FIRTA project 85/57 – Final Report

Studies on the breeding stock of the Western Rock Lobster, *Panulirus cygnus*, in relation to stock and recruitment.

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PREFACE

This document is the final report of research undertaken in FIRTA project 85/57. The project resulted in the collection of a very large quantity of data on particularly the reproductive biology of the western rock lobster. The tagging studies also resulted in incidental information on growth rates and movements of rock lobsters. Only the more important results and conclusions relating to reproductive biology and the method for estimating spawning stock abundance have been included in this report. The more detailed biological information and analyses will be submitted for publication in refereed international journals and the Western Australian Fisheries Department's Report series as appropriate. Acknowledgement of the funding source will made in each article.

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EXECUTIVE SUMMARY

AREAS COVERED BY THE RESEARCH PROGRAMME

Studies on the breeding stock of the western rock lobster, *Panulirus cygnus* George, were conducted to examine the appropriateness of the current measure of the abundance of the breeding stock.

Research cruises, commercial monitoring and laboratory studies were undertaken between 1984 and 1988. Data from these studies have resulted in a significant improvement in the understanding of the reproductive biology of this species. Size-related repetitive breeding is now known to be an important feature of reproductive activity in *P. cygnus*. In addition, an improved, curvilinear fecundity-carapace length relationship now replaces the linear one reported in the early 1970s. The interpretation of research log book data has also been enhanced

The current spawning stock index was reviewed and found to be unrepresentative of the stock as a whole. The basis for the development of a new index (or indices) has been provided by the study.

THE CURRENT SPAWNING STOCK INDEX COMPONENTS AND THEIR VALIDITY

The current spawning stock index is based upon the calculation of the egg production from two traditional "coastal" regions of the western rock lobster fishery. For each of the two coastal regions egg production is derived from log book catch rates of

berried females from the 20-30 fathom depth range in December and January each season. The catch rates are multiplied by a constant area value to give relative numbers of breeding females. This number is further multiplied by an average fecundity figure for the breeding females in each region, resulting in an estimate of the numbers of eggs produced annually. A constant, minor correction factor is then applied to account for the contribution to egg production by the population at the Abrolhos Islands.

A number of problems have been identified with the use of log book catch rates of berried females:

(i) peak catch rates of berried females occur in the November to December period but there is virtually no sampling of the breeding stock by the commercial fleet before mid to late December;

(ii) some fishermen count berried females in their catch while others only estimate the number;

(iii) variability in the individual catch rates is high which may render the index insensitive to changes in abundance;

(iv) the peak breeding period may alter due to variations in environmental conditions, thus, given that the fishing pattern remains relatively constant, log book catch rates may falsely indicate changing densities of breeding females;

(v) if catches of animals which may be legally retained are small and large numbers of berried females are being caught, fishermen quickly move to other areas, a practice which leads to underestimates of spawner abundance;

(vi) catchability (q) is assumed to remain constant over the whole fishery and not to vary between spawning seasons, however, a number of factors affect catchability and this assumption is unlikely to be valid;

(vii) increases in fishing gear efficiency over time and its effect on abundance estimates have not been taken into account (research in this field is being undertaken);

(viii) there are no research log book data for the Abrolhos Islands during the breeding season since the region is closed to fishing at this time, therefore, comparisons between this region and the coast using spawner catch rates are not possible.

Since the previous fecundity-carapace length relationship was linear, and the mean size of breeding female on a regional basis did not appear to vary greatly, a constant fecundity value was considered appropriate. Size-related double spawning and a curvilinear fecundity relationship now make this approach inadequate.

The estimate of surface area between 20 and 30 fathoms has been revised by Mr R. Mahoney of the Western Australian Department of Marine and Harbours. The revised values vary considerably from the first estimates, however, they are constants and recalculation of the current index using the new values did not affect the trends but merely altered the magnitude of the differences between years. Information from fishermen on the distribution of breeding females has shown that data from a wider depth range needs to be considered for an index of abundance to be representative.

The contribution of the Abrolhos Islands to egg production was estimated at 14% from research cruises in January and February of 1979 (near the the end of the breeding season). The view is now held that the Abrolhos Islands contributes at least half of the total number of larvae currently hatched annually in this fishery.

THE NEW SPAWNING STOCK MODEL - BASIC FORM

The new model utilises five geographic regions. For each region estimates of the size of the stock of mature females will be made using the range of data bases that are available for that region. Estimates will be made of the area of habitat within each region for the depth range that is considered. The size-frequency distributions of mature females will be reassessed and the new repetitive breeding and fecundity relationships applied to yield egg production. Egg production from the four coastal areas and the Abrolhos Islands will be combined to provide a Revised Spawning Stock Index.

FUTURE RESEARCH FOR MANAGEMENT

This programme of research has achieved its aim of assessing the applicability of the current index of abundance of the breeding stock of the western rock lobster. Furthermore, it has provided the basis for the calculation of a more representative spawning stock index. However, some additional research is required to allow for the new index to be estimated from the historical data base so that the spawning stock-recruitment relationship for the western rock lobster can be re-examined. This research will involve:

(i) the development of methods for the estimation of the abundance of mature females at the Abrolhos Islands, many of which are below the legal minimum size for capture;

(ii) further investigation of the breeding biology and abundance of spawners in the far northern and far southern regions of the fishery, including the enhancement of commercial data from these regions (i.e. log book coverage, monitoring data, etc.);

(iii) estimating the area of available rock lobster habitat within the depth ranges where spawners occur in each region;

(iv) an examination of annual variability in the catchability of mature females, particularly in the coastal regions of the fishery.

1. INTRODUCTION

Responsible fisheries management aims to maximise yield from a fishery while at the same time maintaining the spawning stock at a level that ensures adequate recruitment to the exploited stock each year. It is therefore essential that any index of the size of the spawning stock accurately reflects the real abundance of breeding females, and hence larvae produced.

The index of abundance of the spawning stock currently used in the management of the western rock lobster fishery was first developed by Morgan (1980a) and later refined by Morgan, Phillips and Joll (1982). This index was developed to represent the approximate number of rock lobster larvae hatched during a breeding season following unsuccessful attempts by CSIRO Fisheries to estimate phyllosoma (larval) abundance directly (Morgan *et al.* 1982).

The Morgan *et al.* (1982) spawning stock index (SSI) combines data from a number of sources and has the form:

$$SSI = C[(CR \times A \times AF)_n + (CR \times A \times AF)_s]$$

where for the regions north (n) and south(s) of $30^{o}S$ latitude:

CR is the average catch rate of berried (ovigerous) females caught in depths of 20 to 30 fathoms during January and February.

A is the approximate sea surface area between the 20 and 30 fathom isobaths representing a gross estimate of the area of spawning ground.

AF is the mean fecundity of the average-sized berried female in the region, estimated from commercial monitoring data and the fecundity relationship reported by Morgan (1972).

C is a constant applied to the sum to adjust for the contribution to egg production by the Abrolhos Islands breeding population. This contribution was set at a constant 14% based on research vessel cruises to the Abrolhos Islands in January and February of 1979.

Morgan *et al.* (1982) used the average of berried female catch rates from log books for January and February as the basis for their index. However, after a later review of the available data, the average of the December and January catch rates in 20 to 30 fathoms was considered to be a better representation of spawner abundance (R. Brown pers. comm.). Thus in the mid 1980s the Morgan *et al.* index was altered slightly to produce the modified index currently in use. This change involved the substitution of the December and January catch rate combination for the January to February average catch rate and a recalculation of the index for the period 1966 to the present.

This index is based upon data from fishermen's catches which are biased towards those areas that are subjected to a reasonable amount of fishing effort. Consequently it does not fully take into account those regions that are

either lightly fished or unfished but which may support significant numbers of breeding females; for example, the northern and southern limits of the fishing grounds and areas partially closed to fishing.

A review of the data and assumptions upon which the SSI has been based revealed that although a great deal is known about the reproductive biology of this species (Sheard 1949, 1962; George 1958; Morgan 1972; Chittleborough 1974, 1976; George, Morgan and Phillips 1979; Morgan 1980b; Morgan, Phillips and Joll 1982; Phillips *et al*. 1983) a number of aspects required reassessment or clarification. For example, the available evidence from previous research suggested that repetitive breeding was important and thus would have a considerable impact on estimates of egg production by this species. Secondly, considering that Chittleborough (1976) hypothesised that a major part of the coastal recruitment (puerulus) could be derived from the Abrolhos Islands spawning stock, the apparently small contribution of this spawning population to total larval production (as used in the current index) needed further investigation. Furthermore, the Abrolhos Islands zone is closed to fishing during the breeding season with the result that detailed research log book and commercial monitoring data are not available during this period.

A research programme was therefore developed to examine these and other aspects of western rock lobster reproductive biology. It was considered that the results of the proposed research would either markedly improve the

current measure of the abundance of the spawning stock, or facilitate the selection of the most appropriate bases from which alternative indices may be derived. This in turn would enhance the understanding of the stock and recruitment relationship for this species. Thus funding was sought to undertake studies on the breeding stock of the western rock lobster with the specific objectives of:

(i) investigating the degree to which repetitive spawning occurs in wild populations throughout the range of the western rock lobster;

(ii) re-examination of the fecundity of this species throughout its range;

(iii) examining ovarian maturation and oocyte development;

(iv) undertaking on-board monitoring of commercial catches in selected locations including the Abrolhos Islands;

(v) more accurately delineating the spawning/breeding grounds of the western rock lobster.

These studies were commenced in 1984 with funding from the Western Australian Fisheries Department's Research and Development Trust Fund. Financial support from F.I.R.T.A. commenced in July 1985 and ceased at the end of June 1988.

2. MATERIALS AND METHODS

2.1 TAGGING AND SAMPLING PROCEDURES

Multiple tag and recapture experiments were conducted from the Fisheries Department's Research Vessel "Flinders", various charter vessels and occasionally Departmental Patrol Vessels, at three locations representing the three major management zones of the fishery. These locations were the Easter Group of the Abrolhos Islands (1984/85) and Two Rocks (1985/86) and Dongara (1986/87) both in the central coastal part of the fishery (Fig. 1). The central coastal region extends from about Geraldton south to Mandurah. In general, monthly cruises of about two weeks duration were undertaken at each location from August or September through to February the following year. The tagging experiments were designed to follow individual female rock lobsters through their breeding cycle to estimate the proportion of females breeding repetitively, and the number of broods of eggs an individual may hatch in a single breeding season.

Rock lobsters were caught in commercially made pots using a combination of baits used widely in the fishery. The carapace length (CL) of each lobster was measured, then it was sexed, assigned a breeding state (if female), tagged and released. Tagged rock lobsters were recaught and re-released during the series of research cruises. Recaptures of tagged rock lobsters were also made by the commercial fleet during the rock lobster season (Nov. 15 to Jun. 30).

While measuring rock lobsters at sea on board commercial vessels the same procedures were adopted except that tagging was not conducted.

Samples for gonad examination and fecundity analyses were collected during research cruises and on commercial vessels.

2.2 MAPPING OF THE BREEDING GROUNDS

To determine the extent of the breeding grounds, fishermen were sent a copy of a chart on which to mark their individual fishing areas and within those areas the locations where berried female rock lobsters were regularly caught. Approximately 220 fishermen (28% of the fishing fleet) returned chart copies. These data were digitised and overlaid with accurately drawn depth contours to provide a more detailed description of the rock lobster breeding grounds than was previously possible. The digitized depth contour data were provided by Mr Rick Mahoney, Chief Cartographer, Engineering Division of the Western Australian Department of Marine and Harbours.

3. RESULTS

3.1 REPRODUCTIVE BIOLOGY

3.1.1 BREEDING SEASON

For the purpose of this report the breeding season is defined as that period in which berried female rock lobsters are present in the population. In general, in the central coastal regions of the fishery, ovigerous females were only found in significant numbers in waters deeper than about 20 fathoms. In contrast to this, berried rock lobsters were found in all depths at the Abrolhos Islands situated near the edge of the continental shelf approximately 60 kilometres from the coast (Fig. 1).

In summary, berried females first appeared in the catches in either late September or early October at all locations. The single exception to this general observation was at the Abrolhos Islands. There, mature female rock lobsters were found to spawn in late August to early September, approximately one month prior to the coastal breeding population. Newly spawned (bright orange) eggs were not usually seen on females after January and the hatching of all eggs was generally complete by the end of February in all locations.

Since the western rock lobster fishery extends over about eight degrees of latitude, spawning times for rock lobsters might be expected to vary due to differences in water temperatures along the coast. However, the evidence collected during this and other studies (George 1958; Sheard 1962) suggests that there is no apparent latitudinal trend in spawning times. This is thought to be due to the warming effect of the Leeuwin Current that flows southward along the edge of the Western Australian continental shelf during autumn, winter and spring. However, the anomalous earlier spawning by rock lobsters at the Abrolhos Islands may reflect the closer proximity of these grounds to the Leeuwin Current.

The research cruises undertaken in this study indicated that the highest catch rate (abundance) of berried female rock lobsters occurred during November at Two Rocks (1986), Dongara (1987) and the Abrolhos Islands (1988). The 1985 Abrolhos Islands sampling which was undertaken in late November and extended into early December also provided the highest catch rate of berried females in that season. Catch rates in December and January at all locations were also relatively high but on the coast were well below November values (Fig. 2).

Peak monthly sample catch rates of 3.57 and 6.13 berried females per pot lift were recorded at the Abrolhos Islands in 1984/85 and 1987/88. These far

exceeded the 0.24 and 0.13 berried females per pot lift at Two Rocks in 1985/86 and Dongara in 1986/87 respectively (Fig. 2).

3.1.2 SIZE AT MATURITY

The size distributions of breeding female rock lobsters recorded for the coastal sites of Dongara and Two Rocks were very similar (Fig. 3). Although sexually mature females in both regions ranged in size from about 80 to 140 mm CL, those found in the northern region (Dongara) were slightly smaller than those from the more southern locality (Two Rocks). The mean sizes of breeding females at Dongara and Two Rocks were 99 mm and 104 mm respectively. In contrast to this, the breeding female rock lobsters at the Abrolhos Islands, with a size range of 44 to 94 mm and a mean size of 73 mm, were much smaller than their coastal counterparts (Fig. 3). In general terms the larger females in all regions were found to commence spawning before the smaller ones.

The size at 50% maturity (SAM) for the population in each of the three regions was estimated from a logistic curve fitted to the combined monthly samples. SAM values of 66 mm, 93 mm and 97 mm were estimated for the Abrolhos Islands, Dongara and Two Rocks populations respectively.

An important and distinctive feature of the sexually-mature female rock lobsters at the Abrolhos Islands is that many of them (76%) were below the legal minimum size for capture of 76 mm CL. The smaller size at maturity of Abrolhos Islands rock lobsters has been hypothesized to be a result of density-dependent growth effects due to the much greater abundance of rock lobsters there, coupled with high fishing mortality on the legal-sized animals. This hypothesis, however, requires investigation.

The size ranges and values for mean size and SAM presented here for rock lobsters at the Abrolhos Islands and the coastal areas are consistent with those reported earlier by Chittleborough (1976), and more recently in the series of publications by Morgan and Barker, and Brown and Barker (see e.g. Brown and Barker 1987).

3.1.3 REPETITIVE BREEDING

The data suggest that all sexually mature female western rock lobsters breed each season. In addition repetitive spawning by individual rock lobsters during a single season has been shown to be a widespread feature of the breeding stock of this species. These conclusions were reached following the analysis of the results from the tagging programmes at Dongara, Two Rocks and the Abrolhos Islands; information gathered from research vessel catches of rock lobsters and

commercial catch monitoring operations from Rottnest, Augusta and Kalbarri. The frequency of repetitive spawning was established using criteria similar to those employed by Berry (1971) in a study of *Panulirus homarus*. Using this method, repetitive spawners were identified as females carrying eggs or bearing an eroded spermatophore, while possessing bright-orange ripe ovaries that were easily visible through the thoraco-abdominal musculature. An eroded spermatophore is indicative of a female having fertilized a batch of eggs which have subsequently hatched. The validity of this method was substantiated by observations made on recaptured tagged individuals and histological examination of ovarian development in rock lobsters.

The best estimates of the frequency of repetitive breeding were provided by the November samples at each location (Table 1). These data suggest that approximately 70% of mature female western rock lobsters are capable of spawning repetitively each season. This estimate appears to be relatively consistent between years and locations. The decline in the percentages of females showing evidence of repetitive spawning later in the breeding season suggests that most females were carrying their second brood, and thus showing no evidence of further reproductive activity.

Repetitively-spawning rock lobsters in the wild do not appear to produce more than two broods of eggs each

breeding season. This conclusion is supported by the observation that the egg incubation times (Chittleborough 1976) at the water temperatures measured would have, in most cases, only permitted the hatching of two broods of eggs each spawning season. It is possible, however, that some of the larger females that begin spawning very early in the breeding season may produce a third batch but there was no direct evidence from the tagging experiments that this occurred in the wild. This conclusion is in agreement with Chittleborough's (1976) observations of three mature female rock lobsters held in aquaria at 25°C with abundant food. Of the seventeen continuous breeding cycles Chittleborough observed over a 2 year period, one female produced three broods once. Two broods were produced in fourteen of the cycles.

Repetitive breeding in the western rock lobster appears size related, with the proportion of females spawning twice at each location increasing with the size of mature female (Fig. 4). This feature is consistent with the observation that larger rock lobsters commence to breed in each season before the smaller ones, and therefore have more time to hatch two broods of eggs.

3.1.4 FECUNDITY

A detailed re-examination of the fecundity of this species has shown that there is no significant

difference (P>0.05) in the number of eggs produced in consecutive broods by a single female during a single breeding season. Thus variation in brood size is not a complicating factor in determining the fecundity-carapace length relationship for this species.

Although there is an indication that animals in the southern coastal portion of the breeding stock produce fewer eggs than their northern counterparts (Fig. 5), no significant geographic variation in fecundity with length was found (P>0.05). The fecundity-carapace length relationship is curvilinear, with the following equation relating the number of newly spawned eggs (F) to carapace length (CL):

$$F = 1.92\ CL^{2.69}$$

3.1.5 BREEDING GROUNDS

Recent information provided by Mr Rick Mahoney of the Western Australian Department of Marine and Harbours has shown that Morgan *et al.* (1982) underestimated the sea surface area between the 20 and 30 fathom isobaths. Their estimates of 6690 and 3500 km^2 for the northern and southern regions respectively contrast with the corresponding new computer-generated values of 9500 and 6500 km^2.

Mature *P. cygnus* do not appear to migrate to, or congregate in, specific isolated areas to spawn and hatch their eggs as some other species do; for

example, *P. ornatus* (MacFarlane and Moore 1986). Instead breeding female *P. cygnus* are found in this species preferred limestone/coral reef habitat throughout its range.

A description of the rock lobster breeding grounds has been obtained from information provided by commercial fishermen (Fig. 6). This has shown that in the central coastal regions the breeding grounds of the western rock lobster, as observed by the fishermen, lie between the 20 to 40 fathom isobaths. In this sector, as in most other regions, breeding rock lobsters were not recorded on the flat sandy or silty bottom in the very deep waters (70+ fathoms) near the continental shelf edge. In these areas fishermen recorded only migratory immature white rock lobsters. Although the majority of breeding females in the central coastal regions occur in the deeper water offshore (20-40 fathoms), the shallow waters along the cliffs north of Kalbarri and at the Abrolhos Islands are also prolific breeding grounds. In addition inshore reefs and islands in the Jurien-Cervantes and Cape Naturaliste-Cape Leeuwin regions are areas in which a moderate number of berried females are regularly caught.

4. DISCUSSION

4.1 LOG BOOK CATCH RATES OF BERRIED FEMALES

The average of berried female catch rates from log books for December and January forms the basis for the current index of the abundance of the spawning stock. Since these catch rates are fundamental to the index, a careful evaluation of both the catch rates and the assumptions made in using them is necessary. In this context the pattern of fishing in the first part of the rock lobster season needs to be carefully considered.

The rock lobster fishing season for the coastal fishery commences on November 15 each year with all of the fishing effort being concentrated initially in shallow water (0-10 fathoms). The annual migration of juvenile ("white") lobsters commences in late November and fishermen follow these migratory animals from the shore out as far as the edge of the continental shelf. Incidental catches of "resident red" rock lobsters are taken at the same time. Thus fishing in the deeper water (20-40 fathoms), where a large proportion of the coastal spawning stock is located, does not occur until about mid to late December through to early January, when the fishing fleet passes through this depth zone. Depending on their catches, the fishermen generally return to the shallow waters from the edge of the shelf during mid to late January.

This study has shown that peak catch rates of berried females occur in the November to December period; however, there is very limited sampling of the breeding stock (i.e. fishing in 20-40 fathoms) by the commercial fleet until mid-December. Furthermore, the berried female catch rates from the log books are derived from a moderately low sampling intensity, since generally only 25 to 30% of the fleet are involved in the voluntary log book programme, and only short periods are spent fishing in the 20 to 30 fathom depth range.

There are additional problems associated with the use of log book spawner catch rates as the basis for a spawning stock index. For example, some fishermen actually count berried females in their catch while others only estimate their numbers. In addition, variability in the individual catch rates is high which may render the index insensitive to changes in abundance. It may also be possible for the peak breeding period to change from year to year with variations in environmental conditions. Thus, given that the fishing pattern of the fishermen remains relatively constant, variations in log book catch rates for December and January may falsely indicate changing densities of breeding females when abundance is actually stable, or vice versa.

One source of bias in the catch rates leads directly to underestimates of population size. This arises from the non random manner in which fishermen set their pots across the fishing grounds. Fishermen search for and concentrate

on areas with local aggregations of rock lobsters; but it is commonly mentioned by fishermen that they quickly move away from areas yielding large numbers of berried females if catches of animals which may be legally retained are small. (Ovigerous females have to be returned to the water and represent no commercial gain for effort expended). This practice introduces bias into the spawner catch rates and leads to underestimates of spawner abundance.

In addition to the specific problems with breeding stock catch rates a number of general problems in the use of catch rates need to be considered. For example, the present spawning index assumes that catchability (q) remains constant between locations and between spawning seasons. However, Morgan (1974) in his research at the Abrolhos Islands documented variations in catchability due to moult stage, water temperature and salinity. Catchability also seems to vary with moon phase and the presence or absence of swell in an area. Since spatial and temporal differences occur in water conditions across the fishing grounds, it is likely that short term catchability variations will occur between locations. There are also indications that catchability changes with size (R. Brown pers. comm.) a feature that may be important in producing a new SSI in view of the large difference in the size of breeding females between the coast and the Abrolhos Islands. Increases in fishing gear efficiency over time need also to be taken into account. Furthermore, competition between pots placed in close proximity to one another, either by the same fisherman or a number of

different fishermen results in bias in catch rates. Such competition yields reduced catch rates and hence underestimates of rock lobster densities. The levels of competition between units of fishing gear in this fishery are not known but unless they remain relatively constant during and between seasons, the catch rates may not provide a useful index of abundance.

The choice of the statistical method of combining the catch rates also requires careful consideration. For the current index, gross combinations of total spawner catch and total related fishing effort over very large areas have been used. Averages based on catch rates from smaller areas should provide more reliable measures of abundance.

It is important to reiterate here that there are no research log book data for the Abrolhos Islands during the breeding season since the region is closed to fishing at this time. Therefore, direct comparisons between this important region and the coast using log book catch rates of berried females are not possible.

4.2 AVERAGE FECUNDITY

Morgan (1972) reported the fecundity-carapace length relationship for the western rock lobster to be a straight line. In addition both Chittleborough (1976) and Morgan (1980b) considered that repetitive breeding occurred only to a very limited extent in the wild populations of *P. cygnus*. Given these conclusions, the fecundity of an

average sized breeding female was all that was required to transform relative numbers of breeding females (catch rate x area) into numbers of eggs produced in a season. This calculation is used in the current index of abundance of the breeding stock.

Although Morgan's (1972) linear relationship of fecundity to carapace length was appropriate over the range of data he examined, the more extensive sampling undertaken in this study has revealed that a curvilinear relationship exists. Notwithstanding this, individual fecundities for lengths over the same range as that studied by Morgan (1972) are very similar, suggesting that egg production by individuals of a particular size has not altered.

Another important result from this study is the much higher incidence of repetitive spawning in the rock lobster breeding stock than was previously thought and the fact that it is size related. In conclusion, these factors, in addition to the curvilinear fecundity relationship, need to be considered in the future calculation of the number of eggs produced by the breeding stock.

4.3 ABROLHOS ISLANDS CONTRIBUTION TO EGG PRODUCTION

The contribution of the Abrolhos Islands breeding population to total egg production from the whole stock was assessed by Morgan *et al.* (1982) at 14%. However, their sampling was conducted during January and February of 1979 to obtain catch rates that were comparable to those used to

represent the abundance of the coastal breeding stock. January and February were considered to provide the most representative catch rates of spawners on the coast. This conclusion was based on berried female catch rates from the research log book programme and has subsequently been found to be inaccurate. It must be remembered that the log book catch rates at this time apply only to the coastal fishery, since the fishing season at the Abrolhos Islands does not commence until March 15. Furthermore, it has now been shown from research sampling that peak catch rates for berried females occur in November to December over the whole fishery and breeding activity is usually at a low level by late February. Thus, an assessment of the contribution by the Abrolhos Islands breeding stock to total egg production based on January-February survey catch rates is likely to significancly underestimate the true situation.

It is important to note that research vessel catch rates of berried females at the Abrolhos Islands in November and December far exceeded comparable values from coastal regions. Furthermore, Abrolhos Islands breeding females are much smaller than their coastal counterparts, with a large proportion being undersize and therefore spawning at least once before recruiting to the commercial fishery. This is in marked contrast to the coastal breeding populations where females mature about two years after recruiting to the fishable stock. These features strongly suggest that the contribution of the Abrolhos Islands breeding stock to total egg production is significantly

greater than previously thought and now considered to be of the order of at least 50%. Moreover, their contribution to total egg production is likely to be variable from season to season with changing population size.

4.4 AREA

The previous estimate of the area between the 20 and 30 fathom isobaths used in the current index has been shown to be inaccurate. However the area values used to calculate relative numbers of breeding females from catch rates are constant. Recalculation of the current index using the new area values did not affect the trends shown by the index, but merely altered the magnitude of the differences between years.

The breeding ground maps have shown that there are no distinct areas in which breeding females aggregate. Breeding rock lobsters are generally caught throughout the middle ground of the continental shelf (20-40 fathoms) in the central coastal regions. Morgan *et al.* (1982) reported that an average of 90% of the total catch of spawning females were caught in the 20-30 fathom depth range during 1966-1980. However, in recent years, the introduction of larger, faster vessels equipped with more sophisticated echo sounders and other electronic devices, has enabled fishermen to explore the deeper waters in more detail. Consequently, this has resulted in greater log book coverage of the deeper waters which in turn has led to a

revised understanding of the location of the breeding grounds.

The breeding ground maps, from fishermen, and the research log book information, have provided a reasonable indication of which areas, or combination of areas, and their associated catch and fishing effort data should be used in any new index of abundance of the spawning stock along the coast. Since the Abrolhos Islands zone is closed to fishing during the breeding season, no breeding female distribution maps are available from the fishermen for this region. However, research cruises to the Abrolhos Islands have indicated that breeding females can be found in all depths.

5. CONCLUDING REMARKS

This study has shown that a number of the assumptions on which the calculation of the existing index of abundance of the breeding stock of the western rock lobster is based are invalid. For example, berried female catch rates from log books are dependent upon the pattern of fishing and thus there are a number of problems associated with catch rates as a measure of average abundance. At the present time only catch rates from 20-30 fathoms are used whereas a more representative index may use data from a wider depth range. Certainly this would be the case at the Abrolhos Islands where large densities of spawners are found in virtually all depths of water.

Catchability between locations and from year to year has been assumed constant because there has been little research into this aspect except at the Abrolhos Islands. Little is known about spatial and temporal variations in catchability on the coast and an investigation of changes in this parameter is required. Sensitivity analyses will assist in assessing the effects of catchability variations on any index utilising catch rates. Morgan's (1974) equation may be used as a first approximation for catchability in coastal regions.

The results of this detailed investigation into repetitive spawning and fecundity in the western rock lobster have shown that the calculation of egg production from various regions of the fishery is not simple and requires a new approach.

This research programme aimed to either improve the current index of abundance of the breeding stock or provide a quantitative base from which a new index (indices) could be derived. This objective has been achieved.

The existing spawning stock index (Fig. 7) combines data from a depth range of only 20 to 30 fathoms. In addition, the average fecundity, in both of the coastal regions, and the Abrolhos Islands' contribution to egg production are treated as constants, together with the area values used in the index. The only variables in the current index are the log book catch rates of berried females for the northern

and southern coastal regions. Thus it is variations in these catch rates between seasons that drive the index.

Given the problems associated with the logbook catch rates of berried females on which the current index is based, the absence of berried female catch rates from the Abrolhos Islands and the knowledge that the Abrolhos Islands breeding population makes a significant and varying contribution to egg production, it is concluded that the current index is inappropriate.

A new biological model is presented to show the components that future indices should contain (Fig. 8). This model provides both a summary of conclusions for the FIRTA funded studies on the breeding stock of the western rock lobster, and at the same time the basis for continuing research in this field.

Although the berried female catch rates will not be totally disregarded, other data sources will provide independent estimates of breeding stock abundance. These sources are the research log book catch rates of all legal-sized rock lobsters, monitoring and commercial catch (ABS) data. Whereas only three regions were considered for the existing index, five regions are now recognised in the new model. Furthermore, depth ranges from which data will be utilised will be widened, based upon the distribution of spawners, and the new relationships for fecundity, double spawning and size at maturity will be input into the new model (Fig. 8).

Since managers are now requesting information on the effects of management options on the fishery on a regional basis, the division of the fishery into five, rather than three units, is justified. In doing so, however, it has become apparent that minimal data are available for the far northern and far southern regions. Because of this, the Revised Spawning Stock Index for the fishery will combine egg production from the Abrolhos Islands and the B Zone and C Zone coastal regions and, initially, use broad estimates for the two remaining coastal zones (Fig. 8).

Continuing research in four areas is required to enhance stock and recruitment analyses which are now under consideration. These are the development of methods to estimate spawner stock size at the Abrolhos Islands (e.g. depletion estimates); the expansion of the far northern and far southern data bases; the estimation of the available rock lobster habitat within the depth ranges to be considered for each region; and an evaluation of annual variation in the catchability of mature females, particularly for the coastal regions. The addition of these data will consolidate the new index (or indices) as a robust measure (or measures) of the abundance of the breeding stock of the western rock lobster.

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Table 1 The percentage of breeding females showing evidence of producing two batches of eggs in a single season. Sampling at the Abrolhos Islands was conducted both in the lagoon region and outside the main reef. In 1984/85 experimental fishing was conducted at monthly intervals except for one cruise during which sampling was conducted in late November and extended into early December. NS - not sampled.

		PERCENTAGE BREEDING TWICE				
LOCATION		OCT	NOV	DEC	JAN	FEB
ABROLHOS (84/85)	INSIDE	76	73		16	13
	OUTSIDE	74	75		16	2
ABROLHOS (87/88)	INSIDE	14	50	42	NS	NS
	OUTSIDE	33	72	57	NS	NS
TWO ROCKS (85/86)		33	77	27	0	0
DONGARA (86/87)		0	60	61	31	0

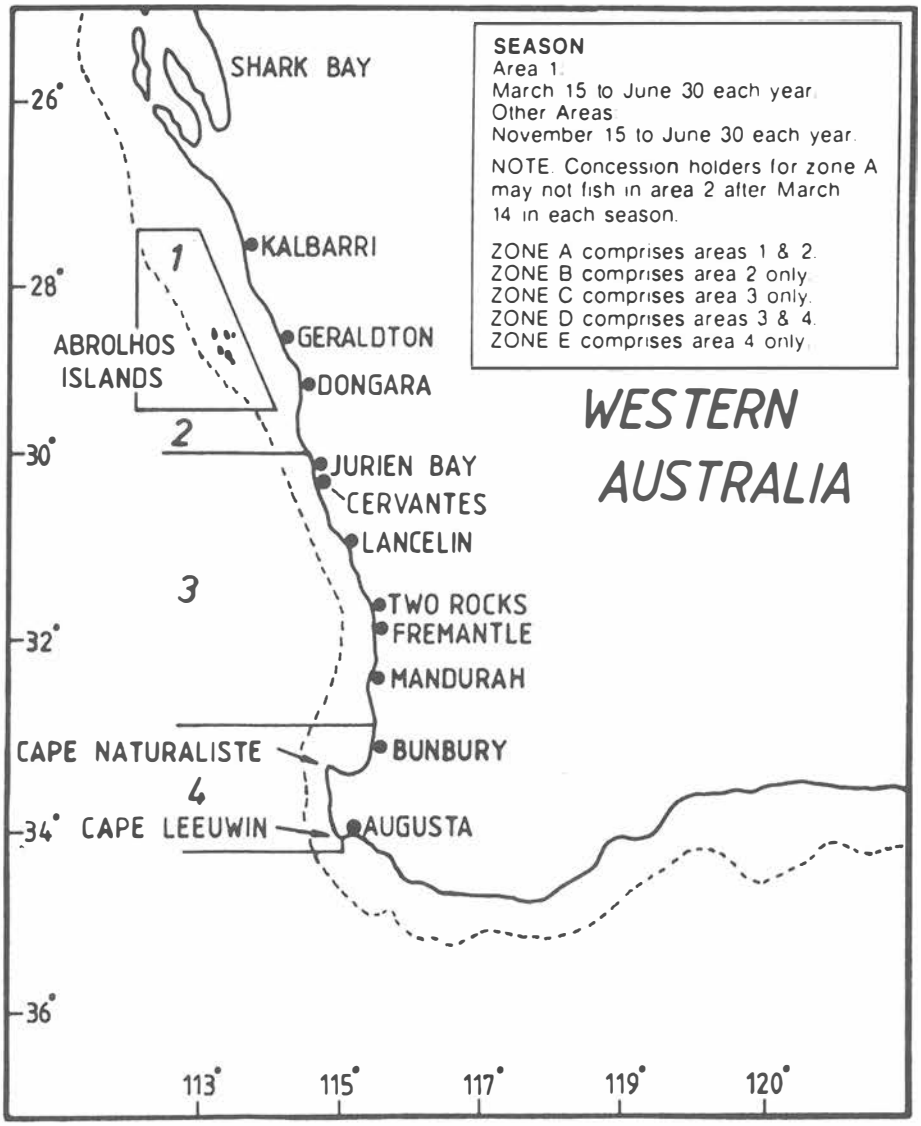

Figure 1. A map of the west coast of Western Australia showing the locations of the places mentioned in the text and the major management zones of the fishery.

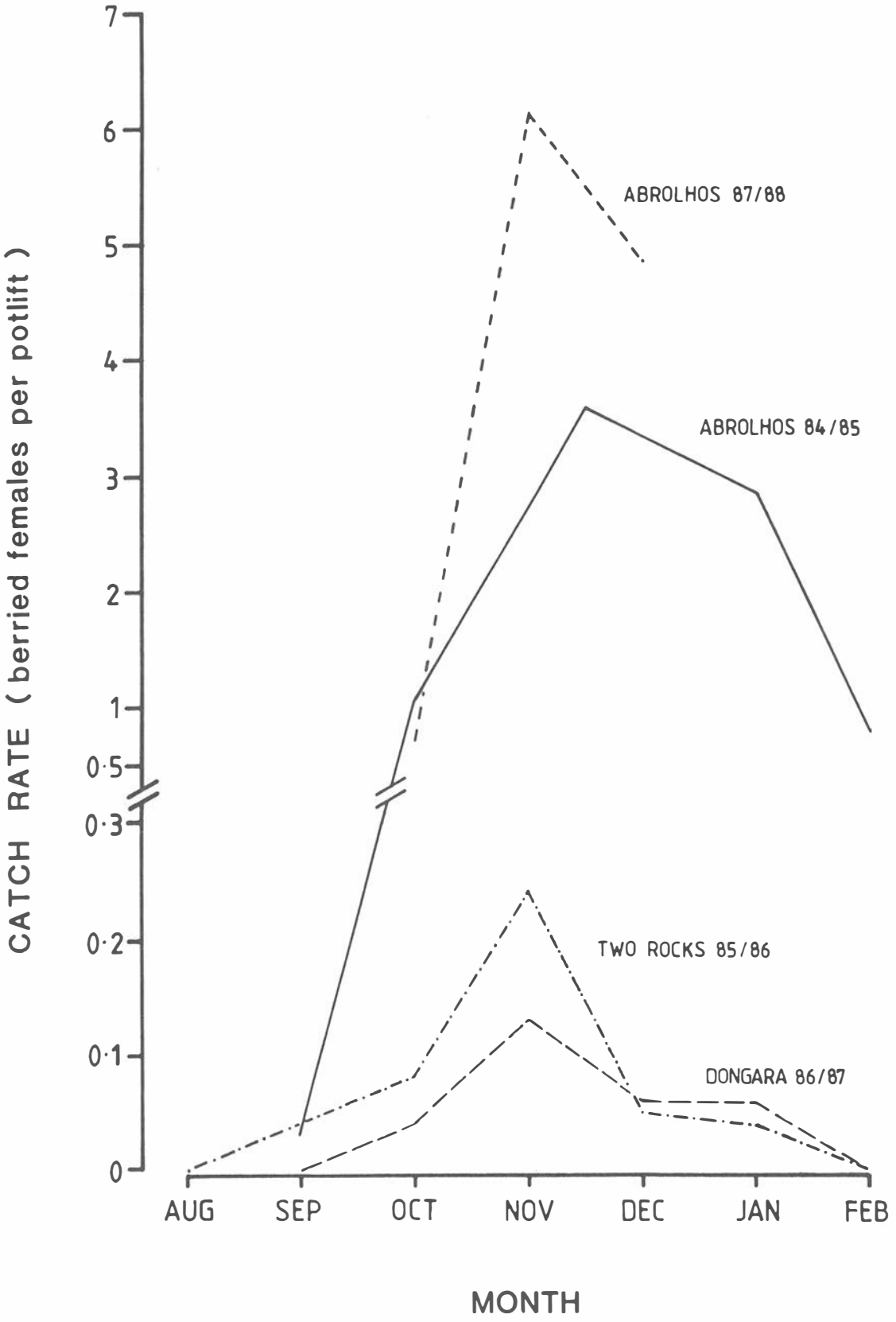

Figure 2. The monthly catch rates of berried female rock lobsters (number per potlift) from research cruise data at the Abrolhos Islands, Dongara and Two Rocks. No sampling was conducted at the Abrolhos Islands in January and February of 1988.

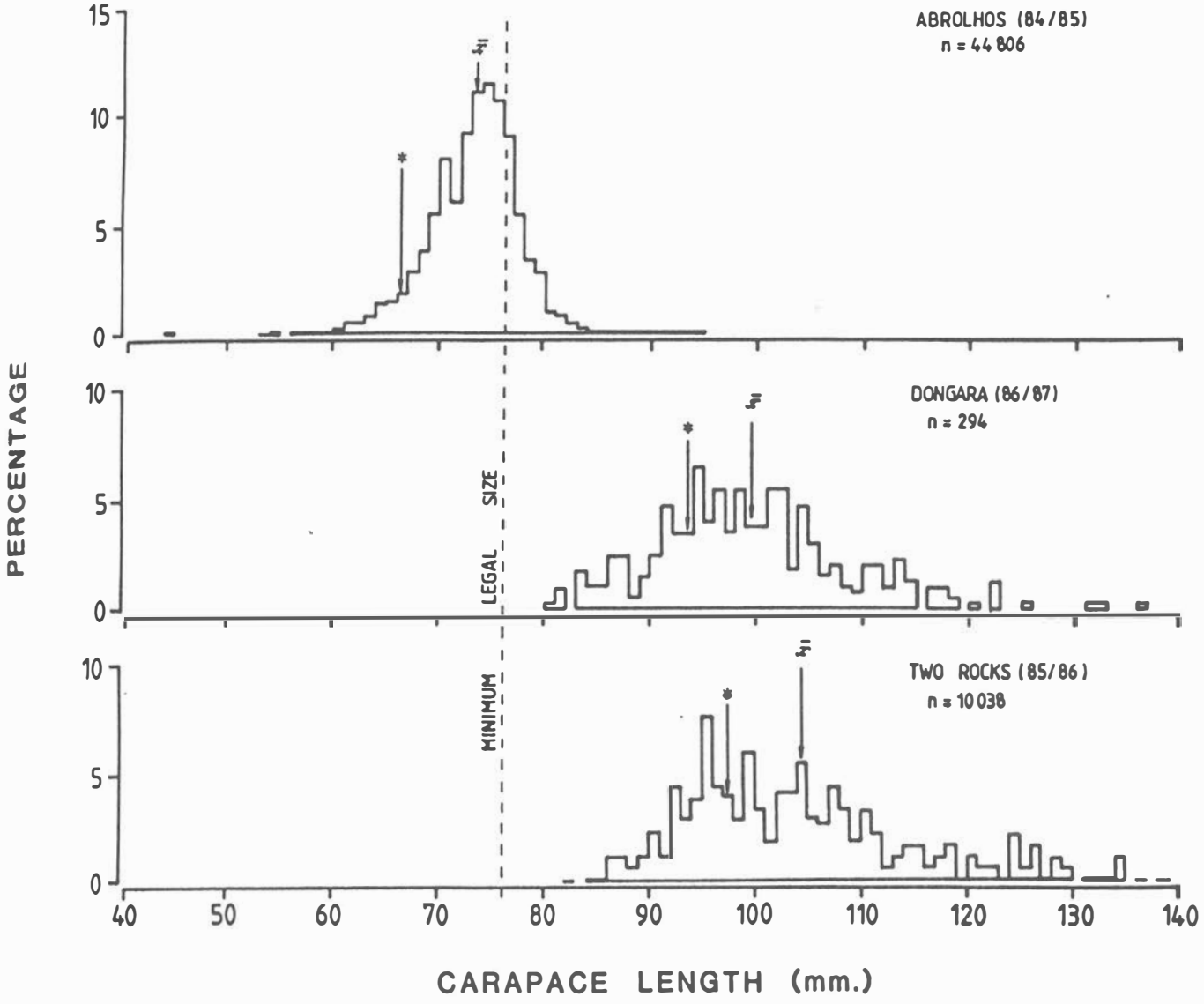

Figure 3. The length-frequency distributions for breeding female rock lobsters at the three research locations. Monthly distributions at each location were weighted by fishing effort and combined. The sizes at 50% maturity(*) and the mean size of breeding females (X̄) are indicated. Sample size (n) and the minimum legal size (76 mm) are also shown.

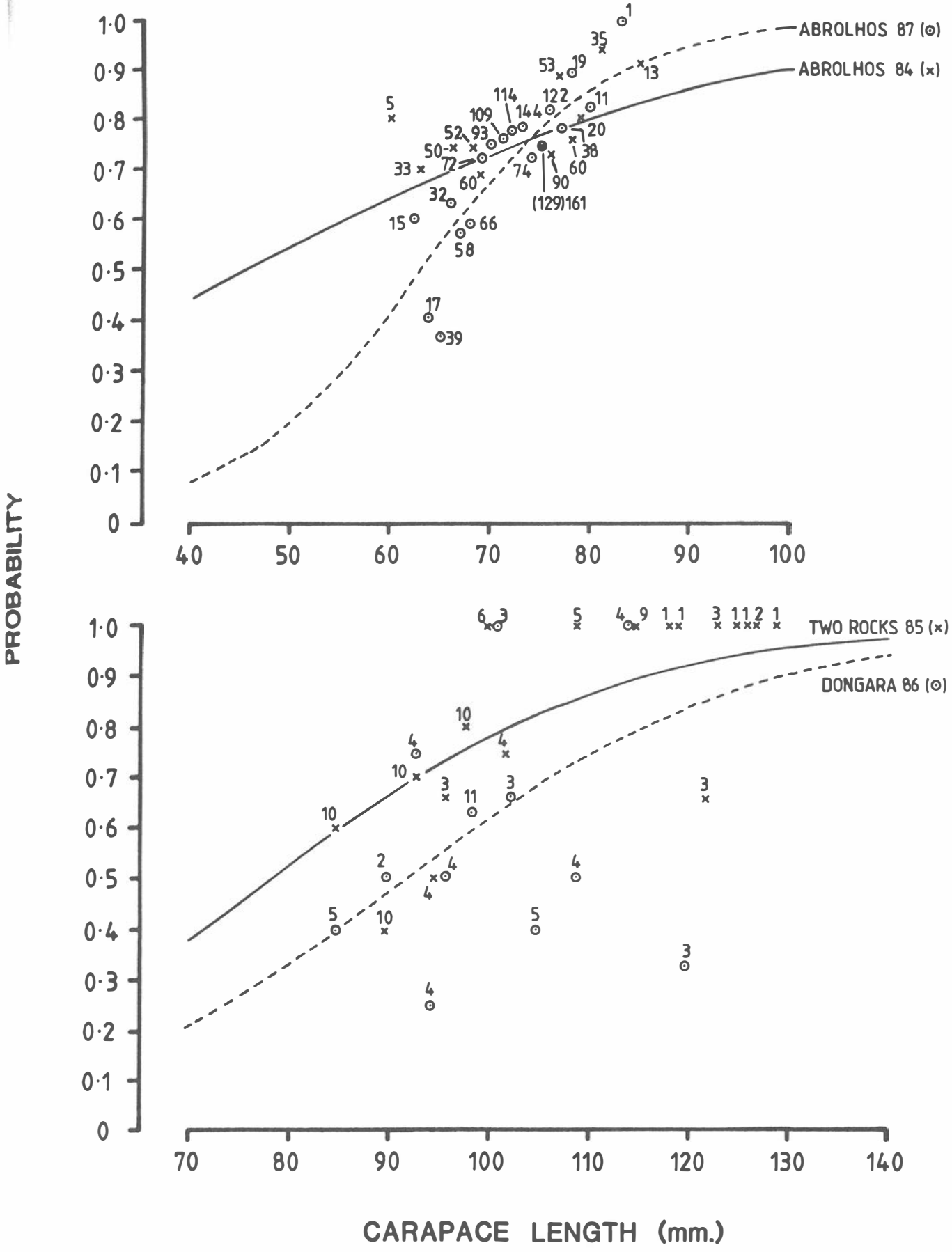

Figure 4. The proportion of breeding females spawning a second time at each carapace length. Logistic curves were fitted to the November research cruise data from the Abrolhos Islands, Two Rocks and Dongara. The raw data points are shown with the sample size above each data point.

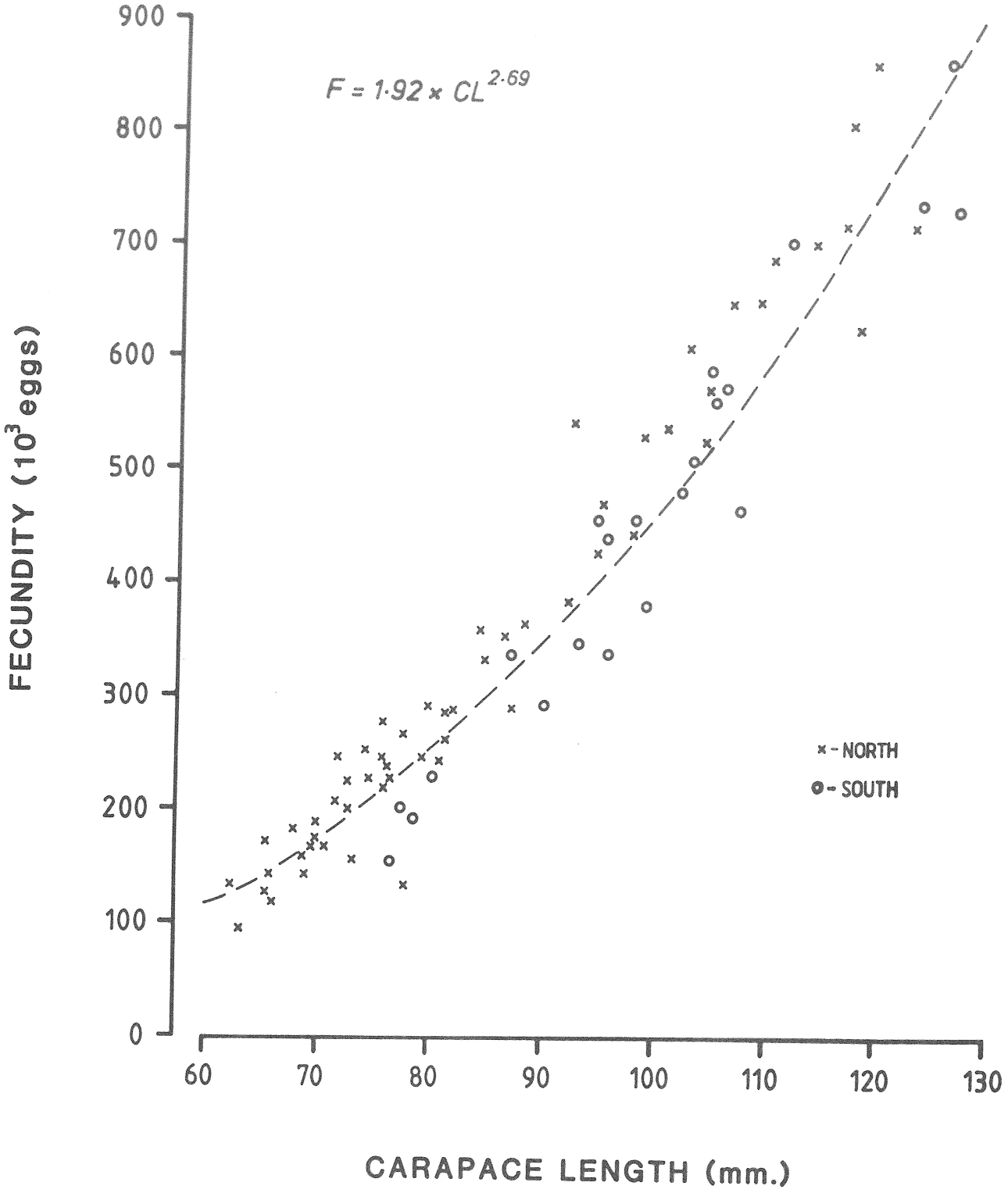

Figure 5. The relationship between fecundity (newly spawned eggs) and carapace length for the western rock lobster. The equation for the fitted curve is given. The northern region is represented by data from the Abrolhos Islands, Kalbarri and Dongara (x) and the southern region by data from Augusta, Two Rocks and Rottnest Island (off Fremantle) (o).

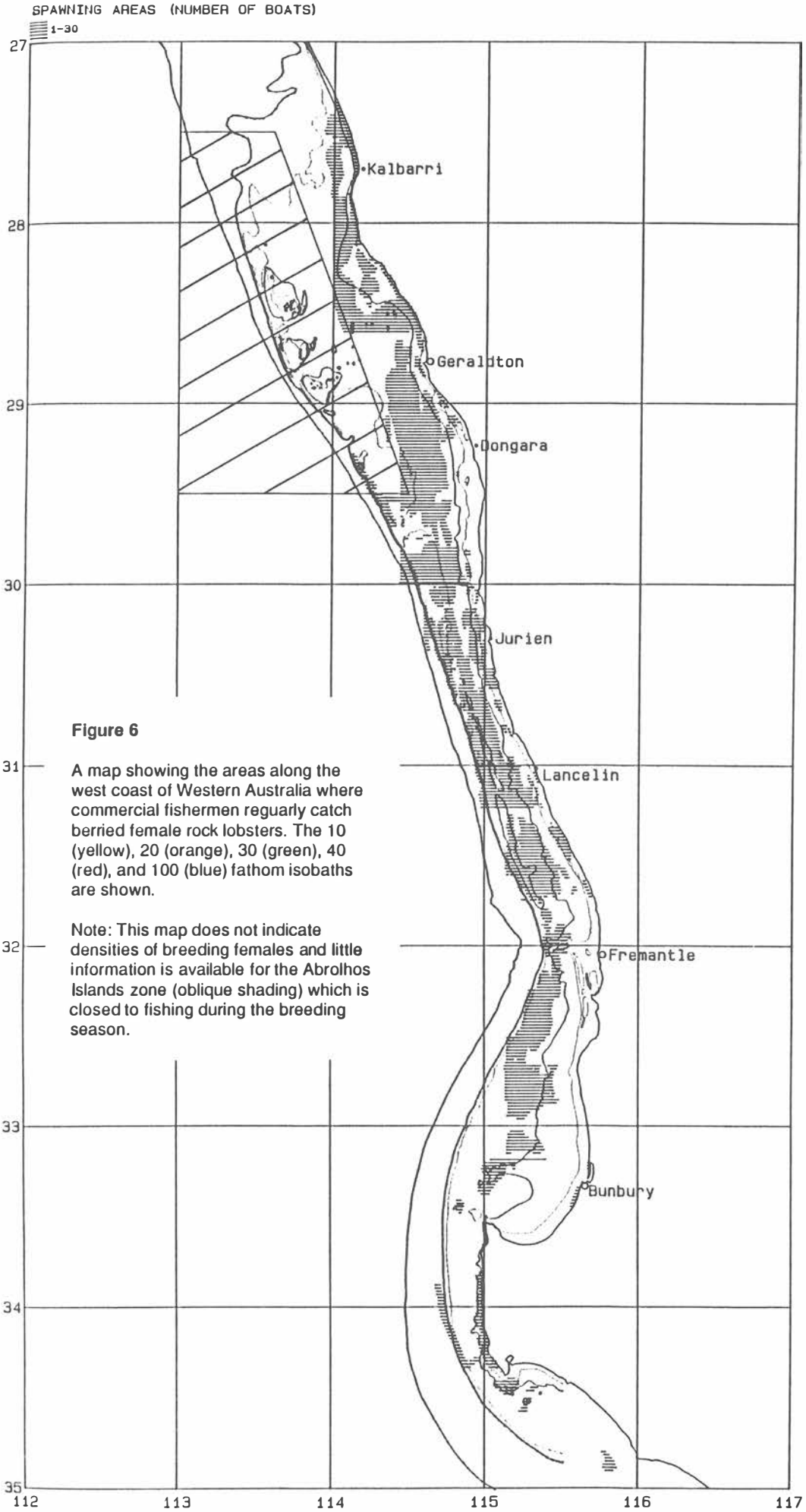

Figure 6

A map showing the areas along the west coast of Western Australia where commercial fishermen reguarly catch berried female rock lobsters. The 10 (yellow), 20 (orange), 30 (green), 40 (red), and 100 (blue) fathom isobaths are shown.

Note: This map does not indicate densities of breeding females and little information is available for the Abrolhos Islands zone (oblique shading) which is closed to fishing during the breeding season.

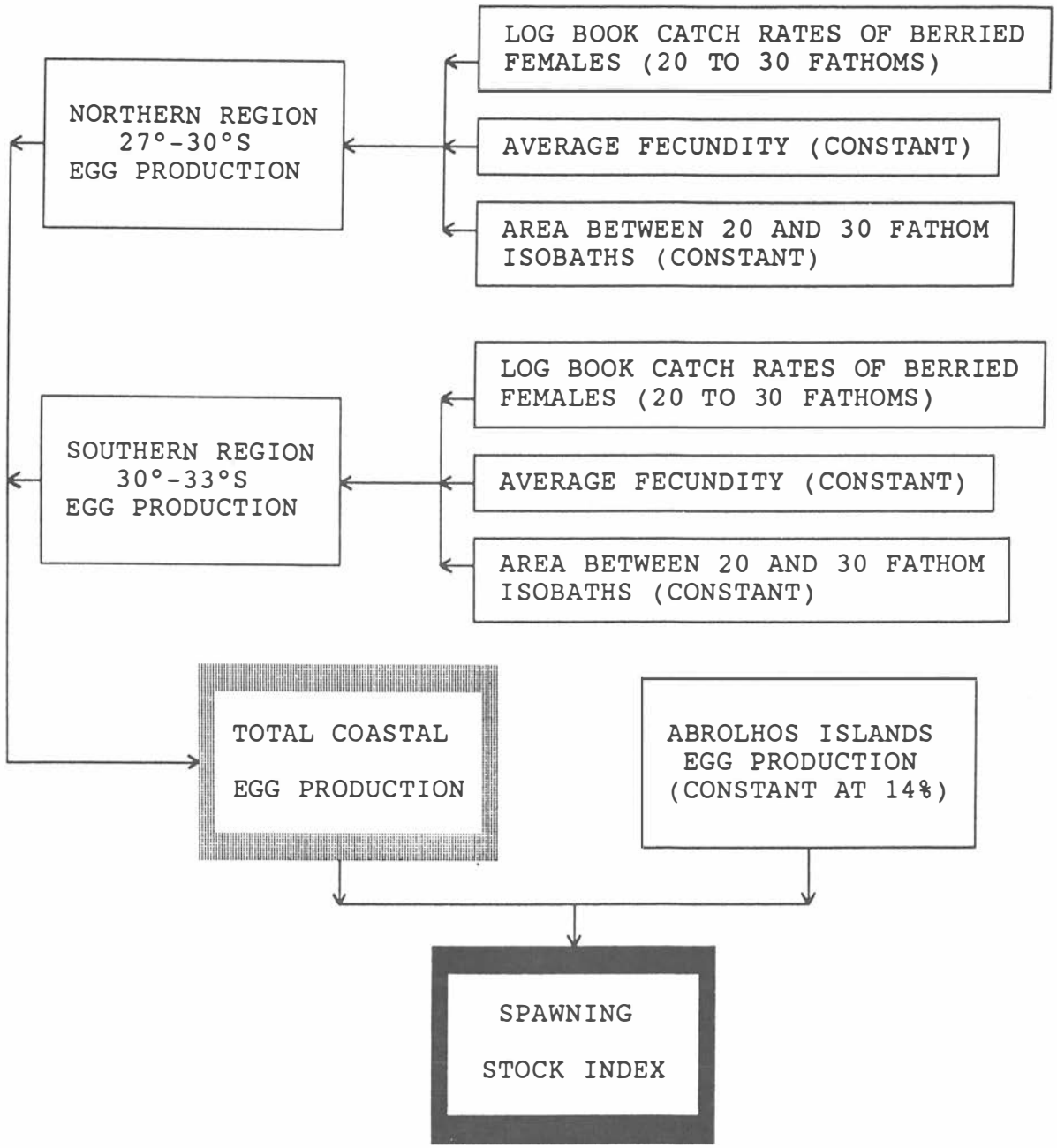

Figure 7. A flow chart describing the index of abundance of the breeding stock of the western rock lobster currently in use.

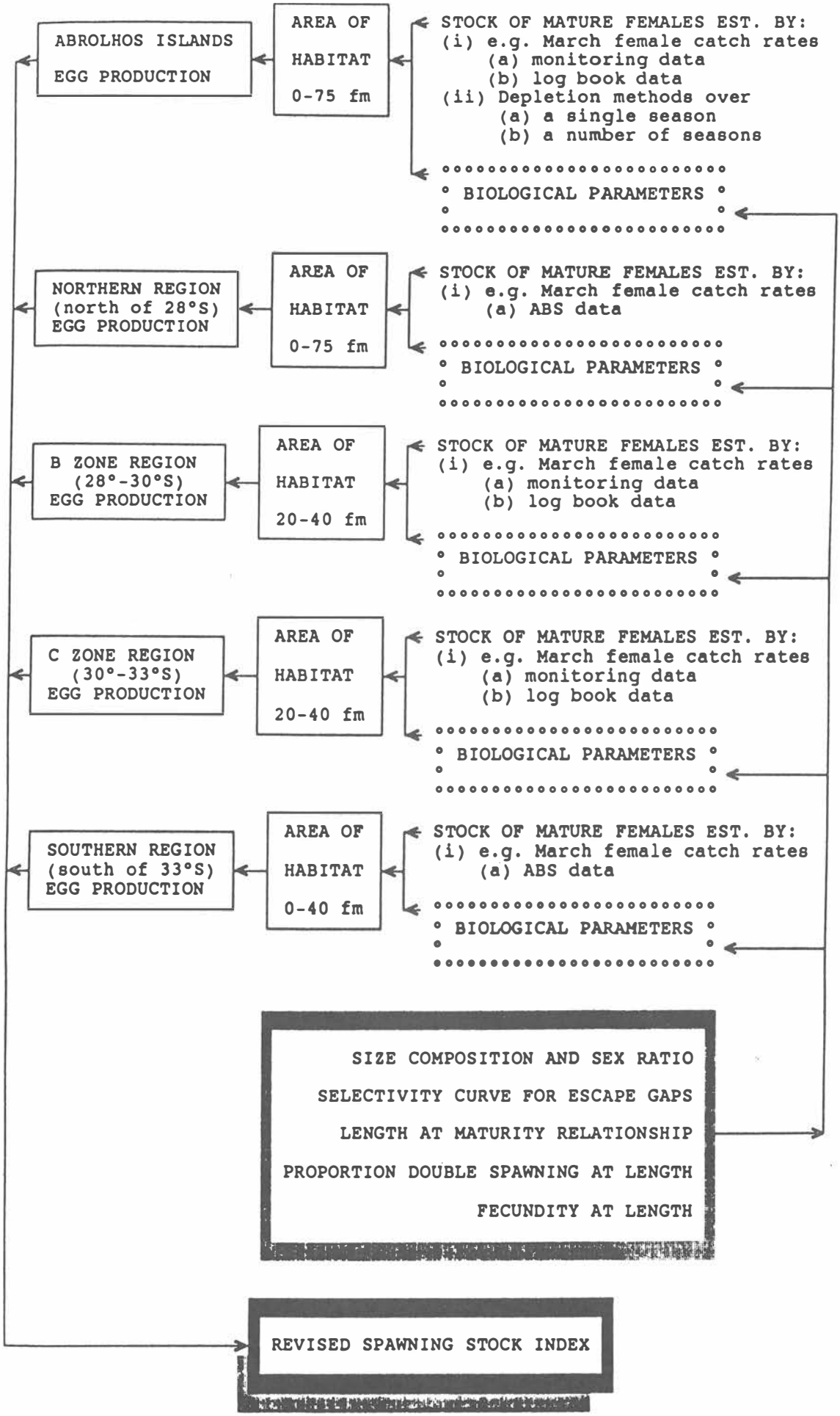

Figure 8. A flow chart indicating the data sources and bases for the development of the future Revised Spawning Stock Index (Indices) for the western rock lobster.