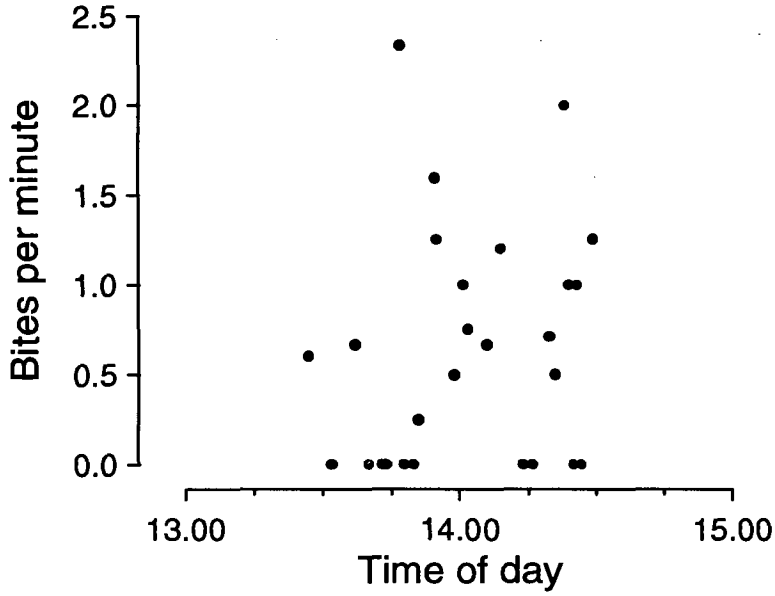


Figure 2.2.6: Feeding rates of individual *L. nebulosus* feeding over the sand while the tourist boat is alongside.

The distribution of totals from 1000 simulated days' feeding suggested that an aggregation of 100 fish would take 867 bites per day on average with 95% of daily values lying between 737 and 1013 (Fig 2.2.7). The area in which most feeding occurred, the area under the boat and pontoon, was approximately 2x10x30 = 600 m^2. An aggregation of 100 fish would account for about 1.5 bites m^{-2} per day if feeding activity was evenly distributed.

2.2.5 Discussion

It is clear that the number of *L. nebulosus* at the Kelso Reef pontoon varies from week to week as well as over a longer term. There are too few data to allow meaningful analysis of effects of season, phase of moon or state of tide on the size of the aggregation, so the reasons for the variation remain unknown. Members of the crew reported that there are occasions, possibly several per year, when there are practically no spangled emperors at the pontoon for several consecutive days. The crew's interpretation was that fishermen came to the pontoon and scared the fish by catching them. This is almost certainly not true, as the fish seem not to spend time near the pontoon when the tourist boat is not there. It may be due to fishing, but this is unlikely to occur at the pontoon.

An earlier monitoring program (Sinclair Knight 1993) found variable numbers of *L. nebulosus* at the pontoon while the tourist boat was alongside (mean = 13.13, SD 14.44 in 180° rapid visual censuses) but none before arrival or after departure. The report did not say how long

before arrival or after departure the counts were made. My observations confirm this and show that the aggregation and dispersion is very quick. The cue that brings the *L. nebulosus* to the pontoon is obscure. Two sets of observations (2 June, Fig. 2.2.1; 18 June, Fig. 2.2.3c) show that the fish arrive shortly after the boat, so they may be responding to propeller noise. This would presumably be audible over a distance of some kilometres, so fish might aggregate from a large area. Observations on 1 June show that the fish appeared at the pontoon before the boat usually arrived and considerable numbers continued to arrive after the normal arrival time had passed (Fig 2.2.2). Mysteriously, on 3 June, a Friday on which no boat was scheduled in winter, no fish were at the pontoon at the normal arrival time or some 15 minutes after. On both these days there had been propeller noise from the boat I chartered, but not for more than an hour prior to the tourist boat's normal arrival time. There had been outboard noise near the pontoon on both days. It seems likely that fish can distinguish among large boats on the basis of propeller noise, outboards would certainly sound different.

The increase in numbers over the time when the boat is along side and behaviour of the fishes towards the small boats suggest that fish were keenly interested in handouts of food. While that may be the principal cause of the aggregation, it is clear that a proportion of fish do feed on natural prey while at the pontoon. Much of the diet of *L. nebulosus* comprises animals taken from the sand. Studies comparing the size frequency of certain common species in the sand and in the guts of *L. nebulosus* from the southern Great Barrier Reef (Jones et al. 1991) show that the fish feed selectively: they select larger individuals from the size spectrum of the bivalve *T. robusta* and avoid the bivalve *Fragum* sp. Observation of the feeding behaviour make it obvious that feeding is not random: *L. nebulosus* that are feeding spend time hovering 0.5 - 1 m above the bottom with their heads pointing slightly down. At intervals they swim purposefully to points on the bottom within about 3 m and, after a brief hesitation, plunge their snouts into the sand, blowing a jet of water out of their mouths as they descend. This blows away the sand and reveals the prey organisms.

Using a simulation to estimate feeding rate avoids assumptions of normality, assuming instead that the values I observed are representative of general *L. nebulosus* feeding activity at the pontoon. This approach has other hazards in that the behaviour modelled in successive iterations may not be truly independent in life. For instance, fishes that feed in one minute are likely to still be feeding in the next, leading to serial correlations between minutes in the real situation that make the model more complex. I ignored this in my simulation with the

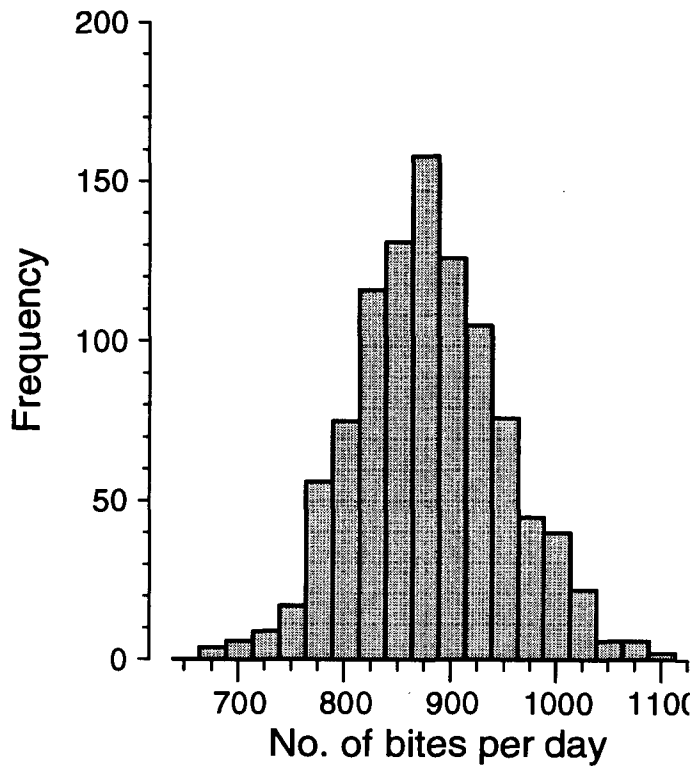


Figure 2.2.7: Frequency distribution for 1000 daily totals of bites by model aggregations of 100 *L. nebulosus* generated by simulation.

justification that counts of numbers of fish in the feeding pose did vary considerably in series of counts 2-3 minutes apart (Fig. 2.2.3), implying that departures from random were not great. All estimates based on simple observations of feeding and counts of bites do not give any estimate of success rates: how many bites produce no prey? Assuming one prey per bite represents an upper limit to prey intake.

On the basis that the *L. nebulosus* do feed during the fraction of the day that they are at the pontoon, I designed a fish exclusion experiment to look for evidence that the large fishes feeding in the sand at the pontoon affected populations of animals that live there in ways that were not evident at similar sites away from the aggregation. This is described in Section 2.4.

2.3 *Behaviour of fishes at the pontoons: (2) Lutjanus bohar at Agincourt Reefs*

2.3.1 Summary

1. Red bass are the most numerous carnivores in the aggregations at Agincourt 4 and Agincourt 2D pontoons.

2. The aggregation disperses at night, but red bass are present at the pontoons well before and after the tourist boats' daily visits.

3. While the red bass fed avidly on seafood provided by the tourist operator, no feeding on natural prey was observed at the pontoon in more than ten hours observations over the day.

2.3.2 Introduction

Red bass, *Lutjanus bohar*, are common on mid-shelf and outer reefs in the northern Great Barrier Reef and form aggregations at a number of the pontoons near Cairns (Appendix 1). They are carnivores, eating fish and crustaceans (Wright et al. 1986), though nothing is recorded concerning the precise identity of prey or the habitats that they might be taken from. I looked at the behaviour of *L. bohar* at the Agincourt Reef pontoons off Port Douglas. Quicksilver Connections have had pontoons at Agincourt reef since 1984. Agincourt Reef is dissected into a number of patches which are identified by a code of numbers and letters. The original pontoon was at Agincourt 2D towards the southern end of the Agincourt complex. There was a second pontoon at Agincourt 3 (in the middle of the complex), but in 1990 this was moved to Agincourt 4 towards the northern end of the reefs. Fish have been fed at the pontoons and red bass have been recorded in aggregations at the pontoons since at least 1989. While red bass fight vigorously when hooked, they have a reputation for being ciguatoxic and so are not sought by anglers.

Once again I started by describing the change in size of the aggregation over the day and by following individual fish to get an estimate of their feeding rate.

Methods: I visited the pontoons at Agincourt Reef for day trips 24, 25 and 26 March and 15 August. I stayed on the Pontoons 9-10 June, 1-3 September and 8-9 November 1994.

Counts: Fishes at the pontoons were counted opportunistically on all trips by snorkellers using hand tally counters. In most cases, a series of scans was made in rapid succession. On occasion, counts were made through the windows of the underwater observatory, though these were discarded if there was doubt that the whole aggregation was visible.

Observations: Snorkellers followed individual fishes for as long as possible up to 10 min. Behaviour was recorded on slates. Particular attention was paid to any predatory behaviour, which is generally obvious as very rapid and directed movements in the presence of prey. Attendance at cleaning stations, obvious interactions with conspecifics etc. were also recorded.

These observations were made on all visits except for the one in November.

2.3.4 Results

Numbers of fishes in the aggregation: The aggregations at the pontoons at Agincourt 4 and Agincourt 2D have varied in size through time and varied during the time of the study

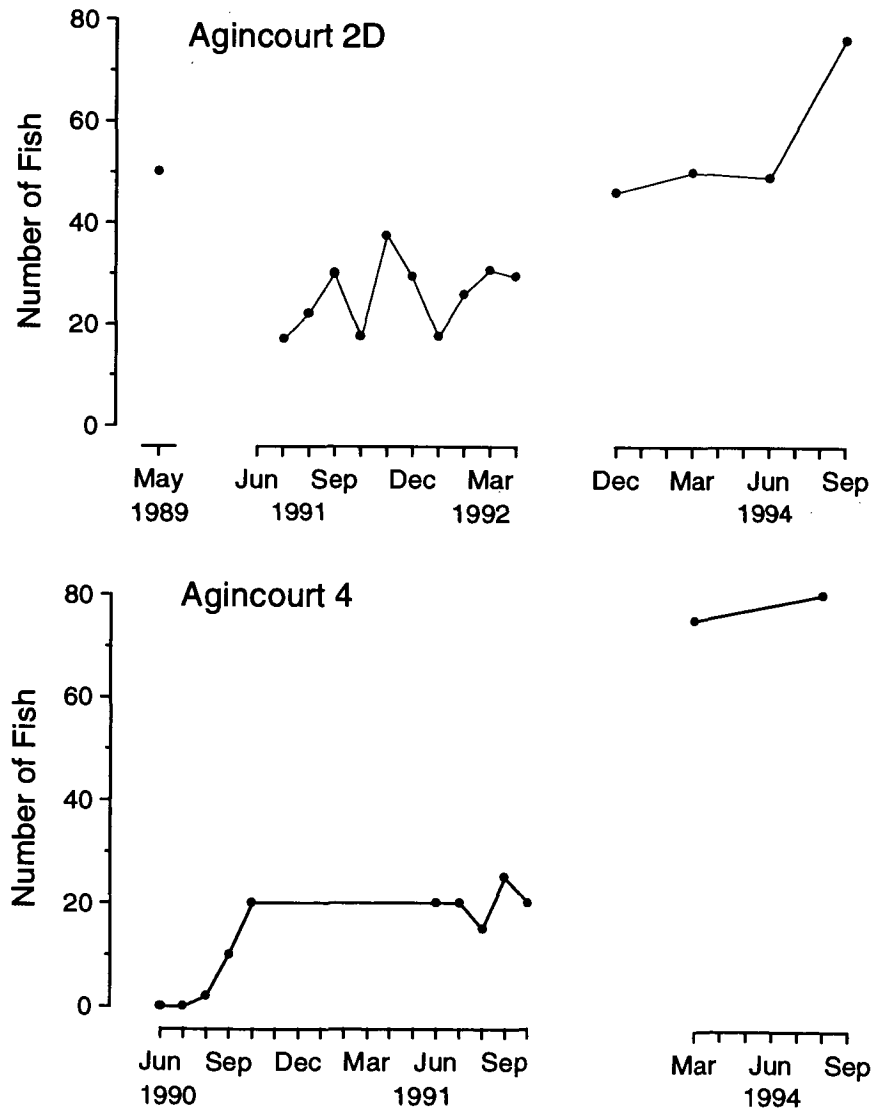


Figure 2.3.1: Changes in numbers of red bass at Agincourt Reef pontoons. 1994 figures are maximum estimates. Additional data from Breen & Breen 1994a.

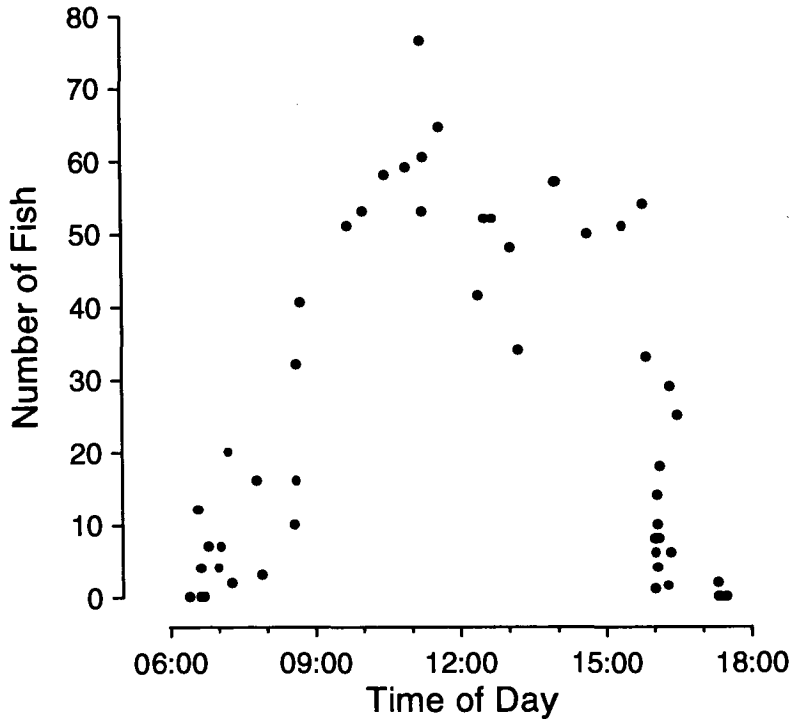


Figure 2.3.2: Counts of *L. bohar* at different times of day at Agincourt 2D. Data from all trips combined.

(Fig 2.3.1). As at Kelso Reef, the members of the aggregation were not always at the pontoon (Fig 2.3.2). The counts plotted in Fig 2.3.2 were accumulated over several visits through the year. The intervals on the abscissa represent Eastern Standard Time; this varies relative to solar time which is likely to be relevant to the fish. None the less, counts in the middle of the day are high and those at dawn and dusk are zero. Small groups of bass could be seen moving across the snorkelling area to the pontoon as the aggregation began to build up around 08:00. The boats arrive at the Agincourt Reef pontoons about 11:30 and depart at 15:00, so, unlike the aggregation of *Lethrinus nebulosus* at Kelso Reef, the aggregations at Agincourt begin to form some hours before the arrival of the tourist boat and persist after the boat's departure. Richards & Gibson (1989) reported a similar pattern (Fig 2.3.3). In the case of one tagged red bass in the aggregation at Agincourt 4 and by scrutinising individuals for skin marks and fin-damage it was clear that a number of the same individuals came to the pontoons each day.

Feeding activity at the pontoons: The Quicksilver staff feed the fish in the aggregation several times in the course of their stay at the pontoons. Feeding consisted either of hand feeding fish to lure them up onto the snorkellers platform or of throwing the food (WA pilchards) into the water in front of the snorkelling platform amongst the snorkellers. Food was generally given a

little at a time over several minutes so a large number of fishes from the snorkelling area and from the aggregation gathered by the end of the feeding period. The red bass were certainly interested in the food and nearly the whole aggregation would move into the snorkelling area alongside the pontoon when feeding was taking place. The red bass also paid attention to the groups of divers because some divers and dive instructors also fed fish to draw them close for photography.

In more than ten hours of focal animal observations under the pontoons or in the adjacent snorkelling areas (about equally divided between the two pontoons Fig 2.3.4), I did not see any behaviour that I could interpret as a predation attempt on natural prey. On one occasion, a fish was seen slowly to bite the ropes attached to the divers' access platform suspended under the pontoon and on another occasion a fish bit the platform itself. From what is known of the diet of *L. bohar* (Wright et al. 1986) they do not take encrusting organisms so it seems unlikely that this was feeding. I did see one instance of attempted predation at the pontoon but outside formal observations: a small red bass (estimated total length 20 cm) in the snorkelling area at Agincourt 2D lunged unsuccessfully at a juvenile planktivorous damselfish, *Neopomacentrus azysron*.

Predation rate near the pontoons: The aggregations began to form some time after dawn and decreased significantly in number well before dusk (Fig 2.3.2). Though the numbers of fish at the pontoon was lower near dawn and dusk, there were red bass within 500 m of the pontoon at

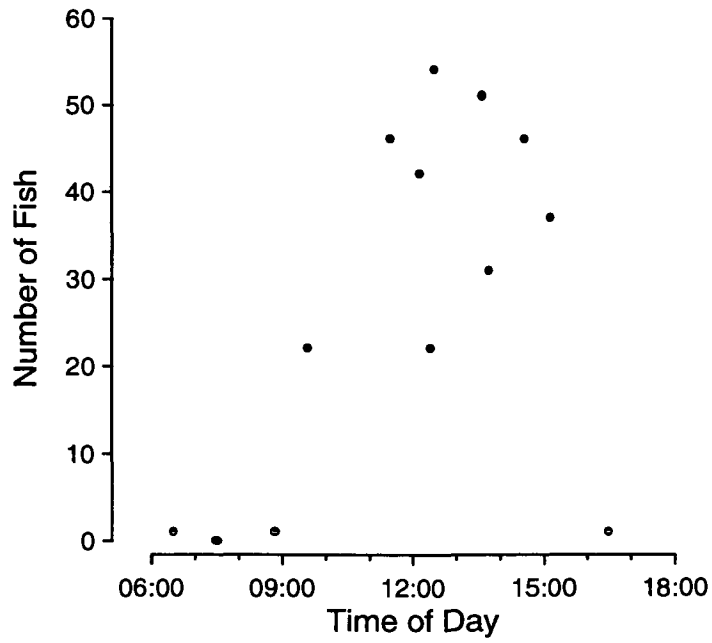


Figure 2.3.3: Counts of red bass at Agincourt 2D from Richards & Gibson (1989).

these times. I made similar observations on such individuals around the pontoon at Agincourt 2D. In more than three hours of observations I saw one possible predatory act: at 07:12 one morning a large red bass suddenly doubled back around a coral head with groups of small damselfishes *Dascyllus aruanus* and *Pomacentrus moluccensis*. I also saw one predatory attempt outside formal observation periods: at 07:22 a small red bass was seen to dart at a group of the damselfish *Chromis atripectoralis* that were feeding in the water column.

2.3.5 Discussion

The main conclusion from this part of the study is that the number of natural prey consumed by red bass in the immediate vicinity of the pontoon is low. Predatory attempts were recognisable because they were seen on a number of occasions, but none was recorded in 10 hours of observations. There is other circumstantial evidence that predation was low at the pontoon. Firstly, most prey species, even planktivores, stay within about 1m of the substrate. When at the pontoon or in the snorkelling area, the red bass spent their time up in the water column, metres above the substrate so well away from potential prey. By contrast, red bass that were followed late in the evening and in the early morning at some distance from the pontoon generally moved along at a height of 1 m or less above the substrate. Secondly, on occasion there were large schools of fusiliers, *Caesio trees* (Breen & Breen, 1994a), and groups of *Chromis* spp. around the pontoon. On many occasions the red bass swam through these schools. Even though the school members were well within the prey size range, they parted only enough to allow the bass to pass; there was no evidence of significant avoidance.

Counts by Richards & Gibson (1989) and myself show that the aggregation disperses before sunset and begins to reform after dawn. Many snappers are nocturnal (Parrish 1987). Published data on timing of feeding activity specifically for *L. bohar* are sparse, but they are likely to be mainly nocturnal, though Ormond (1980 quoted in Parrish 1987) reported some minor diurnal feeding activity by the species.

The presence of an aggregation at the pontoon may not lead to an increase in daytime predation close to the aggregation, but if the aggregation disperses at night to feed, the probability of a prey organism encountering a red bass is possibly higher for prey closer to the source of dispersal: the pontoon. This could in theory be measured by monitoring actual prey survivorship at different distances from the aggregation. This would require extensive time in the field because large sample sizes would be necessary since sources of variation in survival

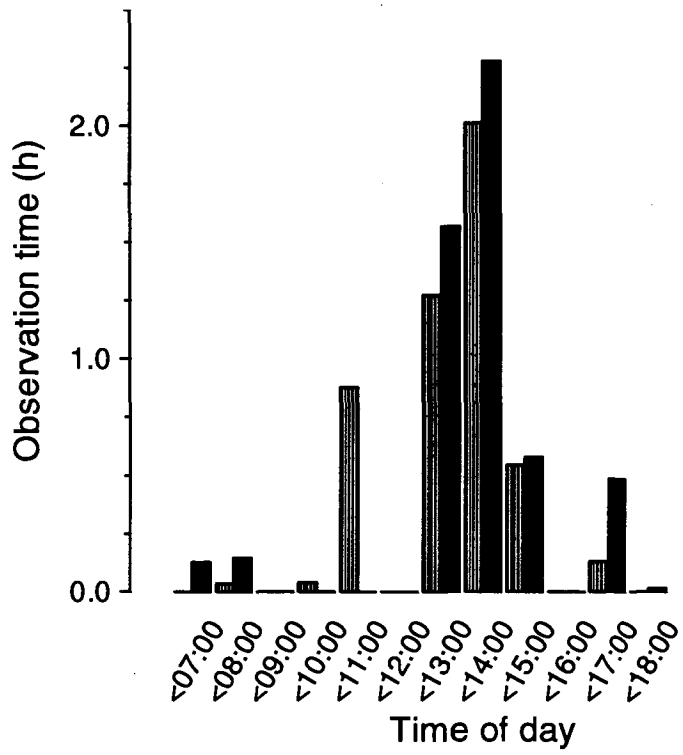


Figure 2.3.4: Distribution of observations of red bass activity over the day. Filled bars = Agincourt 2D, stippled bars = Agincourt 4.

other than predation by red bass would be numerous. Like all survivorship studies it would be important to measure emigration as well as mortality. The scope for the necessary manipulations, such as moving coral to make discreet habitat units, was restricted by the fact that the area was a working tourist facility within the marine park.

2.4 *Studies of the effect of fish feeding on the sand fauna at Kelso Reef*

2.4.1 Summary

1. I used cages to prevent large fish from feeding on animals in the sand in experimental plots at the Kelso Reef pontoon site and at two control sites away from the aggregation for a period of four months.

2. When I compared the change in numbers of all prey, all bivalves and four individual species over the experimental period in caged and uncaged plots, I found no statistical evidence for an effect attributable to feeding by fish.

3. An analysis of the direction of changes in density, rather than their magnitude, gave the same result.

4. The size frequency distributions of bivalves in caged and uncaged plots at the end of the experiment were as different between control areas as between control areas and the pontoon.

5. Though none of the analyses found evidence of changes attributable to feeding activity of fish, any conclusion is tentative because the low numbers of prey and short duration (in biological time) of the experiment meant that only large changes would have been detected.

2.4.2 Introduction

In Section 2.2 I suggested that the spangled emperors, *L. nebulosus*, in the aggregation at the Kelso Reef pontoon were interested in food provided by the tourist operators, but showed that a proportion of them do also feed on animals in the sand while they are at the pontoon. I estimated that an aggregation of an average size, 100 fish, would take about 1.5 bites m^{-2} per day from the area under the pontoon and the moored tourist boat. This raises the question of how much the feeding activities of the fish in the aggregation affects the populations of prey organisms.

There have been a relatively small number of studies of the impact of fish predation on soft-sediment communities associated with coral reefs and the results are equivocal as to the importance of fish predators (Jones et al. 1991). Of particular relevance to my study are those of Jones et al. (1988, 1990, 1991, 1992) who studied the effect of large carnivorous fishes, including *L. nebulosus*, on soft sediments in One Tree Is lagoon on the southern Great Barrier Reef and Cohen (1990) who looked at the benthic infauna near pontoons at Agincourt Reef.

Using evidence of what the fish did eat and what they could eat, I set out to look at the community of animals in the sand and to investigate the effect of fish feeding by using exclusion cages.

2.4.3 Methods

When *L. nebulosus* feed, they blow a jet of water out of their mouths which blows away the sand and reveals the prey which they pick out of the resulting pit. Observations suggest that they do not go deeper than the snout-to-eye distance, which I estimated at 5-7 cm from dead specimens. I therefore set out to sample the larger animals within that depth range in the sand.

Airlift design: In order to sample the animals, I used an airlift dredge. This was conventional (e.g. Prince & Ford 1985) in that it consisted of a 2 m length of 50 mm PVC pipe, with air from a SCUBA bottle introduced via the first stage of a SCUBA regulator and a valve about 10 cm from the bottom. There were some innovations in that the top of the main tube was attached at 45° to another tube. At the upper end this flared out to 90 mm diameter and was attached to a cylinder of plastic filter mesh 3.3x3.3 mm. The cylinder was 0.5 m long and was held in shape by large hose clamps around rings of 90 mm pipe. The lower end of the second pipe led down into a collecting bag of 2 mm synthetic mesh fabric. The purpose of the mesh cylinder was to sieve the sand *in situ*, so the air that came up the tube escaped through the mesh taking the finer material with it. The larger material was retained in the mesh cylinder and dropped down into the collecting bag when the air was turned off. This greatly reduced the amount of material that was removed and then had to be sorted: a sample from 0.5 m^2 to a depth of 5 cm represents about 25 l of lagoon sand, this reduced to less than 0.5 l. A second innovation involved replacing the spring in the first stage of the regulator with a much weaker one so that it gave a regulated 18 psi. Suction depends mainly on the velocity of bubbles in the tube which is determined by the length and diameter of the tube and is not related to the flow of air beyond a certain minimum rate. The reduced airflow did not reduce the suction but allowed many more samples per SCUBA tank.

Table 2.4.1: Pilot samples: means, standard errors and estimated number of samples (*n'*) to give a precision of 0.15 for six common species in quadrats of three sizes: 0.1 m^2 (n=5) 0.25 m^2 (n=5) and 0.5 m^2 (n=8). *untrans* = raw data; *sqrt* = transformed by square root of *x*-0.5.

		0.1 m²		**0.25 m²**		**0.5 m²**	
		untrans	*sqrt*	*untrans*	*sqrt*	*untrans*	*sqrt*
Tellina robusta	Mean	0.0	0.7	0.8	1.1	1.3	1.3
	SE	0.00	0.00	0.49	0.21	0.37	0.15
	n'	--	--	83	9	30	5
Echinoid sp. 1	Mean	0.2	0.8	0.4	0.9	1.1	1.2
(Spatangoid)	SE	0.20	0.10	0.24	0.13	0.23	0.10
	n'	222	4	83	4	14	2
Exotica sp. 1	Mean	1.0	1.1	3.2	1.8	5.3	2.2
	SE	0.55	0.21	1.11	0.29	1.70	0.35
	n'	67	8	27	5	37	9
Umbonium sp.	Mean	0.0	0.7	0.4	0.9	0.9	1.1
	SE	0.00	0.00	0.40	0.17	0.52	0.19
	n'	--	--	222	9	123	12
Echinoid sp. 1	Mean	0.2	0.8	0.6	1.0	4.0	2.1
(regular)	SE	0.20	0.10	0.40	0.18	0.71	0.18
	n'	222	4	99	7	11	3

Pilot samples: Five samples each of 0.1 m^2 and 0.25 m^2 were taken near the pontoon on 13 April 1994. Known prey animals were very rare in samples of either size, so eight 0.5 m^2 samples were taken nearby on 7 May. The precision (SE/mean, Andrew & Mapstone 1987) of prey density estimates was calculated for raw data and for square root transformed data (assuming that the distribution of animals was closer to a Poisson than to a normal distribution). From these estimates of precision, sample sizes necessary for an arbitrarily-chosen mean precision of 0.15 were calculated (Table 2.4.1). It is clear from the table that a substantial number of samples is required to give the chosen precision, even with the application of the transformation, but that larger samples generally give better precision than smaller ones.

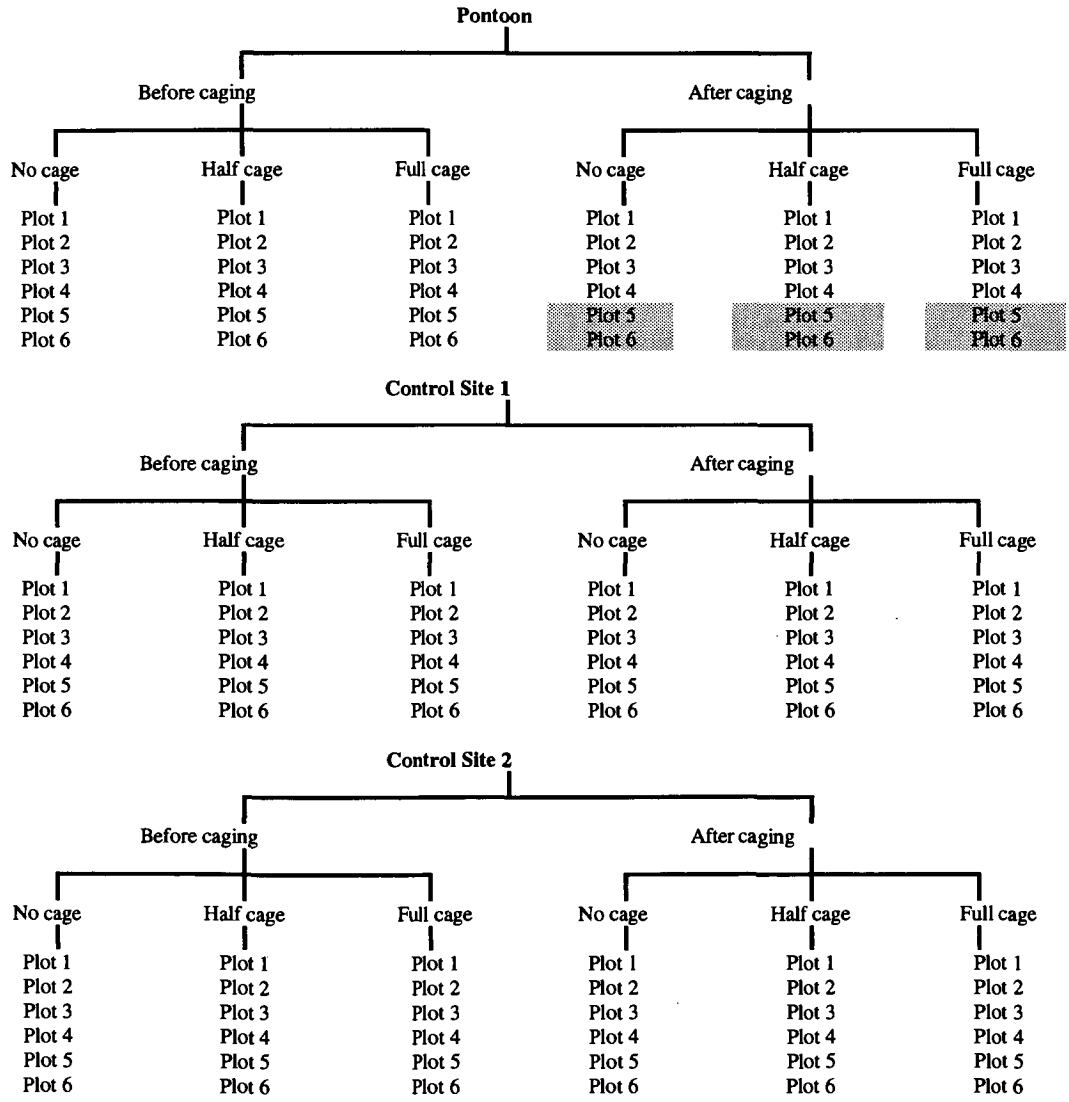


Figure 2.4.1: Schematic experimental design for the predator exclusion experiment. At each of three sites, 36 plots were allocated randomly among two sampling times and three levels of exclusion. Initially there were six replicates for each treatment combination, but two plots from each exclusion level were disturbed by anchor chains at the pontoon before the second sampling.

Predator exclusion experiment: In early June 1994, a predator exclusion experiment was set up to look for differences in the sand fauna produced by excluding large benthic predators such as emperors. Three sites were chosen: the area of sand under the pontoon in which members of the aggregation were observed to feed and two control sites within 500 m that were similar in depth (5-7 m), exposure (sheltered lagoonal areas) and proximity to coral (perimeter of the areas within 10 m of lagoonal coral bommies). No aggregations of carnivorous fishes were seen within 100 m of the control sites, though small groups and individual *L. nebulosus* and Slaty Bream, *Diagramma pictum*, did pass through both areas in the course of my observations. I would expect that the control areas were subjected to background levels of fish predation.

Samples of sand were taken from each study area in October. These consisted of four haphazardly placed cores 5 cm in diameter and 5 cm deep. The samples were dried in an oven at 80°C for three days by which time there was no detectable change in weight per day measuring to 0.01 g indicating that they were uniformly dry. Samples were then shaken through a standard series of geological sieves and the fractions were weighed.

At each site, 36 plots of sand were randomly allocated among three treatment groups (Fig. 2.4.1). Half the plots, six from each treatment group, were sampled at once to provide estimates of prey populations before predator exclusion. Hardware was installed on the remaining plots to produce differing degrees of exclusion. There were three treatment groups. The first group consisted of open plots. These were made up of a central area 50 x 100 cm, surrounded by a 'fence' of fine galvanised wire mesh buried in the sand. The fence mesh had apertures approximately 3 mm on a side and was 5 cm deep. The purpose of the fences around central area of all plots was to minimise dilution of any effect of predators through local migration. The central areas of adjacent plots were 90 cm apart. The second treatment group consisted of exclusion plots. These had a fenced central area as in the open plots, but this was overlaid with an area of chicken wire, 5 cm aperture diameter, 90 x 140 cm. Mesh of this size would have prevented emperors from probing into the sand (as described previously) and probably prevented feeding by other large fish such as Slaty Bream, *Diagramma pictum*. The plots in the third treatment group were treated in the same way as the exclusion plots, but the wire mesh was cut away from over the central, fenced area. The third group of plots was intended as a simple cage control in that the presence of mesh around the edges should cause a degree of turbulence and other potential hydrodynamic effects of the full cages, but the predators had access to the central sampling area.

The initial samples were taken and the cages were installed 2-3 June 1994. Cages were checked 8 June 1994 and two plots beneath the pontoon were relocated because the pontoon rotated with the wind direction and mooring chains came to lie across the plots. All plots were checked

again 27 July 1994. Cages were removed and the remaining plots were sampled 3-4 October 1994 after about four months. At the pontoon site, two plots from each treatment group had been disturbed by the mooring chains. This reduced the replication for the second sampling to four plots per treatment combination and made the analysis unbalanced. Sampling consisted of removing all the sand from the central area of each plot to a depth of 5 cm using the airlift. The coarser fraction of the sediment that was retained was transferred to plastic bags and preserved with alcohol.

Samples were sorted in the laboratory by picking them over at least three times. Gastropods that were in good condition but with no animal visible were cracked to see if they had been alive when collected. The bodies of some small tellinid bivalves tended to come loose from the shells in alcohol, so bivalves that were still articulated but were not obviously damaged or drilled were included. Analyses concentrated on four common organisms that were known prey items and two larger groupings: all bivalves and all potential prey. The latter category included bivalves, echinoids, crabs (except hermit crabs) and those gastropods that were either recorded as prey or

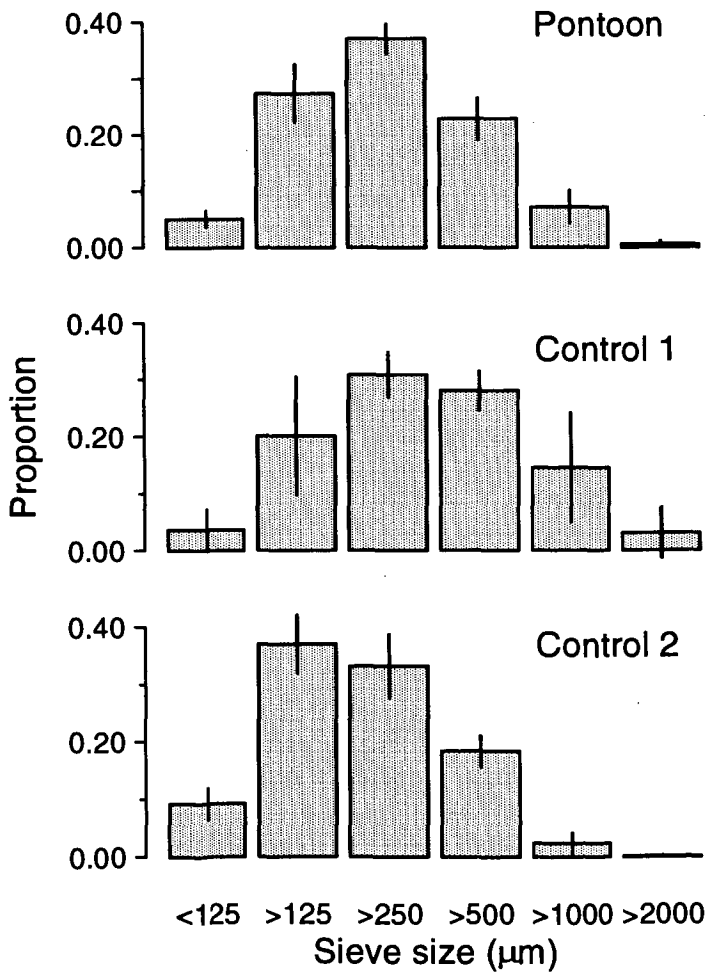


Figure 2.4.2: Proportions of sediment samples from each site retained by geological sieves. Error bars are 95% confidence intervals.

were both taxonomically and morphologically similar to gastropod prey recorded by Jones et al. (1991). I excluded organisms smaller than 3.5 mm long as it unlikely that these were sampled adequately: some were recorded but a proportion is likely to have past through the mesh of the airlift. All gastropod prey were small, but I also excluded a few bivalves that were larger than 35 mm in length as my observation of *L. nebulosus* attempting to crack a *Codakia* (a robust bivalve) 37 mm in length (Section 2.2.4) suggested that this was a reasonable upper limit for vulnerable prey.

2.4.4 Results

Sediment analysis: Analysis of grain sizes showed that there were differences among the sites at Kelso. The sediment at Control site 1 was generally slightly coarser than the sediment at the pontoon (Fig 2.4.1). The sediment at Control site 2 was finer than at either of the other two sites.

Effects on infauna: Because of the replicates lost due to movement of mooring chains under the pontoon, I used 'Type III' sums of squares (SPSS 'unique') as recommended by Shaw & Mitchell-Olds (1993) for unbalanced designs when all treatment combinations are observed but the numbers of observations per cell varies. In analysis of 'BACI' designs such as this, initial evidence of an effect of feeding activity at the pontoon site would be a significant three-way interaction term. More specifically, there should be a significant interaction contrast comparing the interaction involving the difference between caged and open plots between sampling times at the pontoon (where there is an aggregation) with the same interaction pooled over the control sites (where there are no aggregations).

In no analysis was there a significant three-way interaction and in no case was there a significant interaction contrast (Appendices 2-7) but in all cases the power of the test to detect a three-way interaction was low. Considering for instance, the data for density of all potential prey items (Appendix 7): if the means of all other treatment combinations were kept the same and the observed *pattern* of means at the pontoon site at the second visit was maintained (no cage = half cage < full cage), there would have had to be almost a fivefold difference between retransformed means for the caged and uncaged treatments to give a significant interaction contrast.

The data for all the individual species were heteroscedastic, or marginally so, even after transformation; this casts doubt on the probability values from the tests. Underwood (1981) suggests that heteroscedasticity does not affect interpretation of non-significant results because

its effect is to inflate the F-ratio, though this seems to be based on a limited number of simulations.

As an indication of trends, I examined the distributions of the most common 15 species, comparing the numbers in caged and uncaged treatments at the second sampling (after caging for four months) at each site. In cases where the species occurred at all in the samples, I recorded the direction of differences: whether caged > uncaged, caged < uncaged, or the numbers were equal (Table 2.4.2). If fish feeding had an effect, one would expect numbers to be higher in the caged plots at the pontoon, but for there to be no clear pattern between caged and uncaged plots at control sites. This was true when the pontoon site was compared with the combined controls (Kruskal-Wallis statistic = 5.9, exact probability = 0.022). However, the two control sites were at least as heterogeneous (Kruskal-Wallis statistic = 6.9, exact probability = 0.011) with the Control site 1 being similar to the Pontoon and Control site 2 being quite different. Even at this level there was no evidence of a consistent effect due to fish feeding.

Predation by fishes might also affect the size distributions of prey in the different treatments. The simplest manifestation of an effect would be a difference between caged and uncaged plots at the pontoon compared with no difference in control sites. Individual prey species occurred at too low densities or were too unevenly distributed between sites to allow satisfactory comparisons. Bivalves represent a group of prey animals that are relatively homogeneous in shape so there is some justification for considering the size frequency of all species together. I examined the size-frequency distributions of the sum of all bivalves from all caged plots and all uncaged plots at the second collection in October, after the treatments had been in place for four months (Fig 2.4.2). The greatest differences between caged and uncaged plots at the pontoon were in the 2.6-5.0 mm and 5.1-7.5 mm classes (Fig 2.4.2). Control site 1 did not show such

Table 2.4.2: Patterns in relative mean abundance of common prey species at the end of the fish exclusion experiment

	No. of prey spp.		
	cage > uncage	**cage = uncage**	**cage < uncage**
Pontoon	10	1	0
Control site 1	11	3	1
Control site 2	3	8	3

differences, but they were even more exaggerated at Control site 2 than at the pontoon. Once again the control sites appeared to differ from each other as much as either differed from the pontoon site. It is hard to invoke fish feeding activity as an explanation for these differences. The congruence between the size distributions from caged plots and cage control plots suggests that the differences may be a caging artefact.

2.4.5 Discussion

This study produced no statistical evidence that feeding by *L. nebulosus* at the pontoon site affected the abundance of any infaunal prey category. This was true both of the designed analyses of variance and less formal, more broad-scale meta-analyses. While the consistency of results supports the conclusion that fish predation is not important in prey population dynamics, this conclusion must be treated as tentative because of the low power of the individual tests.

The lack of statistical power comes from several sources: first, the pilot sampling showed that prey animals occurred at low density. One method of dealing with this is to sample larger plots. The area of 0.5 m^2 was the largest that was feasible in terms of field time, diving logistics and supply of air. Other studies have used smaller quadrats (0.078 m^2, Cohen [1990]; 0.1 m^2, Jones et al. [1992]). Another solution would be to have more replicate plots, but the area under the pontoon was limited (and the useable area was even more restricted by the presence of mooring chains). There had to be a compromise between size of plots and number of replicates. A third possibility would be to run the experiment for longer: most population phenomena on the reef follow an annual cycle and Jones et al. (1991) did not detect any effects of fish predation on infauna until the second year of their fish exclusion experiment. The effect of feeding would have had to have been very great to be detected in an experiment of this scale in four months but the experiment was constrained by the duration of the task. Cohen (1990) also did not detect any consistent effect of excluding fishes for two months from lagoonal sites at Agincourt Reef when he examined populations of tellinid bivalves. Neither of the other two studies included areas from the immediate vicinity of an aggregation of fishes, though the site where Jones et al. (1992) recorded the highest feeding intensity was a channel area that fishes passed through and was near a site where *Diagramma pictum* aggregated. Neither study recorded predation rates as bites per unit time, though Jones et al. (1992) used the half-life and the area of feeding scars to gain a crude estimate of the time for all sediment to be disturbed by fish feeding. In their area of most intense feeding activity, Jones et al. (1992) estimated that all the sediment would be turned over in 300 days; other areas were used about four times less intensively. Using the estimate of 1.5 bites m^{-2} per day and a mean bite diameter of 8 cm, an equivalent figure for the pontoon site was about 200 days. Both the other studies found higher prey densities than were present in any of the sites at Kelso at the time of my study. Thirty individuals of all prey species combined per square metre was a high value at Kelso (Appendix 7). Jones et al. (1992) recorded a greater number of *Tellina robusta* alone, and many other individual species occurred at similar densities. Cohen (1990) recorded average tellinid densities of about 50 m^{-2}.

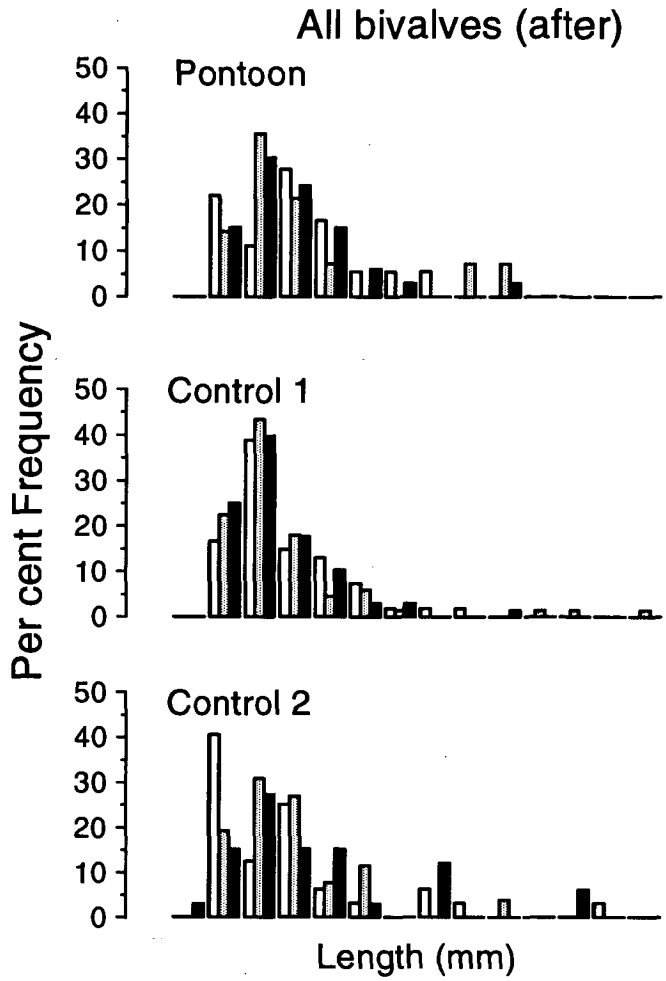


Figure 2.4.3: Size frequency distributions of all bivalves combined across replicates for each treatment at each experimental site in October. Open bars = no cage, light stippling = cage controls, dark stippling = full cages.

Unlike the other studies, I used mesh walls around each sample area which were designed to reduce migration and avoid dilution of effects of predation through immigration. Some organisms such as crabs could clearly climb over and burrowing forms may well have been able to burrow under, since buried obstructions such as pieces of rubble or shells are common in sandy areas near to areas of coral. Because of this, the reduction of dilution due to fences will only be relative.

In summary, a comprehensive study of the effects of fish feeding on the sand fauna would have required time and resources beyond the scope of this task, but the tentative conclusion of this study is that predation by aggregation of *L. nebulosus* is a minor factor in population dynamics of infaunal animals around the pontoon at Kelso Reef.

2.5. *Tagging of fishes from aggregations and evidence of movement*

2.5.1 Summary

1. With the resources of this project it was possible to tag a very limited number of fishes for movement studies - the need to fish at night away from pontoons means that funds for charter boats and the services of experienced anglers are required.

2. The data which were the basis for concern that the formation of aggregations at pontoons led to detectable depletion of populations in the surrounding area were reanalysed and found to provide no evidence of such an effect.

2.5.2 Introduction

One of the concerns expressed by staff of the Marine Park Authority concerning fish aggregations near pontoons was that, by causing fishes to aggregate, pontoons deplete the population of the aggregating species over the adjacent reef. This is of particular concern in edible species since aggregations may be targeted by fishermen, but in any case the formation of an aggregation represents an impact on the natural distribution of fish. The idea of population depletion has its roots in reports to the authority by Fisheries Research Consultants concerning the Wistari Reef pontoon and walkway installation. This monitoring program involved making rapid visual census assessments of fish at the pontoon and at sites away from the pontoon and the authors suggested that the numbers at control sites decreased over time as the aggregation at the pontoon built up.

My original plan was to try to mark fishes away from the pontoons, using distinct tags for different areas of the reef and to monitor the aggregations with the help of the dive staff. This could give evidence of how far some fishes had come. This is distinct from measurement of depletion, but could give evidence of the area of influence.

2.5.3 Methods

I decided to catch fish using large (8/O) hooks from which the barb had been removed. These could generally be removed quickly so the time that the fish was out of water was minimised. For similar reasons I used T-tags (Monarch marking systems) because these are swiftly attached with a 'gun' which inserts the cross-piece of the T between the bases of the dorsal spines. Since I was not concerned to distinguish individuals but only the areas in which they were tagged and I needed to be able to do that without handling the fish, localities were coded by position along the base of the dorsal fin and left or right flank. I modified the basic clothing

tags by cutting the stem to about 25 mm and melting the end into a blob, then inserting a 25 mm length of 'Heatshrink' electrical insulation over the stem and shrinking it into place. When the tags were in position about 25 mm projected from the fishes flank. Heatshrink is available in many colours, though not all are distinguishable underwater and they become obscured by fouling in a matter of weeks.

2.5.3 Results

Tagging at Kelso Reef: At Kelso Reef such a tagging program was impractical within the scope of the project. One of the daily activities offered to guests by Pure Pleasure Cruises is fishing - a small boat takes a group of tourists to one of a number of sites about 500 m from the pontoon. The staff who ran these trips were keen to participate in the project, so I gave them instructions, tagging equipment and data sheets in May, but no *L. nebulosus* were caught up until December 1994. The scope for making fishing trips of my own was limited since the tourist boat visits the pontoon for 3.5 h per day which is a limited time in which to set up a boat, get to a fishing site and get back. While *L. nebulosus* can be caught at any time, they are most commonly caught at night; fishing at night from small boats in reef waters is hazardous and requires considerable backup.

I visited Kelso Reef on a charter boat for two nights in early June while installing the predator exclusion cages. Three *L. nebulosus* from two different overnight anchorages were double-tagged. None was ever seen at the pontoon on subsequent visits.

Tagging at Agincourt Reefs: At Agincourt Reefs, Quicksilver Connections do not offer fishing trips among their daily activities. I enlisted the help of members of the Reef Biosearch team, giving them tagging equipment and devising a scheme for coding different areas of the reef complex by placing tags in different areas of the fishes' anatomy. Reef Biosearch operate '*Kalina*', a 10 m work boat which frequently stays out overnight, though for reasons of safety it is usually moored overnight near one of the pontoons. Twelve *L. bohar* were tagged at a mooring about 200 m from the pontoon at Agincourt 4 in late August and one marked fish was present at the nearby pontoon two days later and was seen there regularly over the following months.

In October 1994, Quicksilver Connections installed a new pontoon on Agincourt 3 and moved their operation from the pontoon at Agincourt 2D to the new pontoon. The aggregation of *L. bohar*, *Kyphosus* spp. and some tame Maori wrasse (*Cheilinus undulatus*) and large triggerfish (*Balistoides viridescens*) remained near the disused pontoon. Quicksilver Connections plan to return the pontoon from Agincourt 2D to Cairns for refurbishing. This would remove any cue

for fishes to remain at the pontoon site and it seemed possible that the *L. bohar* might rejoin local natural aggregations, or even move to the new pontoon. I tagged 20 *L. bohar* at the Agincourt 2D pontoon 8-9 November 1994, but the removal of the pontoon was delayed and it was still in place in late February 1995. No tagged fish had been reported at any other site, though the shift of activities to Agincourt 3 meant that the area around Agincourt 2D was visited less frequently.

Reassessment of the evidence for depletion of populations through aggregation: Concern that the formation of aggregations at pontoons depleted local populations came from the findings of the monitoring program at the Wistari Reef day-trip pontoon (Fisheries Research Consultants 1991). The data on which this was based came from a program involving assessment of fish assemblages at a site near the pontoon and at three control sites to the west of the pontoon along the reef front. The distances between the pontoon and the Control Sites 1-3

Table 2.5.1: Analysis of variance table for reanalysis of counts of 'benthic feeding fishes' at Wistari pontoon and control sites. Log (x + 1) transformed data. Data from Fisheries Research Consultants (1991).

Source of Variation	SS	d.f.	MS	F	p
Trip	0.81	3	0.27	2.32	0.08
Site	1.15	3	0.38	3.32	0.02
Day	1.07	2	0.54	4.63	0.01
Visit	0.37	1	0.37	3.19	0.08
Trip*Site	4.48	9	0.50	4.30	0.00
Trip*(Pontoon vs Controls)	0.64	1	0.64	5.50	0.02
Trip*Day	1.53	6	0.26	2.20	0.04
Site*Day	1.17	6	0.20	1.69	0.13
Trip*Visit	0.52	3	0.17	1.49	0.22
Site*Visit	0.42	3	0.14	1.22	0.30
Day*Visit	0.41	2	0.21	1.78	0.17
Trip*Site*Day	3.13	18	0.17	1.50	0.09
Trip*Site*Visit	0.94	9	0.10	0.90	0.53
Trip*Visit*Day	0.22	6	0.04	0.31	0.93
Site*Day*Visit	1.48	6	0.25	2.13	0.05
Trip*Site*Day*Visit	2.62	18	0.15	1.25	0.22
Within + Residual	22.23	192	0.12		
Total	42.54	287			

were 200 m, 400 m and 2800 m respectively. The relevant analysis used data from four trips to the study site: in December 1989 and in February, June and October of 1990. Each site was visited twice on each of three days during each trip and three rapid visual transects (Thresher & Gunn 1986) were made at each visit. Species were grouped into guilds for analysis.

The authors found a significant Trip x Site interaction for one broad and heterogeneous category of fishes: mobile benthic feeders. A list of the species represented is given in Appendix 8. The authors observed that the numbers of this group of fishes increased through time at the pontoon and decreased at Control sites 2 and 3 (Fig. 2.5.1). They considered the Trip x Site interaction to be 'tentative evidence for fish moving from surrounding areas to the pontoon'.

A full analysis of the data for this category of fishes would involve partitioning the sums-of-squares of interest into single degree-of-freedom contrasts. The report does not give a full analysis of variance table for this analysis and it is hard to examine the distribution of means from the given table of means for all individual treatment combinations. Consultants are required to lodge copies of their original data with GBRMPA, so I reanalysed the data for benthic feeding fishes using combined original counts for the fish species listed in the appendix. The F-ratios in the resulting analysis (Table 2.5.1) differed in detail from those given in the report, though the pattern of significant differences was the same. The original analysis used untransformed data which were severely heteroscedastic, this remained true after log

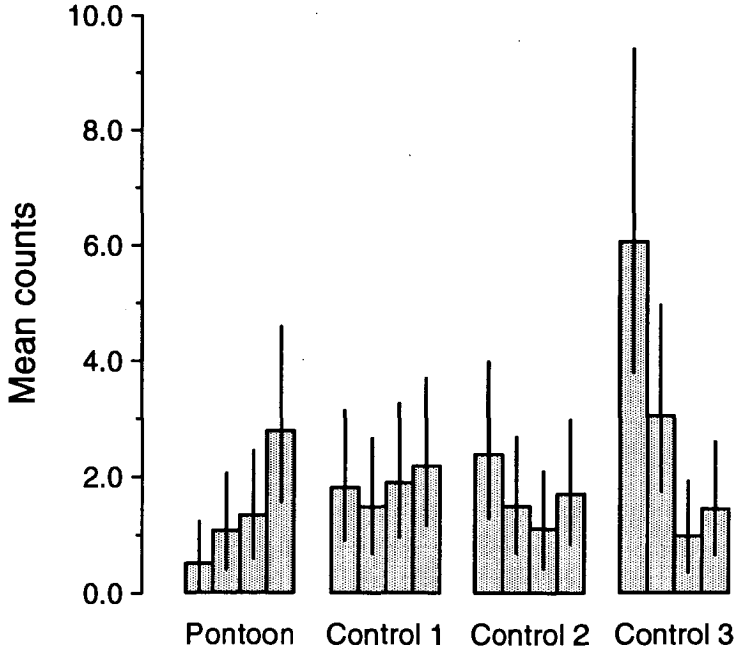


Figure 2.5.1: Mean numbers of 'benthic feeding fish' recorded at the pontoon and three control sites on Wistari Reef during four trips. Error bars are 95% confidence intervals based on the pooled standard error. Values have been retransformed.

Table 2.5.2: Analysis of variance table for reanalysis of counts of 'benthic feeding fishes' at Wistari Reef, **pontoon site omitted**. Log (x + 1) transformed data. Data from Fisheries Research Consultants (1991).

Source of Variation	SS	d.f.	MS	F	p
Trip	1.74	3	0.58	4.66	0.00
Site	0.51	2	0.26	2.06	0.13
Day	1.26	2	0.63	5.06	0.01
Visit	0.08	1	0.08	0.67	0.42
Trip*Site	2.04	6	0.34	2.72	0.02
Trip*Day	2.10	6	0.35	2.81	0.01
Site*Day	0.46	4	0.12	0.93	0.45
Trip*Visit	0.52	3	0.17	1.40	0.25
Site*Visit	0.20	2	0.10	0.79	0.46
Day*Visit	0.46	2	0.23	1.84	0.16
Trip*Site*Day	1.49	12	0.12	0.99	0.46
Trip*Site*Visit	0.51	6	0.08	0.68	0.67
Trip*Visit*Day	0.07	6	0.01	0.10	1.00
Site*Day*Visit	1.23	4	0.31	2.46	0.05
Trip*Site*Day*Visit	1.69	12	0.14	1.13	0.34
Within + Residual	17.99	144	0.12		
Total	32.36	215			

transformation (Cochran's test, $p<0.01$). The Trip x Site interaction was highly significant (Table 2.5.1) so this would probably not be affected. Partitioning this interaction suggests that the change in numbers through time does differ between the pontoon and the average of the three control sites (Table 2.5.1), which might indicate depletion. Examination of the pattern of means (Fig. 2.5.1) suggests that this is due to over-riding differences in the pattern of changes between Control Site 3 and the pontoon. This was confirmed by reanalysing the data omitting the pontoon site altogether (Table 2.5.2). A significant Trip x Site interaction persisted, indicating a lack of coherence in the changes among control sites.

While the original interpretation was based on an incomplete analysis that was suspect for a number of reasons (heteroscedasticity, dubious independence of replicate counts made only minutes apart), the most fundamental problem lies in the combining of a diverse group of species for analysis. The taxa included and the numbers of individuals of each in the whole

data set are given in Appendix 8. The contributions of all species represented by more than 10 individuals to the total count for each site from each trip are plotted in Figure 2.5.2. The large change in numbers of benthic feeders at Control Site 3 between the first and second trip was mainly due to the disappearance of a school of goatfishes (*Parupeneus* spp.). There were also considerable changes in the numbers of *Gymnocranius bitorquatus* (= *G. audleyi*, Randall et al. 1990) at Control Sites 1 and 3. The increase in numbers at the pontoon site was initially largely due to *L. nebulosus* though there was an increase in the number of goatfishes (species unspecified) at the third trip, six months and two censuses after the large school was recorded at Control Site 3. While the total number of benthic feeding fishes may have declined at the one or more control site and increased at the pontoon, the species involved are different. With more detailed analysis, these data provide no evidence that the number of fish moving to the pontoon produced a detectable decrease in densities in the control areas.

2.5.4 Discussion

Doubt has been expressed in another report on monitoring at a tourist pontoon concerning the importance and detectability of migration by fishes in aggregations: the author of a report on the Arlington Reef pontoon monitoring program (Sinclair-Knight 1992a) suggested that tagging studies that are in progress as part of the Effects of Fishing Program have found that movement over distances of several kilometres are common in large reef fishes. If fish were drawn to the pontoons over distances up to 2 km and occurred at densities of 20 per hectare (1 per 50 x 10 m transect), the formation of an aggregation of 150 fish at a pontoon would represent displacement of 0.6% of the population within a 2 km radius. Ayling & Ayling (1994a) provide estimates of the densities of emperors on seven reefs in the Townsville area as assessed using 50 x 5 m transects in various reef zones. Overall, the grand mean for all zones of all reefs is 15 emperors (of all spp.) per hectare. The highest estimated density was 25.3ha-1 in backreef areas of John Brewer Reef. This is for all species of emperor; on average 6.7ha-1 of these were *Lethrinus miniatus* and several other species such as *L. atkinsoni* and *L. olivaceous* are fairly common. A figure of 5ha-1 seems more reasonable for *L. nebulosus* and is similar to values for control sites at Arlington Reef. Even so, an aggregation of 150 animals would only represent 2.4% of the population of *L. nebulosus* within a 2 km radius. Such a small change would be very hard to detect statistically, even with a massive (hence much more expensive) census effort.

In summary, the numbers of fish involved in aggregations at pontoons represent such a small proportion of the estimated local population from which they are likely to be drawn that it is very unlikely that monitoring on any scale envisaged at present would detect any depletion effect. The study that purported to show such an effect in fact produced no such evidence when

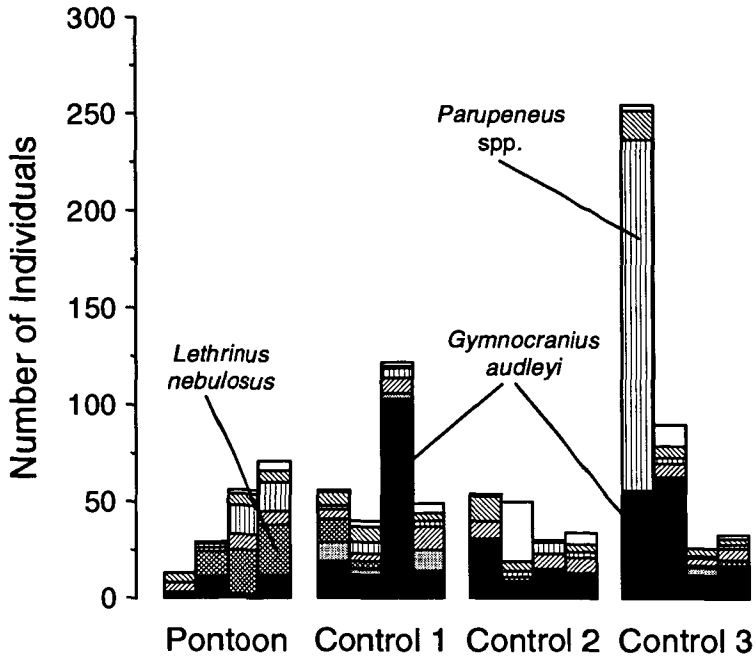


Figure 2.5.2: Contributions of more numerous species (Appendix 8) to the total number of benthic feeding fishes seen at each site at Wistari Reef during four trips.

the data were reanalysed. There is the further point that aggregation at pontoons does not remove fishes from the reef, they continue to live in the area and presumably breed. Aggregation behaviour itself is not unusual and aggregations at pontoons can be looked at as the relocation of natural aggregations to sites determined by human activities. This point is taken up in the next section.

2.6 *General Discussion*

This study has concentrated on the impact of feeding by two of the most widespread and numerous large carnivorous species that aggregate around pontoons. I found little potential for impact of the aggregations through feeding. Both species appear to disperse away from pontoons for much of the time. *Lethrinus nebulosus* at Kelso Reef are only present in any numbers at the pontoon when the tourist boat is along side. While they do feed in the sand under the pontoon, the great variability in densities of their prey meant that locations subject to background levels of feeding were as different from each other as they were from the area under the pontoon. Direct observations of *Lutjanus bohar* suggest that consumption of natural prey near the pontoon occurs at undetectable rates and that they disperse away from the pontoons at night when much of their feeding activity is likely to occur.

While there may be no evidence that the formation of aggregations at pontoons causes any measurable depletion from local populations, their formation at those locations is unarguably a human impact that would be very unlikely to occur otherwise. I would suggest that the impact is inconsequential: aggregations occur naturally, so in the case of aggregations at a pontoon it is only the particular location that is influenced by man. *Lutjanus bohar* in particular, like a large number of other species that feed predominantly at night or in crepuscular periods, tends to form aggregations naturally at particular sites during the day. For *L. bohar* these natural sites are often in areas of current: there is frequently an aggregation at Horseshoe bommie, an isolated patch reef between Agincourt 2D and Agincourt 3 which is exposed to strong tidal currents. Reef Biosearch divers have kept logbooks of varying formality since 1987 and there have been frequent records of an aggregation of *L. bohar* at Horseshoe bommie since at least August 1989. Another example is provided by the pontoon operated by Great Adventures at Norman Reef near Cairns. There is an aggregation of *L. bohar* at the pontoon which may number 135 (Ayling & Ayling 1994b), while about 300 m away along the reef edge there is a detached bommie which supports a much larger natural aggregation (least 500 *L. bohar* in January 1994, personal observation) that includes several other large predatory species. In the past, the crew used to throw food from the semi-submersible as it followed the edge of the reef from the pontoon to the bommie and back again and groups of *L. bohar* would follow the submersible along its route between the two aggregations (A.M. Ayling, pers. comm.).

Lethrinus nebulosus are less rigorous in their adherence to daytime 'roosting' sites than the lutjanids, as is suggested by the way the aggregation at Kelso Reef disperses as soon as the Pure Pleasure boat leaves. Groups of *L. nebulosus* are less cohesive than schools of lutjanids but individuals and small groups of the species appear to be found during daylight in particular areas of at most a few hundred square metres over periods of months to years (pers. obs.).

The apparent lack of predatory impact from aggregations and the suggestion that aggregations represent a relocation of a focus of natural aggregation behaviour within a reef area raise questions about the relevance and efficacy of components of current monitoring programs. Operators fund consultants to count fishes at pontoon sites, where there are aggregations (albeit unnatural), and compare the counts with similar data from control sites without aggregations. It is hard to see what such a comparison reveals. Aggregations at pontoons should at least be compared in some way to natural aggregations.

Much of the behaviour of both species when they are in aggregations at the pontoons is orientated towards the food provided by tourist operators, either from the pontoons or from divers, and there seems little doubt that this is the prime cause for the initial formation of aggregations of these species at pontoons. It may be that the habit of fish feeding started as a

form of garbage disposal for food scraps. The Marine Park Authority now only permits limited feeding with fresh seafood and the tourist operators continue to feed the fish because they feel it adds a dimension to the tourists' experience. Watching the reactions of snorkellers and spectators when a large maori wrasse comes right up onto the snorkelling platform at Agincourt 2D pontoon to be fed suggests that tourists do appreciate the opportunity to see large fishes at close range. If this zoo-like philosophy of reef tourism is replaced by a more wilderness-orientated one, the cessation of fish feeding seems very likely to remove the main motivation for large carnivorous fishes to aggregate at pontoons.

2.7 *Acknowledgments*

I thank Ray Berkelmans, Hamish Malcolm and Jamie Oliver for initial discussions on the subject of fish aggregations. Bill Condon gave permission to work at Kelso and kindly provided transportation; many thanks are due to John Fisher and the crew of '2001' for their helpfulness and good humour. I thank the management of Quicksilver Connections and Quicksilver Dive for allowing me to work at the Agincourt pontoons. Alice Crabtree, Chris Coxon, Andy Dunstan, Phil Laycock and especially Dan Breen helped in many ways with my work at Agincourt Reefs. Special thanks are due to Tony Rouphael for allowing me to participate in field trips that he worked hard to organise. Reg Reddicliffe of Great Adventures allowed me to visit Norman Reef as a possible site.

I thank the following people for their help with the fieldwork: Laura Castell, Jocey Davies, Peter Eaglen, Emma Hutchison, Ron Jones, Kate Kieffer, Lisa Kellogg, Esther Koh, Kylie Pitt, Lin Schwarzkopf, Luke Smith, Bryce Stewart and Alan Zavodny. Steve Edgar sorted many of the samples. Laura Castell and Geoff Jones helped with mollusc taxonomy and Uschi Kaly gave good advice on experimental design. Special thanks to Laura Castell for help and patience beyond the scope of the laws of the Republic of Panama.

2.8 *References*

Andrew, N.L. & B.D. Mapstone (1987). Sampling and the description of spatial pattern in marine ecology. Oceanography and Marine Biology, an annual review. 25: 39-90.

Ayling, A.M., & A.L. Ayling (1992). Norman Reef environmental monitoring project GBRMPA Research Publication No. 19.

Ayling, A.M., & A.L. Ayling (1994a). Bramble Reef replenishment area - 1993 and 1994 surveys. Unpublished report to the GBRMPA.

Ayling, A.M., & A.L. Ayling (1994b). Norman Reef pontoon monitoring program: 1992-93. Unpublished report to the GBRMPA, 51pp.

Breen, D., & B. Breen (1994a) Agincourt 2D Pontoon monitoring study. Unpublished report to GBRMPA 95 pp.

Breen, D., & B. Breen (1994b) Low Isles pontoon baseline study. Unpublished report to GBRMPA 44 pp.

Cohen, B. (1990). A study into the effects of tourist mooring pontoons on the infauna of Agincourt Reefs, on the Great Barrier Reef Unpublished Honours thesis, Dept of Marine Biology, James Cook University, 80 pp.

Fisheries Research Consultants (1991) P & O Resorts P/L, Wistari Reef day-trip pontoon environmental monitoring report. Unpublished report to GBRMPA 38 pp.

Fisheries Research Consultants (1992) P & O Resorts P/L, Wistari walk-way and Wistari Reef day-trip pontoon monitoring report (mobile fishes only). Unpublished report to GBRMPA 14 pp.

Jones, G.P., P.F. Sale & D.J. Ferrell (1988). Do large carnivorous fishes affect the ecology of macrofauna in shallow lagoonal sediments? A pilot experiment. Proc. 6th Int Coral Reef Congr, Townsville 2:77-82.

Jones, G.P., D.J Ferrell & P.F. Sale (1990). Spatial pattern in the abundance and structure of mollusc populations in soft sediments of a coral reef lagoon. Marine Ecology Progress Series 62:109-120.

Jones, G.P., D.J. Ferrell & P.F. Sale (1991). Fish predation and its impact on the invertebrates of coral reefs and adjacent sediments pp. 120-155 [In] Sale, P.F. (ed) The ecology of fishes on coral reefs. Academic Press, San Diego.

Jones, G.P., D.J. Ferrell & P.F. Sale (1992). Fish feeding and dynamics of soft-sediment mollusc populations in a coral reef lagoon Marine Ecology Progress Series 80:175-190.

Parrish, J.D. (1987) The trophic biology of snappers and groupers. Pp. 405-439 in: Polovina, J.J., & S. Ralston: Tropical snappers and groupers: biology and fisheries management. Westview Press, Boulder, Co.

Prince, J.D., & W.B Ford (1985) Use of anaesthetic to standardise efficiency in sampling abalone populations (genus *Haliotis*: Mollusca: Gastropoda). Aust. J. Mar. Fresh. Res. 36, 701-706.

Reef Biosearch (1992) An environmental monitoring program investigating the impacts of the establishment of a pontoon system on an outer barrier reef. Unpublished report to GBRMPA 144 pp.

Richards, W.G., & J.A. Gibson (1989) Ongoing monitoring at Agincourt Reef; short term fluctuations in fish populations and comparison of pontoon and control sites. Unpublished report to GBRMPA 51 pp.

Shaw, R.G., & T. Mitchell-Olds (1993). ANOVA for unbalanced data: an overview Ecology 74: 1638-1645.

Sinclair Knight & Partners (1992a) Arlington Reef EMP, final design. Unpublished report to the GBRMPA, 30 pp.

Sinclair Knight & Partners (1992b) Moore Reef environmental monitoring program event 3. Unpublished report to GBRMPA 64 pp.

Sinclair Knight & Partners (1993) Kelso Reef baseline study. Unpublished report to GBRMPA 47 pp.

Thresher, R.E., & J.S. Gunn (1986). Comparative analysis of visual census techniques for highly mobile, reef- associated piscivores (Carangidae). Environmental Biology of Fishes 17: 93-116.

Underwood, A.J. (1981). Techniques of analysis of variance in experimental marine biology and ecology. Oceanography and Marine Biology, an annual review 19: 513-605.

Walker, M.H. (1978). Food and feeding habits of *Lethrinus chrysostomus* Richardson (Pisces: perciformes) and other emperors on the Great Barrier Reef. Australian Journal of Marine and Freshwater Research 29: 623-630.

Wright, A., P.J. Dalzell & A.H. Richards (1986). Some aspects of the biology of the red bass, *Lutjanus bohar* (Forsskal), from the Tigak Islands, Papua New Guinea. Journal of Fish Biology 28: 533-544.

3. APPENDICES

Appendix 1: Fishes recorded at pontoons on the Great Barrier Reef

Table 3.1.1: Records of species and families of fishes recorded at pontoons on the Great Barrier Reef

	Agincourt 4 Jan 91[1]	Agincourt 2D Sep, Dec 93[2] (mean)	Low Isles Jul 93[3]	Kelso Reef May 92[4]	Norman Reef Jul 93[5]	Moore Reef Jun, Aug 92[6]	Wistari Reef Oct 90[7]	Hardy Reef 1993[8]	Arlington Reef 1992[9]
Cephalopholis argus	1	1.2	-	-	-	-	-	-	-
C. boenak	-	-	1	-	-	-	-	-	-
Plectropomus laevis	-	1.6	-	-	3	-	-	-	-
P. leopardus	-	0.2	-	-	1	-	-	-	-
P. maculatus	-	-	-	-	-	-	3.2	-	-
Epinephelus spp.	-	-	-	-	-	-	1.5	-	-
Epinephelus merra	-	-	1	-	-	-	-	-	-
Diploprion bifasciatum	-	-	-	-	-	-	0.5	-	-
Serranidae	-	-	-	0.07	-	1.35	-	-	1
Carangoides plagiotaenia	-	-	-	-	14	-	-	-	-
Caranx sexfasciatus	-	-	-	-	-	-	-	300	-
Caranx ignobilis	-	-	-	-	-	-	-	3	-
Carangoides gymnostethus	-	-	-	-	-	-	-	50	-
Pseudocaranx nobilis	-	-	-	-	-	-	86.6	-	-
Carangidae	-	1	-	1.27	-	-	-	-	-
Lutjanus bohar	2	47.6	-	-	135	-	-	-	-
L. gibbus	-	11.8	-	-	136	-	-	-	-
L. fulvus	-	-	-	-	4	-	-	-	-
L. russelli	-	-	-	-	7	-	-	-	-
L. carponotatus	-	-	-	-	-	-	-	23	-
Macolor niger	-	0.4	-	-	-	-	-	-	-
Lutjanidae	-	-	-	-	-	0.9	-	-	1.9

Table 3.1.1: Records of species and families of fishes recorded at pontoons on the Great Barrier Reef (cont...)

	Agincourt 4 Jan 91[1]	Agincourt 2D Sep, Dec 93[2] (mean)	Low Isles Jul 93[3]	Kelso Reef May 92[4] (mean)	Norman Reef Jul 93[5]	Moore Reef Jun, Aug 92[6] (mean)	Wistari Reef Oct 90[7] (mean)	Hardy Reef 1993[8]	Arlington Reef 1992[9] (mean)
Plectorhynchus chaetodontoides	-	0.6	-	-	-	-	-	-	-
P. pictus	-	-	-	-	-	-	0.2	-	-
Haemulidae	-	-	-	-	-	-	-	-	1.3
Lethrinus atkinsoni	2	8.6	-	-	-	-	-	-	-
L. miniatus	-	-	-	-	-	-	17.5	-	-
L. nebulosus	1	0.4	-	-	4	-	23.3	-	-
L. obsoletus	1	-	-	-	-	-	-	-	-
Monotaxis grandoculis	4	0.4	-	-	-	-	-	-	-
Lethrinidae	-	-	-	14.4	-	2.55	-	-	4.2
Scolopsis bilineatus	3	-	-	-	-	-	-	-	-
Nemipteridae	-	-	-	0.1	-	1.2	-	-	2.5
Cheilinus undulatus	-	1.8	-	-	6	-	-	4	-
Choerodon fasciatus	-	0.4	-	-	-	-	-	-	-
Choerodon sp.	-	-	-	-	-	-	1.3	-	-
Epibulus insidiator	-	0.6	-	-	-	-	-	-	-
Mulloides flavolineatus	-	60	-	-	-	-	-	-	-
Kyphosus cinerascens	-	0.4	-	-	-	-	-	-	-
K. vaigensis	-	32.4	-	-	75	-	-	-	-
Kyphosus spp.	-	-	-	-	-	-	-	20	-

1. Reef Biosearch 1992
2. Marine Environmental Monitoring 1994
3. Marine Environmental Monitoring 1994
4. Sinclair Knight (1993)
5. Ayling & Ayling (1994)
6. Sinclair Knight (1992)
7. Fisheries Research Consultants (1992)
8. Ayling (pers comm.)
9. Sinclair Knight (1992)

Appendix 2: Distribution of *Tellina robusta* in the fish exclusion experiment

Table 3.2.1: Analysis of variance table for counts of *Tellina robusta* (square root [x + 0.5] transformed data)

Source of Variation	SS	d.f.	MS	F	p
Site	10.26	2	5.13	16.93	0.00
Exclusion treatment	0.69	2	0.34	1.14	0.33
Visit (before / after)	0.04	1	0.04	0.12	0.73
Site*Treatment	0.33	4	0.08	0.27	0.89
Site* Visit	0.95	2	0.47	1.56	0.22
Treatment*Visit	0.01	2	0.01	0.02	0.98
Site*Treatment*Visit	2.31	4	0.58	1.90	0.12
(Pontoon vs Controls)*Treatment*Visit	0.46	1	0.46	1.52	0.22
Within + Residual	25.47	84	0.30		
Total	40.78	101	0.4		

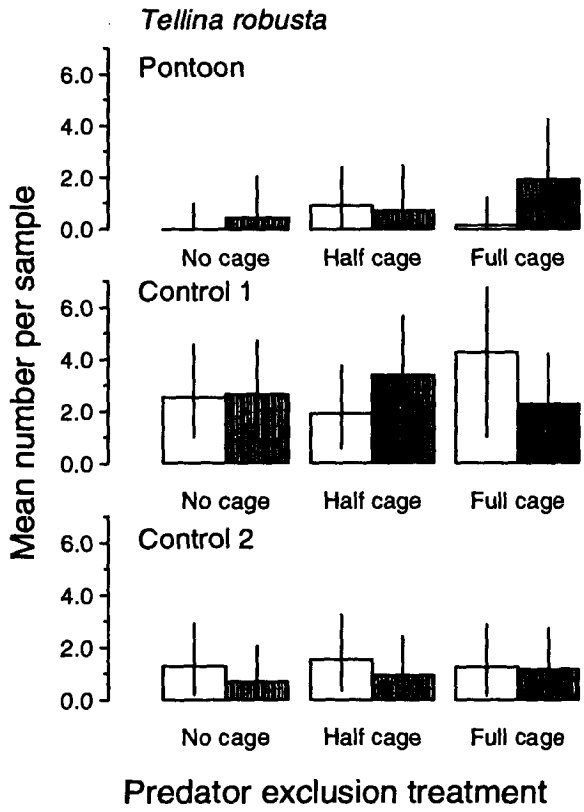


Figure 3.2.1: Fish exclusion experiment; re-transformed means and 95% confidence intervals for numbers of *Tellina robusta* in samples from each experimental site. Unfilled bars =before caging, stippled bars = after 4 months.

Appendix 3: Distribution of Spatangoid echinoids in the fish exclusion experiment

Table 3.3.1: Analysis of variance table for counts of Spatangoid echinoids (square root [x + 0.5] transformed data)

Source of Variation	SS	d.f.	MS	F	p
Site	0.55	2	0.28	3.96	0.02
Exclusion treatment	0.27	2	0.13	1.91	0.15
Visit (before / after)	0.46	1	0.46	6.64	0.01
Site*Treatment	0.25	4	0.06	0.88	0.48
Site* Visit	0.17	2	0.08	1.21	0.31
Treatment*Visit	0.41	2	0.21	2.97	0.06
Site*Treatment*Visit	0.44	4	0.11	1.58	0.19
(Pontoon vs Controls)*Treatment*Visit	0.03	1	0.03	0.36	0.55
Within + Residual	5.86	84	0.07		
Total	8.62	101	0.09		

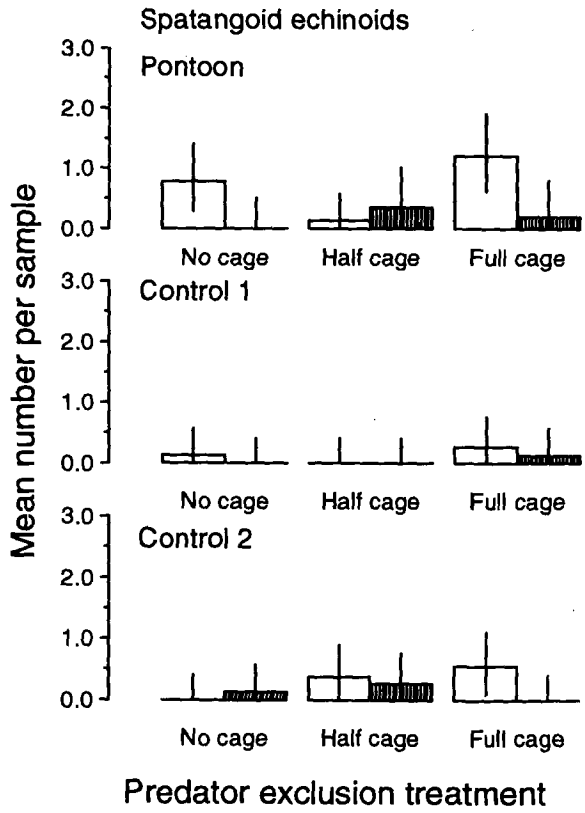


Figure 3.3.1: Fish exclusion experiment; re-transformed means and 95% confidence intervals for numbers of Spatangoid echinoids in samples from each experimental site. Unfilled bars = before caging, stippled bars = after 4 months.

Appendix 4: Distribution of *Exotica* sp. 1 in the fish exclusion experiment

Table 3.4.1: Analysis of variance table for counts of *Exotica* sp. 1 (square root [x + 0.5] transformed data)

Source of Variation	SS	d.f.	MS	F	p
Site	9.31	2	4.65	20.22	0.00
Exclusion treatment	0.05	2	0.02	0.11	0.90
Visit (before / after)	0.96	1	0.96	4.18	0.04
Site*Treatment	0.42	4	0.11	0.46	0.77
Site* Visit	0.12	2	0.06	0.26	0.77
Treatment*Visit	0.10	2	0.05	0.22	0.80
Site*Treatment*Visit	1.90	4	0.47	2.06	0.09
(Pontoon vs Controls)*Treatment*Visit	0.06	1	0.06	0.28	0.60
Within + Residual	19.33	84	0.23		
Total	32.19	101	0.32		

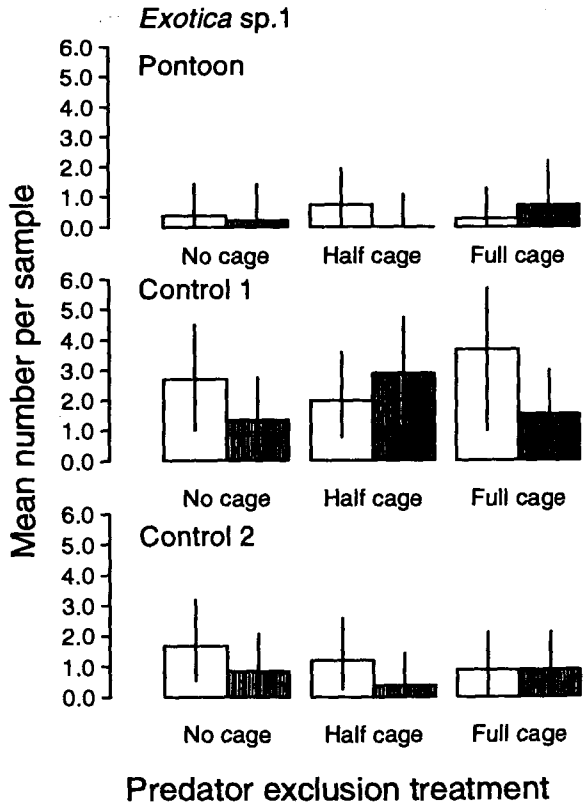


Figure 3.4.1: Fish exclusion experiment; re-transformed means and 95% confidence intervals for numbers of *Exotica* sp. 1 in samples from each experimental site. Unfilled bars =before caging, stippled bars = after 4 months.

Appendix 5: Distribution of *Umbonium* sp. in the fish exclusion experiment

Table 3.5.1: Analysis of variance table for counts of *Umbonium* sp. (square root [x + 0.5] transformed data)

Source of Variation	SS	d.f.	MS	F	p
Site	0.11	2	0.06	0.83	0.44
Exclusion treatment	0.15	2	0.07	1.08	0.34
Visit (before / after)	0.06	1	0.06	0.86	0.36
Site*Treatment	0.20	4	0.05	0.75	0.56
Site* Visit	0.04	2	0.02	0.30	0.74
Treatment*Visit	0.00	2	0.00	0.01	0.99
Site*Treatment*Visit	0.16	4	0.04	0.60	0.66
(Pontoon vs Controls)*Treatment*Visit	0.02	1	0.02	0.30	0.58
Within + Residual	5.63	84	0.07		
Total	6.31	101	0.06		

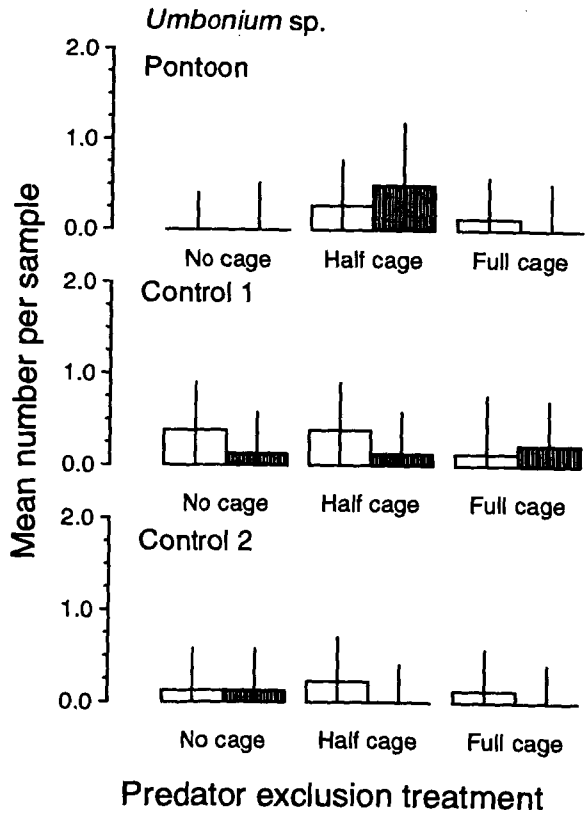


Figure 3.5.1: Fish exclusion experiment; re-transformed means and 95% confidence intervals for numbers of *Umbonium* sp. in samples from each experimental site. Unfilled bars =before caging, stippled bars = after 4 months.

Appendix 6: Distribution of bivalves of edible size in the fish exclusion experiment

Table 3.6.1: Analysis of variance table for counts of bivalves of edible size (square root [x + 0.5] transformed data)

Source of Variation	SS	d.f.	MS	F	p
Site	20.71	2	10.35	18.94	0.00
Exclusion treatment	3.13	2	1.56	2.86	0.06
Visit (before / after)	0.39	1	0.39	0.72	0.40
Site*Treatment	0.97	4	0.24	0.44	0.78
Site* Visit	0.35	2	0.17	0.32	0.73
Treatment*Visit	0.14	2	0.07	0.13	0.88
Site*Treatment*Visit	1.62	4	0.40	0.74	0.57
(Pontoon vs Controls)*Treatment*Visit	0.00	1	0.00	0.00	1.00
Within + Residual	45.93	84	0.55		
Total	73.68	101	0.73		

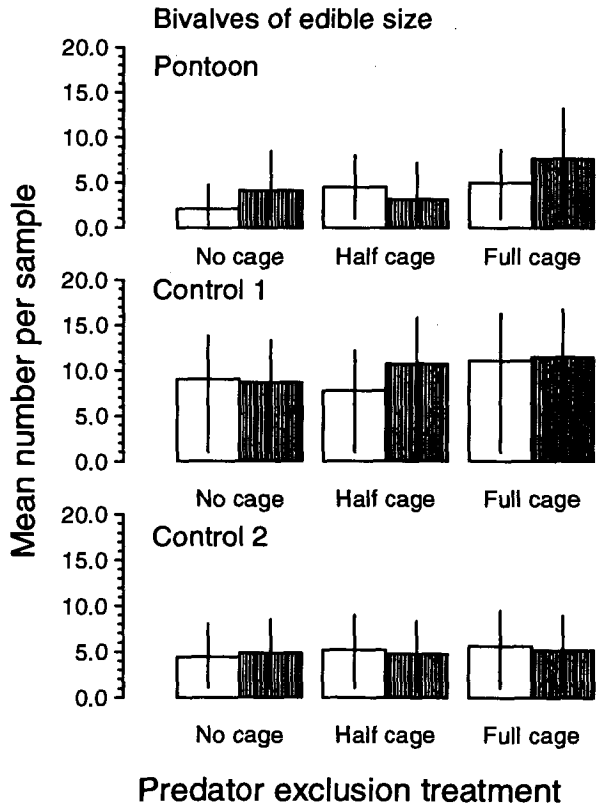


Figure 3.6.1: Fish exclusion experiment; re-transformed means and 95% confidence intervals for numbers of all bivalves of edible size in samples from each experimental site. Unfilled bars =before caging, stippled bars = after 4 months.

Appendix 7: Distribution of all prey organisms in the fish exclusion experiment

Table 3.7.1: Analysis of variance table for counts of all prey organisms (square root [x + 0.5] transformed data)

Source of Variation	SS	d.f.	MS	F	p
Site	13.73	2	6.87	11.72	0.00
Exclusion treatment	3.26	2	1.63	2.79	0.07
Visit (before / after)	0.00	1	0.00	0.00	0.95
Site*Treatment	0.98	4	0.25	0.42	0.80
Site* Visit	0.54	2	0.27	0.46	0.63
Treatment*Visit	0.17	2	0.08	0.14	0.87
Site*Treatment*Visit	1.75	4	0.44	0.75	0.56
(Pontoon vs Controls)*Treatment*Visit	0.04	1	0.04	0.06	0.81
Within + Residual	49.22	84	0.59		
Total	69.33	101	0.69		

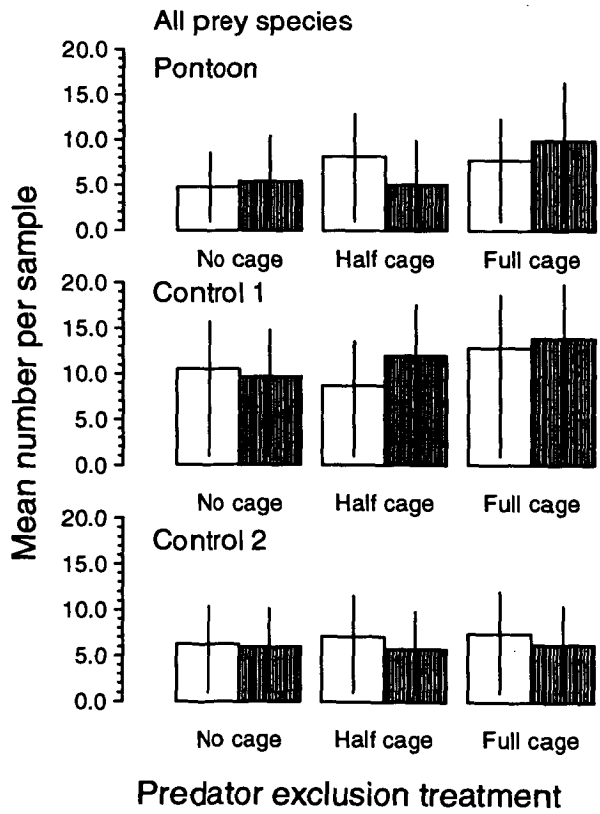


Figure 3.7.1: Fish exclusion experiment; re-transformed means and 95% confidence intervals for numbers of all prey organisms in samples from each experimental site. Unfilled bars =before caging, stippled bars = after 4 months.

Appendix 8: Fishes included in the category 'Benthic carnivores' and the number recorded in the study at Wistari Reef pontoon

Table 3.8.1: Fishes included in the category 'Benthic carnivores' and the total number of each recorded in the study at Wistari Reef pontoon (Fisheries Research Consultants 1991)

Acanthurus mata	3
Acanthurus xanthopterus	72
Acanthurus spp.	8
Chaetodontoplus duboulayi	4
Choerodon spp.	89
Diploprion bifasciatum	13
Epinephelus sp.	1
Gymnocranius bitorquartus	347
Lethrinus choerorhynchus (?)	8
Lethrinus nebulosus	83
Lethrinus miniatus	34
Naso unicornis	3
Parupeneus spp.	247
Plectropomus maculata	27
Plectorhynchus pictus	7
Scolopsis monogramma	96