Fisheries Research Institute

PRELIMINARY STUDY OF THE FISHERY FOR ROCK LOBSTERS OFF THE COAST OF NEW SOUTH WALES

By Steven S. Montgomery

Final Report

FIRDC Grant No. 86/64

May 1990

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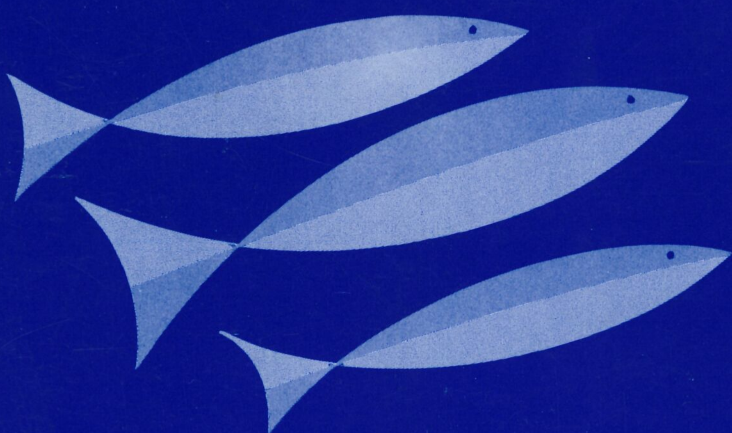

Department of Agriculture New South Wales

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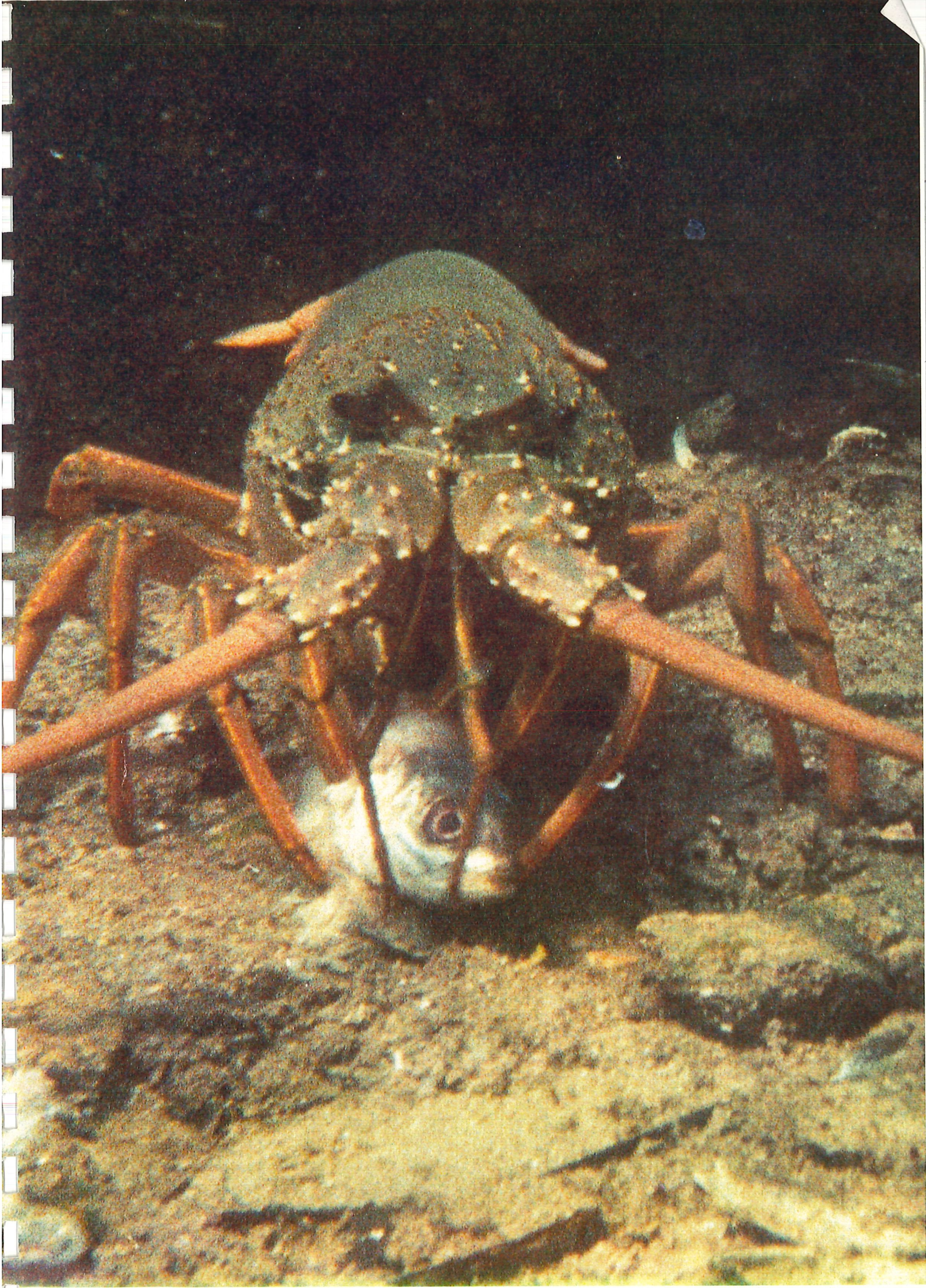
Right: The eastern rock lobster, *Jasus verreauxi*.



CONTENTS

SUMMARY

The objectives of this study were to determine whether catch rates of rock lobsters in the commercial fishery off New South Wales were declining, the size and species composition of catches from the commercial fishery and to ascertain the smallest length at which 50% of female eastern rock lobsters, *Jasus verreauxi* carried eggs. In addition, experiments were done to assess the mortality in this species caused by tagging with different types of external tags.

Rock lobsters have been exploited in waters off New South Wales since 1873. Annual catch per unit effort (kg per fisherman month) for the State as a whole declined over the period for which data were available (1969-70 to 1987-88). Samples from catches from the inshore fishery contained more rock lobsters shorter than the legal minimum length than those from the adjacent offshore fishery. The smallest length at which 50% of female eastern rock lobsters carried eggs during the egg-bearing season was 167 mm C.L.. Only samples from locations north of Port Stephens contained rock lobsters larger than this size. Approximately 64% of the average total landings of rock lobsters in New South Wales came from areas where all eastern rock lobsters sampled were immature. Data suggest that there has been a decline in stock density and an increase in fishing effort. It is recommended that the legal minimum length (104 mm C.L.) be increased by 6 mm per annum until a length of 128 mm C.L. is reached and that a legal maximum length of 167 mm C.L. be applied. The level of fishing effort should not be permitted to increase and a closed season from March 1st to August 31st should apply each year.

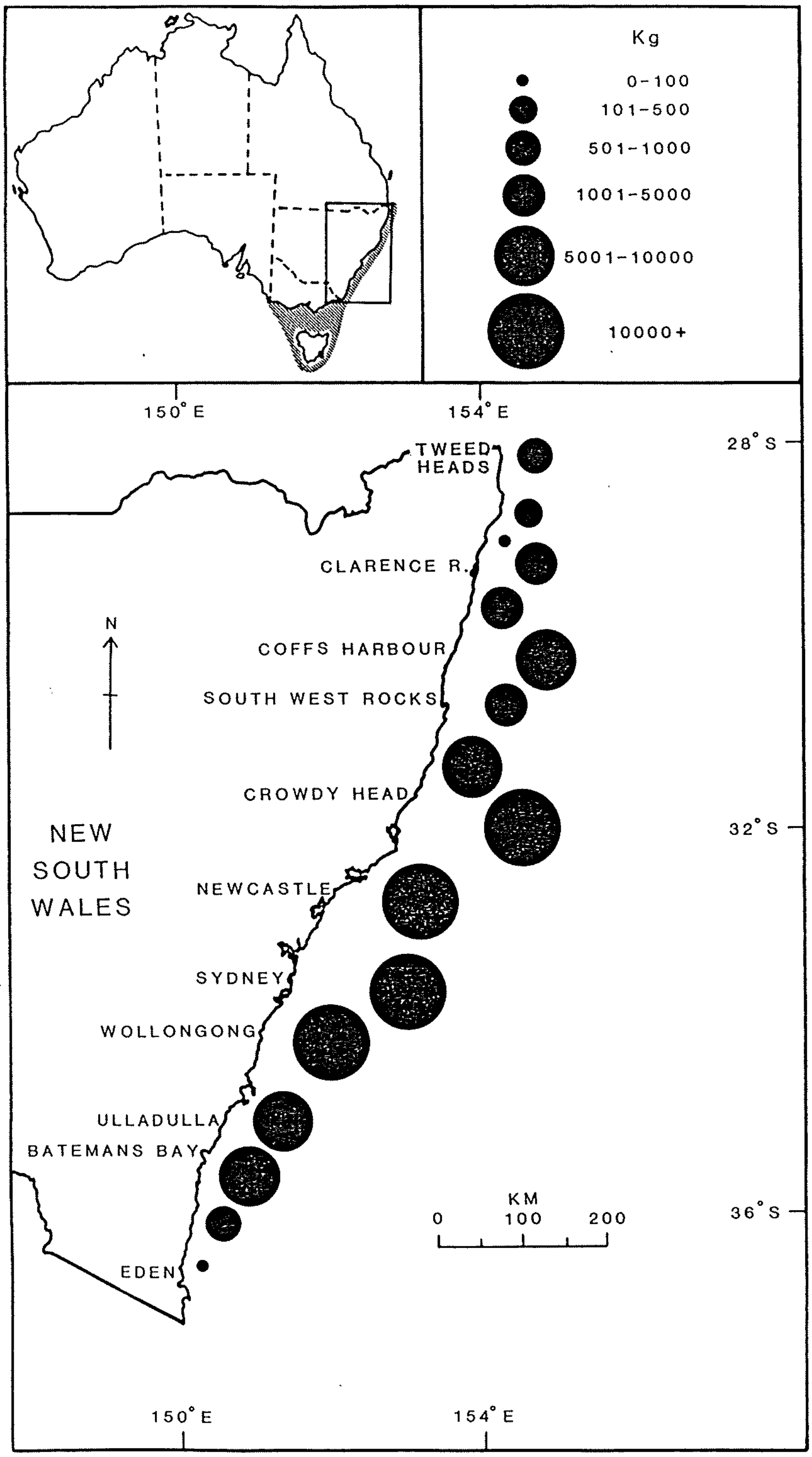


Figure 1. Map of the coast of New South Wales showing the average annual landings of rock lobsters for the period 1979-80 to 1983-84. Filled in circles represent different categories of landings by weight. The major ports of landings of rock lobsters are also shown on the map. The inserted map of Australia shows the distribution of *J. verreauxi*.

INTRODUCTION

Rock lobsters have been exploited off New South Wales since 1873. Reported annual landings averaged 122 tonnes per annum over the 10 year period to 1983-84 (latest year for which data are available from the NSW Agriculture & Fisheries Annual Reports). Based upon current prices at the point of first sale (Annual Reports of the Sydney Fish Marketing Authority), these average annual landings are worth $3 million per annum . In addition to this however, unreported landings are around 70% of those reported.

Four species comprise the commercial catch namely; the eastern rock lobster *Jasus verreauxi*, the southern rock lobster *Jasus novaehollandiae* and the painted rock lobsters *Panulirus longipes longipes* and *Panulirus ornatus*. The eastern rock lobster comprises around 97% of annual landings in New South Wales.

The eastern rock lobster *Jasus verreauxi* (H. Milne Edwards) is the largest species of 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 coastline of Tasmania and thence into Bass Strait as far west as McDonnell Point in South Australia (Figure 1). The species is found also off the North Island of New Zealand where it is of secondary commercial importance to *Jasus edwardsii* (Kensler 1967b).

Our knowledge of the biology of *J. verreauxi* is mainly from studies done on the population in waters off New Zealand (Kensler 1967a,b,c and Booth 1984 a and b). This species matures at a larger size and carries more eggs than other species of spiny lobsters (Morgan 1980). Female *J. verreauxi* first developed seteoed pleopods at 140-159 mm C.L. (antennal carapace length), but did not carry eggs until they were at least 10 mm C.L. larger (Kensler 1967a and Booth 1984a). They breed once a year between October and January and carry between 4 x 10^5 and 2 x 10^6 (Kensler 1967 a and c) eggs. Tagged lobsters of this species in waters off New Zealand have moved distances of over 1000 km along-shore in what is a spawning migration (Booth 1984b). Information on the biology of this species in waters off the east coast of Australia is limited to a preliminary study by Lee (1969) which described the fishery for this rock lobster and a note by MacIntyre (1967). Lee (1969) found females to be mature at 12.5 cm rostral carapace length. He provided little description however, of the definition of a seteoed pleopod and did not compare the size so determined to that at which females first carried eggs. Females carrying eggs were only found in samples from catches taken north of Port Stephens (MacIntyre 1967, Lee 1969).

The legal minimum length for *J. verreauxi* off New South Wales is far shorter than the size at maturity found for the population of the same species off New Zealand. Data from New South Wales Agriculture & Fisheries Annual Reports show that the level of reported landings fell between 1955 and 1978-79, but then rose for the next 5 years. The objective of this preliminary study was therefore to determine the condition of commercial populations of rock lobsters in waters off New South Wales and to ascertain the size at onset of breeding of *J. verreauxi* in waters off New South Wales. In addition experiments were done to find the external tag which caused the least mortality in *J. verreauxi*. This work is contained in three draft manuscripts (attached as appendices) of which the following is a summary.

The Fishery

The fishery for lobsters can be divided according to the depths fished into inshore (1-50 m) and offshore (51-220 m) components. The inshore fishery may operate year round, but the main season for both components varies between ports. Lobsters are caught on fishing grounds out to 20 m depth in traps of various designs (including beehive traps) with the opening usually in the top. Diving is used as a method of capture down to depths of approximately 10 m. Larger traps (2 m x 1.5 m x 1 m) with an opening in the side are used on fishing grounds deeper than 20 m. These gear are usually pulled every 1-2 days. Vessels in the inshore fishery are mostly aluminium planing hulls approximately 5 m in length, powered by at least 25 hp outboard engines.

The timing of the season for the offshore fishery varies between ports. Traps are normally pulled once every 2 weeks but current strength and weather conditions can prolong the period between lifts. Multipurpose vessels with displacement hulls are used in the offshore fishery. Lobsters are taken also as incidental catches by otter trawl and Danish seine vessels operating on grounds deeper than 50 m.

A recreational fishery for rock lobsters also operates within the same depth range as the inshore fishery. In 1982-83 a McNare omnibus survey found that 1% of the 788 people in New South Wales interviewed fished recreationally for lobsters off that state.

Regulations

The following regulations apply to fishing for lobsters off New South Wales.

(i) In 1984 the New South Wales State Government introduced a freeze on the number of vessels licenced to fish in any fishery in State waters off New South Wales. There is no complementary regulation which limits the number of vessels in the rock lobster fishery in Commonwealth waters off New South Wales.

(ii) The lobster trap was defined as a fish trap in the New South Wales Fisheries and Oyster Farms Act 1935 (Appendix 1) until May 1st 1989. Since then it has been defined separately under New South Wales Gazette Notice No. 37 (Appendix 1) for State waters.

(iii) The only method permitted for taking rock lobsters other than trapping is by hand or hand aided by a glove.

(iv) The taking or possession of rock lobster carrying ova is prohibited.

(v) There are legal minimum lengths of 104 mm C.L. and 105 mm C.L for eastern and southern rock lobsters, respectively.

(vi) An amateur fisherman may have in possession only one lobster trap and is limited to a catch of 5 lobsters per day.

METHODS

Overview of the fishery and size at onset of breeding

Data on the level of landings and fishing effort in the fishery for rock lobsters off New South Wales were extracted from three sources of information. Data from the annual reports of the NSW Agriculture & Fisheries were used to provide an historical account of the level of landings in the fishery. Trends in the level of landings, fishing effort and catch per unit of effort were examined from data from fisherman's catch cards held at the above Department's district offices for fisheries inspectors. Data from the records from Fishermen's Cooperatives were used to verify any trends ascertained from the above data.

Data on the length and sex composition of eastern rock lobsters in the catches of commercial vessels was obtained between July 1986 and June 1988. Sampling aboard commercial vessels was done at two principal locations along the coast of New South Wales, namely Crowdy Head and Sydney. Sampling was carried out also at Batemans Bay during 1987-88 and at other major ports of landings of rock lobsters when catches were great. The length of each lobster caught was measured as the straight line distance between the point of union of the second antennae on the antennal platform and the centre of the posterior margin of the carapace (Antennal Carapace Length C.L.) and measurements were rounded down to the nearest mm. Each female lobster was classified as either carrying eggs or, failing this, the degree of development of setae on their pleopods.

Effects of tagging on lobsters

Experiments were done at the NSW Agriculture & Fisheries' Fisheries Research Institute to provide data to determine the most suitable external tag for studying movement, growth and mortality of eastern rock lobsters. Two experiments tested null hypotheses that:

(i) tagging with different types of external tag did not affect the mortality of lobsters, and

(ii) there were no differences in growth between different sexes and sizes of lobsters tagged with different external tags.

The second experiment also included an external mark in the shape of a "v" notch cut into the right uropod.

A third experiment tested the null hypothesis that visual implant tags do not increase the mortality of lobsters.

RESULTS

Overview of the fishery

(i) Landings

The quality of data from all three sources of information on landings was very poor, but was considered adequate to identify trends in the data. The level of landings peaked in 1927 and 1948 and, except for the period 1978-79 to 1985-86, have fallen since. Over the period for which data were available (June 1969 to July 1989), the level of fishing effort was high between 1970-71 and

1972-73, fell in 1973-74, and then rose until 1985-86. The sharp rise in the level of landings and fishing effort between 1978-79 and 1985-86 coincided with an increase in the price paid for rock lobsters.

Trends in the level of annual catch per unit effort differed between that for the State as a whole and individual ports. Data from the State portrayed a downward trend whilst those from individual ports were fluctuating. The units of fishing effort used in this study were imprecise and underestimated fishing effort. There was no information on the number of traps fished or the soak time of the traps. Furthermore, data were not standardised for the advances in technology in fishing equipment. As a consequence of the underestimation of fishing effort, annual catch per unit effort has been overestimated.

Lobsters are caught year round off some ports. Catch rates were greatest between October and February but in general the season began earlier in the year at ports in northern NSW.

(ii) Length Frequency Distributions Of Total Catches

The ratio of sexes of lobsters in most of the annual length frequency distributions constructed from catches from commercial vessels did not vary from 1:1. The shape of these annual length frequency distributions differed between the inshore and offshore fishery at each location and between locations within each component of the fishery ($P < 0.05$). Samples from the inshore fishery contained more lobsters shorter than the legal minimum length than those from the offshore fishery. Those from catches from the offshore fishery contained some larger lobsters than those from the inshore fishery. Samples from Crowdy Head contained some larger lobsters than found at the other two locations. No lobsters larger than the length at onset of breeding were sampled south of Crowdy Head. Average annual reported landings of rock lobsters (all species) from ports south of Crowdy Head in New South Wales accounted for 64% of the average total reported landings of rock lobsters for the State.

Size at onset of breeding

Mature female *J. verreauxi* (with seteoed pleopods) were found only in catches from north of Port Stephens. Female lobsters carrying eggs, however, were only found at the two more northern locations sampled (Crowdy Head and Coffs Harbour). The length at which 50% of female lobsters from samples from catches off Crowdy Head and Coffs Harbour were mature was 160 mm C.L. and 162 mm C.L., respectively. The best estimate of size at onset of breeding came from samples off Crowdy Head and was 167 mm CL. These two sizes are far larger than the present legal minimum length of eastern rock lobsters off New South Wales.

Effects of tagging on lobsters

Two of the three experiments carried out are on-going. Results from these are presented for the period up to 31st August 1989, and therefore must be considered preliminary. So far, the results from experiments designed to compare the effects on lobsters of tagging with various types of external tags have differed. In the first experiment, mortality amongst tagged lobsters within the same treatment differed between sizes of lobsters. There were however, no differences in mortality of tagged lobsters of the same size between treatments. In the second experiment there were no differences in mortality between lobsters tagged with either type of external tag and controls. There were also no differences in mortality between lobsters tagged with toggle tags and those tagged with either T-anchor or dart tags. Mortality among lobsters tagged with T-anchor tags was however, greater than among those tagged with dart tags. That among marked lobsters was lower than among those tagged with toggle or T-anchor tags or controls. There were no differences in mortality between those tagged with dart tags and those marked. In the first experiment tag loss was greater among lobsters tagged with T-anchor tags than among those tagged with either dart or toggle tags. Conversely, in the second experiment there were no such differences. Mortality caused by tagging ranged between 2-22%, 13-28% and 6-12% over both experiments for toggle, T-anchor and dart tags respectively. In addition, the proportion of lobsters that lost their tags ranged between 12-20%, 16-48% and 10-18% over both experiments for toggle, T-anchor and dart tags, respectively. There has been no mortality amongst marked lobsters in the second experiment additional to that amongst untagged (controls) lobsters.

In the third experiment (which is on-going) results have been confounded by greater mortality amongst control lobsters than those tagged with visual implant tags. It has been assumed therefore, that the mortality induced by tagging with visual implant tags is minimal. In addition however, there was a high incidence of tag loss (38%).

It can be concluded from the results so far that either toggle or dart tags are most suitable for experiments on rock lobsters that require the use of an external tag. Growth increment and tag induced mortality appear to depend upon the size of the lobster at the time of tagging. Future tagging experiments in the field to study growth and mortality must therefore be designed to include lobsters of as large a range of lengths as possible.

CONCLUSIONS

Though the quality of data on levels of catch and fishing effort were poor, the common downward trend in catch per unit effort between sets of data indicated that the density of rock lobsters in waters off New South Wales is now less than over past decades. Because *J. verreauxi* comprise over 97% of the landings, it can be assumed that the density of this stock has declined. The quality of data prevented any modelling to determine the level of optimum fishing effort. Consequently, there is no reference level against which to assess whether over-exploitation has occurred.

Furthermore, the eastern rock lobster is exploited at a legal minimum length (104 mm CL) which is far shorter than the size at which female lobsters first breed. A major proportion of average total annual landings of rock lobsters in New South Wales are from ports where only immature eastern rock lobsters (the dominant species in the catch) are caught. A decline in the abundance of rock lobsters was noticed in 1902 and a legal minimum length of 10 in. total length was introduced into the fishery to conserve small lobsters (Report of the Commissioners of Fisheries to the Chief Secretary 1903). This management measure has not been successful in either conserving stock or sustaining yield. It is strongly recommended that management measures be introduced into the lobster fishery of New South Wales in order to conserve the resource until data are available to estimate maximum sustainable yield and optimum fishing effort.

Recommendations to management

Bowen (1980) lists five guiding principles for the management of spiny lobster fisheries, as follows:

i) Precise catch and effort and length-frequency data to understand the effect of fishing on the population.

ii) The setting of a legal minimum size with adequate inspection and legislative backing,

iii) Fishing effort restrictions to maximise the benefit from the resource,

iv) Collection of data on abundance of recruits over a long time span to determine the effect of high levels of exploitation upon the stock-recruitment relationship, and

v) Effective and continuing communication between professional and recreational fishermen.

Before any management measures are introduced however, it is essential to implement a sampling program that will provide accurate information on the level of catch and effort, and the composition of sizes and sexes of total catches of lobsters. These data could best be obtained by a compulsory system of log books and on board monitoring of catches, and should be implemented in both the recreational and commercial fisheries for lobsters in New South Wales. This information is essential to monitor the impact of any management measures introduced in order that the most effective strategy can be pursued.

An increase in the legal minimum length would conserve juvenile lobsters, particularly those on grounds in shallow water. The size at onset of breeding for eastern rock lobsters in waters off New South Wales is 167 mm C.L.(unpublished data). If it is the philosophy of management that animals should have the opportunity to spawn once before being harvested, then there is a need to increase the legal minimum length of *J. verreauxi* to 167 mm C.L.. The legal minimum length for this species in waters off New Zealand is far larger than that off New South Wales. Although a different measurement for legal minimum length is used in New Zealand, the equivalent in antennal carapace length is 155 mm C.L.. This size was introduced to enable the species to spawn at least once before entering the fishery (Kensler 1967a). Booth (1984a) suggested however, that if most *J. verreauxi* were to breed once before being exploited this size should be increased to 160 mm C.L..

Imposing the legal minimum length at the size at onset of breeding for the above reason assumes that there is a stock-recruitment relationship in the population. That this is the case in general, is being questioned increasingly (e.g. Hancock 1980, Winter et al. 1985). The level of recruitment may be determined by other factors (e.g. environmental), rather than the level of abundance of the breeding stock. *J. verreauxi* are highly fecund compared to other rock lobster species, with the number of eggs being roughly proportional to the carapace length of the lobster (Kensler 1967c). Perhaps only a few mature animals of this species are required to maintain recruitment at an acceptable level. However, Winters et al. (1985) concluded for management regimes whose objectives were promulgated on the basis of stock rebuilding, that the most appropriate long-term management strategy was a legal minimum size at or above the size of maturity.

An immediate increase in legal minimum length from 104 mm C.L. to 167 mm C.L. for *J. verreauxi* would be economically catastrophic for the New South Wales rock lobster fishery as it stands. Data on the growth of eastern rock lobsters from unpublished laboratory experiments indicated that *J. verreauxi* of 100-110 mm C.L. increase in size by around 12 mm C.L per year. Booth (1984a) suggested that larger lobsters increased in size by only 6 mm C.L. per year. If the legal minimum length was immediately increased to 167 mm C.L., it would take in excess of 5 years for the first lobsters conserved at 104 mm C.L. to reach the new legal minimum size. Any increase in legal minimum length therefore, should be introduced in annual increments of around 6 mm C.L..

If the legal minimum length were increased to larger than 130 mm C.L., fishing pressure on some grounds (particularly those within the inshore fishery), would be reduced as most lobsters on these grounds would be smaller than the legal minimum length. Similarly, if it were increased to 167 mm C.L. fishing pressure in areas south of Crowdy Heads would be less because few lobsters larger than this size are present in commercial catches.

Furthermore, a proportionally better price is paid for small lobsters (less than 1.5 kg) than for the bigger individuals. Consequently, a legal minimum length set at 167 mm C.L. may cause a fall in the economic yield from the fishery.

An alternate management strategy may be to set both a legal minimum length and a legal maximum length. A legal minimum length of 128 mm C.L. would conserve juvenile lobsters, whilst a legal maximum length of 167 mm C.L. would conserve the remaining spawning stock. The legal maximum length should be imposed immediately and the legal minimum length increased in annual increments of 6 mm C.L., to 128 mm C.L. At this stage the management recommendations should be reviewed in conjunction with data since collected on growth, mortality and movement patterns. This strategy again assumes that there is a stock-recruitment relationship. Imposing a legal maximum length also has the possible disadvantage of protecting lobsters that do not convert food to body weight as efficiently, grow slower and may have a higher natural mortality rate. The result being therefore, that maximum benefit may not be gained from the resource. The strategy of imposing both a legal minimum length and legal maximum length should be reviewed once data are available to determine maximum sustainable yield and the optimum size of first capture.

Hancock (1981) lists the various management measures which can be considered to reduce fishing effort. It is impossible to know what changes in the level of fishing effort are necessary without first knowing the optimum level of fishing effort required to produce maximum sustainable yield. Fishing effort should be stabilised therefore at its present level until the optimum level is known. The number of traps should be limited to 80 per vessel. Escape gaps would be of benefit (Bowen 1963) but probably impractical if the legal minimum size is to be increased annually. Also, before escape gaps can be implemented research is needed to determine the correct gap size. Licences should be non-transferable, at least in the interim, to discourage investment in the fishery and any escalation of fishing effort. Vessel replacements should be restricted to 1 for 1, for both length and engine capacity.

A closed season and/or areas to conserve juvenile rock lobsters whilst they are vulnerable in shallow waters (particulary to diving) also would be of benefit. Virtual area closures may result as the legal minimum length is increased because lobsters on some grounds will be too small to land. The main season for rock lobsters varies latitudinally along the coast of New South Wales. Consequently, one closed season for the whole state may disadvantage some areas but, it is the most effective way to enforce a seasonal closure off New South Wales. It is recommended that all waters off New South Wales be closed for the taking of all species of rock lobsters from March 1st to August 31st inclusive.

Bowen (1980) stresses the necessity for adequate legal systems and enforcement to ensure that management measures are adhered to. For example, Odemar et al. (1975, as cited in Bowen 1980) concluded that the taking of undersize lobsters was the largest factor contributing to the continued decline in stocks of *Panulirus interruptus* in southern California. If these systems are not adequate to enforce the recommendations then the recommendations should be reviewed.

The highest priority for research on spiny lobsters off New South Wales should be to identify the stocks. There are two possible ways in which this can be approached, namely tagging experiments or genetical analysis. Tagging experiments are probably the most useful. These will provide data not only on movement patterns but also on growth and mortality necessary for dynamic pool modelling. A knowledge of stock identification is necessary in the development of any management plan.

Research should also include a sampling strategy to study the abundances and distributions of puerulus stage and juvenile lobsters. These data together with those for the abundances of mature adult lobsters would allow studies into the stock-recruitment relationship of *J. verreauxi*. Understanding the relationship between the level of breeding stock and the level of recruitment is another of the five management guidelines suggested by Bowen (1980). These data would be an index of the strength of individual year classes of lobsters which are shorter than the size of first capture in the stock. Provided they are correlated to landings, it would be possible to advise industry on the expected level of landings in future years (e.g. Phillips 1986). Managers would also have time to respond to changes in the strength of individual year classes before each year class entered the fishery.

The density of *J. verreauxi* in waters off New South Wales has undoubtedly fallen. Measures need to be taken to conserve the resource until estimates of maximum sustainable yield and optimum fishing effort can be obtained. Management will need to weigh the recommendations made against the cost of effective implementation and the value of a sustainable rock lobster fishery. If recommendations are implemented then there will need to be continued research to provide information on stock identification, the relationship between stock and recruitment, and estimates of maximum sustainable yield. Conservation of this resource in the long term can only lead to more sustainable yields.

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APPENDIX 1

TRENDS IN THE LEVEL OF LANDINGS AND POPULATION STRUCTURE OF THE EASTERN ROCK LOBSTER, JASUS VERREAUXI (H. MILNE EDWARDS), IN WATERS OFF NEW SOUTH WALES.

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Trends in the level of landings and population structure of the eastern rock lobster, *Jasus verreauxi* (H. Milne Edwards), in waters off New South Wales

S. Montgomery

ABSTRACT

Rock lobsters have been exploited commercially in waters off New South Wales since 1873. The level of recorded landings peaked in 1927 and 1948, then fell until 1978-79, after which they again rose annually to 1985-86 and have fallen since. During the period for which data were available (1969-70 to 1987-88), the level of fishing effort was high between 1970-71 and 1972-73, fell in 1973-74, and then rose until 1985-86. Annual catch per unit effort (kg per fisherman month) for the State as a whole declined over the period for which data were available (1969-70 to 1987-88). That for the 8 major ports of landings showed a fluctuating trend but, for most ports has fallen since 1985-86. Annual length frequency distributions (constructed from samples from commercial catches) varied in shape between the 3 locations studied, the inshore and offshore fisheries, and the sexes of rock lobsters. The ratio of sexes did not vary from 1:1 and the mean length of males was larger. Samples from catches from the inshore fishery in each location contained more rock lobsters shorter than the legal minimum length than those from the adjacent offshore fishery. Samples from catches taken from offshore also included some larger rock lobsters than those from the inshore fishery. Only samples from Crowdy Head (the northern most location

onset of breeding (167 mm C.L.). Approximately 64% of the average total landings of rock lobsters in New South Wales came from areas where all eastern rock lobsters were immature. Data suggest that there has been a decline in stock density and an increase in fishing effort. It is recommended that the legal minimum length (104 mm C.L.) be increased by 6 mm per annum until a length of 128 mm C.L. is reached and that a legal maximum length of 167 mm C.L. be applied. The level of fishing effort should not be permitted to increase and a closed season from March 1st to August 31st should apply each year.

INTRODUCTION

Rock lobsters have been exploited in waters off the coast of New South Wales (Figure 1) since 1873 (Lee 1969). Reported landings averaged 122 tonnes per annum during the 10 year period to 1983-84 (NSW Agriculture & Fisheries, latest published records). Based upon current prices at the point of first sale, this average landings is worth around $3 million annually. The eastern rock lobster, *Jasus verreauxi* comprises around 97% of the total rock lobster landings off New South Wales. Other species taken are the southern rock lobster, *Jasus novaehollandiae* and several species of painted rock lobsters (mostly *Panulirus longipes longipes* and *Panulirus ornatus*).

Eastern rock lobsters occur in waters off the east coast of Australia from Tweed Heads southwards, around the coast of Tasmania, and then into Bass Strait as far west as McDonnell Point (South Australia). This species also occurs off New Zealand where it is of secondary importance commercially to *Jasus edwardsii* (Kensler 1967b). The southern rock lobster is the target species of the rock lobster fisheries off Tasmania, Victoria and South Australia. It also comprises a very small proportion of the total landings of rock lobsters off Western Australia (around 20 tonnes annually, R. Brown unpublished data). Painted rock lobsters are the target species of fisheries off Queensland and throughout the Indo-West Pacific region (George 1966).

The purpose of this paper is to examine trends in the levels of reported landings of rock lobsters in New South Wales and the structure of that portion of the population of eastern rock lobsters caught by commercial fishing vessels.

The Fishery

The fishery for rock lobsters can be divided into inshore (1-50 m) and offshore (51-220 m) components. The inshore fishery may operate year round, but the main season for both components varies between ports. Rock lobsters are caught on fishing grounds out to 20 m depth in traps of various designs (including beehive traps) with the opening usually in the top (Figure 2a). These gear are usually pulled every 1-2 days. Vessels in the inshore fishery are mostly aluminium planing hulls approximately 5 m in length, powered by at least 25 hp outboard engines (Figure 3a). Diving is used as a method of capture down to depths of approximately 10 m.

Larger traps (2 m x 1.5 m x 1 m) with an opening in the side (Figure 2b) are used on fishing grounds deeper than 20 m. Traps are normally pulled once every 2 weeks but current strength and weather conditions can prolong the period between lifts. Multipurpose vessels with displacement hulls are used in the offshore fishery (Figue 3b). Rock lobsters are taken also as incidental catches by otter trawl and Danish seine vessels operating on grounds deeper than 50 m.

A recreational fishery for rock lobsters also operates within the same depth range as the inshore fishery. In 1982-83 a McNaire omnibus survey found that 1% of the 788 people in New South Wales interviewed fished recreationally for rock lobsters in waters off that state.

Regulations

The following regulations apply to fishing for rock lobsters in waters under the jurisdiction off New South Wales.

(i) In 1984 the New South Wales Government introduced a freeze on the number of vessels licenced to fish in any fishery in State waters off New South Wales. There is no complementary regulation which limits the number of vessels in the rock lobster fishery in Commonwealth waters off New South Wales.

(ii) The rock lobster trap was defined as a fish trap in the New South Wales Fisheries and Oyster Farms Act 1935 (Appendix 1) until May 1st 1989. Since then it has been defined separately under New South Wales Gazette Notice No. 37 (Appendix 1) for State waters.

(iii) The only method other than trapping permitted for taking rock lobsters is by hand or hand aided by a glove.

(iv) The taking or possession of rock lobster carrying ova is prohibited.

(v) There are legal minimum lengths of 104 mm C.L. and 105 mm C.L for eastern and southern rock lobsters, respectively.

(vi) An amateur fisherman may have in possession only one rock lobster trap and is limited to a catch of 5 rock lobsters per day.

METHODS

Landings

Data on landings of rock lobsters and fishing effort were obtained from 3 sources of information. The first was the annual reports of the New South Wales Agriculture and Fisheries. These provided data on the annual landings of rock lobster and a description of the trend in the level of landings of rock lobsters over the course of the fishery. The second source was the individual fisherman's catch cards held at the New South Wales Agriculture and Fisheries' district offices for fisheries inspectors. These two sources were based upon information contained on the fisherman's monthly returns forms (Form 49). Commercial fishermen are required by law to detail their catch by species for the previous month. Individual fisherman's catch cards therefore provided information on the weight of rock lobsters caught per fisherman per month.

The third source of information was the records of landings from Fishermen's Cooperatives located at all major ports of landing in New South Wales. Commercial fishermen are compelled by law to market their landings through these cooperatives. These records provided information on the weight of rock lobsters landed per day by each fisherman. Where possible, trends in the level of landings, fishing effort and annual catch per unit effort obtained from data from fisherman's catch cards have been verified through comparisons with data obtained from the records of fishermen's cooperatives.

Size Distribution Of Total Catches

Catches of rock lobsters from the inshore and offshore fisheries were sampled monthly during the 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 and Narooma (offshore fishery only) during 1987-88 (Figure 1). Data from Batemans Bay and Narooma were combined and are subsequently referred to as Batemans Bay. The inshore fishery operates each year between September and January off Crowdy Head, between June and April off Sydney, and year round off Batemans Bay. The offshore fishery operates each year between March and July off Crowdy Head and between December and February off Sydney and Batemans Bay. Samples were also taken at Coffs Harbour, Wallis Lake and Port Stephens between June 1986 and July 1988 when sufficient quantities of rock lobsters were caught to provide representative samples.

The sex and length of each rock lobster caught on the day of sampling was determined. Length was measured as the straight line distance between the point of union of the second antennae on the antennal platform and the centre of the posterior margin of the carapace (Antennal Carapace Length C.L.). Measurements were rounded to the nearest millimetre.

In addition to this sampling, one commercial fisherman from Crowdy Head measured the length (same measurement as above) and determined the sex of all rock lobsters in his daily catch between September 1986 and December 1988. He was the only fisherman operating off Crowdy Head that fished for rock lobsters all year. This fisherman's method of measuring was checked regularly by research staff to ensure that a standardised procedure was adhered to.

In all data, lengths were grouped using a 5 mm length class (e.g. 100-104 mm C.L). The Kolmogorov-Smirnov Two-Sample Test was used to compare the shape of annual size frequency distributions between sexes within localities and within sexes between localities. The significance level ($P < 0.05$) was Bonferronised (Miller 1966) when comparing more than two samples.

RESULTS

Landings

The quality of data on the level of catch and fishing effort in the rock lobster fishery of New South Wales is very poor. First, there is a high level of unreported landings (estimated to be approximately 70%) in the fishery. As a consequence all sources of data underestimated the real level of landings. Furthermore, there was no accurate unit of fishing effort available. Form 49 records did not provide accurate information on the number of days spent fishing for rock lobsters. A day of landing in the records of Fishermen's Cooperatives may represent more than one days fishing. None of these data provided any information on the number of traps fished per day or the soak time of traps. To assess trends in the level of landings of rock lobsters it has therefore been assumed that the proportion of unreported landings within the fishery has not changed between years. The level of catch so calculated should therefore portray real trends within the fishery. The units of fishing effort used in the present study did not consider either advances in the technology of fishing gear over time or any increases in the number of traps fished by fishermen. These will have had the effect of making fishermen more efficient at catching rock lobsters. For this reason it has been assumed that the units of fishing effort used in this study will have been underestimated. Consequently, annual catch per unit effort will have been increasingly overestimated over the years.

(i) An historical account

Records of landings of rock lobsters off New South Wales have been maintained in one form or another since 1873. Prior to 1927 annual landings were estimated from the total number sold at the various market centres, and thence until 1946 were recorded as the number of rock lobsters landed (Figure 4a). Data from years thereafter have been converted to metric weight. The break in records between 1943 and 1944 can be attributed to no fishing during the Second World War. No data on the average weights of rock lobsters in landings in past years were available. However, if it is assumed that the average weight of rock lobsters in landings at the time was heavier than 500 g (approximate weight of an eastern rock lobster at the legal minimum length at that time), then the first peak in landings in 1929 would be equivalent to in excess of 300 tonnes. A second peak (364 tonnes) was recorded in 1948, after the Second World War. Annual reported landings then declined until 1978-79 and thereafter increased until the last available record from the published annual reports (1983-84) of the New South Wales Agriculture and Fisheries. The economic value of rock lobsters was far less prior to the Second World War than in post-war years (Figure 4b). It has risen since the Second World War primarily because of increases in the price paid for rock lobsters. The sharpest rise occurred during the 1980's and coincided with increases in both price and the level of landings.

(ii) Trends in landings

Fisherman's catch cards provided the longest time series of data on the level of catch and fishing effort. They were also the only source of data available for all sites of landings. For these reasons, these data were used to assess trends in levels of landings and fishing effort. Data are shown for New South Wales and the eight major ports of landings (determined from average annual reported landings over the 10 year period to 1983-84).

The level of landings and fishing effort in these data may be biased by missing information. For example, the records of fishermen who have left the industry may have been destroyed. It was assumed that such events were minimal and that these data provided, at worst, a representative sub-set of fisherman's landings and fishing effort in any year. Representative trends for the level of annual catch per unit effort in the fishery should therefore be portrayed by these data.

Trends in total annual reported landings for New South Wales (Figure 5) followed a similar pattern to that described from data from the annual reports of the New South Wales Agriculture and Fisheries (Figure 4). Data for those years for which there were none from annual reports showed that the level of landings had fallen since 1985-86 (Figure 5). The level of landings from major ports north of Newcastle showed peaks in 1974-75 and in the early 1980's (Figure 6), whilst for ports south of that point it was not as great during the 1970's but rose during the 1980's.

The level of fishing effort (fisherman months) for New South Wales as a whole was high between 1970-71 and 1972-73, fell in 1973-74 and then rose until 1986-87 (Figure 5). The rise since 1974-75 coincided with a rise in prices paid for rock lobsters (Figure 4). A similar pattern was also present in data for each of the eight major ports (Figure 7). Conversely, data from the records of the Fishermen's Cooperative at Coffs Harbour (Appendix 2) suggested that the number of landing days per fisherman had fallen since 1982-83 (the first year for which data were available). A most likely reason for the difference in trends between sets of data is that the unit of fishing effort from the records of the Fishermen's Cooperative (fisherman landing day) may have been affected to a greater extent than fisherman's catch cards (fishermen months) by any increase in the level of unreported landings.

The best available unit of fishing effort from the records of the Crowdy Head Fishermen's Cooperative was the number of fishermen landing rock lobsters at the Cooperative each year. This was because the level of unreported landings in the fishery was very high (personal observation). These data showed a similar trend to that obtained from the fisherman's catch cards for that region and suggested that the level of fishing effort had risen. Interviews with fishermen of long standing in the fishing industry suggested that the number of traps fished at any one time during the 1960's was approximately 30 whereas during the 1980's it was in excess of 100. These trends together with the advances in technology in fishing equipment, leave little doubt that the level of fishing effort in the rock lobster fishery has increased.

Annual catch per unit effort for New South Wales as a whole declined over the period for which data (1969-70 to 1987-88) were available (df = 1,17 F = 21.44 $P < 0.05$). This was most pronounced for years after 1974-75 (Figure 5). Trends in the level of annual catch per unit effort differed between the eight major ports, but fell at most ports since 1984-85 (Figure 8). Data from the records of the Coffs Harbour Fishermen's Co-operative (Appendix 2) showed a similar trend (for the period for which it is available) to that from the fisherman's catch cards. The short time series of data from the Crowdy Head Fishermen's Co-operative showed a fall in 1986-87 (Appendix 3).

(iii) Seasonality of landings

Rock lobsters are harvested all year round at the eight major ports of landings (Figure 9). The period of greatest mean catch per unit effort varied between ports. Generally, mean catch per unit effort was greater later in the year along the south coast of New South Wales. Some ports also had a different season for the inshore (spring-summer) and offshore fishery (autumn-winter), e.g. Coffs Harbour and Crowdy Head.

Size Distribution Of Total Catches

Eastern rock lobsters sampled in this study ranged in length classes between 65-69 mm C.L. and 260-264 mm C.L. (Figures 10 to 14). The ratio of sexes of rock lobsters in most of the annual size frequency distributions constructed from samples from catches of commercial vessels at each location did not vary from 1:1 (X^2 test, $P < 0.05$). Those that did were samples from the inshore fishery off Batemans Bay (1987-88) and Sydney (1986-87) and from the offshore fishery at each location in 1987-88.

The shapes of the annual size frequency distributions varied between components of the fishery (inshore versus offshore) at each location and between locations within each component (Kolmogorov-Smirnov Test, $P < 0.05$). In most cases the shape of these frequency distributions at each location and for each component of the fishery varied between sexes (Kolmogorov-Smirnov Test, $P < 0.05$). Those that did not vary between sexes were from the inshore fishery off Crowdy Head (1986-87) and Sydney (1987-88). In all cases where there was a difference, the mean length of males was larger than that for females.

Samples from the inshore fishery (Figures 10 to 12) contained more rock lobsters shorter than the legal minimum length (104 mm C.L.) than those from the offshore fishery (Figures 13 and 14). There were few rock lobsters larger than 127 mm C.L. in samples from the inshore fishery off Sydney (Figure 11) and Batemans Bay (Figure 12). Samples from the inshore fishery off Crowdy Head (Figure 10) contained some rock lobsters larger than found in those from off Sydney and Batemans Bay.

Samples from catches from the offshore fishery (Figures 12 to 14) at the three locations contained some rock lobsters larger than found in those from the adjacent inshore fishery (Figures 10 to 12). Of all the samples from the offshore fishery, only those from off Sydney (Figure 14) contained any rock lobsters smaller than the legal minimum length. Samples from the offshore fishery off Crowdy Head (Figure 13) again contained some rock lobsters larger than those found in samples from the offshore fishery at the other 2 locations (Figures 12 and 14).

Monthly samples from catches from the inshore grounds (1 to 20 m depth) off Crowdy Head (from June 1987 to July 1989 inclusive) were generally bimodal and contained a considerable number of rock lobsters smaller than the legal minimum length (Figure 15). The size range sampled was similar to annual data for the inshore fishery off Crowdy Head from July 1986 to June 1988 (Figure 10). Rock lobsters larger than the legal minimum length were in greatest numbers between June and November each year. The largest rock lobsters were present in samples taken from catches in September and October each year. Data from similar inshore grounds (1-20 m depth range) off Batemans Bay suggested that the size range of rock lobsters present on these grounds was the same throughout the year (Figure 16).

DISCUSSION

The quality of data used to assess trends in the level of landings and fishing effort was poor. Nevertheless, the similarity in trends for the level of landings and annual catch per unit effort between data from different sources suggests that these trends are representative of what has occurred in the fishery. The level of reported annual landings has peaked twice over the course of the fishery, but has fallen for most years since 1948. The information on the level of fishing effort from the three sources of data was imprecise and there were differences in trends between sources of data. Over the period for which data was available, fishing effort has risen since 1973-74. Both the level of landings and fishing effort rose sharply from 1978-79 to 1985-86 and 1986-87, respectively. Annual catch per unit effort showed different trends between that for New

South Wales as a whole and individual ports. The former showed a fall over the period for which data were available whilst that for the latter fluctuated. The period of the year of greatest mean catch per unit effort also varied between ports.

Trapping did not appear to capture many eastern rock lobsters smaller than 70 mm C.L. Samples from the inshore fishery at each location contained many J. verreauxi shorter than the legal minimum length but no rock lobsters as large as sampled from the offshore fishery. Very few rock lobsters smaller than the legal minimum length were sampled from the offshore fishery. No rock lobsters larger than the size at onset of breeding (167 mm C.L.; unpublished data) were found in samples from catches south of Crowdy Head. Average reported annual landings of rock lobsters (all species) in New South Wales from locations south of Crowdy Head accounted for 64% of the average total reported landings of rock lobsters for the State (Fisherman Catch Card data).

Fishing effort has been increasingly underestimated for recent years because data were not standardised for the advances in technology which have occurred. Fishermen now use faster vessels than in the past, which allows them to get closer to the shoreline and fish more traps than in past years. They also have more sophisticated fish finding equipment which will identify areas of reef. An attempt was made to overcome the imprecision of the units of fishing effort used in this study by using informatiom from fisherman's personal diaries. This was unsuccessful however, primarily because of the small sample size.

Catch per unit of effort can be used as an index of the density of an exploited stock of animals (Gulland 1969). It has been overestimated in this study because the unit of fishing effort was underestimated. Consequently, the downward trend in annual catch per unit effort is conservative. It can be concluded (from the trends in the level of landings, fishing effort and catch per unit effort) that the density of rock lobsters has declined in waters off New South Wales and that this resource has been exploited by an increasing fishing effort.

There were no rock lobsters larger than 160 mm C.L. sampled from catches south of Crowdy Head. Annecdotal reports suggested however, that larger rock lobsters are present on some grounds off Sydney (e.g. Appendix 5) and Jervis Bay (Andrewartha and Montcalm, 1970). Any rock lobsters larger than 160 mm C.L. present off Sydney must either be on different grounds to those fished by commercial vessels sampled in this study or in such low numbers that they were not represented at the level of sampling used. Grounds off Jervis Bay where quantities of rock lobsters larger than 160 mm C.L. were caught, are no longer fished by commercial fishermen because of low catch rates (personal communication with commercial fishermen). It is not known whether these large rock lobsters off Sydney and Jervis Bay represent what is left of once big aggregations of mature rock lobsters.

The shape of the right hand tail of the annual length frequency distributions of rock lobsters (Figures 11 to 17 inclusive), suggested that fishing had little effect upon the rock lobster population. If the rate of fishing mortality is great compared to that for natural mortality (as seems to be the case for other exploited palinurids, Morgan 1980), the proportion of rock lobsters in size classes larger than the legal minimum length should be small compared to those of length classes immediately shorter than the legal minimum length. This pattern was not observed in the annual length frequency distributions in the present study. If the scenario above is true for the eastern rock lobster population, then something must be confounding the pattern observed in the length frequency distributions. It is most likely that some pattern of movement of rock lobsters is occurring.

Herrnkind (1980) reviewed the available data on the movements of spiny rock lobsters. Movements are mostly seasonal, often involve an inshore-offshore directional component and some are along-shore over long distances. It is not uncommon for these along-shore movements to be associated with spawning (Cobb and Wang 1985). Booth (1984b) found that tagged J. verreauxi off New Zealand moved long distances in a north-westerly direction and suggested that this was associated with the onset of breeding. A similar movement pattern by J. verreauxi in waters off New South Wales would explain the results in the present study.

If _J. verreauxi_ is a typical palinurid, then it would be expected to be a long-lived animal with a low natural mortality rate (e.g. Morgan 1980). They are also highly fecund (Kensler 1967c). Tagged individuals of this species have been recaptured more than three years after release (Booth 1984b), whilst some tagged _J. novaehollandiae_ have been recaptured 13 years after release (Anon 1990). The pattern of landings of rock lobsters in New South Wales over the course of the fishery is typical of a marine species with this type of life history that has been exposed to unregulated harvesting (Walters 1986). A decline in the abundance of rock lobsters was first noticed in 1902 when a legal minimum length was introduced to conserve juveniles (Report of the Commissioners for fisheries to the Chief Secretary 1903). This management measure has obviously been unsuccessful in conserving stock abundance and sustaining yield.

No data are available with which to assess whether the fall in stock density of _J. verreauxi_ constitutes over-exploitation. The quality of data on landings and effort was too poor for surplus production modelling. Further, there were no estimates of population parameters from which to model using dynamic pool methods. Consequently, no estimate of the required level of fishing effort to produce optimum yield has been made. Therefore, there is no reference point with which to compare the levels of fishing effort operating in any year. It is therefore difficult to ascertain from the available information how serious the fall in annual catch per unit effort has been biologically.

It is strongly recommended that management measures be introduced into the rock lobster fishery of New South Wales in order to conserve the resource. The management measures introduced should be reviewed once data are available to estimate maximum sustainable yield and optimum fishing effort. Before any of this is done, it is essential that a sampling program be implemented that will provide accurate data on the level of catch and effort, and the composition of sizes and sexes of total catches of rock lobsters. Bowen (1980) lists the collection of such data as one of the five guiding principles in the management of a spiny rock lobster fishery. These data could best be obtained by a compulsory system of log books and on board monitoring of catches. Such a system should be implemented in both the recreational and commercial fisheries for rock lobsters. This information is essential in order to monitor the impact of any management measures introduced so that the most effective management strategy can be pursued.

Bowen (1980) and Hancock (1981) discuss the various management options available for rock lobster fisheries. Of these, a combination of legal minimum length and legal maximum length, restricted fishing effort and a closed season are recommended. A legal minimum length of 12 in. (Total Length, TL) was introduced in 1902 for eastern rock lobsters in New South Wales to conserve juveniles of this species (Report of the commissioners for fisheries to the Chief Secretary 1903). This was reduced to 10 in. TL in 1903 after representations from fishermen from Botany Bay that "because of the small run of crayfish in the south coast waters", a legal minimum length of 12 in. TL "had the effect of throwing out of work a number of cray-fishermen" (NSW Agriculture & Fisheries Annual Report 1903). This reduction in legal minimum length was to be a temporary measure until a study was done to determine the size at which this species "first becomes mature". Unfortunately, this work does not appear to have been done at the time. In 1983 the measure of legal minimum length for rock lobsters was converted from total length to carapace length. Hence the equivalent 10 in T.L. converted to 104 mm C.L..

The size at onset of breeding for eastern rock lobsters in waters off New South Wales is 167 mm C.L.(unpublished data). If it is the philosophy of management that animals should have the opportunity to spawn once before being harvested, then there is a need to increase the legal minimum length of _J. verreauxi_ to 167 mm C.L.. Any increase in the legal minimum length would conserve juvenile rock lobsters, particularly those on grounds in shallow water. The legal minimum length for this species in waters off New Zealand is far larger than that off New South Wales. Although a different measurement for legal minimum length is used in New Zealand, the equivalent in antennal carapace length is 155 mm C.L.. This size was introduced to enable the species to spawn at least once before entering the fishery (Kensler 1967a). Booth (1984a) suggested however, that if most _J. verreauxi_ were to breed once before being exploited this size should be increased to 160 mm C.L..

Imposing the legal minimum length at the size at onset of breeding for the above reason assumes that there is a stock-recruitment relationship in the animal population. These are being questioned increasingly (e.g. Hancock 1980, Winter et al. 1985). The level of recruitment may be determined by other factors (e.g. environmental), rather than the level of breeding stock. _J. verreauxi_ are highly fecund compared to other rock lobster species, with the number of eggs being roughly proportional to the carapace length of the rock lobster (Kensler 1967c). Perhaps only a few mature animals of this species are required to maintain recruitment at an acceptable level. However, Winters et al. (1985) concluded for management regimes whose objectives were promulgated on the basis of stock rebuilding, that the most appropriate long-term management strategy was a legal minimum size at or above the size of maturity.

An immediate increase in legal minimum length from 104 mm C.L. to 167 mm C.L. for _J. verreauxi_ would be economically catastrophic for the New South Wales rock lobster fishery. Data on the growth of eastern rock lobsters from unpublished laboratory experiments indicated that _J. verreauxi_ of 100-110 mm C.L. increase in size by around 12 mm C.L per year. Booth (1984a) suggested that larger rock lobsters increased in size by only 6 mm C.L. per year. If the legal minimum length was immediately increased to 167 mm C.L., it would take in excess of 5 years for the first rock lobsters conserved at 104 mm C.L. to reach the new legal minimum size. Any increase in legal minimum length should be introduced therefore, in annual increments of around 6 mm C.L..

If the legal minimum length was increased to larger than 130 mm C.L., fishing pressure on some grounds (particularly those within the inshore fishery) would be expected to reduce as most rock lobsters on these grounds would be smaller than the legal minimum length. Similarly, if it was increased to 167 mm C.L. fishing pressure in areas south of Crowdy Heads would be expected to be less because few rock lobsters larger than this length are present in commercial catches from there. Furthermore, a proportionally better price is paid for small rock lobsters (less than 1.5 kg) than for the bigger individuals. Consequently, a legal minimum length set at 167 mm C.L. may cause a fall in the economic yield from the fishery.

An alternate management strategy may be to set both a legal minimum length and a legal maximum length. A legal minimum length of 128 mm C.L. would conserve juvenile rock lobsters, whilst a legal maximum length of 167 mm C.L. would conserve the remaining spawning stock. The legal maximum length should be imposed immediately and the legal minimum length increased, in annual increments of 6 mm C.L., to 128 mm C.L. These management recommendations should be reviewed in conjunction with data since collected on growth, mortality and movement patterns. This strategy again assumes that there is a stock-recruitment relationship. Imposing a legal maximum length also has the possible disadvantage of protecting rock lobsters that do not convert food to body weight as efficiently, grow slower, may have a higher natural mortality rate. The result being that maximum benefit may not be gained from the resource. The strategy of imposing both a legal minimum length and legal maximum length should be reviewed once data are available to determine maximum sustainable yield and the optimum size of first capture.

Hancock (1981) lists the various management measures which can be considered to reduce fishing effort. It is impossible to know what changes in the level of fishing effort are necessary without first knowing the optimum level of fishing effort required to produce maximum sustainable yield. Fishing effort should be stabilised therefore at its present level until the optimum level is known. The number of traps should be limited to 80 per vessel. Escape gaps would be of benefit (Bowen 1963), but probably impractical if the legal minimum size is increased annually. Before escape gaps can be implemented research is needed to determine the appropriate gap size. Licences should be non-transferable, at least in the interim, to discourage investment in the fishery and any escalation of fishing effort. Vessel replacements should be restricted to 1 for 1, for both length and engine capacity.

A closed season to conserve juvenile rock lobsters whilst they are vulnerable in shallow waters (particulary to diving) would be of benefit. The main season for rock lobsters varies geographically along the coast of New South

Wales. Consequently, one closed season for New South Wales may disadvantage some areas, but it is the most effective way to enforce a seasonal closure off New South Wales. It is recommended that all waters off New South Wales be closed for the taking of all species of rock lobsters from March 1st to August 31st, inclusive.

Bowen (1980) stresses the necessity for adequate legal systems and enforcement to ensure that management measures are adhered to. For example, Odemar et al. (1975, as cited by Bowen 1980) concluded that the taking of undersize rock lobsters was the largest factor contributing to the continued decline in rock lobster stocks of *Panulirus interruptus* in southern California. If these systems are not adequate to enforce the recommendations then the recommendations should be reviewed.

The highest priority for research on spiny rock lobsters off New South Wales should be to identify stocks. There are two possible ways in which this can be approached; namely tagging experiments or genetical analysis. Tagging experiments are probably the most useful. These will provide data not only on movement patterns but also on growth and mortality necessary for dynamic pool modelling. A knowledge of stock identification is necessary in the development of any management plan.

Research should also include a sampling strategy to study the abundances and distributions of puerulus stage and juvenile rock lobsters. These data, together with data for the abundances of mature adult rock lobsters, would allow studies into the stock-recruitment relationship of _J. verreauxi_. Understanding the relationship between the level of breeding stock and level of recruitment is another of the five management guidelines suggested by Bowen (1980). These data would be an index of the strength of individual year classes of rock lobsters which are shorter than the size of first capture in the stock. Provided they are correlated to landings, it would be possible to advise industry on the expected level of landings in future years (e.g. Phillips 1986). Managers would also have time to respond to changes in the strength of individual year classes before the year class entered the fishery.

The density of _J. verreauxi_ in waters off New South Wales has undoubtedly fallen. Measures need to be taken to conserve the resource until estimates of maximum sustainable yield and optimum fishing effort can be obtained. Management will need to weigh the recommendations made against the cost of effective implementation and the potential value of a sustainable rock lobster fishery. If recommendations are implemented then there will need to be continued research to provide information on stock identification, the relationship between stock and recruitment and estimates of maximum sustainable yield. Conservation of this resource in the long term can only lead to more sustainable yields.

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Figure 1. Map of the coast of New South Wales showing the average annual landings of rock lobsters for the period 1979-80 to 1983-84. Filled circles of various sizes represent different categories of landings by weight. The major ports for landings of rock lobsters are also shown on the map. The inserted map of Australia shows the distribution of *J. verreauxi*.

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Source: Annual Reports of the NSW Agriculture & Fisheries.

Figure 4b. Trends in (A) the price paid for rock lobsters, and (B) value of the fishery at point of first sale in New South Wales. Data are for financial years, with the first half of the year labelled on the x axis.

Source: Annual Reports of the NSW Agriculture & Fisheries.

Annual Reports of the Sydney Fish Marketing Authority

Figure 5. Trends in the level of landings (A), fishing effort (B) and annual catch per unit effort (C) in the rock lobster fishery off New South Wales. The standard error about the annual catch per unit effort value is also shown. Data are for financial years, with the first half of the year labelled on the x axis.

Source: Fisherman Catch Cards.

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Source: Fisherman Catch Cards.

Figure 7. Trends in the level of fishing effort in the fishery for rock lobsters at the eight major ports of rock lobster production. An asterisk (*) denotes no records of landings available. Data are for financial years, with the first half of the year labelled on the x axis.

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Figure 8. Trends in the level of annual catch per unit effort of rock lobsters at the eight major ports of rock lobster production. The standard error about each value is shown, whilst an asterisk (*) denotes no records of landings available. Data are for financial years, with the first half of the year labelled on the x axis.
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Figure 9. Trends in the level of mean catch per unit effort by month at the eight major ports of rock lobster production. The standard error about each mean is shown. Data are for financial years, with the first half of the year labelled on the x axis.
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Figure 10. Annual length frequency distributions of eastern rock lobsters sampled from catches from the inshore fishery off Crowdy Head. The mean ($\bar{x}$), standard error (S.E.), sample size (n) and legal minimum length (▼) are shown.

Figure 11. Annual length frequency distributions of eastern rock lobsters sampled from catches from the inshore fishery off Sydney. The mean ($\bar{x}$), standard error (S.E.), sample size (n) and legal minimum length (▼) are shown.

Figure 12. Annual length frequency distributions of eastern rock lobsters sampled from catches from the inshore and offshore fishery off Batemans Bay. The mean ($\bar{x}$), standard error (S.E.), sample size (n) and legal minimum length (▼) are shown.

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Figure 14. Annual length frequency distributions of eastern rock lobsters sampled from catches from the offshore fishery off Sydney. The mean ($\bar{x}$), standard error (S.E.), sample size (n) and legal minimum length (▼) are shown.

Figure 15. Monthly length frequency distributions of eastern rock lobsters sampled from inshore grounds off Crowdy Head. The sample size (n) and legal minimum length (▼) are shown.

Figure 16. Monthly length frequency distributions of eastern rock lobsters sampled from inshore grounds off Batemans Bay. The sample size (n) and legal minimum length (▼) are shown.

APPENDICES

Appendix 1. Definitions of a lobster trap under the New South Wales Fisheries and Oyster Farmers Act 1935, prior to May 1989 (A) and thereafter (B).

Appendix 2. Trends in the level of landings (A), fishing effort (B) and annual catch per unit effort (C) in the rock lobster fishery off Coffs Harbour Data are for financial years, with the first half of the year labelled on the x axis.

Source: Records of the Coffs Harbour Fishermens Cooperative.

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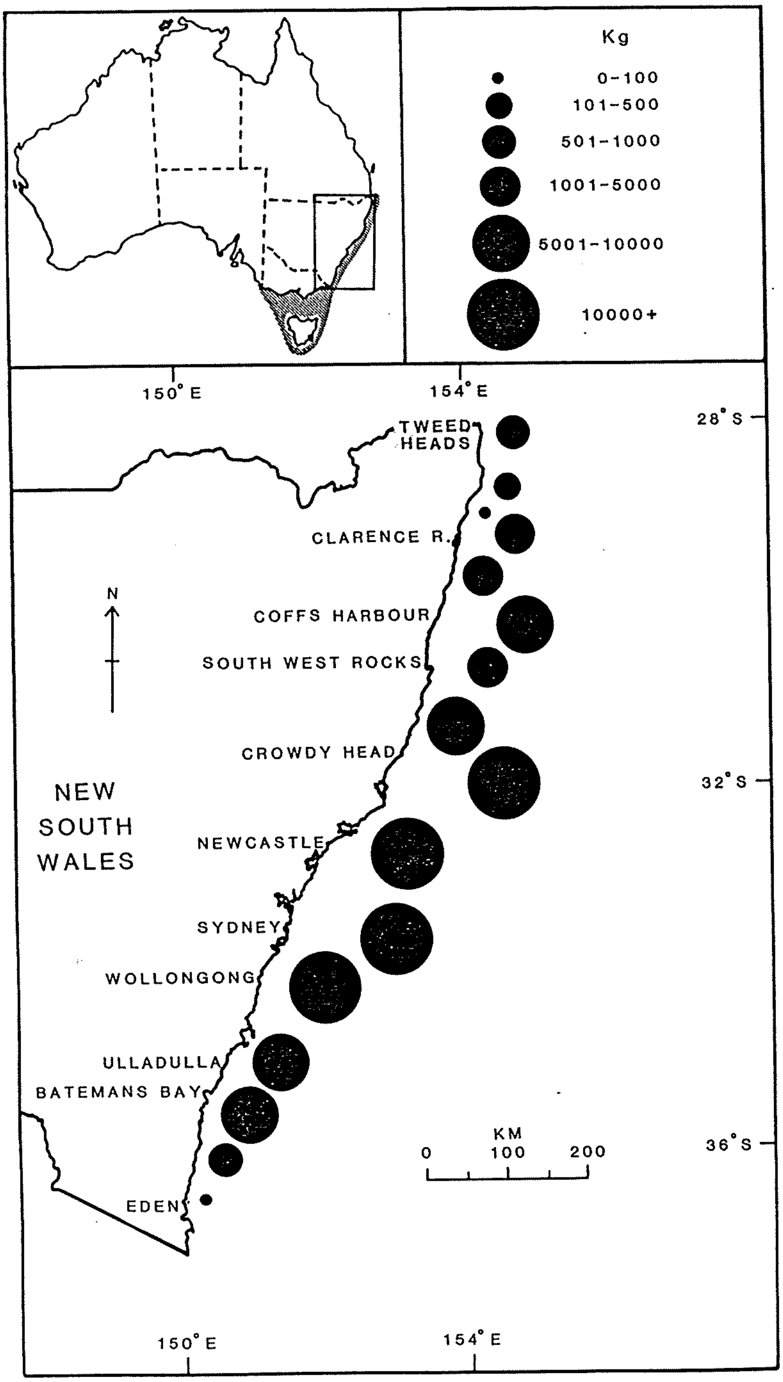
Source: Records of the Crowdy Head Fishermens Cooperative.

Appendix 4. Evidence that eastern rock lobsters do occur off Sydney.

Source: An article in the St George & Sutherland Shire Leader, 11 December 1986, page 70.



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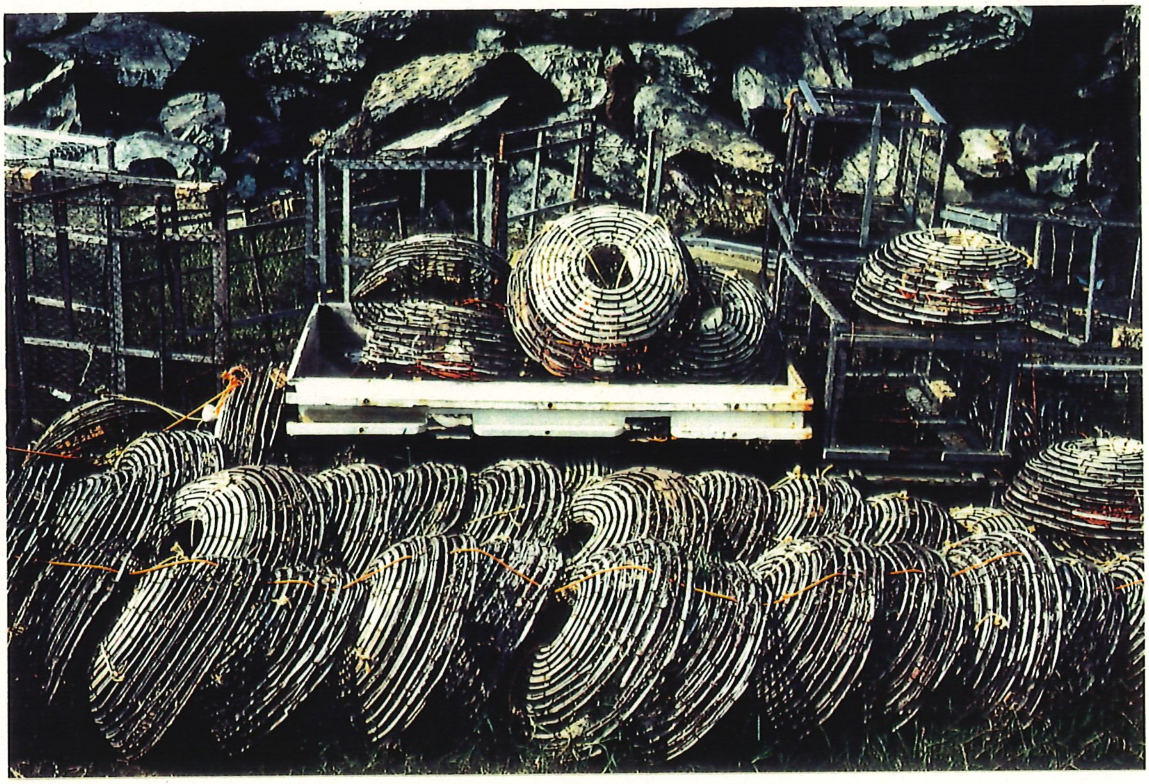

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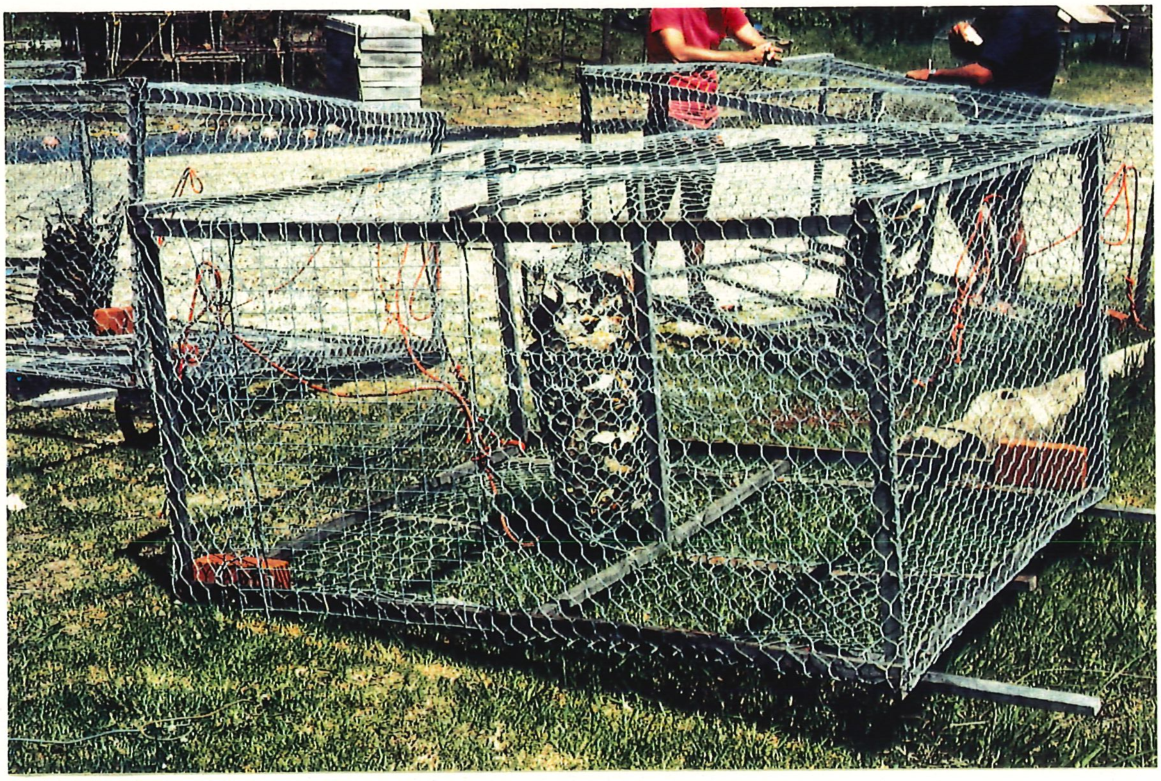


Figure 2b. Traps used in the offshore fishery for rock lobsters off New South Wales.

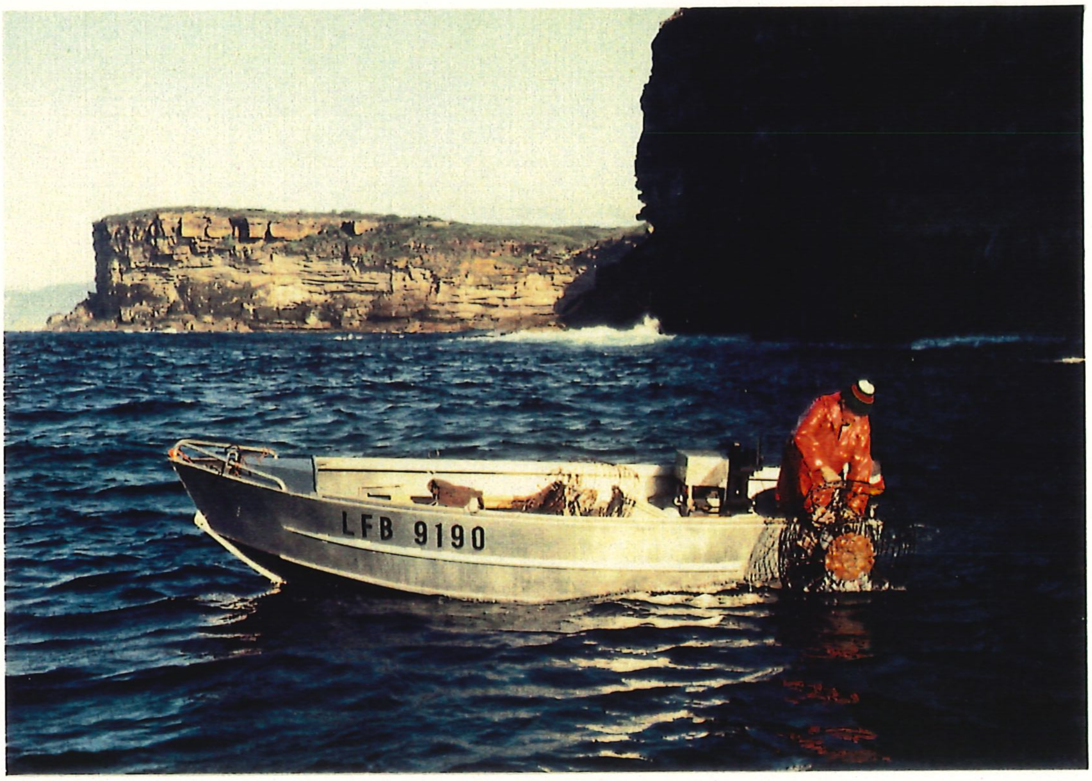
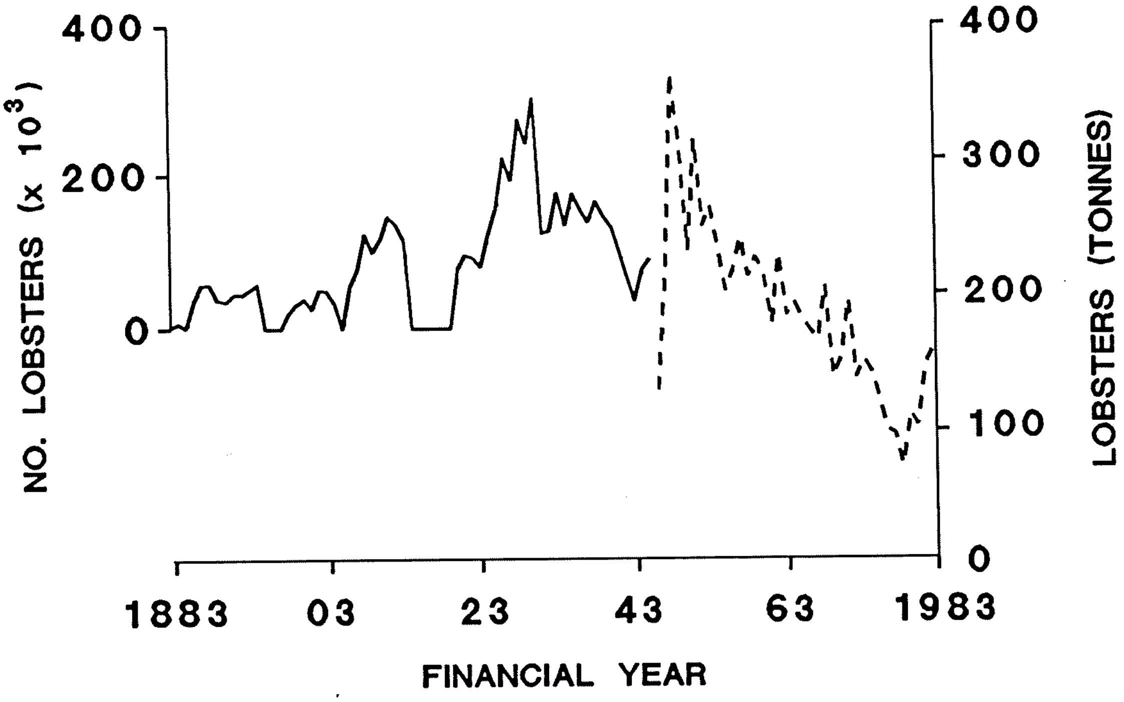


Figure 3a. A typical vessel used in the inshore fishery for rock lobsters off New South Wales.

Figure 3b. Typical vessel used in the offshore fishery for rock lobsters off New South Wales.



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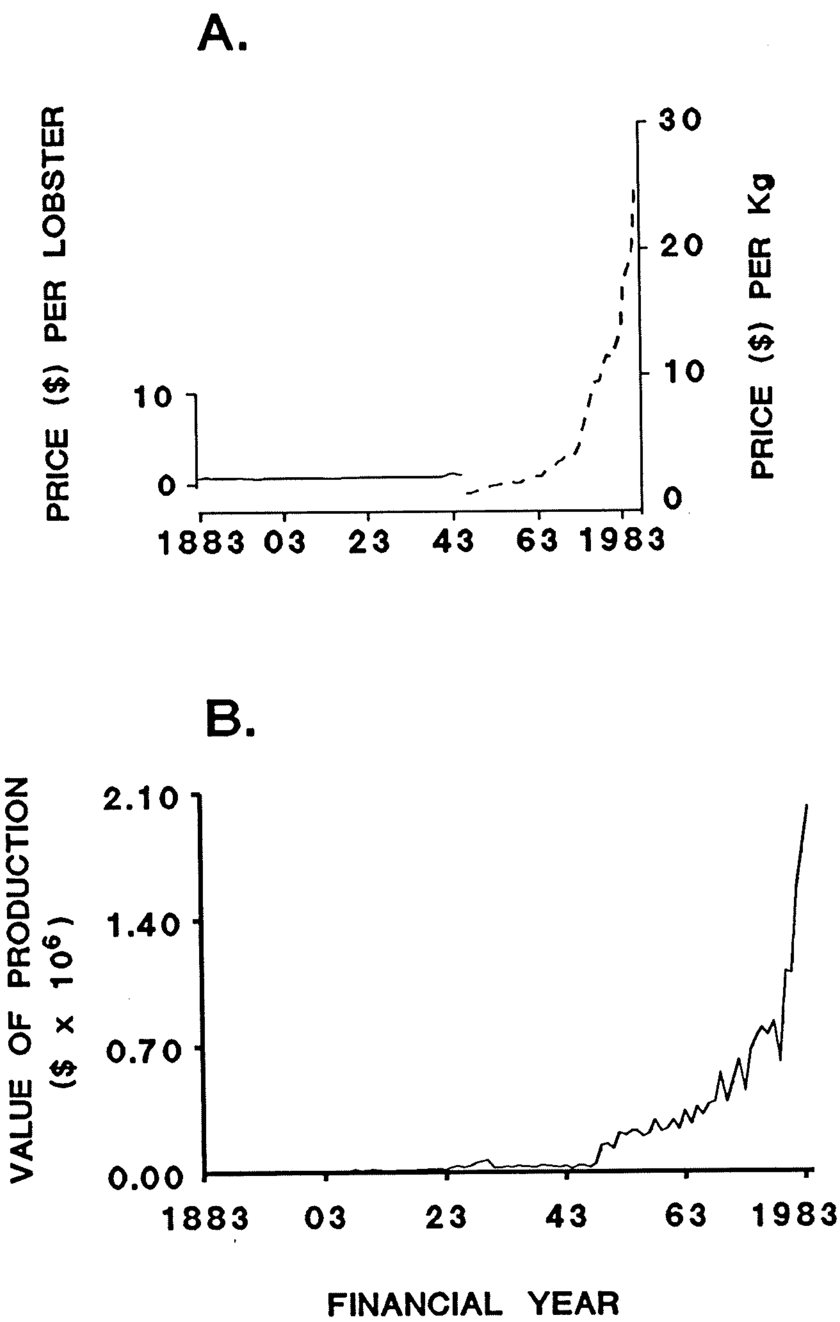

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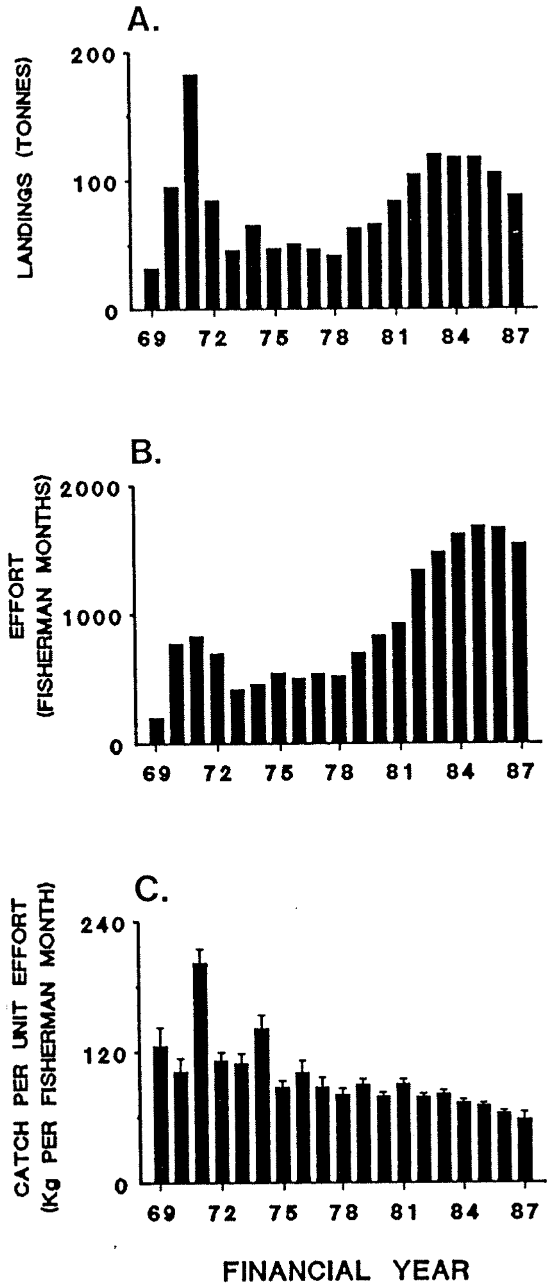

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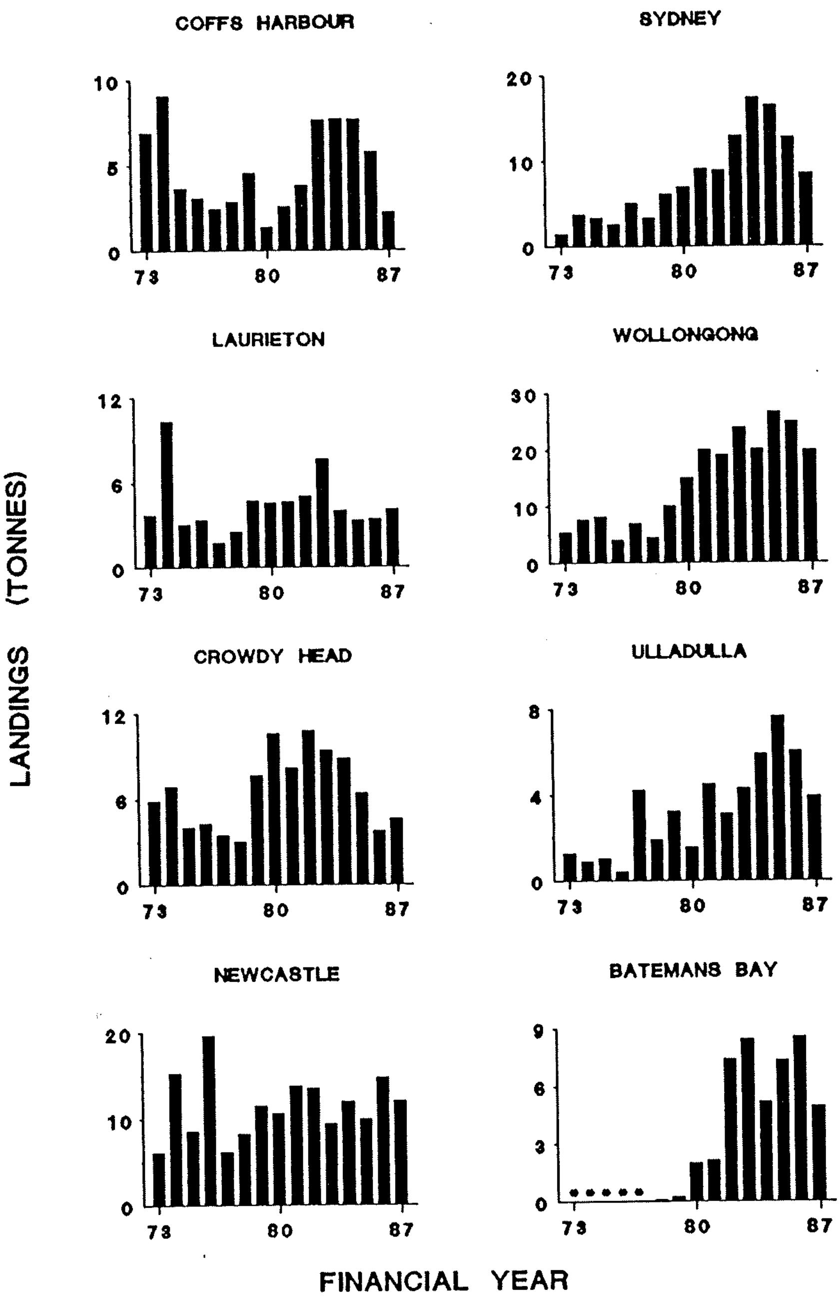

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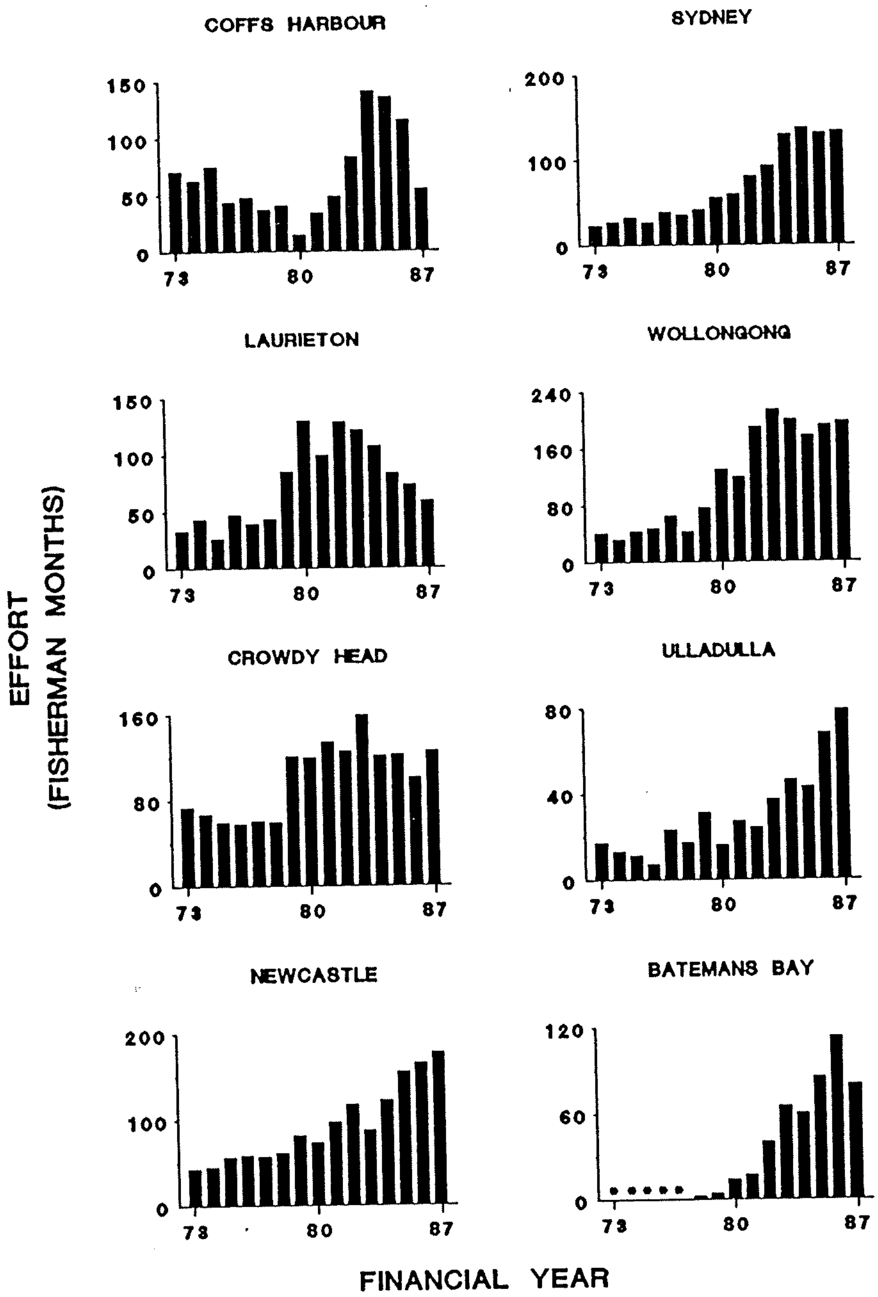

Figure 7. Trends in the level of fishing effort in the fishery for rock lobsters at the eight major ports of rock lobster production. An asterisk (*) denotes no records of landings available. Data are for financial years, with the first half of the year labelled on the x axis.

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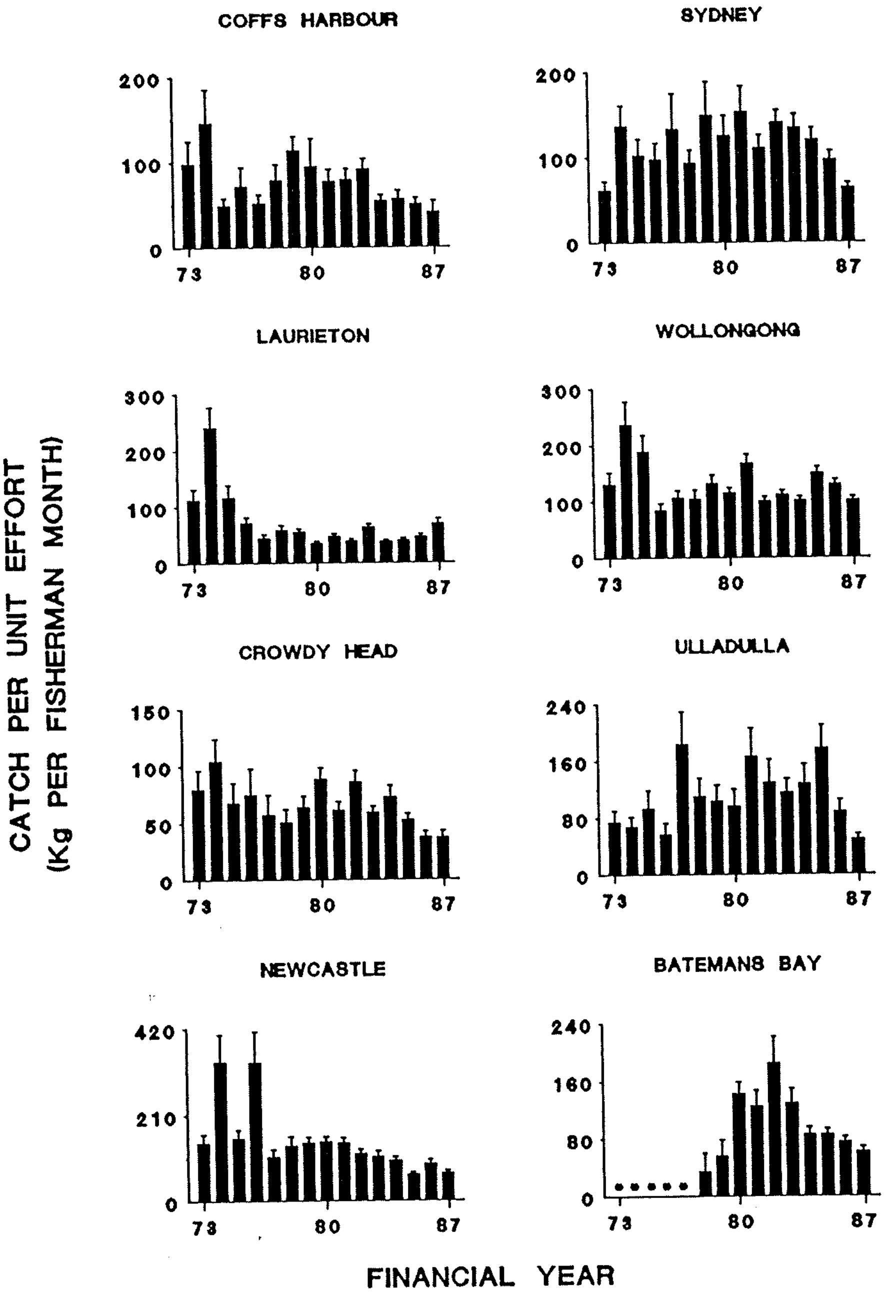

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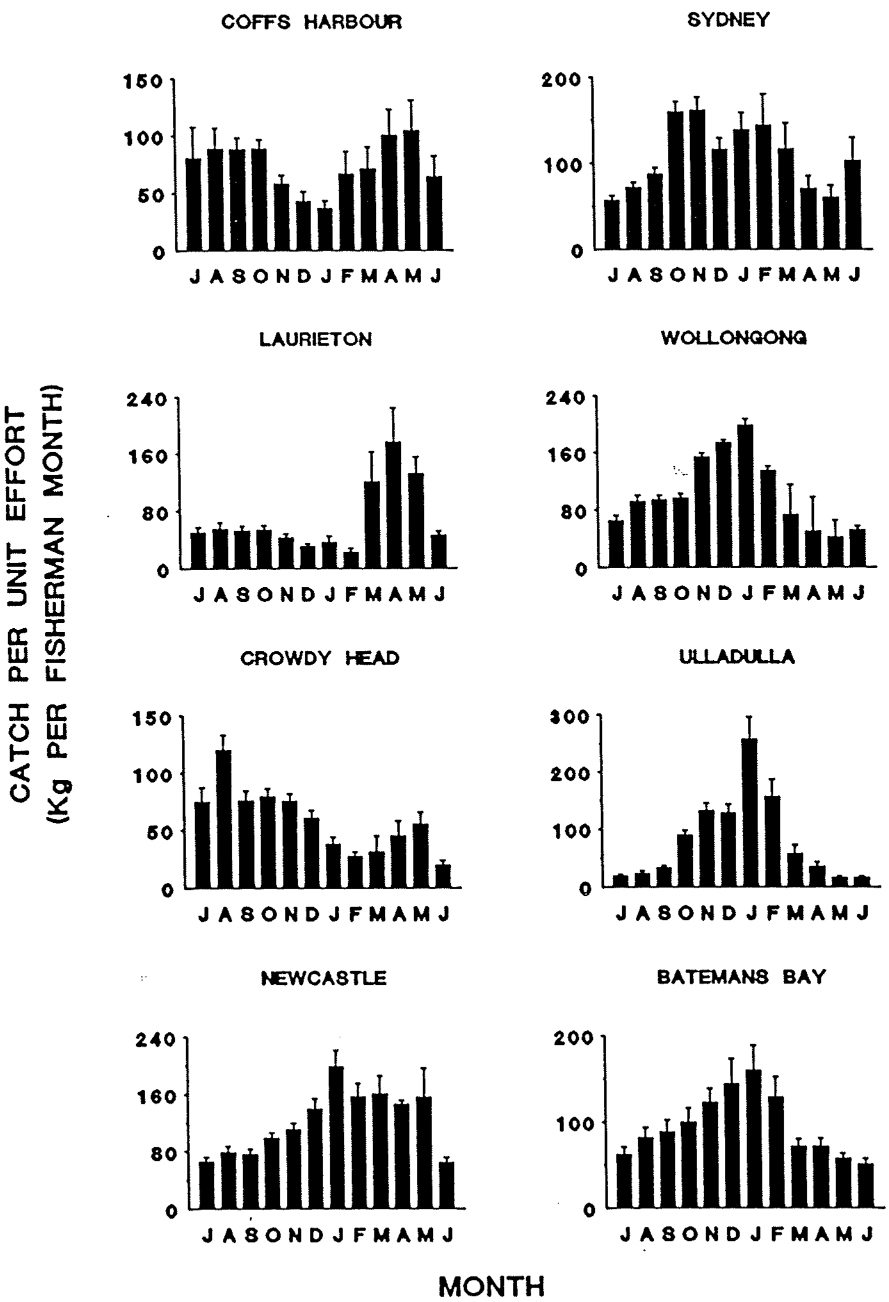

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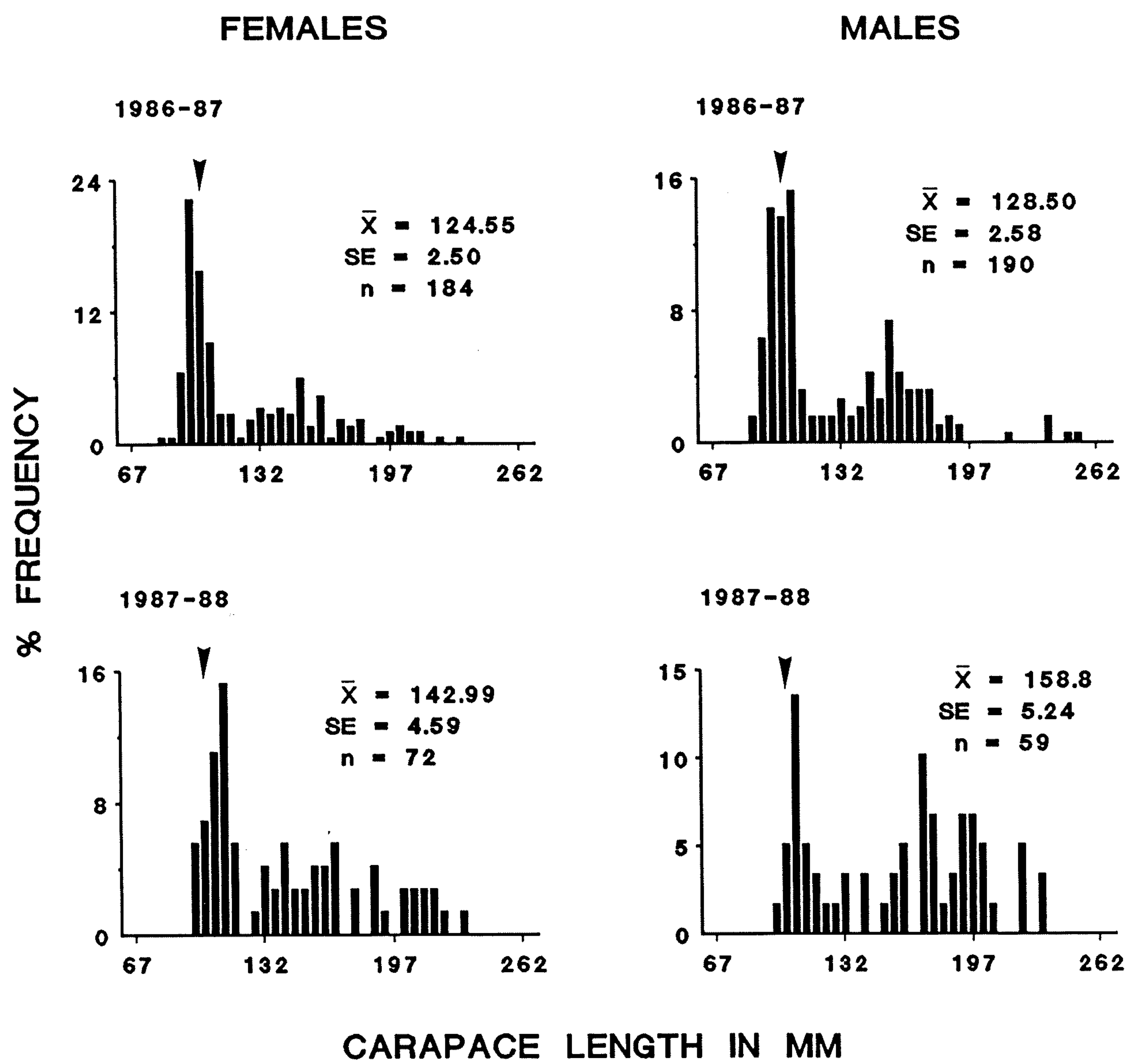

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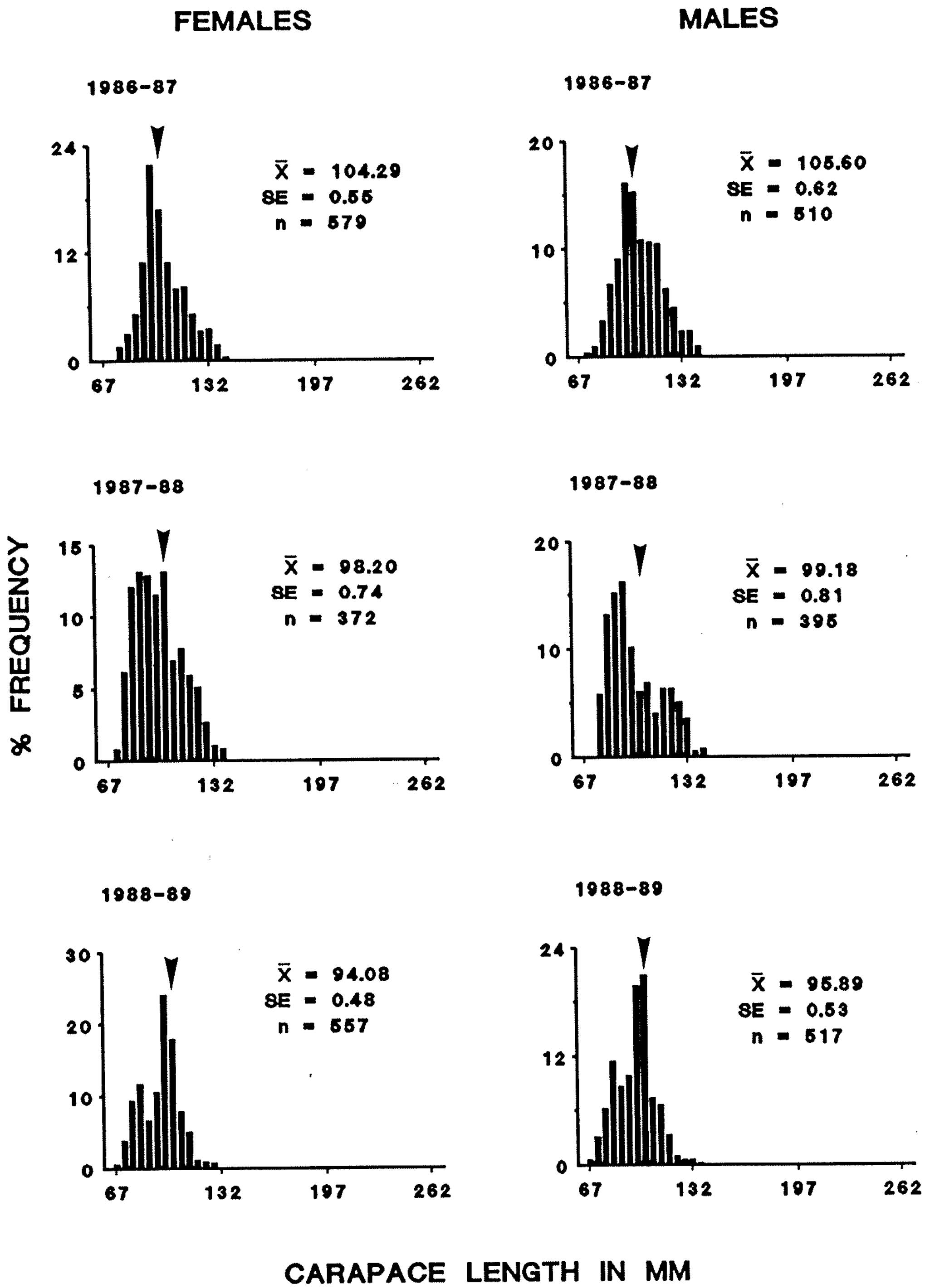

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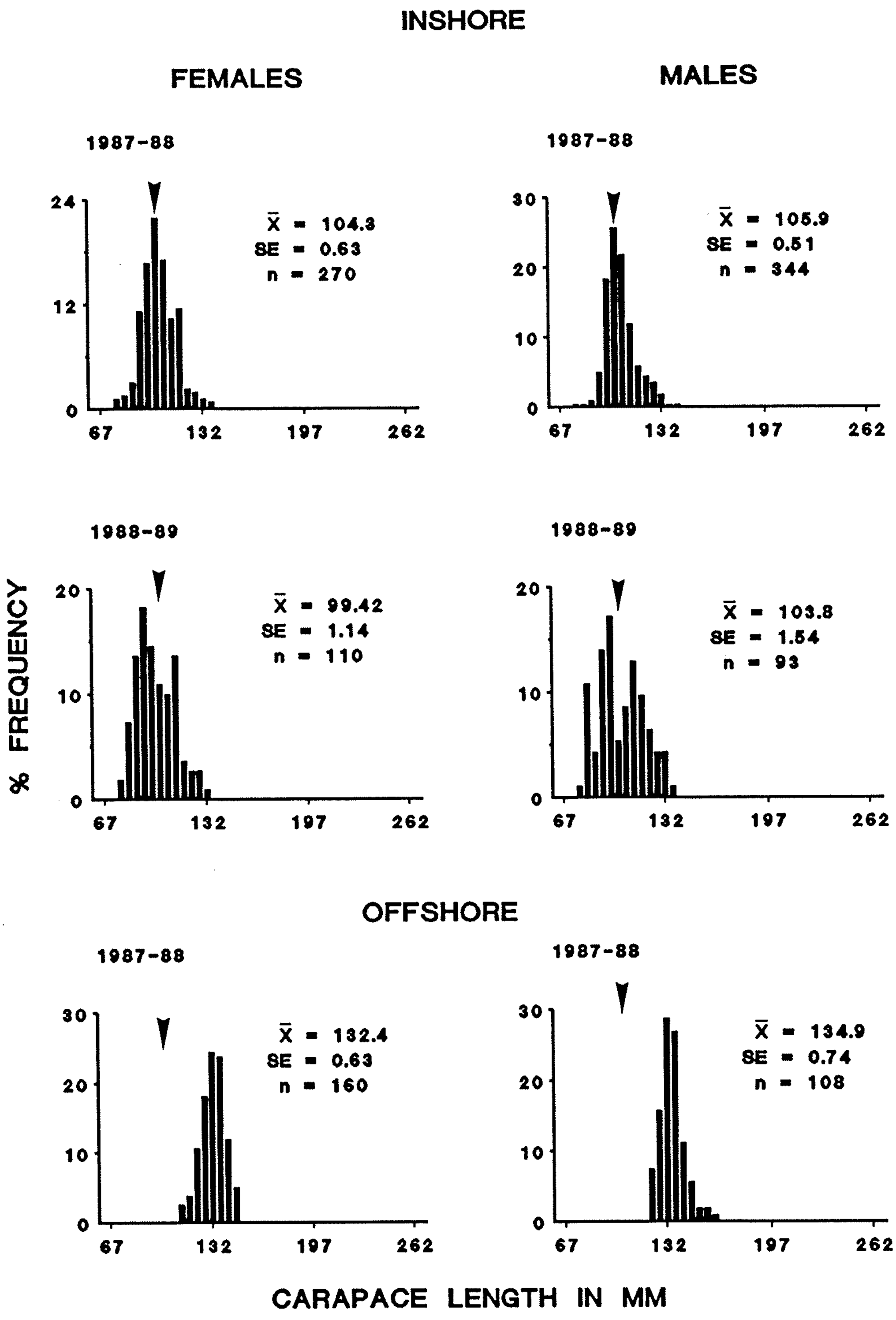
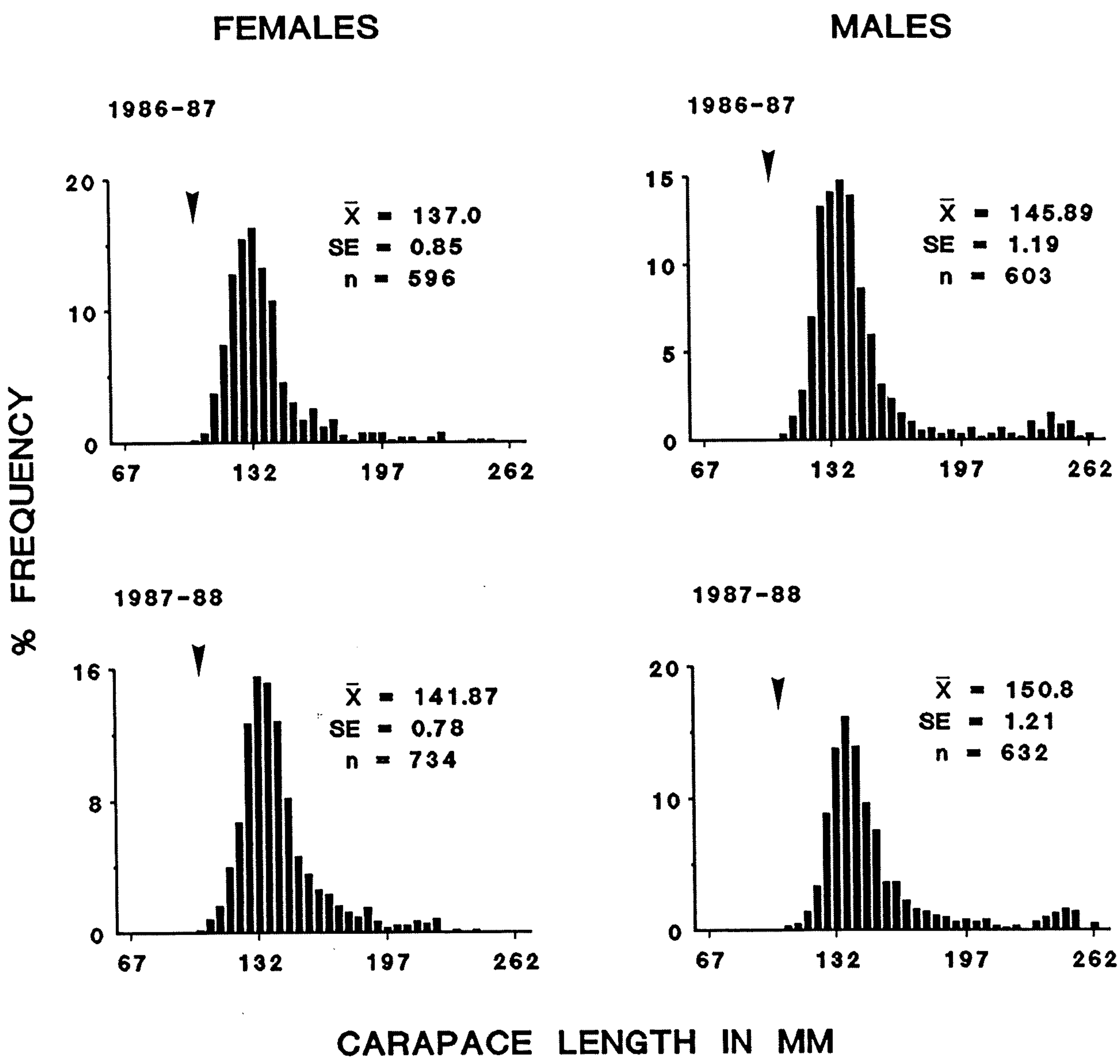


Figure 12. Annual length frequency distributions of eastern rock lobsters sampled from catches from the inshore and offshore fishery off Batemans Bay. The mean ($\bar{x}$), standard error (S.E.), sample size (n) and legal minimum length (▼) are shown.



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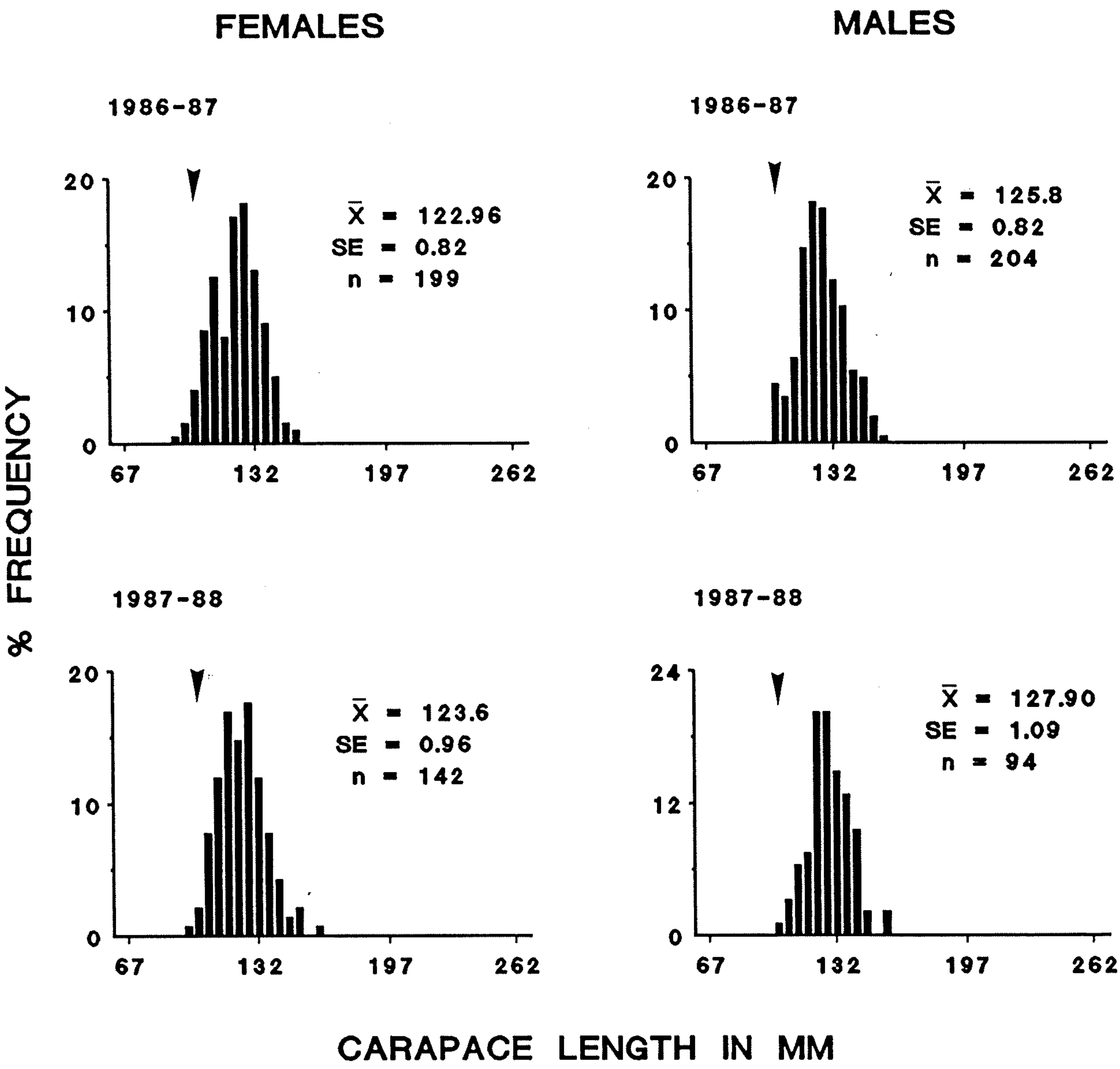

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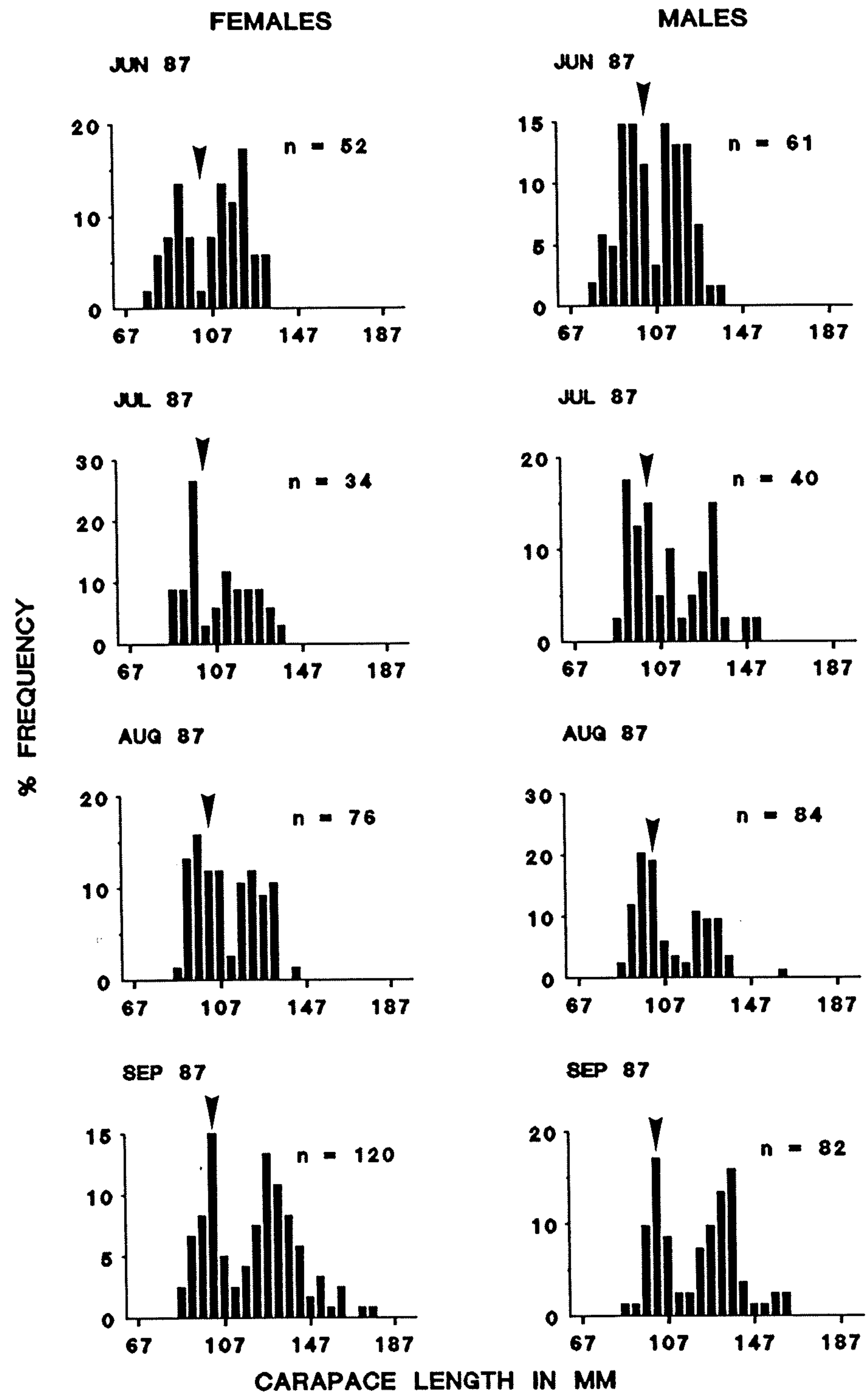

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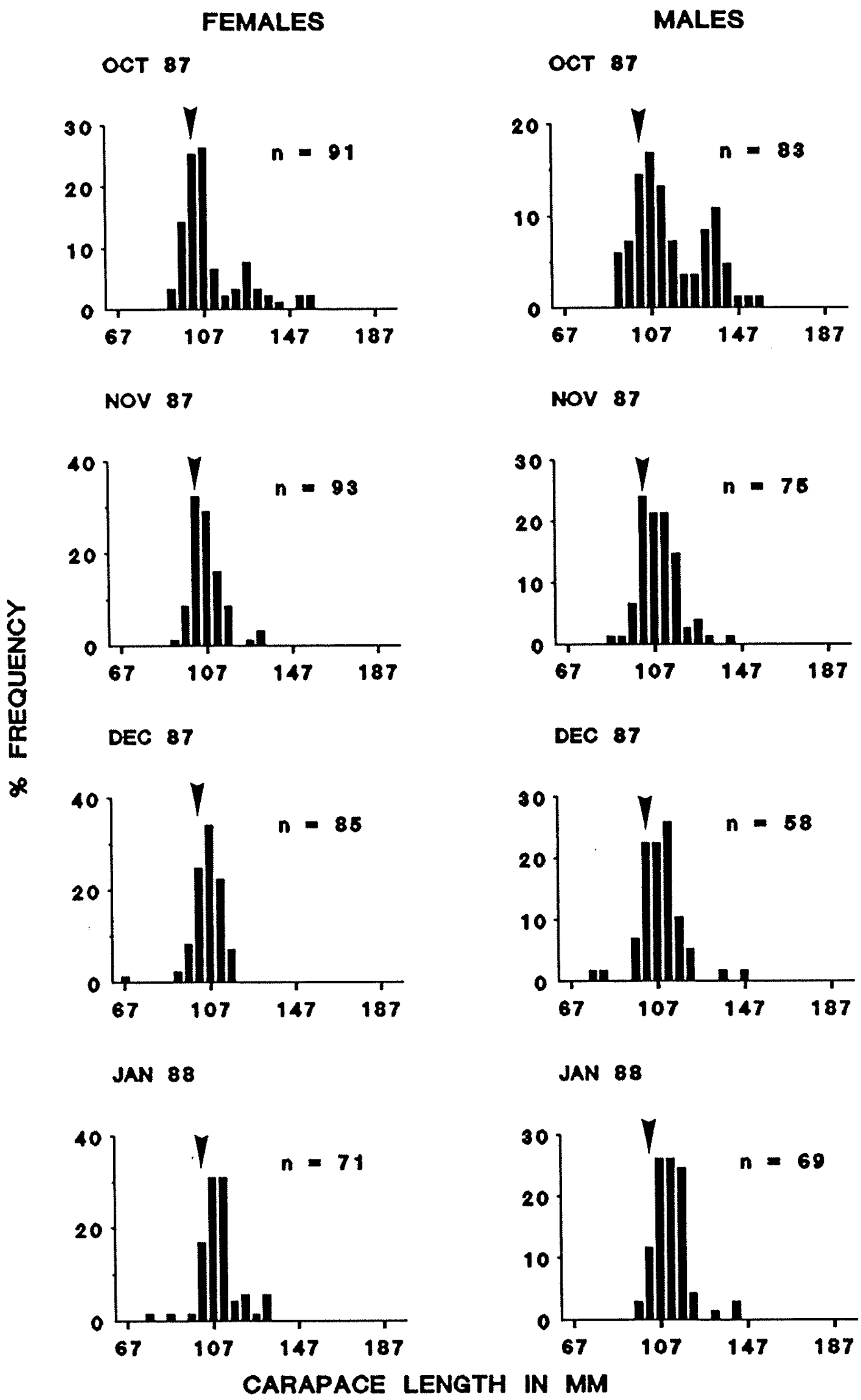
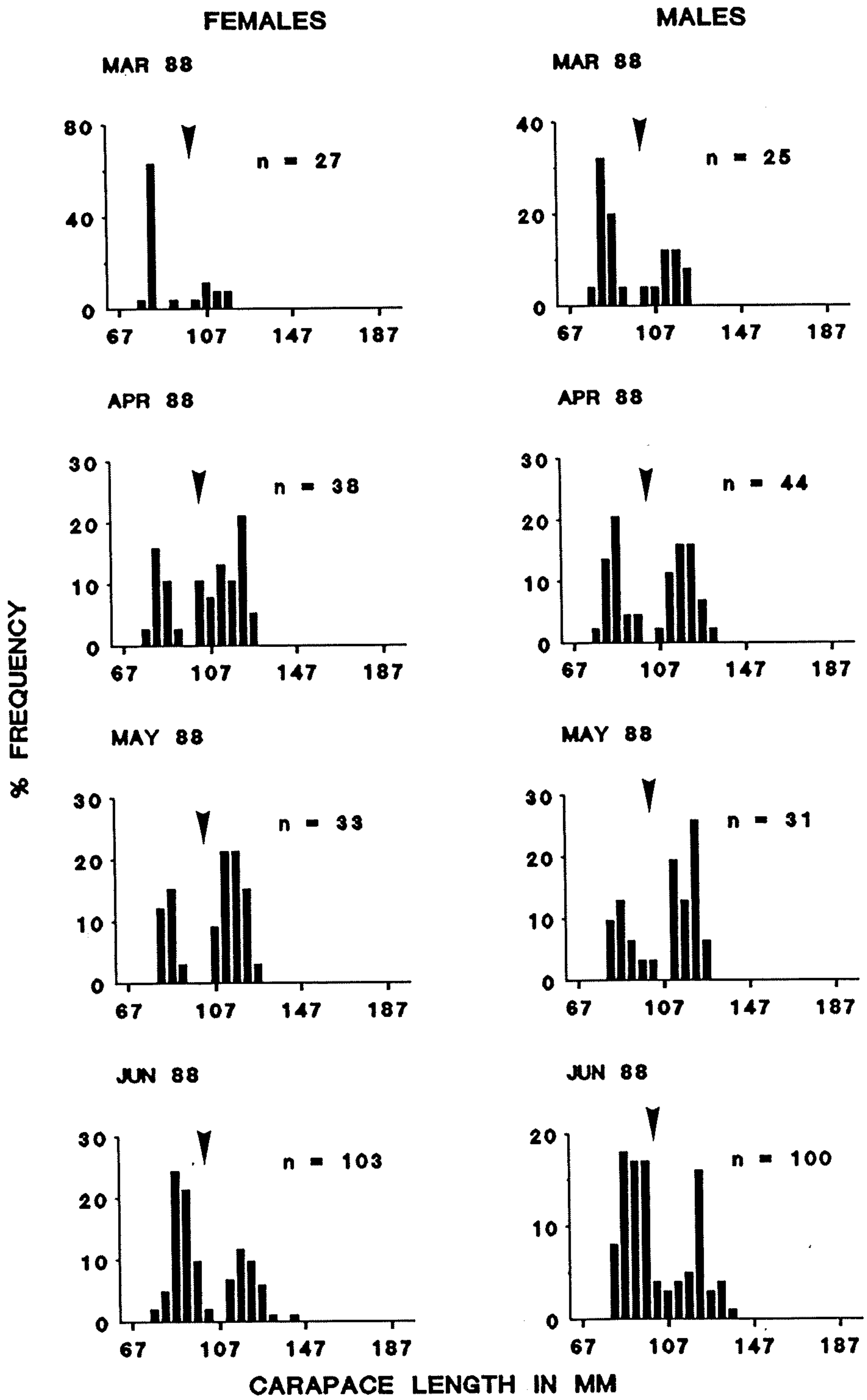


Figure 15 (continued). Monthly length frequency distributions of eastern rock lobsters sampled from inshore grounds off Crowdy Head. The sample size (n) and legal minimum length (▼) are shown.



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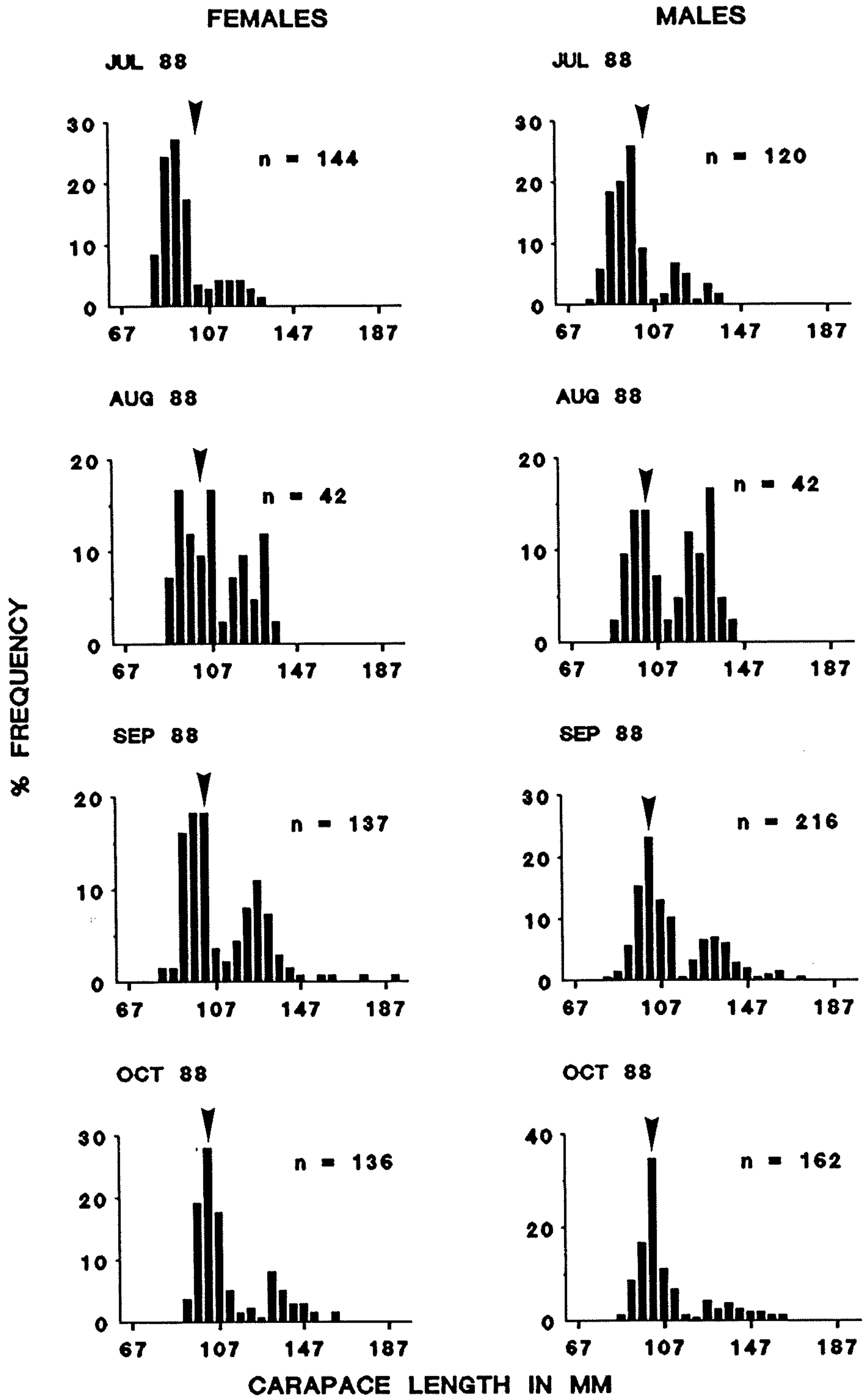

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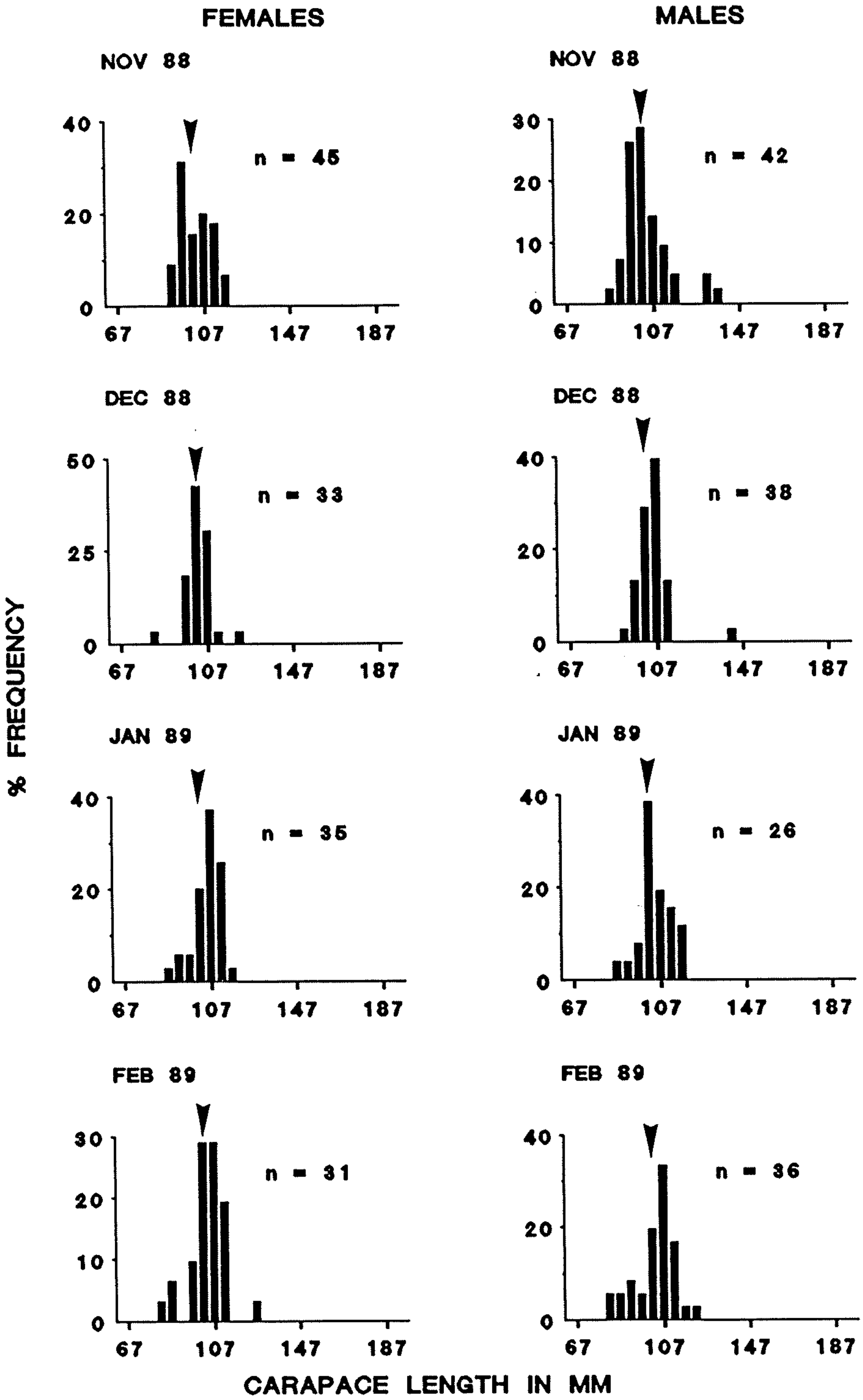

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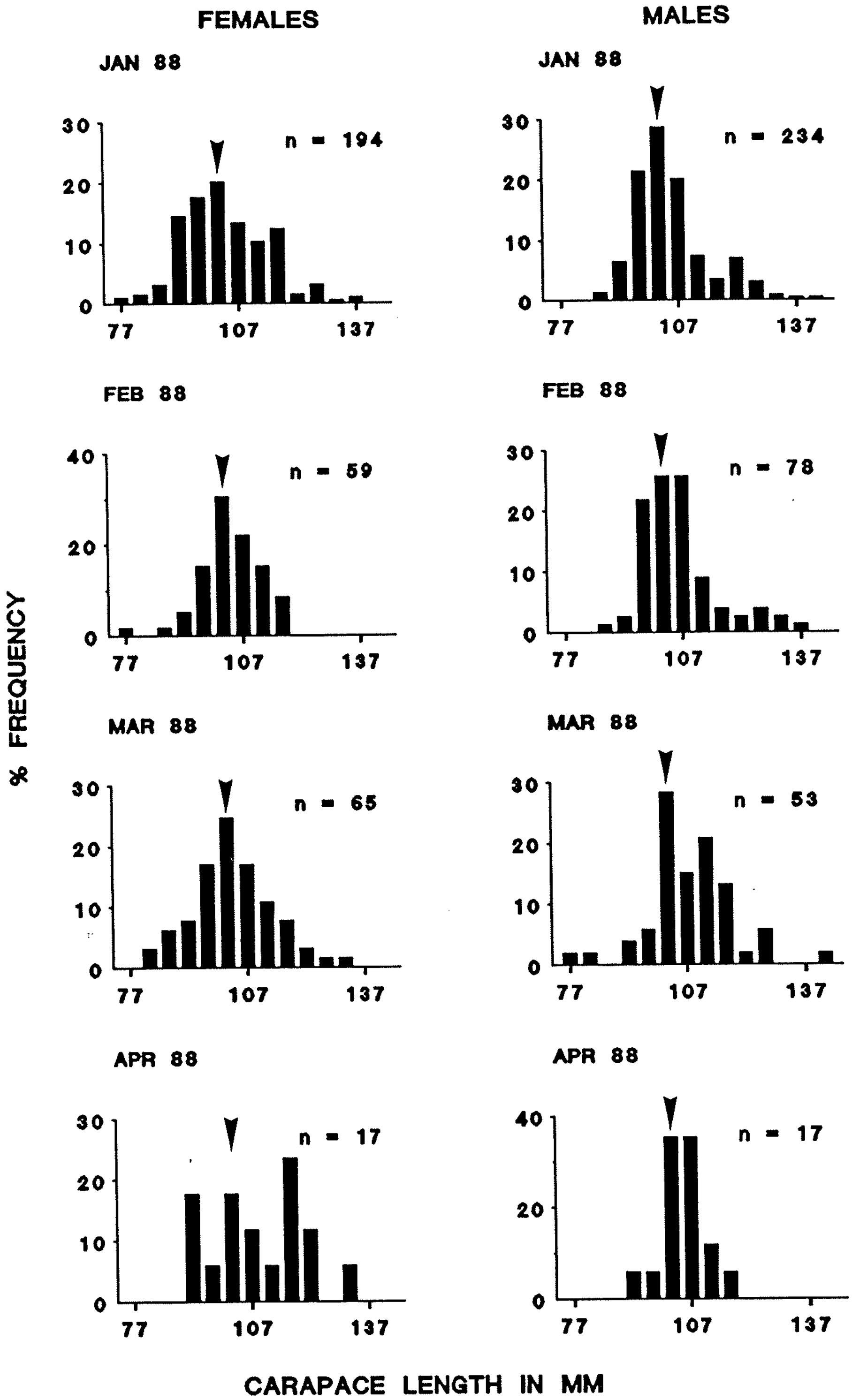

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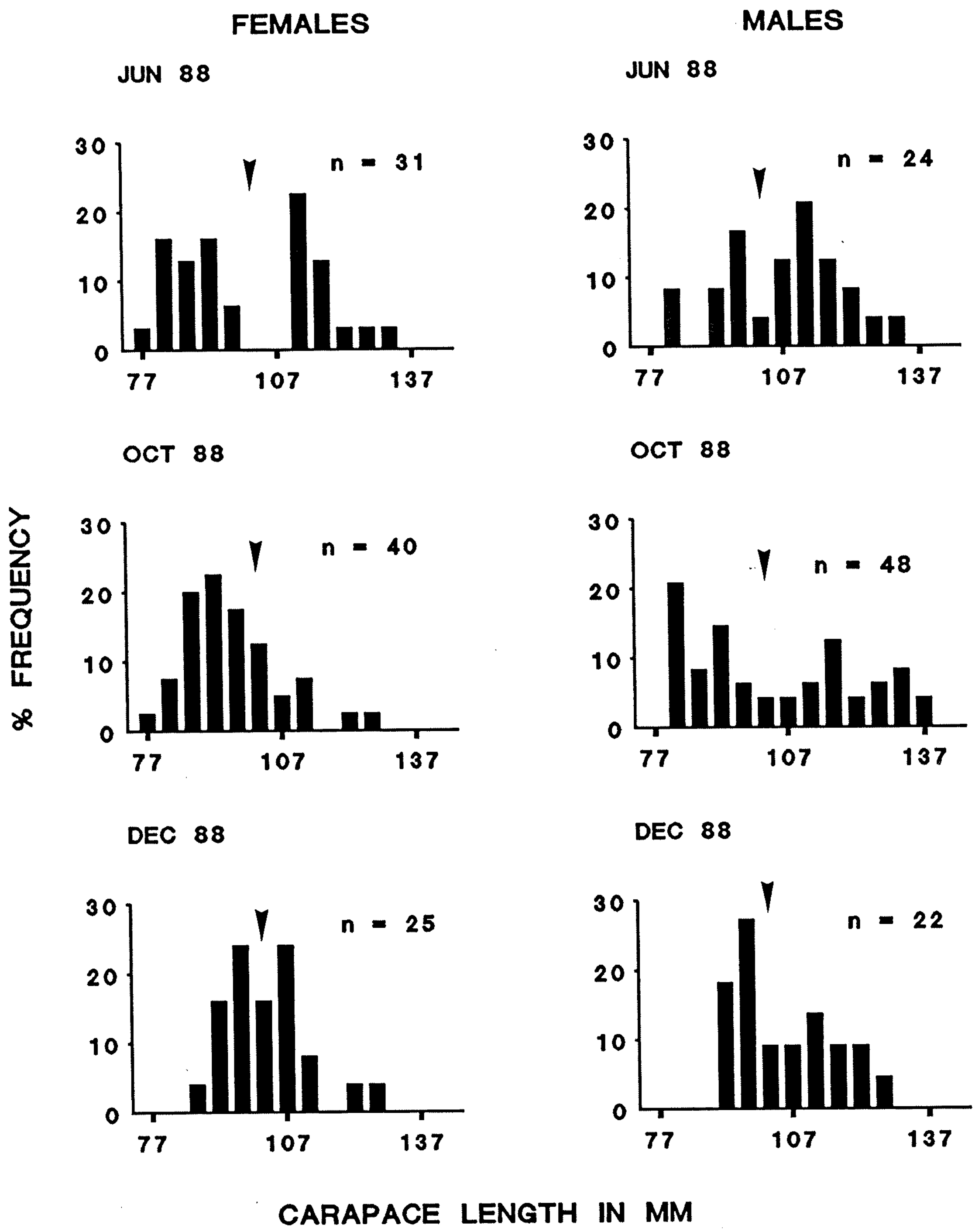


Figure 16 (Continued). Monthly length frequency distributions of eastern rock lobsters sampled from inshore grounds off Batemans Bay. The sample size (n) and legal minimum length ( ) are shown.

Appendix 1

A. Definition of a lobster trap under the Fisheries and Oysters Farmers Act 1935 prior to May 1989.

"FISH TRAP

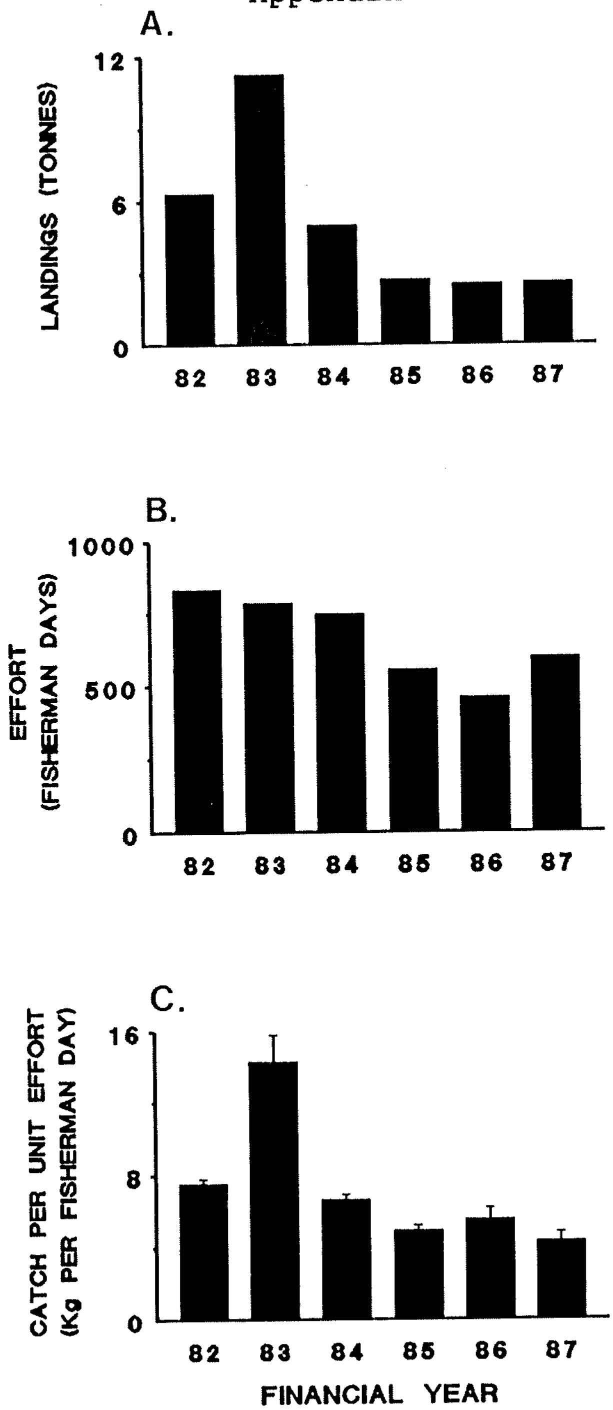
No person shall use or cause to be used for the purpose of taking fish in tidal waters any wire netting fish trap exceeding 6 feet in length, 5 feet in width and 2 feet 6 inches in depth, or having meshes (measured from one plain wire to opposite plain wire) smaller than 2 inches on the top and sides and 1 inch on the bottom."

B. Definition of a lobster trap under the Fisheries and Oysters Farmers Act 1935 after May 1989.

"LOBSTER TRAP

Consists of a rectangular base or floor not exceeding 1 metre by 1 metre (or a circular base not exceeding 1 metre in diameter); has only 1 funnel or entrance (which is situated in the top, roof or apex of the trap and is parallel to the base of the trap); has 2 or more rectangular unobstructed escape gaps (constructed of rigid material) each not less than 30 cm by 6 cm fitted in the trap and so that no part of the escape gap is more than 12 cm above the floor of the trap."

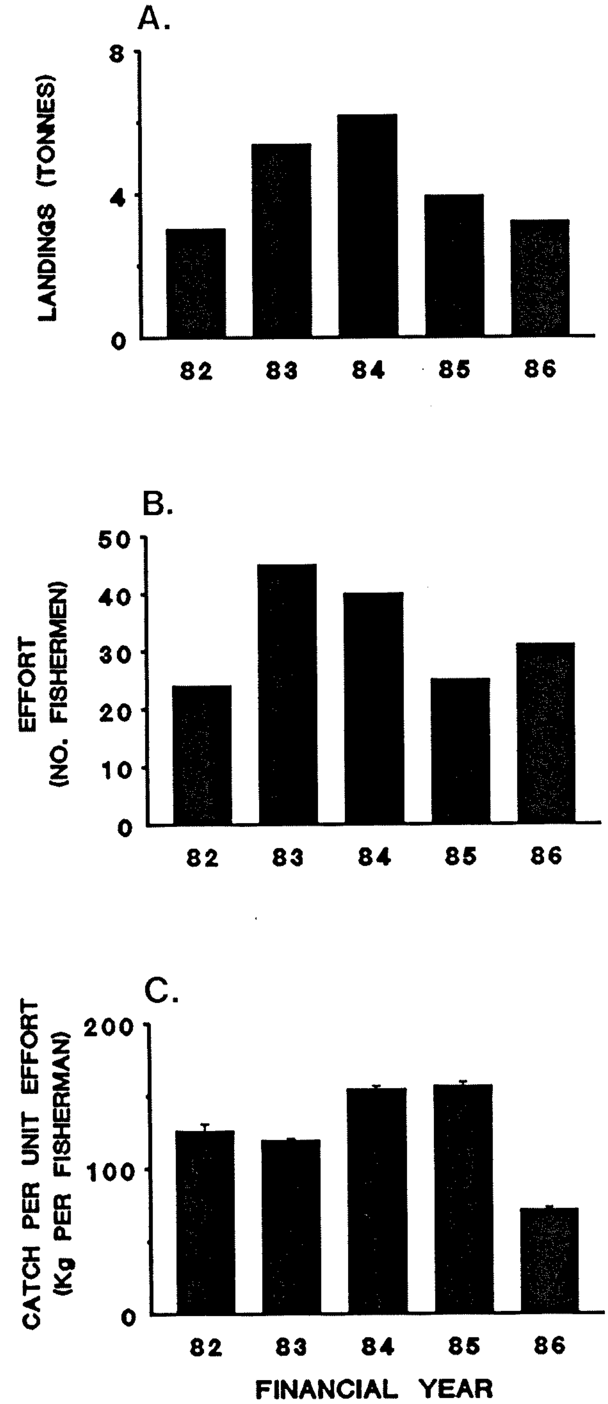
Appendix 2



Trends in the level of landings (A), fishing effort (B) and catch per unit effort (C) in the rock lobster fishery off Coffs Harbour. data are for financial years, with the first half of the year labelled on the x axis.

Source: Records of the Coffs Harbour Fishermen's Cooperative.

Appendix 3



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Source: Records of the Crowdy Head Fishermen's Cooperative.

Appendix 4

THIS colossal crustacean, caught off Coogee's Wedding Cake Island, did not end up on a restaurant's dinner table.

Its catcher, Len Goldsmith of Kingsgrove, thought it deserved a better fate and a bit of notoriety, and took it along to the Australian Museum.

Museum officials agreed and the huge lobster, weighing in at exactly five kg, has been stuffed and will become a permanent exhibit.

Len caught the beast with his bare hands while snorkelling off the rock island three weeks ago.

He said the fellow was just walking along the sea bed some 20 feet below when he scooped it up in glove-clad hands.

Len put it on an inflatable rubber float and towed it back to shore.

The trip back to Kingsgrove must have tired the lobster out, as it was still alive, but not kicking, when Len's mate took the photos.

Wedding Cake Island sounds like a crustacean-lovers delight as one of Len's friends caught a similar-sized lobster the week before.

Len, 20, is a keen spear fisherman and is a member of the Sans Souci Dolphins skin diving club.

Evidence that eastern rock lobsters do occur off Sydney.

Source: An article in the St George & Sutherland Shire Leader, 11 December 1986 page 70.

Appendix 2

SIZE AT ONSET OF BREEDING IN FEMALE *JASUS VERREAUXI* (DECAPODA : PALINURIDAE) OFF NEW SOUTH WALES

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NSW Agriculture and Fisheries

Fisheries Research Institute

P.O. Box 21 Cronulla NSW (Australia) 2230.

Running Head : Size at onset of breeding in *J. verreauxi*

SIZE AT ONSET OF BREEDING IN FEMALE *JASUS VERREAUXI* (DECAPODA : PALINURIDAE) OFF NEW SOUTH WALES

S.S. Montgomery,

ABSTRACT

Mature female eastern rock lobsters were only found in samples from catches off Coffs Harbour and Crowdy Head, the two most northern locations sampled. The smallest length at which 50% of females carried eggs during the egg-bearing season was 167 mm C.L.. This was 7 mm C.L. larger than the length at which 50% of female lobsters first developed setae on the endopodites of the pleopods. It is recommended that the present legal minimum length (104 mm C.L.) be increased to conserve the stock.

INTRODUCTION

A knowledge of the size and/or age at which animals reach maturity can be important in the management of stocks. For example, managers of stocks in the wild need to know the proportion of breeding individuals in the population. They can then maintain this at a level which is considered acceptable by imposing management measures such as a legal minimum size in the fishery (e.g. Winters et al., 1985). Generally, size at first maturity is defined as the first size at which 50% of animals reach sexual maturity (e.g. Somerton 1980).

The maturity of an animal can be detected using either physiological or functional criteria. Secondary characteristics in female rock lobsters that can be used to physiologically determine size at maturity include changes in morphometric relationships, dimorphism of pleopods, condition of ovaries, presence of an external spermatophoric mass and changes in sternal plates (Aiken and Waddy 1980). Functional maturity in female lobsters is usually determined by the presence of eggs and is referred to as the size at onset of breeding (Booth 1984).

The fundamental assumption underlying the determination of maturity by these two sets of criteria is that females at these sizes will produce eggs for fertilisation. In some cases, the size at onset of breeding is larger than that determined from secondary characteristics (e.g. Chittleborough 1976, Booth 1984) and will therefore be the best indicator of maturity. The size at maturity and onset of breeding in a species can also vary between latitudes (e.g. Fielder 1964, Gregory et al. 1982, Campbell and Robinson 1983).

The eastern rock lobster, *Jasus verreauxi* (H. Milne Edwards), is the largest species of spiny lobster (Phillips et al., 1980). It is one of 4 species of spiny rock lobster caught in commercial quantitites along the east coast of Australia (George 1966) and is distributed between north-east Tasmania and Tweed Heads in northern New South Wales (Fig. 1). This species is also found off the coast of New Zealand (Kensler 1967b).

Our knowledge of the reproductive biology of *J. verreauxi* is mainly limited to studies on the population off New Zealand. Females first developed seteoed pleopods at 140-159 mm C.L. (antennal carapace length) and first carried eggs at a size at least 10 mm C.L. larger (Kensler 1967a, Booth 1984). They bred once a year, between October and January and carried between 4×10^5 and 2×10^6 eggs (Kensler 1967 a and c). Information on the biology of this species in waters off the east coast of Australia is limited to a preliminary study by Lee (1969). He claimed that *J. verreauxi* carried eggs between late September and late January, but presented no substantiating data. The smallest size at which females sampled in his study had well developed seteoed pleopods was 125 mm R.C.L. (rostral carapace length).

The aim of the present study was to determine the first size at onset of breeding for female *J. verreauxi* off the coast of New South Wales (Fig. 1). This enabled me to obtain information on the geographical distribution of the breeding stock.

METHODS

The fishery for rock lobsters off New South Wales can be divided into inshore (depths of 1-50 m) and offshore (51-220 m) components. The inshore fishery may operate year round, but the main fishing season for both components varies between ports.

Sampling was done monthly between July 1986 and June 1988 during the inshore and offshore fishing seasons aboard commercial fishing vessels off Crowdy Head and Sydney. Monthly samples were also collected from Batemans Bay between July 1987 and June 1988 and from Coffs Harbour when catches were great.

Each female eastern rock lobster in the catch was classified as either carrying eggs or, failing this, the degree of development of setae on its pleopods (Table 1). Its length was then measured. The definition of well developed setae was based upon observations made on female lobsters that had recently shed eggs. In all cases these had setae on their pleopods which were around 3 cm in length (stage 5, Table 1). Length was measured as the straight line distance between the point of union of the second antennae on the antennal platform and the centre of the posterior margin of the carapace (antennal carapace length C.L.). Measurements were rounded down to the nearest millimetre.

Lengths were grouped using a 5 mm class interval (e.g. 100-104 mm C.L.). Maturity was determined using lobsters from all samples whilst onset of breeding was determined only from samples collected during the breeding season (October-January). A logistic curve was fitted to data to determine the length at maturity and at the onset of breeding. The size at maturity was defined as the length at which 50% of individuals possessed well developed seteoed pleopods (i.e. stages 5 and 6 in Table 1). Similarly, the size at onset of breeding was defined as the length at which 50% of females carried eggs (i.e. stage 6 in Table 1).

RESULTS

Female eastern rock lobsters sampled during this study ranged in length from 70-240 mm C.L. (Fig. 2). Samples from Coffs Harbour and Crowdy Head contained some larger lobsters than samples off Sydney and Batemans Bay. Furthermore, no mature female lobsters were found in samples from Sydney and Batemans Bay.

The smallest mature female found was in the 110-114 mm C.L. size class, and was sampled off Coffs Harbour (Fig. 2). The largest immature female was in the 200-204 mm C.L. size class and was sampled from Coffs Harbour. The length at which 50% of females possessed seteoed pleopods was 160 and 162 mm C.L for samples of lobsters caught off Crowdy Head and Coffs Harbour, respectively (Fig. 3).

Females carrying eggs were only found in catches from Coffs Harbour and Crowdy Head. The smallest female found to be carrying eggs was from the 145-149 mm C.L. size class in samples off Coffs Harbour and Crowdy Head (Fig.4). The most reliable estimate of size at onset of breeding was from samples from Crowdy Head and was 167 mm C.L. (Fig. 4). This length was 7 mm C.L. larger than that at maturity. The size at onset of breeding was also larger (172 mm C.L.) than the first size of maturity for females at Coffs Harbour (Fig. 4).

DISCUSSION

Results from this study provide the substantiating data for the claim of MacIntyre (1967) that female eastern rock lobsters carrying eggs were found only in waters north of Port Stephens (32^{o} 44′ S). In the present study mature female J. verreauxi and those carrying eggs were found only in samples from catches from the two more northern locations (i.e. Coffs Harbour and Crowdy Head). The smallest female lobster with seteoed pleopods was 110-114 mm C.L. whilst Lee (1969) found the smallest such female to be 125 mm R.C.L. (equivalent to about 114 mm antennal carapace length, unpublished data). Length at first maturity and at the onset of breeding were larger from samples from catches off Coffs Harbour than from those further south off Crowdy Head. None of the female lobsters sampled from catches off Sydney and Batemans Bay were larger than the size at maturity (and therefore the size at onset of breeding).

There have been reports of large J. verreauxi in catches from Sydney and Jervis Bay (e.g. Andrewartha and Montcalm, 1970). These large lobsters must be few in number (particularly off Sydney) and sparsely distributed, otherwise they would have been represented in the catches sampled. It can be concluded, therefore that the majority of J. verreauxi south of Port Stephens are immature. Booth (1984) found tagged eastern rock lobsters off New Zealand to move long distances in a north-westerly direction and suggested that this was associated with the onset of breeding. This along-shore pattern of movement has been recorded also for a number of other species of spiny lobsters (e.g. Herrnkind 1980). For these reasons I hypothesize that most J. verreauxi move northwards along the east coast of Australia to spawn.

Female J. verreauxi matured and first carried eggs at larger lengths than for other species of lobsters (e.g. Aiken and Waddy 1980). The lengths at first maturity and onset of breeding determined in the present study were also larger than those described by Booth (1984) for the same species in waters off New Zealand. Geographical differences in sizes of maturity and onset of breeding have been found in other species of spiny lobster (Aiken and Waddy 1980). The most popular hypotheses to explain this are differences in water temperature (Templeman 1936) and density dependence (Chittleborough 1976). It is not known how these factors affect eastern rock lobsters.

No study has been carried out on _J_. _verreauxi_ to compare the development of setae on the pleopods with the development of the ovary. A close association has been found, however, for other species of spiny lobster (e.g. Fielder 1964, Silberbauer 1971, Annala et al., 1980). Differences between size at maturity and size at onset of breeding in _J_. _verreauxi_ were observed in the present study, and by Booth (1984). The secondary characteristic of seteoed pleopods therefore, may not be a suitable criteria for determining sexual maturity in _J_. _verreauxi_. Any legal minimum length set to allow most eastern rock lobsters to breed once before capture should be based therefore on the size at onset of breeding.

The density of eastern rock lobsters off New South Wales has fallen annually since at least 1973-74 (unpublished data). The management policy of having a legal minimum length in this fishery that is far shorter than the size at onset of breeding therefore appears to have been unsuccessful in sustaining yield from the fishery. An increase in the legal minimum length is therefore warranted. If it is considered desirable that most female eastern rock lobsters should breed once before they are susceptible to exploitation, then the legal minimum length for _J_. _verreauxi_ off Australia must be increased to 167 mm C.L. The equivalent legal minimum length (a different measurement for legal minimum size is used), for the same species off New Zealnd is 155 mm C.L. (Kensler 1967a, Booth 1984). Booth (1984) suggested however, that if most J. verreauxi are to breed once before being exploited then this size should be increased to 160 mm C.L..

Imposing a legal minimum length about the size at onset of breeding assumes that there is a stock-recruitment relationship. These relationships are being increasingly questioned (e.g. Hancock 1980, Winters et al., 1985, Cobb and Wang 1985). The level of recruitment may be determined by other factors (e.g. environmental), rather than the level of breeding stock. The yield from the resource is determined also by factors other than the legal minimum length such as growth, mortality, differences in catchability between sizes, and variations in value and market demand with sizes.

If the objective of management is to maintain the abundance of the stock at current levels rather than to increase it, then the legal minimum length may be set shorter than the size at onset of breeding. In this case the level of increase in legal minimum length for J. verreauxi needs to be considered with a knowledge of the factors above. However, very little data on such factors for J. verreauxi are available. Research needs to be done to provide data necessary for the development of a bioeconomic model for the rock lobster fishery off New South Wales. One strategy may be to impose both a legal minimum length and a legal maximum length for eastern rock lobsters until such time as a model is developed. The objective with these would be to conserve juvenile lobsters and to protect the majority of those that are mature, respectively.

ACKNOWLEDGEMENTS

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Table 1. Diagnostic features used to classify the maturity of female *J. verreauxi*.

Features	Stage
No setae	0
small hairs on tip of pleopod	1
small hairs along margin of pleopod	2
1 cm hairs along pleopod	3
2 cm hairs along pleopod	4
3 cm hairs along pleopod	5
carrying eggs	6

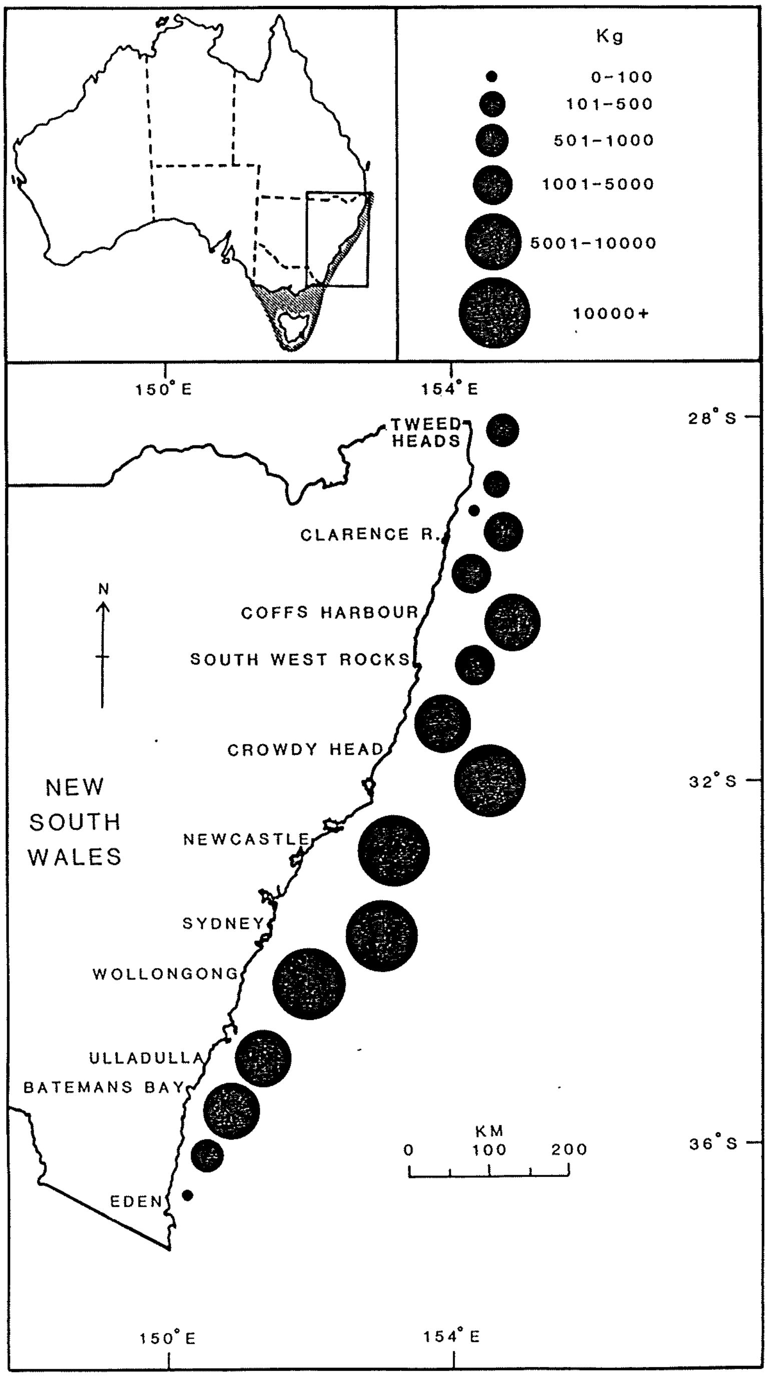
TITLES TO FIGURES

Figure 1. Map of the coast of New South Wales showing the average annual landings of rock lobsters for the period 1979-80 to 1983-84. Filled circles of various sizes represent different categories of landings by weight. The major ports for landings of rock lobsters are also shown on the map. The inserted map of Australia shows the distribution of *J. verreauxi*.

Figure 2. Proportions of female *J. verreauxi* in samples from catches off (A) Coffs Harbour, (B) Crowdy Head, (C) Sydney and (D) Batemans Bay that possessed well developed setae on the endopodites of the pleopods (▩), or were immature (■). Lengths were grouped into 5 mm classes (e.g. 100-104 mm C.L.). The mid-point of the size classes are shown along the x axis. The size at onset of breeding (▼) and sample size (N) are shown.

Figure 3. A logistic curve fitted to the percent of the data for female *J. verreauxi* categorised as mature. The size at maturity is estimated from the 50% percentile. Data are for (A) Crowdy Head and (B) Coffs Harbour, whilst N is the sample size.

Figure 4. A logistic curve fitted to the percent of the data for female *J. verreauxi* categorised as carrying eggs. The size at onset of breeding is estimated from the 50% percentile. Data are for (A) Crowdy Head and (B) Coffs Harbour, whilst N is the sample size.



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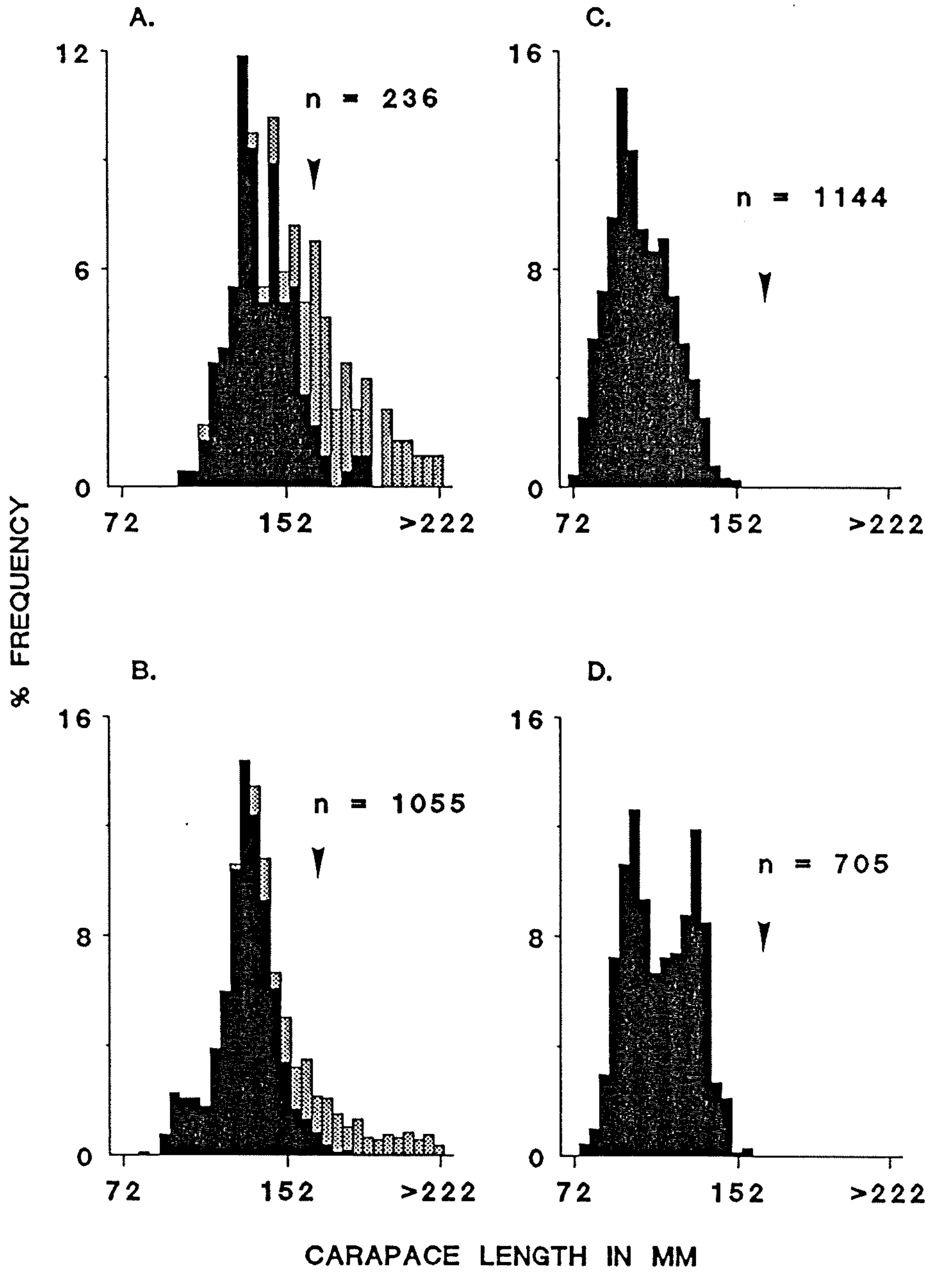

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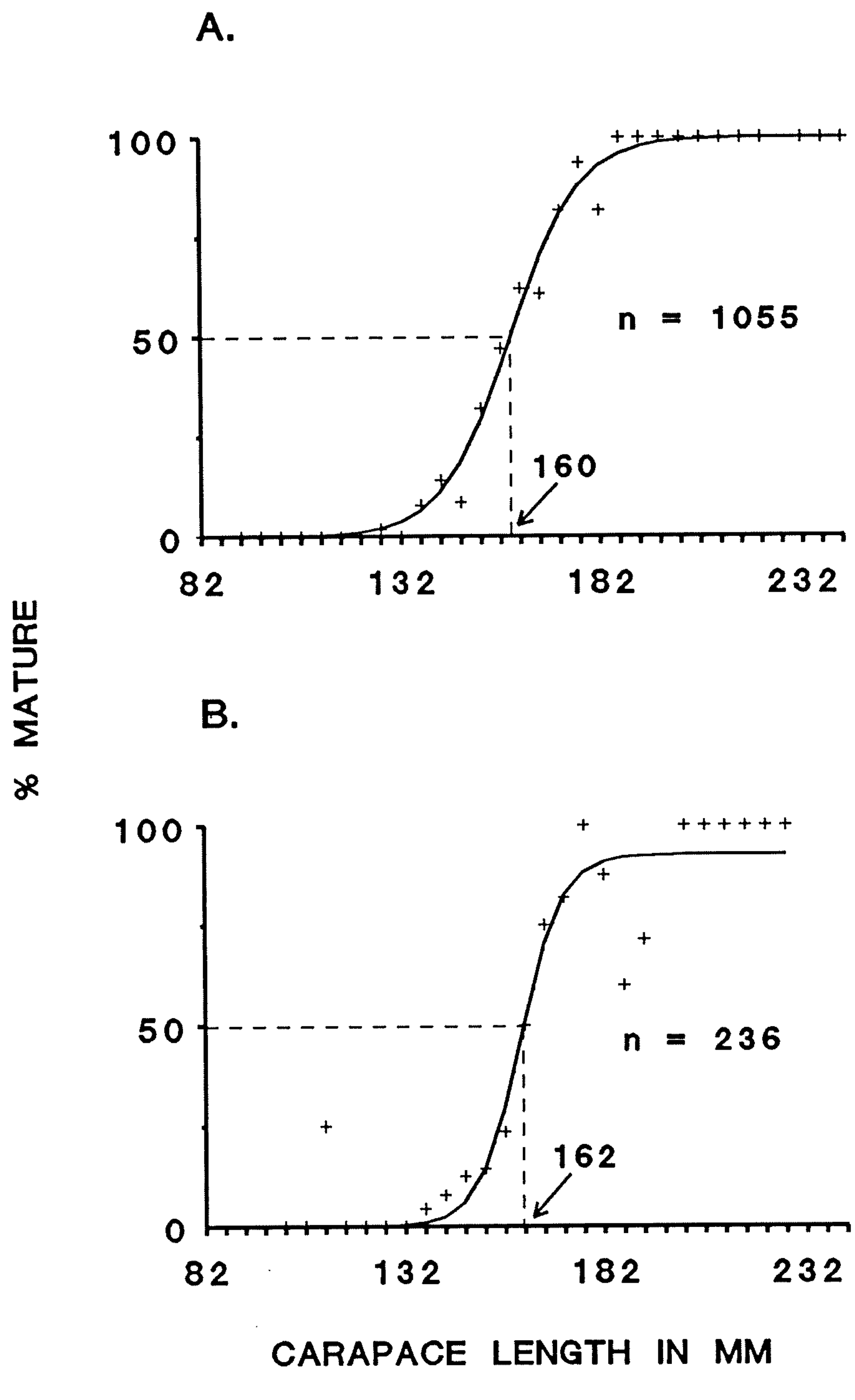

Figure 3. A logistic curve fitted to the percent of the data for female *J. verreauxi* categorised as mature. The size at maturity is estimated from the 50% percentile. Data are for (A) Crowdy Head and (B) Coffs Harbour, whilst N is the sample size.

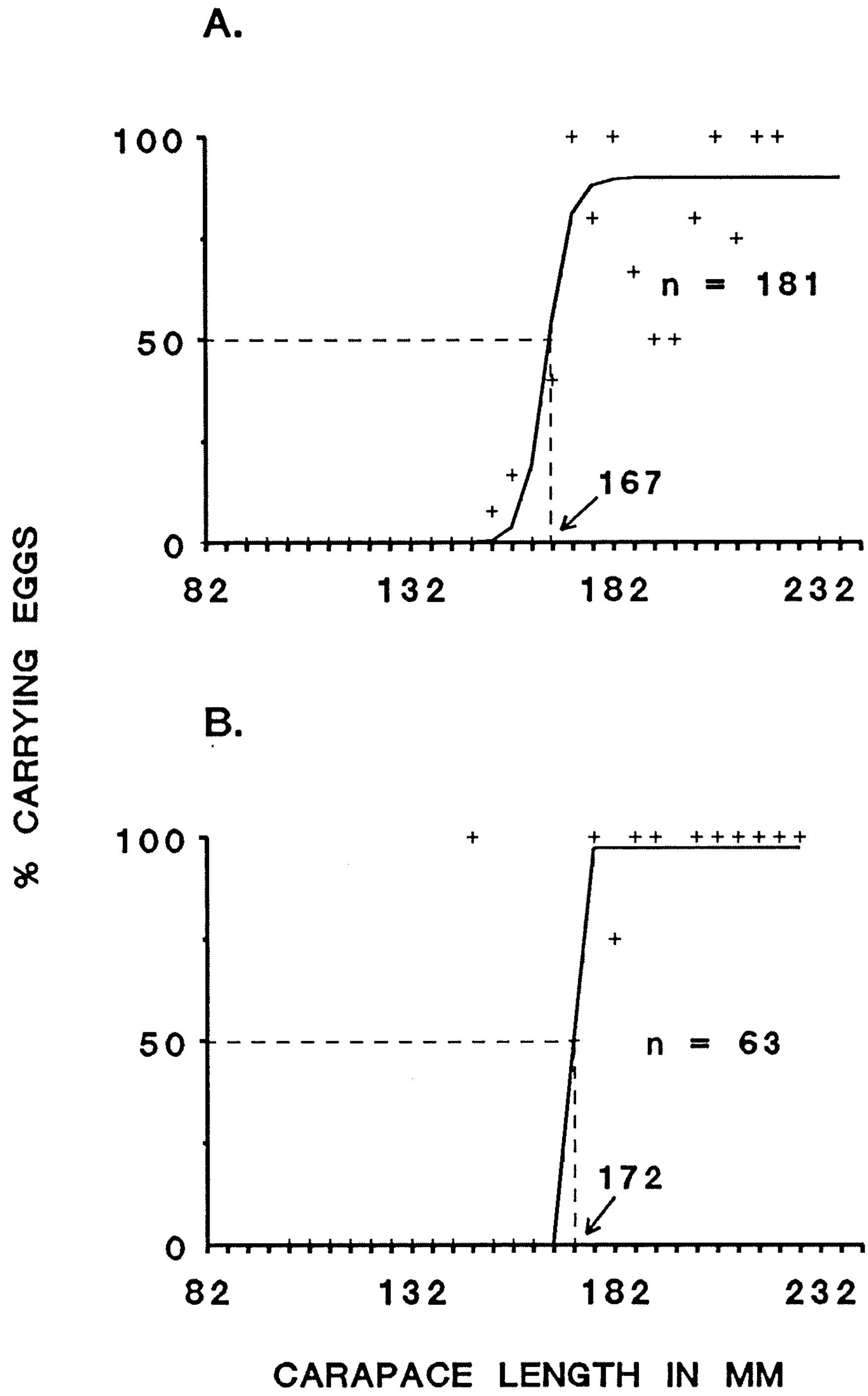

Figure 4. A logistic curve fitted to the percent of the data for female _J. verreauxi_ categorised as carrying eggs. The size at onset of breeding is estimated from the 50% percentile. Data are for (A) Crowdy Head and (B) Coffs Harbour, whilst N is the sample size.

APPENDIX 3

LABORATORY EVALUATIONS OF VARIOUS METHODS OF TAGGING THE EASTERN ROCK LOBSTER J. VERREAUXI (H. MILNE EDWARDS)

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ABSTRACT

Three types of anchor tag (toggle, T-anchor and dart), a mark (V notch) and visual implant tags were assessed under controlled conditions for the effects of tagging on the mortality in eastern rock lobsters. Some experiments are still in progress so results are preliminary. Results from experiments using anchor tags differed in their effects on mortality and tag loss. Mortality among tagged lobsters in the first experiment differed between size classes of lobster within the same treatment, but not between treatments within the one size class. In the second experiment there were no differences in mortality between lobsters tagged with either type of external tag and controls. Mortality did not differ between lobsters tagged with toggle tags and those tagged with either T-anchor or dart tags. That among lobsters tagged with T-anchor tags was greater than among those tagged with dart tags. Marked lobsters had less mortality than among those tagged with toggle or T-anchor tags or controls. Mortality did not differ between those tagged with dart tags and those marked. In the first experiment tag loss was greater among lobsters tagged with T-anchor tags than among those tagged with either dart or toggle tags. In the second experiment there were no such differences. Untagged lobsters had a greater mortality than those tagged with visual implant tags. It was assumed therefore that the mortality induced by tagging with visual implant tags was minimal, but there was a high incidence of tag loss. Either toggle or dart tags are

suitable for use in experiments on _J. verreauxi_ in the field. Growth increment and tag induced mortality appear to depend upon the size of the lobster at the time of tagging.

INTRODUCTION

Tagging and marking has long been used as a method for studying movement, growth, mortality, relative fecundity and population abundance of plants and animals. Excellent reviews of the subject have been presented by Rounsfell (1963), McCormack (1968) Jakobbson (1970), Everhart et. al., (1975) and Burnham et. al., (1987).

The choice of tag or mark should take into account the aim of the study and how the tagged animals will be recaptured. For example, in a tagging experiment to study growth it is important to have recaptures from a wide range of periods at liberty. The tag used therefore, must not only not alter the growth pattern of the animal but in some cases must stay attached to the animal for a long period of time (relative to the life span of the animal). In contrast, a study estimating rates of fishing and natural mortality may require the tag to stay attached to the animal for only a short period. Furthermore, if the public are to be relied upon to report the recapture of tagged animals, then the tagged should be easily recognised on the animal. Finally, it is important to understand how tagging affects the behaviour and physiology of the animal so that data collected from the tagging experiment can be appropriately interpreted.

Several papers have assessed the suitability of different tag types for tagging and marking decapods (e.g. Gray, 1965; Scarratt and Elson, 1965; Cooper, 1970, Lucas, 1972; Gundersen, 1973; Penn, 1975; Marullo et. al., 1976, Farmer, 1981; Bennett and Lovell, 1983; Hill and Wassenberg, 1985). The results of these studies highlight the problem of finding a tag that is readily recognisable and retained after ecdysis. Because they have no internal hard parts into which tags can be anchored, there is a high incidence of tag loss in tagging experiments on crustaceans (e.g. Cooper 1975).

A variety of tags and marks have been used to study rock lobsters including branding (e.g. Gundersen, 1973), uropod punching (e.g. Getchell, 1987), dart tags (e.g. Winstanley, 1976, Gundersen, 1964, 1967), toggle tags (e.g. Chittleborough, 1974; Bennett and Lovell, 1983), sphyrion tags (e.g Scarrat and Elson, 1965; Ennis 1986), micro-wire tags (Wickins et. al., 1986), coded internal tags (e.g. Weingartner, 1982) and telemetric tags (e.g. Ramm, 1980).

This paper assesses the suitability of various tags for studying the movement, growth and mortality of the eastern rock lobster, *Jasus verreauxi*. We require a tag that is firstly clearly visible on the lobster because the public will be the source of recaptured tagged lobsters. Secondly, since movement and growth information are sought, the tag must be retained through ecdysis. Finally, the mortality induced by tagging must be sufficiently low to make a tagging study feasible.

Branding is only evident on crustaceans for a short period (e.g. Cooper 1970) and is therefore not suited to this study. Internal micro-wire tags require specialised detection equipment and are therefore unsuitable where the general public are relied on to recognise the capture of tagged lobsters. Consequently, we sought an external tag which caused the least amount of mortality and was retained in the lobster throughout ecdysis. Booth (1984) used toggle tags to study the movements and growth of J. verreauxi in waters off New Zealand, but he did not report on the effects of this tag upon the animal. In this paper we compare mortality and tag loss among lobsters that had been either tagged with external anchor tags which varied in design of the anchor head, or marked with a "V" notch in the uropod. We also assessed the effect of tag loss and mortality among lobsters tagged with an internal tag which was visible in the animal and could be read macroscopically.

METHODS

Collection of lobsters

Eastern rock lobsters for all experiments were caught by trapping off the Royal National Park, south of Sydney (34 ^{o}S). Lobsters smaller than the legal minimum length (104 mm C.L.) were sorted from the catches of commercial fishermen. They were placed in 40 L containers, covered with hessian bags that had been dampened with seawater and transported by vessel to the Fisheries Research Institute where they were kept in a section of a 1.09 x 10^6 L seawater pool.

All the external anchor tags used in this study were manufactured by Hallprint Pty Ltd (Fig. 1a). Each tag consisted of a spaghetti end attached to a nylon leader and differed only in the design of anchor head attached to the nylon leader. T-anchor and toggle tags were inserted using conventional applicators whilst dart tags were applied with a piece of 2 mm stainless steel rod flattened at one end into a 2 pronged fork to hold the dart. Tags were inserted dorsally through the articular membrane between the carapace and abdomen into the musculature in the posterior region of the cephalothorax. The point of insertion was to the left of the mid-line to avoid damage to nervous and circulatory systems and organs. Animals were measured dorsally along the mid-line between the anterior edge of the antennal platform and the posterior edge of the carapace using dial calipers (antennal carapace length, C.L.). Measurements were rounded down to the nearest mm.

Experiment 1

This experiment was designed to test the null hypothesis that (i) tagging with different types of external tag did not affect the mortality of lobsters; and (ii) there were no differences in growth between different sexes and sizes of lobsters tagged with different types of external tag.

The experiment was done in a covered, 162×10^3 L cement tank partitioned into 4 enclosures (pens) of equal volume. The level of seawater in the tank was controlled to continually allow 20% of the water to be exchanged with that of the neighbouring estuary (Port Hacking, 34 ^{o}S). Air was pumped through a 12 mm diameter manifold in each pen to increase oxygenation and mixing of the water in the tank. Lobsters were housed in shelters (dens) constructed of cement blocks for walls and floor and a 6 mm thick cement sheet for the roof. Lobsters were fed a varied diet of fish (marine spp.), molluscs (Haliotes ruber, Mytilus edulis) and squid (spp.) every 48 hr.

In this experiment were four treatments (T-anchor tags, dart tags, toggle tags and untagged) applied to 3 size categories (small, 80-89 mm C.L.; medium, 90-99 mm C.L.; and large, 100-109 mm C.L.) of male and female lobsters. The entire set of 24 conditions was duplicated in 2 pens, established on consecutive days. In each pen were 5 lobsters of each sex from the large and medium size categories. Because lobsters in the small size category were few, there were only 3 animals of each sex for each external tag treatment and 2 animals of each sex as untagged controls, in each pen from the small size category.

Lobsters were collected over 2 months and the experiment initiated 14 days after the last lobsters had been collected. Seven days before the experiment commenced, lobsters were transferred to the tank and sorted into the three size categories. Lobsters were placed (according to their size category) into 450 L containers of seawater and chosen at random for treatment. Seawater in the containers was exchanged periodically by a 450 L per hr. pump.

Pens were checked every 12 hr for deaths, tag loss and evidence of ecdysis (exuviae) by diving. After the experiment had been underway for 72 hr, it was checked daily. Water temperature on the bottom was measured daily. Salinity was measured during periods of high rainfall, and assumed to be that of seawater at other times.

The experiment was terminated after 66 days when the pumping system failed. During and at the end of the experiment all lobsters and exuviae were inspected for evidence of tag wounds, sexed and measured. These were recorded with the date when the event occurred and, where applicable, the type of tag and its number.

Experiment 2

This experiment tested the same null hypotheses as in experiment 1 except that a mark ("V" notch in the uropod of the lobster) was included as an extra treatment.

This experiment was done in the uncovered, 1.09 x 10^6 L cement pool at the Institute. A 5 hp pump delivered saltwater from a spear-point beneath the substratum of the neighbouring estuary on a 2 hourly rotational basis. Five airlifts placed strategically around the pool provided additional oxygenation and mixing of the water in the pool. One third of the uncovered pool was divided into 8 enclosures of equal volume by partitions made of 1/2" polyethelene netting supported about a 1" PVC frame.

In this experiment were 6 treatments (T-anchor, dart, toggle, mark and untagged) applied to female and male lobsters. The entire set of tags and mark were repeated in 6 pens using 5 lobsters of each sex with each treatment (excluding untagged). Included in this experiment were another set of lobsters of equal sample size (per treatment) to test the effectiveness of tougher ("termite resistant") tubing to stop the destruction of the external spagheti end of the tag. This was, however, considered as a separate experiment and is only mentioned here to indicate the actual number of lobsters in each pen. The results from this experiment are not presented in this paper. Fifty untagged (control) lobsters were assigned to two pens which had been chosen randomly prior to the commencement of the experiment.

Lobsters in the 90-104 mm C.L. size range were collected over a 2 week period and acclimated for a further month before the experiment. Lobsters of this size were the most likely to be tagged in future tagging experiments in the field. The experiment required three consecutive days to establish. Lobsters were separated into sexes and placed into 450 L containers in which seawater was continually exchanged with the pool. Lobsters of each sex were chosen randomly from the containers, treated with one type of tag (including untagged) and assigned to a pen. Lobsters to be marked had a "V" cut into their right hand uropod with scissors. The sequence of treatments and order of pens was chosen randomly. Lobsters not chosen for the experiment were kept in another enclosure in the pool as reserve stock.

During the first 100 days of the experiment, pens were checked for dead lobsters, loose tags and exuviae, by diving daily. Thereafter the experiment was monitored every second day. Dead lobsters were replaced with others from the reserve stock. A lobster of the same sex was chosen at random from this stock, measured, marked using scissors with a "V" notch in the left uropod and placed in the appropriate pen. These lobsters played no role in the experiment other than to remove any confounding effects of density. Water temperature was measured on the bottom of two pens (one on each side of the pool, within the perimeter of the experiment) at the time of monitoring.

Experiment 3

This experiment was designed to test the null hypothesis that visual implant tags (Fig. 1b) do not increase the mortality of lobsters.

Thirty-nine lobsters were chosen at random from a total of 235 individuals held in the uncovered pool for 9 months. The experiment was done in one third of the uncovered pool described in Experiment 2. We used 2 sizes of visual implant tags manufactured by Northwest Marine Technology (small tags were 1 mm x 3 mm; large tags were 2 mm x 3 mm). A hypodermic needle attached to a syringe with a push rod was used to implant the tags through the ventral surface of the articulating membrane between the uropod and the 6th segment. The number of tagged lobsters in each treatment was limited by the number of tags available for the experiment. Fourteen and 28 lobsters were tagged with the small and large tag, respectively. These were placed in an enclosure adjacent to that of the controls in the uncovered pool for use in the above experiments.

The 193 lobsters not selected for tagging functioned as controls. This number was reduced to 30 after 4 months when 163 lobsters were taken from this group.

RESULTS

Experiment 1

At the end of the experiment all lobsters were accounted for. In each pen there were no significant differences in mortality either between different size categories of tagged lobsters within each treatment or between those from different treatments when size categories were combined (Table 1). When pens were pooled, mortality among lobsters tagged with either T-anchor or dart tags varied significantly between size categories. Fewer tagged lobsters in the small size category within each treatment survived. Mortality among tagged lobsters within the same size category did not vary between treatments (including controls). No untagged (control) lobsters died during the experiment.

In each pen, there were significant differences in the incidence of tag loss among lobsters of different size categories within each treatment. Again, fewer tagged lobsters from the small size category retained their tag. The incidence of tag loss was significantly greater among lobsters tagged with a T-anchor tag than those tagged with either toggle or dart tags in pen 1 and dart tags in pen 2 (Table 1). When pens were pooled, there were no differences in the incidence of tag loss between size categories. When size categories were combined, there was significantly more tag loss among lobsters tagged with T-anchor tags than among those tagged with either of the other 2 types of external tag tested.

The proportions that died in the whole experiment were 2.4% of lobsters tagged with toggle tags, 13.6% of those tagged with T-anchor tags and 12% of lobsters tagged with dart tags. An additional 19.6%, 47.7% and 10% of lobsters tagged with either toggle, T-anchor or dart tags, respectively, lost their tag.

Trends in cumulative mortality over time were different between pens and treatments (Fig. 2). Cumulative mortality among lobsters tagged with either T-anchor or dart tags in pen 1 was greatest during the first 48 hr of the experiment. This initial mortality induced by tagging was not as pronounced in pen 2. Mortality among lobsters tagged with toggle tags occurred only in pen 1 and only on the 39th day of the experiment.

The incidence of tag loss among lobsters tagged with the T-anchor tags occurred throughout the experiment (Fig. 3). It was less frequent among lobsters tagged with dart tags and only occurred among those tagged with toggle tags on days 39 and 42, and day 14 in pens 1 and 2, respectively.

Lobsters moulted during the whole experiment but moult frequency was greatest during the first 20 days (Fig. 4). Fifty-nine percent of tagged lobsters underwent ecdysis at least once and retained their tag. The increment of growth of lobsters that survived to the end of the experiment did not vary between either type of tag or sex of the lobster (Table 2). Tagged lobsters that survived to the end of the 66 day experiment and had grown, increased in length by a mean 5.2 mm C.L. (0.32 S.E.)

Experiment 2

This experiment is on-going. Results presented are for the period up until the 31st August 1989 and must therefore be considered as preliminary. With two exceptions there were no differences in mortality within each pen between lobsters tagged with different types of external tag (Table 3). The exceptions were in pen 8 between lobsters tagged with either toggle or T-anchor tags and those tagged with dart tags. The major proportion of mortality among lobsters tagged with toggle or T-anchor tags occurred at a time when mortality among untagged (control) lobsters was also great (Fig 5). With three exceptions there were also no differences in mortality within each pen between those tagged with external tags and those marked. The exceptions were in pen 8 between lobsters tagged with either toggle or T-anchor tags and those marked and in pen 2 between lobsters tagged with T-anchor tags and those marked (Table 3).

When pens were pooled, there were no differences in mortality between lobsters tagged with either dart or T-anchor tags and those tagged with toggle tags (Table 3). However, fewer lobsters tagged with dart tags died than those tagged with T-anchor tags. There were no differences in mortality between lobsters that were untagged and those that were tagged with either toggle or T-anchor tags. Mortality among marked lobsters was lower than among those tagged with toggle or T-anchor tags or untagged. There were no significant differences in mortality between those tagged with dart tags and those marked.

With one exception there were no significant differences in the number of lobsters that lost their tag between external tag treatments within each pen (Table 3). The exception was in pen 6 where significantly more lobsters tagged with dart tags lost their tag than among those tagged with toggle tags. When pens were pooled there were no significant differences in the number of tagged lobsters that lost their tag between external tag types.

The proportions that have died in the experiment were 34% of lobsters tagged with toggle tags; 40% of those tagged with T-anchor tags; and 18 % for lobsters tagged with dart tags. The 12% mortality among untagged lobsters is most probably due to handling and environmental stress. Consequently, the mortality amongst tagged lobsters presumably caused by the tag was 22%, 28% and 6% for toggle, T-anchor and dart tags, respectively. An additional 12%, 16% and 18% of lobsters tagged with either toggle, T-anchor or dart tags, respectively, lost their tag. The mark itself had no effect upon the mortality of lobsters. Stress caused by handling and environmental factors (deaths among controls) accounted for the 10% mortality amongst marked lobsters.

Trends in cumulative mortality over time varied between pens and treatments (Fig. 5). Mortality among lobster tagged with dart or T-anchor tags was continuous over the whole experiment. It was greater among all treatments in all pens (except pen 6) between weeks 26 and 31 than at other times. Because there was also high mortality among untagged lobsters at this time, presumably stresses other than those related to the tag caused the greater mortality. One possible explanation is that there was a lowering in salinity from 36 $^{00}/_{0}$ to 30.2 $^{00}/_{0}$ over this period (because of heavy rain), which coincided also with a period of high moult frequency (Fig. 7).

Tag loss among lobsters tagged with T-anchor tags occurred throughout the experiment, whilst that among lobsters tagged with dart tags was discontinuous (Fig. 6). Tag loss occurred among lobsters tagged with toggle tags only during the period of high moult frequency and the period of low salinity (Fig. 7), around week 30 of the experiment.

The pattern of ecdysis was the same for control and treated lobsters (Fig. 7). It occurred most frequently during the first 3 weeks of the experiment and again between weeks 27 and 34. The latter peak coincided with a higher incidence of death and tag loss among all treatments.

Experiment 3

Again, this experiment is on-going and results until the 31st August 1989 must be considered as preliminary. There was no difference in the number of tagged lobsters that died between the two sizes of visual implant tag (X2 = 0.19, df = 1). The proportion of treated lobsters that died was 69% and 97% amongst those tagged and untagged, respectively. Thirty-eight percent of the tagged lobsters which died had lost their tag.

The number of untagged lobsters that died was greater than amongst tagged lobsters. Furthermore, it was greater than amongst the untagged lobsters in Experiment 2 which began two months later. This greater proportion of deaths may have been the result of additional stress introduced when 140 of the untagged lobsters were removed for another experiment.

Cumulative mortality of untagged lobsters rose faster throughout time than that for tagged lobsters (Fig. 8). Mortality among tagged lobsters first occurred during week 10 of the experiment, 3 weeks after the first mortality among untagged lobsters. Tag loss occurred during the whole experiment (Fig. 9).

DISCUSSION

In tagging experiments on animals both tag loss and mortality reduce the number of tagged animals in the population. The effects of tagging on an animal need to be understood so that data collected from tagging experiments in the field can be adjusted for any bias.

The experiments done in the present study to compare the effects on lobsters of tagging with various types of external tags differed slightly in conclusions. When data in experiment 1 were pooled, mortality among tagged lobsters within each treatment differed between size categories, but did not differ within each size category between tag types. In experiment 2, there were no differences in mortality between lobsters tagged with toggle tags and those tagged with either T-anchor or dart tags. Mortality among lobsters tagged with T-anchor tags was however, greater than among those tagged with dart tags. In experiment 1 tag loss was significantly greater among lobsters tagged with T-anchor tags than among those tagged with either of the other types of external tags. In experiment 2, however, there was no such difference. Tag induced mortality was also influenced by the size of the lobster, as was growth increment.

Preliminary results in the present study also indicate that either marking, or tagging with visual implant tags induced less mortality in J. verreauxi than tagging with external tags. Cooper (1970) also found marking to induce little mortality on lobsters. Further, marks only remain evident on crustaceans for short periods of time (e.g. Cooper, 1970, Bennett and Lovewell 1983). Therefore this form of tagging does not meet the criterion we set that a tag or mark be clearly visible for a long period of time.
Studies by Chittleborough (1974) and Bennett and Lovewell (1983) concluded that a tag based on a toggle type of head were the most suitable for tagging Panulirus cygnus and Homarus americanus, respectively. Neither study compared the mortality induced by tagging or tag loss between the various types of heads used on external tags. Results in the present study suggest that among the external tags tested, tagging with toggle tags had the least effect on lobsters. The effects of tagging with dart tags were, however very similar to those of the toggle tag.

Dart tags appear to have received little consideration in the literature as a possible alternative external tag for tagging lobsters. This is despite dart tags being found to be superior to other types of tags in some tagging studies on various species of fish (e.g. Pepperell in press, Davis and Reid 1982). Studies by Olsen and Fielder (1968), Cooper (1970) and Chittleborough (1974) found a great incidence of tag loss among J. novaehollandiae, P. cygnus and H. americanus, respectively, tagged with dart tags. The tags used, however, were the conventional dart tag where the spaghetti tube connected directly to the dart head, whereas, in the present study, a nylon filament connected the internal anchor to the external spaghetti tube. This configuration seems to reduce tag loss compared to that reported for the conventional dart tag.

T-anchor tags have been used in studies on teleost and some crustacean species (e.g Whitelaw and Sainsbury 1986, Williams 1986). Tagging studies on fish species have reported great incidences of tag loss (e.g. Whitelaw and Sainsbury 1986) which may be associated with the size of the fish being tagged and the proper locking of the tag between the bony parts of the fish (e.g Davis and Reid 1982). Tagging studies on lobsters using T-anchor tags and those with a similar design of head have reported high rates of tag loss (e.g. T-anchor tags, Chittleborough 1974; sphyrion tags, Bennett and Lovewell 1983 and Ennis 1986). Undoubtedly this is because crustaceans have no hard internal parts in to which a tag can be locked. In the present study a longer needle was used in the applicator for T-anchor tags in experiment 2 than in experiment 1. This may have helped to lower the incidence of tag loss amongst lobsters tagged with T-anchor tags in experiment 2 compared to that which occurred in experiment 1. Davis and Reid (1982) also noted the importance of the length of the needle when applying T-anchor tags.

Visual implant tags are a recent development by Northwest Marine Technology (R. Buckley, University Washington, personal cummunication). Preliminary results are confounded by the variability in mortality amongst the untagged (control) lobsters. Mortality amongst untagged lobsters in experiment 2 was greater than among the tagged and untagged lobsters in experiment 3. This may have been caused by additional handling stress introduced into the experiment when 140 of the untagged lobsters in experiment 2 were taken for use in another experiment. Even if the whole of the 12% mortality amongst untagged lobsters in experiment 3 is assumed to be caused by handling (experiment 3 was set up 2 months after experiment 2), the proportion of untagged lobsters that died in experiment 2 is still greater than that amongst lobsters tagged with visual implant tags. It can be assumed therefore that tag induced mortality amongst lobsters tagged with visual implant tags was minimal. The high incidence of tag loss amongst lobsters tagged with the visual implant tag, can be attributed in part to the unfamiliarity of the tagger with this particular tagging process. Under laboratory conditions, Krouse and Nutting (in press) found no induced mortality due to tagging in _H. americanus_ tagged with micro-wire tags. Rates of tag loss were however as high as 48% in tagged lobsters that had moulted once. They concluded that tag loss could be reduced by modifying tagging techniques. Wickins et. al., (1986) also found no induced mortality due to tagging amongst

Homarus gammarus tagged with micro-wire tags under laboratory conditions, but tag loss was as little as 15%. Similarly, Prentice and Rensel (1977) found no mortality induced by tagging and a tag loss of around 5%, amongst the shrimp _Pandalus platyceros_ tagged with micro-wire tags under laboratory conditions. The evidence from these studies using similar tags suggests therefore that tag loss among lobsters tagged with visual implant tags could be reduced with further development of tagging methods. Although visible with the naked eye, this tag would not be sufficiently evident on the lobster that the public could be relied upon to detect tagged animals. These tags would be useful where the researchers carrying out the tagging also recapture all the tagged animals (e.g. under laboratory conditions).

Experiments undertaken in the present study did not conclusively identify one type of external tag as being the most suitable tag for any tagging experiments undertaken on _J. verreauxi_ in the field. Combined tag mortality and tag loss was lowest among lobsters tagged with toggle tags and with dart tags in experiments 1 and 2, respectively. Either of these types of external tag therefore could be used in any future experiments on _J. verreauxi_.

This study has also shown that the growth of _J. verreauxi_ is dependent upon the initial size of the lobster. Furthermore, tag induced mortality appears also to depend upon this size. Future tagging experiments in the field to study growth and mortality must therefore be designed to include eastern rock lobsters of as large a range of lengths as is possible. Data for analysis from recaptures should then be grouped according to the initial size of the recaptured tagged lobster.

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Figure 3. Tag loss among J. verreauxi tagged with different external tags in experiment 1.

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Figure 7. Incidence of exuviae among J. verreauxi tagged with different external tags or marked in experiment 2.

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Figure 9. Tag loss among *J. verreauxi* tagged with visual implant tags in experiment 3.

Table 1 Comparison of three size classes of J. verreauxi tagged with one of three treatments that either died or lost their tag. X^2 values are given for testing the null hypotheses that there were:

A) No differences in mortality or tag loss between size classes within each treatment in each pen, or when pens were pooled (df = 2), and

B) No differences in tag loss between treatments when size classes were combined in each pen or when pens were pooled (df = 1), and

C) No differences in mortality between treatments within each size class when pens were pooled (df = 1).

* indicates significance and NS non significance at p = 0.05.

(T = toggle tag, TA = T-anchor tag, D = dart tag, M = mark, c = control).

TREAT-	MORTALITY						TAG LOSS					
MENT	PEN 1		PEN 2		POOLED		PEN 1		PEN 2		POOLED	
	X^2	P	X^2	P	X^2	P	X^2	P	X^2	P	X^2	P
A)												
Toggle	1.63	NS	0	NS	1.59	NS	1.75	NS	3.41	NS	2.27	NS
T-anchor	5.19	NS	3.68	NS	8.53	*	5.71	NS	0.29	NS	2.56	NS
Dart	3.96	NS	3.96	NS	7.91	*	3.96	NS	1.60	NS	5.25	NS
B)												
T vs TA	1.44	NS	3.07	NS			5.06		3.70	NS	8.03	*
T vs D	0.92	NS	2.94	NS			1.56	NS	0.33	NS	1.76	NS
TA vs D	0.09	NS	3.e^{-3}	NS			11.52	*	6.12	*	16.65	*
C)												
T vs TA	5.87	*	1.89	NS	0.36	NS						
T vs D	4.8	*	0	NS	1.14	NS						
TA vs D	0.11	NS	1.89	NS	2.35	NS						

Table 2 Analysis of growth (in terms of increase in carapace length) of tagged <u>J. verreauxi</u> that survived to the end of experiment 1. Variances were homogeneous, Cochran's test, $P > 0.05$.

Source of Variation	df	MS	F	P
Slopes	5	12.39	1.19	> 0.05
Residual	91	10.41		
Intercepts				
Type of tag	2	4.42	0.42	> 0.05
Sex	1	10.25	0.98	> 0.05
Type of tag x Sex	1	8.87	0.84	> 0.05
Residual	96	10.51		

Table 3. Comparisons of *J. verreauxi* that either died or lost their tag in experiment 2. X^2 values are given for testing the null hypotheses that there were:

A) No differences in mortality between treatments within each pen and when pens were pooled, and

B) No differences in tag loss between treatments within each pen and when pens were pooled.

* indicates significance and NS non significance at p = 0.05 (df = 1).
(T = toggle tag, TA = T-anchor, D = dart tag, M = mark, c = control).

TREAT-	PENS												POOLED	
MENT	1		2		3		4		5		6			
	X^2	P	X^2	P	X^2	P	X^2	P	X^2	P	X^2	P	X^2	P
A)														
T vs TA	0.8	NS	0.0	NS	3.81	NS	2.22	NS	1.05	NS	0.8	NS	0.35	NS
T vs D	0.22	NS	0.95	NS	0.0	NS	0.0	NS	1.05	NS	8.57	*	3.14	NS
TA vs D	1.82	NS	0.95	NS	3.81	NS	2.22	NS	0.0	NS	5.00	*	5.50	*
T vs M	0.0	NS	5.0	*	1.05	NS	2.22	NS	1.05	NS	5.50	*	6.50	*
TA vs M	0.8	NS	5.0	*	6.67	*	0.0	NS	0.0	NS	2.40	NS	9.62	*
D vs M	0.22	NS	2.22	NS	1.05	NS	2.22	NS	0.0	NS	1.05	NS	0.69	NS
C vs T	1.09	NS	1.09	NS	0.96	NS	0.02	NS	2.69	NS	5.93	*	0.57	NS
C vs TA	2.77	NS	1.09	NS	2.77	NS	2.69	NS	0.75	NS	1.44	NS	2.04	NS
C vs D	0.16	NS	0.70	NS	0.96	NS	0.02	NS	0.75	NS	2.69	NS	1.50	NS
C vs D	1.09	NS	3.0	NS	3.0	NS	2.69	NS	0.75	NS	0.75	NS	4.27	*
B)														
T vs TA	1.05	NS	0.39	NS	0.27	NS	0.0	NS	1.05	NS	0.0	NS	1.05	NS
T vs D	0.0	*	1.05	NS	0.0	NS	0.39	NS	5.0	*	0.0	NS	0.62	NS
TA vs D	0.0	NS	2.22	NS	0.27	NS	0.39	NS	2.40	NS	0.0	NS	0.06	NS

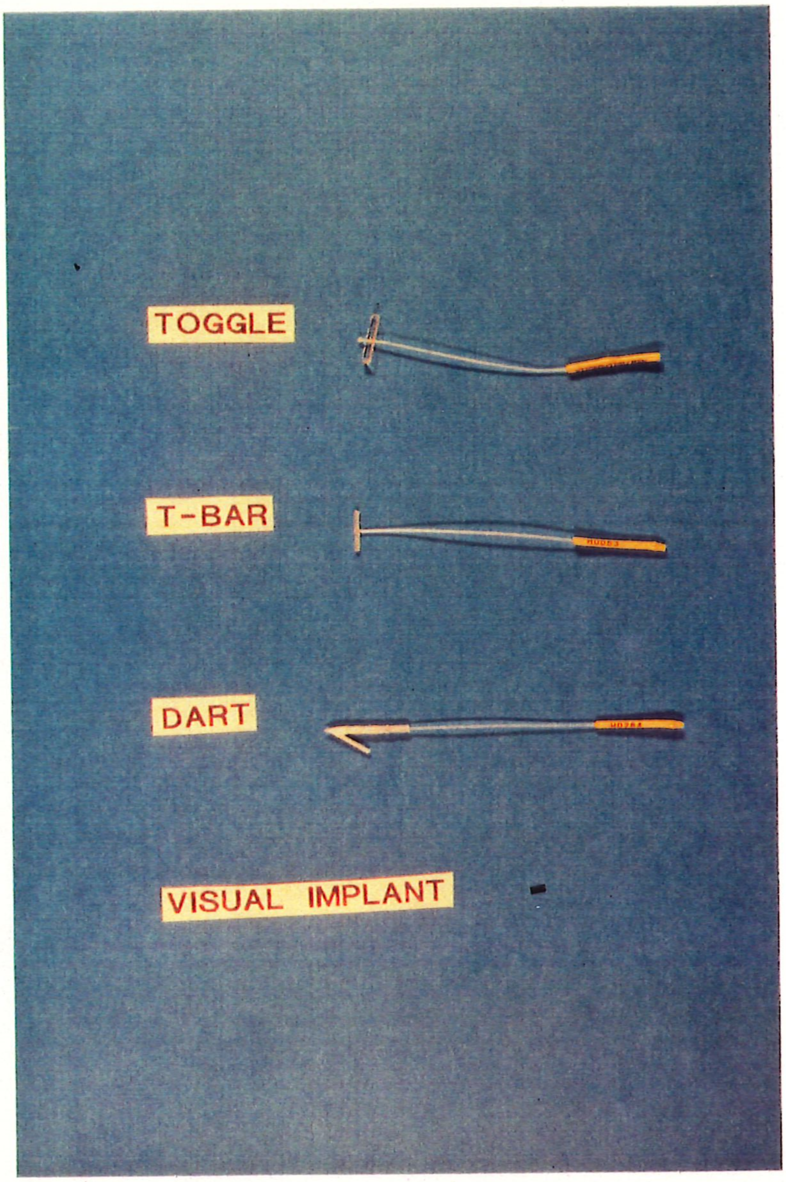

Figure 1a. Types of tags used in experiments.

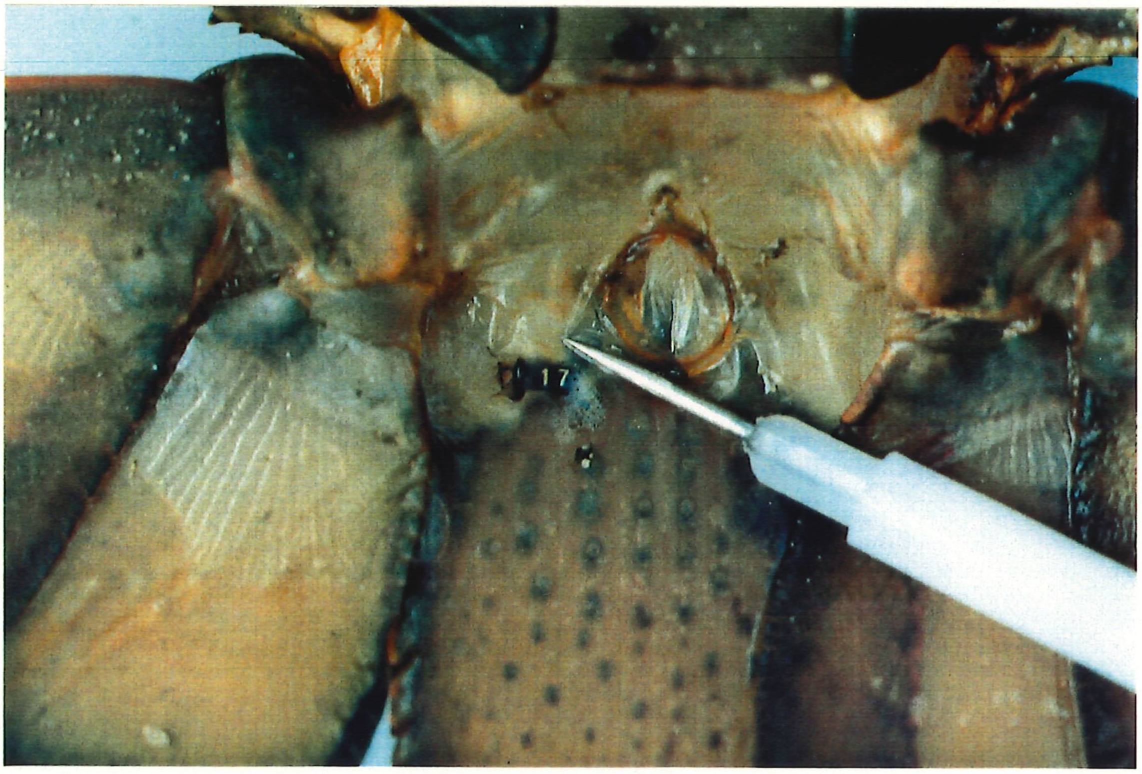

Figure 1b. A visual implant tag in situ.

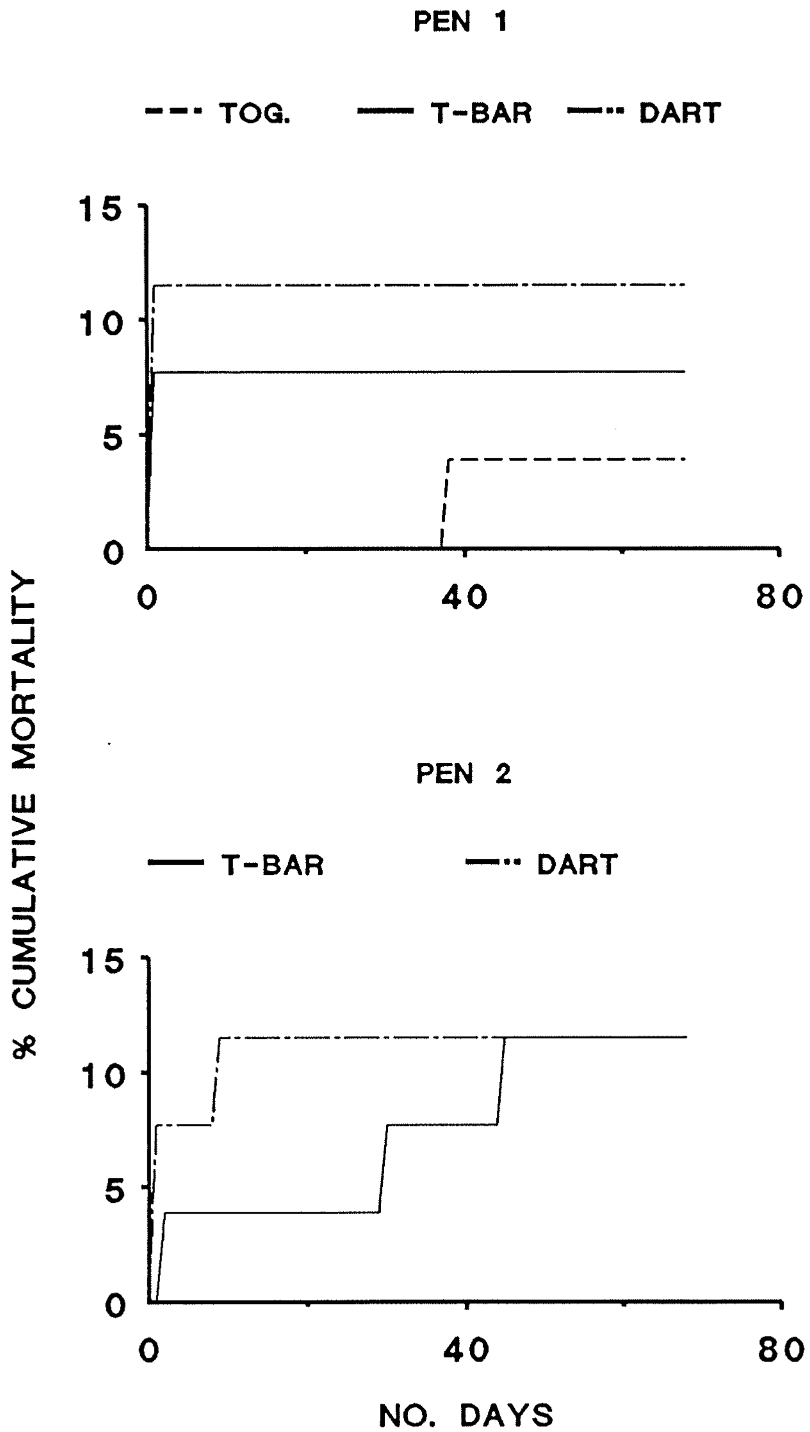

Figure 2. Mortality among J. verreauxi tagged with different external tags in experiment 1. Treatments are only shown when there was mortality within a pen.

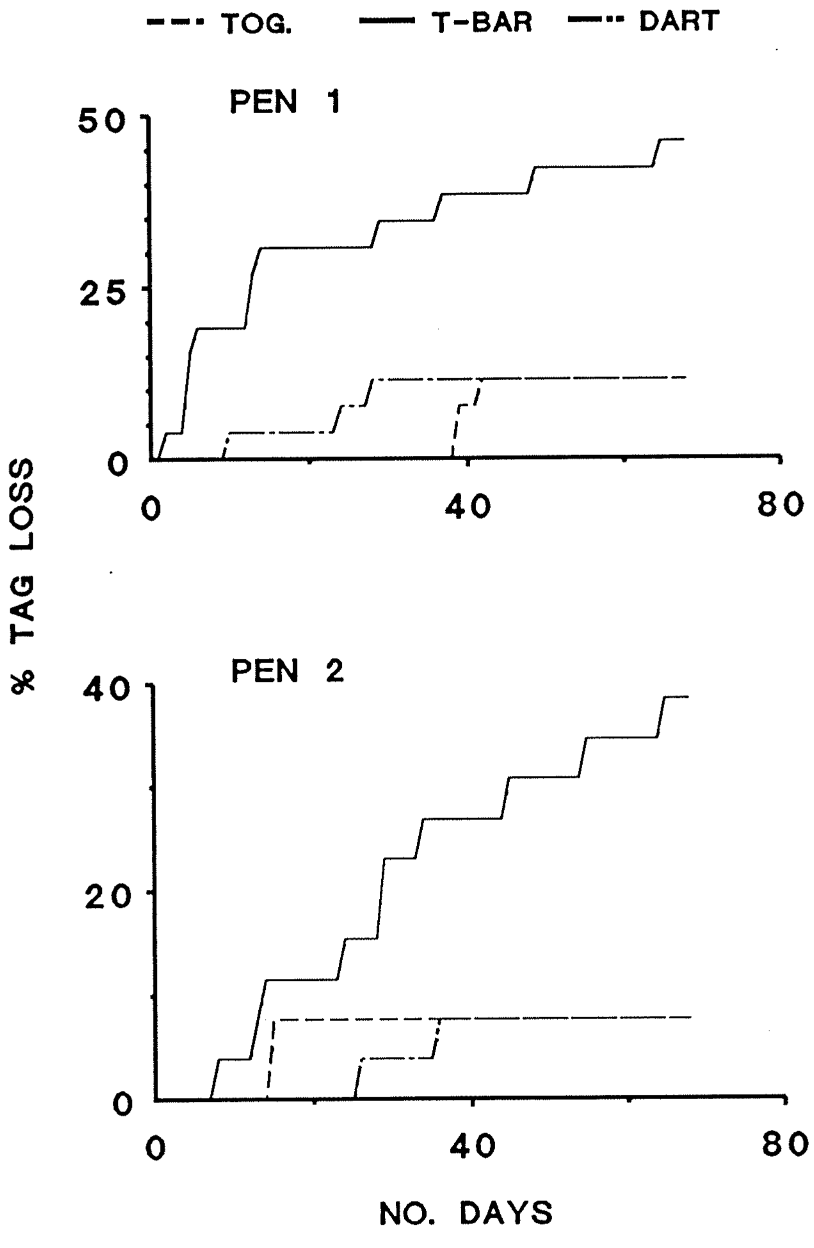

Figure 3. Tag loss among <u>J</u>. <u>verreauxi</u> tagged with different external tags in experiment 1.

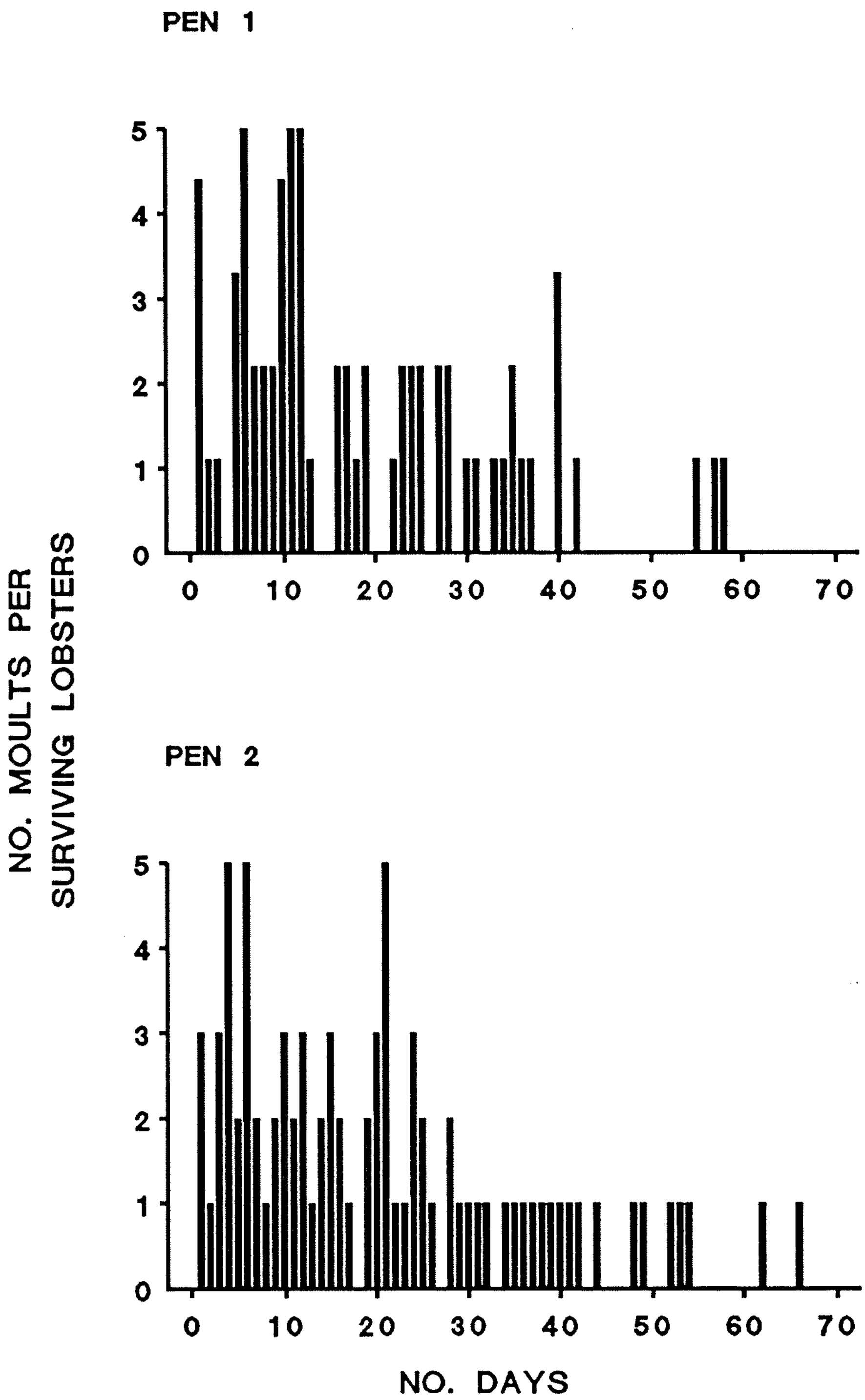

Figure 4. Incidence of exuviae among _J. verreauxi_ tagged with different external tags in experiment 1.

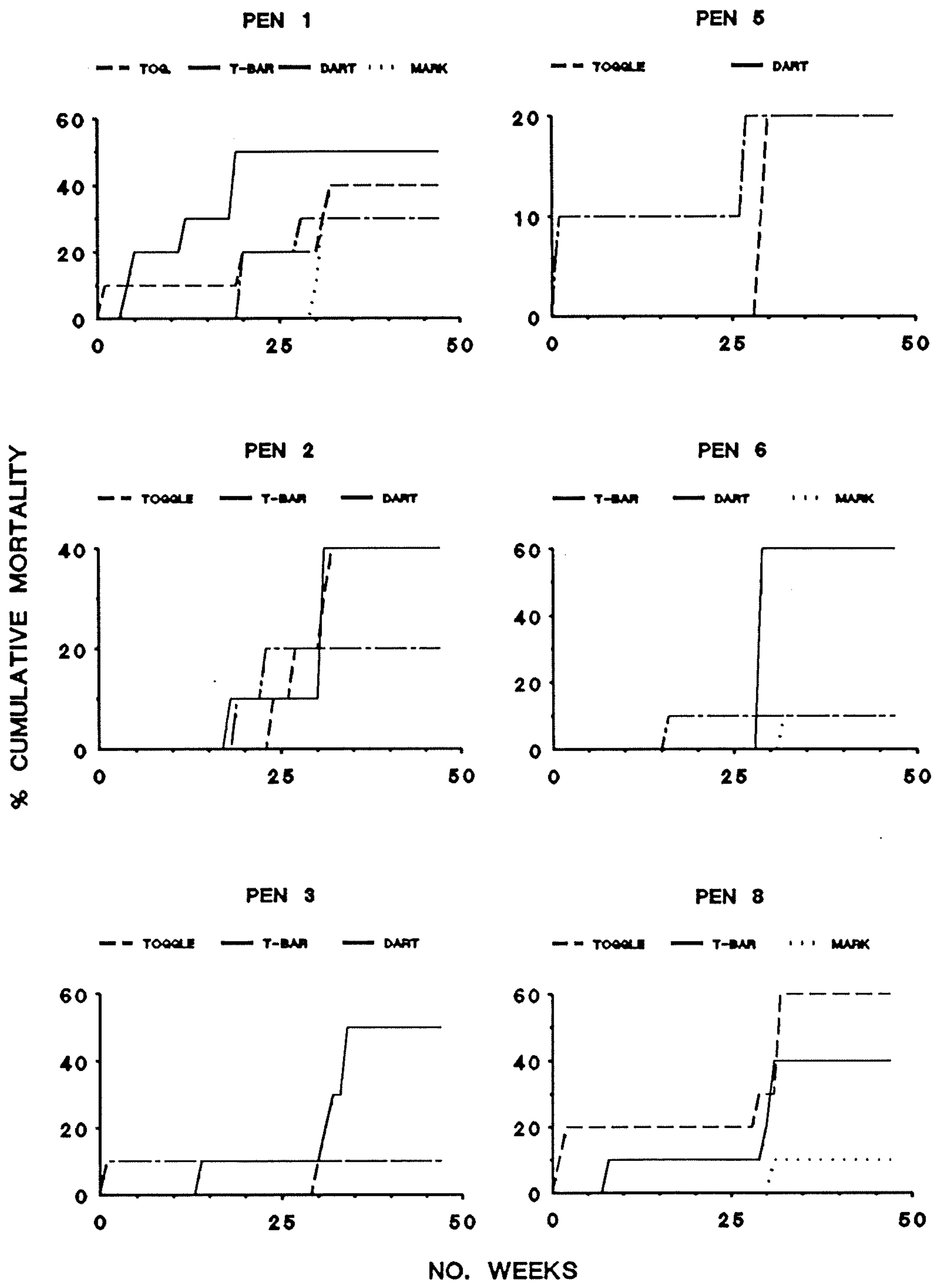

Figure 5a. Mortality among <u>J</u>. <u>verreauxi</u> tagged with different external tags or marked in experiment 2. Treatments are only shown when there was mortality in a particular pen.

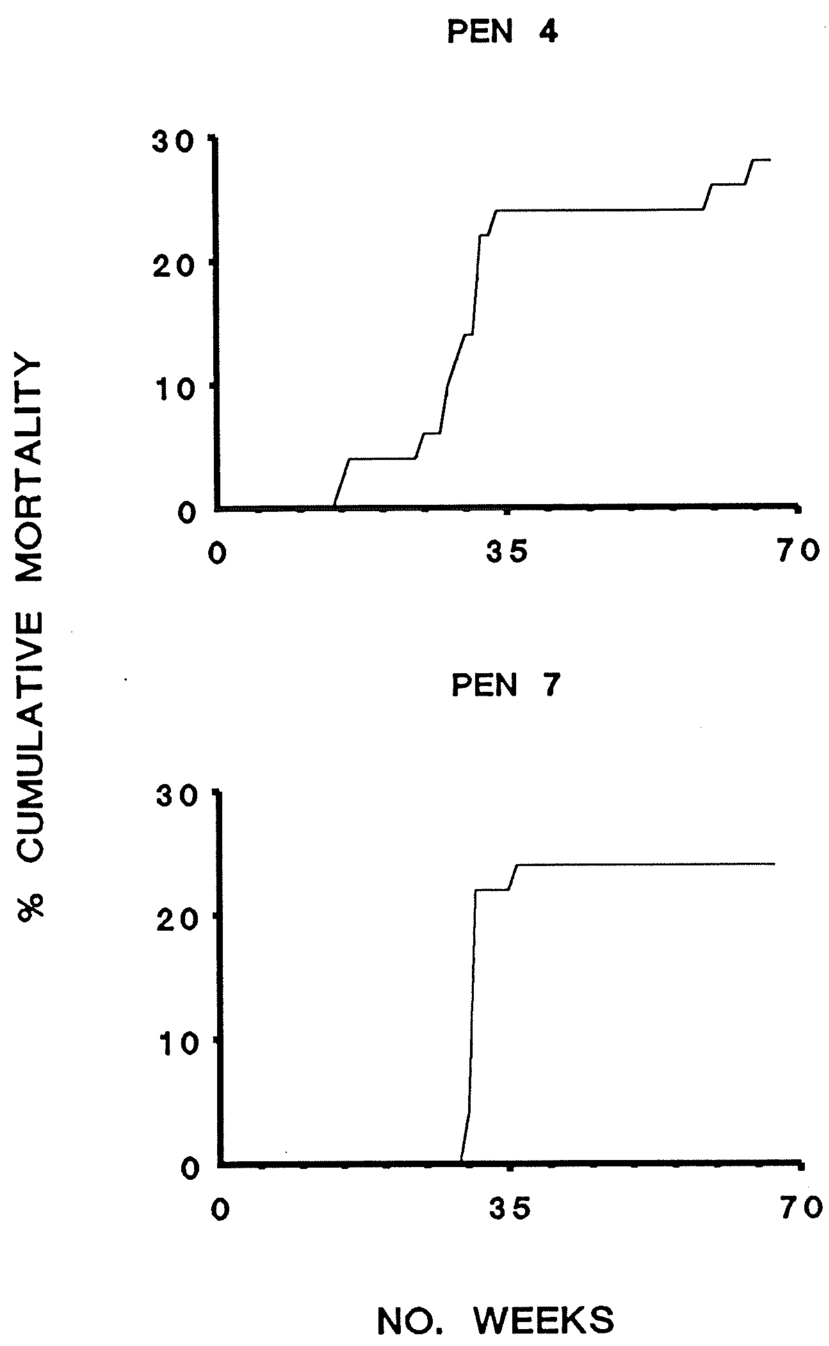

Figure 5b. Mortality among untagged (control) _J_. _verreauxi_ in experiment 2.

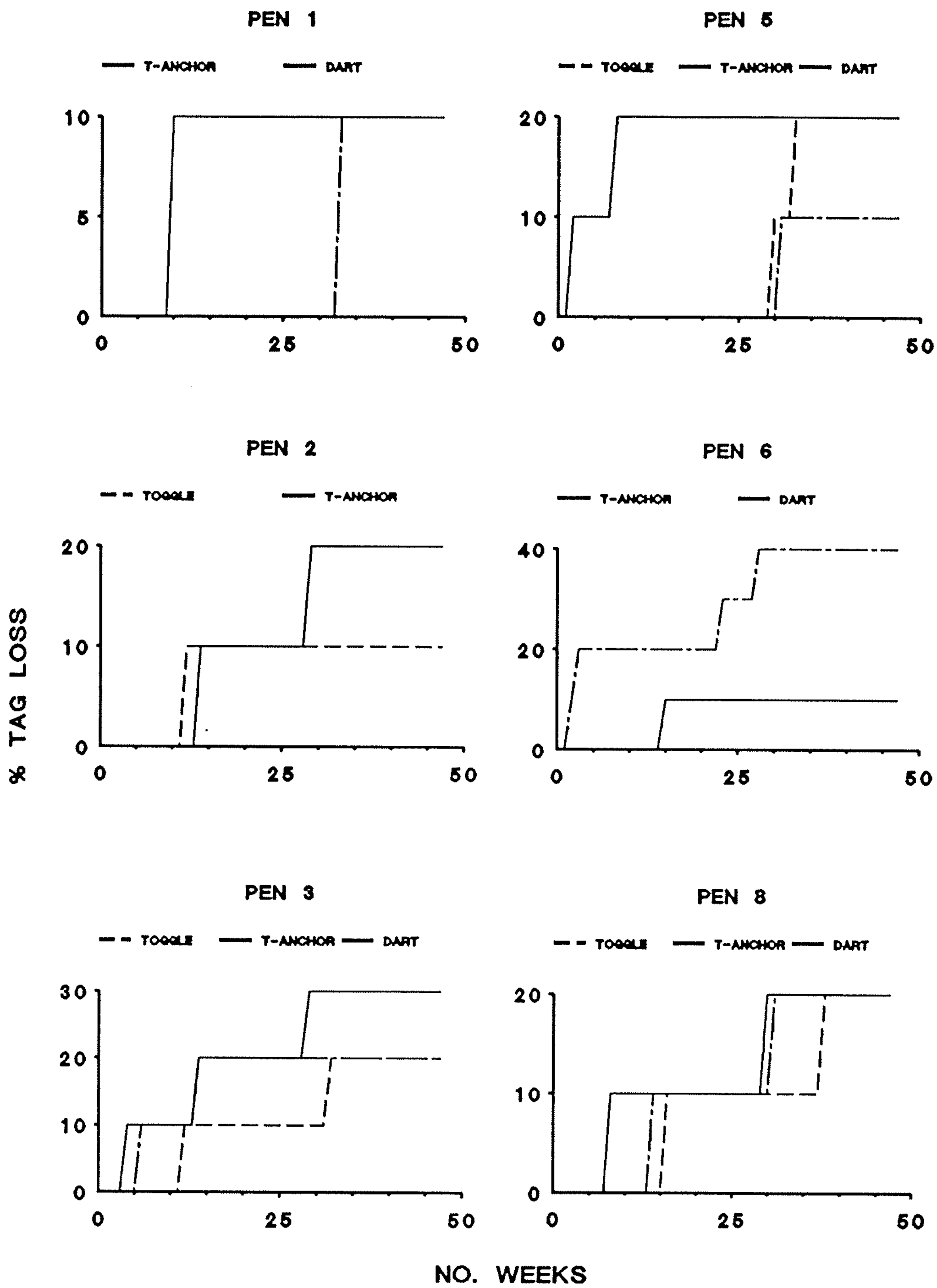

Figure 6. Tag loss among J. verreauxi tagged with different external tags or marked in experiment 2. Treatments are only shown when tag loss occurred within a particular pen.

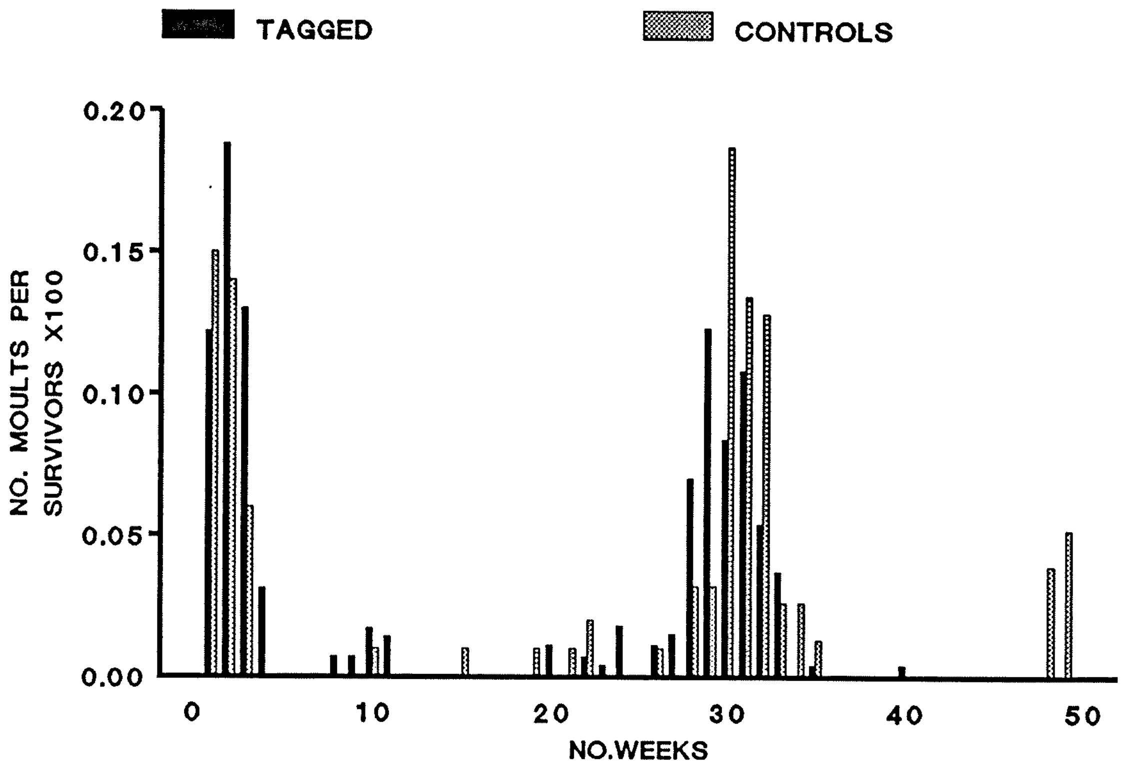

Figure 7. Incidence of exuviae among J. verreauxi tagged with different external tags or marked in experiment 2.

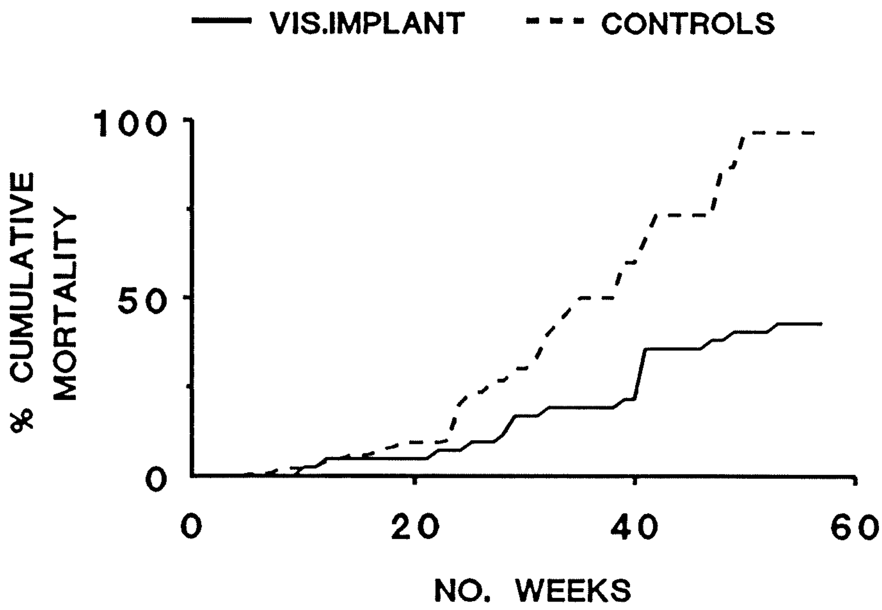

Figure 8. Mortality among J. verreauxi tagged with visual implant tags in experiment 3.

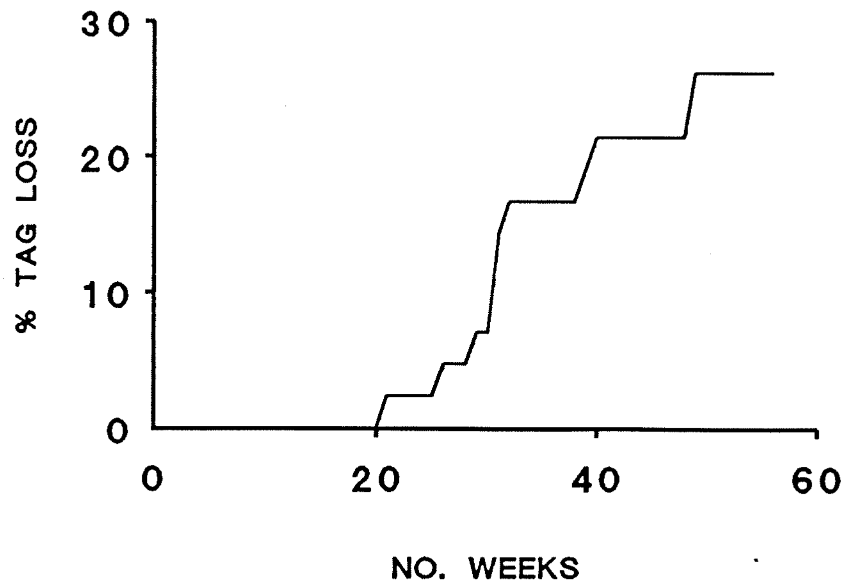

Figure 9. Tag loss among J. verreauxi tagged with visual implant tags in experiment 3.