THE ABUNDANCE OF THE EASTERN ROCK LOBSTER, *JASUS VERREAUXI*, ALONG THE NEW SOUTH WALES COAST

Final report to

The Fisheries Research & Development Corporation

by

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NON-TECHNICAL SUMMARY

92/14 The abundance of the eastern rock lobster *Jasus verreauxi* along the New South Wales coast

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OBJECTIVE:

To establish baseline abundance indices for the eastern rock lobster off New South Wales that can be used by managers to assess the effects on rock lobster populations of the introduction of management measures.

NON-TECHNICAL SUMMARY:

Results from the study funded by the Fishing Industry Research Trust Account (FIRTA Grant No. 86/64) showed that catch rates in the commercial fishery had been falling for many years, and that in excess of 90% of the catch was made up of immature lobsters. In anticipation of greater management eventuating, the New South Wales Fisheries Research Institute has developed a sampling strategy for collecting the information needed to calculate an index of relative abundance for eastern rock lobsters off New South Wales. Research has concentrated upon developing sampling strategies for monitoring the relative abundance of individuals in the post-larval and late juvenile to adult phases of the life cycle. This approach will provide information on the relative abundance of recruits to the population of individuals of sizes subjected to fishing, and of the spawning stock.

Traps and attracting devices (collectors) were found to be the most appropriate methods to survey eastern rock lobsters during the late juvenile to adult phases (inclusive), and post-larval (puerulus) phase of the life cycle, respectively. Sampling strategies should be based upon a sound knowledge of the factors that affect the methods used to collect data, so that the variability caused by external factors is minimised. Observed differences in mean estimates of relative abundance then can be attributed to changes in lobster abundance rather than to "noise" in the sampling methodology.

Experiments were done to investigate the effects of external factors on catches of lobsters from collectors and traps. Subsequently, pilot studies collected information on the variability in catches of lobsters by sampling gear and determined the optimal sampling strategies for surveying the relative abundance of lobsters.

Pueruli were caught on seaweed-type but not crevice-type collectors. For seaweed-type collectors, most pueruli were caught near the surface rather than on collectors set near the bottom. No differences were found in the number of pueruli caught between collectors set at sites with different levels of exposure to sea-swell, or proximity to reef. Generally, most pueruli were caught around the moon-phase of new moon quarter and when the soak-time of the collector was 4 weeks. Results from cost-benefit analyses suggested that 3 collectors within each of 3 sites at each of 6 locations was optimal for monitoring the relative abundance of pueruli.

Commercial fishers use a variety of designs of traps and types of bait to catch lobsters in waters shallower than 20 m. Experimental comparisons of catches between different designs of trap, bait and soak-times found no differences in the number of lobsters caught on grounds in waters shallower than 20 m. In waters deeper than 20 m most commercial fishers use the same design of trap, namely, a large rectangular trap. Results from experiments showed that there were no differences between types of bait but more lobsters were caught in traps left to soak for 14 days than in traps soaked for 3 or 7 days.

Although few lobsters were caught, results of cost-benefit analyses suggested that it was best to sample 5 sets (10 traps per set) on grounds shallower than

20 m in each of 2 surveys at 3 locations. Similarly, on grounds within the depth range of 21-100 m it was best to sample 5 sets (2 rectangular traps per set), in each of approximately 2 surveys, at 3 locations along the New South Wales' coast.

These sampling strategies have now been put in place and are funded by New South Wales' lobster industry to monitor the relative abundance of recruits (pueruli and juveniles) and adults in the population. Such a scheme could provide fishery independent data to assist in the determination of whether management options introduced into the fishery have been successful.

Keywords: lobster, sampling design, abundances.

CHAPTER 1

BACKGROUND INFORMATION

1.1 GENERAL

Rock (spiny) lobsters have been fished off the coast of New South Wales since at least 1873 (Lie 1969). Reported landings for the commercial fishery in 1993-94, the last year before the implementation of management by quota, were around 150 tonnes and worth approximately $5 million. *Jasus verreauxi*, the eastern rock lobster, accounts for more than 97% of the lobsters landed in New South Wales. Other species caught in far fewer numbers are *Jasus edwardsii* in the south of the State and *Panulirus longipes* and *Panulirus ornatus* in the north. This study has concentrated upon investigating the abundance of *J. verreauxi* because of its prominence in the catch and for this reason the other species are not included in this report.

The results of Fishing Industry Research Trust Account (FIRTA) project No. 86/64 indicated that if the eastern rock lobster resource off New South Wales was to be sustainable, additional management measures were needed (see Montgomery 1995 in Appendix 1). Subsequently, the number of rock lobster fishers permitted to fish in the fishery was restricted from 1992 and, in 1994, individual catch quotas were introduced.

1.2 BIOLOGY OF *Jasus verreauxi*

The eastern rock or packhorse lobster, is reportedly the largest rock (spiny) lobster in the world (Phillips et al. 1980). It occurs in waters off the east coast of Australia from Tweed Heads (28° 10′ S) southwards, around the coast of Tasmania, and as far west as Port MacDonnell (38° 03′ S) in South Australia (Fig. 1.1). The species is also found off New Zealand, predominantly around the North Island (Kensler 1967b).

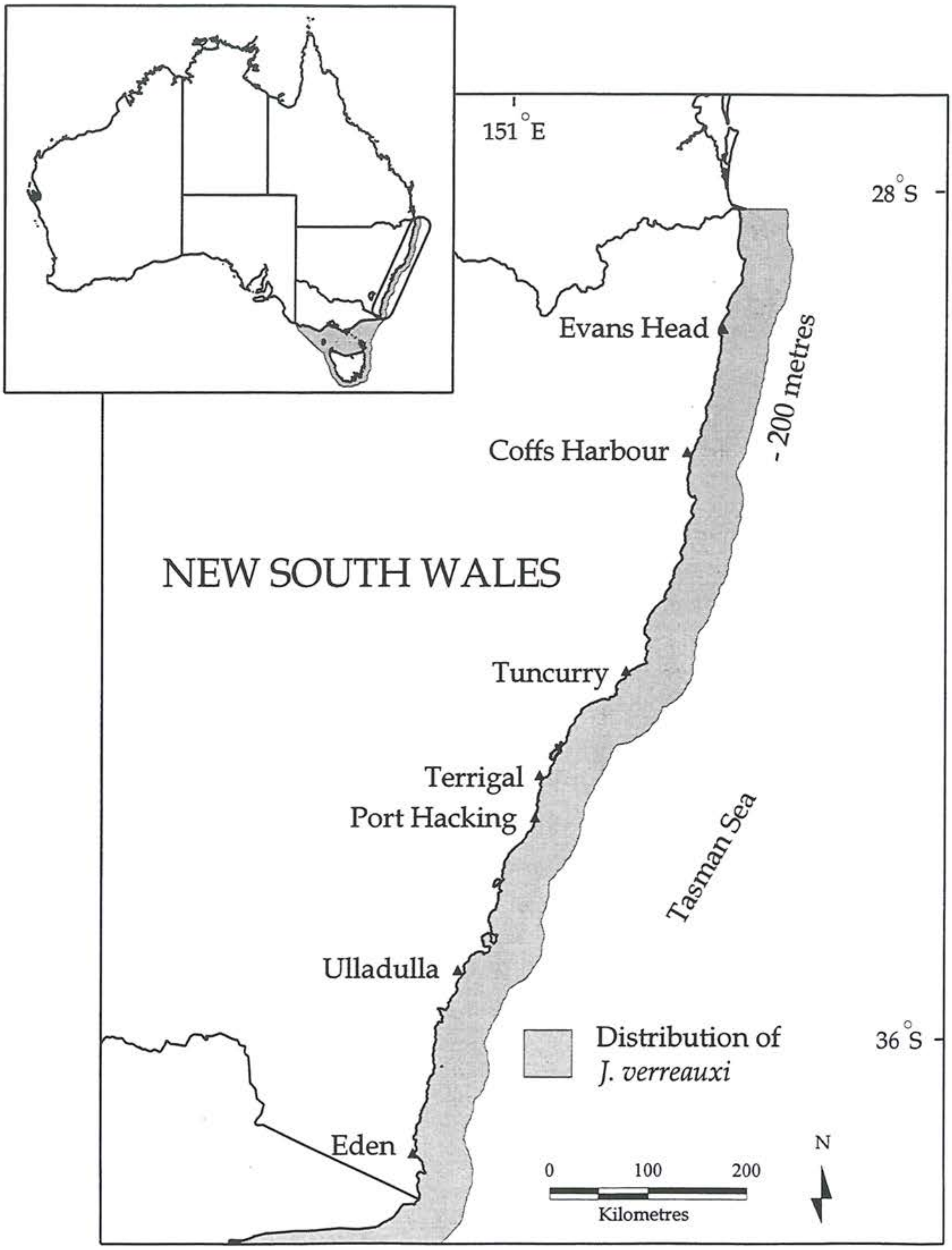

Figure 1.1. Location of places used in experiments to collect information on the relative abundance of *J. verreauxi*.

Although relatively little is known about the biology of *J. verreauxi*, the species appears to have a life-cycle typical of rock lobsters (see Phillips and Sastry 1980, for a review of the life-cycle of the rock lobster). Females off New Zealand are highly fecund, carrying around 1.9 million eggs (Kensler 1967a). The smallest size at which 50 % of females carry eggs in waters off New South Wales is 167 mm CL (Montgomery 1992). Spawning occurs from September to January inclusive (Lie 1969). In waters off New Zealand, the larval phase of *J. verreauxi* is thought to take 9-12 months to complete (Booth 1986). Under laboratory conditions, larvae have developed through 17 phyllosome instars before metamorphosing into a pueruli 189 to 359 days after hatching (Kittaka 1994a, b). The period of the puerulus stage ranged from 18 to 29 days.

Juveniles occur in shallow waters off New South Wales (Montgomery 1990). Tagged juveniles in waters off New Zealand have been found to move distances longer than 900 km in a north-westerly direction, toward areas where the greatest abundance of spawners were found (Booth 1984b).

1.3 THE FISHERY

Currently, eastern rock lobsters are harvested commercially from Ballina (28° 52′ S; NSW) to Mallacoota (37° 34′ S; Vic.). The commercial fishery in New South Wales for lobsters can be divided according to the depths fished into inshore (approximately 1-20 m), mid-shelf (approximetely 21-100 m) and offshore (approximately 101-220 m) components.

The inshore fishery may operate throughout the year but is concentrated in August to December, although this varies between areas. Fishers use traps of various designs (Figure 1.2), a variety of baits (usually fresh fish) and soak-times of up to 3 days. They operate from mostly aluminium planing hull

Figure 1.2 D-shaped (left), rectangular (middle) and Beehive traps (right) used on inshore grounds.

vessels of approximately 5 m in length and powered by at least 25 hp outboard engines. Some fishers dive for lobsters without the assistance of compressed air (as stipulated by regulations), however this operation is not practised widely.

Fishers use large rectangular traps (up to around 2 m x 1.5 m x 1 m, Fig. 1.3a) with an entrance in each of up to 3 of the sides and with a variety of baits (fresh and preserved fish, and animal limbs and organs, Fig. 1.3b) on fishing grounds in waters deeper than 20 m. Multipurpose vessels of planing or displacement hull design are used in the mid-shelf and offshore fisheries. Lobsters are taken also as incidental catches by otter trawl and Danish seine

Figure 1.3(a) Large rectangular traps used on mid-shelf and offshore grounds.

Figure 1.3(b) Types of bait used in traps on mid-shelf and offshore grounds.

vessels operating on grounds deeper than 50 m. Traps are normally pulled once every 2 weeks but current strength and weather conditions can prolong the period between lifts, particularly on offshore grounds. The season for the mid-shelf and offshore fisheries is from September to February and February to August, respectively, but the season can vary between areas.

A recreational fishery for rock lobsters operates on grounds to depths of about 10 m. Virtually nothing is known about the level of catch and fishing effort in this fishery in waters off New South Wales. In 1982-83 a McNare omnibus survey found that a mean of 1% of the 788 people in New South Wales interviewed fished recreationally for lobsters. Estimates from this survey however had a 95% confidence region of ± 3%; i.e. between 0 and 4% of people interviewed went fishing recreationally for lobsters. For the purposes of this report therefore, the recreational catch was considered to be negligible.

Events through history that have most likely impacted upon catch and fishing effort in the fisheries for lobsters are:

1902 A legal minimum length of 104 mm CL for *J. verreauxi*.

1936 Recreational fishers were restricted to 1 pot, hoop, basket or trap. The size of a commercial trap was limited to being smaller than 2 m x 1.5 m x 1 m with at least 50 mm mesh.

1950s During the mid 1950s it became an offence to land females carrying ova.

1968 A daily bag limit of 5 lobsters per person per day was introduced for recreational fishers. Recreational fishers were restricted to taking lobsters by the gear prescribed for commercial fishers or by diving with a gloved hand only.

1980s The use of compressed air for the purpose of taking lobsters was banned.

1984 A freeze on the number of vessels permitted to fish in state waters was introduced.

1992 Permits to fish for lobsters were restricted to 158 fishers in November 1992.

1993 The bag limit for recreational fishers was reduced from being in possession of 5 lobsters per person to being in possession of 2 lobsters per person.

1994 Output controls were introduced on 1 July 1994. A total allowable commercial catch (TACC) of 91.6 tonnes was allocated to permitted fishers.
The TACC increased to 106 tonnes in November.
Sizes of traps were limited to (i) on grounds in less than 10m depth being smaller than 1.2 x 1.2 x 1.2 m or with a circular base smaller than 1.2 m and (ii) on grounds deeper than 10 m smaller than 2 x 2 x 2 m. All with the equivalent of 50 mm mesh.
A legal maximum length of 200 mm CL was introduced into the fishery.

1995 The TACC for 1995-96 was set at 106 tonnes. The number of permits in the fishery increased to 196 during 1995-96.

1996 The TACC for 1996-97 was set at 106 tonnes.

1.4 THE NEED FOR THIS PROJECT

Results from a study funded by FIRTA (Grant No. 86/64) suggested that the relative abundance of *J. verreauxi* off New South Wales had fallen over preceding years (Montgomery 1990, 1995). Further, it was found that the size at onset of breeding (167 mm CL) of females was far longer than the legal minimum length (104 mm CL) applicable in the fishery, and that greater than

90% of lobsters in the annual commercial catch were shorter than the size at onset of breeding (Montgomery 1992, 1995).

The New South Wales' government acted upon the results of the FIRTA funded study by, amongst other measures, restricting from 1992 the number of fishers permitted to operate in the fishery, and then in 1994 introducing individual catch quotas. The objective of this action was to conserve and rebuild the stock.

It was necessary therefore to set in place a sampling strategy that would collect data necessary to assess whether management was being successful in achieving the objective.

The first step was to start collecting accurate information that could be used as an index of relative abundance. A time series of these data is fundamental to the stock assessment of any resource. In most circumstances, it is impossible to count the number of individuals in a population in the wild, so a relative measure must be used as an index of abundance. Indices of relative abundance are measured as the quantity of animals collected per unit of sampling effort. This approach assumes that the index used is proportional to the abundance of animals in the population. It is imperative therefore that the unit of sampling effort be standardised so that the same proportion of those animals present are caught every time sampling is done.

Methods used to collect data to estimate the relative abundance of rock lobster populations can be categorised into visual census and capture methods. Visual census methods include techniques to directly count organisms by use of SCUBA, photography, and/ or the use of manned or remote submersibles. Capture methods use fishing gear to catch consistently (it is assumed) the same proportion of animals present between grounds.

Traps and attracting devices were selected as the most appropriate capture methods to use to collect information about numbers of eastern rock lobsters during the late juvenile to adult phases (inclusive) and post-larval (puerulus) phase of the life cycle, respectively. The patchy distribution of lobsters, the fact that pueruli and early juvenile stages are cryptic and asocial, and that surveys needed to be done on grounds in waters of around 100 m depth where currents can be strong, meant that visual census methods were inappropriate.

Indices of relative abundance for late juvenile and adult stages can be collected from catch and effort data from the fishery or from surveys done independently of the fishery. Fishery dependent sources offer many more observations in the data set and at a cheaper cost than can be afforded through independent surveys. However, data from these sources can be susceptible to many biases including inaccurate recording, the targeting of animals of a particular size and changes in fishing power between fishers and years. For these reasons independent surveys provide more reliable indices of relative abundance. Independent surveys assume even more importance when a fishery is managed by quota because fishers will change their fishing operations (e.g. by targeting bigger animals) to maximise their economic return per individual caught. Fishing by operators therefore becomes less random and standardised, so the risks of bias to fishery dependent data are greater.

Independent surveys should be based upon a sound knowledge of the factors that affect the methods used to collect data. This information allows a sampling strategy to be developed that minimises the variability caused by external factors so that any observed differences in mean estimates of relative abundance can be attributed to changes in lobster abundance rather than to "noise" in the sampling methodology. It is only by this approach of standardising methodology that the sampling strategy employed will stand the test of time.

This study has developed fishery independent surveys of the eastern rock lobster resource. Multi-factorial experiments were used to develop appropriate trapping methods and cost-benefit analyses based on data using these methods determined optimal sampling strategies.

CHAPTER 2

MEASURING THE RELATIVE ABUNDANCE OF PUERULI

2.1 INTRODUCTION

A knowledge of the abundance of individuals recruiting to a population is important for the effective management of that resource. It tells us about when and where recruitment to a population takes place and about the relative "strength" of recruitment to the population among years (commonly referred to as year-class strength). Such information can be used to assess the effect of management on recruitment. It has been used also to predict catches of rock lobsters in future years (e.g. Phillips 1986). Together with estimates of the relative abundance of spawning individuals it can be used to determine whether there is a relationship between the abundance of recruits and spawning individuals in the population (for a review see Hilborn and Walters 1992).

One measure of recruitment in rock lobster populations has been the relative abundance of pueruli settling in nearshore waters. The most common method used to collect information on the relative abundance of pueruli have been attracting devices, commonly referred to as collectors. Collectors may be grouped into two categories, those that imitate seagrasses or algae, referred to as seaweed-type of collectors (hereafter referred to as seaweed-type collectors) and those that simulate holes and crevices, referred to as crevice-type of collectors (hereafter referred to as crevice-type collectors). Seaweed-type collectors are generally set near the surface (e.g. Witham et al. 1968, Phillips 1972, Serfling and Ford 1975) whilst crevice type collectors are generally set near the bottom (e.g. Booth and Tarring 1986, Kennedy et al. 1994).

Catches of pueruli on collectors may be affected by many external factors (see Phillips and Booth 1994 for a review), The size, shape and material of collectors may affect catches. Collectors may need to be protected from sea-swell so that they retain pueruli and do not disintegrate. Further, collectors can be more efficient catchers of pueruli when positioned away from the habitat where pueruli are found. The pattern of settlement of pueruli on collectors is usually seasonal and can be associated with the phase of the moon.

This chapter describes experiments done to determine the impact of several factors on catches of pueruli of external factors. The most effective method was used to examine the hypothesis that the relative abundance of pueruli changed throughout the year and among locations.

2.2 MATERIAL AND METHODS

2.2.1 Effects of type of collector

Two experiments were done to determine whether collectors provide reliable estimates of the relative abundance of pueruli. The materials and methods used in these experiments are described in detail in Montgomery and Kittaka (1994) and Montgomery and Craig (submitted ms, see Appendices 2 and 3).

Design of Collector

The collectors compared were (i) the seaweed-type collector described by Phillips (1972) for sampling *P. cygnus* near the surface (Fig. 2.1a) and (ii) the crevice-type collector described by Booth and Tarring (1986) for sampling *J. edwardsii* near the substratum (Fig. 2.1b). These have been the most popular types of collectors used to sample other species of palinurids around Australia and New Zealand (Phillips and Booth 1994).

Figure 2.1(a) Seaweed-type collector designed by Phillips (1972).

Figure 2.1(b) Crevice-type collector designed by Booth and Tarring (1986).

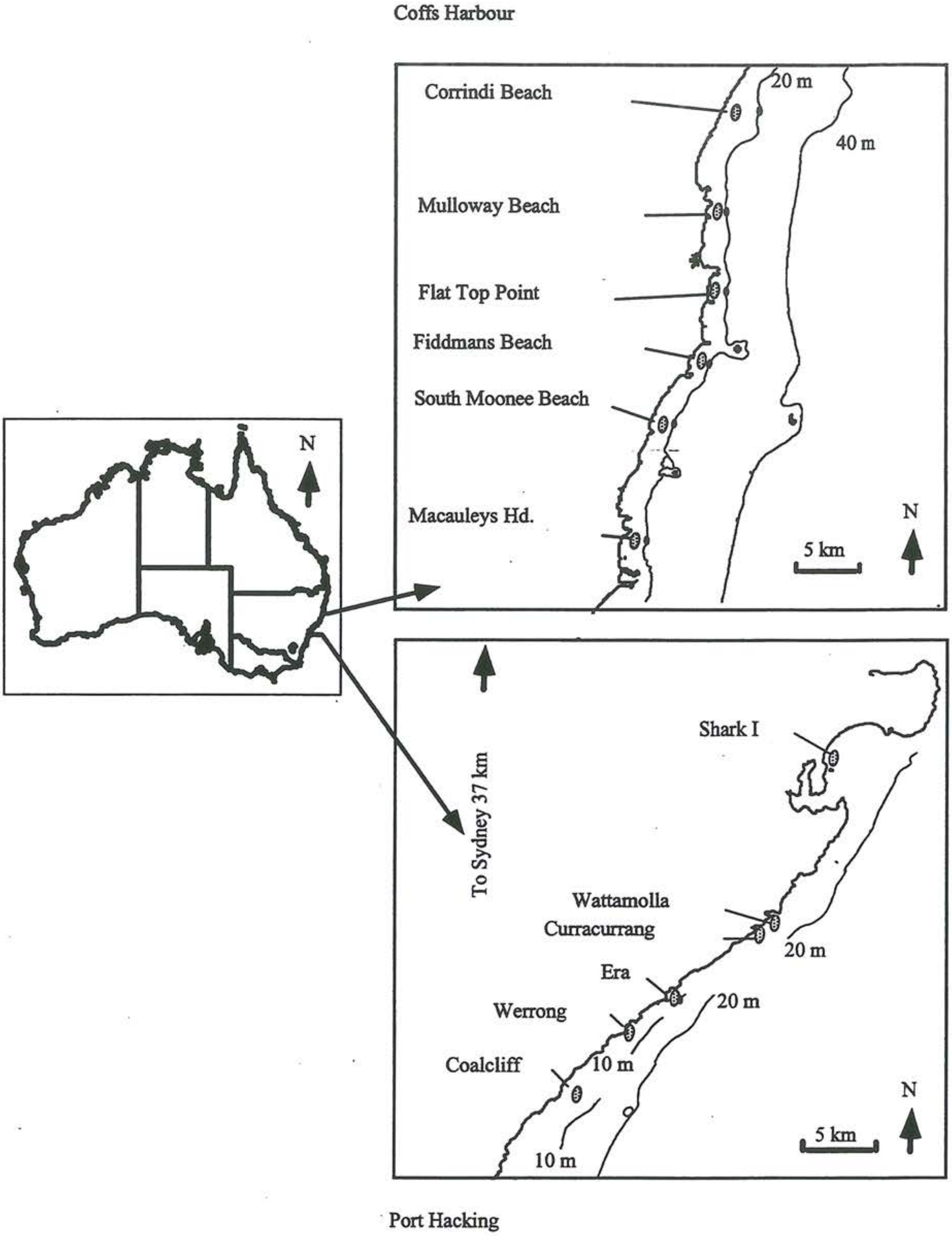

Figure 2.2. Locations of sites used in experiments to investigate the effects on catches of pueruli and post-pueruli off Coffs Harbour and Port Hacking.

Figure 2.3(a) Seaweed-type collector being lifted from the water.

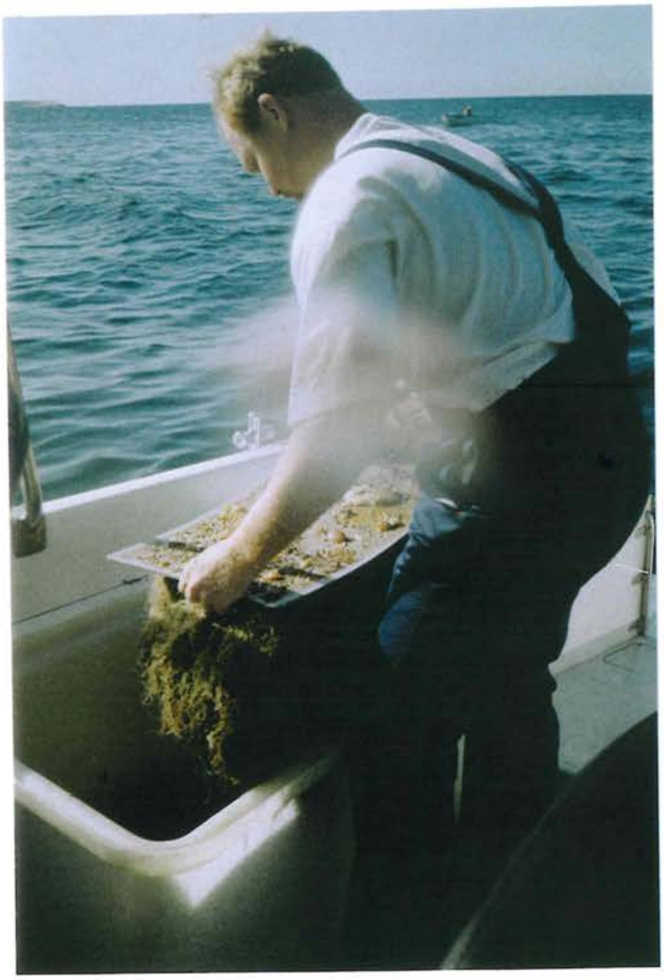

Figure 2.3(b) Shaking a panel from a seaweed-type collector.

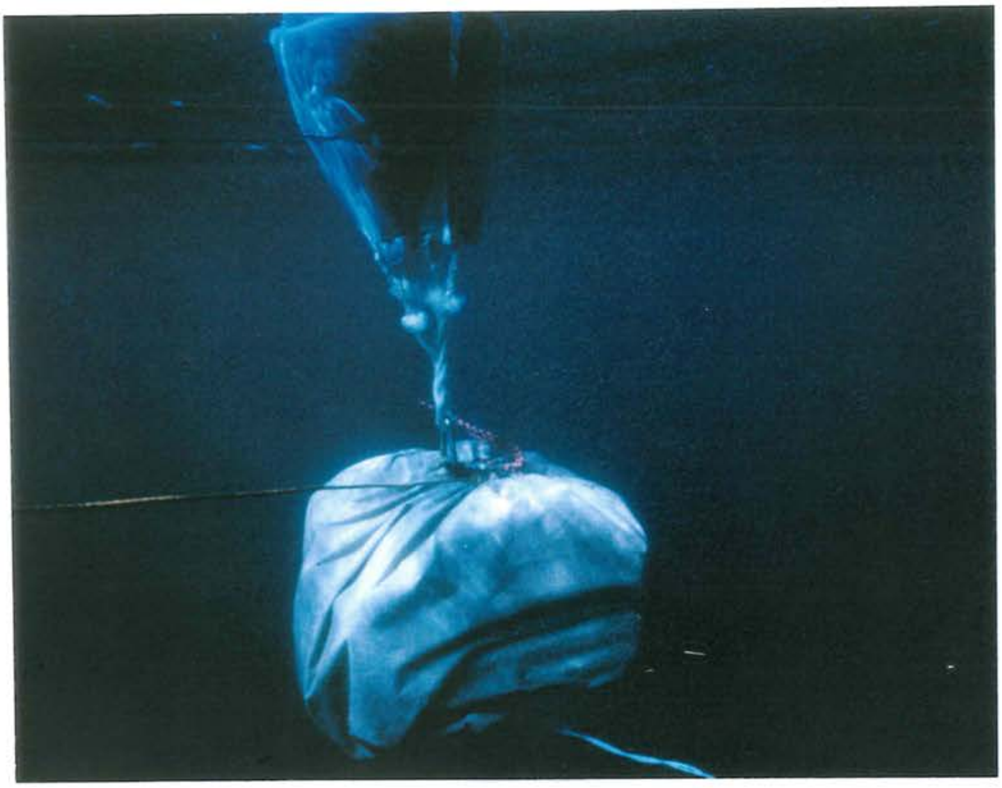

Figure 2.3(c) Crevice-type collector being taken to the surface with the aid of an airbag.

Figure 2.3(d) Scraping the crevices in a crevice-type collector.

2.2.1.1 *Experiment 1*

The null hypothesis of no differences between collectors in catches of pueruli was tested.

Procedure

Ten collectors of each type were randomly set 3 m apart in waters of 10-12 m depth above or along the interface of rock and sand off Shark Island, near Port Hacking (Fig. 2.2). All were sampled fortnightly between October and December 1992 aboard a research vessel. Surface collectors were detached from the mooring by a diver and then taken on board (Fig. 2.3a). Each of the 3 panels was detached from the frame and shaken 30 times into a 320 l container (Fig. 2.3.b). Crevice-type collectors were sampled by a diver placing a bag over the collector, releasing the collector from the mooring and then bringing it to the surface with the aid of an airbag (Fig. 2.3c). The collector was placed in the 320 l container and pueruli were dislodged by probing each crevice with a scraper (Fig. 2.3d). The contents of the 320 l container were inspected and numbers of larval lobsters were counted and transferred to a 20 l container filled with seawater for transporting to the laboratory. In the laboratory lobsters were measured and staged as either pueruli (smooth carapace, transparent or brown in colour) or post-pueruli (spines on carapace and brown in colour). The length of each puerulus was measured as the straight line distance between the point of union of the second antennae and the centre of the posterior margin of the carapace (antennal carapace length, CL).

2.2.1.2 *Experiment 2*

The second experiment was a fully orthogonal design to compare catches of pueruli between types of collectors. It tested the null hypothesis that there were no differences in catches of *J. verreauxi* between seaweed-type and crevice-type collectors.

Experimental Design

In the experiment were the factors Type of Collector (seaweed or crevice) and Position of the collector (near the surface or substratum) and 4 replicates of each treatment were randomly set 3 m apart from each other. The experiment was done initially off Shark Island but, because few pueruli were caught, it was repeated at Curracurrang, also near Port Hacking (Fig. 2.2).

2.2.2 Effects of exposure to waves and position

This experiment tested the null hypothesis that there were no differences in the number of pueruli and post-pueruli between types of collectors set at the surface in waters exposed or unexposed to sea-swell and near or far from reef.

Experimental Design

Factors in the experiment were Exposure (exposed beach or sheltered embayment) and Position (near reef in waters shallower than 5 m and more than 200 m from reef in waters of 10-15 m depth, over bare sand). There were seven replicate seaweed-type collectors of each treatment (i.e. a total of 56 collectors). The experiment was done at 2 sites within each Exposure namely, exposed beaches (Coalcliff and Era) and sheltered bays (Wattomalla and Curracurrang) off the Royal National Park (Fig. 2.2). Collectors were sampled fortnightly from September to December 1993 (inclusive).

2.2.3 Effects of moon-phase and soak-time

The null hypothesis tested was that there were no differences in the number of pueruli caught between different soak-times at different phases of the moon.

Experimental Design

The design had four factors:

(i) Lunar Month (random; 3 levels: first quarter, October 1994 to new moon December 1994 inclusive),

(ii) Phase of the Moon (random; 4 levels: first quarter, full moon, last quarter, new moon),

(iii) Soak-Time (random; 4 levels: 1, 2, 3, or 4 weeks),

(iv) Location (fixed; 2 levels: Coffs Harbour, Port Hacking), and

(v) Sites (6 levels nested within locations, see Fig. 2.2).

There were 4 replicate collectors for each treatment so that at each sampling time 16 collectors were hauled at each location. Throughout the experiment treatments were randomly allocated to available collectors.

The experiment was done at 6 sites off each of the Royal National Park, and Coffs Harbour (Figs. 2.2). When sampled, collectors were pulled aboard a vessel, placed horizontally between bearings at either end of a 320 l container (tumbler) and rotated 30 complete turns clockwise then counter-clockwise (Fig. 2.4). Fauna in the collector dropped to the bottom of the container. Pueruli were counted, staged for development and measured (CL). The stages of development were:

Stage 1: cephalothorax transparent;

Stage 2: cephalothorax transparent, but with digestive gland evident;

Stage 3: cephalothorax cream to brown in colour, digestive gland no longer visible;

Stage 4: whole body cephalothorax brown, but without spines on the cephalothorax;

Stage 5: whole body dark brown and spines on the cephalothorax (post-puerulus); and

Stage 6: whole body green and spines on the cephalothorax (early juvenile) (see Fig 2.5).

Stages 1-4 and 5 equate to the puerulus and post-puerulus stages respectively used in earlier experiments. After the lobsters had been counted and measured, they were returned to the sea.

Figure 2.4(a) Tumbler used to sample seaweed-type collectors.

Figure 2.4(b) Seaweed-type collector being rotated in the tumbler to dislodge pueruli.

Figure 2.5 Pueruli stages 1 (far right) and 3 (middle) and post-puerulus (stage 5; left).

2.2.4 Surveys of the relative abundance of pueruli

Two data sets were used to examine patterns in the relative abundance of pueruli and post-pueruli off New South Wales. The first came from the experiment described here to test the null hypothesis that there are no differences in the relative abundance of pueruli and post-pueruli between locations and sampling times. The second data set came from continuing to monitor collectors at sites established as parts of experiments described in Sections 2.2.1 to 2.2.3.

2.2.4.1 Relative abundance of pueruli and post-pueruli

The random factors Location, Sites and Lunar-Month were used with 3 replicate collectors set at each of 3 sites at each of 6 locations, (Evans Head, Coffs Harbour, Tuncurry, Port Hacking, Ulladulla and Eden), along the coast of New South Wales (Figure 1.1).

Procedure

Sampling was based upon a system of rotating collectors so that each collector was moored at sea for no longer than 3 months at a time. The collectors used in the experiments in Sections 2.2.1 and 2.2.3 continued to be monitored once the experiments were completed. It was found that these collectors, after 5 months of soaking, were too heavy to sample efficiently. Organisms including pyura, barnacles and macro algae attached to the mooring ropes and collectors making the collectors too heavy to retrieve.

Collectors were sampled every 4 weeks during the first quarter of the lunar month because results from experiments in Section 2.2.3 suggested that this combination of soak-time and lunar-phase gave some of the greatest catches of pueruli and post-pueruli. Collectors at locations other than Port Hacking were sampled aboard chartered commercial fishing vessels by assistants stationed at each location. Those off Port Hacking were sampled by staff from the New South Wales Fisheries Research Institute aboard an Institute's vessel.

Cost-benefit analysis

To determine the optimal number of sites and collectors needed to estimate the mean relative abundance of pueruli, cost-benefit analyses were done. The standard cost-benefit analysis procedure was followed (e.g. Snedecor and Cochran 1967, Underwood 1981).

The restricting cost in this study was the amount of money available to sample a location once ($400), after monies had been deducted for the purchase of collectors and establishing and maintaining sampling sites. The costs associated with the sampling were determined from those incurred during the sampling period. The cost for sampling one site was taken as the cost to employ an assistant ($13), whilst the cost to sample an extra collector was the cost of maintaining the mooring and collector ($50 per lunar month of sampling).

Analyses of distributions of lengths

Pueruli and post-pueruli were measured to the nearest 0.1 mm. Samples were pooled from each location to produce length frequency distributions of 0.5 mm length classes.

2.2.4.2 *Continued sampling of collectors used in earlier experiments*

Procedure

Collectors at 6 sites off Port Hacking have been sampled at least monthly since 1992. Also, 7 collectors were set at each of 6 sites off Coffs Harbour in 1994 as part of Section 2.2.3.

The number of pueruli and post-pueruli on each collector were summed and weighted to the soak-time of the individual collector because the number of collectors sampled and soak-time of collectors varied among sites and locations between sampling times. This gave a standardised catch rate that could be used as an index of relative abundance of larvae.

2.3 RESULTS

2.3.1 Effects of type of collector

2.3.1.1 Experiment 1

Details of the results from this experiment can be found in Montgomery and Kittaka (1994, Appendix 2). A total of 23 pueruli and post-pueruli of *Jasus verreauxi* and 1 puerulus of *Jasus edwardsii* were caught in seaweed-type collectors set near the surface. No pueruli or post-pueruli were caught on the crevice-type collectors.

2.3.1.2 Experiment 2

The results from this experiment are detailed in Montgomery and Craig (submitted ms, Appendix 3). A total of 19 pueruli and post-pueruli of *J. verreauxi* were caught in seaweed-type collectors. Again, no pueruli were caught in crevice-type collectors. The mean number of pueruli caught in seaweed-type collectors near the surface was significantly greater than in seaweed-type collectors near the substratum (ANOVA, $p < 0.05$, Fig 2.6).

2.3.2 Effects of exposure and position

A total of 512 pueruli or post-pueruli were caught during the experiment. There was a significant difference in the catch rate of pueruli (all stages of development combined) among Sites within Exposure (ANOVA, $p < 0.05$). More pueruli were caught off Coalcliff the Era (Fig. 2.7). At 3 out of the 4 sites, mean catch rates of lobsters (all stages combined) from collectors set at the deep position were greater (but not significantly so) than mean catch rates from collectors at the shallow position, inferring that collectors set away from reef probably function better at collecting pueruli than collectors set near reef.

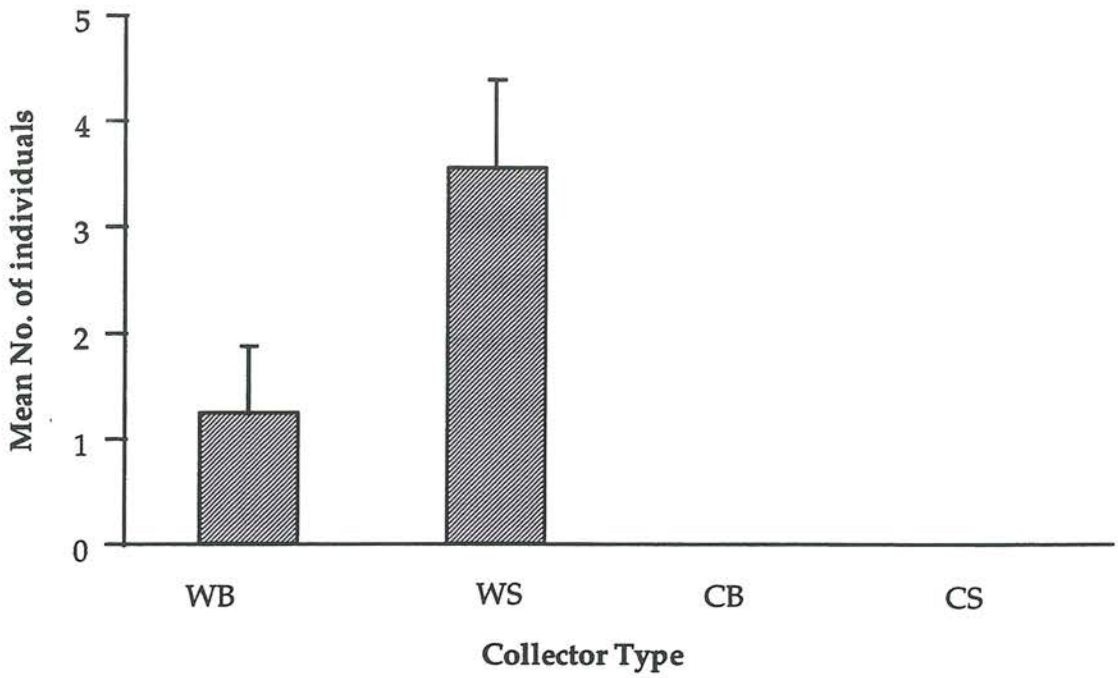

Figure 2.6. Comparison of mean relative abundance (±S.E.) of pueruli and post-pueruli of *J.verreauxi* between sea-weed type (W) and crevice-type (C) collectors, set near the surface (S) or substrate (B).

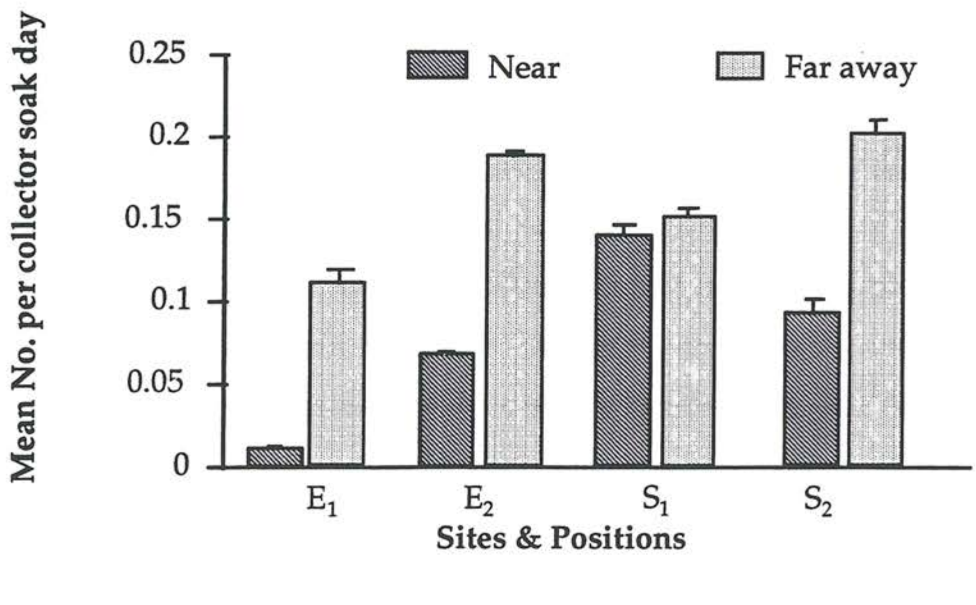

Figure 2.7. Comparisons of the mean relative abundance (±S.E.) of pueruli and post-pueruli of *J.verreauxi* sampled from collectors placed at exposed (Era E_1, Coalcliff E_2) or sheltered (Curracurrang S_1, Wattamalla S_2) sites and near of far from reef.

2.3.3 Effects of moon-phase and soak-time

There was a significant higher order interaction between all factors in the ANOVA (Table 2.1). This indicated that the catch of pueruli and post-pueruli depended upon the lunar-month, moon-phase, soak-time and location (Fig 2.8). In all but 5 Student-Newman-Keuls multiple comparisons (SNK tests) there were no significant differences in mean catches between moon-phases among treatments within the interaction term. On 4 occasions among those comparisons where there was a difference, mean catches were greatest or as great during new moon as at other phases of the moon. In contrast, for the other occasion when there was a difference, mean catches were less at new moon and first quarter than at the other phases of the moon.

In all but 6 multiple comparisons (SNK tests) there were no significant differences between soak-times in mean catches among treatments within the interaction term. On all occasions where there was a significant difference between soak-times among treatments in the interaction term, mean catches from collectors soaked for 4 weeks were greater or as great as at other soak-times. All significant differences among treatments caused by the effect of location were because of greater mean catches off Port Hacking than off Coffs Harbour (Fig. 2.8).

2.3.4 Surveys of the relative abundance of pueruli

2.3.4.1 *Relative abundance of pueruli and post-pueruli*

Mean catch rate of pueruli and post-pueruli depended upon the sampling period and the location sampled (ANOVA, $p < 0.05$). Patterns in mean catch rate within each location and sampling time are shown in Figure 2.9. Most individuals were caught between late September and early December inclusive. When there was a significant difference in mean catch rate between sampling periods within a location, the period of late October to early November had the greatest mean catch rate (SNK tests). The significant difference between locations within the sampling periods was due to greater

Table 2.1. Summary of analyses of variance to determine effect of moon phase and soak time on the catch of puerulus of *Jasus verreauxi* at different locations. Data are a subset of 4 weekly sampling from the data to look at the effects of lunar phase and soak. Data were transfomed by $\log_e$ (x+1).

C= 0.0496 ns (Cochrans test)

ns = Non-significant ($P > 0.05$); * = Significant ($P < 0.05$); ** = Significant ($P < 0.01$)

Treatment	SS	df	MS	*F*	*P*	vs *F*
Month = M	19.79	2	9.90	16.69	ns	MxL
Phase = P	2.56	3	0.85	1.75	ns	PxL
Soak = S	22.80	3	7.60	43.35	**	SxL
Location = L	37.62	1	37.62	107.03	**	RES
MxP	12.36	6	2.06	3.96	ns	MxPxL
MxS	3.07	6	0.51	1.15	ns	MxSxL
MxL	1.19	2	0.59	1.69	ns	RES
PxS	6.79	9	0.75	1.60	ns	PxSxL
PxL	1.46	3	0.49	1.38	ns	RES
SxL	0.53	3	0.18	0.5	ns	RES
MxPxS	7.28	18	0.40	0.64	ns	MxPxSxL
MxPxL	3.12	6	0.52	1.48	ns	RES
MxSxL	2.68	6	0.45	1.27	ns	RES
PxSxL	4.23	9	0.47	1.34	ns	RES
MxPxSxL	11.31	18	0.63	1.79	*	RES
Residual	101.22	288	0.35			
Total	237.97	383				

Table 2.1 (Cont.). SNK comparisons of means for the four factor interaction of the analysis of variance in Table 2.1. The new moon, first quarter, full moon and last quarter phases of the lunar month (M) are abbreviated as NM, FQ, FM and LQ, respectively. Soak-times of 1, 2, 3 and 4 weeks are denoted as S1, S2, S3, and S4, respectively. The locations of Port Hacking and Coffs Harbour are labelled P and C, respectively.

Treatment		Comparison of Means						
Moon-phase		NM		FQ		FM		LQ
C M1	S1:	0	=	0.34 (0.20)	=	0.69 (0.28)	=	0.45 (0.27)
	S2:	0	=	0.62 (0.23)	=	0.75 (0.44)	=	0.80 (0.37)
	S3:	0.35 (0.20)	=	1.27 (0.17)	=	0.62 (0.23)	=	1.43 (0.12)
	S4:	0.35 (0.20)	=	0.62 (0.23)	=	0.85 (0.34)	=	1.24 (0.23)
C M2	S1:	1.10 (0.37)	≥	0.28 (0.28)	=	0.52 (0.33)	=	0
	S2:	0.58 (0.38)	=	1.07 (0.14)	=	0.90 (0.12)	=	1.02 (0.22)
	S3:	0.49 (0.49)	=	1.14 (0.16)	=	0.52 (0.17)	=	1.28 (0.26)
	S4:	1.76 (0.15)	=	1.33 (0.29)	=	1.43 (0.25)	=	1.45 (0.28)
C M3	S1:	0.17 (0.17)	=	0	=	0	=	0
	S2:	1.00 (0.10)	=	0.27 (0.27)	=	0.23 (0.16)	=	0
	S3:	0.75 (0.33)	=	0.62 (0.36)	=	0	=	0
	S4:	0.69 (0.28)	=	0.69 (0.28)	=	0	=	
P M1	S1:	0.45 (0.27)	=	0.35 (0.35)	=	0.62 (0.23)	=	1.10 (0.24)
	S2:	0.68 (0.40)	=	1.00 (0.10)	≤	1.95 (0.37)	=	1.41 (0.27)
	S3:	1.52 (0.31)	=	1.43 (0.35)	=	0.97 (0.33)	=	1.44 (0.28)
	S4:	1.86 (0.65)	=	2.26 (0.22)	≥	1.05 (0.36)	=	0.55 (0.32)
P M2	S1	1.31 (0.46)	=	1.67 (0.33)	=	0.62 (0.23)	=	0.97 (0.56)
	S2:	1.68 (0.27)	=	1.24 (0.46)	=	1.21 (0.44)	=	1.72 (0.15)
	S3:	0.87 (0.30)	=	1.83 (0.30)	=	1.84 (0.64)	=	1.55 (0.06)
	S4:	1.65 (0.40)	=	2.36 (0.10)	=	1.75 (0.39)	=	1.94 (0.30)
P M3	S1:	1.35 (0.48)	≥	0.90 (0.38)	=	0.69 (0)	=	0
	S2:	1.11 (0.30)	=	0.90 (0.31)	=	1.02 (0.44)	>	0.35 (0.35)
	S3:	1.18 (0.42)	=	1.45 (0.18)	=	1.02 (0.22)	=	1.05 (0.36)
	S4:	1.98 (0.30)	=	1.68 (0.57)	=	1.59 (0.28)	=	0.62 (0.23)

Soak-time	S1		S2		S3		S4		S1		S2		S3		S4
C,M1,NM:	0	=	0	=	0.35	=	0.35	P,M1, NM:	0.45	=	0.68	<	1.53	=	1.86
FQ:	0.35	=	0.62	=	1.27	=	0.62	FQ:	0.35	=	1.00	<	1.43	<	2.26
FM:	0.69	=	0.75	=	0.62	=	0.85	FM:	0.62	<	1.95	>	0.97	=	1.05
LQ:	0.45	=	0.80	=	1.43	=	1.24	LQ:	1.10	=	1.41	=	1.44	=	0.55
C,M2,NM:	1.10	=	0.58	=	0.49	<	1.76	NM:	1.31	=	1.68	=	0.87	=	1.65
FQ:	0.28	=	1.07	=	1.14	=	1.33	FQ:	1.67	=	1.24	=	1.83	<	2.36
FM:	0.52	=	0.90	=	0.52	=	1.43	FM:	0.62	=	1.21	<	1.84	=	1.75
LQ:	0	<	1.02	=	1.28	=	1.45	LQ:	0.97	=	1.72	=	1.55	=	1.94
C,M3,NM:	0.17	=	1.00	=	0.75	=	0.69	P,M3,NM:	1.35	=	1.11	=	1.18	=	1.98
FQ:	0	=	0.28	=	0.62	=	0.69	FQ:	0.90	=	0.90	=	1.45	=	1.68
FM:	0	=	0.23	=	0	=	0	FM:	0.69	=	1.02	=	1.02	=	1.59
LQ:	0	=	0	=	0	=	0	LQ:	0	=	0.35	=	1.05	=	0.62

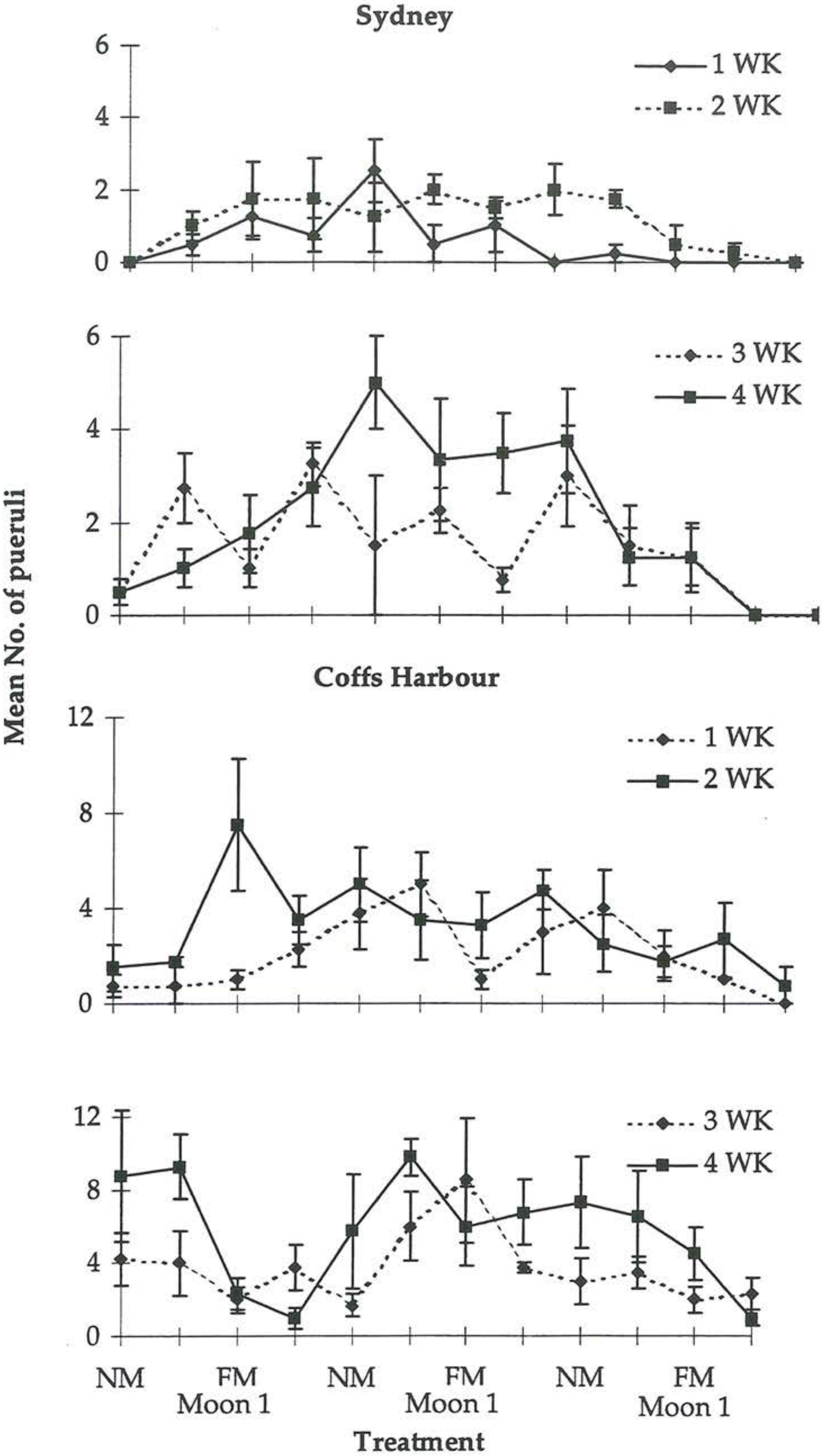

Figure 2.8. Patterns in the mean relative abundance (±S.E) of pueruli and post-pueruli sampled at 4 phases of the moon and soak-time.

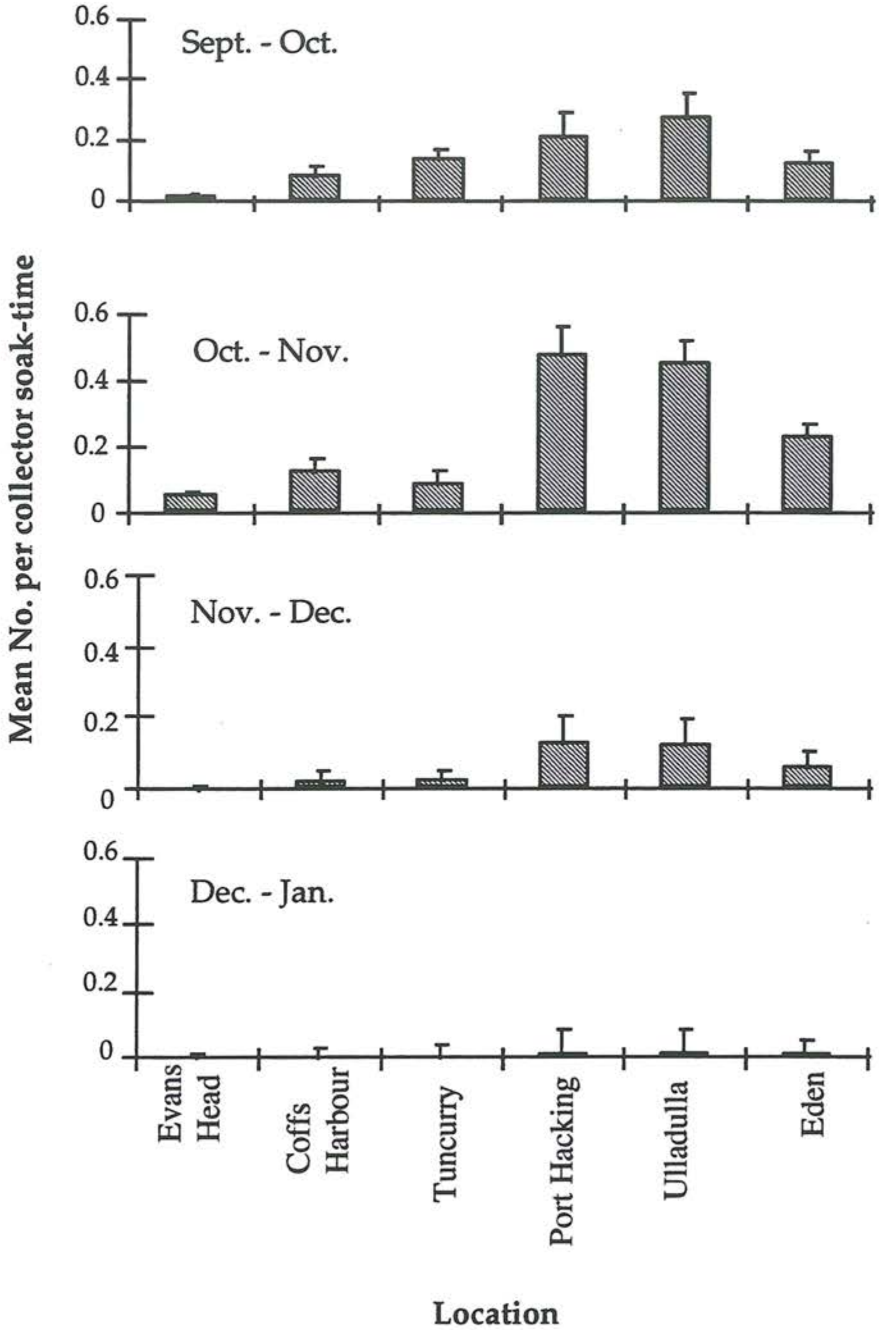

Figure 2.9. Mean (±S.E.) catch rate of pueruli and post-pueruli at each location during the season of puerulus settlement over 1995-96.

mean catch rates at Port Hacking and Ulladulla than at other locations over the sampling period of late October to early November (SNK tests).

Cost-benefit analyses

The optimal number of sites and collectors to sample per location at any one sampling period together with the anticipated sizes of the coefficient of variation are shown in Table 2.2. Because pueruli are caught by collectors for approximately 7 lunar months per year, sampling need not be done in every lunar month of the year. If sampling is done for only 7 lunar months per year when pueruli occur on collectors then 3 collectors within each of 3 sites at 6 locations is optimal. This strategy provides a mean estimate of the relative abundance of pueruli and post-pueruli with a coefficient of variation of around 21%.

Distribution of lengths

Sizes of spiny lobsters caught on collectors ranged from 8.8- 30.0 mm CL and had a mean of 11.9 mm CL (Figure 2.10). Lengths of pueruli (stages 1-4) ranged from 8.8-14.5 mm CL (mean=11.2 mm CL) whilst those of post-pueruli (stage 5) ranged from 8.8-19.5 (mean=12.6) and juveniles (stage 6) ranged from 11.6-30.0 (mean=17.2 mm CL; Figure 2.10).

2.3.4.2 Continued sampling of collectors used in earlier experiments

Temporal patterns in the relative abundance of pueruli and post-pueruli (pooled) caught on collectors off Coffs Harbour, Port Hacking and Shark Island since sampling began at these places are shown in Figure 2.11. Pre-settlement lobsters occurred on collectors from September to January each year, though in 1995-96 some were caught as early as June off Port Hacking. The index of relative abundance was either as great or greatest during sampling at the lunar month in October than at other times each year and was greater off Port Hacking than off Coffs Harbour.

Table 2.2. Summary of cost-benefit analyses to determine the optimum number of collectors per site and number of sites per location per sampling month. Shown also are the standard deviation (SD), mean catch rate of pueruli rate, coefficients of variation (CV) associated with the optima for sampling are shown.

	df	Mean Squares
Locations	5	0.0246
Sites	12	0.0051
Residual	18	0.0029

	Determined	Chosen
Variances:		
among locations	0.0033	
among sites	0.0007	
among collectors	0.0029	
number of locations	6	6
number of sites	2.4	3
number of collectors	3	3
Estimated SD	0.03	0.03
Mean number of pueruli	0.11	0.1121
CV optimal replication	26.4	24.0

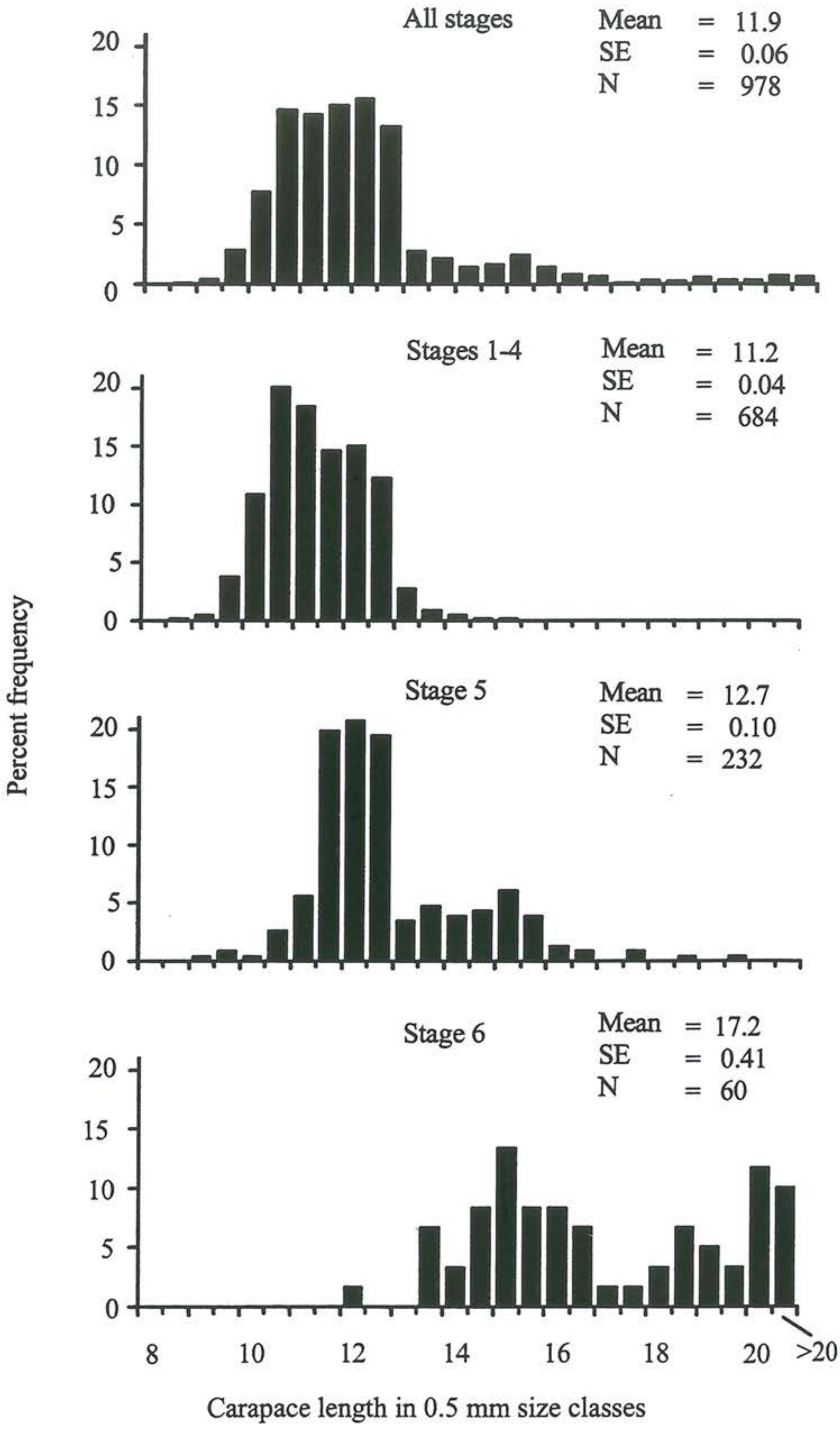

Figure 2.10 Length-frequency distributions of pueruli stages 1-4, post-pueruli (stage 5), early juveniles (stage 6) and total *J. verreauxi* sampled from collectors during the survey in 1995-1996.

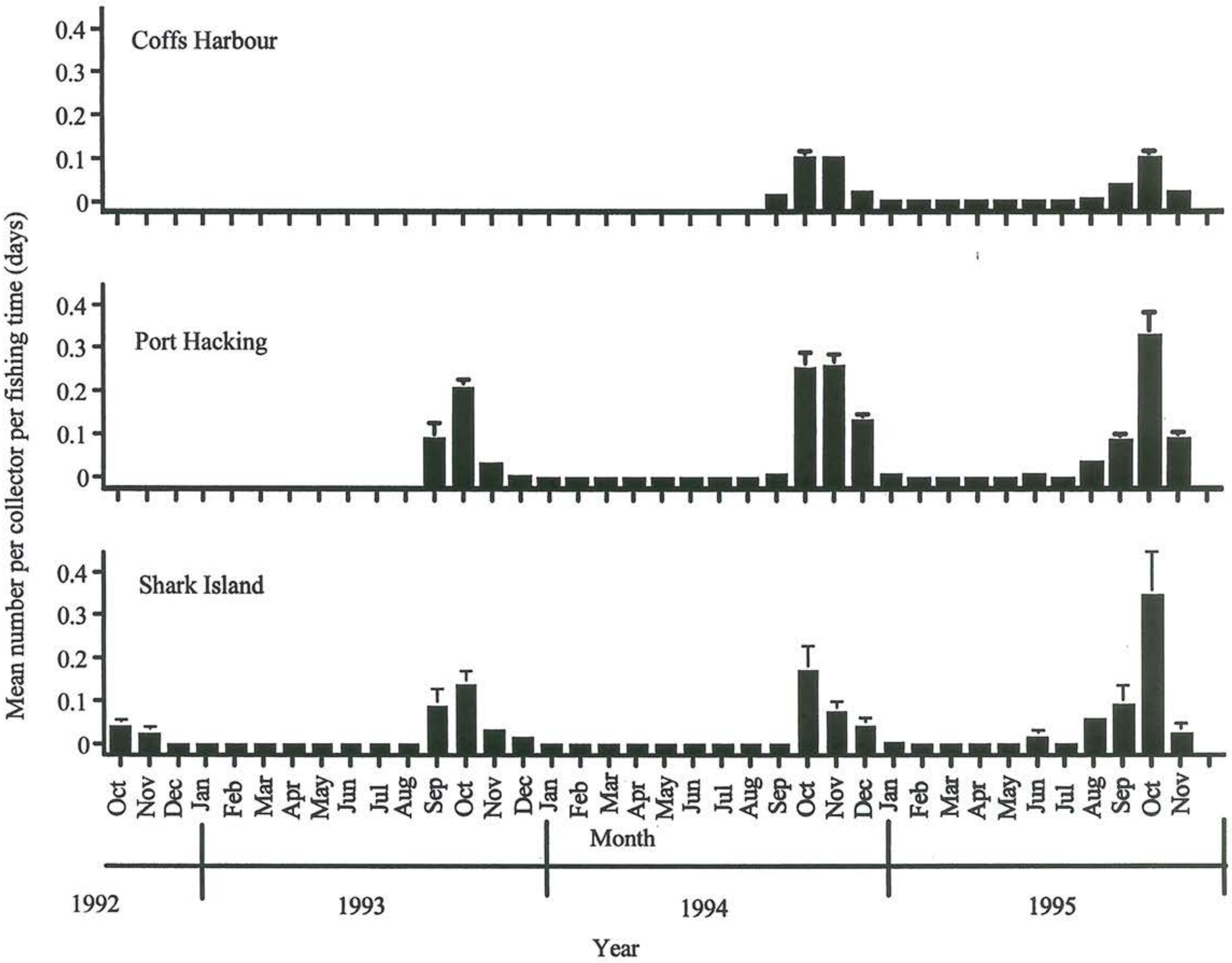

Figure 2.11. Mean relative abundance (+ SE) of pueruli and post-pueruli of J. verreauxi at Shark Island Coffs Harbour and Port Hacking.

2.4 DISCUSSION

Results presented in this chapter showed that collectors were useful for catching pueruli and post-pueruli of *Jasus verreauxi* (see also Montgomery and Kittaka 1994, Appendix 2). Catch rates of pueruli and post-pueruli from collectors can be used as an index of recruitment to the population. When collectors are used to collect information on relative abundance, the effect upon catches of pueruli and post-pueruli of external factors must be known so that a standard sampling strategy can be adopted (Booth and Stewart 1993, Phillips and Booth 1994).

Results in this study suggested that seaweed- type collectors were likely to be the best attracting device to use to sample pueruli of *Jasus verreauxi*. Seaweed-type collectors attracted and retained pueruli and post-pueruli of *J. verreauxi* species whereas crevice-type collectors did not. It may be premature however to conclude that pueruli of *J. verreauxi* can be caught only on seaweed-type collectors because the number of pueruli caught were few.

The design of the seaweed-type collector used by Phillips (1972) was changed by supporting 2 panels of polyethylene fibre on a centre frame rather than 3 panels in a triangular structure (Montgomery and Craig submitted ms, Appendix 3). Also, the collector was attached to a far heavier mooring than used by Phillips (1972). These changes were done to reduce the resistance of the collector to heavy swells. The New South Wales' coast is dominated by exposed, rugged cliffs and beaches rather than sheltered embayments. Phillips and Booth (1994) recommended that seaweed-type collectors be placed in sheltered waters. However, to do this off New South Wales would drastically reduce the area of coastline suitable for collectors and hence possibly bias information collected.

Catch rates of pueruli and post-pueruli of *J. verreauxi* on seaweed-type collectors were affected by the position of the collector in the water column. Possibly, collectors near the surface caught more pueruli and post-pueruli than those near the substratum because they were competing less with natural habitat for lobsters. Collectors near the surface caught lobsters that were still swimming in search of habitat, whereas collectors near the substratum probably attracted individuals that were settling or had already settled to a benthic existence.

Collectors set near the surface also had the advantage that they were easier to sample than crevice-type collectors. The Occupational Health and Safety Guidelines of the New South Wales Government require that 3 divers certified to AS2815.1 level be used when SCUBA diving to sample collectors near the substratum. This reduces the number of staff available to assist with sampling and increases training costs, compared to sampling collectors near the surface. A further advantage in having collectors near the surface is that the collectors can be seen between sampling periods, particularly after big sea-swells. Any loss or damage to collectors therefore can be fixed quickly.

The placement of collectors with respect to exposure to sea-swell and reef did not have a significant effect upon catches of pueruli. Seaweed-type collectors near the surface and away from reef were more successful at attracting pueruli because again these collectors probably did not compete with natural habitat as much as collectors set in shallow waters and in close proximity to reef. Collectors in the deeper water were either too far above the substratum for individuals to move between the substratum and surface or from natural reef further inshore for pueruli and post-pueruli to be influenced to continue moving shorewards.

The pattern in settlement of pueruli and post-pueruli of *J. verreauxi* was not determined solely by the phase of the moon. Other factors such as the direction and strength of currents and winds probably play a role in determining the pattern in settlement (e.g. Caputi et al. 1995). On most occasions when SNK tests identified a significant difference in mean catch between phases of the moon among treatments, the greatest mean catches occurred around new moon. In the present study results from SNK tests showed also that in most cases when there was a significant difference in mean catches between soak-times among treatments, the mean catch of collectors soaked for 4 weeks was as great or greater than those soaked for 1, 2 or 3 weeks.

Pueruli and post- pueruli of *J. verreauxi* occurred in nearshore waters off the coast of New South Wales from June to February but predominantly between September and December (spring) each year. This temporal pattern differed from that reported for most other spiny lobster species (see Booth and Phillips 1994) in that settlement was not continuous throughout the year, and did not peak more than once in a year.

The great variability in the spatial distribution and abundance of pueruli of *J. verreauxi* found in this study is typical of spiny lobster populations (e.g. MacDonald 1986, Marx 1986, Booth 1994, Briones-Fourzan 1994, Herrnkind et al. 1994). Mean catches of pueruli and post-pueruli in the present study tended to be greater at the central and southern locations sampled. This spatial pattern concurs with the pattern in abundance of juvenile *J. verreauxi* shorter than 120 mm CL (around the longest length found on inshore grounds; Montgomery 1995). The abundance of juvenile lobsters shorter than 120 mm CL is greater on inshore grounds off southern sampling locations than northern locations.

Similarly, the greatest relative abundance of *J. verreauxi* shorter than 100 mm CL was found along the southern regions of the east coast of the North Island of New Zealand (Booth 1986). Studies on tagged juvenile *J. verreauxi* off the North Island of New Zealand showed that tagged individuals moved in a north-westerly direction against the prevailing currents toward spawning grounds to the north of the North Island (Booth 1984, 1986). Considering the similarity in length distributions of *J. verreauxi* between Australia and New Zealand it is likely that these lobsters move in a northerly direction off New South Wales.

Distributions of lengths of pueruli and post-pueruli are similar to those reported for other species of inshore palinurids (see Phillips and Sastry 1980, Booth and Phllips 1994). In the experiments described in this chapter, lobsters as long as 30 mm CL were caught on collectors. Most pueruli and post-pueruli though were shorter than 13 and 16 mm CL, respectively.

The difference in mean length between pueruli and post-pueruli among locations represented a moult increment of around 1.4 mm CL. Booth (1979) also estimated the moult increment for *J. edwardsii* from puerulus to post-puerulus to be 1.3 mm CL and suggested that lobsters longer than 13 mm CL in samples may have undergone a second moult. This is most likely the case also for lobsters longer than 13 mm CL in samples in this study.

Results from the experiments described in this chapter were used to develop an optimum sampling strategy for collecting information on the relative abundance of pueruli and post-pueruli of *J. verreauxi* off the coast of New South Wales. These showed that settlement of pueruli is seasonal. Hence, sampling need only be done, between August and January (inclusive). The sampling design was limited by the amount of research funds available. It was decided that at least 3 collectors were needed per site.

CHAPTER 3

THE RELATIVE ABUNDANCE OF JUVENILES AND ADULTS

3.1 INTRODUCTION

Data on the relative abundance of juveniles can be used to complement that for pueruli as an index of recruitment. Information on the relative abundance of juveniles tells us about when and where recruitment to the fishable portion of the population takes place and about the relative "strength" of recruitment to the fishable population each time it occurs (commonly referred to as year-class strength). This information can be used to assess the effect of management on recruitment to the fishable population.

Data about the relative abundance of adults provides information about the abundance of individuals capable of spawning that are in the population. This, together with data about the relative abundance of recruits can be used to determine whether there is a relationship between the abundance of recruits and abundance of spawning individuals in the population (for a review see Hilborn and Walters 1992).

A time-series of data on relative abundance provides knowledge about the biomass of the population. These, together with data on fishing effort, allow scientists to assess the response of populations to exploitation. Data on relative abundance are incorporated into population models to determine the quantity of biomass that can be taken from the population and the likely response of the population to various management scenarios (e.g. Walters et al. 1993).

Factors that affect catches of marine animals in traps have been discussed by Miller (1983). These factors need to be understood so that sampling can be standardised and bias minimised. Apart from environmental considerations, the most important factors to be considered when designing sampling strategies based upon the method of trapping are the shape of the trap, type of bait and soak-time of the trap.

This chapter describes experiments done to quantify the effects of trap-design, bait and soak-time have on catches of lobsters. Results from these experiments were then used to develop a sampling strategy for monitoring the relative abundance of juvenile and adult lobsters.

3.2 MATERIALS AND METHODS

3.2.1 Effects of trap-design, bait-type and soak-time on catches from inshore grounds

Study Sites

Three experiments were done on grounds in water less than 10 m deep off Coalcliff (Fig. 2.2). Commercial fishers considered lobsters to be more abundant in this area than neighbouring grounds.

3.2.1.1 Experiments 1 and 2

The null hypothesis tested, was that on inshore grounds there were no differences in catches of lobsters. between design of traps, types of bait or soak-times.

Procedure

A multi-factorial experiment was done to compare the catches of lobsters between Trap-Design (fixed, D-shape or Beehive; Fig. 1.2), Bait-Type (fixed, Flathead or Redfish) and Soak-Time (random, 1, 2 or 3 nights). There were 3 replicates of each treatment (trap, bait and soak-time combination) set in a random order by commercial fishers. Lobsters caught in each replicate were counted and their lengths measured. The length of all lobsters was measured as the straight line distance between the centre of the posterior margin of the carapace and the front of the base of the antennal platform (CL).

3.2.1.2 *Experiment 3*

The null hypothesis tested was that there were no differences in catches of lobsters on inshore grounds between designs of traps or types of bait.

Procedure

Two designs of rectangular traps were compared with the D-shaped and beehive traps. The experiment was done because commercial fishers thought that a rectangular shaped trap would better serve our purposes when doing surveys. The rectangle traps differed in dimensions and materials (Fig. 1.2). One rectangular trap (R_1) was built of 50 mm weld mesh. The other rectangular trap (R_2) was made of a 6 mm reo-steel frame covered with 50 mm wire mesh. Each trap had a bait bag filled with flathead or blackfish secured into it. The traps were set on three occasions using the same procedure (making a total of 12 replicates for each treatment). Lobsters caught in each trap were counted and the sex and length (CL) of each individual was determined.

3.2.2 Effects of bait-type and soak-time on catches from mid-shelf grounds

An experiment was done to test the null hypothesis that there were no differences in catch rates of lobsters between different types of bait or soak-times. Large rectangular traps each with an entrance in each of 3 sides and covered with 50 mm wire mesh (Fig. 1.3a) were set on grounds in 100-120 m depth in waters off Terrigal.

The random factors Soak-Time (approximately 3, 7 or 14 days) and Bait-Type (brined, cured and fresh fish and cow's hooves; Fig. 1.3b) were orthogonal and there were 5 replicates of each treatment in the experiment. The experiment was done around the moon-phase of new moon in

December 1993 and repeated at the same time of the lunar month in January 1994 (making a total of 10 replicates for each treatment).

Treatments were randomly assigned among the 60 traps in the experiment. Traps were set and hauled from a chartered commercial vessel. Lobsters in each trap were counted, measured and sexed.

3.2.3 Surveys of the relative abundance of juvenile and adult lobsters

Surveys were done to test the null hypothesis that there were no differences in the abundance of lobsters between locations. In the experiment were the random factors Location and Surveys (within each Location). Information collected would be used to determine the optimal sampling strategy for estimating the relative abundances of juvenile and adult lobsters.

Meetings were held with commercial fishers along the coast to identify the type of habitat where lobsters occur, and to discuss sampling strategies. Surveys were restricted to grounds shallower that 100 m and to the period of the year between August and February. Commercial fishers were of the opinion that most of the lobster population was in waters shallower than around 100 m at this time of the year.

A survey location was defined as grounds within a 15 nm length of coast (measured in a straight line) and in waters from the mean high water mark to depths of approximately 100 m. This area was divided into 0.5 x 0.5 nm grids. Lobster habitat within the location was stratified into grounds (i) shallower than approximately 20 m (inshore grounds) and (ii) in waters around 21-100 m depth (mid-shelf grounds). Surveys were restricted to those inshore grounds with vegetated reef and to those mid-shelf grounds with reef or mud substratum.

3.2.3.1 Surveys of inshore grounds

Two surveys were done at each of 3 locations (Coffs Harbour, Tuncurry and Ulladulla), between August and November. Five 0.5 nm grids containing grounds that satisfied the criteria for rock lobster habitat were chosen at random. Commercial fishers were chartered to fish with the research gear in the presence of scientific staff. Grids were located at sea by using navigational bearings read from satellite navigation instruments to find the boundary of each grid. Ten beehive pots each baited with a bag containing 50% flathead and 50% blackfish were set around 15 m apart on grounds within the chosen grid. Traps were pulled after approximately 24 hrs. Lobsters were counted and the sex and length (CL) of each individual was determined. Numbers of lobsters from each of the ten traps within a grid were pooled to give the total number of individuals per set.

3.2.3.2 Surveys of mid-shelf grounds

Two surveys were done within each of two Locations (Sydney and Ulladulla) between October 1995 and February 1996. A set of gear consisted of 2 large rectangular traps separated by 60 m and connected by a single rope (Fig 3.1a and b). There was an entrance on each of three sides of the trap. One trap of each pair had entrances with an internal diameter at the inside edge of about 30 cm, whilst the other trap had entrances with an internal diameter of about 20 cm. Two bags made of wire mesh and containing cattle hooves and brined plus dried mullet as bait, were secured in each trap.

Each set of traps was placed on grounds in each of 6 randomly chosen grids that contained rock lobster habitat. Each set was pulled after soaking for 14 nights and the lobsters were removed. Traps were baited again and placed in six randomly chosen grids to begin the next survey. Lobsters caught were counted and the sex and length (CL) of each individual was determined. Numbers of lobsters from each of the 2 traps within a grid were pooled to give the total number of individuals per set.

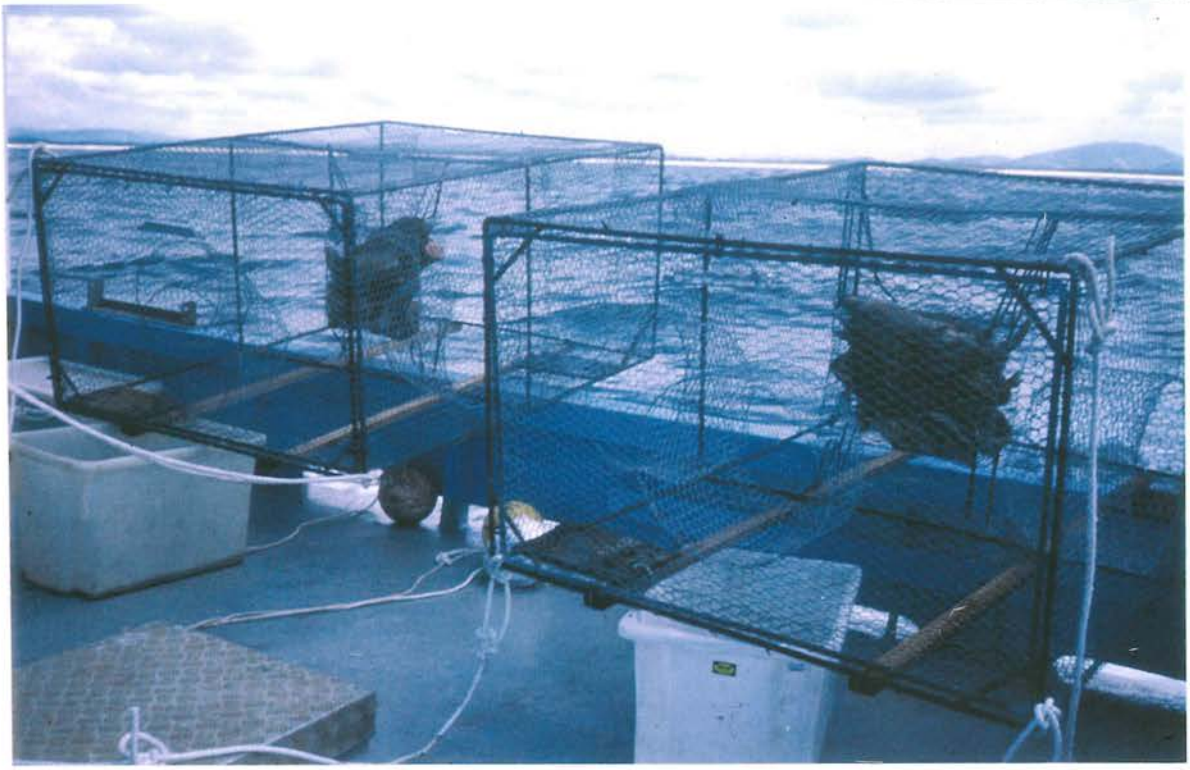

Figure 3.4(a) A set of rectangular traps ready to be shot away.

Figure 3.4(b) Styrene floats mark the traps at the surface.

3.2.3.3 *Cost-benefit analyses*

After the experiment was completed, cost-benefit analyses were done to determine the optimal numbers of sites and traps within sites needed to measure the relative abundance of lobsters at a location. The standard cost-benefit analysis procedure was followed (e.g. Snedecor and Cochran 1967, Underwood 1981).

The restricting cost in this study was the cost of sampling a location ($3,800 and $8,800 for inshore and mid-shelf grounds, respectively). The costs associated with the sampling were determined from those incurred during the sampling period. The cost for doing a survey on inshore grounds at one location was taken as the travel allowance for 3 staff for 5 days, whilst the cost to do a set on inshore grounds was the cost to charter a vessel ($50 per set) plus the cost of a temporary assistant ($13 per set) plus the cost to bait a set of traps ($18). The cost for doing a survey on mid-shelf grounds was the cost to charter a vessel (daily rate of $1,100) plus the travel allowance for 2 staff for 4 days, whilst the cost to do a set on mid-shelf grounds was the cost of a temporary assistant ($13 per set) plus the cost to bait a set of traps ($120).

3.3 RESULTS

3.3.1 Effects of trap-design, bait-type and soak-time on catches from inshore grounds

There were no differences in the mean number of lobsters caught between different Trap-Designs, nor were there any differences in means between Bait-Types or Soak-Times (ANOVA, $p < 0.05$, Figs. 3.2 and 3.3). Based upon these results it was decided that beehive traps baited with flathead and blackfish would be used to survey lobsters on inshore grounds. Traps would be soaked for 24 hours. Beehive traps are easy to handle, commonly used by fishers, and are more resilient to big sea-wells than other designs of traps.

Blackfish and flathead are among the fish species preferred as bait by commercial fishers. A soak-time of 24 hours helps to prevent pilfering of gear.

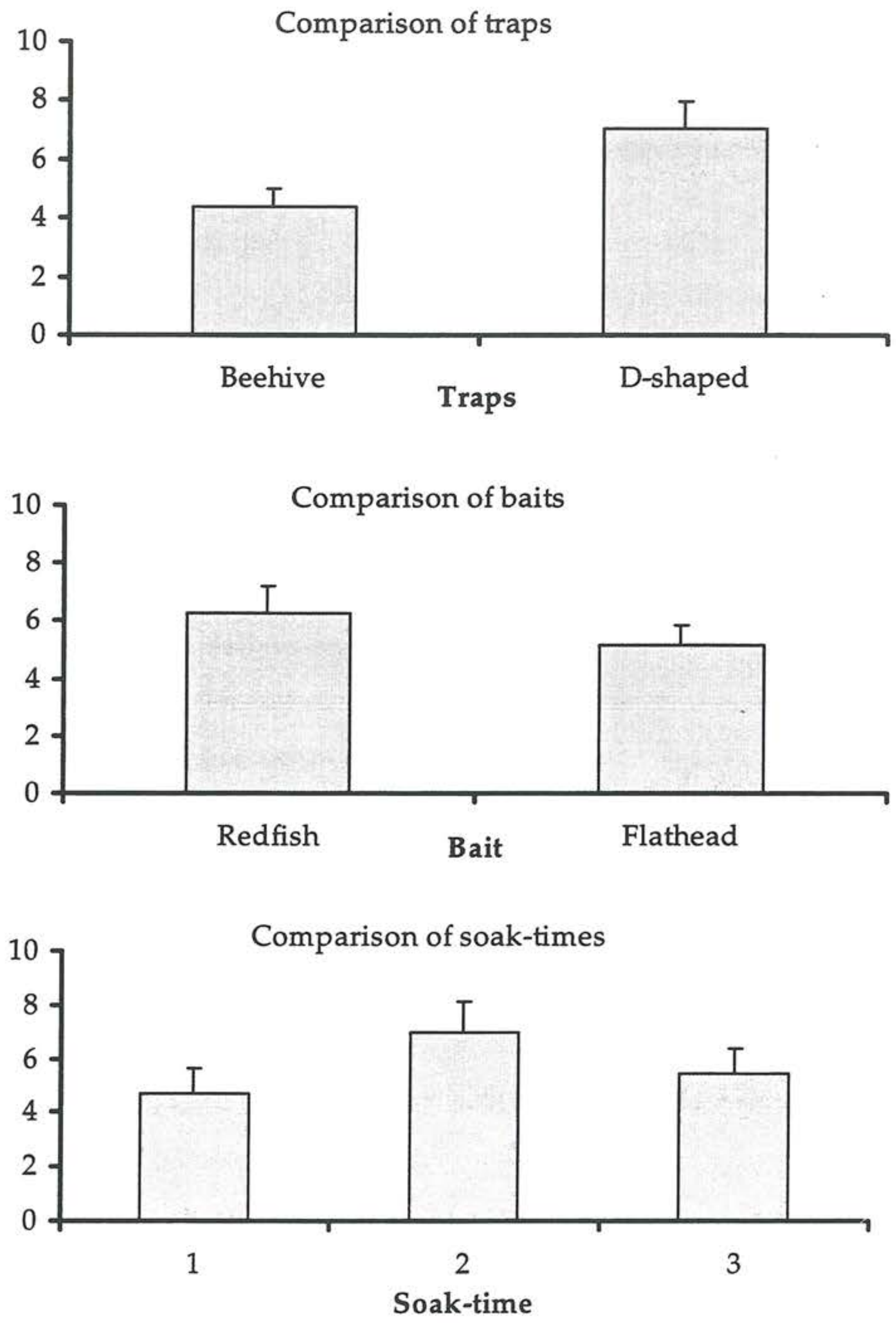

Figure 3.2. Comparisons of mean catches (±S.E) of *J.verreauxi* on inshore grounds between designs of traps, types of bait and soak-times used in experments 1 and 2.

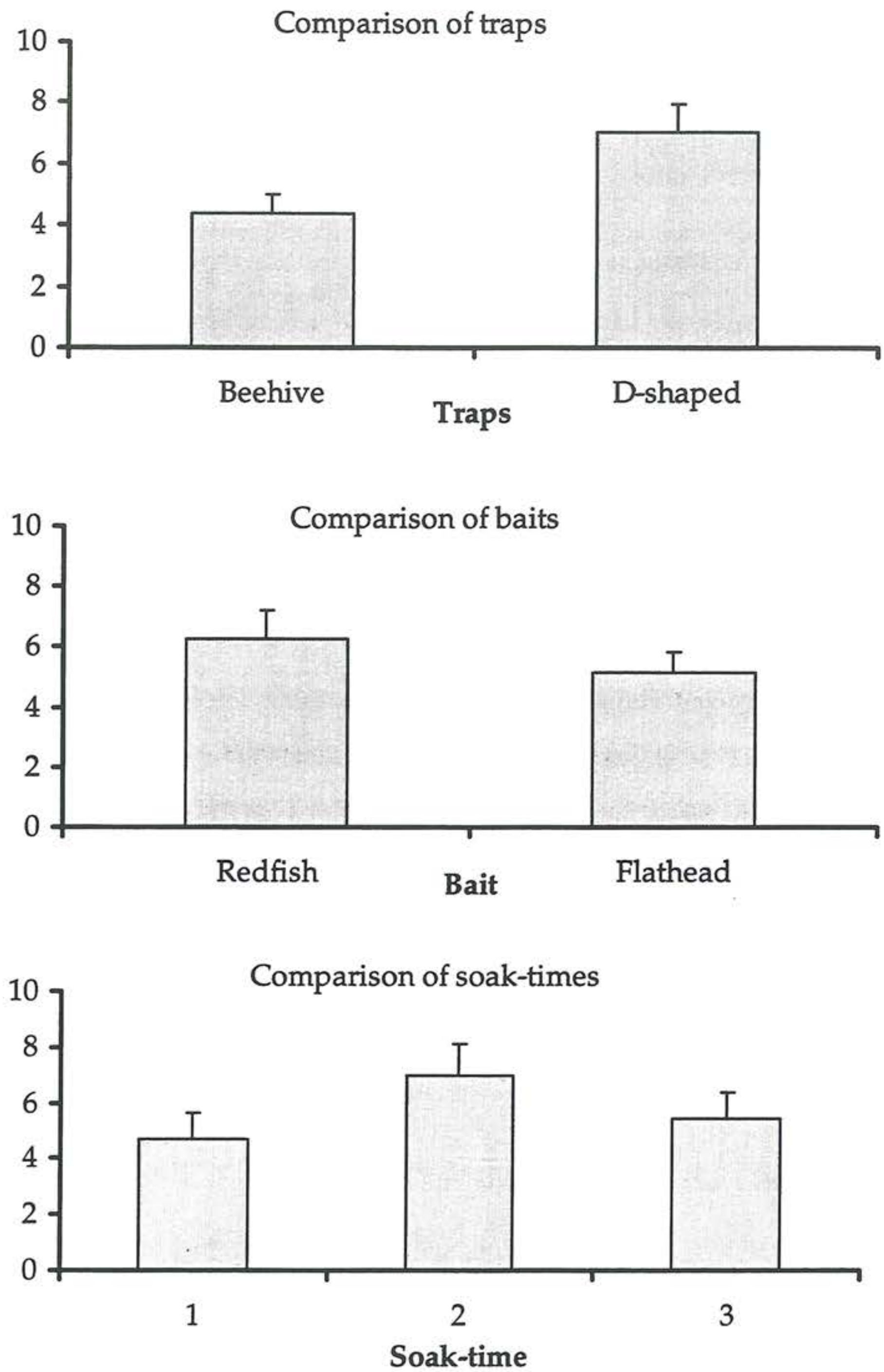

Figure 3.2. Comparisons of mean catches (±S.E) of *J.verreauxi* on inshore grounds between designs of traps, types of bait and soak-times used in experments 1 and 2.

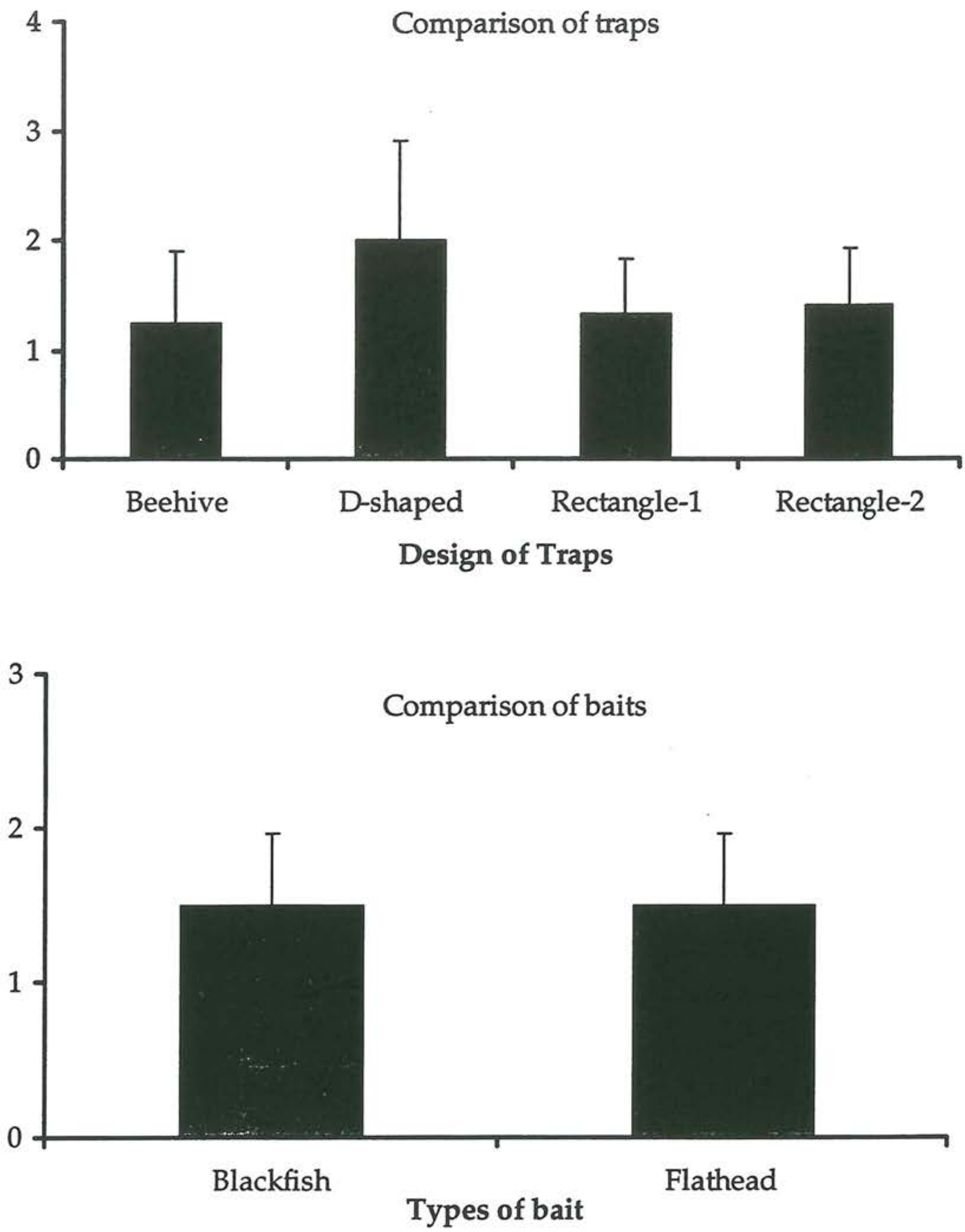

Figure 3.3. Comparisons of mean number (±S.E.) of *J.verreauxi* caught on inshore grounds between designs of traps and types of bait used in experiment 3.

3.3.2 Effects of bait-type and soak-time on catches from mid-shelf grounds

It was not possible to do an ANOVA with these data because the variance between replicates varied between treatments. Examination of means suggested that a greater number of lobsters were caught in traps that had been soaking for approximately 14 days (Fig. 3.4). There appeared to be no differences in the number of individuals caught between Types of Bait. Based upon these results, it was decided that rectangular traps with a mixture of the types of bait used in this experiment would be used to do experiments on mid-shelf grounds. Traps would be soaked for 14 days.

3.3.3 Surveys to collect information on the relative abundance of juvenile and adult lobsters

3.3.3.1 Surveys of inshore grounds

There was a significant difference in the number of lobsters caught between locations (ANOVA, $p < 0.05$ Fig 3.5). However, due to the low numbers caught, the results of the ANOVA were of limited value when interpreting the data. More lobsters were caught off Ulladulla than off Coffs Harbour and Tuncurry, but there was no significant difference in the number of lobsters caught between Coffs Harbour and Tuncurry.

Lobsters in samples from Coffs Harbour, Tuncurry and Ulladulla ranged from 108 - 155, 103 - 141 and 79 - 124 mm CL, respectively.

3.3.3.2 Surveys of mid-shelf grounds

Significantly more lobsters were caught off Sydney than Ulladulla (ANOVA, $p < 0.05$; Fig 3.5). Lengths of lobsters from samples taken off Ulladulla ranged from 110 - 141 mm CL whilst those in samples from Sydney ranged from 106 - 200 mm CL.

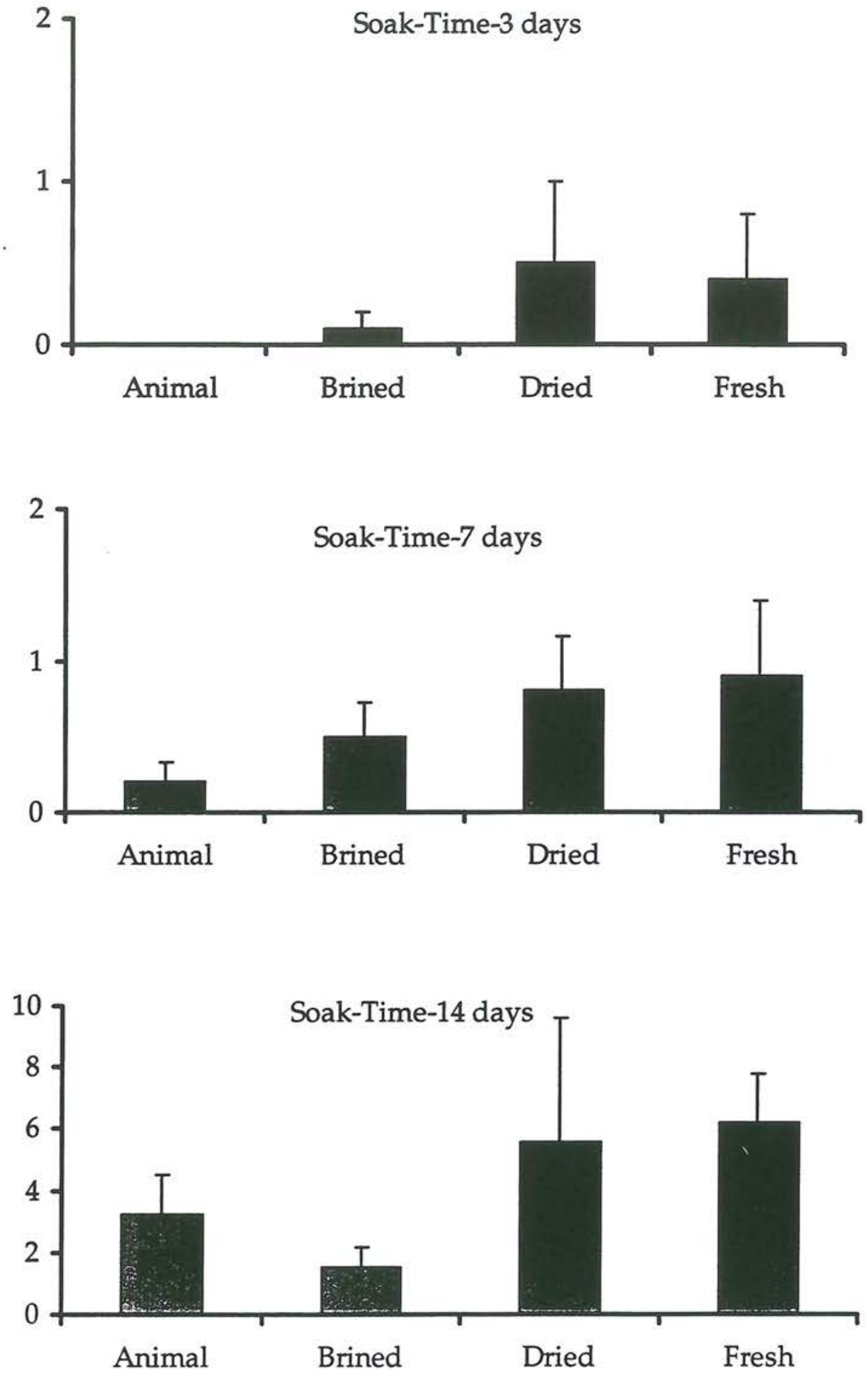

Figure 3.4. Comparisons of mean number (±S.E) of *J.verreauxi* caught on mid-shelf grounds between different types of bait and among various soak-times.

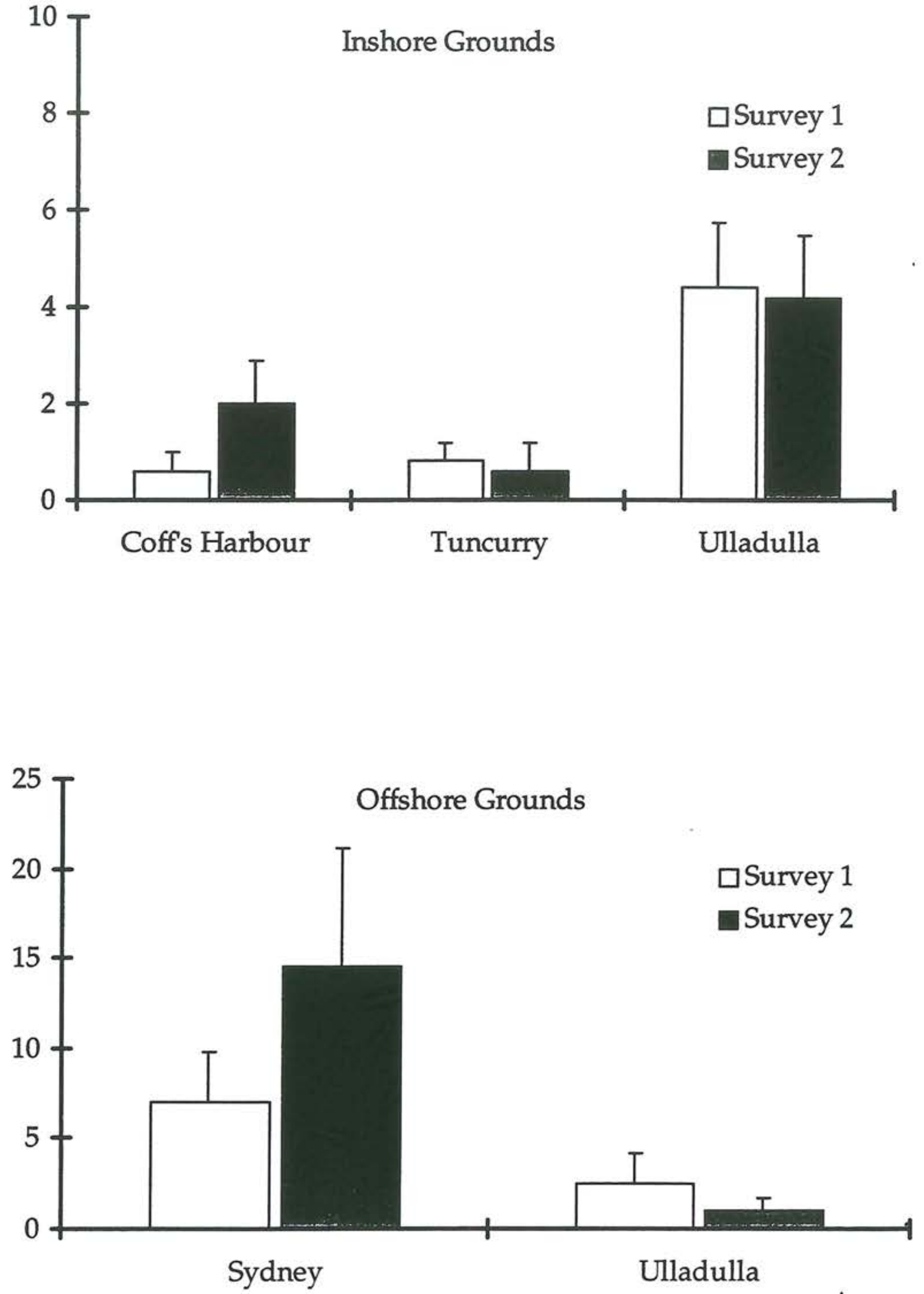

Figure 3.5. Comparisons of mean catch (± S.E.) of *J.verreauxi* caught in fishery independent surveys done on inshore and mid-shelf grounds between locations sampled.

Table 3.1. Summary of cost-benefit analyses to determine the optimum number of sets per survey and number of surveys per location per sampling month. Shown also are the standard deviation (SD), mean catch rate of lobsters coefficients of variation (CV) associated with the optima for sampling are shown.

	df	Mean Squares	
		Inshore	Offshore
Locations	5	37.20	11.10
Surveys	12	5.10	1.17
Residual	18	97.20	1.10

	Inshore		Offshore	
	Determined	Chosen	Determined	Chosen
Variances:				
among locations	5.92		2.48	
among surveys	1.00 (minus variance)		0.04	
among sets	4.05		1.10	
number of locations	3	3	3	3
number of surveys	0.92	2	1.06	2
number of sets	11.63	10	31.11	5
Estimated SD	0.68	0.55	0.26	0.37
Mean number of lobsters	2.1	2.1	6.25	6.25
CV optimal replication	32.5	26.2	4.1	6.0

3.3.3.3 Cost benefit analysis

Surveys of inshore grounds

The variance among surveys and sets, together with the derived optimal number of sets and surveys to be sampled, are shown in Table 3.1. Results suggested that the most optimal dsign for 3 locations was to sample 10 sets, in each of 2 surveys per season. This will provide an estimate of mean abundance of lobsters on inshore grounds with a coefficient of variation of around 25% of the mean value (Table 3.1).

Surveys of mid-shelf grounds

Similarly, the optimal strategy for mid-shelf grounds at 3 locations was to sample 31 sets in 1 survey per season. For reasons of pseudo-replication we chose to do 5 sets (the maximum number of sets that can be processed in a day's fishing) in each of 2 surveys per season. This strategy provided an estimate of the mean relative abundance of lobsters on mid-shelf grounds with a coefficient of variation of around 6% of the mean value (Table 3.1).

3.4 DISCUSSION

Results presented in this study suggested that the design of traps, types of bait and soak-times had little effect upon the number of lobsters caught on inshore grounds. Catches on mid-shelf grounds appeared to be greater when traps were left to soak for at least 14 days.

The designs of traps, types of bait and soak-times compared in this study were those commonly used by commercial fishers. As no differences were observed in catches of lobsters among these factors, we used beehive traps baited with blackfish and flathead to survey inshore grounds. Although D-shaped traps appeared to catch more lobsters (though not significantly more), they were cumbersome to transport, which added to the cost of the surveys. Blackfish and flathead are among the preferred baits used by most commercial fishers operating on inshore grounds and are readily available.

Most lobsters were caught in traps that had been soaking on inshore grounds for 2 days. However experience indicated that pilfering of traps can be a problem. This theft leads to unbalanced replication and a downwards bias in estimates of relative abundance. Using a soak-time of 1 day minimises the risk of pilfering and also allows more grounds to be surveyed within the time available per month.

Greater catches were taken in traps with the longest soak-time compared in this study on mid-shelf grounds. Fourteen days was approximately the longest period of time that gear could be left on any one ground and still have sufficient time to complete the survey. There were no apparent differences between the types of bait compared within the data for a soak-time of 14 days. Hence, a bait consisting of a combination of fresh, brined and dried mullet was used to survey lobsters on mid-shelf grounds. Again, mullet is one of the types of bait most preferred by commercial fishers operating on mid-shelf grounds and is readily available.

Few lobsters were caught during the surveys, making the examination of spatial patterns in abundance difficult. Results from surveys done on inshore grounds did show the same spatial pattern in abundance as data on the relative abundance of pueruli. This lends support to the hypothesis that the central and southern waters of NSW are important nursery areas for *J. verreauxi*.

Fishery independent surveys provided the information needed to develop optimal sampling strategies for collecting information on the relative abundance of juvenile and adult lobsters. The low numbers of lobsters caught at times may have made the estimates of variance used in this study unreliable and, therefore, sampling strategies determined also unreliable. Strategies will need to be revised once more data become available.

At present it is recommended that 10 sets within each of 2 surveys be done on inshore grounds at 3 locations between August and November, the main period for the commercial fishery on inshore grounds. Similarly, it is recommended that 5 sets within each of 3 surveys be done at 3 locations between December and February. Gear on inshore and mid-shelf grounds should be soaked for 24 hrs and 14 days, respectively.

CHAPTER 4

RECOMMENDATIONS AND IMPLICATIONS

4.1 GENERAL

This study has provided sampling strategies for measuring the relative abundance of eastern rock lobsters in waters off New South Wales. The information collected during the pilot studies will be the first year of data in what is hoped will be a continuing time series of data on the relative abundance of eastern rock lobsters.

The study has successfully quantified the impact of several important factors that may affect sampling for *J. verreauxi*. Additionally, pilot studies have been undertaken over both a spatial and temporal range so as to encompass as much of the expected sampling variability as is possible. The sampling strategies recommended, are therefore more likely to be applicable over the range of the species rather than being limited to data collected from one location at one time.

Results from this research suggest that seaweed-type collectors be used for sampling pueruli of *J. verreauxi*. Sea-swell or proximity to reef do not need to be considered when determining placement of collectors. Sampling need only be done between August and January (inclusive), when pueruli occur in nearshore waters. It may be advisable to continue monitoring some collectors throughout the year, to be assured that the pattern observed in this study continues in the long term. It is probably best to sample around the first quarter of the lunar month and to sample every 4 weeks, although this is not a major consideration.

The information about the variability among catches of lobsters during trapping surveys may be unreliable because few lobsters were caught at certain times. The suggested strategy will need to be reviewed therefore once more data become available.

It is recommended that it be assumed that all rock lobster habitat off NSW is known; since the fishery has been operating for over 100 years. Sampling should concentrate on these known grounds which extend to depths of around 200 m. In New South Wales, strong currents make standardised sampling relatively impossible on grounds deeper than 100 m. For this reason fishery dependent data should be the sole source of information on the relative abundance of lobsters on those grounds deeper than 100 m.

It is recommended that fishery independent surveys be done on grounds in waters shallower than 100 m during spring-summer, when most of the lobster population is on these grounds. Grounds in waters shallower than 100 m can be stratified into 2 depth strata that coincide with the structure of the lobster fishery i.e. grounds shallower than 20 m and those between approximately 21 m and 100 m. Beehive traps set for 24 hours with fresh fish as bait should be used to do surveys on inshore grounds. Larger rectangular traps similar to those used by commercial fishers should be used to do surveys on offshore grounds for collecting information on the relative abundance of sub-adult and adult lobsters. A combination of preserved and fresh bait needs to be used in each trap to ensure that some bait remains throughout the soak-time (14 days) and to minimise the impact of dietary differences of lobsters among locations.

Estimates of the relative abundance of rock lobsters in waters off New South Wales should be calculated both from information from the log-book system and from information collected during fishery independent surveys. A log-book system was introduced into the rock lobsters fishery in 1994, but much of the information about fishing effort was of little value because few fishers consistently provided this voluntary information. Information about fishing effort was made compulsory on the log-sheet in 1996. It is hoped that this will give better information about fishing effort than under the voluntary scheme. The log-book system provides a source of information on catch and effort that has many more observations (therefore more precise estimates of mean relative abundance can be calculated) and, is less costly to operate than fishery independent surveys. Fishery dependent data may suffer from biases caused by fishers continually changing their fishing tactics, and incorrectly reporting catches. Similarly, fishery independent surveys to be of value, need to be done at a level of sampling that results in data that is representative of the lobster population. These data can be used then to gauge the accuracy of those collected from the compulsory log-book system.

4.2 BENEFITS

The community and industry will be the main beneficiaries from this research. The sampling strategies developed in this project will provide in the long term, a database that will be the foundation from which government and industry can base their decisions about management options to ensure that the resource is harvested in a sustainable manner. The New South Wales' lobster industry will benefit if harvesting could ultimately approach the optimal yield the resource is capable of sustaining. It will be possible to incorporate into population models the data gathered on catch and effort. This hopefully will allow government and industry to determine years in advance the level of catch for future years in the fishery. Such knowledge should provide industry with the opportunity to manage their business more effectively.

4.3 INTELLECTUAL PROPERTY AND VALUABLE INFORMATION

There is no economic value arising from this project other than the conservation of a seafood resource. The seaweed-type collector and procedures used in this project should be relevant to researchers in general, but particularly to those studying rock (spiny) lobsters.

4.4 FURTHER DEVELOPMENT

Apart from continuing with the independent surveys of the eastern rock lobster resource, there is a need to collect information on catch and effort and sizes of lobsters caught in the commercial and recreational fisheries. A programme of observers on vessels and around shorelines is the most likely method for collecting this information. Information on the rates of growth, mortality and movement, fecundity and reproduction in the eastern rock lobster population is needed so that dynamic population models can be developed. This is probably best done through dedicated tagging studies.

4.5 STAFF

S. Montgomery	Principal Investigator	1 Jan 93 - 31 Dec 95
J. Craig	Fisheries Technician Grade 2	4 Jul 94 - 31 Dec 95
M. Tanner	Fisheries Technician Grade 2	18 May 94 - 31 Dec 95
C. Blount	Fisheries Technician Grade 2	1 Jan 93 - 13 Feb 94
J. Stewart	Fisheries Technician Grade 1	2 Oct 94 - 15 Jan 96
S. Wagland	Fisheries Technician Grade 1	1 Nov 94 - 29 Dec 95
D. Ward	Fisheries Technician Grade 1	5 Jul 93 - 5 Aug 95
P. Brett	Fisheries Technician Grade 1	1 Jan 93 - 25 Oct 95
A. Henderson	Temporary Assistant (Evans Head)	1 Sep 95 - 31Dec 95
G. Cuthbert	Temporary Assistant (Coffs Harbour)	1 Sep 95 - 31Dec 95
M. Tucker	Temporary Assistant (Tuncurry)	1 Sep 95 - 31Dec 95
G. Barrett	Temporary Assistant (Ulladulla)	1 Sep 95 - 31Dec 95
J. Nemec	Temporary Assistant (Eden)	1 Sep 95 - 31Dec 95

4.6 FINAL COST

SOURCE	1992-93 $	1993-94 $	1994-95 $	1995-96 $	TOTAL $
FRDC					
Salaries	1,022	30,778	21,326	24,790	77,916
Operation	13,162	55,162	64,339	107,868	240,531
Capital		600	1,899		2,499
Total	**14,184**	**86,540**	**87,564**	**132,658**	**320,946**
NSWFRI[1]					
Salaries	9,644	43,525	80,691	69,185	203,045
Operations	28,932	130,575	242,073	219,060	620,640
Total	**38,576**	**174,100**	**322,764**	**288,245**	**823,685**

1. Costs for the NSW Fisheries Research Institute are estimates.

ACKNOWLEDGMENTS

Our thanks go to fishers associated with the fishery for rock lobsters off New South Wales for their frankness, advice and assistance. Thanks go particularly to commercial fishers N. Gogerly, G. Bowland, L. Oakley, S. Rosskelly, R. Abercrombie, P. Jackson, A. Robinson, K. Pollock, R. Firkin, K. Smith and R. Fanthom for their services in sampling puerulus collectors and chartering us their vessels to do the fishery independent surveys. Particularly, we wish to thank members of the Lobster Management Adisory Committee (LOBMAC) in New South Wales for their support and for endorsing our research by providing funding to continue the fishery independent surveys developed in this study

We would like to thank Prof. A. Underwood for his unwavering support and his major contribution to the experimental design used in this project We are grateful to all our colleagues at the NSW Fisheries Research Institute who participate in this project and to the casual assistants employed on the project, namely, A. Henderson, G. Cuthbert, M. Tucker, G. Barrett and J. Nemec, Thanks also to Drs N. Andrew and S. Kennelly for listening to our ideas and contributing with their expertise in experimental design. Thanks also go to Mr D. Reid for statistical advice. We would like to acknowledge the contributions to this report of Drs N. Andrew and D. Pollard who provided many comments an earlier draft.

Finally, we would like to thank Dr R.E. Kearney the Director of the NSW Fisheries Institute for the duration of this project, for his support for this project. The board of the Fishing Industry Research & Development Corporation must be acknowledged for their support of research on rock lobsters in New South Wales. This has lead to management measures which it is hoped will rebuild the rock lobster stock off New South Wales.

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APPENDICES

APPENDIX 1

Proceedings of the Fourth International Workshop on Lobster Biology and Management, 1993

PATTERNS IN LANDINGS AND SIZE COMPOSITION OF *JASUS VERREAUXI* (H. MILNE EDWARDS, 1851) (DECAPODA, PALINURIDAE), IN WATERS OFF NEW SOUTH WALES, AUSTRALIA

BY

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ABSTRACT

Available information suggests that the relative abundance of the New South Wales' spiny lobster stock, exploited since at least 1873, has declined over the past 20 years.

Annual landings fluctuated until 1948-49 but have fallen in most years since. Data on fishing effort and CPUE were available only for years from 1969-70 onwards. Fishing effort was stable over most years to 1978-79 but has continued to rise since then. CPUE declined over the period for which data were available; this was attributed to a fall in the abundance of *Jasus verreauxi*, since this species comprises around 97% of the commercial catches of lobsters in New South Wales.

The lengths of *J. verreauxi* in catches from commercial vessels between 1986 and 1988 varied between locations. The spatial pattern in annual distributions of lengths suggests that this species may move along-shore. When data from all sites were combined, only 10% of the *J. verreauxi* sampled were longer than the smallest length at which 50% of females carry eggs (166.5 mm CL).

Although the optimum level of fishing effort could not be determined from the available data, the patterns in landings, effort, and CPUE suggest that measures are necessary to conserve this resource until estimates of maximum sustainable yield and optimum fishing effort can be determined.

RÉSUMÉ

L'information disponible suggère que l'abondance relative du stock de langoustes de Nouvelle-Galles du Sud, exploitées depuis 1873 au moins, a diminué au cours des 20 dernières années. Les débarquements annuels étaient variables jusqu'en 1948-49, mais ont chuté dans la plupart des années qui ont suivi. Des données sur l'effort de pêche et le CPUE étaient disponibles seulement pour les années postérieures à 1969-70. L'effort de pêche était stable jusqu'à 1978-79, mais a augmenté progressivement depuis lors. Le CPUE a diminué tout au long de la période pour laquelle les données sont disponibles: cette baisse a été attribuée à une chute de l'abondance de *Jasus verreauxi*, cette espèce représentant environ 97% des prises commerciales de langoustes en Nouvelle-Galles du Sud.

La taille de *J. verreauxi* dans les prises des bateaux commerciaux de 1986 à 1988 variait suivant les sites. Le modèle spatial de distribution annuelle de taille suggère que cette espèce peut se déplacer le long de la côte. Quand les données pour tous les sites ont été combinées, seuls 10% des *J. verreauxi* échantillonnés avaient une taille supérieure à la plus petite taille à laquelle 50% des femelles portent des oeufs (CL 166.5 mm).

Bien que le niveau optimal de l'effort de pêche n'ait pu être déterminé à partir des données disponibles, les modèles en débarquements, effort, et CPUE suggèrent que des mesures sont nécessaires pour conserver cette ressource jusqu'à ce que des estimations de production soutenue maximale et d'effort de pêche maximal puissent être effectuées.

INTRODUCTION

Information on the quantity and size composition of individuals harvested and changes in the abundance of species are fundamental to the effective management of resources. These provide knowledge about the impact of harvesting on the population and on the temporal and spatial distributions of individuals of different sizes.

Spiny lobsters have been fished off the coast of New South Wales (NSW) since at least 1873 (Lie, 1969). Reported landings averaged 100 tonnes per annum during the 10 years period to 1990-91 (unpublished records of NSW Fisheries), worth approximately $ 3 million annually. These are composed almost entirely of *Jasus verreauxi* (H. Milne Edwards, 1851). Other species taken, but in very small numbers, are *Jasus edwardsii* (Hutton, 1875) in the far south of the State and *Panulirus longipes* (H. Milne Edwards, 1868) and *Panulirus ornatus* (Fabricius, 1798) in the far north.

J. verreauxi is the largest spiny lobster in the world (Phillips et al., 1980). It occurs in waters off the east coast of Australia from Tweed Heads southwards, around the coast of Tasmania, and as far west as Port MacDonnell in South Australia (fig. 1 inset). This species is found also off New Zealand, predominantly around the North Island (Kensler, 1967).

In this paper I describe patterns in the landings of spiny lobsters by the commercial fishery in NSW and in the size composition of the exploited population. This information is then used to assess whether over-exploitation of the *J. verreauxi* stock has occurred.

Description of the fishery

Trapping is the only fishing method used by the commercial fishery. Traps of various design (usually with the entrance in the top) are used on grounds as deep as 10 m and are lifted at least every second day. Larger traps (2 m × 1.5 m × 1 m) with side entrances are used on grounds deeper than 10 m. Traps in water deeper than approximately 50 m are hauled fortnightly, but current strength and weather conditions may prolong the soak time. Regulations that pertain to the commercial fishery are:

(a) a freeze since 1984 on the number of vessels permitted to fish,

(b) traps must be smaller than 2 m × 1.5 m × 1 m and must be made of at least 5 cm mesh,

(c) females carrying ova cannot be landed, and

(d) there is a legal minimum length of 104 mm carapace length (CL) for *J. verreauxi*.

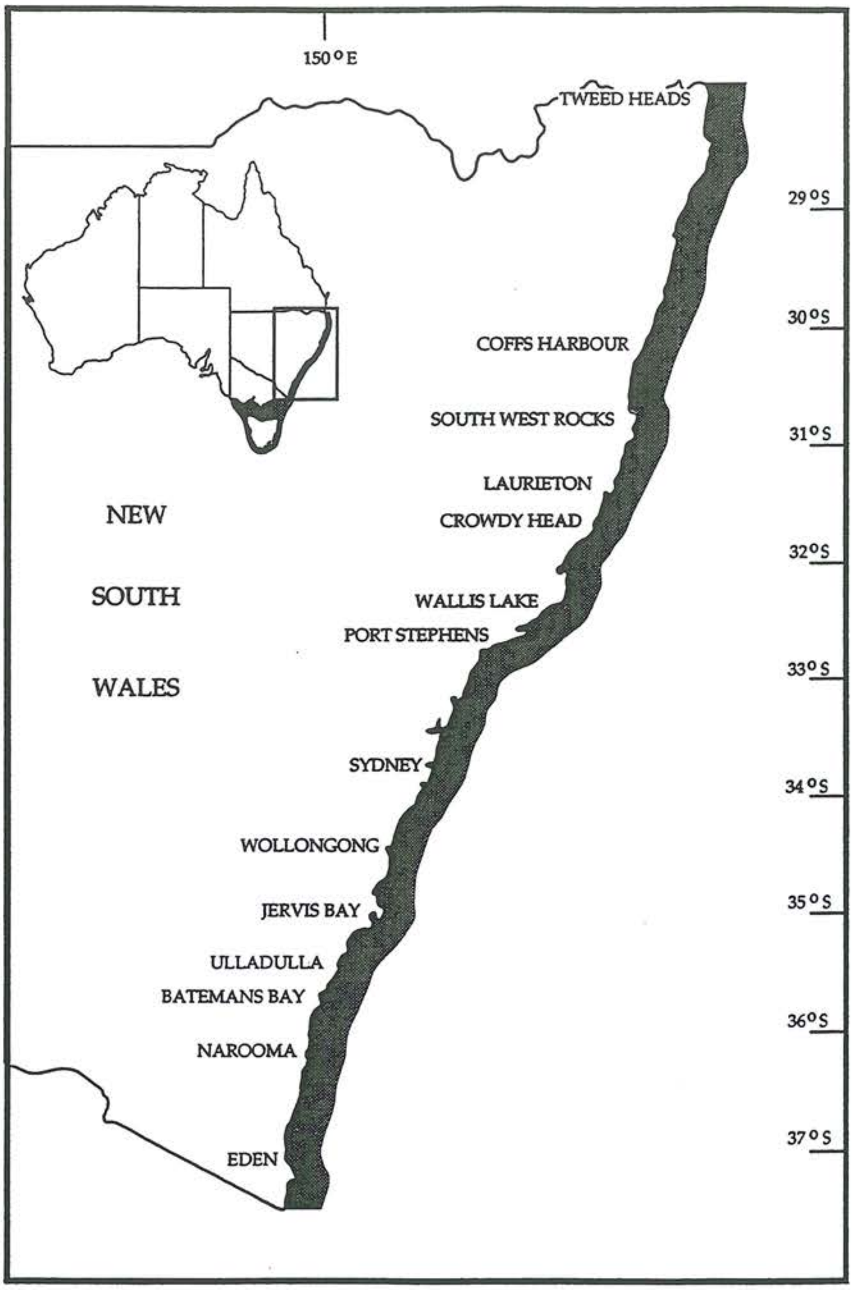

Fig. 1. Map of the coast of New South Wales showing the ports from which sampling was done and those mentioned in the text. It also shows the division of the coast into areas used in the analyses of landings data. The inserted map of Australia shows the distribution of *Jasus verreauxi* (H. Milne Edwards, 1851).

In addition to (b) to (d) above, recreational fishers are restricted to having no more than five spiny lobsters in their possession at any one time.

MATERIALS AND METHODS

Landings, effort, and CPUE

Data on the level of landings in the commercial fishery for lobster were obtained from the annual reports of NSW Fisheries (source (a)). Data from the records of Fishermen's Cooperatives (source (b)) at Coffs Harbour, South West Rocks, Crowdy Head and Wallis Lake (fig. 1) were also collected to verify the patterns in landings observed from source (a). Fishermen's Cooperatives are centres through which fishers are compelled by law to market their catch. Data used to calculate CPUE (catch-per-unit-effort) were from individual fishers' catch cards held at district offices of NSW Fisheries (source (c)). Sources (a) and (c) are information contained on the fishers' monthly returns, which are required by law.

Records of landings of lobsters caught off NSW have been maintained by the NSW Government since 1884 (source (a)). Annual landings were recorded for years up to 1927 as the total number of lobsters sold at the various market centres, from 1927 until 1939-40 as the total number of lobsters landed, and since 1940-41 as the weight of lobsters landed. Information was not available for the periods 1895-1897, 1900-1902 and the financial years 1939-40 and 1942-43 to 1943-44.

Data used in this study are for all species of lobsters combined. Source (a) did not differentiate between species caught until 1988-89, though written statements in the reports for many of the years make it clear that *J. verreauxi* was virtually the only species caught. Source (a) data for the years since 1988-89 suggested that *J. verreauxi* comprised on average 97% of the annual total landings.

Source (c) provided information on the weight of lobsters caught per fisher per month for years as early as 1969-70. This was a subset of the data for the whole fishery because it did not include data from all fishers who had left the fishery prior to 1986. These data were standardized for the number of traps used by each fisher in each decade prior to 1990-91. Experienced fishers were interviewed to find out how many traps were operated per fisher in each of the five decades between 1969-70 and 1991-92. Numbers of traps operated per month were similar between fishers and between different fishing ports; these being 30, 50, 80, and 100 for the 1960's, 1970's, 1980's, and 1990's, respectively.

Size composition of lobsters in total catches

Catches of lobsters from inshore (1-50 m) and offshore (51-220 m) grounds were sampled monthly during fishing seasons between July 1986 and June

1988. Sampling was done aboard commercial vessels off Crowdy Head and Sydney in both years and off Batemans Bay in 1987-88.

Carapace length (CL) was measured as the distance between the point of union of the second antennae on the antennal platform and the centre of the posterior margin of the carapace. Measurements were rounded down to the nearest millimetre. Data were grouped by 5 mm class intervals, weighted by the landings from either inshore or offshore grounds, and compiled into annual distributions.

The Kolmogorov-Smirnov Two-Sample Test (Siegel & Castellan, 1988) was used to compare the shapes of the annual length distributions. Each pairwise comparison among the three locations was adjusted using the Bonferroni inequality so that the significance level of the overall test was approximately 5% (Miller, 1966).

RESULTS

Landings, effort and CPUE

Patterns in landings were similar between sources (a) and (b) for those years when data were available (fig. 2a-b). Those from the records of Fishermen's Cooperatives were similar between ports. Data from two of the Fishermen's Cooperatives sampled are shown in fig. 2b for reasons of brevity. Annual landings fluctuated with irregular periodicity. These were high in 1910, 1930 and 1948-49, then declined to stabilize at lower levels from 1921 to 1923, 1930 to 1941-42 and 1977-78 to 1980-81 (fig. 2a), respectively.

The period from 1873 to 1930 represented the phase of development and growth in the fishery. Landings in years 1916 to 1918 were affected by the First World War, whilst the lower stable landings between 1931 and 1938-39 probably reflected the fishing down of the population. High landings in 1948-49 most likely reflected the stock that had accumulated during the period of reduced fishing over the Second World War. Landings have fallen in most years since 1948-49.

Fishing effort (number of fisher trap months) was stable between 1973-74 and 1978-79, but has increased in most years since then (fig. 2c). It was higher for 1970-71 to 1972-73 because new grounds were found off the continental slope.

Annual CPUE declined from 1969-70 to 1989-90 but has remained stable since (fig. 2c). The exception to this was that it rose in 1971-72 and 1973-74 because new grounds were found. The slope of the regression of CPUE against years was significant ($p < 0.0001$) and negative for the period 1969-70 to 1991-92.

Size distribution of total catches

Lengths of *J. verreauxi* sampled in this study ranged between 68 and 264 mm CL (fig. 3). Distributions of lengths varied between locations (Kolmogorov-

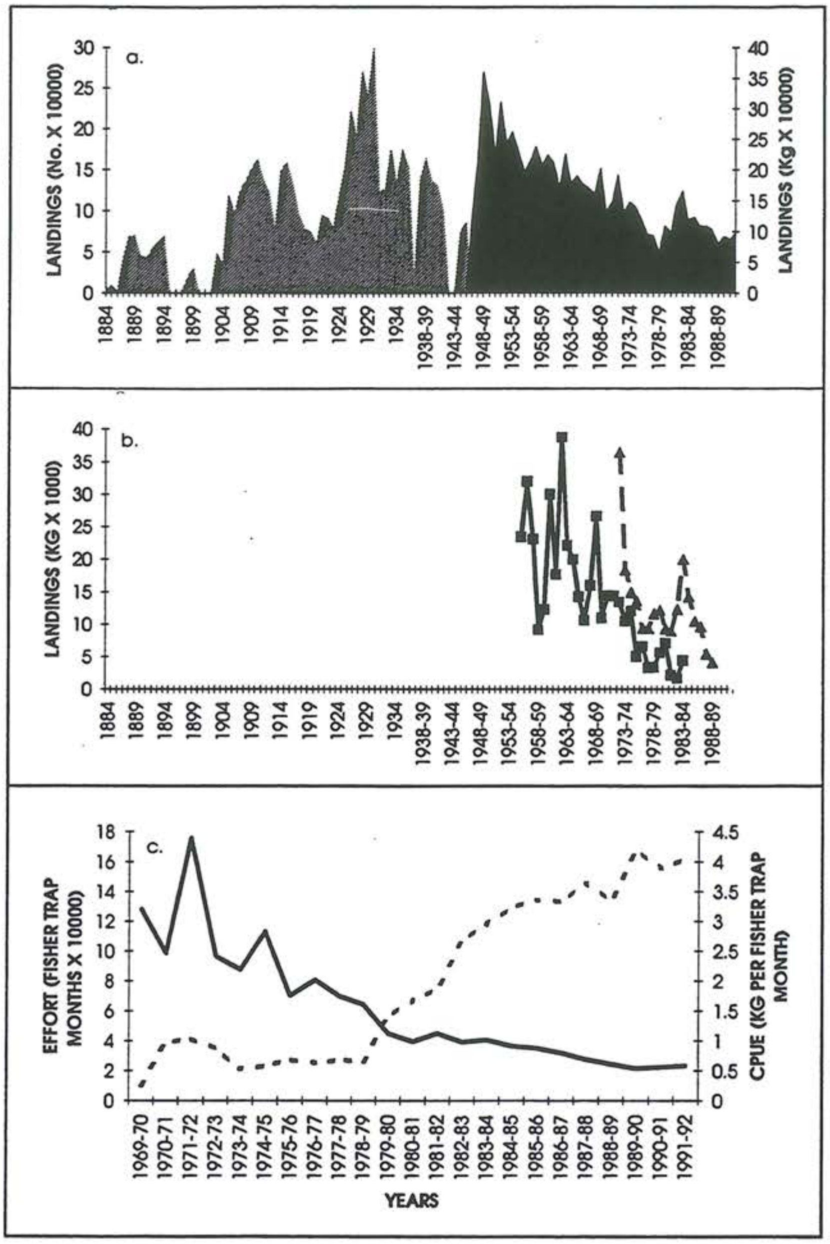

Fig. 2. Patterns in (a-b) the level of landings and (c) fishing effort (broken line) and CPUE of spiny lobsters in New South Wales. In (a), data are shown as total landings in number (hatched) and kg (black), and together with those in (c) come from the records of NSW Fisheries. In (b), data are from the Wallis Lake (broken line) and Crowdy Head (solid line) Fishermen's Cooperatives.

Smirnov Test, $p < 0.05$). The range of lengths in samples from Batemans Bay and Sydney were similar, but samples from Crowdy Head contained some much longer lobsters (fig. 3). Lobsters longer than the smallest length at which 50% of females carry eggs (SOB; 166.5 mm CL; Montgomery, 1992) were found in samples from Crowdy Head only. When data in fig. 3 were weighted by landings (kg) and combined among locations, approximately 10% of the *J. verreauxi* in these samples were longer than the SOB.

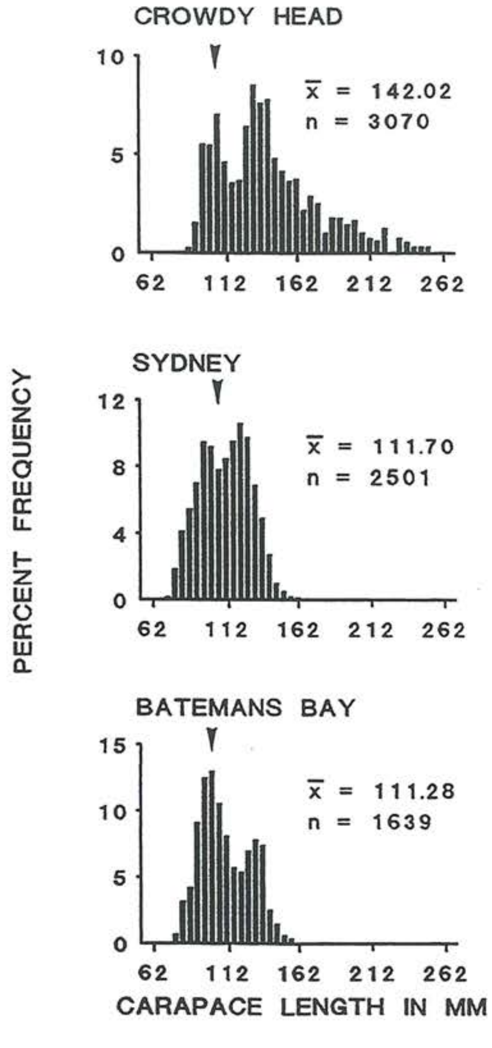

Fig. 3. Annual distributions of the lengths of eastern rock lobsters sampled from catches from Crowdy Head, Sydney and Batemans Bay. The mean ($\bar{x}$), sample size (n) and legal minimum length (arrowhead) are shown.

DISCUSSION

Annual landings of spiny lobsters in NSW have fallen in most years since 1948-49 because there has been a fall in the relative abundance of these animals. There is little doubt that the pattern of change in CPUE between years reflects a decline in the abundance of *J. verreauxi*, because this species comprises around 97% of the landings of lobsters caught off NSW.

There was, however, significant unreporting of landings in the commercial fishery (thought to be as high as 70% of the landings in 1986-87). It is likely that unreported landings have increased between years as markets developed and were greater in years of higher catches. Consequently, landings have been progressively underestimated between years in this study. Irrespective of this, the pattern portrayed is representative of what has occurred in the fishery. It is supported by data from the Fishermen's Cooperatives and anecdotal information from fishers (Montgomery, unpubl.). Data on landings in this study therefore should be considered to be a reliable index of the real level of landings in the fishery.

Indices of relative abundance rely upon the accuracy of the catch and effort information used (for a review see Hilborn & Walters, 1992). Data about fishing effort used in the present study were not standardized for advances in the technology of fishing equipment that have occurred over the course of the fishery (e.g., improved vessels and fish finding equipment). Hence, fishing effort may have been underestimated and CPUE overestimated for the period when data were available. As a consequence, the negative slope of the pattern in CPUE is conservative and could be greater. The fall in CPUE between years was supported by information gained from the records of Fishermen's Cooperatives and talking to commercial fishers (Montgomery, unpubl.). Some fishers keep personal diaries that detail their catch and have photographs of their greatest catches from different years. This information clearly showed that catch rates have declined since the 1960's. Fishers quantified catch rates of lobsters from the 1960's in terms of dozens per trap but now count the individuals because animals are far fewer. Unfortunately, for reasons of confidentiality I cannot provide further formal analyses or summaries of these data. Nevertheless, the trends observed in these diaries confirm the patterns detected from the formal data set derived from the fishers' monthly return form (source c).

Differences in the distribution of lengths between locations could have been caused by either differences in fishing pressure and/or growth of lobsters between locations or some pattern of movement of individuals along-shore. The latter seems the most likely. An along-shore pattern of movement has been reported by Booth (1979, 1984) for *J. verreauxi* in waters off New Zealand and is common among other species of the family Palinuridae (Herrnkind, 1980). Studies need to be done to test the hypothesis that *J. verreauxi* moves along-shore in waters off NSW.

Fishing pressure on immature *J. verreauxi* has increased since 1948-49 because of shifts in landings to the south and an overall increase in fishing effort. Now more than 64% of the annual total landings come from areas where only immature *J. verreauxi* were sampled during the present study. Results in the present study suggested that the abundance of mature animals in the population is low. Assuming that *J. verreauxi* is exposed to fishing for some years before it matures (Montgomery, 1992), then this low abundance is of concern.

CONCLUSION

The quality of the catch and effort data available did not warrant use in a model to determine an optimum yield and fishing effort for the *J. verreauxi* resource. Therefore, there are no reference points (MSY and optimum fishing effort) against which to compare the data in the present study. It is difficult to know, therefore, how biologically serious the fall in annual CPUE has been or whether it amounts to over-exploitation. However, the pattern found in the present study, where there has been a decline in landings and CPUE whilst effort continues to rise, follows that described by Hilborn & Walters (1992: 7) for over-exploitation in an uncontrolled fishery.

Management measures need to be introduced to conserve the resource until estimates of maximum sustainable yield and optimum fishing effort can be obtained.

ACKNOWLEDGMENTS

I would like to thank those commercial fishers who allowed research staff to measure their catches of lobsters. Thanks also go to staff at the Fisheries Research Institute who helped with the sampling aboard commercial fishing vessels. Ms P. Brett prepared the figures for this manuscript, Dr R. West assisted in the collation of information on catch and fishing effort and Messrs D. Reid and G. Gordon provided statistical advice. Comments by Drs N. Andrew, R. Kearney, D. Pollard, A. Sheridan and Messrs K. Rowling and D. Reid improved this manuscript. The comments of the referees and Dr P. Breen also vastly improved this manuscript. This work was funded by the Fishing Industry Research Trust Account in Australia.

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APPENDIX 2

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Proceedings of the Fourth International Workshop on Lobster Biology and Management, 1993

OCCURRENCE OF PUERULI OF *JASUS VERREAUXI* (H. MILNE EDWARDS, 1851) (DECAPODA, PALINURIDAE) IN WATERS OFF CRONULLA, NEW SOUTH WALES, AUSTRALIA

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ABSTRACT

Artificial seaweed collectors set near the surface and crevice collectors set near the bottom were placed in waters of 10 m depth off Cronulla in an attempt to capture pueruli of *Jasus verreauxi*, which had not previously been studied in any detail in Australia. All pueruli and post-pueruli of *J. verreauxi* caught were found on collectors set near the surface, between October and December 1992.

RÉSUMÉ

Des collecteurs artificiels disposés dans les algues près de la surface ainsi que des collecteurs de crevasses, près du fond ont été placés dans les eaux à une profondeur de 10 m au large de Cronulla dans le but de capturer des pueruli de *Jasus verreauxi*, qui n'avaient pas été étudié en détail auparavant en Australie. Tous les pueruli et post-pueruli de *J. verreauxi* collectés ont été trouvés dans les collecteurs placés en surface, entre octobre et décembre 1992.

INTRODUCTION

Spiny lobsters develop from a nauplius larva through a series of phyllosomata before undergoing metamorphosis to a post-larva, commonly referred to as a puerulus. A knowledge of the biology of the puerulus stage in the life cycle of spiny lobsters is important when identifying nursery areas and to the success of any stock enhancement projects (e.g., Serfling & Ford, 1975). Further, the past association between the relative abundance of pueruli and the subsequent catch of lobsters in the commercial fishery has been used to predict the expected levels of catch in the commercial fishery in future years (e.g., Phillips, 1986).

Jasus verreauxi (H. Milne Edwards, 1851), is the largest spiny lobster in the world (Phillips et al., 1980). It occurs in waters off the eastern coast of Australia from Tweed Heads in northern New South Wales southwards, around the coast of Tasmania, and as far west as Port MacDonnell in South Australia (fig. 1). It has been the primary target species in the fishery for spiny lobsters off the coast of New South Wales since at least 1873 (Lie, 1969). This species also occurs in waters off New Zealand (mainly the North Island) where it is of secondary commercial importance to *Jasus edwardsii* (Hutton, 1875) (cf. Kensler, 1967).

In this paper we describe an experiment undertaken to test the null hypothesis that there are no differences in catch rates of pueruli of *J. verreauxi* in waters of 10 m depth off Cronulla between seaweed type collectors set near the surface and crevice type collectors set near the substrate. This is the first time that *J. verreauxi* have been reported as occurring on artificial collectors. The work was part of a project to develop an optimal sampling strategy for collecting information on the distribution and abundance of *J. verreauxi* in waters off New South Wales.

MATERIALS AND METHODS

The experiment was undertaken between October and December 1992 in waters off Shark Island (34°04′S 151°10′E), near the NSW Fisheries Research Institute, to the south of Sydney in New South Wales, Australia (fig. 1).

We selected artificial attracting devices (commonly referred to as "collectors") of the "seaweed" type used by Phillips (1972) and the "crevice" type used by Booth & Tarring (1982) to sample pueruli near the surface and bottom, respectively. Both these collector types have been used successfully to attract

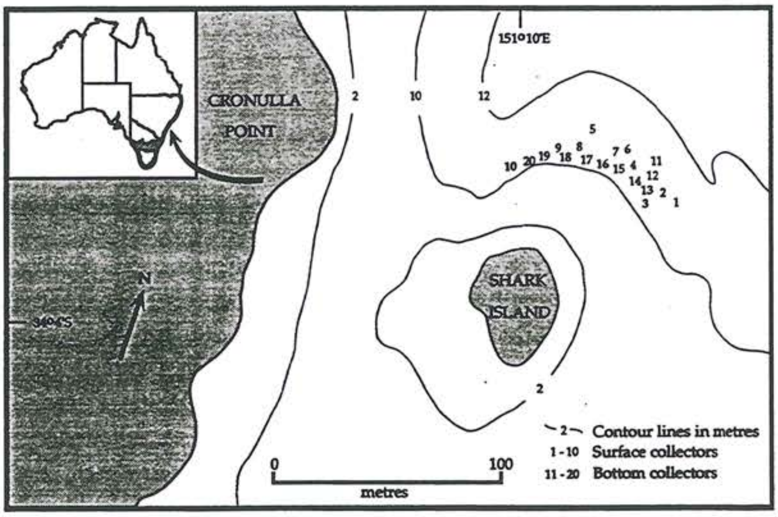

Fig. 1. Location of collectors used to sample pueruli in waters off Shark Island, New South Wales. The inserted map of the coast of Australia shows the distribution of *Jasus verreauxi* (H. Milne Edwards, 1851).

individuals of other species of the family Palinuridae in waters off Australia (e.g., Phillips, 1986; Kennedy, 1991; and Prescott, 1991).

Ten collectors of each type were randomly set 3 m apart in waters of 10-12 m depth above or along the interface of rock and sand off the exposed shore of Shark Island (fig. 1). These were set in this area around the island to minimise the interaction with members of the public who use these waters. Collectors were set either within 30 cm of the surface or 60 cm above the bottom. The experiment was stopped in December 1992 and the crevice collectors removed from the water. Since then we have continued to monitor the seaweed collectors.

All collectors were sampled fortnightly from a research vessel. Some collectors were damaged or lost in heavy seas and were not replaced. Surface collectors were detached from the mooring by a diver and then taken on board. Each of the 3 panels was shaken 30 times into a 250 l container. Crevice collectors were sampled by a diver bringing the collector with a bag over it to the surface. On board, the collector was placed in the 250 l container and each crevice probed to dislodge any pueruli.

Pueruli were transferred to a 20 l container filled with seawater and transported back to the laboratory where they were kept in 230 l tanks (approximately 15 per tank) with flow through seawater. They were identified to species, counted and categorised according to the criteria of Booth (1979). Tanks were inspected daily for moults. Moults were categorised as being from pueruli (clear-brown in colour) or post-pueruli (green) and measured as the antennal carapace length (CL) to the nearest millimetre. The abundance of pueruli was expressed as the number per collector per soak day.

RESULTS

A total 16 pueruli and 12 post-pueruli of *J. verreauxi*, and 1 post-puerulus of *J. edwardsii* have been collected since the experiment commenced in September 1992. All of these were collected off seaweed collectors between October and December 1992 (fig. 2); no pueruli were caught on the crevice collectors. Lengths of moults ranged from 8.1 mm to 12 mm CL and 13.4 mm to 16.6 mm CL for pueruli and post-pueruli of *J. verreauxi*, respectively, whilst that from the post-puerulus of *J. edwardsii* was 20.1 mm CL.

DISCUSSION

Results indicated that the seaweed type collectors set near the surface were more effective at attracting puerulus stages of *J. verreauxi* than the crevice type collectors set near the substrate in waters of 10 m depth off Cronulla, and that these pueruli occur in these waters between October and December.

The results imply that puerulus stages of *J. verreauxi* are surface dwelling

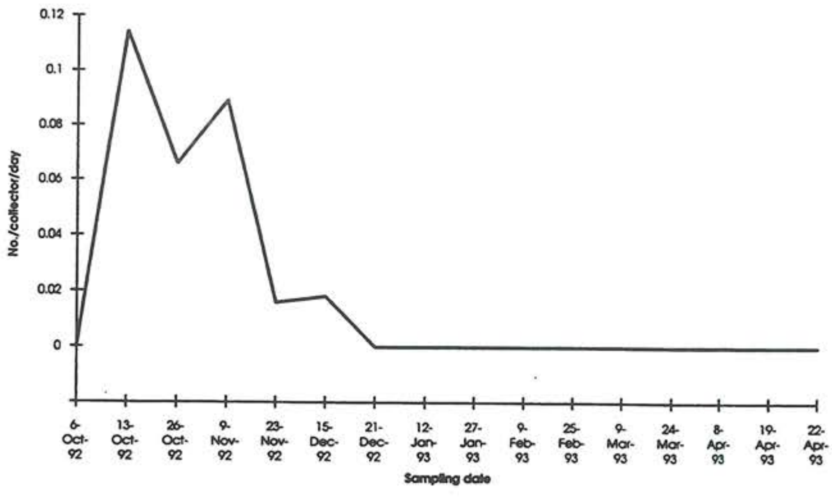

Fig. 2. Catch of pueruli and post-pueruli of *Jasus verreauxi* (H. Milne Edwards, 1851) per collector per soak day off Shark Island, New South Wales.

animals. This is supported by the work of Lie (1969), who collected 4 pueruli of *J. verreauxi* in October from mesh nets set near the surface of waters off Sydney and by reports from commercial fishers that they find "clear spiny lobsters" on the floats and ropes of their trap gear. Other studies have used collectors of various types set near the surface to sample pueruli of different species of the family Palinuridae (cf. e.g., Witham et al., 1968; Phillips, 1972; Serfling & Ford, 1975; and MacDonald, 1986). On the other hand, Booth (1979) found pueruli of *J. edwardsii* on both seaweed and crevice collectors but concluded that crevice collectors were the most cost efficient method for sampling pueruli of this species. Further, he found that there were greater numbers of pueruli of *J. edwardsii* in waters near the bottom than at the surface (Booth et al., 1991).

Results in the present study may have been confounded by the use of different sampling gear between waters near the surface and substrate. There is the possibility that pueruli of *J. verreauxi* present in waters near the bottom were not attracted to the crevice collector. Pueruli of *J. verreauxi* may prefer to live in vegetation rather than hide within or under objects on the substrate like the pueruli of *J. edwardsii*. The preference for vegetation as a habitat is not uncommon among palinurid species, e.g., pueruli of *Panulirus argus* (Latreille, 1804) (cf. Herrnkind & Butler, 1986) and *Panulirus interruptus* (Randall, 1840) (cf. Serfling & Ford, 1975). Observations made by us on pueruli of *J. verreauxi* in aquaria suggested that these pueruli preferred to grasp onto seaweed rather than burrow under or hide among rock substrates. Experiments to determine the spatial distribution of the pueruli of *J. verreauxi* should be undertaken using seaweed collectors set near the bottom and surface.

The work of Lie (1969) also suggested that the time of settlement of pueruli of *J. verreauxi* off Sydney was between October and December, as found in the present study. A seasonal pattern of settlement of pueruli is common among species of spiny lobsters (e.g., Booth & Tarring, 1982; Booth & Bowring, 1988; and MacDonald, 1986). The time of pueruli settlement suggested that *J. verreauxi* has a larval phase of between 9 and 12 months. Booth (1986) estimated this phase to be from 8-12 months, based upon the time of capture of *J. verreauxi* phyllosomata off New Zealand. This lengthy larval life provides time for larvae to be dispersed over a wide area (e.g., see Phillips & McWilliam, 1986). Phyllosomata of *J. verreauxi* have been found offshore from the continental shelves of New Zealand (Booth, 1986) and Australia (McWilliam & Phillips, 1987). Booth (1986) suggested that these animals off New Zealand were returned to nearshore waters by sub-surface drift; a similar movement pattern probably occurs also off Australia.

Pueruli of *J. verreauxi* collected during this experiment were the first to be caught off New South Wales on devices set specifically to collect these animals. The results from this study, although preliminary, show that pueruli of *J. verreauxi* can be caught by using seaweed collectors near the surface but probably not by using crevice collectors near the bottom and that the settlement of pueruli is seasonal.

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APPENDIX 3

Developing A Strategy For Measuring The Relative Abundance Of Pueruli Of The Spiny Lobster *Jasus verreauxi*

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Running Head: Sampling pueruli of *J. verreauxi*

ABSTRACT

Attracting devices ("collectors") have been used to collect information on the relative abundance of the post-larvae (pueruli) of shallow water spiny lobsters. In this paper we compare the effects on catches of pueruli of *J. verreauxi* between the two basic types of collectors. A fully orthogonal experiment was done with factors of Type (sea-weed or crevice-types) and Position (near surface or substratum) of collector to test the null hypothesis that there were no differences in mean catch of pueruli between type of collector. Pueruli were caught only on sea-weed-type of collectors. We concluded that sea-weed-type of collectors positioned near the surface could be used to monitor the relative abundance of pueruli and post-pueruli of *J. verreauxi* and describe a collector that can withstand sea-swells of around 6 m and retain pueruli.

INTRODUCTION

Knowledge of the relative abundance of individuals recruiting to a population provides information about the effect of management on recruitment and, together with information on the relative abundance of spawning individuals, about stock-recruitment relationships (see Hilborn and Walters 1992 for a review). Information on the relative abundance of recruits has been used also to predict the level of catch of spiny lobsters in future years. For example, a relationship between the relative abundance of puerulus in one year, and the catch of legal sized lobsters some years later, has been used to predict the level of catch of *Panulirus cygnus* in the Western Australian rock lobster fishery (Phillips 1986).

After hatching, spiny lobsters develop during the larval phase from a nauplius, through a series of phyllosomata and then metamorphose to a post-larva, commonly referred to as a puerulus (see Booth and Phillips 1994 for a review). The relative abundance of post-larvae (pueruli) occurring in nearshore waters has been measured as an index of recruitment to spiny lobster populations.

Attracting devices commonly referred to as collectors usually have been used to capture pueruli (see Phillips and Booth 1994 for a review). Collectors are typically grouped into two categories; those that imitate seagrasses or algae, commonly referred to as sea-weed-type of collectors, and those that simulate holes and crevices, known as crevice-type of collectors. Pueruli of various species of spiny lobster have been captured by sea-weed-type of collectors set near the surface (Witham et al. 1968, Phillips 1972, Serfling and Ford 1975, MacDonald 1986) or near the substratum (Tholasilingam and Rangoranjan). Crevice-type of collectors have been set near the substratum to sample *Jasus edwardsii* in waters off New Zealand (Booth and Tarring 1986) and Australia (Kennedy et al. 1994).

J. verreauxi occurs off the east coast of Australia from Tweed Heads (28°10′ S) southwards, around the coast of Tasmania, and as far west as Port MacDonnell (38°03′ S) in South Australia (Fig. 1 inset). The fishery off New South Wales, Australia, presently has an annual total allowable commercial catch of 106 tonnes, worth approximately $ 5 million at the point of first sale.

Little is known about the patterns of settlement of pueruli of *J verreauxi*. Montgomery and Kittaka (1994) showed that pueruli could be caught in sea-weed-type collectors of the same design as those described by Phillips (1972). Their experiment compared catches of pueruli in sea-weed-type collectors set near the surface and crevice-type collectors set near the substratum. Montgomery and Kittaka (1994) were unable to make conclusions about the optimal type of collector to use to sample pueruli of *J verreauxi* because both types of collectors tested were not compared near the surface or the substratum. Further when seas were rough, sea-weed-type collectors were lost and crevice-type collectors dislodged.

In this paper we describe an experimental study of factors affecting catches of pueruli of *Jasus verreauxi*. A modified sea-weed-type of collector that is capable of withstanding prolonged periods of rough seas is described.

MATERIALS AND METHODS

Study Sites

The experiment was done between September and November 1992 off Shark Island and then from November 1992 to January 1993, in an embayment called Curracurrang. Both sites were near the NSW Fisheries Research Institute, close to Port Hacking (Sydney), New South Wales, Australia (Fig. 1). Shark Island is an area of sandstone reef approximately 100 m east of the mainland. It is approximately 0.5 m above sea level at ebb tide and is exposed to ocean swells. Rocky reef surrounding the island extends out to waters of around 10 m depth. Curracurrang is 5 m deep at its deepest point and is sheltered from the wind and swell. It is surrounded by high cliffs, has a rocky shoreline and reef extending out to approximately 5m depth. Both sites had forests of kelp (*Ecklonia radiata*) present throughout the rocky reef. Encrusting and filamentous algae and sponges, ascidians and bryozoans made up the understorey.

Procedure

The designs of collectors used were the sea-weed-type of collector described by Phillips (1972) and the crevice-type of collector described by Booth and Tarring

(1986). In the experiment there were two orthogonal factors: Type of collector (sea-weed-type or crevice-type) and Position of the collector (near the surface or substratum), with four replicates in each treatment.

The collectors were sampled weekly off Shark Island and fortnightly off Curracurrang. Collectors had a bag placed over them by a diver before being released from their mooring and taken on board. Those near the substratum were floated to the surface with the aid of an air-bag. Each panel of the sea-weed-type collectors was taken from the frame and shaken 30 times into a 320 l container. Crevice-type collectors were placed in the 320 l container and inspected for pueruli.

The number of pueruli (smooth carapace, transparent or brown in colour) or post-pueruli (spines on carapace and brown in colour) were counted. Data were pooled across sites and times, because so few individuals were caught.

RESULTS

A total of 19 pueruli and post-pueruli of *J. verreauxi* were caught in sea-weed-type of collectors. No lobsters were caught in crevice-type of collectors. The mean number of pueruli and post-pueruli (combined) caught in sea-weed-type of collectors positioned near the surface was greater than in sea-weed-type of collectors near the substratum (ANOVA $P < 0.05$, Fig. 2).

Changes to the design of the collector

Results from the experiment above complemented those of Montgomery and Kittaka (1994) when a total of 28 pueruli and post-pueruli were caught on sea-weed-type of collectors. Sea-weed-type of collectors were obviously the best type of collector for collecting information about the relative abundance of pueruli of *J. verreauxi*. There were problems however with maintaining the collector described by Phillips (1972) during periods of rough seas. Collectors would drag or break away from moorings. We have attempted to address this problem by modifying the Phillip's (1972) design into a flat structure that has less resistance in the water.

The modified collector consisted of two rather than three 61 mm x 35 mm x 0.4 mm PVC panels of "tufts" with polyethylene split rope fibre (used by Phillips 1972) and was supported by a centre frame with a 30 mm polystyrene buoy on the top rather than a triangular frame supported by 20 mm floats (Fig. 3.). A tuft was comprised of 80 g of 500 mm lengths of 125 text fibre. The middle of the tuft was tied with a plastic tie, passed through a hole in the PVC panel and secured by 16 gauge stainless steel wire. The centre frame was made of 1300 x 40 x 6 mm flat stainless steel bar with four 350 x 27 x 16 mm PVC cross members to attach the panels.

Collectors were attached by two 127 mm shark clips to 20 m of 14 mm polyethylene rope and moored to the substratum in waters of 10-12 m depth (Fig. 3). The rope was connected near the substratum by a 10 mm stainless steel shackle to 3 m of 10 mm galvanised chain, which in turn was attached to 3 m of 25 mm long link chain (90 kg) by two 10 mm galvanised shackles. A 25 mm galvanised shackle connected the chain to two 25 kg iron blocks.

DISCUSSION

Results presented in this study supported the conclusion by Montgomery and Kittaka (1994) that sea-weed-type of collectors were more suited than crevice-type of collectors for catching pueruli of *J. verreauxi*. The results provided the additional information necessary to conclude that sea-weed-type of collectors were best positioned near the surface for sampling pueruli of *J. verreauxi*.

Sea-weed-type of collectors attracted and retained pueruli of *J. verreauxi* whereas crevice-type of collectors did not. The number of pueruli caught were few, but the results were consistent with those of Montgomery and Kittaka (1994). Several studies on different species of spiny lobster have found that sea-weed-type of collectors were best for sampling pueruli (e.g. *P. argus* Witham et al. 1968, and *P. interruptus* Serfling and Ford 1975). The greater success of sea-weed-type of collectors probably indicates that pueruli and juveniles of *J. verreauxi* like those of many other species of spiny lobster, prefer the complex structure of vegetation as habitat (for a review see Herrnkind et al. 1994).

Phillips and Booth (1994) recommended that sea-weed-type of collectors be placed in sheltered waters. In contrast, we have described in this study a sea-weed-type of collector capable of withstanding sea-swells of up to around 6 m.

The changes we made to the sea-weed-type of collector used by Phillips (1972) and Montgomery and Kittaka (1994) reduced the resistance of the collector to sea-swells, whilst a heavier mooring kept the collector in place. To have restricted the placing of collectors to only sheltered areas would have drastically reduced the number of possible sampling sites along the coast of New South Wales and as a consequence, the information on relative abundance may have been biased. We found that exposure to sea-swell did not affect catches of pueruli of *J. verreauxi* on sea-weed-type of collectors (unpublished data).

Collectors set near the surface have the advantage that they can be seen between sampling periods, particularly after big sea-swells. Any loss of, or damage to collectors therefore can be quickly fixed.

Other factors that may affect catches of pueruli on collectors other than the type of collector and exposure to sea-swell are the phase of the moon and soak-time of the collector. Some studies on other species of spiny lobster have found an association between the level of catch of pueruli on collectors and the phase of the moon. Peak settlement generally occurs between new moon and first quarter (e.g. *P. cygnus* Phillips and Sastry 1980). However, this pattern is not typical of all species. Studies on *J. edwardsii* (Booth 1989) and *P. interruptus* (Serfling and Ford 1975) found no association between settlement and the lunar cycle.

Phillips and Booth (1994) recommended that collectors should be checked on the basis of a calendar month when the settlement behaviour of the species being studied is not associated to the phase of the moon. For example, several studies have shown that sampling monthly is adequate for *J. edwardsii* (e.g. Booth and Stewart 1993). When the pattern in settlement of pueruli is associated to the phase of the moon, then collectors need to be checked every 4 weeks at that time of the lunar month that maximises catches. For instance, most pueruli of *P. cygnus* settle on sea-weed-type of collectors around new moon, so collectors are sampled after this phase of the moon to make sure that settlement is completed for that lunar month (Phillips 1986).

We sample collectors around the first quarter of the lunar month and leave collectors to soak for approximately 4 weeks between sampling times. Although we have found no association between phase of the moon and level of catch of pueruli, the combination of a 4 week soak-time and sampling around the first quarter of the lunar month provided amongst the greatest catches as other combinations of phase of the moon and soak-time (unpublished data).

In summary, pueruli and post-pueruli of *J. verreauxi* can be caught using sea-weed-type of collectors positioned near the surface. We have found that a sea-weed-type of collector designed as a flat structure such as two panels of rope fibre attached together worked better in rough waters than the triangular structure described by Phillips (1972).

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LIST OF CAPTIONS FOR FIGURES

Figure 1. Location of sites used in the experiment to compare catches of pueruli of *J. verreauxi* between types of collector. The inserted map of Australia shows the distribution of *Jasus verreauxi*.

Figure 2. Mean number of pueruli and post-pueruli caught in sea-weed-type of collectors (W) and crevice-type of collectors (C) set near the surface (S) and substratum (B).

Figure 3. Design of sea-weed-type of collector used to sample pueruli of *J. verreauxi* . The mooring for the collector consists of two 25 kg steel weights (1), 25 mm (2) and 10 mm chain (3), protective hosing (4 and 8) around areas of wear on the rope (5), a polystyrene float (6) and weights (7) to hold the rope away from the bottom and surface, respectively and two shark clips (9) to attach the mooring to a swivel (10) at the base of the collector. The collector consists of two panels of tufts of rope fibre (12) supported by a centre frame(11) and a polystyrene float (13). A handle (14) is used to lift the collector.

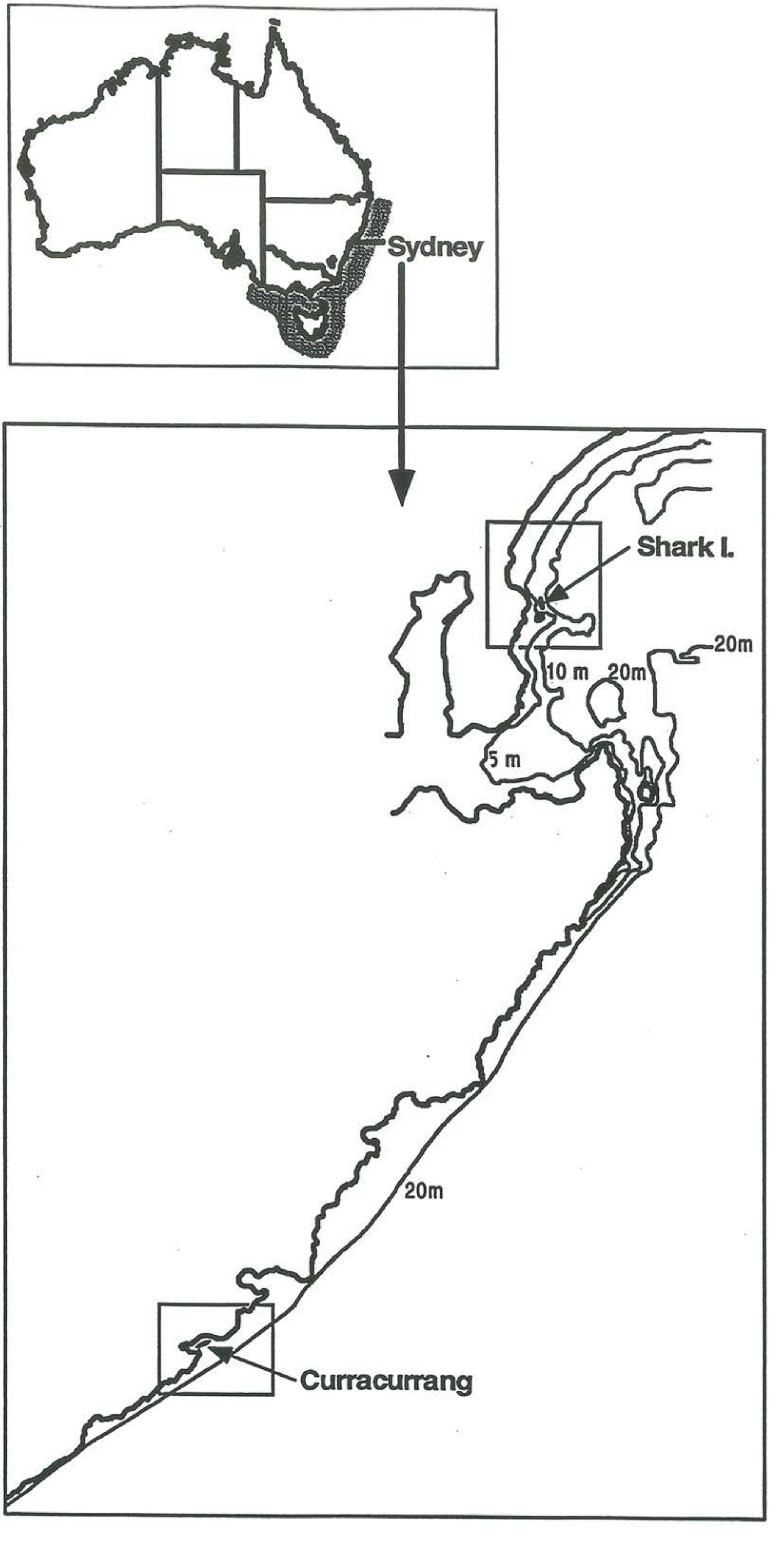
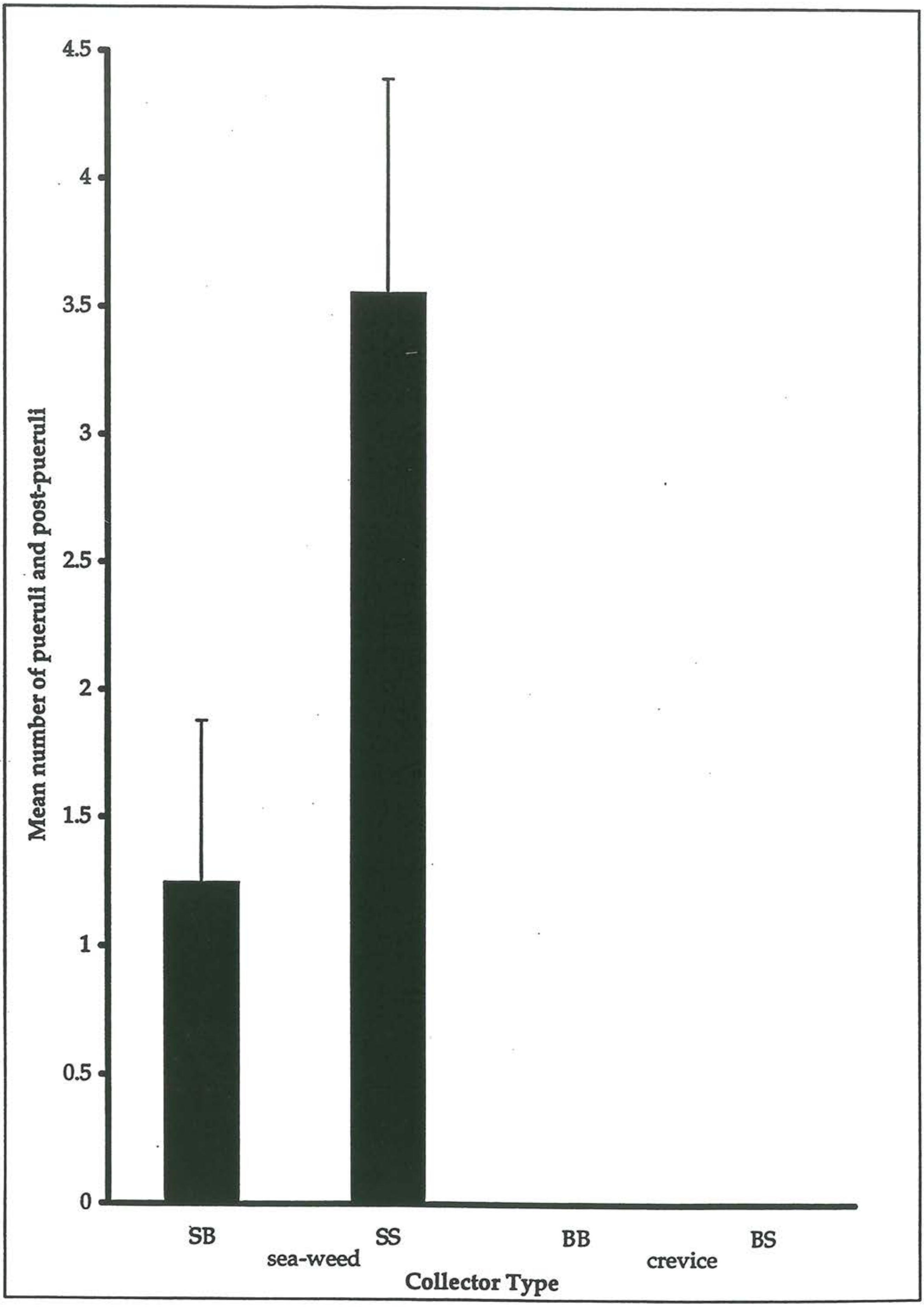


Fig. 1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Mean number of pueruli and post-pueruli
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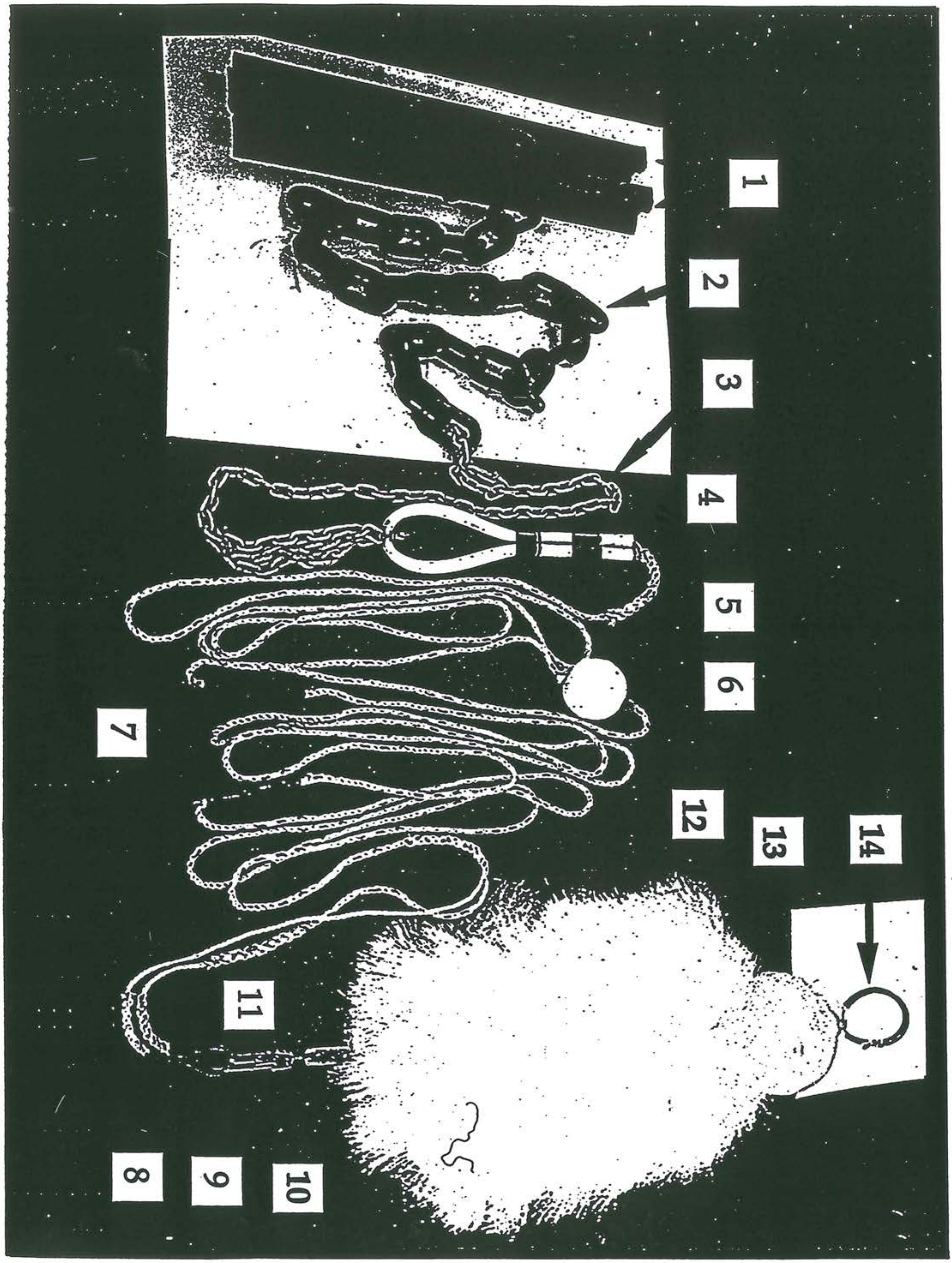
BS
sea-weed
crevice
Collector Type

Fig 2



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