Population Dynamics of the Southern Rock Lobster in South Australian Waters

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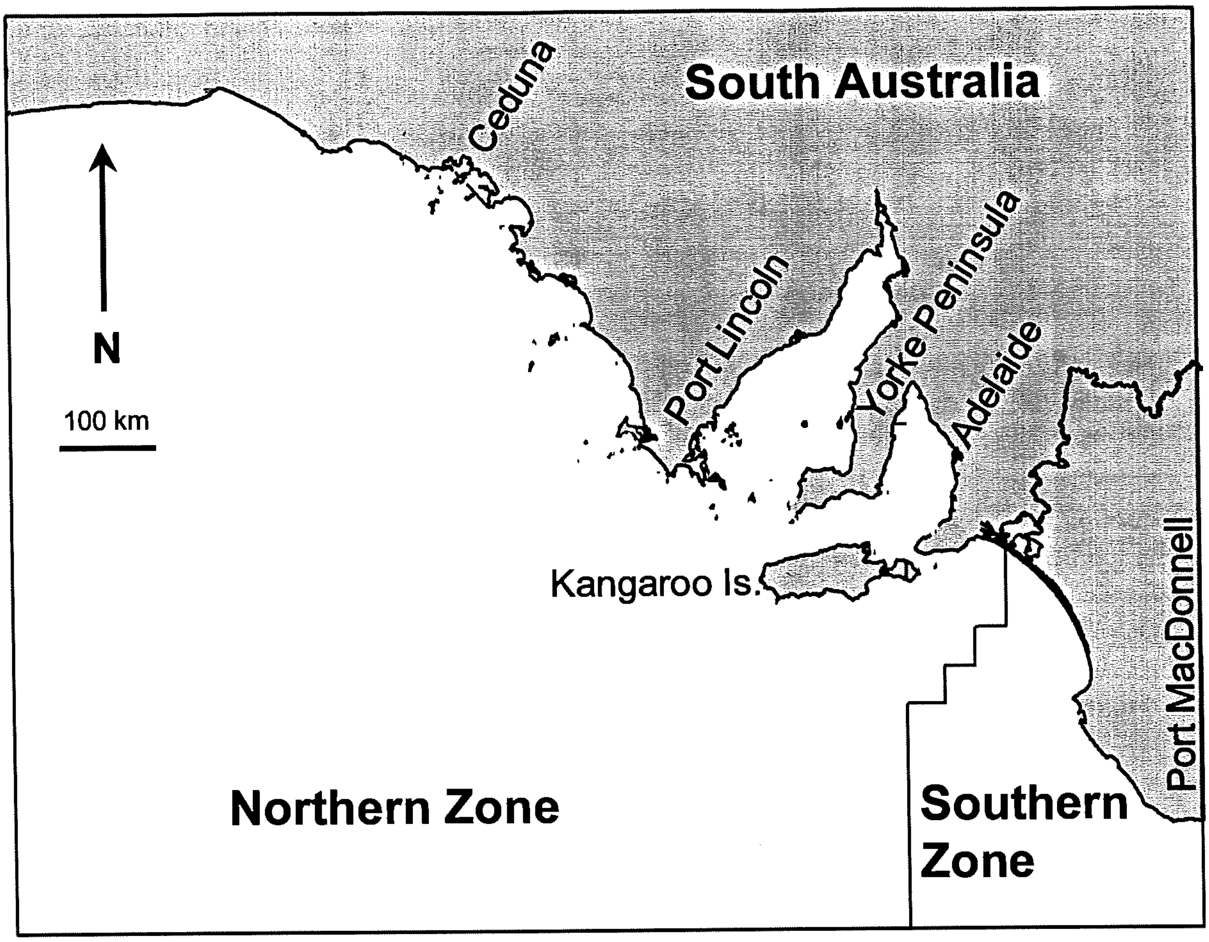
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1. Non Technical Summary

This project was a study of the population dynamics and fishery biology of the southern rock lobster, *Jasus edwardsii*, in South Australian waters. The project had four distinct areas of investigation. These were: (a) biological research to describe key population parameters; (b) development of a comprehensive database of biological and fisheries data; (c) integration of biological and fisheries parameters and data in a computer simulation model of the lobster stock and fishery, and (d) dissemination of the project results and assisting commercial fishers to use the simulation model and other information generated by the project.

Biological and Fishery Research
Before the commencement of the project the South Australian lobster population was known to be geographically highly variable in terms of size composition, the length at which females become sexually mature, and the lengths at which the lobsters become vulnerable to fishing. Thus, the research program was designed to provide information on a fine enough geographical scale to capture this variability. This required a very intensive tagging and sampling program. During the project 61,219 lobsters were tagged and released. From these releases 19,282 recaptures were reported, including multiple captures of many lobsters.

Tag-recapture data were analysed to estimate lobster growth rates in many of the states marine fishing areas (generally one degree square blocks). On a larger geographic scale, growth data from fishing areas with common growth rates were grouped into seven growth zones and re-analysed to estimate the mean growth rate of lobsters in the respective growth zones.

Males' mean annual growth was estimated for carapace lengths of 100 and 140 mm. Annual increments ranged between 10 and 22 for males of 100 mm, and 7 to 13 mm per year for males of 140 mm carapace length. Estimating the females' growth was more complex because females have two distinct growth phases: one during the period of immaturity and another following attainment of sexual maturity. Growth during the two phases was estimated separately. Female growth increments at 100 mm CL, (estimated using data from females of less than 105 mm CL) were between 6 and 15 mm. Data in this size range included both immature and mature females in various proportions depending on the area from which they were taken. Using data from females greater than 105 mm CL, which generally included a high proportion of mature females, the annual growth increments estimated for 120 mm CL were generally between 1 and 2 mm per year. Growth rates of large mature females were so low that it often took several years for them to grow enough that their change in length was detectable.

Variations in growth between geographical areas and between sexes accounted for much of the variability in the size structure of the population and the size at which the females became sexually mature. Lowest growth rates were found in the area of Encounter Bay near the point where the Murray River enters the sea, and in the southern part of the southern zone. The populations in these areas had correspondingly small lobsters. Lobsters inhabiting deep water near the edge of the

continental shelf were also found to grow more slowly than those in shallow water. Highest rates of growth were found to occur on the southern end of the Yorke Peninsula and the State's west coast. These two areas are well known for producing very large lobsters. Growth was intermediate in the remainder of the State's waters.

Spawning females were recorded as small as 75 mm CL during the study period, although reports of smaller spawning females were reported. Some very large (>130 mm CL) immature females were also recorded.

Many fishery science applications use the size at which fifty percent of the females are mature, consequently this value was estimated and used most frequently. The size at which fifty percent of female lobsters were estimated to be mature was between 91 and 116 mm CL in most areas of the state. In most areas fifty percent of the females were not mature until they reached lengths in excess of the legal minimum length. Smallest maturing females were found in the southern part of the southern zone and largest at the southern end of the Yorke Peninsula. The growth rate of females at 100 mm carapace length explained much of the variation in the length at maturity.

Size specific vulnerabilities (the proportion of lobsters of each length likely to be captured with standard fishing gear) were variable. Lobsters were fully vulnerable at the legal minimum length at the southern end of the Southern zone and Encounter Bay. Elsewhere in State waters lobsters may not be fully vulnerable to the fishery until reaching lengths as much as 30 mm greater than the legal minimum length (50 percent vulnerability was not reached until lengths 25 mm greater than the legal minimum length in one area). The length at which the lobsters became vulnerable had significant consequences for yield- and egg-per-recruit. In most areas females become vulnerable to the fishery before reaching maturity, consequently current minimum legal length regulations were important factors in determining egg production in most places.

Lobster movements, measured as straight line distances, and directions were determined from accurate tag release and recapture positions recorded using the global positioning system. Lobsters in most State waters were found to remain close to the site where they were originally captured. There were some exceptions to this; namely lobsters tagged inshore tended to move offshore in most areas, and some lobsters in two specific areas undertook significant long-distance movements. Movements of lobsters from inshore to offshore reefs suggest that inshore reefs may be important nursery grounds, although the full size range of lobsters found inshore indicates that many lobsters do not leave the area. The most extreme depth change recorded during the study was one movement in the southeast of the State from 19 to 140 fathoms (35 to 256m). Lobsters inhabiting reefs near Corny Point (mostly in the sanctuary at Gleesons landing) on the York Peninsula and the coastal reefs in the central part of the Coorong were recaptured as far as 114 km from their point of release. Interestingly, many of these lobsters apparently crossed suitable habitat on their way to the point of recapture and most must have crossed significant distances of open sand bottom habitat.

Immature females were found to move the most. Large lobsters were the least likely to move from their original point of capture.

This project yielded a new method of lobster stock assessment based on information routinely available from the fleet. Landings in kilograms and counts of lobster landed allows estimation of exploitation rate and absolute population numbers by age for a steady state population. The method is referred to as the "qR method" because it was developed to estimate two parameters for this model, q via U, and recruit numbers. The method was further developed to estimate a time series of recruitment and exploitation rates, in a dynamical formulation. The dynamic version was developed to provide parameters for a large spatial model of the South Australian lobster fishery.

Database Development

Research data were stored in various databases, on various computer platforms prior to this project. This situation was due primarily to the rapid growth of computer technology and limited funds for developing a single central database. Non-centralised databases made data difficult to access because knowledge of several databases and operating systems was required.

Developing a central database was one of the fundamental elements of the project, and achieved through the funding provided for the project. Nearly all lobster fishery data are now stored in a single central database with 80 tables, developed in ORACLE™. All data will be included in the future. The database is accessible to a small number of named users through a state government computer network. Greater access, directly to the database, is limited by the cost of licensing users and the need to maintain security. However, extracts and summaries of data from the database that do not reveal data held in confidence will be made available to managers, fishers, and the wider community via the internet.

Computer Modelling

A computer model was developed to model the lobster population and fishery dynamics and present the results in a simple graphical interface. The model is a deterministic, length-based, geographical representation of the lobster stock and fishery. Principal elements of the model are growth, recruitment, mortality, vulnerability, reproductive biology, seasonal catchability, fleet dynamics, and fishing economics (costs and prices). The model runs in fortnightly time steps to simulate the population and fishery dynamics.

Unlike some models used to predict, for example, population sizes and catch rates at some future time under alternative management strategies this simulation model uses what took place in the past as a baseline; then the user changes historical management regimes to make "historical comparisons" between the alternatives. By inference, the user can decide how the changes they made to management in a historical sense and the simulated population response to those changes would apply to the future. The underlying assumption is that the population and fishermen will behave in the future similar to the way they behaved previously. The model is accompanied by a scientific and user guide, and is suitable for use by a wide range of interested user groups.

Extension of Results

During the course of the project three large workshops were convened. The purpose of the workshops was to gather information from fishers, researchers and historical sources, and to develop a model of the fishery which incorporated the information collected. The workshops were extremely transparent research activities where participants were able to contribute as well as learn about the research processes.

Biannual research newsletters were published and circulated to all commercial licence holders. The newsletter performed an important extension link with the fishing industry. Finally, research staff made numerous appearances at port meetings and on fishing vessels to conduct research and explain the program.

The participation of commercial fishers contributed to the success of program in many ways. Fishers adopted and took much of the ownership for the research. Ownership maintained the level of participation and increased the probability that the research results would be accepted and used by the commercial fishery.

The in-kind contribution of the commercial fishery to the research project was substantial and reflected the foregone profit of saleable lobsters returned to the sea. Other in kind contributions included time contributed to tag and report recaptures, and participation in other aspects of the research and modelling workshops.

Glossary of Terms

$g\alpha$ and $g\beta$ are the mean rates of lobster growth at specific lengths α and β. In this document we chose 100 mm CL for α to quantify the mean yearly increase in carapace length around the legal minimum length in the fishery. Thus a $g\alpha$ value of 16 (typical of males) for a given block implies that the male lobsters on average grew 16 mm CL in a year. For females β was chosen as 120 and for males 140 mm CL. The combination of $g\alpha$ and $g\beta$ estimates, once substituted into the GROTAG von Bertalanffy formula allows the calculation of mean annual growth for any desired starting lobster length.

q Catchability coefficient is the average fraction of the population captured by a lobster pot lift.

U Exploitation rate, is fraction of the population, by numbers, harvested in a fishing season.

R Recruitment is the number of lobsters being added to the harvestable population in each year. Larval recruitment is the number of larvae (peuruli) added to the population.

L_v or Vulnerability is the relative likelihood of being caught. The value ranges from 0 (can't be caught) to 1 (maximum likelihood of being caught). Lobsters generally become more vulnerable as the grow but may become less vulnerable when they are very large. L_{v50} is the length at which the animals are 50% vulnerable.

Ovigerous setae are the hair-like structures to which the eggs attach.

Pleopods are the appendages under the lobsters tail, frequently referred to as swimmers or paddles. There are five pairs. Females pleopods are divided into two parts. The inner part carries the eggs and is rod like in appearance; the outer part is used to maintain water circulation around the eggs. The outer part of females resembles the males' pleopod but it is larger on mature females.

L_m This symbol is used to represent the length at which 50 percent of the females are mature.

Spatial refers to geographic area. Example: The spatial distribution of lobsters means where the lobsters are found geographically, and in particular, in which MFA statistical reporting block.

Temporal refers to time. Example: Temporal distribution of effort means the distribution of fishing effort through time on a scale defined in the text.

Model is the term used to describe a mathematical description of how the lobster population changes with time. In general, a mathematical model can describe the observed relationship between any two quantities that can be measured.

F Fishing mortality is the instantaneous rate at which lobsters are removed from the population by fishing (see also Z).

M Natural mortality is the instantaneous rate at which lobsters are removed as a result of natural deaths. The value of *M* usually applies to the fished stock. Small juveniles would experience much higher rates of natural mortality than larger lobsters (see also Z).

Z Total mortality is the sum of *F*+*M*. Example: a population of 1000 individuals will be reduced according to the formula $N_{t+n}=N_t*e^{Z*t}$ where t+n = the time over which the mortality is occurring. So, to calculate the population size after one year at a mortality value of .5 the formula is $N_{t+1}=1000*e^{Z*1}= 607$ survived one year.

Deterministic refers to models which have a single answer because there is no error term associated with any of the parameters of the model. In other words the parameters are considered to be single values without any variation. However, in the real world this is rarely the case. See **Stochastic**.

Stochastic refers to processes or models where more than one outcome is possible because the model parameters or variables in the process are not fixed single values. To illustrate this: $CPUE = q*B$ is a deterministic model while CPUE=q*B+(error term) is the stochastic equivalent. CPUE is returned by the latter as a distribution of all possible CPUEs that vary according to the magnitude of the error term and its particular statistical distribution.

Dynamic(al) refers to processes that consider variation in the variables, such as population abundance, over time.

Steady State refers generally to populations that are neither growing or shrinking because inputs to them (***R***) and removals from them (***F+M***) are constant. This is rarely if ever the actual case, but may approximate the true situation enough for practical purposes of analysis.

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Figure 32. Fitted length-weight curves and raw data for all females (a.) and males (b.). Data included all categories of colour, damage, and sample locations.

Figure 33. Fitted curves of maturity from data collected early and late during the 1992/93 season. In the northern zone marine fishing areas (28, 29, 48/49) early season was defined as November and December, and late season was March through May. Early season in the southern zone marine fishing areas (55, 56, 58) was October through December and late season March and April. Sample sizes are indicated.

Figure 34. Fitted curves of female maturity are presented for nine important marine fishing areas. Curves were fitted for seasonal data from four or five seasons, and data from all season pooled. Marine fishing areas (MFA) are indicated on each graph.

Figure 35. The proportional deviation of single season estimates of the length at which 50% of females are mature is plotted by marine fishing area for four or five season. Note that there is no temporal trend in the deviations.

Figure 36. Female length at maturity in 1- marine fishing areas is plotted against the annual female growth increment at 100mm in the respective area (a); annual growth increment against the number of lobsters per potlift by commercial fishers in the respective fishing area (b); and female length at maturity against lobsters per potlift. Regresssion equations are shown. Note that fishing area 48 and 49 had growth estimates calculated separately but maturity was estimated from pooled data, consequently there are two data points shown in (a) and (b).

Figure 37. Females' meal length at maturity in the indicated marine fishing areas is shown plotted against the mean summer bottom temperature recorded in the respect fishing areas.

Figure 38. The females' length at maturity is plotted against their length at 50% vulnerability by marine fishing areas. The line of equal lengths is plotted for reference.

Figure 39a. Observed length frequency distributions and fitted sample population curves for southern zone areas. Fitted logistic curves of vulnerability also shown for raw and weighted data sets; raw data shown.

Figure 39b. Observed length frequency distributions and fitted sample population curves for northern zone areas. Fitted logistic curves of vulnerability also shown for raw and weighted data sets; raw data shown.

Figure 40. Male carapace lengths at 50 percent vulnerability are plotted against the females' for important marine fishing areas. A line of equal vulnerability is drawn for reference,

Figure 41a. Yield-per-recruit isopleths for male and female lobsters in Marine Fishing Area 15 under conditions of natural mortality of 0.10 and 0.15, and discard mortality of 0.0 and 0.10 for a combination of minimum lengths and fishing mortality rates. Results are expressed as a percentage of the maximum YPR.

Figure 41b. Yield-per-recruit isopleths for male and female lobsters in Marine Fishing Area 48 under conditions of natural mortality of 0.10 and 0.15, and discard mortality of 0.0 and 0.10 for a combination of minimum lengths and fishing mortality rates. Results are expressed as a percentage of the maximum YPR.

Figure 41c. Yield-per-recruit isopleths for male and female lobsters in Marine Fishing Area 56 under conditions of natural mortality of 0.10 and 0.15, and discard mortality of 0.0 and 0.10 for a combination of minimum lengths and fishing mortality rates. Results are expressed as a percentage of the maximum YPR.

Figure 42a. Yield-per-recruit isopleths for combined sexes in Marine Fishing Area 15 under conditions of natural mortality of 0.0 and 0.10 for a combination of minimum lengths and fishing mortality rates. Female minimum lengths increased in unison with the males' to the length of maximum female YPR and were held constant at the value as the males increased further. The highest value of female minimum length used in each analysis is indicated on the graph. Figures graphed are expressed as a percentage of the maximum YPR.

Figure 42b. Yield-per-recruit isopleths for combined sexes in Marine Fishing Area 48 under conditions of natural mortality of 0.0 and 0.10 for a combination of minimum lengths and fishing mortality rates. Female minimum lengths increased in unison with the males' to the length of maximum female YPR and were held constant at the value as the males increased further. The highest value of female minimum length used in each analysis is indicated on the graph. Figures graphed are expressed as a percentage of the maximum YPR.

Figure 42c. Yield-per-recruit isopleths for combined sexes in Marine Fishing Area 56 under conditions of natural mortality of 0.0 and 0.10 for a combination of minimum lengths and fishing mortality rates. Female minimum lengths increased in unison with the males' to the length of maximum female YPR and were held constant at the value as the males increased further. The highest value of female minimum length used in each analysis is indicated on the graph. Figures graphed are expressed as a percentage of the maximum YPR.

Figure 43a. Egg-per-recruit isopleths for females in Marine Fishing Area 15 under conditions of natural mortality of 0.10 and 0.15 and discard mortality of 0.00 and 0.10. EPR is expressed as a percentage of the maximum, ie. Under zero fishing mortality.

Figure 43b. Egg-per-recruit isopleths for females in Marine Fishing Area 48 under conditions of natural mortality of 0.10 and 0.15 and discard mortality of 0.00 and 0.10. EPR is expressed as a percentage of the maximum, ie. Under zero fishing mortality.

Figure 43c. Egg-per-recruit isopleths for females in Marine Fishing Area 56 under conditions of natural mortality of 0.10 and 0.15 and discard mortality of 0.00 and 0.10. EPR is expressed as a percentage of the maximum, ie. Under zero fishing mortality.

Figure 44. Differences (percentage) between SARL assessment model baseline estimates of catch and CPUE in the southern and northern zones and estimates of these variables following an increase in male size limit from 98.5 to 115 mm in 1975 are plotted. Note the much greater immediate effect in the southern zone and the larger positive effect in that zone over the longer term.

Figure 45. Total mortality (Z) values estimated by the Jones and Van Zalinge method are plotted against the carapace length corresponding to the largest length included in the analysis.

Figure 46. Histograms of exploitation rate (U) from 50 runs of simulated data for the catch weight-numbers and Beverton-Holt mean-length methods. The mean lengths were calculated from four sampling intensities, 1%, 5%, 25% and 100% of (simulated) lobsters captured. The mean for the 'true' simulated U was 0.379. The vertical lines represent 0% deviation from 'true', simulated U.

Figure 47. Relationship between weight and age for lobsters from the Northern and Southern Zones.

Figure 48. Intern-annual variation in average weight and CPUE for lobsters in the Northern Zone.

Figure 49. Intern-annal variation in average weight and CPUE for lobsters in the Southern Zone.

Figure 50. Comparison of the fit of the qr model (dashed line) to catch numbers and the weight of the catch in the Northern Zone.

Figure 51. Comparison of the fit of the qr model (dashed line) to catch numbers and the weight of the catch in the Southern Zone.

Figure 52. Annual variation in recruitment estimated as the frequency of lobsters entering the fishery in the Southern Zone (SZ) and the Northern Zone (NZ).

Figure 53. Annual variation in exploitation rate of lobsters fished in the Southern Zone (SZ) and the Northern Zone (NZ).

Figure 54. Comparison of the fit of the dynamic qr model (dashed line) estimate of biomass to catch per unit effort (CPUE) in the Northern Zone.

Figure 55. Comparison of the fit of the dynamic qr model (dashed line) estimate of biomass to catch per unit effort (CPUE) in the Southern Zone.

Figure 56. Comparison of the fit of the dynamic qr model (dashed line) estimate of exploitation rate to recorded effort in the Northern Zone.

Figure 57. Comparison of the fit of the dynamic qr model (dashed line) estimate of exploitation rate to recorded effort in the Southern Zone.

Figure 58. Relationship of biomass estimated from the dynamic qr model to recorded CPUE in the Southern Zone.

Figure 59. Relationship of exploitation rate estimated from the dynamic qr model to recorded effort in the Southern Zone.

Figure 60. Relationship of biomass estimated from the dynamic qr model to recorded CPUE in the Northern Zone.

Figure 61. Relationship of exploitation rate estimated from the dynamic qr model to recorded effort in the Northern Zone.

2. Research Need

South Australia's rock lobster fishery is the states single most valuable fishery. Despite the value of the fishery to the state, little research was done from the mid 1970s to early 1990s. The absence of current research information severely limited assessments of the lobster stock. A continued lack of good research data could have compromised the successful management of the fishery.

The South Australian commercial lobster fishing industry, and government researchers recognised the need to correct the lack of current research information. Equally as important, industry and researchers understood that the way research information was presented to industry and managers was seriously flawed. A better method of presenting information was required if it was to be effectively used in making management decisions.

Objectives for improved communication of research results to end users were prompted by successful fishery computer simulation models such as ABASIM and SHARKSIM which were developed in South Australia. The visual presentation of SHARKSIM made a perceivable impact on its users who were able to watch the animation of the fisheries' history.

The population dynamics study reported here is an attempt to describe the key biological parameters and sources of their variation so as to develop a realistic spatial model of the South Australian rock lobster fishery and present the results via a user-friendly graphical interface.

Provision of research information on the scale it was required for the model was a formidable task. Gathering the volume of data was beyond the capacity of the research team. Consequently commercial fishers became an integral part of the research program and provided the vast majority of data. In most cases, data provided by fishers was of an acceptably high standard, often being similar in quality to the data collected by the researchers.

3. Objectives:

The following objectives were declared when the project was submitted to FRDC for funding. There were no significant deviations from these. However, some of the objectives listed had much higher priority than others and consequently received greater attention.

1. To obtain data (catch & effort, tagging, catch sampling) and analyse it to gain estimates of growth, mortality, catchability, female length at maturity, length weight and movement.

2. To develop a length structured population dynamics model of the fishery that will allow discrimination at the zone and smaller spatial scale.

3. To use the model to identify the most important biological parameters so as to give them highest research priority.

4. To use the model to estimate the sustainable yields, predict outcomes of alternative management strategies and understand the interactions of the two management zones.

5. To provide an accessible, secure database of stock information, improved data validation, and verification.

6. To provide a graphics interface for the models and data to facilitate understanding by industry and management.

7. To transfer results to industry and other user groups.

8. To involve industry in research and educate them about the results and their consequences.

9. To obtain preliminary habitat and oceanographic information to assist in determining critical habitats and physical processes controlling rock lobster distribution and abundance.

4. Field Research Programmes

Objectives

1. To **obtain data** (catch & effort, tagging, catch sampling) and analyse these data to gain estimates of growth, mortality, catchability, female length at maturity, length weight and movement.
2. To **involve industry in research** and educate them about the results and their consequences.
3. To **obtain preliminary habitat and oceanographic information** to assist in determining critical habitats and physical processes controlling rock lobster distribution and abundance.

4.1 Tag/recapture studies

4.1.1 Introduction

Animals are tagged and released in studies of wild populations to study movement, rates of harvest, and growth. In the present study, the estimation of growth rates and patterns of movement were high priorities. The following section describes the program, presents relative statistics, and discusses the overall tag/recapture program. Specific assessments using tagging data are presented in separate sections.

4.1.2 Methods

Lobsters were marked (tagged) with Hallprint T-anchor tags. The tag dimensions were 55 mm in overall length; a shaft length of 30 mm; and T-bar length of 10 mm. Each tag bore the words "SA FISH" and a unique six digit number. Tags were supplied by the manufacturer in strips of 50 tags and these were inserted, into the lobsters, using a Dennison tag-fast® III tag applicator.

Furthermore, modified hypodermic syringes, which dispensed tags singly, were developed specifically for use by volunteer commercial fishers. A groove was cut into the tip of large-gauge, stainless steel needles. The T-anchor of a single tag could be placed into this groove to allow insertion of the tag into the abdominal musculature of the lobster. These modified syringes were, cheaper to make, required less maintenance and were more reliable to operate than the Dennison tag-fast® III applicator.

All tags were inserted ventrally, between the first and second abdominal sterna, into the anterior oblique muscle to a depth of 10 to 20 mm. Some tags penetrated more deeply and were drawn into the musculature following abdominal flexure. Care was taken to insert the tag away from the intestine. Ventral tagging of lobsters is less common than dorsal tagging but has been successfully used in Tasmania (Kennedy pers. comm. 1993). Accordingly, this method was adopted in the current project.

Limited double tagging was undertaken during the third year of the program to study tag loss. This followed a decision to analyse the tagging data for exploitation rates, which was not one of the original aims of the tagging study. When lobsters were double tagged the two tags were inserted on opposite sides of the midline into the same muscle single tags were inserted.

The tagging program was executed by biologists and volunteer commercial fishers who were given individual training. Volunteer fishers aboard approximately 60 of the 265 lobster fishing vessels in South Australia had previously been involved with catch sampling programs and were already familiar with measuring lobsters and recording the information.

The tagging program was conducted using chartered commercial fishing vessels which operated "at cost" for the program[1], by sending biologists on commercial vessels during the season as observers, and by volunteers tagging lobsters from their vessels during routine fishing operations. Charter vessel time was allocated to provide sufficient data from all important fishing grounds in the state.

On chartered vessels most lobsters captured were tagged and released (a small number were sold in year one to subsidise the cost of charters), while sub-legal size lobsters and spawning females were tagged during routine fishing operations. However, during the second year of the program arrangements were made for 21 volunteer fishers in the southern zone to use three additional pots from which all lobsters were tagged and released. This program was subsidised by allocating each fisher additional quota.

Each lobster tagged and released had the following information recorded:

- Date;
- Licence number of vessel;
- Tagger ID;
- Lobster pot number;
- Position of capture and release (usually recorded to hundredths or thousandths of a minute - approximately 2-20 metres);
- Accuracy of position (usually based on the HDGP value displayed by Global Positioning System receiver, or graphical information from the GPS plotter if present);
- Depth of capture and release;
- Substrate type (subjective evaluation of substrate type);
- Bottom type (subjective evaluation of whether the pot was set on main reef areas or fringing or isolated small areas of habitat);
- Tag number(s);
- Tagging position;
- Biological information:
    - carapace length;
    - sex;
    - female reproductive condition (condition of ovigerous setae, presence of eggs);
    - colour;

[1] A lesser amount of tagging was undertaken by a chartered government fishery patrol vessel during the second season and by one commercial vessel paid closer to commercial rates during the third season.

- shell state (hard or soft equating to intermoult, or pre- or post-moult, respectively);
- missing appendages and nature of loss (old or new);

Recapture information was provided by commercial fishers who were requested to record most of the above information at the time of recapture. Each commercial lobster fishing vessel in the state was provided with a kit which included detailed instructions for recording the required data, a set of vernier callipers, and reply-paid post cards on which to record and submit the data. Some vessels had biologists aboard during the season to conduct training.

Fishers were requested to return tagged lobsters to the sea after recording all relevant information. Though this was not compulsory most of the recaptured lobsters were returned. This was done at considerable cost to some fishers, and represents a significant contribution to the research program. A tag lottery was held each year to provide some incentive to return tagging information, however no tag rewards, as such, were paid to fishers.

4.1.3 Results

During the three years of field studies, 61 219 lobsters were tagged and released. The highest density of tagged lobsters was in the south east of the state whereas the lowest density occurred in the western part of the Northern Zone (Fig. 1). Generally, tag numbers were greatest in those areas where fishing was concentrated, with most tagging conducted in the shallower areas of both zones (90% of all tag-recaptures in <60m and <80m depth in the Northern and Southern Zones, respectively). Tagging of lobsters was spread throughout each of the commercial lobster fishing seasons from 1993/94 to 1995/96 (Fig. 2).

The tagged population of lobsters was not the same as the fishable population. The volunteer tagging program contributed 77% of the total number of tagged lobsters. Sub-legal size and spawning females predominate in the volunteer sample population. Consequently, the length frequency distribution of the total tagged sample is biased towards smaller lobsters, particularly for males. This may be seen by comparing the length frequency distribution of the tagged sample with that from the catch monitoring dataset (Fig. 3).

The total number of recaptures to June 1997 were 19,232, with the greatest number being caught in the southern zone (Fig.4). Many recaptures were multiple captures of individual tagged lobsters (Table 1). The highest frequency of recapture was one lobster recaptured 12 times during the project.

Some data quality differences were found between data collected by biologists and the project participants in other categories. Tagging and recapture data from males and females are presented in Figure 5. Frequency histograms of the change in length at a release length of males and females 90 to 100 mm in marine fishing areas 28, 55, and 56 and 58 combined are shown by two capturer category types: volunteer taggers (VT) and ordinary fishers (OF). Regardless of the capturer type the male moult increments are clear from in areas of high and low growth. Female moult increments were not obvious (see section 6.1), however there is no obvious difference in the lengths recorded by the two capturer types. It appeared from these, and other data sets, that the commercial fishers in the state were recording the length data accurately.

In addition to measurement error, errors were made recording tag numbers, positions of release and recapture, sex and reproductive condition. Though not numerically significant these errors resulted in considerable research time being devoted to error correction. Most errors were reported by a small percentage of commercial fishers. It is apparent that some fishers were not able to reliably determine a lobster's sex (Fig. 6). Overall, only 242, or 1 percent, of recaptured lobsters were reported with a different sex than the sex reported at the time of release.

The percentage of females reported to change from a mature reproductive condition to an immature reproductive condition was 9 percent overall. However, most of these unexpected reproductive condition transitions were restricted to lobsters recaptured by fishers inexperienced in determining female maturity, Table 2. Only 1.1 percent of females released and recaptured by biologists and/or volunteer taggers were found to have changed from a long to short setose condition. Some females may loose ovigerous setae at a post-spawning moult. Because the actual loss of long setae could potentially lead to over estimates of the length at maturity it was important to estimate the reporting error in this variable (see section 6.4).

4.1.4 Discussion

Fewer lobsters were tagged and released than forecast at the inception of the program. This was the result of lower research fishing catch rates than anticipated. As a consequence of this, less is known about the growth and movement of lobsters in deep waters and of lobsters on the west coast. However, this did not critically impact on the results of the project as these areas are not exploited as intensively and do not contribute as significantly to the total fishery production as those areas where much information was gained from the tagging program.

In retrospect, a larger number of tag releases may not have substantially increased the data generated, as many commercial fishers were probably near the point where further cooperation was unlikely. Certainly the marginal value of additional tags would have declined rapidly.

There were size and sex biases towards small and female lobsters, respectively, which were anticipated and unavoidable. Less bias would have been desirable because of its potential impact on estimates of growth, movement and exploitation rates. During the second year of tagging in the southern zone arrangements were made to tag the complete size range of lobsters by funding fishers to use three additional pots through the allocation of research quota. This was partially successful: catch rates in research pots were lower than the average commercial catch rates and the average size of lobsters tagged smaller which made the interpretation of these data for catch monitoring problematical. However, this specific program led to many more legal size lobsters being tagged and released than would have otherwise been the case. No system in the northern zone was adopted to enable fishers there to tag lobsters with extra "research pots".

Eliminating a tag-reward system may have reduced the number of reported recaptures, however it also eliminated the need to run a tag-reward scheme which would have incurred significant costs and required a major commitment in human resources to manage the system. As noted above, the only monetary incentive for reporting recaptures was the tag lottery at the end of each season, and a printed reports about the growth and movement of each recaptured lobster were issued to provide feedback. Printed reports of the growth and movement of lobsters tagged and released by volunteer taggers were also sent to each volunteer.

4.2 Catch Sampling

4.2.1 Introduction

Catch sampling data (records of each lobster in sample pots) were required for the analysis of mortality, length at maturity, sex ratio, size specific vulnerability and recruitment. The analysis of length at maturity, vulnerability and mortality are discussed in sections, 6.4, 6.5, and 6.7, respectively.

Sex ratio information is useful for many per-recruit and mortality analyses. The South Australian Rock Lobster Assessment Model uses the information for estimating population egg production, catch and catch rates. If sex ratio is not constant throughout the season then when the stock is fished has important consequences for sex specific fishing mortality rates and egg production.

Estimates of annual pre- and post-recruit abundance (relative or absolute) provide extremely valuable information for understanding the dynamics of the population, and for forecasting the commercial catch. The latter may be useful for setting catch quotas or planning business activities or marketing strategies.

At-sea catch sampling to address these issues was first undertaken in the South Australian fishery in 1991 and has continued since, with varying degrees of participation.

4.2.2 Methods

Catch sampling data were collected in the following ways:

- biologists on charted vessels;
- biologists aboard commercial vessels during commercial fishing operations;
- commercial fishers undertaking commercial fishing operations;
- commercial fishers using three additional "research pots"

Biologists normally sampled all pots pulled during a day of fishing. Volunteer fishers sub-sampled a variable number of pots. Sample pots were marked such that they were easily distinguishable from others, but there was no uniform method of marking.

Fishers were equipped with a kit including vernier callipers, waterproof data sheets, and instructions. The biological data recorded were nearly identical to data recorded in the tagging program (4.1.2). Lobsters landed dead in the pot were recorded with the same detail as live lobsters except where there was too little left of the dead specimen to determine some or all of its biological characteristics. Spatial data were collected by sub sections of Marine Fishing Areas (MFA) or by latitude and longitude. Data on bycatch in the pot was also collected.

Fishers and fishing vessels were not selected randomly from the fleet. Samples were therefore not necessarily taken randomly in terms of geographic position, depth, or fleet catching efficiency. Sample pots were not of a standard design, but probably represented the mixture of pot designs found in the fishery.

During the 1995-96 fishing season the sampling program was modified from purely ad-hoc sampling to a sample design which limited samples to the same period of each month of the season. Fishers were requested to sample seven days during a ten day period centred on the last quarter of each lunar period during the season. The only additional requirement of this design was a calendar of sampling periods and monthly reminders to the fishers doing the sampling.

Biologists' data were used in two different ways. Chartered fishing vessels used for tagging and catch sampling often produced catch rates lower than commercial vessels involved in commercial fishing operations. It was assumed that this was due primarily to charter vessels having lower fishing power than vessels fishing commercially. Data from charters were not used to estimate size specific catch rates. Biologist data collected during commercial operations were treated in the same way as volunteer fisher data. Sampling data from fishers using additional research pots were assessed for bias by a panel of researchers before being used for length frequency and size specific catch rates.

4.2.3 Results

Catch sampling activity diminished from previous years as a result of the emphasis placed on tagging and the enthusiasm for undertaking tagging studies demonstrated by commercial fishers. Sampling statistics for the 1991-92 to the 1995-96 fishing season, inclusive, are presented in Table 3.

4.2.3.1 Sex ratio

Proportions of legal size female lobsters in selected marine fishing areas for each month and season, and all seasons pooled are presented (Table 4). The seasonal proportion was computed using the monthly female proportion weighted by the monthly catch (numbers) in the respective marine fishing area during the respective season (Table 5).

Raw monthly data include all legal size lobsters, including spawning females, which must be returned to the water. In the northern zone there were relatively few spawning females in the catch because of the 1 November starting date for the fishing season. However, in the southern zone there were many more legal size spawning females in the catch because of the season starting on 1 October. To correct for the number of spawning females not landed, the proportion of non-spawning females in each month (derived from the 1995/96 sampling which cover the October and November periods better than other years) was multiplied by the sample numbers of females above the legal length to calculate the number of non-spawning females in each months' sample. These data were used for a seasonal estimate of the proportion of females in the landed catch (Table 6). The proportion of non-spawning females was also used to estimate the pooled monthly proportion of females in the landed catch for six marine fishing areas. Corrected and uncorrected pooled data are shown in Figure 7.

Through the northern zone season, the ratio of females to males in the catch generally declines (Fig. 7b,d). The southern zone season follows a similar trend when spawning females are not considered (Fig.7a,c). However, there is a very marked reduction in the proportion of females in the southern zone landings during October due to a high number of spawning females at that time. Interestingly, there is also a temporary decline within the season, predominantly during February, in most marine fishing areas studied (Figure 7). This may be associated with a female summer moult at this time (see section 6.1).

Though the contrast in the sex ratio is not as great during the South Australian season as it is in the neighbouring Victorian fishery (R. Treble, pers comm), it varies sufficiently such that its monthly value should be taken into consideration when fishery management alternatives are considered. In particular, the large numbers of spawning females in the catch during October in the southern zone clearly have a strong influence on the sex ratio of the landed catch in that month. Because of the scheme of management in that zone is based on a total allowable commercial catch (TACC), closing October and opening of later month would increase mortality on females and reduce egg production. Though fishing during the period when females are carrying eggs may appear to be poor management at first glance, fishing during October in the southern zone improves egg production in that zone.

4.2.3.2 Length Frequencies

Sex specific length frequency data were collected in all important marine fishing areas and are presented (Fig. 8 a-j). Large differences in the lengths of lobsters captured in different marine fishing areas are obvious. These are the result of variable growth rates, (section 6.1), length specific vulnerabilities (section 6.5) and mortality rates (section 6.7).

Inspection of the frequency histograms reveals some of the population heterogeneity within the spatial scale of the marine fishing areas. For example marine fishing areas 28, 39 and 55 show the repeated bi-modality in male lengths (for females the difference was not so clear). This is probably the result of low and high growth areas being present in the one marine fishing area.

The raw data set can be weighted to estimate the length frequency distributions of lobsters at various spatial scales, for example growth zones and management zones. Weighted data sets have been used for bench marking the length frequencies produced by the SA management model.

4.2.4 Discussion

The success of the program has been the result of the cooperation of the commercial fishers in the industry. Maintaining a cooperative program of data collection remains a high priority. In addition, a limited program of data collection from recreational fishers would contribute to our knowledge of the overall harvested population of lobsters.

Though the program was successful in producing many data, all data collected in this program were fishery-dependent. Changes in fishing power, and the spatial distribution of the fishing effort have not been accounted for. Reliance on a dynamic fleet to produce most of the sampling data remains a concern and future programs should include some fishery-independent sampling.

4.3 Sea Temperatures

4.3.1 Introduction

Sea temperature data may be useful in several ways in the South Australian Lobster fishery. Activity patterns, which may increase or decrease catchability, are often effected by temperature. Similarly, growth and females age at maturity (MacDiarmid 1989, Newman and Pollock 1974, Pollock 1995) (see section 6.4) may be a function of water temperature, or subject to variation as a result of inter-annual variations in water temperature (see section 6.1).

Sea water temperatures are also useful for understanding environmental events which may also play a part in the population dynamics of any population. In South Australia upwelling during the summer months (Lewis 1981), when the southeast winds often dominate, is a significant environmental event.

Regardless of the actual effect of temperature on the fishery, fishers frequently ascribe changes in their individual fishing experience to changes in water temperature. Therefore, to effectively discuss fishery dynamics it is important to be able to assess the impact of this important environmental variable.

4.3.2 Methods

Because of the wide spatial distribution of the fishery and the cost of purchase and maintenance of temperature data loggers, fishers were equipped with simple analogue (alcohol) thermometers. During the 1994-95 and 1995-96 54 and 101 fishers participated in the program. Each fisher was normally issued with two thermometers, one for taking sea-surface water temperature and another for taking sea-bottom temperatures. Sampling was undertaken only during the lobster fishing season, when fishers were active on the water. Sampling was either undertaken as an activity on its own or in conjunction with pot sampling for many fishers.

Sea-bottom thermometers were set inside lobster pots during normal fishing activities. They were fixed inside the pot by attaching an elastic cord protruding from each end of the thermometer to the wire mesh of the pot. The design of the bottom temperature thermometer allowed water to enter an outer 50mm diameter PVC tube through two 4 mm holes drilled in its upper cap. Inside the PVC tube, the thermometer was fixed in a smaller diameter tube with silicon adhesive(the bulb of the thermometer was completely encased in the adhesive). During hauling some water exchange between the PVC tube and the surrounding seawater may have occurred, but this was not considered sufficient to significantly alter the recorded bottom temperature.

Surface thermometers were secured inside a protective 50 mm diameter PVC tube, which also acted to collect surface water to record that temperature.

Each thermometer was calibrated against an accurate mercury thermometer, and issued with a number which was recorded and later used to link the calibration data with the raw temperature records. The alcohol thermometers were found to have an accuracy of +- 1 degree Celsius.

Fishers recorded the latitude and longitude, and depth of water where the temperature record was made. During the 1995-96 season fishers were also requested to record the direction of the current. For analysis, these records were translated from latitude and longitude to a marine fishing area.

4.3.3 Results

Sufficient sampling occurred in the southern zone to establish clear time trends in temperature. Thus the results cover sampling done in marine fishing areas 55, 56, and 58.

Two years of surface and bottom temperature data are shown (Fig. 9, 10). The data are presented averaged across all depths sampled and in three depth categories, 0 to < 30 m, 30 to < 60 m and greater than or equal to 60 m. Sample sizes per day and marine fishing area ranged from 0 to several, and the temperatures presented are the average of the daily values.

Upwellings were evident in both years of the study. The period of lowest water temperatures during the fishing season was January and February. These months also recorded the highest water temperatures.

During the 1995/96 season current direction was also recorded. The relationship between current direction on the continental shelf and water temperature are demonstrated in Figure 11. Radar plots are used to plot the current directions recorded. Note that during periods of upwelling, as temperatures are falling that the currents were predominantly SE. During periods of warming there are much more frequent NW currents, and during periods between upwelling the current direction is mixed between SE and NW.

There appears to be little relationship between catch per unit effort and sea-bottom temperatures (Fig.12). However, catch rates during the season were also being effected by recruitment during the summer moult and depletion from fishing activities. Future studies will concentrate on relating water temperature to catchability, estimated from tagging studies.

4.3.4 Discussion

Temperature data collected during the project recorded significant oceanographic events, particularly in the southeast of the state where there was a more intensive sampling. Surface temperatures were found to be closely related to the bottom temperature during most of the season, although during the summer months the water appears to have been less well mixed, particularly during the 1995/96 season. Consequently, surface temperatures are only a relative indicator of bottom temperatures. Remotely sensed data should provide a generally good indication of relative changes in bottom temperature.

The simple thermometers used appeared to be a cost effective way to record surface and bottom temperatures. Fishers were generally interested in having the information and were very willing to participate in the program. However, in the northern zone where fishers work over a wide area, regular recording of temperatures in any one area or depth was difficult to achieve.

The temperature data are limited by their seasonality. A continuous time series of data would be preferable from the perspective of studying its possible effect on growth rates. A continuous record of temperatures at several sites could be compared with data for the same time period to determine what number of permanent data logger sites may be required to capture the spatial variation in temperature. Because temperature data are of interest to a wide range of marine scientists, a cooperative program to record and disseminate the data would be justified.

5. Database development

Objective

To provide an accessible, secure database of stock information, improved data validation, and verification

5.1 Historical development

The South Australia lobster catch and effort data were stored in the GARFIS database system at the state computing facility. This database was professionally maintained, however it was outdated in 1993. Furthermore, it only stored the catch and effort data and there was no provision for storing other lobster fishery data.

There was a clear need for researchers, in the first instance, and fishers to have greater access to all information. ORACLE was chosen as the database engine and development environment. The research program did not have a database server until 1994, consequently development of the South Australian Rock Lobster (SARL) database was originally done on personal computers using ORACLE 6. Data were entered on computers in Port Lincoln, Mount Gambier, and Adelaide. Data files were sent on disk to Adelaide where they were appended to the master database administered by the "information coordinator". Updated copies of the database were then sent back to the regional offices. This situation was extremely undesirable.

To the immense benefit of the lobster project a collaboration between the University of Adelaide and SARDI took place to develop software for spatial analysis of environmental/biological data which was to then be used with the lobster data for a case study. This collaboration provided the university with the case study it needed and the lobster project with access to hardware and software. The university staff member also contributed significantly by assisting with database and other application development.

The original database was migrated to the ORACLE Enterprise Server environment. At this time, the Primary Industries wide area network was established which provided access to the database to the regional offices, albeit via a "dial-up" facility in Port Lincoln until late 1996.

5.2 Database Description

The database structure and user manual is attached as Appendix 2. Currently there are 80 tables in the database.

5.3 Database Discussion

One of the database objectives was to collect historical information on the fishery. The most significant accomplishment in this regard is the inclusion of the catch and effort data from 1974 to 1983, which were previously unavailable since they had never been computerised. These data are critical to the study of recruitment and will add substantially to the information in the time series of catch and effort data. However, not all lobster data were added to the SARL database at the end of the project. Plans exist to add data from the larval recruitment studies, historical at-sea catch sampling, shore side sampling and economic data sources.

Provision of direct access to the SARL database for the fishing industry was indicated in the schematic drawn in the FRDC proposal. This access has not been provided, for a number of reasons. These include jeopardising the security of the database by linking the database server to outside lines. Of greater immediate consequence is the fact that there has been higher priority given to general database development than to report generation which would be necessary to provide access to the database at agreed levels of spatial, fisher, and temporal resolution.

The commitment made to provide greater access to the data was not ignored and provisions will be made to periodically post data on the SARDI web page which meets industry specified parameters.

6. Stock Assessments

6.1 Growth

Objective

To obtain data (catch & effort, tagging, catch sampling) and analyse it to gain estimates of **growth**, mortality, catchability, female length at maturity, length weight and movement

6.1.1 Spatial variation in growth

6.1.1.1 Introduction

Estimates of growth rates are fundamental to the assessment of fish stocks. These serve as inputs for yield-per-recruit and egg-per-recruit analyses. Growth is also an important parameter in the dynamic estimation of annual exploitation rate and recruitment from catch data and from length-frequency samples.

For animals such as rock lobster which cannot be directly aged, growth is inferred from change in length. Because lobsters undergo discrete incremental changes in size by moulting of the exoskeleton, the assumptions of growth differ from conventional models which assume continuous fish growth. Morgan (1980) comprehensively reviewed growth studies for spiny lobsters, concluding that the most adequate description of mean increase in length, as a function of starting length and time, has been provided by the von Bertalanffy (1938) relationship. Phillips et al. (1992) in growth studies of three spiny lobster species, explicitly represented individual variability in growth using the nonlinear random coefficients method of Palmer et al. (1991). A related method, employed in the present study, fits tag data to the von Bertalanffy growth curve using maximum likelihood estimation (Francis 1988).

The aim of this study was to quantify spatial variation in growth and to identify factors which are the main sources of variation in the growth of lobsters.

6.1.1.2 Methods

The large size of the tagging data set permitted estimation of annual growth rates of lobsters in 18 marine fishing areas (Fig. 13).

The von Bertalanffy growth equation was fit to the tag-recapture data using the GROTAG estimator of Francis (1988). This method is based on a reparameterisation of the Fabens (1965) von Bertalanffy equation which expresses change in length (ΔL) as a function of time-at-large (Δt) and starting length (L_1). The growth parameters, K and L_∞, were replaced by g_α and g_β, defined as the mean annual growth rates at arbitrary lengths, α and β. The recapture changes in length over observed times-at-large were fit by maximum likelihood to the transformed ΔL formula (Francis 1988, Eq. 2) by varying g_α and g_β. Furthermore, parameters describing growth variability and seasonality were also estimated. The seasonality function of Pitcher and McDonald (1973) was modified to represent semi-annual peaks in growth to simulate moulting in summer and winter.

Measurement error was set constant at 1 mm, based on the observed dispersion of lengths of lobsters recaptured a short time after release. For short times-at-large, the majority of lobsters did not moult.

The GROTAG method of Francis (1988) assumes a normal likelihood distribution. This implies that the observed growth increments should be normally distributed about the expected mean increment predicted by the von Bertalanffy model. The standard deviation of this spread of observations was assumed to follow an allometric relationship with respect to expected mean annual growth (Francis 1988, Eq. 5). On this basis, the maximum likelihood approach quantifies individual growth variability. From this, confidence bounds were obtained for the estimated parameters.

Three modifications of GROTAG were undertaken. First, South Australian rock lobsters generally moult twice per year, in summer and winter. Seasonal variation in moulting frequency was made explicit by introducing bimodal seasonality to the von Bertalanffy growth function recommended by Morgan (1980). Second, growth data from the individual blocks in each subregion were weighted by the commercial catches. Third, confidence intervals for g_α and g_β were calculated from the likelihood function using the chi-squared method of Venzon and Moolgavkor (1988) employed by Polachek et al. (1993).

In the first stage of analysis, the critical lengths, α and β were chosen by two criteria: that the lengths be relevant for management and stock assessment to obtain annual mean growth estimates, g_α and g_β, in the middle of the size range of the fished population and; that there be adequate recapture data at these lengths. For males and females taken as a whole, α was set to 100 mm carapace length; g_α therefore describes the mean annual growth starting at minimum legal size (98.5 mm in the southern zone, 102 mm in the northern zone). For males, β was 140 mm and, for females taken as a whole, β was 120 mm. These values reflected length frequencies.

Early attempts to fit the von Bertalanffy curve revealed large contrasts in the growth rates of large and small female lobsters. These differences are known to be associated with the declining female growth rates on maturity accompanying the energy demand of reproduction (McKoy and Esterman 1981; Aiken and Waddy 1980; Pollock 1995). By separating the data sets for females into two size ranges, roughly above and below the size of 50% mature (at 105 mm) separate growth curves were estimated for pre- and post-mature females. A similar consideration of female growth was carried out by von Bertalanffy (1938) in his study of laboratory rats, but it remains a rare practice in lobster growth studies (Aldrich and Lawler 1996).

To quantify spatial variation in this study, estimates of the growth of males and females were calculated for 18 marine fishing areas. Neighbouring blocks of similar growth rate were then grouped into six growth subregions. The catch weightings for tag recaptures from each block in the sum of squares residuals in the likelihood function were calculated such that (1), the effective sample size of recaptures from each block was proportional to the commercial catch from that block relative to other blocks in each growth subregion (by numbers) and such that (2), the total weighted sample size was the same as for the raw (unweighted) data set. Combining data into growth subregions increased the sample size for analyses of growth and other assessments such as length-frequency analysis, where sample variability is often high. For areas with sufficient data, samples were also stratified by depth to investigate its effect on the growth rate of lobsters.

Residuals from various fits of the growth curve were studied and normality tests of the residuals were applied to assess goodness of fit. If residuals are uniform and are normally distributed as the GROTAG model assumes, then the continuous description of growth is a suitable approximation.

6.1.1.3 Results

The results are presented in five parts: (1) growth rates by marine fishing area; (2) growth rates by subregion; (3) statistics of model fit; (4) growth variability and; (5) the variation of growth rate for lobsters harvested at different depths.

6.1.1.3.1. Growth Rates by MFA Block

The mean annual rates of growth, g_α and g_β, for male and female lobsters by marine fishing area, are presented in Tables 7 and 8 respectively. Most rapid growth occurred in the far western regions (areas 15 and 27) and in the area of the Yorke (33 and 40) and Fleurieu Peninsulas (44) at the mouths of two hypersaline estuaries. Rapid growth was also evident in the northern parts of the southern zone (51 and 55). The slowest growth occurred near the mouth of the Murray River (46). Lower than average growth rates were also found in the regions which had the highest density and most consistent recruitment of lobsters (as measured by catch rate in numbers) ie. the southern blocks (56 and 58) of the southern zone.

Growth rates for pre- and post-mature females differed markedly. Substantially slower growth was evident for the larger females (Table 9a). In two areas of relatively fast growth (51 and 26), initial results yielded unrealistically large asymptotic size for large females (> 105 mm). Lobsters in these latter blocks are known to mature at larger size (section 6.4). These female data sets were re-subdivided at 110 mm (Table 9b).

The bimodal seasonality function was described by a sinusoidal variation in growth, with peaks at summer and winter, determined by the seasonal phase parameter. Information on the timing of the winter moult was limited since no fishing and thus no tag recoveries occurred from June 1 to October 1. Estimates for the phase parameter revealed no trend in the case of females of carapace length greater than 105 mm. Summer moulting in these tag recaptures was less consistent for mature females. For male and immature female lobsters, the phase indicates higher growth rates during mid-summer from December to the middle of February.

6.1.1.3.2. Growth Rates by Subregion

Eighteen marine fishing areas yielded sufficient sample sizes to assess mean growth in males (Table 7) and females (Table 8). Marine fishing areas with similar growth characteristics were aggregated into 6 subregions of 2 to 6 areas (Tables 10 and 11). These subregions followed the mean annual growth rate trends described for the individual MFA's.

6.1.1.3.3. Growth Rates of Small and Large Females

Growth rates of lobsters below and above the length of 50 percent maturity in the six growth zones were markedly different. Results of the analysis by length category are shown in Table 12.

6.1.1.3.4. Statistics of Model Fit

To test the quality of model fit, two analyses were carried out. The first was visual examination of the residuals. These were the differences between the observed increase in length and that predicted by the GROTAG von Bertalanffy growth model for all the tag-recapture data points in each block or growth subregion. The second was the test of the normality assumption for the variability of individual growth increments.

The plots of residuals for males and females were visually examined with respect to time-at-large, length-at-capture, and expected length difference. Marine fishing area 48 represented a faster growing sub-population in the northern zone. Moulting periodicity was reflected in the seasonal variation in residuals of the von Bertalanffy growth model (VBGF). Apart from this periodicity, no clear patterns were evident in the residuals.

The GROTAG VBGF model assumes that growth variability declines allometrically with expected moult increment. This was supported by the spread of residuals around the length at original capture.

A uniform distribution of residuals about the predicted growth increment indicated that the model successfully described mean growth. High levels of variability were evident. Strong negative growth results were found for females of a greater carapace length at the time of tagging than the derived estimate of L_{∞}. The residuals for the reanalysis of this data set in females below and above 105 mm were uniformly distributed.

Residuals for the southern zone areas appear to have behaved as expected except in two data sets, 55 and 58, where all females were included in the analysis. The satisfactory distributions of the residuals for these female data sets once subdivided into two length ranges (immature 55 and mature 55, and immature 58 and mature 58) add further support to the need to separate females above and below the size of maturity.

6.1.1.3.5. Individual growth variability

Standard deviations, calculated from the GROTAG growth variability equation (Francis 1988, Eq. 5) indicated that males starting at 100 mm vary from about 5 to 7 mm in one year's growth, and males starting at 140 mm vary about 4 to 6 mm above and below predicted mean growth (Table 13a). Similarly, females starting at 100 mm varied from 4 to 6 mm, and females starting at 120 mm varied from 3 to 4 mm above and below predicted mean growth (Table 13b).

6.1.1.3.6. Variation with Depth

The dependence of growth rate on depth was analysed in one block, 55, which had a sufficiently large sample size and a broader range of depths. Lobsters which moved between tag and recapture depths which differed by 20 m or more (< 10%) were excluded from the analysis. The lowest depth stratum, from 0-20 m, yielded substantially lower growth for males and females (Fig. 14). At depths greater than 20m, decreases in growth with depth were apparent. The decline in growth rate was approximately 1 mm yr^{-1} for each 20 m increase in depth.

6.1.1.4 Discussion

Growth rates of lobsters were generally lower in regions where recruitment was high, as identified by catch rate, and thus higher lobster densities overall. In western areas of the northern zone where habitat is highly disaggregated and catches in numbers per pot lift are the lowest, growth rate was fastest. Similarly, in the southern regions of the state, where rocky bottom habitat covers 80% or more, and where puerulus settlement is consistently higher, growth rates were second slowest.

Lobster fisheries, including those in South Australia, have generally recorded long-term catches that exhibit little correlation between parent stock and recruit numbers. Catches of lobsters, by comparison with other exploited marine species, tend to be unusually stable and recruitment overfishing has never been satisfactorily demonstrated. Thus, density dependence has long been suspected at as yet undetermined life history stages in recruitment. Jernakoff et al. (1994) found significantly slower growth for juvenile *Panulirus cygnus* in their first year at the lower density site of two surveyed a result similar to that shown here.

Growth rate of lobsters for the one block investigated, was found to reach a maximum at depths between 20 and 40 m and declined with greater depths. Lobsters harvested in deeper waters described as "speckled", and in deepest exploited waters near the shelf edge, described as "white", have lighter-coloured exoskeletons. The change in colour could be related to food with lower pigment concentrations and possibly also lower nutrient content at these greater depths. This change in diet with depth may also explain slower growth. Since lower levels of harvesting occur in these deeper waters farther from port, there may also be a secondary association with lobster density.

The third and strongest trend is significantly lower growth for mature females. Histograms of moult increment revealed small increases in carapace length and lower moult frequency. Annala and Bycroft (1988), reported both lower moult frequency and smaller growth per moult for mature females of the same species in southwestern New Zealand. McKoy and Esterman (1981) observed similar, substantially lower annual growth for mature females in northeastern New Zealand. Pollock and Roscoe (1977) found a similar strong decline in female moult increment with larger size from tag-recapture measurements of the growth of *Jasus lalandii*. The application of the continuous von Bertalanffy growth model to moulting lobsters appears to have been successful in this tagging study. The uniformity and normality of the residuals was good for times at large above 1 year, which is 1 or 2 moults. High variability in growth increment and the spread of the moult period across three months in summer approximated continuous growth. Furthermore, the absence of recaptures in winter during the closed months from June through September mask potentially strongly discrete growth events during winter such as females moulting before mating in April to June.

6.1.2 Growth analysis: moult dynamics

6.1.2.1 Introduction

In lobsters, growth is facilitated by the periodic shedding (moulting) of the shell. The time between moults and the increase in length at each moult is called the intermoult period and the moult increment respectively. In the previous section, mean annual growth was described in terms of the von Bertalanffy growth equation. The following are described here: (1) the seasonal timing of moulting, (2) the probability of undergoing a moult in each seasonal moult period and, (3) the increment in length for moulting lobsters. Consideration is given to variation with respect to sex, size, fishery zone, and for females, sexual maturity.

6.1.2.2 Methods

6.1.2.2.1 General methods.

Separation of mature and immature females by noting the presence or absence of ovigerous setae revealed no trends in moulting behaviour. The female length at 50 percent maturity (L_m) varied widely across the state (section 6.5). For example, the pooled seasons estimate of L_m for southern zone females ranged from 92 mm CL in MFA 56 to 112 mm CL in MFA 51. Over the whole state, length at maturity (50%) ranged from 89 to 114 mm. For this reason, immature and mature lobsters were separated on the basis of carapace length. Growth increment data were extracted for two size groups for each of male and female lobsters:

- 80-89.9mmCL = small lobsters
- 120-129.9mmCL = large lobsters

6.1.2.2.2 Frequency of moulting.

The frequency distribution of growth increments for male and female lobsters recaptured after 6 month and 1 year periods were examined to describe moulting frequency. Females were subdivided into 3 length classes in the 6 month at large sample. Average moult increments and standard deviations were calculated for male lobsters in the two size groups. Separation of peaks in the growth increment frequency distributions was more difficult for females and average moult increments were not calculated.

6.1.2.2.3 The timing of moulting

The timing of moulting was investigated using 3 methods:

1. Scatter graphs from the tag recaptures:

The timing of moulting was identified by a method similar to that of McKoy and Esterman (1981). Tagging began before the start of the 1993/94 commercial lobster season. Lobsters tagged between the 22nd of August, 1993 (commencement of tagging) and 31st October, 1993 were selected from the available tag-recapture records. Growth increments for male and female lobsters, from the Southern and Northern Zones, were plotted against the month of recapture. Measurement error was ± 1mm.

2. Condition of the carapace was assessed by researchers in the tag recapture program:

Lobsters approaching a moult, and recently-moulted lobsters, have a softer carapace. All lobsters captured at the time of tagging and recapture were inspected for pre- or post-moult state by squeezing the top of the anterior carapace to assess softness.

3. Microscopic examination of pleopods.

Pleopod samples were taken from captured and tagged lobsters during the 1995/96 South Australian lobster season. The moult state was assessed from the pleopod samples using the method of Musgrove (1995).

6.1.2.3. Results

6.1.2.3.1 Frequency of moulting

Male lobsters:

In Tasmania lobsters moult one or two times per year (Kennedy pers. comm.). The pooled length frequency distributions of all growth increments for male lobsters at large for 160 to 200 days showed one major peak. The growth increment of individuals under this peak was around 8 mm CL (Fig. 15 b,d) for both the Northern and Southern Zones.

There were two peaks visible in the frequency distribution of growth increments for male lobsters at large for one year (Fig. 15 a,c). The second (right hand) peak is predominantly made up of males in the 80 – 89.9 mm CL size group. The moult increment was the same for both size ranges studied, supporting the idea that most smaller lobsters moulted twice per year. Furthermore, the 120-129.9 mm CL males were found under the first (left hand) peak, supporting the argument that most of the larger males moulted once per year.

Growth increments at length show that most males had moulted over a one year period at large in both zones (Fig. 16 a,c). Growth increments at length for males over a 6 month period show a proportion of larger individuals (>100mmCL) that had not moulted.

Female lobsters:
Peaks in the frequency distribution of growth increments of females were less obvious than those for males and estimation of average moult increments was not attempted. The pooled length frequency distributions for all growth increments for female lobsters at large for 160 - 200 days showed two major peaks (Fig. 17 b,d). Most small females (<110 mm CL) appear to have moulted whereas most large females (> 120 mm CL) appeared not to have moulted or to have moulted with very small moult increments (< 3.5 mm CL). Females in the intermediate size group (110 – 119.9mmCL) appear under both peaks.

The frequency distribution of females at large for one year also had two broad peaks. Large females (> 120 mm CL) appear under the first (left hand) peak and may have moulted once, or have moulted with a small increment. Small female lobsters (< 120 mm CL) were found under both peaks.

Moult increment at length declined markedly in the large females (>100mmCL) (Fig. 18 a-d).

6.1.2.3.2 Timing of moulting

Moulting of the small size group of southern zone males, tagged before the summer moulting period, was first observed in mid-November 1993 and the majority of recaptures had moulted between this time and the end of summer (Fig. 19a). By early December 1994, increases in carapace length greater than 15 mm provided evidence for lobsters having moulted twice over the full one-year period. All but one or two small males in the recaptured sample moulted over the winter of 1994/95 (Fig. 19b). In the large size group (120-129.9mmCL), a higher proportion of males failed to moult during either the 1993/94 summer or the 1994/95 winter (Fig. 19c,d) than in the small size group (Fig. 19b).

Moulting of small females tagged before summer began in late December (Fig. 20a). By early January most recaptures had undergone a moult. Over the winter of 1994, 18 of 22 females moulted (Fig. 20b). Few of the large females tagged in early summer (Fig. 20c) showed evidence of moulting over the 1993/94 summer, whereas all appeared to have moulted during the 1994 winter. However, the moult increments for sexually mature females may be very small and similar to measurement error of ± 1 mm. The major difference is that larger females undergo very small moult increments and a large proportion appear to moult only once per year (Fig. 20c,d).

Monthly proportions of soft lobsters provided a relative indicator of recent moulting. The absolute percentages of pre- and post-moult lobsters were low, varying from < 1% to 7% of the 1000 or so lobsters tested per month (Fig. 21). The proportions of lobsters with soft carapaces in both male and female lobsters were greatest in the summer months with the male peak in December and the female peak in January (Fig. 21). In 1996 moulting, as indicated by softness, peaked later in summer (February) for both males and females.

The highest percentages of pre-moult male and immature pre-moult female lobsters were found during December-January and during June (Fig. 22). The highest percentages of mature pre-moult females were found in June. However, the proportions of pre-moult male and immature pre-moult females were 6 to 10 percent. The high percentages of mature pre-moult females in May and June (30 and 60% respectively) were based on very small number (about 3) of pre-moult individuals.

6.1.2.3. Discussion

Three qualitative methods of investigating the timing of moulting indicated that moulting may occur over either the summer or winter for both male and female lobsters.

Bias in the distribution of recaptures with time was likely to have affected all three methods for investigating moult timing. Some bias was probably due to changes in fishing effort and to moult cycle-related changes in catchability (McKoy and Esterman 1981, MacDiarmid pers. comm.).

Male lobsters may moult twice per year, once during the summer and once during the winter. Overall, all males at large for a year had moulted by recapture, whereas a proportion had moulted twice. Those that had moulted twice in one year were predominantly smaller males.

Female lobsters appeared to moult at roughly the same time as the males. However, there were marked differences between large and small females with a strong depression in mean annual growth rate after sexual maturity. The small moult increments of large females were close to the measurement error and it was difficult to separate the non-moulting individuals from those that had undergone a small moult increment.

Collection of the tag recapture data was heavily reliant on the commercial fishery which placed some constraints on the size range of animals available for tagging and on the time of year when recaptures could be made. Consequently there are no data from the winter period.

6.2 Movement

Objective

To obtain data (catch & effort, tagging, catch sampling) and analyse it to gain estimates of growth, mortality, catchability, female length at maturity, length weight and **movement.**

6.2.1 Introduction

Knowledge of movement patterns in lobsters helps determine boundaries between fishery management units and the degree of interaction between these units (Annala and Bycroft 1993). The relationship between lobster movement and feeding, reproduction and recruitment is also useful in understanding the dynamics of a fishery (Annala 1981).

Movement of lobsters, *Jasus edwardsii*, in the southern part of South Australia was previously described by Lewis (1975, 1977, 1988). The majority of lobsters in Lewis' study were observed only to undertake short distance movements. Some longer range movements were recorded, frequently from shallow inshore to offshore areas, and it was also suggested that some migrations, as defined by Herrnkind (1977), originated from the Coorong area.

The absence of current research information, and the limited geographical area from which movement data were previously collected, restricted their value in assessments of the fishery, especially as there was the possibility of large scale movements between the fishing zones. Important objectives of this tagging program were therefore to extend our current knowledge of movement to include short, long-term and sequential movements of the fishable population of *Jasus edwardsii*.

6.2.2 Methods

General methods used in the tagging study are described in section 4.1. In this section we make special note of the practice of recording positions at the time of initial capture and each subsequent recapture. Lobsters were always released as close to the point of capture as possible and the position was recorded using the vessel's global positioning system (GPS) to the nearest hundredth of a minute (approximately 18m).

The South Australian lobster fishery is divided into marine fishing areas comprising 1 degree squares used in catch and effort reporting. Only areas with more than 100 recaptures reported were included in the movement analyses. Many areas were then grouped into larger geographically contiguous regions for the purposes of analysis and discussion (Fig. 23). Numbers released and recaptured in each region are shown in Table 14.

The large data set of 16,147 recaptures was carefully edited for errors introduced by incorrect recording, missing information or indecipherable writing. A number of methods to identify possible sources of error or incorrect recording of tag numbers were used, including eliminating lobsters which had changed sex, decreased in carapace length more than the measurement error or were recaptured at a non-valid position, eg. at a position deeper than the continental shelf edge or at a position above the low tide line. After dividing data into regions, this led to the consideration of about 7000 recaptures for the assessment of movement patterns.

To prevent biased estimates of directionality associated with time at liberty (Annala 1981) all our analyses excluded movement data in which the time between release and recapture was less than 30 days (14%).

To minimise bias introduced by an unequal distribution of fishing effort across the study area, data were weighted alternatively by catch and effort (potlifts) and although there was little difference between the results, weighting by catch gave a slightly higher r^2. All statistical analyses were therefore performed on data weighted by the catch in the respective region. Distance as used in the analyses was transformed LDIST=log(Distance+1). Analysis of variance was used to examine the main effects of direction of movement, time at liberty, release depth, sex, maturity and carapace length on distance travelled. Carapace length, sex and maturity of the lobsters used in analyses were those taken at the time of release.

Distances moved used the geodesics between positions of release and recapture and rates of movement were the distances moved divided by the time at liberty. So the values represent minimum distances and rates.

6.2.3 Results

6.2.3.1 Distance and rate of movement

In general, lobsters exhibited a high degree of site fidelity as 73% were recaptured within 1km of the release site and 88% within 5 km, even after up to 3 years at liberty, mean 296 days. The remaining 12% of the population were recorded as moving distances greater than 5 km, 114 km being the longest distance recorded. Numbers of lobsters, by sex and state of maturity, moving distances of 0 to 5, 5 to 20, and greater than 20 km are shown for each release region in Table 15.

The mean displacement over all regions was 2.8 km (SD = 9.0 km) and rates of movement ranged from 0 to 4.5 km/week, mean 0.08 km/week (SD = 0.24 km/week). Mean displacement and rates of movement in each region are shown in Figure 24. The considerable deviation in mean displacement is largely due to a small proportion of lobsters moving longer distances in the Yorke Peninsula and Coorong regions. Lobsters in these regions, regardless of sex or maturity moved greater mean distances at a greater rate than in the other regions. Immature females from the Coorong moved the greatest average distances. The West Coast and Kangaroo Island displayed little displacement from the home range. Both sexes of lobsters in the Southeast displayed slightly higher rates of movement.

Individual lobster movements are shown for the regions in Figures 25, 26 and 27. In the West Coast, Kangaroo Island and Southeast regions, only 7%, 6% and 15% of the tagged lobsters travelled further than 5km respectively. The higher mean displacements from the Coorong and Yorke Peninsula regions can be contributed to 30% and 24% respectively of the overall populations moving more than 5 km. Modal distances travelled were 0.19km (range 0 - 109 km) from the Coorong and 0.12 km (range 0 - 114 km) from Yorke Peninsula. The origin of migration from the Yorke Peninsula region was almost exclusively from within Gleeson's Landing lobster sanctuary (Figure 28) . Only a very small percentage of lobsters released on the outer edges of the reserve were observed to undergo any movement away from the release point.

6.2.3.2 Direction and Depth

There was a significant negative correlation (r = -0.1729, $P < 0.0001$) between depth of release and distance travelled (Figure 29). This was partly due to the greater concentration of tagging inshore, where movement to shallower water was restricted by the shoreline. However, a very strong pattern emerged in which nearly all movement occurred amongst lobsters released inshore whereas nearly all lobsters tagged on offshore reefs remained resident. Of the lobsters that travelled between 5 and 20 km, 77% were from release depths of less than 50m. For lobsters travelling distances greater than 20 km, 80% were originally released in depths of less than 50m. This pattern was evident in all regions.

The majority of movements, of all distance classifications, were in an offshore direction. This implies movement south west for the majority of the coastline (Fig. 30). Lobsters that travelled extended distances from the Coorong and Yorke Peninsula regions, appeared to travel south west over sandy substrate and past typical reef habitat to reach the reefs where they were recaptured.

6.2.3.3 Distance and Sex, Maturity and Length

Immature females moved the greatest distances and egg-bearing females the least. The movement of immature females was significantly greater than that of mature and egg-bearing females in the Kangaroo Island ($P < 0.0134$, $P < 0.0031$), Southeast ($P < 0.0001$, $P<0.0003$) and Yorke Peninsula ($P < 0.0012$, $P < 0.0069$) regions.

In both sexes, lobsters which moved distances greater than 5 km ranged between 100 to 150 mm carapace length (Fig. 31). Lobsters greater than 150 mm CL exhibited little movement. Few very small lobsters were released or recaptured, accordingly the size at which lobsters begin to move long distances was unclear. However distance was not significantly correlated with carapace length.

6.2.3.4 Multiple Recaptures

Nine hundred and thirty one lobsters included in the movement analysis were recaptured multiple times. Of those, only 26 moved distances greater than 5 km during the period between any sequential release and recaptures. Four of these lobsters travelled from the Yorke Peninsula to the Kangaroo Island region. The first was recaptured 97 km from its release position and again a further 17 km away. The second was recaptured at the same location five times during a two month period before being recaptured 80 km away 14 months later. The other two lobsters moved extended distances on one recapture only. The remaining 22 multiple recaptures were released and recaptured in the Southeast region and did not make any substantial movements.

6.2.4 Discussion

Studies that have involved tracking *J. edwardsii*, by electromagnetic tagging and diver observation, have indicated little movement away from the home reef (Ramm 1980, MacDiarmid *et al.* 1991). Lewis (1978) suggested that the foraging range of *J. edwardsii* rarely extends more than 100 m from the home reef when food and shelter are abundant. Our findings of limited movement away from release sites for the majority of the population, even after up to 3 years at liberty, is in agreement with the movements of lobsters along the southern part of the South Australian coast, as reported by Lewis (1975). We found this to be consistent along the entire coast and into deeper water, except for 12% of the population which undertook movements of 5 - 20 km from inshore to offshore reefs, and migrations of greater than 20 km that originated from the coastal reefs in the central part of the Coorong, and from within the boundaries of the lobster sanctuary at Gleeson's Landing.

Migrations have been recorded across the distribution of *J. edwardsii*. Consistent with our findings, recent tagging studies in Victoria (Treble 1996, Dave Hobday, pers. comm.) and Tasmania (Pearn 1994) have revealed small proportions of the populations undertaking long distance movements, generally in an offshore direction. Movements between 5 and 20 km in South Australia were characterised by the same inshore to offshore direction. It should be noted that constraints on east and north-east movements were imposed by the coastline and the limits of suitable lobster habitat in many parts of the states' waters. This undoubtedly contributed to the pre-dominant southwest direction of the migrations observed, in both areas from which long distance movements originated, as well as movements of a short distance elsewhere. However, for lobsters tagged in deeper waters on offshore reefs, where movement is not constrained by the coastline, nearly all lobsters remained resident, and this was evident in all regions.

The large scale migrations of *J. edwardsii* to a single area destination described in New Zealand (Annala and Bycroft 1993, McKoy 1983) were not evident in this study. Within the Yorke Peninsula region migrating lobsters originated from the lobster sanctuary. Lobsters emigrated to the north western end of Kangaroo Island and to many of the scattered reefs and around islands in a southwest arc to the southern end of the Eyre Peninsula. Lobsters within a several kilometre radius of the sanctuary remained at or near their release sites. The extraordinary difference in migration behaviour between the two groups over such a small spatial scale suggests that high lobster density within the sanctuary induced lobsters to move out of this area.

The other region from which many lobsters migrated, the Coorong, has unusual habitat features. Narrow bands of limestone reef run parallel to an expansive sand beach. This reef system is not continuous and only lobsters from the southern segment of the reef were recaptured at any significant distance from their release site. Recaptures of lobsters originating from the southern reefs of the Coorong extended out to continuous limestone reef bottom west of Cape Jaffa, confirming the findings of

Lewis (1975). It is possible that lobsters also moved from the northern reefs, but to areas that were not fished. However this seems doubtful in light of the extensive distribution of fishing effort in the area. Interestingly, the northern reefs, in particular, support a high density of sub-legal lobsters, perhaps the highest in state waters. This result is at odds with the suggestion that density may be the factor behind the migrations from the sanctuary on the Yorke Peninsula.

Factors influencing rock lobster orientation during long distance movements are largely unknown. It has been suggested that, in New Zealand, lobsters travel against prevailing current systems that carry the larvae (Annala 1983, McKoy 1983, Booth 1979). Moore and MacFarlane (1984) also suggested that *Panulirus ornatus* is able to orientate to currents on its breeding migration across the Gulf of Papua. The predominant influence along the South Australian coast is the Flinders Current, which flows north along the coast during summer months, and generally south in winter months. There were no migrations directly into the flow of the Flinders current, in fact the migrations originate in areas which are probably not exposed to the Flinders current to a great extent in either summer or winter. These currents are much stronger in the deeper water where lobsters did not move. Also the direction of travel for migrating lobsters in this study did not have a single area of destination as would be expected from lobsters orientating to a current flow. Long range movements for *J. edwardsii* across its distribution in Australian waters is largely offshore, which in South Australia is generally a south west direction, by nature of the coastline. For other areas, such as Victoria, and the eastern coastline of Tasmania, offshore movements are not necessarily in a south west direction. This suggests that direction of movement is more likely to be associated with lobsters orienting towards deeper water. The long distance movements of *J. edwardsii* in New Zealand also appear to be distinctly seasonal (Annala and Bycroft 1993). At this point, it has not been ascertained whether long distance movements made by some lobsters in South Australia are highly directed short time span (or seasonal) events, or longer term gradual movements. Analyses of the data are complicated by a seasonal fishery, long average times at liberty, and tagging data with the highest numbers of released and recaptured lobsters occurring in the spring of each year. Consistent between lobster movements in New Zealand and South Australia is the fact that the majority of longer movements were made by immature females.

During June and September in South Australia, inshore reef communities are important settlement areas for the puerulus stage. The pueruli grow out of the small crevices they inhabit, allowing the influx of a new settlement. Reef communities just seaward of the settlement area generally contain high densities of juvenile lobsters , while further offshore, smaller numbers of large lobster congregate (Lewis 1978). This is supported in part by the undersize reported in fisher catch records. For example, in the southeast region at depths of less than 50 m, the catch per unit effort of undersize is 1.28, compared to 0.94 for depths greater than 50m. It therefore follows that the juveniles on inshore reefs are important for restocking offshore reefs, evidenced by the offshore movements recorded in this study. This has important implications for developing methods to forecast catch in the fishery and the effect of the spatial distribution of effort on the population dynamics.

6.3 Length-Weight

Objective

Analyse data collected to gain estimates of growth, mortality, catchability, female length at maturity, **length-weight** and movement

6.3.1 Introduction

The length-weight relationship is required for yield-per-recruit analyses, qR estimation of exploitation rate, other practical applications, and to answer frequently asked questions about variability in this relationship of interest to fishers, processors and the public.

6.3.2 Methods

To establish this relationship in South Australia, lobsters were measured and weighed at fish processors as they arrived from the vessels during the 1995-96 season. Lobsters were measured to the nearest 0.1 mm (L)and, weighed to the nearest gram (W) on an electronic balance. Lobsters were removed directly from fishers' bins on acceptance at the processing facility, measured and weighed without further drying or immersion in holding tanks. Consequently, the weight recorded was the weight for which the fishers were paid, which is the value most relevant to assessing the commercial fishery. Sex, shell condition (hard or soft indicating moult state) shell colour (reflecting the depth from which the lobsters were captured), missing appendages, and area of capture were recorded. The total number of lobsters used in this study was 840. Samples were collected at Robe (MFA 55), Port Lincoln (various MFA's), Pondalowie Bay (MFA 40), Carpenters Rocks (MFA 56) and Kingscote (MFA 48&49). A power curve ($W=aL^b$) was fitted to the data using SOLVER (EXCEL™).

The likelihood ratio test (Kimura, 1980) was used to test for differences between fitted length-weight curves by sex, lobsters with and without limb loss, sample location and lobsters of different shell colour.

6.3.3 Results

Significant differences were found between two categories of lobsters: sex and damage category. Males lobsters weighed less than females of the same carapace length. Undamaged lobsters understandably weighed more than those that were missing appendages. There were no significant differences between males with red or speckled shell colours, or between females of different shell colour. No differences were found between males landed in different ports when only undamaged males were compared. It was not feasible to test for differences between females from different ports of landing as the size ranges over which the samples were collected from each port were not homogeneous. Results from likelihood ratio tests are presented in Table 16.

Estimated parameter values for length-weight equations for significantly different groups are presented in Table 17. Predicted length-weight curves and actual data are plotted in Figure 32a and 32b, respectively for males and females. All shell colours, shell state, and damage categories are included.

Regardless of the category of data there was very little variation between predicted and observed weights. In each category length explained more than 95 percent of the variation in weight.

6.4 Female Maturity

Objective

Analyse data collected to gain estimates of growth, mortality, catchability, **female length at maturity**, length-weight and movement

6.4.1 Introduction

Length at maturity is an important biological characteristic of any exploited fish population. The size at which lobsters mature in relation to the LML and exploitation rate will, to a large extent determine the impact the fishery will have on population egg-production. The size at which females become sexually mature is also important in determining the rate of growth of females at different sizes.

Most frequently, maturity studies of lobsters are limited to the study of female maturity. This is because males do not display any external evidence of maturity that is readily identifiable in live specimens. Furthermore, there is evidence that small males are not as reproductively successful as larger males. The results presented here were important inputs into the egg- and yield-per-recruit analyses and the South Australian Rock Lobster Assessment Model.

Some studies of length at maturity were done between 1960 and 1975. The only published study of length at maturity of *J. edwardsii* in South Australia was that of Fielder (1964). That study was based on the examination of secondary sexual characteristics of 855 females from six fishing ports.

6.4.2 Methods

Data used in this analysis were collected over the seasons 1991-92 through 1995-96. Most data were collected by volunteer fishermen in the catch sampling program. Other data were collected by biologists on chartered vessels, and commercial vessels.

The data required were the lobsters' carapace length, sex, condition of the ovigerous setae, presence or absence of eggs, and the date and location where the samples were taken. Females were classified mature if they exhibited any of the following characteristics:

- long ovigerous setae or other associated characters such as, external eggs or;
- evidence of hatched eggs (empty egg cases).

Females were classified as immature if they exhibited either of the following:

- short ovigerous setae (appearing non-setose to the naked eye);
- or 'medium setae' (a few elongated setae at the distal ends of the endopod).

There are several possible ways in which this classification system might lead to either under- or over-estimation of the length at maturity. If mature females lost ovigerous setae, for example during a post-spawning summer moult, and were sampled at that time they would have been classified immature. The other possibility is that immature females might attain long ovigerous setae during a moult prior to the pre-spawning winter moult. To determine how robust this method of classification was to the first possibility, the number of tagged females recorded changing from a long setose or spawning state to a short setose state were counted.

Using catch sampling data from the 1992-93 season, when sample sizes were generally large, the sampling data were analysed to estimate early and late season maturation curves. In the northern zone, marine fishing areas 28 and 48&49, early and late season was defined as November and December, and March through May, respectively. In the southern zone early and late season were October November and December; and late season was February and March (there was no April fishing in that season).

The length at maturity (L_m) is defined as the carapace length at which 50 percent of the females are predicted to be mature. The logistic model:

$$P_m = \frac{1}{1+e^{(-C*(L-Lm))}}$$

was fitted to the proportion of females in 5 millimetre increments which were mature, using SOLVER (EXCEL™) to estimate the parameters L_m and C, where P_m was the proportion mature at length L (defined as the mean length in each 5 mm length interval), C was the shape parameter of the logistic curve.

Data presented were pooled across seasons for a single estimate of L_m in each MFA where enough data were available to estimate this parameter. Catch sampling during the 1994-95 season was not intensive enough to estimate L_m in several marine fishing areas.

6.4.3 Results

Estimated mean sizes at maturity and the range of sizes across which the females matured varied spatially, intra- and inter-annually.

Some females were recaptured with short setae following their release in a long setose condition. Most of the females for which a transition from long to short setae was recorded were recaptured by inexperienced fishers.. Only 1.1 percent of females recaptured by biologists and volunteer taggers were recorded to have undergone the transition. Consequently, the assumption of retention of ovigerous setae appears to be valid.

Data from the 1992-93 season were used to compare early and late season estimates of Lm in marine fishing areas where data allowed these comparisons. In marine fishing areas 48&49, 55, and 56 there was little difference between the maturation curves. However in marine fishing area 28 there was a 15 mm difference in the estimated L_m (Fig. 33). It was assumed that this was an artefact of sampling, and that early or late, or samples taken over the whole fishing season allow 'unbiased' estimates of maturation. The sampling was relatively intensive during the two periods in area 28 (n= 1214 and 1227 in the two periods) indicating the high degree of variation within the population and the need for intensive sampling programs. Although there was little change in the estimated length of 50 percent maturity in the other areas, the shape of the maturation curves was quite variable between early and late sampling periods (Fig. 33).

Estimates of the maturity curve parameters are presented in Table 18. These include estimates from data collected during several fishing seasons and an estimate for a pooled data set in each of the selected fishing areas. Plots of the curves estimated from the pooled data are presented in Figure 34. Although there was considerable variation in the maturation curves between years, there was no evidence to suggest that the population maturation processes were variable. There were no apparent trends in the temporal variation between marine fishing areas as would be expected if the whole population responded to changes in their biotic or abiotic environment. Both negative and positive correlations between marine fishing areas over time (Table 19 and Fig. 35), suggested that interannual variation in L_m was also a sampling artefact, due to the high spatial heterogeneity in the population. Pooled datasets were thought to provide the best estimates of the maturation curves.

Comparisons between marine fishing areas were made using pooled datasets generally comprising five seasons of sampling data except in marine fishing area 55 where data collected over four seasons were used. Tests of significance (Kimura 1982) demonstrated that there were significantly different maturation curves in most of the of the marine fishing areas tested. Pairwise comparisons between maturation curves in all marine fishing areas included in the study are presented in Table 20.

Most of the variation in L_m was explained by the annual growth increment at 100 mm CL (G_α ,see section 6.1) (Fig. 36a). A significant positive correlation (P<0.01) between length at maturity and the annual growth increment of small females was found.

Growth rate also appears to be related to lobster density, as indexed by the number of lobsters per potlift (all sizes and sexes), and accordingly a significant negative correlation (0.01<P<0.05) between growth and population density was observed. These data are plotted in Figure 36b, with the model:

$$g_\alpha = \frac{a}{(1+bCa_n)}$$

describing relationship between female growth at 100 mm (g_α) and the catch per potlift in numbers (Ca_n), fitted to the data. Length at maturity is plotted against catch per potlift in Figure 36c. The relationship between length at maturity and catch rate was clearly a secondary function of the growth rate and population density relationship.

Maturation curves from marine fishing areas which were not significantly different from each other belonged to those areas where catch rates were similar. However, in all comparisons where the difference in catch rates was greater that 0.63 lobsters per potlift there were significant differences ($P<0.015$) between the maturation curves.

Length at maturity is shown plotted versus mean summer bottom temperature in the respective fishing areas in Figure 37. Future studies should use a stepwise multiple regression approach to determining the relationship of length at maturity to a wider range of variables including depth, temperature, and catch rates by depth.

Length at maturity was found to be greater than the respective legal minimum length in most part of the state. Only females in marine fishing areas 56 and 58 mature at mean lengths significantly less than the legal minimum length. Minimum lengths play an important role in conserving egg production in most areas as 50 percent maturity is reached at lengths greater than the length of 50 percent vulnerability (Fig. 38). Depending on the females' vulnerability at lengths near the legal minimum length, the percentage of pre-reproductive females in the landed female catch ranged from 9 to 36 percent.

6.4.4 Discussion

The use of females' secondary sexual characteristics (ovigerous setae) appeared to be a satisfactory way to study the maturity of females in this population. Once attaining long ovigerous setae females appear to retain them. This was supported by the very low numbers of large females recorded with short setae, and a very low loss recorded in the tagging study when only the data of experience recorders was used. Nevertheless, studies of egg-bearing females during the winter months would provide the best confirmation for our estimates, however because of the closed season during the winter months it was not possible to do this.

Estimates of the parameters of the logistic curve which was used to describe the maturity of females varied spatially and temporally. However, variations were not consistent across either scale. It appears that most of the variation observed was the result of the sampling and reflects the degree to which the population varies. It is most likely that variation in growth rate explains most of the variation in maturity. Consequently, sampling programs must be designed to sample on a spatial scale which corresponds to the spatial variation in growth to produce invariant estimates of maturity or to sample for length frequency analysis. In this study we chose to use estimates of maturity from the five year pooled data sets since these provided the most comprehensive sampling of the population, and there was no indication that there were any real temporal trends.

Some species have responded to exploitation by compensating the loss of egg production due to reduced survival by producing more eggs at a given size, or by reproducing earlier. Size of maturity in the Hawaiian spiny lobster, *P. marginatus*, declined since a fishery developed for that species (Polovina 1989). However, in South Australia the reverse is probably true. Lower population densities are highly correlated with higher rates of growth. It follows that as density declined in response to fishing, growth rate would have increased and the size at which the females matured would have therefore increased.

6.5 Size Specific Vulnerability

Objective

To obtain data (catch & effort, tagging, catch sampling) and analyse it to gain estimates of growth, mortality, **catchability**, female length at maturity, length weight and movement.

6.5.1 Introduction

Estimates of size specific vulnerability were required for per-recruit analyses, the South Australian Rock Lobster Assessment Model, and estimates of mortality using length based and age-weight based assessments.

Vulnerability often changes as individual animals grow in length and get older due to changes in behaviour., physical dimensions, or spatial distribution. Length frequency distributions from various parts of South Australia suggested that lobster vulnerability, at a given size, varied significantly between areas. Some of the variation was accounted for by growth rates. Where growth rates were low, a particular length interval may comprise more ages than in a corresponding length interval from an area of high growth. Consequently the apparent abundance of the slow growing group may have been greater than that of the faster growing group. However, growth rates alone did not explain all of the variability in vulnerability.

The impact fishing has on the stock is related to how vulnerable the stock is at various lengths in relation to the legal minimum length. For example, if lobsters are relatively invulnerable to the fishing gear at lengths moderately greater than the legal minimum length, then moderate increases or decreases in that length have little impact on yield or egg production. Similarly, increases in fishing effort increase fishing mortality only on lobsters that are vulnerable. If lobsters mature at a length smaller than the length at which they became vulnerable then greater fishing effort has only a moderate impact on egg production. Conversely, if lobsters do not mature until they reach a size where they are highly vulnerable, changes in fishing effort have a much greater effect on egg production.

6.5.2 Methods

Size specific vulnerabilities were estimated separately for males and females from most important marine fishing areas. Two methods were used. The first method is a two step process that uses length frequency data from various marine fishing areas and the von Bertallanfy growth parameters, L_∞ and K. In the first step, the theoretical sample population curves were fitted to length-converted catch curves by weighted least squares, where the weights used was the sample size, using the Solver routine in Excel. The length frequency samples used were five year, pooled data sets from specific marine fishing areas. The model was fitted from the point where the highest frequency was observed, which should be approximately the length at which the lobsters were fully vulnerable. Two parameters, N and Z, were estimated by this method, where N is the initial cohort size and Z is the total mortality rate. The model fit was:

$$N_{s(t+dt)} = \frac{((1-e^{(-Z*dt)})}{Z}$$

where $N_{s(t+dt)}$ it the predicted population you would sample at time t plus the time theoretically taken to grow to the next length.

Lobsters that grow rapidly move through the intervals quickly. Therefore, the probability of being captured in any one length interval, where growth is rapid, is small. Higher frequencies in the catch are expected for slower growing lobsters. When growth declines, for example when females become mature, it is possible to accumulate more lobsters in a length interval than were predicted to be in a preceding length interval.

A better description of the females' growth was found by describing the growth of small, generally immature females, and larger, generally mature females, separately (see section 6.1). In this analysis, a single estimate of the time a female lobster would spend in a length interval (*dt*) was calculated by weighting the two estimates of *dt* (from the separate growth parameters) by the proportion of females mature at the respective length. For small females this would result in the estimate of *dt* being approximately equal to the *dt* estimated from the growth of small females. For large females the reverse was true. In two marine fishing areas there was a discontinuity in the estimated *dt*. However, in the other areas the transition from one growth curve to the other was quite smooth.

The second step was to fit a logistic curve to the observed proportion of the theoretical sample population present in the length frequency data collected in the field. The model was:

$$V_L = \frac{1}{1+e^{(-C*(L-LV50))}}$$

where V_L was the vulnerability of lobsters of a given carapace length (L), C was the shape parameter of the logistic curve, and L_{V50} was the carapace length at which the vulnerability is 0.5. The model was fit by least squares using Solver (EXCEL™).

6.5.3 Results

Results of the fitted sample population curves to the observed length frequency distributions are presented in Figure 39. Also, presented in Figure 39 are the vulnerability curves fit to the proportion of the sample population observed in the length frequency distributions. A weighted and unweighted were fit. The fits were almost identical, however the weighted model was chosen as the preferred model.

Size specific vulnerability was spatially variable. Estimated $Lv50$ values ranged from 85 to 125 mm, Table 21. Lobsters were vulnerable at the smallest lengths in the southeast of the state and at larger lengths in the northern and western parts of the fishery. Estimated $Lv50$ values from males and females were very similar for five of the seven marine fishing areas, Table 21. However, the males estimated $Lv50$ tended to be slightly greater than that of females. In marine fishing areas 55 and 39 the males $Lv50$ was much greater than the respective estimate for females (Fig. 40).

The estimated vulnerabilities of males and females at legal size are shown in Table 22. These ranged from 0.13 to 1.0 for females and 0.16 to 0.97 for males. Lobsters in the southern zone were generally much more vulnerable at the legal minimum length than lobsters northern zone. This was only partially due to the smaller legal minimum length in the southern zone.

6.5.4 Discussion

Estimating the size specific vulnerability of lobsters by the method used required information about the length structure of the population and growth rates. The particular model used expressed growth as a continuous process, which it is not. However, good fits of the von Bertalanffy growth model to growth data suggest that this is a reasonable approximation, see section 6.1. This approximation was not thought to limit the usefulness of these results.

There is also the assumption of a steady state in the population. Mortality rates during the five year period of data collection may not have remained constant. Likewise, recruitment may have varied. Combining five years of data will hopefully minimise the effect of any deviations from these important assumptions. Visual examination of the length frequency data and the generally good fit of the model to the data suggest that the method was generally applicable to these data.

Of greater concern was the spatial heterogeneity of the population within marine fishing areas producing strongly bimodal length frequency distributions in marine fishing areas 39 and 55. The results depend on the relative sampling intensity in the areas of high and low growth within the marine fishing area. If these areas are sampled in proportion to the population size then the method may estimate the mean vulnerability quite well. However, if the samples were not in proportion to the population size, then the mean vulnerability will either be under or over estimated for lobsters in an the area. It should also be noted that the data on which the growth estimates are made must also be taken from the whole population in the area in proportion to the population size of the slow and fast growing lobsters to prevent bias in the result. The divergence between the estimated $Lv50$ estimates for females and males in marine fishing areas 39 and 55 suggest that either the growth estimates or the length frequency sampling for the area may not reflect the population means.

6.6 Per-recruit analyses

Objective

To use the model to estimate the sustainable yields, **predict outcomes of alternative management strategies** and understand the interactions of the two management zones.

6.6.1 Introduction

Per-recruit analyses offer a valuable means of assessing the impacts of fishing mortality and legal minimum lengths, and indirectly fishing seasons, on equilibrium per-recruit yields in units of weight or eggs.

The analyses presented also allow for the assessment of the impact on discard mortality on yield- and egg-per-recruit. Large minimum legal lengths and high numbers of discards may significantly reduce yield- and egg-per-recruit if discard mortality is high. This may lead to very different conclusions about the effectiveness of a particular minimum legal length or rate of fishing mortality.

6.6.2 Methods

The average yield-per-recruiting male, female, and both sexes combined, and the average number of eggs per recruiting female were estimated in a spread sheet model. The model was used to estimate YPR and EPR for several of the principal MFA's for a range of values of F, M, and discard mortality (F_d). Note that F_d is referred to as m_r in the qR section that follows in 6.7.. Calculations began with 1 million "recruits" of 70 mm CL of each sex. These were then "grown" according to the estimated von Bertalanffy growth parameters for the respective sex and MFA. Outputs from the model were the grams per-recruit that went to catch, natural mortality, and discard mortality. The maximum YPR was estimated by using the EXCEL™ Table Function to find the maximum YPR by varying F and LML for specified M and F_d values. The maximum yield for both sexes was the sum of the yield of the individual maximums. Maximum equilibrium egg production was estimated by setting F to zero.

Length-specific vulnerabilities used in the model were derived by the methods described in section 6.5 and length specific maturity schedules used were estimated by methods described in section 6.4.

Values of F used in the analyses were chosen on the basis of current fishing mortality estimates from the zones and those levels of mortality which might be reasonably expected to occur. For example, in some cases improved YPR was obtained at higher fishing mortality than those above. However, for reasons of egg production and acceptable catch rates, YPR results for higher fishing mortalities are not presented. Natural mortality of 0.10 and 0.15 were used with discard mortality rates of 0.0 and 0.10 (no discard mortality, and about 10 percent of the discards dying). Therefore, there are a total of four sets of results for each sex for each MFA.

The rate of discard mortality in the South Australian fishery was unknown, but could be potentially important. Several estimates of discard mortality from other lobster fisheries have been made by direct observation and by tag-recapture studies. In New Zealand, Annala (1984) estimated 15 percent mortality if lobsters are exposed to air for 10 minutes and 90 percent when exposed for 80 minutes. Brown and Caputi (1986) estimated discard mortality of 11.6 percent in the Western Australian lobster fishery before handling practices were improved, and less than 4 percent thereafter. Since handling practices in South Australia are generally very good, it is likely that the rate falls somewhere between 4 and 10 percent.

6.6.3 Results

Results are presented in Figures 41 to 43 by marine fishing area (15, 48, and 56), sex, and four combinations of natural and discard mortality.

Depending on growth and mortality rates, maximum yield-per-recruit was achieved from lengths close to the present minimum legal lengths and fishing mortality near its current estimated rate, to lengths much closer to the estimated maximum length of the lobsters in the respective area. Results consistently showed that maximum values for males were reached near their estimated maximum lengths under the condition of extremely high fishing mortality because of their relatively high growth rates and estimated low natural mortality. What the analyses suggest is a strategy of allowing males to grow to very large sizes and then catching them vary rapidly when their growth begins to slow so their accumulated yield will not be lost through natural mortality. This is impractical and some other combination of length and mortality should be selected that meets additional objectives such as fishing mortality rates that produce acceptable catch rates and a length such that the product meets market place expectations. Females because of their slower growth generally, and specifically their reduction in growth after reaching maturity, required much higher rates of fishing mortality to maximise their yields and minimum lengths much more in line with current regulations.

6.6.3.1 Northern zone

In many northern zone MFA's vulnerabilities were low at the legal minimum length, section 6.5,Table 22. Consequently, small LML's have relatively little effect on YPR because few small lobsters are caught relative to their abundance.

As discussed above, male YPR in all MFA's increased as the LML increased and reached a maximum at carapace lengths well above any practical minimum length regardless of the rate of natural mortality used (0.10 and 0.15) and discard mortality (0.0 and .10). However, there was little contrast in the YPR of males over the range of LML's near 102 millimetres and in the range of likely fishing mortality. For example, increasing the males' LML from 102 to 115 increases YPR by approximately 5 percent. It should be noted that the slightly higher YPR corresponds with results from the South Australian Rock Lobster Assessment Model where higher catches are predicted when the LML is raised to 115 mm (Fig. 44). The model also indicates that it takes several years to reach the new equilibrium during which time total yields are marginally lower. Higher natural mortality and discard mortality predicably favoured smaller (but still large) LML's, in the YPR studies.

At the current LML a slight improvement in male YPR was realised at *F* equal to 0.2 than at the higher *F* estimated for a number of northern zone MFA's when natural mortality was set at 0.1. If natural mortality is higher than 0.1, then the current *F* or slightly higher produced better YPR.

There was little change in female YPR over the range of LML's and fishing mortalities examined. However, over most carapace lengths YPR increased as a function of *F* to a maximum value. YPR only declined at high fishing mortality values when natural mortality was 0.10 and discard mortality was 0.1. As for males, higher *M* and discard mortality favoured a smaller LML (Fig. 41a,b). Because female growth declines markedly after they reach reproductive maturity, a higher LML only makes sense if natural mortality is very low or if fishing mortality is extremely high. Breen and Kendrick (1994) point out that the *F* required to maximise female YPR is higher partly as a result of their lower vulnerability due to the presence of eggs on mature females for part of the season. This is probably more important in the southern zone due to the earlier start of the fishing season in that zone. However, high fishing mortality is not advisable for reasons of the males' YPR, egg production and catch rates in the fishery, (see below).

Yield-per-recruit of the two sexes combined was estimated allowing the size limits for males and females to vary in parallel to the size at which the females maximum YPR was produced. Thereafter the females size was held constant while the males was allowed to increase (Fig. 42a,b). The model could be used to evaluate any combination of lengths at a future time.

Egg production increased when fishing mortality decreased and/or the LML increased, as must be expected. Results from MFA's 15 and 48 are shown in Figure 43a,b. At the current LML and estimated fishing mortality, egg-per-recruit was estimated to be approximately 25 to 40 percent of maximum (the condition where there is no fishing mortality). Using higher natural mortality in the analysis (M=0.15) produced higher estimates of current egg-per-recruit because higher natural mortality reduced the estimate of the average number of eggs produced by a female during her lifetime (under the no fishing scenario) by shortening their expected lifetime and thereby reducing their average fecundity.

Discard mortality had the greatest effect where the vulnerability of pre-recruit lobsters is highest. Because of low vulnerability below the LML in many parts of the northern zone discard mortality did not dramatically effect the results.

6.6.3.2 Southern zone

Results in the southern zone were similar to the northern zone. Males returned the highest YPR at very large legal minimum lengths under conditions of high fishing mortality. Improved YPR was possible by increasing the LML, or by reducing fishing mortality and holding the LML at or near the current size (Fig.41c). Improved male YPR from moderate increases in minimum length were greater in the southern zone than the northern zone as a result of the greater vulnerability near the current LML, and lower growth rates. The YPR results correspond with results from the SA management model (Fig. 44). All results were sensitive to the value of natural and discard mortality. Discard mortality of ten percent favours lower fishing mortality rates, even if the LML is large. Lower LML's are also favoured. Discard mortality was more important in MFA 56 and 58 than elsewhere in the state because of the higher vulnerability of lobsters at legal size in these MFA's. This vulnerability translates into much higher discard rates.

The female YPR in areas of lower growth rates of the southern zone did not improve with increases in minimum length except if natural mortality was held at 0.10 and there was no discard mortality. With natural mortality of 0.15 and discard mortality of 0.10 YPR actually improved if the minimum length was reduced. (Fig. 41c). It would appear that the females LML is set at approximately the correct length to provide near maximum YPR under current conditions in the southern zone, although in higher growth areas of the zone slightly larger minimum length values might provide for marginally better yields.

Like the northern zone females' YPR generally increased at the present LML as a function of increasing *F*, however only under the condition of zero discard mortality. For reasons of egg production higher fishing mortality rates should be avoided even if slight increases in YPR were possible.

Estimates of the YPR for the two sexes combined were between the estimates of each sex, as must be expected. The model was run with the minimum sizes for both sexes changing in parallel until the size where the females maximum yield was returned, as described above. A maximum of a 16 percent increase in YPR was possible for combined sexes in MFA 56 through increases in minimum length or reduced *F* (Fig. 42c).

Egg-per-recruit was lowest in MFA 55 where 50 percent of females were not mature until approximately 106 millimetres carapace length, but had reached approximately 50 percent of full vulnerability at the LML. Estimates of egg production at the current LML ranged from approximately 10-12 percent in MFA 55 at the current estimated *F* and low *M*, to approximately 20 percent in MFA 56 (Fig. 43c). Egg production as a percentage of the maximum possible is greater in the higher *M* scenario, for the reasons discussed above, but remains relatively low.

Results for YPR and EPR in both zones are remarkably similar to those reported by Annala and Breen (1989). Although those authors point out that reducing *F* achieved increases in YPR for males similar to those reported here, they did not make mention of the positive impact of reducing *F* on catch rates, fishery stability and sustainability. These may be as equally important as improved YPR.

6.7 Estimating Mortality

Objectives

To obtain data (catch & effort, tagging, catch sampling) and analyse it to gain estimates of growth, **mortality**, catchability, female length at maturity, length weight and movement.

6.7.1 Introduction

Estimating rates of fishing mortality are fundamental to understanding the dynamics of fished populations and their response to fishing. All estimates in fisheries are subject to error. Here we use several methods to estimate mortality of lobsters. These fall into one of three categories: length based, age based, and tag recapture. The three approaches offer relatively independent ways of assessing mortality, except for where the length and age based methods use common estimates of growth. Comparison of estimates through time and space and between independent methods is one way of ensuring that gross errors are not being made in the estimation of this important parameter.

6.7.2 Length Based methods

The following methods use information about growth and the length distribution of the catch to estimate total mortality, *Z*. Length based and other indirect methods of estimating mortality are used because it is not possible, at the present time, to age *Jasus edwardsii* directly.

Three methods were used to estimate total mortality (*Z*), and from this, fishing mortality (*F*) and exploitation rate (*U*) [2]. All length based methods make the assumption of steady state. We know that in two of the MFA's in the state a significant number of lobsters migrate into adjacent areas. We estimate mortality only in the adjacent areas where we believe the effect of immigration is negligible because of the relatively large resident populations.

[2] The term exploitation rate is used two ways in the literature. Here it refers to the proportion of the available stock (biomass) removed by fishing, it is abbreviated U. The other definition of exploitation rate is the quotient of: fishing mortality divided by total mortality (F/Z) and is abbreviated E.

Growth estimates used in the following methods were calculated by the methods described in section 6.1. Length frequency data were collected through the voluntary catch monitoring program and by biologists as previously described. The length frequency data was used to estimate mortality for each of five seasons where sample sizes permitted and were pooled for a single estimate of mortality during the five year period. Mortality estimates were calculated independently for the sexes and then combined as the weighted average of the two estimates based on the sex ratio in the landed catch.

6.7.2.1 Beverton-Holt method of estimating *Z* from length frequency data

The Beverton-Holt equation for estimating *Z* (Beverton and Holt 1956) was applied to all of the selected MFA's with high production. Where lobsters were equally vulnerable to exploitation from the LML to the maximum size this method was used in the conventional way. However, lobsters were fully exploited at legal size in only a few MFA's. If lobsters below the length of full vulnerability are omitted from the analysis the method over estimates *Z*. Therefore, the lobsters from the size immediately greater than LML were included in the analysis. However, inclusion of lobsters below the length at which they are fully vulnerable does not completely eliminate the problem of overestimating mortality, since the length frequency sample underestimates the numbers of lobsters which incur a lower fishing mortality as a result of their lower vulnerability (see discussion of length based methods).

The equation describing the relationship between the total mortality rate and the mean length of lobsters above the length of full exploitation (and in our case LML) is:

$$Z = \frac{(L_\infty - \bar{L})}{(\bar{L} - L_c)},$$

where $\bar{L}$ is the mean length of lobsters between the legal size and L_C is the length where lobsters are fully recruited or in this case the legal minimum length.

Analyses were carried out to determine the sensitivity of mortality rate estimates to the selection of the maximum size used in the Beverton-Holt analysis. These showed the maximum carapace length included in the analysis had little impact on the estimate of *Z*, provided the end point selected was not extremely small with respect to L_∞. The result is not unexpected because the numbers of lobsters in the length distribution near L_∞ are low, consequently their inclusion or omission has relatively little effect on $\bar{L}$. Selection of the smallest size included in the analysis potentially has a much greater effect on the results because of the high abundance of lobsters near LML.

6.7.2.2 Jones and van Zalinge method for *Z* from catch curve analysis

The Jones and van Zalinge (1981) method requires length frequency data and the same growth parameters used by the Beverton-Holt (1956) equation, above. The method was applied to the same data sets as the Beverton-Holt analysis.

The model equation is:

$$\ln C(L, L_\infty) = a + \frac{Z}{K} * (\ln L_\infty - L)$$,

where $C(L, L_\infty)$ is the accumulated catch between size L and L_∞. The estimate of total mortality (Z) is K * slope from the regression equation (see below).

Sequential regressions of the natural log of $C(L, L_\infty)$ in increments of 2 millimetres carapace length for males and 1 millimetre carapace length for females, due to the smaller range of useable data, were calculated. An average estimate of Z for lobsters greater than the length of full exploitation was calculated by weighting the individual estimates by the sample size and by the time it takes to grow from one length group to another.

It was observed that the Jones-van Zalinge analyses frequently indicated that mortality increased with size to some point and then decreased again (Fig. 45). The fitted population curve (next section) often resulted in an underestimate of the number of large (old) lobsters. There are two possible explanations for these results. The first is that growth parameters sometimes over-estimate the age of large lobsters or that the vulnerability of larger lobsters is lower. The latter explanation correlates with observations of large lobsters escaping from pots (R Lewis pers. comm.) resulting in their lower vulnerability. Tagging data from this study also suggest lower vulnerability of large lobsters.

6.7.2.3 Z estimated by fitting "sample" population length distribution to length converted catch curve

A method to estimate Z using length frequency data from MFA's where lobsters were not fully exploited at LML was developed. The rationale for the method was: to have the observed numbers of lobsters of any age there must have been, on average, that number plus the number lost through mortality at the preceding age. Because of the particular growth characteristics of males and females this may translate to an estimated length frequency distribution very similar to the length distribution you would see by extrapolating backwards from the observed length frequency distribution, to one that is counter intuitive, where the numbers of lobsters in length intervals actually decreases as the lengths become smaller. The latter case is typical of female lobsters which have marked declines in growth after attaining reproductive maturity.

For each length in the size frequency sample the age was calculated from the inverse von Bertalanffy growth equation and the respective growth parameters. The difference between the age at one length and the age at the next length was used to estimate the time taken to grow from one size to the next[3]. This time is referred to as *dt*.

The EXCEL™ routine SOLVER was used to fit the model:

$$N_{s(t+dt)} = \frac{((1-e^{(-Z*dt)})}{Z}$$

as described in section 6.5. N_{st} and $N_{s(t+dt)}$ are the numbers at time *t*, and *t* + the estimated time required to grow to the next length increment(*dt*). Plots of the data and fitted sample population curve are presented in Figure 39a-c.

The next step was to estimate a weighted *Z* for lobsters of legal size and larger, taking into account the lower vulnerability (and therefore lower fishing mortality) of lobsters between LML and the length of full exploitation. This was done by estimating the value of Z for each length. First, the Z value estimated in the fitting process was multiplied by the estimated vulnerability at each length. Second, the estimated Z for each length was weighted by the sample population size of that length to obtain the weighted mean.

This method was applied to the pooled data sets from most important marine fishing areas.

6.7.3 Age based methods

6.7.3.1 Estimating age-specific population numbers and exploitation rate from catch-by-weight, catch-by-numbers, and weights-at age: steady state

6.7.3.1.1. Introduction

Commercial catch data have served as the input for the majority of stock assessment models developed for management of marine invertebrate and fish stocks (Hilborn and Walters 1992), including those for lobster fisheries (Yoshimoto and Clarke 1993; Polovina and Mitchum 1993). The fraction of the population harvested annually, *U*, is an important parameter which provides an estimate of absolute population abundance if catches are known. Unless independent estimates of total population size are available, perhaps from census survey or tagging (Beverton and Holt 1956), *F* must be inferred from stock structure. Because no techniques been developed to age lobsters,

[3] This is only an approximation because lobsters do not grow continuously in length because of moulting.

length-based methods have been used to estimate U in most lobster populations to date (Morgan 1980).

In this section, a new method of lobster stock assessment is presented based on commercial catch log data. This method allows estimation of exploitation rate and absolute population numbers by age for a steady state population. Because of their high value and method of capture, and for compliance verification, catch in lobster fisheries is sometimes reported by both weight of catch and numbers of individuals landed. For the South Australian rock lobster fishery, annual catches by number and weight are available for the northern and southern zones.

This method was developed to provide parameters for a large spatial model of the South Australian lobster fishery. It is also referred to as the "qR method" because it was developed to estimate two parameters for this model, q via U, and recruit numbers. The dynamics of effort movement among model spatial blocks, the complexity of spatially distributed puerulus settlement, and the size-structured formulation of this spatial model make dynamical estimation procedures unwieldy. Consequently, steady-state as time-average approximations of these two quantities were sought.

The principal innovation of this approach is to employ, in addition to catch measured by weight, catch expressed as numbers of individuals harvested. The mathematical advantage gained by adding catch-by-numbers to a steady state fishery model is that the additional equation yields a system with equal numbers of equations and unknowns. Thus, the variables, U and population numbers-at-age, can be solved for exactly. The basic model is a system of finite difference equations which, under assumption of steady state, reduce to a system of algebraic equations. The first two equations relate population numbers in each age class, to the expected weight and number captured, given exploitation rate, U, and a constant natural mortality. The remaining cohort equations are familiar, relating numbers in age a to numbers in the next older age class, a + 1.

Two models were considered. The first describes a short-lived (or heavily exploited) population with only two age classes contributing to the harvestable stock. The resulting system of three equations can be solved analytically, yielding closed-form solutions for U, N_1, and N_2. The second model was developed for the lobster population in South Australia and assumes 13 harvestable age groups. Numerical solutions provided an estimate of steady state exploitation rate and population numbers for each age class in the fishable stock.

Estimates of exploitation rate from the steady state qR (catch weight-numbers) method were compared with those estimates derived from length-frequency samples.

A second method of validation testing was also performed. The qR and Beverton-Holt methods were tested with a simulated data set. These data were obtained from a simulation of the lobster fishery where individual lobsters were grown from the time of settlement to harvestable size. Sampling was done at the time of the harvest simulation event.

6.7.3.1.2 Data

The principal inputs to this analysis were (1) average catch by weight, C^w; (2) average catch by number, C^n; (3) average age-specific weights of all age classes making a significant contribution to the catch, $\{w_a; a=1,. . .,n_a\}$; and (4) an estimate of yearly (discrete rather than instantaneous) natural mortality, M_d. Furthermore, this particular formulation had three additional parameters that allowed for a more elaborate description of harvest mortality and survival in the recruitment age group (hereafter referred as "age 1" since only harvested age classes are represented). These were: (5) the relative vulnerability of recruitment-year class individuals, v_1; (6) an estimate of the fraction of this recruit age class which was above the legal size, f_R; and (7) an estimate of release mortality of undersize in this partially-recruited first age group, m_r.

For the South Australian rock lobster fishery, catch data include weight and numbers landed annually since 1983. The time averages for annual reported catch-by-numbers (C^n) and catch-by-weight (C^w) were taken over all available years, 1983–1994.

Length data were available for five years, and for the two zones of this fishery.

Growth data were used to estimate the age-specific weights for the two zones of the South Australian lobster population.

6.7.3.1.3 Methods

6.7.3.1.3.1 Model Assumptions

The method is age-based. A stationary age-structure is assumed yielding straightforward cohort equations for the numbers in each age group as a function of those in the age class below. For example, the number of 3-year-olds (taken at the start of each fishing season), was assumed to equal the number of 2-year-olds the previous year, minus those that were harvested and those that died naturally. The latter two mortality terms were both written as constants (discrete yearly natural mortality, M_d and exploitation rate, U) times the numbers of individuals of age group 2 present. Under-reporting was not considered in the models presented below.

The method for estimating U was based on applying a full set of equations for the two reported forms for catch, by numbers and weight, together with an equation for each pair of successive cohorts in the fishable stock. Two examples are provided below. A choice must be made of how many cohorts to include as making a significant contribution to annual landings.

6.7.3.1.4 Models

6.7.3.1.4.1 Two Age-Group Model

The example below assumes two age groups of fishable size in the exploited stock. The population variables were the numbers of individuals in each age class of harvestable size, $\{N_1, N_2\}$, at the start of the fishing season. The third variable was the annual fraction removed by harvesting, the exploitation rate, U. Both U and the discrete natural mortality coefficient, M_d, were assumed to be constant over time and for all age groups above the first.

Three enhancements of the harvest description were added for the first, recruitment, year class. First, reduced vulnerability, v_1, relative to the constant vulnerability (of 1) assumed for older age groups was allowed. Second, a specific fraction, f_R, of recruitment-age lobsters, was assumed to reach legal size. In South Australia, as in many lobster fisheries, those which are captured but are below the legal minimum length must be returned to the water. Third, for that fraction of the recruitment year class that do not reach fishable size but nevertheless are captured in fishers' pots, an incidental mortality of m_r, above the anticipated natural mortality, was incurred. Thus, $v_1\, U N_1$ lobsters of recruitment age are captured in pots, $v_1\, f_R\, U N_1$ are legal size and kept, and of those $v_1\,(1 - f_R)\, U N_1$ sub-legal lobsters returned to water, $m_r\, v_1\,(1 - f_R)\, U N_1$ incur additional incidental mortality.

The input data were the means for annual catch by weight, C^w, and catch by numbers, C^n, and the average weights $\{w_1, w_2\}$ of age 1 and 2 captured lobsters.

The system of three equations describing the two steady-state catches and the survivors to age 2, were:

$$C^w = v_1\, f_R\, U\, N_1\, w_1 + U\, N_2\, w_2 \quad (1.1)$$

$$C^n = v_1\, f_R\, U\, N_1 + U\, N_2 \quad (1.2)$$

$$N_2 = N_1 - M_d\, N_1 - v_1\, f_R\, U\, N_1 - m_r\, v_1\,(1 - f_R)\, U\, N_1 \quad (1.3)$$

This was solved for the variables, $\{U, N_1, N_2\}$.

6.7.3.1.5 Example: South Australian Rock Lobster

The steady state equations describing the mean catch by weight, catch by number were as follows:

$$C^n = v_1\, f_R\, U\, N_1 + \sum_{a=2}^{13} U\, N_a . \quad (2.1)$$

$$C^w = v_1\, f_R\, U\, N_1\, w_1 + \sum_{a=2}^{13} U\, N_a\, w_a . \quad (2.2)$$

The cohort equations are analogous to (1.3):

$$N_2 = N_1 - M_d\, N_1 - v_1\, f_R\, U\, N_1 - m_r\, v_1\,(1 - f_R)\, U\, N_1 , \quad (2.3)$$

and

$$N_a = N_{a-1} - M_d N_{a-1} - U N_{a-1} , \qquad \text{for all a} = 3, \ldots , 13. \qquad (2.4\text{-}2.15)$$

As above, the recruitment year class was divided between those large enough to harvest and those returned to the water, with mortality incurred on each assumed in the same manner as for the two variable system. A total of thirteen age groups in the fishable stock was chosen arbitrarily, but these are believed to comprise a large fraction of the catch.

Recruitment parameters $\{v_1, f_R\}$ were chosen as {1, 0.5}. Annual discrete mortality parameters, $\{Md, mr\}$, were set to {0.084, 0.140} in the northern zone and {0.073, 0.138} in the southern zone. These latter values were chosen to achieve an instantaneous rate of natural mortality of $M = 0.1$ employed widely in Australasian *Jasus edwardsii* lobster fisheries (eg Annala and Breen 1989) and supported by one long-term mark-recapture study carried out by Kennedy (Department of Primary Industry and Fisheries, PO Box 192B, Hobart TAS 7001, Australia, pers. comm.).

This algebraic system of 14 variables in 14 unknowns was solved numerically.

6.7.3.1.6 Data simulator

To test the precision and accuracy of this approach and the Beverton-Holt method, a lobster fishery simulation, patterned loosely after that of Hampton and Majkowski (1987), was constructed. The simulation considered individual lobsters in two life history stages, those below and above 88.5 mm, which is 10 mm below the legal harvestable size. Only male lobsters were considered, i.e. no protection was offered for egg-bearing females and growth parameters were chosen to be typical of males in South Australian MFA block 55, with means of $K = 0.19$ and $L_\infty = 200$ mm. Four processes were represented: yearly settlement at size 11 mm; von Bertalanffy juvenile growth to 88.5 mm; twice-yearly moulting for adults above 88.5 mm; and mortality, with a monthly time step, under probabilities of death by natural causes ($M = 0.1$) or harvest ($F = 0.4$). Moult increment was 10 mm for all adult lobsters up to 150 mm, and then declined linearly to 0 at the L_∞ value of 200 mm. Moulting probability varied depending on each lobster's predicted von Bertalanffy growth for half a year, ΔL_{VB}, which is determined by its size at the time of the summer and winter moults. Since mean growth per half year equals moult probability times moult increment, moult probability was calculated using ΔL_{VB}/(moult increment). Thus at each moulting month, January and June, the probability of moulting for each lobster was calculated and a random number drawn to determine whether the lobster did moult in that moult period. If so, its length was increased by the designated moult increment.

A constant number of 950 pueruli were settled per year (in summer, no winter settlement was employed). Juvenile growth and mortality processes were characterised by variability, using random numbers to sample from normal distributions with designated standard deviations. Growth was allowed to vary among individual juvenile lobsters by random sampling at time of settlement with SD_K =

0.02 and $SD_{L\infty} = 20$. K and L_∞ values were fixed (again at 0.19 and 200 mm) for all adults in the moulting phase of growth.

The mortality submodel was run each simulation month. The probability of death for each lobster was $F / 7 + M / 12$ during the seven months of the fishing season, and $M / 12$ in the five months closed to fishing. If a lobster died in months of fishing, a second random number was drawn to determine whether death was due to capture or natural causes.

Simulation catch was used to test the two methods. Annual catch in weight was calculated by multiplying each lobster when harvested by its weight from a weight-length relationship, ($w(L) = 0.000483 * L^3$), and summing over all harvested lobsters in the simulation year. For the Beverton-Holt mean lengths, 1% and 25% of the catch were sampled, and their mean length calculated.

The simulation was run 20 times, for 20 years each. Mean catches by weight and numbers and mean lengths were calculated by averaging over year 12 to 20 from each run. The estimates of U for the two methods employing these outputs yielded twenty estimates of U for three tested cases: (1) the catch weight-numbers method; and the Beverton-Holt method with a sampling intensity of (2) 1%, and (3) 25%.

6.7.3.1.7 Results

6.7.3.1.7.1 Two age-group model

By abbreviating

$$
\begin{aligned}
M_R &= f_R + m_r - f_R\, m_r \\
C_1 &= -C^w + C^n\, w_1 \\
C_2 &= -C^w + C^n\, w_2 \\
D &= -C^w + C^w\, M_d - C^w\, f_R\, v_1 + C^n\, f_R\, v_1\, w_1 + C^n\, w_2 - C^n\, M_d\, w_2 \\
W &= -w_1 + w_2\,,
\end{aligned}
$$

the analytic solution of the model with two harvested age groups (Eqs. 1.1-1.3) is written

$$
\begin{aligned}
N_1 &= M_R\, (C_2)^2 \,/\, [f_R\, W\, D] \\
N_2 &= M_R\, v_1\, C_1\, C_2 \,/\, [-W\, D] \\
U &= D \,/\, [M_R\, v_1\, C_2].
\end{aligned}
$$

6.7.3.1.7.2 Example: South Australian Rock Lobster

The vectors of weight versus age for the two zones of the South Australian fishery are presented in Table 23. These weights were used to obtain estimates of U for the years

1991-95 in seven of the blocks of greatest production (Table 23) as solutions of Eqs. 2.1-2.14.

These two areas of high density and large total catch were in the southern zone, where catches have been relatively steady since the late 1960's. Thus, these blocks appear from the catch and effort time series to be much better approximations of a steady state. In the northern zone, effort has been steadily building over those years, peaking in 1991. Effective effort may have increased substantially in the northern zone with the advent of GPS and colour sounders, and with the use of larger and faster vessels which have allowed exploration of a wider range of often isolated fishing habitats in this large coastal region. Some of the large lobsters captured in the northern zone may be remnants of the virgin stock. Thus, the northern zone was developing during most of the years of 1983-94 over which catch averages were calculated and its dynamics may not be well characterised as a steady state. In part, this may explain the generally closer agreement obtained between Beverton-Holt and the method presented here for southern zone blocks 55, 56 and 58. Furthermore, because of substantially higher total catch in these blocks, survey sample sizes for the length spectra were larger.

6.7.3.1.7.3 Simulated Data

The histograms of exploitation rate estimates for twenty simulated data sets are presented in Figure 46. The monthly exploitation rate employed in the simulation was 0.4 / 7. This was chosen to yield an annual value of $U = 0.4$ spread over seven open months in the simulation, which is the length of the season in the South Australian fishery. The catch weight-numbers method provided an estimate for the mean of about 0.38, with a standard error (as standard deviation of a sample of means) of 0.004 or about 1%.

Two estimates were obtained for the Beverton-Holt mean-length estimate of U, at two sample sizes, i.e. 1% and 25% of the total catch measured. These yielded less precise estimates with estimated U values spanning a wide range.

There appears to be a bias in the estimates from the two methods. The apparent bias in the catch weight-numbers method was much greater than the standard error. The length-based method gave estimates greater than the "true" value, at around 0.42.

However, to further investigate this apparent bias, U was estimated using a more direct definition, i.e. catch numbers divided by starting population size at the beginning of the fishing season. This is closer to the definition assumed by the yearly discrete formulation of the catch weight-numbers method. Using this definition, the simulated data (before analysis by either method) gave values about 0.37. Thus, observed estimates from the catch weight-numbers method (0.38) fall between the two simulation values that can be obtained using these two definitions. Similar corrections were also incorporated into the Beverton-Holt method which generated estimates of F. The U values graphed in Figure 46 were calculated assuming that the Baronov relationship holds, i.e. $U = (F / (F + M)) \{1 - \exp[-(F+M)]\}$.

6.7.3.1.8 Discussion

The goal of this study was to demonstrate a method to obtain exploitation rate, and by implication, absolute population numbers, using only reported catches. Catch by weight alone does not permit an accurate estimation of U because a given catch may represent a large fraction of a small population or vice versa. The inclusion of catch by numbers allows the calculation of two quantities not derived from catch by weight alone, exploitation rate, and absolute population size.

The advantage of including catch numbers, in combination with catch-by-weight, is to provide the mean weight of harvested lobsters. Since higher exploitation levels shorten the average lifespan and thus lower mean size of the exploited-age population, mean weight conveys information about exploitation rate. The same principle is employed in the Beverton-Holt method, which also assumes a steady state age/size structure, but uses mean length rather than mean weight.

The estimation of exploitation rate was done without use of effort data. In the past, the second quantity most often added to a stock assessment based on catch data is catch-per-unit-effort, taken as a measure of relative abundance. Problems with CPUE as an index of biomass have been often demonstrated. Catch rates may because of factors other than abundance, such as environment, improved skill and harvesting technology. Alternatively, catch rates may change little with stock abundance as in the case of fisheries which are serially depleted, or where stocks continuously aggregate, leaving a relatively constant density for harvesting as their total population size declines.

For these reasons, catch by number and by weight are suggested to be more powerful quantities than catch by effort (CPUE data) upon which to base stock assessment. Catch by number and by weight are less subject to exogenous variability and to bias than CPUE data, and they allow estimation of exploitation rate directly. A dynamic model based upon information that can generate estimates of U in every year must accommodate only the lags and changes in stock structure in fitting to time series rather than employing observed changes as the means to carry out that estimation.

The steady state method presented does not need a time series of catch data. A steady state approach was developed before a dynamic one for several reasons. First, the spatial distribution of exploitation rates in the various fishing blocks was sought. More specifically, spatially-based estimates of catchability and mean levels of recruitment. Second, the method of using catch by numbers with catch by weight was novel and a comparison with existing methods using real and simulated data was appropriate. Third, for dynamic solutions, one of the most difficult task is to obtain starting values.

6.7.4 Dynamic model fitting to Catch-by-Weight and Catch-by-Number in the Two Management Zones of the SA Rock Lobster Fishery

6.7.4.1 Introduction

In the previous section the steady state qR method was described. The same principles are employed here to extend the basic qR approach to a dynamical formulation. The inputs are similar, but catches are given on a yearly basis rather than taken as averages. Outputs include annual estimates of exploitation rate, recruitment, and by inference, the age-specific absolute population numbers. These estimates have obvious utility in assessing stocks of rock lobsters.

Several additional outcomes were achieved. The qr method provides absolute numbers in each postulated age class in each year for which there are catches by weight and number. From these, a measure of yearly egg production and fishable biomass can be calculated from fecundity-at-age and weight-at-age. The qR estimates are absolute rather than relative measures.

6.7.4.2 Data and Parameters

The principal inputs, in addition to annual catches by weight $\{C^{w}_{t}$; t = 1983,….,1995} and by numbers $\{C^{n}_{t}$; t = 1983,….,1995}, were the (average) weights at age, $\{w_a$; a = 1, . . , 14} of harvested lobsters (Fig. 47). A "year", indicated by subscript "t", refers to the full fishing season in each zone. Thus, C^{w}_{1983} represents the catches from October 1983 through April 1984 in the Southern Zone, and from November 1983 to May 1984 in the Northern Zone. Thirteen age groups were assumed for the fishable stock of lobsters which together would constitute most of the harvestable population. Additional parameters were used to provide more detail about the vulnerability, v_1, of the recruitment age class; the fraction of this age group that had reached legal size, f_R; and the release mortality of undersize, m_r. These parameters, including the derivation of weights-at-age, were described in section 6.5.

The catch-by-numbers in the present database go back to 1983 but there are data to 1971 still to be entered.

6.7.4.3 Methods

A dynamic, age-based approach can potentially allow the representation of the time lags of changes in exploitation, together with intervening growth of survivors in the stock, to be accommodated explicitly in predictions of year-by-year catches by weight and numbers.

The time series for the Northern Zone (Fig. 48) shows that average weight reached a minimum in 1988 at a time when CPUE began a rise to unprecedented levels. This suggested that a recruitment of harvestable lobsters occurred about 1988 resulting in increased catches in 1991. Alternatively, fishers claim that fishing intensity was rising at this time because of a shift from part- to full-time targeting of lobster, an increase in the landed price of lobsters, and improvements in catching ability brought about by GPS navigational technology and colour sounders.

An increase in CPUE was also recorded (Fig. 49) in the Southern Zone without the large and long-term increase in average weight evident in the Northern Zone.

The model population variable $\{N_{a,t};\ a = 1, \ldots, 13;\ t = 1983, \ldots, 1995\}$ represented the numbers of lobsters in the fishable stock at the beginning of each simulation year. It was assumed that an initial age vector $\{N_{0a};\ a = 1, \ldots, 13\}$ for the first year, 1983, must be given. The parameters of the integration over subsequent years were the time series for exploitation rate, $\{U_t;\ t = 1983, \ldots, 1995\}$, and for yearly recruitment, $\{R_t;\ t = 1983, \ldots, 1995\}$. The parameters U_t and R_t were allowed to vary to fit annual catches by weight and numbers. The algorithm to follow describes how the model population variable (for all years after the first) and catches by weight $\{mC^w{}_t;\ t = 1983, \ldots, 1995\}$ and by numbers $\{mC^n{}_t;\ t = 1983, \ldots, 1995\}$ in all years were calculated. The algorithm uses the rate equations that underlie the qR model.

In the first integration year, since $\{N_{0a}\}$, U_{1983} and R_{1983} are given, the model catches were calculated directly:

$$mC_t^n = v_1\, f_R\, U_1\, R_1 + \sum_{a=2}^{13} U_1\, N0_a\,.$$

$$mC_t^w = v_1\, f_R\, U_1\, R_1\, w_1 + \sum_{a=2}^{13} U_1\, N0_a\, w_a\,.$$

$v_1\ f_R\ U_1$ represents the fraction of the recruit age class, R_1, harvested and landed.
The catches by number and weight to be taken were then calculated in each subsequent year:

$$mC_t^n = v_1\, f_R\, U_t\, R_t + \sum_{a=2}^{13} U_t\, N_{a,t}\,.$$

$$mC_t^w = v_1\, f_R\, U_t\, R_t\, w_1 + \sum_{a=2}^{13} U_t\, N0_a\, w_a\,.$$

These losses, which include only landed catch were included in the cohort integration to follow. The integration proceeded by calculating the decline in each cohort due to losses from natural and fishing mortality. The losses for the recruitment year class included those from release mortality, m_r, from the fraction of that age class which is captured ($v_1\ U_1$) but below legal size ($1 - f_R$) and thus returned to the sea.

$$N_{2,t} = R_{t-1} - M_d\, R_{t-1} - v_1\, f_R\, U_{t-1}\, R_{t-1} - m_r\, v_1\, (1 - f_R)\, U_{t-1}\, R_{t-1}\,.$$

For all higher age classes, the cohort mortality was a simple factor reflecting natural mortality and exploitation rate. Note that the natural mortality, M_d, was discrete rather than the standard instantaneous natural mortality coefficient used in continuous time.

$$N_{a,t} = N_{a-1,t-1} - M_d\, N_{a-1,t-1} - U_{t-1}\, N_{a-1,t-1} \quad \text{for all a} = 3, \ldots 13.$$

Thus, given the $\{N_0\}$, $\{U_t\}$ and $\{R_t\}$ input vectors, the model predicted catches, $\{mC^n{}_t\}$ and $\{mC^W{}_t\}$ for all years.

The sum of square differences between observed and model catches,

$$SSQ \quad = \quad \sum_{y=1983}^{1995} \left[\frac{(mC_t^n - C_t^n)}{C_t^n} \right]^2 \quad + \quad \sum_{y=1983}^{1995} \left[\frac{(mC_t^W - C_t^W)}{C_t^W} \right]^2$$

included two sum components, for catches by weight and by number. In earlier formulations of this algorithm, the division by observed catches in each term was omitted. Because the absolute magnitudes of catches by number were higher, so were their difference terms in the sum. Therefore the catches by number were found to dominate with a visibly poorer fit to the catches by weight. When the terms in the sum were re-scaled to relative rather than absolute differences, this bias was alleviated.

To numerically solve for the $\{U_t\}$ and $\{R_t\}$, the SSQ was minimised. In practice, this was achieved in two stages. First, the minimisation routine was run allowing $\{U_t\}$ and $\{R_t\}$ to vary. For this first approach, the steady state qR estimates of U and R from each year were taken as starting values. This resulted in solutions which fitted well in later years, from about 1990 onward, but deviated in the first year particularly, as the age vector in the initial year, 1983, namely $\{N_{0a}\}$, was taken as a constant from the steady state 1983 qR solution. In the second stage, the estimated time series of $\{U_t\}$ and $\{R_t\}$ from stage 1 were taken as the starting values, and $\{N_{0a}\}$ was also allowed to vary, together with $\{U_t\}$ and $\{R_t\}$.

The qR solution also provided absolute numbers with age, $\{N_{a,t}\}$, for all years. The numbers, $\{N_{1,t}\}$, of age 1's are the recruits, $\{R_t\}$. Similarly, the age vector in the first year was N_0, $\{N_{a,1}\} = \{N_{0a}\}$. The remaining estimates for $\{N_{a,t}\}$ were derived directly from the R and U time series, and thus are not independent. Yearly (approximately start-of-season) biomass was calculated from the numbers-at-age and weights-at-age:

$$B_t = \sum_{a=2}^{13} N_a w_a \ .$$

Yearly egg production was calculated from the numbers-at-age and fecundity-at-age:

$$S_t = \sum_{a=2}^{13} N_a p_a \ .$$

6.7.4.4 Results

Given uncertainties in other inputs, notably M and the weights-at-age, the fits of catch by numbers and weight were as close as practically required for both the Northern and Southern zones (Figs. 50 and 51). The rise and fall of catches in the Northern Zone has been smooth. In the Southern Zone, it has been more variable with less overall deviation from the mean.

The recruitment time series in the Southern Zone was relatively constant, with the exception of the single year increase in 1991, when catches peaked in both zones (Fig. 52). The rise in annual recruit numbers in the Northern Zone was spread over a longer time period, the qR solution reflecting the smooth change in the catches to which the qR model was fitted. Exploitation rate, *U*, largely followed catches in their rise and fall (Fig. 53).

Besides the fit to catches by weight and numbers, a second form of model validation was possible. The qR model did not use the effort time series in estimation. Therefore, these data remain to provide an additional, independent test of the qR model solutions. Two comparisons are possible, using catch per unit effort, and using effort itself.

The comparison of CPUE by weight (as kg per potlift) with the qR measure of biomass for the Northern Zone showed good correspondence (Fig. 54). CPUE in this plot has been re-scaled for presentation such that the mean is equal to that of the qR biomass time series. The agreement of qR biomass with CPUEw enhances confidence in using CPUEw as a reliable indicator of stock abundance. It may also be taken as independent validation of the qR model solution.

The outcome for CPUEw versus qR biomass was less consistent in the Southern Zone (Fig. 55). The fit was good until 1991. From that year on CPUE continued to rise whereas the qR solution indicated no comparable increase in biomass. This is explained by the imposition of strong management restrictions on effort starting in mid-season 1992, including the closure of the last month (April) and the imposition of a quota system in 1993. Because overall catches declined in 1992 and 1993 from the 1991 peak, a strong rise in catch rate suggests that these restrictions in effort made each potlift more efficient. Catch rates at the end of each season are normally substantially lower.

The second validation comparison was between qR estimates of yearly exploitation rate and reported annual effort, as total numbers of potlifts. As with CPUE and qR biomass, the fit was good in the Northern Zone and diverges in 1992 in the Southern Zone. The steady rise in potlifts in the Northern Zone, and decline following the peak in 1991 was matched in the qR exploitation rate yearly estimates (Fig. 56). One apparent divergence is in the first year, 1983, where the qR model output predicted a higher level of exploitation than in 1984 although 1983 nominal effort was lower.

In the Southern Zone (Fig. 57) the fit was good until 1991, when overall effort declined more rapidly than the qR-estimated exploitation rate. As with CPUE, this would be explained by a mean catch rate per lift which rose with the imposition of April closure in 1992 and quota from 1993 onward. This implies a higher exploitation rate per potlift, i.e. a higher average catchability from 1992 under tighter effort and catch regulation.

Because of the divergence in predicted and actual values in the Southern Zone after 1991, no formal regression was attempted relating absolute biomass to CPUEw (Fig. 58) and exploitation rate to annual potlifts (Fig. 59).

In the Northern Zone, the close fit for all years apart from 1983 provided for relatively close fitting regressions. Because of the lack of close fit in the first year, and the assumptions needed to estimate the age vector in the first year, the 1983 point was removed. The results for qR-estimated biomass versus CPUEw show a linear trend (Fig. 60). The regression is described as

$$B = 724.8 + 2329\ CPUEw.$$

Standard error of the regression intercept was 379.1, or ± 52%. For the more important slope parameter, standard error was 287.75, or ±12%.

This result achieves the first designated goal for the Northern Zone, to relate absolute biomass to the chosen indicator of stock density, CPUE by weight, with quantified measures of uncertainty. A catch rate of 1.3 kg potlift^{-1} implies an average biomass of 3750 t ± 750 t. A catch rate of 1.0 kg potlift^{-1} implies an average biomass of 3050 t ± 670 t.

The second relationship to be addressed was between exploitation rate, *U*, and annual effort (Fig. 61). Two features of this regression for the Northern Zone are encouraging for its reliable application to management. First, the agreement of the two time series, qR-*U* and reported potlifts, was good. The regression formula, with intercept, is written

$$U = -0.0246 + 4.16 \times 10^{-7}\ E.$$

Second, the regression line intercept for Northern Zone *U* versus *E* was not significantly different from zero indicating that the qR measure of *U* has the property of reducing to zero when effort is zero. The intercept was set to zero and a second estimate of slope obtained. The resulting regression ($r^2 = 0.84$) was

$$U = 3.81 \times 10^{-7}\ E,$$

giving an estimate of catchability, $q = 3.81 \times 10^{-7}$.

6.7.4.5 Discussion

The qR model solution for biomass and exploitation rate may provide a more reliable measure than CPUE and effort as total potlifts because it relies only on total catches and average weight. However the fundamental Schaefer catch relationship, which assumes proportionality between catch and abundance, breaks down for the Southern Zone because annual catch is externally constrained under quota, rather than being proportional to stock abundance. It might be possible to fit the data on shorter time steps, weekly or monthly, at the beginning and middle of the fishing seasons, when this proportionality is more likely to hold. To test the power of different approaches to capture the dynamics, individual-based models, used for testing the steady state qR approach could be applied to generate simulated data sets to investigate the anticipated distortion in the information received from the lobster fishery when quotas and end-of-season closures are imposed.

The information used in the qR approach offers a number of practical advantages. The use of weight as a growth measure, rather than length, is advantageous in that weight, especially for larger and thus older animals, is a more accurate measure. Weight has a linear relationship with age, continuing to increase by amounts which are distinguishable for all but the largest animals. The measurement error of weight values measured at rock lobster ports, is about 3 significant digits, whereas for length is reliably measured to 2 significant digits. Counts of lobsters landed is even more accurate, not only because a count is discrete, but because the numbers in question must be accurate for compliance purposes and failure to properly enter the accurate number landed is a Fisheries Act code violation.

Under quota, unreported catch is a potential source of error. This will affect the estimates of absolute recruit numbers more strongly than that of exploitation rate. Because exploitation rate is implicitly derived from the *average* weight landed, under-reporting will have little effect on the measure of average weight if the size of the unreported catch is not greatly different from the reported catch. However, under-reporting would result in a comparable underestimate of total population numbers, and thus of total recruits. However, the annual trend in recruits should not be greatly biased if the non-reporting is consistent from year to year. The application of catch quotas since 1993 may have provided additional incentive for under-reporting of rock lobster catches.

The most reliable stock assessments are those which use several sources of data and methods of analysis. Consistent outcomes of different procedures gives confidence and provides a robust stock assessment.

6.7.5 Tagging based methods

6.7.5.1 Introduction

Tagging data have been used to study exploitation rate directly. This method is truly independent from the other methods used to estimate exploitation rate (both age and length based methods rely on common estimates of growth.

6.7.5.2 Methods

Tagging data are being analysed using three separate models.

6.7.5.2.1 Simple accounting model

The simplest model is a an accounting system which keeps track of the tagged population at risk of capture. This is done by accounting for tag releases, and the re-release recaptured (as reported), and natural mortality during and between seasons.

The model also incorporates tag retention and reporting rate variables, which are specified (see below). Weekly exploitation rates (number of recaptures/population at risk) are calculated and summed to produce an estimate of the exploitation rate during the season. The model is applied to specific marine fishing areas, and zones.

The model was written as:

$$N_{t+1} = (N_t - rC_t + R_t)e^{-M} + pT_t \qquad (1)$$

where:

- N_t = number of tagged lobsters at risk to harvest in week t of the study
- C_t = number of tagged lobsters caught and reported in week t
- R_t = number of tagged lobsters released after capture in week t
- T_t = number of lobsters tagged in week t
- r = tag reporting rate (ratio of total tags caught to tags reported)
- M = natural mortality plus long term tag loss rate per week
- p = initial tag loss plus tag-induced mortality rate.

For this simple population model, we know T_t, C_t, and R_t, and we must either provide independent estimates of the parameters (r, M, p) or somehow estimate these from the recovery data. Note that the model should not be applied to populations so small that N cannot safely be treated as a continuous variable with respect to the survival rate e^{-M}; we apply eq. (1) for catchability analysis only to space-time cases for which N>100. Further, eq. (1) ignores movement of lobsters among statistical units.

6.7.5.2.2 Maximum likelihood model for weekly tagged cohorts

The second, more complex, model was used for the relatively large, closed tag cohorts created on weekly time scales by tagging at the Zone spatial scale. This model assumes a week-Zone cohort c N_c was created at initial size $pT_{c,m'}$ for each week m' when tagging took place, then declined over weeks m according to the decay relationship

$$N_{c,m+1} = N_{c,m}(1 - U_{c,m})e^{-M^*} \qquad (2)$$

where M^*=weekly natural mortality rate

$U_{c,m}$=weekly exploitation rate suffered by cohort c during month m, estimated from total captures $rC_{c,m}$ during the week of all cohorts c' present in the zone that week:

$$U_{c,m} = \frac{r\sum_{c'} C_{c',m}}{\sum_{c'} N_{c',m}} \qquad (3).$$

This model differs from eq. (1) in using recoveries from all cohorts present in any month to provide an overall exploitation rate estimate for that month, which is then applied to predict decline in abundance of each cohort subject to the rate. It can be used to provide estimates of natural mortality M and tag retention proportion p as well as exploitation rates, since it predicts the number of recoveries $\hat{R}_{c,m}$ that should have been observed for each month from each cohort over time after tagging as $\hat{R}_{c,m} = (1/r)U_{c,m}N_{c,m}$. These predicted recovery rates are strongly dependent on p and

M ($\hat{R}_{c,m}$ predicted to be low for months m long after m', if M were high or p low), and can thus be compared to observed recovery rates $R_{c,m}$ to provide best-fitting estimates of p,M by a maximum likelihood criterion. We assume that each $R_{c,m}$ is distributed as an independent Poisson variable, with mean $\hat{R}_{c,m}$. This results in the following reduced log likelihood function to be maximised:

$$L = -\sum_{c,m} [\hat{R}_{c,m} - \ln(\hat{R}_{c,m}) R_{c,m}] \qquad (4)$$

(This is the log Poisson likelihood with terms involving only the data dropped; it depends on model parameters like M through the dependence of $\hat{R}_{c,m}$ on these parameters). Maximisation's were done using SOLVER (EXCEL™).

6.7.5.3 Discussion

Work is continuing on each method. The tagging study was not originally intended to provide estimates of mortality rates directly, however there appears to be value in considering these methods. The results from this work will be useful for evaluating how useful tagging might be for providing an independent annual assessment of mortality rates in future.

6.7.3 Estimates

Estimated F and U values are presented for males, females and combined sexes in Table 24. Estimated fishing mortalities are the total mortalities minus the assumed natural mortality of 0.10. Approximate exploitation rates (U) based on the tabled F values are presented in Table 25. Empty cells are the result of inadequate data sets, or uncertain parameter estimates (inputs to the mortality models). Results in each table are presented by season, for all seasons pooled and by method of estimation, except for the steady state qR results which are presented only for annual data for combined sexes.

Results were relatively consistent through time within each MFA for each method. As noted above the use of several methods to produce similar results provided some confidence that the results were relatively precise.

Highest rates of exploitation in the southern zone are found in MFA 56 and 58, where about 50 to 55 percent of the stock was removed by fishing annually. MFA 55 results indicate lower rates of exploitation around 40 to 45 percent.

Rates of exploitation are generally lower in the northern zone and ranged from 15 to 20 percent in MFA 15 to approximately 40 percent in MFA 39.

7. Extension of Results

Objectives
To **transfer results to industry and other user groups**.

To involve industry in research and educate them about the results and their consequences

Summary

From its inception, this project was meant to be a partnership between fishers, researchers and managers. There was a strong focus on involving the commercial fishers in every aspect of the work, and the success of the project as a whole is testimony to the success of involving them.

Extension of methods, as well as results, was primarily done in one of three ways. Primary contact was made by researchers visiting vessels and crews, often spending time at sea with them. During the research program researchers spent some time on more than half of the vessels in the fleet. Time on vessels usually allowed for plenty of exchange of ideas and information from biologists to fishers and from fishers to biologists.

There was also more formal contact between researchers, fishers and managers during annual research workshops. Three major workshops were convened during the term of the project, in June 1994, August 1995 and September 1996. The first workshop was convened to analyse results from the first year of research, but more importantly to begin to develop the population/fishery model which was a critical component of the project. Development of the model was expedited through the contributions made by Professor Carl Walters of the University of British Columbia. Before the workshop Dr Walters had developed a prototype model using the model framework he had developed for the Western Australian fishery. During the workshop the model was further adapted to the South Australian fishery by changing some of its components and adding new parameter estimates.

Working groups were established to report back to the workshop on specific aspects of the lobsters biology or fishery dynamics. Fishers were part of each working group and in some they provided the greatest input of information needed for the model. A report of the first workshop is attached.

The next workshop expanded on the first, primarily by analyses of the data from the field program, which by the time of the second workshop provided the first really good dataset for the analysis of growth rates, movement, maturity etc. The second workshop also demonstrated more about how the model could be used to assess the management options open to the fishery.

The final workshop was intended to explore, in greater detail, some plausible management options in the fishery. This was attempted so that fishers, in particular, would be made aware of the underlying assumptions, parameter estimates and the workings of the model such that their overall understanding and confidence in the model would be enhanced. The workshop also demonstrated the other models and means of assessing southern rock lobster stocks being used interstate and in New Zealand.

The workshops provided and important forum for researchers working on lobster biology, stock assessment, and modelling to meet and exchange information. In fact, the attendance of researchers, and several fishers, from other fisheries contributed significantly to each workshop.

During 1994 and 1995 researchers travelled to meet fishers in nine major ports in the state prior to the beginning of those seasons. During these meetings many of the workshop outcomes were presented so that fishers who did not attend the workshops were not completely excluded. The meetings also gave the fishers an opportunity to see and talk to the project staff. Importantly, these meetings were used to solicit and maintain the fishers support and involvement in the project. Attendance at these meetings ranged from very poor in one port to excellent in most others.

Six volumes of the Lobster Research Newsletter were published during the project. The newsletter provided reports on specific aspects of the work and reported on points of particular interest. They were meant to inform and enthuse project participants. Copies of these newsletters have been previously forwarded to FRDC.

To briefly summarise, there were exceptional opportunities for the extension of the results of this project to the commercial fishers and other researchers. Not all of these opportunities were completely capitalised on, however it is unlikely that any more extension could have been reasonably expected of the project.

8. Benefits

The benefits from the project generally fall into one of four categories: information (data), results (parameter estimates), methods (means by which to take advantage of the information and results); education.

Information
The project has produced a large volume of data. Many of the data have been analysed in one way or another. However, the data will form the basis for many future analyses and continue to produce useful results long after the project is over. Properly catalogued, and archived the data themselves will continue to be of immense benefit.

Results
We have provided estimates of nearly all of the population/biological variables which are important to the dynamics of this population. The results on their own have value, but are made much more valuable by virtue of having a means to use them.

Methods

The project has led to numerous methods of using the data and results of many analyses. Foremost amongst these is the spatial model of the fishery. This model uses virtually all of the parameter estimates derived during the project. Two, possibly three, new methods were developed to estimate mortality rates which allow more use of the data collected.

Education

The project educated every participating sector. Fishers learned research methods, and knowledge of the results. Research staff learned new methods, and learned how to work more closely with the fishers and how to effectively communicate their results to them.

Summary

The project has laid a solid foundation for the management of the lobster fishery in South Australia. In itself this is a valuable benefit to the state. Ultimately, how these data and assessment tools are used in the future by managers, fishers and researchers will determine their final value..

9. Intellectual Property

As custodian of the rock lobster stock, the South Australian government will own all data and information about the resource gained from the project either by employees or contractors. In principle, for the foreseeable future, these data and information will be treated as being in the public domain (and made available to third parties at the cost of extraction), but subject to the strictest guidelines to protect the confidentiality of individual fishers. The South Australian government will retain all rights to the software, but no charge will be made for its use in other Australian rock lobster fisheries.

10. Further development

Many analyses are yet to be done using data already collected and entered into the database. Most of the data from the 1996/97 fishing season have not been analysed because of deadlines for analyses for the completion of the research program in December 1996. More long-term tag recapture data will provide better estimates of growth in some areas and of females in particular.

Tag recoveries will continue to be recorded and entered into the database. It is estimated that a further 1000 to 2000 recoveries will be recorded during the 1997/98 season. Most of these recoveries will have been at liberty for three or four years.

The South Australian Rock Lobster Assessment Model will continue to be updated as new parameter estimates are available. The database will continue to develop. New tables are added to incorporate more historical data as they become available, and the database will be extended to accept data from the puerulus settlement dynamics program .

It is clear that many fishers are still unaware of the full potential to use the information that they helped collect during this project. Extension of the results through continued interactions with fishers in port, zone and management committee meetings should be a specific focus for the coming year.

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Appendices:

1. Database structure and user manual
2.Model user manual and scientific guide

References.

Aiken, D. E., and S. L. Waddy (1980). Reproductive biology of lobsters. In 'The Biology and Management of Lobsters'. (Eds. J. S. Cobb and B. F. Phillips.) pp. 215-276. (Academic Press: New York.)

Aldrich, J. C. and Lawler, I. F. (1996). The model-free analysis of growth curves. *Marine Ecology* **17(1-3)**, 491-500.Annala, J. H., and Breen, P. A. (1989). Yield- and egg-per-recruit analyses for the New Zealand rock lobster, *Jasus edwardsii*. *New Zealand Journal of Marine and Freshwater Research* **23**: 93-105.

Annala, J. H. (1981). Movements of rock lobsters *(Jasus edwardsii)* tagged near Gisborne, New Zealand. *New Zealand Journal of Marine and Freshwater Research* **15**: 437-443.

Annala, J. H. (1983). New Zealand rock lobsters: biology and fishery. *Fisheries Research Division, Occasional Publication* No. **42**.

Annala, J. H. and Bycroft, B.L. (1988). Growth of rock lobsters (*Jasus edwardsii*) in Fiordland, New Zealand. *New Zealand Journal of Marine and Freshwater Research* **22**: 29-41.

Annala, J. H.; Bycroft, B.L. (1993). Movements of rock lobsters *(Jasus edwardsii)* tagged in Fiordland, New Zealand. *New Zealand Journal of Marine and Freshwater Research* **27**: 183-190.

Anonymous (1978). SA rock lobsters travel up to 44 miles. *Australian Fisheries.* **37**, 38.

Beverton, R. J. H., and Holt, S. J. (1956). A review of methods for estimating mortality rates in exploited fish populations, with special reference to sources of bias in catch sampling. *Rapports et proces-verbaux des reunions, Conseil international pour l'Exploration de la Mer* **140**, 67-83.

Brown, R.S. & Caputi, N. 1986. Conservation of recruitment of the western rock lobster (*Panulirus cygnus*) by improving survival and growth of undersized lobsters captured and returned by fishermen to the sea. Abstract in Workshop on Rock Lobster Ecology and Management. ed B.F. Phillips. CSIRO Marine Laboratories Report 207

Fabens, A. J. (1965). Properties and fitting of the von Bertalanffy growth curve. *Growth* **29**: 265-89.

Fielder, D. R. (1964). The spiny lobster, *Jasus lalandii,* (H. Milne Edwards) in South Australia. II. Reproduction. *Australian Journal of Marine and Freshwater Research* **15**(2):133-144.

Francis, R. I. C. C. (1988). Maximum likelihood estimation of growth and growth variability from tagging data. *New Zealand Journal of Marine and Freshwater Research* **22**: 42-51.

Hampton, J., and Majkowski, J. (1987). A Simulation Model for Generating Catch Length-Frequency Data. In 'Length-Based Methods in Fisheries Research'. (Eds. D. Pauly and G. R. Morgan.) pp. 193-202. (International Center for Living Aquatic Resources Management: Kuwait.)

Herrnkind, W. F. (1977). Movement patterns in palinurid lobsters. *In*: Phillips, B.F.; Cobb, J.S. *eds*, Workshop on lobster and rock lobster ecology and physiology. *CSIRO Division of Fisheries and Oceanography circular* **7**: 209-244.

Hilborn, R. and Walters, C. J. (1992). 'Quantitative Fisheries Stock Assessment: choice, dynamics and uncertainty.' (Chapman and Hall: London.)

Jernakoff, P., Fitzpatrick, J., Phillips, B.F., and De Boer, E. (1994). Density and growth in populations of juvenile wester rock lobsters, *Panulirus cygnus* (George) **45**: 69-81.

Lewis, R. K. (1975). Report on studies of the western population of the southern rock lobster. *South Australian Fishing Industry Council* **4**: 9-14.

Lewis, R.K. (1977). Studies on juvenile and adult stages of western population of southern rock lobster (*Jasus novaehollandiae* Holthius) in the south-east region of South Australia, (abstract) p.34. *In* Phillips, B.F.; Cobb, J.S. *Eds*, Workshop on Lobster and Rock Lobster Ecology and Physiology. *CSIRO Divsion of Fisheries and Oceanography circular*. **7**, Melbourne.

Lewis, R. K. (1988). Southern rock lobster (*Jasus novaehollandiae*) - a review of the Zone S fishery. Internal Report. *South Australian Department of Fisheries, Adelaide*. 13p.

MacDairmid, A.B. (1989) Size at onset of maturity and size-dependant reproductive output of female and male spiny lobsters *Jasus edwardsii* (Hutton) (decapoda, Palinuridae) in northern New Zealand. *N.Z. J. Exp. Mar. Biol. Ecol. 127*: 229-243.MacDiarmid, A. B.; Hickey, B.; Maller, R.A. (1991). Daily movement patterns of the spiny lobster *Jasus edwardsii* (Hutton) on a shallow reef in northern New Zealand. *Journal of Experimental Marine Biology and Ecology* **147**: 185-205.

McGarvey, R. (1994). An age-structured open-access fishery model. *Canadian Journal of Fisheries and Aquatic Sciences*, **51**: 900-12.

McKoy, J. L. (1983). Movements of rock lobsters, *Jasus edwardsii* (Decapoda:Palinuridae), tagged near Stewart Island, New Zealand. *New Zealand journal of marine and freshwater research* **17**: 357-366.

McKoy, J. L. and Esterman, D.B. (1981). Growth of rock lobsters (*Jasus edwardsii*) in the Gisborne region, New Zealand. *New Zealand Journal of Marine and Freshwater Research* **15**: 121-136.

Moore, R. and MacFarlane, J.W. (1984). Migration of the ornate rock lobster, *Panulirus ornatus* (Fabricius), in Papua New Guinea. *Australian journal of marine and freshwater research*. **35**:197-212.

Morgan, G. R., (1980). Population dynamics of Spiny Lobsters. In 'The Biology and Management of Lobsters'. pp. 189-217. (Eds. J. S. Cobb and B.F. Phillips.) Academic Press, New York.

Musgrove, R. (1995) Condition and its assessment in the southern rock lobster, *Jasus edwardsii*. FRDC Report 95/017.

Newman G. G. and D. E. Pollock. Growth of the Rock lobster *Jasus lalandi* and Its Relationship to the Benthos. *Marine Biology* **24:** 339-346

Palmer, M. J., Phillips, B. F. and Smith, G. T. (1991). Application of nonlinear models with random coefficients to growth data. *Biometrics* **47**: 623-35.

Pearn, R. (1994). Rock lobster tagging shows movement occurs. *Fishing Today*. **7(5)**:27-29.

Phillips, B. F., Palmer, M. J., Cruz, R. and Trendall, J. T. (1992). Estimating growth of the Spiny Lobsters *Panulirus cygnus, P. argus* and *P. ornatus. Australian Journal of Marine and Freshwater Research* **43**: 1177-88.

Pitcher, T. J. and MacDonald, P. D. M. (1973). Two models for seasonal growth in fishes. *Journal of applied ecology* **10**: 599-606.

Polacheck, T.R., Hilborn, R., and Punt, A. E. 1993. Fitting surplus production models: comparing methods and measuring uncertainty. Canadian Journal of Fisheries and Aquatic Sciences **50**: 2597-2607.

Pollock, D. E (1995). Changes in Maturation Ages and Sizes in Crustacean and Fish populations. *S. Afr. J. Mar. Sci* **15:** 99-103

Pollock, D. E. and Roscoe, M.J. (1977). The growth at moulting of crawfish *Jasus tristini* at Tristan da Cunha, South Atlantic. *J. Cons. Int. Explor. Mer* **37(2)**: 144-146.

Pollock, D.E. & Melville-Smith, R. 1993. Decapod life histories and reproductive dynamics in relation to oceanography off southern Africa. S.Afr. J. Mar. Sci. **13**: 205-212

Polovina, J. J. 1989. Density Dependence in the Spiny Lobster, Panulirus marginatus, in the Northwestern Hawaiian Islands. Can. J. Fish. Aquat. Sci. **6**:660-665.

Polovina, J. J., and Mitchum, G.T. (1993) Spiny lobster recruitment and sea level: results of a 1990 forecast. *Fishery Bulletin*, **92**: 203-205.

Ramm, D. C. (1980). Electromagnetic tracking of rock lobsters *(Jasus novahollandiae). Australian journal of marine and freshwater research.* **31**:263-269.

Treble, R. J. (1996). The southern rock lobster *(Jasus edwardsii)*: Fisheries biology and abundance estimation. *PhD Thesis*. Department of Zoology, The University of Melbourne.

Venzon, D.J., and Moolgavkar, S.H. (1988). A method for computing profile-likelihood-based confidence intervals. Applied Statistics **37**: 87-94.

von Bertalanffy, L. (1938). A quantitative theory of organic growth (Inquiries on growth laws II). *Human Biology*, **10(2)**: 181-213.

Yoshimoto, S. S., and Clarke, R.P. (1993). Comparing dynamic versions of the Schaefer and Fox production models and their application to lobster fisheries. *Canadian J. of Fisheries and Aquatic Sciences*, **50**: 181-189.

Table 1. Frequency of recapture of lobsters to June 1997 is presented.

Number of times recaptured (recapture category)	Individual lobsters in category	Recaptures accounted for by this category
1	10657	10657
2	2514	5028
3	726	2178
4	205	820
5	74	370
6	20	120
7	8	56
8	4	32
9	1	9
12	1	12
Total	14210	19282

Table 2. Numbers and percentage of females recorded mature at the time of release and immature at the time of recapture is presented by category of capturer.

Capturer category at release	Capturer category at recapture	Number of long setose females released	Number long setose releases recaptured as short setose	Percent change
volunteer tagger	volunteer tagger	5553	121	2.2%
volunteer tagger	skilled fisher	460	19	4.1%
volunteer tagger	ordinary fisher	3978	310	7.8%
biologist	volunteer tagger	2890	31	1.1%
biologist	biologist	48	0	0.0%

Table 3. Numbers of pots and lobsters sampled during the catch monitoring programme are presented from the 1991/92 to the 1995/96 fishing seasons.

Season	Pots Sampled	Lobsters sampled
1991/92	22894	48998
1992/93	27964	55134
1993/94	20742	39609
1994/95	5770	8503
1995/96	12905	25333

Table 4. Monthly proportions of females in the catch are presented for six fishing areas and five fishing seasons and as pooled estimates across seasons. The fraction of the females of legal size females that were not spawning during the 1995/96 season are also presented and used to correct for the numbers of females in the landed catch in other seasons.

MFA 55	Oct	Nov	Dec	Jan	Feb	Mar	Apr
91/92		0.58	0.50	0.40	0.39	0.48	0.35
92/93	0.46	0.52	0.55	0.55	0.51	0.51	0.39
93/94	0.52	0.72	0.68	0.60	0.61	0.49	0.39
94/95	0.51	0.61	0.56	0.44	0.27	0.33	0.29
95/96	0.49	0.57	0.57	0.46	0.48	0.48	0.52
pooled	0.50	0.58	0.54	0.48	0.47	0.49	0.39
correction for spawning	0.76	0.86	0.97	0.98	1.00	1.00	1.00
corrected pooled	0.38	0.50	0.52	0.47	0.47	0.49	0.39
MFA 56							
91/92		0.44	0.37	0.34	0.36	0.41	0.45
92/93	0.52	0.52	0.48	0.44	0.45	0.42	0.45
93/94	0.60	0.47	0.49	0.47	0.40	0.43	0.51
94/95	0.39	0.51	0.69	0.54	0.39	0.40	0.45
95/96	0.46	0.52	0.51	0.44	0.40	0.98	0.45
pooled	0.52	0.51	0.47	0.41	0.39	0.41	0.45
correction for spawning	0.51	0.81	0.95	0.99	0.99	1.00	1.00
corrected pooled	0.26	0.41	0.45	0.41	0.39	0.41	0.45
MFA 58							
91/92	0.54	0.51	0.50	0.39	0.41	0.42	0.52
92/93	0.51	0.37	0.59	0.48	0.49	0.43	0.49
93/94	0.60	0.47	0.49	0.47	0.40	0.43	0.51
94/95	0.39	0.51	0.69	0.54	0.45	0.40	0.49
95/96	0.54	0.59	0.45	0.48	0.45	0.58	0.45
pooled 58	0.54	0.51	0.54	0.47	0.45	0.47	0.49
correction for spawning	0.63	0.88	1.00	0.98	1.00	0.97	1.00
corrected pooled	0.34	0.45	0.54	0.47	0.45	0.45	0.49
MFA 28	Nov	Dec	Jan	Feb	Mar	Apr	May
91/92	0.53	0.53	0.48	0.45	0.43	0.44	0.42
92/93	0.55	0.56	0.50	0.44	0.44	0.42	0.42
93/94	0.63	0.54	0.45	0.42	0.42	0.41	0.34
94/95	0.60	0.57	0.40	0.46	0.53	0.41	0.50
95/96	0.58	0.55	0.49	0.47	0.45	0.34	
pooled	0.58	0.55	0.47	0.45	0.44	0.42	0.43
correction for spawning	0.91	0.98	1.00	0.98	1.00	1.00	1.00
corrected pooled	0.53	0.54	0.47	0.44	0.44	0.42	0.43
MFA 39							
91/92	0.49	0.52	0.38	0.38	0.43	0.45	0.38
92/93	0.53	0.59	0.54	0.44	0.50	0.49	0.34
93/94	0.55	0.64	0.47	0.41	0.46	0.42	0.26
94/95	0.56	0.56	0.45	0.43		0.00	0.36
95/96	0.58	0.55	0.43	0.40	0.53	0.60	0.47
pooled	0.53	0.55	0.45	0.41	0.48	0.47	0.37
correction for spawning	0.91	0.98	1.00	0.98	1.00	1.00	1.00
corrected pooled	0.48	0.54	0.45	0.41	0.48	0.47	0.37
MFA 48							
91/92	0.54	0.48	0.47	0.39	0.49	0.42	0.45
92/93	0.56	0.54	0.50	0.47	0.48	0.45	0.43
93/94	0.71	0.51	0.54	0.47	0.33	0.27	0.43
94/95	0.67	0.67	0.46	0.39	0.46	0.39	
95/96	0.45	0.57	0.56	0.56	0.67	0.50	0.40
pooled	0.53	0.53	0.51	0.44	0.49	0.39	0.43
correction for spawning	0.89	0.98	0.99	1.00	1.00	1.00	1.00
corrected pooled	0.47	0.52	0.51	0.44	0.49	0.39	0.43

Table 5. Presented are the weighted seasonal proportions of the catch which were females of legal length. The weights applied were the monthly catch, in numbers, of the respective marine fishing area. Spawning females were included as "catch" in this table.

	season				
MFA	91/92	92/93	93/94	94/95	95/96
28	0.48	0.50	0.50	0.49	0.51
39	0.49	0.53	0.53	0.55	0.57
48	0.48	0.51	0.50	0.42	0.52
55	0.46	0.53	0.53	0.51	0.51
56	0.40	0.47	0.46	0.45	0.52
58	0.50	0.50	0.47	0.49	0.52

Table 6. Presented are the weighted seasonal proportions of the landed catch which were female. As above the catch numbers from the respective marine fishing area were used to weight the catches and the proportion of spawning females observed in each month and area were used to correct for females which could not be landed because of their egg-bearing condition.

	season				
MFA	91/92	92/93	93/94	94/95	95/96
28	0.48	0.49	0.49	0.49	0.50
39	0.47	0.51	0.51	0.53	0.55
48	0.47	0.50	0.49	0.42	0.51
55	0.43	0.52	0.51	0.47	0.49
56	0.36	0.44	0.43	0.44	0.50
58	0.45	0.48	0.44	0.48	0.49

Table 7. The GROTAG parameter estimates, mean annual growth at 100 and 140 mm CL for male lobsters by Marine Fishing Area (MFA).

MFA	%L	g100	%U		%L	g140	%U	n
58	14.15	14.48	14.81		6.64	7.54	8.50	844
56	14.65	14.97	15.30		7.96	8.71	9.49	1188
55	16.93	17.32	17.72		12.41	13.03	13.64	1263
51	15.83	17.12	18.54		12.11	13.64	15.35	83
50	14.38	15.55	16.83		6.76	10.11	13.61	79
49	16.74	17.53	18.34		8.49	9.33	11.10	244
48	17.58	18.50	19.28		9.73	11.50	13.35	224
38	15.14	16.15	17.23		7.75	8.83	10.12	164
44	17.40	19.90	22.62		8.58	10.44	12.67	33
26	18.45	19.50	20.54		10.27	10.93	12.66	108
39	17.75	18.29	18.81		9.77	10.31	13.48	439
28	17.59	18.31	18.91		7.35	8.21	9.33	275
40	19.99	20.52	21.06		13.04	14.12	15.21	246
33	19.45	20.25	21.15		9.81	12.05	14.47	130
15	20.25	21.57	22.79		13.04	13.75	14.56	69
27	19.53	21.01	22.58		9.68	12.11	15.82	40
30	17.73	19.26	20.86		8.17	10.35	12.66	20
46	8.95	9.75	10.65		5.40	7.76	10.58	86

Table 8. The GROTAG parameter estimates, mean annual growth at 100 and 120 mm CL for female lobsters by Marine Fishing Area (MFA).

MFA	%L	g100	%U		%L	g120	%L	n
58	0.029	6.66	0.029		0.074	2.10	0.057	1309
56	0.025	6.79	0.024		0.039	2.68	0.062	1818
55	0.011	9.68	0.008		0.008	5.52	0.012	2723
51	0.062	11.94	0.051		0.047	6.57	0.066	155
50	0.057	8.24	0.059		0.172	3.33	0.000	209
49	0.056	8.78	0.059		0.095	3.58	0.185	282
48	0.029	11.14	0.013		0.013	4.78	0.066	336
38	0.065	7.79	0.070		0.095	4.09	0.118	193
26	0.063	9.47	0.064		0.081	4.40	0.119	203
44	0.107	12.81	0.166		0.201	6.21	0.170	31
39	0.026	10.17	0.015		0.015	3.45	0.036	875
28	0.040	9.47	0.054		0.083	3.47	0.084	395
33	0.035	14.91	0.040		0.164	4.50	0.478	86
40	0.417	14.22	-0.021		0.025	7.66	0.025	392
27	0.061	13.49	0.080		0.235	5.46	0.201	62

Table 9a. The GROTAG parameter estimates, mean annual growth for female lobsters less than the length of 50 percent maturity, by Marine Fishing Area.

MFA	%L	g90	%U		%L	g100	%U	n
58	0.035	9.51	0.037		0.051	5.87	0.054	1100
56	0.035	9.35	0.037		0.047	6.08	0.048	1417
55	0.034	13.85	0.035		0.038	9.90	0.039	1154
51	0.106	13.73	0.139		0.095	12.89	0.096	61
50	0.069	10.71	0.075		0.104	7.86	0.112	127
49	0.075	12.23	0.086		0.081	8.47	0.087	185
48	0.053	15.54	0.054		0.058	11.07	0.057	218
38	0.084	10.27	0.096		0.099	7.55	0.115	117
44	0.157	15.87	0.188		0.212	14.05	0.289	18
39	0.041	14.80	0.041		0.043	10.26	0.043	497
28	0.056	14.03	0.058		0.057	10.20	0.060	268
33	0.195	5.91	0.251		0.233	4.65	0.210	72
40	0.043	17.71	0.045		0.048	14.77	0.050	229
27	0.108	16.99	0.103		0.067	14.25	0.086	49
26	0.085	12.56	0.097		0.124	9.85	0.140	139

Table 9b. The GROTAG parameter estimates, mean annual growth for female lobsters greater than the length of 50 percent maturity, by Marine Fishing Area.

MFA	%L	g110	%U		%L	g120	%U	n
58	0.099	3.96	0.101		0.112	2.69	0.153	209
56	0.062	4.83	0.066		0.078	2.93	0.090	401
55	0.018	6.28	0.014		0.013	4.76	0.015	1569
51	0.054	9.49	0.041		0.036	6.70	0.046	7
50	0.039	9.21	0.028		0.100	6.26	0.087	82
49	0.109	4.20	0.063		0.056	3.59	0.100	97
48	0.100	5.81	0.122		0.100	4.03	0.084	118
38	0.145	4.68	0.147		0.110	3.91	0.140	76
44								*13
39	0.061	4.60	0.063		0.062	2.58	0.058	378
28	0.085	4.27	0.062		0.044	3.18	0.076	127
33								*14
40	0.038	7.05	0.037		0.028	5.39	0.035	163
27								*13
26								*64

Table 10. The GROTAG parameter estimates, mean growth at 100 and 140 mm CL for male lobsters, by growth zone.

Growth Zone	MFA	g100	g140
WNZ (western northern zone)	1-15, 18, 27	20.40	13.40
HNZ (high growth northern zone)	26, 28, 39, 48	18.29	10.97
YRK (Yorke Peninsula)	33, 40, 44	20.61	13.56
CNZ (central northern zone)	38, 49, 50	17.06	10.15
NSZ (northern southern zone)	50, 51, 55	17.42	12.58
SSZ (southern southern zone)	56, 58	14.86	8.12

Table 11. The GROTAG parameter estimates, mean growth at 100 and 120 mm CL for all female lobsters, by growth zone.

Growth Zone	MFA	g100	g120
WNZ (western northern zone)	1-15, 18, 27	12.59	8.19
HNZ (high growth northern zone)	26, 28, 39, 48	10.47	3.65
YRK (Yorke Peninsula)	33, 40, 44	14.48	7.20
CNZ (central northern zone)	38, 49, 50	8.64	3.66
NSZ (northern southern zone)	50, 51, 55	10.02	5.71
SSZ (southern southern zone)	56, 58	6.86	2.65

Table 12. The GROTAG parameter estimates, mean growth at 90 and 100 mm CL for females less than the length of 50 percent maturity and growth at 100 and 120 mm CL for female lobsters greater than the length of 50 percent maturity, by growth zone.

		< 50 %mature			>50 % mature	
Growth Zone	MFA	g90	g100		g100	g120
WNZ (western northern zone)	1-15, 18, 27	17.00	12.57		5.11	4.39
HNZ (high growth northern zone)	26, 28, 39, 48	14.78	10.75		4.10	2.91
YRK (Yorke Peninsula)	33, 40, 44	18.49	14.72		8.36	5.90
CNZ (central northern zone)	38, 49, 50	11.87	8.04		4.32	3.73
NSZ (northern southern zone)	50, 51, 55	14.16	10.38		6.62	5.00
SSZ (southern southern zone)	56, 58	9.47	5.89		4.43	2.84

Table 13a. Standard deviations for mean annual growth at lengths of 100 and 140 mm CL for male lobsters, by growth zones.

Growth Zone	100	140
WNZ (western northern zone)	4.95	4.42
HNZ (high growth northern zone)	6.29	5.42
YRK (Yorke Peninsula)	4.74	4.56
CNZ (central northern zone)	5.79	4.94
NSZ (northern southern zone)	6.92	6.21
SSZ (southern southern zone)	5.65	4.76
Total southern zone	6.30	5.56

Table 13b. Standard deviations for mean annual growth at lengths of 100 and 120 mm CL for all female lobsters, by growth zone.

Growth Zone	100	120
WNZ (western northern zone)	4.23	3.82
HNZ (high growth northern zone)	5.09	3.64
YRK (Yorke Peninsula)	4.95	3.61
CNZ (central northern zone)	4.48	3.14
NSZ (northern southern zone)	5.75	4.20
SSZ (southern southern zone)	4.72	3.62

Table 14. Number of tagged lobsters released and recaptured in five movement regions between August 1993 and May 1996, by sex at time of release. Note: Female lobsters may have changed reproductive status between release and recapture. M = male; IMF = immature female; MF = mature female; EBF = egg-bearing female.

Movement region	**Numbers released**				**Numbers recaptured**				Mean time at liberty
	M	**IMF**	**MF**	**EBF**	**M**	**IMF**	**MF**	**EBF**	
West Coast	3121	2873	1351	337	568	273	510	23	328
Kangaroo Is.	4302	4527	1010	1344	885	561	930	119	314
Yorke Pen.	1578	1671	139	276	319	192	212	13	309
Coorong	634	593	92	99	76	42	88	22	361
Southeast	11894	9391	6397	4054	3342	1798	3039	982	277

Table 15. Numbers of lobsters moving distances of defined intervals, by sex and reproductive status at time of release. M = male; IMF = immature female; MF = mature female; EBF = egg-bearing female. West Coast (WC); Kangaroo Island (KI); Yorke Peninsula (YP); Coorong (CO); South East (SE).

Region	**0 - 5 km**				**>5 - 20 km**				**>20 km**				**Total**
	M	**IMF**	**MF**	**EBF**	**M**	**IMF**	**MF**	**EBF**	**M**	**IMF**	**MF**	**EBF**	
WC	314	128	285	14	15	9	13	1	6	7	5	1	798
KI.	463	255	553	64	24	12	13	1	12	10	5	0	1412
YP	153	72	102	6	16	12	12	0	30	25	8	1	437
CO	27	19	36	8	3	2	0	2	11	13	7	0	128
SE	1164	601	1230	411	209	117	160	46	31	24	16	6	4015

Table 16. Results of pairwise comparisons of length-weight curves using likelihood ratio tests.

Comparison	Probability
Male v Female	0.000
Female damaged v female undamaged	0.001
Red undamaged Female v speckly undamaged female	0.675
Red damaged female v speckly damaged female	0.636
Damaged male v undamaged male	0.000
Speckly damaged male v red damaged male	0.936
Speckly undamaged male v red undamaged male	0.523
Undamaged Port Lincoln male v undamaged Robe male	0.349
Undamaged Port Lincoln male v undamaged Pondalowie male	0.687
Undamaged Port Lincoln male v undamaged Carpenters Rocks male	0.137
Undamaged Robe male v undamaged Carpenters Rocks male	0.126
Undamaged Robe male v undamaged Pondalowie male	0.276
Undamaged Carpenters Rocks male v undamaged Pondalowie male	0.081

Table 17. Parameter values of the length-weight equations for male and female lobsters, including only lobsters with no damage, and all lobsters in the sample of each sex.

undamaged lobsters only			all lobsters in sample		
parameters	male	female	parameters	male	female
a	0.00058	0.00090	a	0.00054	0.00090
b	2.96582	2.8913	b	2.9796	2.8875
R^2	0.989	0.975	R^2	0.989	0.970
n	343	286	n	456	383

Table 18. Estimates of the mean length at maturity (Lm) in Marine Fishing Areas during five seasons and all seasons pooled, and the values of the parameter C of the logistic length of maturity curve which describes the steepness of the curve.

	Marine Fishing Areas								
season	**15**	**28**	**39**	**40**	**48/49**	**51**	**55**	**56**	**58**
Mean lengths at maturity									
1991/92	110.4	105.3	103.9	113.5	100.8	111.6	109.8	91.0	96.9
1992/93	108.9	103.4	104.0	112.6	101.1	107.2	103.7	90.4	98.8
1993/94	103.0	101.4	103.5	111.2	103.9	115.5	104.2	92.9	96.0
1994/95	99.0	103.1	107.1	113.5	103.2			95.6	
1995/96	102.6	100.4	98.5	114.5	106.0	116.0	107.8	92.0	95.6
pooled	106.2	103.0	104.1	112.5	102.0	112.4	106.3	91.7	96.9
"C" Parameter									
1991/92	0.1680	0.1700	0.0943	0.2504	0.1422	0.0980	0.1143	0.1246	0.1737
1992/93	0.2631	0.1971	0.0832	0.1376	0.1604	0.0938	0.1298	0.1736	0.1283
1993/94	0.0894	0.2106	0.1121	0.1316	0.1696	0.1855	0.1023	0.1689	0.1882
1994/95	0.1770	0.2625	0.0830	0.2511	0.1906			0.2293	
1995/96	0.1504	0.1665	0.0866	0.1301	0.1274	0.2084	0.1099	0.1793	0.1442
pooled	0.1525	0.1944	0.0920	0.1365	0.1534	0.1173	0.1134	0.1663	0.1528

Table 19. Correlations between area-seasonal deviations of the mean length at maturity from the average of all seasonal estimates on the respective areas.

MFAs	**15**	**28**	**39**	**40**	**48/49**	**51**	**55**	**56**	**58**
15									
28	0.63								
39	-0.10	0.60							
40	-0.07	0.03	-0.35						
48/49	-0.72	-0.92	-0.62	0.24					
51	-0.82	-0.67	-0.63	0.08	0.83				
55	0.25	0.35	-0.31	0.72	0.01	0.27			
56	-0.90	-0.26	0.46	0.01	0.39	0.90	-0.13		
58	0.75	0.60	0.64	-0.17	-0.80	-0.99	-0.39	-0.13	

Table 20. Matrix of probabilities that curves of maturation were common between areas, determined by likelihood ratio tests. Non significant (P>0.05)probabilities are highlighted.

MFAs	**15**	**28**	**39**	**40**	**48/49**	**51**	**55**	**56**	**58**
15									
28	0.0004								
39	0.0152	0.0012							
40	0.0000	0.0000	0.0000						
48/49	0.0000	0.0991	0.0055	0.0000					
51	0.0000	0.0000	0.0085	0.0580	0.0000				
55	0.0570	0.0029	0.9747	0.0001	0.0195	0.0168			
56	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000		
58	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	

Table 21. Parameters of the logistic vulnerability model are presented by sex and MFA for weighted (by sample size) and unweighted data. A subjective assessment of the model is indicated, where Re is reliability g = good; m = moderate; and p = poor (see discussion section 6.5).

	Female					**Male**				
	Unweighted Model		**Weighted model**			**Unweighted Model**		**Weighted model**		
MFA	**c**	**L_{50V}**	**c**	**L_{50V}**	**Re**	**c**	**L_{50V}**	**c**	**L_{50V}**	**Re**
58	0.269	89.73	0.299	89.94	g	0.282	88.33	0.312	88.37	g
56	0.423	87.14	0.499	87.35	g	0.311	88.52	0.340	88.58	g
55	0.158	89.70	0.130	87.79	p	0.098	97.95	0.098	97.95	m
48/49	0.140	94.98	0.128	94.41	m	0.179	95.99	0.177	95.79	m
40						0.141	108.51	0.150	108.01	m
39	0.201	85.80	0.202	85.48	p	0.100	106.00	0.097	105.67	m
28	0.102	103.11	0.147	103.74	m	0.115	104.27	0.097	105.58	m
15	0.116	117.31	0.130	116.98	m	0.071	127.51	0.071	125.42	m

Table 22. Estimated vulnerability at the relevant legal minimum length (LML), by sex and marine fishing area.

MFA	LML	female vulnerability at LML	male vulnerability at LML
58	98.5	0.93	0.96
56	98.5	1.00	0.97
55	98.5	0.80	0.51
48/49	102	0.73	0.75
40	102	0.50	0.29
39	102	0.97	0.41
28	102	0.44	0.41
15	102	0.13	0.16

Table 23. Average weights, by age, for harvested lobsters in the northern and southern zones, starting from the age of recruitment a_R. The value for a_R is equivalent to the number of years the lobster was in the fishable stock.

a_R	Northern zone (weight kg)	Southern zone (weight kg)
1	0.516	0.446
2	0.782	0.658
3	1.044	0.890
4	1.288	1.131
5	1.508	1.375
6	1.701	1.614
7	1.868	1.846
8	2.012	2.066
9	2.134	2.273
10	2.237	2.465
11	2.324	2.643
12	2.396	2.807
13	2.457	2.956

Table 24. Fishing mortality values estimated for five fishing seasons and pooled season data, by the methods of Beverton and Holt, Jones and Van Zalinge, fitted population curve and qR. Values are shown for eight of the important marine fishing areas by sex and combined.

Season	Method	15	28	39	40	48/49	55	56	58
Males									
91/92	Bev/Holt	0.16	0.24	0.57	0.62	0.52	0.58	0.98	1.55
	Jones/Van						0.44	0.80	1.15
92/93	Bev/Holt	0.15	0.23	0.47	0.38	0.40	0.51	0.94	0.65
	Jones/Van						0.49	0.85	0.64
93/94	Bev/Holt	0.18	0.22	0.47	0.73	0.46	0.55	0.70	0.65
	Jones/Van						0.57	0.59	0.58
94/95	Bev/Holt	0.13	0.22	0.55		0.44	0.56	0.78	
	Jones/Van						0.75	0.66	
95/96	Bev/Holt	0.18	0.31	0.67	0.46	0.57	0.44	0.73	0.85
	Jones/Van						0.43	0.68	0.87
pooled	Bev/Holt	0.16	0.24	0.53	0.48	0.47	0.50	0.87	0.81
	Jones/Van	0.27	0.27	0.65	0.54	0.49	0.44	0.71	0.70
	Fit curve				0.42	0.28	0.37	0.56	0.67
Females									
91/92	Bev/Holt		0.18	0.36	0.43	0.47	0.28	0.92	0.89
	Jones/Van						0.23	0.80	0.81
92/93	Bev/Holt		0.18	0.19	0.24	0.41	0.33	0.64	0.60
	Jones/Van						0.38	0.56	0.54
93/94	Bev/Holt		0.15	0.25	0.21	0.36	0.39	0.58	0.77
	Jones/Van						0.38	0.49	0.64
94/95	Bev/Holt		0.17	0.25		0.36	0.39	0.39	
	Jones/Van						0.39	0.37	
95/96	Bev/Holt		0.21	0.31	0.29	0.54	0.26	0.54	0.80
	Jones/Van						0.30	0.51	0.72
pooled	Bev/Holt		0.18	0.25	0.28	0.47	0.33	0.61	0.71
	Jones/Van		0.11	0.28	0.36	0.38	0.30	0.52	0.63
	Fit curve					0.17		0.55	0.36
Combined Sexes									
91/92	qR	0.11	0.34	0.55	0.37	0.56	0.43	0.77	0.84
	Bev/Holt		0.21	0.47	0.53	0.49	0.45	0.96	1.30
	Jones/Van						0.35	0.80	1.02
92/93	qR	0.12	0.31	0.51	0.28	0.52	0.40	0.74	0.78
	Bev/Holt		0.21	0.33	0.32	0.41	0.41	0.79	0.63
	Jones/Van						0.43	0.71	0.59
93/94	qR	0.13	0.29	0.50	0.32	0.48	0.36	0.66	0.81
	Bev/Holt		0.19	0.36	0.46	0.42	0.47	0.64	0.70
	Jones/Van						0.48	0.54	0.61
94/95	qR	0.12	0.30	0.44	0.28	0.45	0.34	0.64	0.83
	Bev/Holt		0.19	0.40		0.39	0.47	0.58	
	Jones/Van						0.56	0.51	
95/96	qR	0.12	0.33	0.42	0.24	0.50	0.33	0.64	0.86
	Bev/Holt		0.26	0.48	0.38	0.55	0.35	0.63	0.82
	Jones/Van						0.37	0.59	0.79
pooled	Bev/Holt		0.21	0.39	0.38	0.47	0.42	0.75	0.76
	Jones/Van		0.19	0.47	0.46	0.44	0.37	0.62	0.67
	Fit Curve					0.23		0.56	0.52

Table 25. Exploitation rates (*U*) derived from estimates of fishing mortality shown in Table 24 in the case of the three length based methods or directly by the qR method. Estimates shown for five fishing seasons and pooled season data Values are shown for eight of the important marine fishing areas by sex and combined.

Season	Method	15	28	39	40	48/49	55	56	58
Males									
91/92	Bev/Holt	15	21	44	46	41	44	62	79
	Jones/Van						35	55	68
92/93	Bev/Holt	14	20	38	32	33	40	61	48
	Jones/Van						39	57	47
93/94	Bev/Holt	17	20	38	52	37	42	50	48
	Jones/Van						44	44	44
94/95	Bev/Holt	12	20	42		36	43	54	
	Jones/Van						53	49	
95/96	Bev/Holt	17	27	49	37	44	36	52	57
	Jones/Van						35	49	58
pooled	Bev/Holt	15	21	41	38	38	40	58	55
	Jones/Van	24	24	48	42	39	36	51	51
	Fit curve				34	24	31	43	49
Females									
91/92	Bev/Holt		17	30	35	37	25	60	59
	Jones/Van						20	55	56
92/93	Bev/Holt		16	17	22	34	28	47	45
	Jones/Van						39	57	47
93/94	Bev/Holt		14	22	19	31	32	44	54
	Jones/Van						32	39	47
94/95	Bev/Holt		16	22		30	32	32	
	Jones/Van						32	31	
95/96	Bev/Holt		19	26	25	41	23	42	55
	Jones/Van						26	40	51
pooled	Bev/Holt		17	22	24	37	28	46	51
	Jones/Van		10	25	30	32	26	40	47
	Fit curve					16		42	30
Combined Sexes									
91/92	qR	10	29	43	31	43	35	54	57
	Bev/Holt		19	38	41	39	36	62	73
	Jones/Van						29	55	64
92/93	qR	12	27	40	24	40	33	52	54
	Bev/Holt		19	28	27	34	34	55	47
	Jones/Van						35	51	45
93/94	qR	12	25	39	28	38	30	48	56
	Bev/Holt		17	30	37	34	37	47	51
	Jones/Van						44	44	44
94/95	qR	11	26	36	25	36	29	47	56
	Bev/Holt		18	33		33	38	44	
	Jones/Van						43	40	
95/96	qR	12	28	34	21	40	28	48	58
	Bev/Holt		23	38	31	43	30	47	56
	Jones/Van						31	44	55
pooled	Bev/Holt		19	32	32	38	34	53	53
	Jones/Van		17	37	37	35	31	46	49
	Fit Curve					20		43	41

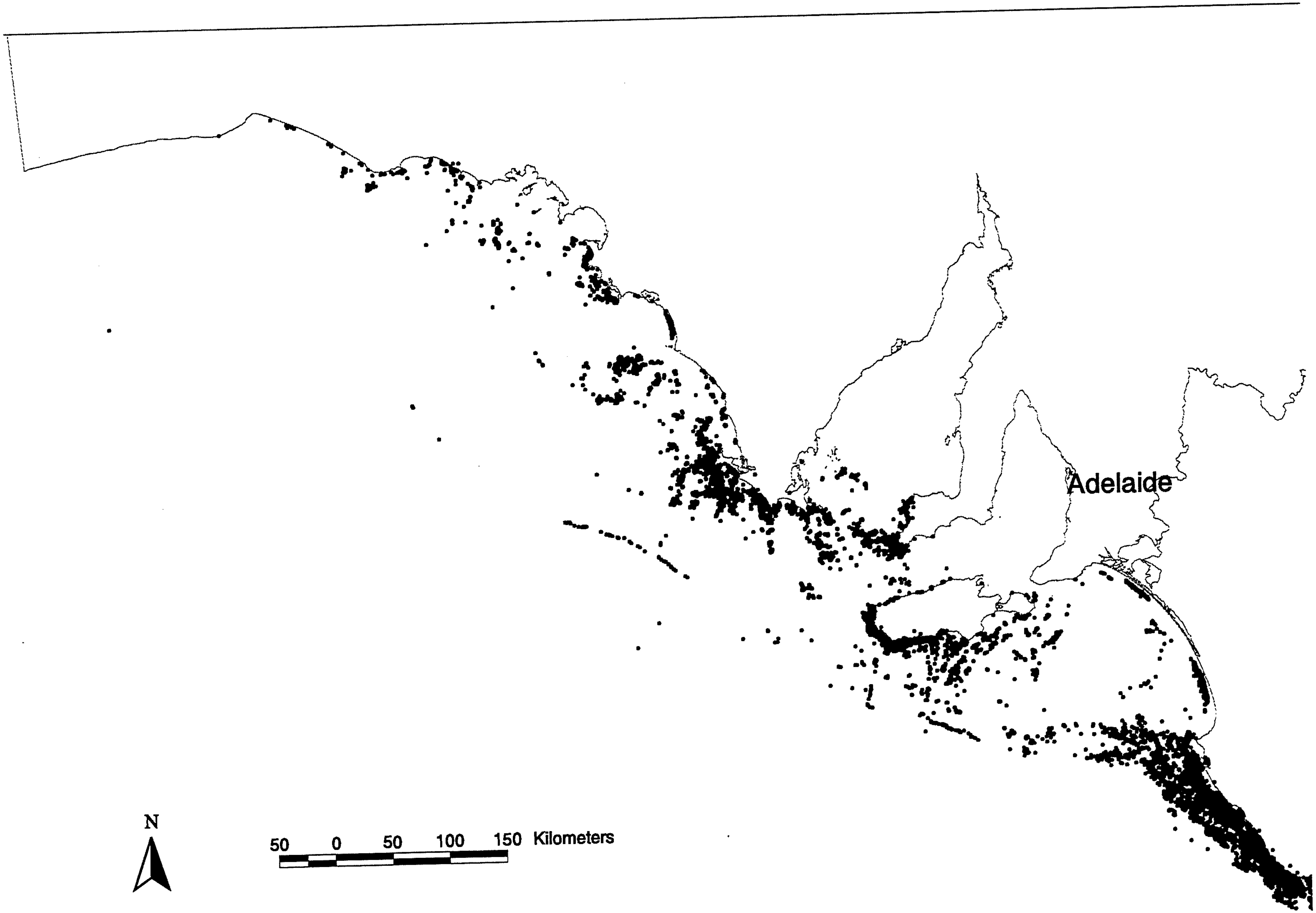


Fig 1. Release Positions for Lobsters Tagged 1993-1996

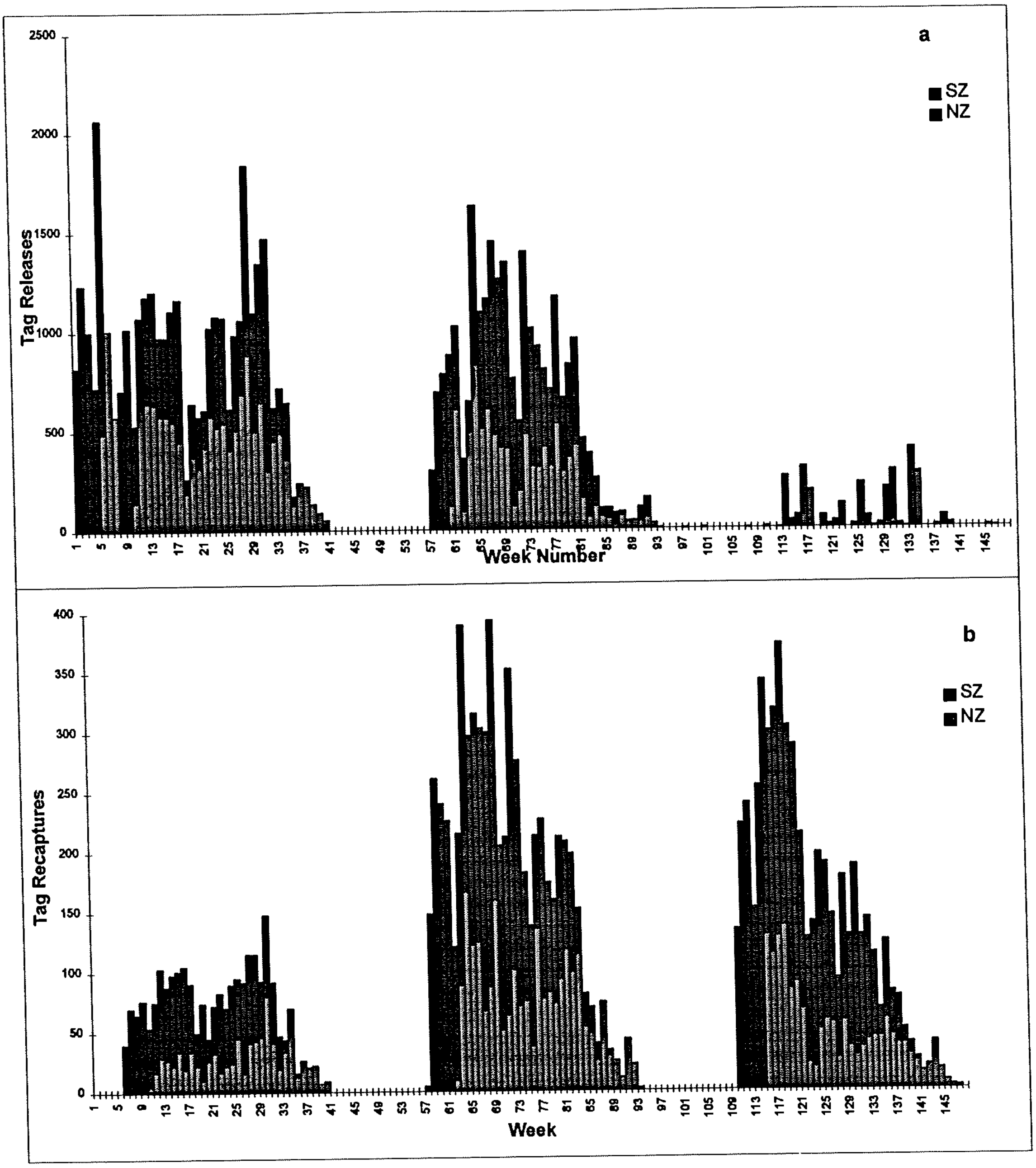


Figure 2. Tag releases (a) and recaptures (b) by week of study in the northern and southern zones. Week 1 commenced on 26 August 1993.

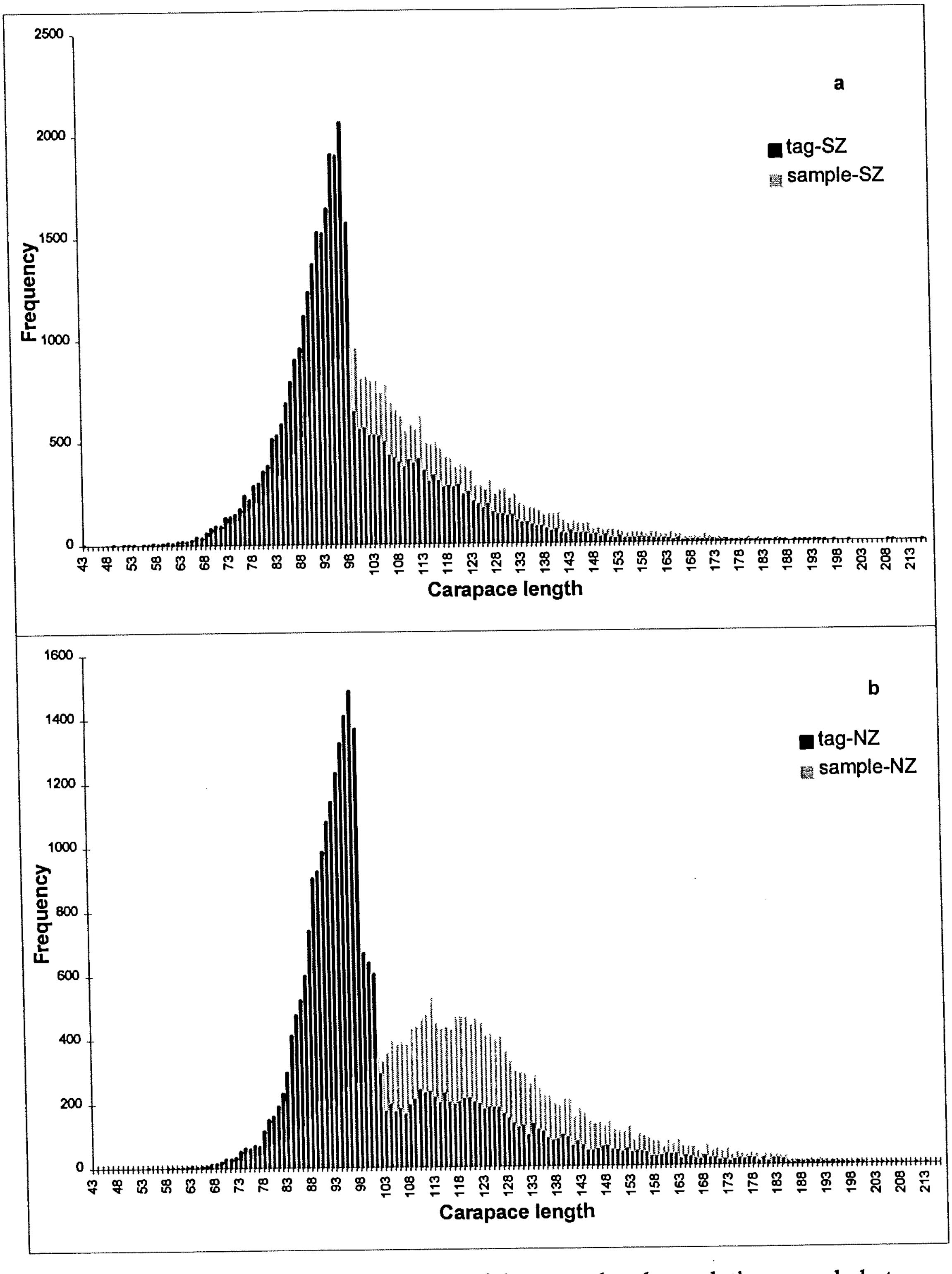


Figure 3. Length frequency distributions of the tagged and population sampled at sea in the southern zone (a) and northern zone (b).

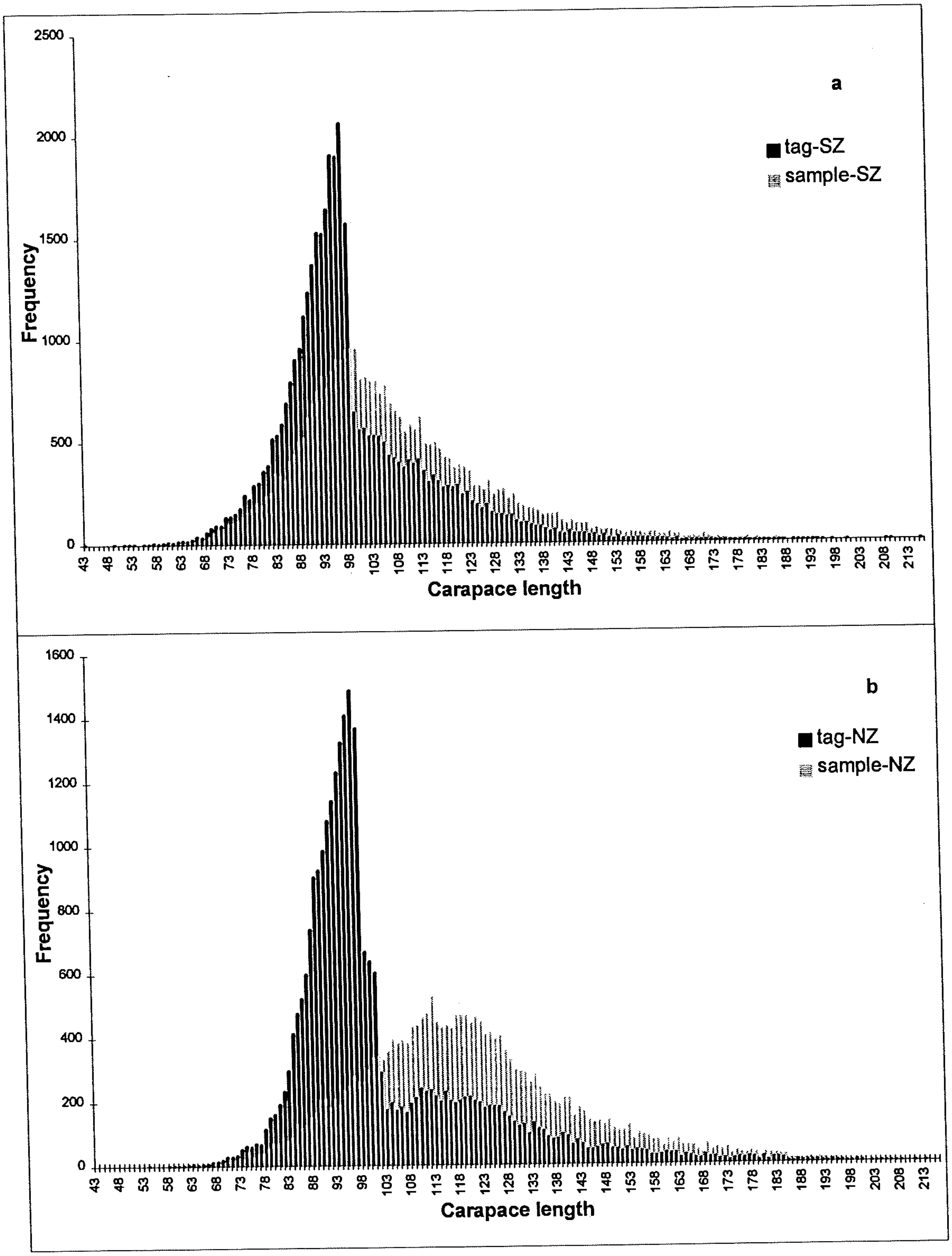


Figure 3. Length frequency distributions of the tagged and population sampled at sea in the southern zone (a) and northern zone (b).

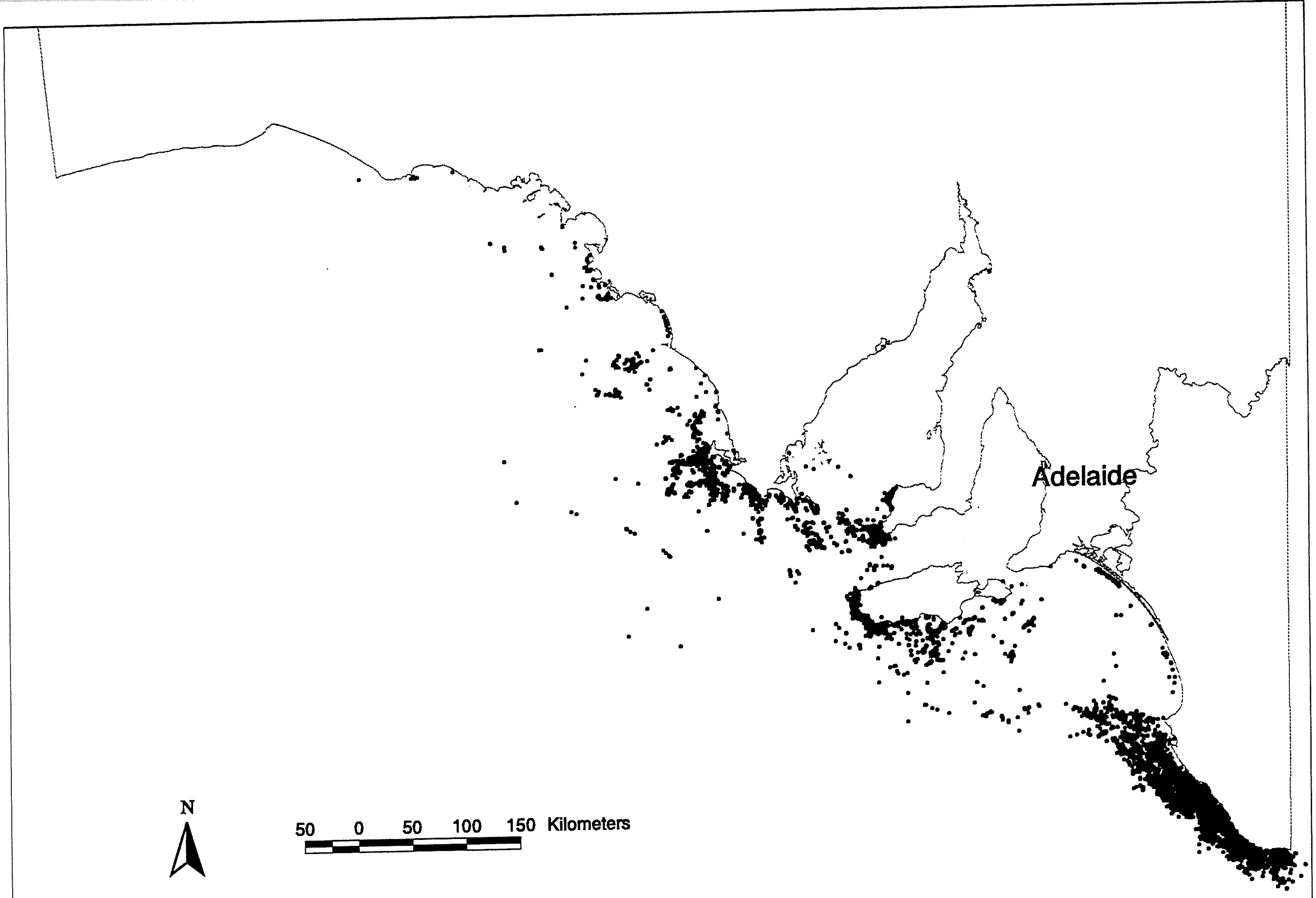


Fig 4. Recapture Positions for Lobsters Tagged 1993-1996

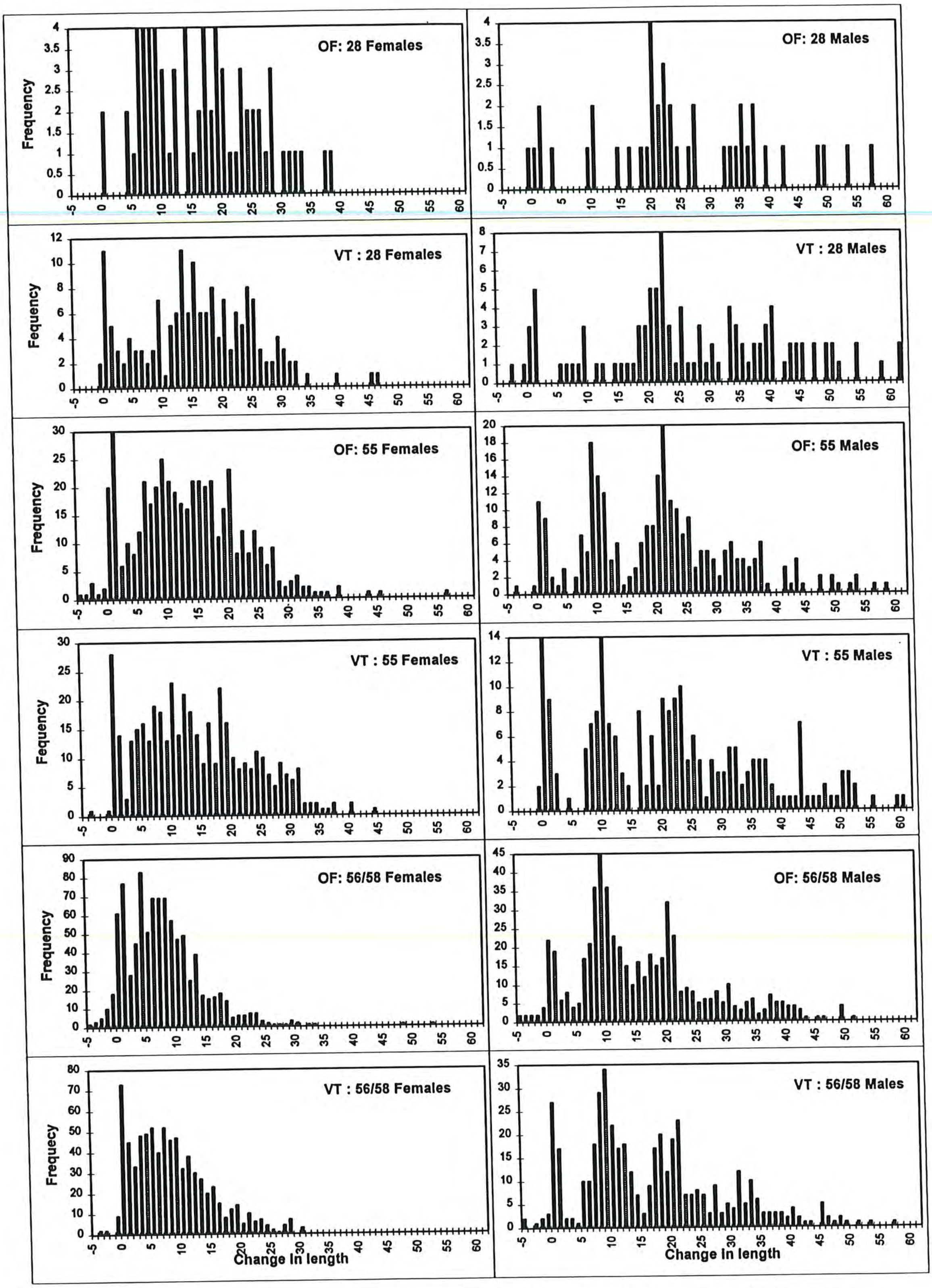


Figure 5. Change in length of 90-100 mm female and male lobsters measured in Marine fishing areas 28, 55, and 56 and 58 combined presented by capturer categories of volunteer taggers (VT), ordinary fishers (OF). All lobsters in these "populations" were originally released by biologists or volunteer taggers.

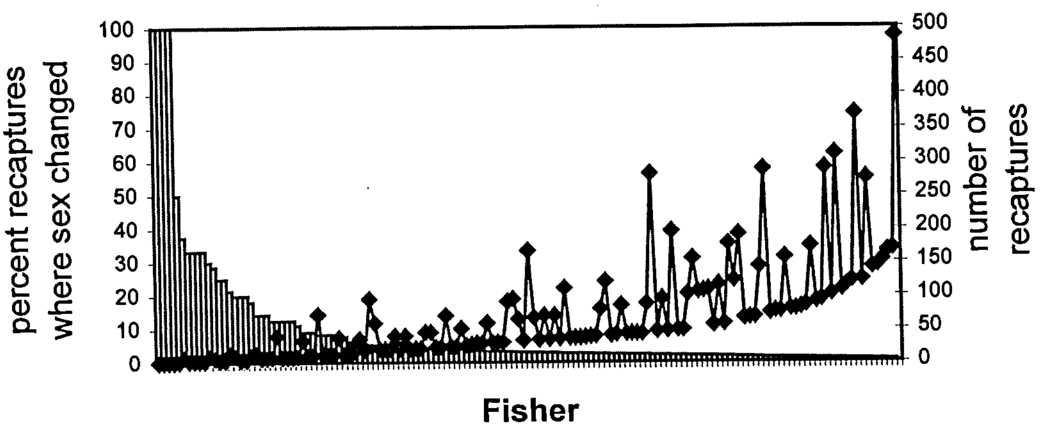


Figure 6. Percent of recaptured lobsters where the sex recorded at recapture was not the same as the sex recorded at the time of release (bars), and the number of recaptures reported by the corresponding fishers (line). Note that most of the apparent errors were reported by a few fishers who recaptured only a few lobsters.

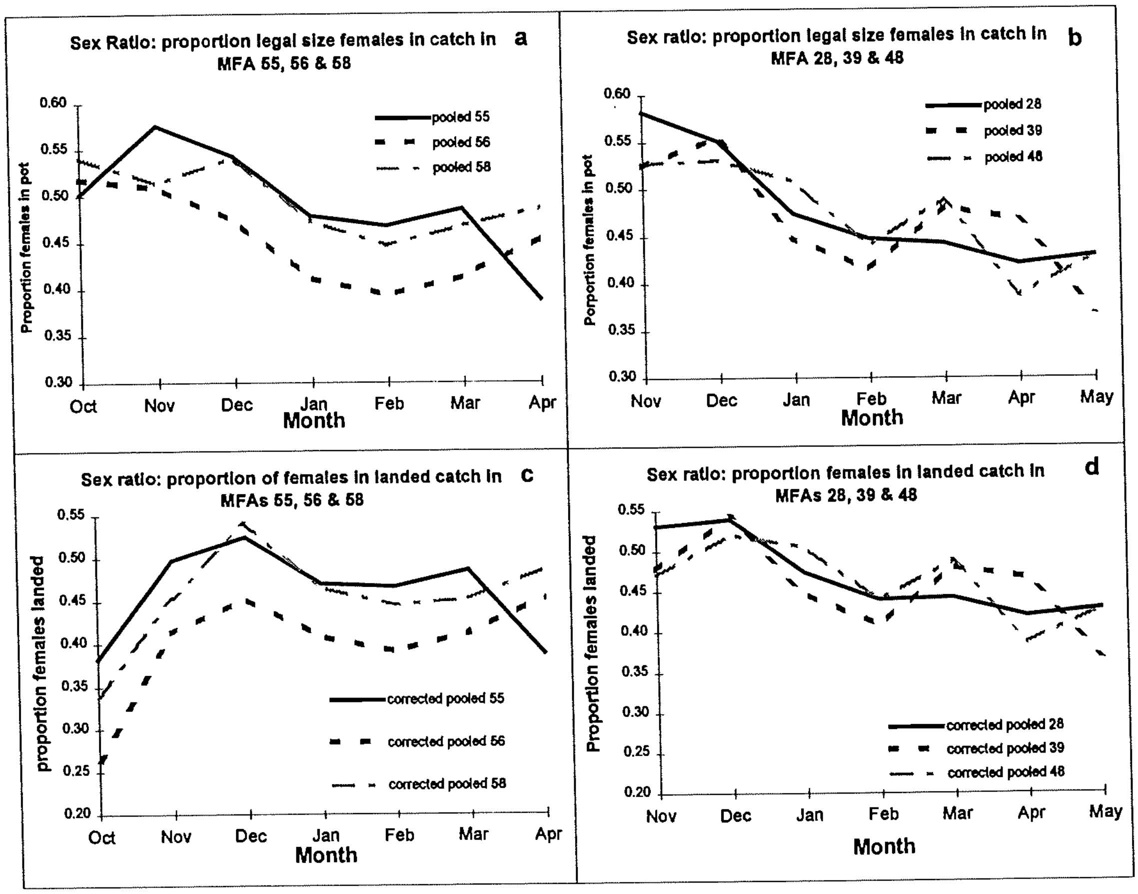


Figure 7. The proportion of females brought to the surface in lobster pots (a, b) and actually landed (c,d) are presented fro the southern zone marine fishing areas 55, 56, and 58, and northern zone areas 28, 39, and 48. Data graphed were pooled data sets from the 1991/92 to 1995/96 seasons.

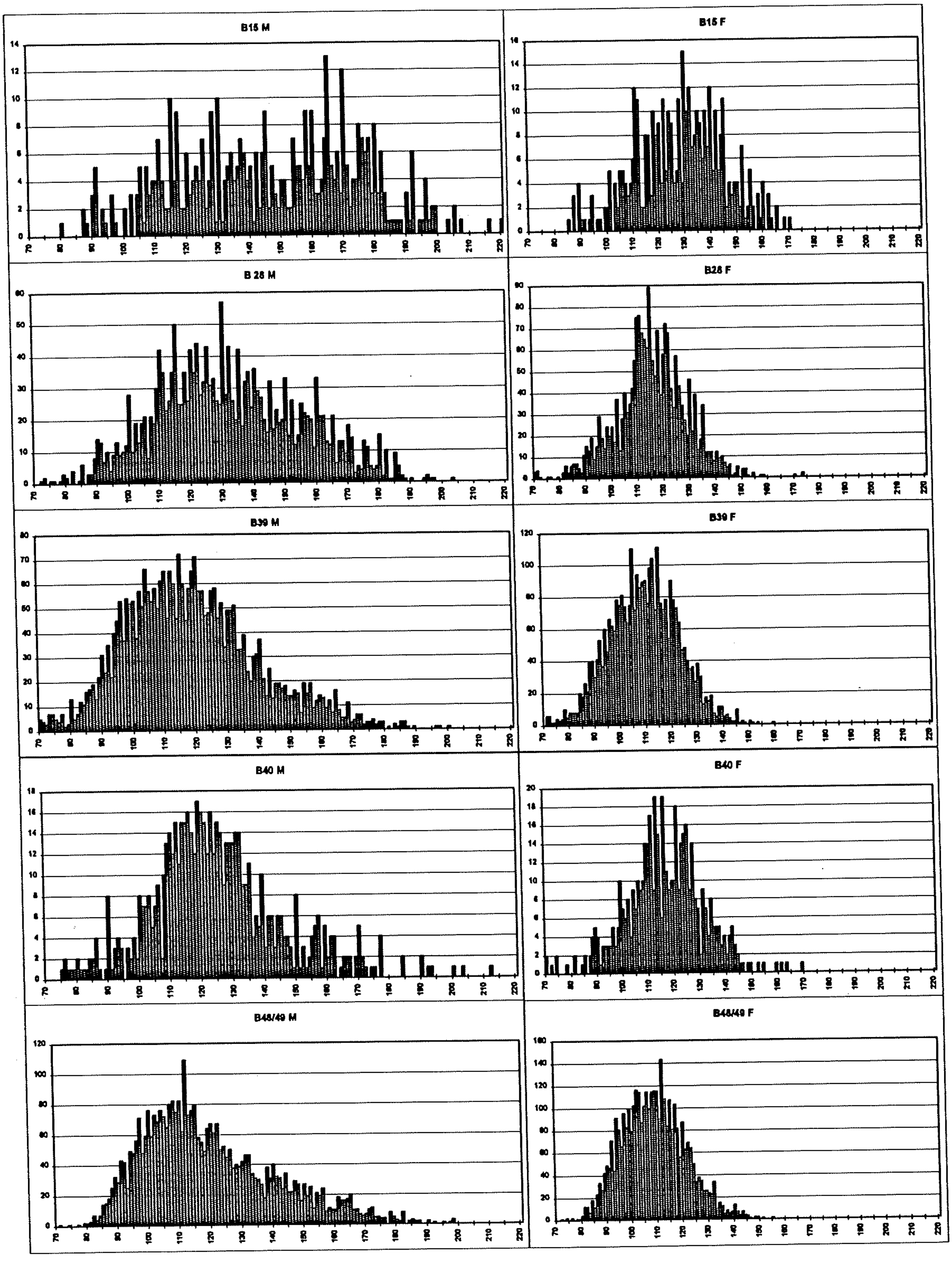


Figure 8a. Length Frequency histograms of the lobsters sampled in the indicated northern zone fishing areas during the 1991/92 fishing season.

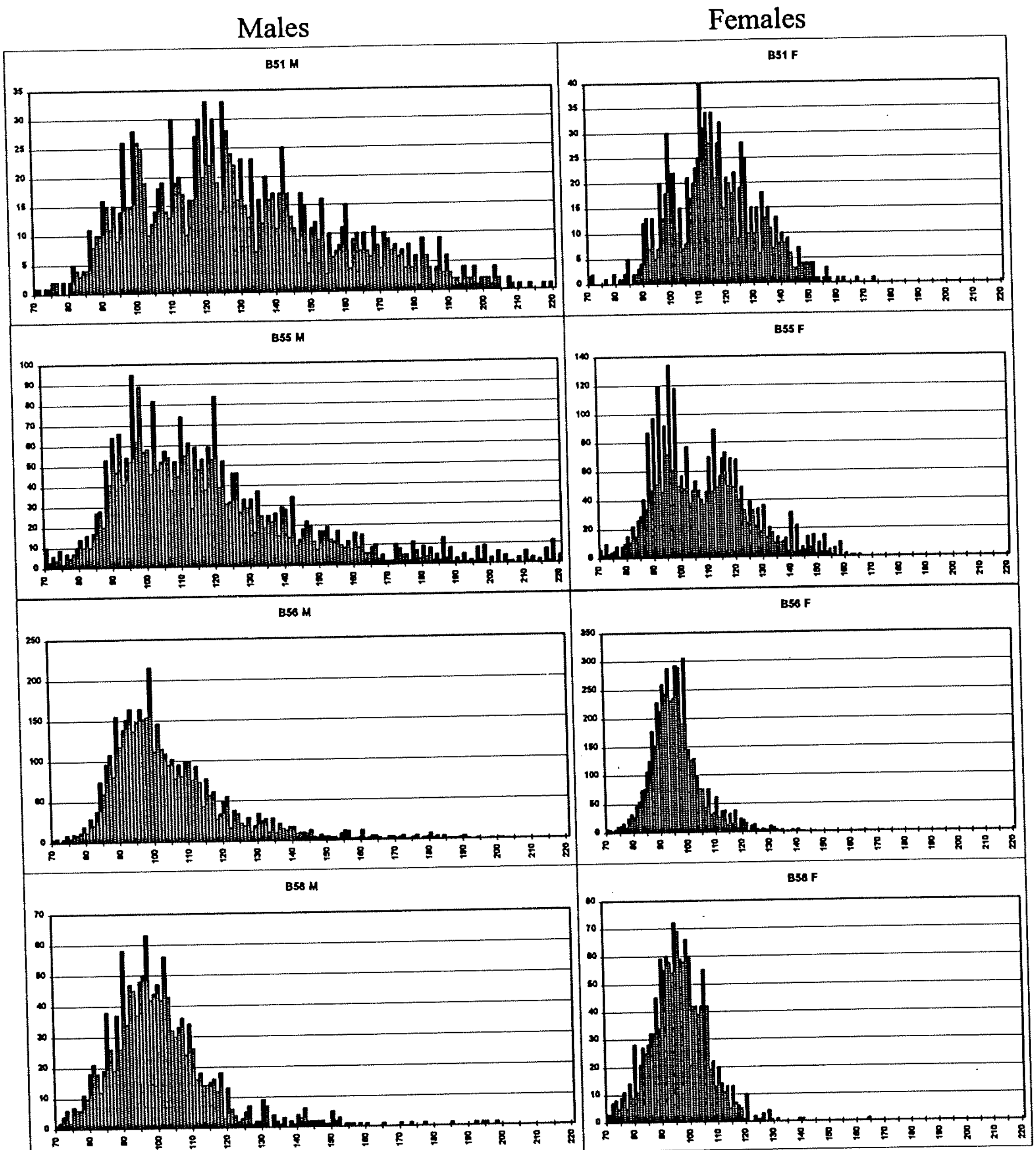


Figure 8b. Length Frequency histograms of the lobsters sampled in the indicated southern zone fishing areas during the 1991/92 fishing season.

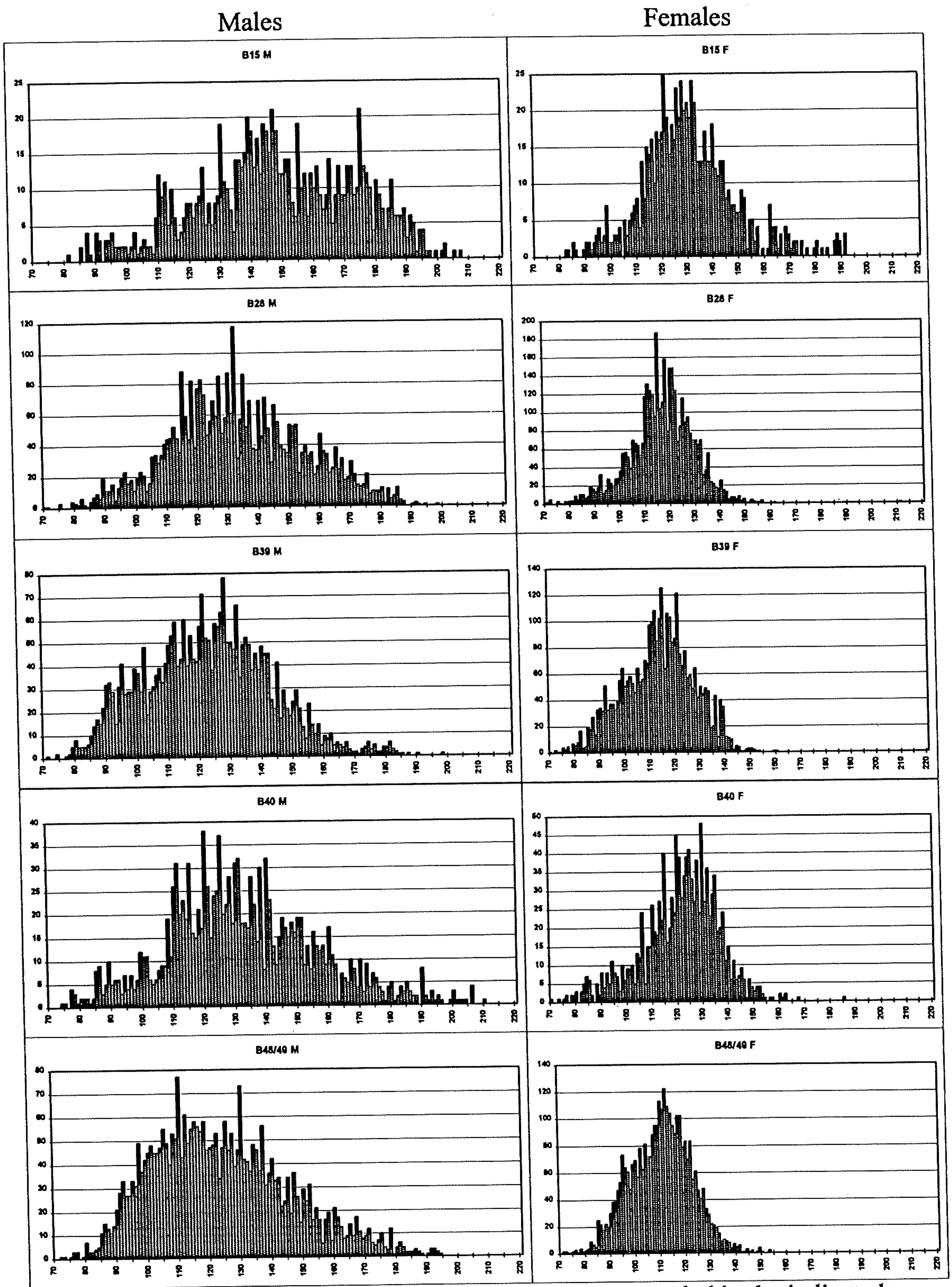


Figure 8c. Length Frequency histograms of the lobsters sampled in the indicated northern zone fishing areas during the 1992/93 fishing season.

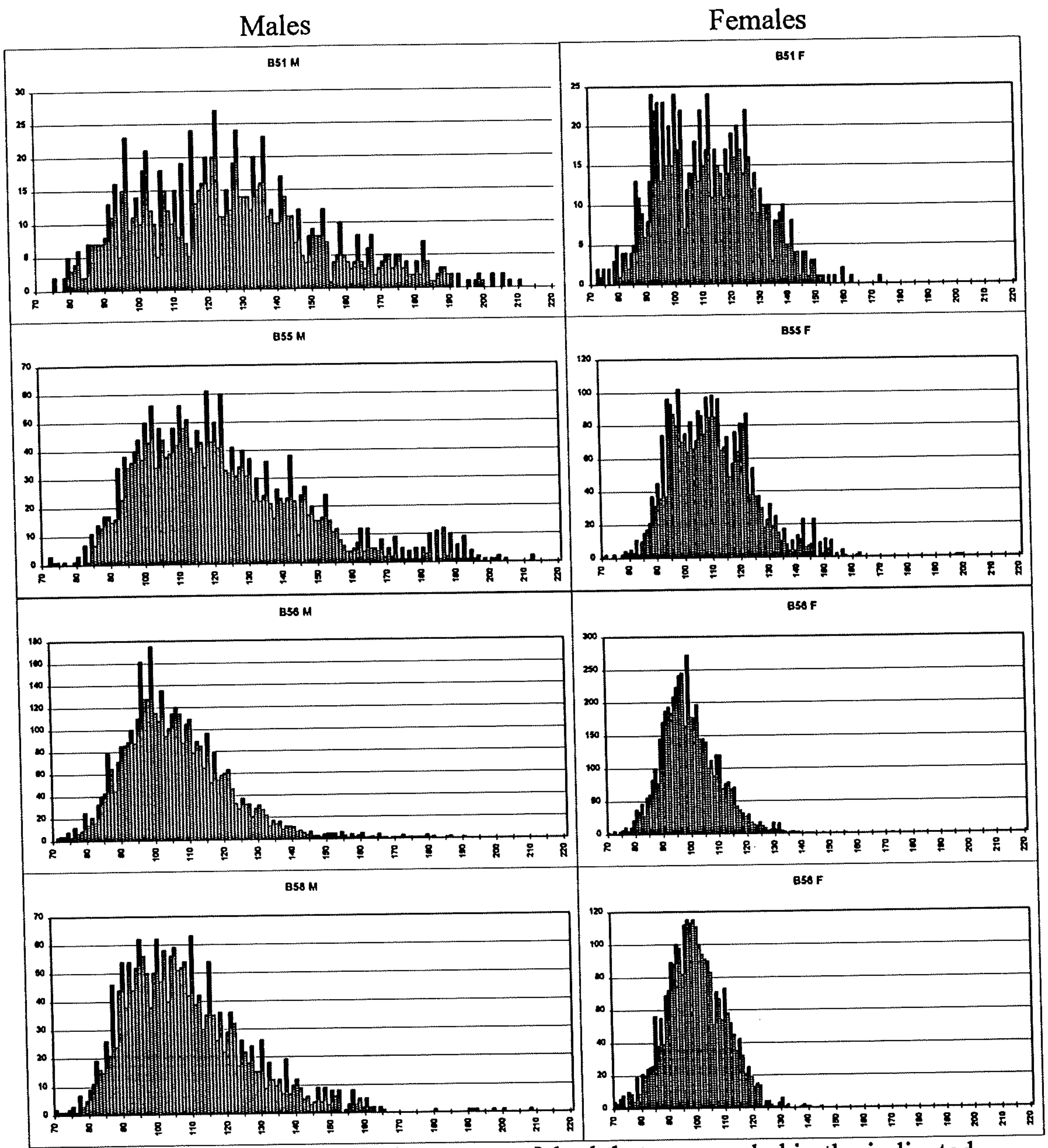


Figure 8d. Length Frequency histograms of the lobsters sampled in the indicated southern zone fishing areas during the 1992/93 fishing season.

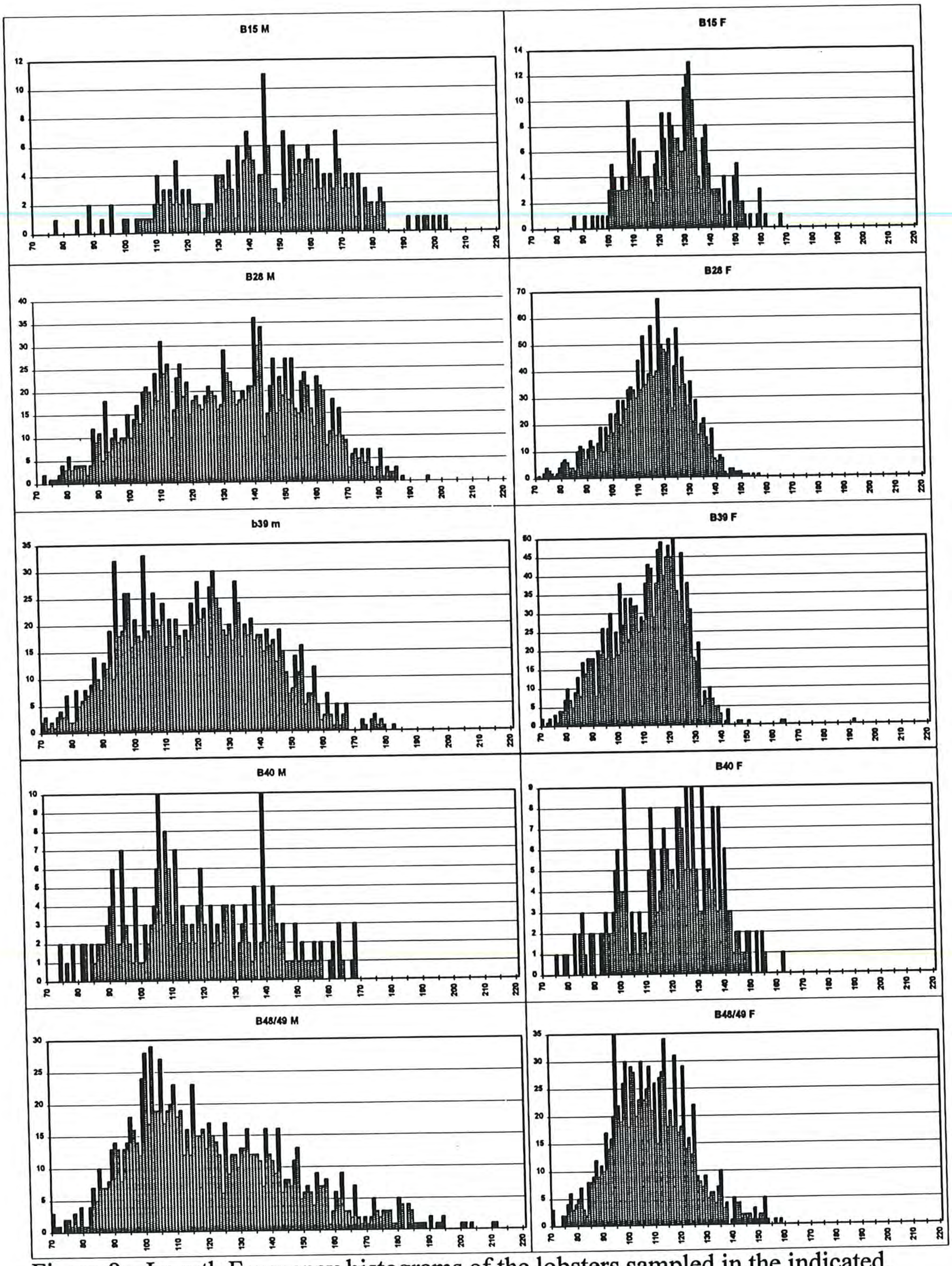


Figure 8e. Length Frequency histograms of the lobsters sampled in the indicated northern zone fishing areas during the 1993/94 fishing season.

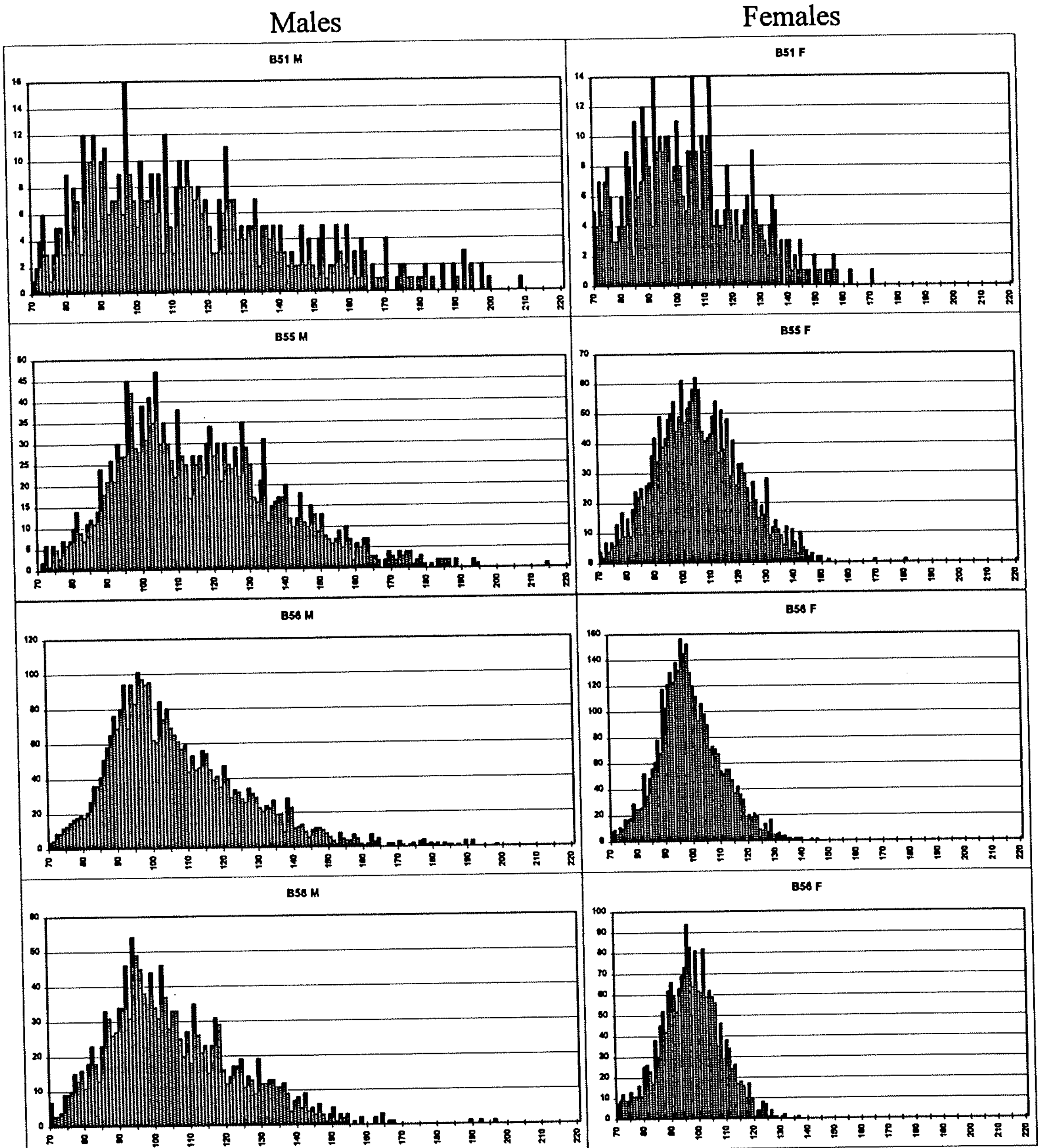


Figure 8f. Length frequency histograms of lobsters sampled in the indicated southern zone fishing areas during the 1993/94 fishing season.

Males Females

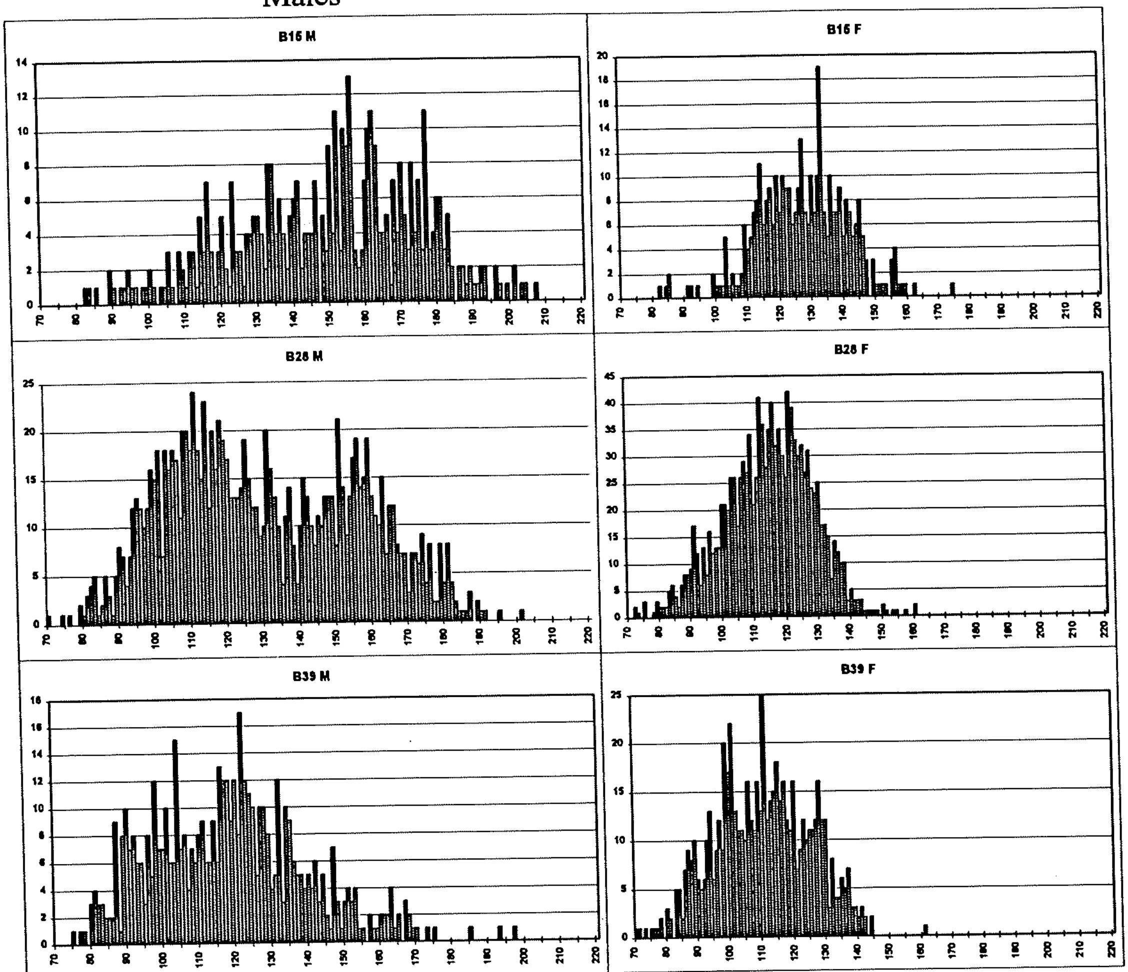


Figure 8g. Length frequency histograms of lobsters sampled in the indicated northern zone fishing areas during the 1994/95 fishing season.

Males Females

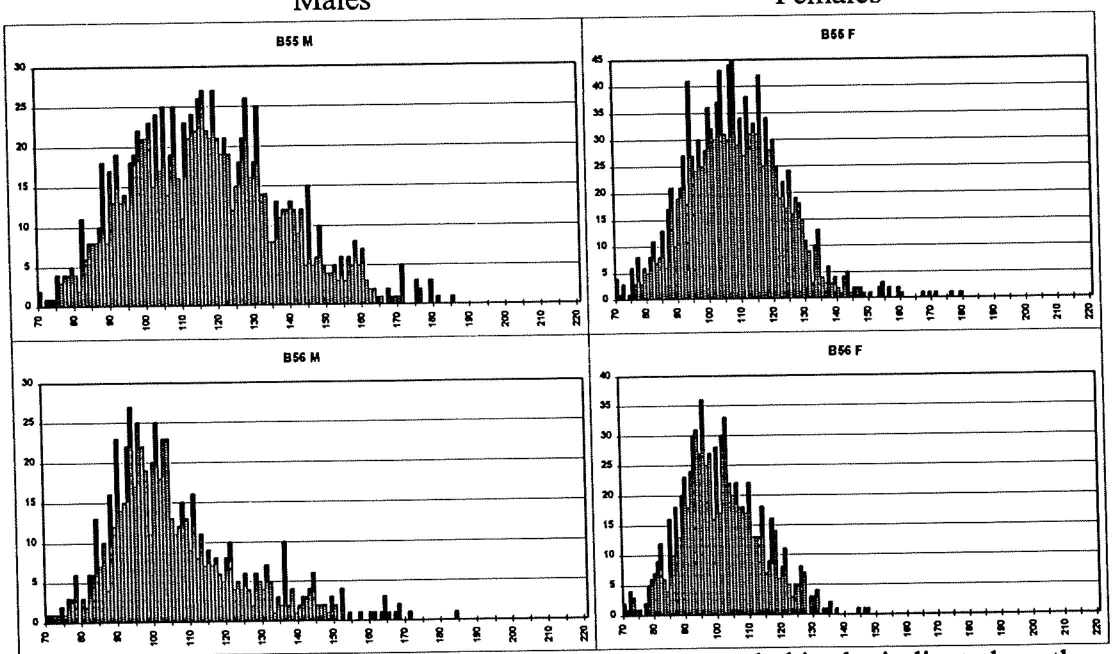


Figure 8h. Length frequency histograms of lobsters sampled in the indicated southern zone fishing areas during the 1994/95 fishing season.

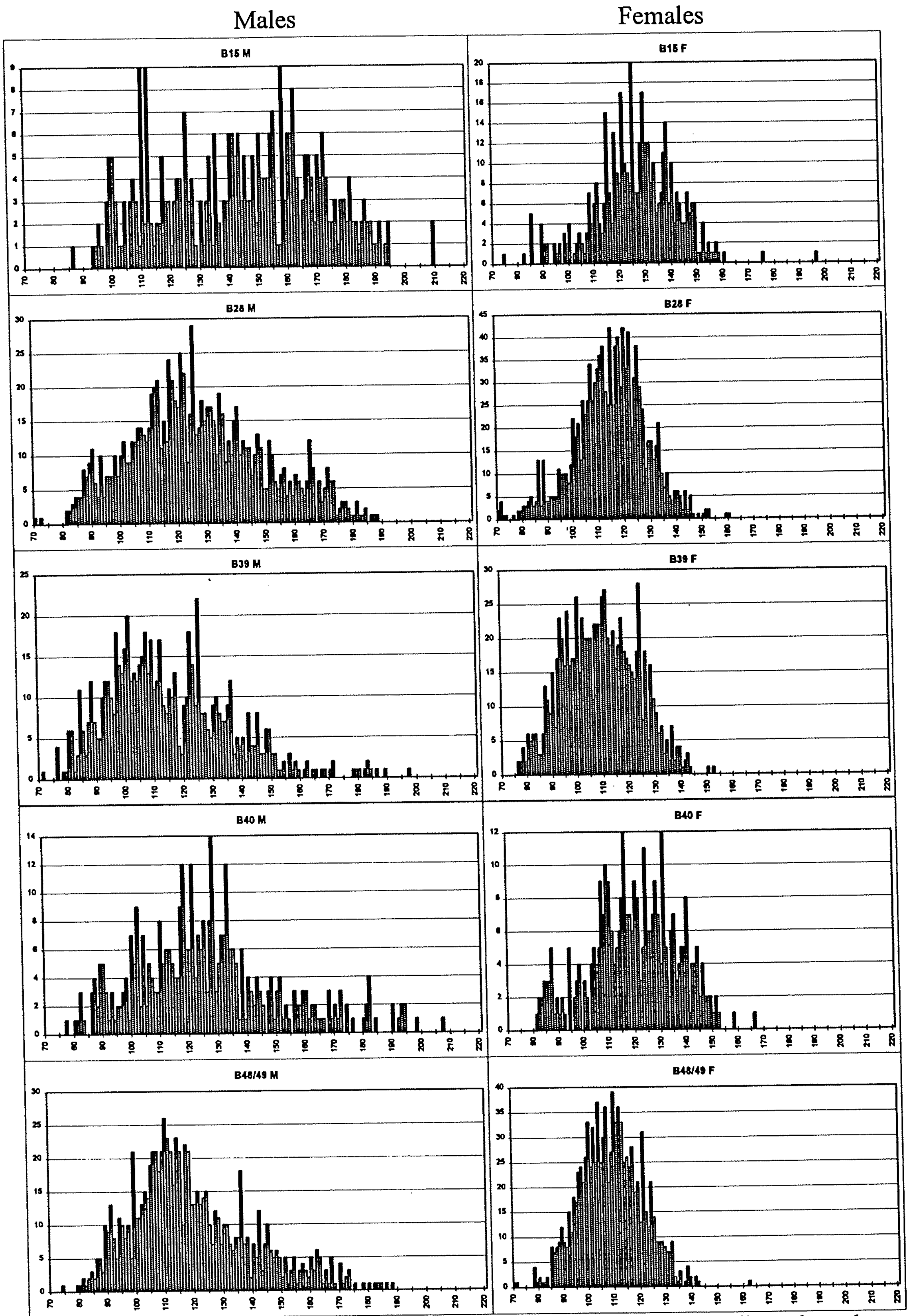


Figure 8i. Length frequency histograms of lobsters sampled in the indicated northern zone fishing areas during the 1995/96 fishing season.

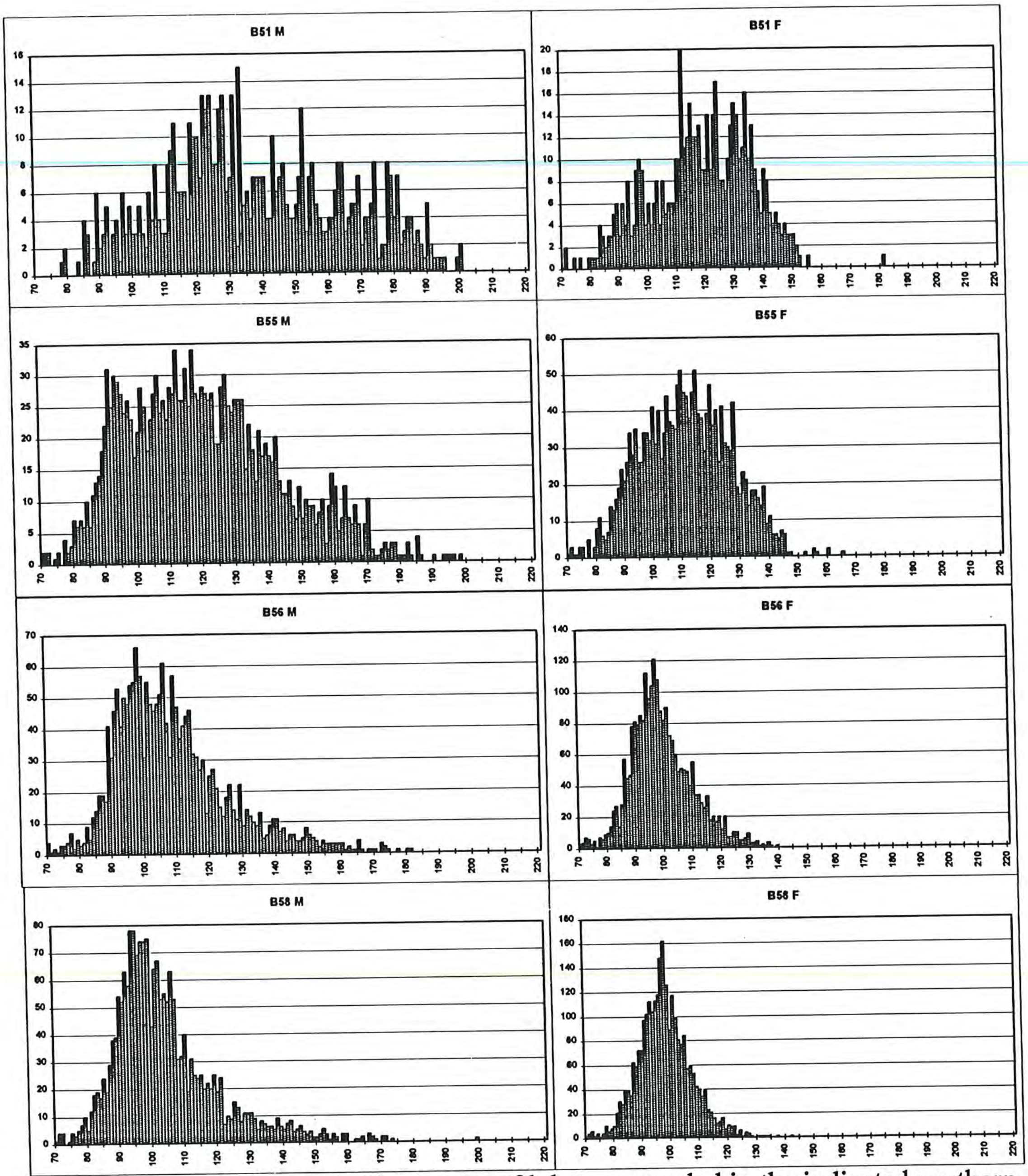


Figure 8j. Length frequency histograms of lobsters sampled in the indicated southern zone fishing areas during the 1995/96 fishing season.

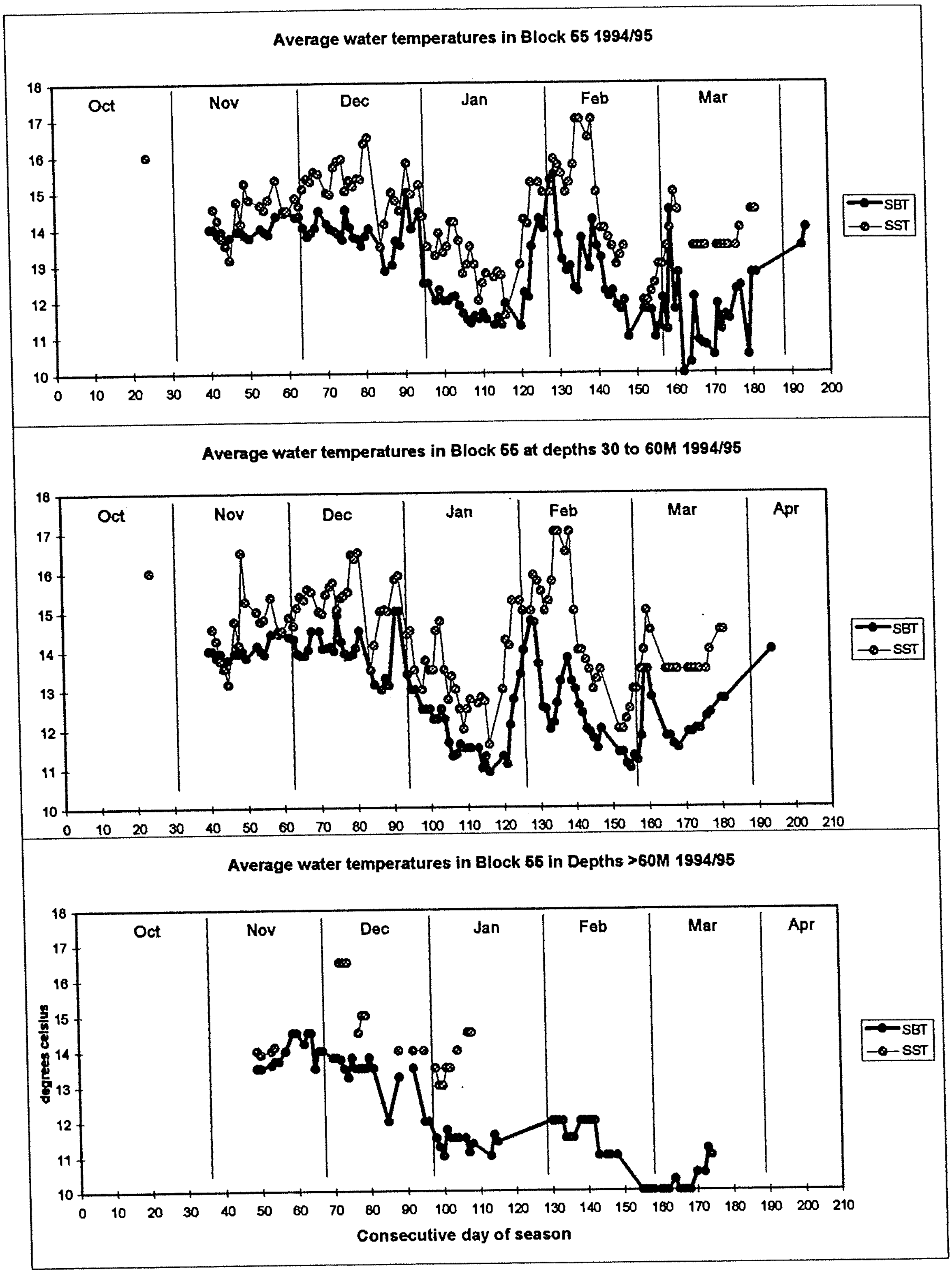


Figure 9a. Surface and bottom water temperatures in marine fishing area 55 are graphed as averages across all depths, and in depth intervals as indicated. All data from the 1994/95 season.

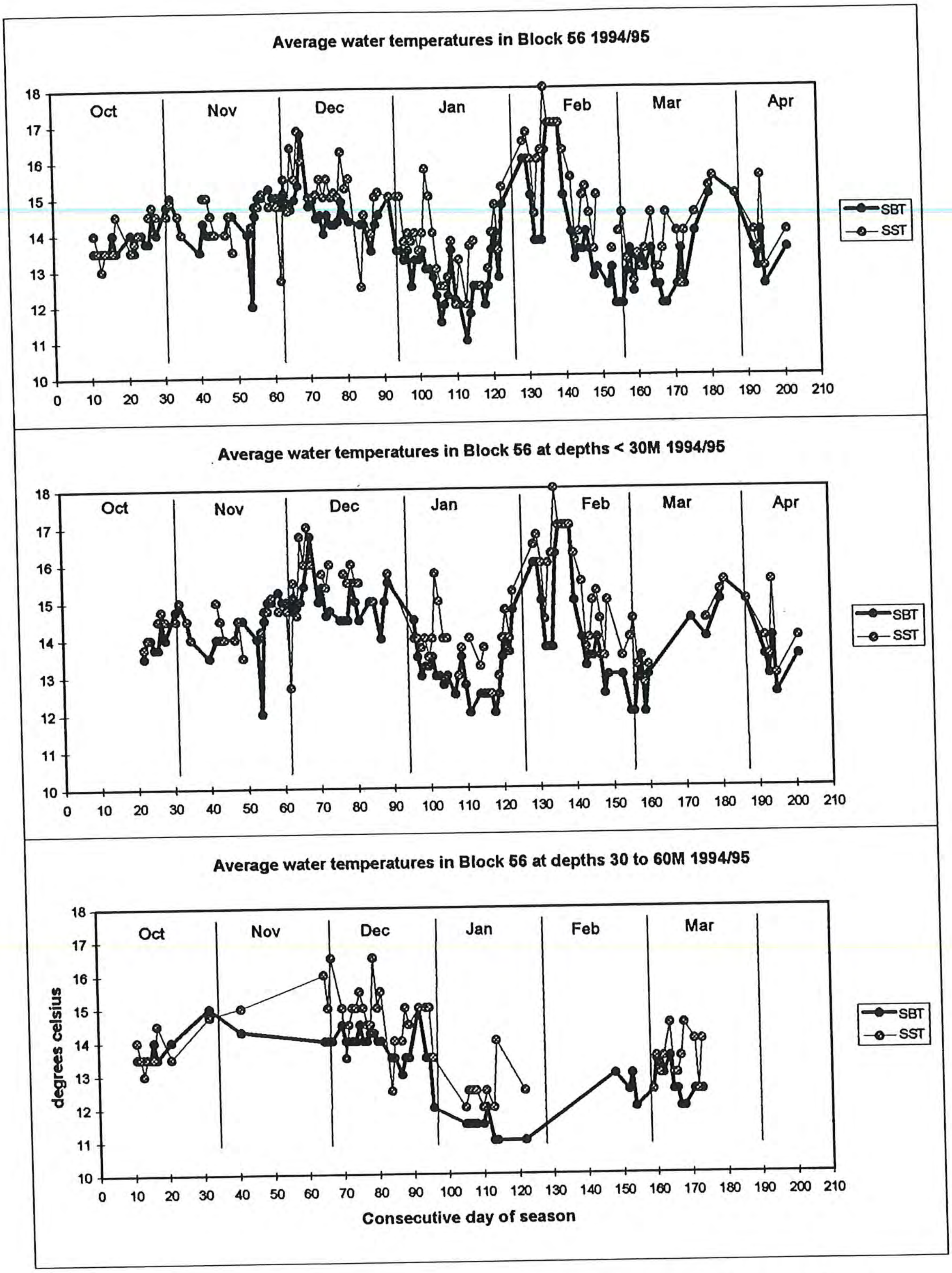


Figure 9b. Surface and bottom water temperatures in marine fishing area 56 are graphed as averages across all depths, and in depth intervals as indicated. All data from the 1994/95 season.

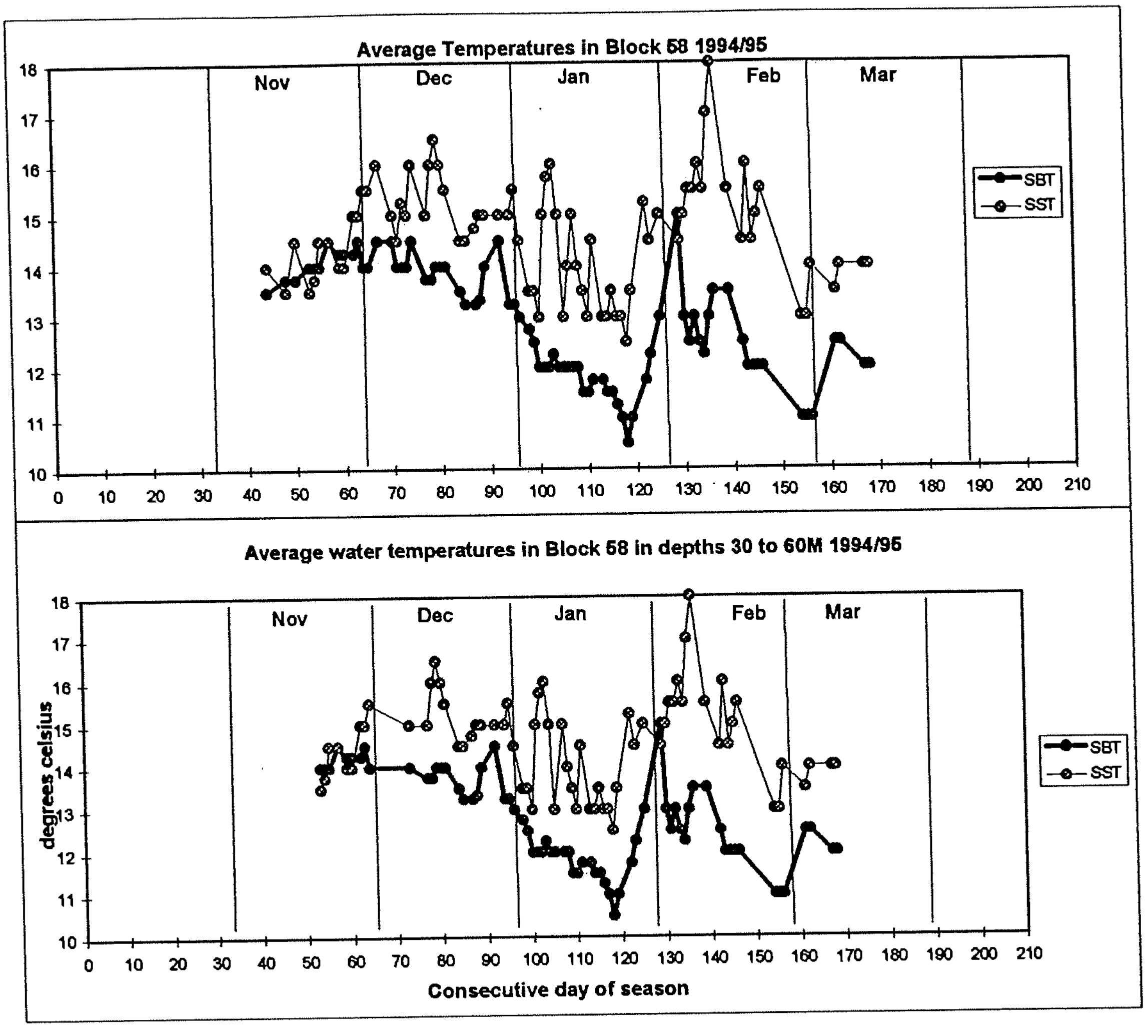


Figure 9c. Surface and bottom water temperatures in marine fishing area 58 are graphed as averages across all depths, and in depth intervals as indicated. All data from the 1994/95 season.

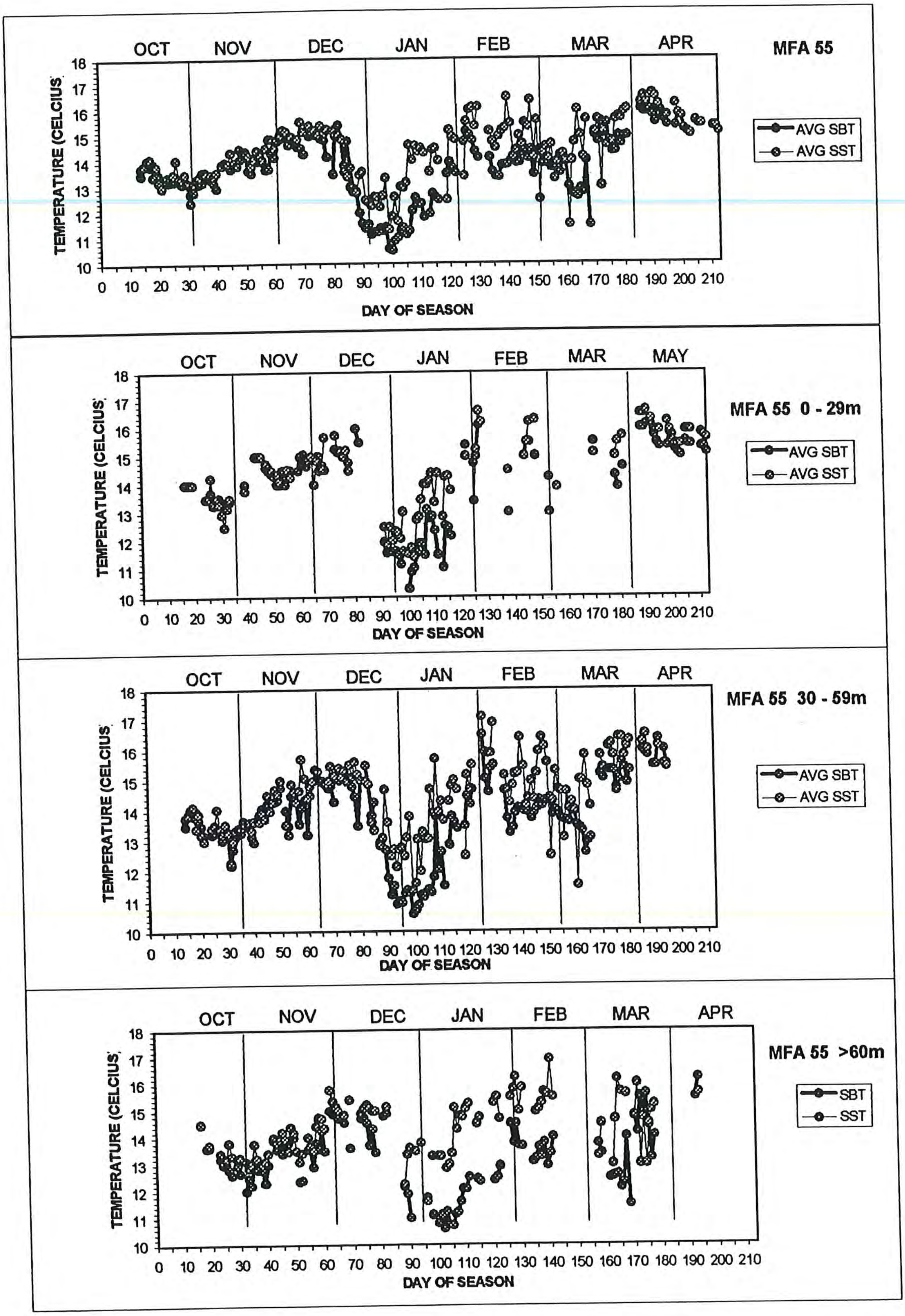


Figure 10a. Surface and bottom water temperatures in marine fishing area 55 are graphed as averages across all depths, and in depth intervals as indicated. All data from the 1995/96 season.

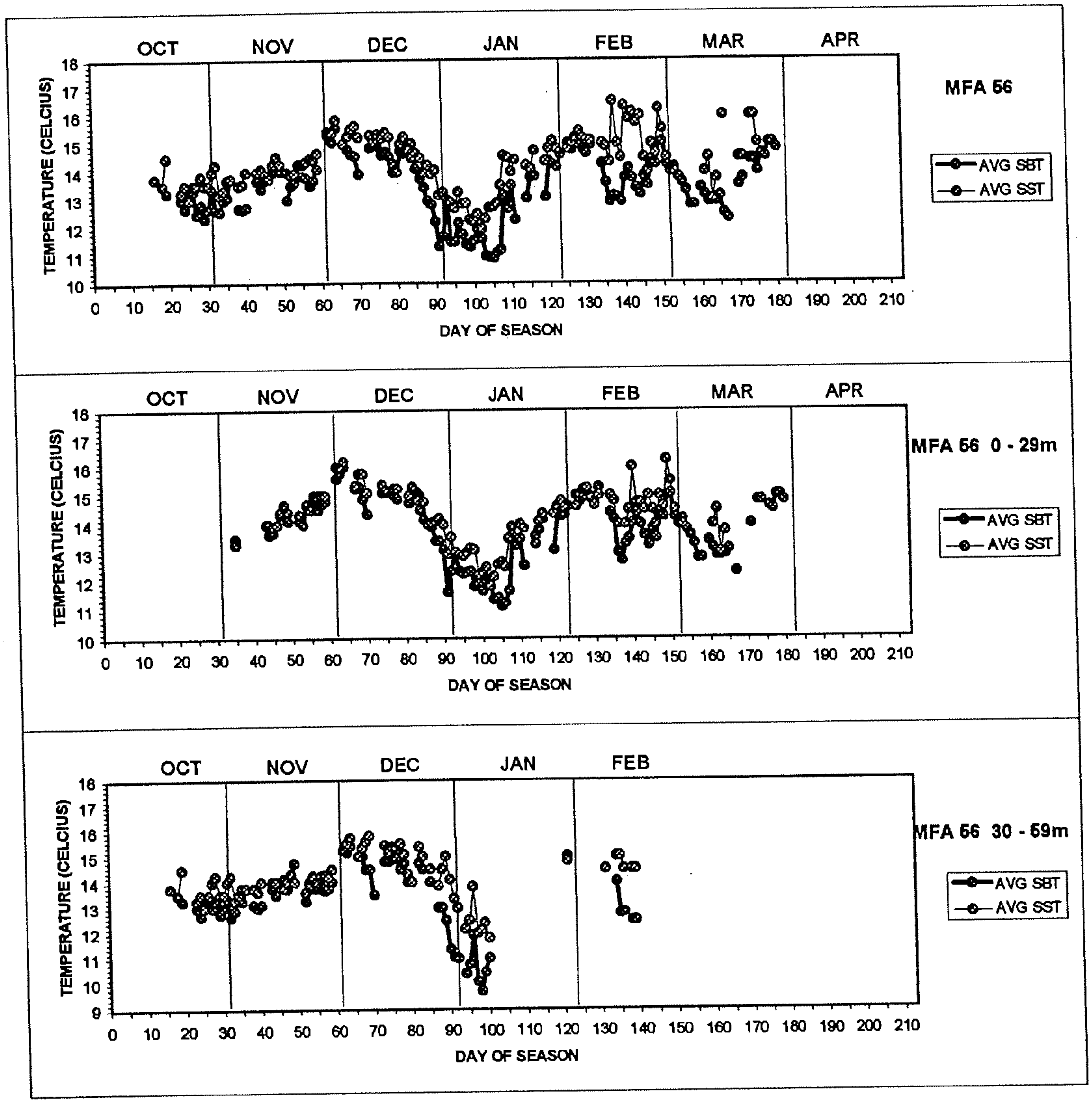


Figure 10b. Surface and bottom water temperatures in marine fishing area 56 are graphed as averages across all depths, and in depth intervals as indicated. All data from the 1995/96 season.

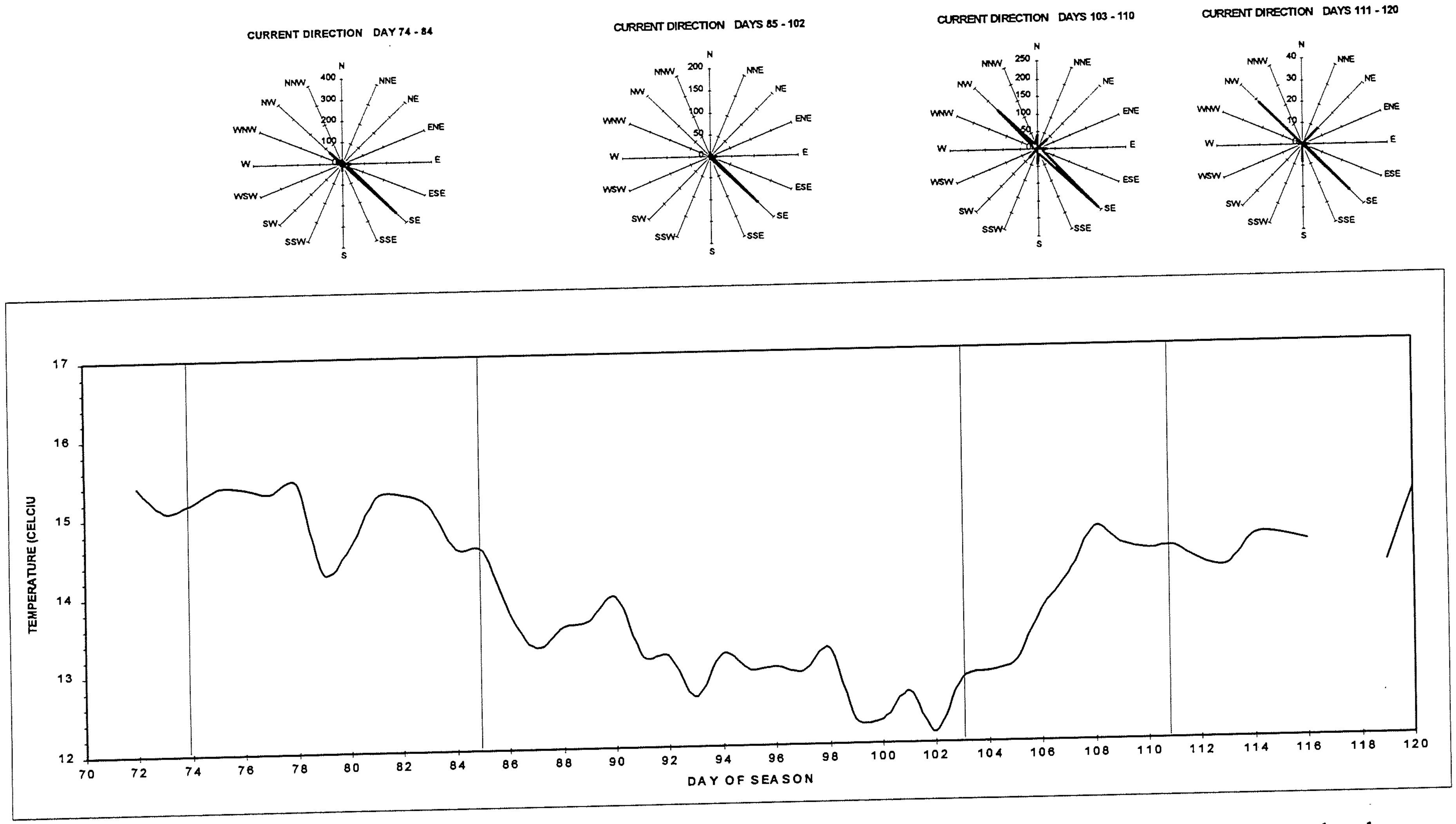


Figure 11a. Mean sea surface temperatures are shown during consecutive days of the 1995/96 season along the southeast cosat. Also shown are radar graphs of current direction recorded by fishers during the correspoinding periods. Day 70 was 9 December 1995.

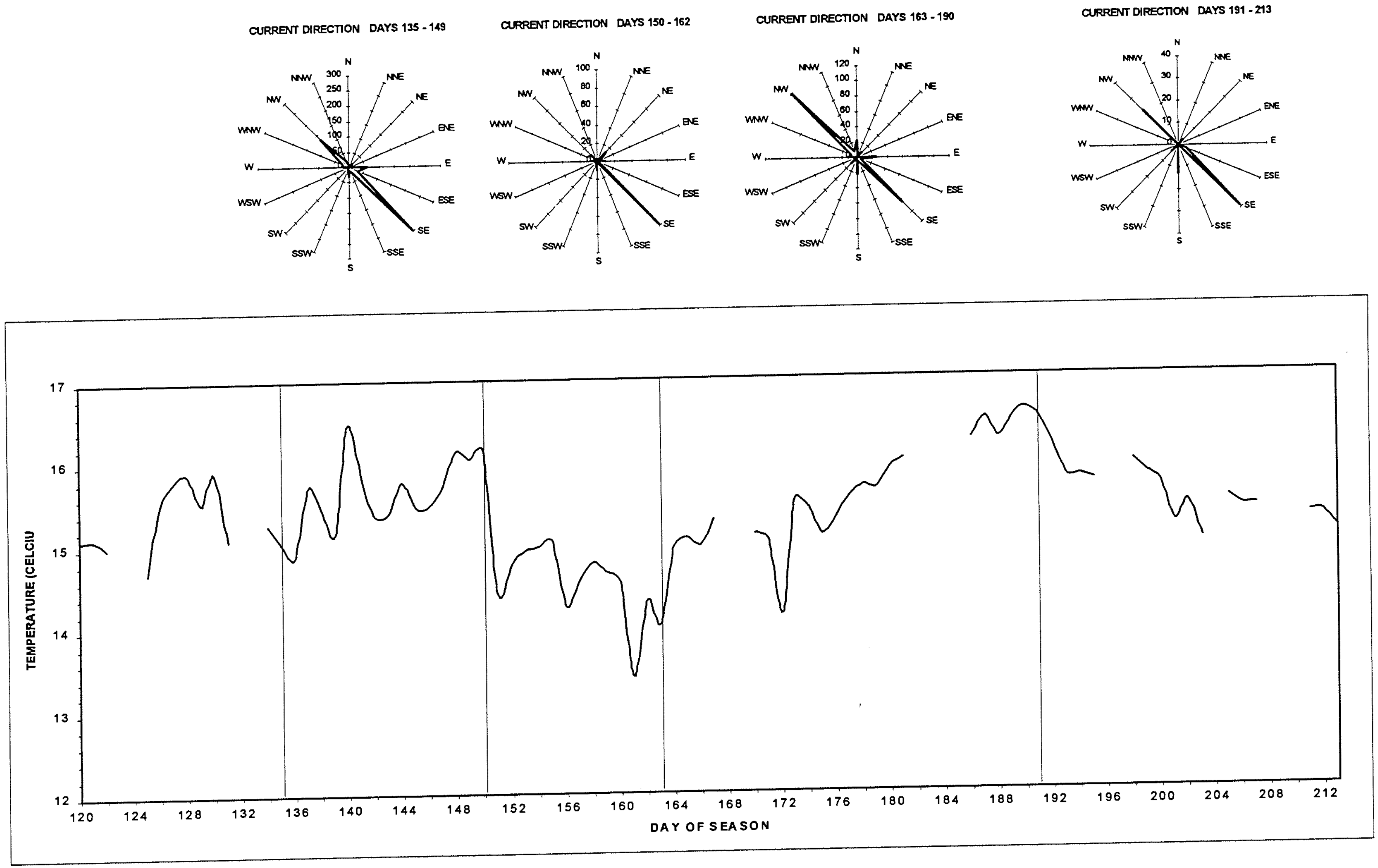


Figure 11b. Mean sea surface temperatures and current directions shown for latter half of the 1995/96 season along the southeast coast

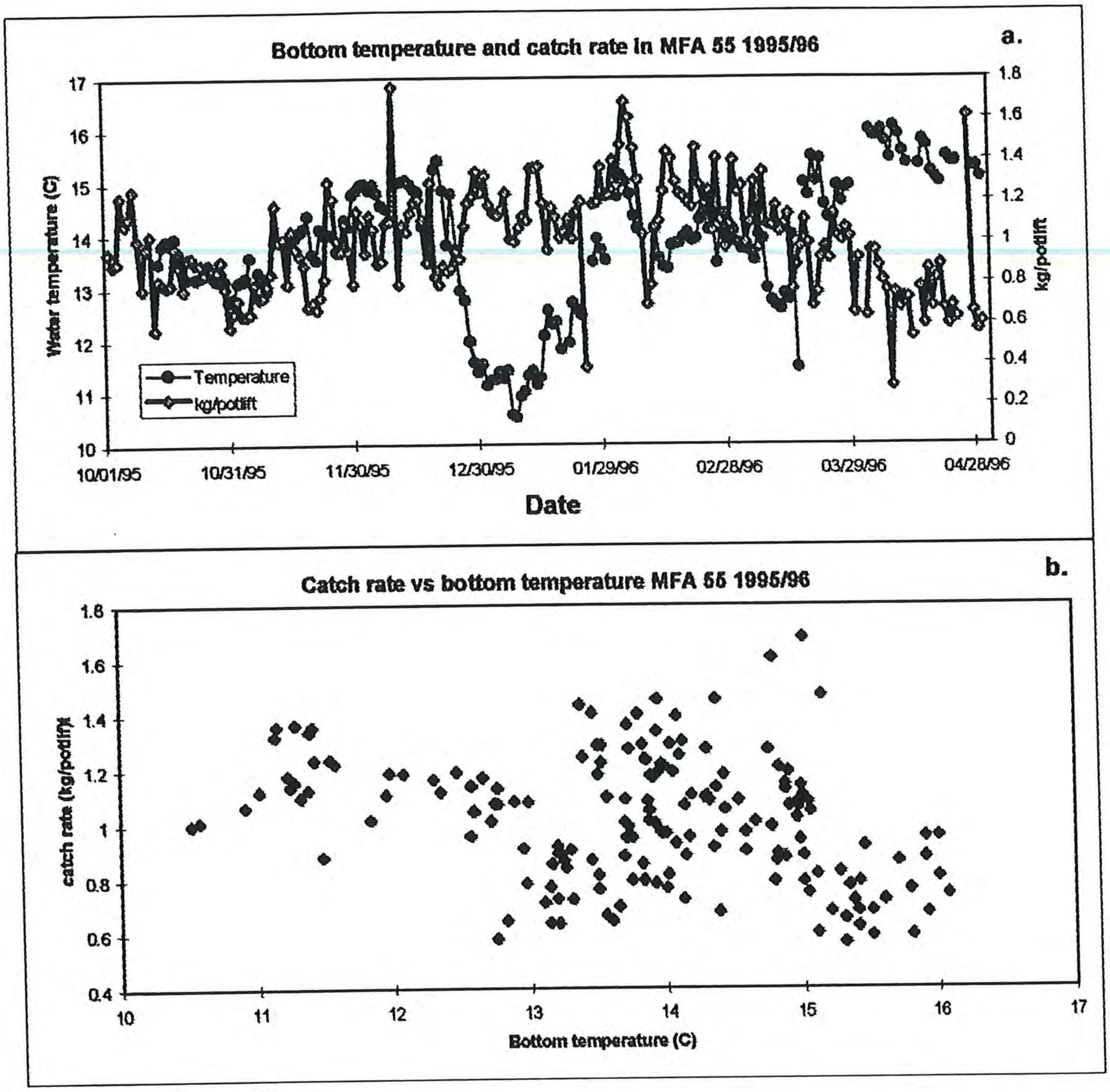


Figure 12. Temporal changes in catch rate and bottom water temperature are plotted together (a), and catch rate is plotted versus bottom water temperature (b).

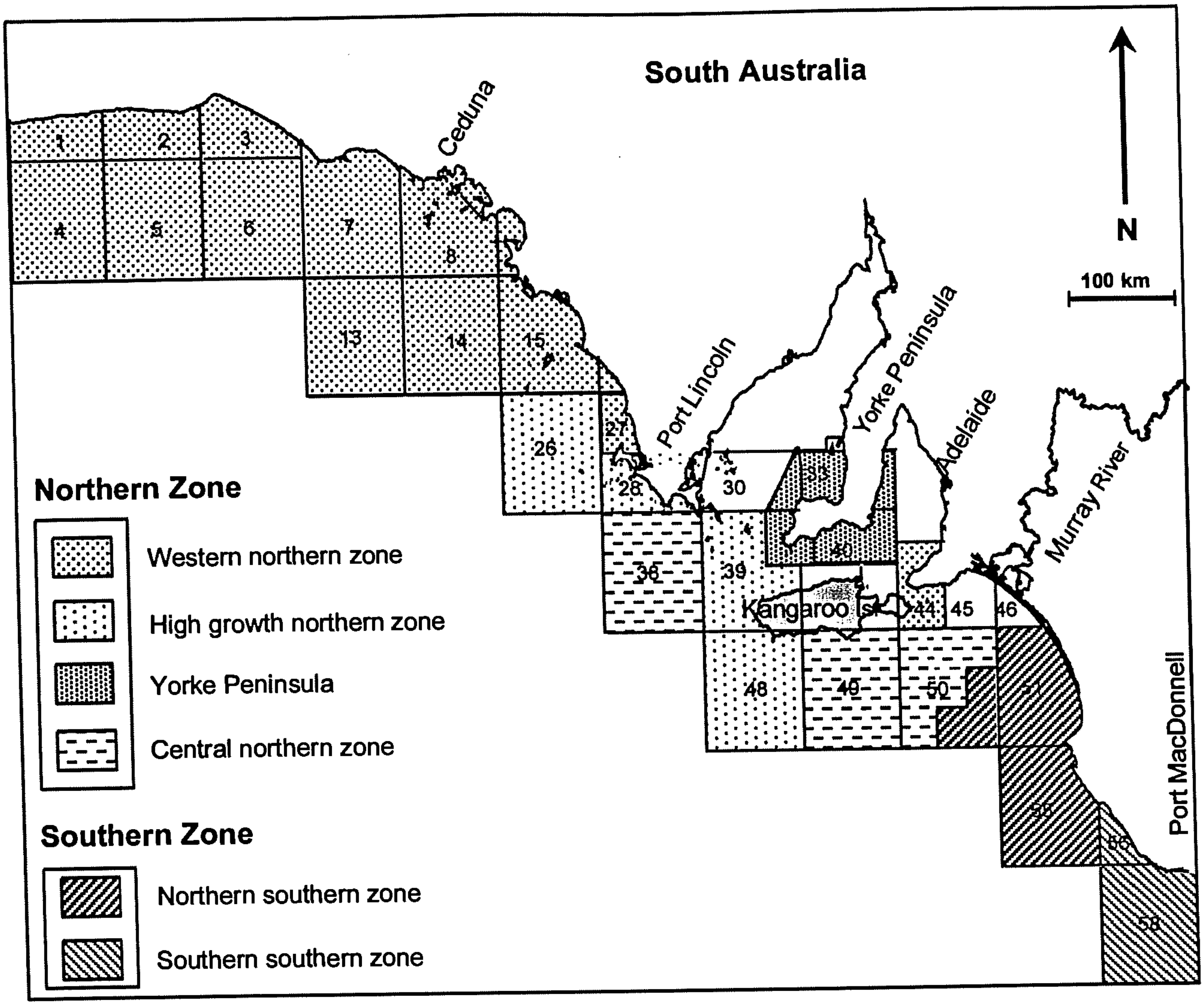


Figure 13. Map of South Australia showing Marine Fishing Area (MFA) blocks and subregions of uniform growth

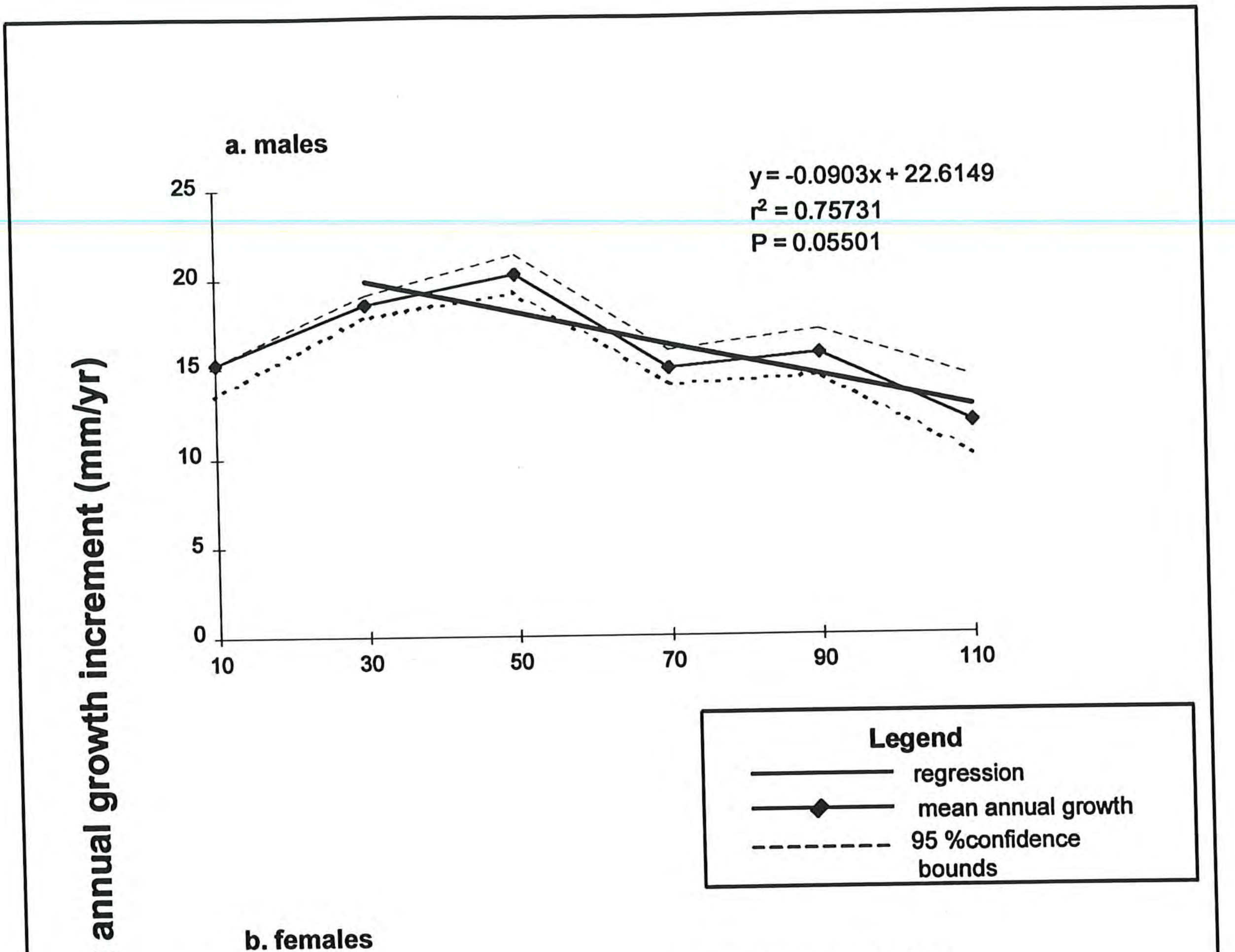


Figure 14: depth versus g_α and g_B for males and females from the northern part of the Southern Zone

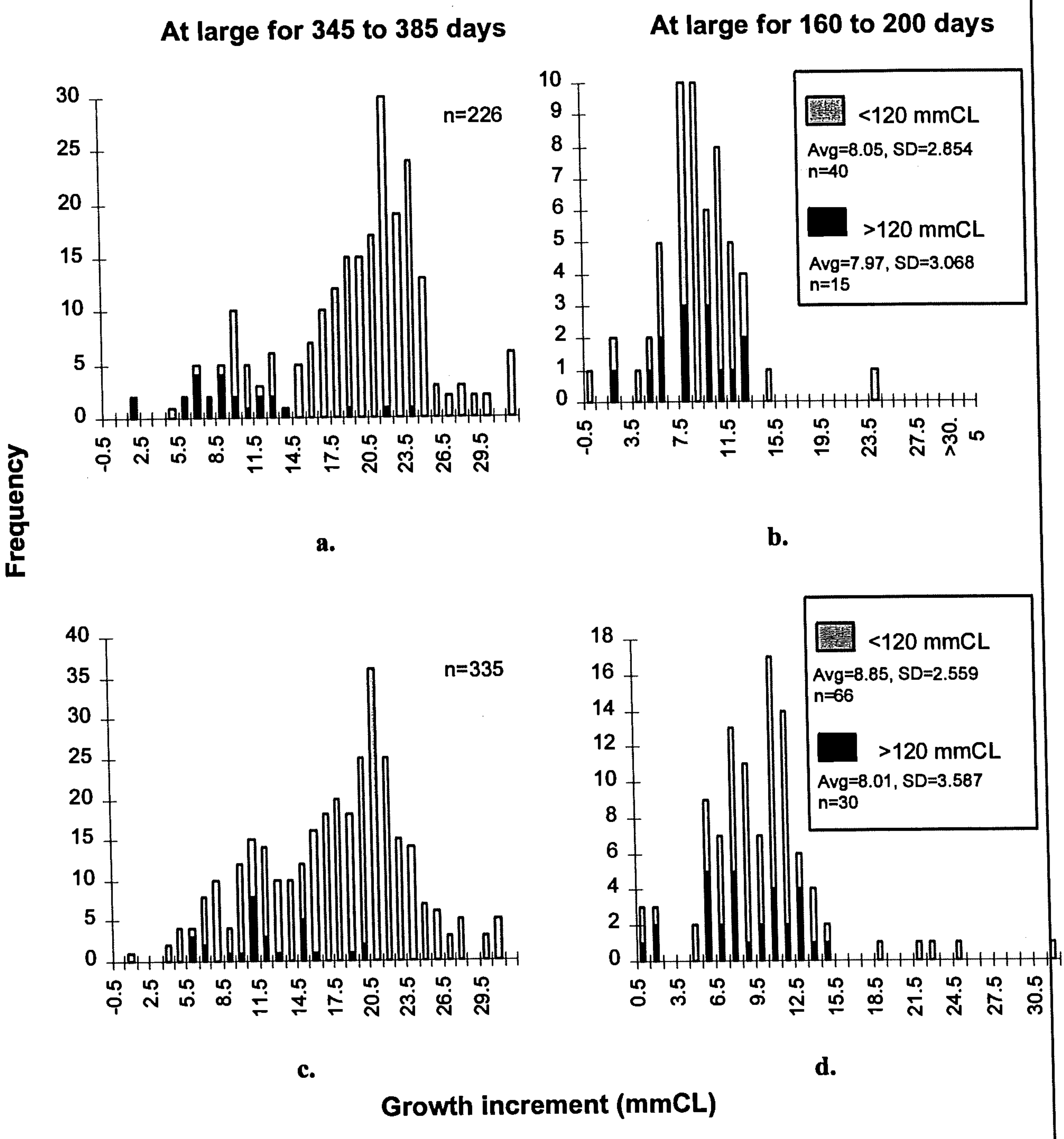


Figure15. a) Northern zone males at large 345 to 385 days, b) Northern zone males at large 160 to 200 days, c) Southern zone males at large 345 to 365 days, d) Southern zone males at large 160 to 200 days

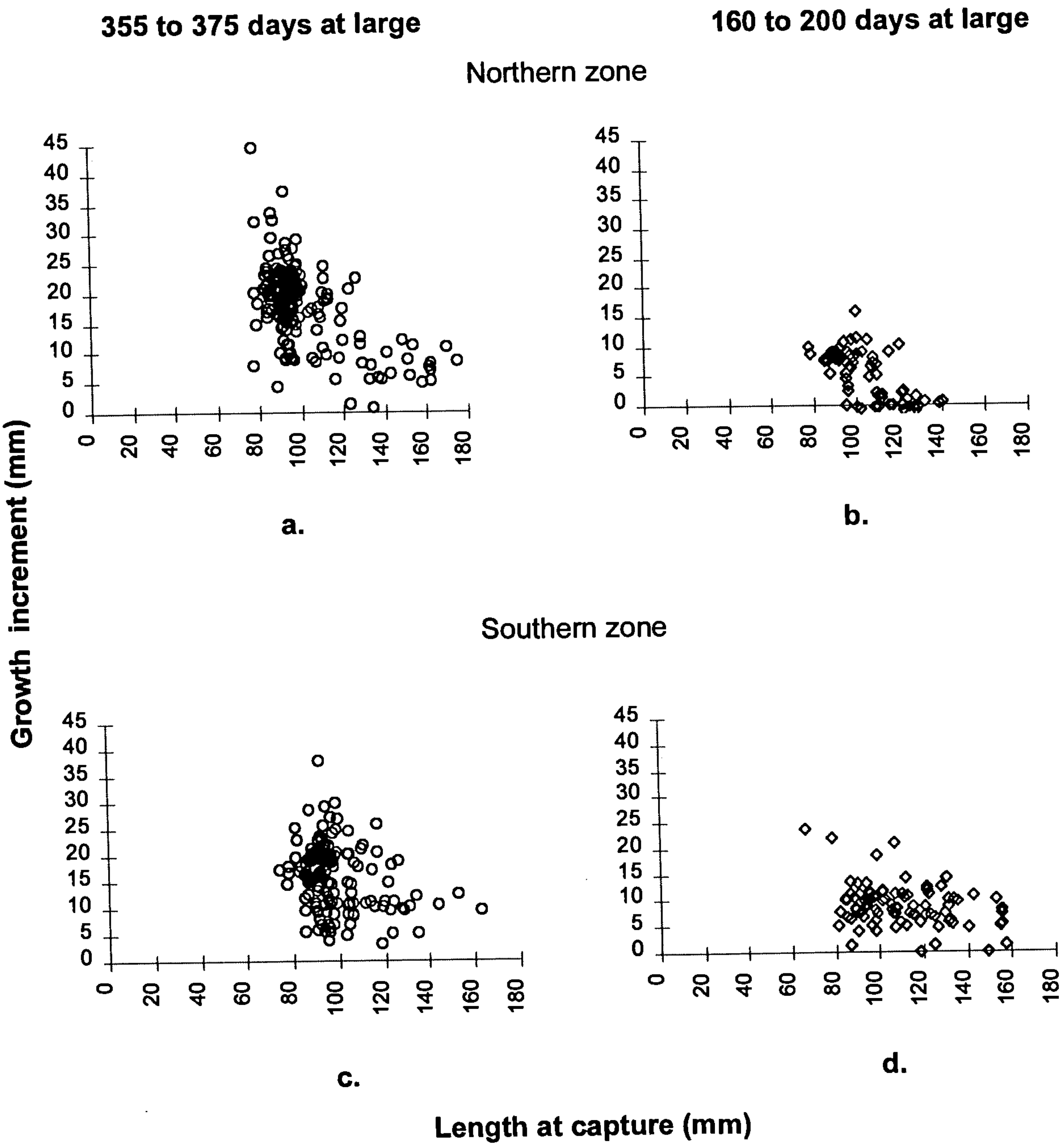


Figure 16: Moult increment for male lobsters at large for 6 month and 12 month periods. a) Northern zone, at large for 12 months, b) Northern zone at large for 6 months, c) Southern zone, at large for 12 months, d) Southern zone, at large for 6 months

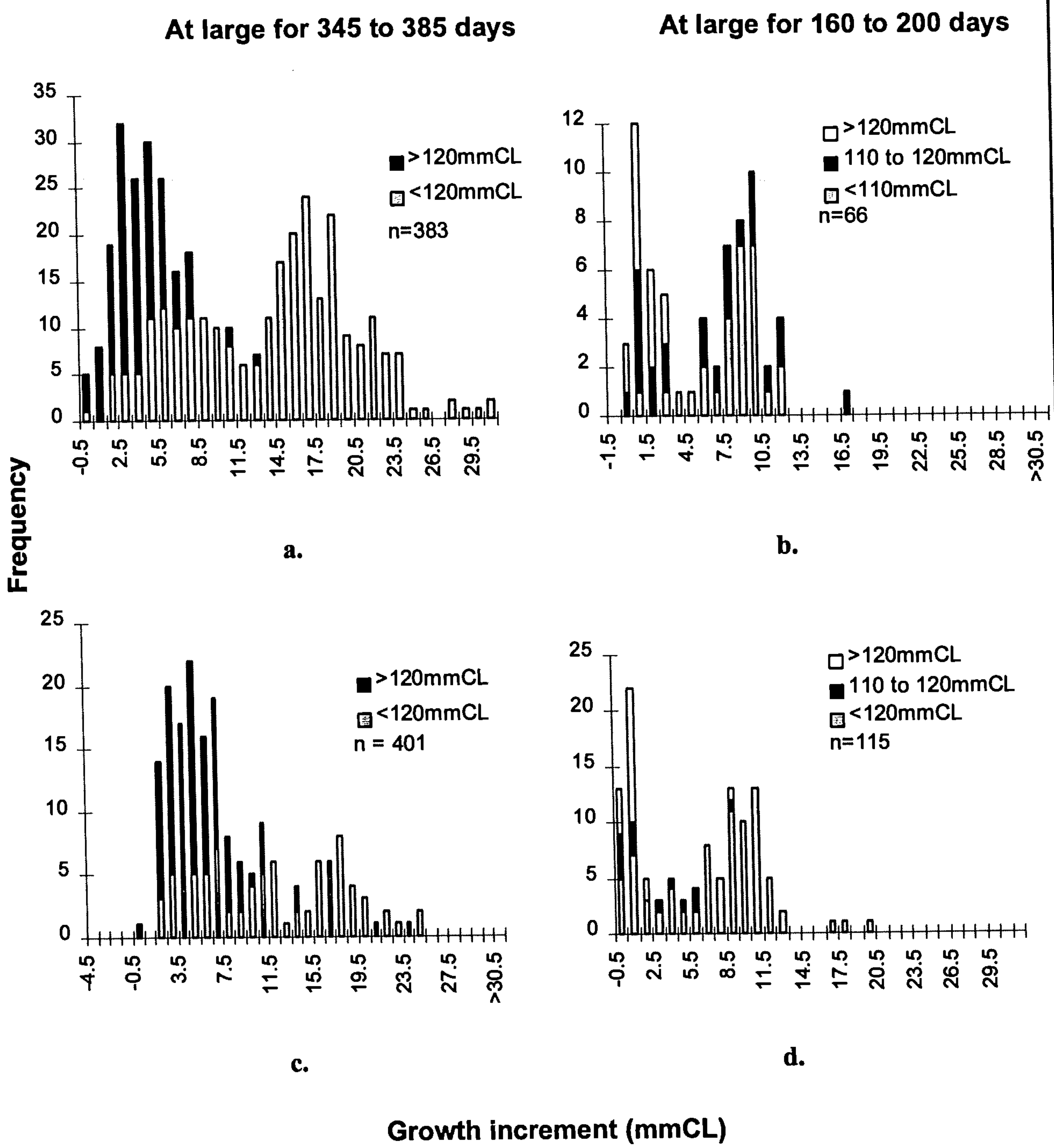


Figure 17. a) Northern zone females at large 345 to 385 days, b) Northern zone females at large 160 to 200 days, c) Southern zone females at large 345 to 365 days, d) Southern zone females at large 160 to 200 days

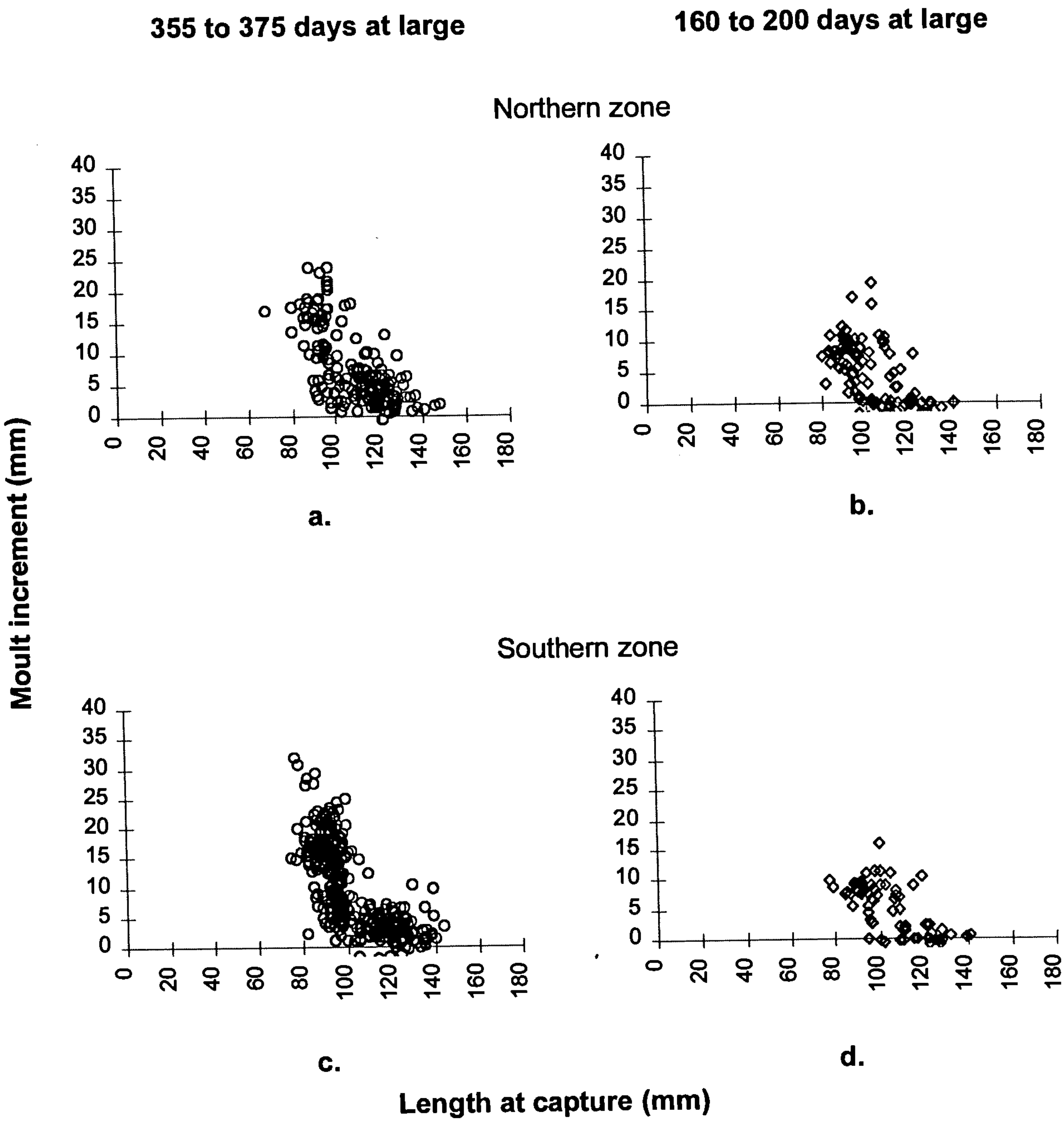


Figure 18: Moult increment for female lobsters at large for 6 month and 12 month periods a) Northern zone, at large for 12 months, b)Northern zone at large for 6 months, c) Southern zone, at large for 12 months, d) Southern zone, at large for 6 months

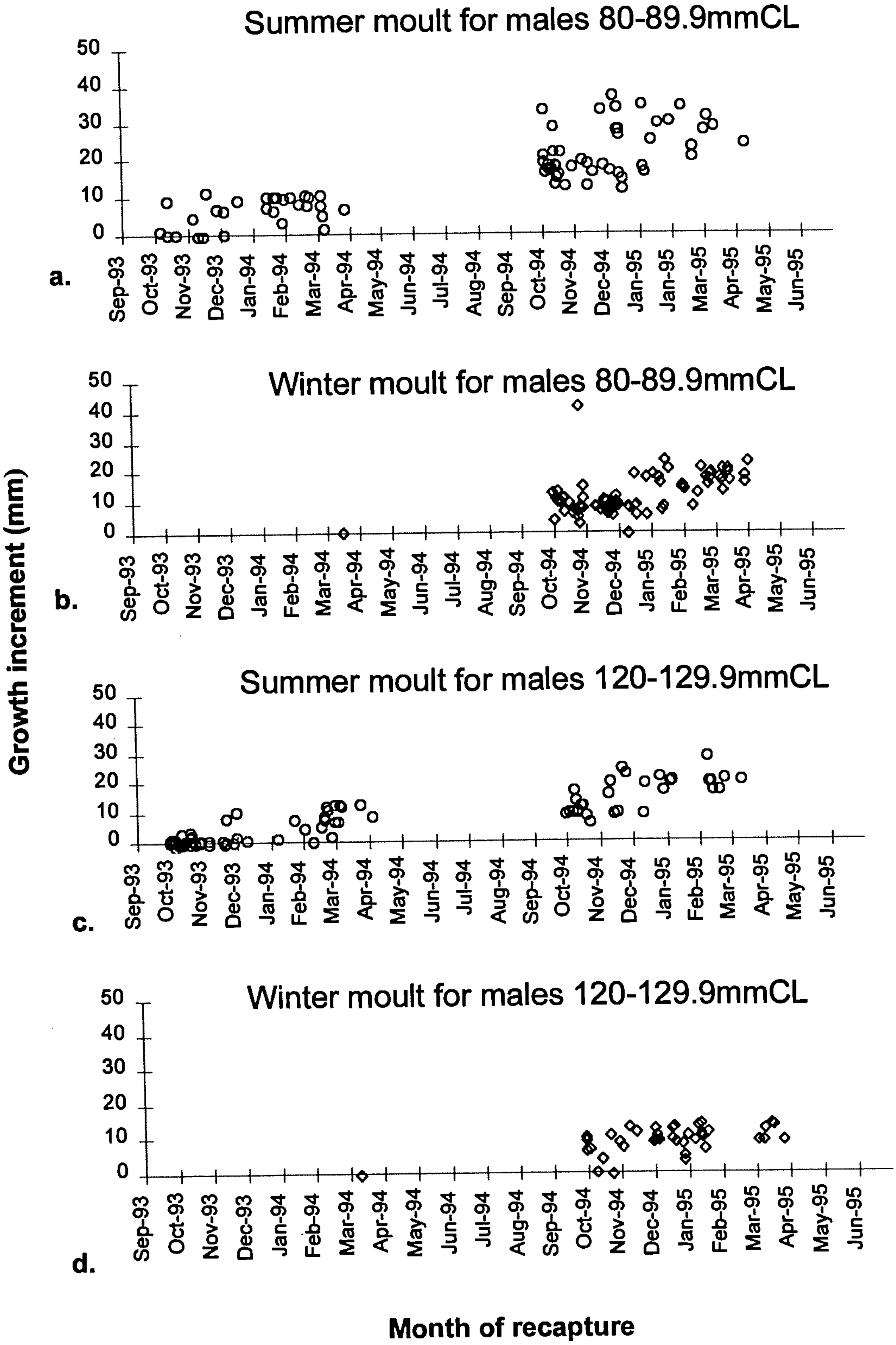


Figure 19. Moulting in southern zone male lobsters. a) 80-89.9mmCL, tagged August 22, 1993 to October 31 1993. b) 80-89.9mmCL, tagged 1 March to 30 April 1994. c) 120-129.9mmCL, tagged 22-August 1993 to 31 October 1993. d) 120-129mmCl, tagged 1 March to 30 April 1994.

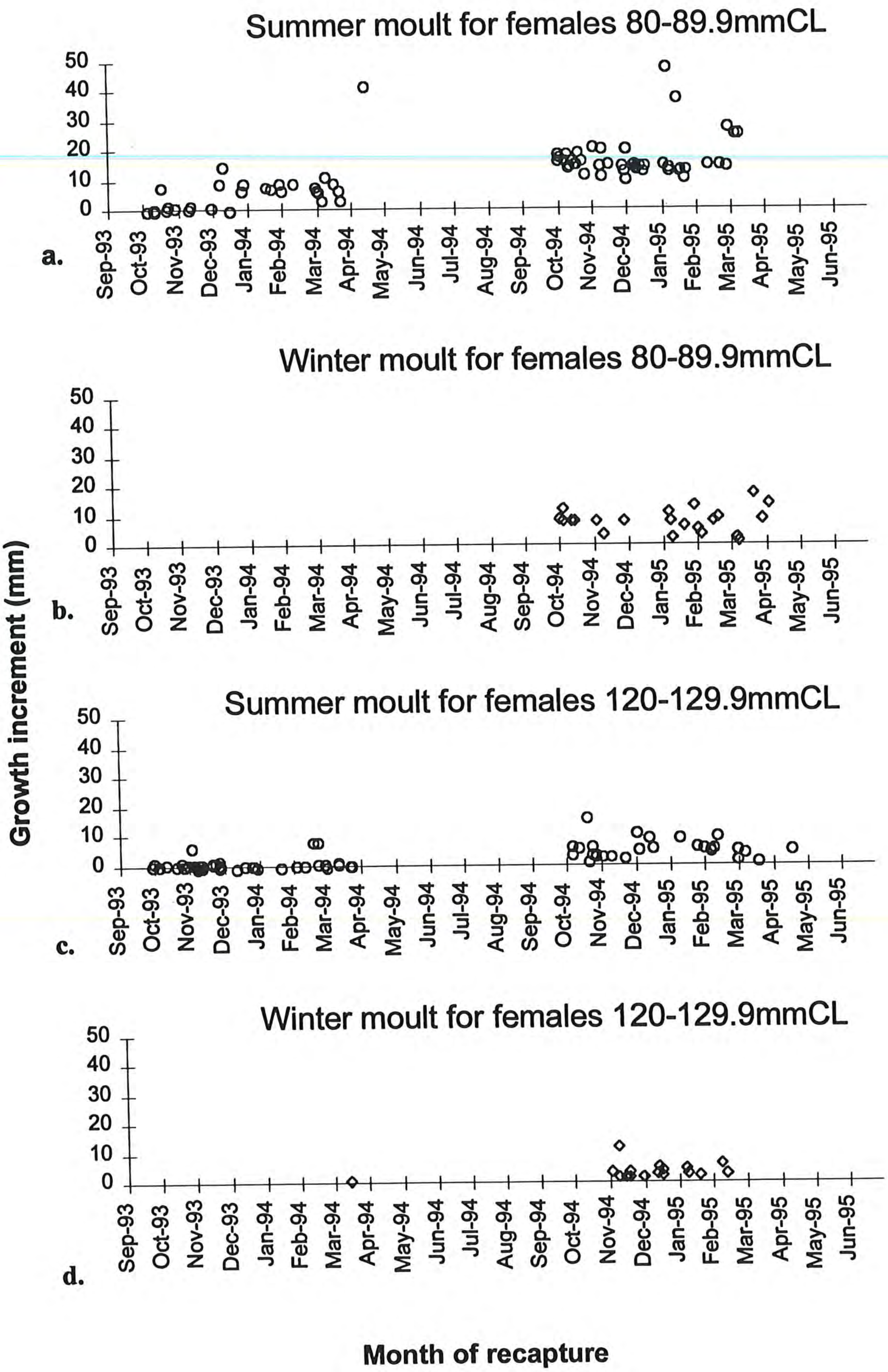


Figure 20. Moulting in southern zone female lobsters. a) 80-89.9mmCL, tagged August 22, 1993 to October 31 1993. b) 80-89.9mmCL, tagged 1 March to 30 April 1994. c) 120-129.9mmCL, tagged 22-August 1993 to 31 October 1993. d) 120-129mmCl, tagged 1 March to 30 April 1994.

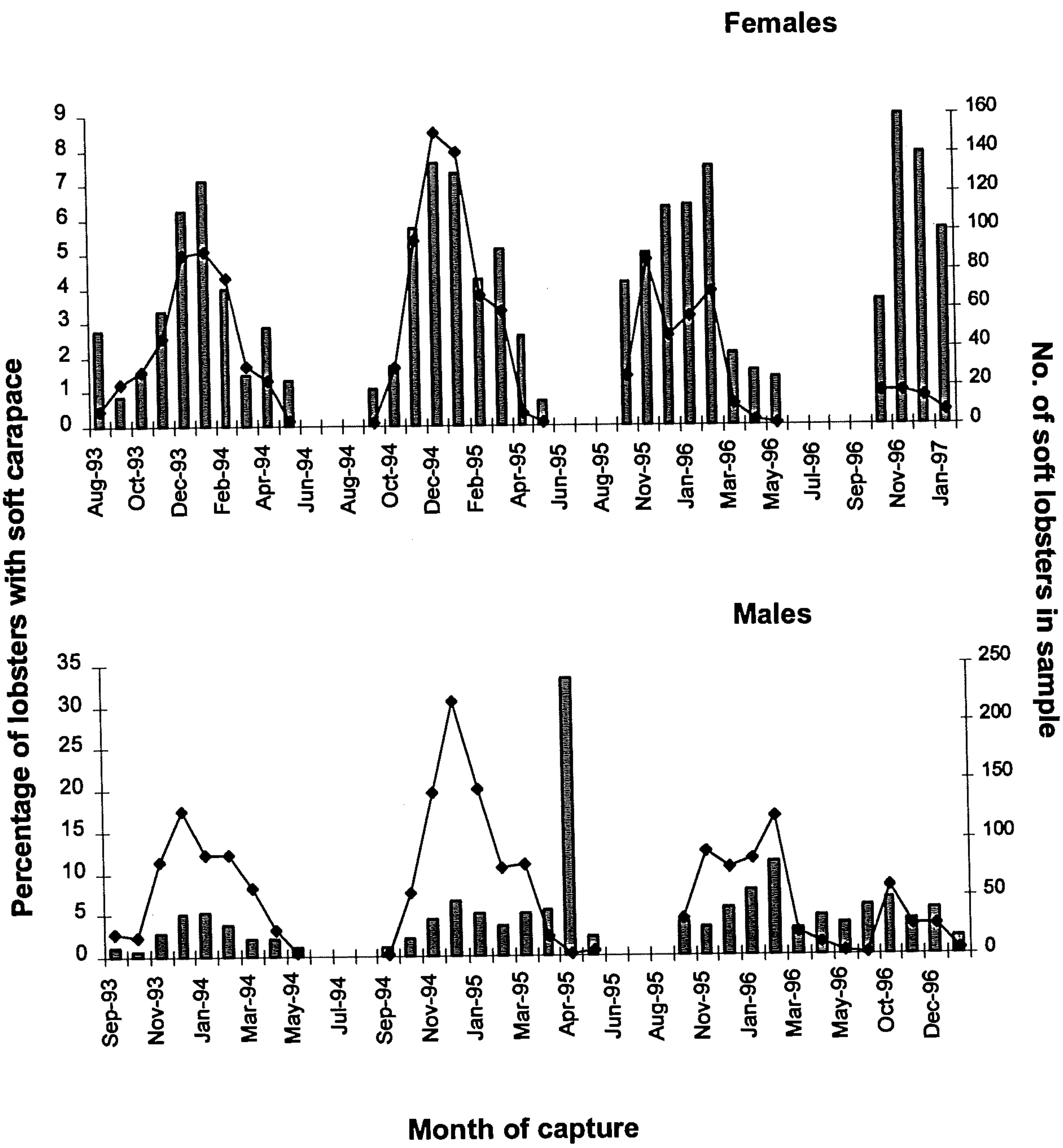


Figure 21. a) Percentage of recent post-moult females in tagged sample.
b) Percentage of recent post-moult males in tagged sample

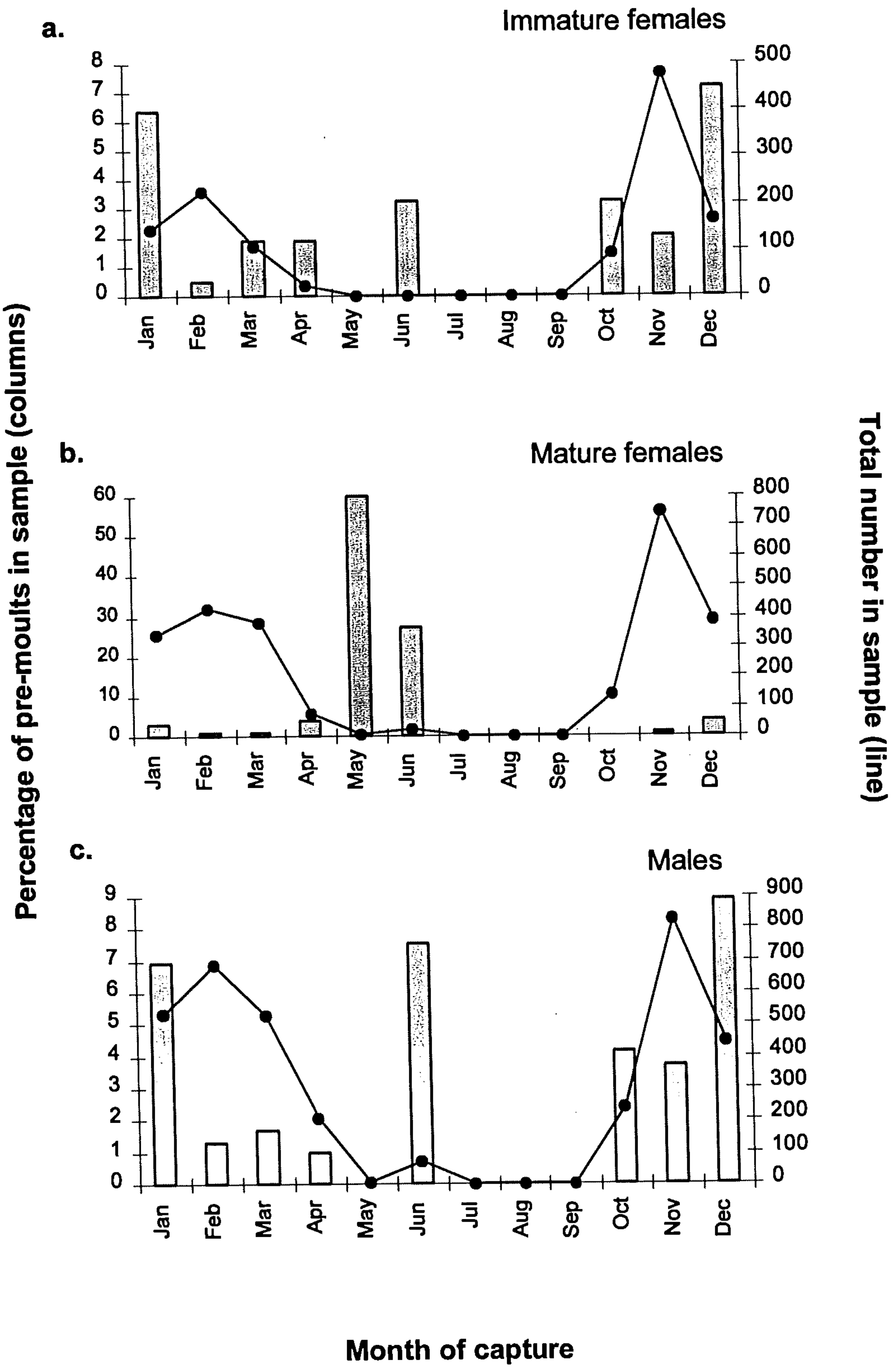


Figure 22. percentages of pre-moult individuals in 1994/95 season sample. a) immature females, b) mature females, c) males.

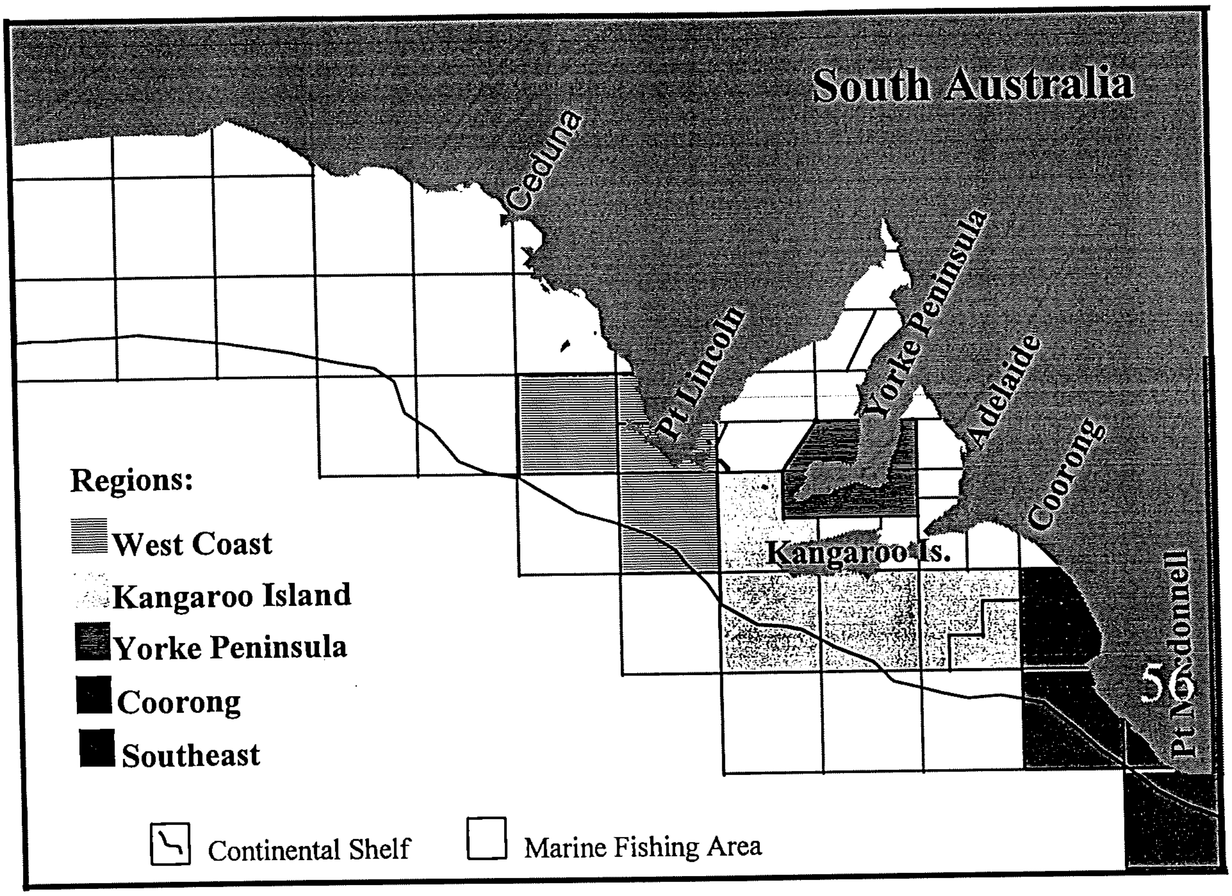


Figure 23. Five regions analysed for movements of rock lobster.

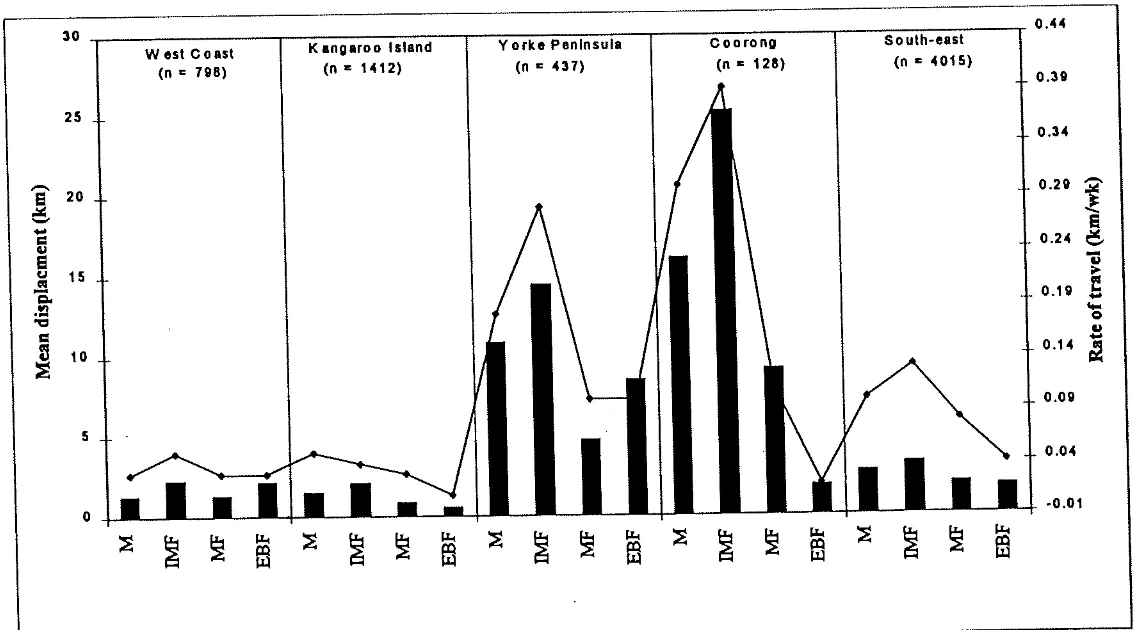


Figure 24. Mean displacement (▬) and rate of travel (—♦—) in five movement regions. (M = male; IMF = immature female; MF = mature female; EBF = egg-bearing female)

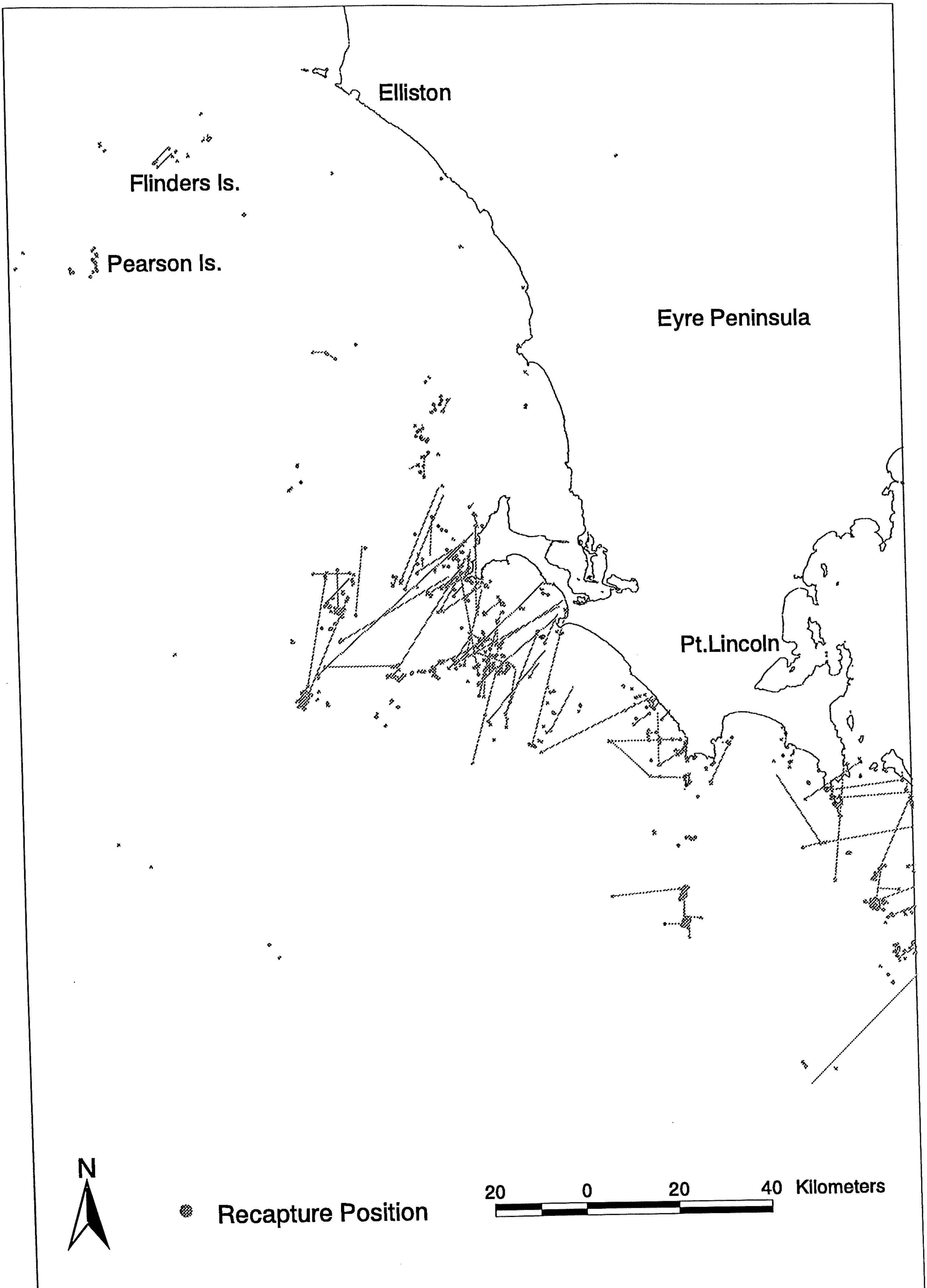


Fig 25 Straightline distances between release and recapture for West Coast Region

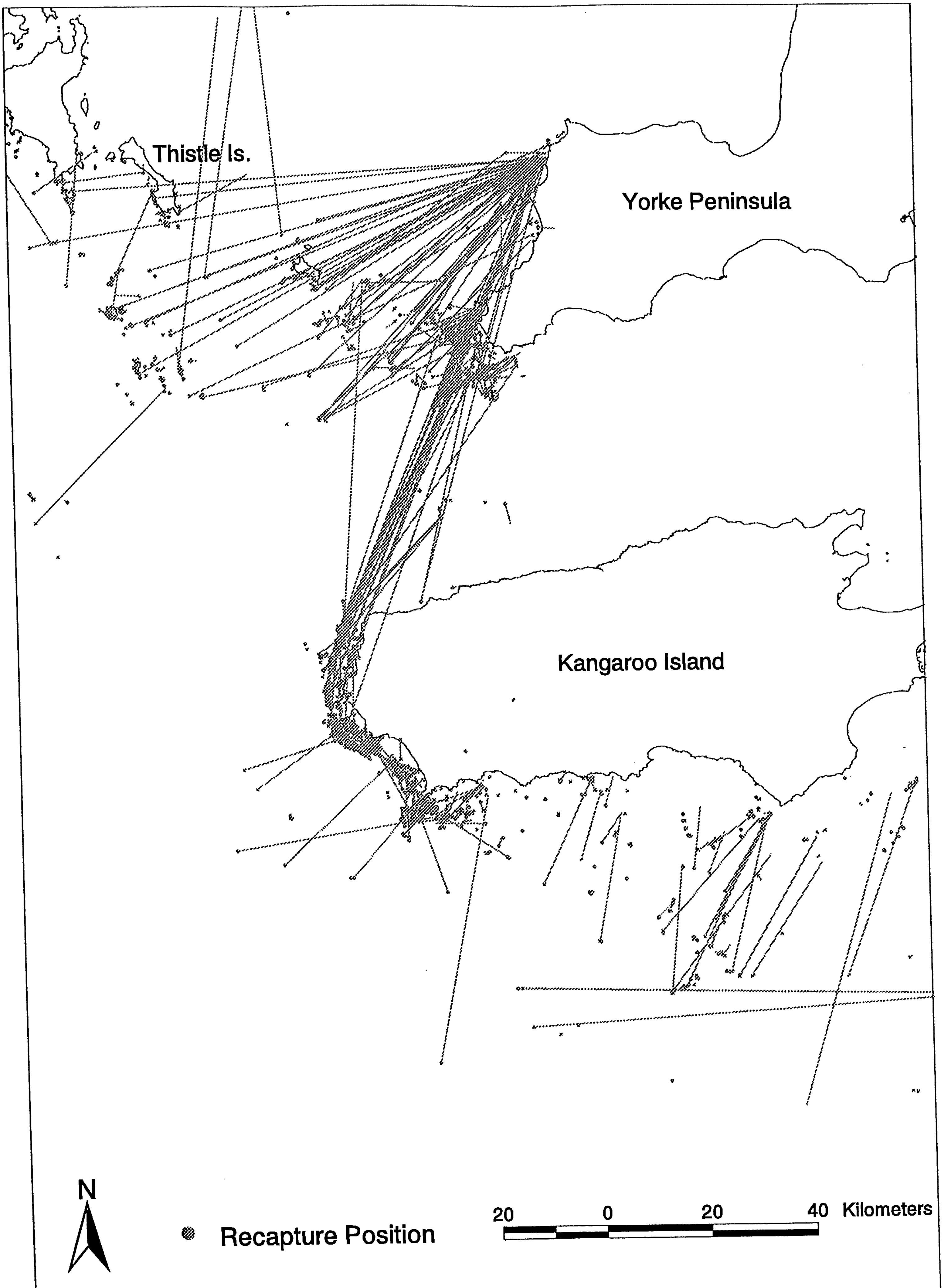


Fig 26. Straightline distances between release and recapture for Yorke Peninsula and Kangaroo Island Regions

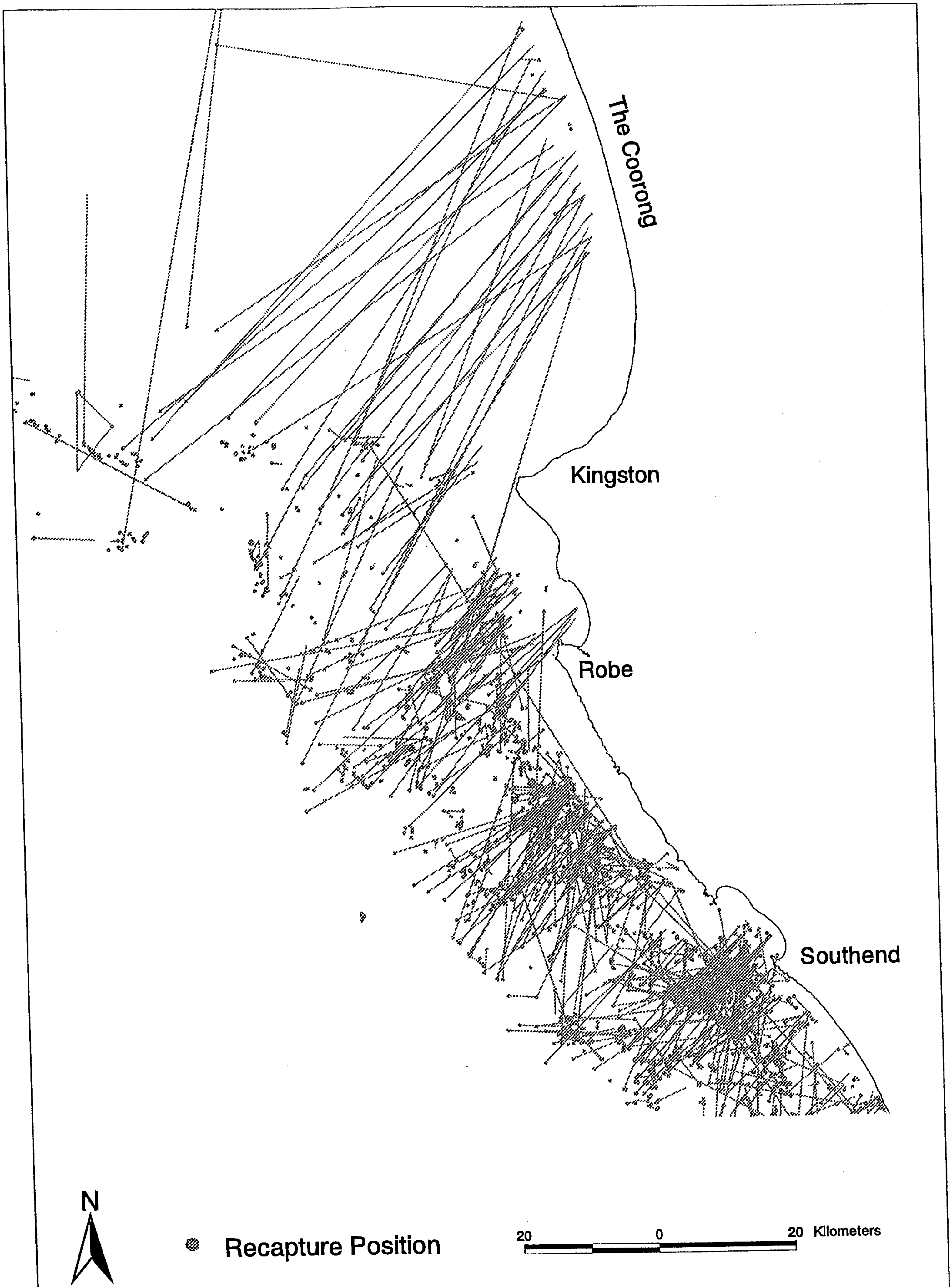


Fig 27. Straightline distances between release and recapture for Coorong and Southeast Regions

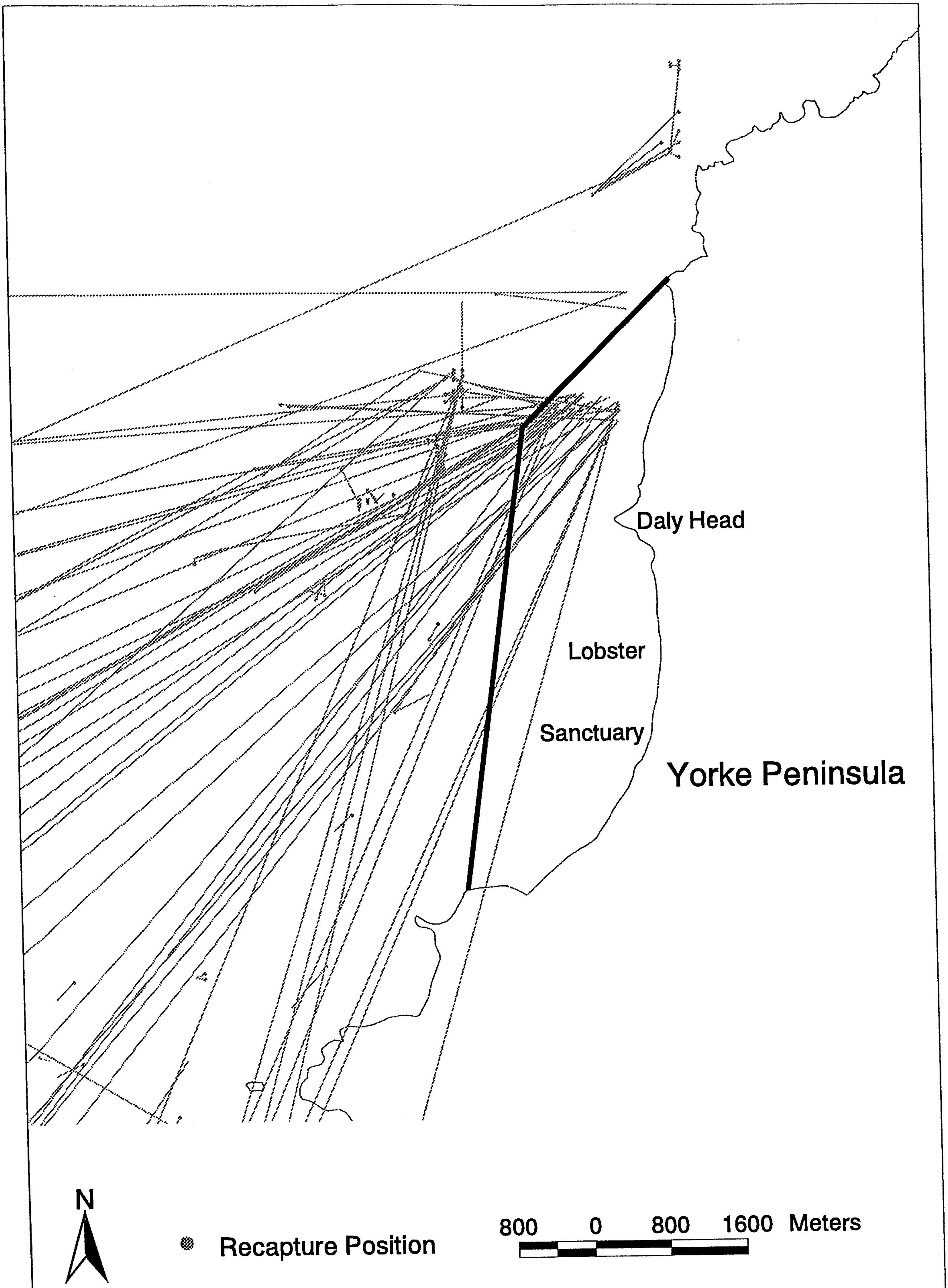


Fig 28. Migrations originating from the lobster sanctuary, Yorke Peninsula

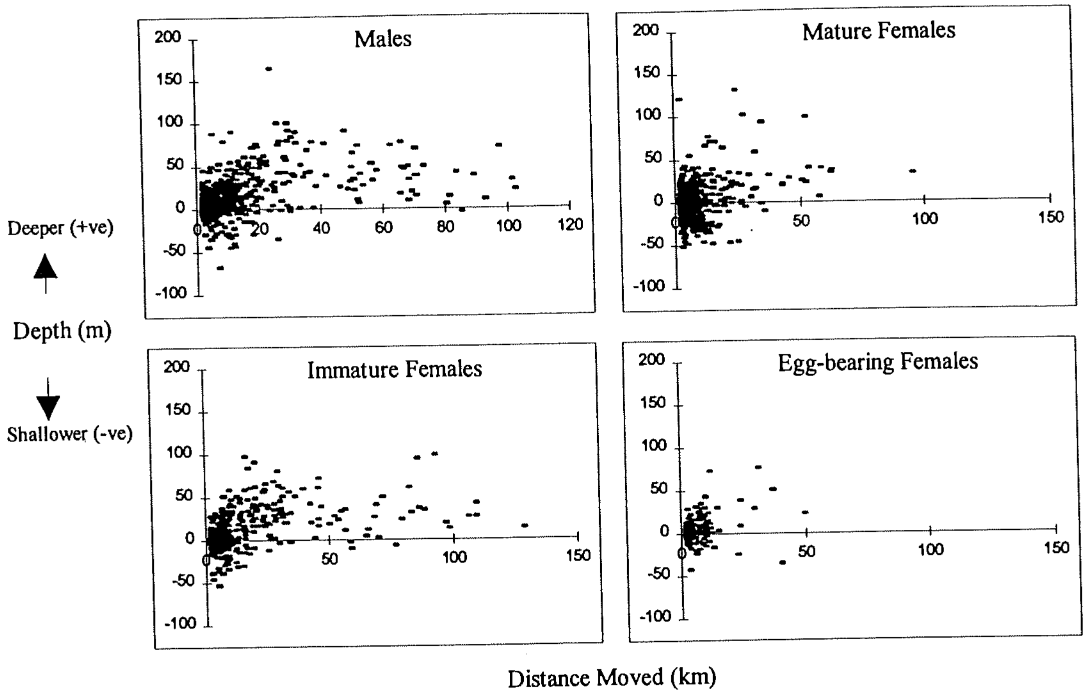


Figure 29. Change in depth made by lobsters moving distances greater than 1km, presented by sex and reproductive status.

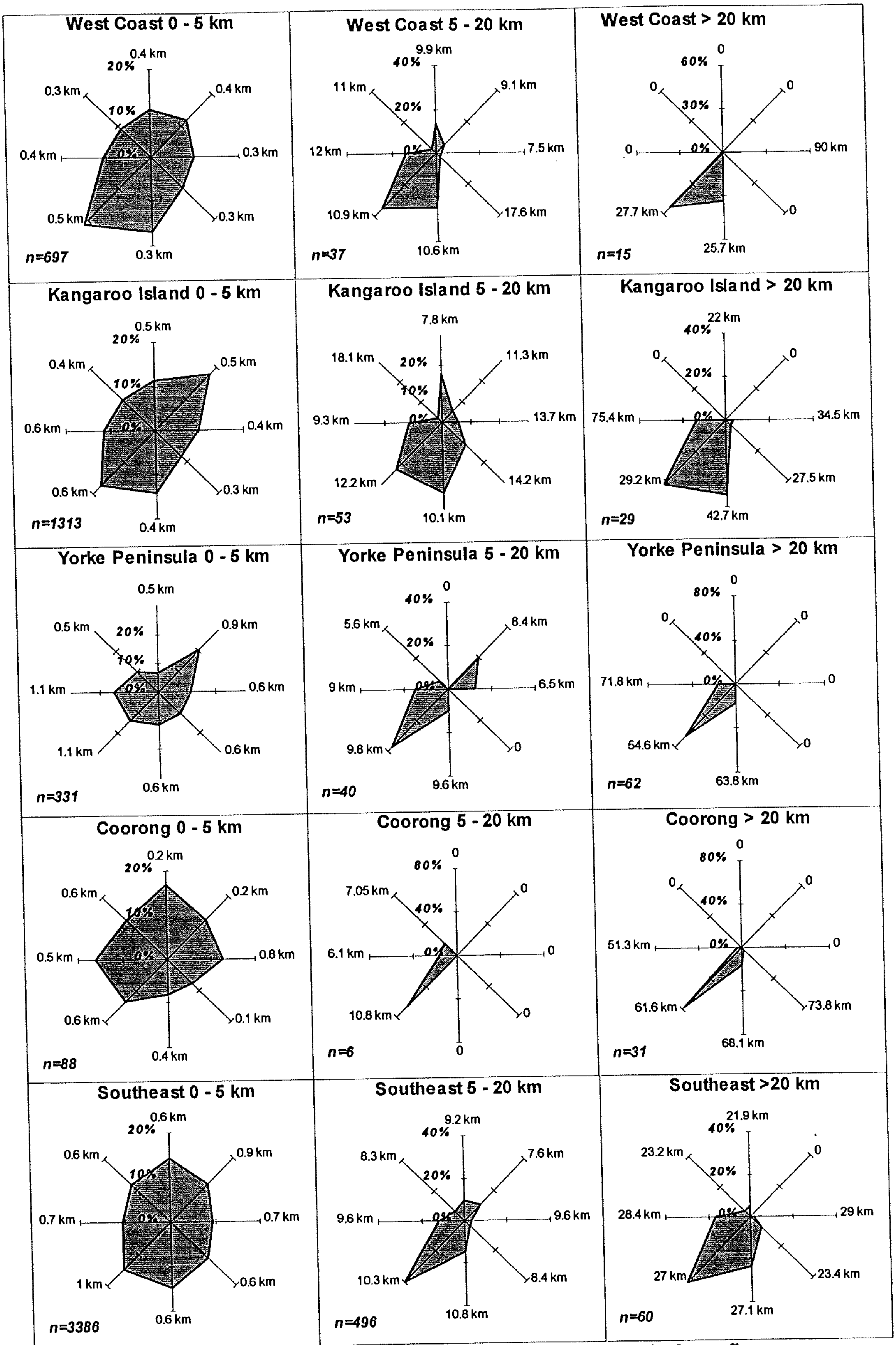


Figure 30. Direction of movement in defined distance intervals from five movement regions. Mean distances (km) moved in each cardinal direction are shown in bold font at the end of each axis. The shaded areas represent the percentage of lobsters moving in the respective directions (scale shown on north axis).

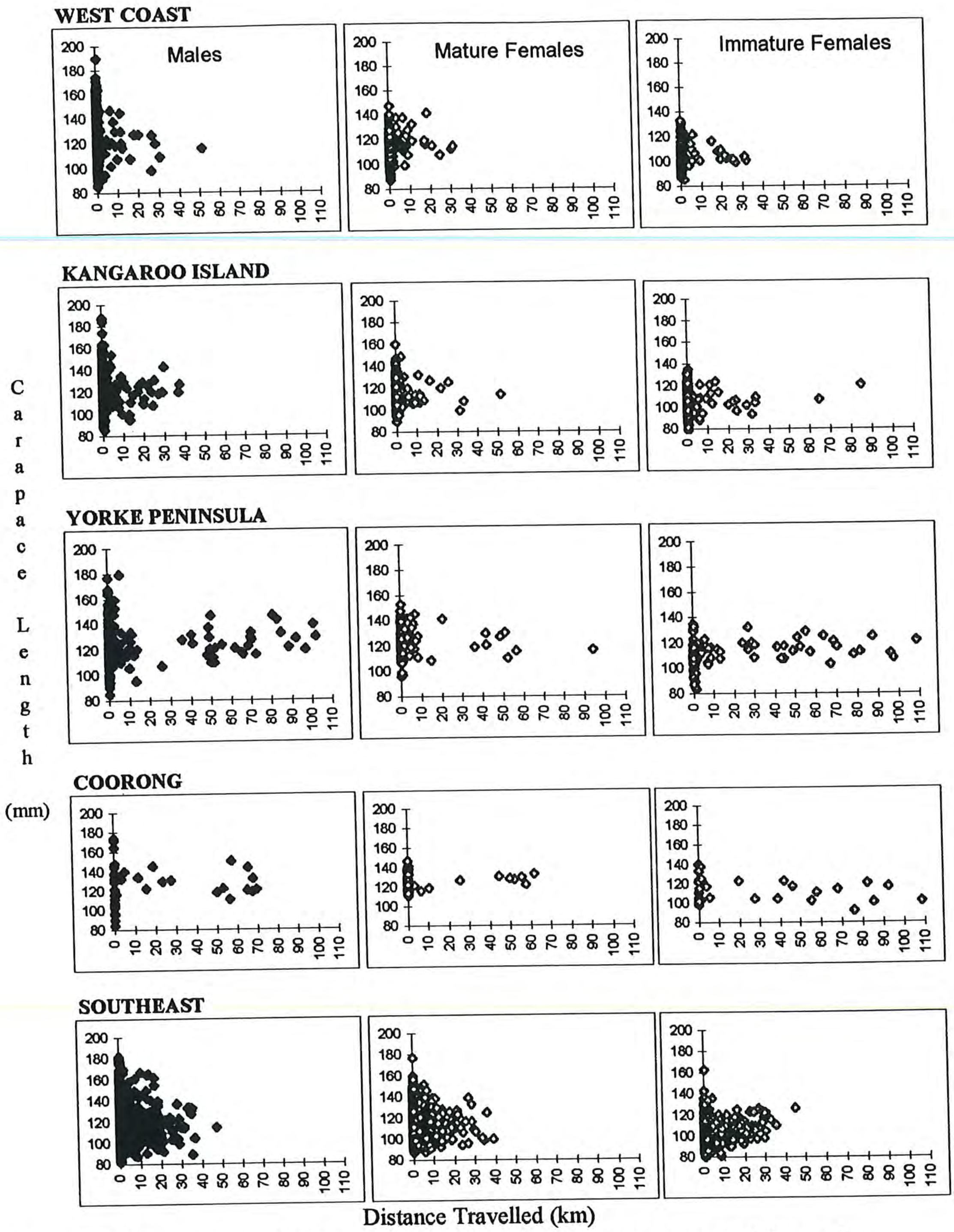


Figure 31. Distances travelled in five movement regions are presented for males, immature and mature females, plotted as carapace length versus distance travelled.

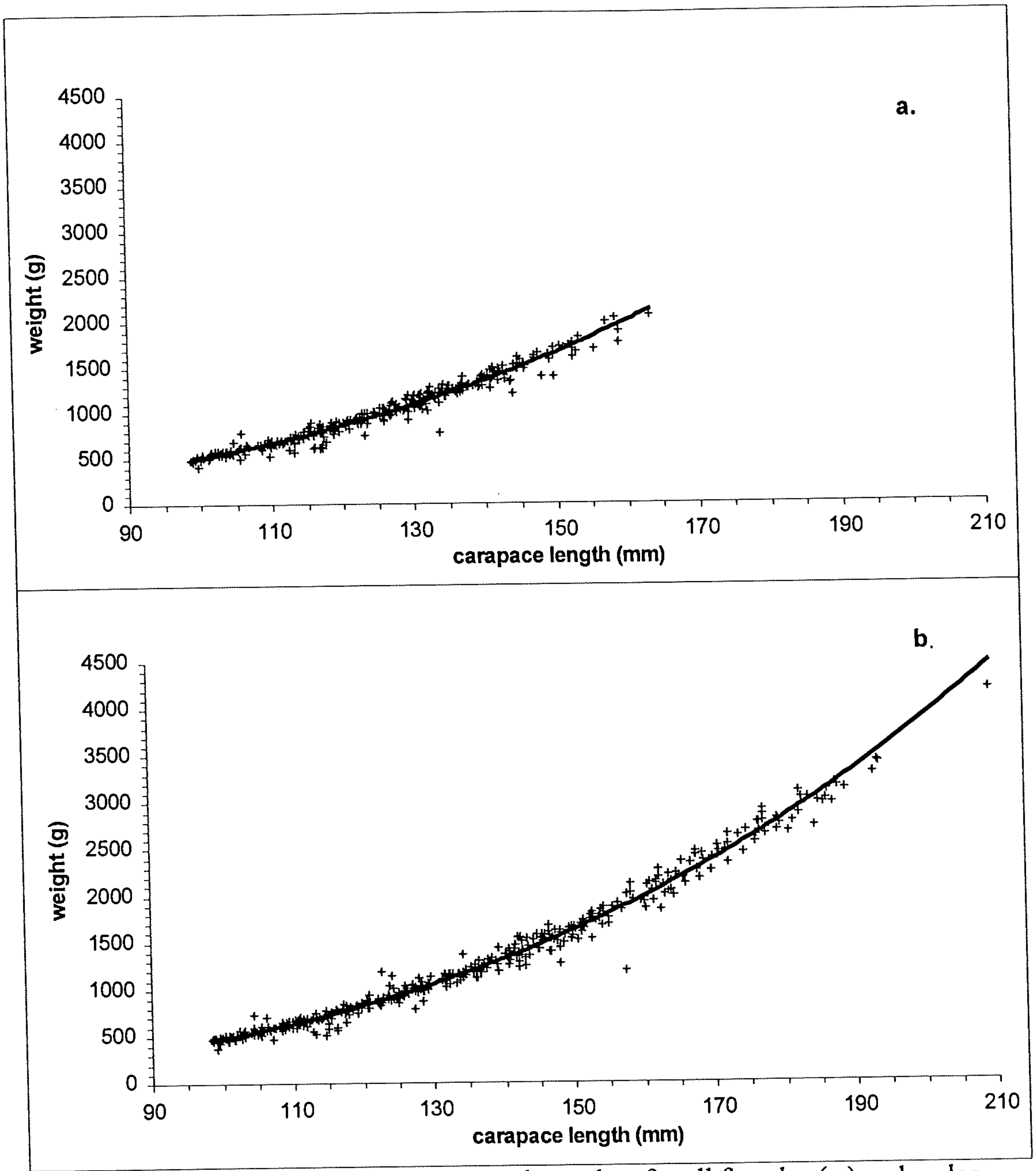


Figure 32. Fitted length-weight curves and raw data for all females (a.) and males (b.). Data included all categories of colour, damage, and sample locations.

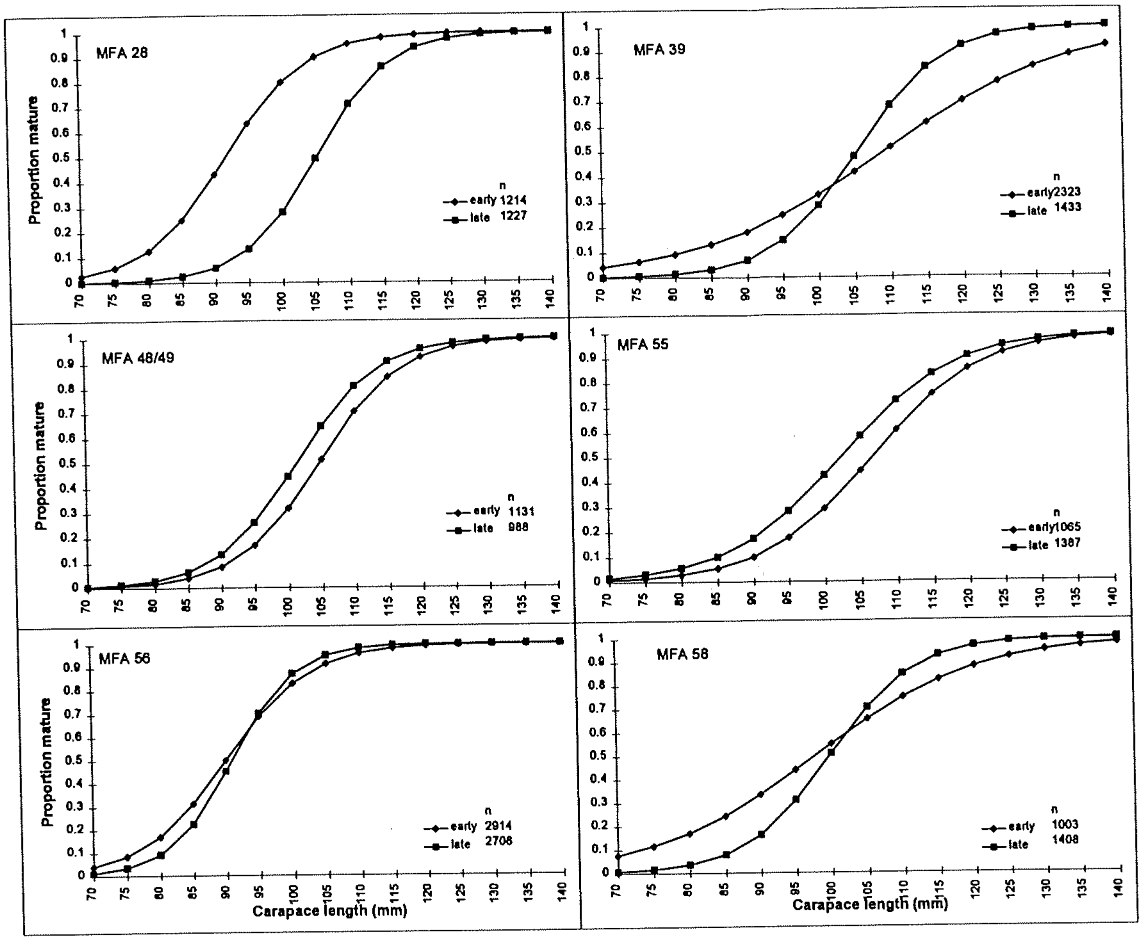


Figure 33. Fitted curves of maturity from data collected early and late during the 1992/93 season. In the northern zone marine fishing areas (28, 39, 48/49) early season was defined as November and December, and late season was March through May. Early season in the southern zone marine fishing areas (55, 56, 58) was October through December and late season March and April. Sample sizes are indicated.

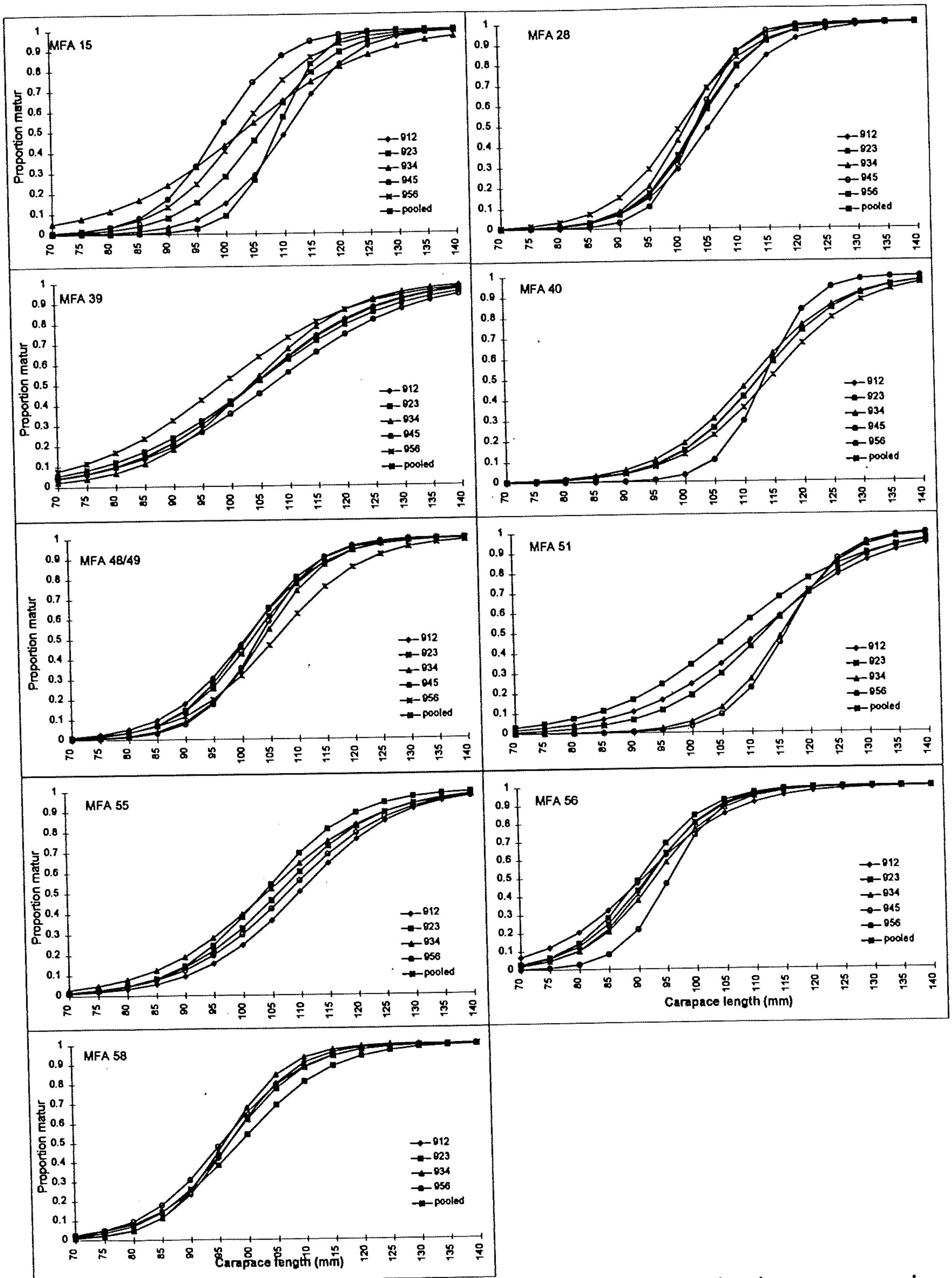


Figure 34. Fitted curves of female maturity are presented for nine important marine fishing areas. Curves were fitted for seasonal data from four or five seasons, and data from all seasons pooled. Marine fishing areas (MFA) are indicated on each graph.

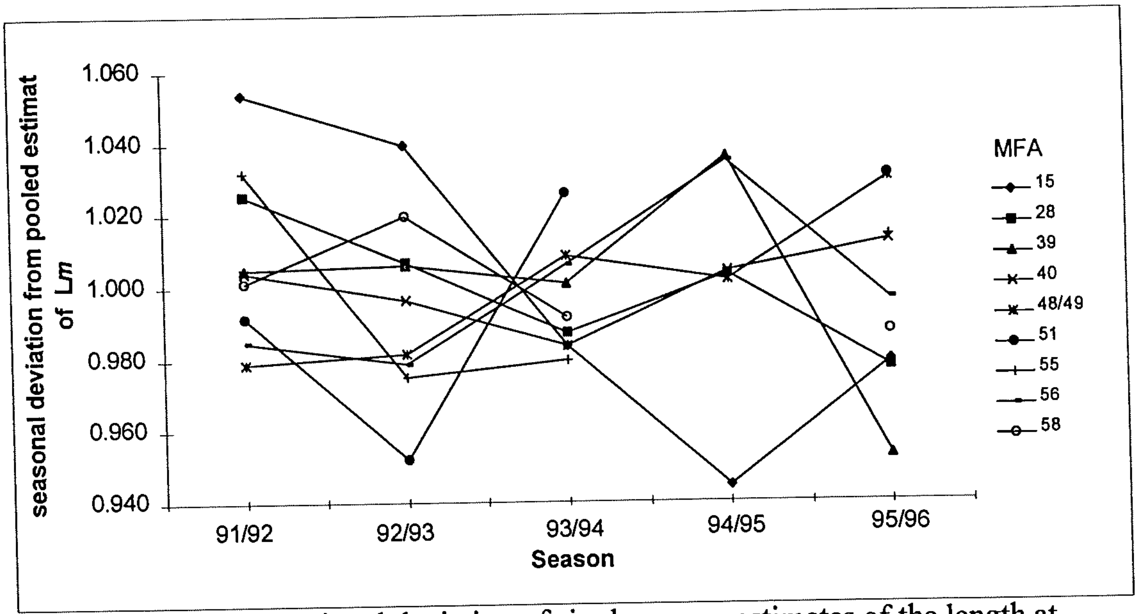


Figure 35. The proportional deviation of single season estimates of the length at which 50% of females are mature is plotted by marine fishing area for four or five seasons. Note that there is no temporal trend in the deviations.

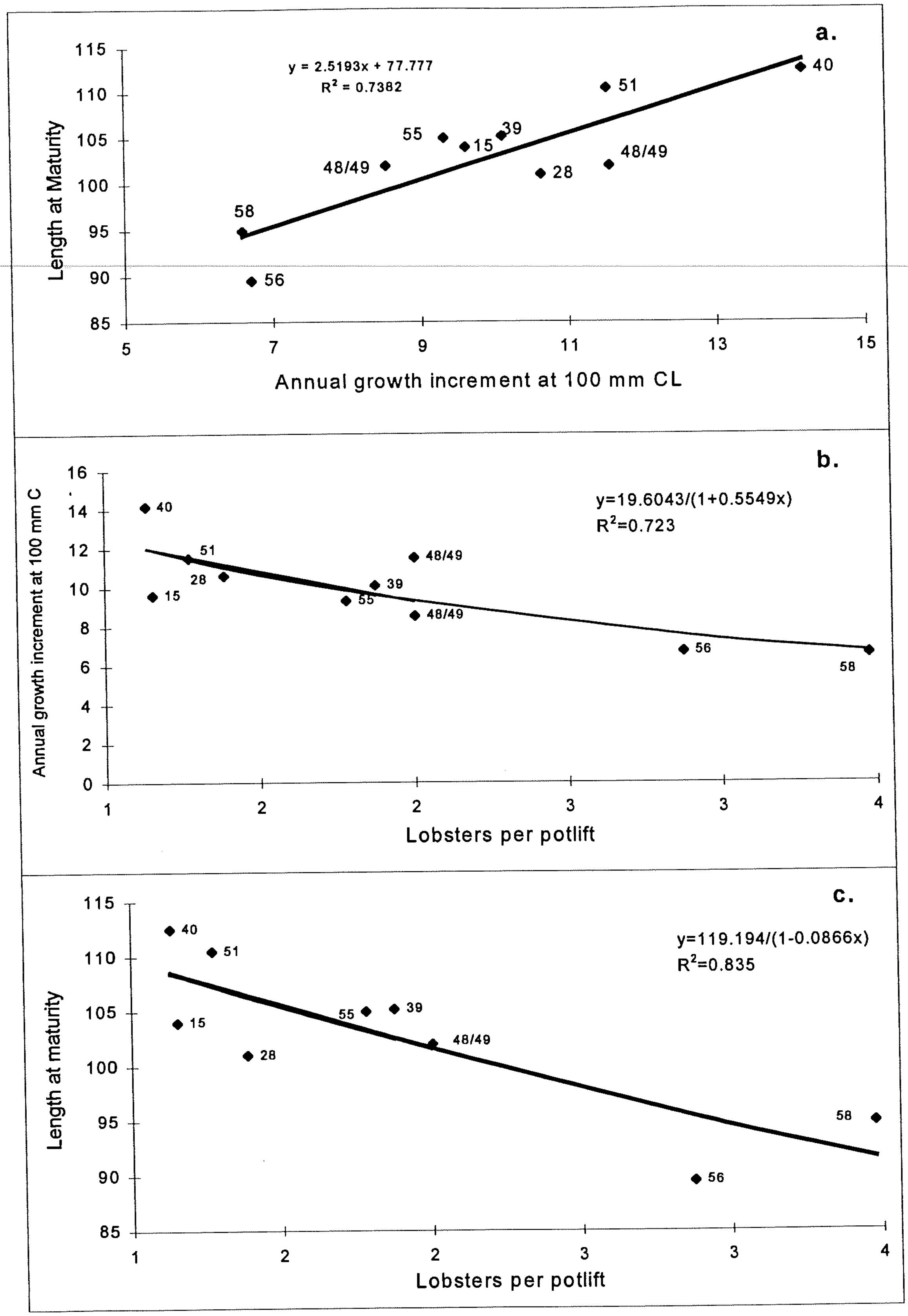


Figure 36. Female length at maturity in 10 marine fishing areas is plotted against the annual female growth increment at 100 mm in the respective area (a); annual growth increment against the number of lobsters per potlift by commercial fishers in the respective fishing area (b); and female length at maturity against lobsters per potlift. Regression equations are shown.. Note that fishing area 48 and 49 had growth estimates calculated separately but maturity was estimated from pooled data, consequently there are two data points shown in (a) and (b).

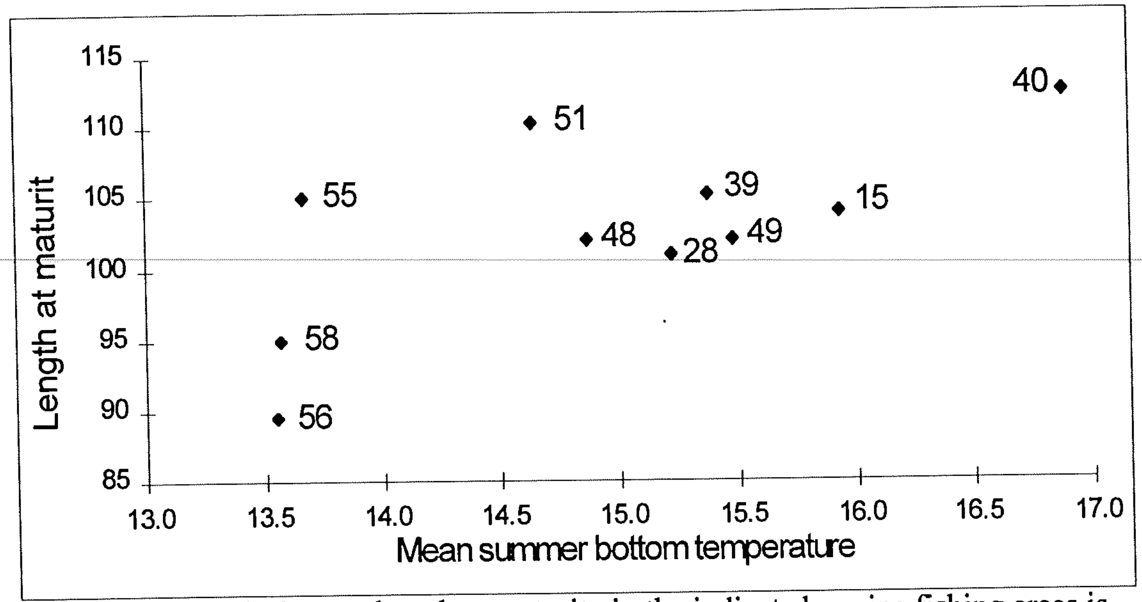


Figure 37. Females' mean length at maturity in the indicated marine fishing areas is shown plotted against the mean summer bottom temperature recorded in the respective fishing areas.

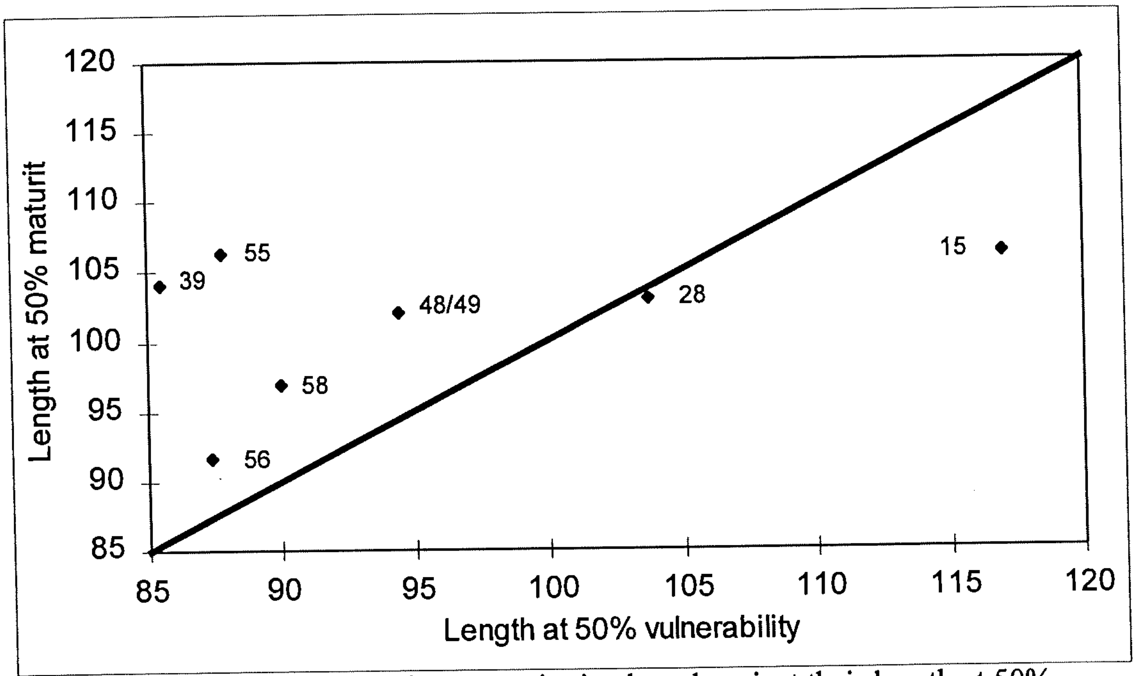


Figure 38. The females' length at maturity is plotted against their length at 50% vulnerability by marine fishing areas. The line of equal lengths is plotted for reference.

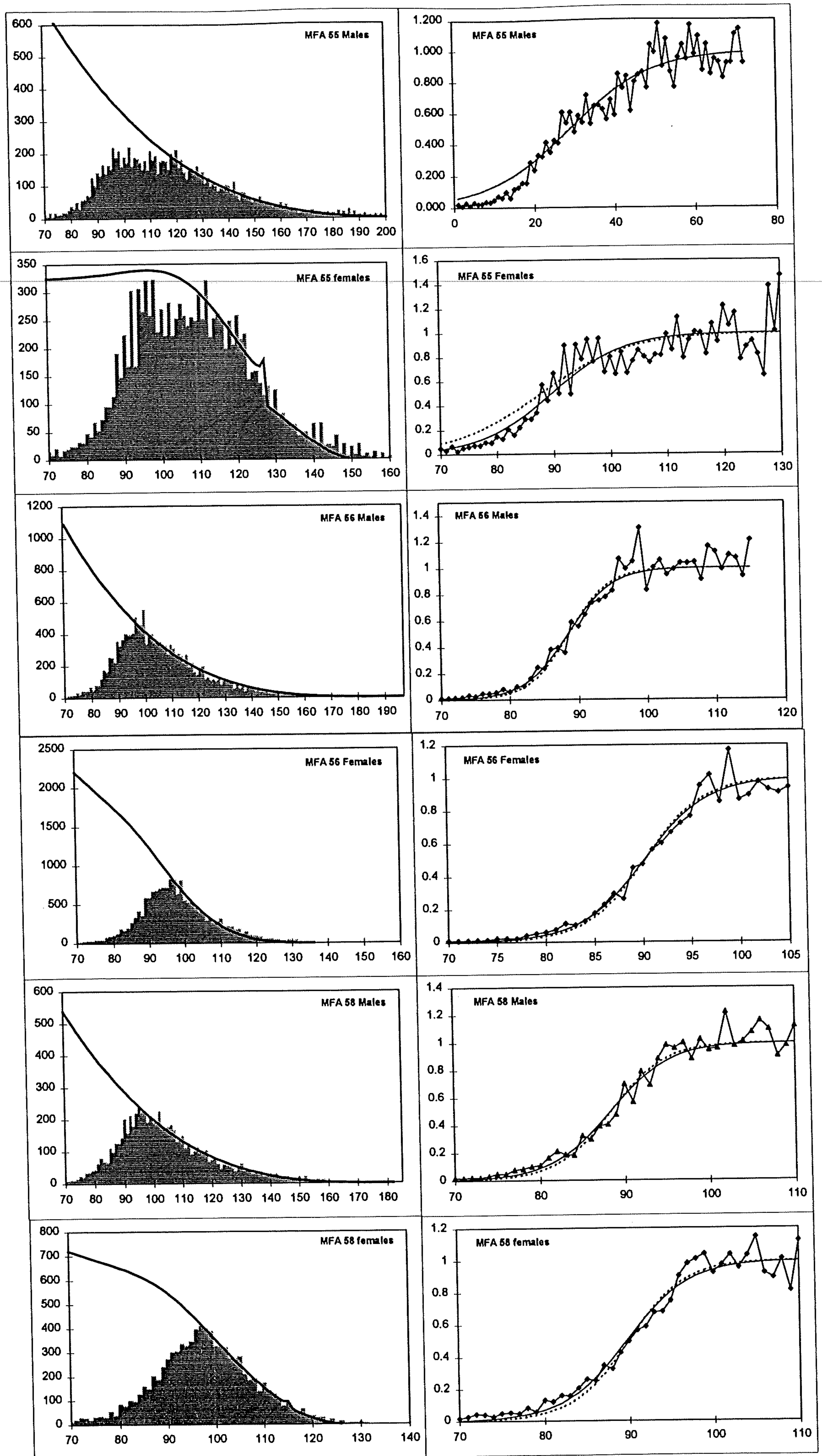


Figure 39a. Observed length frequency distributions (▮) and fitted sample population curves (——)for southern zone areas. Fitted logistic curves of vulnerability also shown for raw (——)and weighted data sets (........); raw data shown (—◆—).

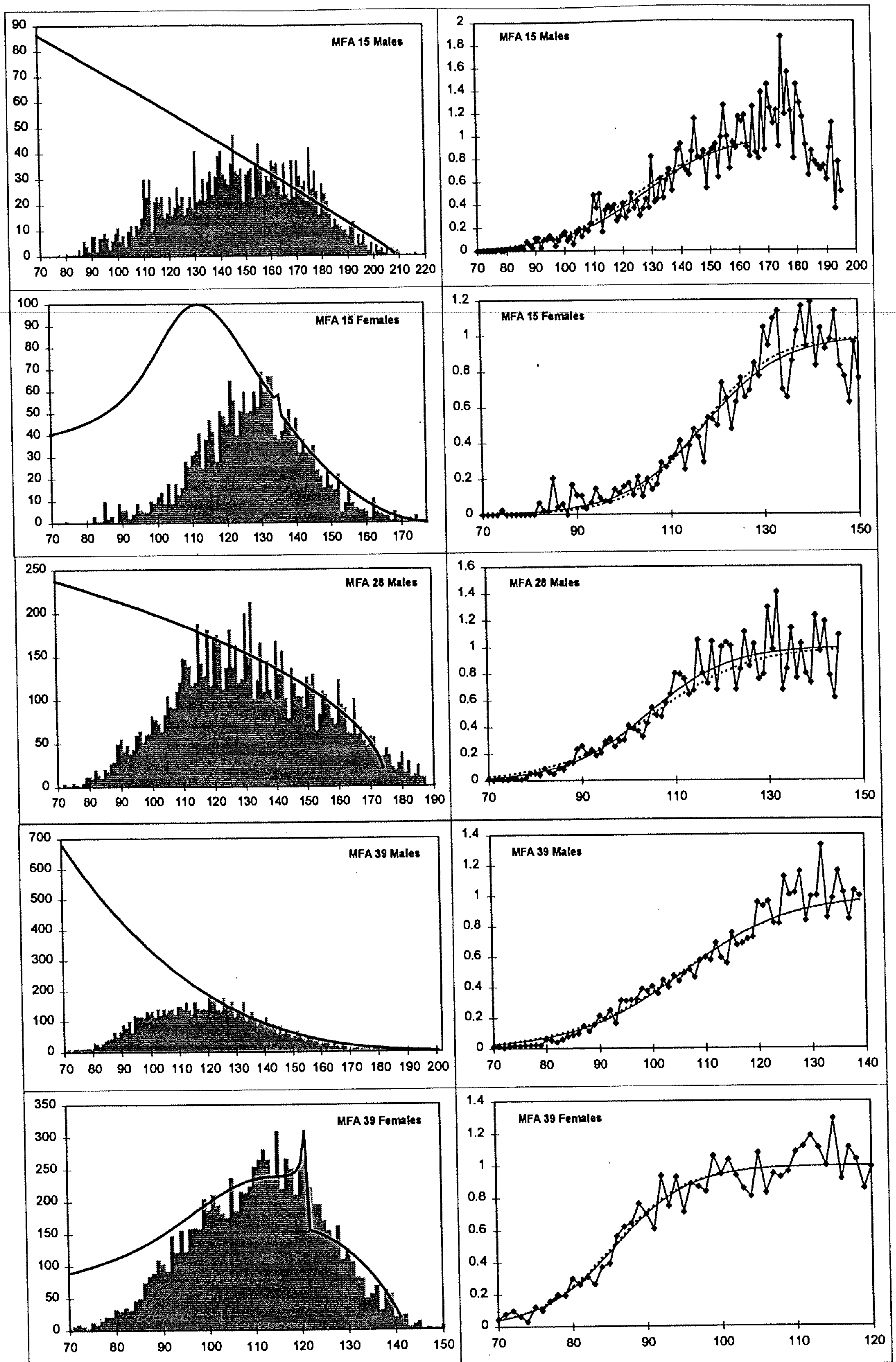


Figure 39b. Observed length frequency distributions (▮) and fitted sample population curves (——)for northern zone areas. Fitted logistic curves of vulnerability also shown for raw (—)and weighted data sets (........); raw data shown (—◆—).

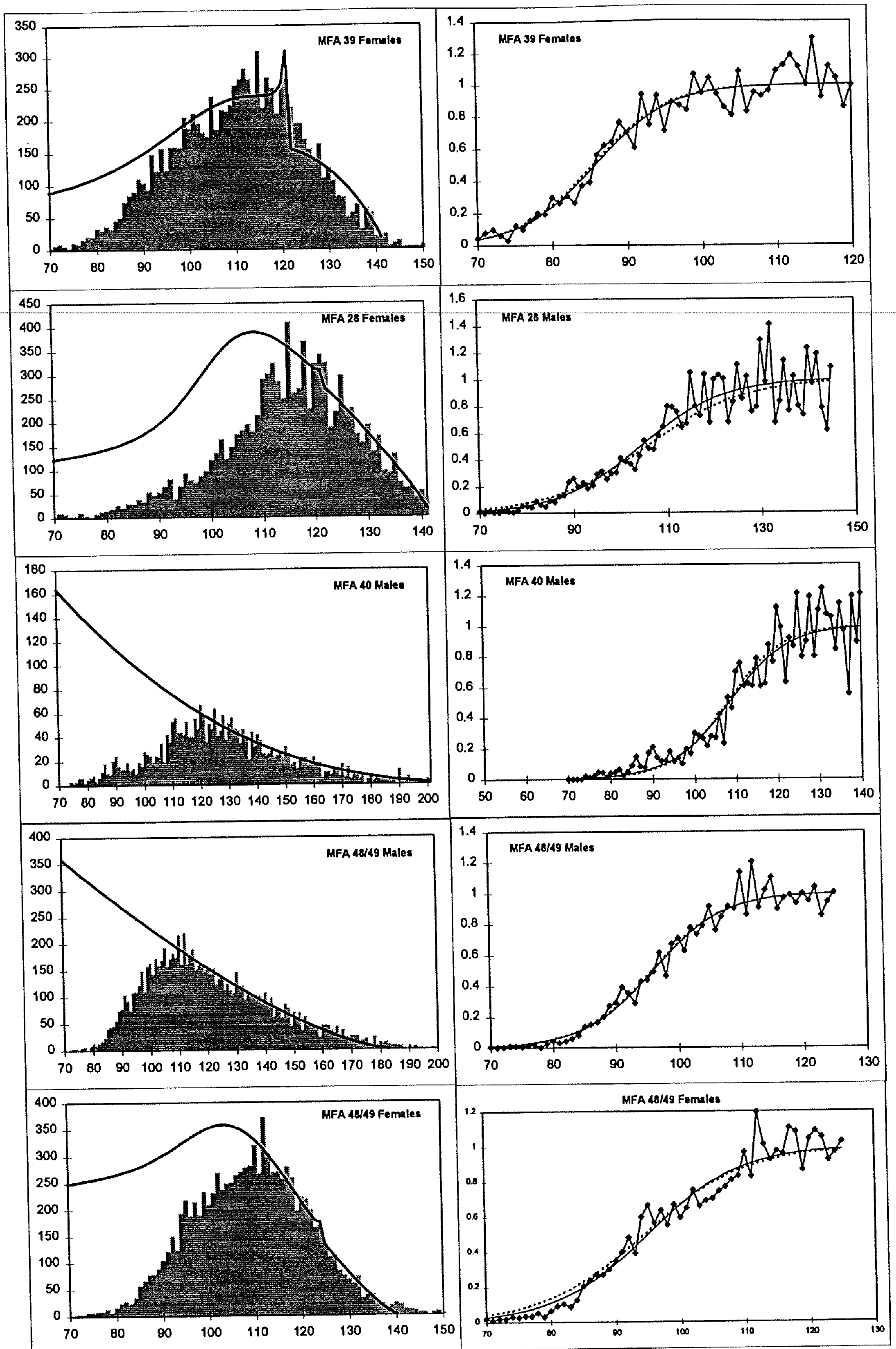


Figure 39b. Continued

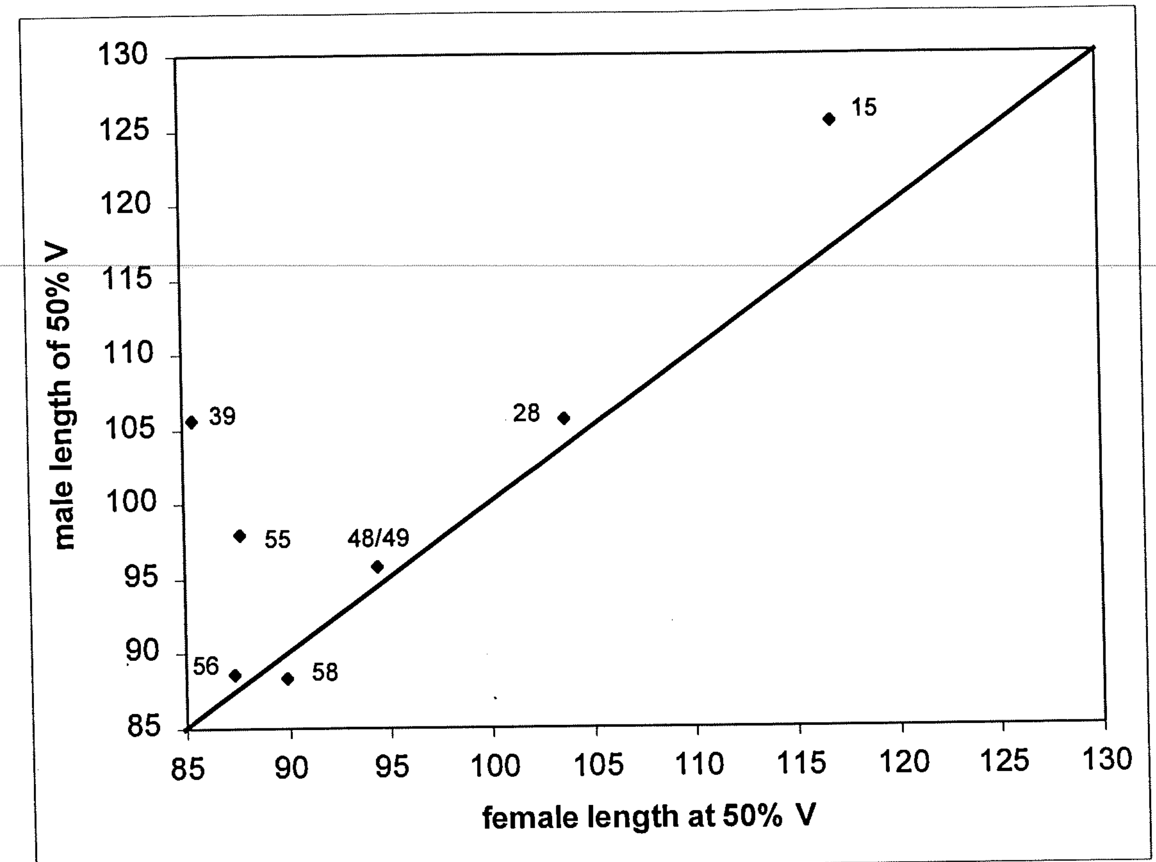


Figure 40. Male carapace lengths at 50 percent vulnerability are plotted against the females' for important marine fishing areas. A line of equal vulnerability is drawn for reference.

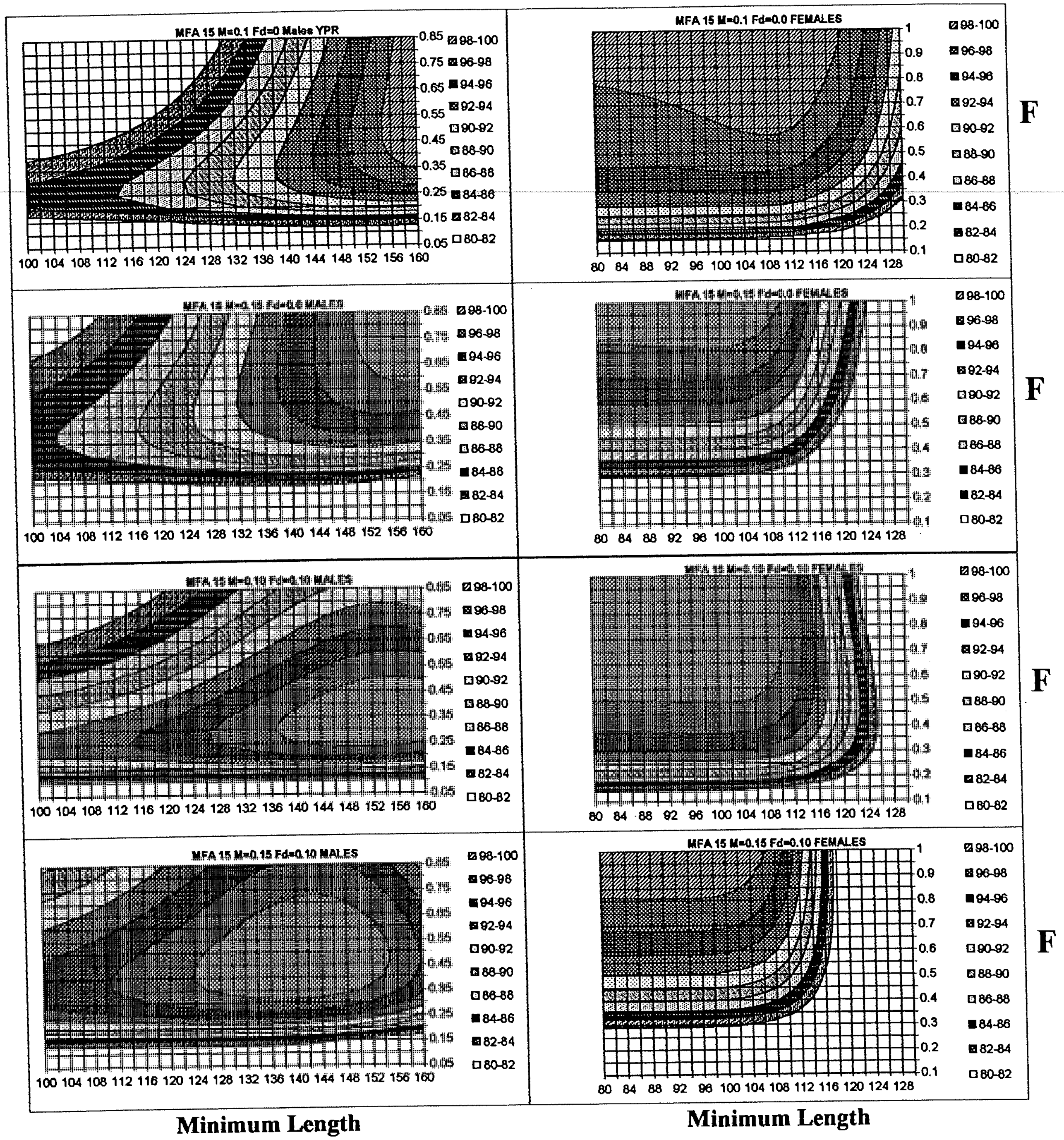


Figure 41a. Yield-per-recruit isopleths for male and female lobsters in Marine Fishing Area 15 under conditions of natural mortality of 0.10 and 0.15, and discard mortality of 0.0 and 0.10 for a combination of minimum lengths and fishing mortality rates. Results are expressed as a percentage of the maximum YPR.

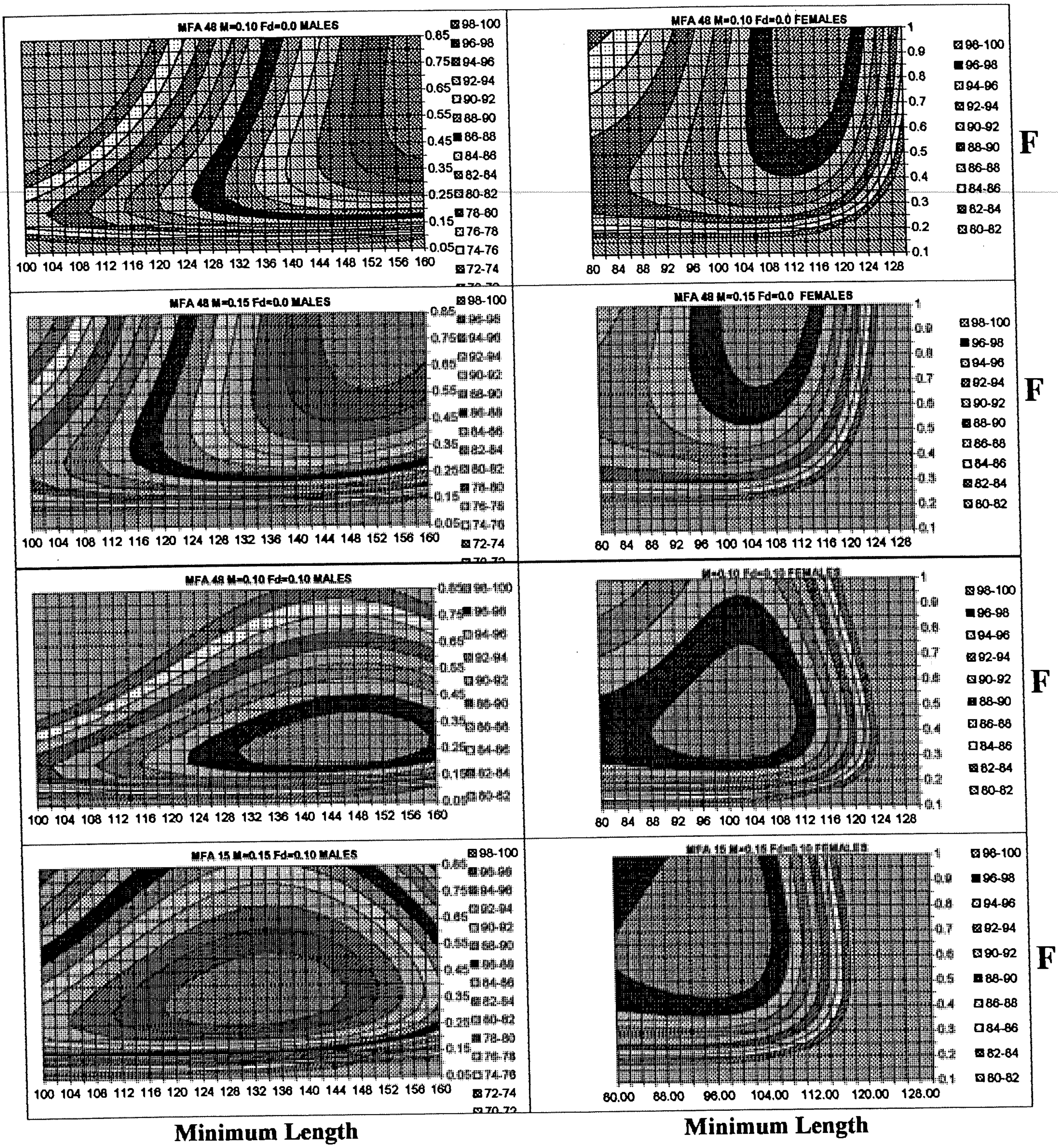


Figure 41b. Yield-per-recruit isopleths for male and female lobsters in Marine Fishing Area 48 under conditions of natural mortality of 0.10 and 0.15, and discard mortality of 0.0 and 0.10 for a combination of minimum lengths and fishing mortality rates. Results are expressed as a percentage of the maximum YPR.

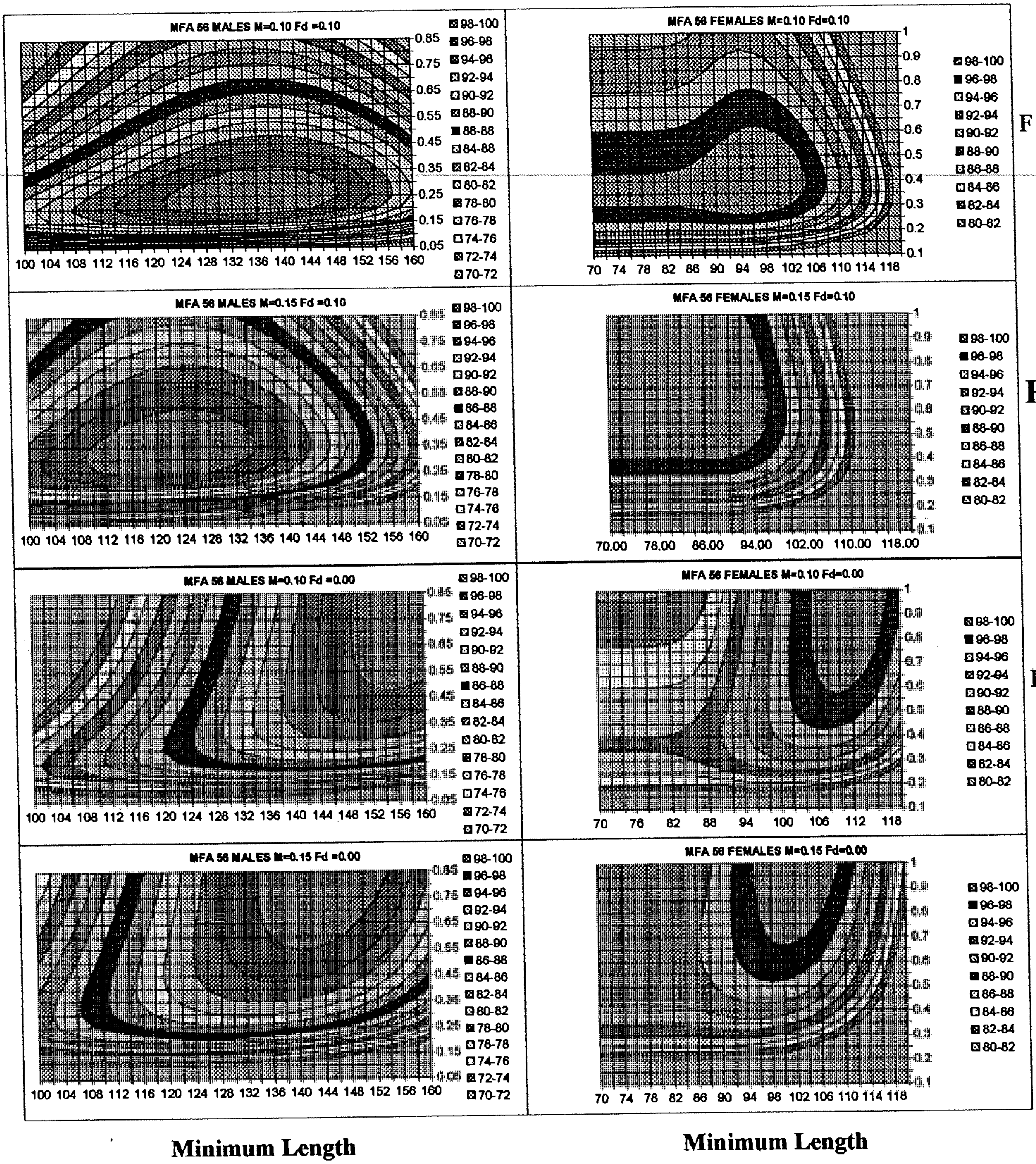


Figure 41c. Yield-per-recruit isopleths for male and female lobsters in Marine Fishing Area 56 under conditions of natural mortality of 0.10 and 0.15, and discard mortality of 0.0 and 0.10 for a combination of minimum lengths and fishing mortality rates. Results are expressed as a percentage of the maximum YPR.

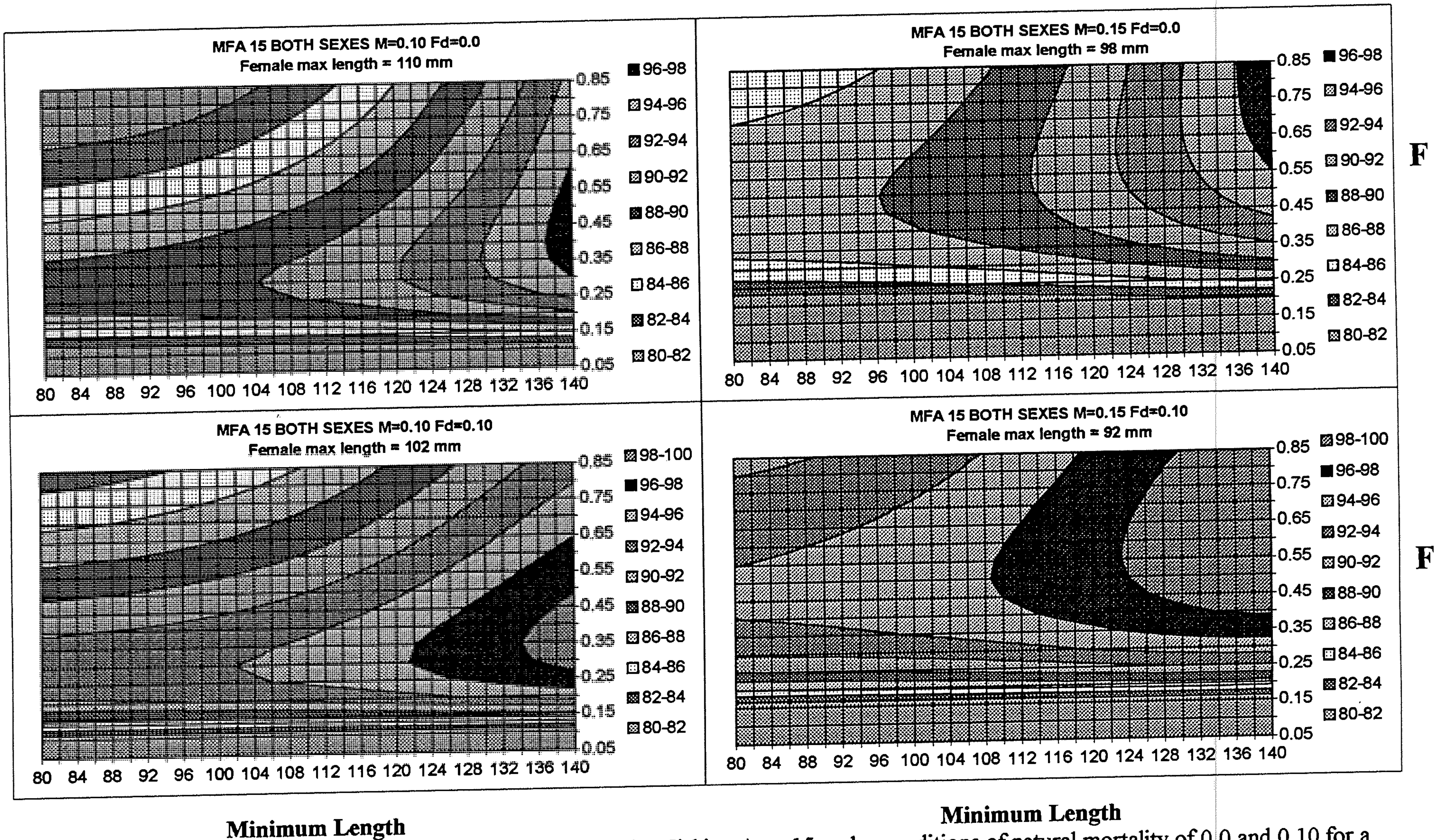


Figure 42a. Yield-per-recruit isopleths for combined sexes in Marine Fishing Area 15 under conditions of natural mortality of 0.0 and 0.10 for a combination of minimum lengths and fishing mortality rates. Female minimum lengths increased in unison with the males' to the length of maximum female YPR and were held constant at the value as the males increased further. The highest value of female minimum length used in each analysis is indicated on the graph. Figures graphed are expressed as a percentage of the maximum YPR.

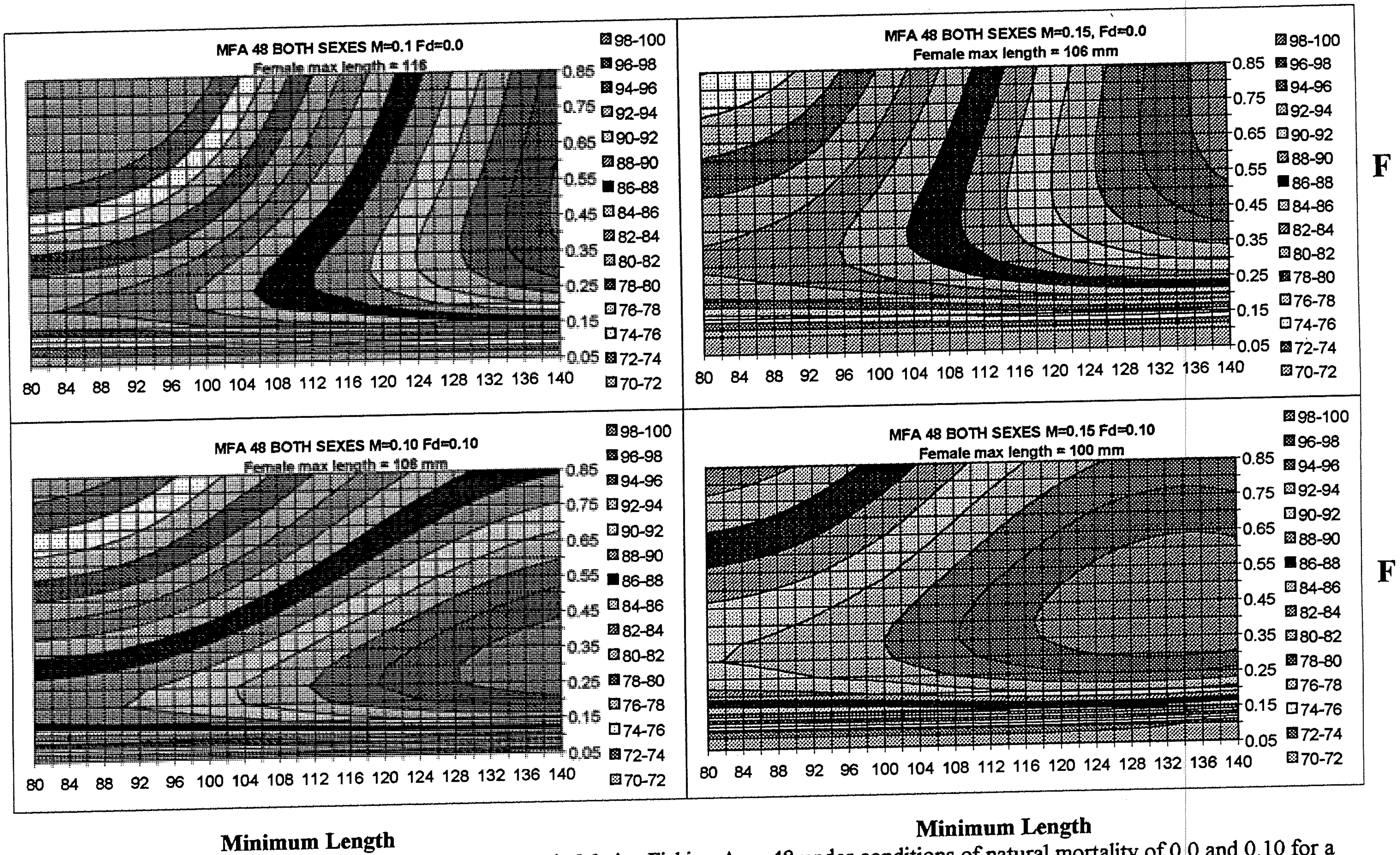


Figure 42b. Yield-per-recruit isopleths for combined sexes in Marine Fishing Area 48 under conditions of natural mortality of 0.0 and 0.10 for a combination of minimum lengths and fishing mortality rates. Female minimum lengths increased in unison with the males' to the length of maximum female YPR and were held constant at the value as the males increased further. The highest value of female minimum length used in each analysis is indicated on the graph. Figures graphed are expressed as a percentage of the maximum YPR.

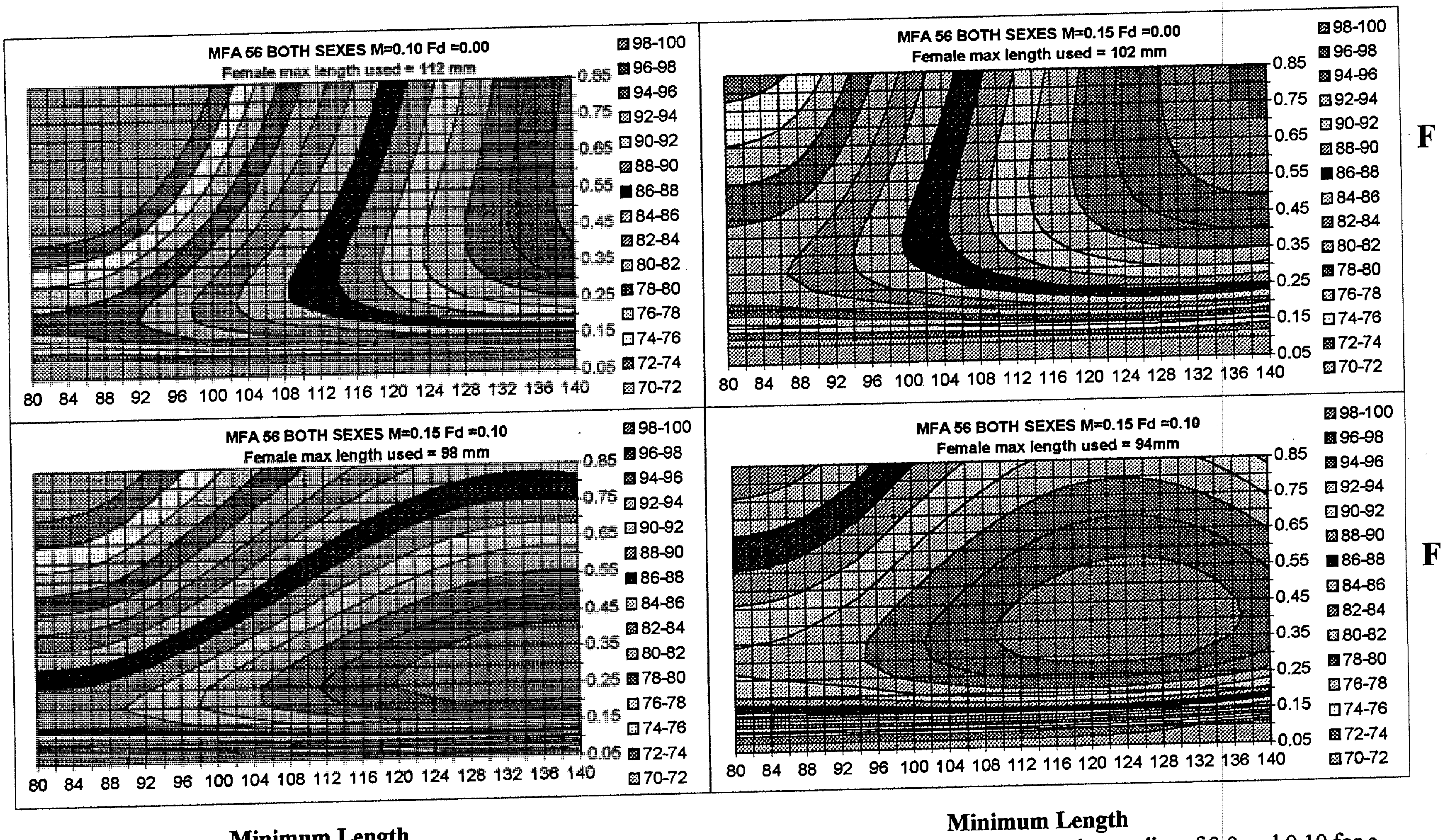


Figure 42c. Yield-per-recruit isopleths for combined sexes in Marine Fishing Area 56 under conditions of natural mortality of 0.0 and 0.10 for a combination of minimum lengths and fishing mortality rates. Female minimum lengths increased in unison with the males' to the length of maximum female YPR and were held constant at the value as the males increased further. The highest value of female minimum length used in each analysis is indicated on the graph. Figures graphed are expressed as a percentage of the maximum YPR.

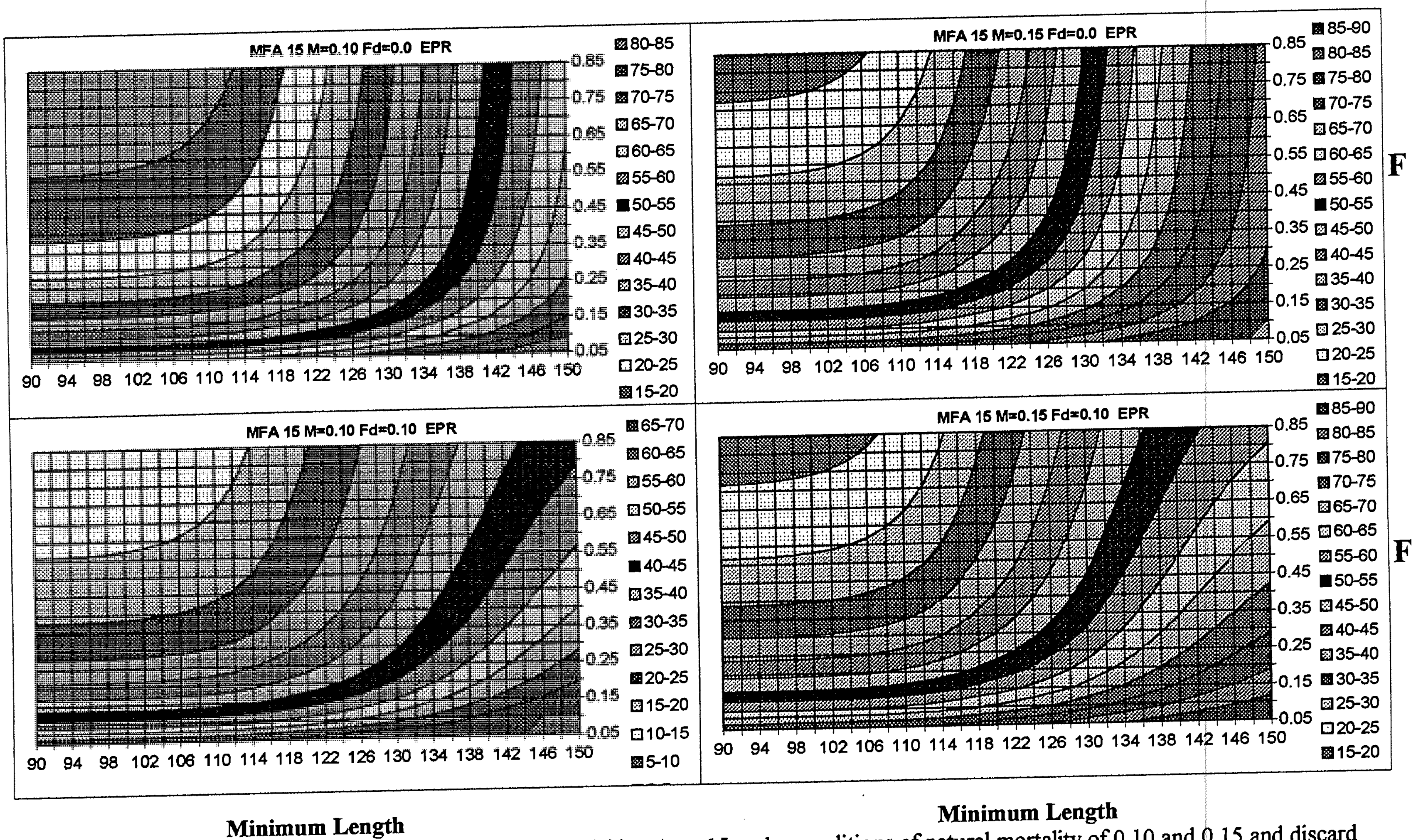


Figure 43a. Egg-per-recruit isopleths for females in Marine Fishing Area 15 under conditions of natural mortality of 0.10 and 0.15 and discard mortality of 0.00 and 0.10. EPR is expressed as a percentage of the maximum, ie. under zero fishing mortality.

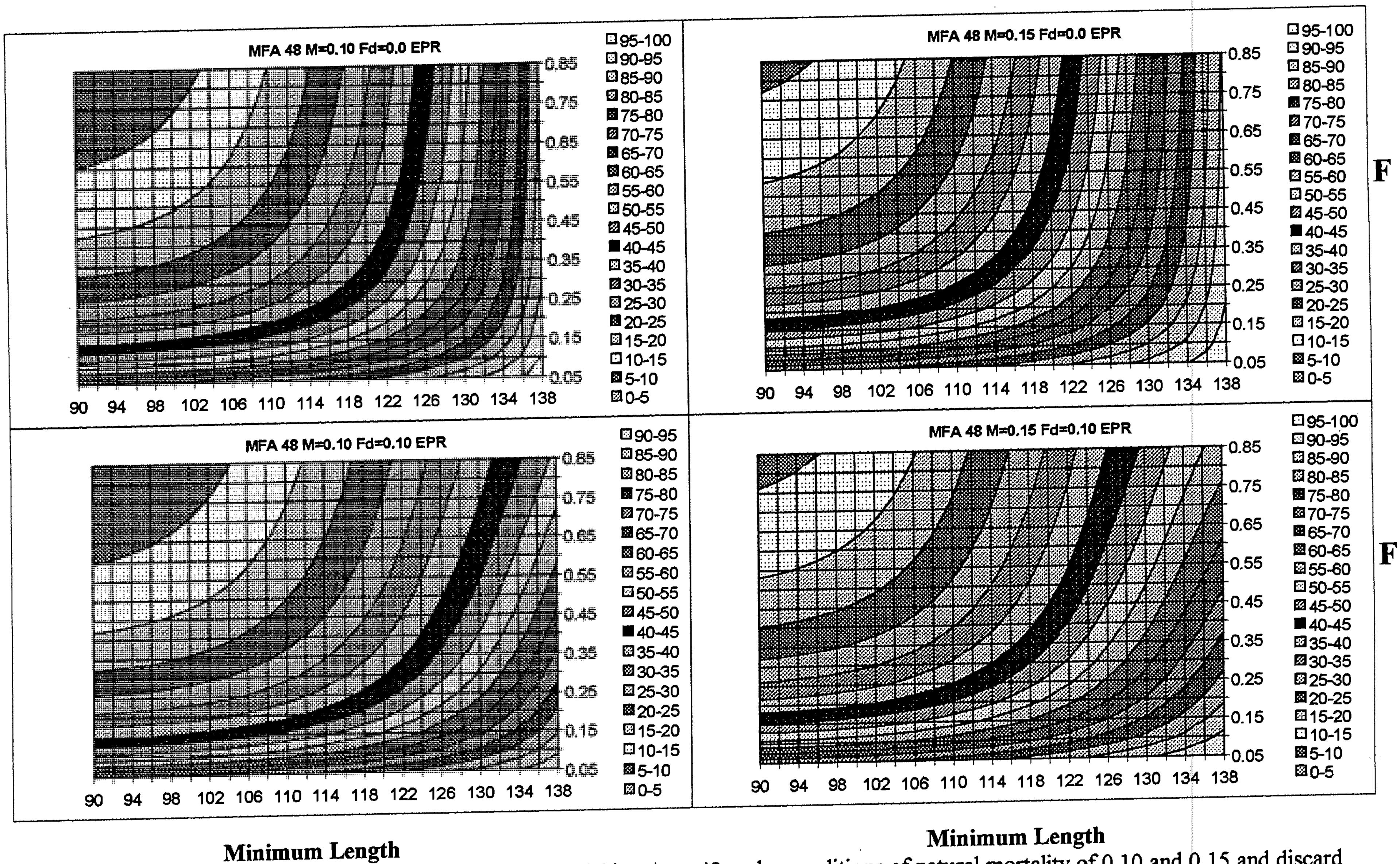


Figure 43b. Egg-per-recruit isopleths for females in Marine Fishing Area 48 under conditions of natural mortality of 0.10 and 0.15 and discard mortality of 0.00 and 0.10. EPR is expressed as a percentage of the maximum, ie. under zero fishing mortality.

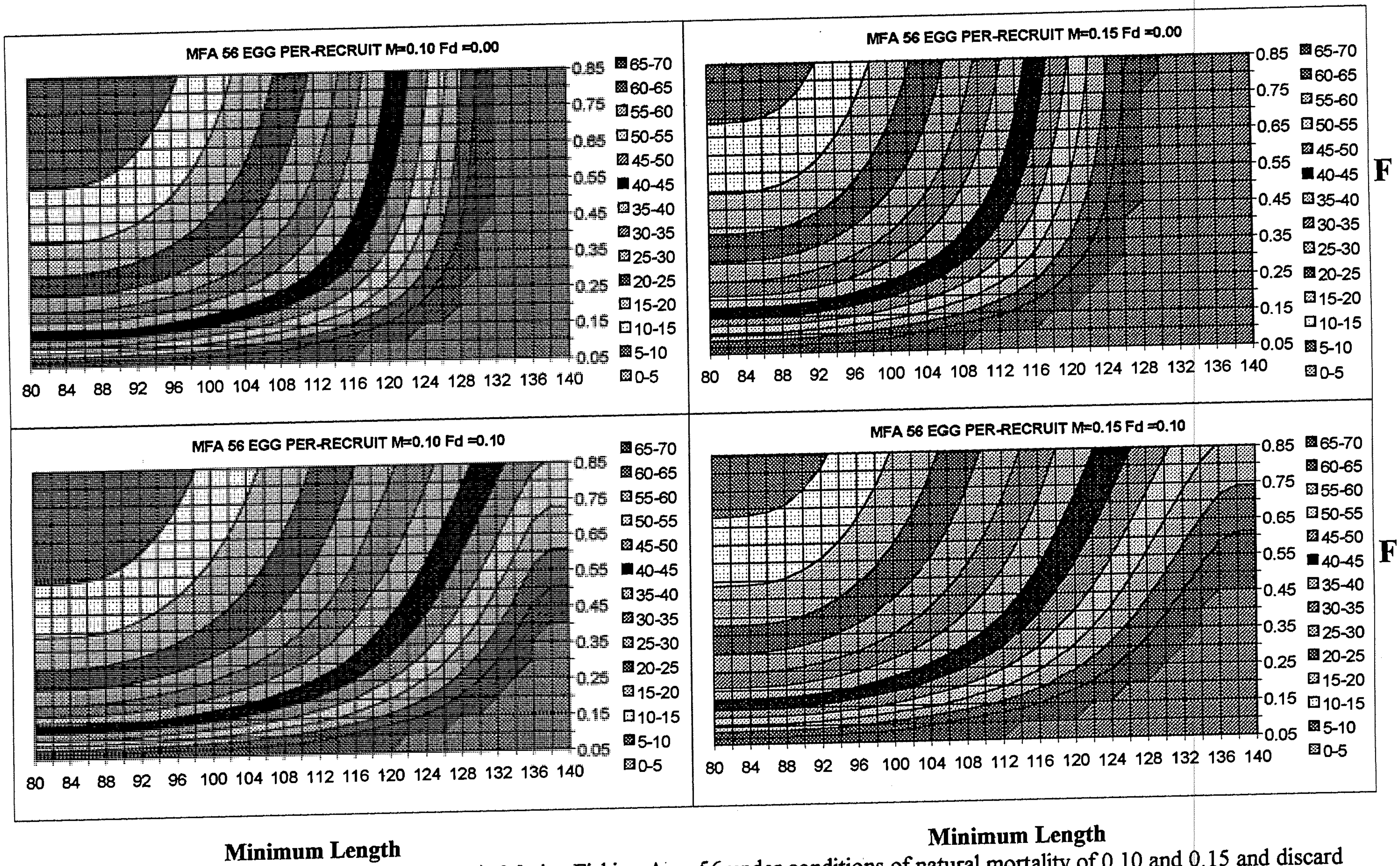


Figure 43c. Egg-per-recruit isopleths for females in Marine Fishing Area 56 under conditions of natural mortality of 0.10 and 0.15 and discard mortality of 0.00 and 0.10. EPR is expressed as a percentage of the maximum, ie. under zero fishing mortality.

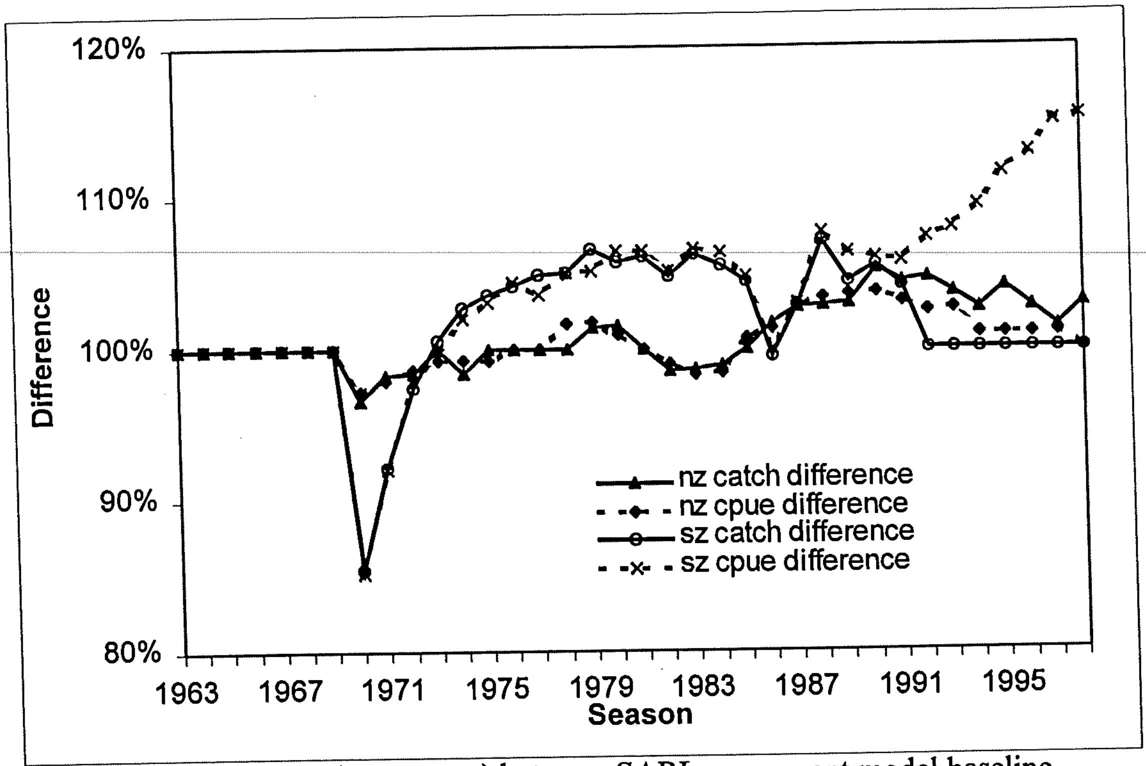


Figure 44. Differences (percentage) between SARL assessment model baseline estimates of catch and CPUE in the southern and northern zones and estimates of these variables following an increase in male size limit from 98.5 to 115 mm in 1975 are plotted. Note the much greater immediate effect in the southern zone and the larger positive effect in that zone over the longer term.

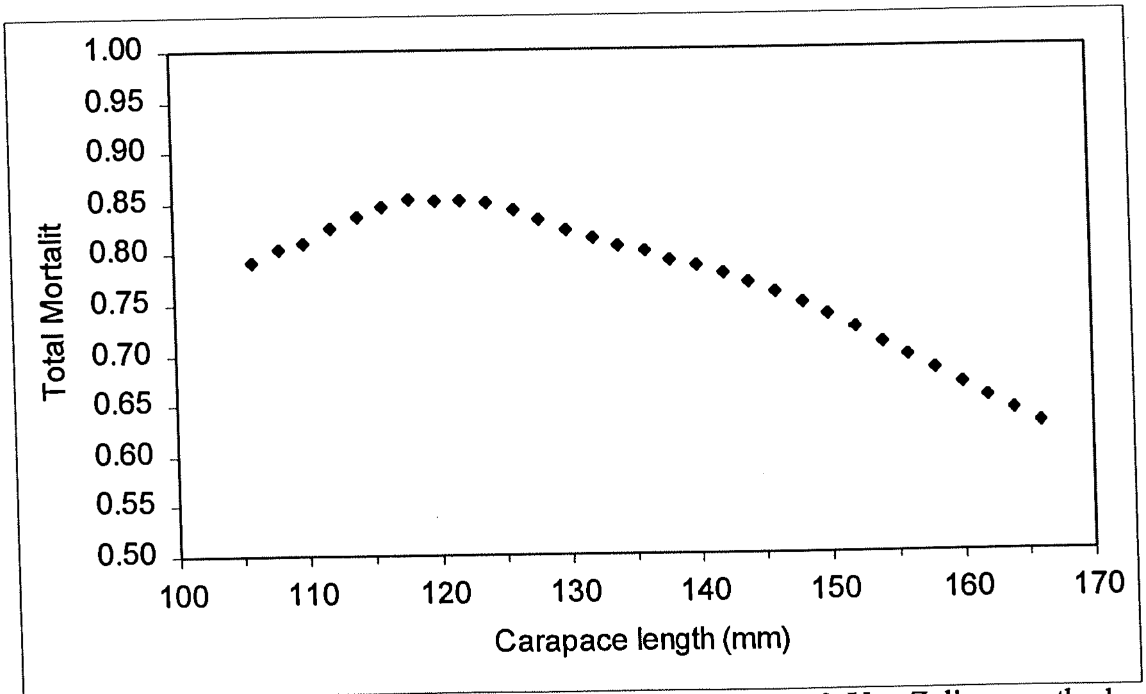


Figure 45. Total mortality (Z) values estimated by the Jones & Van Zalinge method are plotted against the carapace length corresponding to the largest length included in the analysis.

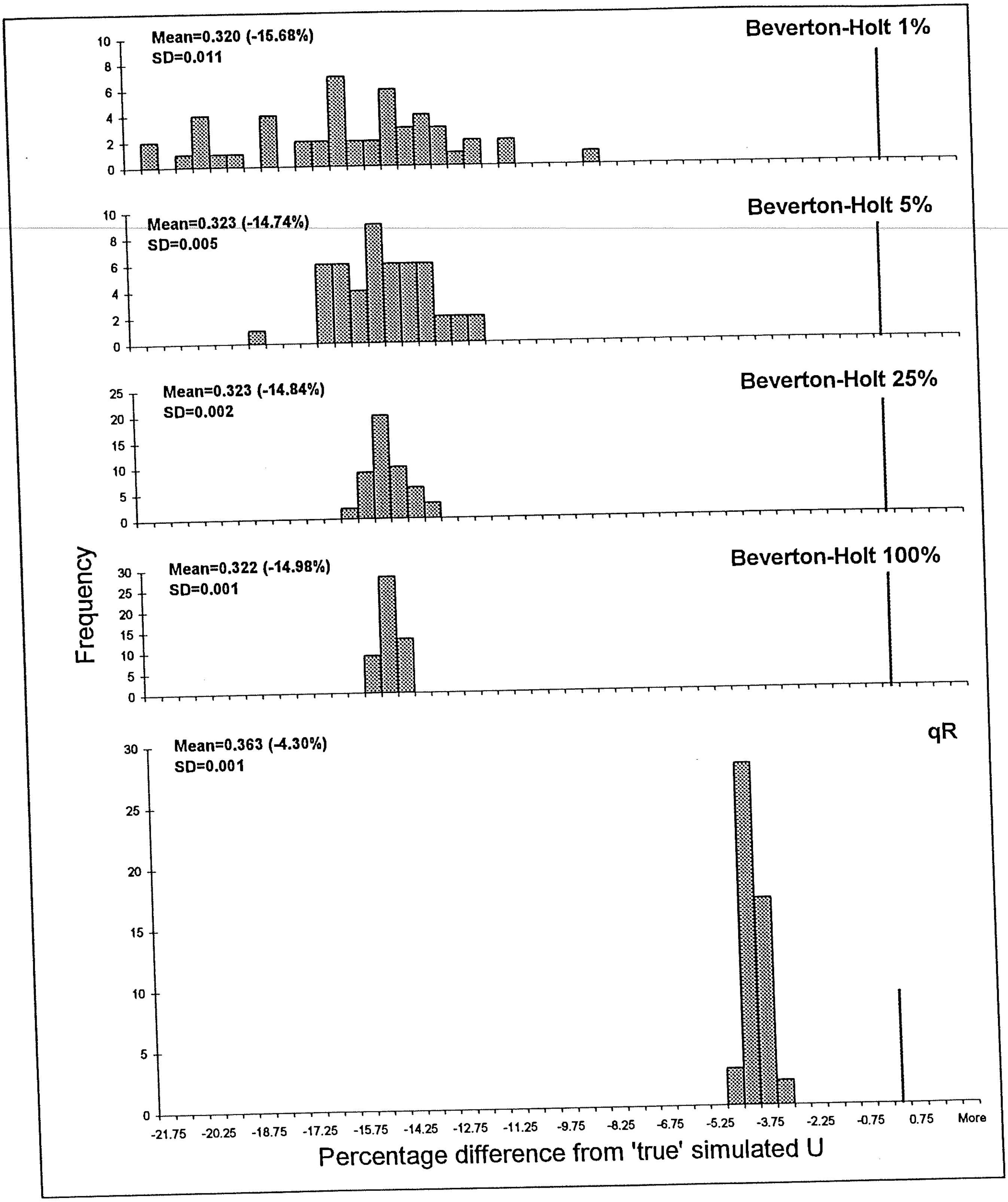


Figure 46. Histograms of exploitation rate (*U*) from 50 runs of simulated data for the catch weight-numbers and Beverton-Holt mean-length methods. The mean lengths were calculated from four sampling intensities, 1%, 5%, 25% and 100% of (simulated) lobsters captured. The mean for the 'true', simulated *U* was 0.379. The vertical lines represent 0% deviation from the 'true', simulated *U*.

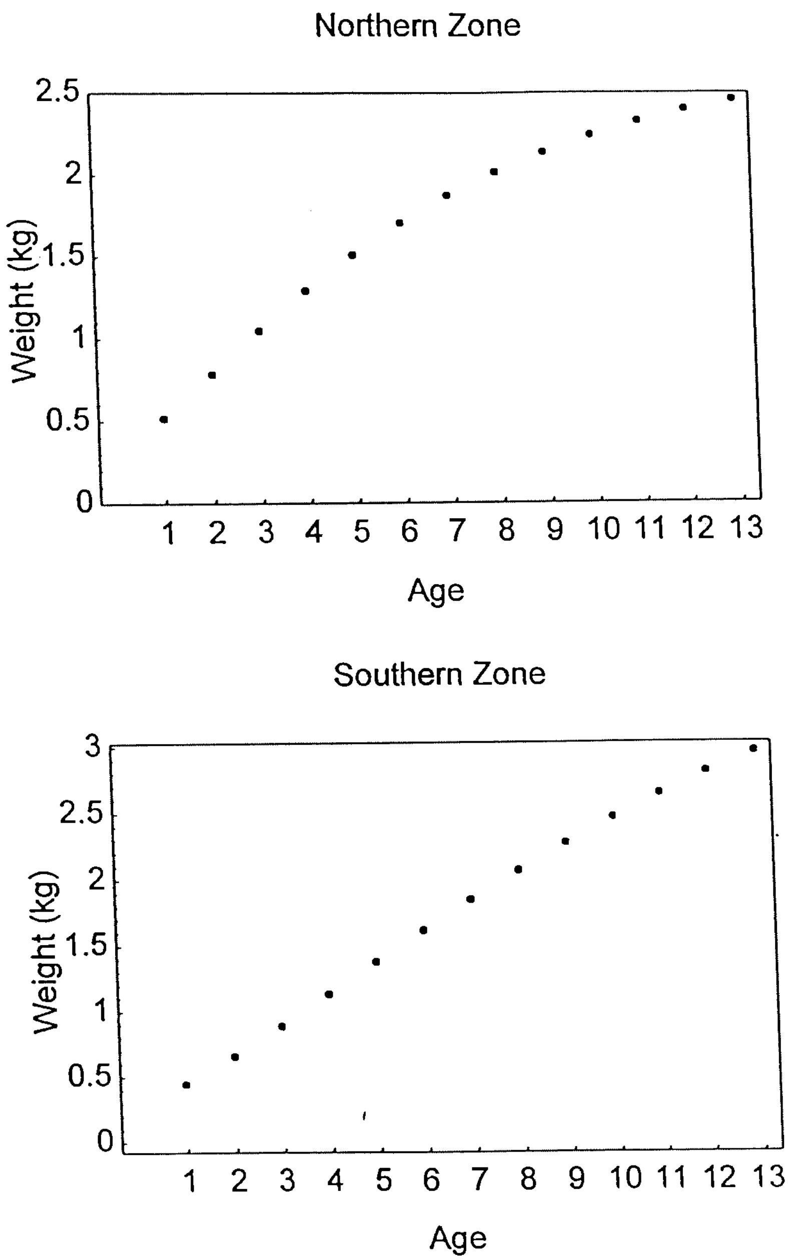


Figure 47. Relationship between weight and age for lobsters from the Northern and Southern Zones.

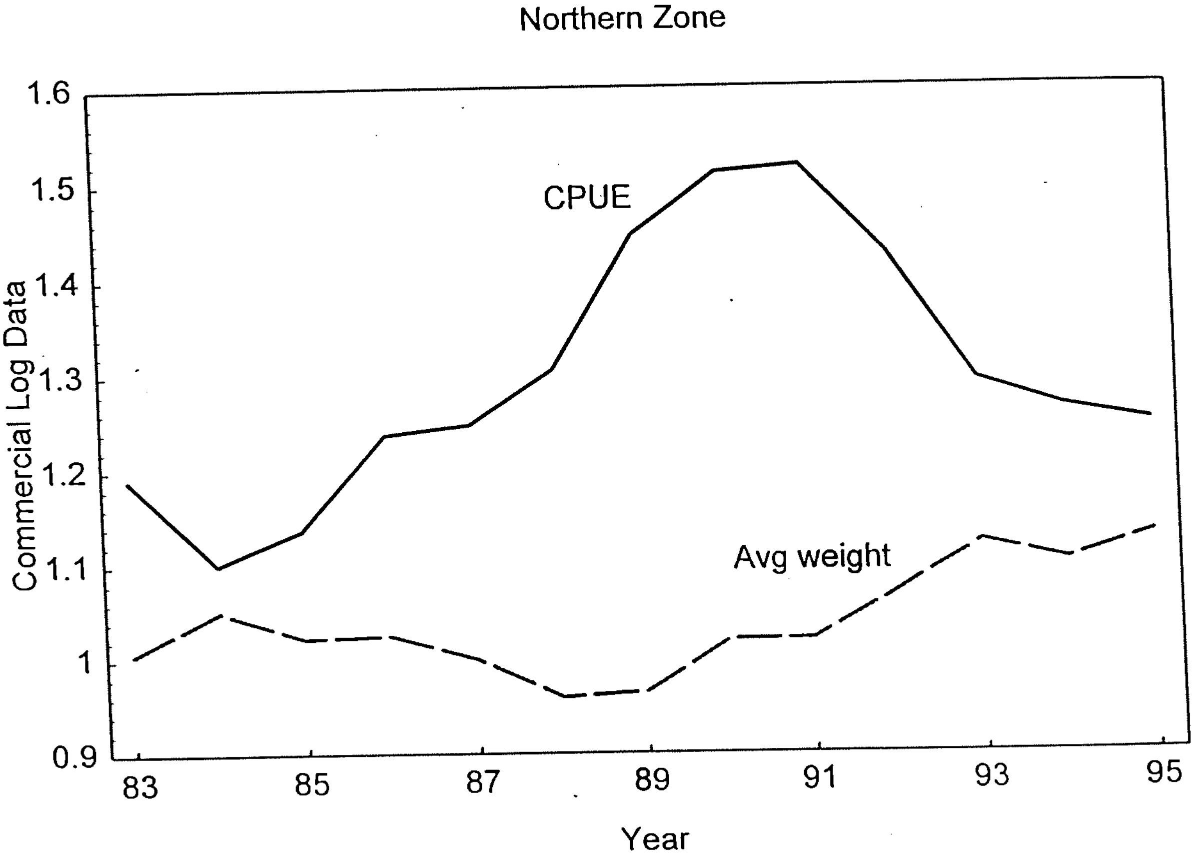


Figure 48. Inter-annual variation in average weight and CPUE for lobsters in the Northern Zone

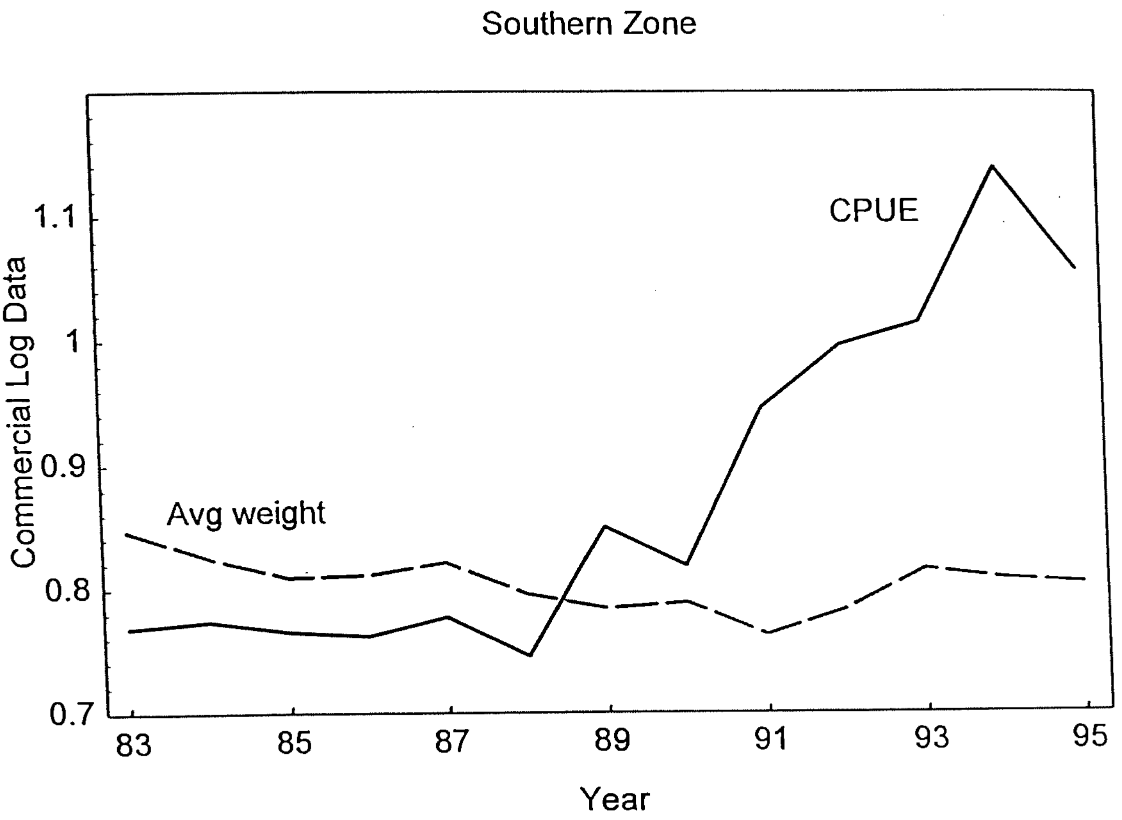
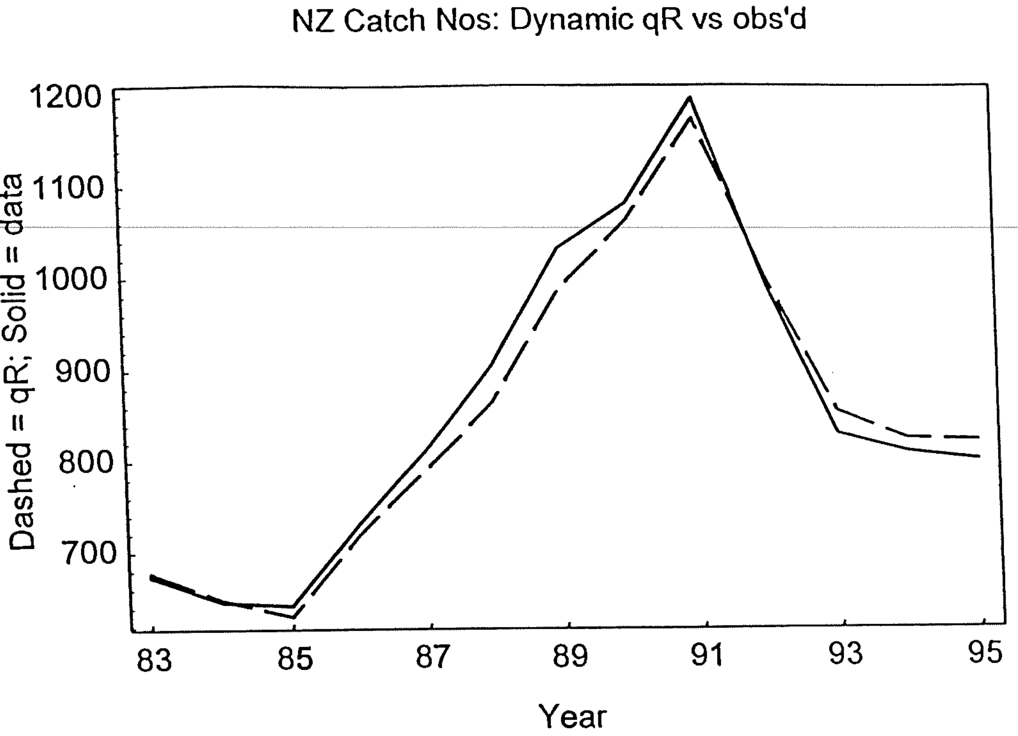


Figure 49. Inter-annual variation in average weight and CPUE for lobsters in the Southern Zone



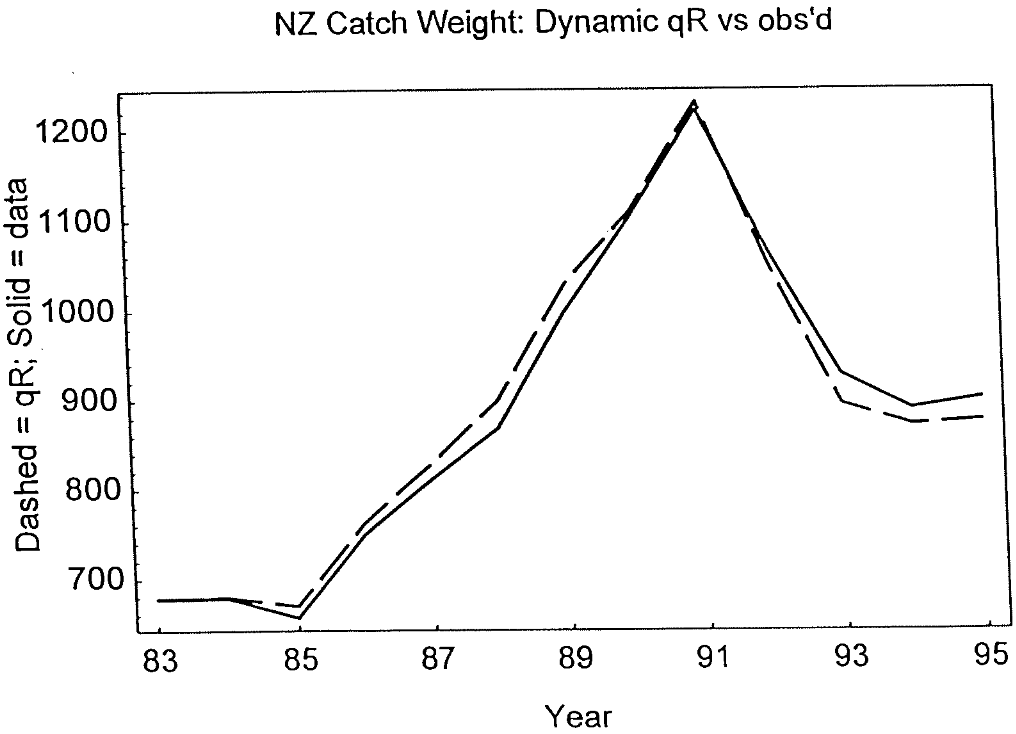


Figure 50. Comparison of the fit of the qr model (dashed line) to catch numbers and the weight of the catch in the Northern Zone.

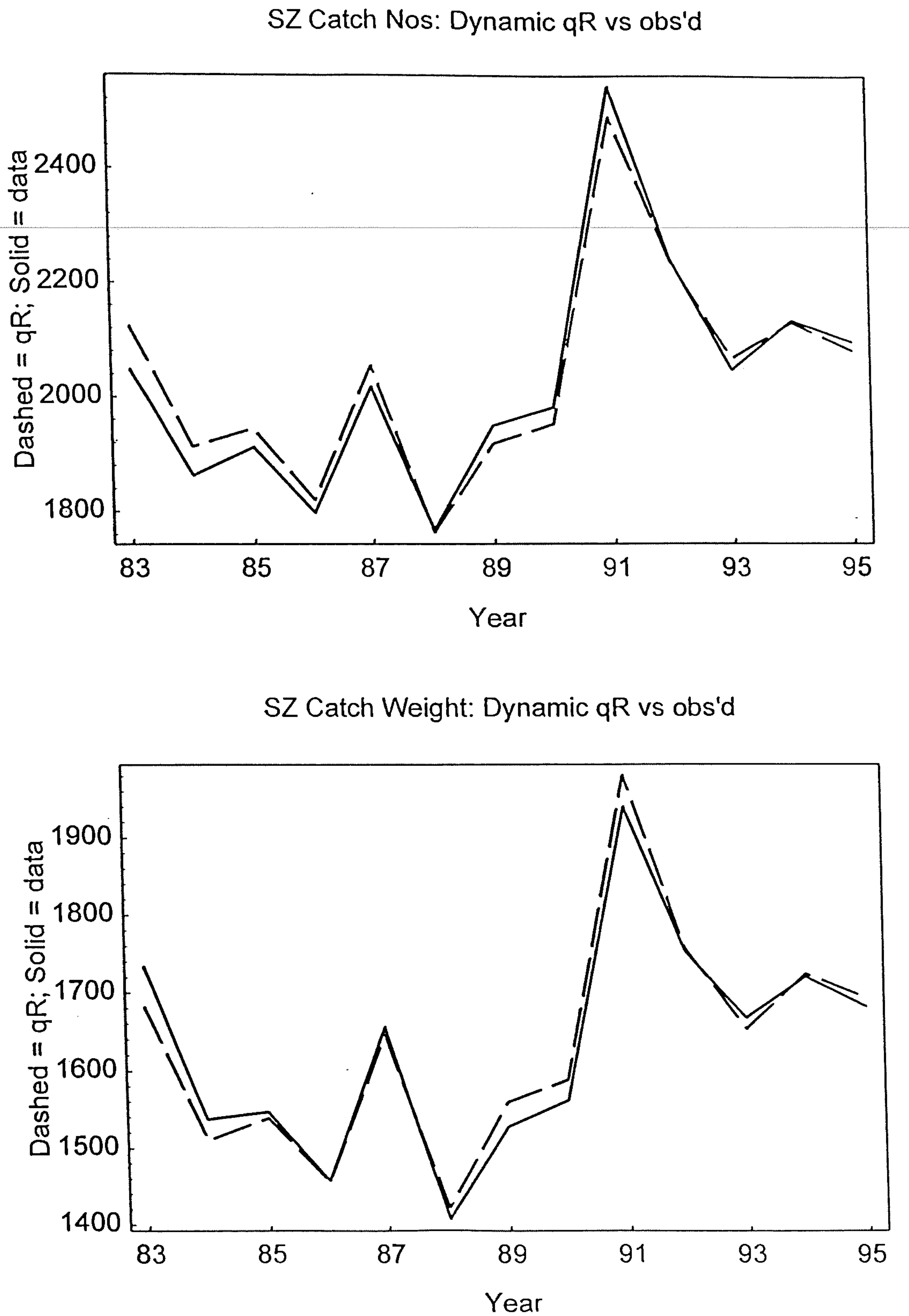


Figure 51. Comparison of the fit of the qr model (dashed line) to catch numbers and the weight of the catch in the Southern Zone.

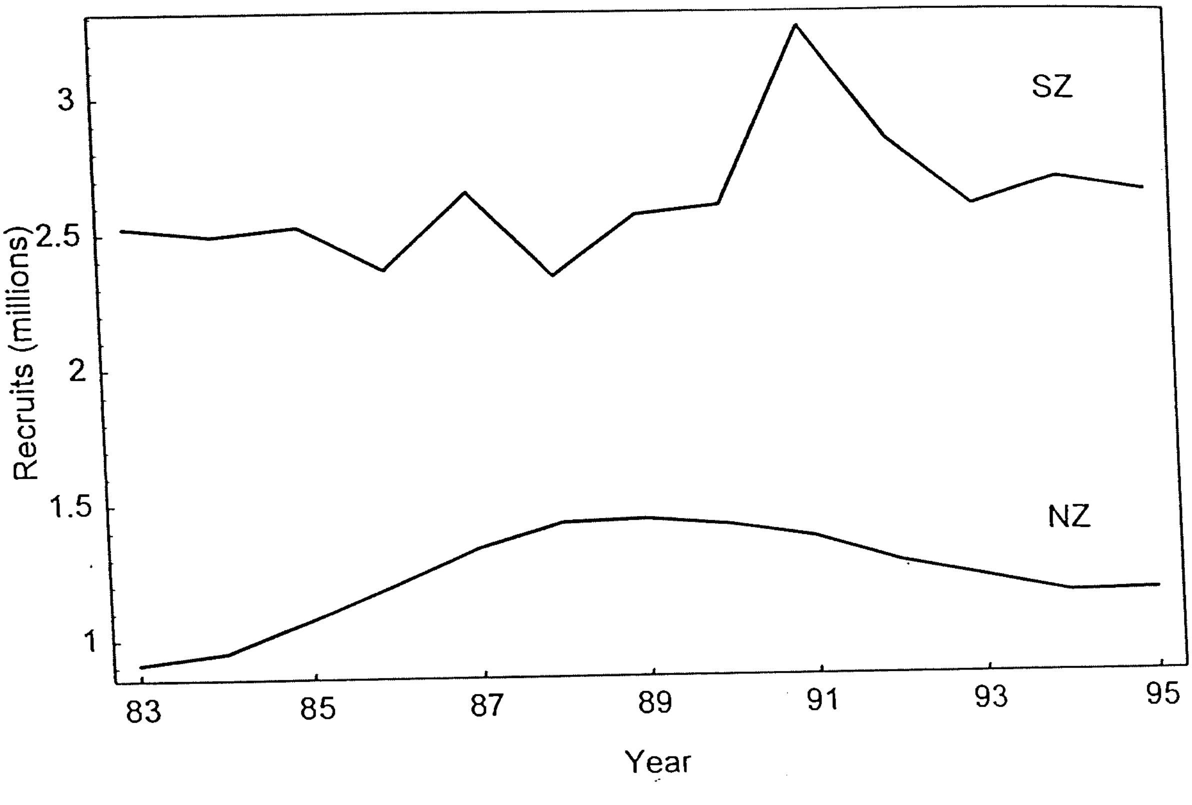


Figure 52. Annual variation in recruitment estimated as the frequency of lobsters entering the fishery in the Southern Zone (SZ) and the Northern Zone (NZ).

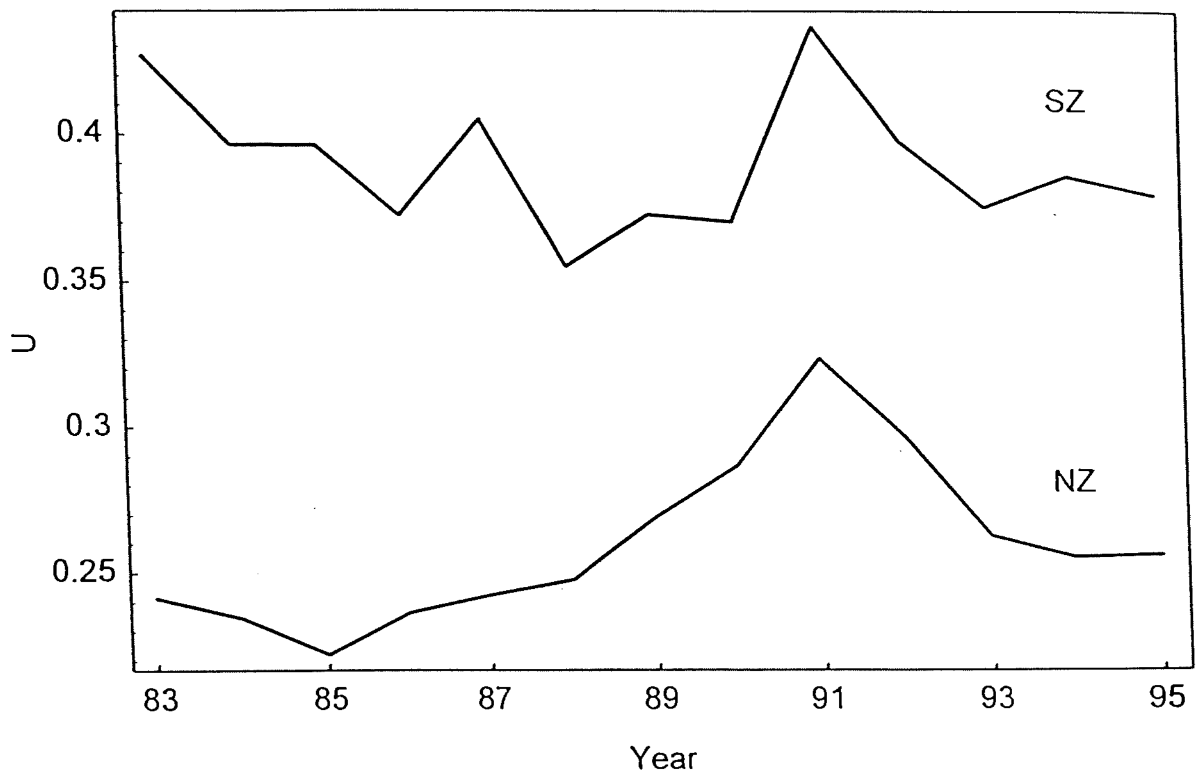


Figure 53. Annual variation in the exploitation rate of lobsters fished in the Southern Zone (SZ) and the Northern Zone (NZ).

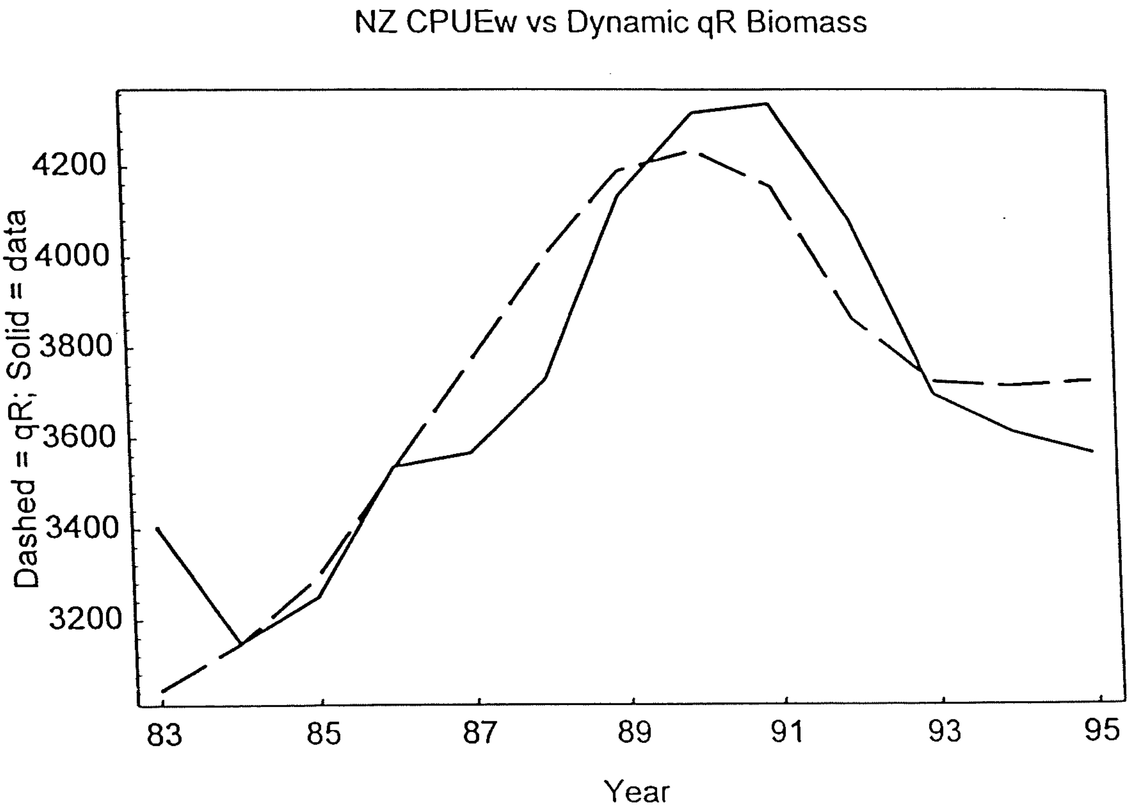


Figure 54. Comparison of the fit of the dynamic qr model (dashed line) estimate of biomass to catch per unit effort (CPUE) in the Northern Zone.

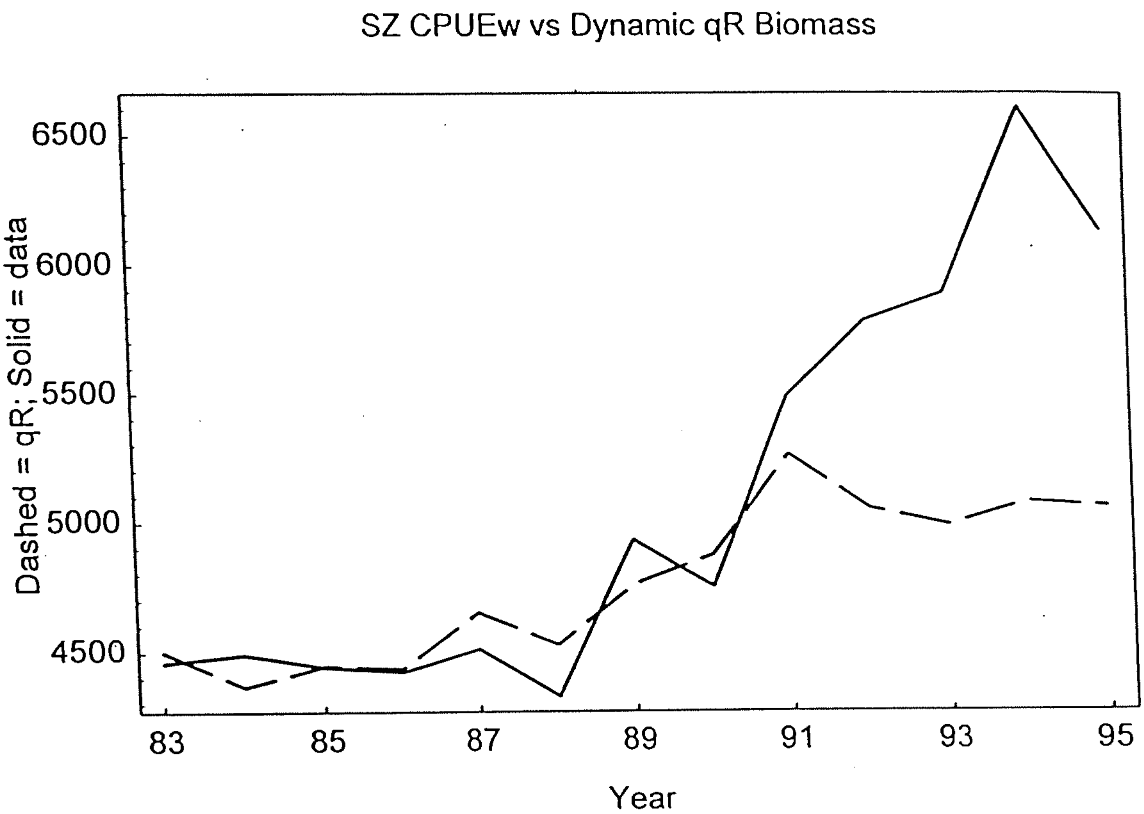


Figure 55. Comparison of the fit of the dynamic qr model (dashed line) estimate of biomass to catch per unit effort (CPUE) in the Southern Zone.

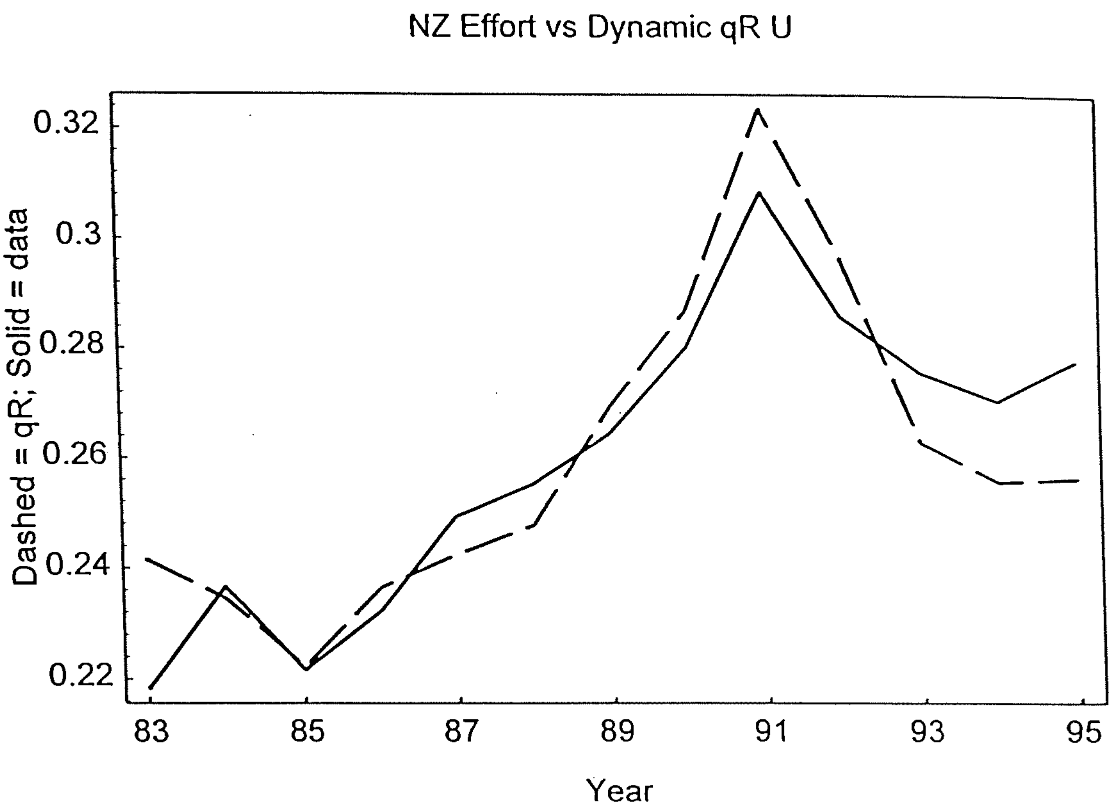


Figure 56. Comparison of the fit of the dynamic qr model (dashed line) estimate of exploitation rate to recorded effort in the Northern Zone.

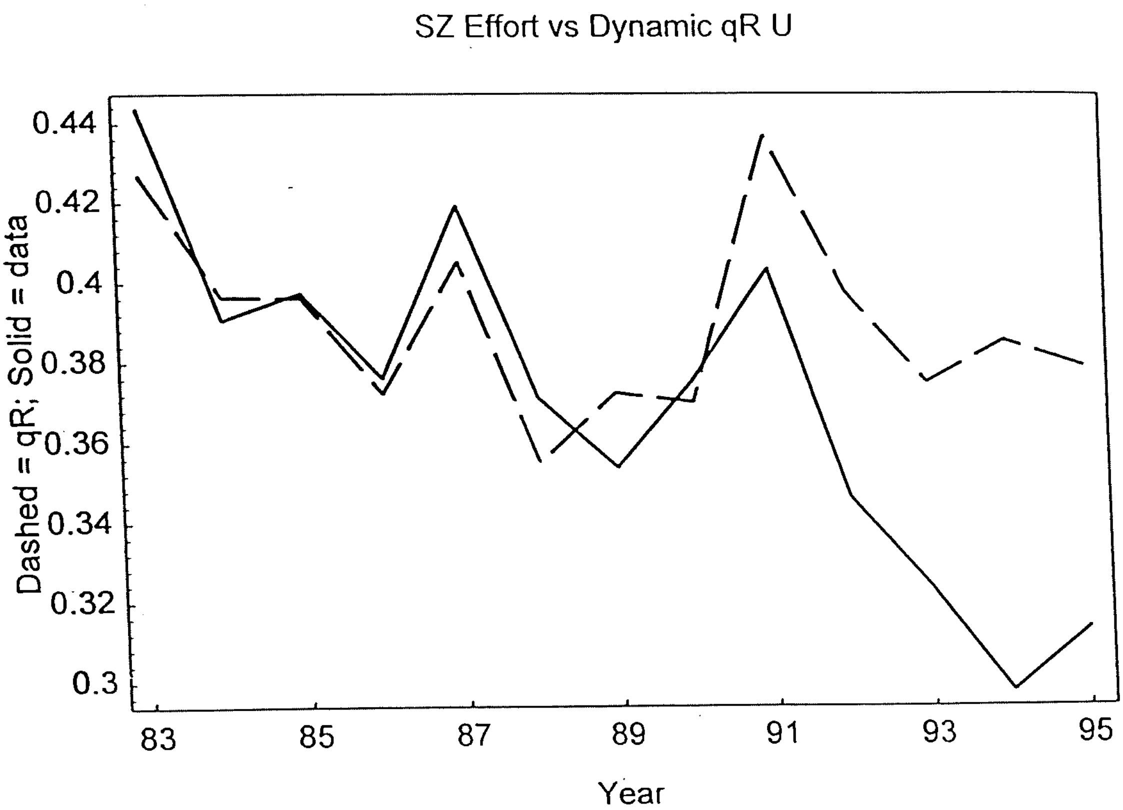


Figure 57. Comparison of the fit of the dynamic qr model (dashed line) estimate of exploitation rate to recorded effort in the Southern Zone.

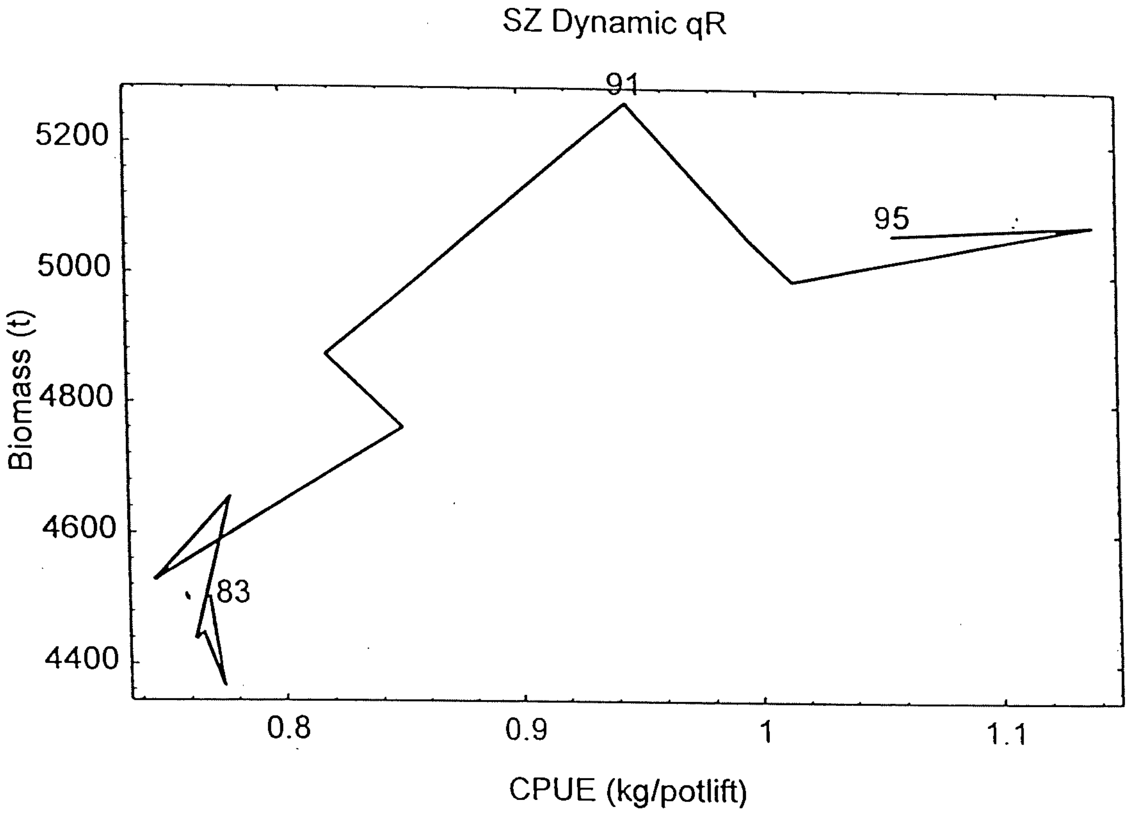


Figure 58. Relationship of biomass estimated from the dynamic qr model to recorded CPUE in the Southern Zone.

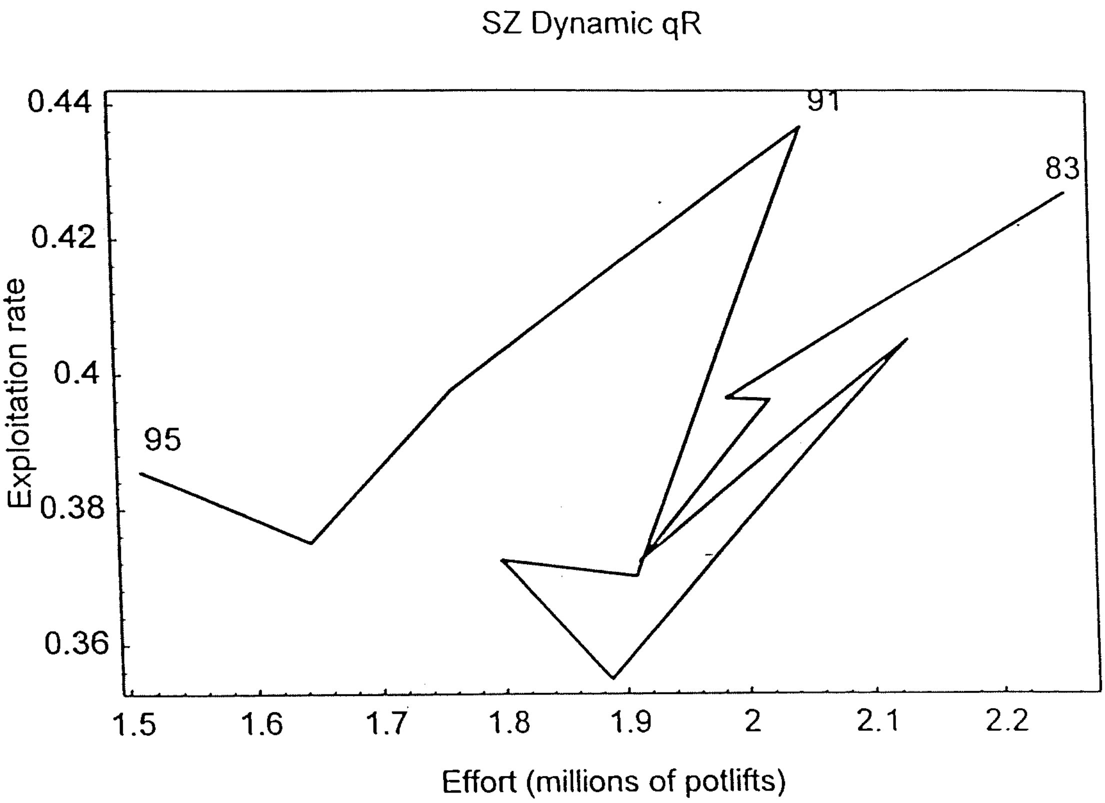


Figure 59. Relationship of exploitation rate estimated from the dynmic qr model to recorded effort in the Southern Zone.

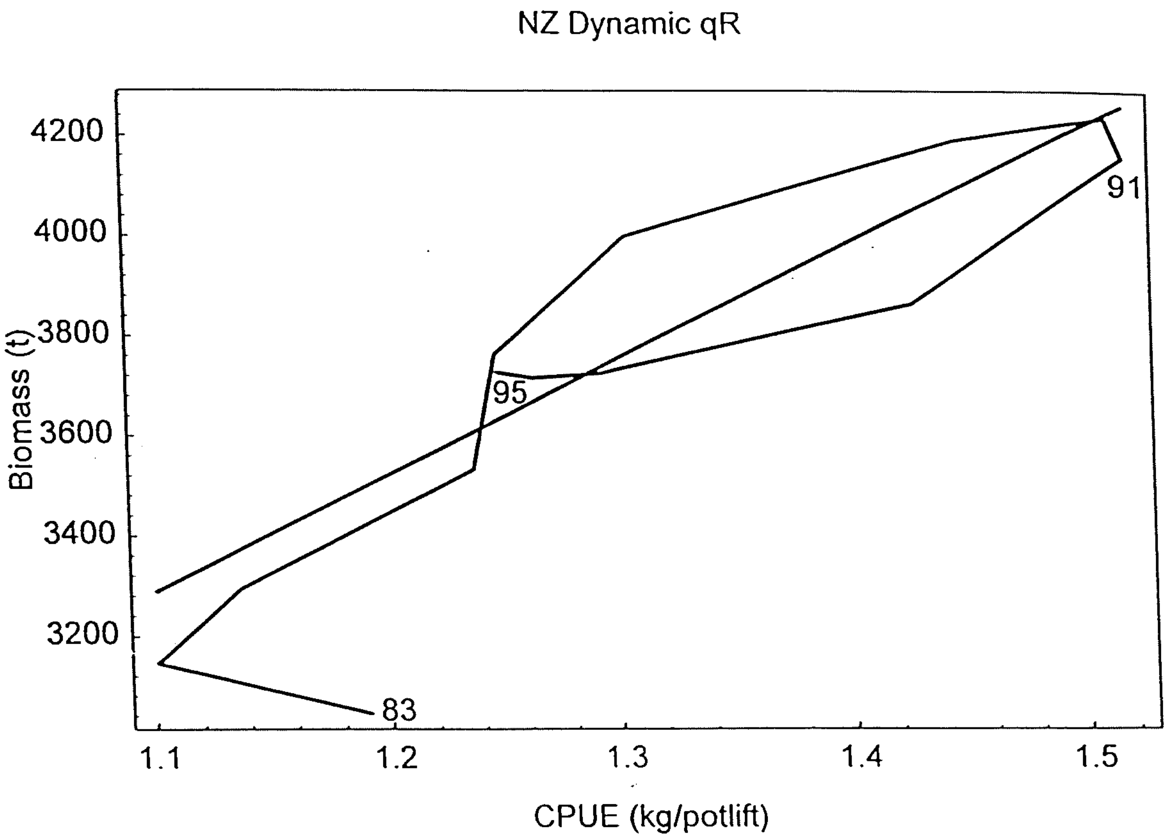


Figure 60. Relationship of biomass estimated from the dynamic qr model to recorded CPUE in the Northern Zone.

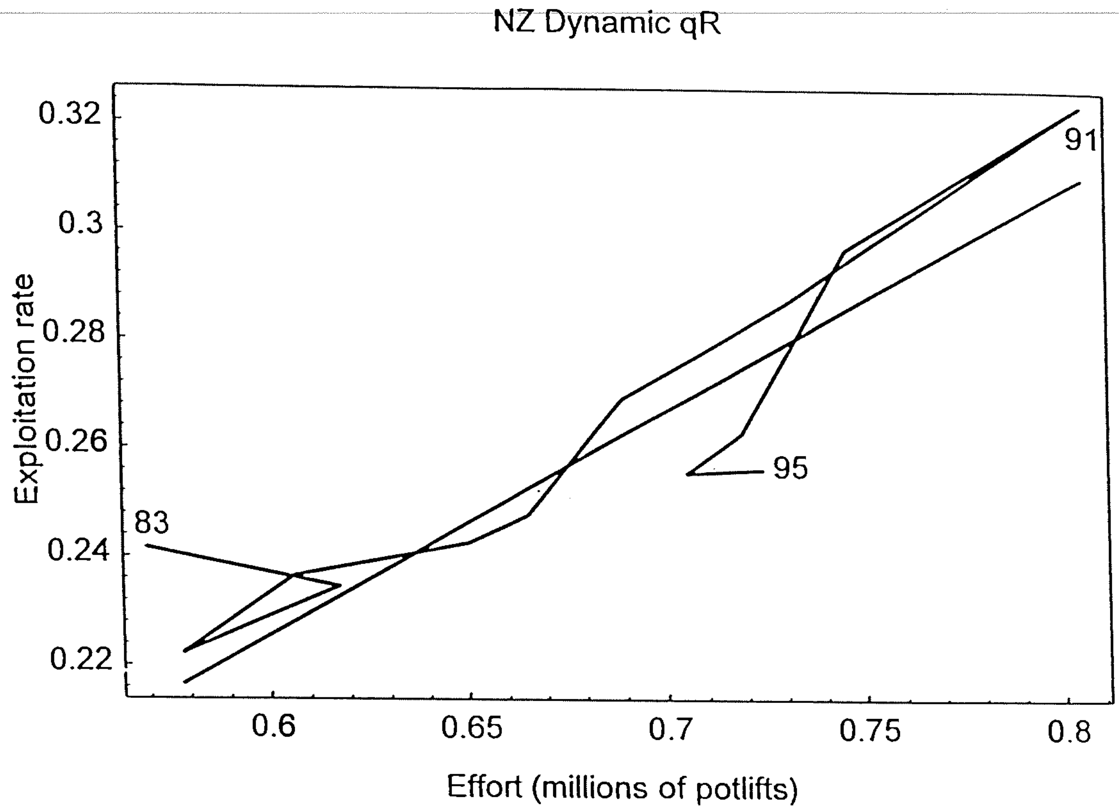


Figure 61. Relationship of exploitation rate estimated from the dynamic qr model to recorded effort in the Northern Zone.

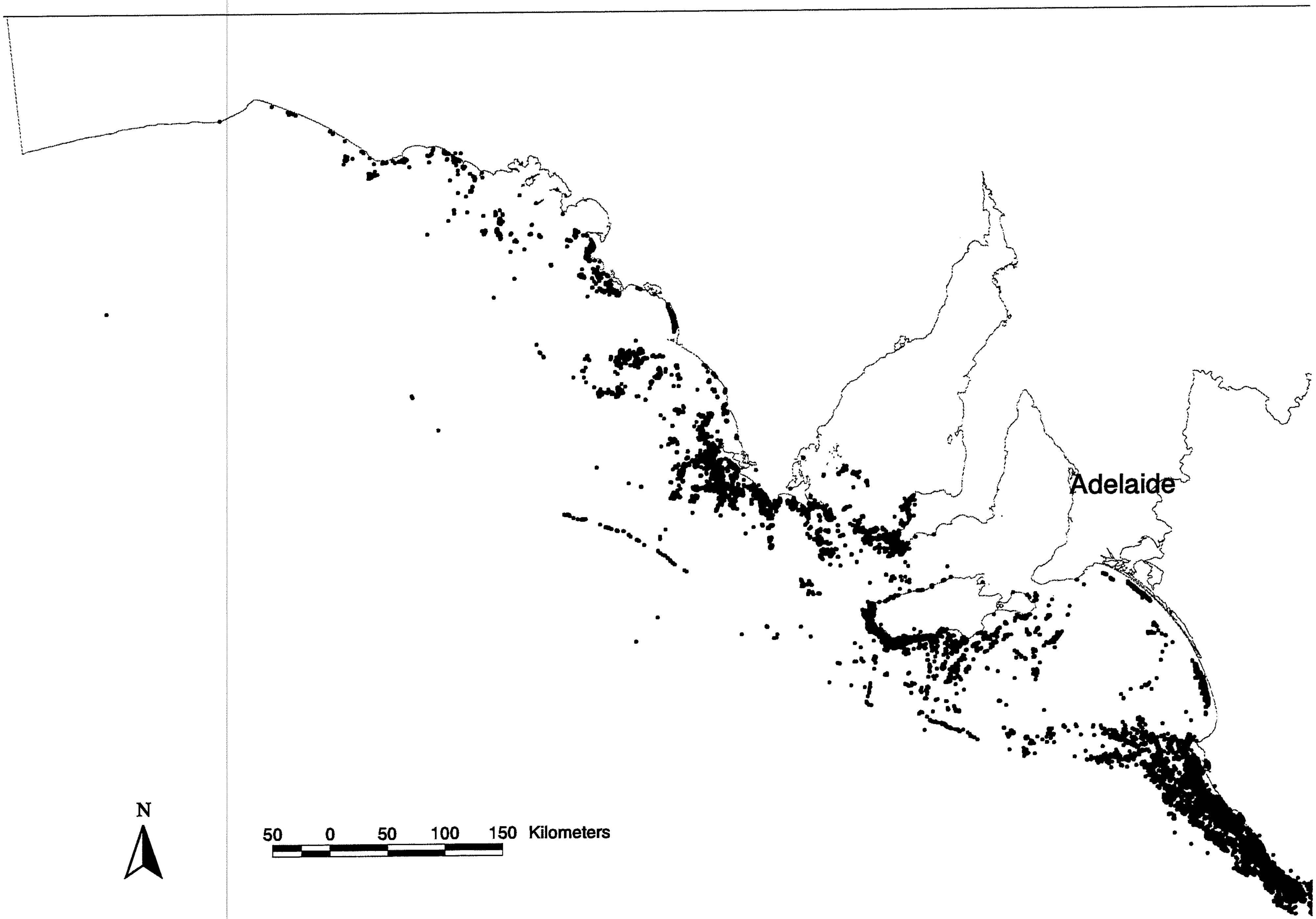


Fig 1. Release Positions for Lobsters Tagged 1993-1996

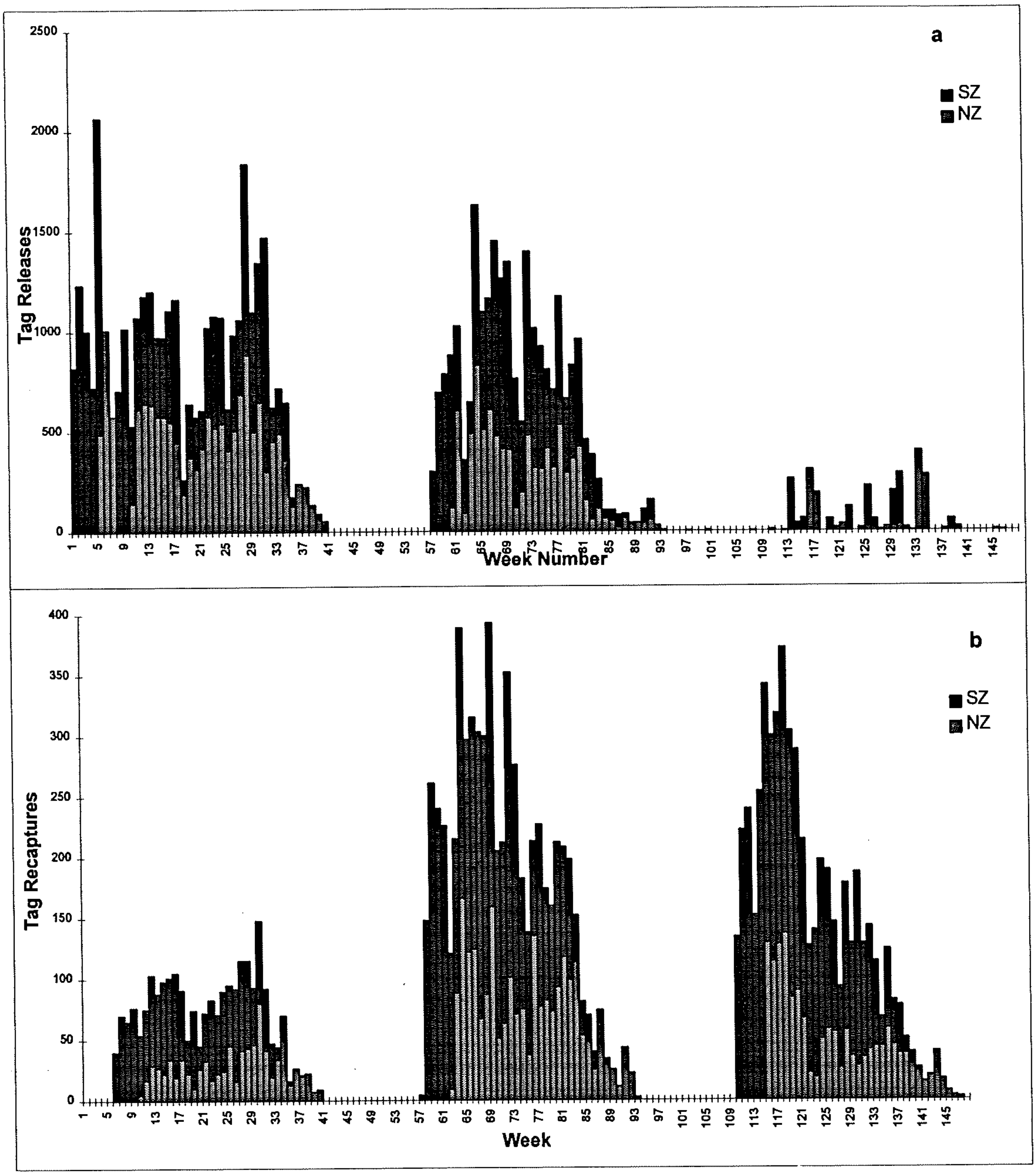
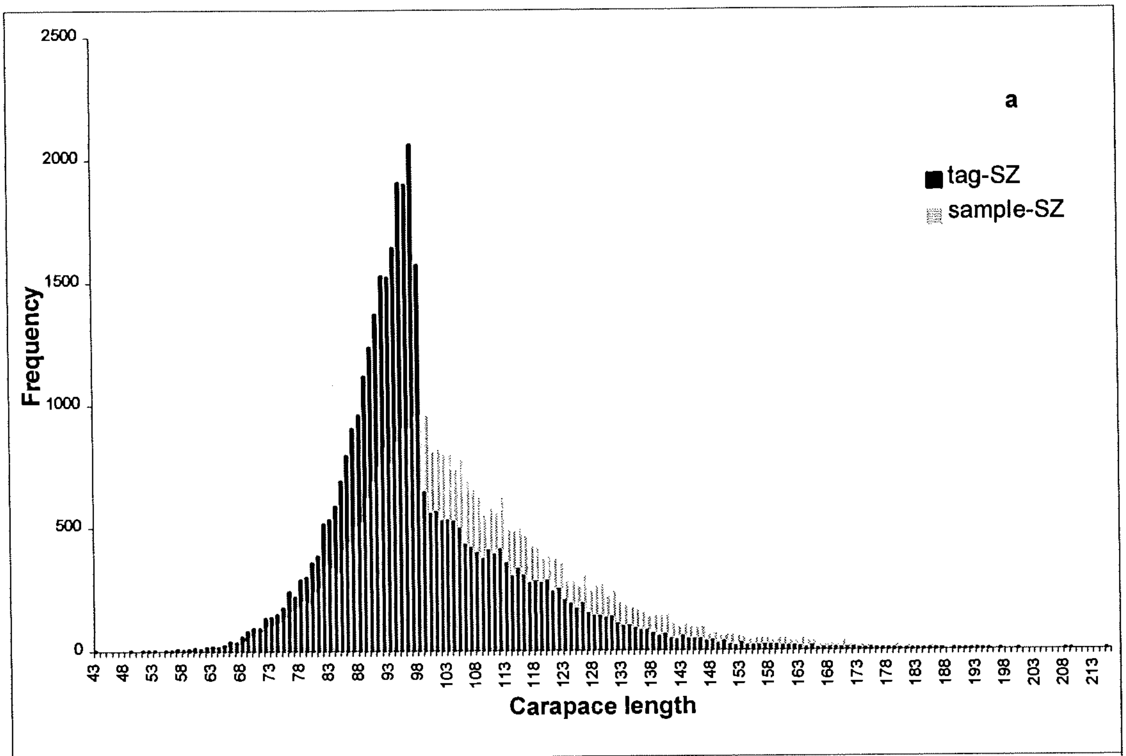


Figure 2. Tag releases (a) and recaptures (b) by week of study in the northern and southern zones. Week 1 commenced on 26 August 1993.



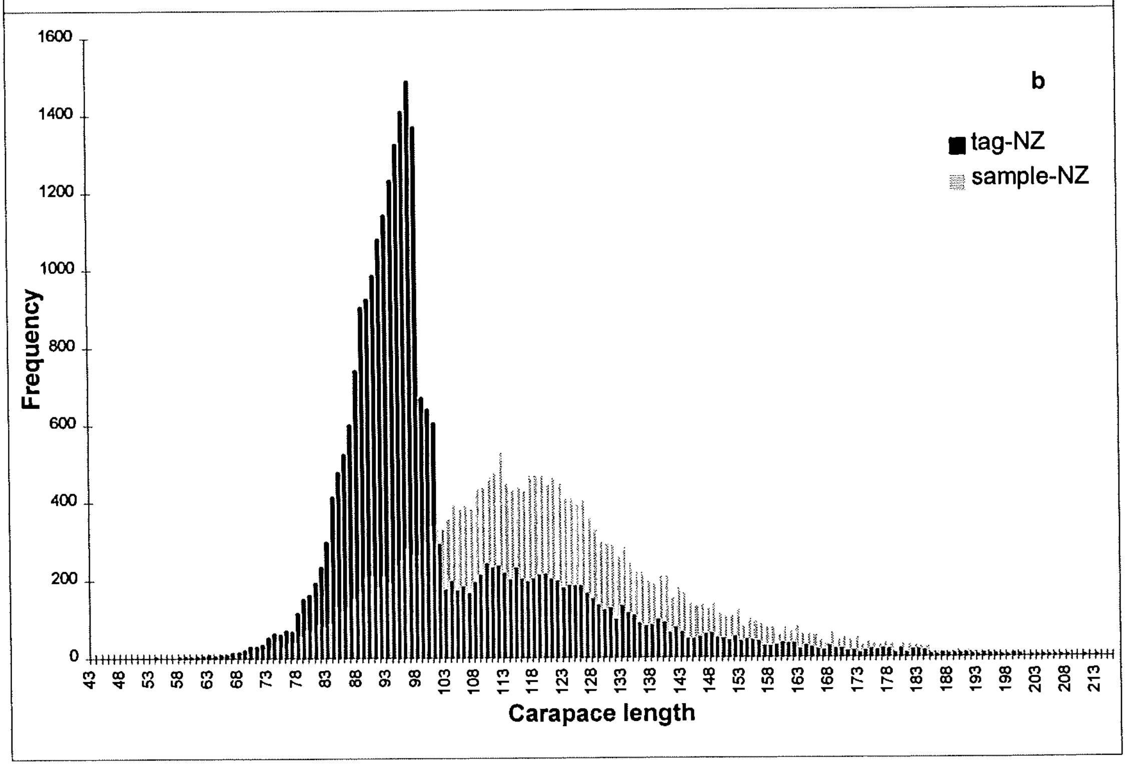


Figure 3. Length frequency distributions of the tagged and population sampled at sea in the southern zone (a) and northern zone (b).

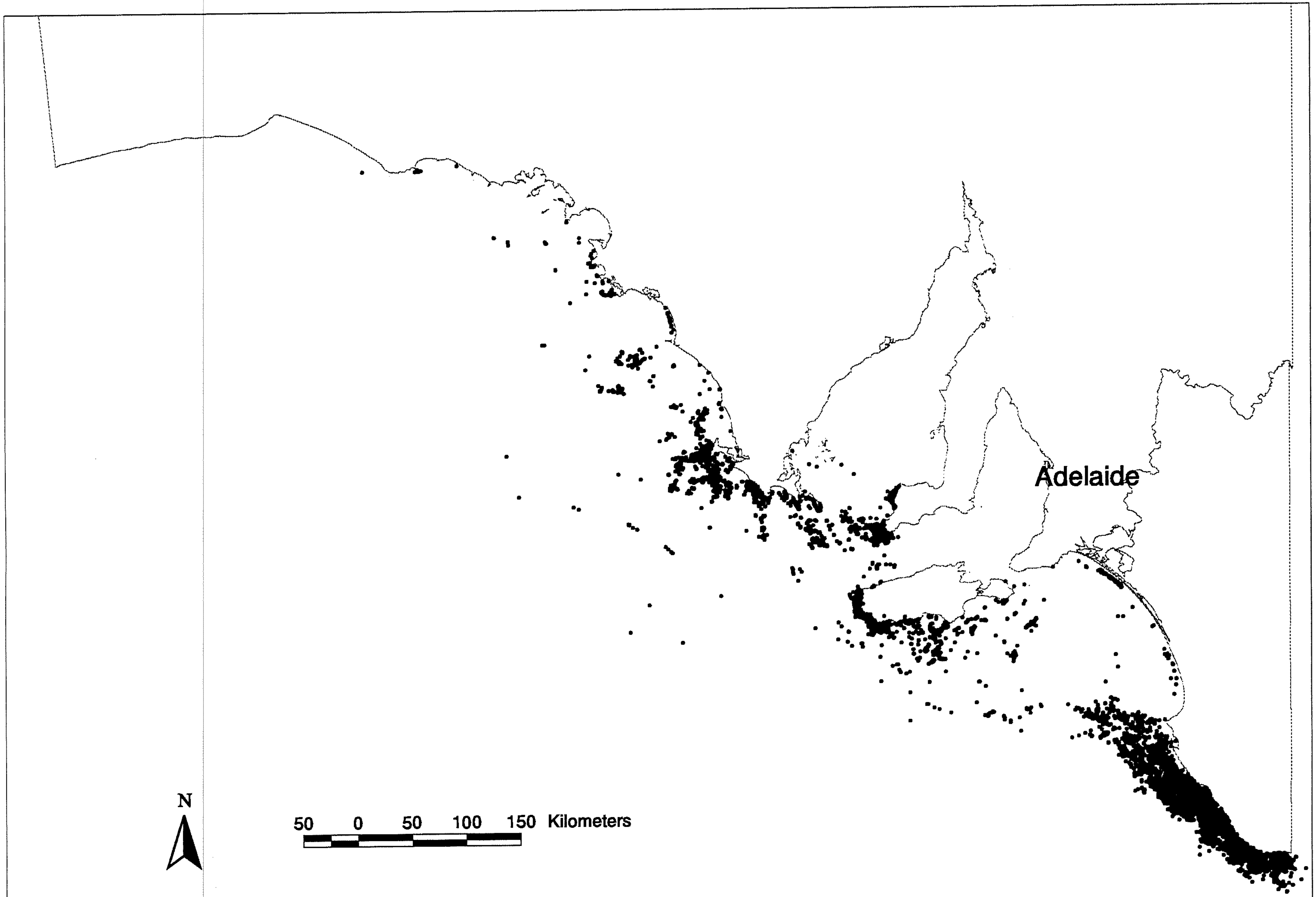


Fig 4. Recapture Positions for Lobsters Tagged 1993-1996

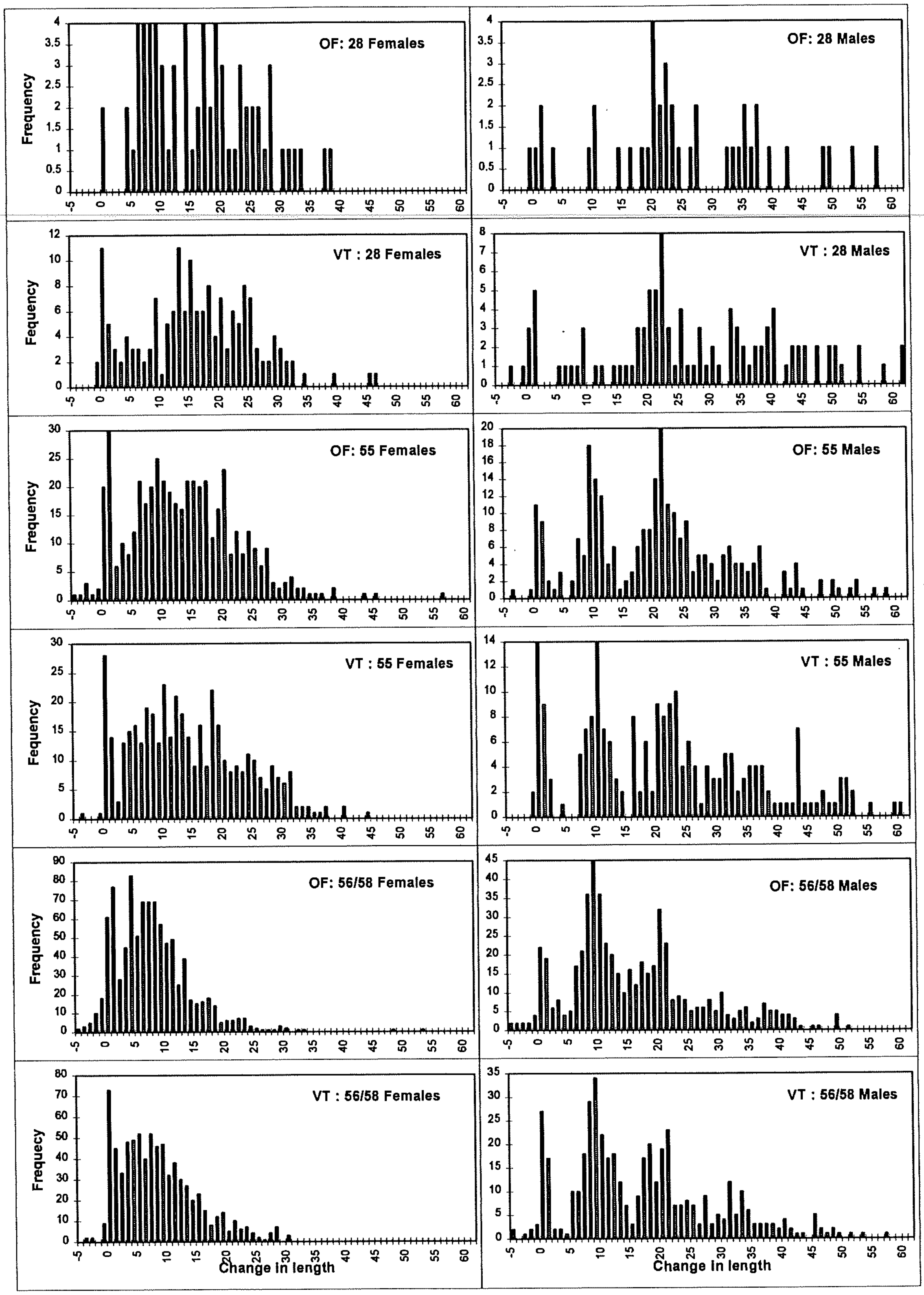


Figure 5. Change in length of 90-100 mm female and male lobsters measured in Marine fishing areas 28, 55, and 56 and 58 combined presented by capturer categories of volunteer taggers (VT), ordinary fishers (OF). All lobsters in these "populations" were originally released by biologists or volunteer taggers.

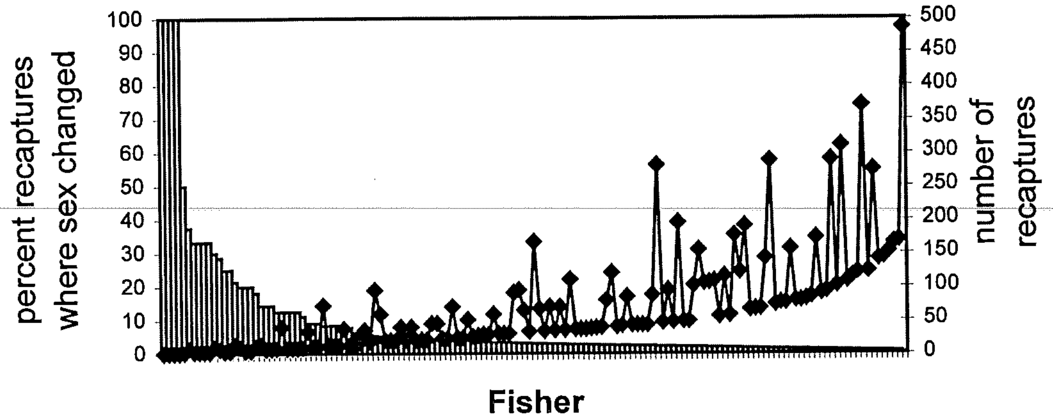


Figure 6. Percent of recaptured lobsters where the sex recorded at recapture was not the same as the sex recorded at the time of release (bars), and the number of recaptures reported by the corresponding fishers (line). Note that most of the apparent errors were reported by a few fishers who recaptured only a few lobsters.

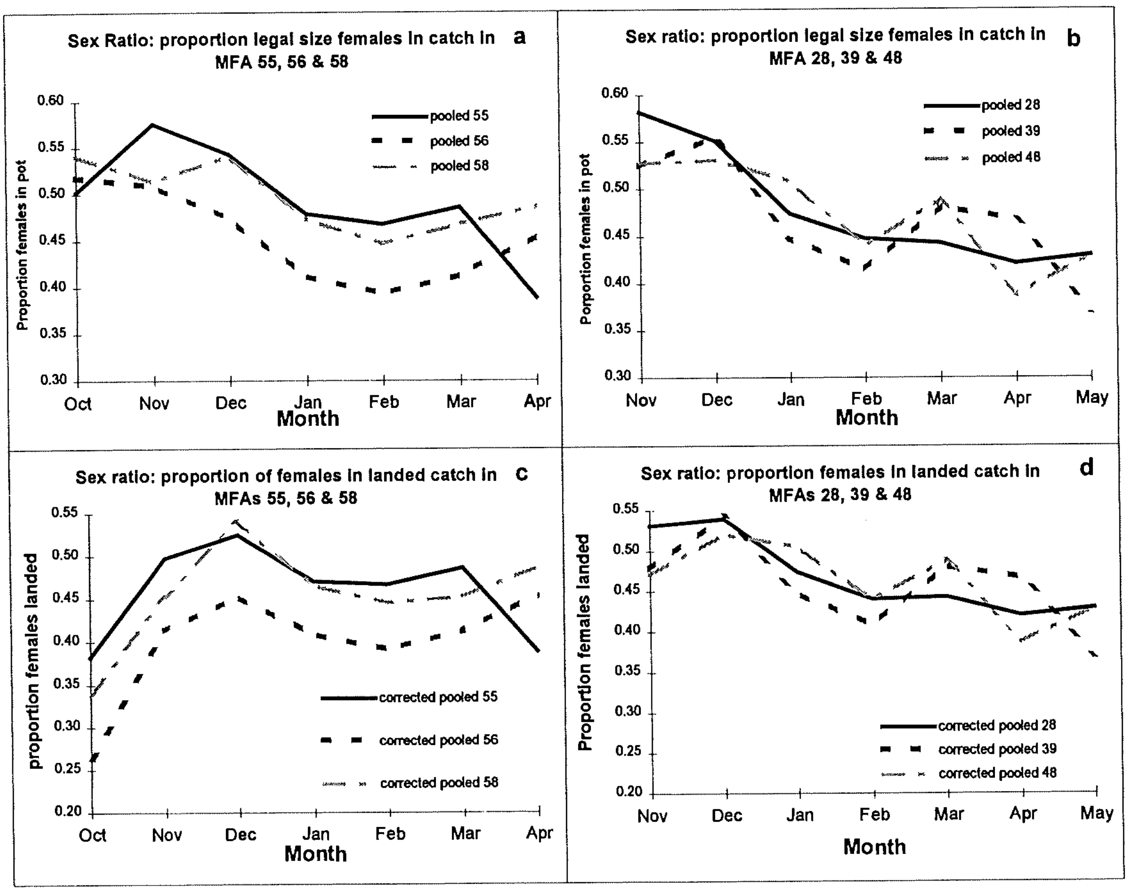


Figure 7. The proportion of females brought to the surface in lobster pots (a, b) and actually landed (c,d) are presented fro the southern zone marine fishing areas 55, 56, and 58, and northern zone areas 28, 39, and 48. Data graphed were pooled data sets from the 1991/92 to 1995/96 seasons.

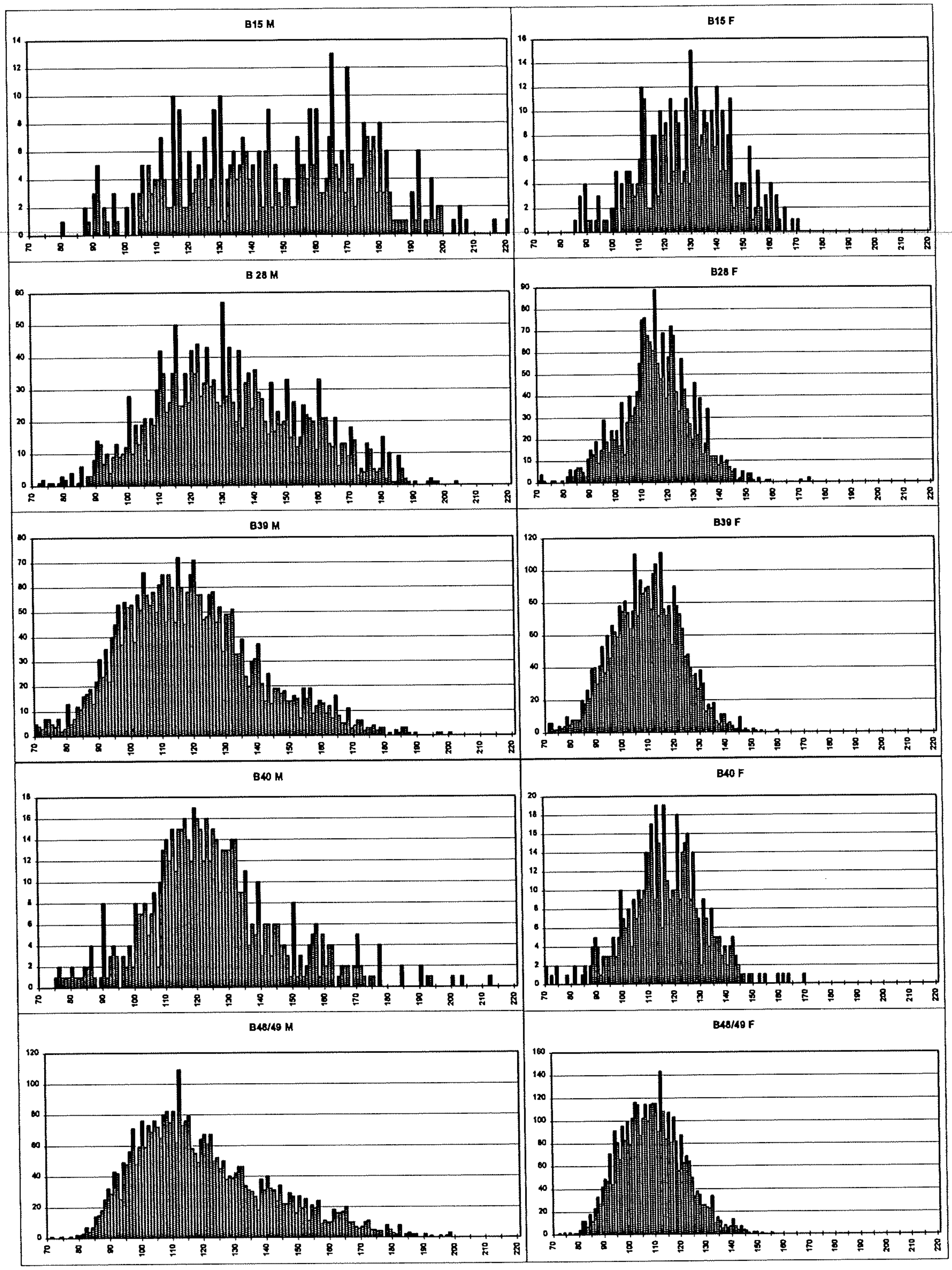


Figure 8a. Length Frequency histograms of the lobsters sampled in the indicated northern zone fishing areas during the 1991/92 fishing season.

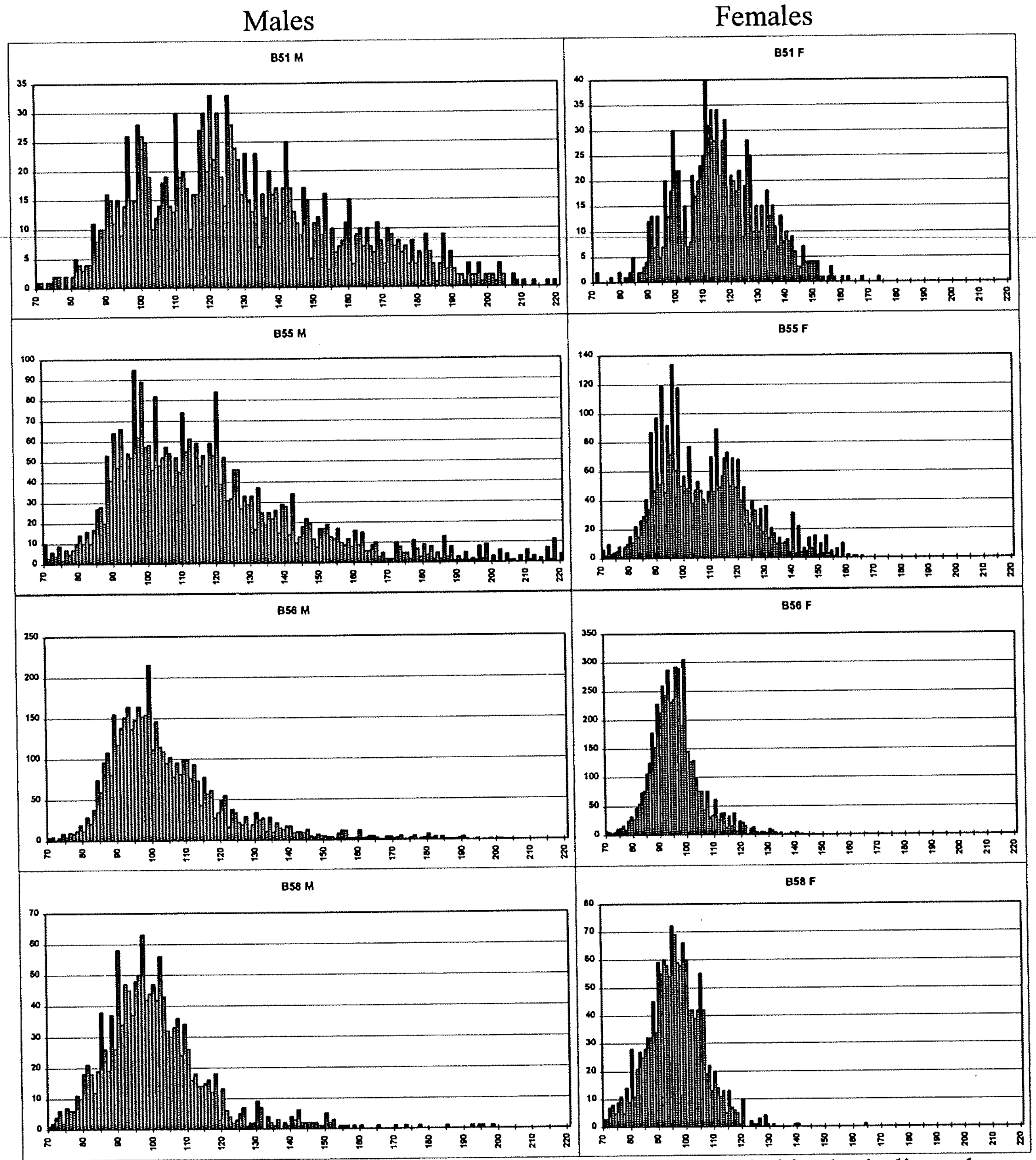


Figure 8b. Length Frequency histograms of the lobsters sampled in the indicated southern zone fishing areas during the 1991/92 fishing season.

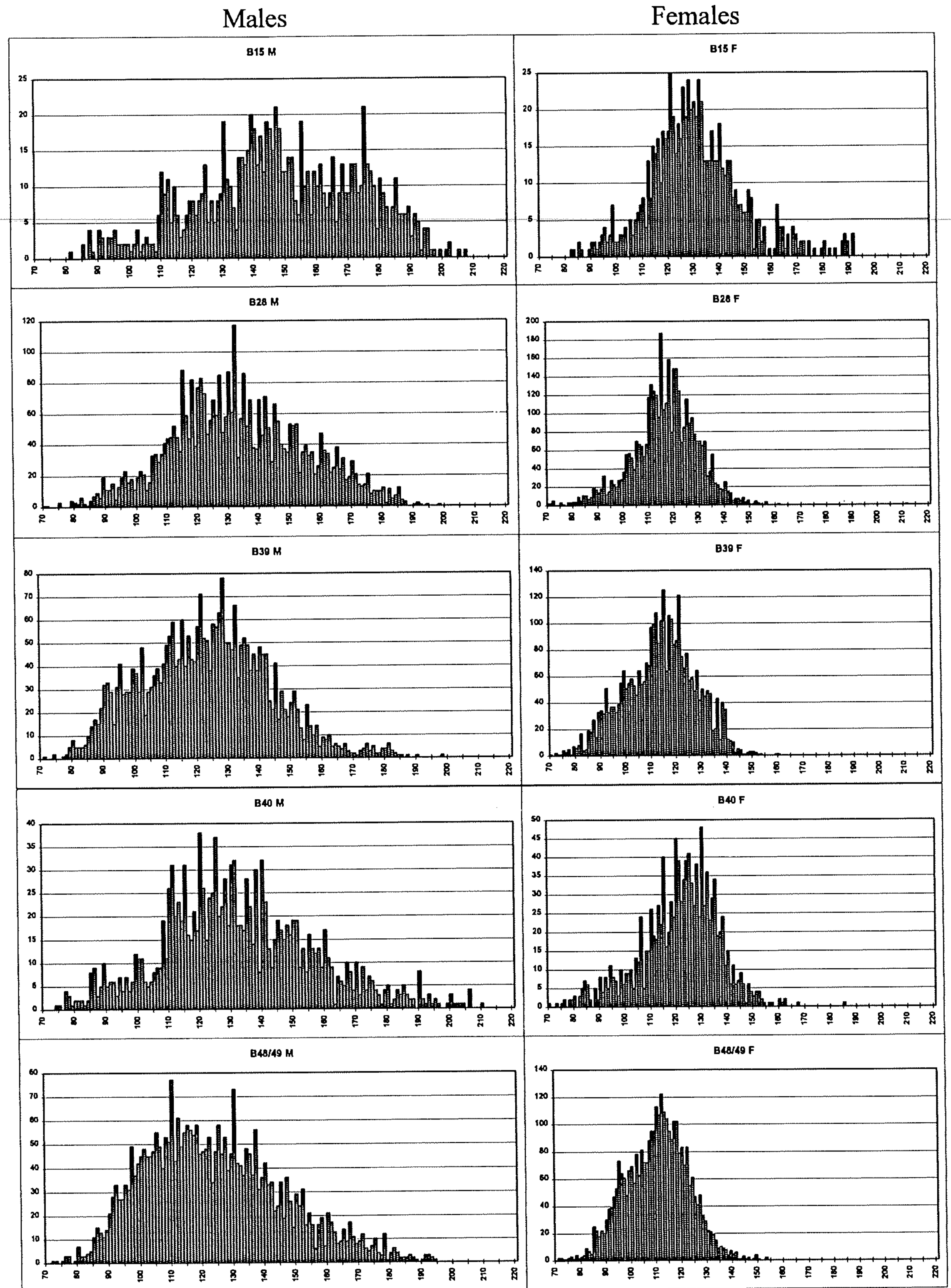


Figure 8c. Length Frequency histograms of the lobsters sampled in the indicated northern zone fishing areas during the 1992/93 fishing season.

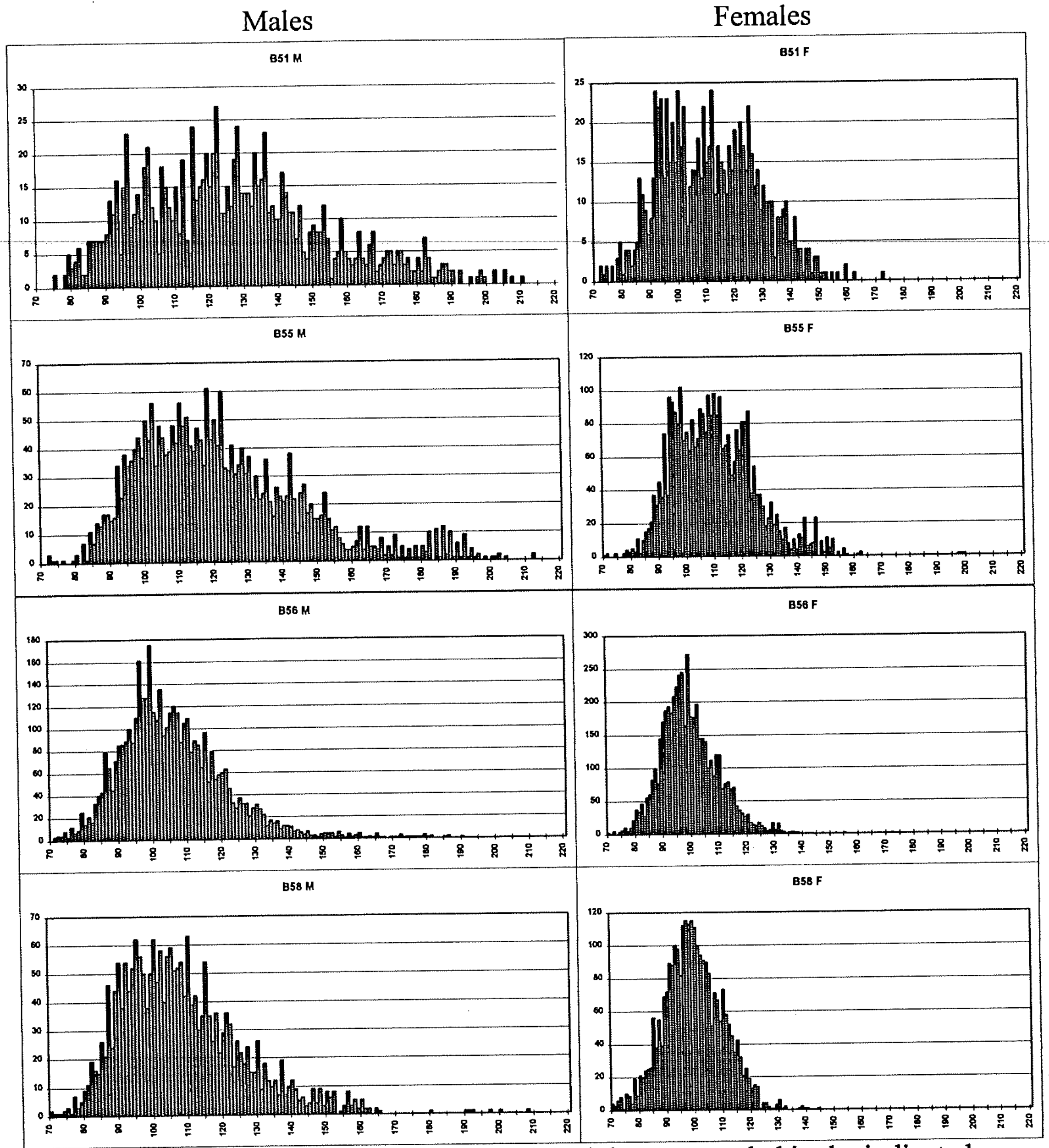


Figure 8d. Length Frequency histograms of the lobsters sampled in the indicated southern zone fishing areas during the 1992/93 fishing season.

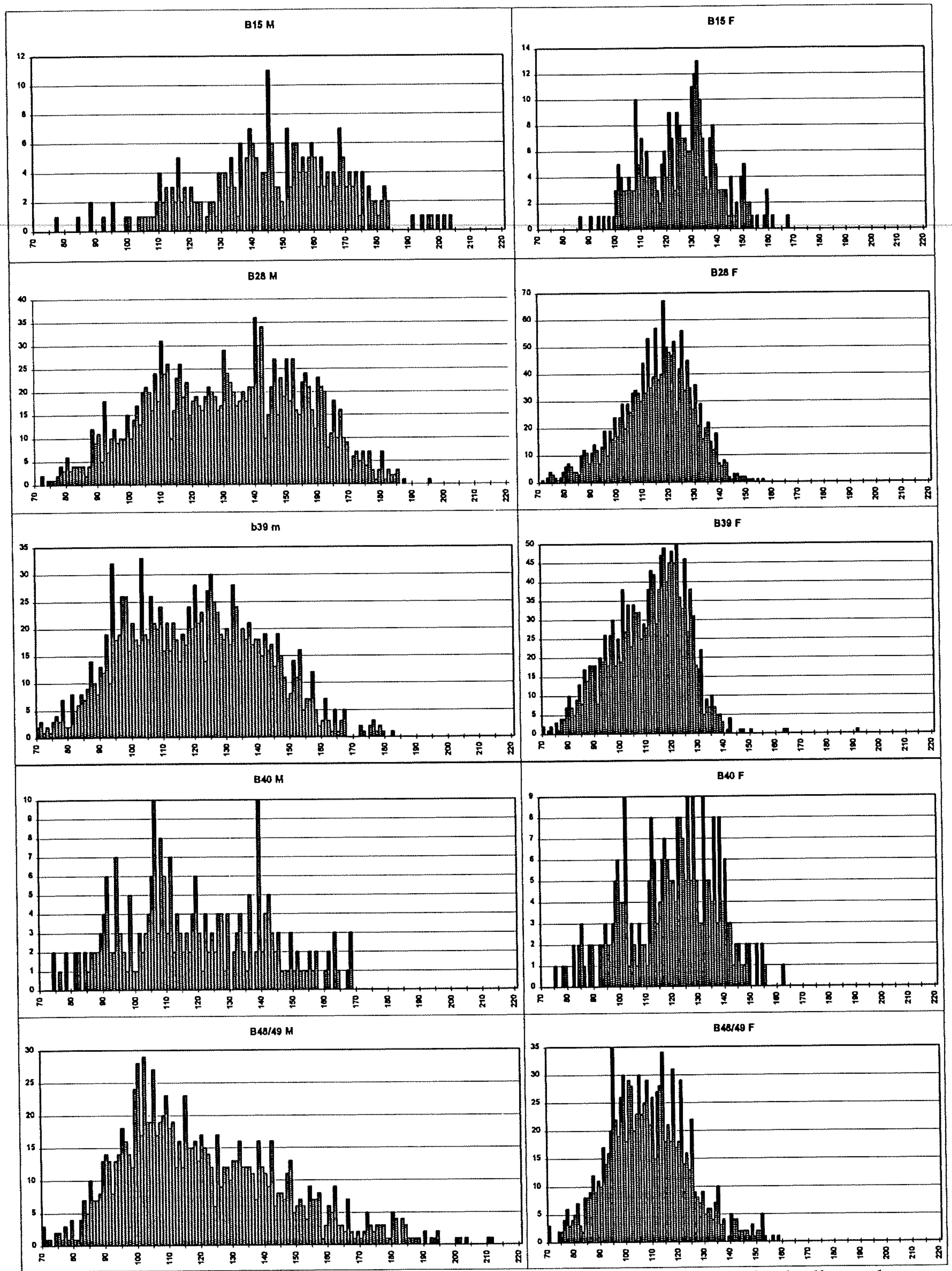


Figure 8e. Length Frequency histograms of the lobsters sampled in the indicated northern zone fishing areas during the 1993/94 fishing season.

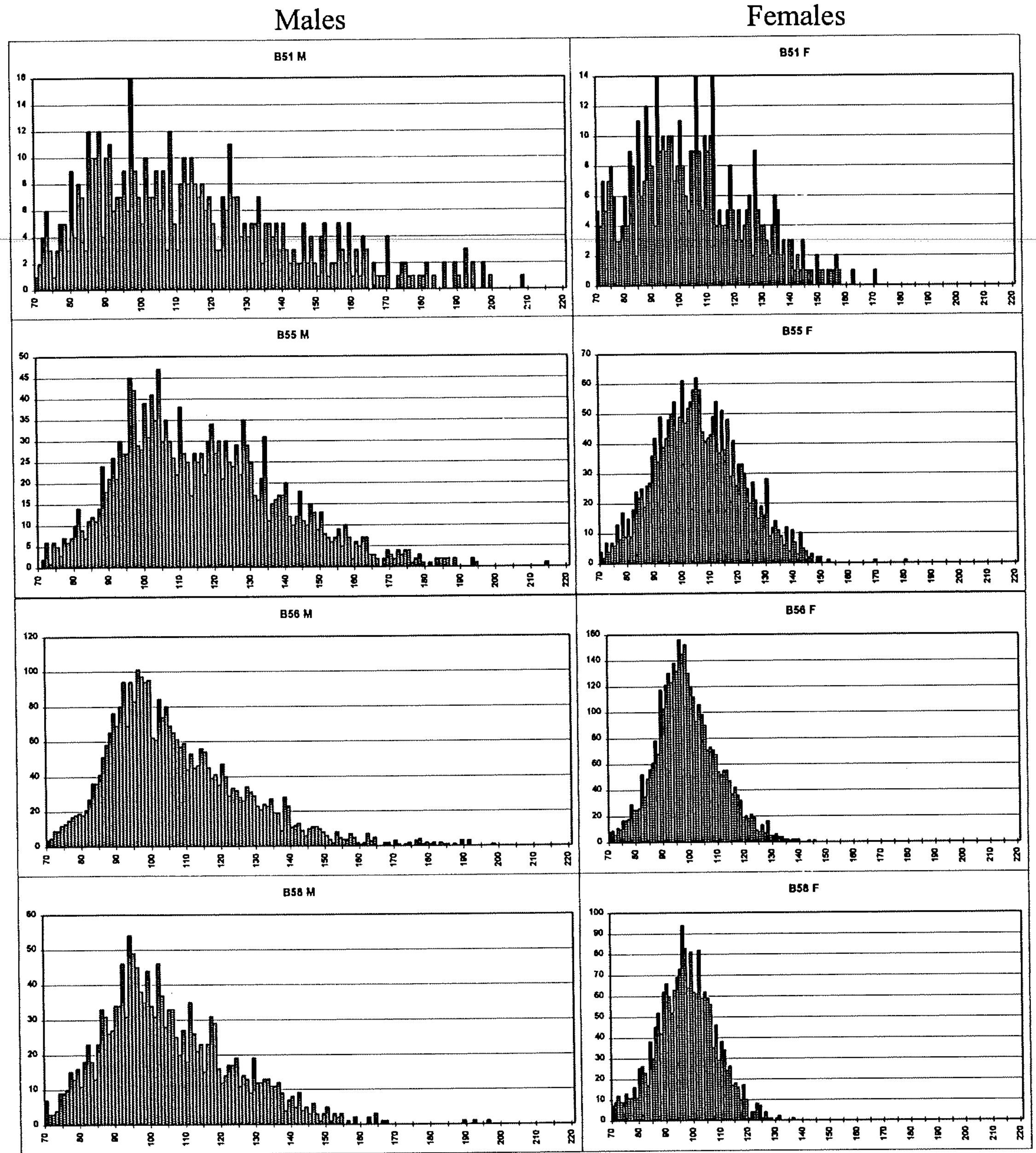


Figure 8f. Length frequency histograms of lobsters sampled in the indicated southern zone fishing areas during the 1993/94 fishing season.

Males Females

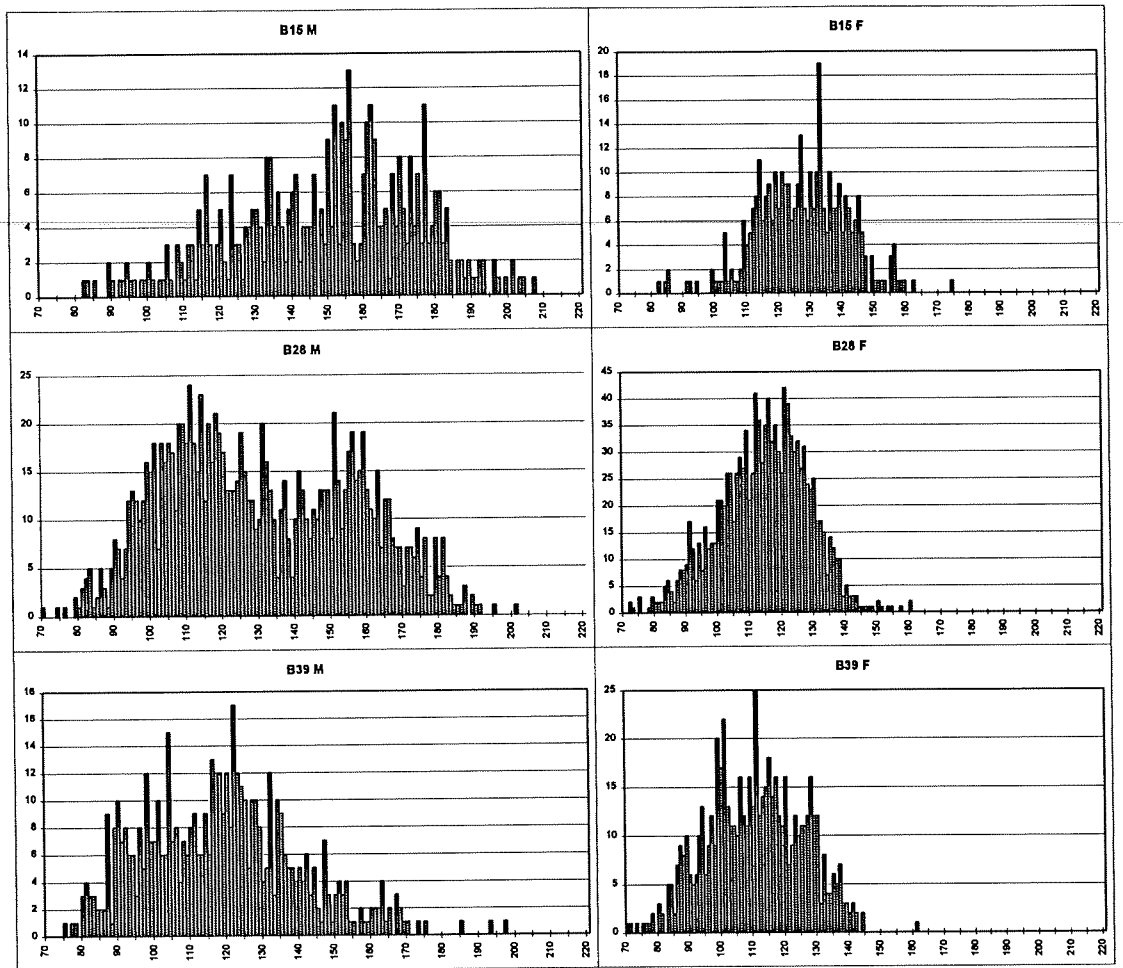


Figure 8g. Length frequency histograms of lobsters sampled in the indicated northern zone fishing areas during the 1994/95 fishing season.

Males Females

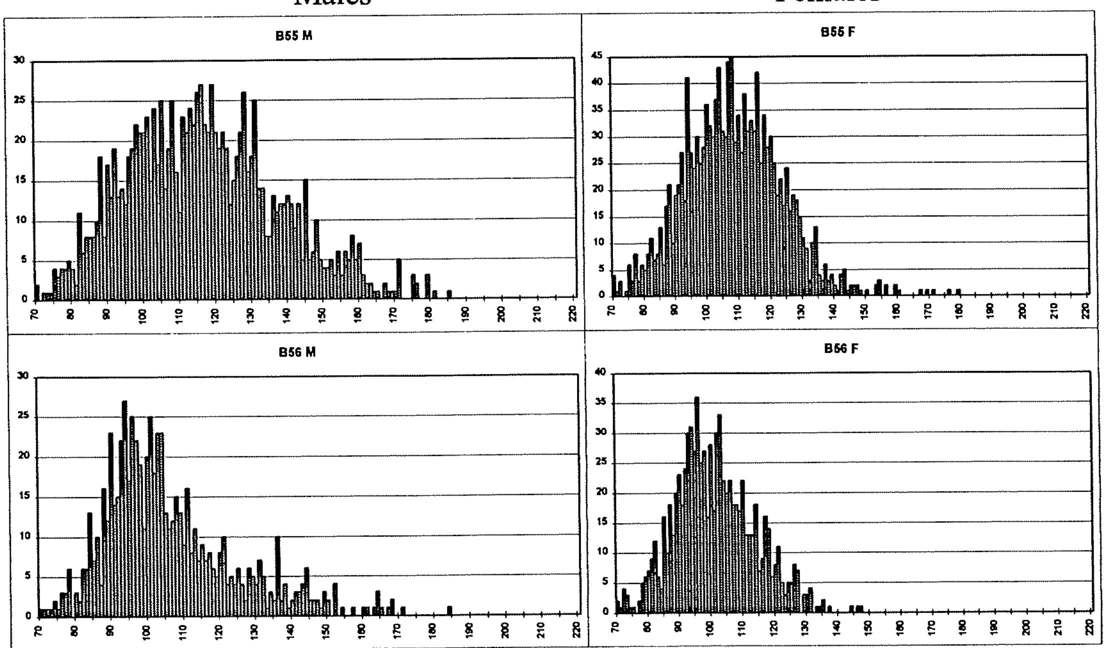


Figure 8h. Length frequency histograms of lobsters sampled in the indicated southern zone fishing areas during the 1994/95 fishing season.

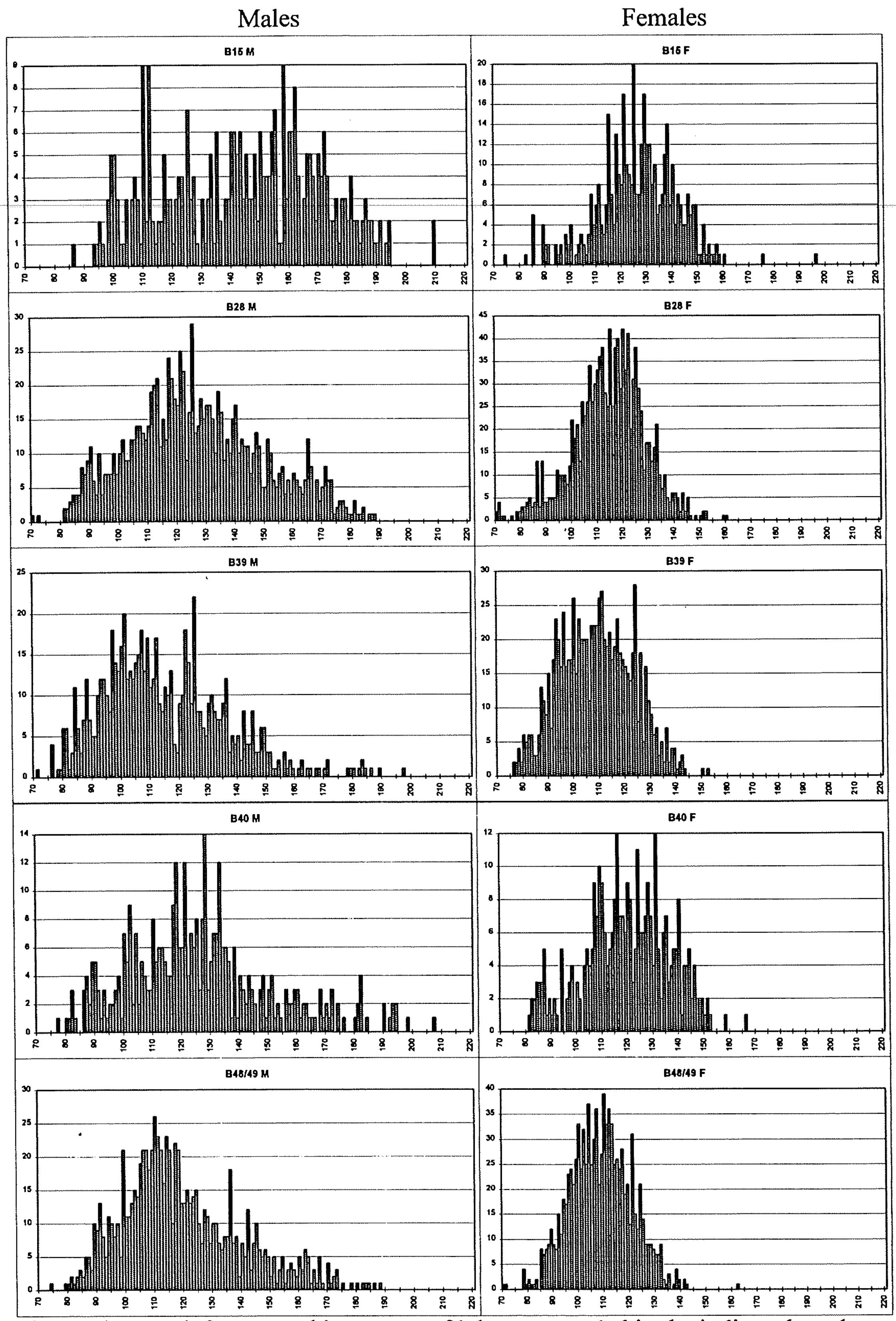


Figure 8i. Length frequency histograms of lobsters sampled in the indicated northern zone fishing areas during the 1995/96 fishing season.

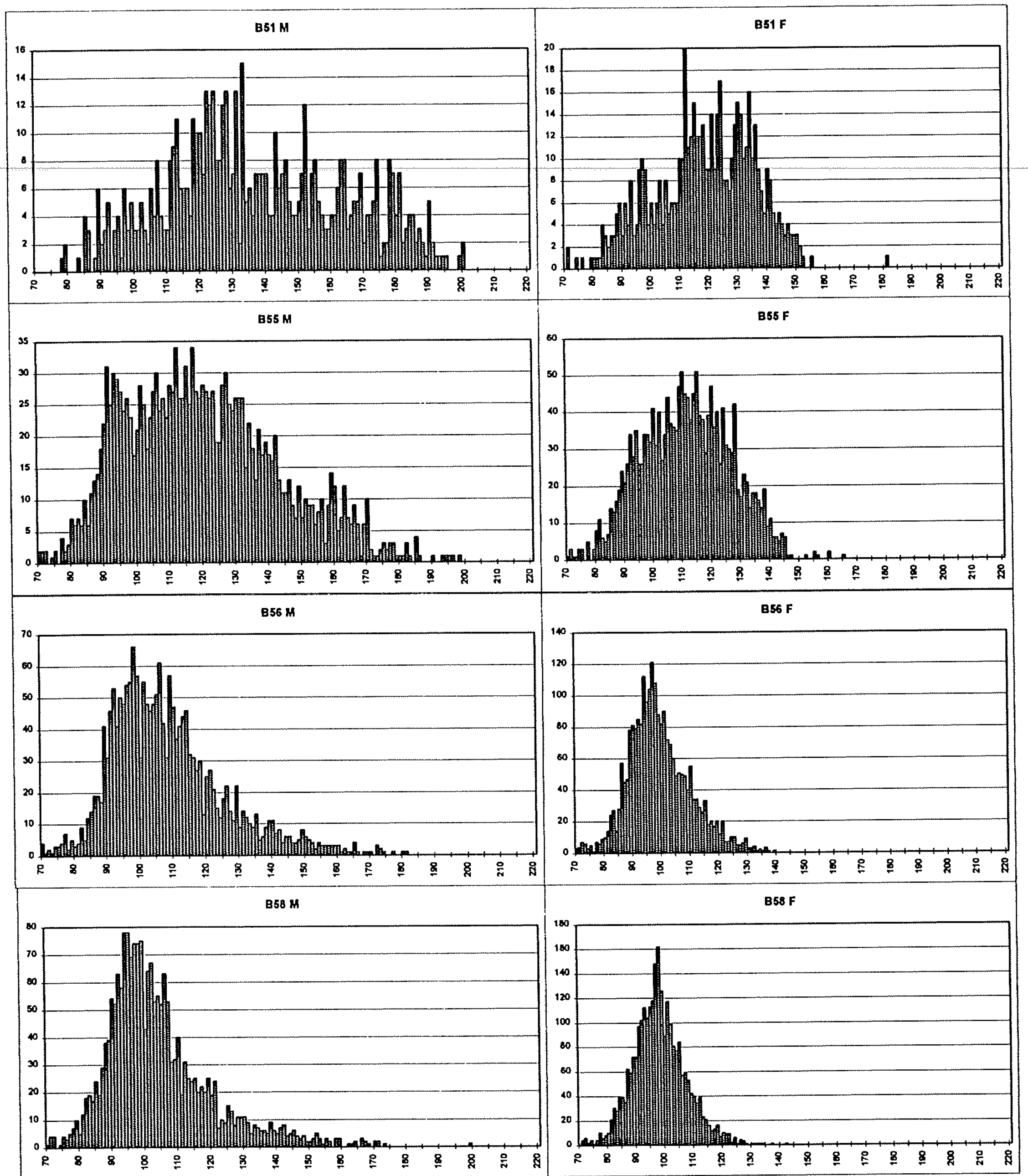


Figure 8j. Length frequency histograms of lobsters sampled in the indicated southern zone fishing areas during the 1995/96 fishing season.

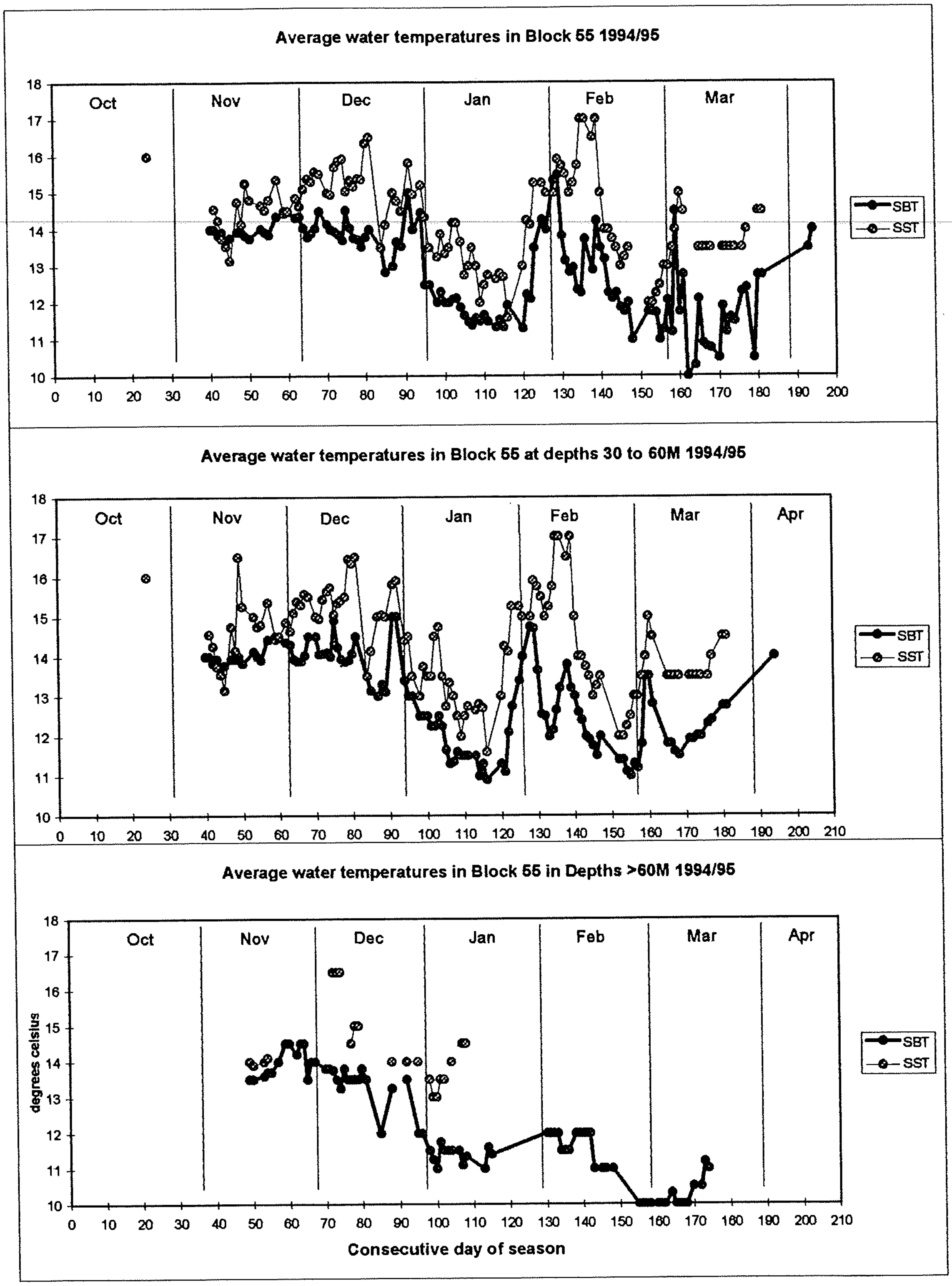


Figure 9a. Surface and bottom water temperatures in marine fishing area 55 are graphed as averages across all depths, and in depth intervals as indicated. All data from the 1994/95 season.

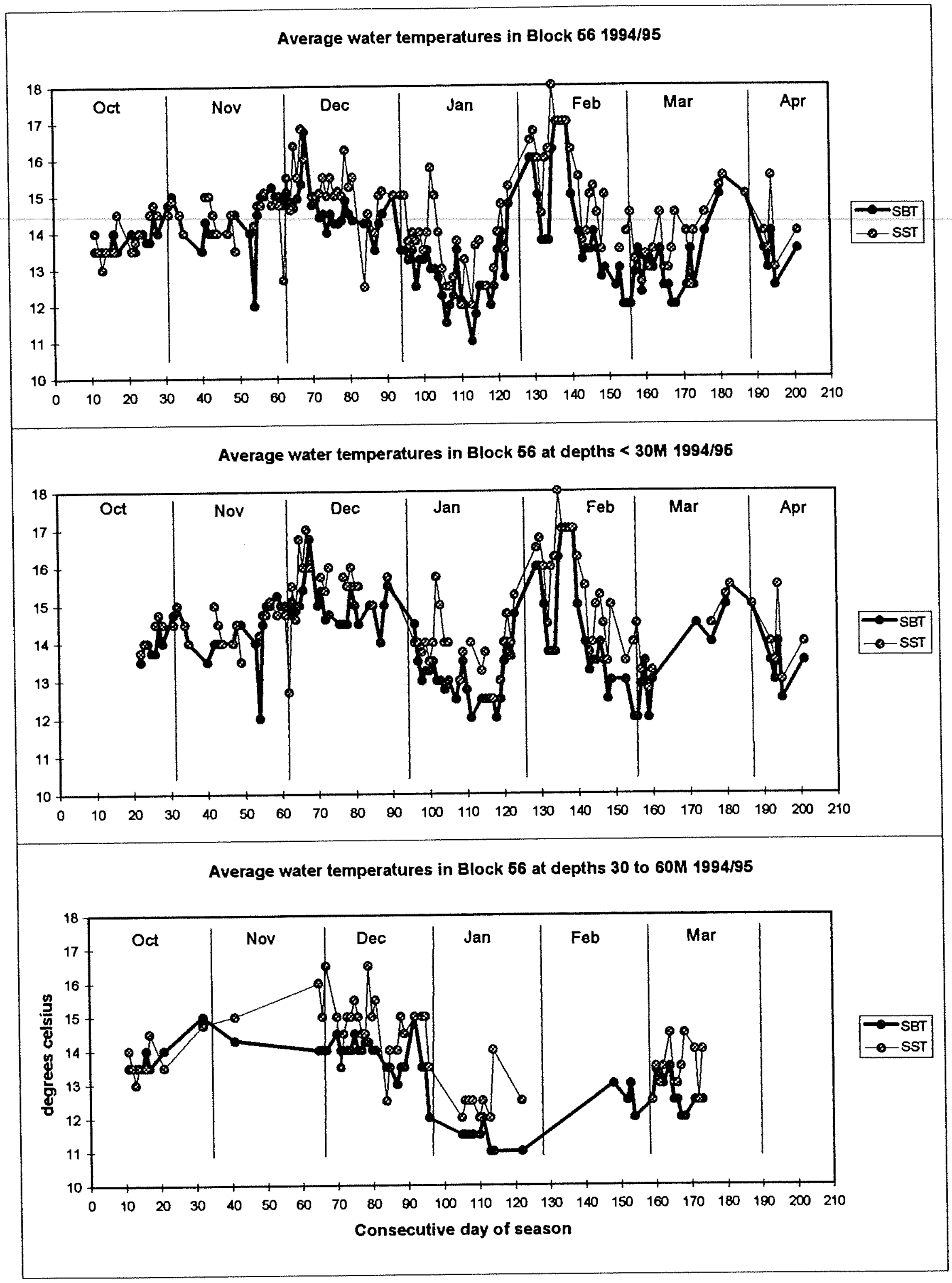


Figure 9b. Surface and bottom water temperatures in marine fishing area 56 are graphed as averages across all depths, and in depth intervals as indicated. All data from the 1994/95 season.

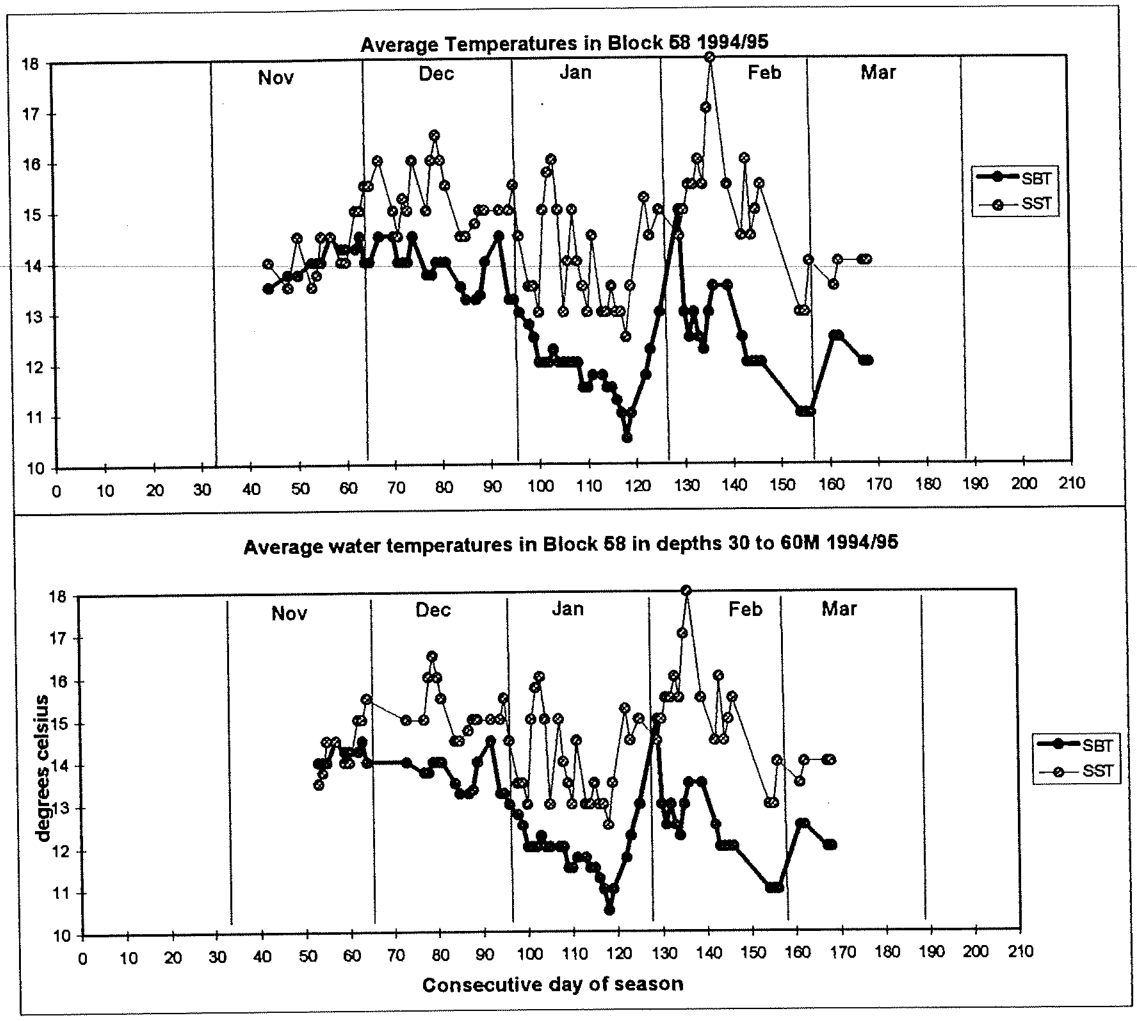


Figure 9c. Surface and bottom water temperatures in marine fishing area 58 are graphed as averages across all depths, and in depth intervals as indicated. All data from the 1994/95 season.

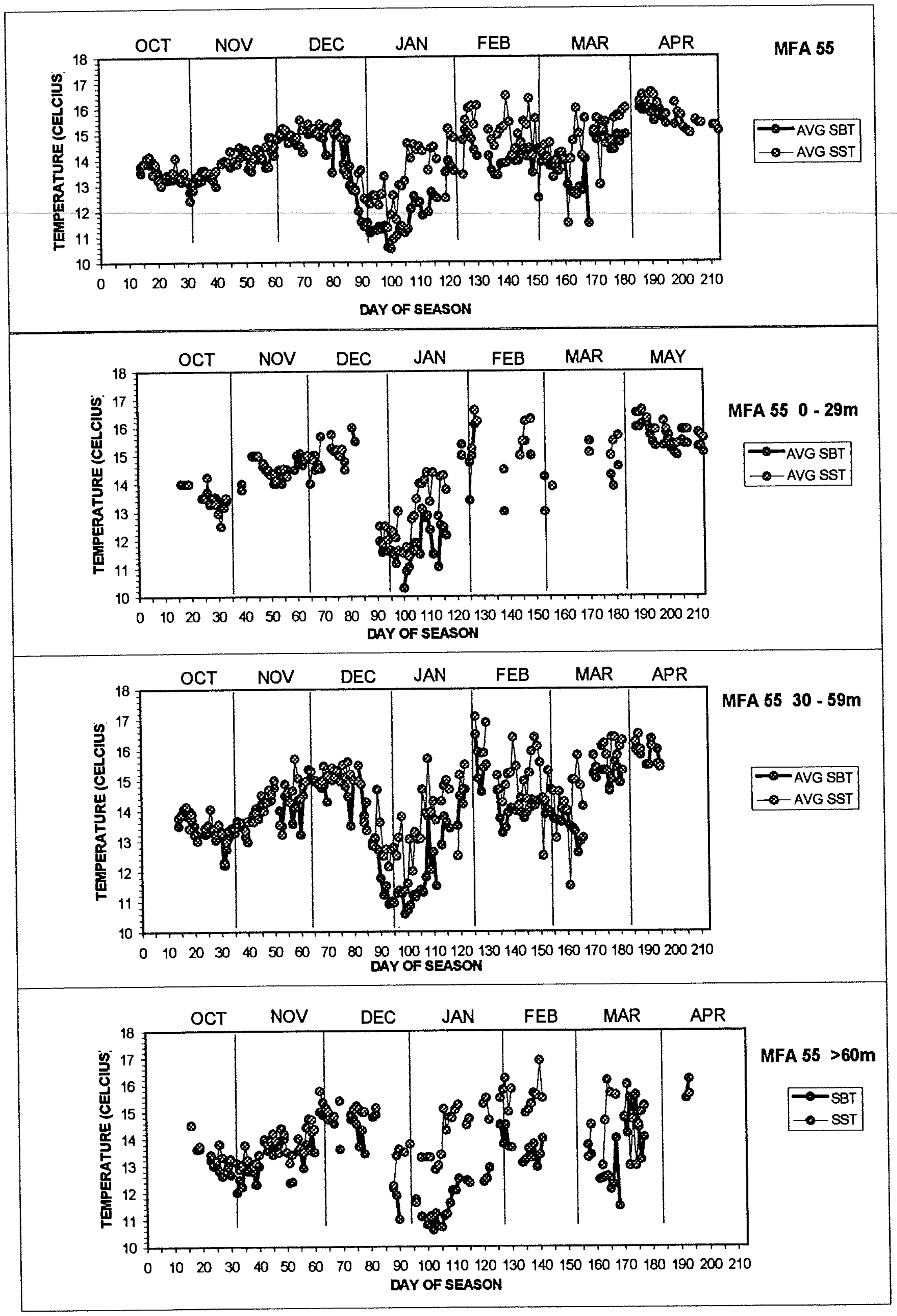


Figure 10a. Surface and bottom water temperatures in marine fishing area 55 are graphed as averages across all depths, and in depth intervals as indicated. All data from the 1995/96 season.

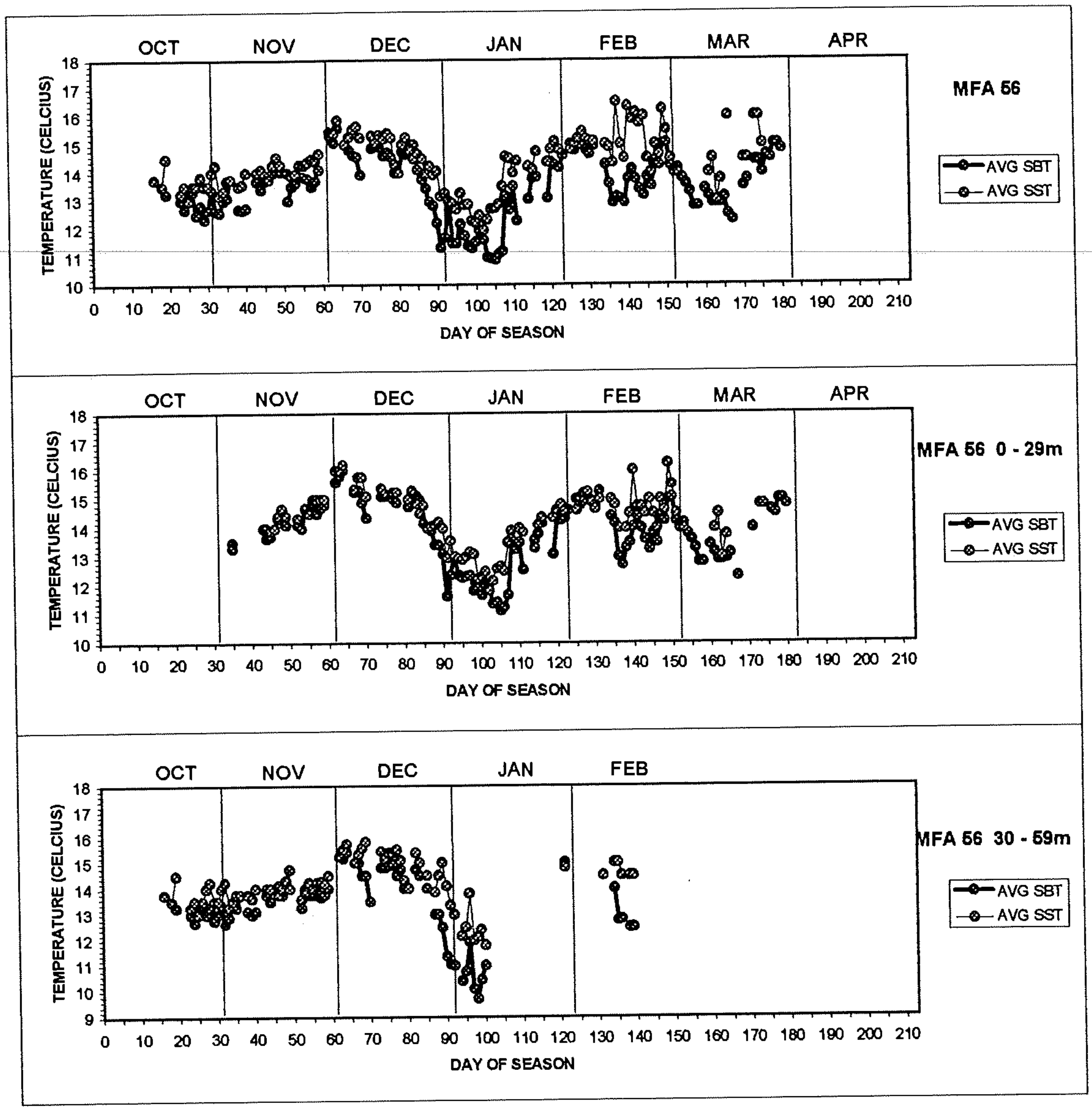


Figure 10b. Surface and bottom water temperatures in marine fishing area 56 are graphed as averages across all depths, and in depth intervals as indicated. All data from the 1995/96 season.

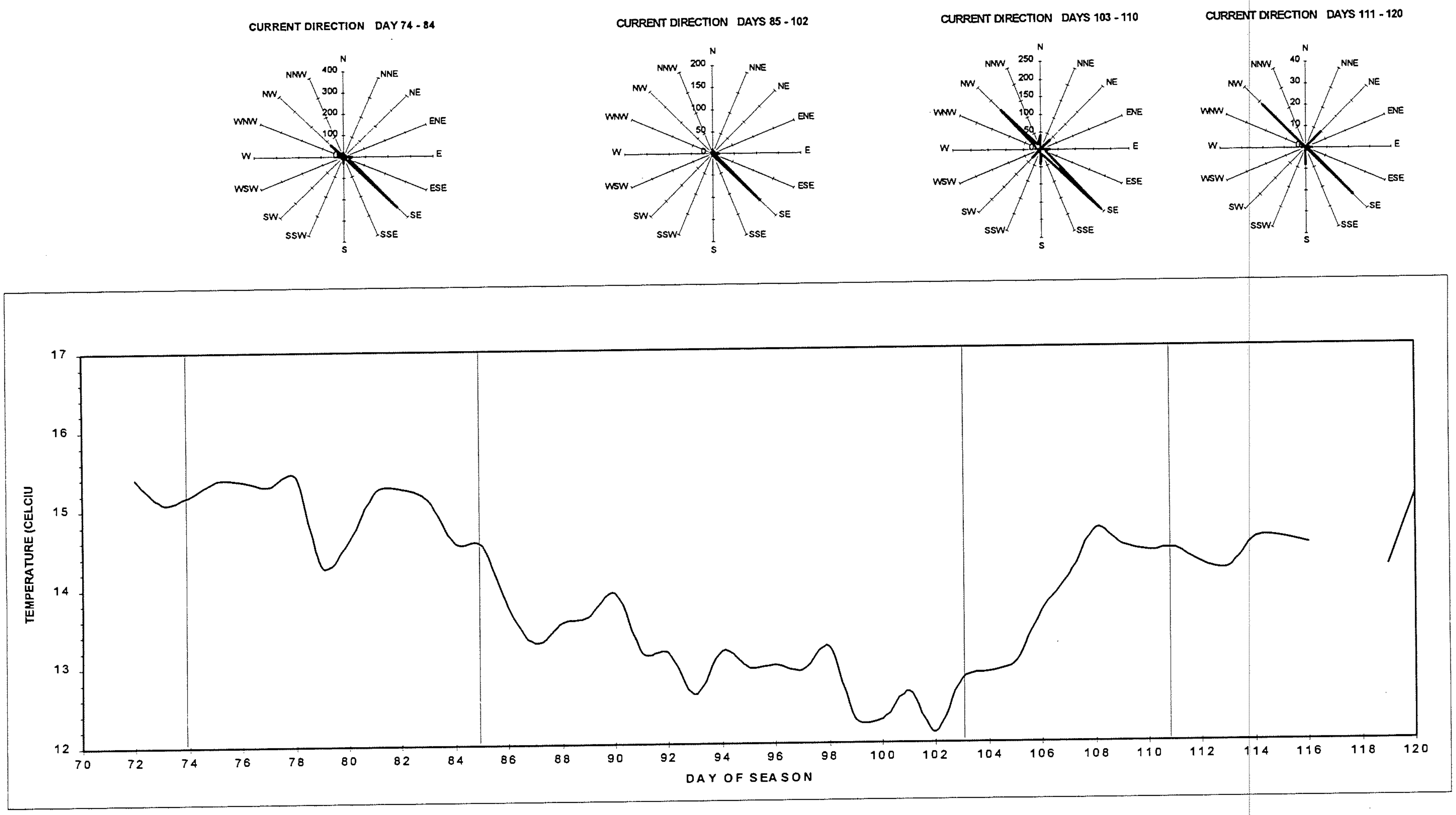


Figure 11a. Mean sea surface temperatures are shown during consecutive days of the 1995/96 season along the southeast cosat. Also shown are radar graphs of current direction recorded by fishers during the correspoinding periods. Day 70 was 9 December 1995.

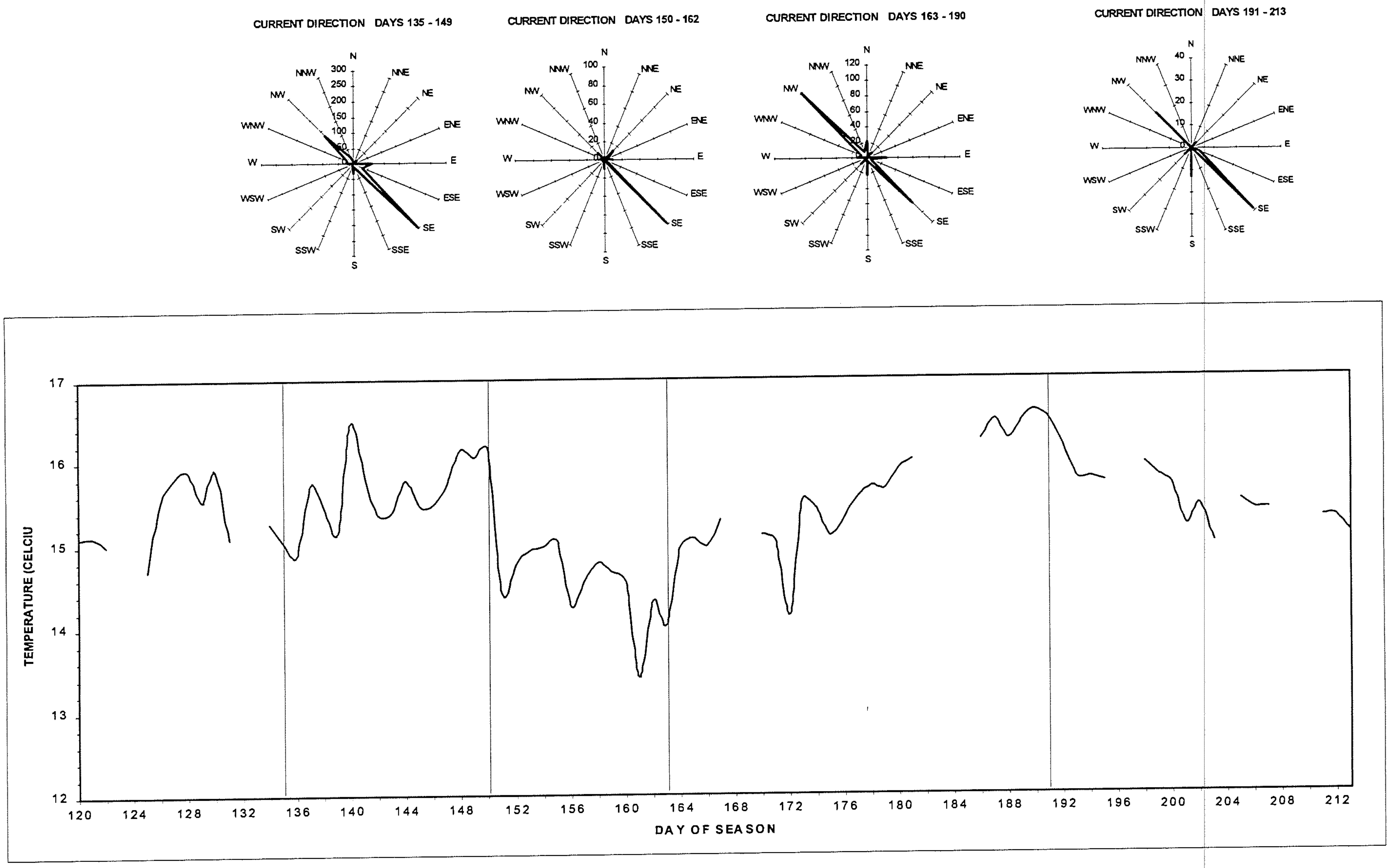


Figure 11b. Mean sea surface temperatures and current directions shown for latter half of the 1995/96 season along the southeast coast

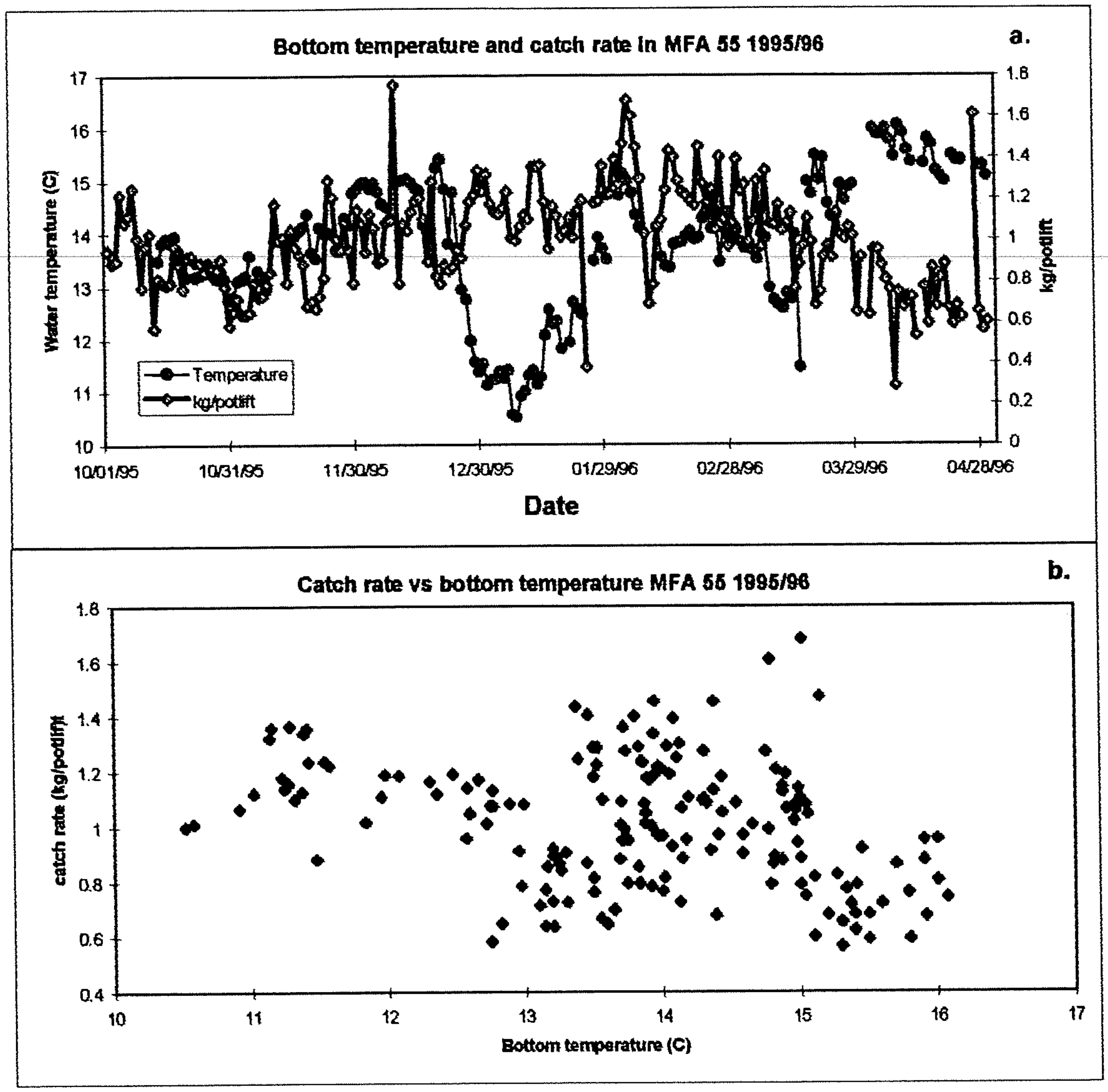


Figure 12. Temporal changes in catch rate and bottom water temperature are plotted together (a), and catch rate is plotted versus bottom water temperature (b).

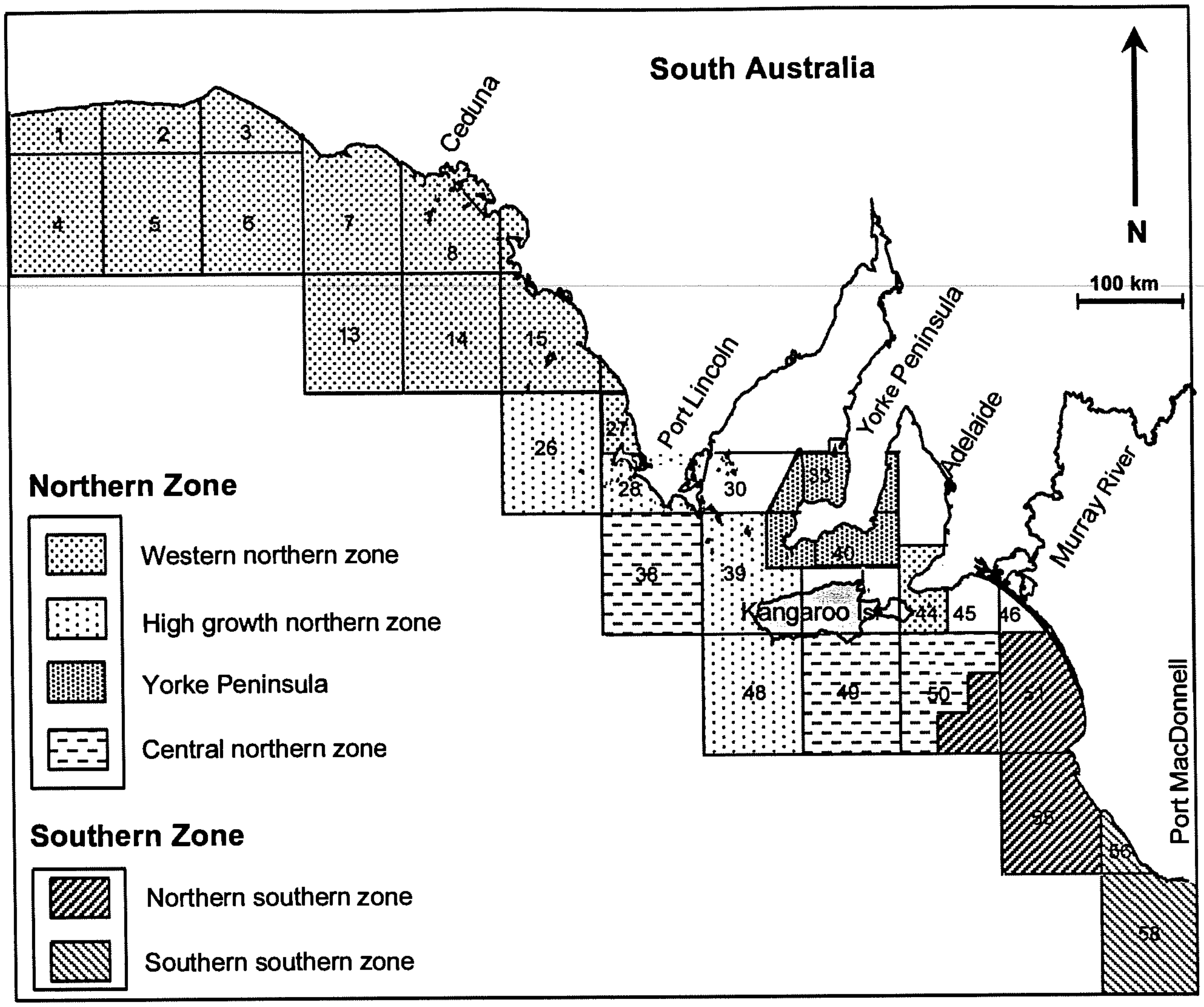


Figure 13. Map of South Australia showing Marine Fishing Area (MFA) blocks and subregions of uniform growth

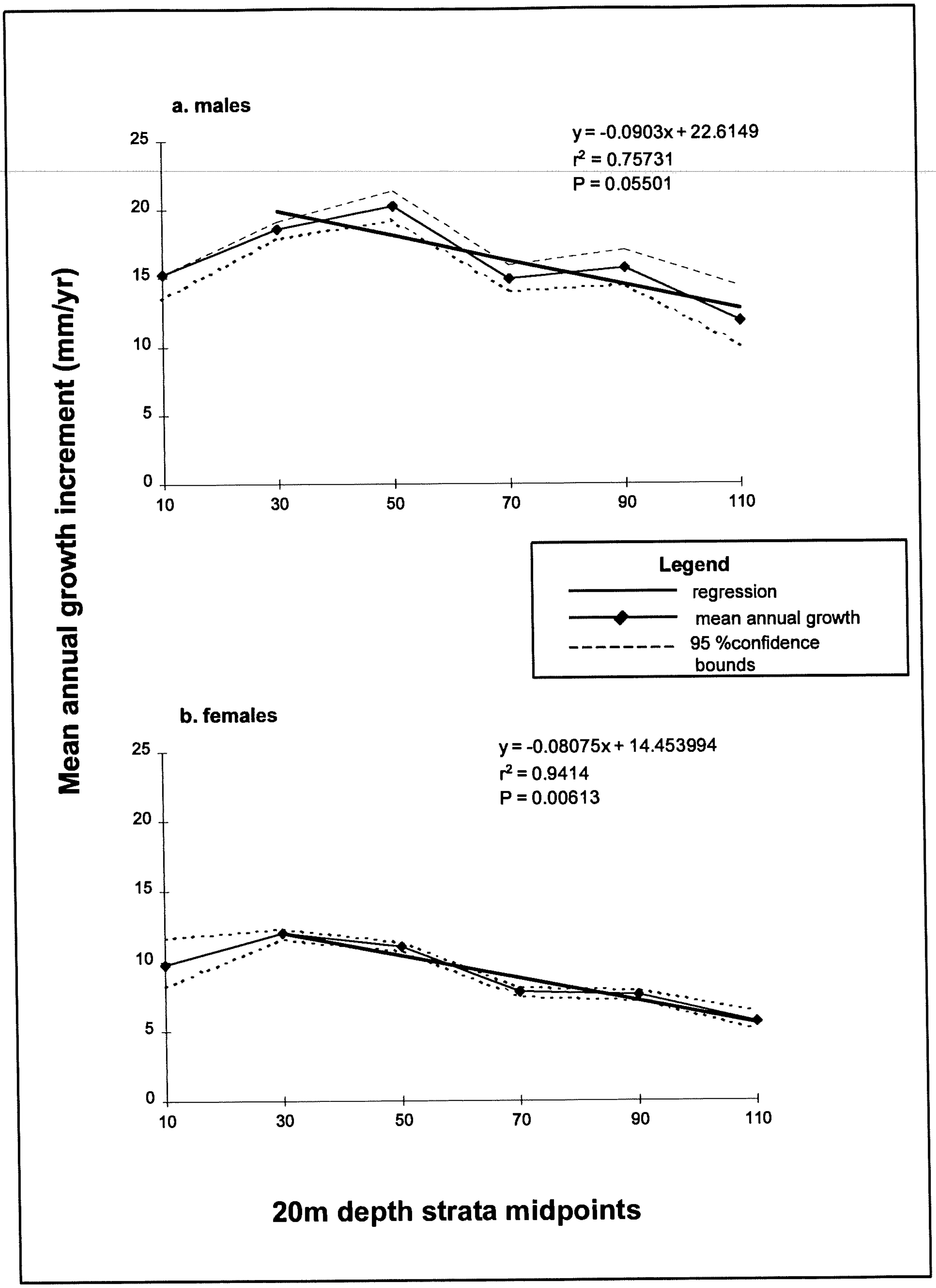


Figure 14: depth versus g_α and g_B for males and females from the northern part of the Southern Zone

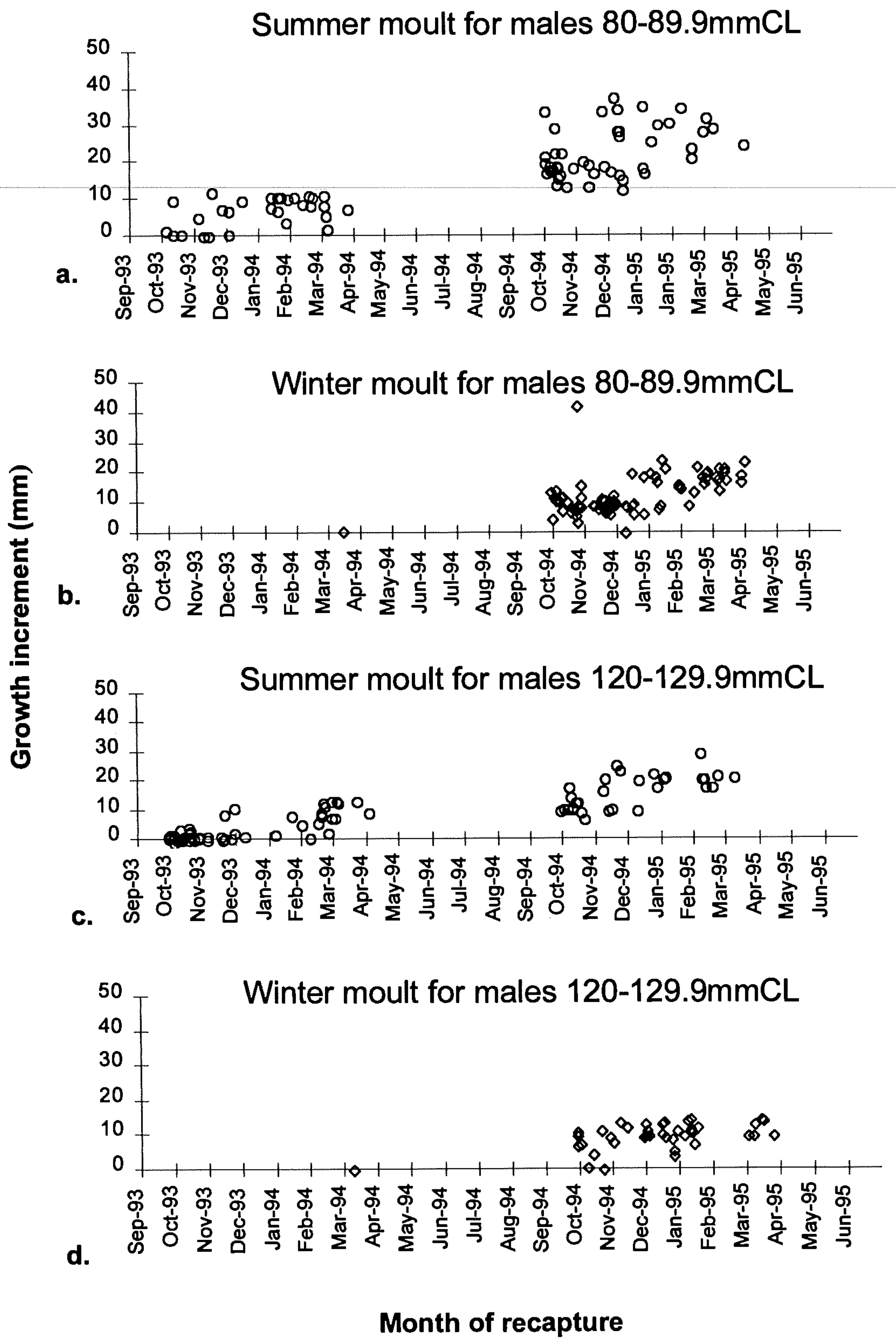


Figure 19. Moulting in southern zone male lobsters. a) 80-89.9mmCL, tagged August 22, 1993 to October 31 1993. b) 80-89.9mmCL, tagged 1 March to 30 April 1994. c) 120-129.9mmCL, tagged 22-August 1993 to 31 October 1993. d) 120-129mmCl, tagged 1 March to 30 April 1994.

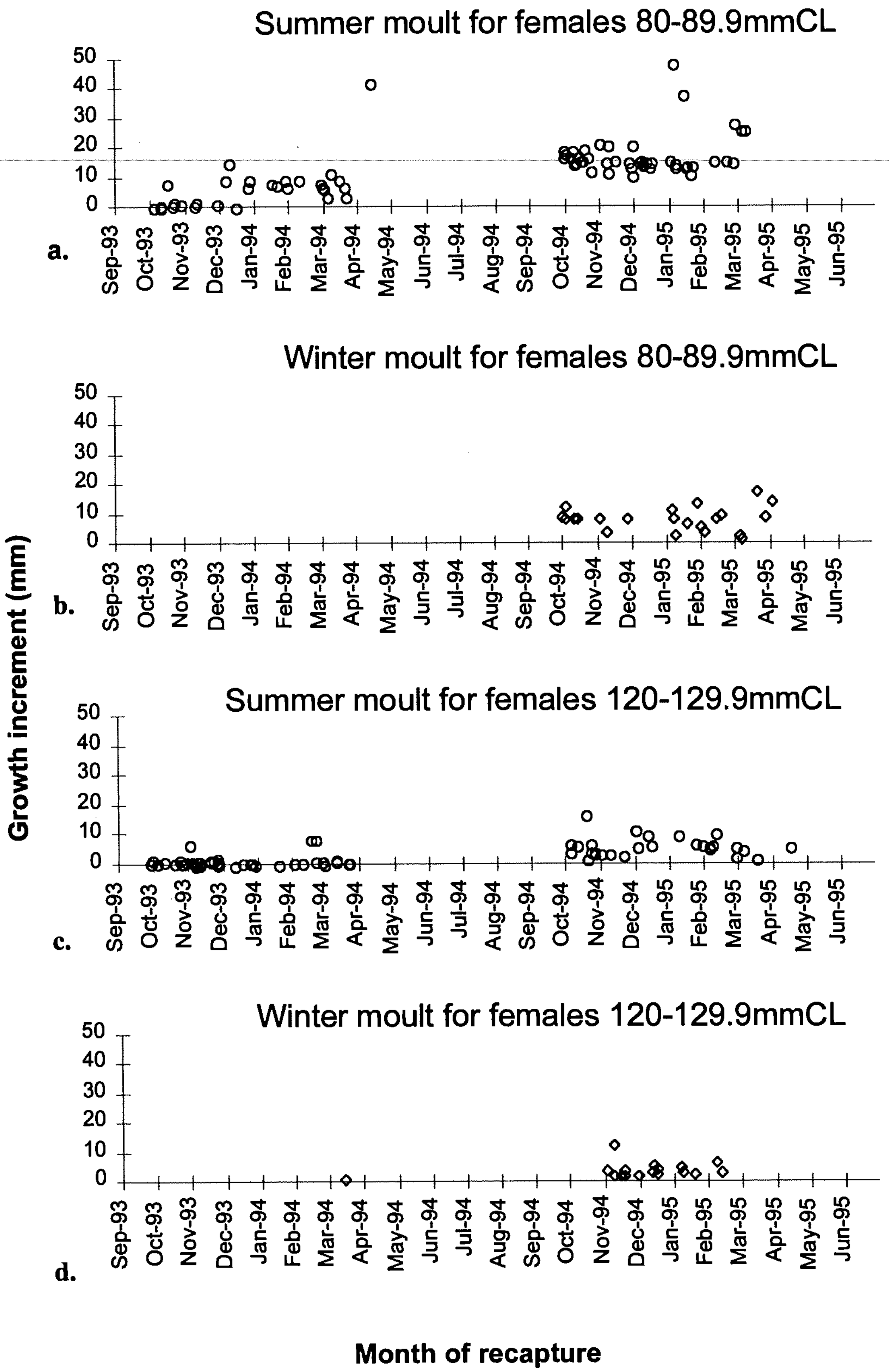


Figure 20. Moulting in southern zone female lobsters. a) 80-89.9mmCL, tagged August 22, 1993 to October 31 1993. b) 80-89.9mmCL, tagged 1 March to 30 April 1994. c) 120-129.9mmCL, tagged 22-August 1993 to 31 October 1993. d) 120-129mmCl, tagged 1 March to 30 April 1994.

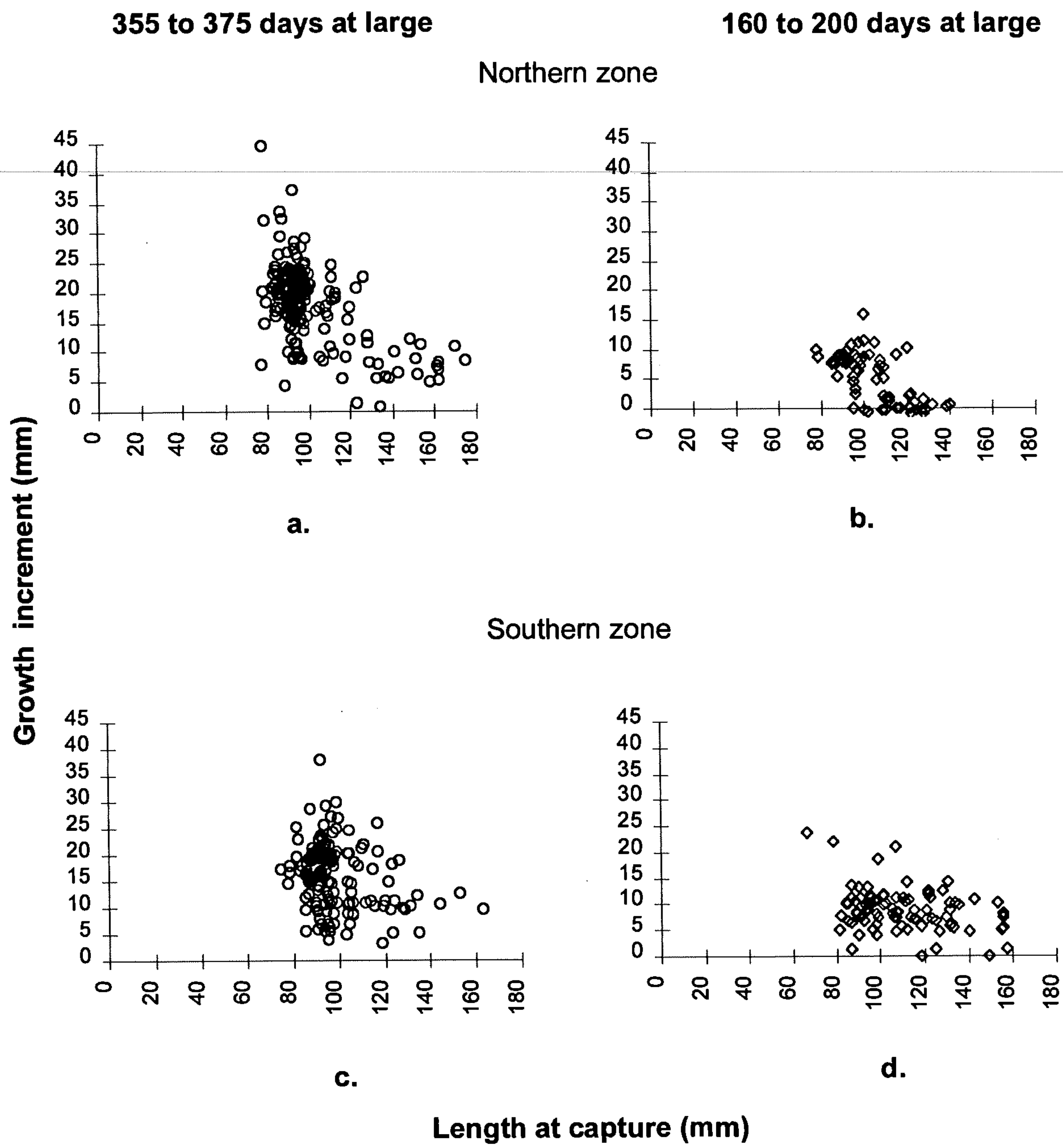


Figure 16: Moult increment for male lobsters at large for 6 month and 12 month periods. a) Northern zone, at large for 12 months, b) Northern zone at large for 6 months, c) Southern zone, at large for 12 months, d) Southern zone, at large for 6 months

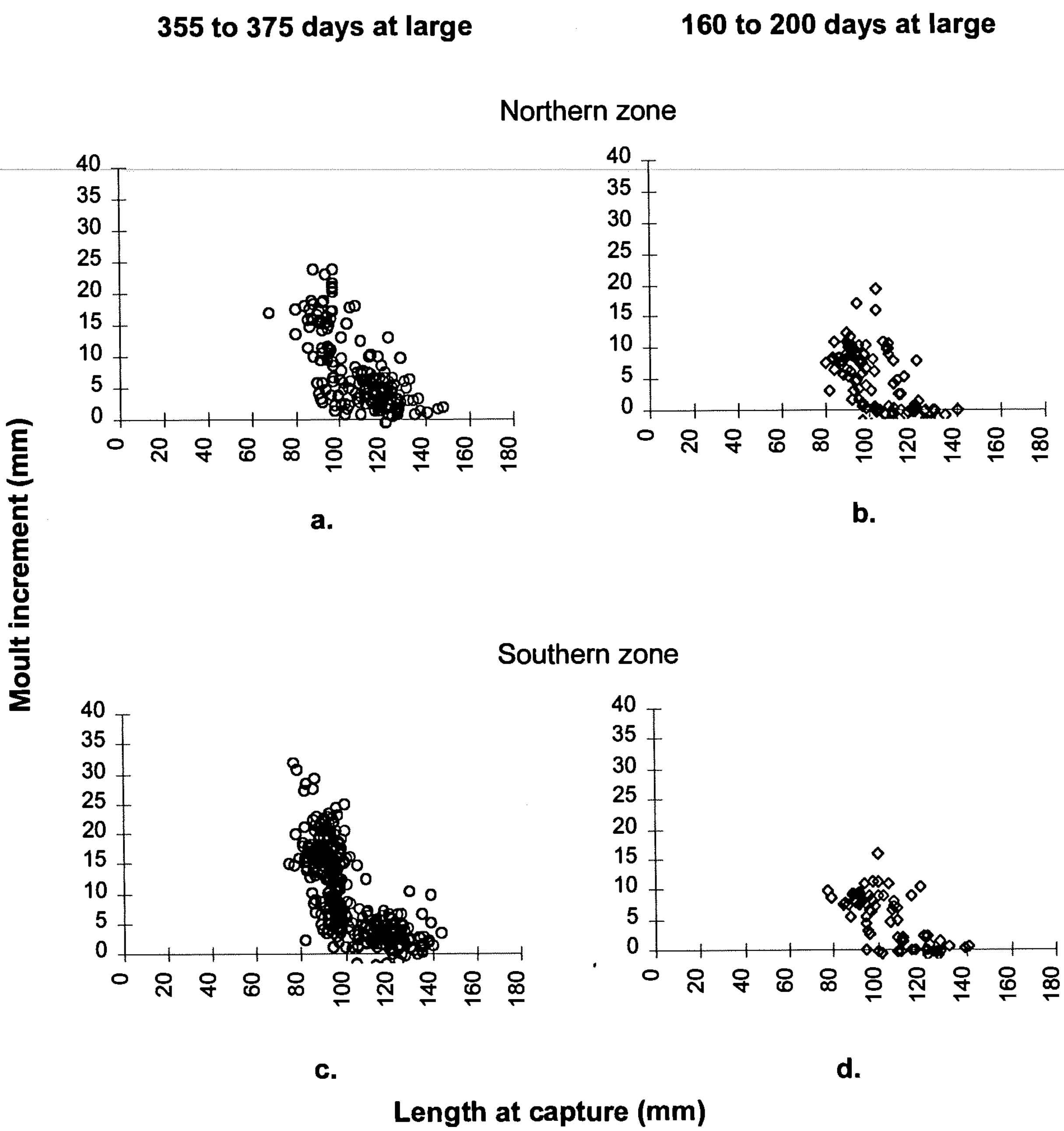


Figure 18: Moult increment for female lobsters at large for 6 month and 12 month periods a) Northern zone, at large for 12 months, b)Northern zone at large for 6 months, c) Southern zone, at large for 12 months, d) Southern zone, at large for 6 months

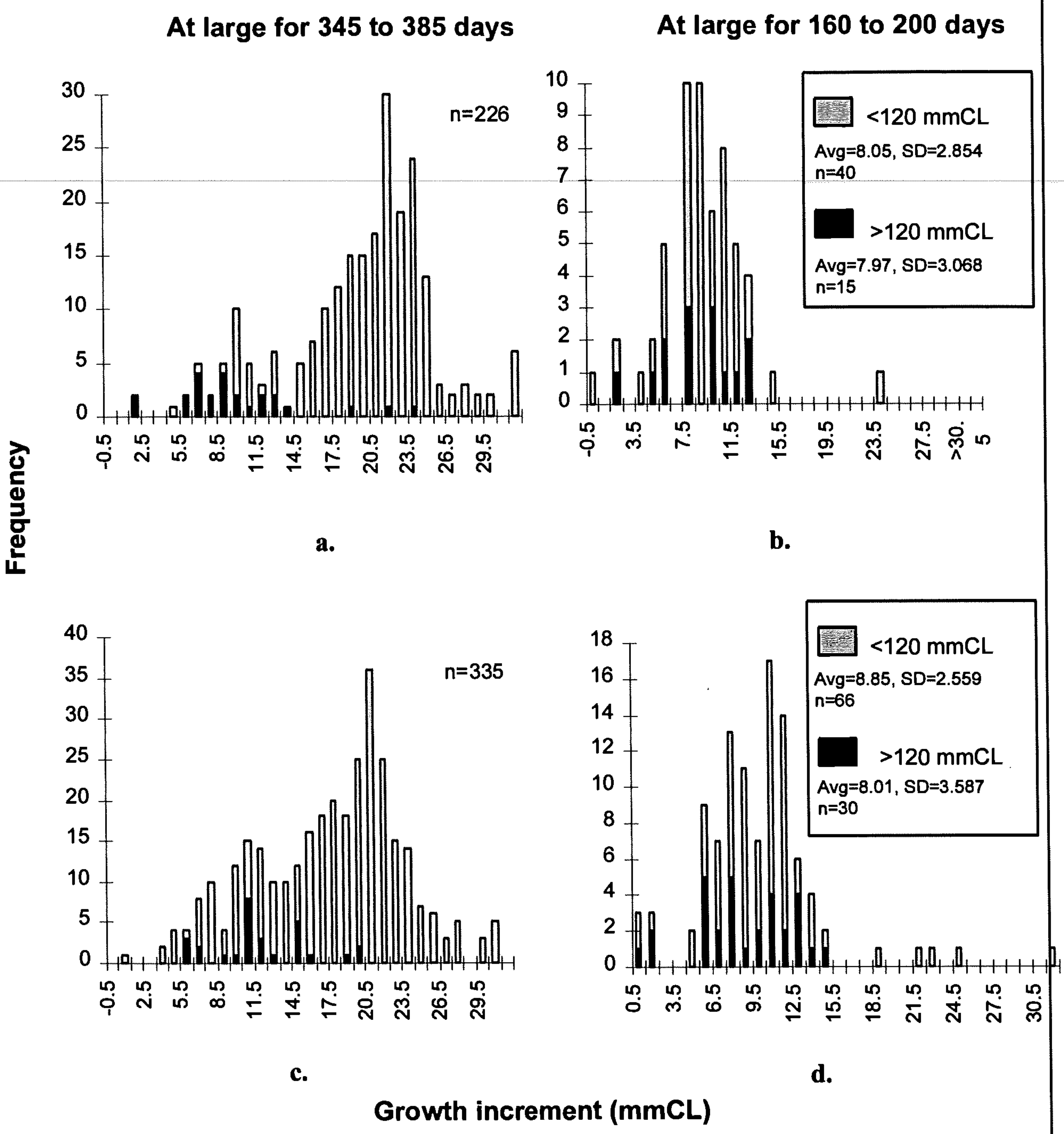


Figure15. a) Northern zone males at large 345 to 385 days, b) Northern zone males at large 160 to 200 days, c) Southern zone males at large 345 to 365 days, d) Southern zone males at large 160 to 200 days

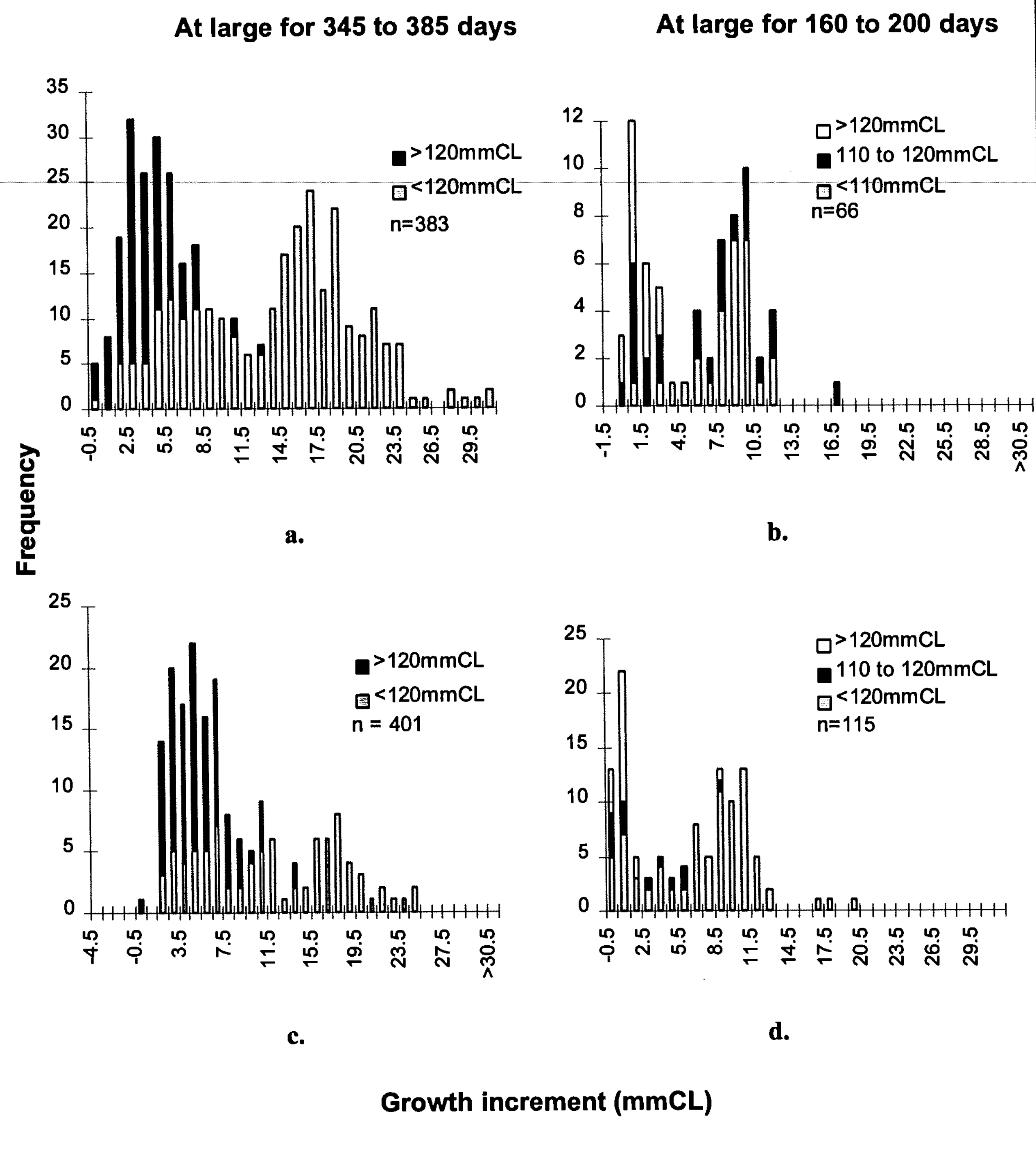


Figure 17. a) Northern zone females at large 345 to 385 days, b) Northern zone females at large 160 to 200 days, c) Southern zone females at large 345 to 365 days, d) Southern zone females at large 160 to 200 days

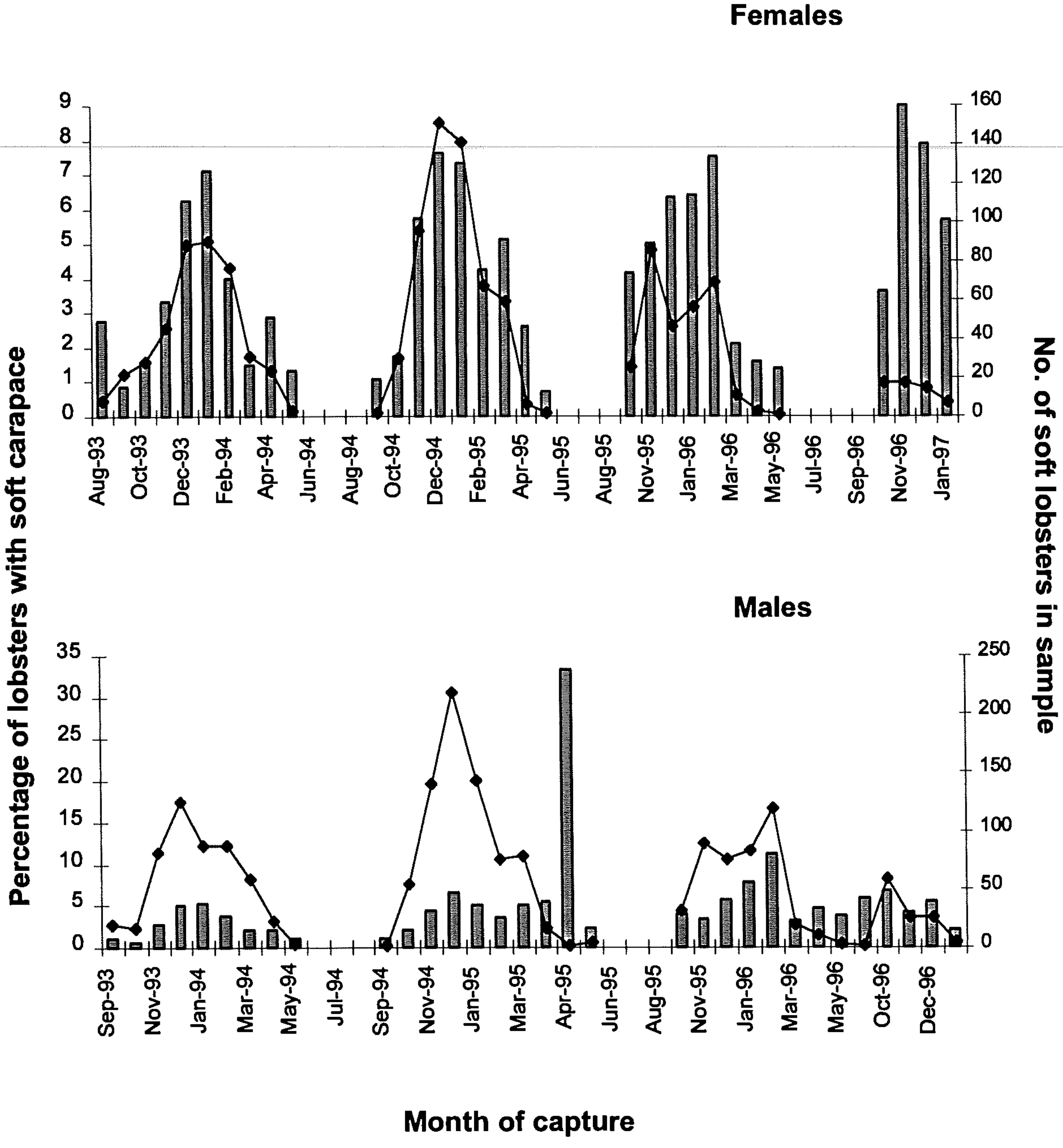


Figure 21. a) Percentage of recent post-moult females in tagged sample.
b) Percentage of recent post-moult males in tagged sample

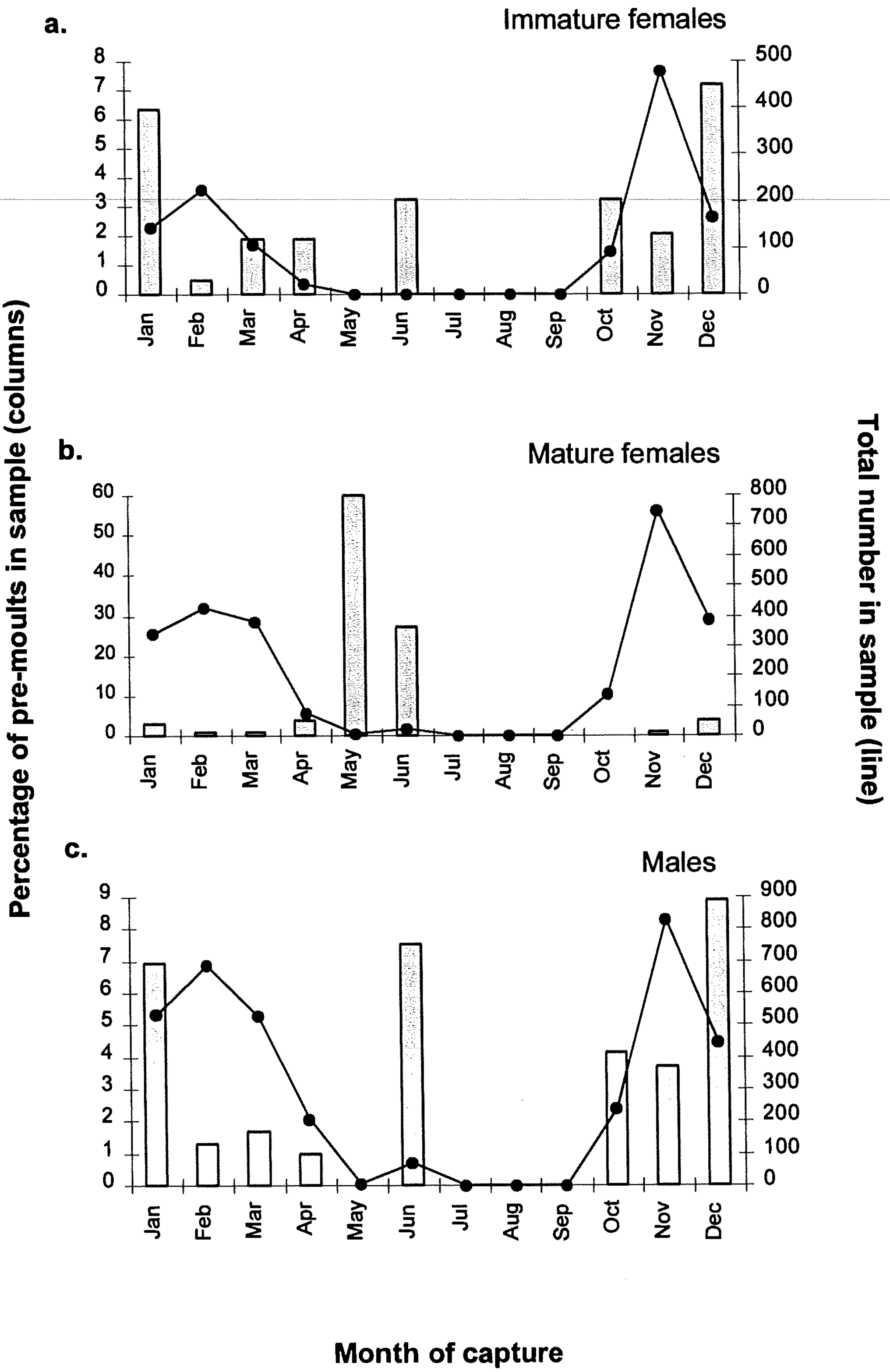


Figure 22. percentages of pre-moult individuals in 1994/95 season sample. a) immature females, b) mature females, c) males.

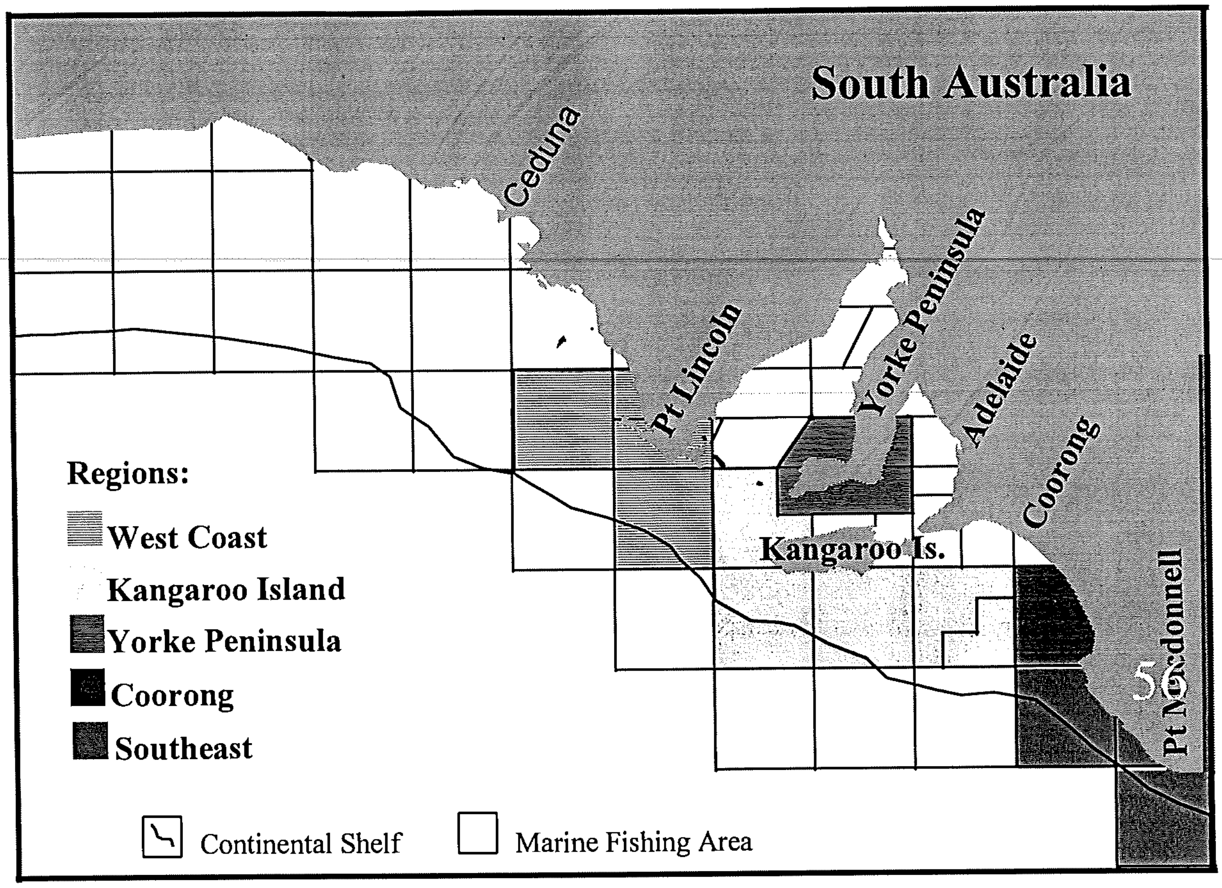


Figure 23. Five regions analysed for movements of rock lobster.

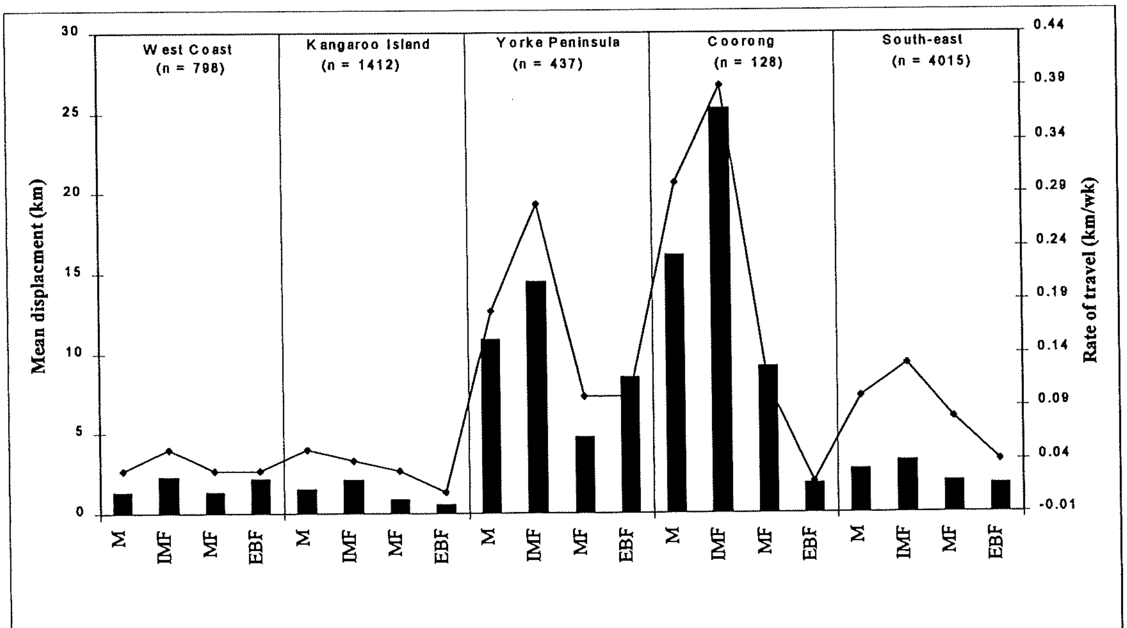


Figure 24. Mean displacement (▬) and rate of travel (—♦—) in five movement regions. (M = male; IMF = immature female; MF = mature female; EBF = egg-bearing female)

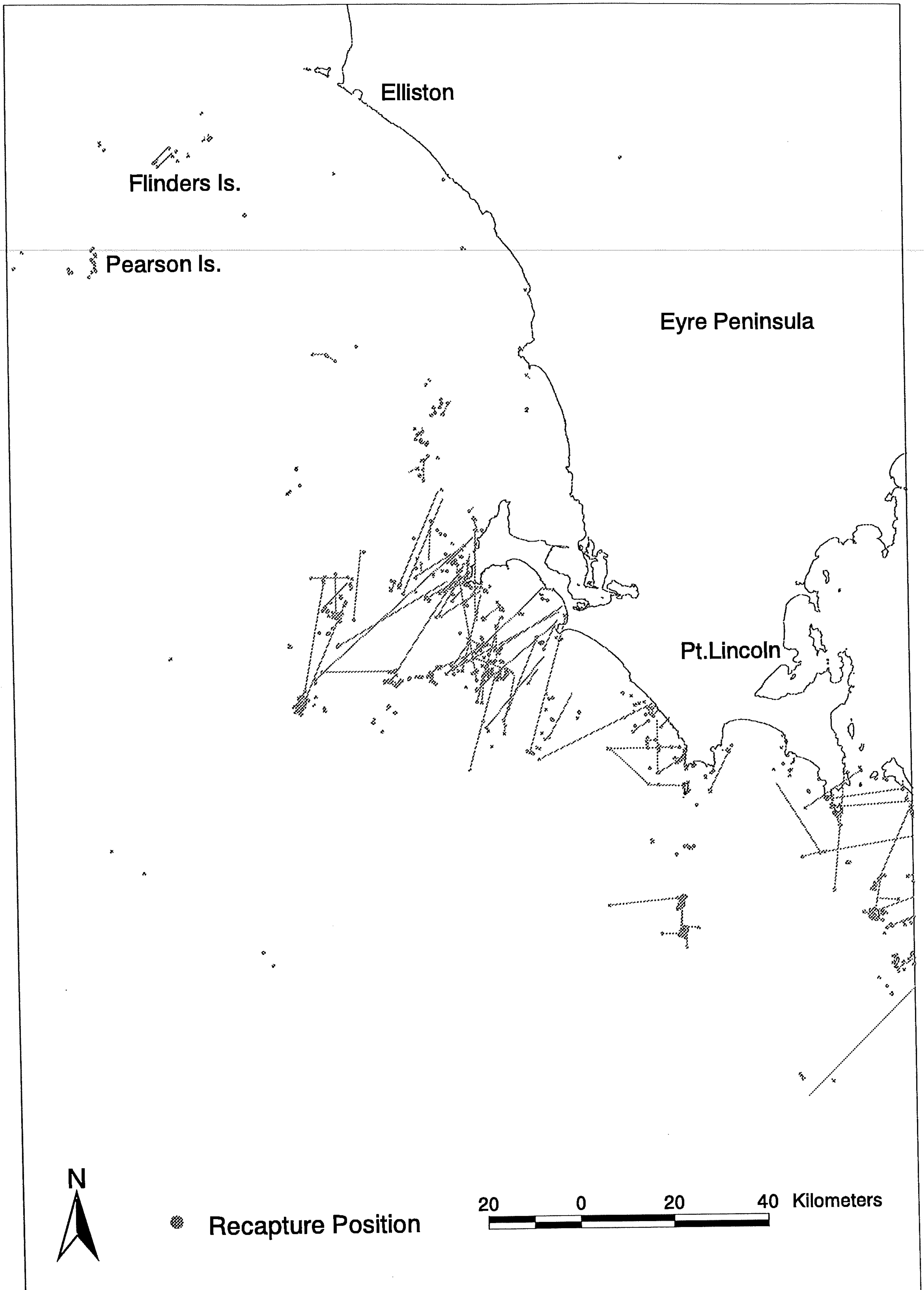


Fig 25. Straightline distances between release and recapture for West Coast Region

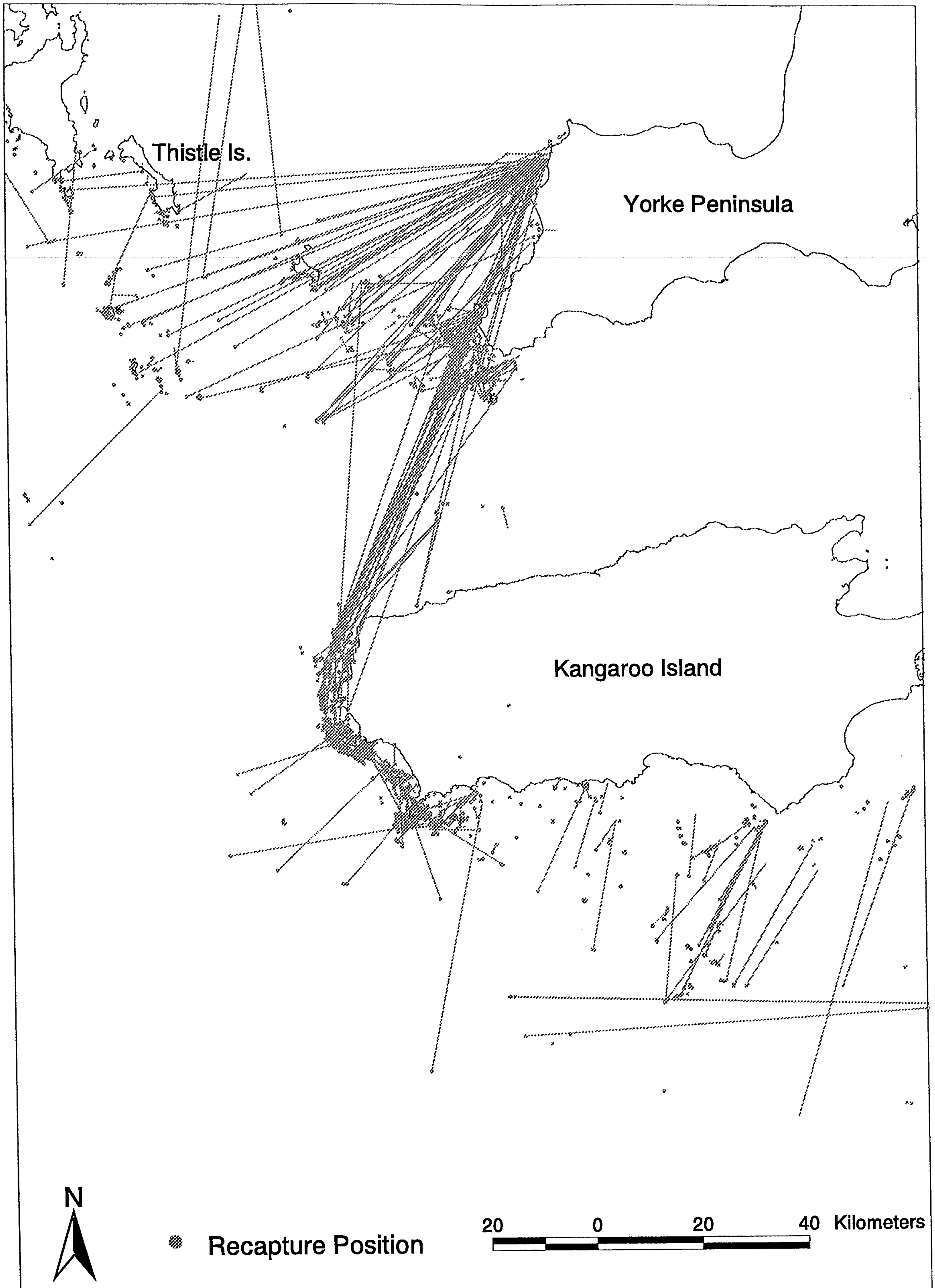


Fig 26. Straightline distances between release and recapture for Yorke Peninsula and Kangaroo Island Regions

Fig 27. Straightline distances between release and recapture for Coorong and Southeast Regions

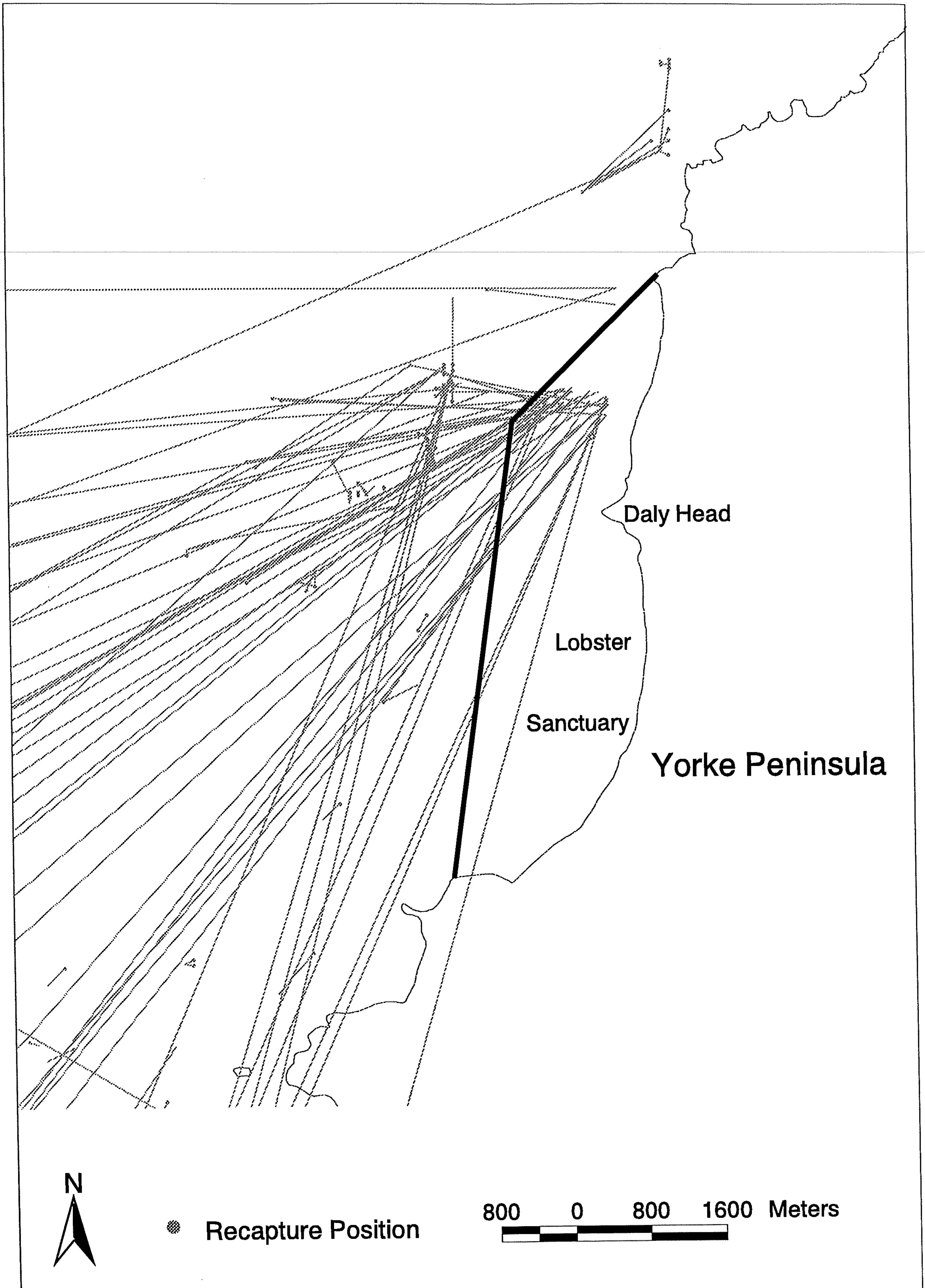


Fig 28. Migrations originating from the lobster sanctuary, Yorke Peninsula

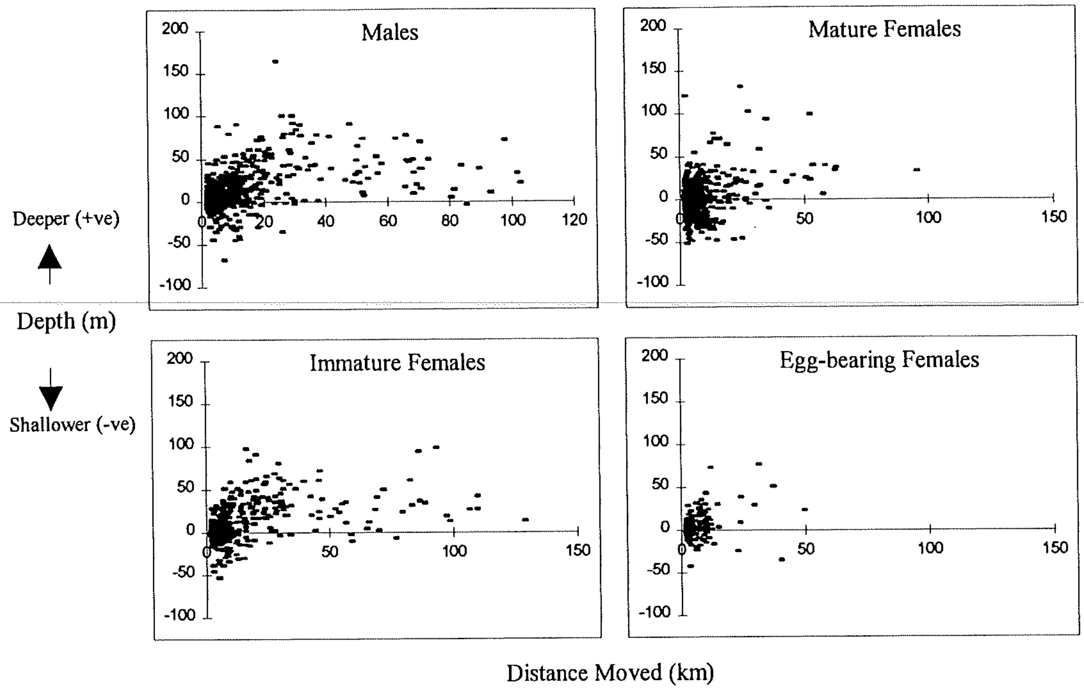


Figure 29. Change in depth made by lobsters moving distances greater than 1km, presented by sex and reproductive status.

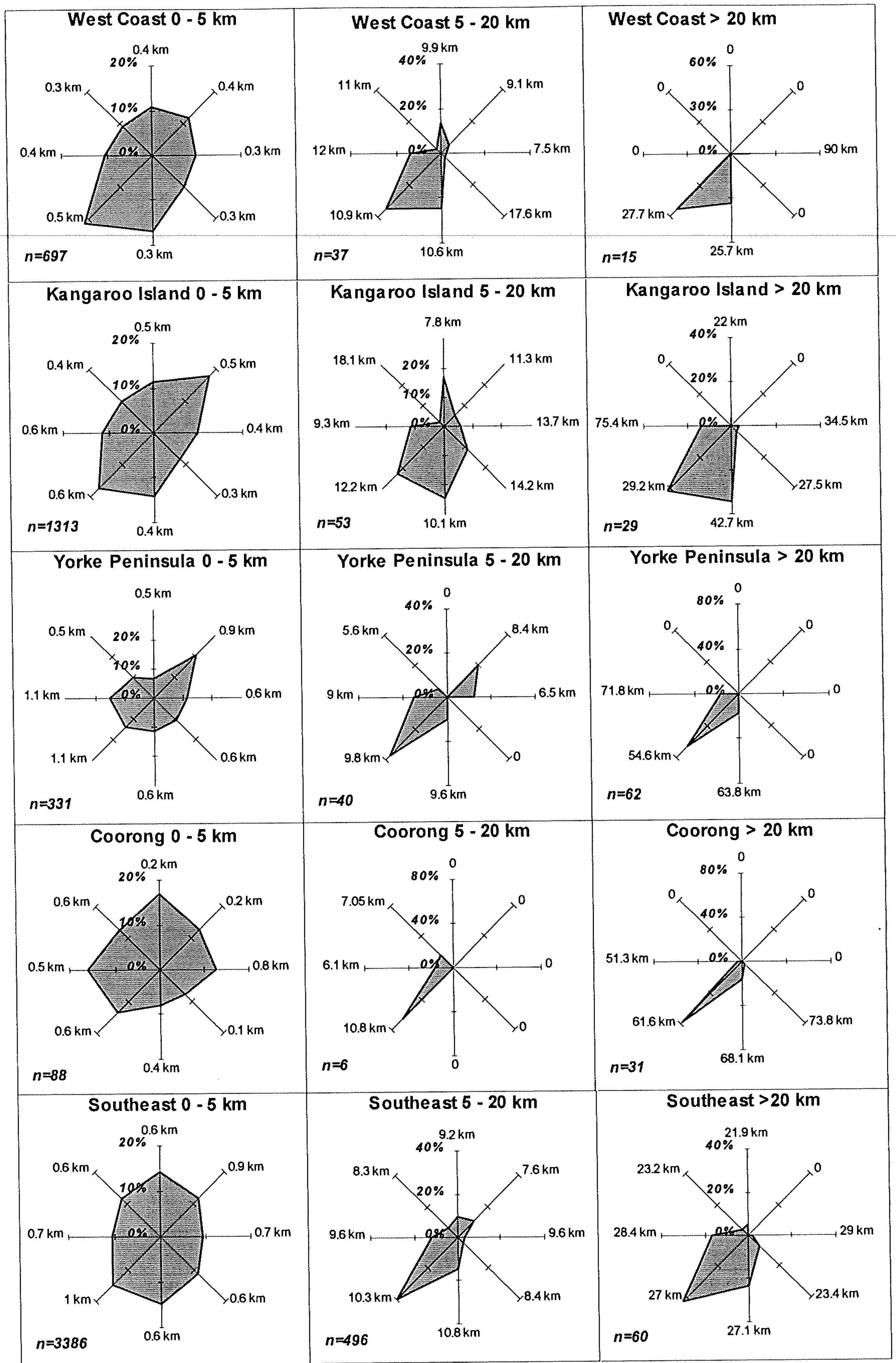


Figure 30. Direction of movement in defined distance intervals from five movement regions. Mean distances (km) moved in each cardinal direction are shown in bold font at the end of each axis. The shaded areas represent the percentage of lobsters moving in the respective directions (scale shown on north axis).

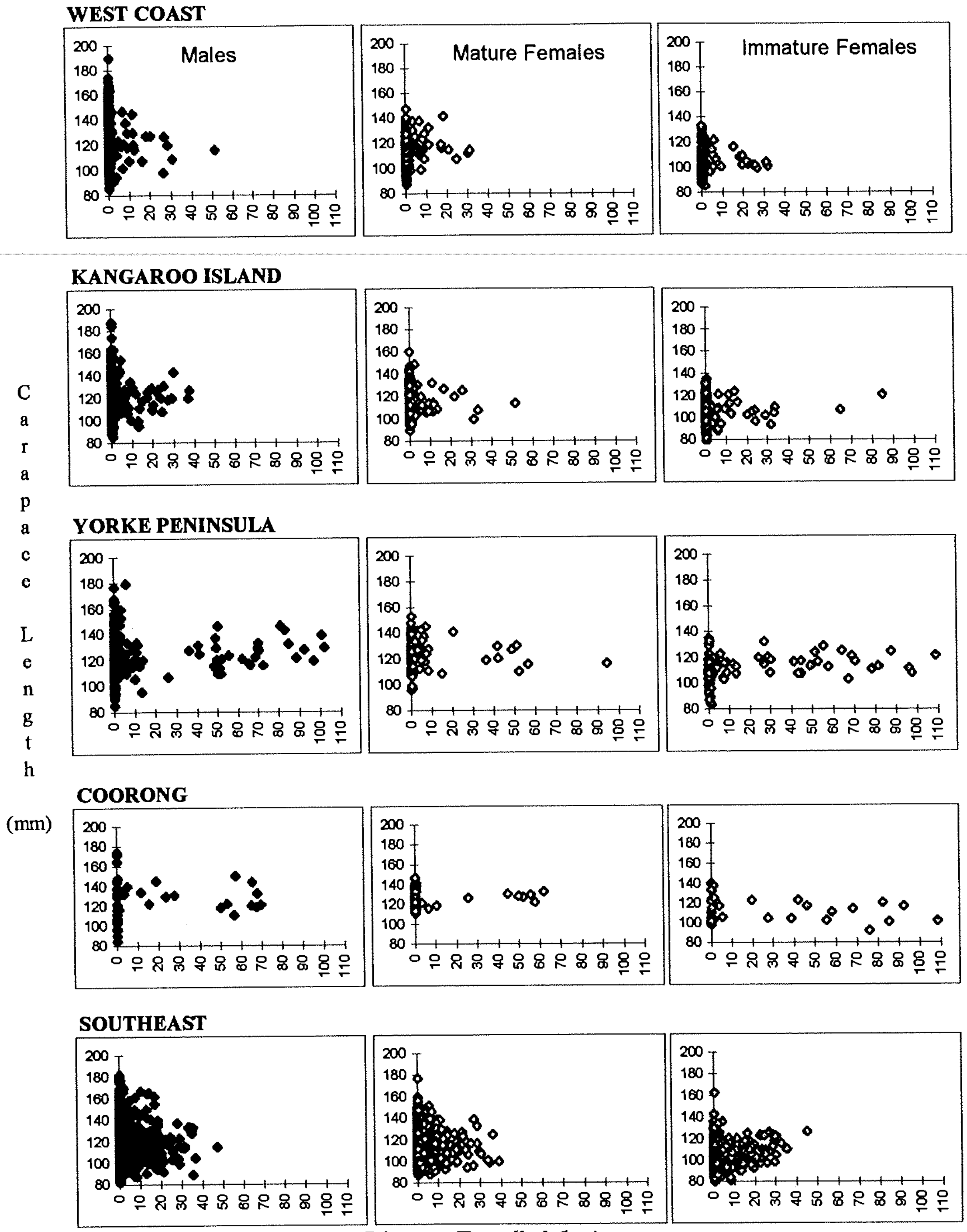


Figure 31. Distances travelled in five movement regions are presented for males, immature and mature females, plotted as carapace length versus distance travelled.

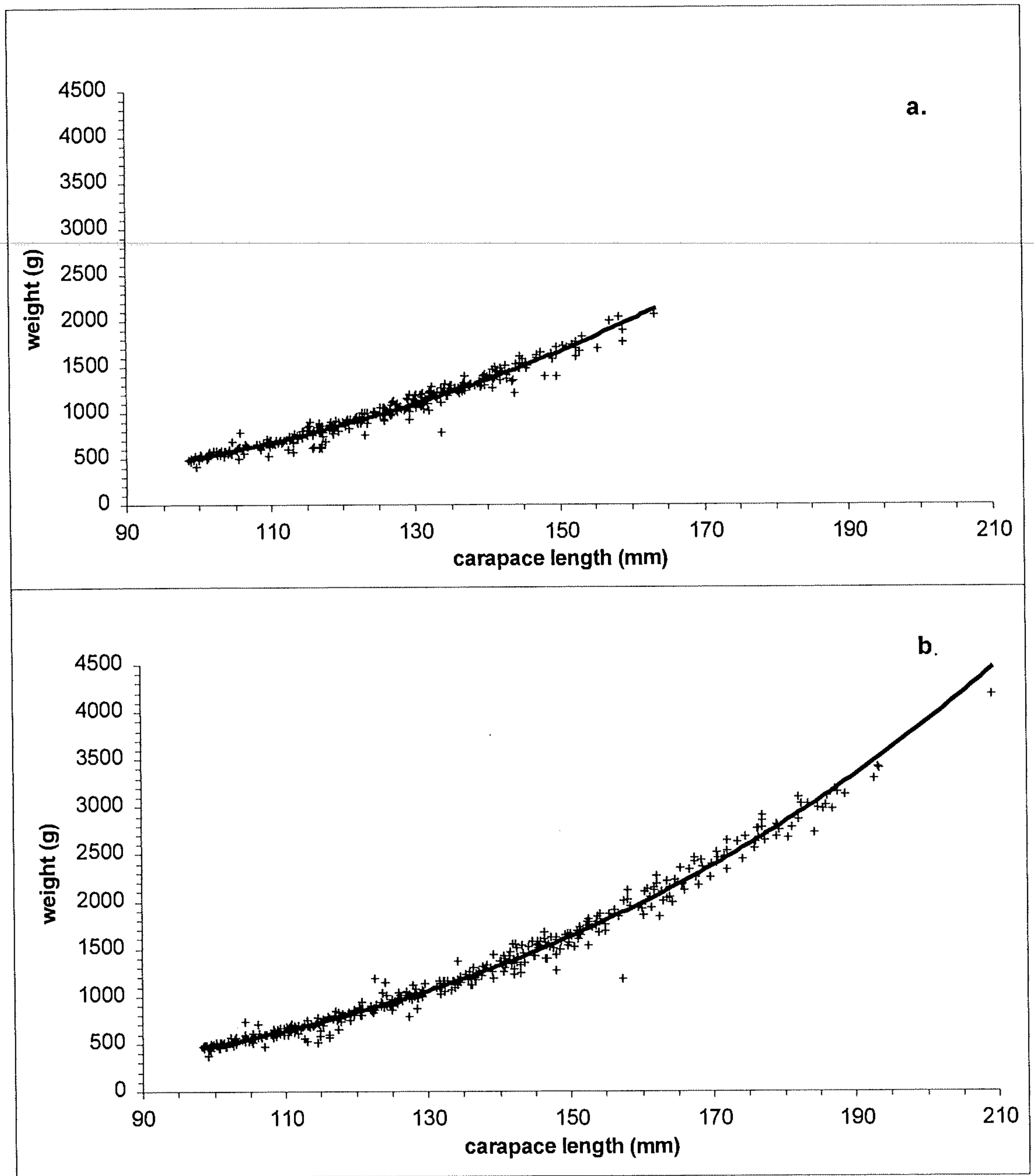


Figure 32. Fitted length-weight curves and raw data for all females (a.) and males (b.). Data included all categories of colour, damage, and sample locations.

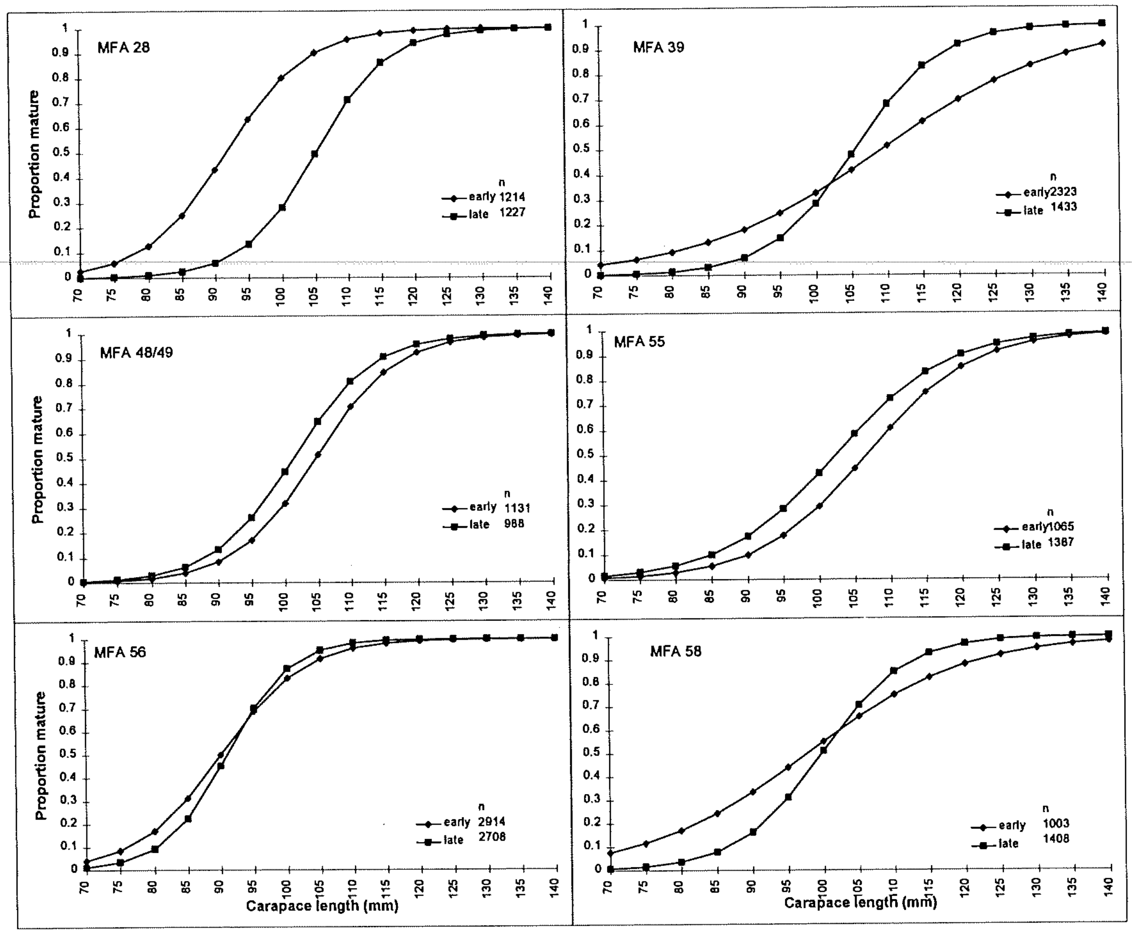


Figure 33. Fitted curves of maturity from data collected early and late during the 1992/93 season. In the northern zone marine fishing areas (28, 39, 48/49) early season was defined as November and December, and late season was March through May. Early season in the southern zone marine fishing areas (55, 56, 58) was October through December and late season March and April. Sample sizes are indicated.

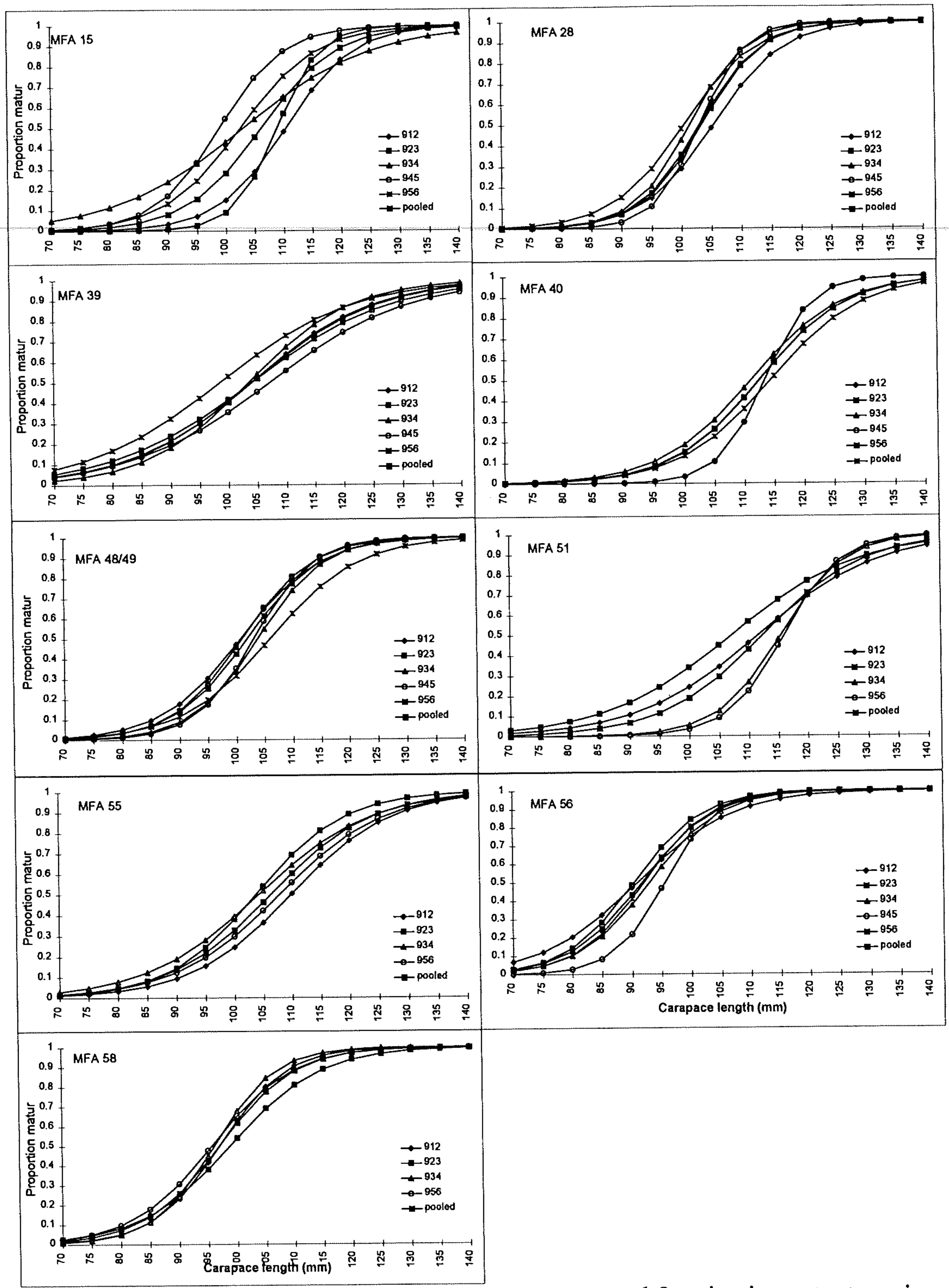


Figure 34. Fitted curves of female maturity are presented for nine important marine fishing areas. Curves were fitted for seasonal data from four or five seasons, and data from all seasons pooled. Marine fishing areas (MFA) are indicated on each graph.

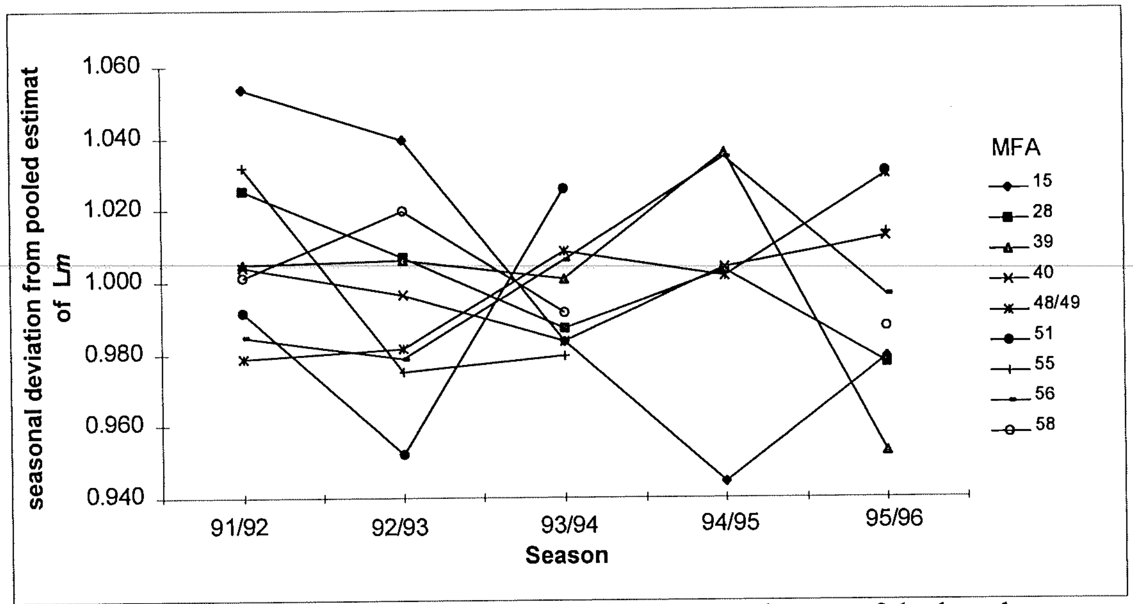


Figure 35. The proportional deviation of single season estimates of the length at which 50% of females are mature is plotted by marine fishing area for four or five seasons. Note that there is no temporal trend in the deviations.

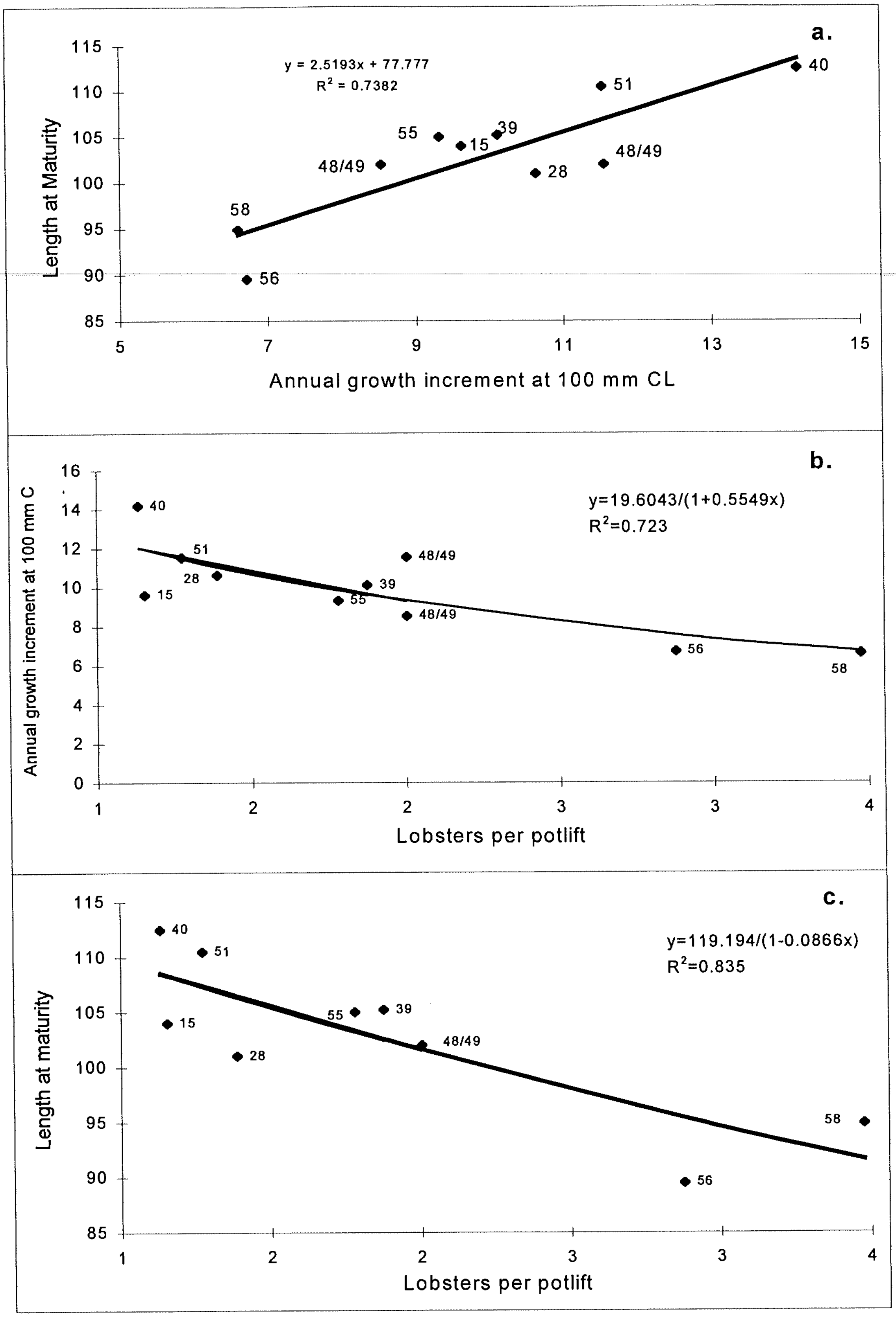


Figure 36. Female length at maturity in 10 marine fishing areas is plotted against the annual female growth increment at 100 mm in the respective area (a); annual growth increment against the number of lobsters per potlift by commercial fishers in the respective fishing area (b); and female length at maturity against lobsters per potlift. Regression equations are shown.. Note that fishing area 48 and 49 had growth estimates calculated separately but maturity was estimated from pooled data, consequently there are two data points shown in (a) and (b).

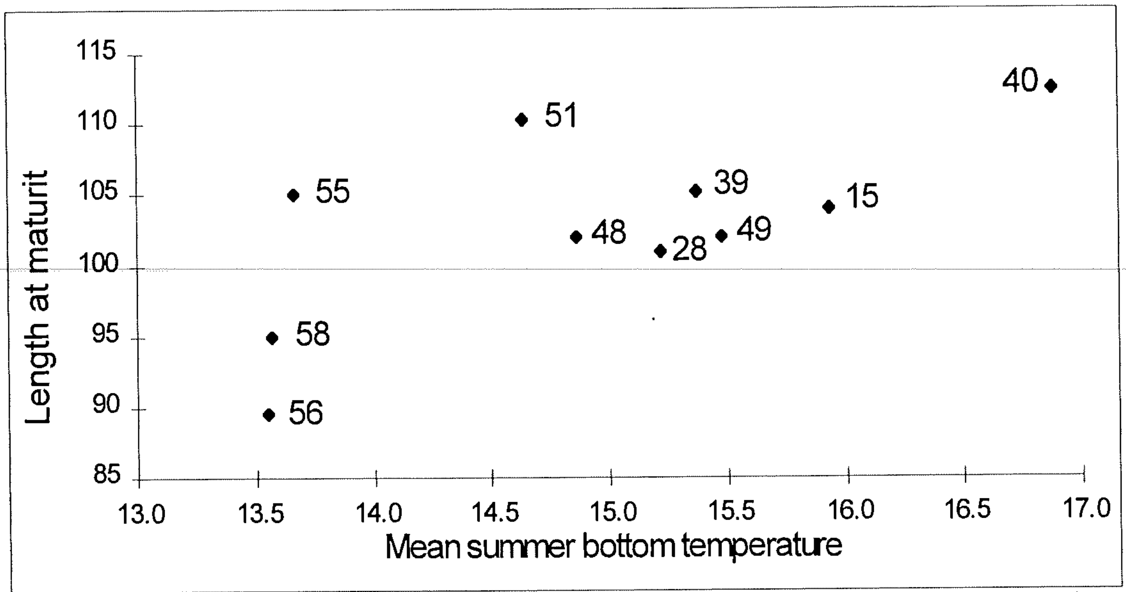


Figure 37. Females' mean length at maturity in the indicated marine fishing areas is shown plotted against the mean summer bottom temperature recorded in the respective fishing areas.

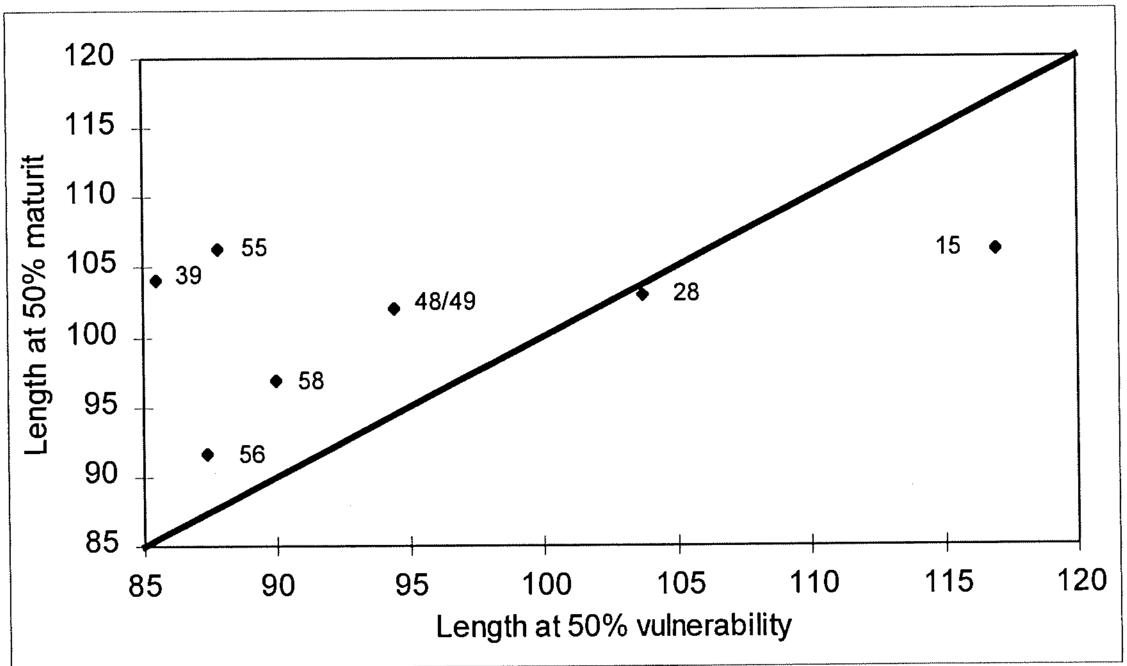


Figure 38. The females' length at maturity is plotted against their length at 50% vulnerability by marine fishing areas. The line of equal lengths is plotted for reference.

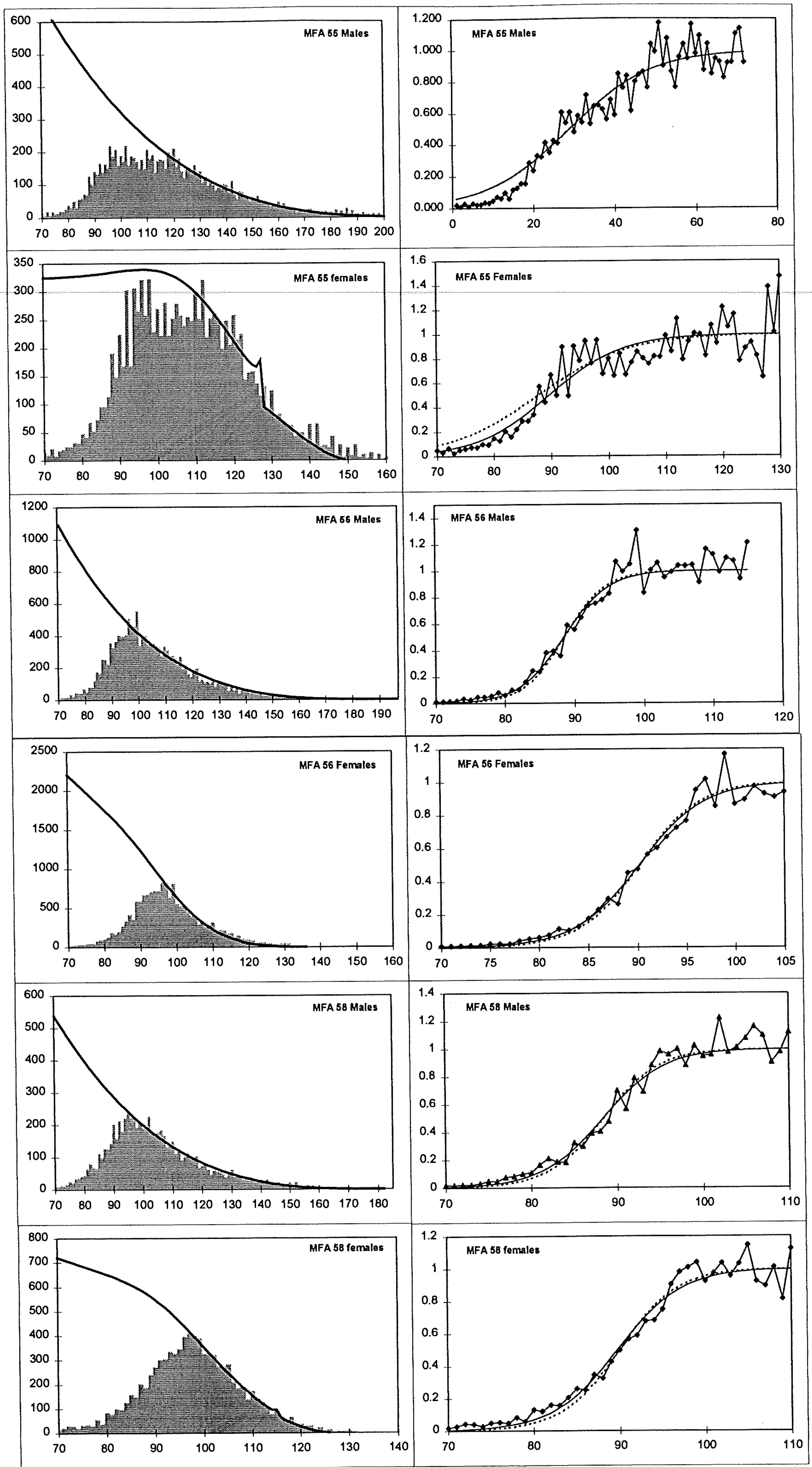


Figure 39a. Observed length frequency distributions (▮) and fitted sample population curves (——)for southern zone areas. Fitted logistic curves of vulnerability also shown for raw (——)and weighted data sets (·······); raw data shown (—◆—).

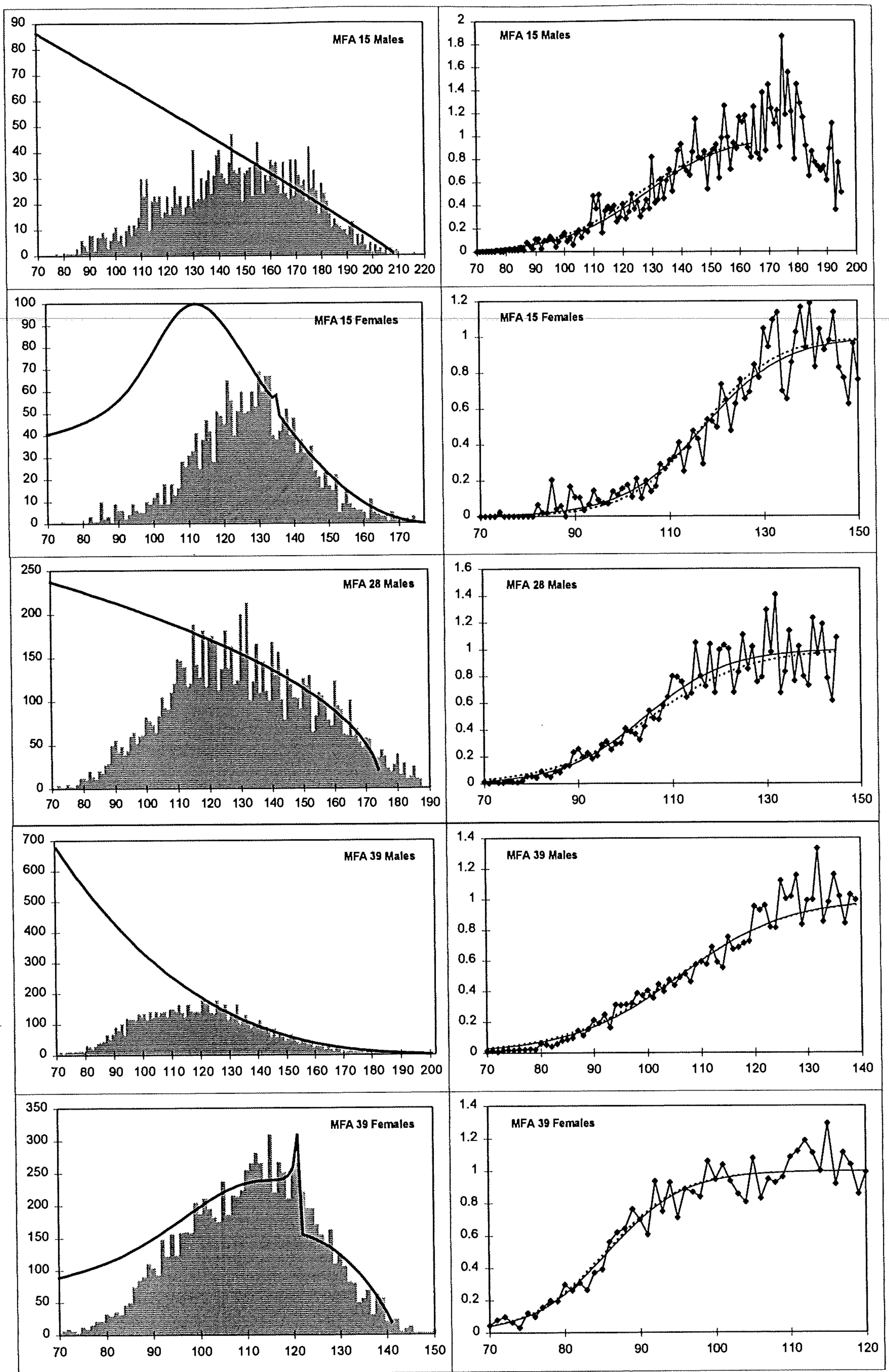


Figure 39b. Observed length frequency distributions (▮) and fitted sample population curves (——)for northern zone areas. Fitted logistic curves of vulnerability also shown for raw (—)and weighted data sets (........); raw data shown (—◆—).

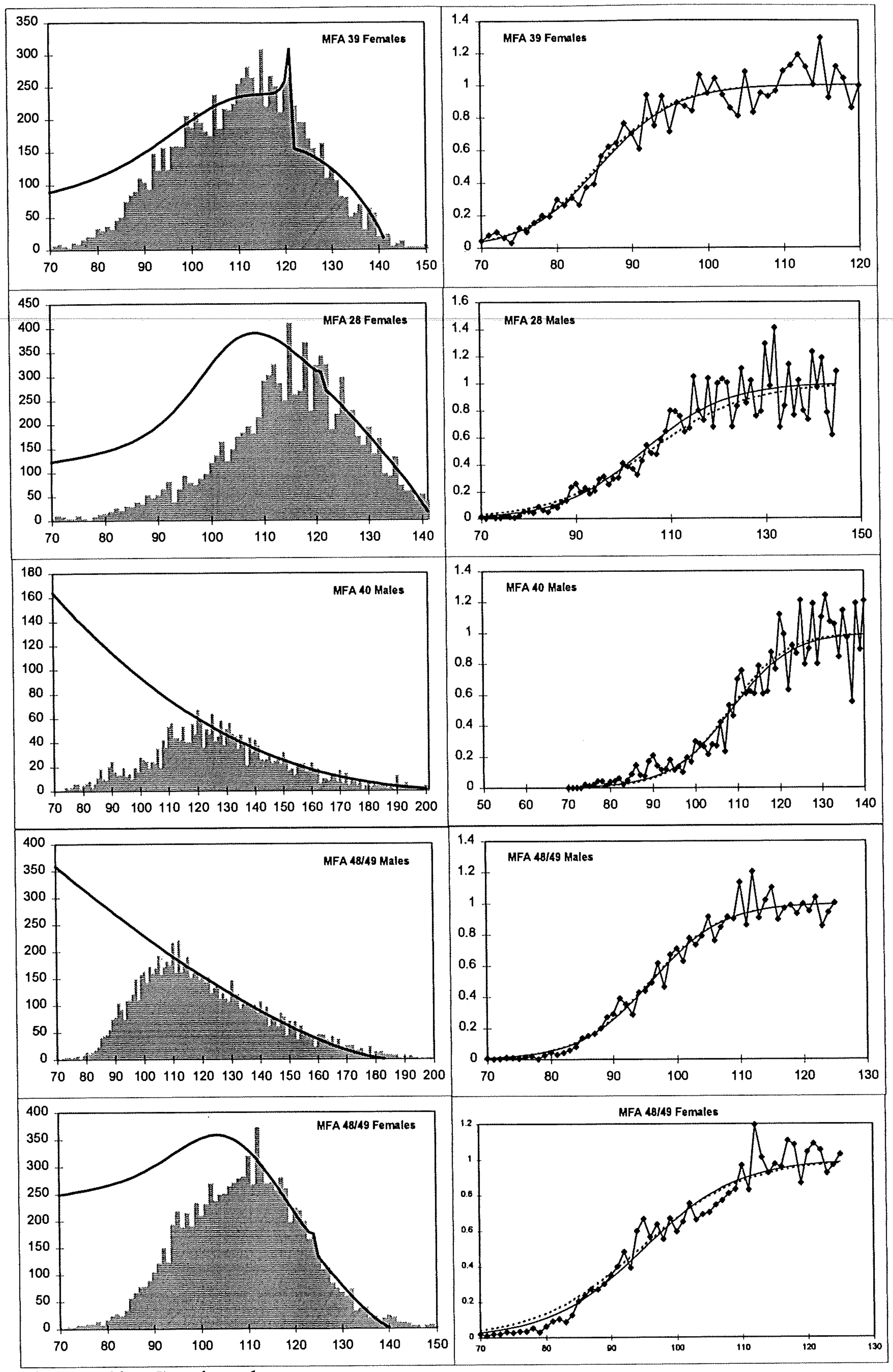


Figure 39b. Continued

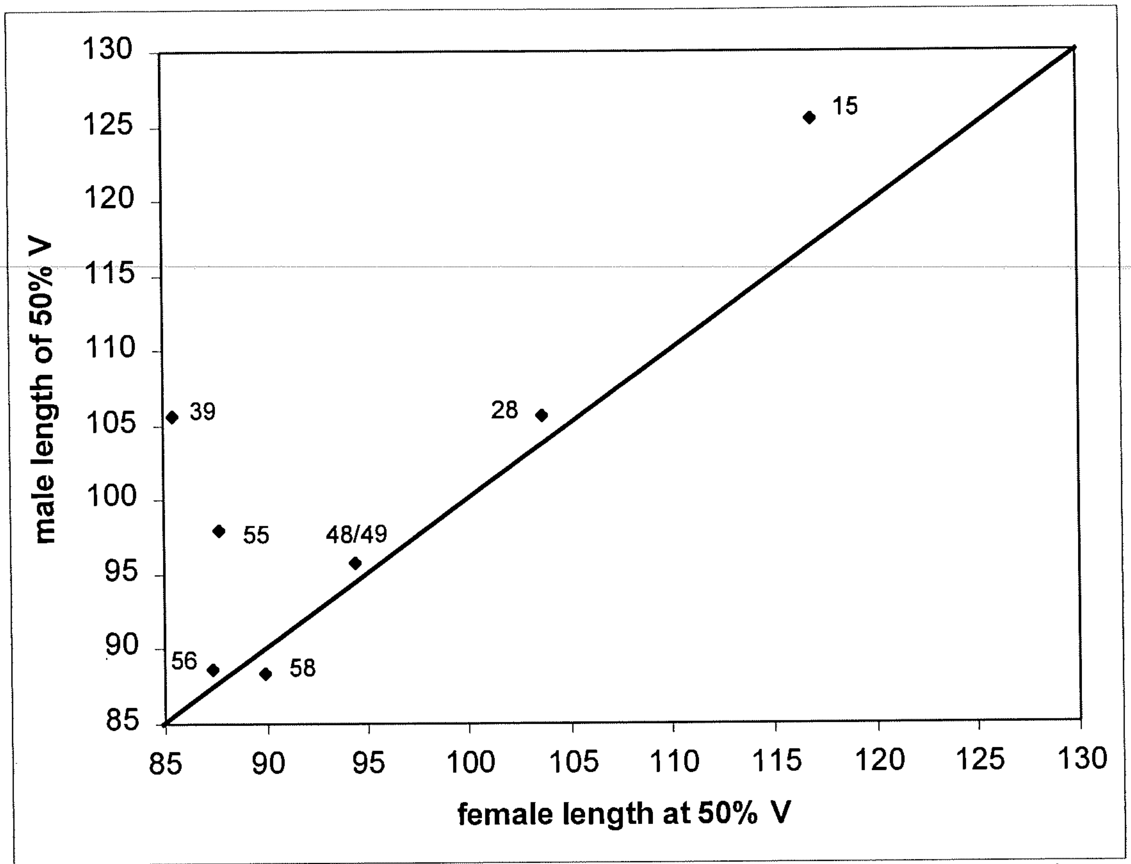


Figure 40. Male carapace lengths at 50 percent vulnerability are plotted against the females' for important marine fishing areas. A line of equal vulnerability is drawn for reference.

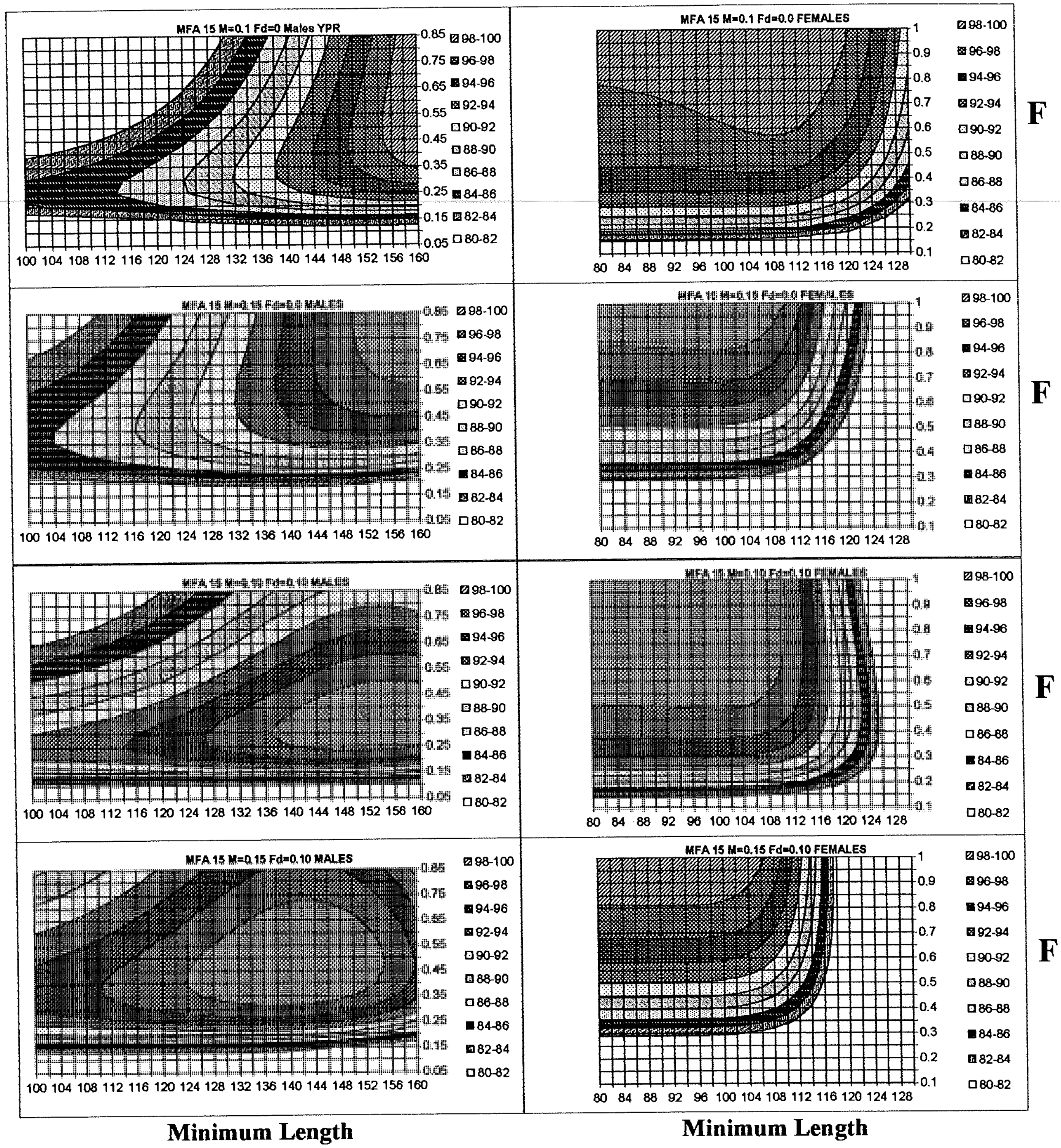


Figure 41a. Yield-per-recruit isopleths for male and female lobsters in Marine Fishing Area 15 under conditions of natural mortality of 0.10 and 0.15, and discard mortality of 0.0 and 0.10 for a combination of minimum lengths and fishing mortality rates. Results are expressed as a percentage of the maximum YPR.

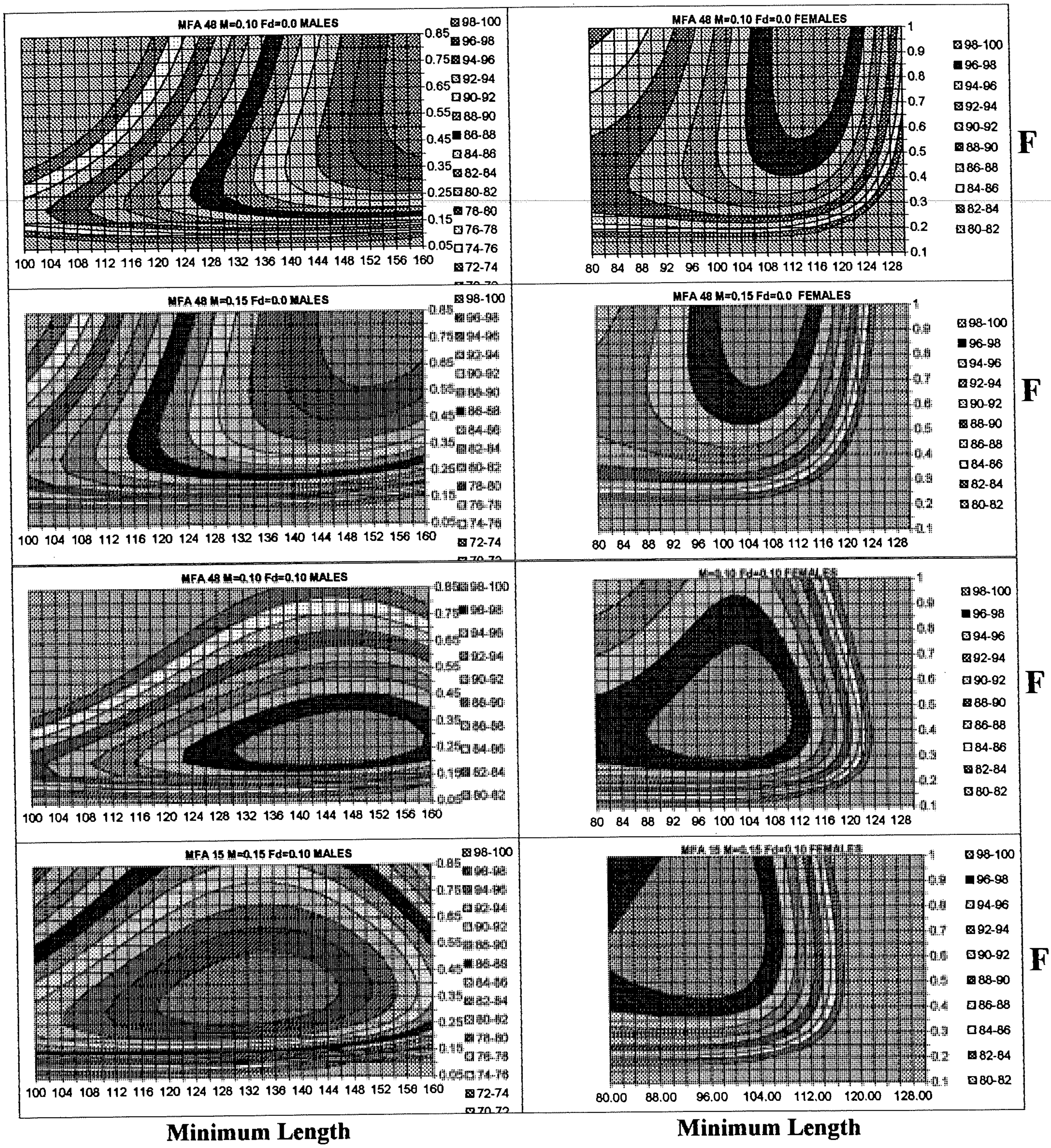


Figure 41b. Yield-per-recruit isopleths for male and female lobsters in Marine Fishing Area 48 under conditions of natural mortality of 0.10 and 0.15, and discard mortality of 0.0 and 0.10 for a combination of minimum lengths and fishing mortality rates. Results are expressed as a percentage of the maximum YPR.

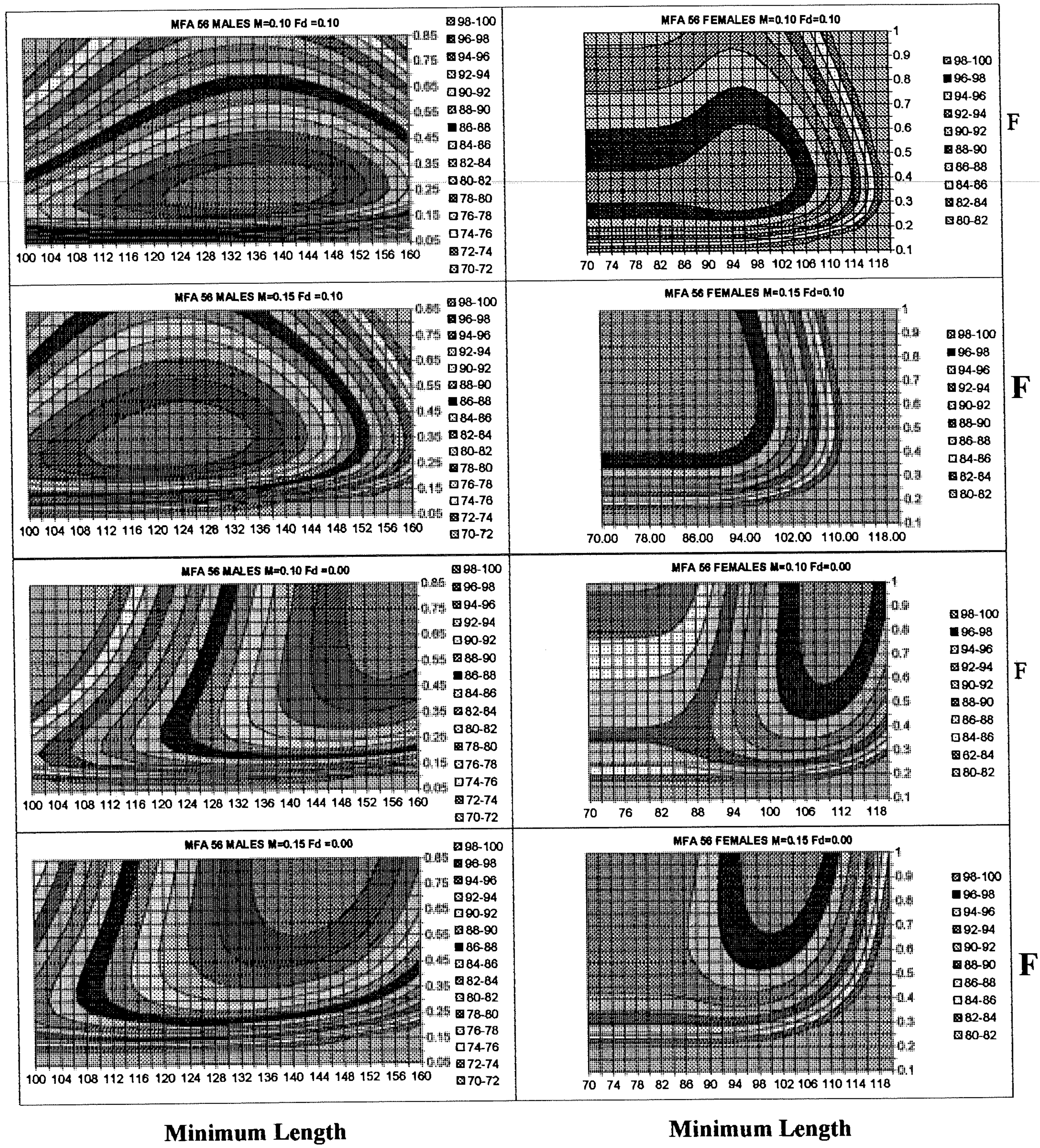


Figure 41c. Yield-per-recruit isopleths for male and female lobsters in Marine Fishing Area 56 under conditions of natural mortality of 0.10 and 0.15, and discard mortality of 0.0 and 0.10 for a combination of minimum lengths and fishing mortality rates. Results are expressed as a percentage of the maximum YPR.

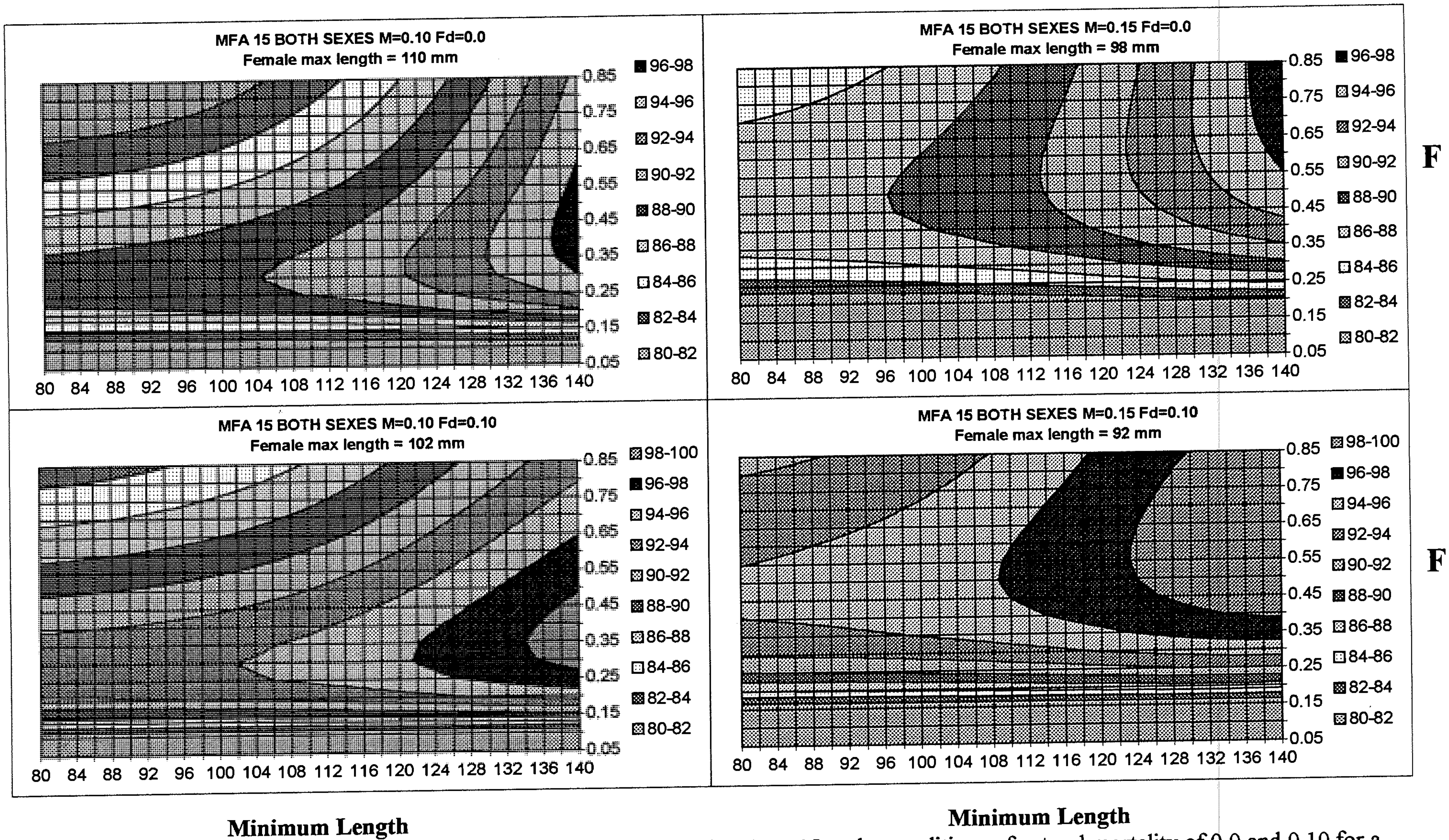


Figure 42a. Yield-per-recruit isopleths for combined sexes in Marine Fishing Area 15 under conditions of natural mortality of 0.0 and 0.10 for a combination of minimum lengths and fishing mortality rates. Female minimum lengths increased in unison with the males' to the length of maximum female YPR and were held constant at the value as the males increased further. The highest value of female minimum length used in each analysis is indicated on the graph. Figures graphed are expressed as a percentage of the maximum YPR.

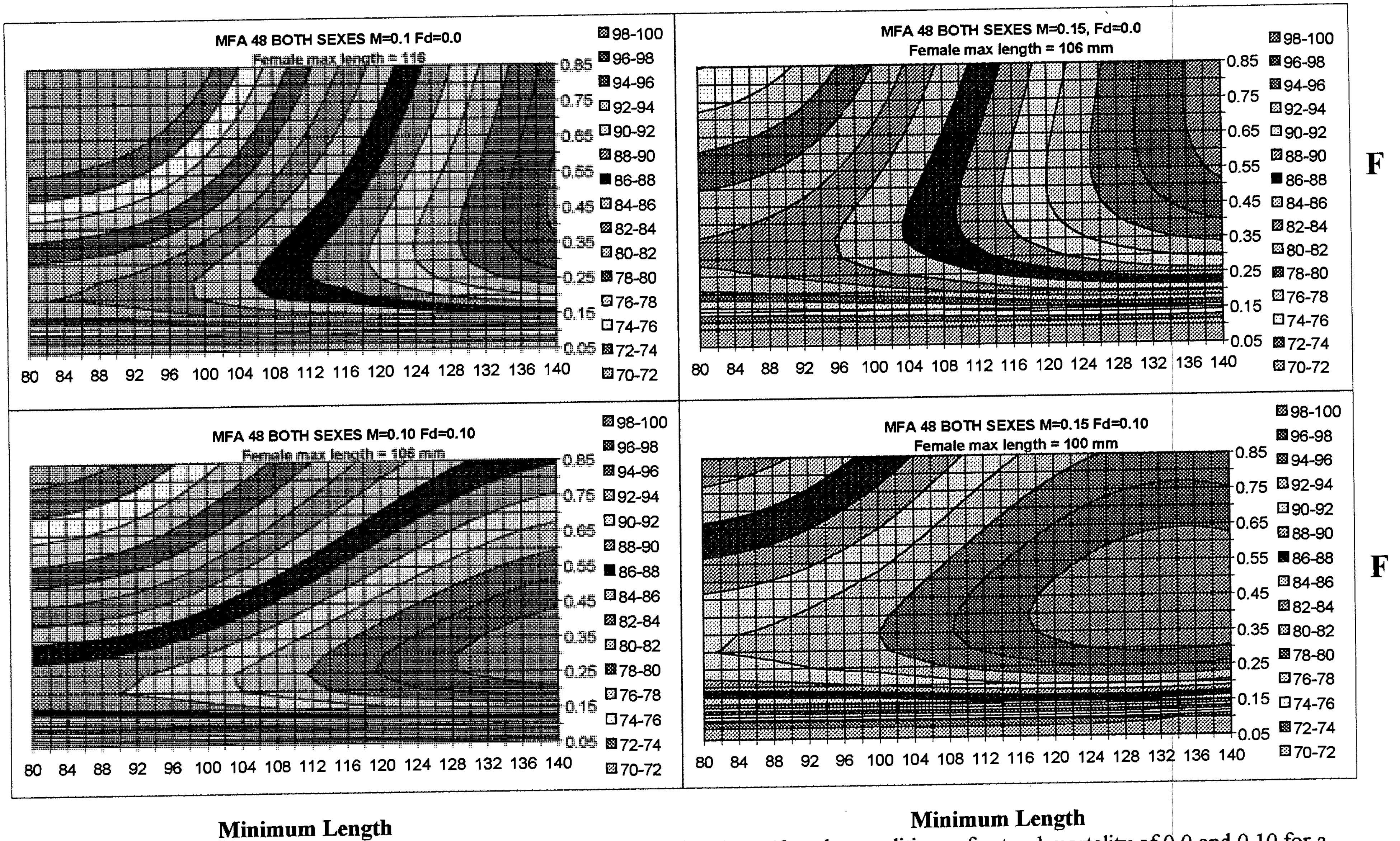


Figure 42b. Yield-per-recruit isopleths for combined sexes in Marine Fishing Area 48 under conditions of natural mortality of 0.0 and 0.10 for a combination of minimum lengths and fishing mortality rates. Female minimum lengths increased in unison with the males' to the length of maximum female YPR and were held constant at the value as the males increased further. The highest value of female minimum length used in each analysis is indicated on the graph. Figures graphed are expressed as a percentage of the maximum YPR.

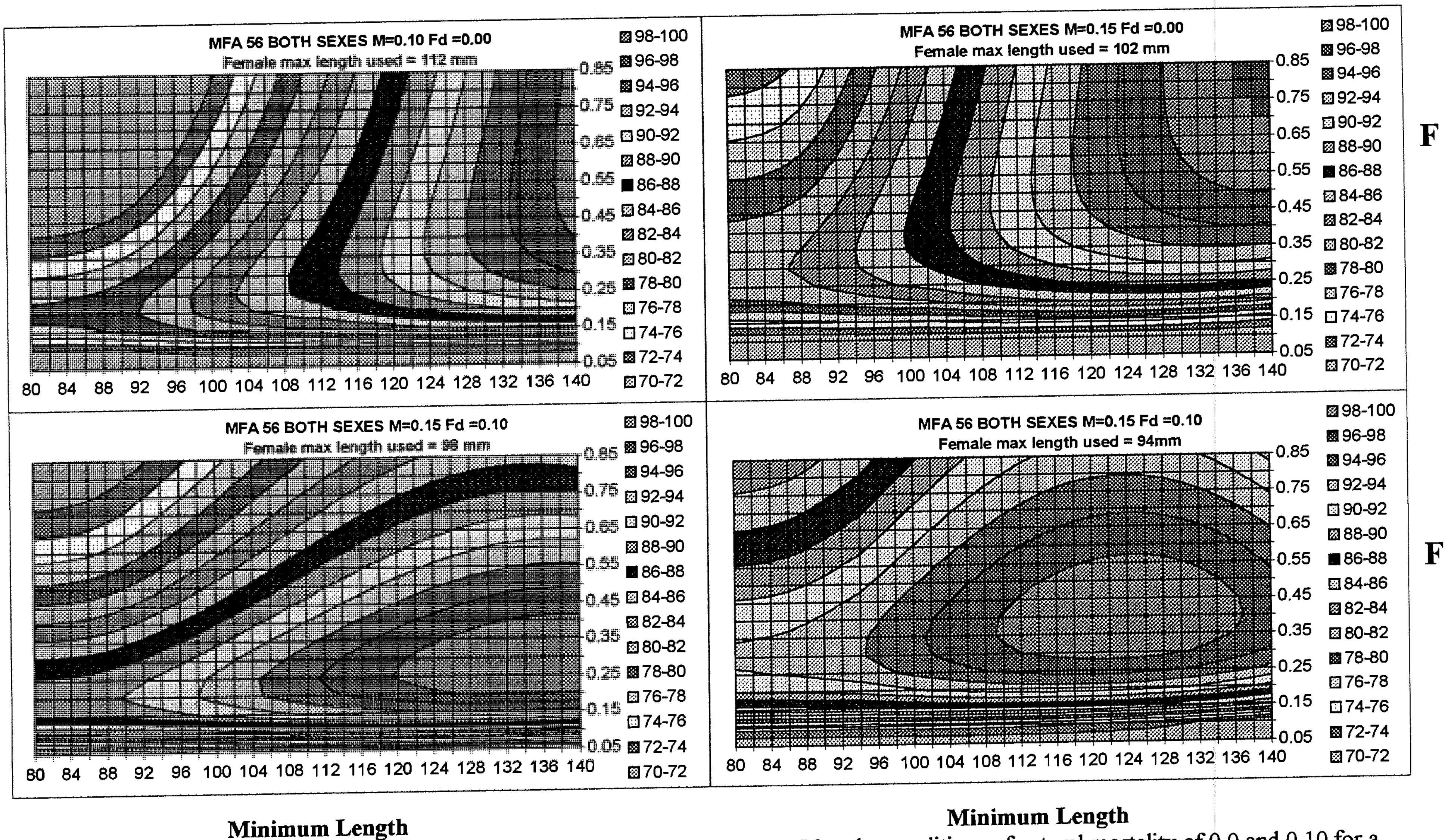


Figure 42c. Yield-per-recruit isopleths for combined sexes in Marine Fishing Area 56 under conditions of natural mortality of 0.0 and 0.10 for a combination of minimum lengths and fishing mortality rates. Female minimum lengths increased in unison with the males' to the length of maximum female YPR and were held constant at the value as the males increased further. The highest value of female minimum length used in each analysis is indicated on the graph. Figures graphed are expressed as a percentage of the maximum YPR.

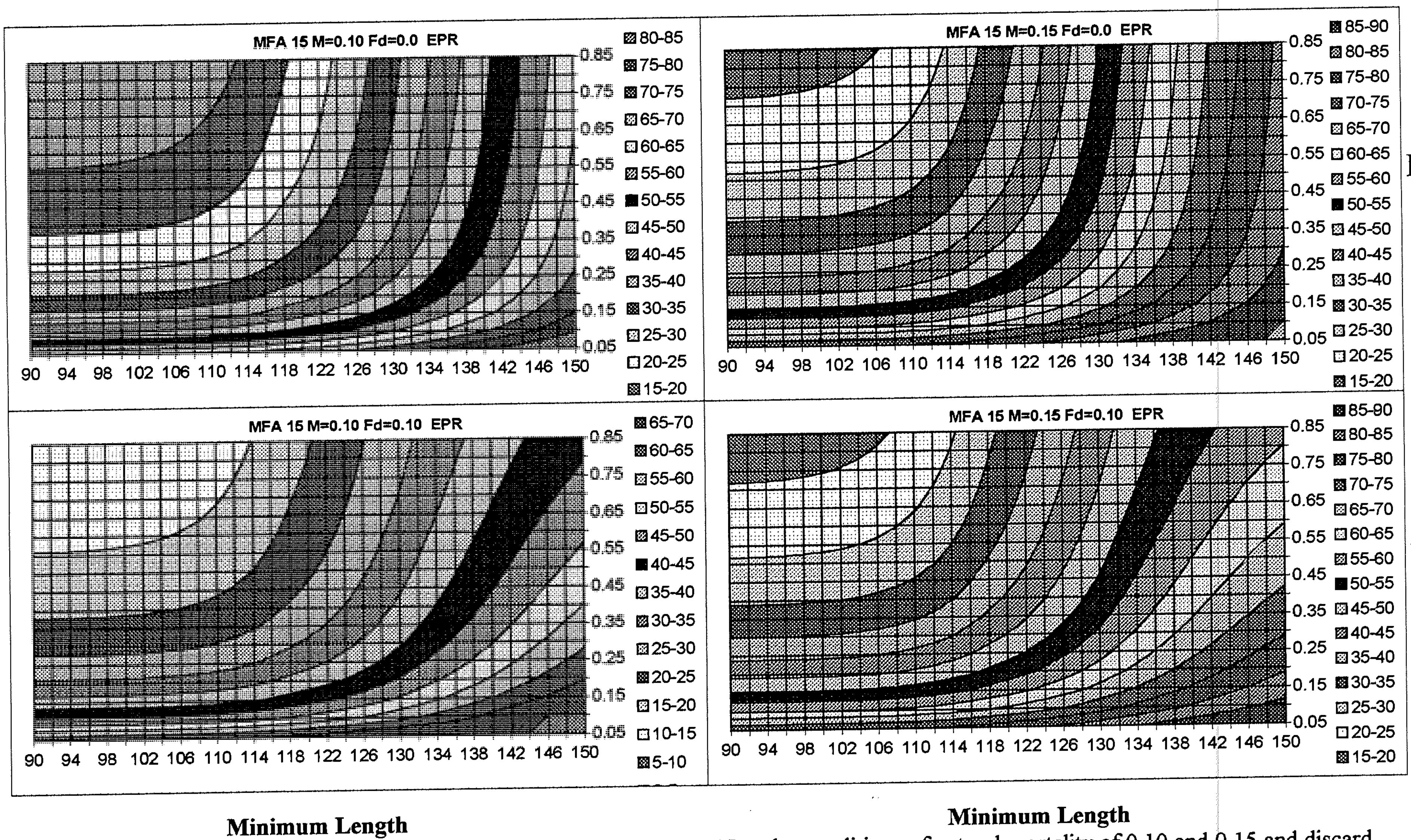


Figure 43a. Egg-per-recruit isopleths for females in Marine Fishing Area 15 under conditions of natural mortality of 0.10 and 0.15 and discard mortality of 0.00 and 0.10. EPR is expressed as a percentage of the maximum, ie. under zero fishing mortality.

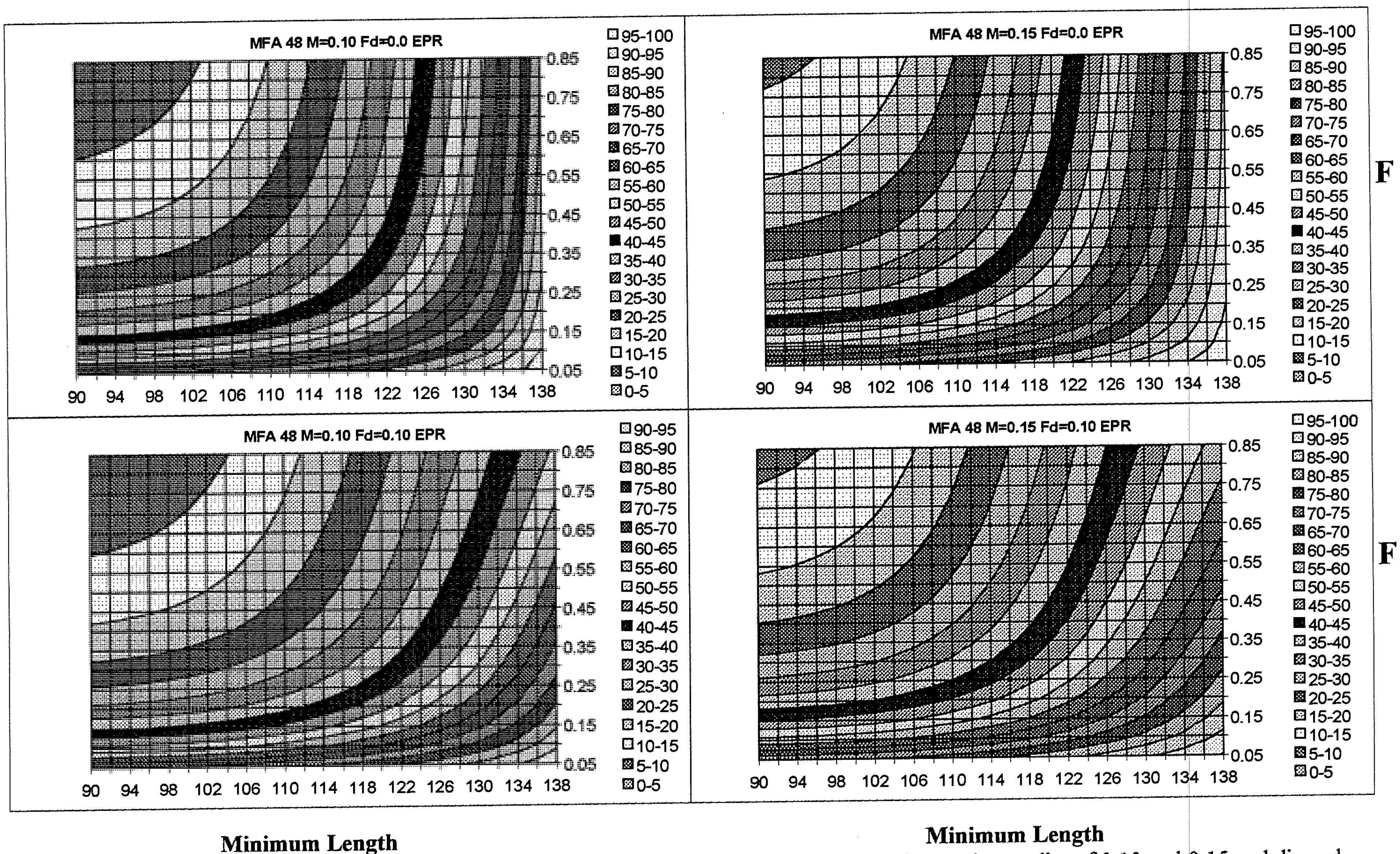


Figure 43b. Egg-per-recruit isopleths for females in Marine Fishing Area 48 under conditions of natural mortality of 0.10 and 0.15 and discard mortality of 0.00 and 0.10. EPR is expressed as a percentage of the maximum, ie. under zero fishing mortality.

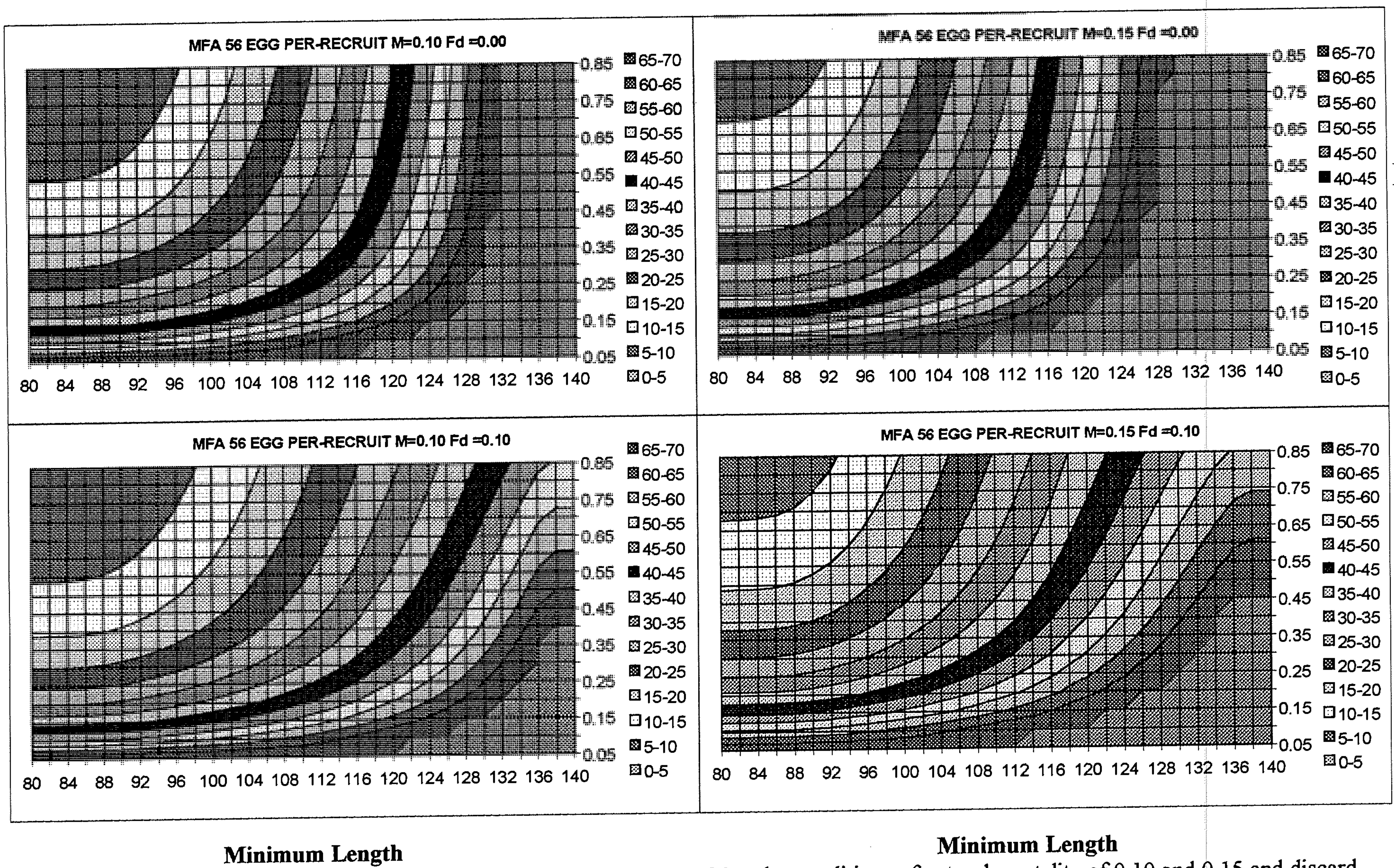


Figure 43c. Egg-per-recruit isopleths for females in Marine Fishing Area 56 under conditions of natural mortality of 0.10 and 0.15 and discard mortality of 0.00 and 0.10. EPR is expressed as a percentage of the maximum, ie. under zero fishing mortality.

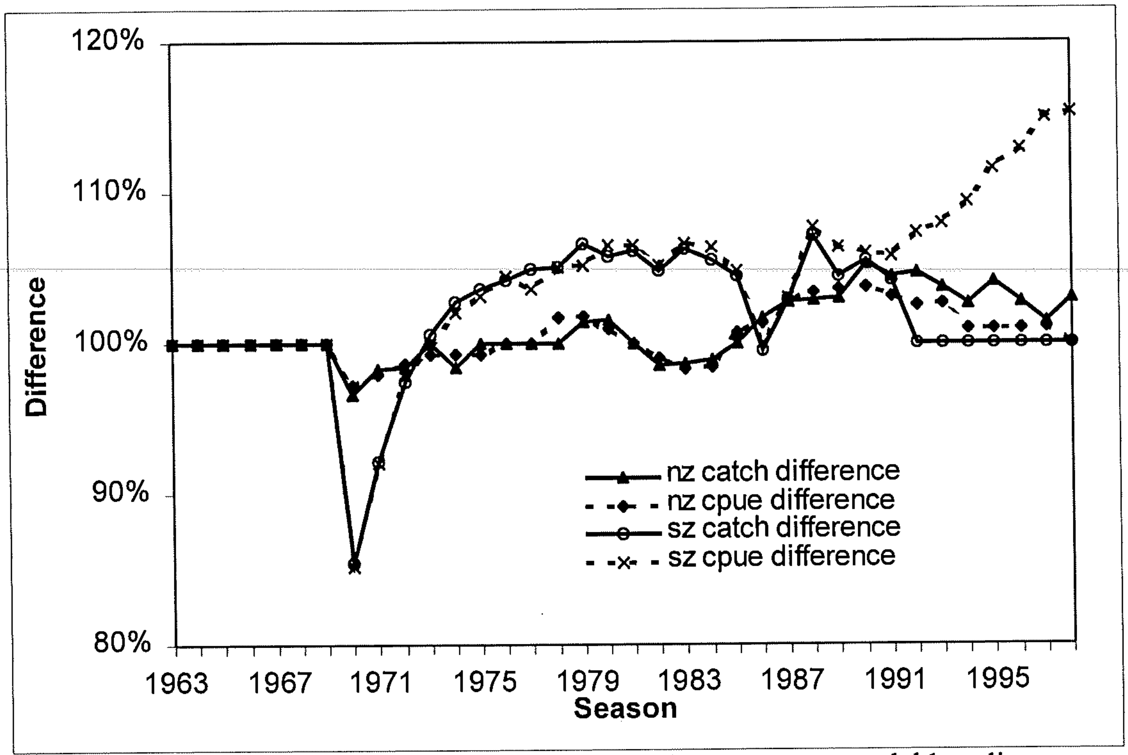


Figure 44. Differences (percentage) between SARL assessment model baseline estimates of catch and CPUE in the southern and northern zones and estimates of these variables following an increase in male size limit from 98.5 to 115 mm in 1975 are plotted. Note the much greater immediate effect in the southern zone and the larger positive effect in that zone over the longer term.

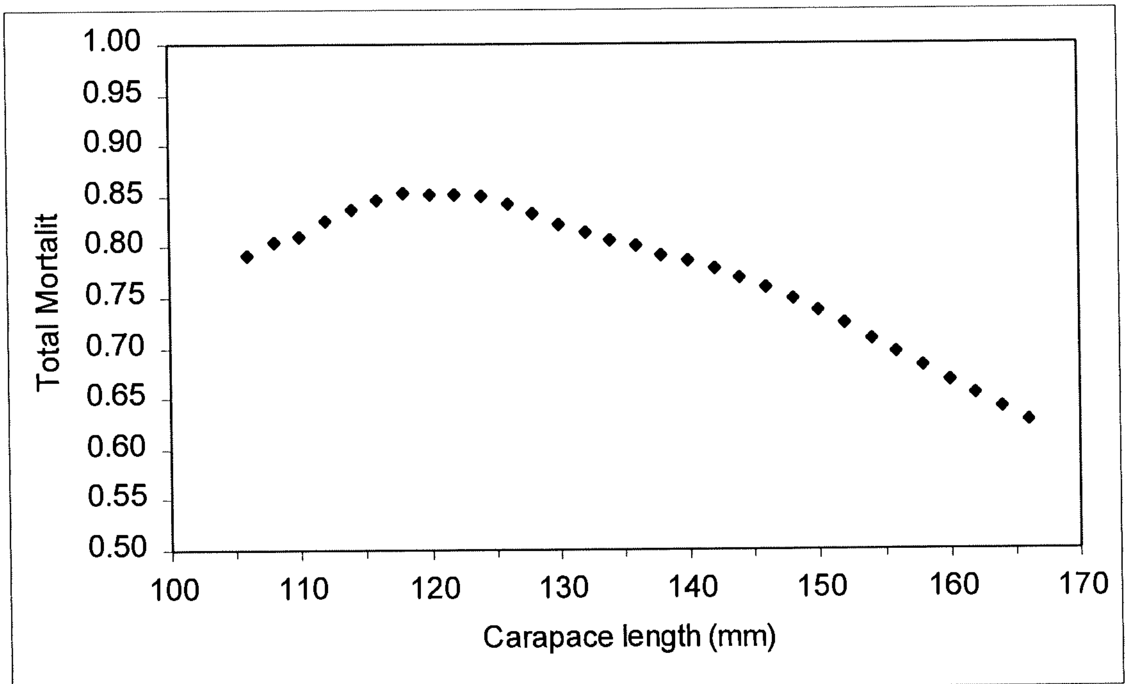


Figure 45. Total mortality (Z) values estimated by the Jones & Van Zalinge method are plotted against the carapace length corresponding to the largest length included in the analysis.

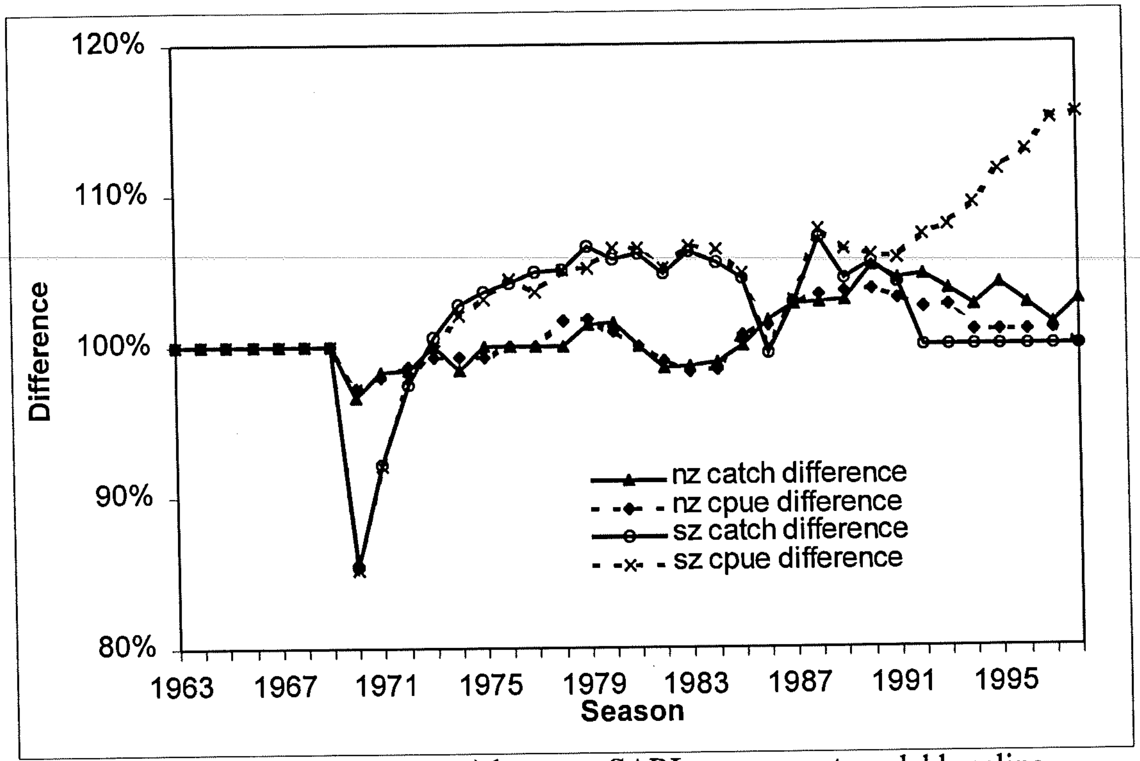


Figure 44. Differences (percentage) between SARL assessment model baseline estimates of catch and CPUE in the southern and northern zones and estimates of these variables following an increase in male size limit from 98.5 to 115 mm in 1975 are plotted. Note the much greater immediate effect in the southern zone and the larger positive effect in that zone over the longer term.

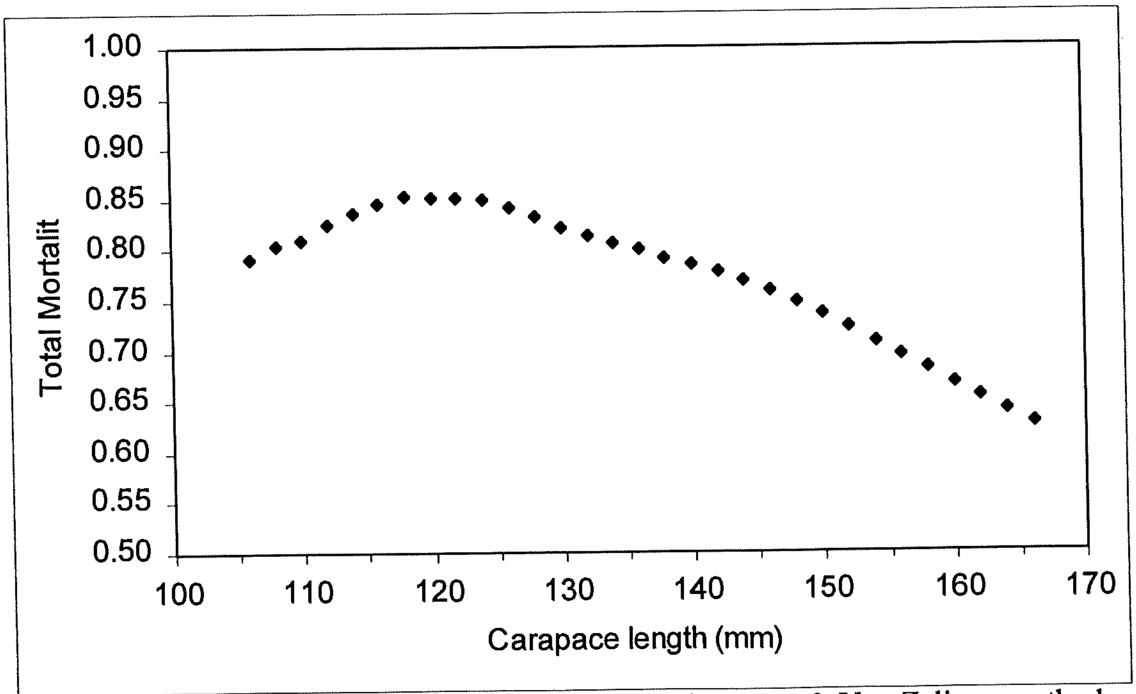


Figure 45. Total mortality (Z) values estimated by the Jones & Van Zalinge method are plotted against the carapace length corresponding to the largest length included in the analysis.

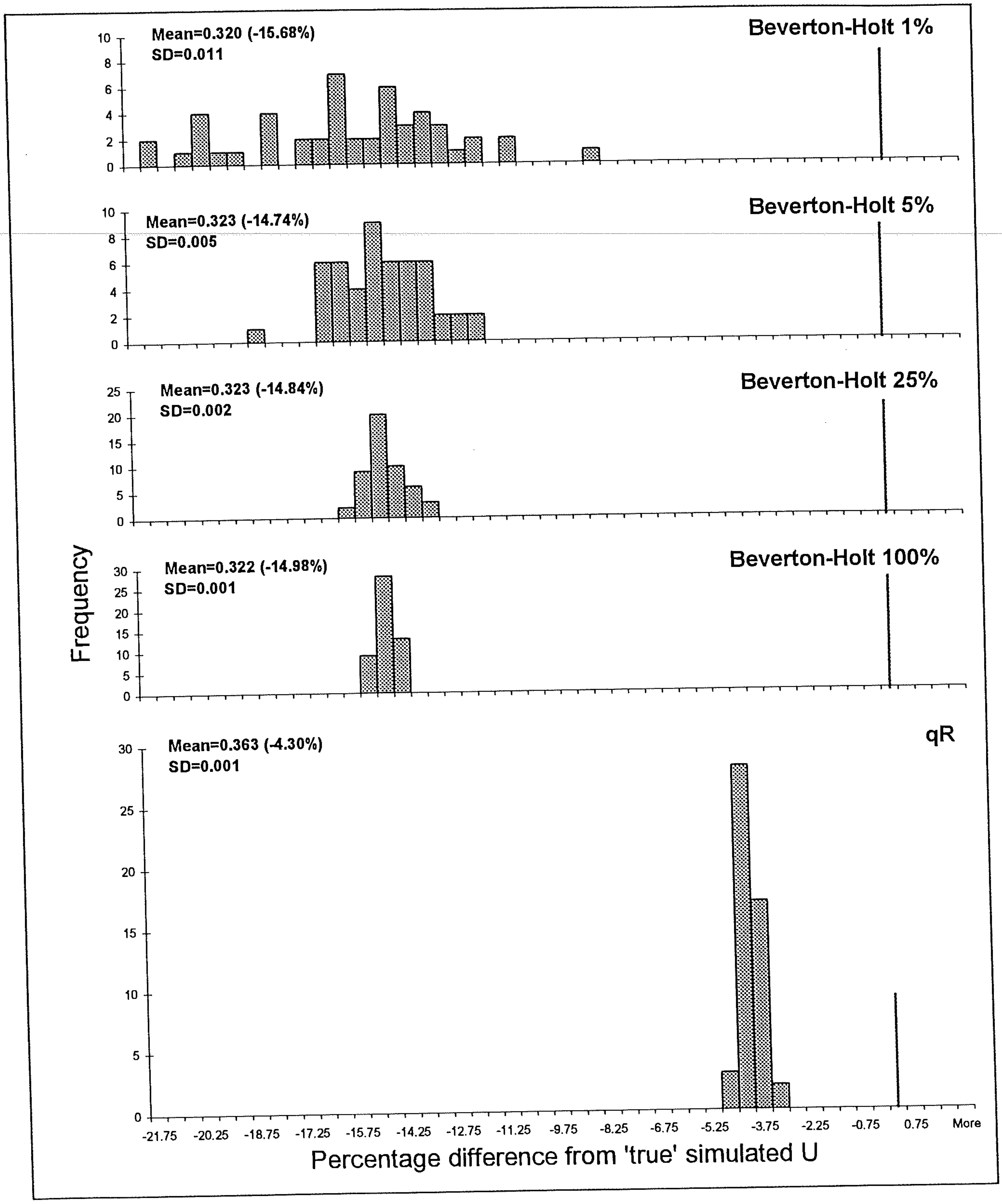


Figure 46. Histograms of exploitation rate (*U*) from 50 runs of simulated data for the catch weight-numbers and Beverton-Holt mean-length methods. The mean lengths were calculated from four sampling intensities, 1%, 5%, 25% and 100% of (simulated) lobsters captured. The mean for the 'true', simulated *U* was 0.379. The vertical lines represent 0% deviation from the 'true', simulated *U*.

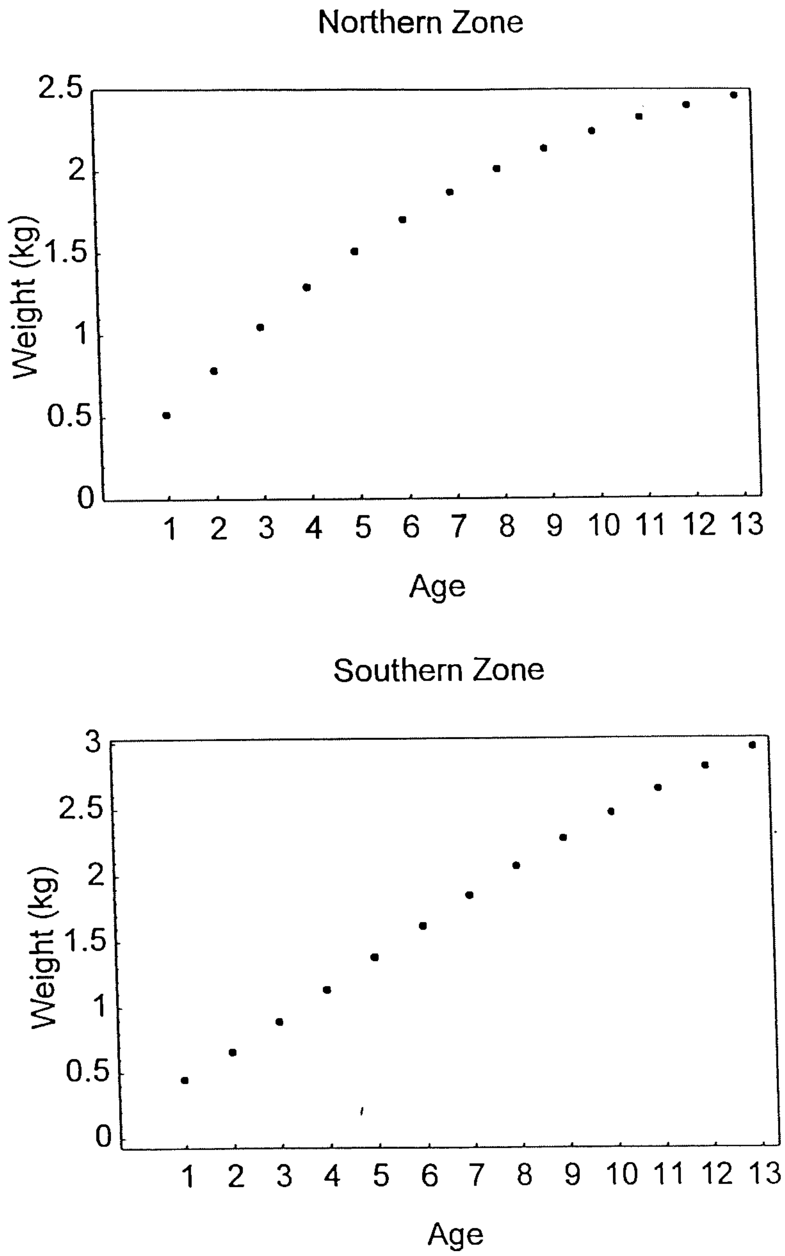


Figure 47. Relationship between weight and age for lobsters from the Northern and Southern Zones.

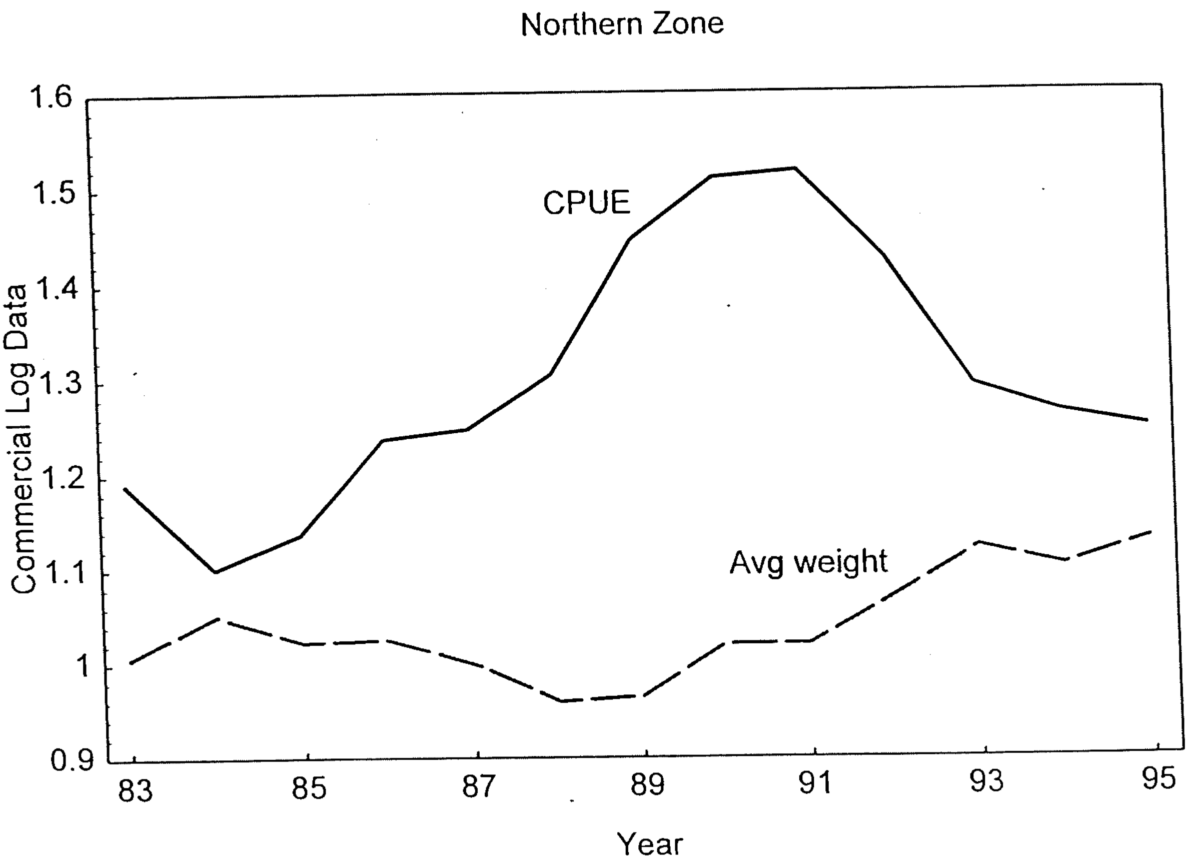


Figure 48. Inter-annual variation in average weight and CPUE for lobsters in the Northern Zone

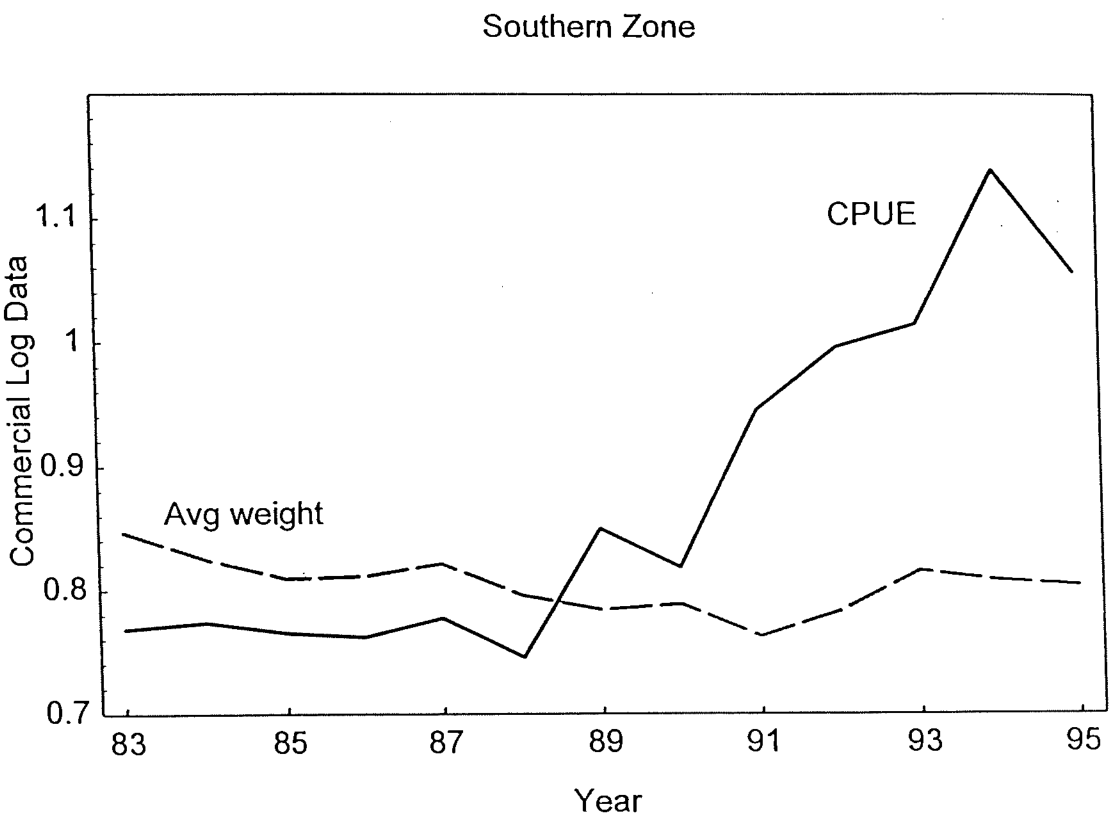
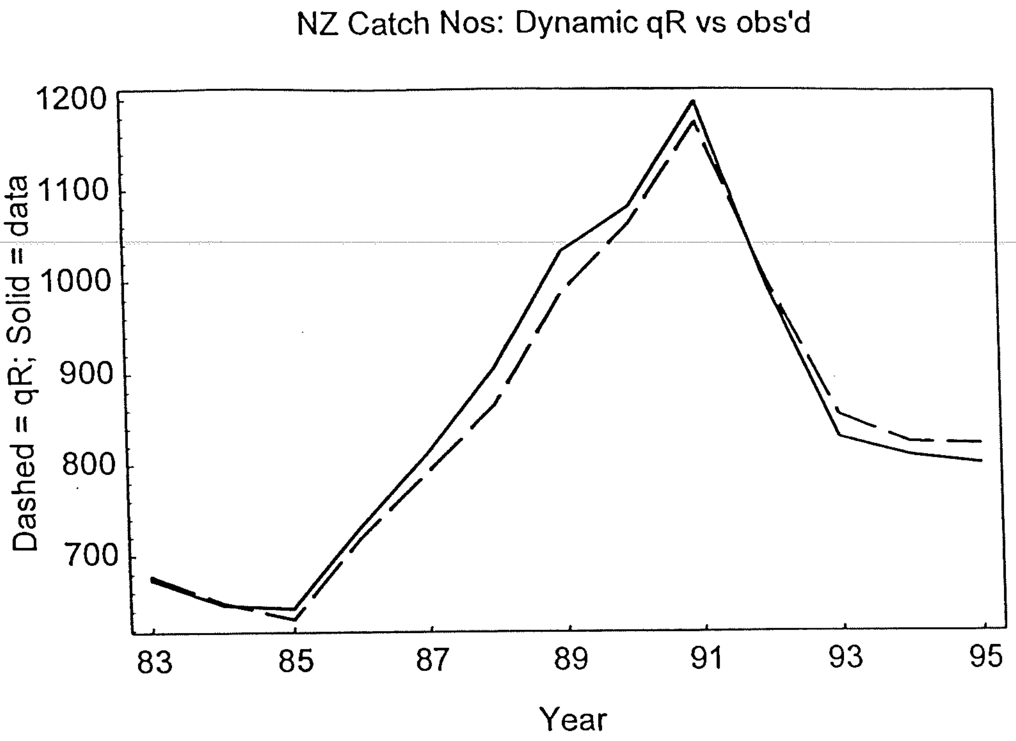


Figure 49. Inter-annual variation in average weight and CPUE for lobsters in the Southern Zone



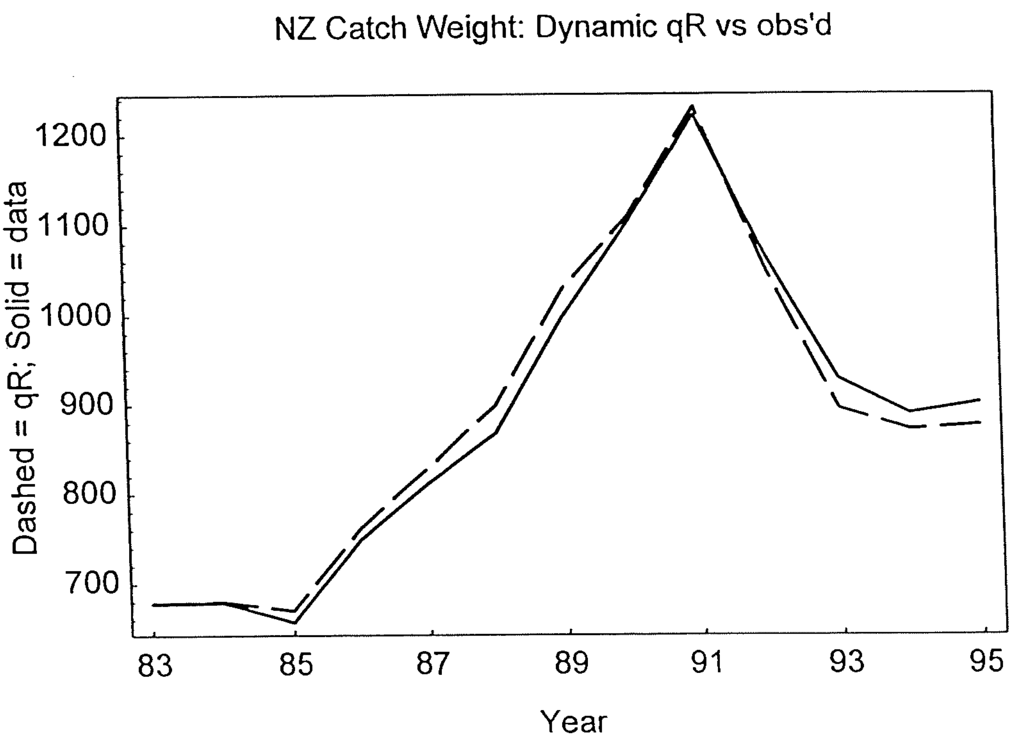
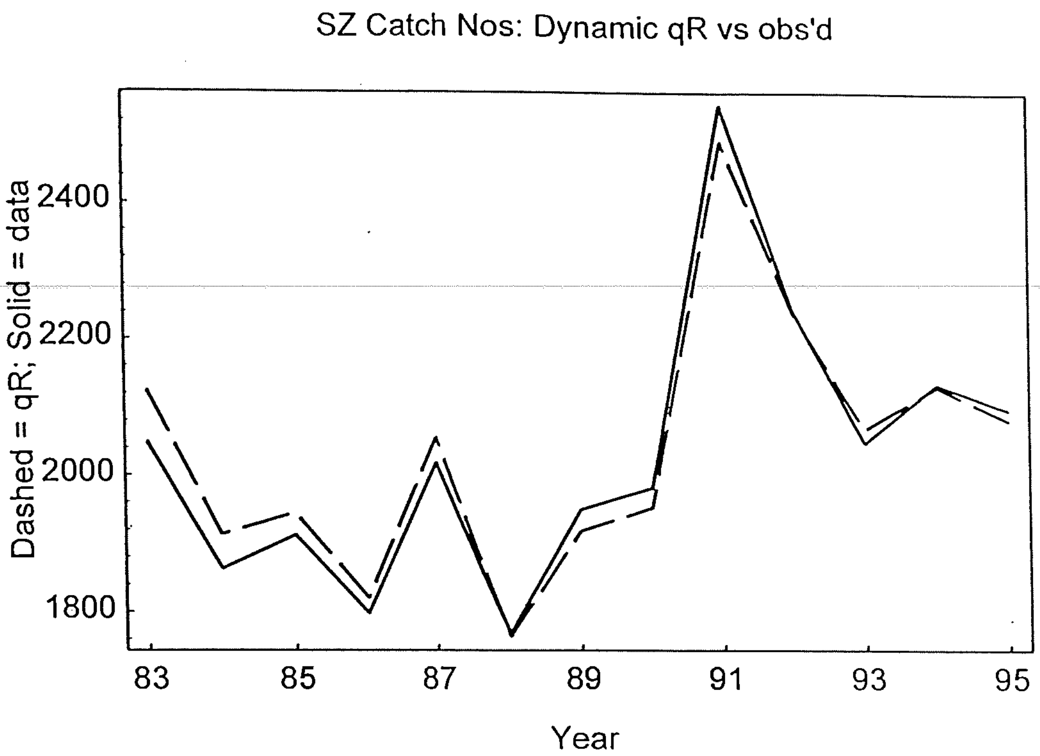


Figure 50. Comparison of the fit of the qr model (dashed line) to catch numbers and the weight of the catch in the Northern Zone.



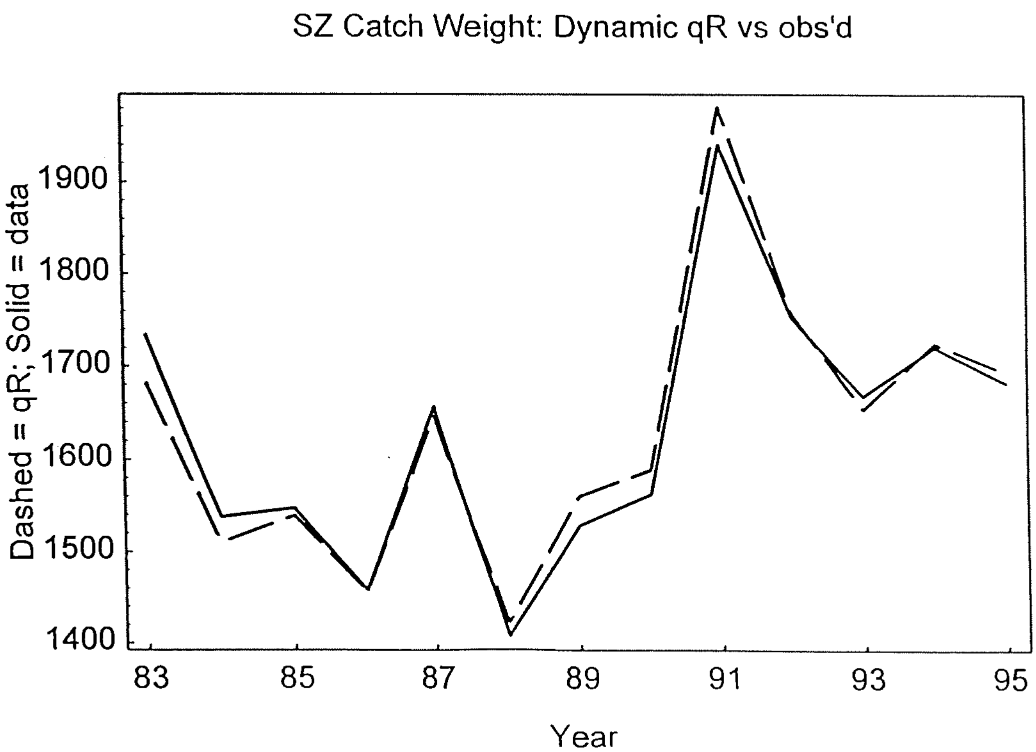


Figure 51. Comparison of the fit of the qr model (dashed line) to catch numbers and the weight of the catch in the Southern Zone.

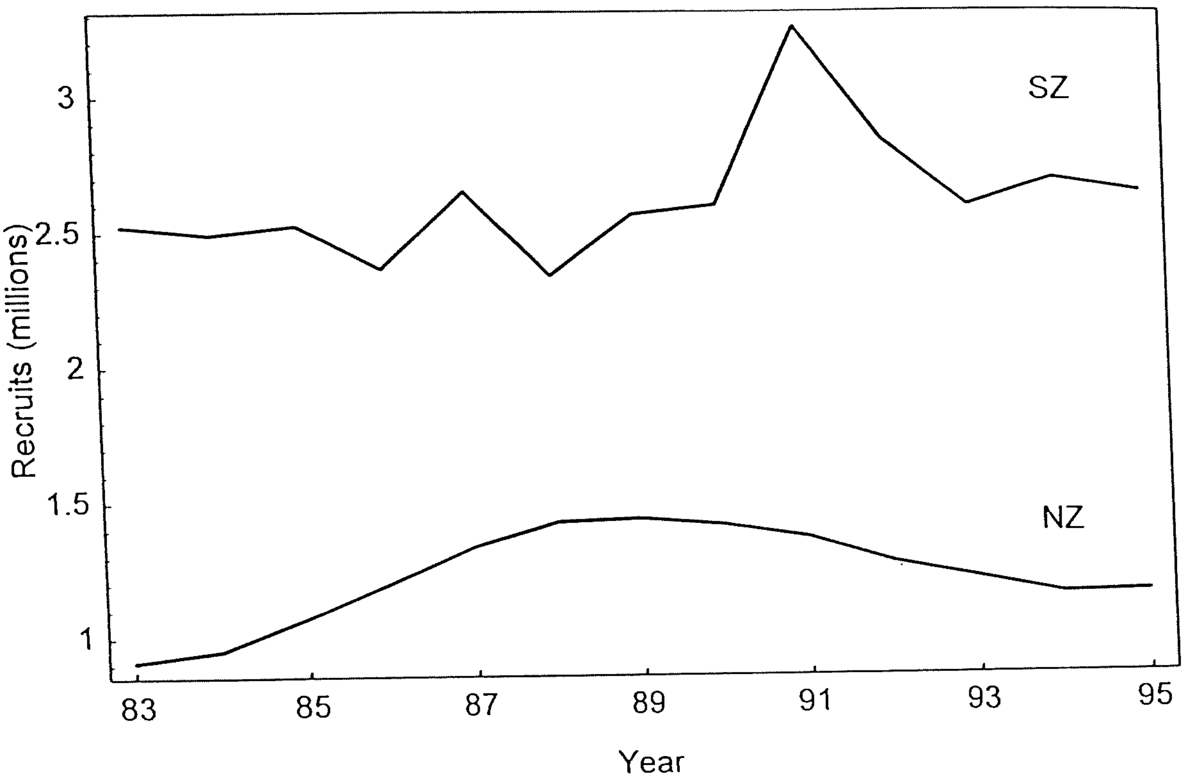


Figure 52. Annual variation in recruitment estimated as the frequency of lobsters entering the fishery in the Southern Zone (SZ) and the Northern Zone (NZ).

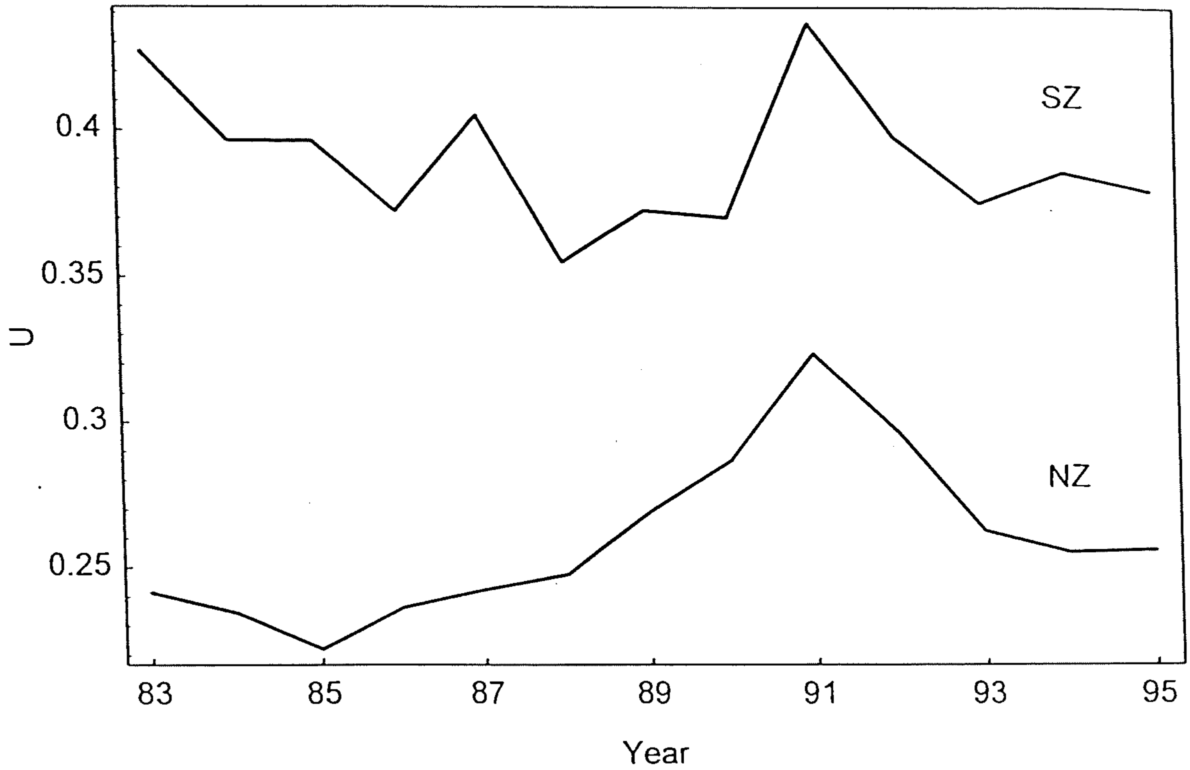


Figure 53. Annual variation in the exploitation rate of lobsters fished in the Southern Zone (SZ) and the Northern Zone (NZ).

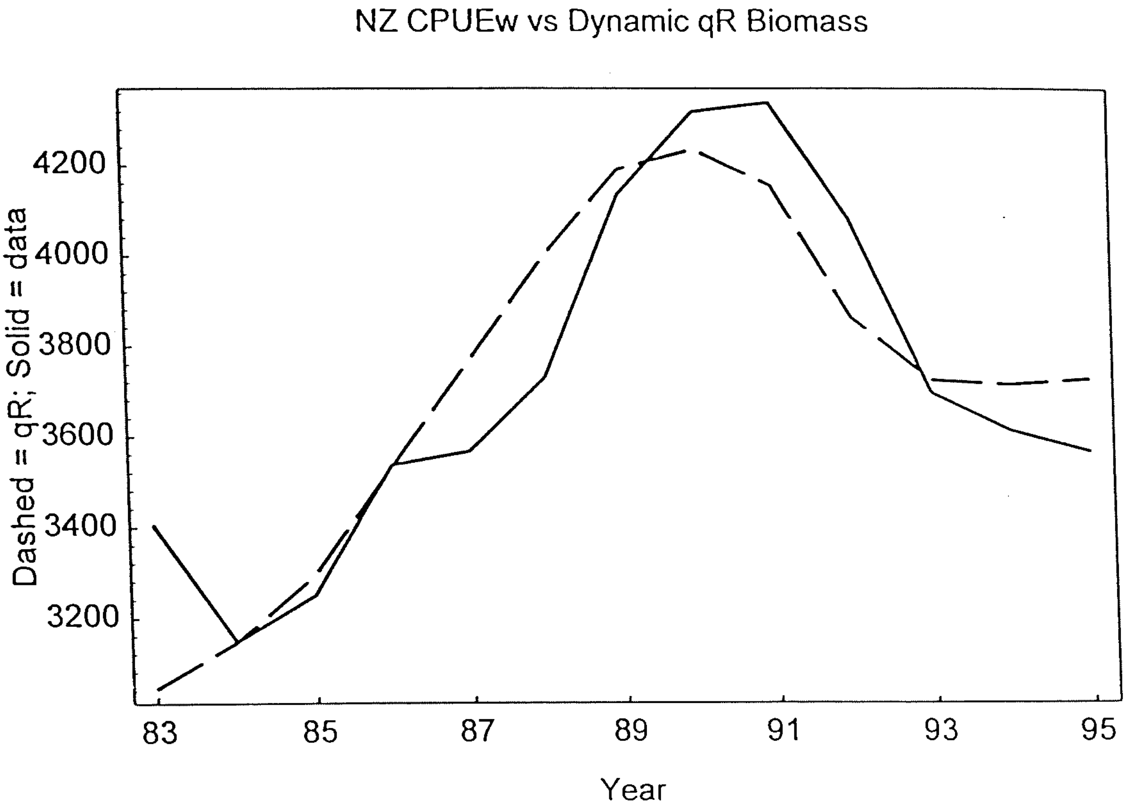


Figure 54. Comparison of the fit of the dynamic qr model (dashed line) estimate of biomass to catch per unit effort (CPUE) in the Northern Zone.

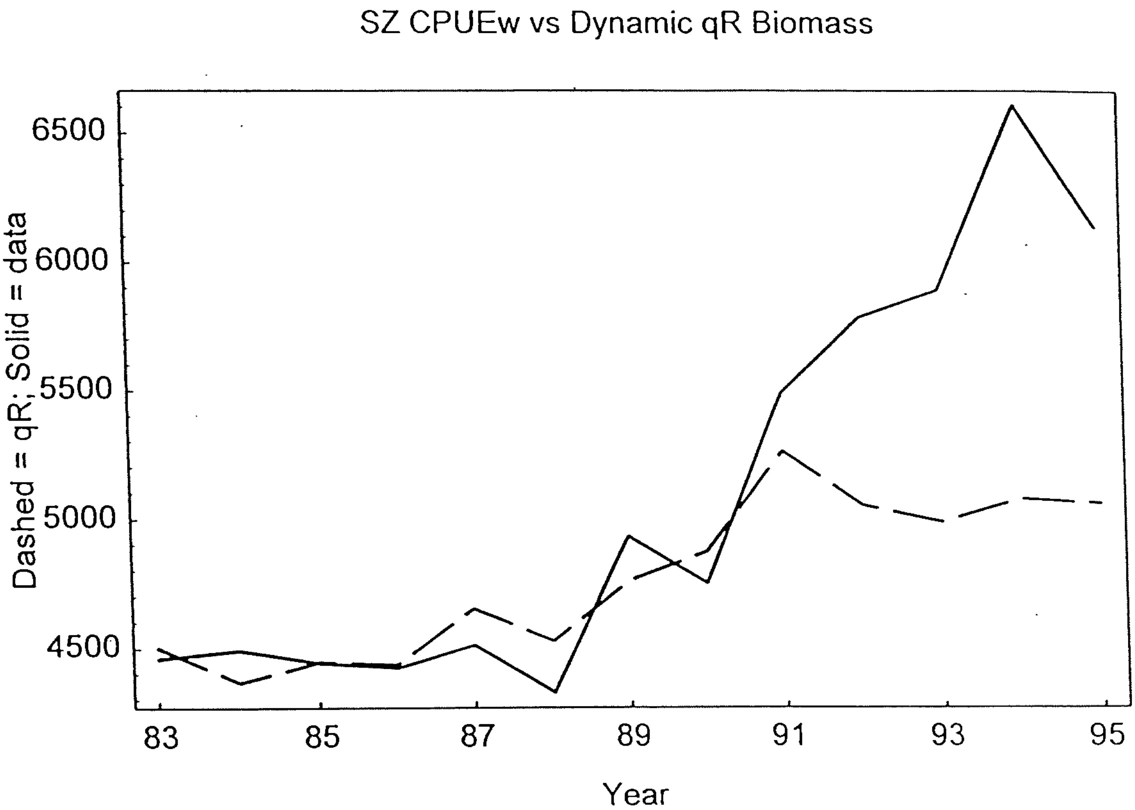


Figure 55. Comparison of the fit of the dynamic qr model (dashed line) estimate of biomass to catch per unit effort (CPUE) in the Southern Zone.

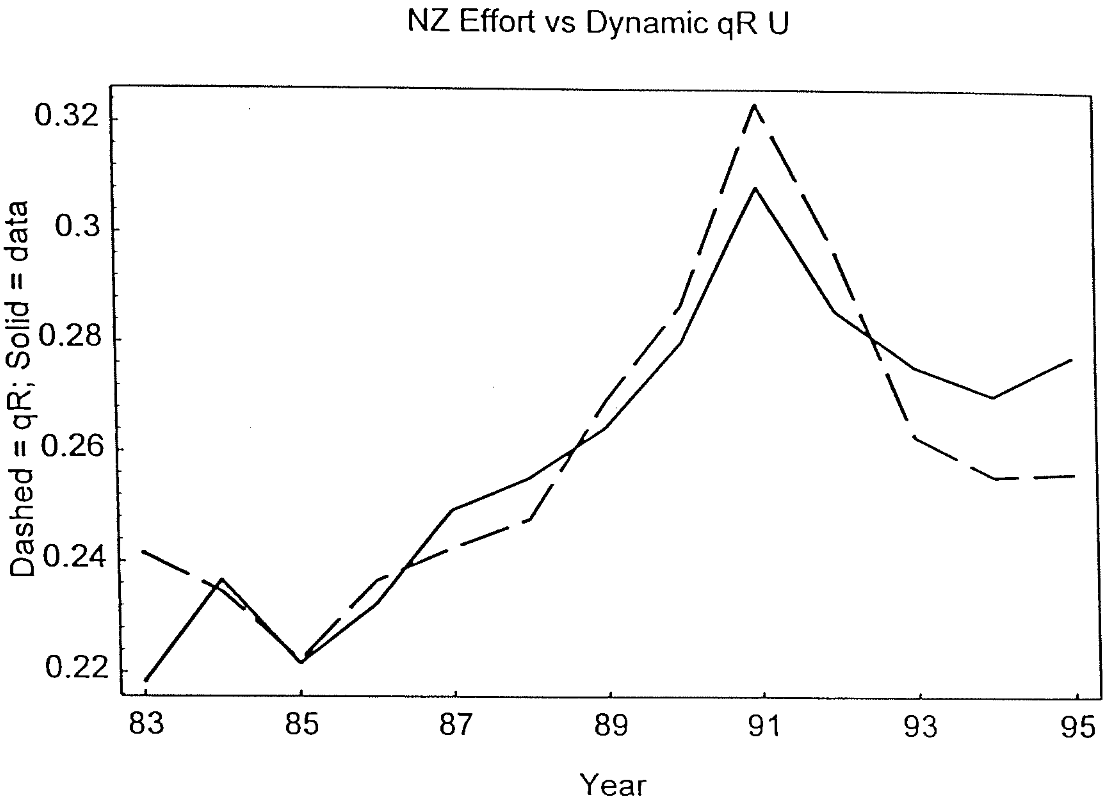


Figure 56. Comparison of the fit of the dynamic qr model (dashed line) estimate of exploitation rate to recorded effort in the Northern Zone.

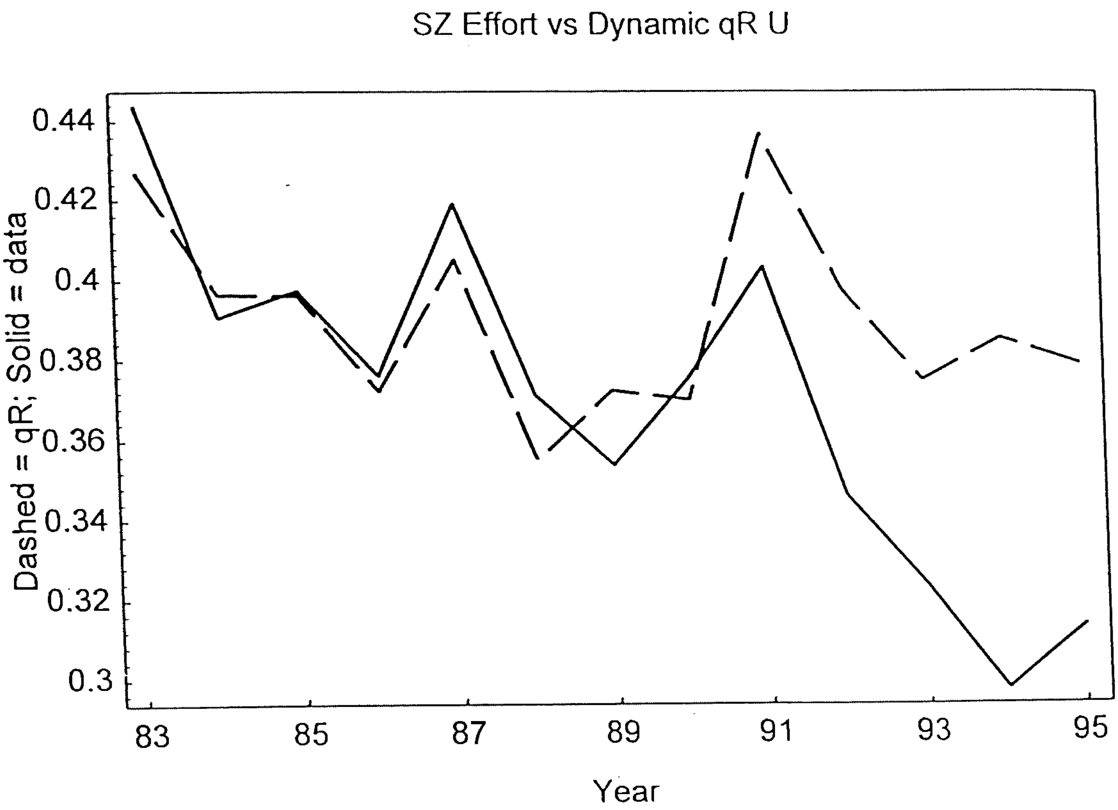


Figure 57. Comparison of the fit of the dynamic qr model (dashed line) estimate of exploitation rate to recorded effort in the Southern Zone.

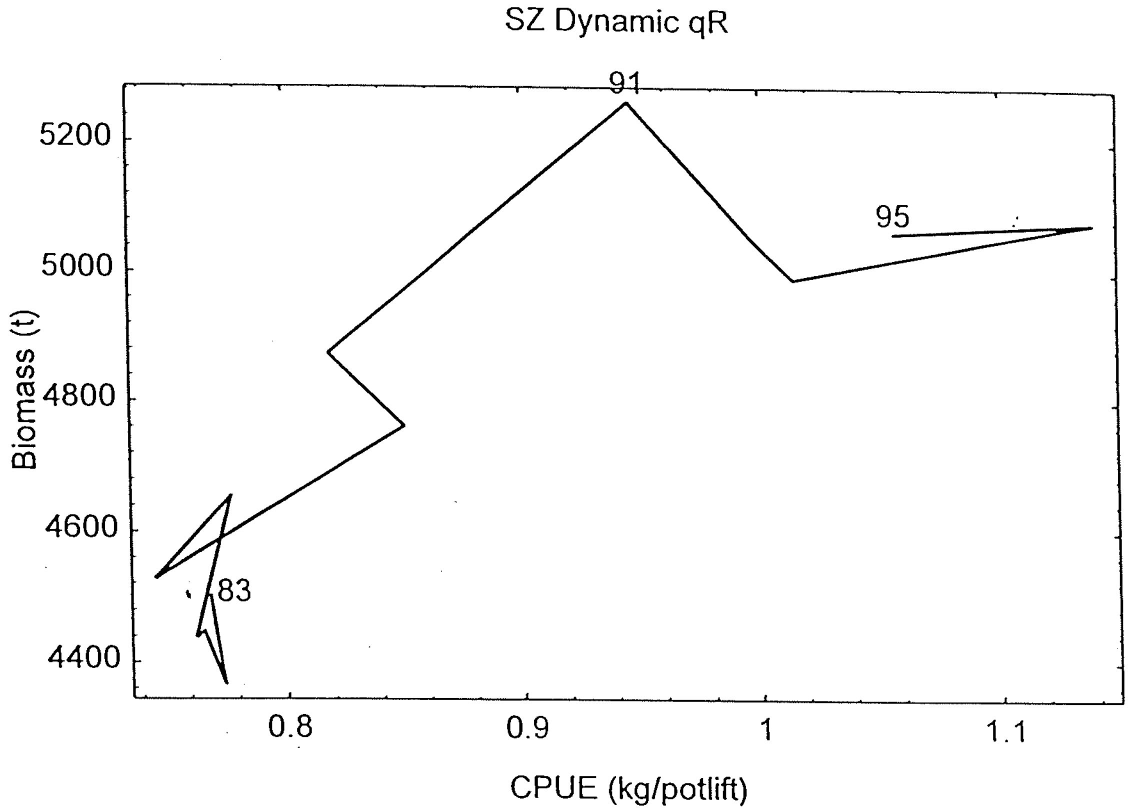


Figure 58. Relationship of biomass estimated from the dynamic qr model to recorded CPUE in the Southern Zone.

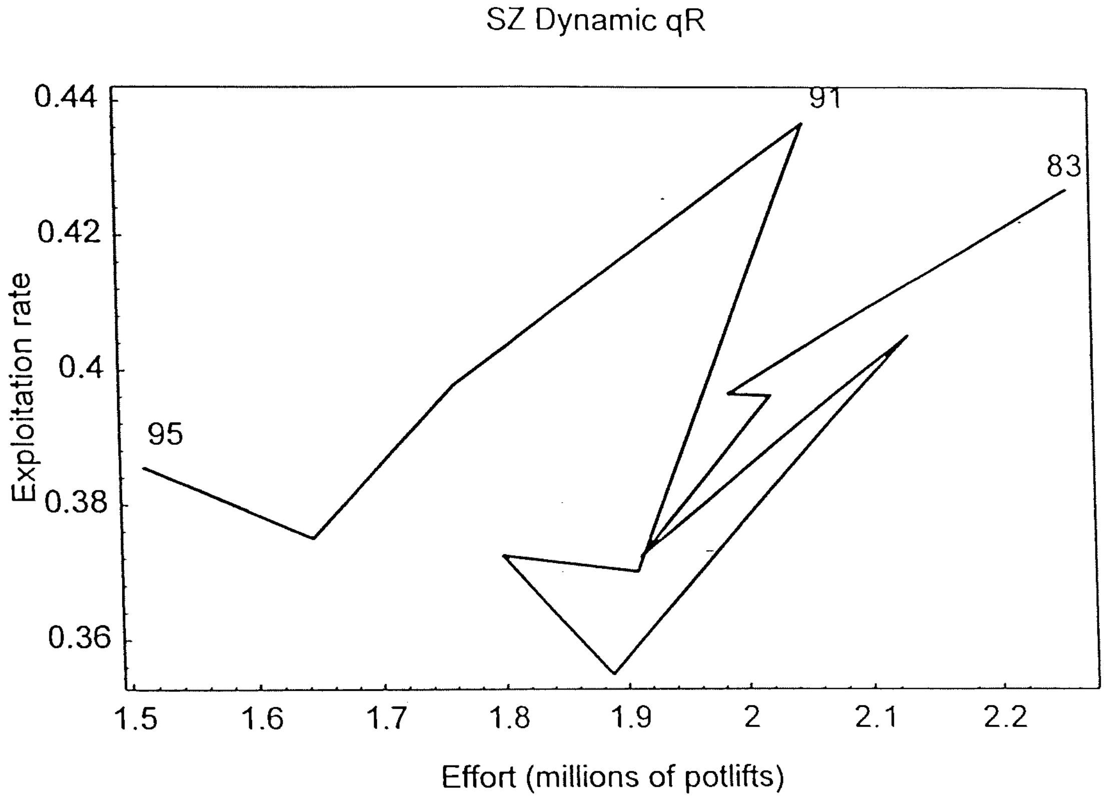


Figure 59. Relationship of exploitation rate estimated from the dynmic qr model to recorded effort in the Southern Zone.

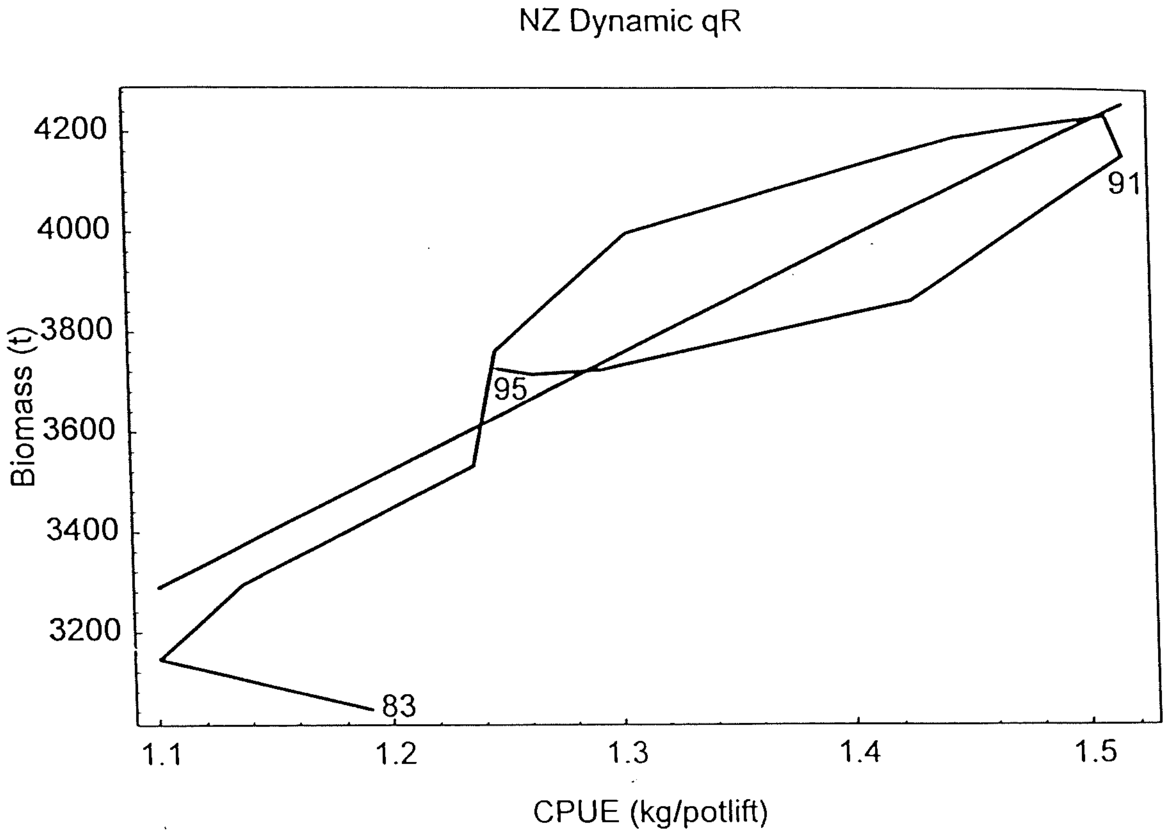


Figure 60. Relationship of biomass estimated from the dynamic qr model to recorded CPUE in the Northern Zone.

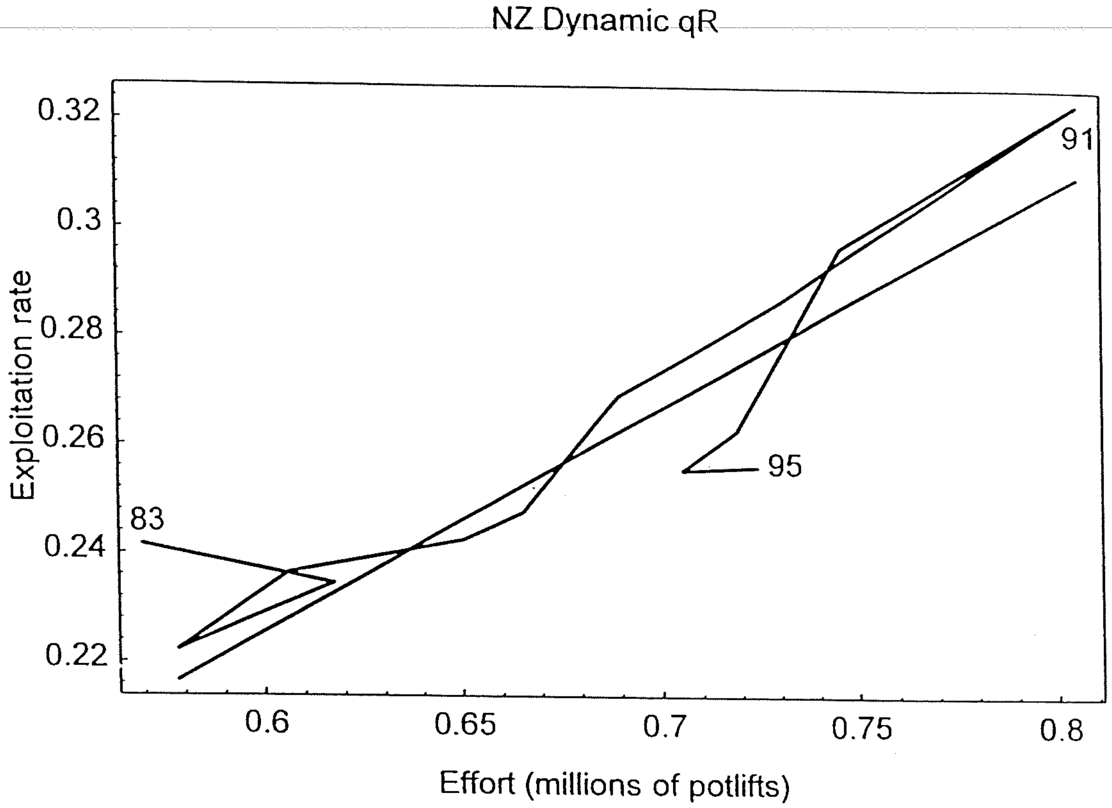


Figure 61. Relationship of exploitation rate estimated from the dynamic qr model to recorded effort in the Northern Zone.

Table 1. Frequency of recapture of lobsters to June 1997 is presented.

Number of times recaptured (recapture category)	Individual lobsters in category	Recaptures accounted for by this category
1	10657	10657
2	2514	5028
3	726	2178
4	205	820
5	74	370
6	20	120
7	8	56
8	4	32
9	1	9
12	1	12
Total	14210	19282

Table 2. Numbers and percentage of females recorded mature at the time of release and immature at the time of recapture is presented by category of capturer.

Capturer category at release	Capturer category at recapture	Number of long setose females released	Number long setose releases recaptured as short setose	Percent change
volunteer tagger	volunteer tagger	5553	121	2.2%
volunteer tagger	skilled fisher	460	19	4.1%
volunteer tagger	ordinary fisher	3978	310	7.8%
biologist	volunteer tagger	2890	31	1.1%
biologist	biologist	48	0	0.0%

Table 3. Numbers of pots and lobsters sampled during the catch monitoring programme are presented from the 1991/92 to the 1995/96 fishing seasons.

Season	Pots Sampled	Lobsters sampled
1991/92	22894	48998
1992/93	27964	55134
1993/94	20742	39609
1994/95	5770	8503
1995/96	12905	25333

Table 4. Monthly proportions of females in the catch are presented for six fishing areas and five fishing seasons and as pooled estimates across seasons. The fraction of the females of legal size females that were not spawning during the 1995/96 season are also presented and used to correct for the numbers of females in the landed catch in other seasons.

MFA 55	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**
91/92		0.58	0.50	0.40	0.39	0.48	0.35
92/93	0.46	0.52	0.55	0.55	0.51	0.51	0.39
93/94	0.52	0.72	0.68	0.60	0.61	0.49	0.39
94/95	0.51	0.61	0.56	0.44	0.27	0.33	0.29
95/96	0.49	0.57	0.57	0.46	0.48	0.48	0.52
pooled	0.50	0.58	0.54	0.48	0.47	0.49	0.39
correction for spawning	0.76	0.86	0.97	0.98	1.00	1.00	1.00
corrected pooled	0.38	0.50	0.52	0.47	0.47	0.49	0.39
MFA 56							
91/92		0.44	0.37	0.34	0.36	0.41	0.45
92/93	0.52	0.52	0.48	0.44	0.45	0.42	0.45
93/94	0.60	0.47	0.49	0.47	0.40	0.43	0.51
94/95	0.39	0.51	0.69	0.54	0.39	0.40	0.45
95/96	0.46	0.52	0.51	0.44	0.40	0.98	0.45
pooled	0.52	0.51	0.47	0.41	0.39	0.41	0.45
correction for spawning	0.51	0.81	0.95	0.99	0.99	1.00	1.00
corrected pooled	0.26	0.41	0.45	0.41	0.39	0.41	0.45
MFA 58							
91/92	0.54	0.51	0.50	0.39	0.41	0.42	0.52
92/93	0.51	0.37	0.59	0.48	0.49	0.43	0.49
93/94	0.60	0.47	0.49	0.47	0.40	0.43	0.51
94/95	0.39	0.51	0.69	0.54	0.45	0.40	0.49
95/96	0.54	0.59	0.45	0.48	0.45	0.58	0.45
pooled 58	0.54	0.51	0.54	0.47	0.45	0.47	0.49
correction for spawning	0.63	0.88	1.00	0.98	1.00	0.97	1.00
corrected pooled	0.34	0.45	0.54	0.47	0.45	0.45	0.49
MFA 28	Nov	Dec	Jan	Feb	Mar	Apr	May
91/92	0.53	0.53	0.48	0.45	0.43	0.44	0.42
92/93	0.55	0.56	0.50	0.44	0.44	0.42	0.42
93/94	0.63	0.54	0.45	0.42	0.42	0.41	0.34
94/95	0.60	0.57	0.40	0.46	0.53	0.41	0.50
95/96	0.58	0.55	0.49	0.47	0.45	0.34	
pooled	0.58	0.55	0.47	0.45	0.44	0.42	0.43
correction for spawning	0.91	0.98	1.00	0.98	1.00	1.00	1.00
corrected pooled	0.53	0.54	0.47	0.44	0.44	0.42	0.43
MFA 39							
91/92	0.49	0.52	0.38	0.38	0.43	0.45	0.38
92/93	0.53	0.59	0.54	0.44	0.50	0.49	0.34
93/94	0.55	0.64	0.47	0.41	0.46	0.42	0.26
94/95	0.56	0.56	0.45	0.43		0.00	0.36
95/96	0.58	0.55	0.43	0.40	0.53	0.60	0.47
pooled	0.53	0.55	0.45	0.41	0.48	0.47	0.37
correction for spawning	0.91	0.98	1.00	0.98	1.00	1.00	1.00
corrected pooled	0.48	0.54	0.45	0.41	0.48	0.47	0.37
MFA 48							
91/92	0.54	0.48	0.47	0.39	0.49	0.42	0.45
92/93	0.56	0.54	0.50	0.47	0.48	0.45	0.43
93/94	0.71	0.51	0.54	0.47	0.33	0.27	0.43
94/95	0.67	0.67	0.46	0.39	0.46	0.39	
95/96	0.45	0.57	0.56	0.56	0.67	0.50	0.40
pooled	0.53	0.53	0.51	0.44	0.49	0.39	0.43
correction for spawning	0.89	0.98	0.99	1.00	1.00	1.00	1.00
corrected pooled	0.47	0.52	0.51	0.44	0.49	0.39	0.43

Table 5. Presented are the weighted seasonal proportions of the catch which were females of legal length. The weights applied were the monthly catch, in numbers, of the respective marine fishing area. Spawning females were included as "catch" in this table.

	season				
MFA	**91/92**	**92/93**	**93/94**	**94/95**	**95/96**
28	0.48	0.50	0.50	0.49	0.51
39	0.49	0.53	0.53	0.55	0.57
48	0.48	0.51	0.50	0.42	0.52
55	0.46	0.53	0.53	0.51	0.51
56	0.40	0.47	0.46	0.45	0.52
58	0.50	0.50	0.47	0.49	0.52

Table 6. Presented are the weighted seasonal proportions of the landed catch which were female. As above the catch numbers from the respective marine fishing area were used to weight the catches and the proportion of spawning females observed in each month and area were used to correct for females which could not be landed because of their egg-bearing condition.

	season				
MFA	**91/92**	**92/93**	**93/94**	**94/95**	**95/96**
28	0.48	0.49	0.49	0.49	0.50
39	0.47	0.51	0.51	0.53	0.55
48	0.47	0.50	0.49	0.42	0.51
55	0.43	0.52	0.51	0.47	0.49
56	0.36	0.44	0.43	0.44	0.50
58	0.45	0.48	0.44	0.48	0.49

Table 7. The GROTAG parameter estimates, mean annual growth at 100 and 140 mm CL for male lobsters by Marine Fishing Area (MFA).

MFA	%L	g100	%U		%L	g140	%U	n
58	14.15	14.48	14.81		6.64	7.54	8.50	844
56	14.65	14.97	15.30		7.96	8.71	9.49	1188
55	16.93	17.32	17.72		12.41	13.03	13.64	1263
51	15.83	17.12	18.54		12.11	13.64	15.35	83
50	14.38	15.55	16.83		6.76	10.11	13.61	79
49	16.74	17.53	18.34		8.49	9.33	11.10	244
48	17.58	18.50	19.28		9.73	11.50	13.35	224
38	15.14	16.15	17.23		7.75	8.83	10.12	164
44	17.40	19.90	22.62		8.58	10.44	12.67	33
26	18.45	19.50	20.54		10.27	10.93	12.66	108
39	17.75	18.29	18.81		9.77	10.31	13.48	439
28	17.59	18.31	18.91		7.35	8.21	9.33	275
40	19.99	20.52	21.06		13.04	14.12	15.21	246
33	19.45	20.25	21.15		9.81	12.05	14.47	130
15	20.25	21.57	22.79		13.04	13.75	14.56	69
27	19.53	21.01	22.58		9.68	12.11	15.82	40
30	17.73	19.26	20.86		8.17	10.35	12.66	20
46	8.95	9.75	10.65		5.40	7.76	10.58	86

Table 8. The GROTAG parameter estimates, mean annual growth at 100 and 120 mm CL for female lobsters by Marine Fishing Area (MFA).

MFA	%L	g100	%U		%L	g120	%L	n
58	0.029	6.66	0.029		0.074	2.10	0.057	1309
56	0.025	6.79	0.024		0.039	2.68	0.062	1818
55	0.011	9.68	0.008		0.008	5.52	0.012	2723
51	0.062	11.94	0.051		0.047	6.57	0.066	155
50	0.057	8.24	0.059		0.172	3.33	0.000	209
49	0.056	8.78	0.059		0.095	3.58	0.185	282
48	0.029	11.14	0.013		0.013	4.78	0.066	336
38	0.065	7.79	0.070		0.095	4.09	0.118	193
26	0.063	9.47	0.064		0.081	4.40	0.119	203
44	0.107	12.81	0.166		0.201	6.21	0.170	31
39	0.026	10.17	0.015		0.015	3.45	0.036	875
28	0.040	9.47	0.054		0.083	3.47	0.084	395
33	0.035	14.91	0.040		0.164	4.50	0.478	86
40	0.417	14.22	-0.021		0.025	7.66	0.025	392
27	0.061	13.49	0.080		0.235	5.46	0.201	62

Table 9a. The GROTAG parameter estimates, mean annual growth for female lobsters less than the length of 50 percent maturity, by Marine Fishing Area.

MFA	%L	g90	%U		%L	g100	%U	n
58	0.035	9.51	0.037		0.051	5.87	0.054	1100
56	0.035	9.35	0.037		0.047	6.08	0.048	1417
55	0.034	13.85	0.035		0.038	9.90	0.039	1154
51	0.106	13.73	0.139		0.095	12.89	0.096	61
50	0.069	10.71	0.075		0.104	7.86	0.112	127
49	0.075	12.23	0.086		0.081	8.47	0.087	185
48	0.053	15.54	0.054		0.058	11.07	0.057	218
38	0.084	10.27	0.096		0.099	7.55	0.115	117
44	0.157	15.87	0.188		0.212	14.05	0.289	18
39	0.041	14.80	0.041		0.043	10.26	0.043	497
28	0.056	14.03	0.058		0.057	10.20	0.060	268
33	0.195	5.91	0.251		0.233	4.65	0.210	72
40	0.043	17.71	0.045		0.048	14.77	0.050	229
27	0.108	16.99	0.103		0.067	14.25	0.086	49
26	0.085	12.56	0.097		0.124	9.85	0.140	139

Table 9b. The GROTAG parameter estimates, mean annual growth for female lobsters greater than the length of 50 percent maturity, by Marine Fishing Area.

MFA	%L	g110	%U		%L	g120	%U	n
58	0.099	3.96	0.101		0.112	2.69	0.153	209
56	0.062	4.83	0.066		0.078	2.93	0.090	401
55	0.018	6.28	0.014		0.013	4.76	0.015	1569
51	0.054	9.49	0.041		0.036	6.70	0.046	7
50	0.039	9.21	0.028		0.100	6.26	0.087	82
49	0.109	4.20	0.063		0.056	3.59	0.100	97
48	0.100	5.81	0.122		0.100	4.03	0.084	118
38	0.145	4.68	0.147		0.110	3.91	0.140	76
44								*13
39	0.061	4.60	0.063		0.062	2.58	0.058	378
28	0.085	4.27	0.062		0.044	3.18	0.076	127
33								*14
40	0.038	7.05	0.037		0.028	5.39	0.035	163
27								*13
26								*64

Table 10. The GROTAG parameter estimates, mean growth at 100 and 140 mm CL for male lobsters, by growth zone.

Growth Zone	MFA	g100	g140
WNZ (western northern zone)	1-15, 18, 27	20.40	13.40
HNZ (high growth northern zone)	26, 28, 39, 48	18.29	10.97
YRK (Yorke Peninsula)	33, 40, 44	20.61	13.56
CNZ (central northern zone)	38, 49, 50	17.06	10.15
NSZ (northern southern zone)	50, 51, 55	17.42	12.58
SSZ (southern southern zone)	56, 58	14.86	8.12

Table 11. The GROTAG parameter estimates, mean growth at 100 and 120 mm CL for all female lobsters, by growth zone.

Growth Zone	MFA	g100	g120
WNZ (western northern zone)	1-15, 18, 27	12.59	8.19
HNZ (high growth northern zone)	26, 28, 39, 48	10.47	3.65
YRK (Yorke Peninsula)	33, 40, 44	14.48	7.20
CNZ (central northern zone)	38, 49, 50	8.64	3.66
NSZ (northern southern zone)	50, 51, 55	10.02	5.71
SSZ (southern southern zone)	56, 58	6.86	2.65

Table 12. The GROTAG parameter estimates, mean growth at 90 and 100 mm CL for females less than the length of 50 percent maturity and growth at 100 and 120 mm CL for female lobsters greater than the length of 50 percent maturity, by growth zone.

		< 50 %mature			>50 % mature	
Growth Zone	MFA	g90	g100		g100	g120
WNZ (western northern zone)	1-15, 18, 27	17.00	12.57		5.11	4.39
HNZ (high growth northern zone)	26, 28, 39, 48	14.78	10.75		4.10	2.91
YRK (Yorke Peninsula)	33, 40, 44	18.49	14.72		8.36	5.90
CNZ (central northern zone)	38, 49, 50	11.87	8.04		4.32	3.73
NSZ (northern southern zone)	50, 51, 55	14.16	10.38		6.62	5.00
SSZ (southern southern zone)	56, 58	9.47	5.89		4.43	2.84

Table 13a. Standard deviations for mean annual growth at lengths of 100 and 140 mm CL for male lobsters, by growth zones.

Growth Zone	100	140
WNZ (western northern zone)	4.95	4.42
HNZ (high growth northern zone)	6.29	5.42
YRK (Yorke Peninsula)	4.74	4.56
CNZ (central northern zone)	5.79	4.94
NSZ (northern southern zone)	6.92	6.21
SSZ (southern southern zone)	5.65	4.76
Total southern zone	6.30	5.56

Table 13b. Standard deviations for mean annual growth at lengths of 100 and 120 mm CL for all female lobsters, by growth zone.

Growth Zone	100	120
WNZ (western northern zone)	4.23	3.82
HNZ (high growth northern zone)	5.09	3.64
YRK (Yorke Peninsula)	4.95	3.61
CNZ (central northern zone)	4.48	3.14
NSZ (northern southern zone)	5.75	4.20
SSZ (southern southern zone)	4.72	3.62

Table 14. Number of tagged lobsters released and recaptured in five movement regions between August 1993 and May 1996, by sex at time of release. Note: Female lobsters may have changed reproductive status between release and recapture. M = male; IMF = immature female; MF = mature female; EBF = egg-bearing female.

Movement region	**Numbers released**				**Numbers recaptured**				Mean time at liberty
	M	**IMF**	**MF**	**EBF**	**M**	**IMF**	**MF**	**EBF**	
West Coast	3121	2873	1351	337	568	273	510	23	328
Kangaroo Is.	4302	4527	1010	1344	885	561	930	119	314
Yorke Pen.	1578	1671	139	276	319	192	212	13	309
Coorong	634	593	92	99	76	42	88	22	361
Southeast	11894	9391	6397	4054	3342	1798	3039	982	277

Table 15. Numbers of lobsters moving distances of defined intervals, by sex and reproductive status at time of release. M = male; IMF = immature female; MF = mature female; EBF = egg-bearing female. West Coast (WC); Kangaroo Island (KI); Yorke Peninsula (YP); Coorong (CO); South East (SE).

Region	**0 - 5 km**				**>5 - 20 km**				**>20 km**				**Total**
	M	**IMF**	**MF**	**EBF**	**M**	**IMF**	**MF**	**EBF**	**M**	**IMF**	**MF**	**EBF**	
WC	314	128	285	14	15	9	13	1	6	7	5	1	798
KI.	463	255	553	64	24	12	13	1	12	10	5	0	1412
YP	153	72	102	6	16	12	12	0	30	25	8	1	437
CO	27	19	36	8	3	2	0	2	11	13	7	0	128
SE	1164	601	1230	411	209	117	160	46	31	24	16	6	4015

Table 16. Results of pairwise comparisons of length-weight curves using likelihood ratio tests.

Comparison	Probability
Male v Female	0.000
Female damaged v female undamaged	0.001
Red undamaged Female v speckly undamaged female	0.675
Red damaged female v speckly damaged female	0.636
Damaged male v undamaged male	0.000
Speckly damaged male v red damaged male	0.936
Speckly undamaged male v red undamaged male	0.523
Undamaged Port Lincoln male v undamaged Robe male	0.349
Undamaged Port Lincoln male v undamaged Pondalowie male	0.687
Undamaged Port Lincoln male v undamaged Carpenters Rocks male	0.137
Undamaged Robe male v undamaged Carpenters Rocks male	0.126
Undamaged Robe male v undamaged Pondalowie male	0.276
Undamaged Carpenters Rocks male v undamaged Pondalowie male	0.081

Table 17. Parameter values of the length-weight equations for male and female lobsters, including only lobsters with no damage, and all lobsters in the sample of each sex.

undamaged lobsters only			all lobsters in sample		
parameters	male	female	parameters	male	female
a	0.00058	0.00090	a	0.00054	0.00090
b	2.96582	2.8913	b	2.9796	2.8875
R^2	0.989	0.975	R^2	0.989	0.970
n	343	286	n	456	383

Table 18. Estimates of the mean length at maturity (L*m*) in Marine Fishing Areas during five seasons and all seasons pooled, and the values of the parameter C of the logistic length of maturity curve which describes the steepness of the curve.

	Marine Fishing Areas								
season	**15**	**28**	**39**	**40**	**48/49**	**51**	**55**	**56**	**58**
Mean lengths at maturity									
1991/92	110.4	105.3	103.9	113.5	100.8	111.6	109.8	91.0	96.9
1992/93	108.9	103.4	104.0	112.6	101.1	107.2	103.7	90.4	98.8
1993/94	103.0	101.4	103.5	111.2	103.9	115.5	104.2	92.9	96.0
1994/95	99.0	103.1	107.1	113.5	103.2			95.6	
1995/96	102.6	100.4	98.5	114.5	106.0	116.0	107.8	92.0	95.6
pooled	106.2	103.0	104.1	112.5	102.0	112.4	106.3	91.7	96.9
"C" Parameter									
1991/92	0.1680	0.1700	0.0943	0.2504	0.1422	0.0980	0.1143	0.1246	0.1737
1992/93	0.2631	0.1971	0.0832	0.1376	0.1604	0.0938	0.1298	0.1736	0.1283
1993/94	0.0894	0.2106	0.1121	0.1316	0.1696	0.1855	0.1023	0.1689	0.1882
1994/95	0.1770	0.2625	0.0830	0.2511	0.1906			0.2293	
1995/96	0.1504	0.1665	0.0866	0.1301	0.1274	0.2084	0.1099	0.1793	0.1442
pooled	0.1525	0.1944	0.0920	0.1365	0.1534	0.1173	0.1134	0.1663	0.1528

Table 19. Correlations between area-seasonal deviations of the mean length at maturity from the average of all seasonal estimates on the respective areas.

MFAs	**15**	**28**	**39**	**40**	**48/49**	**51**	**55**	**56**	**58**
15									
28	0.63								
39	-0.10	0.60							
40	-0.07	0.03	-0.35						
48/49	-0.72	-0.92	-0.62	0.24					
51	-0.82	-0.67	-0.63	0.08	0.83				
55	0.25	0.35	-0.31	0.72	0.01	0.27			
56	-0.90	-0.26	0.46	0.01	0.39	0.90	-0.13		
58	0.75	0.60	0.64	-0.17	-0.80	-0.99	-0.39	-0.13	

Table 20. Matrix of probabilities that curves of maturation were common between areas, determined by likelihood ratio tests. Non significant (P>0.05)probabilities are highlighted.

MFAs	**15**	**28**	**39**	**40**	**48/49**	**51**	**55**	**56**	**58**
15									
28	0.0004								
39	0.0152	0.0012							
40	0.0000	0.0000	0.0000						
48/49	0.0000	0.0991	0.0055	0.0000					
51	0.0000	0.0000	0.0085	0.0580	0.0000				
55	0.0570	0.0029	0.9747	0.0001	0.0195	0.0168			
56	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000		
58	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	

Table 21. Parameters of the logistic vulnerability model are presented by sex and MFA for weighted (by sample size) and unweighted data. A subjective assessment of the model is indicated, where Re is reliability g = good; m = moderate; and p = poor (see discussion section 6.5).

	Female					**Male**				
	Unweighted Model		**Weighted model**			**Unweighted Model**		**Weighted model**		
MFA	**c**	**L50V**	**c**	**L50V**	**Re**	**c**	**L50V**	**c**	**L50V**	**Re**
58	0.269	89.73	0.299	89.94	g	0.282	88.33	0.312	88.37	g
56	0.423	87.14	0.499	87.35	g	0.311	88.52	0.340	88.58	g
55	0.158	89.70	0.130	87.79	p	0.098	97.95	0.098	97.95	m
48/49	0.140	94.98	0.128	94.41	m	0.179	95.99	0.177	95.79	m
40						0.141	108.51	0.150	108.01	m
39	0.201	85.80	0.202	85.48	p	0.100	106.00	0.097	105.67	m
28	0.102	103.11	0.147	103.74	m	0.115	104.27	0.097	105.58	m
15	0.116	117.31	0.130	116.98	m	0.071	127.51	0.071	125.42	m

Figure 22. Estimated vulnerability at the relevant legal minimum length (LML), by sex and marine fishing area.

MFA	LML	female vulnerability at LML	male vulnerability at LML
58	98.5	0.93	0.96
56	98.5	1.00	0.97
55	98.5	0.80	0.51
48/49	102	0.73	0.75
40	102	0.50	0.29
39	102	0.97	0.41
28	102	0.44	0.41
15	102	0.13	0.16

Table 23. Average weights, by age, for harvested lobsters in the northern and southern zones, starting from the age of recruitment a_R. The value for a_R is equivalent to the number of years the lobster was in the fishable stock.

a_R	Northern zone (weight kg)	Southern zone (weight kg)
1	0.516	0.446
2	0.782	0.658
3	1.044	0.890
4	1.288	1.131
5	1.508	1.375
6	1.701	1.614
7	1.868	1.846
8	2.012	2.066
9	2.134	2.273
10	2.237	2.465
11	2.324	2.643
12	2.396	2.807
13	2.457	2.956

Population Dynamics of the Southern Rock Lobster in South Australian Waters

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S A R D I

SOUTH AUSTRALIAN RESEARCH AND DEVELOPMENT INSTITUTE

SANZFLFA Inc.

SEPFA Inc.

FISHERIES RESEARCH & DEVELOPMENT CORPORATION

PROJECT NUMBER: 93/087

Appendices

South Australian Rock Lobster Database Report

Tables

Field Name	Type	Size	Nullable	Indexes
PRIMARY_KEY				

CAPTURE

Stores data common to both tag releases and recaptures of lobsters, mostly biological data.

CAPTURE_ID	**NUMBER**	**6**	No	**CAP_PK (Unique)**
TAG_NUMBER	NUMBER	6	No	CAP_TAGNUM_IX
LENGTH	NUMBER	4.1	No	
LENGTH_DECIMAL	VARCHAR2	1	No	
COLOUR_CODE	VARCHAR2	1	No	
SEX_CODE	VARCHAR2	1	No	
REPRODUCTIVE_STATE_CODE	VARCHAR2	2	No	
MOULT_STATE_CODE	VARCHAR2	1	No	
CAPTURE_STATUS_CODE	VARCHAR2	1	No	
RELEASE_STATUS_CODE	VARCHAR2	1	No	
CAPTURER_TYPE_ID	NUMBER	2	No	
LOBSTER_ID	NUMBER	6	No	CAP_LOBID_IX

CAPTURER_TYPE

This table is mostly a quality control device that categorises the people that report data for the tagging database.

CAPTURER_TYPE_ID	**NUMBER**	**2**	**No**	**CTYPE_PK (Unique)**
CAPTURER_TYPE_CODE	VARCHAR2	2	No	CTYPE_UNQ_CTYPE (Unique)
CLASS	VARCHAR2	20	No	

CAPTURE_ERROR

List of errors related to individual captures of a lobster, linked to CAPTURE table.

CAPTURE_ID	**NUMBER**	**6**	**No**	**CAP_ERR_PK (Unique)**
ERROR_CODE	**NUMBER**	**3**	**No**	**CAP_ERR_PK (Unique)**
SUB_CODE	NUMBER	2	Yes	
COMMENTS	VARCHAR2	240	Yes	

CAPTURE_HISTORY

History of changes made to individual capture records.

CAPTURE_ID	NUMBER	6	Yes	CAPTURE_HISTORY_IX
TAG_NUMBER	NUMBER	6	Yes	
LENGTH	NUMBER	4.1	Yes	
LENGTH_DECIMAL	VARCHAR2	1	Yes	
COLOUR_CODE	VARCHAR2	1	Yes	
SEX_CODE	VARCHAR2	1	Yes	
REPRODUCTIVE_STATE_CODE	VARCHAR2	2	Yes	
MOULT_STATE_CODE	VARCHAR2	1	Yes	
CAPTURE_STATUS_CODE	VARCHAR2	1	Yes	
RELEASE_STATUS_CODE	VARCHAR2	1	Yes	
CAPTURER_TYPE_ID	NUMBER	2	Yes	
LOBSTER_ID	NUMBER	6	Yes	
MODIFICATION_USER	VARCHAR2	10	Yes	
MODIFICATION_DATE	DATE		Yes	

CAPTURE_POSITION

Temporary table used in Recapture & Tagger reports, and some other scripts. Hold the position of the original tag of a lobster.

TAG_NUMBER	NUMBER	6	No	CAPTURE_POSITION_IX (Unique)
LATITUDE	NUMBER		Yes	
LONGITUDE	NUMBER		Yes	

CONTACT

List of people used throughout the database.

CONTACT_ID	**NUMBER**	**4**	**No**	**CONT_PX (Unique)**
SURNAME	VARCHAR2	30	No	
INITIALS	VARCHAR2	6	Yes	
GIVEN	VARCHAR2	25	Yes	
SECOND	VARCHAR2	25	Yes	
RES_ADDR_LINE_1	VARCHAR2	50	Yes	
RES_ADDR_LINE_2	VARCHAR2	50	Yes	
RES_ADDR_LINE_3	VARCHAR2	50	Yes	
RES_ADDR_LINE_4	VARCHAR2	50	Yes	
RES_POSTCODE	NUMBER	4	Yes	
PHONE	VARCHAR2	15	Yes	
MOBILE	VARCHAR2	15	Yes	
FAX	VARCHAR2	15	Yes	
POST_ADDR_LINE_1	VARCHAR2	50	Yes	
POST_ADDR_LINE_2	VARCHAR2	50	Yes	
POST_ADDR_LINE_3	VARCHAR2	50	Yes	
POST_ADDR_LINE_4	VARCHAR2	50	Yes	
POST_POSTCODE	NUMBER	4	Yes	

DAMAGE

Records damage to limbs and antenna of a individual capture of a lobster.

CAPTURE_ID	**NUMBER**	6	No	**DAM_PK (Unique)**
APPENDAGE_CODE	**VARCHAR2**	**2**	No	**DAM_PK (Unique)**
DAMAGE_CODE	VARCHAR2	1	No	

ENGINE_FUEL_TYPE

Lookup table of the types of fuel used on fishing vessels for the Gear and Vessel database.

ENGINE_FUEL_TYPE_CODE	**CHAR**	**1**	No	**PK_ENG_FUEL (Unique)**
ENGINE_FUEL_TYPE	VARCHAR2	20	No	UQ_ENG_FUEL_TYPE (Unique)

ENGINE_MANUFACTURER

List of manufacturers of marine engines used in Gear and Vessel database.

ENGINE_MANUFACTURER_ID	**NUMBER**	**3**	**No**	**PK_ENG_MANUF (Unique)**
ENGINE_MANUFACTURER	VARCHAR2	20	No	UQ_ENG_MANUF (Unique)

EQUIPMENT

List of the equipment contained on each vessel recorded in the Gear and Vessel database.

VESSEL_ID	NUMBER	5	Yes	EQUIP_VESSELID_IX
EQUIPMENT_TYPE_CODE	CHAR	1	No	
EQUIPMENT_MANUFACTURER_ID	NUMBER	3	Yes	
EQUIPMENT_MODEL	VARCHAR2	20	Yes	

EQUIPMENT_MANUFACTURER

List of manufacturers of equipment that could be used on a fishing vessel in the Gear and Vessel database.

EQUIPMENT_MANUFACTURER_ID	NUMBER	3	No	**PK_EQUIP_MANUF (Unique)**
EQUIPMENT_MANUFACTURER	VARCHAR2	20	No	UQ_EQUIP_MANUF (Unique)

EQUIPMENT_TYPE

List of types of equipment that can be found on a fishing vessel in the Gear and Vessel database.

EQUIPMENT_TYPE_CODE	**CHAR**	**1**	**No**	**PK_EQUIP_TYPE (Unique)**
EQUIPMENT_TYPE	VARCHAR2	25	No	UQ_EQUIP_TYPE (Unique)

ERROR_CODES

Lookup table listing the types of errors that can occur within the databases.

ERROR_CODE	**NUMBER**	**3**	**No**	**ERR_CODE_PK (Unique)**
SUB_CODE	**NUMBER**	**2**	**No**	
SEVERITY	NUMBER	1	No	
DESCRIPTION	VARCHAR2	240	No	

ERROR_TYPES

Lookup table that categorises the ERROR_CODES table into the tables that the ERROR_CODE records correspond to.

TYPE	**VARCHAR2**	**10**	**No**	**ERR_TYPE_PK (Unique)**
ERROR_CODE	**NUMBER**	**3**	**No**	

HULL_CONSTRUCTION

Lookup table of the types of hull constructions used for fishing vessels in the Gear and vessel database.

HULL_CONSTRUCTION_CODE	**CHAR**	**1**	**No**	**PK_HULL_CONST (Unique)**
HULL_CONSTRUCTION	VARCHAR2	20	No	UQ_HULL_CONST (Unique)

HULL_DESIGN

Lookup table of the types of hull designs used for fishing vessels in the Gear and vessel database.

HULL_DESIGN_CODE	**CHAR**	**1**	**No**	**PK_HULL_DESGN (Unique)**
HULL_DESIGN	VARCHAR2	20	No	UQ_HULL_DESIGN (Unique)

LF_DATA

This table along with the LF_HEADER table contain length frequency data that will be imported into the current tagging table structure, eventually.

LIC_NO	VARCHAR2	4	Yes
TRIP_DATE	DATE		Yes
POT_ORDER	NUMBER	2	Yes
SEX_CODE	VARCHAR2	1	Yes
REPRODUCTIVE_STATE_CODE	VARCHAR2	2	Yes
LENGTH	NUMBER	3	Yes

LF_HEADER

This table along with the LF_DATA table contain length frequency data that will be imported into the current tagging table structure.

LIC_NO	VARCHAR2	4	Yes
TRIP_DATE	DATE		Yes
BLOCK	NUMBER	2	Yes
QUADRANT	VARCHAR2	1	Yes
RECORDER	VARCHAR2	3	Yes
SWELL_HEIGHT	NUMBER	3.1	Yes
WIND_SPEED	NUMBER	2	Yes
WIND_DIRECTION	VARCHAR2	3	Yes
POT_ORDER	NUMBER	2	Yes
DOUBLE_LIFT	VARCHAR2	1	Yes
DEPTH	NUMBER	3	Yes
DEPTH_UNITS_CODE	VARCHAR2	1	Yes
PRED_NUM_1	NUMBER	2	Yes
PRED_ID_1	VARCHAR2	2	Yes
PRED_NUM_2	NUMBER	2	Yes

PRED_ID_2	VARCHAR2	2	Yes	

LICENCE

Table holding information relating to licence holders within the Rock Lobster Fishery. Currently has a field REGISTRATION_NO that may or may not be needed once the old catch & effort data is entered.

LIC_NO	**CHAR**	4	No	**LIC_PK (Unique)**
OWNER_CONTACT_ID	**NUMBER**	4	No	**LIC_PK (Unique)**
MASTER1_CONTACT_ID	NUMBER	4	Yes	
MASTER2_CONTACT_ID	NUMBER	4	Yes	
NO_OF_POTS	NUMBER	3	Yes	
DEPTH_UNITS_CODE	CHAR	1	Yes	
START_DATE	DATE		No	
END_DATE	DATE		Yes	
REGISTRATION_NO	VARCHAR2	4	Yes	

LICENCE_RECAPTURE_REPORT_DONE

This table is used by the Recapture by Licence report, and contains the list of recaptures that have already been reported on so that an incremental report doesn't re-report them. BTW this report hasn't actually be created yet.

TAG_NUMBER	NUMBER	6	Yes
RECAPTURE_DATE	DATE		Yes
REPORT_DATE	DATE		No

LOBSTER

This table links a lobster_id from the capture table to the tag_numbers that are associated with a lobster, also what type of tag it is and where on the lobsters body it was placed.

TAG_NUMBER	**NUMBER**	6	No	**LOB_PK (Unique)**
LOBSTER_ID	NUMBER	6	No	**LOB_IX_LOBID**
TAG_TYPE	VARCHAR2	8	No	
POSITION_TAGGED_CODE	VARCHAR2	1	No	

LOBSTER_ERROR

List of errors related to individual lobsters, linked to LOBSTER table.

LOBSTER_ID	**NUMBER**	6	No	**LOB_ERR_PK (Unique)**
ERROR_CODE	**NUMBER**	3	No	**LOB_ERR_PK (Unique)**
SUB_CODE	NUMBER	2	Yes	
COMMENTS	VARCHAR2	240	Yes	

LOG_DATA

Catch and Effort daily data.

TRIP_ID	**NUMBER**	5	No	**LOGD_PK (Unique)**
DAY	**NUMBER**	2	No	**LOGD_PK (Unique)**
TRIP_DATE	DATE		Yes	LOGD_IX_DATE
AREA_CODE	NUMBER	2	Yes	
DEPTH	NUMBER	6.3	Yes	
DEPTH_ENTERED	NUMBER	3	Yes	
POTS	NUMBER	3	Yes	
SPECIES_CODE	VARCHAR2	3	Yes	
CATCH_WEIGHT	NUMBER	6.2	Yes	
CATCH_NUMBER	NUMBER	4	Yes	
OTHER_UNDERSIZE	NUMBER	4	Yes	
OTHER_DEAD	NUMBER	3	Yes	
OTHER_SPAWNERS	NUMBER	4	Yes	
OCTOPUS_WEIGHT	NUMBER	5.2	Yes	
OCTOPUS_NUMBER	NUMBER	2	Yes	
KING_CRAB_WEIGHT	NUMBER	5.2	Yes	

KING_CRAB_NUMBER	NUMBER	2	Yes
KING_CRAB_POTS	NUMBER	3	Yes

LOG_DATA_ERROR

List of errors related to individual LOG_DATA records. Note that the data entry form for the Catch and Effort data hasn't been modified yet to allow for entry to this table.

TRIP_ID	**NUMBER**	**5**	**No**	**LOGD_ERR_PK (Unique)**
DAY	**NUMBER**	**2**	**No**	**LOGD_ERR_PK (Unique)**
ERROR_CODE	**NUMBER**	**3**	**No**	**LOGD_ERR_PK (Unique)**
SUB_CODE	NUMBER	2	Yes	
COMMENTS	VARCHAR2	240	Yes	

LOG_DATA_HISTORY

History of changes to individual LOG_DATA records. This table is populated by a trigger that fires after any modifications to the LOG_DATA table.

TRIP_ID	NUMBER	5	Yes	LOG_DATA_HISTORY_IX
DAY	NUMBER	2	Yes	LOG_DATA_HISTORY_IX
TRIP_DATE	DATE		Yes	
AREA_CODE	NUMBER	2	Yes	
DEPTH	NUMBER	6.3	Yes	
DEPTH_ENTERED	NUMBER	3	Yes	
POTS	NUMBER	3	Yes	
SPECIES_CODE	VARCHAR2	3	Yes	
CATCH_WEIGHT	NUMBER	6.2	Yes	
CATCH_NUMBER	NUMBER	4	Yes	
OTHER_UNDERSIZE	NUMBER	4	Yes	
OTHER_DEAD	NUMBER	3	Yes	
OTHER_SPAWNERS	NUMBER	4	Yes	
OCTOPUS_WEIGHT	NUMBER	5.2	Yes	
OCTOPUS_NUMBER	NUMBER	2	Yes	
KING_CRAB_WEIGHT	NUMBER	5.2	Yes	
KING_CRAB_NUMBER	NUMBER	2	Yes	
KING_CRAB_POTS	NUMBER	3	Yes	
MODIFICATION_USER	VARCHAR2	10	Yes	
MODIFICATION_DATE	DATE		Yes	

LOG_HEADER

Catch and Effort monthly header for daily data.

TRIP_ID	**NUMBER**	5	No	**LOGH_PK (Unique)**
LIC_NO	CHAR	4	No	LOGH_IX_LIC_NO, LOGH_TRIP (Unique)
PLACE_OF_LANDING_CODE	VARCHAR2	3	No	
MONTH	NUMBER	2	No	LOGH_TRIP (Unique)
YEAR	NUMBER	4	No	LOGH_TRIP (Unique)
DEPTH_UNITS_CODE	CHAR	1	No	
OWNER_CONTACT_ID	NUMBER	4	Yes	

LOG_HEADER_ERROR

List of errors related to individual LOG_HEADER records. Note that the data entry form for the Catch and Effort data hasn't been modified yet to allow for entry to this table.

TRIP_ID	**NUMBER**	5	No	**LOGH_ERR_PK (Unique)**
ERROR_CODE	**NUMBER**	3	No	**LOGH_ERR_PK (Unique)**
SUB_CODE	NUMBER	2	Yes	
COMMENTS	VARCHAR2	240	Yes	

LOG_HEADER_HISTORY

History of changes to individual LOG_HEADER records. This table is populated by a trigger that fires after any modifications to the LOG_HEADER table.

TRIP_ID	NUMBER	5	Yes	LOG_HEADER_HISTORY_IX
LIC_NO	VARCHAR2	4	Yes	
PLACE_OF_LANDING_CODE	VARCHAR2	3	Yes	
MONTH	NUMBER	2	Yes	
YEAR	NUMBER	4	Yes	
DEPTH_UNITS_CODE	VARCHAR2	1	Yes	
OWNER_CONTACT_ID	NUMBER	4	Yes	
MODIFICATION_USER	VARCHAR2	10	Yes	
MODIFICATION_DATE	DATE		Yes	

LOG_LINK

Link between LOG_DATA and LOG_HEADER. This table is used so that a blank record can be returned for a day that is not fished rather than no record at all.

TRIP_ID	**NUMBER**	**5**	**No**	**LOGL_PK (Unique)**
DAY	**NUMBER**	**2**	**No**	**LOGL_PK (Unique)**

LOG_VALUE

Source : log/val_table.sql
Stores the prices of lobster, king crab and octopus so that the old GARFIS fishery value reports can be run.

YEAR	NUMBER	4	Yes
MONTH	NUMBER	2	Yes
ZONE	CHAR	1	Yes
VALUE	NUMBER	5.2	Yes
OCTOPUS_VALUE	NUMBER	5.2	Yes
KING_CRAB_VALUE	NUMBER	5.2	Yes

LOG_WEIGHT

This table stores the catch weights for the individual days once the welling has been calculated. The script log/log_calc.sql performs the welling calculations.

TRIP_ID	NUMBER	5	No	LOG_WEIGHT_IX (Unique)
DAY	NUMBER	2	No	LOG_WEIGHT_IX (Unique)
CATCH_WEIGHT	NUMBER	6.2	Yes	
OCTOPUS_WEIGHT	NUMBER	5.2	Yes	
KING_CRAB_WEIGHT	NUMBER	5.2	Yes	

LOV_FIELDS

These two tables are used within the data entry forms to provide a simple, centralised and consistent "list of values" list for fields that are common between forms. These tables is taking over from the REF_CODES table. This table provides a link between the field name within the form (and tables) and the allowable values in the LOV_VALUES table.

FIELD_NAME	**VARCHAR2**	**25**	**No**	**(Unique)**
DOMAIN	VARCHAR2	25	No	

LOV_VALUES

This table contains the allowable values for a certain type of field. Used in conjunction with the

DOMAIN	VARCHAR2	24	No
ABBREVIATION	VARCHAR2	3	No
MEANING	VARCHAR2	20	No

LSCODE

This table contains a description of the LSCODE field of the POT_MFA, RECAPTURE_MFA and RELEASE_INFO_MFA tables that is generated by ARCINFO when it converts each records lat and long to and MFA.

LSCODE	NUMBER	1	Yes
DESCRIPTION	VARCHAR2	15	Yes

MFA

Contains Marine Fishing Area code, minimum and maximum lat, long and area in square metres(?) as calculated by ARCINFO.

AREA_CODE	**NUMBER**	**2**	No	**MFA_PK (Unique)**
MIN_POSITION_ID	NUMBER	5	No	
MAX_POSITION_ID	NUMBER	5	No	
AREA	NUMBER	15	Yes	

MONITORING

Stores addition data for each pot lift if the trip type is catch monitoring.

TRIP_DAY_ID	**NUMBER**	**5**	**No**	**MON_PK (Unique)**
POT_ORDER	**NUMBER**	**3**	**No**	**MON_PK (Unique)**
ESCAPE_GAP	CHAR	1	Yes	
BOTTOM_TEMP	NUMBER	4.2	Yes	
SURFACE_TEMP	NUMBER	4.2	Yes	

OLD_LOG_DATA

Historical Catch and Effort daily data.

TRIP_ID	**NUMBER**	**7**	No	**OLD_PK (Unique)**
DAY	**NUMBER**	**2**	No	**OLD_PK (Unique)**
AREA_CODE	NUMBER	2	Yes	
DEPTH	NUMBER	3	Yes	
POTS	NUMBER	3	Yes	
KING_CRAB_POTS	NUMBER	3	Yes	
SPECIES_CODE	VARCHAR2	3	Yes	
CATCH_WEIGHT	NUMBER	6.2	Yes	
CATCH_NUMBER	NUMBER	4	Yes	
OTHER_UNDERSIZE	NUMBER	4	Yes	
OTHER_DEAD	NUMBER	3	Yes	
OTHER_SPAWNERS	NUMBER	4	Yes	
OCTOPUS_WEIGHT	NUMBER	5.2	Yes	
OCTOPUS_NUMBER	NUMBER	2	Yes	
KING_CRAB_WEIGHT	NUMBER	5.2	Yes	
KING_CRAB_NUMBER	NUMBER	2	Yes	
BLOCK	NUMBER	5	Yes	

OLD_LOG_HEADER

Historical Catch and Effort monthly header for daily data.

TRIP_ID	**NUMBER**	**7**	No	**OLH_PK (Unique)**
LIC_NO	CHAR	4	Yes	
PLACE_OF_LANDING_CODE	VARCHAR2	3	No	
MONTH	NUMBER	2	No	OLH_YEAR_MONTH_IX
YEAR	NUMBER	4	No	OLH_YEAR_MONTH_IX
DEPTH_UNITS_CODE	CHAR	1	No	
WEIGHT_UNITS_CODE	CHAR	1	No	
NUMBER_UNITS_CODE	CHAR	1	No	
REGISTRATION_NO	VARCHAR2	4	Yes	
OWNER_CONTACT_ID	NUMBER	4	Yes	

OLD_LOG_LINK

Link between OLD_LOG_DATA and OLD_LOG_HEADER. This table is used so that a blank record can be returned for a day that is not fished rather than no record at all.

TRIP_ID	**NUMBER**	**7**	**No**	**OLL_PK (Unique)**
DAY	**NUMBER**	**2**	**No**	**OLL_PK (Unique)**

PLACE_OF_LANDING

Lookup table listing ports that fishermen report landing their catch in the Catch and Effort database.

PLACE_OF_LANDING_CODE	**VARCHAR2**	**3**	**No**	**POL_PK (Unique)**
PLACE_OF_LANDING	VARCHAR2	50	No	

PLEOPOD

Main and only table in the Pleopod database. Data entered through the Pleopod form.

LIC_NO	VARCHAR2	4	Yes
OWNER_CONTACT_ID	NUMBER	4	Yes
TRIP_DATE	DATE		Yes
POT_ORDER	NUMBER	3	Yes
LENGTH	NUMBER	4.1	Yes
LENGTH_DECIMAL	CHAR	1	Yes
SEX_CODE	CHAR	1	Yes
REPRODUCTIVE_STATE_CODE	CHAR	2	Yes
STAGE	VARCHAR2	2	Yes
COMMENTS	VARCHAR2	240	Yes

POSITION

This table contains all of the latitudes and longitudes used in the database, links to recapture, pot, etc.

POSITION_ID	**NUMBER**	**6**	**No**	**POS_PK (Unique)**
LAT_DEG	NUMBER	2	No	
LAT_MIN	NUMBER	5.3	No	
LONG_DEG	NUMBER	3	No	
LONG_MIN	NUMBER	5.3	No	

POSITION_ERROR

List of errors related to individual POSITION records.

POSITION_ID	**NUMBER**	**6**	**No**	**POS_ERROR_PK (Unique)**
ERROR_CODE	**NUMBER**	**3**	**No**	**POS_ERROR_PK (Unique)**
SUB_CODE	NUMBER	2	Yes	
COMMENTS	VARCHAR2	240	Yes	

POSITION_HISTORY

History of changes made to POSITION records.

POSITION_ID	NUMBER	6	Yes	POSITION_HISTORY_IX
LAT_DEG	NUMBER	2	Yes	
LAT_MIN	NUMBER	5.3	Yes	
LONG_DEG	NUMBER	3	Yes	
LONG_MIN	NUMBER	5.3	Yes	
MODIFICATION_USER	VARCHAR2	10	Yes	
MODIFICATION_DATE	DATE		Yes	

POT

Stores information relating to each pot that is pulled on a trip.

TRIP_DAY_ID	**NUMBER**	**5**	**No**	**POT_PK (Unique)**
POT_ORDER	**NUMBER**	**3**	**No**	**POT_PK (Unique)**
DEPTH	NUMBER	4.1	No	
GPS_ACCURACY_CODE	VARCHAR2	1	No	
POT_SAMPLING	VARCHAR2	1	No	

DOUBLE_LIFT	VARCHAR2	1	No	
TAGGER_CONTACT_ID	NUMBER	4	No	POT_TGRID_IX
POSITION_ID	NUMBER	6	No	POT_UNQ_POSID (Unique)
COMMENTS	VARCHAR2	240	Yes	
DEPTH_CONVERTED	NUMBER	10.7	Yes	
BOTTOM_TYPE_CODE	CHAR	1	Yes	
BOTTOM_CONDITION_CODE	CHAR	1	Yes	

POT_CAPTURE

Link between and individual capture record and the pot that it came from.

TRIP_DAY_ID	**NUMBER**	**5**	**No**	**PC_PK (Unique), PX_TDID_POT_IX**
POT_ORDER	**NUMBER**	**3**	**No**	**PC_PK (Unique), PX_TDID_POT_IX**
CAPTURE_ID	**NUMBER**	**6**	**No**	**PC_PK (Unique), PC_UNQ_CAPID (Unique)**

POT_ERROR

Errors relating to individual pots.

TRIP_DAY_ID	**NUMBER**	**5**	**No**	**POT_ERR_PK (Unique)**
POT_ORDER	**NUMBER**	**3**	**No**	**POT_ERR_PK (Unique)**
ERROR_CODE	**NUMBER**	**3**	**No**	**POT_ERR_PK (Unique)**
SUB_CODE	NUMBER	2	Yes	
COMMENTS	VARCHAR2		Yes	

POT_HISTORY

History of changes to individual pot records.

TRIP_DAY_ID	NUMBER	5	Yes	POT_HISTORY_IX
POT_ORDER	NUMBER	3	Yes	POT_HISTORY_IX
DEPTH	NUMBER	4.1	Yes	
GPS_ACCURACY_CODE	VARCHAR2	1	Yes	
POT_SAMPLING	VARCHAR2	1	Yes	
DOUBLE_LIFT	VARCHAR2	1	Yes	
TAGGER_CONTACT_ID	NUMBER	4	Yes	
POSITION_ID	NUMBER	6	Yes	
COMMENTS	VARCHAR2	240	Yes	
DEPTH_CONVERTED	NUMBER	10.7	Yes	
BOTTOM_TYPE_CODE	CHAR	1	Yes	
BOTTOM_CONDITION_CODE	CHAR	1	Yes	
MODIFICATION_USER	VARCHAR2	10	Yes	
MODIFICATION_DATE	DATE		Yes	

POT_PREDATOR

Link between a pot and the predators that can be found in them.

TRIP_DAY_ID	**NUMBER**	**5**	**No**	**PP_PK (Unique)**
POT_ORDER	**NUMBER**	**3**	**No**	**PP_PK (Unique)**
PREDATOR_ID	**NUMBER**	**2**	**No**	**PP_PK (Unique), PP_IX_PREDID**
NUMBER_OF_PRED	NUMBER	2	Yes	

PREDATOR

A list of the predators that can be found in a pot.

PREDATOR_ID	**NUMBER**	**2**	**No**	**PRED_PK (Unique)**
PREDATOR_CODE	CHAR	2	No	PRED_UNQ_PRED (Unique)
PREDATOR	VARCHAR2	30	No	
AFFECT_DATA	CHAR	1	No	

RECAPTURE

Information relating the a recapture of a lobster.

CAPTURE_ID	**NUMBER**	**6**	**No**	**RECAP_PK (Unique)**

RECAPTURE_DATE	DATE		No	
GPS_ACCURACY_CODE	VARCHAR2	1	No	
DEPTH_UNITS_CODE	VARCHAR2	1	No	
DEPTH	NUMBER	4.1	No	
POSITION_ID	NUMBER	6	Yes	RECAP_UNQ_POSID (Unique)
RECAPTURER_CONTACT_ID	NUMBER	4	Yes	
LIC_NO	VARCHAR2	4	Yes	RECAP_LIC_NO_IX
RECAPTURER_NAME	VARCHAR2	60	Yes	
COMMENTS	VARCHAR2	240	Yes	
DEPTH_CONVERTED	NUMBER	10.7	Yes	
OWNER_CONTACT_ID	NUMBER	4	Yes	
BOTTOM_TYPE_CODE	CHAR	1	Yes	
BOTTOM_CONDITION_CODE	CHAR	1	Yes	

RECAPTURE_DISTANCE

This table is used by the RECAPTURE REPORT, the records contain the distance and direction moved between recaptures and should be recalculated before the report is run.

TAG_NUMBER	**NUMBER**	6	No	**RECAP_DIST_PK (Unique)**
RECAPTURE_DATE	**DATE**		No	**RECAP_DIST_PK (Unique)**
DISTANCE	NUMBER		Yes	
DIRECTION	CHAR	3	Yes	

RECAPTURE_ERROR

Error relating to individual recapture records.

CAPTURE_ID	**NUMBER**	6	No	**RECAP_ERR_PK (Unique)**
ERROR_CODE	**NUMBER**	3	No	**RECAP_ERR_PK (Unique)**
SUB_CODE	NUMBER	2	Yes	
COMMENTS	VARCHAR2	240	Yes	

RECAPTURE_HISTORY

History of changed made to recapture records.

CAPTURE_ID	NUMBER	6	Yes	RECAPTURE_HISTORY_IX
RECAPTURE_DATE	DATE		Yes	
GPS_ACCURACY_CODE	VARCHAR2	1	Yes	
DEPTH_UNITS_CODE	VARCHAR2	1	Yes	
DEPTH	NUMBER	4.1	Yes	
POSITION_ID	NUMBER	6	Yes	
RECAPTURER_CONTACT_ID	NUMBER	4	Yes	
LIC_NO	VARCHAR2	4	Yes	
RECAPTURER_NAME	VARCHAR2	60	Yes	
COMMENTS	VARCHAR2	240	Yes	
DEPTH_CONVERTED	NUMBER	10.7	Yes	
OWNER_CONTACT_ID	NUMBER	4	Yes	
BOTTOM_TYPE_CODE	CHAR	1	Yes	
BOTTOM_CONDITION_CODE	CHAR	1	Yes	
MODIFICATION_USER	VARCHAR2	10	Yes	
MODIFICATION_DATE	DATE		Yes	

RECAPTURE_LOG

Table used to log the progress of the recapture distance scripts used for the recapture/tagging reports.

TAG_NUMBER	NUMBER	6	Yes
RECAPTURE_DATE	DATE		Yes
ERROR_CODE	NUMBER		Yes

RECAPTURE_POSITION

Temporary table used in Recapture & Tagger reports, and some other scripts. Holds the position of each recapture of a lobster.

TAG_NUMBER	NUMBER	6	No	RECAPTURE_POSITION_IX
RECAPTURE_DATE	DATE		No	
LATITUDE	NUMBER		Yes	
LONGITUDE	NUMBER		Yes	

RECAPTURE_REPORT

This table is simply an optimisation in the development of the Recapture Report. The table is created as a select * from the RECAPTURE_BY_RECAPTURER_VIEW and is only used because using the view directly is too slow.

CAPTURE_ID	NUMBER	6	Yes
CONTACT_ID	NUMBER	4	Yes
RECAPTURER_CONTACT_ID	NUMBER	4	Yes
TAG_NUMBER	NUMBER	6	Yes
RECAPTURE_DATE	DATE		Yes
POSITION_ID	NUMBER		Yes

RECAPTURE_REPORT_DONE

This table records each recapture once it has been reported in a Recapture Report, this is for Incremental Recapture Reports, so that lobsters aren't reported twice. It should probably use CAPTURE_ID rather that RECAPTURE_DATE and TAG_NUMBER, as these sometimes change is an error is discovered in those fields.

TAG_NUMBER	**NUMBER**	6	No	**RRD_PK (Unique)**
RECAPTURE_DATE	**DATE**		No	**RRD_PK (Unique)**
REPORT_DATE	DATE		No	

REF_CODES

This table was originally created to duplicate the field constraints, within forms, from Oracle version 7 in Oracle version 6. It is gradually being phased out, and replaced with real constraints and the LOV_% tables.

RV_DOMAIN	VARCHAR2	100	Yes	RC_IX_DOMAIN
RV_LOW_VALUE	VARCHAR2	240	Yes	
RV_HIGH_VALUE	VARCHAR2	240	Yes	
RV_MEANING	VARCHAR2	240	Yes	
RV_ABBREVIATION	VARCHAR2	240	Yes	
RV_TYPE	VARCHAR2	10	Yes	

REGISTRATION

This table will (could?) eventually be used once the old log data (pre-1982) has been entered to link registration number and owner to licence number.

REGISTRATION_NO	VARCHAR2	4	Yes
LIC_NO	CHAR	4	Yes
OWNER_CONTACT_ID	NUMBER	4	Yes

RELEASE_INFO

Position and depth of recaught lobsters that were released in a different position from were they caught.

CAPTURE_ID	**NUMBER**	6	No	**REL_PK (Unique)**
POSITION_ID	NUMBER	6	Yes	REL_UNQ_POS (Unique)
DEPTH_UNITS_CODE	VARCHAR2	1	Yes	
DEPTH	NUMBER	4.1	Yes	
DEPTH_CONVERTED	NUMBER	10.7	Yes	

TAG

Contains different types of tags used in the tagging program. Pretty redundant considering only one type of tag has been used.

TAG_TYPE	**VARCHAR2**	**8**	**No**	**TAG_PK (Unique)**
COLOUR	VARCHAR2	20	Yes	
DESCRIPTION	VARCHAR2	240	Yes	
LOW_VALUE	NUMBER	6	Yes	
HIGH_VALUE	NUMBER	6	Yes	

TAGGERS

This table is used to determine what type of tagger (ie. volunteer, biologist) a person is and when they fist became that type. This table is more reliable than the CAPTURER_TYPE_ID field in the capture table.

CONTACT_ID	NUMBER	4	No
CAPTURER_TYPE_ID	NUMBER	2	No
START_DATE	DATE		Yes

TAGGER_REPORT

This table is simply an optimisation in the development of the Tagger Report. The table is created as a select * from the RECAPTURE_BY_TAGGER_VIEW and is only used because using the view directly is too slow.

CAPTURE_ID	NUMBER	6	Yes
CONTACT_ID	NUMBER	4	No
RECAPTURER_CONTACT_ID	NUMBER	4	Yes
TAG_NUMBER	NUMBER	6	No
RECAPTURE_DATE	DATE		No
POSITION_ID	NUMBER		Yes

TARGETED_SPECIES

Lookup table of the types of fish that fishermen try to catch for the Catch and Effort database.

SPECIES_CODE	**VARCHAR2**	**3**	**No**	**TS_PK (Unique)**
SPECIES	VARCHAR2	30	No	

TEAM

USERNAME	VARCHAR2	30	Yes
ROLE	VARCHAR2	30	Yes

TRIP_DAY

TRIP_DAY_ID	**NUMBER**	**5**	**No**	**TD_PK (Unique)**
LIC_NO	VARCHAR2	4	No	TD_UNQ_LIC_DATE (Unique)
TRIP_DATE	DATE		No	TD_UNQ_LIC_DATE (Unique)
DEPTH_UNITS_CODE	VARCHAR2	1	No	
TRIP_TYPE	VARCHAR2	1	No	
WIND_DIRECTION_CODE	VARCHAR2	3	No	
SWELL_HEIGHT	NUMBER	4.2	Yes	
WIND_SPEED	NUMBER	2	Yes	
RECORDER	VARCHAR2	240	Yes	
LOCATION	VARCHAR2	240	Yes	
OWNER_CONTACT_ID	NUMBER	4	No	
CURRENT_DIRECTION	VARCHAR2	3	Yes	

TRIP_DAY_ERROR

TRIP_DAY_ID	**NUMBER**	**5**	**No**	**TD_ERR_PK (Unique)**
ERROR_CODE	**NUMBER**	**3**	**No**	**TD_ERR_PK (Unique)**
SUB_CODE	NUMBER	2	Yes	
COMMENTS	VARCHAR2	240	Yes	

TRIP_DAY_HISTORY

TRIP_DAY_ID	NUMBER	5	Yes	TRIP_DAY_HISTORY_IX
LIC_NO	VARCHAR2	4	Yes	
TRIP_DATE	DATE		Yes	
DEPTH_UNITS_CODE	VARCHAR2	1	Yes	
TRIP_TYPE	VARCHAR2	1	Yes	
WIND_DIRECTION_CODE	VARCHAR2	3	Yes	
SWELL_HEIGHT	NUMBER	4.2	Yes	
WIND_SPEED	NUMBER	2	Yes	
RECORDER	VARCHAR2	60	Yes	
LOCATION	VARCHAR2	240	Yes	
OWNER_CONTACT_ID	NUMBER	4	Yes	
CURRENT_DIRECTION	VARCHAR2	3	Yes	
MODIFICATION_USER	VARCHAR2	10	Yes	
MODIFICATION_DATE	DATE		Yes	

VESSEL

Main table in the gear and vessel database. One record for each fishing vessel in the database.

VESSEL_ID	**NUMBER**	**5**	**No**	**PK_VESSEL (Unique)**
LIC_NO	CHAR	4	No	UQ_LIC_YEAR (Unique)
YEAR_OF_ENTRY	NUMBER	4	No	UQ_LIC_YEAR (Unique)
VESSEL_NAME	VARCHAR2	20	No	
DECK_HANDS	NUMBER	1	Yes	
HOME_PORT	VARCHAR2	3	Yes	
VESSEL_MANUFACTURER_ID	NUMBER	3	Yes	
YEAR_OF_PURCHASE	NUMBER	4	Yes	
YEAR_OF_CONSTRUCTION	NUMBER	4	Yes	
HULL_DESIGN_CODE	CHAR	1	Yes	
HULL_CONSTRUCTION_CODE	CHAR	1	Yes	
CRUISING_SPEED	NUMBER	3.1	Yes	
MAXIMUM_SPEED	NUMBER	3.1	Yes	
BOAT_LENGTH_METRES	NUMBER	4.2	Yes	
BOAT_LENGTH_FEET	NUMBER	2	Yes	
BOAT_LENGTH_INCHES	NUMBER	2	Yes	
BEAM_METRES	NUMBER	4.2	Yes	
BEAM_FEET	NUMBER	2	Yes	
BEAM_INCHES	NUMBER	2	Yes	
UNLADEN_DRAUGHT_METRES	NUMBER	4.2	Yes	
UNLADEN_DRAUGHT_FEET	NUMBER	2	Yes	
UNLADEN_DRAUGHT_INCHES	NUMBER	2	Yes	
GROSS_TONNAGE	NUMBER	3.1	Yes	
MAXIMUM_DAYS	NUMBER	2	Yes	
NUMBER_OF_ENGINES	NUMBER	1	Yes	
ENGINE_MANUFACTURER_ID	NUMBER	3	Yes	
ENGINE_YEAR_OF_MAKE	NUMBER	4	Yes	
ENGINE_MODEL	VARCHAR2	20	Yes	
ENGINE_BRAKE_HORSEPOWER	NUMBER	4	Yes	
ENGINE_FUEL_TYPE_CODE	CHAR	1	Yes	
ENGINE_FUEL_CAPACITY	NUMBER	5	Yes	
AUX_ENGINE_MANUFACTURER_ID	NUMBER	3	Yes	
AUX_ENGINE_YEAR_OF_MAKE	NUMBER	4	Yes	
AUX_ENGINE_MODEL	VARCHAR2	20	Yes	
AUX_ENGINE_OUTPUT	NUMBER	3.1	Yes	
AUX_2ND_ENGINE_MANUFACTURER_ID	NUMBER	3	Yes	
AUX_2ND_ENGINE_YEAR_OF_MAKE	NUMBER	4	Yes	

AUX_2ND_ENGINE_MODEL	VARCHAR2	20	Yes
AUX_2ND_ENGINE_OUTPUT	NUMBER	3.1	Yes
POT_WEIGHT	NUMBER	2	Yes
LARGE_POTS	NUMBER	2	Yes
STANDARD_POTS	NUMBER	2	Yes
ESCAPE_GAPS	NUMBER	3	Yes
WELL_CAPACITY	NUMBER	2	Yes
TANK_CAPACITY	NUMBER	3.1	Yes
FREEZER	CHAR	1	Yes
COMMENTS	VARCHAR2	240	Yes

VESSEL_MANUFACTURER

Lookup table of the names of manufacturers for the gear and vessel database.

VESSEL_MANUFACTURER_ID	**NUMBER**	**3**	**No**	**PK_VESSEL_MANUF (Unique)**
VESSEL_MANUFACTURER	VARCHAR2	20	No	UQ_VESL_MANUF (Unique)

ZONE

This lookup table breaks the MFA's into common zones, currently the North and South fishing zones, North, Central & South 'research' zones and growth zones.

AREA_CODE	NUMBER	2	No	Z_AREA_IX
ZONE	CHAR	1	No	
SUBZONE	CHAR	1	Yes	
GROWTH_ZONE	VARCHAR2	5	Yes	

Views

AREA_VIEW

Links MFA, ZONE and POSITION tables to provide all the information relating to MFA's.

```
select m.area_code, z.zone, z.subzone, z.growth_zone,
        p1.latitude min_latitude, p1.longitude min_longitude,
        p2.latitude max_latitude, p2.longitude max_longitude
from mfa m, zone z, position_dd p1, position_dd p2
where z.area_code(+) = m.area_code
and p1.position_id = m.min_position_id
and p2.position_id = m.max_position_id
```

CAPTURE_ERROR_VIEW

Link CAPTURE_ERROR and ERROR_CODES tables to provide descriptions and comments with errors.

```
select ce.capture_id, severity, description, comments
from error_codes ec, capture_error ce
where ec.error_code = ce.error_code
  and ec.sub_code = ce.sub_code
```

CAPTURE_VIEW

View used in forms.

```
select pc.trip_day_id, pc.pot_order, c.*, l.position_tagged_code,
        d.l1, d.l2, d.l3, d.l4, d.l5, d.la,
        d.r1, d.r2, d.r3, d.r4, d.r5, d.ra
from pot_capture pc, capture c, damage_view d, lobster l
where c.capture_id = pc.capture_id
and d.capture_id = pc.capture_id
and l.tag_number = c.tag_number
```

DAMAGE_VIEW

Alternate format for DAMAGE table.

```
select c.capture_id,l1.damage_code l1,l2.damage_code l2,l3.damage_code l3,
        l4.damage_code l4,l5.damage_code l5,la.damage_code la,
        r1.damage_code r1,r2.damage_code r2,r3.damage_code r3,r4.damage_code r4,
        r5.damage_code r5,ra.damage_code ra
        from damage l1,damage l2,damage l3,damage l4,damage l5,damage la,
        damage r1,damage r2,damage r3,damage r4,damage r5,damage ra,capture c
        where l1.capture_id(+) = c.capture_id
                and l1.appendage_code(+) = 'L1'
                and l2.capture_id(+) = c.capture_id
                and l2.appendage_code(+) = 'L2'
                and l3.capture_id(+) = c.capture_id
                and l3.appendage_code(+) = 'L3'
                and l4.capture_id(+) = c.capture_id
                and l4.appendage_code(+) = 'L4'
                and l5.capture_id(+) = c.capture_id
                and l5.appendage_code(+) = 'L5'
                and la.capture_id(+) = c.capture_id
                and la.appendage_code(+) = 'LA'
                and r1.capture_id(+) = c.capture_id
                and r1.appendage_code(+) = 'R1'
                and r2.capture_id(+) = c.capture_id
                and r2.appendage_code(+) = 'R2'
                and r3.capture_id(+) = c.capture_id
                and r3.appendage_code(+) = 'R3'
                and r4.capture_id(+) = c.capture_id
                and r4.appendage_code(+) = 'R4'
                and r5.capture_id(+) = c.capture_id
                and r5.appendage_code(+) = 'R5'
                and ra.capture_id(+) = c.capture_id
                and ra.appendage_code(+) = 'RA'
```

EQUIPMENT_VIEW

```
select vessel_id, e.equipment_type_code, equipment_type,
        e.equipment_manufacturer_id, equipment_manufacturer,
        equipment_model
from equipment e, equipment_manufacturer em, equipment_type et
where em.equipment_manufacturer_id = e.equipment_manufacturer_id
        and et.equipment_type_code = e.equipment_type_code
```

LAST_RETURN

This view is used in the catch and effort forms to fill in the month for a new return.

```
select lic_no, to_date('01'||to_char(month,'00')||to_char(year,'0000'),
  'DDMMYYYY') date_of_last_return
  from log_header lh1
  where to_number(to_char(to_date('01' ||to_char(month,'00')||
to_char(year,'0000'),'DDMMYYYY'),'J')) =
   (
    select max(to_number(to_char(to_date('01' ||to_char(month,'00')||
to_char(year,'0000'),'DDMMYYYY'),'J')))
     from log_header lh2
     where lh2.lic_no = lh1.lic_no
   )
```

LOBSTER_ERROR_VIEW

Link LOBSTER_ERROR and ERROR_CODES tables to provide descriptions and comments with errors.

```
select le.lobster_id, severity, description, comments
from error_codes ec, lobster_error le
where ec.error_code = le.error_code
  and ec.sub_code = le.sub_code
```

LOG_DATA_ERROR_VIEW

Link LOG_DATA_ERROR and ERROR_CODES tables to provide descriptions and comments with errors.

```
select lde.trip_id, lde.day, severity, description, comments
from error_codes ec, log_data_error lde
where ec.error_code = lde.error_code
  and ec.sub_code = lde.sub_code
```

LOG_DATA_VIEW

The main view for looking and the post-1993 catch and effort data.

```
select lh.trip_id,lh.lic_no,date_mgmt.season_my(lh.month, lh.year) season,
                date_mgmt.dmy_to_date(ld.day,lh.month,lh.year) trip_date,
    lh.year,lh.month,ld.day,lh.place_of_landing_code,
    lh.depth_units_code,ld.depth,ld.depth_entered,ld.area_code,ld.pots,
    ld.species_code,lw.catch_weight,ld.catch_number,ld.other_undersize,
    ld.other_dead,ld.other_spawners,lw.octopus_weight,ld.octopus_number,
    lw.king_crab_weight,ld.king_crab_number,ld.king_crab_pots,
                ld.catch_weight catch_weight_entered,
                ld.octopus_weight octopus_weight_entered,
                ld.king_crab_weight king_crab_weight_entered
   from log_header lh,log_data ld, log_weight lw
   where ld.trip_id = lh.trip_id
                and lw.trip_id = lh.trip_id
                and lw.day = ld.day
```

LOG_DETAIL

This view is used within the catch and effort form, it is used so that days that aren't fished till show up in the form.

```
select ll.trip_id,ll.day,trip_date,area_code,depth,depth_entered,
pots,species_code,
    catch_weight,catch_number,other_undersize,other_dead,other_spawners,
    octopus_weight,octopus_number,king_crab_weight,king_crab_number,king_crab_p
ots
   from log_data ld, log_link ll
    where ld.trip_id(+) = ll.trip_id
    and ld.day(+) = ll.day
```

LOG_HEADER_ERROR_VIEW

Link LOG_HEADER_ERROR and ERROR_CODES tables to provide descriptions and comments with errors.

```
select lhe.trip_id, severity, description, comments
from error_codes ec, log_header_error lhe
where ec.error_code = lhe.error_code
  and ec.sub_code = lhe.sub_code
```

LOG_SEASON_VIEW

LOG_VIEW with season field added.

```
select lh.trip_id,lh.lic_no,date_mgmt.season_my(lh.month,lh.year) season,
    date_mgmt.dmy_to_date(ll.day,lh.month,lh.year) trip_date,
    lh.year,lh.month,ll.day,lh.place_of_landing_code,
    lh.depth_units_code,ld.depth,ld.depth_entered,ld.area_code,ld.pots,
    ld.species_code,lw.catch_weight,ld.catch_number,ld.other_undersize,
    ld.other_dead,ld.other_spawners,lw.octopus_weight,ld.octopus_number,
    lw.king_crab_weight,ld.king_crab_number,ld.king_crab_pots,
    ld.catch_weight catch_weight_entered,
    ld.octopus_weight octopus_weight_entered,
    ld.king_crab_weight king_crab_weight_entered
 from log_header lh,log_link ll,log_data ld, log_weight lw
 where ld.trip_id(+) = ll.trip_id
      and ld.day(+) = ll.day
      and lw.trip_id(+) = ll.trip_id
      and lw.day(+) = ll.day
      and ll.trip_id = lh.trip_id
```

LOG_VIEW

Another view of the catch and effort data, this one is used within the forms.

```
select lh.trip_id,lh.lic_no,date_mgmt.dmy_to_date(ll.day,lh.month,lh.year) trip
_date,
    lh.year,lh.month,ll.day,lh.place_of_landing_code,
    lh.depth_units_code,ld.depth,ld.depth_entered,ld.area_code,ld.pots,
ld.other_dead,ld.other_spawners,lw.octopus_weight,ld.octopus_number,
    lw.king_crab_weight,ld.king_crab_number,ld.king_crab_pots,
    ld.catch_weight catch_weight_entered,
    ld.octopus_weight octopus_weight_entered,
    ld.king_crab_weight king_crab_weight_entered
 from log_header lh,log_link ll,log_data ld, log_weight lw
 where ld.trip_id(+) = ll.trip_id
      and ld.day(+) = ll.day
      and lw.trip_id(+) = ll.trip_id
      and lw.day(+) = ll.day
      and ll.trip_id = lh.trip_id
```

LOV

List of Values, this view is used within forms to simplify list of values handling.

```
select field_name, abbreviation, meaning
        from lov_fields f, lov_values v
        where v.domain = f.domain
```

OLD_LOG_DATA_VIEW

View used in old catch and effort form.

```
select lh.trip_id,lh.lic_no,
  date_mgmt.dmy_to_date(ld.day,lh.month,lh.year) trip_date,
  lh.year,lh.month,ld.day,lh.place_of_landing_code,
  decode(lh.depth_units_code, 'F',ld.depth*1.8288, ld.depth) depth,
  ld.area_code, ld.pots, ld.king_crab_pots, ld.species_code,
  decode(lh.weight_units_code, 'P',ld.catch_weight*0.45359237, ld.catch_weight)
catch_weight,
  decode(lh.number_units_code, 'D',ld.catch_number*12, ld.catch_number) catch_number,
  ld.other_undersize, ld.other_dead,ld.other_spawners,
  ld.octopus_weight,ld.octopus_number,
  ld.king_crab_weight,ld.king_crab_number
 from old_log_header lh, old_log_data ld
 where ld.trip_id = lh.trip_id
```

OLD_LOG_DETAIL

View used in old catch and effort form.

```
select ll.trip_id,ll.day, area_code, block, depth,
        pots, king_crab_pots, species_code,
        catch_weight,catch_number,
        other_undersize,other_dead,other_spawners,
  octopus_weight,octopus_number,
        king_crab_weight,king_crab_number
 from old_log_data ld, old_log_link ll
 where ld.trip_id(+) = ll.trip_id
  and ld.day(+) = ll.day
```

OLD_LOG_SEASON_VIEW

Old catch and effort data view, joins all of it, plus season.

```
select lh.trip_id,lh.lic_no,date_mgmt.season_my(lh.month, lh.year) season,
  date_mgmt.dmy_to_date(ll.day,lh.month,lh.year) trip_date,
  lh.year,lh.month,ll.day,lh.place_of_landing_code,
  decode(lh.depth_units_code, 'F',ld.depth*1.8288, ld.depth) depth,
  ld.area_code, ld.pots, ld.king_crab_pots, ld.species_code,
  decode(lh.weight_units_code, 'P',ld.catch_weight*0.45359237, ld.catch_weight)
catch_weight,
  decode(lh.number_units_code, 'D',ld.catch_number*12, ld.catch_number) catch_number,
  ld.other_undersize, ld.other_dead,ld.other_spawners,
  ld.octopus_weight,ld.octopus_number,
  ld.king_crab_weight,ld.king_crab_number
 from old_log_header lh, old_log_link ll, old_log_data ld
 where ld.trip_id(+) = ll.trip_id
   and ld.day(+) = ll.day
   and ll.trip_id = lh.trip_id
```

OLD_LOG_VIEW

Old catch and effort data view, joins all of it, plus season.

```
select lh.trip_id,lh.lic_no,
  date_mgmt.dmy_to_date(ll.day,lh.month,lh.year) trip_date,
  lh.year,lh.month,ll.day,lh.place_of_landing_code,
  decode(lh.depth_units_code, 'F',ld.depth*1.8288, ld.depth) depth,
  ld.area_code, ld.pots, ld.king_crab_pots, ld.species_code,
  decode(lh.weight_units_code, 'P',ld.catch_weight*0.45359237, ld.catch_weight)
catch_weight,
  decode(lh.number_units_code, 'D',ld.catch_number*12, ld.catch_number) catch_number,
  ld.other_undersize, ld.other_dead,ld.other_spawners,
  ld.octopus_weight,ld.octopus_number,
  ld.king_crab_weight,ld.king_crab_number
 from old_log_header lh, old_log_link ll, old_log_data ld
 where ld.trip_id(+) = ll.trip_id
   and ld.day(+) = ll.day
   and ll.trip_id = lh.trip_id
```

PLEOPOD_ERROR_VIEW

An attempt to match pleopod data to tagging data to indicate where errors might be.

```
select td.lic_no, td.owner_contact_id, td.trip_date, c.length,
p.pot_order pot_order
from trip_day td, pot p, pot_capture pc, capture c
where c.capture_id = pc.capture_id
and pc.trip_day_id = p.trip_day_id
and pc.pot_order = p.pot_order
and p.trip_day_id = td.trip_day_id
and td.trip_date >= (
   select min(trip_date)
   from pleopod)
```

POSITION_DD

Conversion of position table to decimal degrees.

```
select position_id,lat_deg+lat_min/60.0 latitude, long_deg+long_min/60.0 Longitude
from position
```

POSITION_ERROR_VIEW

Link POSITION_ERROR and ERROR_CODES tables to provide descriptions and comments with errors.

```
select pe.position_id, severity, description, comments
  from error_codes ec, position_error pe
  where ec.error_code = pe.error_code
    and ec.sub_code = pe.sub_code
```

POSITION_VIEW

Handy view that contains capture position and recapture position.

```
select tag_number, trip_date,p1.latitude cap_lat,p1.longitude cap_long,
recapture_date, p2.latitude rel_lat,p2.longitude rel_long
from position_dd p1,position_dd p2,capture c,pot_capture pc,pot p,recapture r,t
rip_day td
where p2.position_id(+) = r.position_id
and p1.position_id(+) = p.position_id
and td.trip_day_id(+) = p.trip_day_id
and p.trip_day_id(+) = pc.trip_Day_id
and p.pot_order(+) = pc.pot_order
and pc.capture_id(+) = c.capture_id
```

```
and r.capture_id(+) = c.capture_id
```

POT_ERROR_VIEW

Link POT_ERROR and ERROR_CODES tables to provide descriptions and comments with errors.

```
select pe.trip_day_id, pe.pot_order, severity, description, comments
from error_codes ec, pot_error pe
where ec.error_code = pe.error_code
  and ec.sub_code = pe.sub_code
```

POT_POSITION

Used in trip day form.

```
select
        p.trip_day_id,
        p.pot_order,
        p.depth,
        p.gps_accuracy_code,
        p.pot_sampling,
        p.double_lift,
        p.tagger_contact_id,
        p.position_id,
        p.comments,
        p.depth_converted,
        p.bottom_type_code,
        p.bottom_condition_code,
        pn.lat_deg,
        pn.lat_min,
        pn.long_deg,
        pn.long_min
 from pot p,
        position pn
 where pn.position_id = p.position_id
```

POT_VIEW

Expanded pot view to include monitoring data and position.

```
select pot.*, p.lat_deg,p.lat_min, p.long_deg,p.long_min,
      m.escape_gap, m.bottom_temp, m.surface_temp
from pot, monitoring m, position p
where p.position_id = pot.position_id
  and m.trip_day_id(+) = pot.trip_day_id
  and m.pot_order(+) = pot.pot_order
```

PP_VIEW

Pot position view, this view is used by ARCINFO to convert pot positions to MFA's.

```
select trip_day_id*1000+pot_order pot_id, longitude,latitude*-1 latitude,
      trip_day_id, pot_order
from pot,position_dd p
where p.position_id = pot.position_id
```

PREDATOR_VIEW

View to links predators in a pot.

```
select pp.*, p.predator_code, p.predator
from pot_predator pp, predator p
where p.predator_id = pp.predator_id
```

RECAPTURE_BY_LICNO_VIEW

View to be used in producing recapture report for licence holders.

```
select distinct c.capture_id, r1.lic_no lic_no, r2.lic_no recapturer_lic_no,
      c.tag_number, r2.recapture_date,
      decode (r1.lic_no, r2.lic_no, r2.position_id, null) position_id
from recapture r1,recapture r2, capture c
where c.capture_id = r2.capture_id
and c.tag_number in (
      select tag_number
      from capture c2, recapture r3
      where c2.capture_id = r3.capture_id
        and r3.lic_no = r1.lic_no)
```

RECAPTURE_BY_RECAPTURER_VIEW

View used to produce recapture report for recapturer.

```
select distinct c.capture_id,
       r1.recapturer_contact_id contact_id, r2.recapturer_contact_id,
       c.tag_number, r2.recapture_date,
       decode (r1.recapturer_contact_id, r2.recapturer_contact_id, r2.position_id,
       null) position_id
from recapture r1,recapture r2, capture c
where c.capture_id = r2.capture_id
  and c.tag_number in (
       select tag_number
       from capture c2, recapture r3
       where c2.capture_id = r3.capture_id
         and r3.recapturer_contact_id = r1.recapturer_contact_id)
```

RECAPTURE_BY_TAGGER_VIEW

View used to produce recapture by tagger report.

```
select r.capture_id, p.tagger_contact_id contact_id,
       r.recapturer_contact_id, rc.tag_number, r.recapture_date,
decode(p.tagger_contact_id, r.recapturer_contact_id,r.position_id, null) position_id
from recapture r, capture rc, capture cc, pot_capture pc, pot p
where pc.trip_day_id = p.trip_day_id
  and pc.pot_order = p.pot_order
  and cc.capture_id = pc.capture_id
  and cc.lobster_id != -1
  and rc.lobster_id = cc.lobster_id
  and rc.capture_status_code = 'R'
  and r.capture_id = rc.capture_id
```

RECAPTURE_ERROR_VIEW

Link RECAPTURE_ERROR and ERROR_CODES tables to provide descriptions and comments with errors.

```
select pe.capture_id, severity, description, comments
from error_codes ec, recapture_error pe
where ec.error_code = pe.error_code
  and ec.sub_code = pe.sub_code
```

RECAPTURE_VIEW

Main view used in recapture report.

```
select r.capture_id, r.recapture_date, r.recapturer_name,
       r.recapturer_contact_id, r.lic_no, r.gps_accuracy_code,
       r.depth_units_code, r.depth, r.depth_converted,
       r.position_id, r.comments, r.owner_contact_id,
       r.bottom_type_code, r.bottom_condition_code,
       pn.lat_deg, pn.lat_min, pn.long_deg, pn.long_min,
       cap.tag_number, cap.lobster_id, cap.length,
       cap.length_decimal, cap.colour_code, cap.sex_code,
       cap.reproductive_state_code, cap.moult_state_code,
       cap.capture_status_code, cap.release_status_code,
       cap.capturer_type_id, ri.position_id rel_position_id,
       ri.depth_units_code rel_depth_units_code, ri.depth rel_depth,
       ri.depth_converted rel_depth_converted, rpn.lat_deg rel_lat_deg,
       rpn.lat_min rel_lat_min, rpn.long_deg rel_long_deg, rpn.long_min rel_long_min
 from recapture r, position pn, capture cap, release_info ri, position rpn
 where pn.position_id(+) = r.position_id
   and cap.capture_id  = r.capture_id
   and ri.capture_id(+) = r.capture_id
   and rpn.position_id(+) = ri.position_id
```

RELATE

Utility view, shows relationship between tables, according to primary and foreign keys.

```
select a.table_name parent, b.table_name child
from user_constraints a, user_constraints b
where b.r_constraint_name = a.constraint_name
and a.constraint_type = 'P'
```

RELEASE_POSITION

Don't know if this view is used anymore.

```
select ri.capture_id, ri.depth_units_code, ri.depth,
    ri.position_id, pn.lat_deg, pn.lat_min, pn.long_deg, pn.long_min
from release_info ri, position pn
where pn.position_id(+) = ri.position_id
```

RIP_VIEW

Another ARCINFO view, to convert release position to MFA.

```
select capture_id, longitude,latitude*-1 latitude
from release_info r, position_dd p
where p.position_id = r.position_id
```

RP_VIEW

Another ARCINFO view, to convert recapture position to MFA.

```
select capture_id, longitude, latitude*-1 latitude
from recapture r,position_dd p
where p.position_id = r.position_id
```

TAGGING_VIEW

View used within trip day form.

```
select pc.trip_day_id, pc.pot_order, pc.capture_id,
  c.tag_number, c.length, c.length_decimal,
  c.colour_code, c.sex_code, c.reproductive_state_code,
  c.moult_state_code, c.capture_status_code, c.release_status_code,
  c.capturer_type_id, l.lobster_id, l.tag_type,
  l.position_tagged_code, ct.capturer_type_code, ct.class
from pot_capture pc, capture c, lobster l, capturer_type ct
where pc.capture_id = c.capture_id
  and l.tag_number = c.tag_number
  and c.capturer_type_id = ct.capturer_type_id
```

TAG_VIEW

Information about when a lobster was tagged and recaught.

```
select td.lic_no,td.trip_date,pc.pot_order,
  l.tag_number,l.lobster_id,
  r.lic_no rlic_no,r.recapture_date,
  c.sex_code,c.length
from lobster l,capture c,pot_capture pc,trip_day td,recapture r
where td.trip_day_id(+) = pc.trip_day_id
  and pc.capture_id(+) = c.capture_id
  and c.tag_number(+) = l.tag_number
  and r.capture_id(+) = c.capture_id
```

TRIP_DAY_ERROR_VIEW

Link TRIP_DAY_ERROR and ERROR_CODES tables to provide descriptions and comments with errors.

```
select tde.trip_day_id, severity, description, comments
from error_codes ec, trip_day_error tde
where ec.error_code = tde.error_code
  and ec.sub_code = tde.sub_code
```

TRIP_DAY_SEASON

Trip day table with season field added.

```
select trip_day_id, date_mgmt.season(trip_date) season
from trip_day
```

VESSEL_VIEW

View containing all the info about vessels.

```
select vessel_id, lic_no, year_of_entry,
  vessel_name, deck_hands, home_port,
  v.vessel_manufacturer_id, vessel_manufacturer,
  year_of_purchase, year_of_construction,
  v.hull_design_code, hull_design,
  v.hull_construction_code, hull_construction,
  cruising_speed, maximum_speed,
  boat_length_metres, boat_length_feet, boat_length_inches,
  beam_metres, beam_feet, beam_inches,
  unladen_draught_metres, unladen_draught_feet, unladen_draught_inches,
  gross_tonnage, maximum_days, number_of_engines,
  v.engine_manufacturer_id, e1.engine_manufacturer,
  engine_year_of_make, engine_model, engine_brake_horsepower,
  v.engine_fuel_type_code, engine_fuel_type,
  engine_fuel_capacity,
  v.aux_engine_manufacturer_id, e2.engine_manufacturer aux_engine_manufacturer,
  aux_engine_year_of_make, aux_engine_model, aux_engine_output,
```

```
  v.aux_2nd_engine_manufacturer_id,
  e3.engine_manufacturer aux_2nd_engine_manufacturer,
  aux_2nd_engine_year_of_make, aux_2nd_engine_model, aux_2nd_engine_output,
  pot_weight, large_pots, standard_pots,
  large_pots+standard_pots total_pots, escape_gaps,
  well_capacity, tank_capacity, freezer
from vessel v, engine_manufacturer el, engine_manufacturer e2,
  engine_manufacturer e3, hull_construction hc, hull_design hd,
  vessel_manufacturer vm, engine_fuel_type ft
where el.engine_manufacturer_id(+) = v.engine_manufacturer_id
  and e2.engine_manufacturer_id(+) = v.aux_engine_manufacturer_id
  and e3.engine_manufacturer_id(+) = v.aux_2nd_engine_manufacturer_id
  and vm.vessel_manufacturer_id = v.vessel_manufacturer_id
  and hc.hull_construction_code = v.hull_construction_code
  and hd.hull_design_code = v.hull_design_code
  and ft.engine_fuel_type_code = v.engine_fuel_type_code
```

Reports

Recapture

Source : Recapture Full v2, Recapture Incremental v2, recap/recap_dist_full.sql, recap/recap_dist.sql
Created in Oracle Reports 2.0, and therefore requires and X-windows session to modify and run.
Stored in the database. These reports rely upon the recap_dist scripts to create RECAPTURE_DISTANCE tables that store the distances and directions between recaptures. They also depend upon the table RECAPTURE_REPORT which is simply created by selecting all of the rows from the RECAPTURE_BY_RECAPTURER_VIEW view (for performance while running & testing the report).

```
Rock Lobster                          RECAPTURE REPORT                      Page 1 of 4
Research Programme
Box 120
Henley Beach   5022

Ph.  (08) 200 2418
Fax. (08) 200 2481


            F. P. Prune
            Box 12
            Victoria Bay

                                  5411
```

Dear Fred,

Please find below a list of the lobsters that have been reported as being recaptured. Please note that the positions of the lobsters is confidential information, so we have only provided you with the positions for the lobsters you have given us details on. Should any of this information be incorrect please inform us so that we can change our records. Should you have and enquires regarding this report please don't hesitate to contact us at the above address.

Tag Number	Length	Date	Days	Growth	Travelled		Latitude	Longitude	S	C	M	R
006313	094.70	02-JAN-95	451	23.9	E	>=1,<10	35 21.681	136 42.455	M	S	H	NA
006316	126.70	05-DEC-93	58	.5	W	<0.1			F	R	H	LS
		25-NOV-94	413	4	SW	>=0.1,<1			F	R	H	LS
		19-DEC-94	437	3.6	E	>=10,<100	35 20.848	136 20.848	F	R	H	LS
006400	089.30	13-FEB-95	490	29.8	SE	>=0.1,<1	35 16.930	136 46.297	F	R	H	LS
006402	132.00	18-JAN-95	464	16.5	NW	>=0.1,<1	35 16.302	136 46.695	M	R	H	NA
006410	124.20	23-JAN-95	469	21.8	S	>=0.1,<1	35 16.773	136 46.096	M	R	H	NA
006415	083.70	23-JAN-95	469	27.4	S	>=0.1,<1	35 16.764	136 46.009	F	R	S	LS
012729	082.00	12-DEC-94	393	27.1	E	>=10,<100	35 09.360	136 05.000	F	R	H	SS
012773	130.00	18-JAN-95	424	1	S	>=0.1,<1	35 16.150	136 46.494	F	R	H	LS
024519	111.30	14-JAN-95	353	18.7	SE	>=10,<100	35 19.042	136 38.260	M	R	H	NA
039027	143.40	07-JAN-95	72	0	NW	>=1,<10	35 19.893	136 52.866	F	R	H	LS
044255	091.90	31-JAN-95	76	-.1	NE	>=0.1,<1	35 16.674	136 46.160	F	R	H	SS
044290	089.20	31-JAN-95	74	8.6	SE	>=0.1,<1	35 16.801	136 46.150	F	R	S	SS

Tagger

Source : Tagger Full v2
Based on the recapture report. As this report has only been run once an incremental version hasn't been produced yet. Also uses RECAPTURE_DISTANCE tables, but uses the TAGGER_REPORT table which is created from the RECAPTURE_BY_TAGGER_VIEW view. See RECAPTURE REPORT for example.

Forms

Tagging

Source : forms/error/tagging.inp, forms/error/cap.inp, forms/error/double.inp
There is currently a ¾ developed version of this form (forms/new/Tag.inp) integrating all of it's parts, and generally tidying up the 100's of modifications that have been made to it over it's life.

```
------------------------------------ Trip -------------------------------------
 Lic No C001   Trip Date 19-NOV-93            Swell Height   .00   Depth Units F
Recorder GF                                   Wind Spd 10 Dir SE   Curnt Dir
Location ALTHORPE ISLAND                                  Trip Type C Err N
------------------------------------ Pot --------------------------------------
Pot Depth   Lat  (S)    Long  (E)   Bot'm GPS Pot  Db Tagger       Comments      Err
Ord          .  '        .  '       Ty Cd Acc Smp Lf Surname
  2  10.0 35 22.242 136 52.102  L  L  G   T  F  Ferguson, Greg   Imported Reco
  3  10.0 35 22.272 136 52.091  L  L  G   T  F  Ferguson, Greg   Imported Reco
  4  10.0 35 22.735 136 52.101  L  L  G   T  F  Ferguson, Greg   Imported Reco
  5   8.0 35 22.330 136 52.046  L  L  G   T  F  Ferguson, Greg   Imported Reco
  6  12.0 35 22.361 136 52.040  L  L  G   T  F  Ferguson, Greg   Imported Reco
  7  13.0 35 22.387 136 52.030  L  L  G   T  F  Ferguson, Greg   Imported Reco
  8  12.0 35 22.414 136 52.001  L  L  G   T  F  Ferguson, Greg   Imported Reco
  9  12.0 35 22.391 136 52.005  L  L  G   T  F  Ferguson, Greg   Imported Reco
 10  12.0 35 22.418 136 51.971  L  L  G   T  F  Ferguson, Greg   Imported Reco
 11   9.0 35 22.471 136 51.916  L  L  G   T  F  Ferguson, Greg   Imported Reco
 12   4.0 35 22.464 136 51.934  L  L  G   T  F  Ferguson, Greg   Imported Reco
 13  11.0 35 22.538 136 51.866  L  L  G   T  F  Ferguson, Greg   Imported Reco
 14  12.0 35 22.580 136 51.793  L  L  G   T  F  Ferguson, Greg   Imported Reco
-------------------------------------------------------------------------------
[F4] Exit   [F2] Error   [F3] Lobster
Select LICENCE NUMBER from list ...                          <List><Replace>
Count:  1            v
```

```
------------------------------------ Trip -------------------------------------
 Lic No C001   Trip Date 19-NOV-93            Swell Height   .00   Depth Units F
Recorder GF                                   Wind Spd 10 Dir SE   Curnt Dir
Location ALTHORPE ISLAND                                  Trip Type C Err N
------------------------------------ Pot --------------------------------------
Pot Depth   Lat  (S)    Long  (E)   Bot'm GPS Pot  Db Tagger       Comments      Err
Ord          .  '        .  '       Ty Cd Acc Smp Lf Surname
  8    12 35 22.414 136 52.001  L  L  G   T  F  Ferguson, Greg   Imported Reco
---------------------------------- Lobster ------------------------------------
Has Dbl Tag     Tag     Pos  Capt  Rel    Length   Clr Sex Rep Mlt  L    R    LR
Err Tag Type    Number  Tgd  Code  Status Crpce Dec         St  St  1234512345AA
        TYPE_1  011962  V    BI    R      140.4  1   R   M  NA  H         000  O
        TYPE_1  011963  V    BI    R      120.0  1   R   M  NA  H

-------------------------------------------------------------------------------
[F4] Exit   [F2] Error Information   [F3] Double Tag
Select TAG TYPE from list ...                                <List><Replace>
Count: *2
```

Recapture

Source : forms/error/recap.inp, forms/error/double.inp

```
                    Recapture Details of Tagged Lobsters
                                             Depth measurements in: F Fathoms
Date:              09-FEB-94                  GPS Accuracy : G Good
Name:              Ferguson, Greg                       Licence No : C001
Capturer Type: BI Biologist

                              Latitude: 34 08.866      Longitude: 135 14.367
Depth:     5.0                                     Bottom Cover: H Heavy
Bottom Type: G Granite

Tag No.: 021455      Carapace Length:  97.1 Dec: 1   Moult State: H Hard
Colour: R Red           Sex: M Male      Reproductive State: NA Not Applicable

Damage:                 Comments:

Release Status: R   Depth:        Latitude:            Longitude:
                                   Errors
Type   S Description                        Comments
Recap
Captur
Lobstr
Pos'n
RelPos
— [F2] Double Tag — [F3] Tag Release — [F4] Exit
Enter the date of the recapture                               <Replace>
Count:  1          v
```

Catch and Effort

Source : forms/log/log.inp

South Australian Commercial Rock Lobster Log — RL0000

Licence Holder: P999 F.L. Prune — Main Place of Landing: VIC Victoria Bay — Mo: 11 — Year: 1994 — Dpt.Uts: Meters

Day	MFA	Dth	Pots RL	Pots KC	Trgt Spec	Catch Weight	Catch No.	Other U.Siz	Other Dead	Other Spwn	Octopus Weight	Octopus No	King Crab Weight	King Crab No
1	3	13	59		RL	96.00	48							
2	3	13	59		RL	96.00	48							
3	3	13	59		RL	108.00	54	2						
4	3	13	59		RL	142.00	71							
5	3	13	59		RL	66.00	33							
6														
7	3	15	59		RL	62.00	31	1	1					
8	3	15	59		RL	38.00	19							
9	3	25	59		RL	124.00	62							
10	3	25	59		RL	80.00	40							
Totals			1239			1390.00	971	4	6	3				

InsInsert a new log F7 Enter a Query   F8 Execute the QueryF4 Exit

Enter the Licence Number   <List><Replace>

Count: 1   v

Old Catch and Effort

Source : forms/old_log/old_log.frm

This form was based on the catch and effort form. Modified to allow for entry of registration number and surname, so that once all the data is entered the link between registration number & surname and licence number can be found.

```
22104  South Australian Commercial Rock Lobster Log                RL0001

Mo Year Reg. Lic. Surname          Main Place of Landing Dpt.Uts Wt.Uts No.Uts
11 1983      P999 Prune            UUU Unknown           Metres  Kilos  Single

Day MFA   Dth  Pots   Trgt   Catch          Other             Octopus     King Crab
    Block      RL  KC Spec   Weight  No.  U.Siz Dead Spwn   Weight  No  Weight  No
 1
 2   39   50   55     RL      85.00   98    1                 0.00   0
 3   39   55   26     RL      64.00   74    9          1      0.00   0
 4   39   55   55     RL     103.00  118    7    2    13      1.00   1
 5   39   55   55     RL      47.00   54    7    2     6      0.00   0
 6   39   60   55     RL      55.00   63    6    8    11      6.00   3
 7   39   60   55     RL      61.00   70    6    2     8      0.00   0
 8   39   55   55     RL      47.00   54    7          7      0.00   0

Totals          1380        1567.00 1856   276  126   114    52.00  20

Avg. Wt. Excluding Today   .85 Wt. for this No.        No. for this Wt.

InsInsert a new log F7 Enter a Query    F8 Execute the QueryF4 Exit
Enter the Month                                                 <Replace>
Count:  1          v
```

Contact

Source : forms/contact/contact.inp

```
Date 24-SEP-96              Contact Screen               Version  2.80

                    CONTACT                          |      ASSOCIATIONS
                                Initials      Id     |  Owner         C005
Surname                         J.H.          305    |  Master 1      R001
PRESCOTT                                             |  Master 2
Given                       Second                   |
JIM                         HOMER                    |     CAPTURER TYPE
Residential Address                                  |  Type BI  From 01-JAN-80
Dept. Of Primary Industries                          |  Biologist
Regional Headquarters Building                       |
Jubilee Highway East                                 |  Type       From
Mt. Gambier                                          |
Postal Address                                       |
P. O. Box 1846                                       |      RELATED DATA
Mt. Gambier                                          |  Fish Tagged
                                                     |  Days Tagging
                                  Postcode 5290      |  Fish Recaught
Phone   087 242930                                   |  No. Of Pots
Mobile  018 805858                                   |  Max. Pots Tagging
Fax     087 351380                                   |

Count: *1                                                      <Replace>
```

Licence

Source : forms/licence/licence.inp

```
Date 24-SEP-96                       Licence Screen                     Version  2.10

 Lic.    Owner                        Master1                  Master2
 C001    Harvey, Roger
  Reg       No. Pots          Depth Units F Start Date 01-JAN-60 End Date

 C002    Tasmanian
  Reg       No. Pots          Depth Units F Start Date 01-JAN-60 End Date

 C003    Duck, Rubber
  Reg       No. Pots          Depth Units F Start Date 01-JAN-60 End Date

 C004    Childs, Shane
  Reg       No. Pots          Depth Units   Start Date 01-JAN-60 End Date

 C005    Prescott, Jim              Duncombe-Wall, Deborah
  Reg       No. Pots          Depth Units   Start Date 01-JAN-60 End Date

 N002    Beck, David                Retsas, C.J.
  Reg NL4A No. Pots 59        Depth Units   Start Date 01-JAN-60 End Date

[F9-1] Contact
                                                               <Replace>
Count:   6              v
```

Pleopod

Source : forms/pleopod/pleopod.inp

```
1995/96 pleopod sampling

 Mon Day   Lic  Pot Len.   Sex Cond.  Stg   Comments
 OCT 11    S018      99.2   M   NA     5    softish
 OCT 11    S018     100.0   F   SS     5
 OCT 11    S018     100.4   F   LS     5
 OCT 11    S018     100.9   M   NA     5
 OCT 11    S018     101.3   F   LS     5
 OCT 11    S018     101.5   M   NA     5
 OCT 11    S018     101.7   F   LS     5
 OCT 11    S018     102.7   M   NA     5
 OCT 11    S018     102.8   F   LS     5
 OCT 11    S018     104.3   M   NA     7
 OCT 11    S018     104.9   M   NA     5
 OCT 11    S018     105.9   F   LS     5
 OCT 11    S018     106.1   M   NA     5
 OCT 11    S018     106.7   F   LS     5
 Trip Date Lic  Pot Len.   Same
 11-OCT-95 S018      99.2



 Enter the Month                                              <Replace>
 Count:  14             v
```

Gear and Vessel

Source : forms/gear/gear.inp

```
— LICENCE ———————————————————————————————————————
 Licence No.            N002          Number of Deckhands 2

 Usual Home Port   THV THEVENARD      Year of Entry        1996
— BOAT ——————————————————————————————————————————
 Current Vessel Name    AUSTRAL EAGLE

 Vessel Manufacturer    BOB MCCLAREN

 Year Of Purchase       1978     Year Of Construction Of Vessel 1978

 Hull Design D DISPLACEMENT          Hull Construction T TIMBER

 Normal Cruising Speed  8.0                 Maximum Speed  9.0

 Boat Length 16.20metres   Beam  5.49metres  Unladen Draught  2.13metres
             '  "                '  "                          7'  "

 Gross Tonnage          55.0         Capacity to Stay At Sea 15
[PgDn] NAV. & FISH EQUIP.|[PgUp] MANUFACTURERS|[F4] Exit|[Ctrl-F6] Commit|
Enter value for : LIC_NO                                 <List><Replace>
Count:  1          v
```

```
— DESCRIPTION OF MAIN ENGINE(S) ———————————————————
 Number of Engines 1

 Manufacturer        DETROIT          Year of Manufacture      1975

 Model               8V71             Brake Horsepower          220

 Fuel Type           D DIESEL         Capacity of Fuel Tanks   6000
— AUXILIARY ENGINE ————————————————————————————————
 Manufacturer        ONAN             Year of Manufacture      1987
 Model               4B               Output                   37.0
 - 2ND AUXILIARY ENGINE -
 Manufacturer                         Year of Manufacture
 Model                                Output
— FISHING GEAR ————————————————————————————————————
 No. of Pots in Total           59    Av. Weight of Pots       45

 No. of Large Pots              59    No. of Standard Pots

 How Many Pots Have Escape Gaps?
[PgDn] NAV. & FISH EQUIP.|[PgUp] MANUFACTURERS|[F4] Exit|[Ctrl-F6] Commit|
Enter value for : NUMBER_OF_ENGINES                           <Replace>
Count:  1          v
```

```
— LOBSTER STOWAGE ————————————————————————————————
 Well Capacity                        Tank Capacity 40.0

 Do You Have a Freezer? T

— NAVIGATION AND FISH FINDING EQUIPMENT ——————————

 Equipment Type              Manufacturer           Model
 W WEATHER FAX               FURUNO
 G GPS                       FURUNO                 GP500
 P PLOTTER                   FURUNO                 GD180
 C SOUNDER                   FURUNO                 FCV291
 C SOUNDER                   FURUNO                 FE502 MK2
 S SONAR                     FURUNO                 CH14
 R RADAR                     FURUNO

 LOBSTER STOWAGE            | NAV. & FISH EQUIP.       | BOTH
 [PgUp] MANUFACTURERS       | [PgUp] LOBSTER STOWAGE   | [F4] Exit
 [PgDn] NAV. & FISH EQUIP.  | [PgDn] MANUFACTURERS     | [Ctrl-F6] Commit
Enter value for : WELL_CAPACITY                               <Replace>
Count:  1          v
```

Sequences

CAPTURER_TYPE_SQ
CAPTURER_TYPE (CAPTURER_TYPE_ID)

CAPTURE_SQ
CAPTURE (CAPTURE_ID)

CONTACT_SQ
CONTACT (CONTACT_ID)

ENGINE_MANUFACTURER_SQ
ENGINE_MANUFACTURER (ENGINE_MANUFACTURER_ID)

EQUIPMENT_MANUFACTURER_SQ
EQUIPMENT_MANUFACTURER (EQUIPMENT_MANUFACTURER_ID)

LOBSTER_SQ
LOBSTER (LOBSTER_ID)

OLD_TRIP_ID_SQ
OLD_LOG_HEADER (TRIP_ID)

POSITION_SQ
POSITION (POSITION_ID)

PREDATOR_SQ
PREDATOR (PREDATOR_ID)

TRIP_DAY_SQ
TRIP_DAY (TRIP_DAY_ID)

TRIP_ID_SQ
LOG_HEADER (TRIP_ID)

VESSEL_MANUFACTURER_SQ
VESSEL_MANUFACTURER (VESSEL_MANUFACTURER_ID)

VESSEL_SQ
VESSEL (VESSEL_ID)

Roles

DATA_ENTERER

Limited access only to objects involved in SARL forms processing.

RESEARCHER

Extended access to objects involved in SARL forms processing and limited access to other SARL related objects.

INFORMATION_COORDINATOR

Access to all SARL related objects.

Packages

DATE_MGMT

```
function dmy_to_date (d number, m number, y number) return date;
```
Convert d, m, y to date.
```
function days_in_month (m number, y number) return number;
```
Return number of days in m month of y year.
```
function dmy_to_julian (d number, m number, y number) return number;
```
Convert d, m and y to julian date.
```
function date_to_julian (d date) return number;
```
Convert d to julian date.
```
function days_from (d1 date, d2 date) return number;
```
Return the number of days .d1 is ahead of d2
```
function month_of_next_month (m number, y number) return number;
```
Return the month following the month m of year y.
```
function year_of_next_month (m number, y number) return number;
```
Return the year following the month m of year y.
```
function month_of_last_month (m number, y number) return number;
```
Return the month preceeding the month m of year y.
```
function year_of_last_month (m number, y number) return number;
```
Return the year preceeding the month m of year y.
```
function season (d date) return number;
```
Return the fishing season that d falls in.
```
function season_my (m number, y number) return number;
```
Return the fishing season that month m and year y fall in.
```
function fortnight (d date) return number;
```
Return the fortnight of a month the d falls in.
```
function fortnight_dmy (d number, m number, y number) return number;
```
Return the fortnight of a month the date d, m, y falls in.

DEPTH_MGMT

```
function m_to_f (m number) return number;
```
Convert m from metres to fathoms.
```
function f_to_m (f number) return number;
```
Convert f from fathoms to metres.
```
function convert_depth (d number, u char) return number;
```
Convert d between metres and fathoms depending upon units u.

ERROR_MGMT

```
function check_capture (in_capture_id number) return number;
```
Check capture records for consistency.
```
function check_length (in_capture_id number) return number;
```
Check lengths of lobsters for consistency.
```
function check_recapture (in_capture_id number) return number;
```
Check recapture records for consistency.
```
function check_release (in_capture_id number) return number;
```
Check release_info records for consistency.
```
function check_movement (in_capture_id number) return number;
```
Check lobster movement for consistency.
```
function check_lobster (in_lobster_id number) return number;
```
Check lobster records for consistency.
```
function check_sex (in_lobster_id number) return number;
```
Check lobster sex for consistency.
```
function check_position (in_position_id number) return number;
```
Check position records for consistency.
```
function delete_error (table_name char, field_name char, field_value integer, descr
char) return integer;
```
Delete an error record from the error table table_name where the primary field field_name has the value field_value and the error is of type descr.
```
function insert_error (table_name char, field_value integer, descr char, comments char)
return integer;
```
Insert an error record into the error table table_name where the primary field field_name has the value field_value and the error is of type descr, with a comment.

POS_MGMT

```
function dms_to_dd (degs number, mins number, secs number) return number;
```

Convert degrees, minutes and seconds to decimal degrees.

```
procedure dd_to_dms (dd number, degs out number, mins out number, secs out number);
```

Convert decimal degrees to degrees, minutes and seconds.

```
function dm_to_dd (degs number, mins number) return number;
```

Convert degrees and decimal minutes to decimal degrees.

```
procedure dd_to_dm (dd number, degs out number, mins out number);
```

Convert decimal degrees to degrees and decimal minutes.

```
function distance (lat1 number,long1 number, lat2 number,long2 number) return number;
```

Return the distance between two points in nautical miles.

```
function direction (lat1 number,long1 number, lat2 number,long2 number) return varchar2;
```

Return the direction between two points, using 8 compass points.

```
procedure dist_dir (lat1 number,long1 number, lat2 number, long2 number, dist out
number, dir out char);
```

Return the distance and direction between two points, using 8 compass points.

```
function direction2 (lat1 number,long1 number, lat2 number,long2 number) return
varchar2;
```

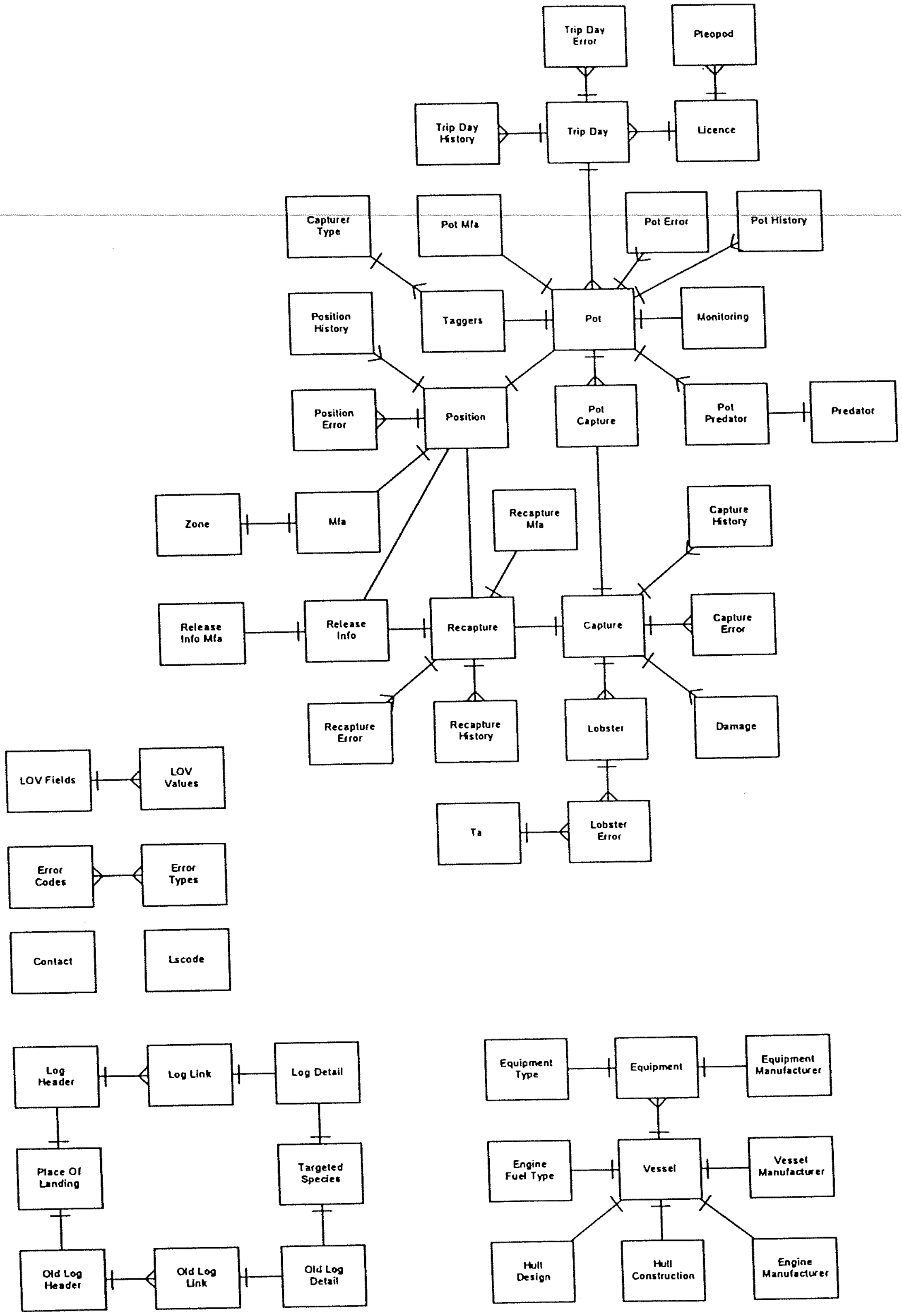
Return the direction between two points, using 4 compass points.

```
procedure dist_dir2 (lat1 number,long1 number, lat2 number, long2 number, dist out
number, dir out char);
```

Return the distance and direction between to points, using 4 compass points.

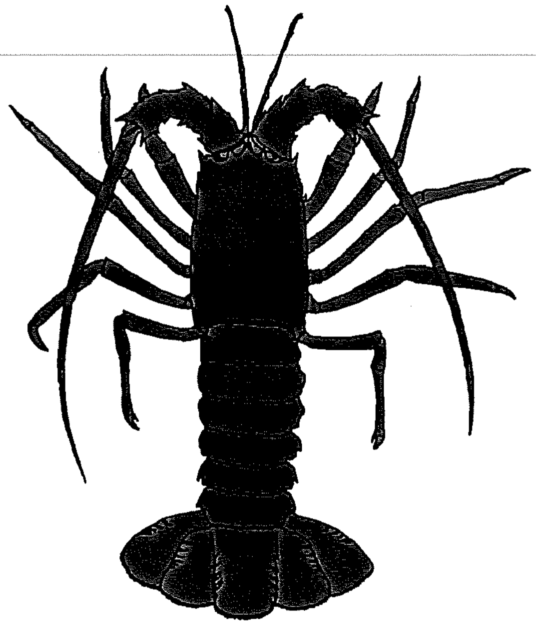
Size

The database is currently approximately 600MB in size, with usually between 1 and 6 concurrent users.


Trip Day Error
Pleopod
Trip Day History
Trip Day
Licence
Capturer Type
Pot Mfa
Pot Error
Pot History
Position History
Taggers
Pot
Monitoring
Position Error
Position
Pot Capture
Pot Predator
Predator
Zone
Mfa
Recapture Mfa
Capture History
Release Info Mfa
Release Info
Recapture
Capture
Capture Error
Recapture Error
Recapture History
Lobster
Damage
LOV Fields
LOV Values
Ta
Lobster Error
Error Codes
Error Types
Contact
Lscode
Log Header
Log Link
Log Detail
Equipment Type
Equipment
Equipment Manufacturer
Place Of Landing
Targeted Species
Engine Fuel Type
Vessel
Vessel Manufacturer
Old Log Header
Old Log Link
Old Log Detail
Hull Design
Hull Construction
Engine Manufacturer

South Australian Rock Lobster

Fishery Management Model



Scientific Guide

July 1997

SARDI
SOUTH AUSTRALIAN RESEARCH AND DEVELOPMENT INSTITUTE

SANZFLFA Inc.

SEPFA Inc.

FISHERIES RESEARCH & DEVELOPMENT CORPORATION

by Rick McGarvey
Paul Gaertner
Janet Matthews

SARDI Aquatic Sciences
PO Box 120
HENLEY BEACH SA 5022

"Fisheries are complex dynamic systems that are difficult to measure, understand, and manage. Interactive graphics models are computer-based tools that offer benefits to scientists, managers, fishers, conservationists, educators, trainers, students, the community, and media. .... models use techniques of visualization .... to significantly improve our ability to analyze, understand, and manage fisheries, communicate this understanding and educate others. ..."

P. Sluczanowski, R.K. Lewis, J. Prince, and J. Tonkin,
"Interactive Graphics Computer Models for Fisheries Management",
Proceedings of the World Fisheries Congress.

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1. Introduction

This Scientific Guide is designed to be used by modellers and programmers who seek to update or reprogram the Lobster Management Model or interface. It should be consulted in conjunction with the User Guide which contains an introduction and all information users need to run simulations in the model software for testing management strategies in the South Australian rock lobster fishery. The User Guide provides instructions for installation, a summary of the model interface, and a description of every menu item, including how to change model parameters, how to select management policies for testing, how to run the model, how to display the output, and how to carry out statistical tests on the model output. In addition, it provides two detailed examples of simulations for testing size limits and quota, gives an overview of the basic model dynamics, and includes a glossary. This Scientific Guide supplements the User Guide with technical information on program structure and explicit presentation of the rate equations of the model. Both User and Scientific Guides are included in the model interface Help section.

The goals of the SARLMOD project were fourfold:

- To develop a tool to assist management of the resource;
- To involve fishers and scientists together in a collaboration to undertake research for management of the resource;
- To implement a commercial quality model software interface, so that anyone, specifically fishers can use the model to test strategies that they feel might be recommended;
- To bring together in one description, separate data analyses, including natural mortality, growth, catch, regulation, and economics of this exploited population, for the purpose of testing management policies by simulation.

1.1. Model Overview

The SARLMOD software consists of five main components:

- The Rock Lobster Model
- The Delphi Graphical User Interface
- Statistical and Analytical Toolboxes
- Delphi Database
- Geographical Information System

1.1.1. The Rock Lobster Model

The lobster population variable is defined for both sexes, each of 11 8-mm length classes, and for each spatial cell. The spatial dynamic model consists of five basic components:

- Stock-recruitment
- Growth by moulting
- Allocation of fishing effort spatially among model cells
- Harvest
- Economics

These components, in particular, the associated file structures and model rate equations are described for these submodels below. A detailed examination of an earlier version of the model, and outcomes for resource management strategies tested is outlined by Walters et al. (1997).

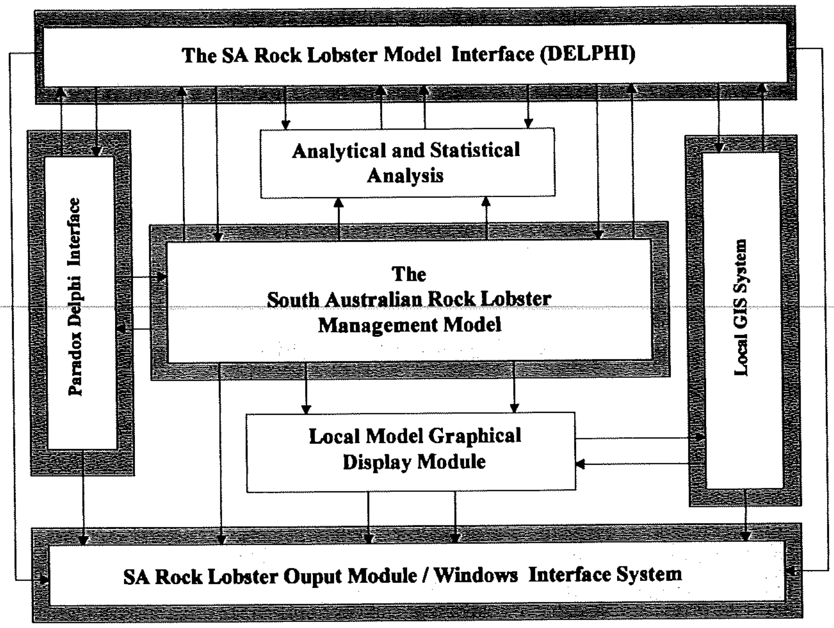

Figure 1: SARLMOD Components

1.1.2. The Delphi Graphical User Interface

The graphical user interface was developed using the Delphi programming language. It allows easy control of the model and the display of model results. The mouse is used to select the menus needed to perform the following tasks:

File: Open and save model projects, generate text summaries ie "reports of input or output, select default settings for printing, and export data to Excel or any other word processor or spreadsheet. The speed buttons also allow you to execute the most widely used of these commands;

Parameters: Change parameters for the model run;

Management: Specify the management strategy you want to test;

Run: Run the model;

Results: Display the outputs of the model run;

Analysis: Calculate statistics for the model or data variables and graph any variables or combination of variables;

Window: Control the output display;

Help: Refer to Help on the use of the model and its scientific basis. This Scientific Guide and the User Guide are included in full in the **Help**. The equations of the model are available under **Help|Scientific Manual|Lobster Management Model|Simulation Module.**

"Dialog boxes" will appear when you choose menu items. These allow you to enter selections and values. Screens containing model output will appear in the Model display area.

1.1.3. Statistics, Data Analysis and Graphing

The Statistical menu provides a range of statistics including descriptives, frequencies, bivariate correlation and partial correlation, comparison of means, one-way analysis of variance, t-test for independence, t-test for paired data, linear, exponential, power and logarithmic regression, cross correlations and auto-correlations. These statistics are partitioned into five groups: Summary Statistics, Correlations, Means, Curve Fitting and Time Series.

Other analytical toolboxes include a least squares curve fitting analysis component which can be used to analyse up to four sections of the output time series data, and an indicator creation toolbox which is used to combine variables in such a way as to create meaningful new variables.

Moreover, summary variables for important outputs, notably catch, effort, and adult and juvenile abundance can be extracted from specific spatial cells of the fishery using the GIS system described below. These also can be combined algebraically, plotted, fitted, and statistically analysed in the **Analysis** menu.

1.1.4. The Delphi Database System

The model inputs and outputs are permanently stored in a database. The Delphi development environment is a Pascal language with built in links to an underlying database. The database is designed using Paradox 5.0 tables and the Delphi database desktop manager. The Delphi database system provides the initial model parameters, initial values of the variables, and all management regulatory settings. Model output is also stored there at the conclusion of each model run. These model output variables are then available for analysis and graphical display.

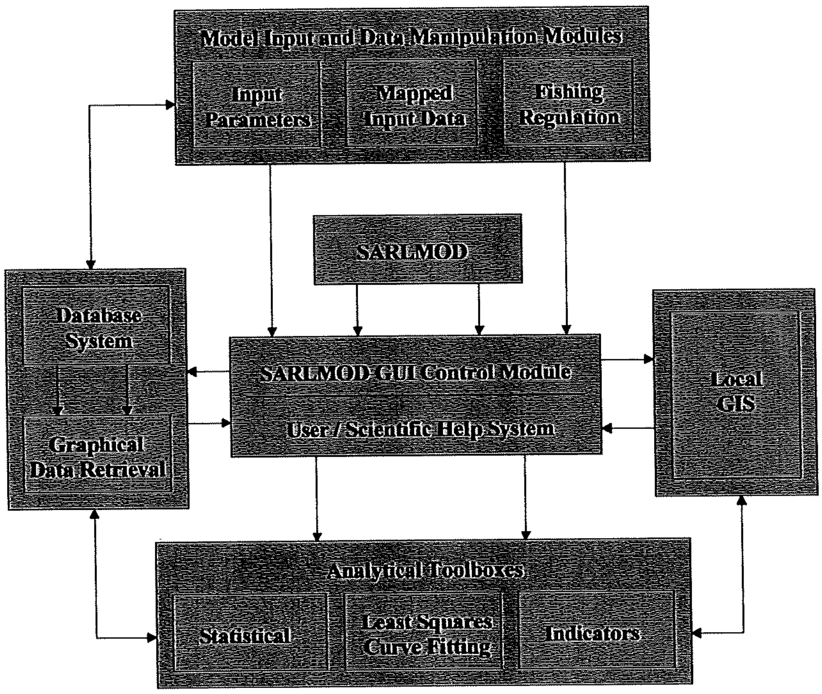

Figure 2: The SARLMOD Component Interactions

1.1.5. The Geographical Information System

The SARLMOD Geographical Information System (GIS) provides users with a mechanism for obtaining cell-by-cell information about any of the model variables. Inside **Results|Graph Results** or **Analysis|Select Data,** the cells are chosen by clicking with the mouse on the displayed map.

Provided in **Results|Graph Results** and in **Analysis|Curve Fitting** are graphing tools. **Results|Graph Results** includes bar, line, stacked and pie graphs, 3 dimensional and 2 dimensional views and a facility to rotate the graph view horizontally and vertically. The graph tool also provides the ability to print and copy the graph to other Windows applications.

1.1.6. Projects

The Delphi model structure is built around a project, in this case "lobster.dpr". This contains the interface and provides a direct link to the Delphi database.

2. Lobster Management Model

For simplicity, the model has been divided into two pieces, an initialisation module and a simulation module (Figure 3). It should be noted that due to restrictions in the Delphi compiler and to speed up model execution, input modules that contain yearly data values are read before each simulation year. Programmers should also be aware that the simulation model does not read or write to the Paradox database system. All reading from and writing to the database is carried out by the main SARLMOD system before and after the simulation model execution.

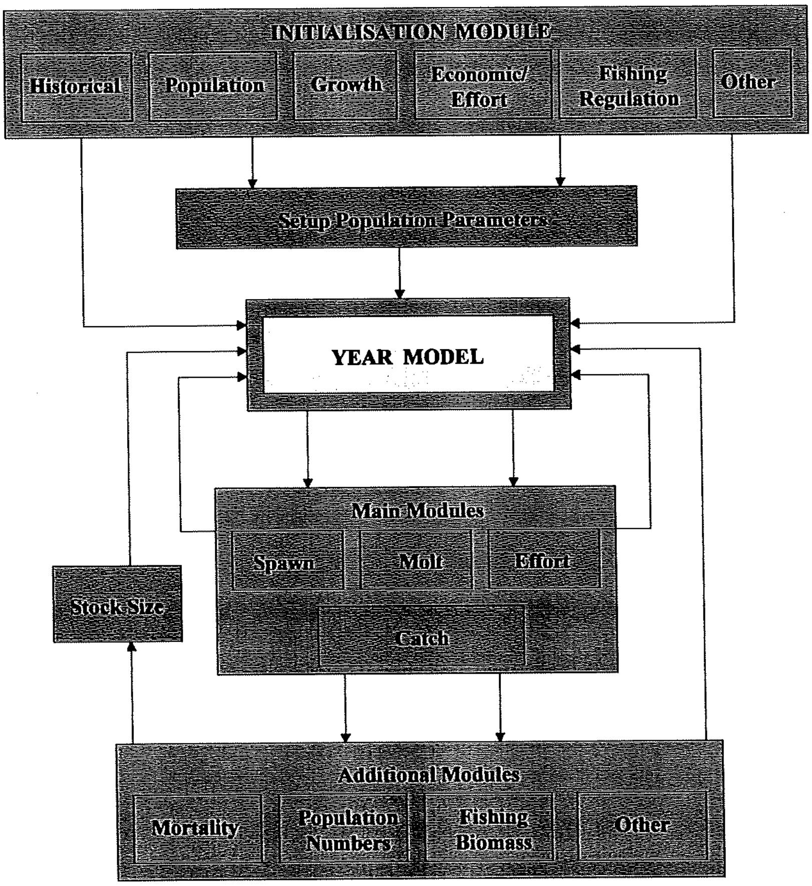

Figure 3: Model Structure

2.1. Initialisation Module

2.1.1. Historical Data

The initialisation of the historical data is performed in the procedure **ReadHistory** in the main model source file. The procedure reads input from the historical data files **'sa6894.his'** and **'sa.lfh'**. Note that these files are not contained within the Delphi database.

Historical data read from sa6894.his includes:

Historical effort for both the Northern and Southern Zone.
Historical catch for both the Northern and Southern Zone.

Historical data read from sa.lfh includes:

Historical length proportions of lobster for the 11 sizes.

The lobster simulation model does not require the historical length proportion data. This data is displayed for comparison with the simulated size length frequencies. It can be deleted from the model code without causing any compilation or simulation run time errors.

2.1.2. Fishing Regulations

The redesign of the fishing regulation input parameters makes it unnecessary for the entire regulation data set to be read in during the initialisation phase. Thus, the simulation module initialises the fishing regulations for a given year at the commencement of that simulation year. The fishing regulation input procedure is located in the **InitRegulation** procedure in yearly module, "Yrmodel". Fishing regulation input parameters are contained in five input '**.dat**' files called **nzregs**, **szregs**, **tacreg**, **regpots** and **regzone**, the format of which is the same as the corresponding database tables. The initial values of each of these tables are as follows:

nzregs & szregs:

These tables contain yearly data for the fishing regulation minimum, mid-range lower, mid-range upper and maximum legal length sizes for both males and female for each simulation year. Initially, values are set to a single value given below. Note that 999 indicates that no limit is in force.

	Minimum	Mid-Range Low	Mid-Range High	Maximum
Female (NZ)	98.5 (102 after 1994)	999	999	999
Male (NZ)	98.5 (102 after 1994)	999	999	999
Female (SZ)	98.5	999	999	999
Male (SZ)	98.5	999	999	999

Note: When displayed in the management strategy edit window 999 values are converted to 0.0.

tacreg:

The **tacreg** data file contains the yearly data for TAC quota in tons. Initially TAC quota is set to no quota in force, except in the Southern Zone after 1993, where the actual values are used.

regpots:

This database table includes data on the number of escape gaps and pots licensed. Initial values are:

number of escape gaps : 3
number pots licensed nth zone : 3950
number pots licensed sth zone : 11923

regzone:

The regzone table contains data related to the proportion of historical effort allowed by fortnight for both the Northern and Southern Zones.

	Oct (1)	Oct(2)	Nov(1)	Nov(2)	Dec(1)	Dec(2)	Jan(1)	Jan(2)
North	0	0	1	1	1	1	1	1
South	1	1	1	1	1	1	1	1

	Feb(1)	Feb(2)	Mar(1)	Mar(2)	Apr(1)	Apr(2)	May(1)	May(2)
North	1	1	1	1	1	1	1	1
South	1	1	1	1	1	1	0	0

	Jun(1)	Jun(2)	Jul(1)	Jul(2)	Aug(1)	Aug(2)	Sep(1)	Sep(2)
North	0	0	0	0	0	0	0	0
South	0	0	0	0	0	0	0	0

Although it is not necessary to input the regpots or regzone at each the beginning of each simulation year, it was felt that it should be done in order to keep the fishing regulation inputs in a single procedure. Consequently, making future changes to the model is as easy as possible.

2.1.3. Overall Population and Harvest Parameters

Input of the population, harvest and vulnerability parameters have been divided to reduce the amount of memory necessary for the simulation model. All the parameters are initialised in the **InitialPopulation** procedure in the main module and some are re-initialised in the **InitPopulation** procedure in the yearly module.

Population and harvest input parameters are contained within four '**.dat**' files named **poppar1**, **poppar2**, **poppar3** and **poppar4**. The initial values of each of these tables are as follows:

poppar1:

Natural Mortality Rate (m)	: 0.1
Nth Zone Catchability coefficient (q)	: 15
Sth Zone Catchability coefficient (q)	: 3
Length-weight parameter in (W = a L^b)	: $a = 2.8 \times 10^{-7}$, $b = 3.12$

poppar2:

Nth Zone Illegal catch fraction of commercial	: 0.050
Sth Zone Illegal catch fraction of commercial	: 0.050
Nth Zone Recreational catch fraction of commercial	: 0.050
Sth Zone Recreational catch fraction of commercial	: 0.050
Nth Zone Fraction of catch brought up dead in pots	: 0.035
Sth Zone Fraction of catch brought up dead in pots	: 0.040

poppar3:

Stock-recruit slope (max recruit per 1000 eggs)	: 20.1
Maximum average recruits (82-90 mm) per year NZ	: 1.02
Maximum average recruits (82-90 mm) per year SZ	: 3.1
Map row where peak recruitment occurs	: 10
North-South variance of recruitment distribution	: 50
Relative drop off in recruitment rate/cell distribution offshore	: 2
Sex ratio proportion of recruits that are females	: 0.5

poppar4:

Northern Zone	: $\alpha = 3$, $\beta = 5$, $\gamma = 0.55$
Southern Zone	: $\alpha = 1$, $\beta = 2$, $\gamma = 0$

2.1.4. Population Vulnerability Parameters

Population vulnerability input parameters are contained in two '**.dat**' files named **seasvul** and **sizevul**. The initial values of each of these tables are as follows:

seasvul:

Contains input data for the seasonal vulnerability of females and males in both the Northern and Southern Zones for the 24 fortnight periods within each simulation year.

Males & Females

	Oct (1)	Oct(2)	Nov(1)	Nov(2)	Dec(1)	Dec(2)	Jan(1)	Jan(2)
North	0.7	0.7	0.8	0.8	0.8	0.9	0.9	1.0
South	0.6	0.6	0.7	0.7	0.7	0.7	0.9	1.0

	Feb(1)	Feb(2)	Mar(1)	Mar(2)	Apr(1)	Apr(2)	May(1)	May(2)
North	0.9	0.9	0.8	1.0	0.9	0.8	0.8	0.8
South	1.0	0.9	0.8	0.8	0.8	0.8	0.7	0.7

	Jun(1)	Jun(2)	Jul(1)	Jul(2)	Aug(1)	Aug(2)	Sep(1)	Sep(2)
North	0.7	0.7	0.7	0.6	0.7	0.8	0.8	0.9
South	0.7	0.7	0.7	0.6	0.7	0.8	0.8	0.9

sizevul:

Contain data related to the vulnerability of individual length lobsters, from 82 mm to 162+ mm in 8mm steps.

Size (mm)	Vulnerability
82	0.00
90	0.50
98	1.00
106	1.00
114	0.90
122	0.90
130	0.85
138	0.80
146	0.80
154	0.75
162+	0.70

2.1.5. Regional Growth and Fecundity Parameters

Regional growth and fecundity parameters are initialised in the **InitialGrowth** procedure in the main module. The parameters are contained in four '**.dat**' files **fgrowth, mgrowth, growpar** and **gthcpmat**. The initial values of each of these tables are as follows:

fgrowth:

This database contains input data related to the proportions moulting by region, season and length for female lobsters, for the four main fishing areas:

	Hi grow NZ				Central NZ				South SZ				North SZ			
len	Nov	Feb	May	Aug	Nov	Feb	May	Aug	Nov	Feb	May	Aug	Nov	Feb	May	Aug
82	0.6	0.7	0.5	0.0	0.4	1.0	0.4	0.0	0.1	0.4	0.4	0.7	0.6	0.7	0.5	0.0
90	0.8	0.6	0.4	0.0	0.5	0.9	0.3	0.0	0.1	0.3	0.3	0.6	0.8	0.6	0.4	0.0
98	0.7	0.3	0.3	0.0	0.4	0.4	0.2	0.0	0.1	0.1	0.2	0.3	0.7	0.3	0.3	0.0
106	0.7	0.3	0.2	0.0	0.5	0.3	0.1	0.0	0.1	0.1	0.1	0.3	0.7	0.3	0.2	0.0
114	0.5	0.2	0.0	0.0	0.3	0.3	0.0	0.0	0.1	0.1	0.0	0.0	0.5	0.2	0.0	0.0
122	0.3	0.1	0.0	0.0	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.1	0.0	0.0
130	0.2	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.1	0.0	0.0
138	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
146	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
154	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
162+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

mgrowth:

This database contains input data related to the proportions moulting by region, season and length for male lobsters, for the four main fishing areas:

	Hi grow NZ				Central NZ				South SZ				North SZ			
len	Nov	Feb	May	Aug	Nov	Feb	May	Aug	Nov	Feb	May	Aug	Nov	Feb	May	Aug
82	0.3	0.7	0.5	1.0	0.6	0.7	0.5	0.5	0.1	0.5	0.3	1.0	0.3	0.7	0.5	1.0
90	0.3	0.7	0.4	1.0	0.6	0.7	0.4	0.5	0.1	0.5	0.3	1.0	0.3	0.7	0.4	1.0
98	0.3	0.7	0.3	0.9	0.6	0.7	0.3	0.5	0.1	0.5	0.2	0.8	0.3	0.7	0.3	0.9
106	0.3	0.6	0.3	0.9	0.6	0.6	0.3	0.5	0.1	0.4	0.2	0.8	0.3	0.6	0.3	0.9
114	0.3	0.5	0.3	0.9	0.6	0.5	0.3	0.5	0.1	0.4	0.2	0.8	0.3	0.5	0.3	0.9
122	0.2	0.5	0.3	0.8	0.4	0.5	0.3	0.5	0.1	0.4	0.2	0.8	0.2	0.5	0.3	0.8
130	0.2	0.5	0.3	0.8	0.4	0.5	0.3	0.5	0.1	0.4	0.2	0.8	0.2	0.5	0.3	0.8

138	0.0	0.5	0.2	0.8	0.0	0.5	0.2	0.4	0.0	0.4	0.1	0.7	0.0	0.5	0.2	0.8
146	0.0	0.5	0.1	0.8	0.0	0.5	0.1	0.4	0.0	0.4	0.1	0.7	0.0	0.5	0.1	0.8
154	0.0	0.5	0.0	0.5	0.0	0.5	0.0	0.3	0.0	0.4	0.0	0.5	0.0	0.5	0.0	0.5
162+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

growpar:

Contains fecundity vs length input parameters: afec and bfec, where

afec · length^bfec (1000 eggs/mm)

afec = 0.235   bfec = 2.912

gthcpmat:

Holds data for the female percent mature vs length parameter: cpmat and pmat50, for the four main fishing areas, hi grow NZ, central, south SZ and north SZ.

	Hi gro NZ	Central	South SZ	North SZ
cpmat	0.170	0.180	0.150	0.100
pmat50	101	103	112	102

2.1.6. Economic and Effort Dynamics

Economic and Effort parameters are initialised in two procedures, the first is **InitialEffort** in the main module and the second, **InitEconomic** in the yearly module.

Effort Parameters

Contained within the **effprice.dat** input file, effort parameters include the price for each of the 24 fortnight periods per year.

Fortnight	Price	Fortnight	Price	Fortnight	Price	Fortnight	Price
Oct (1)	30	Jan (1)	26	Apr (1)	34	Jul (1)	38
Oct (2)	30	Jan (2)	26	Apr (2)	34	Jul (2)	38
Nov (1)	30	Feb (1)	24	May (1)	38	Aug (1)	38
Nov (2)	30	Feb (2)	24	May (2)	38	Aug (2)	38
Dec (1)	26	Mar (1)	32	Jun (1)	38	Sept (1)	38
Dec (2)	26	Mar(2)	32	Jun (2)	38	Sept (2)	38

Note: The main module also inputs the percentage variation of the base fortnightly price for each simulation year. Initially, the price variation is set to 0.0, hence there is no change from the base price given above. This input is contained within the **SimLobsterModel** procedure.

Economic Parameters

Contained within the **effort.dat** input file it includes the following general economic parameters:

Crew share % of gross income	: 14
Skipper share % of gross income	: 20
Variable costs per potlift (fuel, bait, 1/3 of repairs) $	: 5.00
Fixed cost per potlift	: 10.00
Price Elasticity, > 100t fortnight	: -0.10
cpue (kg/pot night) above which typical fisherman will pull pots daily	: 1.00
maximum pot lifts per month	: 22
effort model type (0 = simulated, 1 = fixed at historical)	: 1

Coefficient of linear trend in fixed cost since 1968 (as a+b*year)

Northern	a:	0.2717	b:	0.0145
Southern	a:	1.9690	b:	0.0000

2.1.7. Mapped Information

Mapped data is read into the Initialise procedure within the main module. The mapped information data is held within a single file called **mapped.dat**. The file contains regional data related to the regulation zone, growth region, settlement index, habitat index and refuge area. Regions within the system go from top left to bottom right. The initial values of each of these are as follows:

	r 1	r 2	r 3	r 4	r 5	r 6	r 7	r 8	r 9	r 10
regulation	1	1	1	1	1	1	1	1	1	1
growth region	1	1	1	1	1	1	1	1	2	2
settlement index	2	2	1	2	1	3	1	1	1	5
habitat index	1	1	1	1	1	1	1	1	1	1
refuge area	1	1	1	1	1	1	1	1	1	1

	r 11	r 12	r 13	r 14	r 15	r 16	r 17	r 18	r 19	r 20
regulation	1	1	1	1	1	1	1	1	1	1
growth region	2	2	2	1	2	2	2	1	1	1
settlement index	1	5	1	4	1	1	4	2	2	3
habitat index	1	1	1	1	1	1	1	1	1	1
refuge area	1	1	1	1	1	1	1	1	1	1

	r 21	r22	r 23	r 24	r 25	r 26	r 27	r 28	r 29	r 30
regulation	1	1	1	1	1	1	1	1	1	1
growth region	1	2	2	2	2	1	3	3	2	2
settlement index	1	1	1	1	1	7	1	1	4	4
habitat index	1	1	1	1	1	1	1	1	1	1
refuge area	1	1	1	1	1	1	1	1	1	1

	r 31	r 32	r 33	r 34	r 35	r 36	r 37	r 38	r 39	r 40
regulation	1	1	1	2	2	1	1	1	1	2
growth region	2	2	2	2	1	2	2	2	2	2
settlement index	4	3	1	1	5	1	1	1	1	1
habitat index	1	1	1	1	1	1	1	1	1	1
refuge area	1	1	1	1	1	1	1	1	1	1

	r 41	r 42	r 43	r 44	r 45	r 46	r 47	r 48	r 49	r 50
regulation	2	2	2	2	2	2	2	2	2	2
growth region	2	1	1	1	1	1	3	3	3	3
settlement index	1	1	10	13	10	22	13	13	1	1
habitat index	1	1	1	1	1	1	1	1	1	1
refuge area	1	1	1	1	1	1	1	1	1	1

2.2. Simulation Module

2.2.1. Spawn Module

This module carries out annual production of new recruits to the fishery into the smallest size class, 82-90 mm. It employs a Beverton-Holt stock-recruitment relationship. In practice, parameters of this relationship have been set so that over the effective realistic range of stock egg production, recruitment is nearly constant.

Purpose: To predict the total number of eggs released in each simulation year from 1968 to 2003.
Module: The spawn module is stored in the unit file **spawn.pas**.
Module Declaration:

procedure Spawning(**var** recruits : r260array; time : Integer; map : mapped; recruitmax : r2array; surmax : Real; Fecundity : r411array; **var** n : narray; **var** totaleggszone : r2array);

Module Outputs: recruits, totaleggszone

Declaration types:

r260array	: array [1..2,1..60] of Real
r2array	: array[1..2] of Real
r411array	: array[1..4,1..11] of Real
mapped	: array[1..50] of Tmapz
narray	: array[1..11,0..1,1..50] of Real

Tmapz = record
regula, growth, psettle, habitat, refuge : Integer

$$\text{totaleggs(nz)} = \sum_{j=1}^{\text{reg(nz)}} \sum_{i=1}^{\text{nsizes}} \text{fecundity[growth(j), i]} \cdot \text{n[i,0,j]}$$

$$\text{totaleggs(sz)} = \sum_{j=1}^{\text{reg(sz)}} \sum_{i=1}^{\text{nsizes}} \text{fecundity[growth(j), i]} \cdot \text{n[i,0,j]}$$

$$\text{totalegg} = \text{totaleggs(nz)} + \text{totaleggs(sz)}$$

$$\text{recruits(year, iz)} = \frac{\text{surv max} \times \text{totaleggs}}{1 + \text{surv max}\left(\frac{\text{totaleggs}}{\text{recruit max(iz)}}\right)}$$

Variable Definitions:

fecundity	: fertility
totaleggs	: total number of eggs over each zone
recruits	: total number of recruitments per zone for each year
recruitmax	: maximum number of recruits
survmax	: maximum survival
totaleggs	: total number of eggs over each zone

2.2.2. Moult Module

The growth of lobsters occurs by moulting. From the tagging study undertaken in conjunction with this model project, it was shown that moulting is a roughly semi-annual event, with lobsters moulting in summer and winter. To represent this discrete growth, a transition matrix of "pmolt" parameters is called from the database. The two moult periods are the first fortnight of January, and of July. For each size, and sex, and in each of 3 growth subregions, the pmolt value gives the probability of moulting from the present length class into the next higher length bin. These pmolt probabilities of moulting are then multiplied through by the corresponding population numbers, yielding the numbers of simulation lobsters subsequently added to the next higher length class.

Purpose: Calculate the moulting and natural survival per two week time step
Module: The moult module is stored in the unit file **molt.pas**.
Module Declaration:

procedure Molt(iftnt, time : Integer; survivestep, pfemrecs : Real; recruits : r2array; map : mapped;
var psettlezone : r250array; **var** n : narray; precruit : Real; imoltnumber : Integer;
pmolt : pmoltarray);

Module Outputs: psettlezone, n

Declaration types:

r2array : array[1..2] of Real
pmoltarray: array[1..4.1..11.0..1,1..4] of Real
mapped : array[1..50] of Tmapz
narray : array[1..11,0..1,1..50] of Real

Tmapz = record
regula, growth, psettle, habitat, refuge : Integer

$$\left.\begin{array}{ll} n(i,isx,j) = n(i,isx,j) + molt(i-1); & i = 11 \\ n(i,isx,j) = n(i,isx,j) - molt(i) + molt(i-1); & i = 2,\ldots,10 \\ n(i,isx,j) = n(i,isx,j) - molt(i); & i = 1 \end{array}\right\} \; isx = 0,1; \;\; j = 1, nregs$$

$$n(i,isx,j) = n(i,isx,j) \cdot survivestep \quad \text{for } i = 1,..,11; \; isx = 0,1; \; j = 1,...,50$$

$$n(1,0,j) = n(1,0,j) + (precruit \cdot recruits(yrs,iz) \cdot psettlezone(iz,j)) \cdot pfemrecs$$

$$n(1,1,j) = n(1,1,j) + (precruit \cdot recruits(yrs,iz) \cdot psettlezone(iz,j)) \cdot (1 - pfemrecs)$$

Variables Definitions

n	: number females and males in each region
molt	: lobster growth in each region
nregs	: number of regions
survivestep	: Stock-recruit slope (max recruit per 1000 eggs)
pfemrecs	: Sex ratio proportion of recruits that are female
recruits	: number of recruits for Northern and Southern Zone
psettlezone	: proportions of 82-90 mm's settling by cell in each zone

2.2.3. Fishing Effort

Annual fishing effort in the model can be calculated using dynamical rate equation, or may be fixed at the yearly historical reported levels. In most uses of the model to date, the latter option is used. Once the total effort for the year is determined, these potlifts are allocated by fortnight through the fishing season, and spatially among cells of the model. The equations that carry out this allocation are described below. When quota is imposed, the reduction in effort through the season is also simulated in this submodel, as are two additional regulatory strategies, closed seasons and closed areas.

Purpose: Predict the fishing effort over all regions for one 15-day step
Module: The fishing effort module is stored in the unit file **effort.pas**.
Module Declaration:

procedure Effort(time, iftnt : Integer; **var** cpue, attract : regarray; cpueforone, maxlifts, wpastecpue : Real; **var** totaleffort, totalattract : r2array; **var** bestcpue, iquotazone, iquota0zone : i2array; **var** TACzone, monthopen, yearcatchzone, catchzonewt, cpu, potsbyzone94, peffort : r2array; **var** yeareffortoffshore : real; **var** effort, catch : regarray; map : mapped; historicaleffortzone : r2array; expectedcpue : regarray);

Declaration Types:

regarray : array[1..50] of Real
r2array : array[1..2 of Real
i2array : array[1..2] of Integer
mapped : array[1..50] of Tmapz

Tmapz = record
regula, growth, psettle, habitat, refuge : Integer

$$\text{cpu}(i) = \frac{\text{catch}(i)}{\text{effort}(i)} \quad i = 1, \ldots, \text{nregions}$$

$$\text{tmpexpected} = \sum_{i=1}^{\text{reg}(j)} \text{wpastcpue} \cdot \text{expectedcpue}(i) + (1 - \text{wpastcpue}) \cdot \text{cpu}(i)$$

$$\text{expectedzonecpue}(\text{nz}) = \begin{cases} \text{tmpexpected} / \text{nregs} & \text{if reg}(j) \neq 0 \text{ and tmpexpected} \neq 0 \\ 1 & \text{otherwise} \end{cases}$$

$$\text{daysperset}(i) = \frac{\text{cpueforone}}{\text{expectedzonecpue}(i)} \quad i = 1, \ldots, 2$$

$$\text{daysperset} = \begin{cases} 5 & \text{if daysperset} > 5 \\ 1 & \text{if daysperset} < 1 \\ \text{daysperset} & \text{otherwise} \end{cases}$$

$$\text{totaleffort}(i) = \left(\frac{\text{historicaleffort}(i)}{\text{histnftntsopen}(i)} \right) \cdot \text{peffortok}(i) \quad i = 1,2$$

$$quotareducprop(i) = ceTAC\left[1 - e^{\left(-aeTAC\left(\frac{TAC - yearcatch(i)}{TAC}\right)\right)}\right] \quad i = 1,2$$

$$\text{totaleffort}(i) = \text{avgftntlyeffort}(i) \cdot \text{quotareducprop} \cdot \text{peffortok}(i) \quad i = 1,2$$

$$\text{totaleffort} = \begin{cases} \dfrac{\text{TAC} - \text{yearcatchzone}(i)}{\text{cpu}(i)} & \text{if yearcatchzone} + \text{catchzonewt} > \text{TAC} \\ \text{totaleffort}(i) & \text{otherwise} \end{cases} \quad i = 1,2$$

$$\text{totaleffort}(i) = \begin{cases} \text{totaleffort}(i) & \text{if iquotazone } \neq 1 \\ 0 & \text{if iquotazone} = 1 \text{ and yearcatchzone} > \text{TAC} \\ & \text{or iquota0zone } = 2 \end{cases} \quad i = 1,2$$

$$\text{totaleffort}(i) = \begin{cases} 0 & \text{if monthopen}(i) > 7 \\ \text{totaleffort}(i) & \text{otherwise} \end{cases} \quad i = 1,2$$

$$\text{attract}(i) = \frac{\text{exp ectedcpue}(i)}{(1 + \text{wide}(i) - \text{row}(i))^2} \quad i = 1, \ldots, \text{nregions}$$

$$\text{totalattract}(i) = \sum_{j=1}^{\text{nreg}(i)} \text{attract}(j) \quad i = 1,2$$

$$\text{effortf}(i) = \frac{\text{totaleffort}(\text{zone}_i) \cdot \text{attract}(i)}{\text{totalattract}(\text{zone}_i)} \quad i = 1, .., \text{nregions}$$

$$\text{offshore}(i) = \begin{cases} \displaystyle\sum_{i=1}^{\text{nregions}} \text{effortf}(i) & \text{if row}(i) < \text{wide}(i) \\ 0 & \text{otherwise} \end{cases} \quad i = 1, \ldots, \text{nregions}$$

Main Variables Definitions

cpu	: cost per unit for Northern and Southern Zone
catchf	: catch per regions
effortf	: fishing effort per region
wpastcpue	: past cost per unit effort
expectedcpue	: expected cost per unit effort for each region
daysperset	: days per set
cpueforone	: cost per unit for one
expectedzonecpue	: expected Northern and Southern Zone cpue
totaleffort	: total fishing effort for year
historical effort	: historical fishing effort
peffortok	: proportion of historical effort by fortnight

ceTAC	: constant
aeTAC	: constant
yearcatch	: catch per year
avgftntlyeffort	: average effort for fortnight
yearcatchzone	: year catch zone

2.2.4. Catch Module

The catch submodel accounts for all known sources of lobster mortality, associated with harvest. Lobsters are removed by commercial harvest, deaths in the pots before pot recovery (usually by predators), recreational catch, unreported commercial and other illegal catch, and release mortality of undersize and egg bearing females. This submodel accounts for regulation by size limits.

Purpose: Predict catch over areas for one 15-day step.
Module: The catch module is stored in the unit file **catch.pas**.
Module Declaration:

procedure Catch(time, iftnt : Integer; q : r2array; ibinrhshinge, ibinlhshinge, imaxtog, ihingetog, ibinlegalmaxlen, ibinlegalminlen : ilt2array; lhshinge, rhshinge, legalmaxlen, legalminlen : rlt2array; wpastcpue; real; weight : rl1tlarray; var catchzonewt, effortzone, uweek, catchzonenos, popnoszone, totflossesftnt : r2array; yearcatchzonesexnos; r2tlarray; var fortntcatch : real; effort; catch : regarray; map : mapped pspawners : r2tlarray; var n : narray; yearcatchzonesizesexnos : r2112array; var expectedcpue : regarray; rvulseason : r2tlarray; rvul : rl1array);

Declarations Types

r2array	: array[1..2] of Real
ilt2array	: array[0..1,1..2] of Integer
rlt2array	: array[0..1,1..2] of Real
rl1tlarray	: array[1..11,1..2] of Real
r2tlarray	: array[1..2,0..1] of Real
regarray	: array[1..50] of Real
mapped	: array[1..50] of Tmapz
narray	: array[1..11,0..1,1..50] of Real
r2112array	: array[1..2,1..11,0..1] of Real
rl1array	: array[1..11] of Real

Tmapz = record
regula, growth, psettle, habitat, refuge : Integer

2.2.5. Stock Size Module

For a number of the submodels above, totals of population size of juveniles (length classes 1 and 2) and adults (length classes 3+) must be summed. This is carried out below.

Purpose : Adds the total stock over cells and ages, generate map abundance index array
Module : The stock size module is stored in the unit file **stock.pas**.
Module Declaration:

procedure Stock(time : Integer; nlegalstartseason : r2array; map : mapped; var n : narray);

Declarations Types

r2array	: array[1..2] of Real
mapped	: array[1..50] of Tmapz

narray : array[1..11,0..1,1..50] of Real

Tmapz = record
regula, growth, psettle, habitat, refuge : Integer

$$\text{celladult}(i) = \sum_{j=3}^{\text{nsizes}} n(j,0,i) + n(j,1,i) \quad i = 1,\ldots,\text{nregions}$$

$$\text{cellyoung}(i) = \sum_{j=1}^{2} n(j,o,i) + n(j,1,i) \quad i = 1,\ldots,\text{nregions}$$

$$\text{adult} = \sum_{i=1}^{\text{nregions}} \text{celladult}(i)$$

$$\text{young} = \sum_{i=1}^{\text{nregions}} \text{cellyoung}(i)$$

$$\text{nlegalstartseason}(j) = \sum_{i=1}^{\text{nreg}(j)} \text{celladult}(i) \quad j = 1,2$$

$$\text{youngcell}(i) = \frac{\text{cellyoung}(i)}{\text{cellsize}} \quad i = 1,\ldots,\text{nregions}$$

$$\text{adultcell}(i) = \frac{\text{celladult}(i)}{\text{cellsize}} \quad i = 1,\ldots,\text{nregions}$$

3. Report Generation

3.1. Input Parameter Reports

3.1.1. Population and Harvest Report

South Australian Rock Lobster Fishery Management Model
Version 4.0

General Population Parameters

	NZ	SZ
Illegal catch fraction of commercial	0.05	0.05
Recreational catch fraction of commercial	0.05	0.05
Fraction of catch brought by dead in pots	0.04	0.04

Stock-recruit slope (max recruit per 1000 eggs)	:	20.10
Maximum average recruits (82-90 mm) per year NZ	:	1.02
Maximum average recruits (82-90 mm) per year SZ	:	3.10
Map row where peak recruitment occurs	:	10.00
North-South variance of recruitment distribution	:	50.00
Relative drop off in recruitment rate/cell offshore	:	2.00
Sea ratio proportion of recruits that are females	:	0.50

Natural Mortality Rate (m)	:	0.10
Catchability Coefficient (q) NZ	:	15.00
Catchability Coefficient (q) SZ	:	15.00
len-wt parameter in W = a*L^b	a:	0.0000002800
	b:	3.12

Recruitment Scaling Factors

Northern Zone:
- alpha = 3.0000
- beta = 5.0000
- gamma = 0.5500

Southern Zone:
- alpha = 1.0000
- beta = 2.0000
- gamma = 0.0000

3.1.2. Growth and Fecundity Report

South Australian Rock Lobster Fishery Management Model
Version 4.0

Growth and Fecundity Parameters

Proportions moulting by region and season
Females

	Hi gro NZ				Central NZ				South SZ				North SZ			
len	Nov	Feb	May	Aug	Nov	Feb	May	Aug	Nov	Feb	May	Aug	Nov	Feb	May	Aug
82	0.6	0.7	0.5	0.0	0.4	1.0	0.4	0.0	0.1	0.4	0.4	0.7	0.6	0.7	0.5	0.0
90	0.8	0.6	0.4	0.0	0.5	0.9	0.3	0.0	0.1	0.3	0.3	0.6	0.8	0.6	0.4	0.0
98	0.7	0.3	0.3	0.0	0.4	0.4	0.2	0.0	0.1	0.1	0.2	0.3	0.7	0.3	0.3	0.0
106	0.7	0.3	0.2	0.0	0.5	0.3	0.1	0.0	0.1	0.1	0.1	0.3	0.7	0.3	0.2	0.0

114	0.5	0.2	0.0	0.0	0.3	0.3	0.0	0.0	0.1	0.1	0.0	0.0	0.5	0.2	0.0	0.0
122	0.3	0.1	0.0	0.0	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.1	0.0	0.0
130	0.2	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.1	0.0	0.0
138	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
146	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
154	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
162	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Proportions moulting by region and season

Males

	Hi gro NZ				Central NZ				South SZ				North SZ			
len	Nov	Feb	May	Aug	Nov	Feb	May	Aug	Nov	Feb	May	Aug	Nov	Feb	May	Aug
82	0.3	0.7	0.5	1.0	0.6	0.7	0.5	0.5	0.1	0.5	0.3	1.0	0.3	0.7	0.5	1.0
90	0.3	0.7	0.4	1.0	0.6	0.7	0.4	0.5	0.1	0.5	0.3	1.0	0.3	0.7	0.4	1.0
98	0.3	0.7	0.3	0.9	0.6	0.7	0.3	0.5	0.1	0.5	0.2	0.8	0.3	0.7	0.3	0.9
106	0.3	0.6	0.3	0.9	0.6	0.6	0.3	0.5	0.1	0.4	0.2	0.8	0.3	0.6	0.3	0.9
114	0.3	0.5	0.3	0.9	0.6	0.5	0.3	0.5	0.1	0.4	0.2	0.8	0.3	0.5	0.3	0.9
122	0.2	0.5	0.3	0.8	0.4	0.5	0.3	0.5	0.1	0.4	0.2	0.8	0.2	0.5	0.3	0.8
130	0.2	0.5	0.3	0.8	0.4	0.5	0.3	0.5	0.1	0.4	0.2	0.8	0.2	0.5	0.3	0.8
138	0.0	0.5	0.2	0.8	0.0	0.5	0.2	0.4	0.0	0.4	0.1	0.7	0.0	0.5	0.2	0.8
146	0.0	0.5	0.1	0.8	0.0	0.5	0.1	0.4	0.0	0.4	0.1	0.7	0.0	0.5	0.1	0.8
154	0.0	0.5	0.0	0.5	0.0	0.5	0.0	0.3	0.0	0.4	0.0	0.5	0.0	0.5	0.0	0.5
162+	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Fecundity vs Length: afec and bfec in afec*length^bfec (1000 eggs/mm)
afec = 0.2350   bfec = 2.9120

Female percent mature vs length
using logistic formula 1/(1+exp(-cpmat*(length-pmat50)))

	Hi Gro NZ	Central NZ	South SZ	North SZ
cpmat	0.170	0.180	0.150	0.100
pmst50	101.0	103.0	112.0	102.0

3.1.3. Economics and Effort Report

South Australian Rock Lobster Fishery Management Model
Version 4.0

Economics and Effort

Price by Fornight

Fortnight	Price	Fortnight	Price	Fortnight	Price	Fortnight	Price
Oct (1)	30	Jan (1)	26	Apr (1)	34	Jul (1)	38
Oct (2)	30	Jan (2)	26	Apr (2)	34	Jul (2)	38
Nov (1)	30	Feb (1)	24	May (1)	38	Aug (1)	38
Nov (2)	30	Feb (2)	24	May (2)	38	Aug (2)	38
Dec (1)	26	Mar (1)	32	Jun (1)	38	Sep (1)	38
Dec (2)	26	Mar (2)	32	Jun (2)	38	Sep (2)	38

Crew share % of gross income 14.00
Skipper share % of gross income 20.00
Variable costs per potlift (fuel, bait, 1/3 repair) $ 5.00
Price Elasticity, > 100t fortnight -0.10

Fishing Effort Response Parameters

cpue (kg/pot night) above which typical fisherman pull pots daily: 1.00
Maximum share % of gross income: 22.00
Effort model type (0 = simulated, 1 = fixed at historical): 1

Coefficient of linear trend in fixed cost since 1968 (as a+b*year)
Northern a: 0.2717 b: 0.0145
Southern a: 1.9690 b: 0.0000

Fixed cost = (a+b*year) x $ 10.00 per potlift

% Price variation of the above price in the given year

Time	%Price variation
1963	0
1964	0
1965	0
1966	0
1967	0
1968	0
1969	0
1970	0
1971	0
1972	0
1973	0
1974	0
1975	0
1976	0
1977	0
1978	0
1979	0
1980	0
1981	0
1982	0
1983	0
1984	0
1985	0
1986	0
1987	0
1988	0
1989	0
1990	0
1991	0
1992	0
1993	0
1994	0
1995	0
1996	0
1997	0
1998	0
1999	0
2000	0
2001	0
2002	0
2003	0

Number of pots licensed by 1994: NZ = 3950.00 SZ = 11923.00
Number of escape gaps: 3

3.1.4. Mapped Information Zones

```
South Australian Rock Lobster Fishery Management Model
                          Version 4.0


Regulation Zones
 ---------------------------
| 1 1                        |
| 1 1                        |
|  1 1                       |
|   1 1                      |
|    1 1                     |
|    1 1    1   1            |
|     1 1 1 1 1 1 1 1        |
|     1 1 1 1       1 1      |
|           1 1 1 1 1 2 2    |
|           1 1 1 1 2 2 2    |
|                     2 2    |
|                      2 2   |
|                       2 2  |
|                       2 2  |
 ---------------------------
Legend to Regulation Zone Map
   1 = Northern Zone
   2 = Southern Zone


Growth Regions
 ---------------------------
| 1 1                        |
| 1 1                        |
|  1 1                       |
|   1 1                      |
|    2 2                     |
|    2 2    2   1            |
|     2 2 2 1 1 1 1 2        |
|     2 2 2 1       3 3      |
|           2 2 2 2 2 2 1    |
|           2 2 2 2 2 2 1    |
|                     1 1    |
|                      1 1   |
|                       3 3  |
|                       3 3  |
 ---------------------------
Legend to Growth Regions Map
   codes are region numbers corresponding to growth and fecundity patterns set under
growth and fecundity pars
```

Settlement Index

```
 ---------------------------
| 2 2                        |
| 1 2                        |
|  1 3                       |
|   1 1                      |
|    1 5                     |
|    1 5    1   4            |
|     1 1 4 2 2 3 1 1        |
|     1 1 1 7       1 1      |
|           4 4 4 3 1 1 5    |
|           1 1 1 1 1 1 1    |
|                     10 13    |
|                      10 22   |
|                       13 13  |
|                        1 1  |
 ---------------------------
```

Legend to Settlement Index Map
values are index of relative settlement vs distance offshore

Habitat Size Index

```
 ---------------------------
| 1 1                        |
| 1 1                        |
|  1 1                       |
|   1 1                      |
|    1 1                     |
|    1 1    1   1            |
|     1 1 1 1 1 1 1 1        |
|     1 1 1 1       1 1      |
|           1 1 1 1 1 1 1    |
|           1 1 1 1 1 1 1    |
|                     1 1    |
|                      1 1   |
|                       1 1  |
|                       1 1  |
 ---------------------------
```

Legend to Habitat Size Index Map
1 = large area
2 = very small area

Closed (refuge) Areas

```
 ---------------------------
| 1 1                        |
| 1 1                        |
|  1 1                       |
|   1 1                      |
|    1 1                     |
|    1 1    1   1            |
|     1 1 1 1 1 1 1 1        |
|     1 1 1 1       1 1      |
|           1 1 1 1 1 1 1    |
|           1 1 1 1 1 1 1    |
|                     1 1    |
|                      1 1   |
|                       1 1  |
|                       1 1  |
 ---------------------------
```

Legend to Closed (refuge) Area Map
0 = closed to fishing
1 = open to fishing

3.1.5. Management Strategies

Fishing Regulations

South Australian Rock Lobster Fishery Management Model
Version 4.0

Fishing Regulation Report

Proportion of Historical Effort allowed by Fortnight

Northern				Southern			
Fortnight	Prop.	Fortnight	Prop.	Fortnight	Prop.	Fortnight	Prop.
Oct (1)	0.0	Apr (1)	1.0	Oct (1)	1.0	Apr (1)	1.0
Oct (2)	0.0	Apr (2)	1.0	Oct (2)	1.0	Apr (2)	1.0
Nov (1)	1.0	May (1)	1.0	Nov (1)	1.0	May (1)	0.0
Nov (2)	1.0	May (2)	1.0	Nov (2)	1.0	May (2)	0.0
Dec (1)	1.0	Jun (1)	0.0	Dec (1)	1.0	Jun (1)	0.0
Dec (2)	1.0	Jun (2)	0.0	Dec (2)	1.0	Jun (2)	0.0
Jan (1)	1.0	Jul (1)	0.0	Jan (1)	1.0	Jul (1)	0.0
Jan (2)	1.0	Jul (2)	0.0	Jan (2)	1.0	Jul (2)	0.0
Feb (1)	1.0	Aug (1)	0.0	Feb (1)	1.0	Aug (1)	0.0
Feb (2)	1.0	Aug (2)	0.0	Feb (2)	1.0	Aug (2)	0.0
Mar (1)	1.0	Sep (1)	0.0	Mar (1)	1.0	Sep (1)	0.0
Mar (2)	1.0	Sep (2)	0.0	Mar (2)	1.0	Sep (2)	0.0

Regulation of minimum and maximum legal size limits (in mm)
(note that a value of 0.0 indicates no limit in force)

Minimum and Maximum legal size limit (Yr = 1963)

	Minimum	Mid-range lower bound	Mid-range upper bound	Maximum
Females (NZ)	98.5	80.0	80.0	80.0
Male (NZ)	98.5	80.0	80.0	80.0
Females (SZ)	98.5	80.0	80.0	80.0
Males (SZ)	98.5	80.0	80.0	80.0

Quota TAC (9999 indicates no quota) (tons): NZ = 700.0 SZ = 700.0

Regulation of minimum and maximum legal size limits (in mm)
(note that a value of 0.0 indicates no limit in force)

Minimum and Maximum legal size limit (Yr = 1971)

	Minimum	Mid-range lower bound	Mid-range upper bound	Maximum
Females (NZ)	98.5	80.0	80.0	80.0
Male (NZ)	98.5	80.0	80.0	80.0
Females (SZ)	98.5	80.0	80.0	80.0
Males (SZ)	98.5	80.0	80.0	80.0

Quota TAC (9999 indicates no quota) (tons): NZ = 700.0 SZ = 700.0

Regulation of minimum and maximum legal size limits (in mm)
(note that a value of 0.0 indicates no limit in force)

Minimum and Maximum legal size limit (Yr = 1979)

	Minimum	Mid-range lower bound	Mid-range upper bound	Maximum
Females (NZ)	98.5	80.0	80.0	80.0
Male (NZ)	98.5	80.0	80.0	80.0
Females (SZ)	98.5	80.0	80.0	80.0
Males (SZ)	98.5	80.0	80.0	80.0

Quota TAC (9999 indicates no quota) (tons): NZ = 700.0 SZ = 700.0

Regulation of minimum and maximum legal size limits (in mm)
(note that a value of 0.0 indicates no limit in force)

Minimum and Maximum legal size limit (Yr = 1987)

	Minimum	Mid-range lower bound	Mid-range upper bound	Maximum
Females (NZ)	98.5	80.0	80.0	80.0
Male (NZ)	98.5	80.0	80.0	80.0
Females (SZ)	98.5	80.0	80.0	80.0
Males (SZ)	98.5	80.0	80.0	80.0

Quota TAC (9999 indicates no quota) (tons): NZ = 700.0 SZ = 700.0

Regulation of minimum and maximum legal size limits (in mm)
(note that a value of 0.0 indicates no limit in force)

Minimum and Maximum legal size limit (Yr = 1995)

	Minimum	Mid-range lower bound	Mid-range upper bound	Maximum
Females (NZ)	102.0	80.0	80.0	80.0
Male (NZ)	98.5	80.0	80.0	80.0
Females (SZ)	102.0	80.0	80.0	80.0
Males (SZ)	98.5	80.0	80.0	80.0

Quota TAC (9999 indicates no quota) (tons): NZ = 700.0 SZ = 1720.0

Regulation of minimum and maximum legal size limits (in mm)
(note that a value of 0.0 indicates no limit in force)

Minimum and Maximum legal size limit (Yr = 2003)

	Minimum	Mid-range lower bound	Mid-range upper bound	Maximum
Females (NZ)	102.0	80.0	80.0	80.0
Male (NZ)	98.5	80.0	80.0	80.0
Females (SZ)	102.0	80.0	80.0	80.0
Males (SZ)	98.5	80.0	80.0	80.0

Quota TAC (9999 indicates no quota) (tons): NZ = 700.0 SZ = 1720.0

3.2. Result Reports

3.2.1. Data Selection Report

Report for the baseline run. The report was generated for a variable selected from the Select Data dialog box.

```
South Australian Rock Lobster Fishery Management Model
                        Version 4.0

                  Variable Selection Report
                  -------------------------


The following variables have been selected for analysis


total egg production (NZ)


Data associated with the selected variables

1.  total egg production (NZ)

1963 478.430000
1964 491.290000
1965 503.220000
1966 506.360000
1967 507.270000
1968 497.170000
1969 495.440000
1970 496.290000
1971 497.520000
1972 498.790000
1973 496.150000
1974 488.900000
1975 481.810000
1976 474.010000
1977 464.500000
1978 443.760000
1979 419.630000
1980 395.330000
1981 390.490000
1982 405.860000
1983 444.350000
1984 499.550000
1985 551.730000
1986 583.580000
1987 580.610000
1988 566.230000
1989 540.440000
1990 515.110000
1991 486.000000
1992 456.430000
1993 430.080000
1994 408.060000
1995 390.420000
1996 376.700000
1997 366.240000
1998 358.330000
```

3.2.2. Least Squares Curve Fitting Report

```
South Australian Rock Lobster Fishery Management Model
                        Version 4.0


                Least Squares Analysis Report

 Variable Selected:  total egg production (NZ)


Equation1:
-----------
Time: 1968 - 1978

Equation: y = 488.3497 * x^0.0111

Statistics

No. of Observations                    : 11
Mean                                   : 6.2086
Variance                               : 0.0002
Standard Error of the Mean             : 0.0046
Total Sum of Squares                   : 0.0025
Regression Sum of Squares              : 0.0007
Standard Deviation                     : 0.0159
Coeff. of Determination (r squared)    : 0.2684
Linear Correlation Coefficient         : 0.5182
Standard Error                         : 0.0144


Equation2:
-----------
Time: 1978 - 1986

Equation: y = 1569.5876 * x^-0.4649

Statistics

No. of Observations                    : 9
Mean                                   : 6.1067
Variance                               : 0.0074
Standard Error of the Mean             : 0.0287
Total Sum of Squares                   : 0.0667
Regression Sum of Squares              : 0.0601
Standard Deviation                     : 0.0913
Coeff. of Determination (r squared)    : 0.9011
Linear Correlation Coefficient         : -0.9493
Standard Error                         : 0.0307


Equation3:
-----------
Time: 1986 - 1993

Equation: y = 5.8771 * x^1.4277

Statistics

No. of Observations                    : 8
Mean                                   : 6.2086
Variance                               : 0.0237
Standard Error of the Mean             : 0.0544
Total Sum of Squares                   : 0.1897
Regression Sum of Squares              : 0.1715
Standard Deviation                     : 0.1646
```

```
Coeff. of Determination (r squared) : 0.9044
Linear Correlation Coefficient      : 0.951
Standard Error                      : 0.055


Equation4:
-----------
Time: 1993 - 2003

Equation: y = 74554.2615 * x^-1.4972

Statistics

No. of Observations                 : 11
Mean                                : 6.0858
Variance                            : 0.0239
Standard Error of the Mean          : 0.0466
Total Sum of Squares                : 0.2624
Regression Sum of Squares           : 0.2603
Standard Deviation                  : 0.162
Coeff. of Determination (r squared) : 0.9921
Linear Correlation Coefficient      : -0.9961
Standard Error                      : 0.0151
```

3.2.3. Graph Results Report

```
South Australian Rock Lobster Fishery Management Model
                     Version 4.0

                 Chart Display Report


The following variables have been selected for analysis

fishable biomass by zone (SZ)

Data Values

Time   fishable biomass by zone (SZ)

   1967  4.604985
   1968  4.607235
   1969  4.666678
   1970  4.681695
   1971  4.588511
   1972  4.660975
   1973  4.828655
   1974  4.819923
   1975  4.872961
   1976  5.014506
   1977  5.020175
   1978  5.354029
   1979  5.089856
   1980  4.826982
   1981  4.588688
   1982  4.328865
   1983  4.348686
   1984  4.275831
   1985  4.355583
   1986  4.233731
   1987  4.297127
   1988  4.506257
   1989  4.922223
   1990  5.240058
   1991  5.448040
```

1992	5.602548
1993	5.937758
1994	6.199924
1995	6.411769
1996	6.541686
1997	6.665750
1998	6.789688
1999	6.915635
2000	7.045522
2001	7.180353
2002	7.320690
2003	0.000000
2004	0.000000
2005	0.000000
2006	0.000000
2007	0.000000

3.2.4. Catch Length Frequencies Report

Length Size Frequencies Report

Relative Fish Size Vulnerabilities (mm)

Relative Fish Sizes:

Females Northern Zone (Baseline)

	82	90	98	106	114	122	130	138	146	154	162
1963	0.0000	0.0000	0.7335	0.4870	0.3654	0.2035	0.0917	0.0489	0.0159	0.0039	0.0003
1964	0.0000	0.0000	0.6119	0.5305	0.4142	0.2498	0.0872	0.0447	0.0094	0.0023	0.0002
1965	0.0000	0.0000	0.4673	0.4553	0.4913	0.3554	0.1189	0.0530	0.0070	0.0017	0.0001
1966	0.0000	0.0000	0.4292	0.3846	0.4580	0.4350	0.1673	0.0691	0.0054	0.0013	0.0001
1967	0.0000	0.0000	0.4220	0.3631	0.4101	0.4497	0.2093	0.0905	0.0042	0.0010	0.0001
1968	0.0000	0.0000	0.4221	0.3597	0.3839	0.4340	0.2330	0.1133	0.0032	0.0008	0.0001
1969	0.0000	0.0000	0.4220	0.3590	0.3726	0.4155	0.2429	0.1348	0.0025	0.0006	0.0000
1970	0.0000	0.0000	0.4200	0.3571	0.3673	0.4026	0.2463	0.1542	0.0020	0.0005	0.0000
1971	0.0000	0.0000	0.4212	0.3545	0.3621	0.3927	0.2464	0.1711	0.0016	0.0004	0.0000
1972	0.0000	0.0000	0.4227	0.3529	0.3576	0.3848	0.2449	0.1854	0.0013	0.0003	0.0000
1973	0.0000	0.0000	0.4297	0.3539	0.3530	0.3760	0.2406	0.1955	0.0010	0.0003	0.0000
1974	0.0000	0.0000	0.4327	0.3587	0.3539	0.3689	0.2341	0.2005	0.0008	0.0002	0.0000
1975	0.0000	0.0000	0.4342	0.3621	0.3576	0.3656	0.2276	0.2020	0.0007	0.0002	0.0000
1976	0.0000	0.0000	0.4348	0.3631	0.3600	0.3654	0.2234	0.2026	0.0005	0.0001	0.0000
1977	0.0000	0.0000	0.4348	0.3625	0.3606	0.3662	0.2215	0.2039	0.0004	0.0001	0.0000
1978	0.0000	0.0000	0.4363	0.3610	0.3587	0.3663	0.2211	0.2061	0.0004	0.0001	0.0000
1979	0.0000	0.0000	0.4404	0.3608	0.3558	0.3643	0.2203	0.2080	0.0003	0.0001	0.0000
1980	0.0000	0.0000	0.4446	0.3628	0.3544	0.3611	0.2184	0.2084	0.0002	0.0001	0.0000
1981	0.0000	0.0000	0.4494	0.3651	0.3541	0.3581	0.2158	0.2074	0.0002	0.0000	0.0000
1982	0.0000	0.0000	0.4477	0.3681	0.3549	0.3572	0.2144	0.2074	0.0002	0.0000	0.0000
1983	0.0000	0.0000	0.4112	0.3628	0.3663	0.3709	0.2223	0.2163	0.0001	0.0000	0.0000
1984	0.0000	0.0000	0.4201	0.3422	0.3560	0.3782	0.2290	0.2243	0.0001	0.0000	0.0000
1985	0.0000	0.0000	0.4922	0.3487	0.3263	0.3503	0.2176	0.2148	0.0001	0.0000	0.0000
1986	0.0000	0.0000	0.5898	0.3833	0.3083	0.2989	0.1853	0.1843	0.0001	0.0000	0.0000
1987	0.0000	0.0000	0.6874	0.4244	0.3026	0.2486	0.1440	0.1429	0.0000	0.0000	0.0000
1988	0.0000	0.0000	0.7315	0.4622	0.3143	0.2213	0.1125	0.1080	0.0000	0.0000	0.0000
1989	0.0000	0.0000	0.7033	0.4837	0.3469	0.2282	0.0997	0.0882	0.0000	0.0000	0.0000
1990	0.0000	0.0000	0.6461	0.4794	0.3794	0.2605	0.1035	0.0811	0.0000	0.0000	0.0000
1991	0.0000	0.0000	0.5840	0.4601	0.3992	0.3033	0.1200	0.0833	0.0000	0.0000	0.0000
1992	0.0000	0.0000	0.5202	0.4342	0.4091	0.3474	0.1458	0.0932	0.0000	0.0000	0.0000
1993	0.0000	0.0000	0.4763	0.4049	0.4051	0.3816	0.1745	0.1076	0.0000	0.0000	0.0000
1994	0.0000	0.0000	0.2823	0.4292	0.4346	0.4433	0.2225	0.1381	0.0000	0.0000	0.0000
1995	0.0000	0.0000	0.2839	0.4296	0.4129	0.4326	0.2371	0.1538	0.0000	0.0000	0.0000
1996	0.0000	0.0000	0.2768	0.4325	0.4114	0.4208	0.2422	0.1663	0.0000	0.0000	0.0000
1997	0.0000	0.0000	0.2819	0.4266	0.4068	0.4134	0.2437	0.1776	0.0000	0.0000	0.0000
1998	0.0000	0.0000	0.2937	0.4316	0.3990	0.4009	0.2401	0.1847	0.0000	0.0000	0.0000
1999	0.0000	0.0000	0.3053	0.4433	0.3976	0.3862	0.2312	0.1864	0.0000	0.0000	0.0000
2000	0.0000	0.0000	0.3152	0.4552	0.4009	0.3748	0.2201	0.1837	0.0000	0.0000	0.0000
2001	0.0000	0.0000	0.3230	0.4649	0.4057	0.3680	0.2098	0.1786	0.0000	0.0000	0.0000
2002	0.0000	0.0000	0.3288	0.4722	0.4103	0.3648	0.2014	0.1724	0.0000	0.0000	0.0000
2003	0.0000	0.0000	0.3330	0.4778	0.4142	0.3638	0.1953	0.1660	0.0000	0.0000	0.0000

Males Northern Zone (Baseline)

1963	0.000	0.000	0.373	0.331	0.287	0.234	0.196	0.172	0.139	0.110	0.108
1964	0.000	0.000	0.232	0.322	0.309	0.253	0.206	0.188	0.157	0.122	0.160
1965	0.000	0.000	0.191	0.207	0.222	0.248	0.242	0.236	0.202	0.160	0.243
1966	0.000	0.000	0.194	0.197	0.176	0.175	0.188	0.235	0.237	0.204	0.343
1967	0.000	0.000	0.199	0.204	0.178	0.157	0.148	0.183	0.211	0.221	0.448
1968	0.000	0.000	0.205	0.212	0.186	0.161	0.142	0.155	0.171	0.195	0.525
1969	0.000	0.000	0.210	0.217	0.191	0.166	0.145	0.149	0.150	0.163	0.559
1970	0.000	0.000	0.213	0.219	0.194	0.169	0.148	0.149	0.145	0.145	0.568
1971	0.000	0.000	0.217	0.223	0.196	0.170	0.148	0.150	0.143	0.137	0.566
1972	0.000	0.000	0.221	0.225	0.197	0.170	0.148	0.150	0.143	0.134	0.561
1973	0.000	0.000	0.228	0.231	0.199	0.170	0.148	0.149	0.142	0.131	0.552
1974	0.000	0.000	0.230	0.235	0.205	0.174	0.150	0.150	0.141	0.129	0.536
1975	0.000	0.000	0.232	0.238	0.208	0.178	0.154	0.152	0.142	0.128	0.518
1976	0.000	0.000	0.234	0.239	0.209	0.180	0.156	0.155	0.144	0.129	0.504
1977	0.000	0.000	0.235	0.240	0.210	0.180	0.156	0.156	0.146	0.131	0.496
1978	0.000	0.000	0.237	0.240	0.209	0.179	0.156	0.156	0.146	0.132	0.494
1979	0.000	0.000	0.241	0.243	0.210	0.178	0.154	0.155	0.146	0.132	0.492
1980	0.000	0.000	0.244	0.246	0.212	0.179	0.154	0.154	0.144	0.131	0.487
1981	0.000	0.000	0.247	0.248	0.213	0.180	0.154	0.153	0.143	0.129	0.481
1982	0.000	0.000	0.242	0.251	0.216	0.182	0.155	0.154	0.143	0.129	0.477
1983	0.000	0.000	0.215	0.228	0.211	0.187	0.163	0.162	0.151	0.135	0.498
1984	0.000	0.000	0.238	0.226	0.193	0.171	0.155	0.162	0.154	0.139	0.511
1985	0.000	0.000	0.294	0.262	0.204	0.160	0.136	0.142	0.140	0.130	0.483
1986	0.000	0.000	0.359	0.310	0.233	0.169	0.130	0.121	0.113	0.106	0.407
1987	0.000	0.000	0.419	0.360	0.261	0.182	0.133	0.112	0.094	0.081	0.310
1988	0.000	0.000	0.433	0.388	0.286	0.199	0.142	0.114	0.088	0.067	0.233
1989	0.000	0.000	0.401	0.380	0.297	0.220	0.163	0.130	0.097	0.068	0.195
1990	0.000	0.000	0.359	0.352	0.288	0.228	0.180	0.154	0.119	0.081	0.189
1991	0.000	0.000	0.318	0.321	0.271	0.224	0.187	0.173	0.144	0.103	0.209
1992	0.000	0.000	0.278	0.286	0.250	0.216	0.187	0.184	0.165	0.129	0.254
1993	0.000	0.000	0.257	0.263	0.230	0.202	0.179	0.186	0.175	0.148	0.310
1994	0.000	0.000	0.146	0.268	0.231	0.201	0.178	0.188	0.184	0.167	0.388
1995	0.000	0.000	0.148	0.277	0.233	0.192	0.165	0.173	0.171	0.162	0.430
1996	0.000	0.000	0.142	0.271	0.238	0.199	0.167	0.166	0.160	0.152	0.455
1997	0.000	0.000	0.150	0.274	0.233	0.195	0.167	0.166	0.155	0.143	0.467
1998	0.000	0.000	0.158	0.286	0.239	0.194	0.162	0.161	0.151	0.136	0.464
1999	0.000	0.000	0.164	0.297	0.247	0.199	0.163	0.157	0.145	0.129	0.449
2000	0.000	0.000	0.169	0.306	0.254	0.204	0.166	0.158	0.142	0.123	0.428
2001	0.000	0.000	0.173	0.313	0.260	0.208	0.169	0.159	0.141	0.120	0.406
2002	0.000	0.000	0.176	0.318	0.263	0.211	0.171	0.161	0.142	0.119	0.387
2003	0.000	0.000	0.179	0.322	0.266	0.213	0.173	0.163	0.144	0.119	0.371

Females Southern Zone (Baseline)

1963	0.000	0.000	0.892	0.516	0.329	0.144	0.051	0.017	0.002	0.000	0.000
1964	0.000	0.000	0.844	0.568	0.345	0.143	0.036	0.012	0.001	0.000	0.000
1965	0.000	0.000	0.741	0.529	0.422	0.201	0.044	0.013	0.000	0.000	0.000
1966	0.000	0.000	0.703	0.494	0.418	0.252	0.065	0.018	0.000	0.000	0.000
1967	0.000	0.000	0.721	0.497	0.394	0.241	0.074	0.022	0.000	0.000	0.000
1968	0.000	0.000	0.746	0.503	0.383	0.222	0.071	0.025	0.000	0.000	0.000
1969	0.000	0.000	0.760	0.505	0.377	0.213	0.068	0.027	0.000	0.000	0.000
1970	0.000	0.000	0.756	0.508	0.380	0.211	0.066	0.029	0.000	0.000	0.000
1971	0.000	0.000	0.747	0.508	0.385	0.215	0.066	0.030	0.000	0.000	0.000
1972	0.000	0.000	0.745	0.503	0.385	0.219	0.067	0.031	0.000	0.000	0.000
1973	0.000	0.000	0.750	0.503	0.380	0.218	0.068	0.032	0.000	0.000	0.000
1974	0.000	0.000	0.740	0.507	0.385	0.218	0.067	0.032	0.000	0.000	0.000
1975	0.000	0.000	0.728	0.505	0.392	0.223	0.068	0.033	0.000	0.000	0.000
1976	0.000	0.000	0.729	0.501	0.390	0.226	0.070	0.034	0.000	0.000	0.000
1977	0.000	0.000	0.723	0.502	0.391	0.228	0.071	0.035	0.000	0.000	0.000
1978	0.000	0.000	0.713	0.501	0.396	0.231	0.072	0.036	0.000	0.000	0.000
1979	0.000	0.000	0.709	0.501	0.397	0.234	0.073	0.037	0.000	0.000	0.000
1980	0.000	0.000	0.691	0.497	0.405	0.242	0.076	0.038	0.000	0.000	0.000
1981	0.000	0.000	0.713	0.487	0.391	0.241	0.078	0.041	0.000	0.000	0.000
1982	0.000	0.000	0.731	0.491	0.380	0.231	0.076	0.042	0.000	0.000	0.000
1983	0.000	0.000	0.730	0.497	0.382	0.226	0.074	0.041	0.000	0.000	0.000
1984	0.000	0.000	0.735	0.499	0.382	0.223	0.071	0.040	0.000	0.000	0.000
1985	0.000	0.000	0.732	0.503	0.385	0.223	0.070	0.038	0.000	0.000	0.000
1986	0.000	0.000	0.717	0.502	0.394	0.228	0.071	0.038	0.000	0.000	0.000
1987	0.000	0.000	0.747	0.494	0.378	0.224	0.070	0.037	0.000	0.000	0.000
1988	0.000	0.000	0.722	0.507	0.389	0.224	0.071	0.037	0.000	0.000	0.000
1989	0.000	0.000	0.735	0.497	0.387	0.225	0.070	0.037	0.000	0.000	0.000
1990	0.000	0.000	0.754	0.496	0.379	0.218	0.068	0.035	0.000	0.000	0.000

1991	0.000	0.000	0.835	0.497	0.340	0.189	0.059	0.030	0.000	0.000	0.000
1992	0.000	0.000	0.776	0.534	0.370	0.187	0.055	0.028	0.000	0.000	0.000
1993	0.000	0.000	0.695	0.523	0.418	0.222	0.062	0.030	0.000	0.000	0.000
1994	0.000	0.000	0.674	0.498	0.421	0.251	0.073	0.033	0.000	0.000	0.000
1995	0.000	0.000	0.650	0.493	0.423	0.264	0.083	0.037	0.000	0.000	0.000
1996	0.000	0.000	0.632	0.484	0.427	0.275	0.090	0.042	0.000	0.000	0.000
1997	0.000	0.000	0.621	0.477	0.427	0.282	0.096	0.047	0.000	0.000	0.000
1998	0.000	0.000	0.616	0.472	0.425	0.286	0.099	0.052	0.000	0.000	0.000
1999	0.000	0.000	0.610	0.470	0.424	0.289	0.101	0.056	0.000	0.000	0.000
2000	0.000	0.000	0.604	0.468	0.425	0.292	0.103	0.059	0.000	0.000	0.000
2001	0.000	0.000	0.598	0.465	0.426	0.295	0.104	0.061	0.000	0.000	0.000
2002	0.000	0.000	0.592	0.463	0.427	0.299	0.106	0.063	0.000	0.000	0.000
2003	0.000	0.000	0.586	0.461	0.428	0.303	0.108	0.065	0.000	0.000	0.000

Males Southern Zone (Baseline)

1963	0.000	0.000	0.484	0.387	0.302	0.224	0.173	0.137	0.101	0.074	0.068
1964	0.000	0.000	0.404	0.470	0.336	0.221	0.154	0.124	0.090	0.070	0.081
1965	0.000	0.000	0.378	0.365	0.297	0.257	0.199	0.154	0.108	0.082	0.109
1966	0.000	0.000	0.403	0.369	0.259	0.203	0.174	0.166	0.132	0.102	0.142
1967	0.000	0.000	0.443	0.410	0.279	0.193	0.141	0.125	0.107	0.099	0.153
1968	0.000	0.000	0.473	0.437	0.296	0.201	0.138	0.107	0.082	0.074	0.141
1969	0.000	0.000	0.489	0.449	0.303	0.204	0.139	0.104	0.074	0.061	0.128
1970	0.000	0.000	0.487	0.452	0.307	0.208	0.143	0.106	0.073	0.056	0.117
1971	0.000	0.000	0.482	0.449	0.308	0.212	0.147	0.110	0.076	0.056	0.110
1972	0.000	0.000	0.483	0.446	0.306	0.211	0.147	0.112	0.078	0.058	0.108
1973	0.000	0.000	0.488	0.451	0.305	0.207	0.145	0.111	0.078	0.059	0.107
1974	0.000	0.000	0.479	0.451	0.310	0.212	0.146	0.111	0.078	0.059	0.105
1975	0.000	0.000	0.470	0.443	0.310	0.217	0.152	0.115	0.080	0.060	0.105
1976	0.000	0.000	0.472	0.442	0.305	0.213	0.151	0.116	0.082	0.061	0.107
1977	0.000	0.000	0.467	0.442	0.307	0.214	0.150	0.116	0.082	0.063	0.110
1978	0.000	0.000	0.459	0.436	0.308	0.217	0.153	0.118	0.084	0.064	0.112
1979	0.000	0.000	0.455	0.437	0.307	0.215	0.154	0.119	0.085	0.064	0.113
1980	0.000	0.000	0.442	0.423	0.307	0.222	0.159	0.123	0.088	0.067	0.118
1981	0.000	0.000	0.465	0.428	0.294	0.209	0.152	0.121	0.088	0.069	0.125
1982	0.000	0.000	0.479	0.440	0.296	0.202	0.143	0.113	0.083	0.067	0.127
1983	0.000	0.000	0.474	0.442	0.304	0.209	0.144	0.111	0.079	0.063	0.125
1984	0.000	0.000	0.480	0.445	0.303	0.208	0.145	0.111	0.078	0.060	0.119
1985	0.000	0.000	0.477	0.448	0.307	0.211	0.146	0.111	0.078	0.059	0.113
1986	0.000	0.000	0.461	0.436	0.310	0.219	0.153	0.116	0.081	0.061	0.113
1987	0.000	0.000	0.497	0.450	0.297	0.202	0.144	0.112	0.079	0.060	0.109
1988	0.000	0.000	0.459	0.443	0.315	0.218	0.149	0.113	0.080	0.062	0.111
1989	0.000	0.000	0.485	0.443	0.301	0.209	0.149	0.114	0.080	0.060	0.109
1990	0.000	0.000	0.500	0.444	0.305	0.208	0.144	0.110	0.078	0.059	0.103
1991	0.000	0.000	0.569	0.488	0.295	0.182	0.123	0.093	0.065	0.049	0.087
1992	0.000	0.000	0.483	0.482	0.336	0.220	0.140	0.096	0.064	0.047	0.082
1993	0.000	0.000	0.426	0.429	0.326	0.244	0.173	0.126	0.081	0.055	0.091
1994	0.000	0.000	0.429	0.417	0.301	0.225	0.171	0.138	0.098	0.068	0.102
1995	0.000	0.000	0.408	0.412	0.304	0.225	0.166	0.135	0.102	0.079	0.119
1996	0.000	0.000	0.396	0.401	0.300	0.227	0.169	0.137	0.102	0.083	0.136
1997	0.000	0.000	0.391	0.394	0.295	0.224	0.168	0.138	0.104	0.085	0.151
1998	0.000	0.000	0.387	0.391	0.292	0.222	0.167	0.138	0.105	0.086	0.162
1999	0.000	0.000	0.382	0.389	0.291	0.221	0.167	0.138	0.104	0.087	0.171
2000	0.000	0.000	0.378	0.387	0.291	0.222	0.167	0.138	0.105	0.087	0.177
2001	0.000	0.000	0.373	0.385	0.290	0.222	0.168	0.139	0.105	0.087	0.181
2002	0.000	0.000	0.369	0.382	0.289	0.222	0.169	0.140	0.106	0.088	0.185
2003	0.000	0.000	0.364	0.379	0.287	0.222	0.169	0.141	0.107	0.090	0.190

3.2.5. Time Plots Report

Management Strategy Report (Northern Zone)

Total Egg Production (Basline)

Time	Total Eggs	(Northern Zone)
1963	596.5200	242.1600
1964	835.9900	337.8300
1965	886.1300	398.6200
1966	908.3500	437.0200

1967	912.4100	461.3800
1968	917.3100	478.4300
1969	925.2400	491.2900
1970	943.9700	503.2200
1971	958.4700	506.3600
1972	964.6200	507.2700
1973	947.6000	497.1700
1974	954.7600	495.4400
1975	973.6400	496.2900
1976	974.7100	497.5200
1977	981.5900	498.7900
1978	993.3600	496.1500
1979	986.8100	488.9000
1980	1012.7000	481.8100
1981	978.4400	474.0100
1982	942.7400	464.5000
1983	899.5000	443.7600
1984	851.1900	419.6300
1985	829.5000	395.3300
1986	817.8000	390.4900
1987	840.9300	405.8600
1988	866.2200	444.3500
1989	928.9100	499.5500
1990	1000.4500	551.7300
1991	1071.2300	583.5800
1992	1097.9600	580.6100
1993	1110.1500	566.2300
1994	1101.9900	540.4400
1995	1107.6500	515.1100
1996	1102.1000	486.0000
1997	1091.1000	456.4300
1998	1075.8300	430.0800
1999	1064.8700	408.0600
2000	1058.8000	390.4200
2001	1057.1900	376.7000
2002	1059.3300	366.2400
2003	1064.5200	358.3300

Earnings per pot by zone (Baseline)

Time	Northern Zone
1963	1.0110
1964	1.9727
1965	1.9331
1966	2.0269
1967	2.0479
1968	2.0154
1969	1.8853
1970	2.0899
1971	2.0387
1972	2.3381
1973	1.9198
1974	1.7694
1975	1.7039
1976	1.6519
1977	1.7424
1978	1.8487
1979	1.7906
1980	1.7722
1981	1.7867
1982	1.9405
1983	1.7320
1984	1.7139
1985	1.4364
1986	1.5687
1987	1.9273
1988	2.3549

1989	2.8715
1990	3.3943
1991	3.9112
1992	3.4692
1993	3.1774
1994	2.6877
1995	2.5279
1996	2.2042
1997	1.8870
1998	1.6303
1999	1.4121
2000	1.2258
2001	1.0736
2002	0.9536
2003	0.8591

Catch by zone (Baseline)

Time	NZone	NZhist
1963	0.3679	0.5389
1964	0.5691	0.5389
1965	0.5630	0.5389
1966	0.5867	0.5389
1967	0.5960	0.5389
1968	0.5944	0.5389
1969	0.5698	0.5014
1970	0.6268	0.6438
1971	0.6233	0.6021
1972	0.7068	0.7106
1973	0.6142	0.6771
1974	0.5847	0.5972
1975	0.5760	0.6201
1976	0.5705	0.5408
1977	0.6006	0.6074
1978	0.6360	0.5824
1979	0.6307	0.5814
1980	0.6352	0.6692
1981	0.6488	0.6295
1982	0.7012	0.6949
1983	0.6657	0.6780
1984	0.6792	0.6793
1985	0.6173	0.6564
1986	0.6561	0.7497
1987	0.7444	0.8109
1988	0.8395	0.8684
1989	0.9550	0.9973
1990	1.0761	1.1036
1991	1.2054	1.2217
1992	1.1048	1.0642
1993	1.0445	0.9298
1994	0.9472	0.8918
1995	0.9203	0.8918
1996	0.8602	0.8918
1997	0.8010	0.8918
1998	0.7540	0.8918
1999	0.7150	0.8918
2000	0.6823	0.8918
2001	0.6565	0.8918
2002	0.6372	0.8918
2003	0.6231	0.8918

CPUE by zone (Baseline)

Time	NZone	NZhist
1963	1.0252	1.5017
1964	1.5856	1.5017
1965	1.5687	1.5017
1966	1.6347	1.5017
1967	1.6607	1.5017
1968	1.6561	1.5017
1969	1.6444	1.4470
1970	1.6152	1.6590
1971	1.5734	1.5200
1972	1.5174	1.5256
1973	1.4742	1.6252
1974	1.4608	1.4919
1975	1.4461	1.5568
1976	1.4320	1.3574
1977	1.4130	1.4290
1978	1.3825	1.2660
1979	1.3528	1.2470
1980	1.3266	1.3975
1981	1.2951	1.2565
1982	1.2451	1.2339
1983	1.1668	1.1883
1984	1.0985	1.0987
1985	1.0677	1.1353
1986	1.0821	1.2364
1987	1.1447	1.2469
1988	1.2605	1.3040
1989	1.3835	1.4448
1990	1.4722	1.5098
1991	1.4967	1.5170
1992	1.4808	1.4264
1993	1.4522	1.2927
1994	1.3422	1.2637
1995	1.3041	1.2637
1996	1.2190	1.2637
1997	1.1350	1.2637
1998	1.0685	1.2637
1999	1.0131	1.2637
2000	0.9669	1.2637
2001	0.9303	1.2637
2002	0.9029	1.2637
2003	0.8829	1.2637

Bibliography

Walters, C., J.H. Prescott, R. McGarvey, and J. Prince. 1997. Management options for the South Australian rock lobster fishery: a case study of cooperative assessment and policy design by fishers and biologists. Can. Spec. Publ. Fish. Aquat. Sci. 125, in press.

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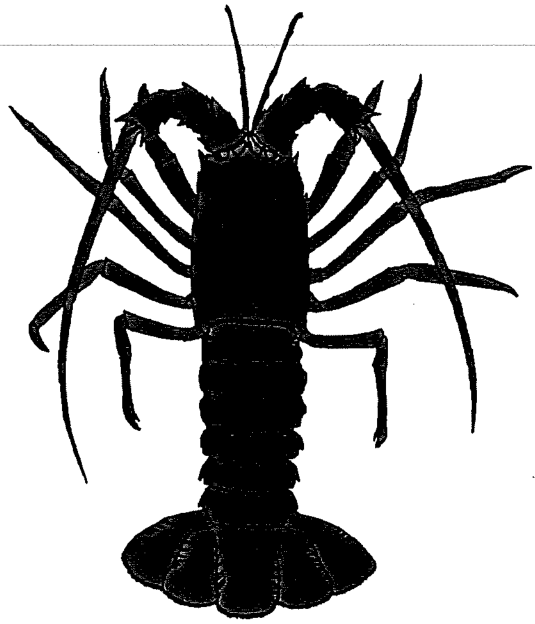
SOUTH AUSTRALIAN ROCK LOBSTER
FISHERY MANAGEMENT MODEL



User Guide

July 1997

SARDI
SOUTH AUSTRALIAN RESEARCH AND DEVELOPMENT INSTITUTE

SANZFLFA Inc.

SEPFA Inc.

FISHERIES RESEARCH & DEVELOPMENT CORPORATION

by Rick McGarvey
Paul Gaertner
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SARDI Aquatic Sciences
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"Fisheries are complex dynamic systems that are difficult to measure, understand, and manage. Interactive graphics models are computer-based tools that offer benefits to scientists, managers, fishers, conservationists, educators, trainers, students, the community, and media. .... models use techniques of visualization .... to significantly improve our ability to analyze, understand, and manage fisheries, communicate this understanding and educate others. ..."

P. Sluczanowski, R.K. Lewis, J. Prince, and J. Tonkin,
"Interactive Graphics Computer Models for Fisheries Management",
Proceedings of the World Fisheries Congress.

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1. Introduction

1.1. Model Overview

The South Australian Rock Lobster Fishery Management Model (SARLMOD) represents some of what we know about the rock lobster fishery around the South Australian coastline. The model is one of many tools used to help fishers, scientists and managers make strategic management decisions.

Mathematical models such as this one are developed for specific purposes and involve many assumptions. With all models you need to be aware of the underlying assumptions, and the degree of confidence and uncertainty, associated with the model. Therefore this model should not be used for anything other than what it was designed for. This model is **not** an exact duplicate of the real world. It is **not** an actual rock lobster stock. It is limited by the extent and accuracy of research to date, our overall understanding, and what is feasible to model.

The rock lobster model within SARLMOD allows the simulation of different lobster management strategies as well as parameter scenarios. Management options can be implemented easily with the use of menu screens. Results from management scenarios that you find interesting can be stored in project files for later use and future investigation. The model represents the changes in the lobster stock and of fishing effort across the state's marine fishing areas and over time. The model recreates the change in the lobster population under different levels and regulations of fishing. It allows you to test management strategies for this resource. The three variables are: time, location and carapace length.

Time: The model predicts how abundance and effort change over fortnightly time steps. Each year is represented by 24 fortnights allowing the model to show the effect of seasonal changes, such as growth, recruitment, migration, closed fishing periods and redistribution of fishing effort.

Location: The model follows the change in stock and effort in each quarter-area of each one degree square Marine Fishing Area block. (These are called model **cells.**)

Carapace Length: The model follows the change in the numbers of lobsters in each 8 mm size class. There are 11 size classes: 10 classes between 82 mm to 162 mm and one size class for lobsters of 162 mm and greater.

1.1.1. Historical Information

The simulation of the rock lobster population begins in October 1968 when the Southern Zone season opens. The model simulates the changes in the rock lobster population until the year 2003. All the time plots run only from 1968 when the fishery became limited entry and a regular system for collecting catch and effort data was established. We give the model 5 years before 1968 to allow the catches and lobster populations to "equilibrate", meaning to settle down to predict what was observed.

By 1968 we assume a new equilibrium had already been reached in the Southern Zone fishery where the population had settled down to well below its virgin levels. For the most part, the very high catch rates of the 1940's and 1950's were already a thing of the past, and most (but not all) of the older virgin stock crays had been taken.

1.1.2. The Delphi Graphical User Interface

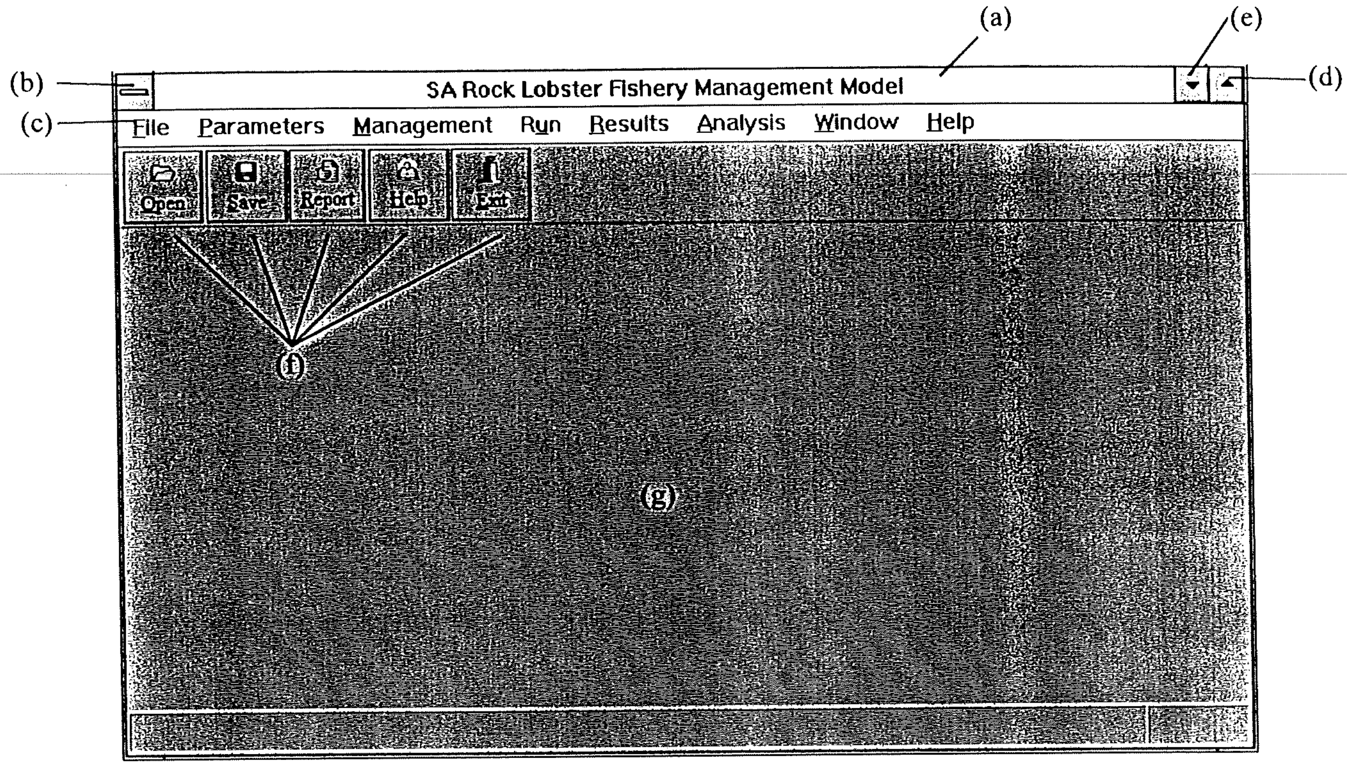

Figure 1: Graphical User Interface.

(a) **Title bar** - includes the name of the current project.
(b) **Control-menu box** - double click on this to close a window or dialog box.
(c) **Menu bar** - contains the menus from which you choose commands.
(d) **Maximise button** - click on this button to enlarge a window to fill the screen. This button will then be replaced by the **restore button.**
(e) **Minimise button** - reduces the window to an icon.
(f) **Speed buttons** - shortcuts for commonly used menu commands.
(g) **Model display area** - space below the speed buttons where input and output is displayed.

The graphical user interface, (Figure 1), was developed using the Delphi programming language. It allows easy control of the model and the display of model results. Using the mouse, select the menus needed to perform the following tasks:

File: Open and save model projects, generate text summaries ie "reports" of input or output, select default settings for printing, and export data to Excel or any other word processor or spreadsheet. The speed buttons also allow you to execute the most widely used of these commands;
Parameters: Change parameters for the model run;
Management: Specify the management strategy you want to test;
Run: Run the model;
Results: Display the outputs of the model run;
Analysis: Calculate statistics for the model or data variables and graph any variables or combination of variables;
Window: Control the output display;
Help: Refer to Help on the use of the model and its scientific basis. This User Guide and the Scientific Guide are included in full in the **Help**. The equations of the model are available under **Help|Scientific Manual|Lobster Management Model|Simulation Module**.

"Dialog boxes" will appear when you choose menu items. These allow you to enter selections and values. Screens containing model output will appear in the Model display area.

1.1.3. Projects

The data for any management strategy, both the regulations you choose, and any other parameters you change, together with all outputs from the overlay, can be stored for later use. This collection of inputs and outputs is called a "project". The files containing each project end with a ".pro" extension. You choose the first eight characters for the project name so that the full name, for example, might be "mypolicy.pro". The procedures for saving and reloading projects are included in Section 3.3, "File Menu".

The "baseline" project contains the model's reconstruction of the history of the fishery. The file, "baseline.pro", is stored in your model subdirectory, and will be automatically loaded with the model. When you then impose a new management policy that you'd like to test and run it, the new outcome appears overlayed with the results of the baseline run for comparison. This allows you to see whether the newly tested policy enhances catch, CPUE, egg production and earnings.

2. Installation

2.1. Computer requirements

To load and run the model you will need:

1. an IBM compatible computer with a 386 chip or higher and maths coprocessor (ie. a DX model, not SX).
2. at least 8 megabytes of disk space and 4 megabytes of RAM.

2.2. Installation

The SA Rock Lobster Fishery Management Model (SARLMOD) is contained on three 3.5" diskettes.

To install SARLMOD:

1. Execute Windows
2. Insert the Installation disk (disk 1) into the 3.5" drive
3. Select **Run** from the Program Manager **File** Menu.
4. In the command line type the drive which contains the installation disk followed by **install.**
   For example: **a:\install**
5. Choose **OK.**
6. Insert disks 2 and 3 when prompted.

SARLMOD will then install from the disks into the directory **c:\sarlmod**. If this directory does not already exist it will be created. A dialog box will appear asking if you want to create a Windows program group. Click on the Yes button. Another dialog box will then appear asking you the same question, to which you again click on **Yes.** The program group will then be automatically created which will contain the SARLMOD icon.

2.3. Executing SARLMOD

To run SARLMOD:

1. Open the program group (SA Rock Lobster Model)
2. Double click the red SARLMOD icon.

2.4. Creating a Backup

Backups are very important. If you do not backup your software disks and they get damaged or lost then you will have to obtain another copy of the software. Thus it will be easier to make a backup copy of the disks using the Copy Disk command in the File Manager. To ensure the backup copy is not corrupted install SARLMOD from the backups and not the original disks.

2.5. Getting Started

- To start the model package, double click on the red SARLMOD icon located in the **SA Rock Lobster Model** program group in the **Windows Program Manager** or the **Programs** folder if Windows 95 is used. The "SA Rock Lobster Fishery Management Model" window will appear. This is described in more detail in Chapter 4, "Model Commands", however the following provides a brief summary of some of the model commands.

- The **Parameters** and **Management** menus can be used to change parameter values and alter management strategies, described in sections 4.1 and 4.3. The new strategies are tested by choosing **Overlay Scenario** from the **Run** menu. The model will take approximately 1 minute to run on a Pentium 90 computer.

- The **Results** and **Analysis** menus are used to display and analyse the output. The model Results are represented by time plots, length frequency histograms, and maps showing how the lobster population changes over time. The baseline scenario, before management is imposed, is automatically loaded and displayed. Time plots for catch, catch per potlift, net revenues, and total egg production resulting from the changes will be overlayed with the baseline plots for comparison. Information on running the model with changed parameter values and management choices is given in section 4.4.

- Each time the model is rerun, with new parameter values or a new management strategy that you want to be able to reuse in the future, you can save the output and all input parameters as a new project. To do this click on the **Save** speed button, or select **Save As...** from the File menu, which will bring up the "Save SARLMOD Project" dialog box. SARLMOD will ask you if you want to save the current project immediately after the model has completed its run. Clicking on Yes will bring up the dialog box. Type in the new project name of your choice making sure to add the **.pro** extension to any project name chosen. Click **OK** to save this new project.

- If users wish to re-open a previously saved project, select **File|Open Project** and click on the appropriate project name, or select **File|New Project** to start a new project. When a project is loaded its name appears in the Model title bar.

3. Basic Model Functions

In this chapter we will present the use of two of the menus, **File** and **Window**. The **File** menu allows you to save and create projects, setup the printer, export information from the model, and exit the program. The **Window** menu allows you to manipulate input and output screens inside the model display area. In the next chapter we discuss the menus which are used to control the model.

In order to more easily use the package, it is helpful to learn about the Windows environment. The following is a brief introduction to the basic Windows functions. Use the Windows Help facility to obtain more detailed information on these features.

3.1. Using Menu Commands

Menu Bar

Located below the title bar, along the top of the application window, the Menu Bar gives you access to all SARLMOD commands. To view all the commands in a menu, do one of the following:

1. Click the menu name or
2. Press ALT+ *n*, where *n* represents the underlined letter in the menu name. For example, press ALT+F to open the File menu.

Choosing a Menu Command

You can choose commands with the mouse or by pressing key combinations.
Mouse:

1. Point to a menu name.
2. To display the menu, click the left mouse button.
3. Point to a command name.
4. Click the command name with the left mouse button.

Keyboard:

1. To make the menu bar active, press the ALT key.
2. To display a menu, press the underlined letter in the menu name.
3. To choose a command, press the underlined letter in the command name.

A command name followed by an ellipsis (...) indicates that a dialog box exists so you can set the options you want. See section 3.2.4, "Setting Dialog Box Options".

3.2. Dialog Boxes

To open a SARLMOD dialog box select an item from the main menu. For example selecting **Population and Harvest** from the **Parameters** menu will cause the "Population and Harvest Parameters" dialog box to be displayed (Figure 2). When a dialog box is opened, any previously selected information will be displayed. If no information has been selected then the default settings are shown.

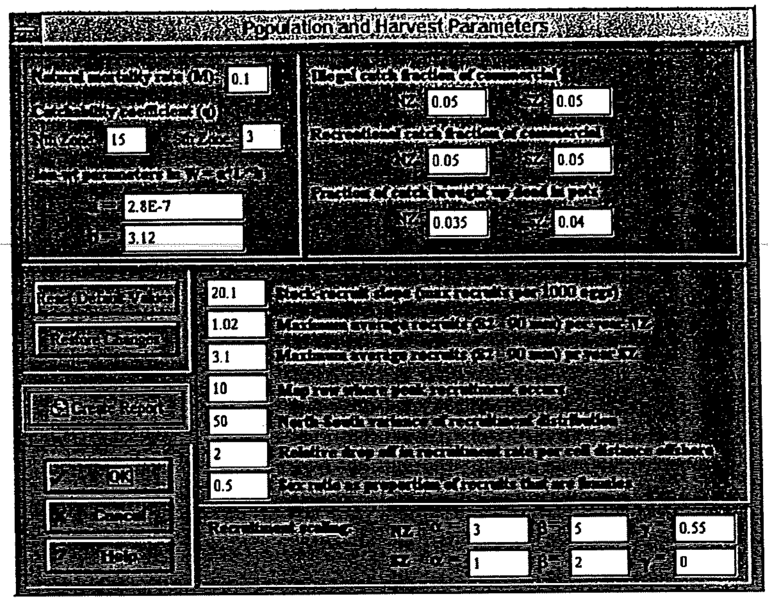

Figure 2: "Population and Harvest Parameters" dialog box.

3.2.1. Moving around Dialog Boxes

To move between dialog box options either:

1. use the mouse to click the item or area you wish to be selected, or
2. use the TAB key to move the cursor index to the indicated section and then use the arrow keys to select the item to be selected.

3.2.2. Moving a Window / Dialog Box

You can position document windows and dialog boxes anywhere in the application window. For example, you can move and size two graphic windows so they appear side by side as you work. However, you cannot move a window that has been enlarged to its maximum size.

To move an application window or dialog box
Mouse:
Point to the title bar of the window or dialog box and drag it to the new position.

Keyboard:

1. From the application Control menu, choose Move (ALT + SPACEBAR, M).
2. To position the outline of the window, use the arrow keys. To return the window to its former location, press ESC.
3. When the window appears where you want it, press ENTER.

To move a document window
Point to the title bar and drag it to the new position.

3.2.3. Setting Dialog Box Options

1. Point to the option and click the left mouse button, or
2. Hold down the ALT key and press the underlined letter in the option name.

To carry out the options you set

1. Choose the **OK** button or
2. Press ENTER.

To cancel changes to options settings

1. Choose the **Cancel** button.
2. Press ESC.

3.2.4. Closing a Dialog Box

Dialog boxes can be closed in one of two ways:

1. **Cancel**; either
   (a) click on the **Cancel** button, or
   (b) double-click the control-menu box, which is a small horizontal line located in the upper, left hand corner of the window (Figure 1).

This will cause all action performed during the session to be cancelled and the previously selected information to be re-installed.

2. **OK**

This will cause all actions performed during the session to be saved.

3.3. File Menu

The **File** Menu includes commands that enable you to create a new project, open and close existing project files, save created projects and provides you with a means to print graphs and reports as well as exit the package.

3.3.1. Creating a new Project

From the File menu, choose **New Project** (ALT + F, N). This will start the model with an empty project file allowing the user to create a new project. You can create an original project or one based on a project that already exists. SARLMOD gives the new project a temporary name, such as Untitled.pro, until you save it with a unique filename.

3.3.2. Opening Projects

1. From the File menu, choose **Open Project** (ALT + F, O).
2. Click on the name of the project you want to open.

If the project you want to open is not listed in the File Name box, do one or more of the following:
(a) In the Drives box, select a new drive.
(b) In the Directories box, select a new directory.
(c) In the List Files Of Type box, select the type of project you want to open with its 3 character extension.

3. Choose the **OK** button.

IMPORTANT: If a non-project file is selected to be opened. The system will not operate correctly.

Note: You can see a list of all the files with a specific extension in a drive or directory by doing the following: In the File Name box, type an asterisk (*), before a period (.) and the extension. For example, to see all the files with a .PRO extension in a directory, type *.PRO in the File Name box. To see all the files in a directory, type *.*

3.3.3. Saving Projects

Following the completion of a model run, SARLMOD will ask whether you want to save the project. If you choose Yes, the "Save SARLMOD Project" dialog box will appear where you can type in the name of the project. Type in the name you choose in place of the asterisk under File Name. If you later make further changes you'd like to keep, click on the **Save** speed button and click on the active project in the list below to re-save under its current name and location. The Save As command will allow the user to save either a new project under a specific name, or to make a copy of an existing project file by saving it under a different name.

3.3.4. Closing Projects

While there is no specific command to close the active project, there are three implicit ways to leave a project: If you choose **Exit**, **Open Project** or **New Project** the present project will be closed or replaced. It is recommended that you save changes to your project before leaving it; if a project is closed without being saved, you will lose all changes made since the last time it was saved. SARLMOD will display the "Save SARLMOD Project" dialog box before closing an unnamed project unless you are exiting, in which case any unsaved changes will be lost.

3.3.5. Generating Reports

Reports are (ASCII) text files that can exported into word processors or spreadsheets. The **Generate Report** menu option, under the **File** menu, gives you access to all the reports, and allows you to choose which of them to include in a complete file summary of the model project you presently have open. This same "Customise Model Report" dialog box is also immediately accessible at any time by pressing the **Report** speed button. By clicking on **Create Report** from the **Parameters** windows, or choosing **Create** from the **Report** speed button dialog box, you will see the report. You can type in additional comments or information and edit the file using the **Edit** menu. This allows model parameters, management regulations, and the resulting model outputs to be exported to other Windows applications. Reports can also be generated for any variables that you select under **Analysis|Select Data** menu option.

3.3.6. Printer Setup

The Printer Setup command displays the "Print Setup" dialog box. If you need to alter the selection of default printer, go to Windows Program Manager (outside the model interface), select the **Main** program group, and choose **Control Panel|Printers**. Clicking on the **Setup** button allows you to change the orientation, scaling, paper size, paper source and number of copies printed for the printer chosen as the default.

3.3.7. Export

The **Export** menu option allows users to copy model inputs and output, as selected variables, to a format that can be read by spreadsheet applications such as Excel and Lotus.

To export model data:

1. Use the **Analysis|Select Data** menu option to select data variables to be exported.
2. Once variables have been selected, choose **File|Export** to copy the data variables to a text file. The variables in each line are separated by a comma.
3. Replace the * by a name with eight letters or less in the **File Name** text box. The default file name extension **.exp** is already included.

Note: If no data has been selected an error message will appear asking the user to select data.

3.3.8. Exit SARLMOD

To quit SARLMOD, either

1. from the File menu, choose **Exit** (ALT + F, X), or
2. click on the Exit speed button

If you have made changes to your active project since you last saved, then you should use the **File|Save** option before leaving SARLMOD, or all changes will be lost.

3.4. Window Menu

The **Window** menu allows the user to control the layout of the windows on the screen. The menu includes commands to arrange and close windows. The five menu options are described below:

The **Cascade** command stacks all open edit windows so each is the same size as all others and only part of each underlying window is visible.

The **Tile** command arranges the open windows so they cover the entire model display area without overlapping one another.

The **Arrange Icons** command leaves icons evenly spaced, beginning at the lower left corner of the model display area. All open windows must be minimised or this command is disabled.

To reduce all open windows to icons, choose **Minimize All.**

The **Close All Windows** command closes all open windows in the model display area. If text was modified since the last time you saved it, a dialog box will open asking if you want to save the file before closing the window.

4. Model Commands

This chapter will present the use of the **Parameters, Management**, **Run**, and **Results** menus. These allow you to choose parameters, select management strategies for testing, run the simulation with your chosen strategy, and display the results.

4.1. Parameters Menu

You can change all model parameters as explained below. Normally, however, it will *not be necessary* to change parameters. Default values will be automatically employed by the simulation if no new parameters are chosen. The default values have been estimated by fitting to the tag-recapture, catch-log and length-frequency data from the fishery.

4.1.1. Catch Vulnerabilities

Lobsters are captured with varying likelihood, ie varying "vulnerability", depending on the time of year and lobster size. The instructions below allow you to edit the seasonal and relative size vulnerabilities for the Northern and Southern Zones. To change the catch vulnerability parameters, select **Parameters|Catch Vulnerabilities.**

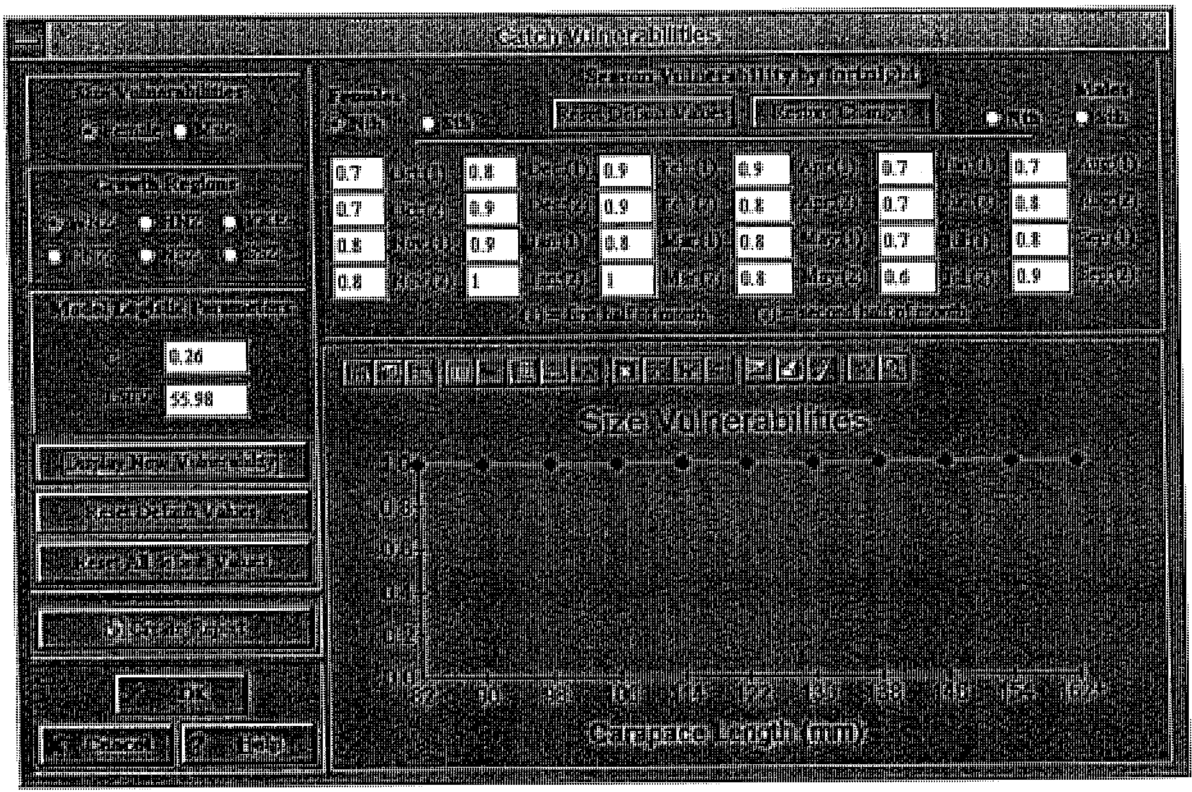

Figure 3: "Catch Vulnerabilities" dialog box.

Editing Vulnerabilities by Size

Vulnerabilities by size are divided into six regions, Western NZ, High Growth NZ, Yorke Peninsula, Central NZ, Northern SZ and Southern SZ. The shape of the curve that specifies increasing vulnerability with size class is determined by the two parameters for the logistic curve, C and L50V, associated with each growth region. Vulnerabilities in the present model yield little decline in vulnerability with smaller size, because these gave the best model fit of Catch Length Frequencies to historical data. The values of these parameters are changed as follows:

1. Select the radio buttons corresponding to the sex and the growth region of the size parameters to be modified.
2. Type the new value into the text boxes for the parameter(s) to be changed.
3. To display the new logistic curve of vulnerabilities by length class, hit the Display New Vulnerabilities button.
4. To recover the original default values, press **Reset Default Value**.
5. Once completed, to accept changes, press **OK**. **Cancel** deletes any changes and restores the previously saved values.

Editing Vulnerabilities by Season

1. Select the set of values to be changed, (eg Females Northern Zone) by clicking on one of the four radio buttons located at the top left and right of the **Season Vulnerability by fortnight** area.
2. Click the mouse in the edit box beside the fortnight to be edited and type the new value.
3. To set default values, press **Reset Default Values**, or to restore the last change of values, press **Restore Changes.**
4. To save changes press **OK**, or **Cancel** to delete any changes and restore old values.

4.1.2. Population and Harvest Parameters

To open the "Population and Harvest Parameters" dialog box (Figure 4) select **Parameters|Population and Harvest**. These are parameters associated with the lobster population biology and harvest apart from vulnerabilities.

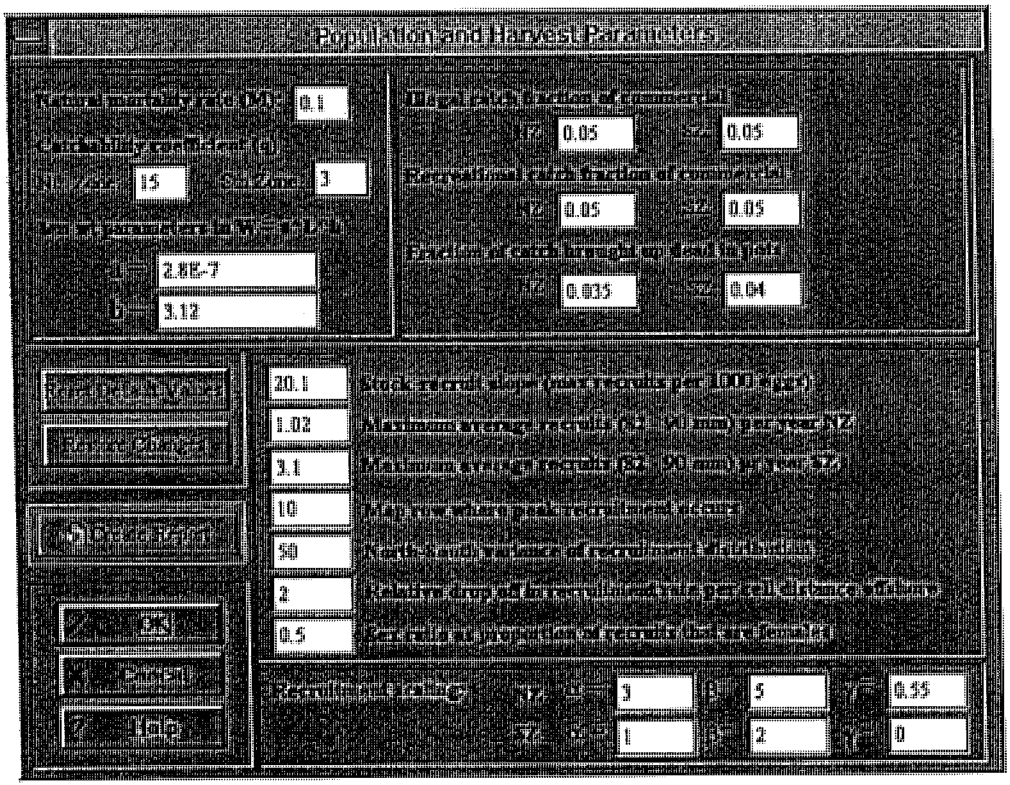

Figure 4: "Population and Harvest Parameters" dialog box.

To edit population values:

1. Click the mouse in the edit box alongside the parameter you wish to edit.
2. Type the new value for that parameter. Use Backspace as needed.

3. To save the changes, click **OK**. If **Cancel** is selected your changes will be undone and old values reinstated.

To set population defaults:

To set the population defaults press the **Reset Default Values** button. Once selected, all parameters will be changed to their default values. Use the **Restore Changes** button to restore the most recently changed values.

4.1.3. Growth and Fecundity Parameters

The parameters describing the growth of lobsters by proportion moulting each season, and the eggs produced annually (fecundity) by females of different lengths can be displayed by selecting **Parameters|Growth and Fecundity** (Figure 5).

Fecundity parameters
To change the parameters describing how fecundity changes with length, type the new values in the boxes provided.

Regional and Seasonal Moulting Proportions
In order to edit the proportion moulting by region and season:

1. Select the lobster sex and region from the **Proportion Moulting by Region and Season** area. For example, select Females and Hi-gro NZ.

   Once selected, the graph window (Figure 5) will display the seasonal moulting proportions for each lobster length from 82 to 162+ (mm).

2. To edit the seasonal proportions, use the **Moult Period Graph Edit** radio buttons to select season of moult proportions to edit. Then click on the graph to set proportions to new values.

3. To save the values, press **OK. Cancel** undoes changes and leaves previously saved values unchanged. **Reset Default Values** restores default values.

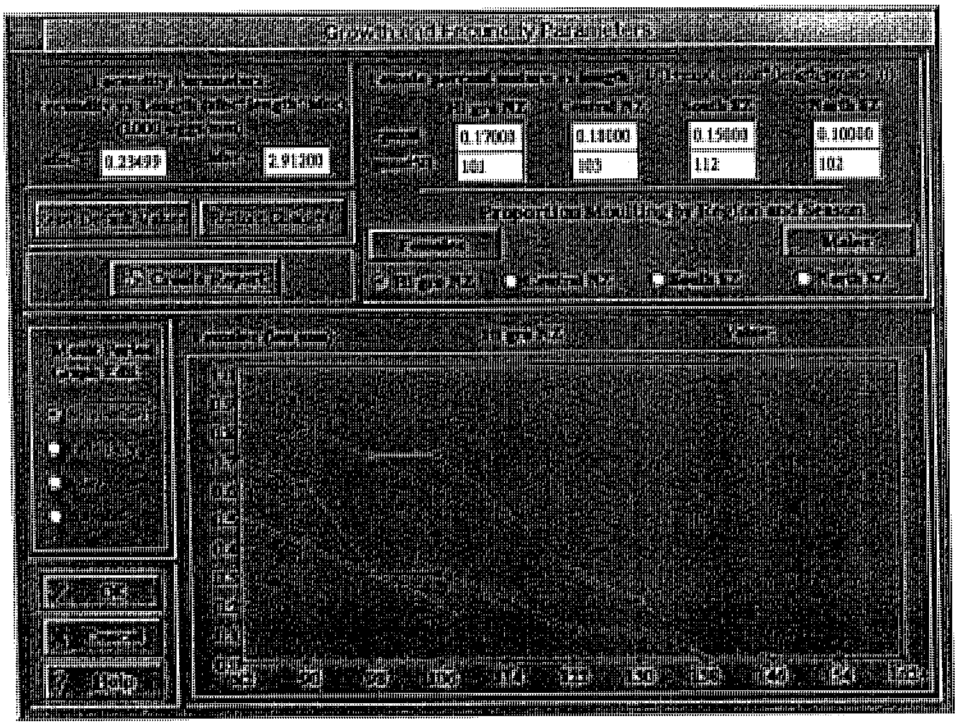

Figure 5: Growth and Fecundity Parameters.

Female percent mature vs length parameters

To edit the Female percent mature vs length parameters, simply type in the alternative parameter values in the boxes provided.

To save the values press **OK**. Press **Cancel** to delete the changes and restore old values. Press **Reset Default Values** to reset the values to their default. Note that pressing **Reset Default Values** will reset all changes made elsewhere within the dialog box if they haven't been saved.

4.1.4. Economics and Effort Parameters

This dialog box contains the economic and effort parameters available to the user for editing. Parameters include: price per fortnight, response parameters, fishing effort response parameters and the price variation parameter. The "Economics and Effort" dialog box (Figure 6) is displayed by selecting **Parameters|Economics and Effort.**

Editing Economic Parameters

1. Select the set of values to be changed.
2. Click the mouse in the edit box along side the fortnight to be edited and then type the new value.
3. Press **Reset Default Values** to restore the default values, or **Restore Changes** to reinstate the most recently changed set of values.
4. To save your changes press **OK**, or **Cancel** to delete any changes and restore the last saved values.

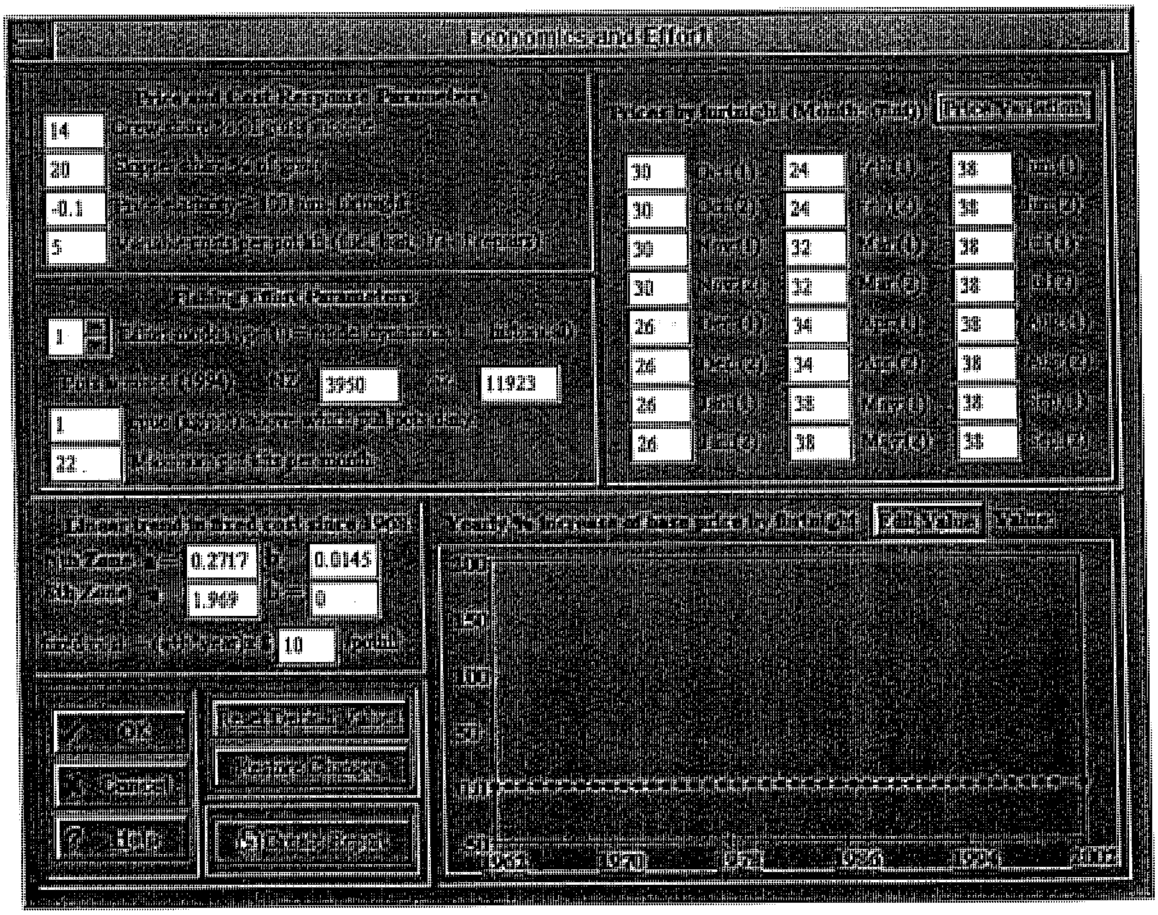

Figure 6: Economics and Effort Parameters.

Changing the yearly % price variation

To change the percentage increase of the base price by fortnight:

1. Click the **Price Variation** button (top, right, Figure 6) to display the graph of yearly percent increase (or decrease).
2. Use the mouse to alter the graph line as desired. This will raise or lower the base price values given in the **Prices by fortnight** table above. Alternatively, click on the **Edit Value** button above the graph and click inside the **Year of Change** edit box and type in the year you want the price change to take effect and the percentage increase desired under **New Value.** For instance, a value of "50" will result in a 50% increase in the baseline price for all the fortnights of each year affected, while a value of "-20" will result in a 20% decrease. This limit will apply for all subsequent years or until a second year is chosen and a new value entered. The new values will be automatically shown in the graph. **Reset Default Values** will restore the Price Variation to its default of 0, meaning prices as indicated in the Prices by Fortnight table.
3. Once completed click the **OK** button to save the changes, or click **Cancel** to restore the previously saved values.

Changing Price and Cost Response Parameters

Costs will determine how much is subtracted from gross landing revenues in calculating the Earnings per pot per year Time Plot. Crew share and skipper share costs can be set to the percent desired. The variable costs are expenses that are reduced when fewer potlifts are used to take a year's catch and were estimated from fisher supplied data at approximately $5 per pot retrieval.

Price elasticity allows for a lower expected price when the supply, as catch per fortnight, is large.

Linear Trend in Fixed Cost since 1968 (for each fleet overall) is modelled differently in the two zones. In the Southern Zone, since mean effort has been roughly constant since 1968, no variation in fixed cost is assumed. A constant fixed cost of $19.69 is assumed. This is based on the assumptions that the outlays for boats, gear, mooring, license and insurance fees, etc. have increased at the same rate as inflation, and that the acceleration in capital expenditure for larger vessels in recent years was roughly offset by the decline in total number of vessels. In the Northern Zone, where fixed costs for the fleet overall have risen with the steady rise in effort, the linear increasing trend was fitted to data (giving the "b" parameter).

Changing Fishing Effort Response Parameters

The default value of 1 under **Effort model type** implies that historical effort values are being read into the model directly, and the parameters for **Pots Licensed, CPUE above which pull pots daily** and **Maximum pot lifts per month**, which will dynamically predict yearly effort are not being used. Setting Effort model type to 0 will allow the values for these parameters to be changed, which can be done by typing in the new values in the appropriate boxes.

4.1.5. Mapped Information

Parameter values resolved by spatial cell can be edited with the five maps. These control:

Regulation zone.
Growth region.
Puerulus settlement index.
Habitat size index.
Closed refuge areas.

To edit the values of these parameters via the maps

1. Open the Mapped Information dialog box by selecting **Parameters|Mapped Information**.
2. Select one of the five parameter maps from the **Mapped Values for Cells** section on the right hand side of the dialog box. Once selected, the regional values on the map will change to their respective values for that parameter.
3. To edit any regional value, click the region. Notice, that the selected regional value now appears in the **Edit Cell Value** box in the upper right corner of the window.
4. Now use the up and down arrow keys to adjust the value. To restore the parameter to its default value press **Reset Default Value.**
5. Once all values have been edited the mapped parameters can be saved by pressing **OK**. Pressing **Cancel** will delete the changes and restore previously saved values. Press **Reset All Default Values** to reset all of the values in a selected parameter map to their defaults.

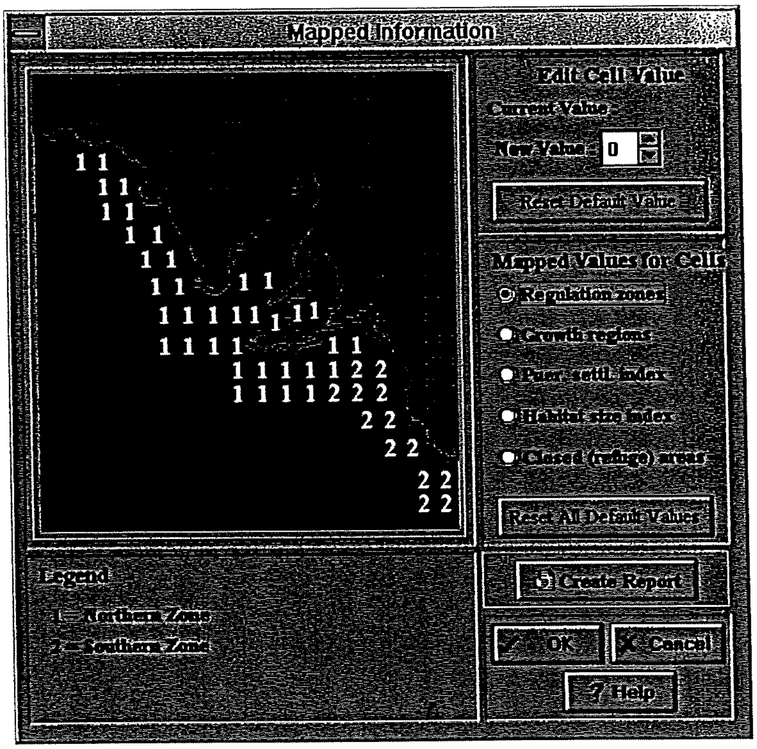

Figure 7: Mapped Information - Regulation Zones.

Figure 7, shows the regulation zones for the regions, "1" indicates a Northern Zone region and a "2" indicates a Southern Zone region. Note that users will only be allowed to change between these values. For example, entering "3" is not permitted.

4.2. Saving a new Baseline Scenario

The baseline scenario is the model's reconstruction of the history of the fishery. It is not anticipated that users will need to alter the baseline parameters. However, you may, if you choose, create a new baseline scenario based on a different set of parameter values. It would first be wise to save the existing baseline scenario file under a different name so that it is not overwritten when you save the new one as baseline.pro. Do this by

1. After first opening the model, click on **File|Save As...** which will bring up the "Save SARLMOD Project" dialog box.

2. Click on baseline.pro to bring it up into the File Name box, and change the name to something like baselin1.pro and click on **OK** or press ENTER.

Now you can create a new baseline scenario without losing the existing one.

1. Make changes to the parameter values as desired.
2. Execute the model by selecting **Run|Baseline Scenario**. Following the completion of the model run, SARLMOD will ask whether you want to save the project. Click on **No.**
3. To save the new baseline, you need to select **File|Save as Baseline**. This will automatically be saved as baseline.pro and in all future overlays will appear as the baseline model default.

4.3. Management Menu

4.3.1. Fishing Regulations

This is the most important input screen for use of this model as a management tool. The **Fishing Regulations** screen allows you to select the fishery management policies that you choose to test. Three basic forms of regulation can be imposed on this simulated fishery: size regulations, effort controls, and quota.

To adjust the fishing regulations select **Management|Fishing Regulations**. The "Fishing Regulations" dialog box (Figure 8) allows users to regulate the minimum and maximum legal size (in mm). A mid-range of length can also be made illegal. Use the **Regulate Size Limits** box to adjust the minimum, maximum and mid-range size limits for females and males in both the Northern and Southern Zone.

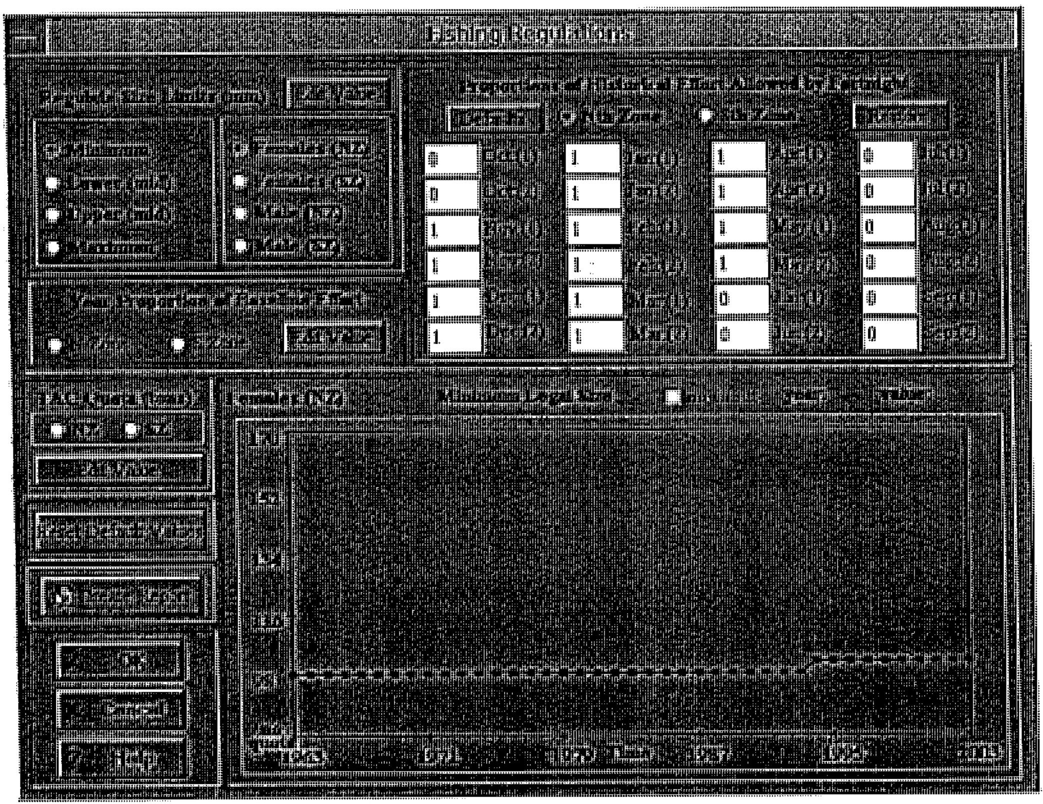

Figure 8: "Fishing Regulations" dialog box.

To change size limits:

1. Select a size limit to regulate and a zone to apply the regulation. For example selecting **Minimum** and **Female (NZ)** will display the graph of minimum length (by year) for female lobsters in the Northern Zone.
2. The mouse is used to vary the size regulation on the graph. Hold down the left mouse button and drag the mouse to adjust the limit for the years desired.
   There is a second way to alter size limits. Click on the **Edit Value** button located above **the Regulate Size Limits** radio buttons. The "Table Entry Screen" will appear. Choose the year starting from which your new size limit will take effect, and after clicking the mouse inside the appropriate edit box, type in the year and new value. This limit will apply for all subsequent years or until a second year is chosen and entered with a new limit. The new values will be automatically updated in the graph.
   Section 5.1 provides an example of running the model with an increased minimum size limit.
3. Once all regulations have been set, click the **OK** button to save the changes. To delete changes and restore the previously selected values, press **Cancel.** To restore the regulations to the default settings, press the **Reset Default Values** button.

Year Proportion of Baseline Effort

Year Proportion of Baseline Effort provides you with a means of controlling the number of potlifts that are used in both the Northern Zone and Southern Zone. This is done as a proportion of the baseline values in the **Economics and Effort** parameters screen. Select the radio button corresponding to the zone you are interested in which will bring up the graph showing the current proportions which has a default value of 1. Effort can be changed by using the mouse to drag the line to a new position, or by clicking the Edit Value button and typing in the year of change and new proportion. Note that the **New Value** that you type in must be expressed as a proportion of the baseline effort. For example, to increase the yearly effort by 20%, type in "1.2" and to decrease the yearly effort by 20%, type in "0.8". To reset the values to their default, click **Reset Default Values.**

Quota

Currently there is no quota set for the Northern Zone, but in the Southern Zone a quota of 1740 t was introduced in 1994, reduced to 1720 t in 1995. To change these values select the zone for which you want to change or introduce quota by clicking on the corresponding radio button under **TAC Quota (tons)**. The graph for yearly quota will be displayed. You can choose the level of yearly quota by dragging on a section of the graph or by using the **Edit Value** button as described above.

Historical Effort Allowed

The proportion of historical effort allowed by fortnight for each of the Northern and Southern Zones can be adjusted by changing each of the given fortnightly values.

To edit historical values:

1. Select the set of values to be changed.
2. Once a set of values has been selected click the mouse in the edit box along side the fortnight to be edited and then type the new value.
3. To restore the default values, press **Defaults,** or to recover the most recent saved change press **Restore.**
4. To save changes press **OK,** or **Cancel** to delete any changes and restore old values.

4.3.2. Simulation Time

The default simulation time for the model is 41 years (1963 to 2003). However, users can change this default setting by selecting **Management|Simulation Time.** An error message will appear if users enter an incorrect time or a time that is too short or too long for the model. User selected simulation times, should be between 10 and 41 years.

4.4. Executing the Model

Once management regulations have been selected, the model can be executed by selecting **Run|Overlay Scenario.** This will cause the following window to be displayed.

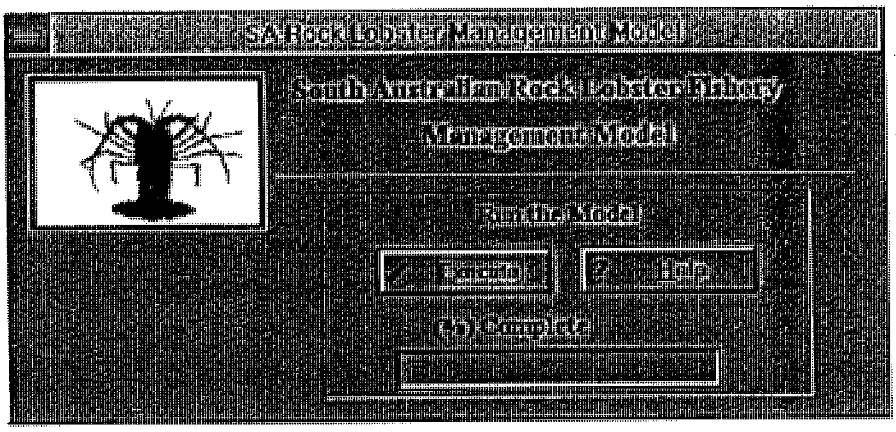

Figure 9: Run Model dialog box.

Run the model by clicking on **Execute**. To cancel the model run and return to the main application window, click on the control menu box and select **Close**. Note that the model, once activated, **cannot** be stopped by the user and will terminate when the simulation is completed. The model results with the new regulations (or parameter values) will appear in the graphs overlayed with the baseline scenario for comparison.

Multiple model runs are possible. With each run, the previous overlay run will be replaced. If you wish to save the previous model run, do so before changing any parameters or imposing new regulations. SARLMOD will prompt you to save the project once the run has finished.

4.5. Results

4.5.1. Adult and Juvenile Density Maps

To display the Adult and Juvenile density maps, select **Results|Density Maps**. The Juvenile Density maps represent the numbers per unit area of juveniles (sublegals in the 82 - 98 mm carapace size range) in each cell of the model. The Adult Density maps present the number of adult lobsters that are 98 mm or greater in carapace length.

Note: Each cell on the map covers one fourth of a full one-degree-square Marine Fishing Area.

Displaying Density Maps

Density maps can be displayed for any of the simulated years. Simply use the slider below each of the maps to change the displayed year. Click in the **Link Sliders** box to move both sliders at the same time.

4.5.2. Catch length frequencies for Southern and Northern Zones

To display the catch length frequencies select **Results|Catch Length Frequencies**. On selection, four graphs will appear displaying information on the proportions of the catch in each length class. A "Graphics Server" icon will also appear at the bottom of the Windows screen indicating a graphics window is open.

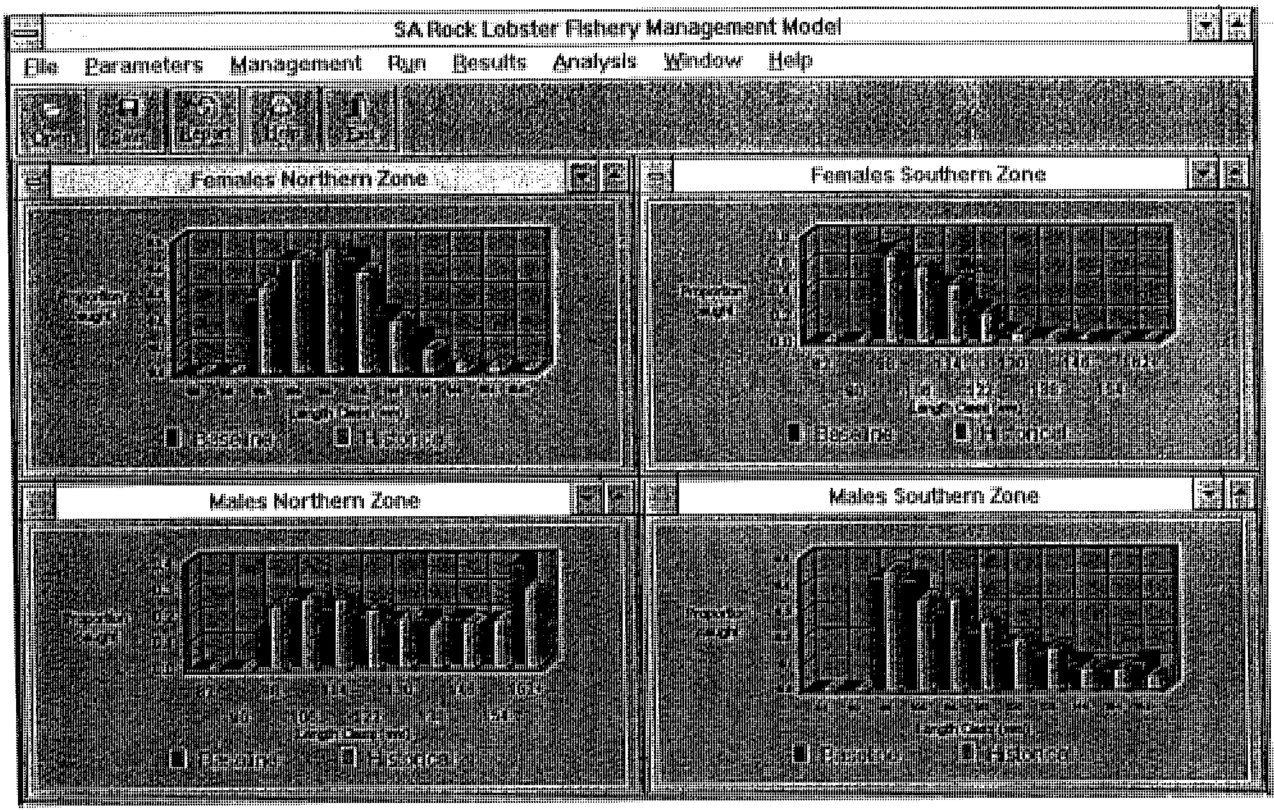

Figure 10: Catch Length Frequencies.

Each graph can be enlarged to fill the screen by clicking on the maximising button in its upper right hand corner (see Figure 1). To reduce the plot to its original size, click on the *lower* of the two restore buttons. Enlarging will provide the user with extra tools that are not displayed if the graph is under a specified size (Figure 11). These tools include a year slider and a choice of alternative graphing styles.

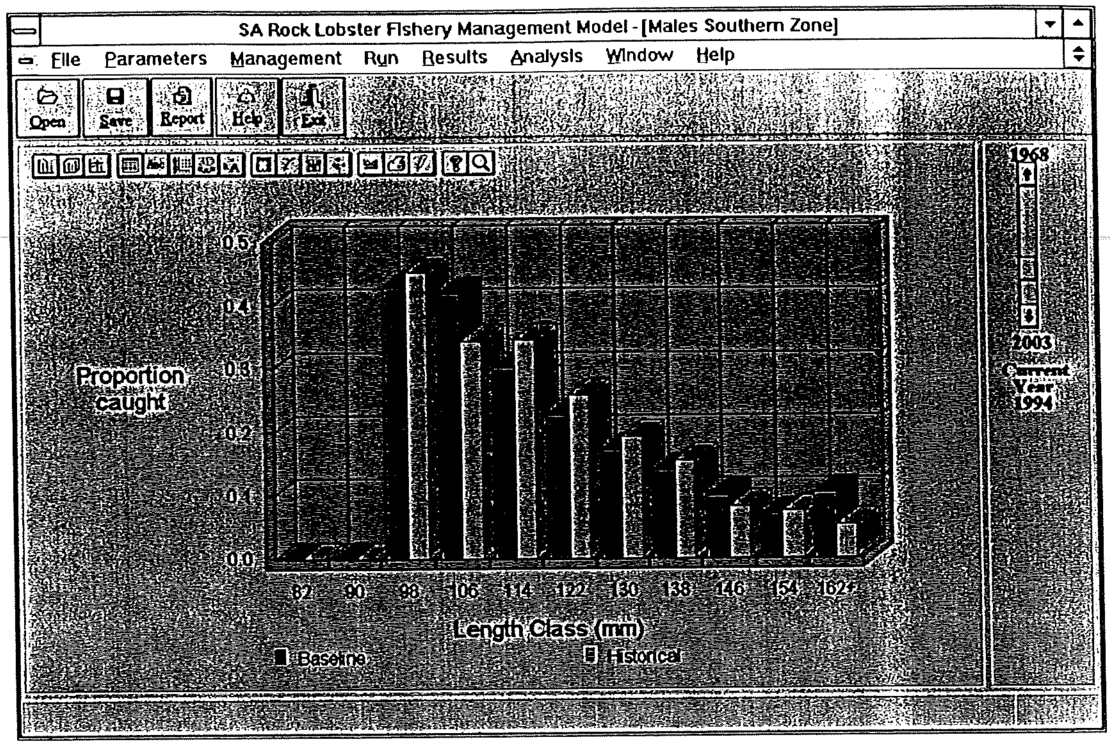

Figure 11: Enlarged Catch Length Frequencies.

These graphs show the breakdown of the lobster catches by length. Each bar indicates the proportion of the catch that falls in each 8 mm length class, for males and females in each zone. The lower bound of each length class is indicated by the number below each bar. By dragging the year slider up or down, you can display the model catch frequencies for any year desired. The **blue** bars show the baseline model-simulated catch frequencies and the green bars display the historical measured length-frequencies for years when sampling was undertaken, 1975, 1984 and 1994. Figure 11 displays the model and fishery-sampled catch frequencies for 1994. These graphs are used for model validation. Comparing the baseline and data length frequencies shows how accurately the model represents the changes in lobster population size structure over time and by sex and zone.

You can close them by selecting **Window|Close All Windows**, or they will close automatically if you open **Results|Time Plots**. The "Graphics Server" icon will also disappear.

4.5.3. Time Plots

While length frequencies serve primarily as model validation, the principal model outputs for testing fishery management strategies are the time plots. These present the yearly levels of four critical variables for managing the lobster resource before (as baseline plot) and after (as overlay plot) the imposition of the strategies you choose to test. Both the historical data and the model baseline result are always displayed. Following the run of a management strategy, the additional overlay plot is added.

To display graphs of Catch per Potlift, Earnings per pot per year, Total catch by zone, and Egg production, select **Results|Time Plots** (Figure 12). Plots for the Northern and Southern Zones can be viewed individually by selecting either **Results|Northern Zone** or **Results|Southern Zone**. The following paragraphs explain what each of these graphs refers to and how each result is calculated.

Catch per Potlift

This panel shows the annual average model and historical catch per potlift in each zone in kilograms from 1968 to 2003.

Earnings per pot per year

This panel presents approximate average yearly earnings in thousands of dollars per licensed pot from 1968 to 2003. Earnings are calculated as revenue minus the costs of fishing. Costs are calculated by adding fixed cost and variable cost per potlift, and crew and skipper shares, as percentages. In the Northern Zone, fixed cost is modelled to increase with the rising trend in overall effort from 1968 to 1995. In the Southern Zone, fixed costs are assumed constant for all simulation years.

Total catch by zone

This panel shows the total annual commercial catch (in thousands of tons) for each zone, showing both model output and historical data, from 1968 to 2003.

Egg production

This screen panel displays the total number of eggs released by females in each simulation year from 1968 to 2003 for each zone. In addition, the Northern and Southern Zones' contributions are added to show total lobster egg production for the state.

The model reflects lobster price variations through the season but for all model years the same prices are used. The **Parameters|Economics and Effort Dynamics** menu screen displays the assumed prices for each fortnight as well as the cost parameters, all of which you can change as described above.

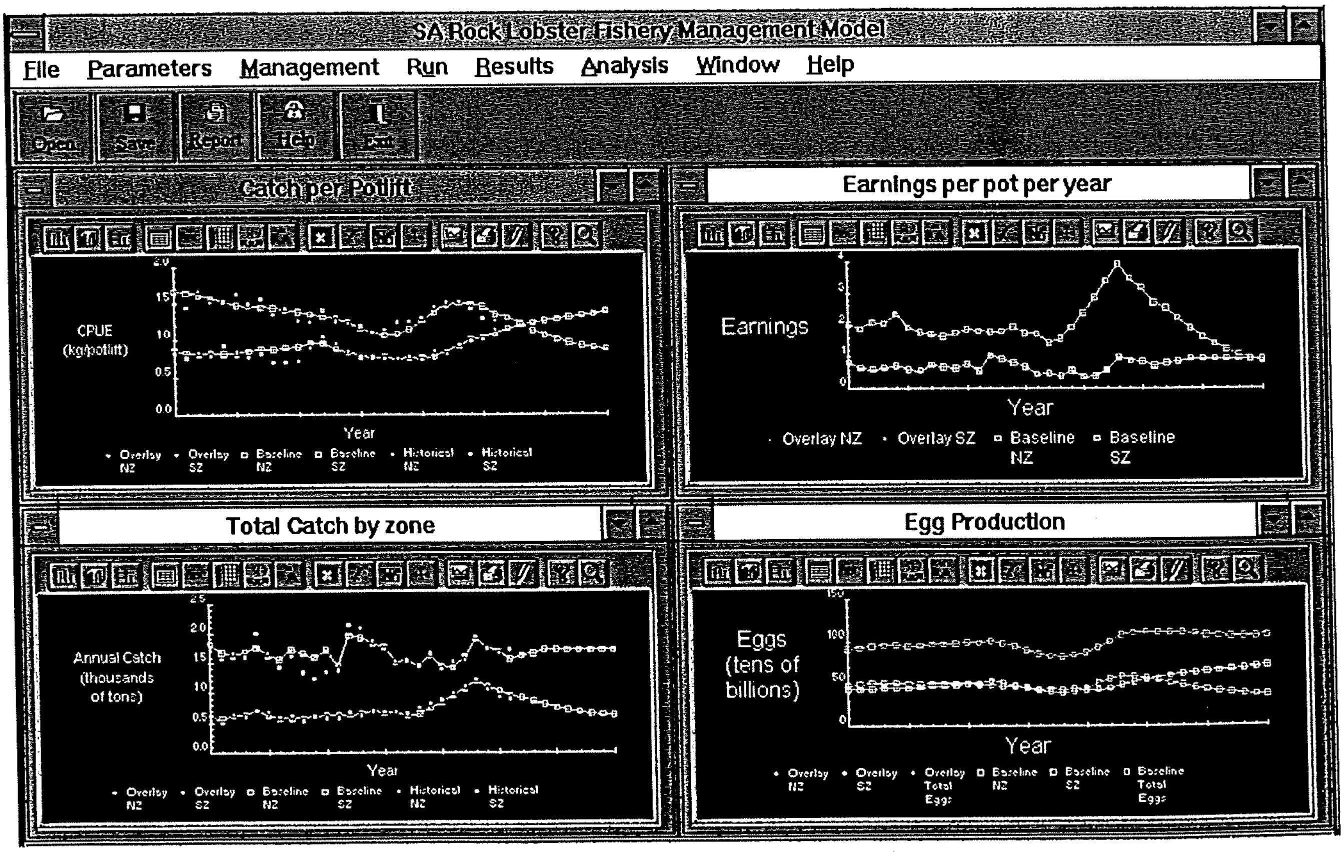

Figure 12: Time Plots.

4.5.4. Graph Results

Complementing the four critical variables displayed with the **Time Plots** menu option, **Results|Graph Results** allows users to construct time plots for an extensive list of model output variables. These variables can be further differentiated spatially in the fishery coastal region. In addition to spatial breakdown by fishery management zone, Northern and Southern, the user may also select any set of model spatial cells, and plot the variables chosen from this designated spatial subregion. The length frequencies and population densities for adults and juveniles, can also be plotted by designated spatial subregion.

To display the standard GIS result module (Figure 13), select **Results|Graph Results.**

Note: A maximum of four variables can be selected at any time for display and all variables selected must cover the same time interval.

Selecting variables to graph

1. Select the zone you are interested in to display variables by clicking on the radio button for either **Nth Zone, Sth Zone** or **Both.** If you want to display variables for specific cells from the Northern and Southern Zones click on the **By Cell** radio button and highlight the region by clicking on individual cells on the map. If you want to look at length frequencies for males and females by zone, click on the **Length** radio button; for adult and juvenile density by zone, click on the **Density** radio button.
2. Once the appropriate radio button has been selected, the variables permitted for graphing will appear in the first variable list box titled **Variables.** Selecting a complete zone or the entire state fishery **(Both)** will give you a larger choice of variables to graph than will choosing a subregion using the **By Cell** option which has six variables to choose from, namely those in the model that are differentiated by spatial cell.
3. To select a variable for graphing either double click the variable or single click the variable and click on the right arrow button located between the variable boxes.
4. After selecting a variable you will see it appear in the second variable list box, titled **Selected.**

De-selecting variables

To remove a variable from the selected list:

1. Either, double click the variable, or single click the variable and click the left arrow button between the variable boxes.
2. After de-selecting a variable you will see it disappear from the selected variable list box.
3. To clear the entire selected list box, click the **Clear List** button.

Once a variable has been selected click the **Graph Data** button to display the variable plots. Note that more than one variable can be displayed at any one time, however, displaying variables with large differences in values will result in some variables not being visible on the graph.

Once a variable has been graphed, users can use the graph toolbar to produce a range graphs for the data. These range from **line graphs** to **bar** and **pie charts.** By using the graph **copy** and **print** buttons users can print or send the graph to the windows clip board to be pasted into other window applications such as Word for Windows.

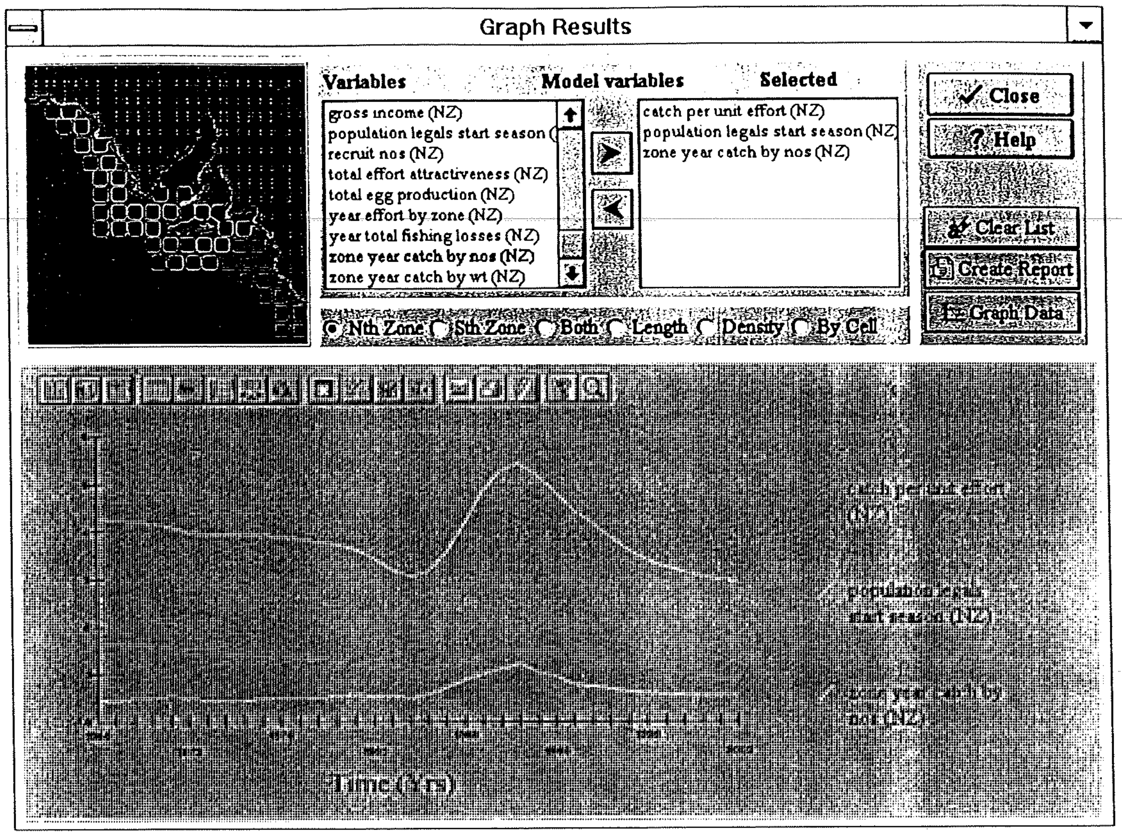

Figure 13: The **Graph Results** GIS display.

5. Examples: Testing Two Management Strategies

In this chapter we present two detailed step-by-step examples to demonstrate how the model is used to test specific management strategies. We consider (1) an increase in minimum length, and (2) quota.

The basic purpose of this model is to test different management options. You can choose from a wide range of management regulations or combine a number of different regulations at one time. For example, you can change the length of the fishing season, control numbers of potlifts, change the minimum and maximum legal size of lobsters, or introduce a quota. The last three policies can be controlled on a year-by-year basis.

The following is an overview of how to test different management options:

- Select the **Management** menu and choose **Fishing Regulations**. To choose the strategy for testing, make changes to any of the parameters found there as described in Section 4.3.1 above and confirm your choice by clicking **OK**. You can also alter the simulation time of the model, set by default at 41 years, by selecting **Management|Simulation Time**.

- Choose **Run|Overlay Scenario** to run the model for the strategy you are interested in. Looking in **Results**, you can now compare your option with the model's historical reconstruction. Does your management strategy result in increases or decreases in catches, earnings or total egg production?

- At first, introduce one change at a time. When you understand the effects of one management change try an additional one and do another model run. This will allow you to compare the effects of each strategy on egg production, catch, catch-per-unit effort, and revenues.

5.1. Changing minimum legal size

To change the minimum legal size (carapace length), follow these steps:

1. Inside the **File** menu choose **New Project**. This avoids combining your most recent regulation changes with previous ones.
2. From the **Management** menu choose **Fishing Regulations**.
3. You can now impose a new legal minimum length. Select the radio button next to **Minimum,** located in the **Regulate Size Limits** section of the screen. Then click on the radio button next to **Females (NZ)** which will cause a graph to appear at the bottom of the screen. The present legal minimum size is plotted for all years. Click on the graph line to the left of any of the data marker squares and its value will appear at the top right corner of this graph box (98.5 mm). In the Northern Zone, the limit rises to 102 mm starting in 1994, the year that policy was adopted. Other size regulations include maximum size limits, above which lobsters are protected. You can also protect a slice of mid-range lengths somewhere above the minimum. When setting both an upper and lower limit you must allow at least one full size class between them. You will not be able to impose a maximum size limit and a mid-range size class at the same time. An error message reminder will appear when chosen size limits cannot be simulated by the catch limit submodel.

   Changing size limits can be done in two ways as described in Section 4.3.1. Positioning the mouse on the graph line and dragging it to a new position allows users to graphically edit size limits. This is advantageous in choosing limits that you wish to vary smoothly over a number of years.

   However, to set exact values of size limit that remain constant over subsequent years, a second method is available: Click on the **Edit Value** button next to **Regulate Size Limits (mm)** and type in the year of change and new size limit. All subsequent years will conform to the new value unless a later year and value are chosen. To set a new limit of 110 mm for NZ Females, (1) click on **Edit Value**; (2) type in "1975" under **Year of Change**, (3) type in "110" under **New Value**, and (4) choose **OK**.

To set a minimum legal size of 110 mm for all lobsters from 1975 onwards, do the same for **Females (SZ)**, **Males (NZ)**, and **Males (SZ)**, by clicking on the corresponding radio buttons and typing in the new values.

4. Confirm these changes by again clicking **OK**. Clicking on **Cancel** will delete any changes and reset the default values.
5. To run the model with the new regulations, choose **Run|Overlay Scenario** from the menu. Click on **Execute,** or press ENTER when the "Run Model" dialog box appears. While the model is running (approximately one minute) try to predict what you think will be the outcome of your chosen strategy.
6. After the model has run, a dialog box will appear asking you if you wish to save the model results. If you choose **Yes**, the "Save SARLMOD Project" dialog box will appear. Type in a project name, making sure to add the ".pro" extension to the name, and click **OK**.
7. Display the outcome of the model run by clicking **Results** and selecting the output you are interested in. In particular, choose **Time Plots** to display Catch per Potlift, Earnings per pot per year, Total Catch by zone and Egg Production. From these graphs you see that the principal effect of an increase in minimum size is an increase in egg production, especially in the Southern Zone whose contribution for the option run is shown in white (Figure 14). To display the time plots for one zone at a time, select **Results|Southern Zone** or **Results|Northern Zone**.

   Immediately following the rise to 110 mm in 1975, the Southern Zone catches decline substantially due to the large percentage of lobsters presently harvested between 98.5 and 110 mm. However in the Northern Zone an increase in minimum length appears to have little effect on total catches. The **Catch Length Frequency** graphs for both zones reflect the shift to higher percentages of larger lobsters. The "Overlayed" length frequencies (blue bars) now reveal 3 size classes of zero catch (82-90, 90-98, 98-106) and the fourth size class of 106-114 mm is now only half exploited. Under the baseline minimum length policy (green bars), only two full size classes (82-90 mm and 90-98 mm) are excluded.
8. If you want to save this management strategy, and haven't done so already, do it before making any further changes. To save them as a project you can re-examine and modify later, click on the **Save** speed button, or **File|Save As...** to bring up the dialog box. Type in a new project name, making sure to add the .pro extension, and click **OK**.

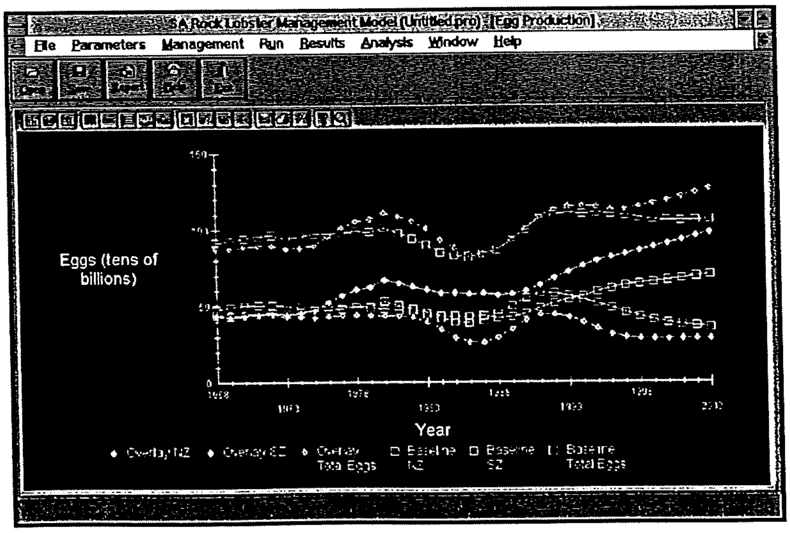

Figure 14: Egg Production.

5.2. Introducing a quota

Another regulatory policy that can be imposed on the model fishery is a quota, a fixed annual upper limit on total catch. To test this strategy, select **File|New Project**, then bring up the **Management|Fishing Regulations** screen as before, and proceed as follows:

1. Click on the radio button next to **NZ** in the **TAC Quota** section of the Fishing Regulations screen. This graph, of all zeros, indicates there is no quota system in place. However, clicking on the radio button next to **SZ** reveals that there is a quota of around 1700 tons, introduced in 1993. Modify this graph so that a quota of 1700 tons begins in 1973 by dragging the corresponding section of the quota line up so it is a bit lower than the present quota for the years 1973-1995.

   A fixed quota of 1700 tons can be also be imposed using the **Edit Value** button. To try this second method, first hit **Reset Default Values** to restore the baseline quota levels. Click the **Edit Value** button under **TAC Quota**, enter "1973" under the **Year of Change** and "1700" under **New Value**, and hit **OK**.

2. To accept this management strategy for the overlay run to follow, hit **OK** again.

3. Run the model, by selecting the **Overlay Scenario** option from the **Run** menu and clicking **Execute** when the "Run Model" dialog box appears.

4. When the model has finished running, view the effects of a change in quota by selecting **Results** followed by **Southern Zone**, which will display time plots for the Southern Zone only, since no management change was tested in the Northern Zone.

   Quota in the Southern Zone at a bit below present levels (1720 tons) has a small but important stabilising effect on catches. The quota first acts to limit catch in the historical peak years of 1981-82 and 1982-83. By restricting catch during that peak, lobsters grew larger and catches remained higher in all subsequent years except 1991. Revenues were enhanced accordingly. This result assumes no unreported catch losses.

5. If you haven't already done so, save the project by clicking the **Save** speed button, typing in a new name for the project with the .pro extension, and clicking **OK**.

6. Analysis of Model Output

The **Analysis** menu provides a number of options used to statistically analyse, summarise, and graph the output data produced by the Rock Lobster Model. **Select Data** allows the user to choose particular variables from the output database for use in the other menu options. These variables can be chosen by cell or zone, and are given as yearly outputs. **Statistics** allows you to carry out a range of standard statistical computations on the selected model variables. The **Curve Fitting** menu option allows you to piecewise fit selected model variables to a number of standard continuous curves. **Indicator** makes it possible to create compound variables combining any of the selected variables arithmetically using a graphical pocket calculator. These compound variables can be subsequently graphed or analysed. Thus, **Analysis** allows you to choose any arithmetic combination of model output, for any set of spatial cells, and statistically analyse and graph them.

6.1. Select Data

To choose from a list of output variables from the model run, open the "Select Data" dialog box by choosing **Analysis|Select Data.** There are three basic kinds of variables to statistically analyse: (1) time series, selected by clicking on **Northern Zone, Southern Zone** and **Combined Zones** radio buttons (2) mapped information of adult and juvenile lobster abundance, selected using **Density,** (3) length frequencies, selected using **Catch Lgth Freq.** Furthermore, certain time series variables, namely those that vary spatially, can be selected for any subregion of cells that the user chooses, using **By Cell.**

Note: Unlike the **Graph Results** menu option, up to 50 variables can be selected for analysis, the only stipulation being that all variables selected are of the same length.

Selecting variables to graph

1. Select the zone you are interested in to display the list of variables. This can be Northern Zone, Southern Zone, or combined Northern and Southern Zones, or a specific subregion of user-selected cells within the state. To select a specific subregion of cells, click on the **By Cell** radio button and click the mouse in any of the cells on the map. To de-select a cell, click it again. Details of the use of **By Cell, Density, and Catch Lgth Freq** are found in Section 4.5.4, **Graph Results.**
2. Once the spatial zone is selected, a list of all available variables will appear in the list box titled **Variables.**
3. To select a variable for graphing or statistical analysis either (1) double click the variable or (2) single click the variable and select the down arrow button.
4. After selecting a variable you will see it appear in the lower list box, titled **Selected Variables.**
5. If a management overlay has already been run, the baseline time series variables can be selected in addition to the overlay model time series. To select both baseline and overlay variables, click the box next to **Include Baseline Variables.**

De-selecting variables

If a user wishes to remove a variable from the selected list:

1. Either, double click the variable, or single click the variable and select the up arrow button.
2. After de-selecting a variable you will see it disappear from the **Selected Variables** list box.
3. To clear the entire selected list box, click the **Clear Selection** button.

After selecting the variables, click **OK** to instruct the model to extract the requested data from the model output database. Once variables have been selected, the **Statistics, Curve Fitting** and **Indicator** options will be enabled. Data must be selected in order to use these menu options.

6.2. Statistics Analysis

The **Statistics** menu provides a range of statistics including means and variances, frequencies, bivariate correlation, partial correlation, comparison of means, one-way analysis of variance, t-test for independence, t-test for paired data, linear, exponential, power and logarithmic regression, cross-correlation and auto-correlation. These statistics are partitioned into five groups: Summary Statistics, Correlation, Means, Curve Fitting and Time Series.

To Use: After selecting the variables for analysis using **Analysis|Select Data,** choose **Analysis|Statistics.** The 'Statistics Analysis' dialog box will appear providing the following options:

6.2.1. Summary Statistics

Summary statistics are provided for all selected variables.

Note: Summary statistics produces large amounts of output and Notepad memory in some machines capacity (notably those with pre-Windows 95 operating systems) may be exceeded if a large number of variables are selected. If an error message appears telling you that Notepad is not large enough, open the file in any other word processor.

6.2.1.1. Descriptive Summaries

These provide a list of standard statistics, such as means, standard deviations, etc. for variables desired.

To Use:
1. Choose **Summary|Descriptives** from the **Statistics** menu.
2. Select any of the variables from your list to display summary statistics by double clicking on the variable or single clicking it and then clicking the right arrow button.
3. Click in the box next to the output you would like displayed. The following descriptive statistics are available for each selected variable:

Mean:
Number of observations in the data set (this is always included with the output).
Mean of the data set.
Median/quartiles:
First quartile (value that has 25% of the observations below it, when sorted in ascending order).
Median (middle value in the data set).
Third quartile (value that has 75% of the observations below it, when sorted in ascending order).
Variance: Standard deviation and variance.
SE Mean: Standard error of the mean.
Range: Range of values in the data set.
Min and Max: Minimum and maximum values in the set.
Mode: The most commonly occurring value.
Sum: The sum of all the values in the data set.

The following provide a measure of the shape of the distribution of values:
Skewness: Measures how much the distribution is "tilted" to the left or right of the mean.
Kurtosis: Measures how peaked or flat the distribution is relative to a normal curve.
SE skewness: Standard error of the skewness.
SE kurtosis: Standard error of the kurtosis.

6.2.1.2. Frequencies

This analysis allows the user to partition the values of the selected variables into frequency histograms.

To Use: 1. Choose **Summary|Frequencies** from the **Statistics** menu.

2. Select any of the variables from your list by double clicking on the variable or single clicking it and clicking the right arrow button.
3. Click in the box next to the summary output statistics you would like displayed under **Summary and Distribution Statistics.**

If the **Display Frequency Table** box is selected, the following frequency output is displayed in tabular form:

Each observation in ascending order.
The number of times each observation occurred (count).
The cumulative count.
The observation's percentage of occurrence in the entire data set.
The cumulative percentage of occurrences.

6.2.2. Correlations

6.2.2.1. Bivariate

Correlation quantifies the similarity between two variables. For instance we would anticipate a high correlation between yearly "fishable biomass" and "population legals start season" since both would tend to rise and fall together. This option allows calculation of the standard correlation coefficient, "r", between any two selected variables.

To Use: 1. Choose **Correlation|Bivariate** from the **Statistics** menu.
2. Select at least two variables. The **OK** button will remain off until the required number of variables have been selected.

The correlation coefficients can be displayed in tabular form or as a matrix by clicking in the appropriate box. Other output options include:

Descriptive statistics:

The mean of each data set.
The standard deviation of each data set.
The number of cases.

Covariance/Cross-Product Deviations:

The cross-product deviations.
The variance-covariance.

6.2.2.2. Partial Correlations

Sometimes the correlation between two variables can be biased by the effect of another. Partial correlation calculates the correlation between the two variables while holding the third variable constant, therefore removing its effects.

To Use: 1. Choose **Correlation|Partial** from the **Statistics** menu.
2. Select one controlling variable and two variables to be correlated. The **OK** button will remain off until the required number of variables have been selected.

As with the Bivariate correlations the partial correlation coefficients and degrees of freedom can be displayed in tabular form or as a matrix, with the option of also displaying the following:

Descriptives:

Mean.
Standard Deviation.
Minimum and Maximum values.
The number of observations.

Zero Order Correlations:
The zero order partial correlation coefficients.
The zero order partial degrees of freedom.

6.2.3. Means

6.2.3.1. Comparison of Means

ANOVA statistical tests are used to compare two or more means of variables.

To Use: 1. Choose **Means|Comparison of Means** from the **Statistics** menu.
2. Choose one dependent variable and up to five independent variables by selecting the variable and clicking on the appropriate arrow button. The **OK** button will remain off until the required number of variables have been selected.

This procedure will provide a comparison of means for each combination of the one dependent variable with the chosen independent variables. Each combination is then split into groups.

Clicking in the **Descriptives** box produces the following output for each group:
The value of the group.
The sum of the observations that fall within the group.
The mean of these observations.
The standard deviation of these observations.
The variance of these observations.
The sum of square.
The number of these observations.

Click in the **ANOVA Table** box to perform an ANOVA. If there is more than one group the following ANOVA output is listed for the Between Groups source, Linearity source, Deviation from Linearity Source and the Within Groups source:
Degrees of freedom.
Sum of square.
Mean square.
F-statistic.

If there are more than three groups the **Eta-test** and/or **test for linearity** can be performed by clicking in the appropriate boxes and produces the following:

Eta.
Eta-square.
r.
r-square.

6.2.3.2. One Way ANOVA

To Use: 1. Choose **Means|One Way ANOVA** from the **Statistics** menu.
2. Choose one factor variable and up to five dependent variables by selecting the variable and clicking on the appropriate arrow button. The **OK** button will remain off until the required number of variables have been selected. The confidence interval may be computed at the 90%, 95% or 99% level of confidence, by clicking on the appropriate radio button.

Clicking on the Analysis of variance check box will compute the one way analysis of variance for each combination of the one dependent variable with the chosen factor variables. Each combination is split into groups according to a user specified range. Clicking in the **Descriptives** box produces the following output for each group (including the entire data set) within this range:

The mean of the observations.
The standard deviation of these observations.
The standard error of the observations.
The minimum value in the group.
The maximum value in the group.
Number of observations in the group.
The confidence interval.

If there are more than two groups the ANOVA table can be generated by clicking in the **Analysis of variance** box. The following ANOVA output is listed for the Between Groups source, Within Groups source and Total Groups Source:

Degrees of freedom.
Sum of square.
Mean square.
F-statistic.

6.2.3.3. t-test for two independent samples

t-tests are used to compare the means of two samples and calculate whether they are significantly different, based on the level of variation each sample exhibits.

To Use: 1. Choose **Means|T Test Indep.** from the **Statistics** menu.
2. Select at least one test variable and only one group variable using the appropriate arrow buttons. The **OK** button will remain off until the required number of variables have been selected.

After choosing a suitable **Cut Off Value**, the following **Descriptives** can be displayed:

The length of the data set.
The mean of both data sets.
The standard deviation of both data sets.
The standard error of the mean for both data sets.
Differences of the means for groups 1 and 2.

Clicking in the **Mean Testing** box will result in the following statistics computed for equal variances and unequal variances:

Degrees of freedom.
t-statistic.
Standard error of difference.
95% confidence interval.

6.2.3.4. t-test for two paired samples

A paired t-test is used when the two sets of data points occur in pairs. While an independent t-test compares the means of both data sets, the paired t-test compares the *differences* between each pair of points. It is useful in that it removes any yearly biases by looking at the differences in data values for each year rather than comparing the mean over all years. For example, comparing a variable such as CPUE (baseline) with CPUE after running a management strategy should be done as a paired t-test.

To Use: 1. Choose **Means|T Test Pairs** from the **Statistics** menu.
2. Select a variable and move it into the 'Current Selection' box using the appropriate arrow button. Do the same for another variable.

3. With two variables now in the Current Selection box, move them into the 'Paired Variables' box by clicking on the appropriate button. (There is no need to select the variables for this move; clicking the button will move them both across).
These steps can be repeated for more pairs of variables, however the **OK** button will remain off until the required number of variables have been selected.

The following statistics can be produced by clicking in the **Descriptives** box:
The mean of both data sets.
The standard deviation of both data sets.
The standard error of the mean for both data sets.
The number of observations in each data set.

Clicking in the **Correlation** box will produce the following:
The number of pairs.
The correlation coefficient between the two data sets.
The covariance.

The **Paired Differences** statistics computed are:
Paired difference of the mean.
Paired difference of the standard error mean.

Finally, the t-statistics are computed by clicking in the **t-value** box and choosing a **Confidence Interval**:
Paired t-value.
Degrees of freedom.
Paired confidence interval.

6.2.4. Curve Fitting

This analysis tool allows you to test whether functional relationships exist between two variables and how accurately you can predict the value of one variable from the value of another. This is done by plotting the variables, with the independent variable(s) along the x-axis and the dependent variable (the one being predicted) along the y-axis. This analysis fits a curve to the data and provides the coefficients of the fitted curve. The curves can be linear, exponential, power or logarithm.

6.2.4.1. Linear

This option performs linear regression on two or more data sets as selected by the user. The linear regression equation is of the form: $y = \text{constant} + ax_1 + bx_2 + \ldots$, where y is the dependent variable, x_1, x_2,... are the independent variables and a, b,... are the coefficients to be estimated.

To Use: 1. Choose **Curve Fitting|Linear** from the **Statistics** menu.
2. Select one dependant variable and at least one, but no more than five independent variables by using the appropriate arrow buttons. The **OK** button will remain off until the required number of variables have been selected.

Regression diagnostics include the following options and associated output:

Variable Summary:
The coefficient value for every coefficient in the regression equation.
SE of these values.
t-statistic for these values.

ANOVA Table

Linearity:
Standard error.
R-squared.

Multiple R-square value.
Adjusted R-square value.

Durbin Watson statistic.

Residual Analysis:
Mean.
Standard deviation.
Min.
Max.
Number of observations.
are displayed for PRED, RESID, ZPRED and ZRESID

Descriptives:
Mean.
Standard deviation.
Minimum.
Maximum.
Number of observations.

6.2.4.2. Exponential

This option performs exponential regression on two or more data sets as selected by the user. The regression equation is of the form: $y = \text{constant} + e^{ax_1} + e^{bx_2} + \ldots$, where y is the dependent variable, $x_1, x_2,\ldots$ are the independent variables and a, b,... are the coefficients to be estimated.

To Use: 1. Choose **Curve Fitting|Exponential** from the **Statistics** menu.
2. Select one dependant variable and at least one, but no more than five independent variables by using the appropriate arrow buttons. The **OK** button will remain off until the required number of variables have been selected.
Output is the same as that listed in linear regression.

6.2.4.3. Power

This option performs power regression on two or more data sets as selected by the user. The regression equation is of the form: $y = \text{constant} + x_1^a + x_2^b + \ldots$, where y is the dependent variable, $x_1, x_2,\ldots$ are the independent variables and a, b,... are the coefficients to be estimated.

To Use: 1. Choose **Curve Fitting|Power** from the **Statistics** menu.
2. Select one dependant variable and at least one, but no more than five independent variables by using the appropriate arrow buttons. The **OK** button will remain off until the required number of variables have been selected.
Output is the same as that listed in linear regression.

6.2.4.4. Logarithm

This option performs logarithmic regression on two or more data sets as selected by the user. The regression equation is of the form: $y = \text{constant} + a \ln(x_1) + b \ln(x_2) + \ldots$, where y is the dependent variable, $x_1, x_2,\ldots$ are the independent variables and a, b,... are the coefficients to be estimated.

To Use: 1. Choose **Curve Fitting|Logarithm** from the **Statistics** menu.
2. Select one dependant variable and at least one, but no more than five independent variables by using the appropriate arrow buttons. The **OK** button will remain off until the required number of variables have been selected.
Output is the same as that listed in linear regression.

6.2.5. Time Series Graphs

6.2.5.1. Cross Correlation Function (CCF)

Cross-correlations quantify a series of correlation functions between two variables, usually time series, like yearly fishable biomass, or yearly stock and recruitment. The "lag" is the number of years of displacement between the two series. For instance, the cross-correlation of recruitment and adult population numbers might be maximum at a "lag" of one year, since it would take a year for a big peak in recruitment (sublegal sized lobsters) to enter the fishable stock. The cross-correlation at lag 0 is the same as the standard correlation.

To Use: 1. Choose **Time Series|CCF** from the **Statistics** menu.
2. Select at least two variables by using the arrow button. The **OK** button will remain off until the required number of variables have been selected.

For a given data set, and a user-selected number of lags, this graph contains the cross correlation coefficient at lag k, and the standard error of the cross correlation function.

6.2.5.2. Sample Autocorrelation Function (ACF)

The autocorrelation of a time series variable is similar to the cross-correlation function, but for a single variable with itself. The autocorrelation at lag 0 will always be 1, meaning the correlation of a variable with itself will always be 100%. The correlation at lag 1, measures the relative closeness of values one year apart. A slowly varying time series will have a high autocorrelation at lag 1. Autocorrelations can be used to identify cycling time series. For instance a series with a 10-year cycle trend will have an autocorrelation peak at lag 10, because values in the series that are 10 years apart will tend to be similar.

To Use: 1. Choose **Time Series|ACF**from the **Statistics** menu.
2. Select variables by using the arrow button. Autocorrelation works on single variables of time.

For a given data set, and a user-selected number of lags, this graph displays the sample autocorrelation coefficient at lag k, and the standard error of the sample autocorrelation is also displayed. The user has the choice of method for the standard error estimation; either **Bartlett's Approximation** or **Independence Model,** assuming errors are white noise.

Note that for each **Statistics** menu option that involves selecting data to be analysed, the choice of data is restricted to the variable selection made before the **Statistics** option was invoked. However, different variables can be chosen at any time by selecting **Analysis|Select Data** from the main menu, and adding or removing more variables to the list of already selected variables.

6.3. Least Squares Curve Fitting

This menu item allow users to fit any selected variable to a choice of three continuous curve functions, linear, power, or exponential. For any particular choice of function, the full range of the data series can be partitioned into as many as four subdivisions and each subdivision fitted separately. The formulas for the fitted curves can be displayed using **Show Statistics** or exported and printed using **Create Report**.

To use: 1. Select the variables to graph using **Analysis|Select Data**.
2. Choose **Analysis|Curve Fitting** from the menu.

To select a variable to fit, click the down arrow on the drop down list provided under the graph. The list of previously selected variables is displayed. Once a new variable has been selected the graph will automatically change to plot the new variable.

The three sliders at the bottom of the screen can be used to divide the interval (1968-2003) into a maximum of four separate subintervals indicated by blue vertical lines on the screen. Breaking the interval up in this way allows the selected function to be fit separately to each portion of graph contained in each subinterval, resulting in a closer overall fit. Because the first and second dividing lines are both initially set on the left edge of the graph (1968), you will not be able to move the first slider until the second slider is moved.

Least Squares Curve Fitting Functions

The formulas for the three types of functions available for fitting are as follows:

Linear	**Exponential**	**Power**
$y = ax + b$	$y = a*e^{bx}$	$y = ax^b$

Least Squares Curve Fitting Changing between Functions

To change between the selected functions simply select the function required (lower right hand corner of the dialog box). For each function the following statistics are available:

r squared	:	a measure of the strength of the correlation of the fitted function to data.
Standard Error	:	square root of the average squared difference between the observed and predicted y-values.
SST Value	:	sum of the squared deviations of the observed data values from their mean.
SSR Value	:	amount of variation in the observed y-values that is not explained by the equation or the total squared error made in using the equation to predict the observed y-values.
St. Deviation	:	a measure of the spread of the distribution of data values from their mean.
Number of observations	:	number of observations in the data set.
Linear correlation coeff.	:	used to describe the strength of the linear relationship between two variables.
Standard Error of the Mean	:	displays the standard error of the mean of the observations (dependent y-variable).
Variance	:	the average of the squares of the deviations of the y-values from their mean.
Mean	:	mean of the y-values.

Least Squares Curve Fitting Changing Between Statistics and Function

To view the formula equations and the statistics of the fit listed above, select the **Show Statistics** button located on the lower right hand corner of the dialog box. To return from the statistics to the graph, select the **OK** button located on the lower right hand corner of the dialog box.

6.4. Indicator Creation

This menu option is used to create new variables which are arithmetic combinations of previously selected variables. The new compound variables can be saved and then graphed and analysed, just as standard variables are, using the **Analysis** menu.

Creating an Indicator

1. Choose the variables you wish to combine using **Analysis|Select Data**.
2. Select **Analysis|Indicator** from the menu to bring up the **Indicator Creation** dialog box (Figure 15).
3. A list of your selected **Variables** is displayed. Next to each variable in the list is a letter, (a), (b), (c), etc. Use this list and the accompanying number key pad to create the indicator equation that defines the new variable.
4. For instance, to make a new indicator variable which is the sum of variables (a) and (b),
   (i) Click on the first variable in the list, (a);
   (ii) Hit **Select**;
   (iii) Click on the "+" symbol on the keypad;
   (iv) Click on the second variable, (b), and hit **Select**;
   Once completed, the indicator equation appears in the equation edit box at the top of the window.
5. Type a name you choose for the new indicator in the **New Variable** edit box at the top left of the window.
6. Press **Clear** to start over at any time. **Del** removes symbols in the equation one at a time.
7. Press **Calculate/Add** to calculate and add the new variable to the selected variable list.
8. A dialog box appears asking if you wish to copy the new variable to the project data file. Press **Yes**.
9. Hit **OK** to exit the Indicator dialog box. The new variables will now be available in the **Statistics** and **Curve Fitting** menu options.

Note: An error message will be displayed if the given equation is incorrect or can not be calculated for any reason.

Examples of valid expressions:

(25 + 30.2)
100.0 - (2.0*a)
(2.0 + a)*b
(1.5*b)

Examples of invalid expressions:

1+ 2 + 3	Requires parentheses.
(1+2)+(2*a))	Parentheses do not match.

The **Indicator Creation** menu option also allows you to sum the values of a chosen variable over a specific number of years. To do this,

1. Click on a variable in the list;
2. Hit **Select**;
3. Click on the Σ **Sum Variable** button;
4. In the "sumvars" dialog box, type in the **Start Year** and **End Year** which the variable will be summed over, and click **OK**.
5. The value of the variable summed over the selected years will appear in the box below the Σ **Sum Variable** button.

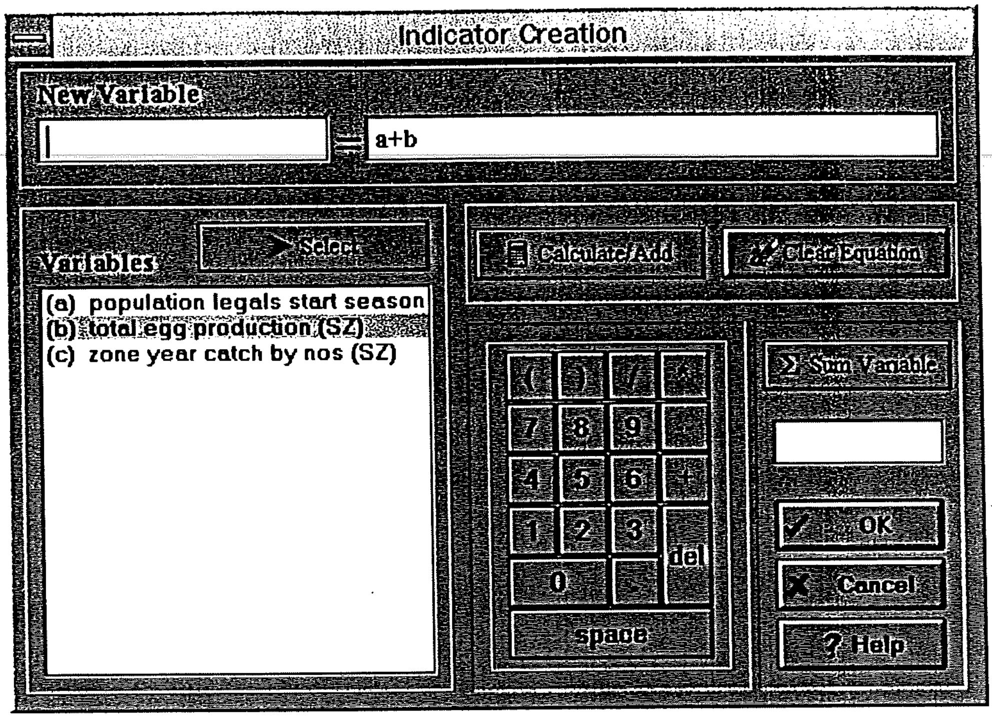

Figure 15: Indicator Creation dialog box.

7. Model Processes

7.1. What the model includes

The following processes of the South Australian lobster fishery are explicit in the model:

1. Growth. Four moult periods per year are assumed. (This may change in a future versions.) With each moult period, male and female lobsters in each growth subregion can grow into the next higher 8 mm length class. The proportions of lobsters that moult are shown in the **Growth and Fecundity Parameters** screen. These parameters specify the proportion of lobsters in each size, sex and growth subregion that are assumed to grow 8 mm or more in that moult period, as estimated from the tag-recapture data set.

2. Migration. The tagging program results indicate very little movement of lobsters in SA, roughly 90% showing no movement at all. In this version, migration is therefore omitted from the model dynamics to save computation time and memory.

3. Catch. The catch submodel is the most detailed, principally because it is the component which management has the ability to control, and because it affords the most abundant information in the form of catch logs and length-frequency catch monitoring. This submodel incorporates:
   a) legal commercial catch;
   b) illegal catch, assumed, by default to be 5%;
   c) recreational catch, assumed by default, to be 5%;
   d) release mortality of undersize and female spawners of 15%;
   e) lobsters coming up dead in pots, often by octopus and other predators, set at 3.5 % in the Northern Zone and 4% in the Southern Zone;
   f) changing vulnerability by size;
   g) changing vulnerability through the season;
   h) a wide range of management controls, which you as model user control as described above.

4. Effort movement. The potlifts in each fortnight are allocated among the spatial cells of the model fishery according to two factors. Greater effort in the upcoming fortnight is attracted to cells where
   a) catch rate was higher the previous fortnight;
   b) catch rate was higher in that cell the year before.

5. Recruitment by cell. Annual recruitment in the model is constant for the years up to 1983 and after 1995. From 1983 to 1995, variability in recruit numbers is incorporated, taken from the qR catch data analysis using catches by weight and by number. The parameters α, β, and γ in **Population and Harvest Parameters** permit modification of the input recruit variability time series over these years. Spatially, the recruits are allocated among the cells according to historical observed trend in catches, and undersize.

6. Natural mortality is set equal to an average of 10% per year. This important parameter can vary from area to area and year to year. Its precise value cannot be easily measured, and is usually given as a reasonable rough estimate in most fisheries around the world.

7.2. What the model does not include

Mathematical models represent the processes they simulate, like catch and growth, in a simple manner. Since not all processes are understood and quantified, some features of the real fishery must be simplified or omitted. For South Australian lobsters, the two most important processes for which the available data or understanding is not sufficient to include in the model are

1. dependence of recruitment on egg production, and
2. the dependence of growth and recruitment on stock density.

Since the processes of population reproduction are not fully represented, this model can be best classified as a "spatial dynamic yield-per-recruit" model. In other words, for each lobster that does reach 82 mm, this model tells how best to husband the resource to obtain the greatest yield in weight, and the highest egg production.

We believe the assumption of constant (or during 1983-1995, externally specified though variable) recruitment is not a bad approximation because total catches varied little over the 40 years of relatively high exploitation in the Southern Zone. Thus catches appear to be largely independent of rates of exploitation. Relatively stable catches over a wide range of levels of exploitation is observed as the rule in lobster fisheries worldwide. However it is one of the principal long-term goals of the South Australian fisheries research program, to develop methods to extract a better understanding of recruitment dynamics, and to quantify the levels of annual recruitment. The reconstruction of recruitment variability back to 1983 is the first step towards that goal. This is also one of the crucial goals of the ongoing catch monitoring survey program, now under development.

Glossary

cell: see "spatial cell" below.

CPUE: "Catch per unit effort" is commercial landed catch per potlift, also often referred to as the "catch rate". It is given in kilos per potlift. CPUE will always be taken as an average over a specific area and time, notably over the Northern and Southern Zones, fortnightly or annually.

density: Number of lobsters per square kilometre.

exploitation rate: Exploitation rate is the fraction of lobsters removed each season through fishing, from the pool of legal-size lobsters present at the start of the season. The exploitation rate is a crucial management parameter. It quantifies the percentage of the stock harvested yearly.

fortnight: In the model, the time step over which changes in the lobster population are calculated are loosely termed "fortnights". These are actually half-months, 24 time steps to a model year. As the model simulation moves through the season, changes in the variables are calculated each fortnightly time step.

length: "length" is the lobster carapace length, in millimetres. The legal minimum length for lobsters in the Southern Zone is 98.5 mm. In 1994/95 this was raised to 102 mm in the Northern Zone, a change which is programmed into the model. The lobster population in the model is divided into 8 mm length classes, 82-90 mm, 90-98 mm, etc.

model: A "model" is a mathematical re-creation of the change in the lobster population through the historical years of the fishery. In this model the lobster "variable" keeps track of the numbers of males and females, in each of 11 length categories, in each "spatial cell". By considering how many would die by fishing or natural causes, how many would migrate in or out of each spatial cell, how fast they grow, and how fast they recruit to the stock, the computer model calculates how the model lobster population variable will change every half-month, from 1962 onward.

parameters: Parameters in the model are the values that must be estimated from data. They describe things like how fast lobsters in each sex, and growth subregion grow, or how many eggs a female would produce, or how much a lobster would weigh in each of the 11 length categories.

recruitment: In general fisheries terminology, recruitment refers to the numbers of young lobsters entering the fishery each year, by growing up to legal size. In this model, recruitment refers to the number of new lobsters added each year to the youngest size grouping, 82-90 mm, which is evidently below the minimum legal sizes of 98.5 and 102 mm.

simulation: "Simulation" is used interchangeably with "model".

spatial cell: These are the smallest units of coastal ocean area in which the model lobster population is kept account of. In area, each spatial cell of the model is one-fourth of a one-degree Marine Fishing Area statistical block bounded by the lines of latitude and longitude. In the **Mapped Information** menu option of the **Parameters** menu, you will find maps of the **Regulation Zones** (which are the Northern and Southern Zones), the **Growth Regions** in which the lobsters tend to grow with similar rates, the **Settlement Index** which identifies the relative averages densities of lobster puerulus settlement, the **Habitat Size Index** which specifies the approximate fraction of rock bottom lobster habitat, and the **Closed Area** map which shows the cells closed to fishing.

variable: These are the basic quantities in the model changing each fortnight. Specifically, the variables are the numbers of lobsters of each sex and length class, in each spatial cell, and the numbers of potlifts being set in each fortnight, in each spatial cell.

vulnerability: This is the probability of a lobster, residing in a given spatial cell, will be captured by an average potlift. "Vulnerability" varies with the size and sex of lobster, and the fortnight of the fishing season.

year: The first fortnight of the model year begins October 1 at the start of the Southern Zone fishing season which runs 7 months through April. The Northern Zone season runs a month later, from November through May.

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