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Survey sampling design and length-frequencey data analysis for ongoing monitoring and model parameter evaluation in the South Australian rock lobster fishery

FRDC Project No. 95/138

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Janet M. Matthews, David A. Fournier, John E. Feenstra,
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South Australian Research & Development Institute

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Table of Contents

List of Figures

List of Tables

95/138 **Survey sampling design and length-frequency data analysis for ongoing monitoring and model parameter evaluation in the South Australian rock lobster fishery**

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Objectives:

1. To establish a formal protocol for a length-frequency sampling survey which satisfies the two basic statistical criteria of accuracy and precision, specifically,
    (1) non-biased means
    (2) quantifiable variances.
2. To incorporate the desires of the fishing industry in the practicalities of length sampling, through extensive consultation and workshops, where fishers will ultimately decide the protocol adopted, while still conforming to the criteria of 1. above that assure the quality of survey information.
3. To assess the range of stock assessment methods available for analysing length frequencies to estimate the fundamental population dynamic parameters describing the South Australian lobster fishery, notably, annual recruitment, annual egg production, mortality, and size structure.

Non-technical Summary:

This project was undertaken to enhance the quality of information from the South Australian southern rock lobster catch monitoring survey. Data on the sizes and sex, and reproductive state of lobsters harvested, gathered in the on-going catch-monitoring program by fishers and on-board researchers, provide direct information about recruitment, egg production, and sex ratios in the catch. These are used to infer relative levels of exploitation, which in turn are used to evaluate the effectiveness of alternative management options (e.g. minimum length). The survey data also provide essential inputs to the suite of models currently employed for resource management in the South Australian rock lobster fishery.

These objectives were achieved at an earlier stage than planned. Thus, the third objective was expanded. In reviewing length-based stock assessment approaches, it was decided that further development of modelling methods, incorporating both catch and effort data and length-frequency survey information, would enhance resource assessment.

Modelling in the project consisted of four parameter estimation modelling subprojects:

4. To develop an individual-lobster-based data simulator. Simulated data allow reliability testing of stock assessment models because the 'true' stock parameter values, to be estimated, are known.
5. To test and improve the 'qR' dynamic model, currently employed in yearly South Australian lobster stock assessment. This estimation algorithm incorporates size as yearly mean weight of an average lobster in the catch. This model was tested with simulated data generated in Objective 4.
6. To develop a dynamic stock assessment model which uses the length-frequency data gathered in the catch-monitoring program as input. This age-based estimation model

was written with AD Model Builder parameter estimation software in collaboration with Dr. David Fournier.

7. To estimate moult-transition probabilities of lobster growth. A model was developed and implemented, enhancing a method developed by Punt et al. (1997), that allows a purely length-based model estimation for stock assessment. The moult-transition probabilities will be incorporated in SARLMOD (the spatial management model developed in FRDC Program 93/086) to update the lobster growth submodel.

Fishers' preferences for on-board survey protocol was canvassed in mailed poll responses, in port meetings, and in a well-attended state fishery wide workshop. A large majority preferred sampling a few pots over a proportionally greater number of fishing days, rather than all pots on a few days.

Statistical analysis of the 1996/97 pot sampling data showed that fewer pots on more days produces a survey with a substantially lower sample variance, i.e. it would give a considerably more representative sample of the overall numbers harvested in each length class. Most critically for improving the quality of the catch monitoring information would be the inclusion of more fishers' catches, i.e. more licences participating in the volunteer survey program.

Thus the results of Objectives 1 and 2 were mutually compatible. The statistically superior survey protocol was also the one that fishers preferred.

Several recommendations of this study have been implemented or are under discussion:

1. Requested precision for lobster carapace length measurement was reduced to 1 mm.
2. The project conclusion that greater participation is the most cost-effective method to carry out catch monitoring has been presented at meetings with fishers and the research subcommittee. The latter has unanimously endorsed this shift of survey protocol. Specifically, fishers suggested a 1-pot-per-day sampling regime, identified in Chapter 2 to be the most economically efficient assuming uniform cost per pot sampled.
3. SARDI researchers are working to expand the number of fishers participating in pot sampling. The immediate response was good and fishers have been volunteering for catch monitoring in greater numbers.

The following recommendations are offered for future improvements in the quality and usefulness of catch monitoring data:

1. Extensive length-frequencies samples were gathered (under the direction of Jim Prescott and with strong industry collaboration) in the two fishing seasons 1991/92 and 1992/93 before the current rock lobster Oracle database was developed. These data should be incorporated into the Oracle database.
2. These additional two years of catch monitoring data, in combination with the two most recent, now comprise a time series of 8 years in length, long enough to form meaningful yearly indicators of recruitment and egg production. These should be added to yearly stock assessments.

Generally, the results of Chapters 2 and 3 indicate that the quality of the data is high. The level of fisher participation is good to excellent. Catch monitoring will thus continue to serve as an on-going basis for fishery stock assessment and management.

Background

The Fishery

The southern rock lobster (*Jasus edwardsii*) fishery in South Australia (SA) is the state's largest in terms of export income. Lobsters are exported live to Asian markets. Management of this resource has two goals, codified in state fisheries legislation: (1) to assure that exploitation is sustainable in the long term, and (2) to optimise (net economic) return. For both of these goals, information about changes in the population and the level of its exploitation is needed. Without detailed knowledge of the population, reliable evaluation of existing management strategies cannot be undertaken. Commercial catch sampling provides an opportunity to examine population level processes and to assess the effectiveness of management of the rock lobster resource.

The fishery is managed differently in two management zones, the Northern and Southern (Figure 1).

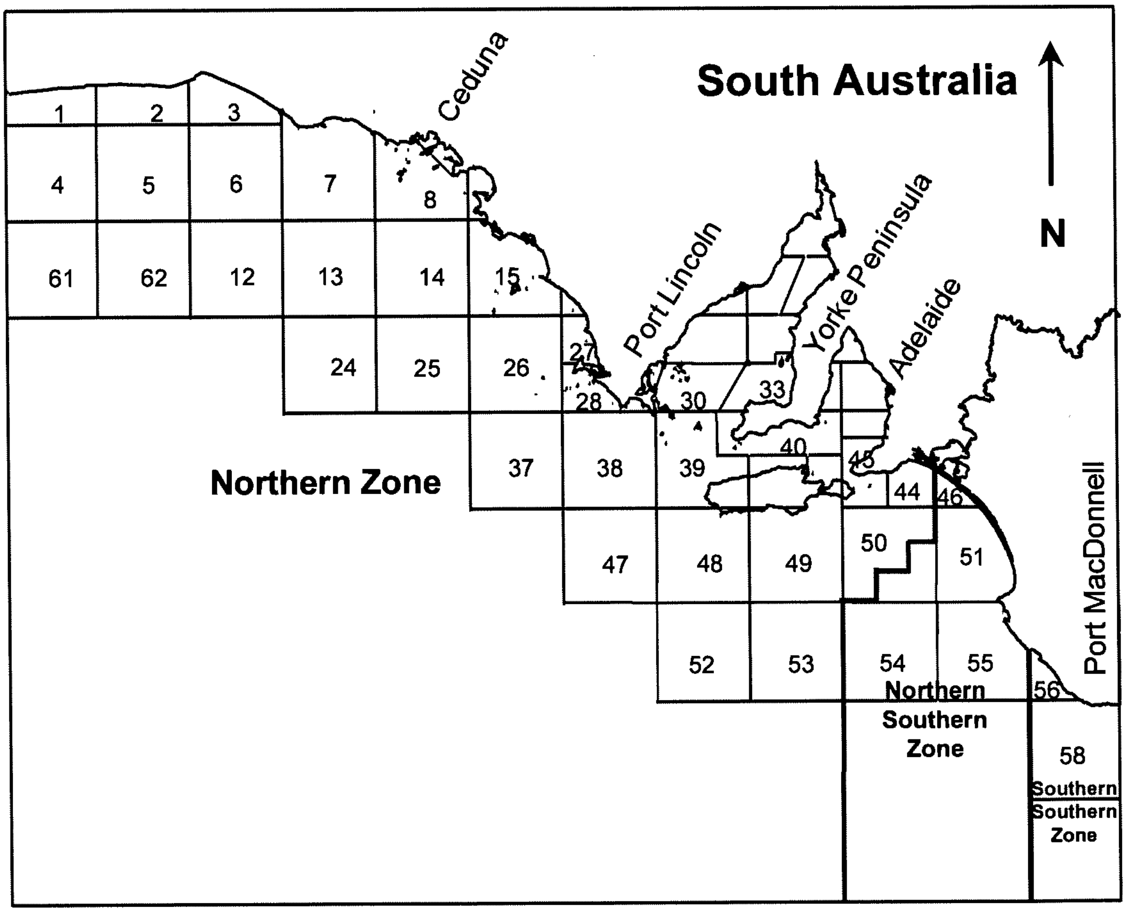


Figure 1. Map of South Australia showing the two management zones.

In both zones there is limited entry. In the 1996/97 season, there were 76 licence holders operating vessels in the Northern Zone and 186 licenced vessels in the Southern Zone. Both zones are open for seven-month fishing seasons, November to May in the Northern Zone and October to April in the Southern Zone. A licence entitles a vessel to set a fixed number of pots in the water for harvesting, ranging from 25 to 60 pots in the Northern Zone and 40 to 80 in the Southern Zone. Minimum sizes of 98.5 mm carapace length (CL) in the Southern Zone and 102 mm CL in the Northern Zone require fishers to return smaller sized lobsters to the sea.

Lobsters in the commercial fishery are captured in baited traps ('pots'). These are set on or near the rocky substrate which this species inhabits. Pots are baited with lower cost fish, often Australian salmon or Murray carp, and set in the afternoon. Vessels retrieve their pots the following morning. The commercial harvest comprises approximately 95-98% of the total.

In the Northern Zone, fishing is limited by effort controls i.e. limiting the total days available to be fished by the fleet. In addition to restrictions on boat length and engine size and not pulling gear more than once per day, a system of individual time closures, each of about a week long, were implemented in 1994/95. During the seven-month season, total days of fishing are further reduced by allowing vessel operators a choice of closure options (McGarvey and Prescott 1998).

In the Southern Zone, in 1993/94, individual quotas were established, allocating a total allowable catch of 1720 tons distributed amongst the fleet in proportion to each licence's designated pot holding.

Currently there are three principal sources of data for assessing the lobster population: (1) commercial catch logs, reporting totals of catch (by weight and numbers) and effort as pot lifts; (2) catch monitoring, where the contents of individual pots are examined and the characteristics of captured lobsters recorded; and (3) tag-recovery data, gathered from a large tag-recapture study with fishers reporting back length and location of recaptured tagged lobsters found in the commercial pots.

The catch monitoring survey

This project is devoted to examining the utility of commercial catch monitoring data. In particular the study aims to develop methods to quantify the population structure as different age or size classes. For instance, as the level of exploitation rises, the stock structure will shift to generally younger and smaller lobsters. Traditional sources of data such as catch per unit effort do not provide information on the size or age structure of the population. Catch monitoring, has been undertaken in the South Australian rock lobster fishery since 1991/92 (Prescott et al. 1997a). Because the age of lobsters cannot be determined, the stock structure is categorised by lobster size.

In addition, other important aspects of stock structure are recorded on the catch monitoring form for each animal captured in sample pots, notably, sex, and if female, the presence or not of eggs. In the absence of eggs, the sexual maturity status is assessed by the length of the setae. Setae are long thick hairs on which extruded eggs are carried by females for about four months over winter before hatching into the water column in early to late spring. The colour of the lobster, and any missing body parts are also noted.

GPS location of each pot in latitude-longitude with the maximum accuracy commercial GPS units (roughly 30 m resolution), depth, and swell height are also recorded. Some volunteer fishers attach a state-research-supplied thermometer to one of their pots, providing daily bottom temperature.

Also recorded are other species retrieved in the pots, notably lobster predators such as octopus, and more commonly in the Northern Zone, fish.

In previous (and subsequent) years to 1996/97, both volunteer fishers and researchers on-board non-volunteer vessels measured lobsters in the catch monitoring program. However in the year of this study, the 1996/97 lobster fishing season, only volunteer fisher sampling was carried out.

It is not possible to survey the lobster population directly, without diving or submarines, the cost of which is largely prohibitive. Thus, all three data sources come from the subset of the population that comes up in lobster traps. Thus, the survey is of the *catch*. The program of survey catch monitoring that this project seeks to design optimal protocol for is undertaken to obtain estimates of the catch numbers in each length class.

The goal of dynamic fishery stock assessment is to make inferences about changes in the population overall. This is undertaken by analysing the data using age- or length-based fishery population models. Without the ability to age individuals directly, the basic quantities sought in stock assessment, mortality, recruitment, and fishable biomass, require the combination of both stock structure (ie mean weight of lobsters in the catch, or the sampled survey length frequencies) and a reliable measure of growth. The growth of lobsters is derived from the tag-recapture database.

Data is entered, stored and retrieved from an Oracle 7.0 database, currently maintained on a Windows NT server in the SARDI/PIRSA network.

Need

The SA rock lobster catch monitoring program, a key component of stock assessment, currently has no clear sampling protocol, and formal methods to calculate unbiased estimates of numbers captured by length class have not been formulated.

The needs to be fulfilled by this study may be expressed by the questions that it seeks to answer:

1. Which sampling protocol do fishermen prefer?
2. What is the optimum number of pots to sample on each sampling day to yield the lowest sample variance?
3. In the framework of the established theory of survey design (Cochran 1977), what general classification is the lobster catch monitoring survey?

4. What formula is used to obtain non-biased estimates of numbers harvested, both overall, and in each designated length class?
5. What is the formula to be used in calculating sample variance?
6. In sampling non-volunteer vessels' catch by researchers, is there a more efficient way to sample length-frequencies of the overall catch?

The following questions address the use of the data in stock assessment:

7. Is there a way to use information on size of capture obtained from commercial catch logs to estimate yearly recruitment, biomass and exploitation rate?
8. Can catch and mean weight data taken from commercial samples provide reliable assessments?
9. Can a flexible estimation model be developed to generate length-based growth descriptions, giving the probabilities of moult transition to larger length classes?
10. Will a moult probability model improve the description of mean growth, in particular, for females, where significant slowing in growth rate following maturity renders the Von Bertalanffy description less accurate?

Objectives

The following objectives were set in the project proposal and contract:

1. To establish a formal protocol for a length-frequency sampling survey which satisfies the two basic statistical criteria of accuracy and precision, specifically,
   (1) non-biased means
   (2) quantifiable variances.

2. To incorporate the desires of the fishing industry in the practicalities of length sampling, through extensive consultation and workshops, where fishers will ultimately decide the protocol adopted, while still conforming to the criteria of 1. above that assure the quality of survey information.

3. To assess the range of stock assessment methods available for analysing length frequencies to estimate the fundamental population dynamic parameters describing the South Australian lobster fishery, notably, annual recruitment, annual egg production, mortality, and size structure.

These objectives were achieved at an earlier stage in the project than planned. Thus, the third objective was expanded. In reviewing length-based approaches, it was decided (with FRDC approval) that further development of modelling methods for rock lobster stock assessment, incorporating catch data totals and length-frequency survey information, would enhance stock assessment capabilities in the South Australian rock lobster fishery.

Modelling in the project consisted of four parameter estimation modelling subprojects. These may be divided into two general categories: (1) Dynamic fishery stock assessment, and (2) length-based lobster growth. Three stock assessment models will be developed in the first category. Taken together, the model objectives are fourfold:

4. To develop an individual-based data simulator. Computer simulation of the growth and capture of lobsters in a fishery will incorporate individual lobster life histories, with properties of mortality and growth closely resembling SA rock lobster. This simulation will generate data for which the parameters to be estimated with stock assessment models are precisely known (since they are user-chosen inputs to the simulation). These simulated ('fake') data will allow reliability testing of the stock assessment model (5) below. Simulated data to be generated will include length frequencies, patterned after the catch-monitoring data employed in management of the SA lobster resource.

5. To test and improve the 'qR' dynamic model, based on catches by weight and number. This stock assessment estimation algorithm incorporates size as yearly mean weight of an average lobster in the catch. The steady state version of this model, and a preliminary version of its dynamic formulation was undertaken in FRDC Project 93/086 and 93/087. Enhancement of this model and its testing with the individual-based data simulator to be constructed as Objective 4 are objectives of the current project.

6. To develop a dynamic length-fitting model using AD Model Builder parameter estimation software in collaboration with Dr. David Fournier.

7. To estimate moult-transition probabilities, yielding a length-based model of growth compatible with length-based stock assessment and management.

Chapter 1: Industry consultation in sampling protocol design

Introduction

This chapter addresses Objective 2: "To incorporate the desires of the fishing industry in the practicalities of length sampling, through extensive consultation and workshops, where fishers will ultimately decide the protocol adopted, while still conforming to the criteria of Objective 1. ((1) non-biased means, (2) quantifiable variances) that assure the quality of survey information."

This project deals with establishing survey protocols for catch monitoring. Extensive consultation with fishers in designing the sampling protocol was carried out. The various stages of this consultation, and the results, as decisions made by fishers and scientists in group forum, are described in this chapter.

In the fishing season of this study, 96/97, no research sampling was undertaken. The sampling was carried out entirely by commercial fishers at sea. Since all legal sized lobsters captured are kept, no economic incentive for under-reporting is introduced.

Methods

Industry consultation and decision-making, primarily during the winter closure of 1996, had four basic stages:

1. Preliminary discussions on survey design and anticipated extent of fisher participation were held with peak management bodies, notably the management committees, and specific fishers who are active in leading these groups:
    (1) Northern Zone Integrated Management Committee,
    (2) South Australian Northern Zone Rock Lobster Fishermen's Association,
    (3) The Southeast Professional Fishermen's Association, in the Southern Zone,
    (4) The Kingston port association, held at an opportune time during this consultation,
    (5) Northern Zone Management Plan Sub-Committee,
    (6) Individuals and fishermen's body representatives.

2. A survey opinion poll was mailed to all licence holders requesting their input on questions of survey design. Two general survey method options were offered:
    (1) Sampling be done by hired scientists and technicians working from commercial fishing boats, or
    (2) Fishers do the pot sampling on a voluntary basis.

In the case where fisher sampling was undertaken, three further questions were posed:
    (i) Do fishers support compensating those fishers who do participate in research sampling?
    (ii) If so, what form of compensation do they favour? In-kind, as extra quota in the Southern Zone and a few more days of fishing in the Northern Zone, or direct financial compensation.

(iii) As individuals, would they volunteer as participants in a fisher-based measurement program?

A one-day workshop was convened to which all fishers were invited to attend. The meeting date was chosen when a large proportion of fishers were in town attending a large fishery-wide meeting being held in Adelaide. The purpose of this workshop was to provide an opportunity for fisher input to the survey design. Also attending was the international consultant in statistics and fishery survey design, Dr Michael Pennington. The goal was to reduce the range of choices for survey designs to two or at most three, which could be formed into a mailed ballot to all fishers. The results, presented below, achieved more, reaching a general consensus on the broader issues and sampling protocol specifics among all fishers attending. Three basic sampling options were chosen, basically (A) sampling all the pots on each sample boat-day, with a small number of days, (C) sampling 3–5 pots each sample day, with a proportionally larger number of days, and (B) a compromise between A and C, sampling 10 pots.

4. Letters were sent to all fishers explaining the 3 survey Options, A, B and C. A postage paid response was available from those wishing to volunteer, with a form to send back with their option choice.

5. A tour of all the lobster ports in both zones (6 ports in the Southern Zone, 3 in the Northern Zone) was organised and undertaken (Appendix 3G) to present the details of the chosen sampling protocol to fishers, mainly those volunteer fishers who would participate. For each sampling option, survey protocol was explained and sampling materials, including forms, callipers, and thermometers were distributed to survey participants (Appendices 3H and 3I). The value of length frequencies in stock assessment and thus management was explained graphically.

6. The full season of sampling was then undertaken. Pots were marked at the beginning of the season. Data (described in Background section above) were recorded by fishers and entered into the rock lobster database. The survey was undertaken in two parts, spring and autumn. Close telephone communication was maintained between field coordinating researchers and the volunteer fishers. The data entry form used in the survey by volunteer fishers during this project is included in Appendix 4.

7. The analysis of this season's pot sampling data had two goals: (1) To determine the optimum level of sampling at each level of the sample hierarchy, i.e. to determine how many pots per boat day yield the lowest sample variance for a given amount of work. (2) Non-biased formulas ('estimators') for the mean numbers harvested in each length class, and the variance of that estimate were carried out. These analyses are presented in Chapters 2 and 3 respectively.

Results

Many of the communications with fishers were mailed. Copies of these are included in Appendix 3, and will be referred to below.

The development of survey protocol in close collaboration with fishers themselves and the first half-year of the survey sampling have been completed. Expectations were exceeded in levels of fisher participation and uniformity of fisher consensus on choice of sampling protocol.

- Results of poll (Appendices 3A and 3B) strongly indicated a preference for fishers collecting survey data, with 96% of license holders in the Northern Zone and 84% in the Southern Zone expressing that preference. There was also support for compensation to fishers who participated as volunteers in catch monitoring. Majorities (Northern Zone 54%, and Southern Zone 59%) supported granting increased numbers of days to fish in the Northern Zone and some additional quota in the Southern Zone.
  The response rate to the poll was relatively low: 30% in the Northern Zone and 23% in the Southern Zone. The high percentages of those that did respond expressing future willingness to participate in the program (75% in each zone) suggests that the poll reflects the opinions of those who do take an interest, often direct, in research.
- A Survey Design Workshop (Appendices 3C and 3D) was convened to complete the design of sampling protocol. 38 fishers attended along with all members of the rock lobster research group and Dr. Mike Pennington, the fishery survey design consultant. The following decisions were reached:

1. Fishers would carry out the length-frequency sampling in both zones in the course of their daily fishing operations.
2. No compensation would be offered as encouragement to those that participated. Though the survey poll reflected willingness by fishers to offer quota (Southern Zone) or extra days of fishing (Northern Zone), it was decided by fishers at the meeting that this could bias the reported results.
3. Two surveys would be undertaken: two or more months in spring and two or more months in late summer.
4. Three sampling zones were established, Northern Zone, Northern Southern Zone, and Southern Zone. These were chosen to equalise measurement work required of volunteers in different areas. In SA, typical total numbers of (legal and sublegal size) lobsters captured per pot lift increases from north to south.
5. Three sampling protocol options (Appendices 3E and 3F) were formulated and adopted.
   Option A: Sample all pots aboard set on a small number (5, 4, or 3) of fishing days
   Option B: Sample a medium fraction (1/5, 1/7, or 1/10) of pots set over 10 days in spring and 10 days in autumn.
   Option C: Sample a small number of pots (1/15, 1/21, or 1/30) over 30 days.

- Percentages of vessels expressing interest in volunteering in the sampling program increased from south to north. For the spring survey, in the southern and northern sampling areas of the Southern Zone, 32% and 53% of the vessels have volunteered to participate, representing a total sample 0.8% and 1.3% of the pot lifts. In the Northern Zone fishery, 80% of the vessels volunteered, a prospective sample of 2.8% of the pot lifts.
- The spring and autumn surveys were completed. Percentages of vessels actually participating in the sampling program were lower than the numbers who signed up to volunteer. Participation rates were higher in the Northern Zone, a more recently developed fishery with higher catch rates overall. In the Southern Zone, 31% and 17%

of the vessels participated in spring and autumn respectively, yielding a total sample 0.33% of the pot lifts for the year overall. In the Northern Zone fishery, 50% of the vessels in the spring and 23% in the autumn volunteered, sampling 0.83% of the pot lifts.

Table 1.1. Sampling protocol options for the SA rock lobster catch monitoring survey, 1996/97.

	Sampling Region		
Option	Northern Zone	N Southern Zone	S Southern Zone
Option A	5 days, all pots	4 days, all pots	3 days, all pots
Option B	10 days, 1/5th pots	10 days, 1/7th pots	10 days, 1/10th pots
Option C	30 days, 1/15th pots	30 days, 1/21th pots	30 days, 1/30th pots

Discussion

The continued participation of fishers, and their contribution to the decisions of sampling protocol reflect the historical high level of interest in research by SA rock lobster industry. The survey, this year with no additional sampling by scientists, yielded a total sample of 11665 pots and length measurements of 24270 lobsters. The sampled length frequencies are presented in Chapter 3.

Among the three options, the majority of fishers preferred option C, making that judgement based on convenience, i.e. the least additional work to their daily fishing operations. This option (of fewer pots measured on more days) is shown in Chapter 2 to be statistically the most efficient, yielding the lowest sample variance for a given number of pots sampled.

Chapter 2: Optimum design to minimise sample variance

Introduction

This is the first of two chapters to address Objective 1: "To establish a formal protocol for a length-frequency sampling survey which satisfies the two basic statistical criteria of accuracy and precision, specifically, (1) unbiased or consistent estimators of means, and (2) quantifiable variances." It is implied in this objective, to seek a survey protocol that minimises the variances of these estimated means. The goal in this chapter, and one of the primary objectives of this project, is to achieve the most cost effective description of the size composition of catch, by measuring a small part (less than 1%).

The statistical method used to analyse the predicted effect of different sampling protocols is called *variance components*, also known as *random effects models* (Searle et al. 1992). It applies to cases such as the SA rock lobster catch-at-length survey where there are several levels in a sampling protocol hierarchy, namely pots sampled on a given boat-day, boat-days for a given licence, and licences from among all those in the fleet. The licence (i.e. boat and skipper in the fleet) is the highest level of sampling hierarchy, denoted by Cochran (1973) as the *primary sampling unit.* The term random effects, reflects the lack of control of samples at each level of the hierarchy. The experimental conditions (that is the particular pots being measured) are random. Variance components refers to the goal of the analysis i.e. to estimate the variance at each sampling level, the components due to variation among pots, among days, and among licences. These components are considered to be independent of the other levels of the sampling hierarchy, but will each reflect both variation in the population, and in the choice of sample units randomly chosen.

Two principal characteristics of the lobster catch that the survey seeks to measure are length and abundance quantified by the statistics of mean length of lobsters harvested, and the mean number per pot lift. In this Chapter, the variance components of these two specific quantities will be analysed to determine the optimum sampling protocol.

The estimation of the variance component is straightforward for the lowest level of the sampling hierarchy, sampled pots: it is the average of the observed variances within each day from sampled pot lifts, taken over all the days sampled. However, at higher levels of the hierarchy, for instance in estimating the variance at the licence level, the mean length or number per pot lift must be calculated from the sample days for that licence, and pots sampled on those days. The variance among means from each licence does not quantify the variation only among licences but, by default, will also include the variation of lower levels, due to pots and days. The goal of variance components analysis is to use the mean variance at each level, and to assess the contribution to the overall variance of the estimate due to each individual level of the sample hierarchy. Thus, the sample size at that level can be adjusted accordingly to reduce the overall uncertainty.

Figures 2.1a, 2.1b and 2.2 present examples of sampled numbers per pot at the three stages of the sampling hierarchy, pot, day, and licence. The first source (or variance component) is in the numbers of lobsters caught in each pot during a single trip by a fisher. For example, the plot of the number of legal-size lobsters caught in each pot sampled by a randomly chosen fisher on each trip day (Figure 2.1) shows two pots were sampled on day 1. In one pot there were no lobsters and in the other pot, three. The second source of variability is caused by the differing numbers of lobsters that are caught per trip by a fisher. The numbers per pot lift, averaged over all sampled pots in each sampling day for one randomly chosen fisher (Figure 2.1b), indicates that the daily averages vary less than numbers per pot (Figure 2.1a) but still exhibit considerable variation. The last variance component is the variation among licences, due to the varying catching powers of different vessel/skippers in the fleet, together with environmental conditions and capture luck on the days (and pots) they sampled. The survey-estimated mean numbers per pot lift by fishers who participated in the 1996 spring survey in the Northern Zone (Figure 2.2) exhibit less overall variation than day-to-day averages for a particular fisher (Figure 2.1b), varying from about 1 to 3 lobsters per pot lift. However, the overall results will indicate that between-licence variability is the largest contribution to imprecision in the final overall estimates of numbers per pot and numbers in each length class, due to the relatively larger total numbers of days and pots that are measured.

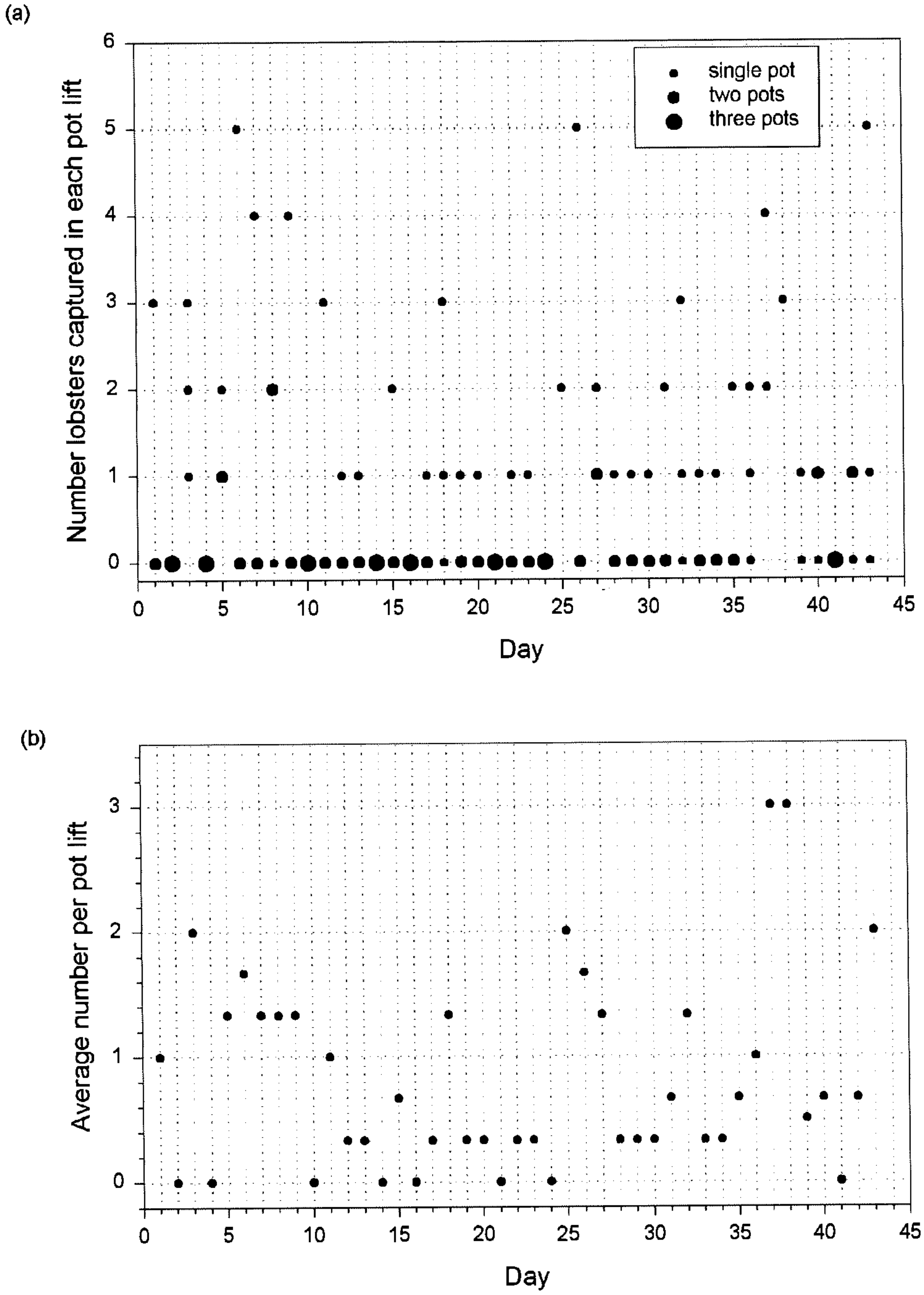


Figure 2.1. Variation in numbers of lobsters captured.
(a) Pot-to-pot variation in numbers of lobsters captured* and (b) day-to-day variation in average number of lobsters, per pot per day for an individual licence in spring, Northern Zone.
*Note: multiple pots containing equal numbers of lobsters on the same day are represented by larger points as described in the legend.

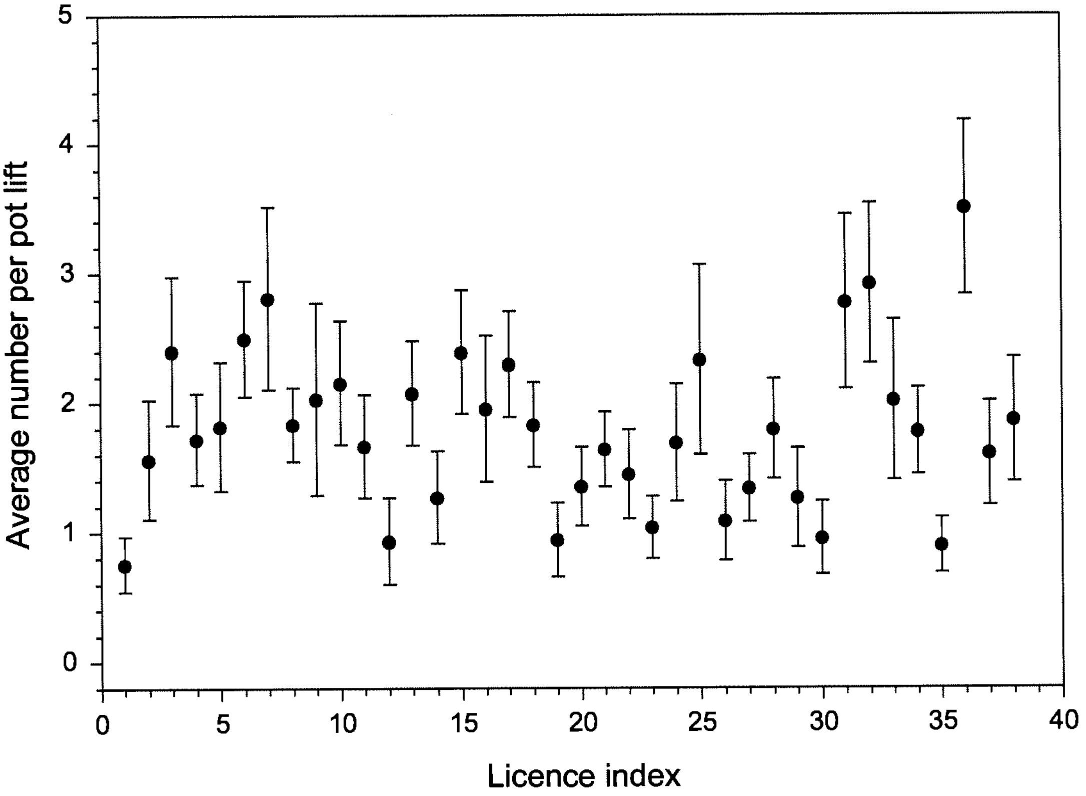


Figure 2.2. Average number of lobsters per pot per licence, spring, Northern Zone.

Methods

In order to compare sampling strategies, a model is needed that relates the precision of an estimate to various sampling protocols. Letting $\hat{\bar{Y}}$ denote the estimated number of lobsters caught per pot in a survey zone and season, either overall, or in a particular length class. Then the variance of $\hat{\bar{Y}}$ is given approximately by (Box et al. 1978, Box and Tiao 1973)

$$Var(\hat{\bar{Y}}) \approx (1-f_1)\frac{\sigma_L^2}{l} + (1-f_2)\frac{\sigma_D^2}{l\bar{d}} + (1-f_3)\frac{\sigma_P^2}{l\bar{d}\,\bar{p}}, \tag{2.1}$$

where

- σ_P^2 is the component of variance caused by the pot-to-pot variability in catch within a trip;
- σ_D^2 is the variance component due to trip to trip differences in catch by each fisher;
- σ_L^2 is the fisher to fisher (i.e. licence) variance component;
- l is the number of fishers collecting data;
- $\bar{d}$ is the average number of days each fisher sampled;
- $\bar{p}$ is the average number of pots sampled per trip by all the fishers;
- f_l is the proportion of the fishers in the survey;

- f_2 is the average proportion of the number of days fished by each fisher (who participated in the survey program) in which samples were taken.
- f_3 is the average proportion of pots set during a sample day that were sampled.

The form of Eq. (2.1) provides direct information about which sampling protocols are likely to give the greatest reduction in sample variance. Sampling more pots per trip (i.e. increasing $\bar{p}$) only reduces the last term in Eq. (2.1), leaving the contribution of the other terms, due to variance among days and licences, unaffected. Sampling pots from more days (increasing $\bar{d}$) for each licence reduces the variance contributed by the last two components, pots and days. Finally, if the number of licences sampled were increased (*l*), then all three sources of variability would be reduced. Thus, in general, the most efficient sampling design for sampling a fixed number of pots (ignoring the relative costs of using the different sampling schemes) would be to collect pots from as many licences as possible and then from as many days fished by each licence as possible.

The survey (catch-monitoring) data from 1996/97 will be analysed in this (and the next) chapter partitioned into six data sets, spring and autumn, for each of three sampling subregions (Chapter 1, Methods, point 6.)

Results

Variance components were estimated for each (of the three) individual stages or levels of the sampling hierarchy.

The actual values of the variance components for future surveys are, of course, unknown but estimates based on data from previous surveys can be used to indicate their relative size and their effect on the precision of the estimators. Estimates of the three variance components were calculated for the six survey data sets (Table 2.1).

Table 2.1. Estimates of the variance components for the number of lobsters caught per pot during the 1996-1997 season. The variance component $\hat{\sigma}_T^2$ is the estimated total variance, $\hat{\sigma}_L^2$ is the licence component, $\hat{\sigma}_D^2$ is the trip component, $\hat{\sigma}_P^2$ is the pot component, and n is the total number of pots sampled. Legal-size, as well as all lobsters sampled, are analysed.

Northern Zone

Survey, legal	$\hat{\sigma}_T^2$	$\hat{\sigma}_L^2$	$\hat{\sigma}_D^2$	$\hat{\sigma}_P^2$	n
spring	3.97	0.18	0.52	3.29	3954
autumn	3.36	0.14	0.42	2.81	1995

Survey, all	$\hat{\sigma}_T^2$	$\hat{\sigma}_L^2$	$\hat{\sigma}_D^2$	$\hat{\sigma}_P^2$	n
spring	5.46	0.31	0.75	4.41	3954
autumn	5.01	0.17	0.77	4.09	1995

N Southern Zone

Survey, legal	$\hat{\sigma}_T^2$	$\hat{\sigma}_L^2$	$\hat{\sigma}_D^2$	$\hat{\sigma}_P^2$	n
spring	5.10	0.41	0.00	4.93	2109
autumn	3.07	0.53	0.00	2.72	1359

Survey, all	$\hat{\sigma}_T^2$	$\hat{\sigma}_L^2$	$\hat{\sigma}_D^2$	$\hat{\sigma}_P^2$	n
spring	7.90	1.07	0.14	6.74	2109
autumn	4.51	0.82	0.00	3.88	1359

S Southern Zone

Survey, legal	$\hat{\sigma}_T^2$	$\hat{\sigma}_L^2$	$\hat{\sigma}_D^2$	$\hat{\sigma}_P^2$	n
spring	7.01	0.97	0.00	6.25	1463
autumn	3.04	0.13	0.08	2.89	787

Survey, all	$\hat{\sigma}_T^2$	$\hat{\sigma}_L^2$	$\hat{\sigma}_D^2$	$\hat{\sigma}_P^2$	n
spring	18.92	3.04	0.00	16.80	1463
autumn	8.09	0.42	0.04	7.71	787

The largest variance component for all the six survey data sets is the pot-to-pot component, σ_P^2. The day-to-day component, σ_D^2, is relatively large in the Northern Zone compared with its value in the two Southern Zone sub-regions. The licence-to-licence component, σ_L^2, contributes relatively more to the variance in the Southern Zone.

The results of the variance components analysis can be used to build a model to assess different survey designs. Each design designates the allocation of sampling effort among licences, days for each licence, and pots on each day. The goal is to find sampling protocols giving the lowest predicted sample variance. The estimates of the variance components were substituted into Eq. (2.1) and this equation used to assess the effect of various sampling schemes on the precision of the abundance estimators. For example, Table 2.2 compares sampling designs from the spring survey in the Northern Zone.

Table 2.2. Assessment of various sampling designs
for estimating the number of lobsters per pot lift in the Northern Zone.

Sampling strategy	Number of licences sampled	Days sample		Pots sampled			Standard error (% of mean)	Effective sample size
		Per licence	Total	Per day	Per licence	Total		
Data (means)	38	17.3	657	6.0	104.1	3945	3.70 %	1413
Option A	38	3	114	35	105	3990	5.20 %	709
Option B	38	10	380	10	100	3800	4.00 %	1216
Option C	38	35	1330	3	105	3990	3.50 %	1584
Increase number of licences sampled								
(1)	50	10	500	3	30	1500	3.90 %	1253
(2)	75	17	1275	3	51	3825	2.30 %	3559

The first line in Table 2.2 presents the results for the 1996/97 survey as it was actually conducted. The standard error (column 8) is for the estimate of the mean catch per pot calculated using the ratio estimator (see Chapter 3). The last column, the effective sample size, quantifies how well the sampling design performed compared with (not physically realisable) simple random sampling. If it were possible to take a simple random sample from all the pots set during the season, then it would be sufficient to sample 1413 pots from all the pots that were set to get the same precision as was obtained by sampling 3945 pots (column 7) using the hierarchical sampling design inherent in the fishery. The reason the effective sample size is smaller than the number of pots sampled is that the number (and length) of lobsters in pots from the same trip, or from trips made by the same fisher, tend to be more similar than those in the entire population of pots that were set.

An assessment of three design options for sampling a total of around 3990 pots is presented in the next three rows (Table 2.2). Option A, sampling approximately 35 pots each trip for 3 trips, is the least efficient whereas Option C, sampling 3 pots per trip for 35 trips, is the most efficient of the three options, yielding the lowest standard error (highest effective sample size) for the same number of pots sampled.

For the present sampling intensity, 50% of the remaining variance (given the sample sizes for pots, days, and licences as allocated) is due to licence-to-licence variability (Figure 2.2). Even though the licence component only makes up 4.45% of the total variance (Table 2.3), the catch rates among fishers are statistically different (see Table 2.4) and this component can only be reduced further if the number of fishers sampled is increased.

Table 2.3. Estimates of the variance components for the number of lobsters per pot in Northern Zone, spring.

Source	Sum of Squares	Df	Mean Square	Var. Comp.	(%)
License	962.5	37	26.0138	0.1770	4.45
Day	3913.4	619	6.3221	0.5171	12.99
Pot	10832.4	3297	3.2855	3.2855	82.56

Table 2.4. Analysis of variance comparing the catch rates (catch-by-weight per pot lift) of participating volunteer fishers (data from Northern Zone, spring survey).

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between licenses	62.5	37	26.01	6.91	0.0000
Within license	14745.8	3916	3.76		

The last two sampling strategies considered in Table 2.2 hypothesise an increase in the number of fishers taking samples. The first scenario assumes 50 fishers, rather than 38, each sampled 3 pots during 10 trips. The precision of the estimated catch per pot for the fishery (3.9%) is better than that obtained from option 2 (4%) even though the total number of pots sampled (1500) is much fewer than for option 2 (3800). The number of pots sampled per fisher is also much smaller (30 versus 105 pots for option 2). If all the fishers participated, then for the same number of pots presently sampled, the estimate will be much more precise than the current estimate (last row in Table 2.2). It may be noted from Eq. (2.1) that if all fishers collected samples then the variability caused by licence-to-licence differences in catch would be zero since f_l would then equal 1.

The analysis for optimising survey design for estimating the length-frequency distribution of lobster catch yielded results similar to those for numbers above. Estimated variance components for length have the additional variance component, σ_W^2, which is due to lobsters varying in length within a pot.

The variance component model for estimating mean length ($\bar{y}$) is

$$Var(\bar{y}) \approx (1-f_1)\frac{\sigma_L^2}{l} + (1-f_2)\frac{\sigma_D^2}{l\bar{d}} + (1-f_3)\frac{\sigma_P^2}{l\bar{d}\bar{p}} + (1-f_4)\frac{\sigma_W^2}{l\bar{d}\bar{p}\bar{w}}, \qquad (2.2)$$

where the first three components correspond to their analogues in Eq. (2.1), and the remaining variance component, σ_W^2 is the variance in length within a pot, $\bar{w}$ is the average number of lobsters measured per pot and f_4 is the average proportion of lobsters measured in each sampled pot. Since all the lobsters are measured in a pot, f_4 is equal to 1 and hence the last term in equation (2) is equal to zero.

The estimated variance components for length (Table 2.5) are presented for spring and autumn in each survey zone.

Table 2.5. Estimates of the variance components for estimated length of lobsters caught. The variance component $\hat{\sigma}_T^2$ is the estimated total variance, $\hat{\sigma}_L^2$ is the license component, $\hat{\sigma}_D^2$ is the trip component, $\hat{\sigma}_P^2$ is the pot component, $\hat{\sigma}_W^2$ is the within pot component and n is the total number of lobsters measured.

Zone 1

Survey, legal	$\hat{\sigma}_T^2$	$\hat{\sigma}_L^2$	$\hat{\sigma}_D^2$	$\hat{\sigma}_P^2$	$\hat{\sigma}_W^2$	n
1	239.3	20.4	16.9	16.6	186.1	5689
2	381.3	29.4	36.1	19.6	298.8	2551

Survey, all	$\hat{\sigma}_T^2$	$\hat{\sigma}_L^2$	$\hat{\sigma}_D^2$	$\hat{\sigma}_P^2$	$\hat{\sigma}_W^2$	n
1	338.2	35.1	23.7	33.1	247.6	7014
2	470.9	37.9	36.9	55.3	344.4	3098

Zone 2

Survey, legal	$\hat{\sigma}_T^2$	$\hat{\sigma}_L^2$	$\hat{\sigma}_D^2$	$\hat{\sigma}_P^2$	$\hat{\sigma}_W^2$	n
1	211.7	44.0	11.3	12.5	146.8	3228
2	475.0	63.2	24.3	66.5	325.6	1510

Survey, all	$\hat{\sigma}_T^2$	$\hat{\sigma}_L^2$	$\hat{\sigma}_D^2$	$\hat{\sigma}_P^2$	$\hat{\sigma}_W^2$	(n)
1	304.8	62.1	4.3	38.8	204.0	3954
2	577.9	83.9	19.6	109.8	364.6	1936

Zone 3

Survey, legal	$\hat{\sigma}_T^2$	$\hat{\sigma}_L^2$	$\hat{\sigma}_D^2$	$\hat{\sigma}_P^2$	$\hat{\sigma}_W^2$	n
1	100.7	8.7	0.0	10.9	82.8	3226
2	237.2	18.1	0.0	54.5	187.0	1003

Survey, all	$\hat{\sigma}_T^2$	$\hat{\sigma}_L^2$	$\hat{\sigma}_D^2$	$\hat{\sigma}_P^2$	$\hat{\sigma}_W^2$	n
1	149.5	11.6	0.0	13.0	125.7	6276
2	291.7	13.3	0.0	57.6	232.6	1972

As was the case for numbers, the licence component accounted for a large part of the remaining variance of the estimates. Since the last term in Eq. (2) equals zero, the licence component contributed considerably more than it did for numbers to the variance of the estimates as indicated by the relative size of the remaining components (columns 3 through 5 in Table 2.5). The same conclusion holds for length as for numbers i.e., it is best to sample as many fishers as possible to estimate the catch length-frequency distribution as numbers caught in each length class.

Discussion

This chapter has been based on data from the program of volunteer fisher sampling which provides by far the most cost-effective source of length-frequency information. The present protocol for volunteer sampling, namely option C, of 2, 3, or 4 pots sampled per day is optimal.

The problem of reduced effective sample size is much less severe than with finfish surveys that have been examined previously (Pennington and Volstad 1991; 1994). Pot lifts are relatively small sample units compared with the haul of a net, and the variation in the total numbers of animals gathered in different pot lifts is much less extreme. Lobster pot lifts thus serve as an effective sample unit overall and the improvements that we recommend are fine tuning of a now demonstrably effective survey method.

The second stratum of sampling, of vessels (i.e. licences) that do not participate in the volunteer survey, is currently undertaken by researchers who choose licences and days and measure all lobsters brought up in pots on the chosen sample trip-day (in general opportunistically). The results above, indicating that sampling all pots for a small number of days is the least efficient sampling regime, imply that researcher effort is currently being used in the least efficient sampling protocol. The principal opportunity for improving both precision and accuracy of the survey estimates is afforded by (1) extending the number of volunteer fishers, and (2) more widely covering the catch of vessels that do not participate in the catch monitoring program. We consider these two approaches in turn.

More fishers could potentially be encouraged to participate if the amount of work in sampling was reduced. The results above suggest that this can be accomplished and overall survey precision increased (if more fishers participated), by allowing fewer pots to be sampled on each sample trip-day. The current standard of three pots implemented fishery-wide following the initial recommendations of this project in 1997/98 may not be onerous for some. However, those who wish to sample only 2 pots (or even 1 pot) per sample trip-day should be encouraged to participate.

A second way that the workload can be reduced with no significant loss of information for stock assessment and management is to relax the current specified carapace length measurement tolerance from 0.1 mm to 1 mm. The current 0.1 mm measurement precision is greater than needed since lobster length measurements are always aggregated into length classes of, at smallest, 1 mm in width. Sample variation among 1 mm length frequencies has in most recent years resulted in the choice of 2 mm or 4 mm as the sensible length-class bin width. A nominated precision of 1 mm is therefore always adequate. Requiring more significant digits than needed requires more time in measuring each lobster and opens the possibility of more recording or measurement errors.

The sensible unit of cost for the non-volunteer stratum is a researcher-day. In the past fishing season, 97/98, 90 sample days were undertaken by researchers on board non-volunteer vessels.

The second way to increase the number of fishers in the data set, and hence increase the precision of the survey length-frequency estimates, would be to sample the catch of non-participating fishers when their catch is landed. As noted, it is most important to get a sample of pots from as many fishers and trips as possible. Increasing the number of fishers sampled would also reduce any bias in the estimates caused by the participating fishers not being representative of the entire fisher population.

In covering non-volunteer vessels, two basic options are presented:
1. The current approach of measuring all pots on a single vessel-day.
2. Doing port sampling randomly and subsampling to measure say 20 lobsters from 10 vessels.

Employing the variance components model of Eq. (2.1), we consider the following port sampling design posed for comparing the relative sampling power of these two options.

Instead of sampling at sea, suppose a researcher spent the day sampling from 10 vessels coming into port and assume that the researcher measured the lengths of 20 lobsters chosen randomly from each from vessel. These would be non-volunteer-sampling vessels currently accessible only to researchers sent on board to measure all the lobsters on a day-trip. Applying estimates of the length variance components from Northern Zone, spring (first line in Table 2.5) in Eq. (2.2), it follows that the variance of the estimate of mean length based on port sampling would be 50% smaller than the variance obtained by sampling all the pots from a single vessel (18.8 versus 37.7).

Thus port sampling has the potential to yield considerably more improvement for determining the distribution of catch lengths (in addition to what is obtained from volunteers) than single-trip on-board sampling. The problems of port sampling are four-fold:

1. It could be difficult to get truly random samples. Lobsters are carried from the vessel in plastic fish bins of three basic sizes most common in the Southern Zone being a 'Nally' bin of dimensions 370 mm x 390 mm x 560 mm in size, and in the Northern Zone, of dimensions 490 mm x 330 mm x 550 mm. A fisher typically lands 2–5 bins. The likely strategy is to sample a fixed proportion, ideally all of the lobsters, from a bin. The one partly full bin in each fishers' landed catch would not be sampled. Then random sampling would be achieved by random selection from the set of full bins of lobsters. In practice, a small study should be conducted to determine the best way to collect a random sample of lobsters from each vessel.
2. The second potential obstacle to port sampling is the violation of handling protocol employed by processors. Any protocol that compromised product quality would not be acceptable. If researchers could develop a method to immerse lobsters in sea water

while subsampling, this obstacle could potentially be mitigated. Ideally, sampling would take place inside the processor's facility, where the lobsters are cooled and re-immersed in sea water, thus eliminating this liability of port sampling.

3. Perhaps the most important loss of information in port sampling is the location of pots set. Spatial catch monitoring information has up till now been aggregated into MFA blocks for use in conjunction with catch data. In that case, no loss of information would occur, since the block where a particular fisher fished on a given day is already entered in the catch database. In future however, as the computational power, spatial detail of stock assessment methodology, and management need for spatial information increases, the much higher spatial resolution that on-board pot-by-pot sampling affords could become operative. However, much of this objection to pot sampling is mitigated by the fact that most (8 out of 10 for the scenario considered above) of the vessel days that could be covered by the port sampling of non-volunteer landings are not currently measured at all. Therefore there would be no loss of spatial resolution, or of information of any kind.

4. The last liability of port sampling is that no undersize lobsters or females bearing eggs, which are returned to the sea when captured, would be measured. However four considerations mitigate against this limitation:
   (1) Sufficient numbers are measured by the on-board volunteer program, to get a good measure of totals of undersize lobsters.
   (2) Undersize numbers (though not by individual measured lengths) are counted and reported in the catch logs required of all commercial fishers.
   (3) Catch length-frequency data for stock management in SA rock lobster is used in conjunction with catch totals (catches by weight and number, and numbers of pot lifts) from the commercial landings. Since catch data totals count only legal-size lobsters, the length distribution of undersize is not directly employed in stock assessment. This is the case, for example, with both dynamic stock assessment models developed in this project (see Chapters 5 and 6).
   (4) To date, all indicators of undersize employed as measures of yearly recruitment (Prescott et al. 1997a; Prescott et al. 1997b; McGarvey et al. 1997b; Prescott et al. 1998; McGarvey et al. 1998) use the undersize numbers reported in catch data. Because these are a complete census of the catch rather than a sample, catch numbers are not subject to sample variability. They are, however, subject to non-reporting or approximate reporting error by fishers, whose primary activity at sea is to capture lobsters not count the ones they throw back. This problem of poor counts of undersize appears to have been substantial in the early years of its inclusion on catch log forms, 1983 to the late 1980's, but seems to have improved substantially in the 1990s (Prescott et al. 1998) and undersize CPUE for the months of November through March is the accepted indicator for undersize abundance in current and recent stock assessments (Prescott et al. 1997a; Prescott et al. 1997b; McGarvey et al. 1997; Prescott et al. 1998; McGarvey et al. 1998).

Perhaps the strongest argument for port sampling is expressed in the success of previous experience. Historically, port sampling was the favoured method of length-frequency sampling in South Australia, doubtless because of the very large samples that could be measured at relatively low cost and time expended, yielding yearly samples of 26,500 lobsters measured for length in 1960/61, 177,000 lobsters in 1975, and 193,000 in 1984/85 (Lewis 1986), compared with 24,500 in the 1996/97 survey.

Chapter 3: Estimation of non-biased mean abundance and sample variance

Introduction

This Chapter addresses Objective 1: "To establish a formal protocol for a length-frequency sampling survey which satisfies the two basic statistical criteria of accuracy and precision, specifically,

(1) non-biased means
(2) quantifiable variances."

To properly estimate mean numbers harvested by length class, from the catch-monitoring data, four inputs are needed:

1. Data, as sample numbers of length-measured lobsters from a sample of pots lifted in the fishery.
2. Survey design, notably quantifying the numbers of pots sampled on each sampling trip-day, numbers of sample trip-days for each licence, and the numbers of licences participating in volunteer catch monitoring.
3. Survey frame, the total numbers of pots harvested, total number of days per licence fished, and the total number of licences in the fleet.
4. Formulas to estimate
    (1) (non-biased) total numbers harvested from these data inputs;
    (2) sample variances of these estimates, ie standard errors of these means.

Below we present a non-biased estimator for mean numbers harvested. This formula is applied to estimate total numbers harvested and to estimate numbers for each individual length class. The latter quantify catch length-frequencies, calculated for the six data sets (spring and autumn, in the three survey zones).

A formula is also presented for the standard error of the estimates of mean numbers harvested. These provide confidence bounds on numbers harvested for each length class.

Methods

The ratio estimator adopted takes advantage of the fact that the numbers of pot lifts by each licence on each trip day are known from catch log data. This yields a three-stage ratio estimator. The survey catch number per pot lift is scaled upward, through survey days and licences, to obtain a survey-derived estimate of total numbers harvested.

Notating the numbers of lobsters sampled by licence, *l*, on sample trip-day, *d*, in pot, *p*, by Y_{ldp}, the survey-estimated catch-number-per-pot-lift (ie CnPUE) for that trip-day is written:

$$\hat{\bar{Y}}_{ld} = \frac{\sum_{p=1}^{np_{ld}} Y_{ldp}}{np_{ld}} \qquad (3.1.1)$$

where

- np_{ld} = number of survey pot lifts by licence, *l*, on sample trip-day, *d*.

It may be noted that for all formulas, the bar over a quantity, such as $\bar{Y}$, indicates an average per pot lift (or per licence); hat "^" indicates the quantity is a survey-derived estimate; lower case "n" are totals of pot lifts, days or licences in the sampling survey; upper case "N" are fishery totals.

The survey estimate of mean CnPUE for licence *l* (where the contribution to mean CnPUE is weighted by the proportion of fishery pots set each sample day) is

$$\hat{\bar{Y}}_{l} = \frac{\sum_{d=1}^{nd_l} Np_{ld} \cdot \hat{\bar{Y}}_{ld}}{Np_{ld}}, \qquad (3.1.2)$$

and the estimated mean CnPUE for all the licences is

$$\hat{\bar{Y}} = \frac{\sum_{l=1}^{nl} Np_{l} \cdot \hat{\bar{Y}}_{l}}{Np_{l}}, \qquad (3.1.3)$$

where

- Np_{ld} = number of fishery pot lifts by licence, *l*, on trip-day, *d*;
- Np_{l} = number of fishery pot lifts by licence, *l*;
- Np = total number of fishery pot lifts;
- nl = total number licences participating in survey sampling;
- nd_{l} = number of survey sampling days by licence, *l*.

Thus, the ratio estimator of *total numbers* harvested, $\hat{Y}$, from survey numbers sampled for the three-stage estimation protocol, is the total pot lifts set in the fishery, Np, times the survey estimate of CnPUE for the fishery overall:

$$\hat{Y} = Np \cdot \hat{\bar{Y}}. \qquad (3.1.4)$$

This formula (3.1, written in four nested equations, 3.1.1-3.1.4) was applied to the six data sets to obtain estimates for fishery lobster numbers harvested overall. Length frequencies, as mean numbers harvested in each length class, were also calculated using

(3.1), by restricting the input data Y_{ldp} to numbers of lobsters measured that fall into each length class. For SA length frequencies presented below, 4 mm length bins were used.

The derived estimator for the variance of the ratio estimate $\hat{Y}$ is written:

$$Var(\hat{Y}) = \frac{Np^2\ (1-f_1)\ \sum_{l=1}^{nl} Np_l^{\ 2} \cdot (\hat{\bar{Y}}_l - \hat{\bar{Y}})^2}{\overline{Np_l}^{\ 2} \cdot nl\,(nl-1)}, \qquad (3.2)$$

where

- $\overline{Np_l} \equiv \sum_{l=1}^{nl} Np_l \Big/ nl \equiv$ average number of fishery pot lifts per licence;

f_l retains the definition in Chapter 2, as the proportion of licences participating in survey sampling.

Results

The length-frequency distributions for 1996/97, quantified by survey-estimated mean numbers (Eq. 3.1) in each length class, are presented in Figure 3.1. Error bars, calculated using Eq. (3.2), quantify one standard error for each length class (i.e. each 4 mm bin).

Mean numbers in successive length classes vary relatively smoothly between bins. This amount of bin-to-bin variation is of similar magnitude to the error bars indicating general agreement with confidence bound estimates.

Three patterns are evident. (1) Males grow to a much larger size than do females. (2) In the Northern Zone (NZ) relatively more lobsters are captured in autumn than in spring compared with the SZ. This is due to the difference in open season months. The NZ fishery starts in November, whereas the Southern Zone (SZ) starts a month earlier. “Spring” for all data sets was defined to be through December 31. In the NZ this includes only 2 months (November and December) leaving 5 months for autumn. In the SZ, ‘spring’ includes 3 months and autumn 4 months. Moreover, in the SZ, under quota, many licences reach their individual quota and stop fishing before season’s end. (3) One not previously observed feature of these distributions is the larger numbers of males captured in the autumn for all three regions suggesting relatively higher catchability of large males later in the season.

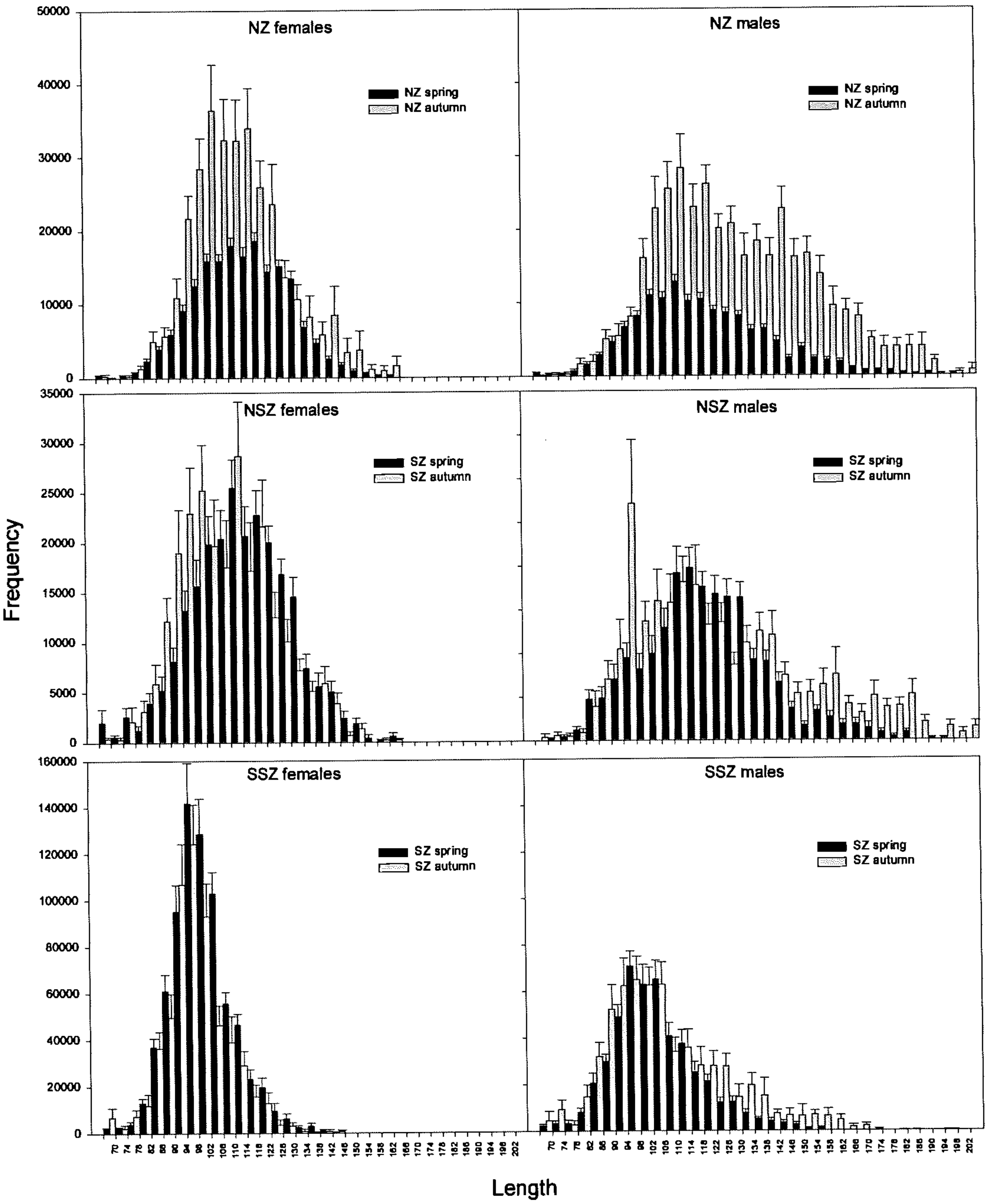


Figure 3.1. Length frequencies, of total numbers harvested, in 4 mm bins. Numbers harvested in each length category were calculated using Eq. (3.1) applied to survey lobsters measured falling into that bin, considering pots set and days fished by each licence.

The higher moments of all six length distributions were calculated from the numbers in each 4 mm bin (Table 3.1).

Table 3.1. Higher moments of the length distributions for (a) males and (b) females. Moment ratios were calculated from the length frequencies shown in Figure 3.1. Skewness = $\frac{\mu_3}{(\mu_2)^{3/2}}$ and kurtosis = $\frac{\mu_4}{(\mu_2)^2}$ where μ_3 and μ_4 are the 3rd and 4th central moments.

(a)	NZ		NSZ		SSZ	
	spring	autumn	spring	autumn	spring	autumn
SD	20.95	24.00	19.73	26.98	14.14	19.08
skewness	0.65	0.42	0.46	0.68	0.87	0.92
kurtosis	3.43	2.57	3.46	2.70	4.53	3.66

(b)	NZ		NSZ		SSZ	
	spring	autumn	spring	autumn	spring	autumn
SD	14.83	15.06	15.56	15.54	10.37	9.96
skewness	0.04	0.51	-0.02	0.34	0.61	0.66
kurtosis	2.67	3.09	2.79	2.71	3.93	4.22

Discussion

The programming for these calculations (Eqs. 3.1 and 3.2) is complex. Raw data must be aggregated into ragged variables with up to six dimensions. Catch log data, specifically numbers of pots, days, and licences, in the fishery must also be incorporated. The practice undertaken in the past is to ignore the varying numbers of pots, days, and licences used to sample the lengths, i.e. to ignore the numbers of units at each stage of the sampling hierarchy and form histograms from raw data. That simpler approach results in potentially biased estimates of numbers in each length class negating the calculation of standard errors. However, in the case of SA rock lobster, comparing the two sets of length distributions so calculated (from Eq. 3.1, and more simply using only raw data) indicated that the error introduced by the less accurate method is not substantial.

In the length-fitting stock assessment model of Chapter 6, and in most recent length-data-based modelling (Punt and Kennedy 1997; Zheng et al. 1995), the models are fitted to the full binned catch numbers-at-length, e.g. Figure 3.1. The alternative is to fit stock assessment models to the higher moments. This would substantially reduce the computation time required to converge to a solution making more practical the incorporation of length information directly into dynamic assessments.

Because of the variable nature of length information, moments could yield annual stock assessment estimation comparable to that obtained by fitting to the full length distributions. Moments calculated from these distributions can be used to form (quite generally) more smooth distributions themselves. Given (1) relatively high levels of sample variability for lengths, particularly at the tails where modest differences from the moment-generated or implied distributions might be most evident, and (2), the need to incorporate growth into any length-data fitted stock assessment, the use of moments would, in most cases (those where these two sources of error are small) be a relatively modest contribution to overall error. Lengths are used primarily with invertebrate stocks for which ageing techniques are not available. Invertebrate growth is often characterised by high individual and spatial variation in growth, and would thus be a greater source of error than the use of moments in fitting to lengths.

The model-predicted length distributions will generally be smooth like the distributions defined by the observed moments., It is this smooth population structure, where sample variation is averaged out, which the model seeks to capture.

One feature that needs to be explicit in model fit is the absolute level of numbers captured, i.e., the y-axis scaling in Figure 3.1 which would be accommodated by simply adding a term for total numbers captured to the fitted log-likelihood.

Chapter 4: Individual-based data simulator

Introduction

The basic quantities that comprise the output of stock assessment models, such as recruitment and exploitation rate, are parameters estimated by fitting the model to data. These outputs are then provided to resource managers as biological performance indicators upon which management decisions are, in part, made. Because of the crucial role they play in resource management it is important to assess the reliability of these parameters derived as model outputs.

The confidence bounds on parameter estimates are most commonly generated from the shape and, specifically, the variance of the likelihood function, which is optimised in formal statistical parameter estimation. This variance is a measure of how closely the model fits to the data. When the fit is close, the variance of the likelihood is small and the estimated confidence bounds will also be small, implying a high reliability of the estimated parameters. Thus measures of model fit serve to quantify the precision of the estimates.

We follow notational convention and refer to the entire algorithm used to estimate stock parameters from data as an *estimator*. The estimator includes (1) the assumed stock assessment dynamic model with the parameters to estimate, (2) the likelihood function, and (3) the method of maximising the likelihood function to obtain the estimates of the parameters and their confidence bounds. The estimator, a mathematical object, is applied to data to generate the indices used to manage fish stocks.

However, one feature of the overall reliability of these estimators is not quantified by measures of model fit, namely *bias*. Thus while the precision of parameter estimates can be estimated by this approach, the *accuracy* cannot. The reason that model fit cannot detect bias, is that for any given set of assumptions, the numerical power of model-fitting routines will always adjust the parameters until the best possible fit is obtained. But model accuracy depends on how 'true' the assumptions were, i.e., how much the exploitable population and associated harvest regime satisfies the assumptions of the model. Thus, the confidence bounds derived from measures of model fit can sometimes understate the uncertainty in the parameters estimated. In the history of fishery science there are cases where a model estimation procedure failed to successfully reproduce the 'true' parameter values even when the underlying assumptions of the estimation model being tested were used to generate the simulation data. For example, Ludwig and Walters (1985) showed that traditional steady state production models gave superior estimates of optimum effort compared with the delay-difference approach of Deriso (1980).

In order to test the reliability of model assumptions and, more generally, to evaluate the output from a model estimation procedure (the estimator), it is necessary to use *simulated data sets*.

The basic approach to generating simulated data for testing estimators is to program a simulation of the fish stock inside a computer. The various processes such as natural mortality, catch, recruitment, and growth assumed to influence the real fishery are incorporated in the simulation.. In general, we choose a data simulator method and population process dynamics that includes more detail than the estimation model can practically assume. For instance, some of the estimator's assumptions such as continuous uniform growth, or constant recruitment, are not assumed in the data simulator. Instead, for lobsters, seasonal growth and recruitment may be simulated as discrete processes via twice yearly moulting. Year-to-year variation in recruitment may also vary in a more arbitrary predetermined way which the modeller is free to control. Thus, the simulation model can be used to generate data sets including catches by weight and numbers, and catch length-frequencies, which are used as data input to test the stock assessment estimation procedure.

With simulation-generated data, we know the 'true' values of the fishery indices such as yearly recruitment, or yearly exploitation rate--the modeller assigns these values before running the simulation. The estimator to be tested is then applied to the simulated data set and estimates are obtained for the parameters sought. How well it was able to infer the 'true' parameter values is immediately evident by simple comparison.

There are basically two forms of population model: aggregated and individual-based. With aggregated models, the common form for most fishery models, the population variable is a count of the numbers of animals in various classes, or categories. For instance, with length-based lobster fishery models, the population variable keeps a count of the numbers of lobsters in each length class. The sum over all the length classes gives the total lobster population abundance. Estimation models, in general, are almost always of this aggregated form.

A more detailed description of population processes can be attained using individual-based model formalism. In this case, each individual lobster in the population is accounted for. For instance, as each lobster grows, its individual length is recorded to increase. At the current state of computer power and estimator statistical theory, no fishery estimation models have been built to date (to our knowledge) using an individual-based formalism. Individual-based models are, however, ideal for data simulation because they allow much more detailed biological histories to be represented than in aggregated models. Individual variation in growth and mortality is naturally represented. Relatively complicated growth and reproductive life histories can be simulated. As many processes as desired of death, both natural and by fishing, of reproduction, movement, or growth can be incorporated. The lobster fishery data simulator developed in this project is an individual-based simulation model.

In this chapter we describe a data simulator that was generated in the course of this project. It has been used to test a number of estimation procedures principally those currently used to manage the SA lobster stock.

Methods

Individual-based modelling

The simulation employed a monthly time step, representing the changes to each individual by a fixed set of events that could occur. Each event, death, settlement (birth) or increase in length (growth) corresponded to one of the life history or capture processes being simulated. Some events, notably mortality, occurred with a specified probability in each monthly time step. In this way, the random nature of capture for each individual was explicit in the simulated data sets generated. Growth by moulting always occurred (with probability 1) at each semi-annual moulting period.

Fishery processes

The simulator incorporated four basic processes of the life history and capture of lobsters:

1. yearly recruitment, as yearly settlement of puerulus;
2. growth, continuous for juveniles (assuming a von Bertalanffy relationship with age), and discrete moulting growth for lobsters of legal fishable size;
3. natural death; and
4. harvest in the fishery.

1. Puerulus settlement. Female lobsters release eggs yearly, in the spring. These metamorphose into larvae known as phyllosomes which spend a pelagic life of a year or more commonly drifting 1000 km from their natal sites (Booth and Phillips 1994). The principal source of variation in recruitment of lobsters and therefore the principal source of yearly variation in harvestable year class strength, is in the yearly rate of larval settlement inshore preceding metamorphosis into early-stage juvenile lobsters (pueruli) of size around 11 mm CL. Model analysis of catch data (Chapter 5) indicates the magnitude of SA lobster settlement may undergo a periodic trend with about a 10-year cycle. A notable feature in recent years was the large peak in recruitment observed for lobsters in both zones of the South Australian fishery about 1991.

For model estimation testing, four time-varying recruitment patterns were generated by specifying the annual numbers of settled pueruli: (1) a 'constant' yearly settlement, (2) a yearly random variation, (3) 10-year cycling with added multiplicative random variation, and (4) a single-year peak of high settlement (five times the mean over all years) (Figure 4.1). Mean settlement numbers for all four series were set at 10,000. Time of settlement varied for individuals with a standard deviation of 1 month around the July 15 mean.

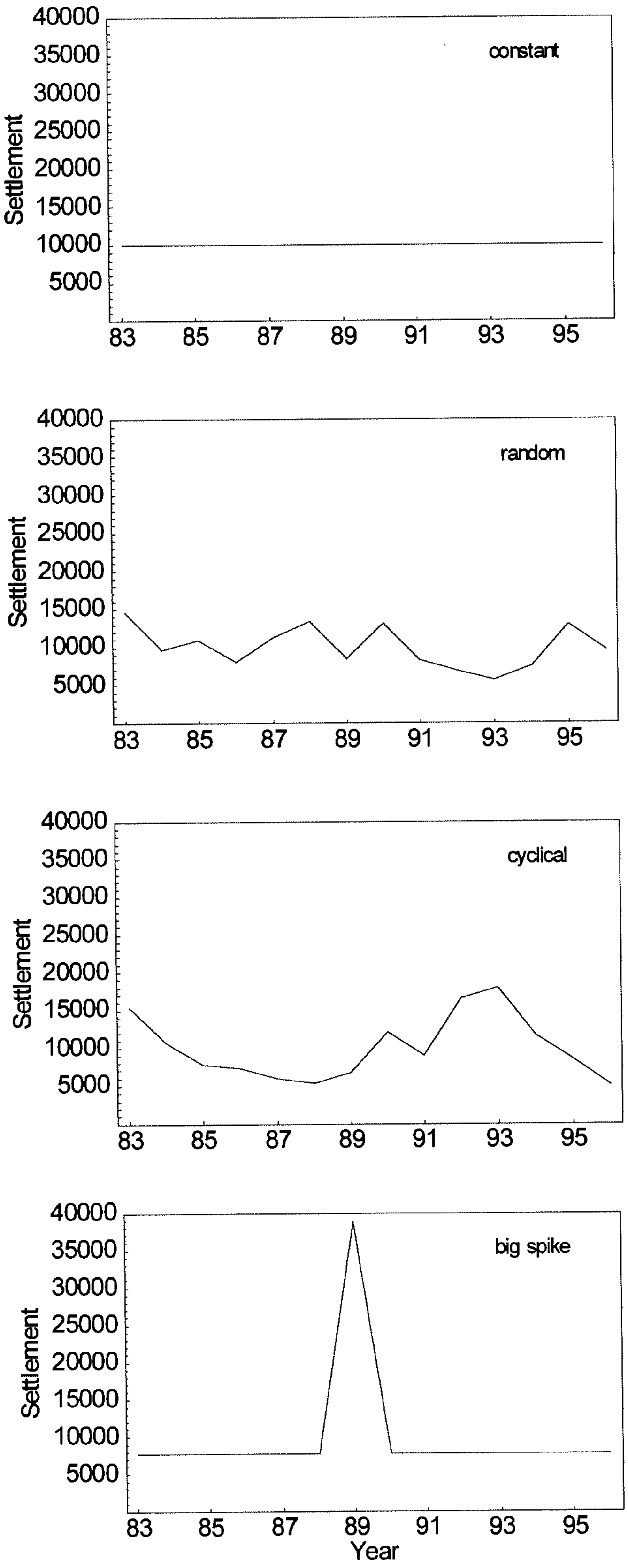


Figure 4.1. Four patterns for simulation puerulus settlement time series: (a) constant, (b) random, (c) cyclical, and (d) 'big spike'.

2. Growth. Adults of South Australian *Jasus edwardsii* lobsters grow by moulting generally twice yearly. This discrete growth process was explicit for simulated adult lobsters defined as those of fishable size. At approximately peak time of moulting through the simulation year, July 1 and January 1, the length of each was increased by one-half year's mean growth.

Parameters for mean annual growth were based on typical rates of growth of lobsters in the Northern Southern Zone of South Australia (McGarvey et al., in press) with von Bertalanffy coefficients of $K = 0.19$ and $L_\infty = 200$ mm for males, and $K = 0.243$ and $L_\infty = 146.5$ mm for females. Variation in growth rates among individuals was incorporated by randomly choosing the K and L_∞ values for each simulated lobster at its time of settlement. A normal distribution was sampled with the mean values of K and L_∞ given above and coefficients of variation for both growth parameters set = 0.3. These growth parameter values were retained by each lobster throughout its life.

Females commence the slower growth regime only after reaching maturity. To simulate the rising proportion of mature females with size, the probability of each female producing viable eggs once they reach 88.5 mm (PMAT) is sampled from the estimated logistic maturity curve (ranging from 0 to 1): PMAT=1.0/(1.0 + EXP(-C*(length-Lm))) where C = 0.11 and Lm = 98.5. If a random number is less than PMAT then new slower-growth K and L_∞ are randomly selected. If she is not deemed mature then she keeps her original K and L_∞ and is tested again at the next moult.

For growth of juvenile individuals, from settlement to within 10 mm of the legal minimum length, a continuous von Bertalanffy growth formula was used. Juveniles were kept effectively inactive to minimise computer processing time until the moulting stage of growth above 88.5 mm (CL). They then joined the pool of moulting animals, were moulted by their individual designated increment, and became subject to risk of death by natural mortality or fishing. Lobsters captured at a length below LML were returned to the live population.

3. Natural mortality. In each monthly time step each adult lobster (> 88.5 mm CL) is subject to risk of natural death. The annual rate of natural mortality was set to be constant at $M = 0.1$, the accepted value for southern rock lobsters (Kennedy, Department of Primary Industry and Fisheries, PO Box 192B, Hobart TAS 7001, pers. comm.; Annala and Breen 1989) and closely related species (Johnston and Bergh 1993). This yields a monthly probability of death by natural causes of $M/12 = 0.0083$. A random number was drawn for each lobster in each of the five winter months closed to fishing and if it was less than $M/12$ the lobster died by natural causes.

4. Fishing mortality. In the 7 months of fishing (taken as October through April as in the SA Southern Zone), the probability of capture in each month was $F/7$. The yearly fishing mortality, F, was set at 0.4. This approximates the level of exploitation of SA rock lobster, with slightly higher levels estimated in the Southern Zone and lower in the Northern Zone. Because both natural death and capture have non-zero probabilities, the mortality process was simulated in two steps. First a random number was drawn to determine whether death by either cause occurred. This event occurs with probability $M/12 + F/7$. If the lobster died, a second random number was drawn to determine whether death was due to capture or natural causes, with probabilities of $(F/7)/(F/7 + M/12)$ and $(M/12)/(F/7 + M/12)$ respectively.

Simulation Procedure

Input parameters and the settlement time series were programmed into the simulation. Starting with the first year of settlement, the simulation with a constant recruitment was run for an initial period of 15 years to allow the establishment of an equilibrium population structure (of ages and lengths). For the last 14 simulation years of each run, the 14-year (in general, time variant) recruitment series was imposed.

Simulated data were obtained from the catch. Each time a lobster was captured, the number of lobsters in the simulated catch number total was increased by 1. The catch weight total was also augmented by the weight of the individual calculated from its length at the month of death using the weight-length relationship, $w = 0.483 \cdot l^3$, where weight w is given in kg and length l in mm CL.

To simulate sampling of length frequencies from the catch, a random number was drawn with each capture to determine whether its length was measured. This simulates perfect random sampling with user-specified sample size. A 1% sample probability was simulated which is similar to (but slightly greater than) that provided by SA length-sample surveys (see Chapter 1). Data sets can be generated using this simulation which impose various forms of bias or imprecision in the length measurement process but this was not carried out in the runs presented below. The length of each sampled lobster at time of capture was recorded and length-frequency histograms generated.

Results

The simulated data time series for the recruitment pattern case of a single-year of high settlement in 1985 (Figure 4.2) show the lags among the three response variables: puerulus settlement, mean lobster weight in the catch, and the reported catch total.

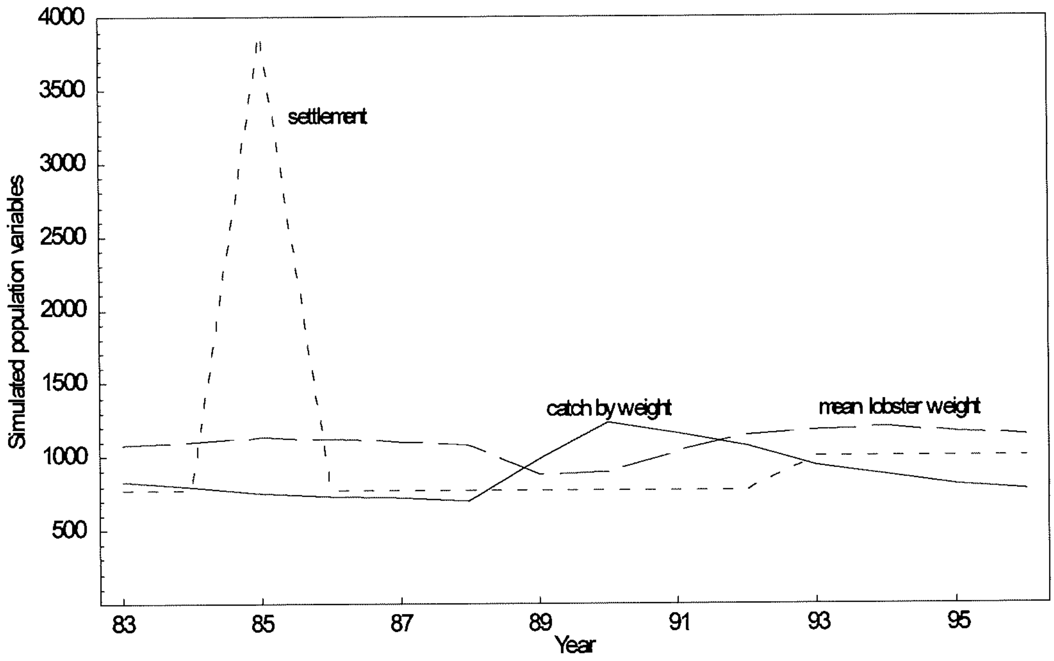


Figure 4.2. Simulation of 'big spike'.
Settlement, mean weights, and catch by weight of landed simulated lobsters for the case of a single large pulse of settled post-larvae, settling in 1985 and recruiting to the legal stock in 1989 and 1990.

Four years following the single-year pulse in settlement, recruitment to the fishable stock occurred. This rise in recruitment induced the sharp decline in mean weight of harvested lobsters in 1991, and a subsequent 3-4 year rise in catch as that large-recruitment year class grew through the harvestable stock. The simulated catches by weight and numbers will be used to test the stock assessment method of Chapter 5.

Simulated length-frequencies (Figure 4.3) show the influence on stock structure when a recruitment pulse enters and passes through the fishery. The 1989 distribution exhibits the substantial rise in numbers of younger individuals. It is notable that with the levels of growth variability assumed (lower than those measured using a normal likelihood in the GROTAG estimates of growth (McGarvey et al., in press)) no individual year-class modes (i.e. age-class peaks) emerge.

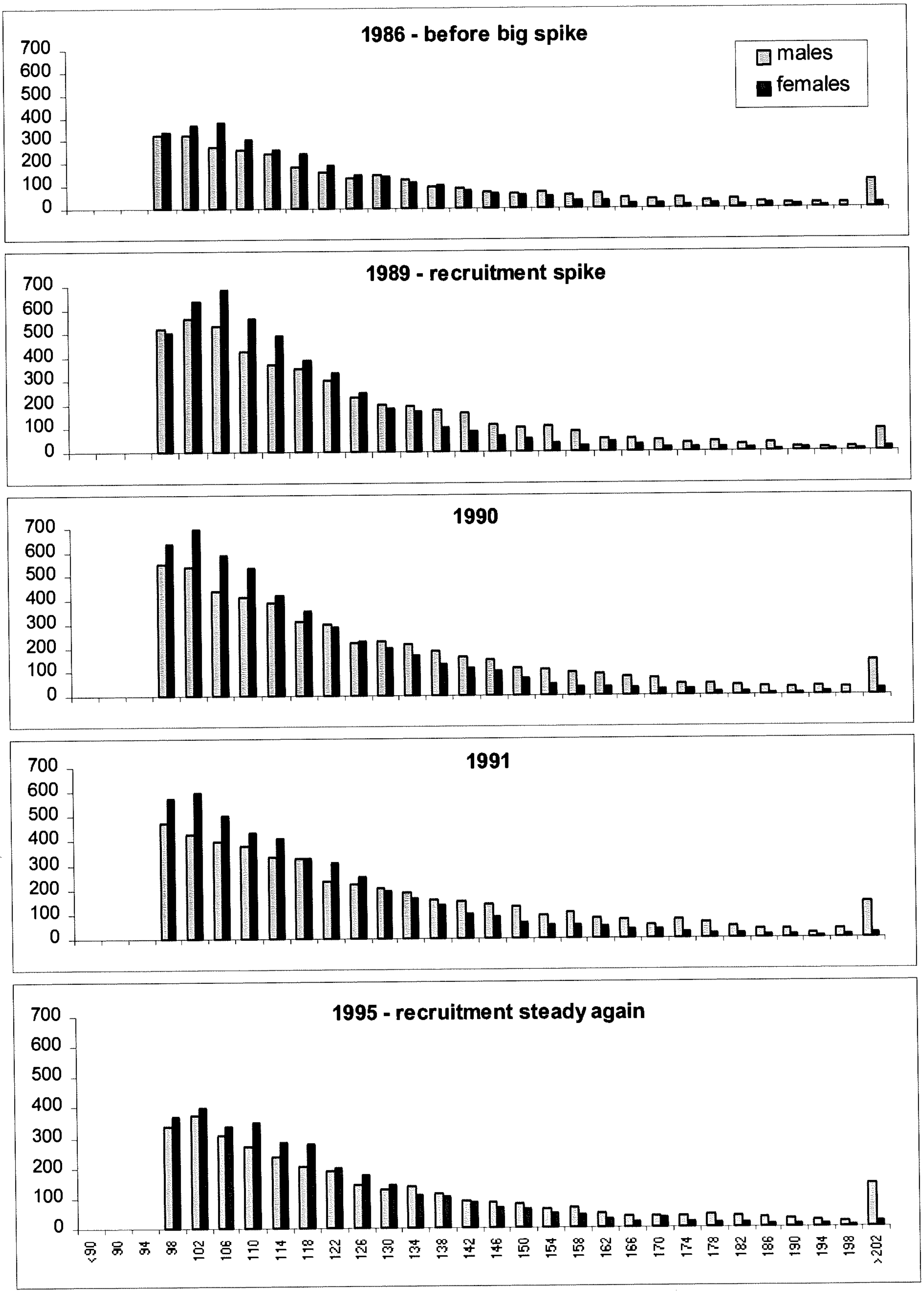


Figure 4.3. Simulated length-frequencies for the case of a big spike of recruitment.

This data simulator has been employed to test the current method of stock assessment in SA, the 'qR' model, in both its steady state (McGarvey et al. 1997a) and dynamic (Chapter 5) formulations. Specific assumptions of these models that the simulator was designed to test include:

1. commercial catch under-reporting,
2. yearly recruitment variability,
3. the use of a yearly time-step in the dynamic qR model,
4. the assumption of the qR model that all fishable biomass is present at the start of the season. This assumption follows the adoption of a year time step, but is inaccurate to the extent that moulting occurs in summer, which is mid-season, during which the fishable biomass grows with growth and recruitment to legal size.
5. The form of the natural survival factor in the dynamic qR model (see Eqs. 5.2.1 and 5.2.2). This was modified in response to earlier simulation testing to achieve reduced exploitation rate bias.
6. Number of age classes to explicitly represent in the model. This was increased from 13 to 20 following improved outcomes in the simulation.

Applied to testing the steady state form of the qR model, two results were obtained using the simulated data sets (McGarvey et al. 1997a). First, it is possible to obtain estimates (slightly biased) of average exploitation rate and estimates (largely unbiased) of absolute recruit numbers ('R') using only total catch by weight and total catch by number. Second, the estimate of exploitation rate (steady-state average) is not affected by catch under-reporting if the same percentage of under-reporting applies to both catches by weight and catches by number. The estimate of recruit number (steady-state average) is reduced by exactly the percentage of under-reporting. This second result implies that the steady-state qR estimator effectively works (via minimisation of the likelihood) by deriving an estimate of exploitation rate (U) from mean weight and then deriving total population and recruit numbers by combining the exploitation rate estimate, U, with data for total catch to infer the total biomass needed to generate that catch, i.e. $N = C / U$.

This is a novel method of estimating total population biomass, exploitation rate, and recruitment. The steady state qR method can provide estimates of these parameters using only catch data, together with a measure of mean weight at age in the catch. In fisheries where numbers harvested can be added to the catch log form, or in fisheries where numbers harvested are already reported, this method could potentially provide very substantial increases in the information provided to managers with low additional cost.

Sensitivity analysis (carried out with simulated and real fishery data sets) point to the principal requirement of the method—it is sensitive to inaccuracy in the required input of mean weights-at-age in the catch. Absolute age is not needed. Instead the weights of animals in their first year in the fishable stock, second year in the fishable stock, and so on provide principal inputs to the model. In fisheries where this method is considered for use, care should be taken to obtain the most precise unbiased estimates of weights-at-age in the commercial catch. In SA, using the extensive tag database (established from FRDC Projects 086/93 and 087/93), the measures of mean annual growth are accurate to approximately ± 2-10%.

Sensitivity analysis and simulated data with the steady state qR method also revealed that the recruitment estimates are both robust (relatively insensitive to error in the inputs) and are unexpectedly accurate. In contrast, estimates of exploitation rate are sensitive to error in the inputs, and exhibit underestimation bias. This bias is investigated further for the yearly dynamic version of the model, using simulated data, in Chapter 5.

Discussion

Simulated data sets are gaining wider use in evaluation of fishery stock assessment but have not to our knowledge been applied outside SA in lobster stock assessment.

In general, length-data based assessment involves a two-step chain of inference requiring knowledge of the growth of the "fish": (1) from numbers-at-length through growth modelling to infer numbers-at-age, and (2) from numbers-at-age to yearly survival. The longer chain of inference means that errors in the input assumptions (e.g. growth, mortality, natural mortality) will generally tend to yield greater errors in the final output than would occur when age composition data are available.

The simulated data produced in this project were used to assess the fishery stock assessment model presented in Chapter 5.

Chapter 5: Reliability testing of the qR model

Introduction

This FRDC project (95/138) ran concurrently with a large rock lobster population dynamics project (93/086 & 93/087 "Population Dynamics of the Southern Rock Lobster in South Australian Waters"). The present study aimed to develop methods of length-frequency sampling from the catch with modelling as a secondary focus. The principal model common to the studies above, the 'qR' method, was developed by South Australian lobster modellers during the overlapping year of the two projects. This report adds to those aspects not covered in the Final Report of 93/086 & 93/087. In particular, we present results of simulation testing of the dynamic version of the qR model. The programming and generation of simulated data sets for use in testing lobster assessment methods was funded under the current project, 95/138.

This Chapter will present tests of the dynamic model with data from the simulator presented in Chapter 4. This simpler version of the 'qR' model tested with simulated data includes only catches by weight and number to provide information on recruitment, exploitation rate and biomass in a dynamically changing fishery. The basis for this approach is that a decline in mean lobster weight can be caused by one of two changes in the population, either increased levels of exploitation so that larger individuals become less abundant, or by an increase in recruitment bringing greater numbers of smaller lobsters. The latter effect is illustrated in Figure 5.1 for the Northern Zone. As catches began to increase in the mid-1980's, the size of individual lobsters decreased. This result is consistent with increased recruitment. The same pattern is exhibited by the simulated data set for the case of a single-year pulse of recruitment (Figure 4.2).

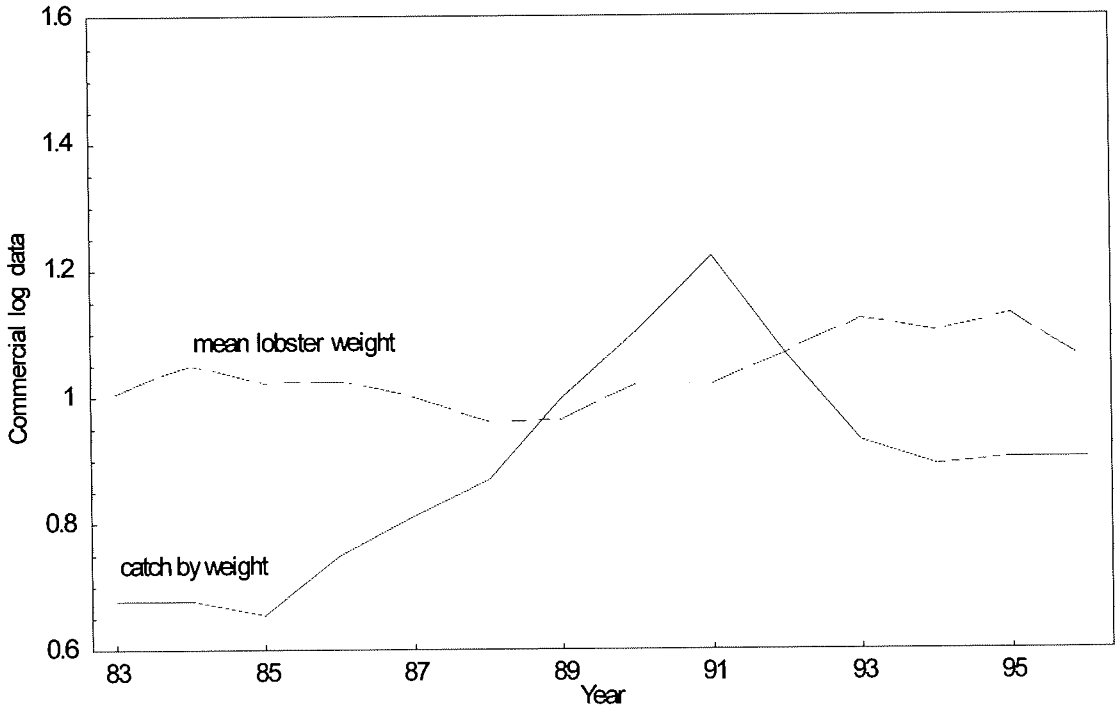


Figure 5.1. Catch and mean weight, Northern Zone.
Annual reported catch by weight (thousands of tonnes), and catch by weight (kg) divided by catch by numbers of lobsters landed, for the Northern Zone of the South Australian southern rock lobster fishery, 1983/84 to 1996/97.

A second version of the 'qR' model will also be presented in this Chapter which uses effort data. This version serves as the current stock assessment tool for SA lobster fisheries. Data including catch by numbers have recently been entered from 1970 allowing the reconstruction of a yearly recruitment. In this modified version of the qR approach, rather than estimating exploitation rate in each year as an independent parameter, catchability, "q", is estimated. We refer to this approach as the 'qR model' because q and recruitment are the two principal parameters estimated.

The qR model is a method for estimating historical recruitment time series and exploitation rate, and thus total biomass, from catch data. In particular, the method requires total yearly catch by both weight and by numbers, and if desired, yearly effort. It is a dynamic size-based estimator in that the fundamental information added to total catch is the mean weight of an average harvested lobster, obtained as total weight of catch divided by total numbers captured.

Mean weight of harvested lobsters permits inference about the level of exploitation. As exploitation rises, mean weight decreases. The level of harvesting, quantified by the fraction of the fishable stock removed by exploitation is a critical parameter of fishery stock assessment. It is known as exploitation rate, or 'U', when it is quantified as a simple proportion of the population size at the start of the fishing season (i.e. $U = 0.23$ implies 23% of the fishable stock was harvested that year). It is known as fishing mortality, F, when it is estimated as an instantaneous rate of the fishable stock being harvested. An estimate of U allows estimation of total (absolute) fishable biomass, B, when taken in combination with total catch, written in its simplest form as $B = C / U$. The second basic quantity that the model estimates is yearly recruitment.

Methods

The method is age-based with an annual time step and requires a vector of age-specific mean weights.

Data and Parameters

Simulated data (Chapter 4) were used to test the 'pure qR' age-structured model (5.2), using only catches by weight and number. Catch log totals from the Northern Zone South Australian lobster fishery were taken as data input for the more complete third model (5.3), in which effort data are incorporated into the model fit.

We denote the data inputs (whether simulated or real) of annual lobster catch totals by weight as $\{C^w_t; t = 1983, \ldots, 1996\}$ and catch totals by numbers as $\{C^n_t; t = 1983, \ldots, 1996\}$. A "year", indicated by subscript "t", will refer to the full fishing season in each zone. For example C^{W}_{1983} represents the Northern Zone total catch in kilograms from November 1983 to May 1984. Average (constant) weights at age, $\{w_a; a = 1, . . , 20\}$, of harvested lobsters are required. Age a = 1 refers to the youngest fishable age class, some assumed portion of which is above the legal minimum length. These weights were derived (McGarvey et al., in press) from fits to mark-recapture data of a von Bertalanffy model which considered individual variation (Francis 1988) to estimate mean annual growth. Male and female weights-at-age were combined in proportion to the sex ratios reported in monthly catch samples and the proportion of total catch in that month. An instantaneous natural mortality rate, $M = 0.1$ yr^{-1}, was assumed.

Additional parameters were employed to provide more detail about the vulnerability, v_1, of the recruitment age class, the fraction of this age group that have reached legal size, f_R, and the release mortality of under-size, m_r. Because these parameters apply only for the youngest harvestable year class, changing capture vulnerability with age, made explicit by Deriso (1980) and Fournier and Doonan (1987), is considered here only for recruits. Using only two inputs, catches by weight and number, we can derive two outputs in the models below, recruit numbers and exploitation rate. Thus the qR model can provide no information about selectivity, i.e. the variation in catchability with size. Length samples from the catch are a principal data source for this additional output. Fournier and Doonan (1987) used higher moments from measured length distributions to estimate selectivity.

South Australian lobster fishers report the numbers of 'under-size' lobsters brought up in pots, which were measured to be below the legal size limit, and subsequently released. The "pre-recruit index" (PRI) is calculated as numbers of undersized lobsters reported in catch logs during the months from November through March, divided by the numbers of pot lifts in those 5 months in each fishing season since 1983/84. The annual pre-recruit index will be compared with model-predicted yearly recruitment.

Fishers reported annual numbers of lobster traps set (i.e. 'pot lifts') yielding the effort time series $\{E_t; t = 1983, . . ,1996\}$. In the first of two Northern Zone age-structured models below, effort was not used. This allowed second and third validation comparisons: model-predicted yearly exploitation rate with effort, and model-estimated biomass with CPUE. In the second variant of age-structured model, effort was employed, leaving PRI and CPUE for validation.

The simulated yearly time series of catch totals by number and weight (see Chapter 4), were used as input data to test the capacity of the model to reconstruct recruitment, exploitation rate, and biomass. The 'true' values of yearly recruitment were calculated as numbers of simulated lobsters reaching fishable size in the moult periods before and during each seven-month fishing season. 'True' exploitation rates were calculated as population numbers at the beginning of each season divided by the total numbers captured.

Delay-Difference Model

The first dynamic model of fisheries stock assessment by Deriso (1980), known as delay-difference, used catches by weight and effort as data. The weight-at-age vector was formed by a linear relationship between weights in successive ages. An independent estimate of natural mortality is also required. The delay-difference models of Deriso (1980) and Schnute (1985) were based on the assumptions of (1), a biomass production (i.e. stock-recruitment) relationship, (2) a hypothesised relationship between changes in CPUE and model biomass, and (3) a single biomass change equation.

To illustrate the basic method of the qR model and to indicate how it follows from previous methods, a delay-difference formalism adapted for use with catches by weight and number is presented. The assumptions (1) to (3) above will not be employed. Unlike the models of Deriso (1980) and Schnute (1985), where the biomass and numbers equations were combined into a single equation for biomass (for a review of this derivation, see Hilborn and Walters 1992, Chapter 9), separate equations describe predicted catch by weight and catch by numbers. The additional equation for catch numbers permits estimation of an additional output in each year.

Model variables are as follows:

$N_{a,t}$	Population variable, number of lobsters of age a, at the start of year t
R_t	Number of recruits at start of year t
U_t	Exploitation rate (fraction harvested) in year t
$\hat{C}^n_t$	Model catch by numbers in year t
$\hat{C}^w_t$	Model catch by weight in year t
N_t	Total population number start of year t
B_t	Biomass of lobsters at start of year t.

Three basic assumptions characterising most delay-difference models (Deriso 1980; Schnute 1985; Fournier and Doonan 1987) were employed:

(1) Survival rate was a product of those from natural mortality = e^{-M} and fishing mortality (1 - U). These were thus assumed independent.
(2) The population is age-structured. Recruitment is yearly. Thus ages follow the conventional cohort relationship: $N_{a,t} = N_{a-1,t-1} * e^{-M} * (1 - U_{t-1})$;
(3) Mean weight-at-age is described by $w_a = \alpha + \rho w_{a-1}$, (i.e. a linearly increasing function of mean weight in the age below).

The derivation of model time-step iteration equations employing these three assumptions followed a delay-difference derivation procedure similar to that of Deriso (1978) (see also Fournier and Doonan 1987; Hilborn and Walters 1992) but with difference equations for catches by weight and number rather than population biomass and numbers yielding:

$$\hat{C}^n_t = U_t e^{-M} [N_{t-1} - \hat{C}^n_{t-1}] + U_t R_t \tag{5.1.1}$$

$$\hat{C}^w_t = U_t e^{-M} [\alpha N_{t-1} + \rho B_{t-1} - \alpha \hat{C}^n_{t-1} - \rho \hat{C}^w_{t-1}] + U_t R_t w_1 . \tag{5.1.2}$$

This model is fitted to the two catch time series allowing the solution yielding U_t and R_t in each year. Equal numbers of data points (catches by weight and number) and unknown parameters (U_t and R_t) in each year means the parameters are solved for uniquely.

Formulation directly in terms of catches by number and weight, rather than biomass as Deriso did, allowed direct comparison (i.e. square-differencing) with yearly catch data in model-fitting objective functions. This obviates fitting to a ratio of sample means (CPUE or mean weight) with associated complications in quantifying the error of a ratio. Sums over all ages in each year to obtain total yearly population numbers and biomass can be calculated subsequent to estimation (from catches and estimated $\{U_t\}$ and $\{R_t\}$). Employing catch by numbers in the delay-difference formalism allows each year's recruitment to be estimated as an independent parameter. The same principal is found the age-structured models to follow.

Age-Structured Models

In the two age-structured versions of the qR model, variable names from the delay-difference form were retained. The model population variable $\{N_{a,t};\ a = 1, \ldots, 20;\ t = 1983, \ldots, 1996\}$ represents the numbers of lobsters in the fishable stock at the beginning of each simulation year. Twenty age groups of harvestable size were assumed. Yearly exploitation rate $\{U_t;\ t = 1983, \ldots, 1996\}$ and recruitment $\{R_t;\ t = 1983, \ldots, 1996\}$ (henceforth denoted $\{U_t\}$ and $\{R_t\}$) were estimated by fitting model catches to data. Natural and fishing mortality were assumed constant for all ages above the first (recruitment) year class.

An initial age vector is required to begin the yearly lobster population iteration. Parameters R_0 and U_0 were defined to construct the initial age vector, $\{N_{a,0}\}$, for the year, defined as year 0, preceding the first year of the iteration procedure, i.e., the year before the data time series begin. The initial age-vector, $\{N_{a,0}\}$, is constructed from R_0 and U_0 assuming it has a stationary age structure. In model (5.2) estimation, R_0 and U_0 were set equal to the first-year estimated values of R_{1983} and U_{1983}. In model (5.3), which employs fewer parameters than data input values, R_0 and U_0 varied as additional estimated parameters.

The cohort equation for survivors from the recruitment (age 1) class yields numbers at age 2 in each yearly time step:

$$N_{2,t} = R_{t-1}\, e^{-M}\, [1 - v_1\, f_R\, U_{t-1} - m_r\, v_1\, (1 - f_R)\, U_{t-1}] \qquad (5.2.1)$$

The factor $v_1\, U_t$ represents the fraction of the recruit age class, R_t, brought up in pots, of which $v_1\, f_R\, U_t$ being of legal size, were landed. The losses for the recruitment year class also include release mortality, m_r, from the fraction of the recruitment age class which is captured ($v_1\, U_t$) but below legal size ($1 - f_R$) and thus returned to the sea.

For all higher age classes, cohort losses are due only to natural mortality and exploitation:

$$N_{a,t} = N_{a-1,t-1}\, e^{-M}\, [1 - U_{t-1}] \qquad \text{for all ages } a = 3, \ldots, 20. \qquad (5.2.2)$$

Natural mortality follows that of the delay-difference model above using an exponential multiplicative survival factor, employed in the models of Deriso (1980), Collie and Sissenwine (1983), Schnute (1985), as discussed by Hilborn and Walters (1992, p. 332):

Deaths in the cohort equations (5.2.1-5.2.2) due to harvesting were summed to yield predicted catches by number and weight:

$$\hat{C}_t^n = v_1 f_R U_t R_t + \sum_{a=2}^{20} U_t N_{a,t} . \tag{5.2.3}$$

$$\hat{C}_t^w = v_1 f_R U_t R_t w_1 + \sum_{a=2}^{20} U_t N_{a,t} w_a . \tag{5.2.4}$$

The third model, a variant of model (5.2) above, incorporates effort data available from the catch logs of the Northern Zone fishery. In the data simulator, no effort, apart from the specified monthly fishing mortality of $F / 12$ was represented. (To incorporate effort, independent of F would involve postulating a relationship between E and F. The likely form of this relationship is not self-evident and was thus not implemented in the data simulator.) Setting

$$U_t = (q_0 + q_1 t + q_E E_t) E_t , \tag{5.3}$$

and substituting this expression for each occurrence of U_t in (5.2) above, q_0, q_1, and q_E, rather than U_t in each year were estimated. This reduces the number of free parameters by the number of years minus three. The additional terms $q_1 t$ and $q_E E_t$ allow investigation for trends of catchability with time and with increasing effort.

A normal (observation) error was assumed. There is no process error (Polacheck et al. 1993) since no stock-recruitment relationship is assumed and variability in population reproduction is explicit in that each year the recruit number is a separate estimated parameter as noted. A normal likelihood with constant variance was assumed for the variation of observed catches by weight and number. The sum of squares defining the assumed normal likelihood function,

$$SSQ = \sum_{t=1983}^{1996} \left[\frac{\hat{C}_t^n - C_t^n}{C_t^n} \right]^2 + \sum_{y=1983}^{1996} \left[\frac{\hat{C}_t^w - C_t^w}{C_t^w} \right]^2 \tag{5.4}$$

includes two sum components, for catches by weight and for catches 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 also were their difference terms in the sum, and the catches by number were found to dominate the resulting fit, with a visibly poorer fit to the catches by weight. When the terms in the sum were re-scaled to be relative rather than absolute differences this bias was alleviated.

To numerically solve for $\{R_t\}$ and $\{U_t\}$, the log-likelihood was maximised by minimising the SSQ. Starting values for parameters $\{R_t\}$ and $\{U_t\}$ were obtained using steady-state solutions of the model (McGarvey et al. 1997a) employing data catches, C^n_t and C^w_t, from each fishing season and solving for steady-state estimates for each year independently.

The solutions of both age-structured models generate estimates of (absolute) numbers with age, $\{N_{a,t}\}$, for all years. Age-1 numbers $\{N_{1,t}\}$ are obtained directly as the estimated recruit parameters $\{R_t\}$. Population numbers for older ages $\{N_{a,t}, a \geq 2\}$ were derived by substituting the estimated $\{R_t\}$ and $\{U_t\}$ time series into the cohort iteration equations and thus are not independent. Yearly mean biomass was calculated from the age-specific population numbers and weights:

$$B_t = \sum_{a=1}^{13} N_{a,t}\, w_a \ . \qquad (5.5.1)$$

Yearly egg production was calculated similarly using the age-specific fecundity, $\{p_a\}$:

$$S_t = \sum_{a=1}^{13} N_{a,t}\, p_a \ . \qquad (5.5.2)$$

Results

Two forms of model validation were undertaken, using simulated data sets, and using independent time series from the Northern Zone fishery. In Figures 5.2 to 5.7, model output time series are plotted as dashed lines; data (whether from individual-based simulation or the Northern Zone catch statistics) are shown as solid lines.

Simulated Data

Tests with simulated data of Chapter 4 were undertaken to identify bias, and possibly other inaccuracy, in model reconstruction of output time series. Four recruitment patterns were tested: (a) constant, (b) random, (c) cyclical, and (d) 'big spike'.

The model-reconstructed yearly recruit numbers (Figure 5.2) exhibited unexpectedly close agreement with the 'true' simulated levels. For the case of a single year of higher settlement, juvenile growth variability over the 4 years from settlement to fishable size, spreads the single peak of settled pueruli in 1985 across two years of recruitment to the fishable stock. This feature was successfully captured by the qR model output. Similar success appeared for the other three recruitment patterns with no evidence of bias.

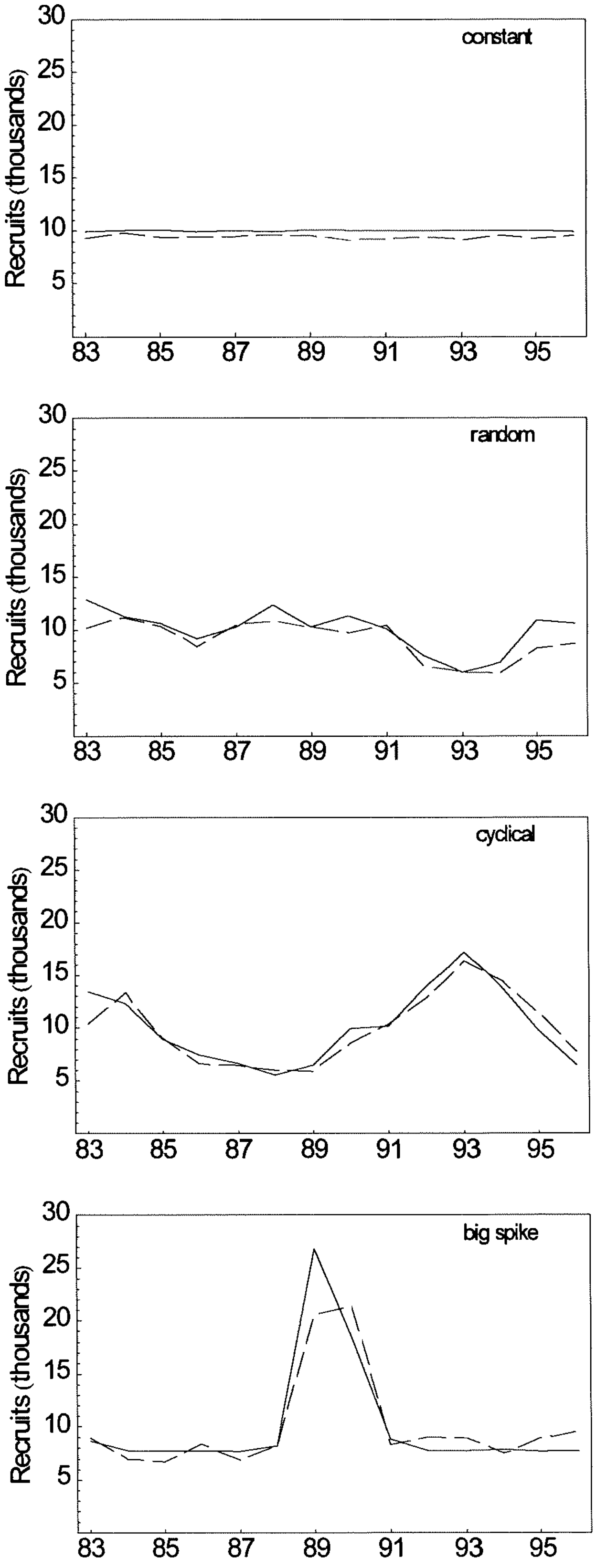


Figure 5.2. Model-estimated yearly recruitment (dashed line plot) and simulated 'true' recruit numbers (solid).

The model estimator was noticeably less successful at recapturing the simulated history of yearly exploitation rate (Figure 5.3). Model *U* values averaged over all years were underestimated by 7, 4.5, 11 and 13%. This bias is further expressed in the model estimates of yearly biomass (Figure 5.4), which underestimate by averages of 18, 19, 13 and 11%.

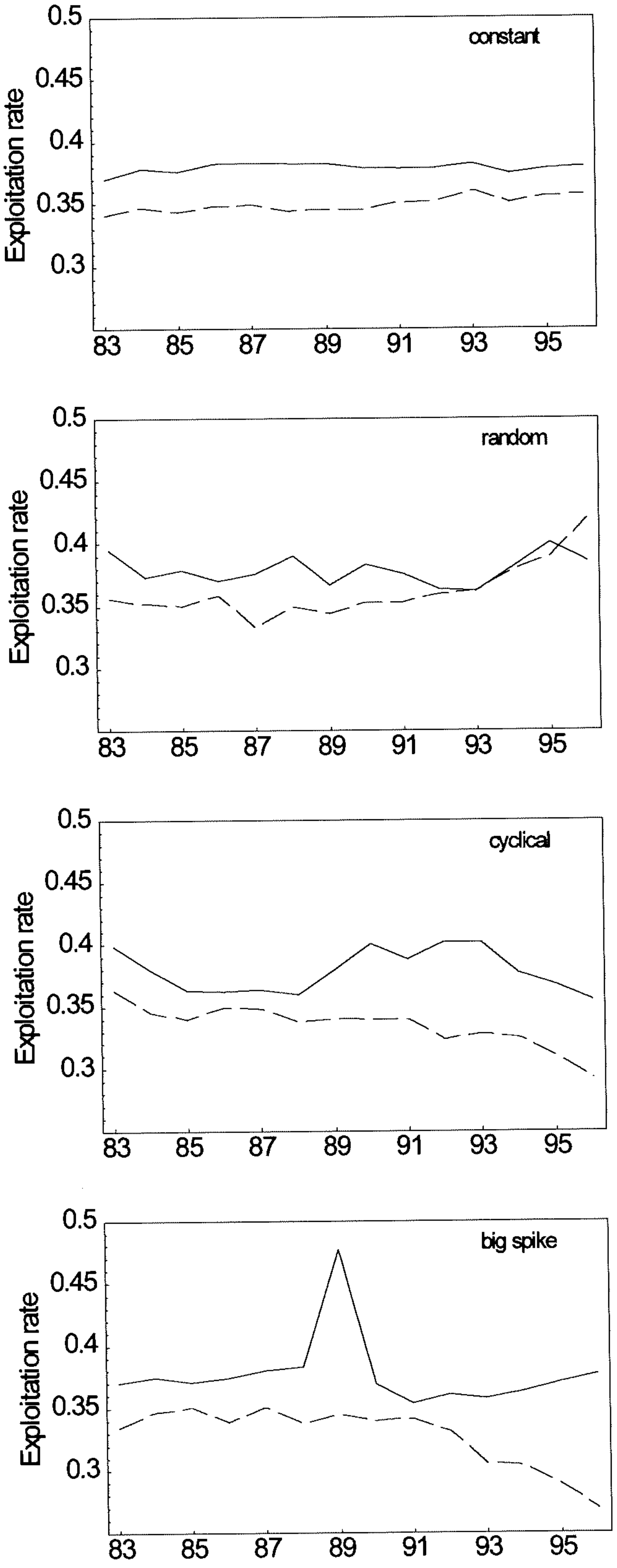


Figure 5.3. Model-derived exploitation rate (dashed line plot) and simulated 'true' exploitation rate (solid). Four recruitment patterns of Chapter 4 were tested.

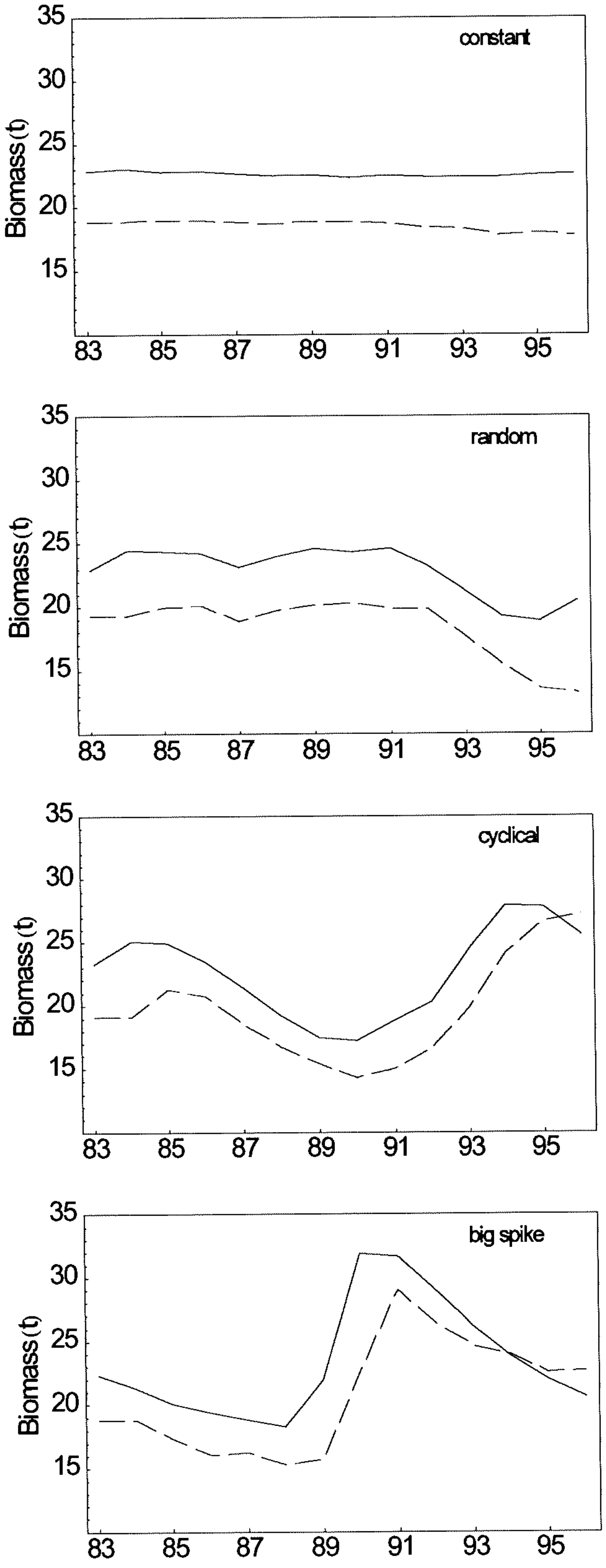


Figure 5.4. Model-derived total population biomass and simulated 'true' biomass. Four recruitment patterns of Chapter 4 were tested.

Northern Zone Rock Lobster

The effort-inclusive model (5.3) was fit to catches by number and by weight, C^n_t and C^w_t, back to 1970. The resulting model catch time series, $\hat{C}^n_t$ and $\hat{C}^w_t$, yielded good agreement with data (Figure 5.5) reflecting the peaks that were evident in the first or second year of each decade. The closeness of the fit of the dynamic qR model results from the freeing of recruitment, R_t, to be a fitted parameter in each year for which data are available. The rises and falls of Northern Zone landings have been relatively smooth. Not illustrated is the steady rise of total effort over those years which explains, at least in part, the general rising trend in catch over that time. The second factor is the development of improved fishing technology (Global Positioning Systems, colour echo sounders), notably in the late 1980's which provided access to previously unexploited areas.

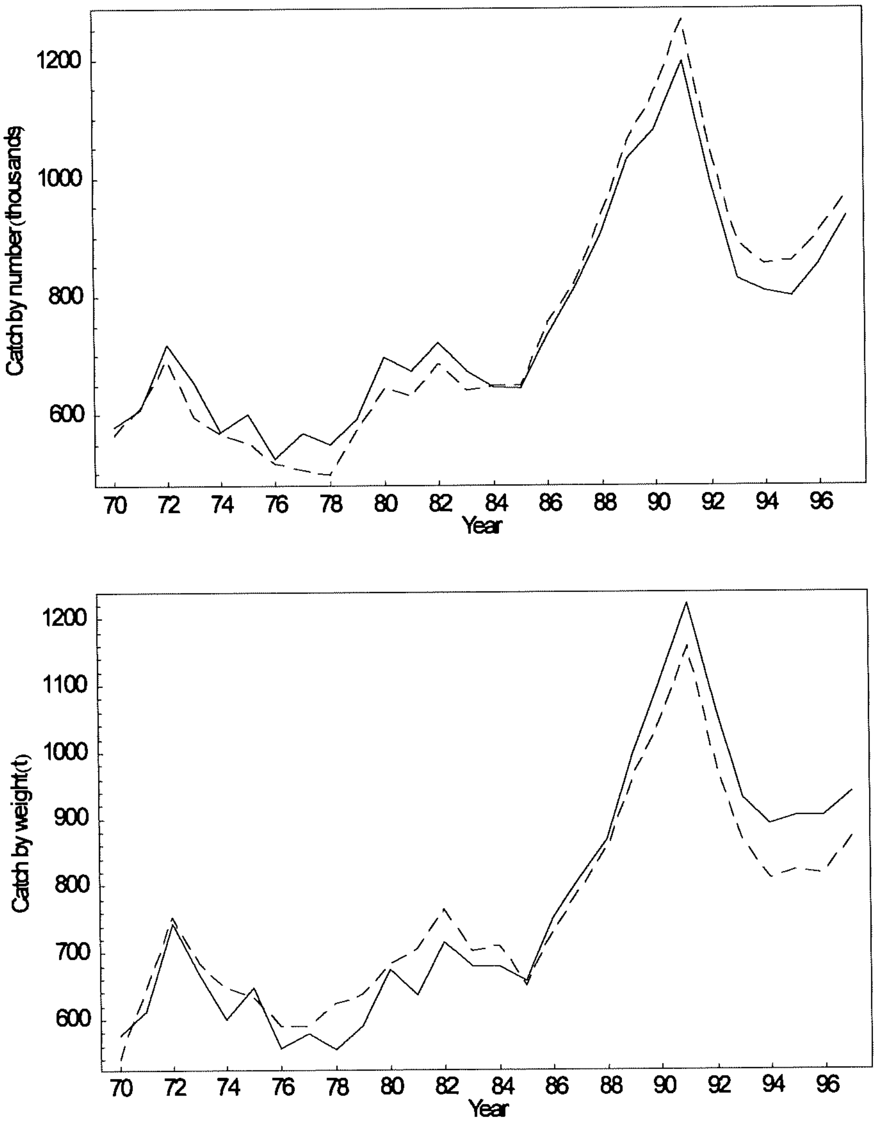


Figure 5.5. Fits to catch-by-weight and catch-by-number of model (5.3) where exploitation rate is assumed proportional to effort.

The recruitment time series (Figure 5.6.) inferred from the fit to catches of Figure 5.5 over these years exhibit some tendency for longer-term rises and falls, and noticeable year-to-year variation. The pre-recruit index (PRI) available from 1983 after which numbers of under-size lobsters in the commercial catch were reported indicates general agreement with qR-reconstructed recruitment. As PRI (as under-size reported lobsters) is independent of catches by weight and numbers of legal size lobsters in the commercial catch logs, this agreement is additional confirmation of the qR approach in modelling year-to-year recruitment variation. Furthermore within the confidence bounds of the estimates of exploitation rate, *U*, these model recruitment numbers are an index of absolute numbers of new lobsters entering the fishable stock annually.

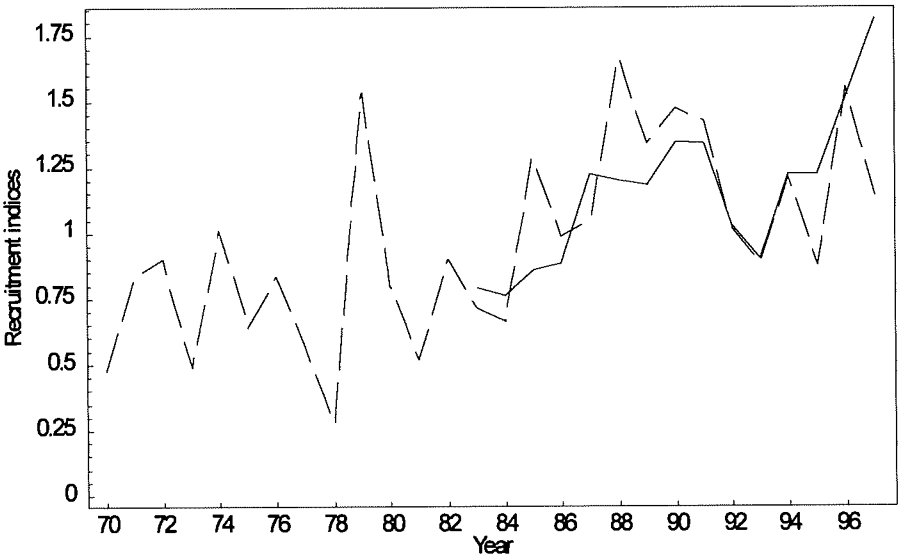


Figure 5.6. Derived recruitment series for the effort-dependent age-structured model (5.3) compared with Northern Zone pre-recruit index (PRI), calculated from numbers of reported under-size per pot lift November through March.

The variation in the model recruitment series resembles year-to-year environmental variation thought to typify yearly larval survival and settlement success for many marine species. It is not known if this feature is an artefact of estimation and data or a genuine reflection of low (lag 1) autocorrelation in yearly recruitment. The most probable indication is that it is both. However, the extreme variation above is not expressed in the model recruitment series from simulated data (Figure 5.2), in which the 'true' recruitment shows much less temporal variability.

With regard to whether these peaks are due to single years of high recruitment, or a general trend of rise and fall, the evidence here, in both the catch-log index of undersize lobsters PRI, and in model output, is for higher recruit numbers spread over a number of years.

The sharp rise in PRI during 1994–1996 reflects, in part, the increase in legal minimum capture length from 98.5 to 102 mm in 1994. No parallel increase in total catch or CPUE is evident as it had been in the earlier years of higher PRI.

The second validation comparison, of model (5.3) biomass with reported CPUE by weight (CPUEw) (Figure 5.7) yielded close agreement.

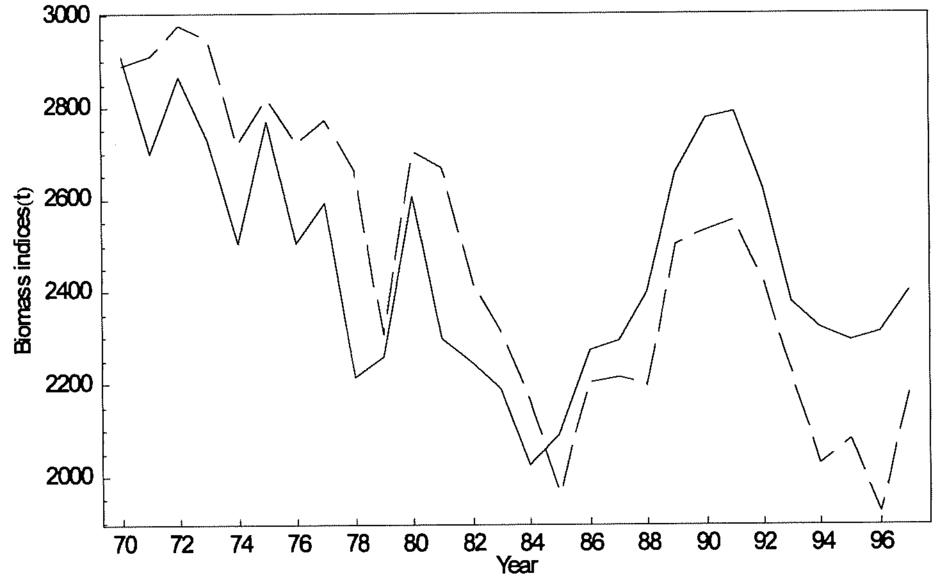


Figure 5.7. Derived model (5.3) biomass compared with reported CwPUE (catch-by-weight-per-unit-effort).

In Eq. (5.3), exploitation rate was assumed proportional to effort and, to second order, to any underlying trends through time and with mean levels of effort itself. In estimation, q_1 and q_E were both found to be negative. Averaged over years, the $q_E E_t$ term was 4 times greater than $q_1 t$, though both were about 2 orders of magnitude (80 and 360 times) smaller than q_0, indicating that these trends in catchability were not strong. Since catchability is thought to have increased with time, a negative q_1, though small, was unanticipated.

Discussion

A practical objective in stock assessment is to devise a data-model synthesis that offers the best trade-off between information and cost. As the models above require no additional yearly independent or scientific measurement, they represent a low-cost option. The results, particularly with simulated data sets, suggest that the addition of catch by numbers to commercial catch logs can yield accurate reconstructions of recruitment time series and can be considered an efficient source of fishery stock assessment information.

When Deriso formulated his original model (1980) to be fitted to catch by weight, and catch per unit effort, these were (and remain) the most widely available commercial catch data. However, it is natural to apply Deriso's (1980) formalism to the data set of catches by both weight and by number, together with effort, since it was derived in terms of two equations, one for population biomass and one for total population numbers. Reducing the two equations to one for biomass alone (Deriso 1980, Eq. (2); see also Hilborn and

Walters 1992, p. 334) required a number of additional less self-evident assumptions which could in part explain its less than satisfactory performance (Ludwig and Walters 1985).

The qR model offers several advantages. It avoids or, in the case of the model variant where *U* is set to a function of effort and time, reduces problems associated with assuming that biomass is proportional to CPUE. By allowing recruitment to be estimated independently in each year, the model requires no assumption of a stock-recruitment relationship. As counting lobsters is generally simpler than the measurement of the length of a lobster, the method uses data that are less expensive and would possibly yield lower measurement error. Moreover, the measure of mean size (mean weight, as catch-by-weight over catch-by-number) is based on a much larger sample size, all the reported catch. Assuming measurement error from counting versus measuring lobsters is the same, if the measured length sample is 1% of the total catch (higher but of the same magnitude as the SA catch monitoring sample), the mean size from a catch log total would be approximately the square-root of sample size or 10 times more precise.

In addition to the mean size, length samples provide higher moments of the size distribution. One way to evaluate how much additional information is made available by surveying for the full length distributions is to calculate sample variances of these higher moments (see Chapter 3).

The qR model cannot estimate variation in selectivity with size. For this, length samples (Fournier and Doonan 1987), or tagging data (Punt et al. 1997) are needed.

The qR approach differs from the majority of previous dynamic stock assessment methods using catch data in two ways: (1) it allows recruitment to be a free parameter, and (2) it does not depend primarily on catch-per-unit-effort as a measure of relative abundance.

Problems with CPUE as an index of biomass have been well documented (Hilborn and Walters 1992, pp. 175-194). Hilborn and Walters (1992) have noted that biomass dynamic models can often yield non-realistic outcomes such as negative estimates for catchability and biomass. If year-to-year contrast in the catch data is low, or if the changes in CPUE result from factors other than or in addition to fishing-induced changes in total biomass, these inferences will not be precise.

However, when CPUE does reflect biomass as it does in many cases, strict assumptions are required to infer estimates of fishing mortality. In biomass dynamic models (e.g. Pella and Tomlinson 1969; Schnute 1977), the *changes* in CPUE (or other biomass index) from year to year are assumed to result from catches plus natural mortality, balanced by yearly biomass increases specified by an hypothesised production (i.e. stock-recruitment) relationship. Then total mortality is estimated as the level of natural plus fishing mortality sufficient to induce these (absolute) changes in overall biomass. Moderate fractional errors in predicted yearly biomass growth or losses due to natural mortality will result in relatively large errors in the yearly *difference* in model-predicted biomass since the absolute magnitudes of production and natural mortality will be relatively large compared with their yearly differences. The crucial assumption of a stock recruitment relationship is rarely thought to hold for lobsters, and the yearly recruitment variation which often obscures this relationship will often be a substantial source of error in biomass dynamic model estimation. Crucial also is the assumed production model variation in mean growth with population density, about which little is usually known. Polacheck et al. (1993), in a comprehensive analysis of the biomass dynamic method, showed that for simulated data sets the only error, known as observation error, needing to be explicitly considered is in the equation that relates biomass to CPUE. This may be explained by the fact that the information in this relationship is included in the model as a second order process, i.e., as a series of relative changes which are assumed to have caused comparable changes in biomass, rather than as direct information about the population as in the case of mean size. Errors in this assumed relationship are thus magnified. This might also explain the occasional occurrence of nonsense (negative) estimates. Thus, the biomass dynamic method is sensitive to error in the assumption of proportionality between biomass and CPUE and yet, in practice, this relationship often holds only to an approximate degree.

For these reasons, catch by weight and by number may offer a number of advantages over catch by weight and effort in estimating annual absolute population size and, specifically, recruitment. Mean size estimators yield an independent estimate of R and U for each year of the data time series. A dynamic extension of this method must therefore accommodate only the lags and changes in stock structure (e.g. from variations in recruitment and levels of effort) rather than using observed changes for the estimation. Such a method allows each year's U and R estimate to be obtained independently so that dynamic fitting serves principally to make self-consistent the changes and associated time lags of U and R. It is therefore likely to be more robust than biomass dynamic models. The method can be applied for short time series (as short as one year). Its estimation precision is not affected by lack of level of contrast in annual data. In the simulation outputs above, the method appears to have reproduced recruitment equally well with steady state or dynamically changing fisheries.

When effort was added in the Northern Zone analysis, model-derived biomass tracked CPUE, as one would anticipate. Bias in the relationship of CPUE to biomass would thus be incorporated in the model fit. Whether effort improves the accuracy of the model estimation would depend on these biases, and possibly other factors which are difficult to evaluate. The availability of a yearly biomass time series obtained without effort data (from catches by weight and number, i.e. from catch and mean size) provides at least one approach to assessing the relationship between biomass and CPUE. If fishing mortality were proportional to effort, which appears to be the case in SA rock lobster, then the bias in exploitation rate evident in the simulation results would be, perhaps substantially, reduced. Tests with data from simulations which incorporate effort, and include assumptions of the closeness of the relationship of F to E have not been undertaken. However, these could provide more insights into possible reduction in the bias of U and B shown in Figures 5.3 and 5.4.

Stock assessments which are based on several sources of data and methods of analysis are more likely to produce credible results. When there is congruence in independent analyses confidence in the outcomes is greater. The model of Chapter 6 incorporates length information into the formalism of the model presented above.

This 'qR' method based on catches by weight and number thus appears suited for applications specifically designed to estimate annual recruitment from commercial time series. The use of catch numbers rather than, or in addition to, effort as the second time series of input, offers an additional stock assessment approach based on mean weight. The method can be cost effective and avoids errors in relating relative abundance to catch per unit effort that can characterise biomass dynamic approaches.

Chapter 6: Length-fitting stock assessment model

Introduction

This chapter addresses the third objective, "To assess the range of stock assessment methods available for analysing length-frequencies to estimate the fundamental population dynamic parameters describing the South Australian lobster fishery, notably, annual recruitment, annual egg production, mortality, and size structure."

The age of an individual lobster cannot presently be determined. This project, as in other assessments of lobster stocks, has focused on "length-based" methods.

A number of length-based estimation methods have been published to derive the fundamental population dynamical parameters of a fish stock from length-frequency samples. Steady-state methods, which assume the population structure is unchanging, appeared first. In practice, more realistically where temporal change of varying degrees in inevitable, steady-state methods seek to carry out an estimate of average values of the population, where the average of data over one or several years is employed. Steady-state methodologies include ELEFAN (Pauly 1987), "Z/K estimators" (Ssentongo and Larkin 1973; Powell 1979) notably including the mean-length method of Beverton and Holt (1956, 1957), and length-cohort analysis (Jones 1984). The estimation of mean levels of mortality is useful and these steady-state estimators, particularly the Beverton-Holt mean length method employed in South Australian rock lobster (Prescott et al. 1997b) have been shown to be robust (see review volume by Pauly and Morgan (1987)). However in modern applications to lobster assessment, *yearly* estimates of stock size and exploitation rate, and thus dynamic models, are needed.

Dynamic approaches to length-based stock assessment include MULTIFAN (Fournier et al. 1990), the generalised theory of Schnute (1987) and Schnute et al. (1989a, 1989b), and CASA, the Kalman filter method of Sullivan et al. (1990). Of these, Schnute's approach has not yet been applied in fisheries assessment so remains untested. Our experience with CASA, a copy of which we obtained from Gallucci, did not prove fruitful under testing. With simulated data, we did not succeed in getting it to yield probable parameter estimates. MULTIFAN is no longer supported by Fournier who wrote the package and has recommended against its use.

Due to the lack of available dynamic length-based model software, we began the process of developing a length-based model for SA rock lobster. However, full development has been deferred since the South Australian rock lobster industry are satisfied that existing methods, notably the qr method, provide for a satisfactory assessment of lobster stocks.

Methods

The length-based model is a theoretical outgrowth of the qR method, being age-based and using catches by weight and catches by number as inputs. Features enhancing biological and fishery realism in the new model include:

1. monthly (rather than yearly) time step;
2. lobsters differentiated by sex and growth subregion;
3. summer and winter recruitment;
4. fitting to length distribution data, as well as to catches by weight and numbers, and to effort;
5. growth explicitly considering individual variation;
6. selectivity by length.

The model is programmed and runs under the model parameter estimation software developed by Dr Fournier, AD Model Builder (ADMB), which is distinguished by its remarkable speed in minimisation, and thus convergence to a solution.

Results

The model, with, 269 parameters, converges in roughly two hours in ADMB, reflecting its detailed model structure

We present the model output and data length frequencies to which the model is fitted for males (Figure 6.1) and females (Figure 6.2). Also included in the objective function are fits to catches by weight and catches by number.

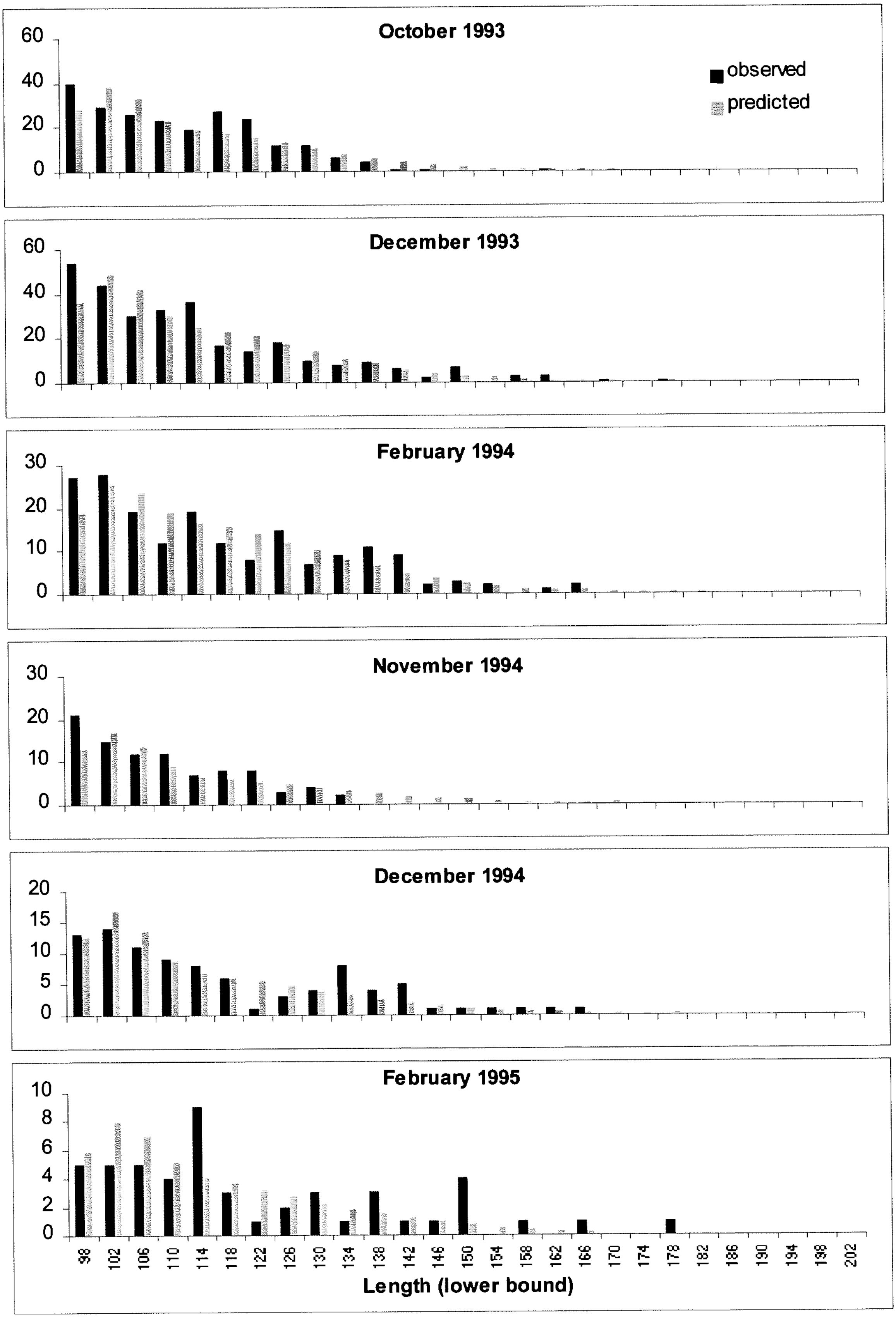
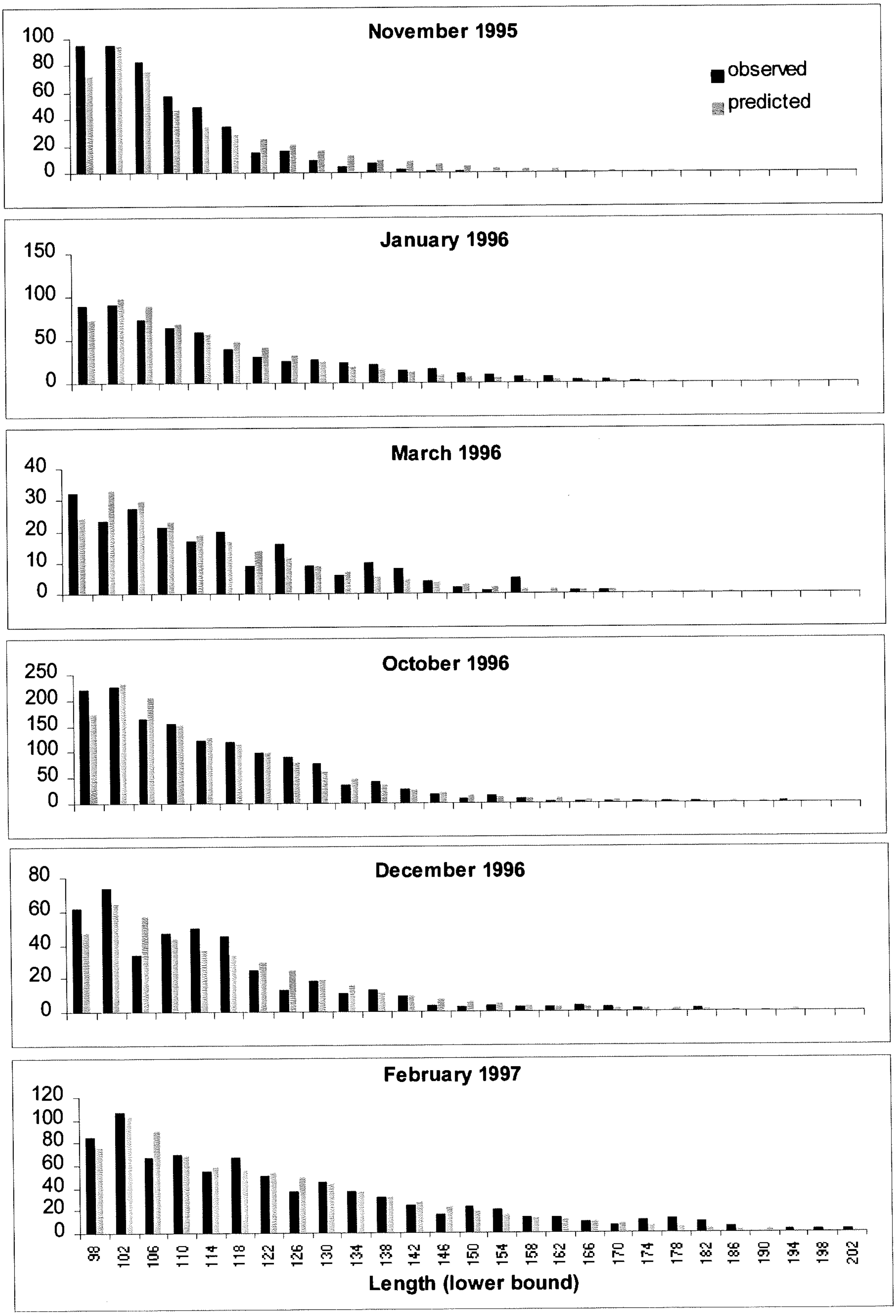


Figure 6.1. Model and survey length-frequencies for male lobsters in the SSZ (Southern Southern Zone) SA rock lobster fishery. (a, this page) months with larger survey sample sizes for the first two seasons since length sampling began. (b, on next page) months from last two seasons of length sampling.


November 1995

January 1996

March 1996

October 1996

December 1996

February 1997

Figure 6.1b.

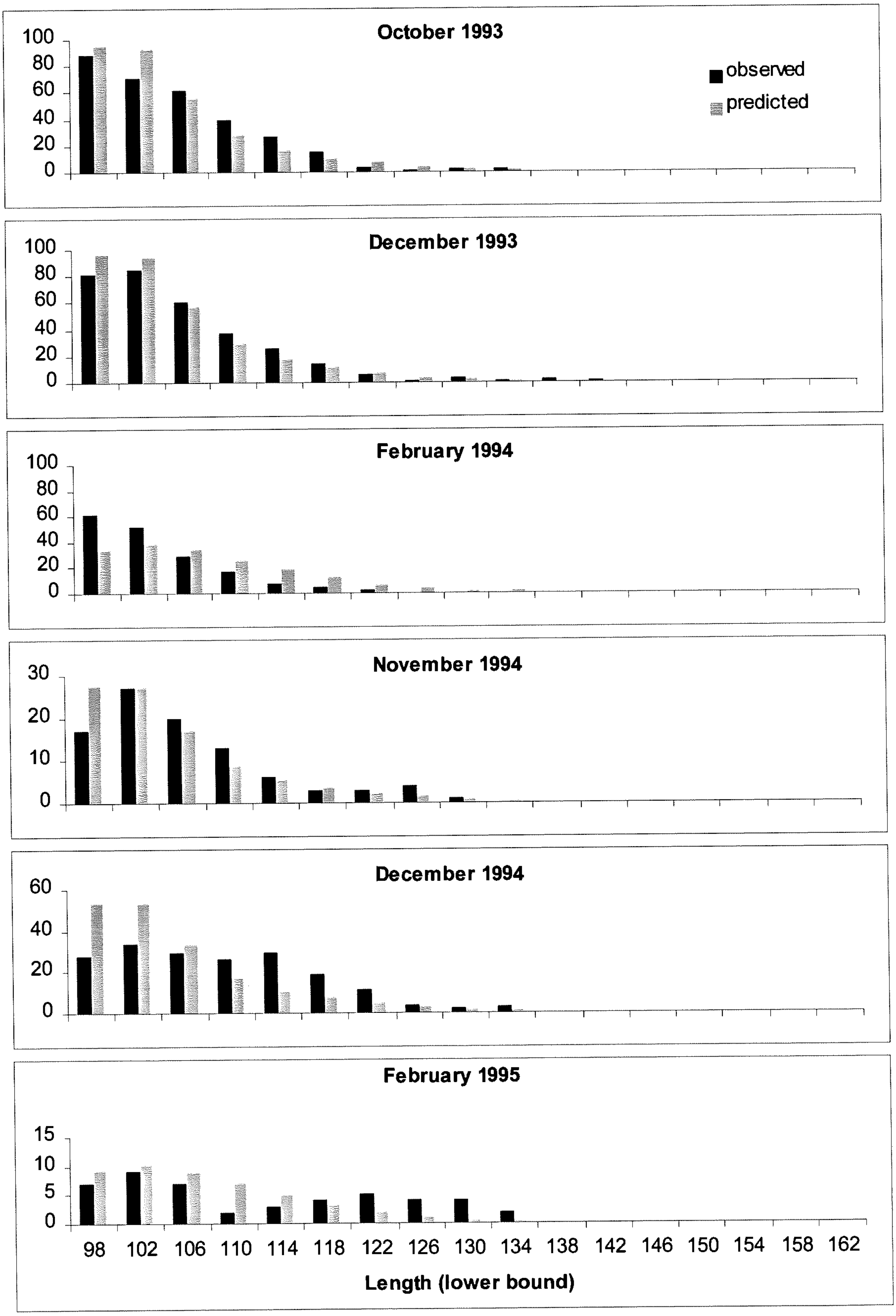
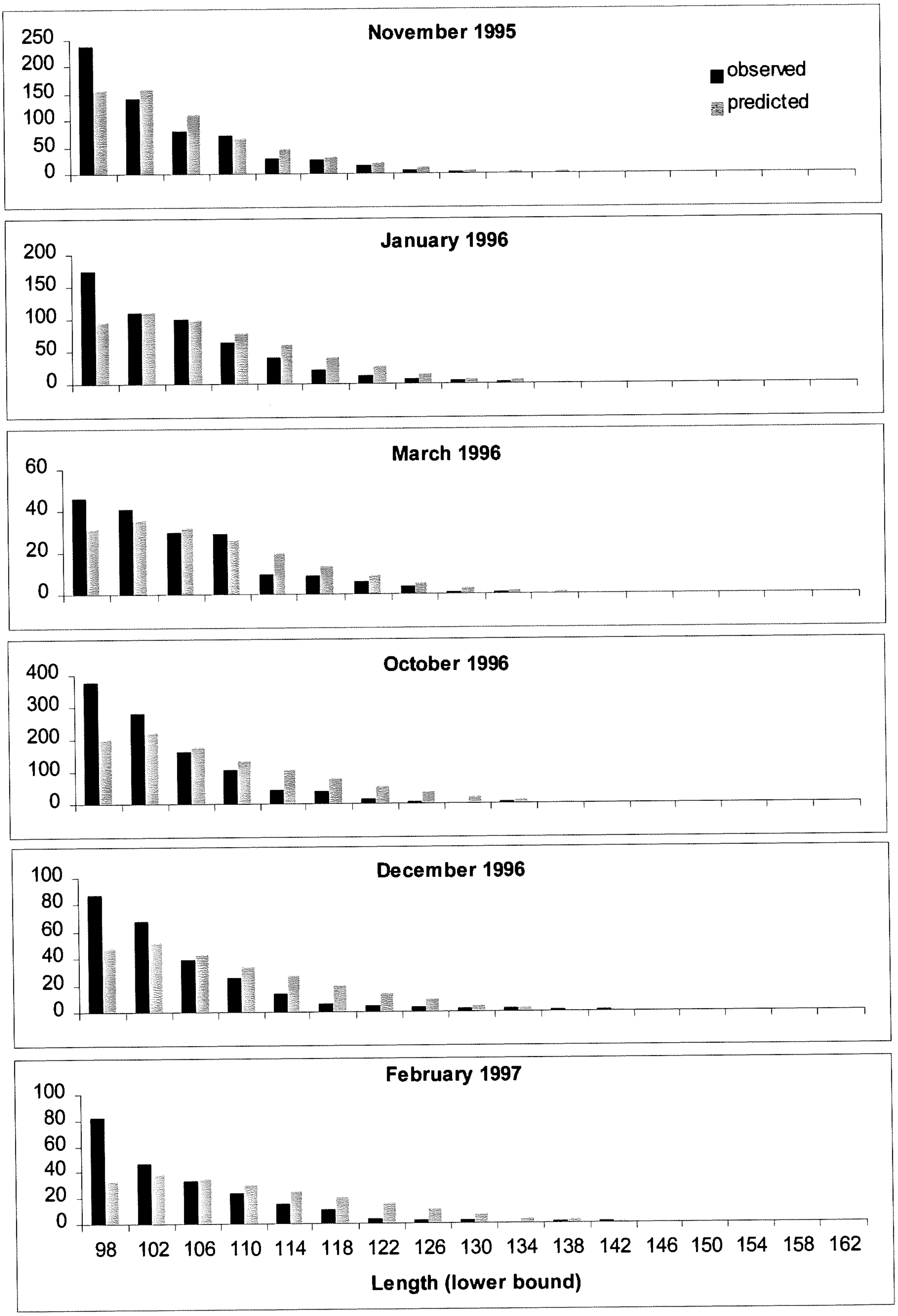


Figure 6.2. Model and survey length-frequencies for female lobsters in the SSZ (Southern Southern Zone). (a, this page) months with larger survey sample sizes for the first two seasons since length sampling began. (b, on next page) months from last two seasons of length sampling.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December 1996

February 1997

Figure 6.2b.

The general fit to the length frequency samples is good.

With hindsight, the Southern Zone was not an optimal test data set for model development, in particular, the years following imposition of catch quotas in 1994. Quota obscures or modifies the relationship between catch and stock abundance which underlies nearly all stock assessment models.

Confidence bounds were not obtained thus far. ADMB (and all asymptotic methods) require that the hessian at the negative log-likelihood minimum should be positive definite. In our case, examination of the eigenvalues revealed that all (269) were positive except for one which was fractionally below zero. Small improvements to the model in future would yield confidence bounds on all derived parameters.

Discussion

The model presented here is fitted to length-frequency and commercial catch data, and employs age as the population structure variable. Punt and Kennedy (1997) have recently developed a length-based stock assessment model which uses length as the population structure variable. The growth estimation model that we have fitted to tag recapture data and described in Chapter 7 is applicable for use with the latter purely length-based stock assessment model type.

The question of which of the two length-based model types best captures yearly population change from the data available remains to be addressed. Age-based models have the strong advantage of a one-to-one cohort relationship from one time period to the next. Numbers of lobsters in a given age class constitute a well-defined cohort. Any increase in time by one year or month will always imply the same increase in cohort age. It follows that any changes in the cohort size must be due to removals from that cohort by fishing or natural mortality. As catch is usually the best known data input, this makes the cohort depletion equation relatively reliable. With length-based formalism, the decline in numbers in a particular length category may be due to mortality, but also to the spreading of the age-class peak with variation in growth among individuals. This lack of one-to-one mapping allows an additional opportunity for the most important source of error in length-based models, the confounding of error or variation in growth with mortality.

Length-based models have the advantage that once lobster numbers in each category (i.e. length class) are predicted by the model, comparing them to data length frequencies is direct, requiring no mapping from numbers in age class to spread of model-predicted lengths-at-age.

The most appropriate model choice in the tradeoff between length- versus age-based models will, perhaps to a considerable extent, depend on the nature and accuracy of the growth model description available. Assessing the relative strengths of these two approaches remains an objective of future lobster stock assessment research.

Chapter 7: Moult probability growth model

Introduction

Growth in fish and aquatic invertebrates is usually modelled as a continuous process. The von Bertalanffy (1938) and more elaborate related growth curves (Richards 1959; Schnute 1981) assume continuous growth of the animal through time. Seasonal variation in growth is included by adding sinusoidal factors to the instantaneous growth rate.

However, crustacea grow discontinuously by periodic shedding of the exoskeleton (moulting). To improve on a continuous curve for lobsters, growth can be modelled as discrete events, occurring at specific moments in time.

A number of ways to represent discrete growth are possible. The times between moulting events for lobsters doubtless vary, so the moult frequency could be represented as a random variable. Likewise, the moult increment, the increase in lobster shell carapace length, would also vary continuously (ie is chosen from a continuous range of real positive numbers) and among individuals.

Varying degrees of this variation are explicit in models of growth. The data simulator (Chapter 4) represents variation in moult increment among individuals as a continuously varying quantity. However, variation in moult-frequency is not explicit in the data simulation as currently formulated.

With aggregated models used in most stock assessment, individual variation cannot be made explicit.

The specific form of growth model used in assessment will depend on its application. One can classify assessment models into two general categories; age-based or length-based, depending on how the population is structured. In age-based models which fit to mean weight or length as inputs (including those of Chapter 5 and 6; Schnute 1987; Fournier and Doonan 1987), an age-based growth model is required.

For explicitly length-structured models (Punt and Kennedy 1997; Bergh and Johnston 1992), where numbers of lobsters are partitioned into discrete length categories, growth is most sensibly represented as a function of starting length. For each length category, at each time of moulting, a fraction of those lobsters in that length class may grow to the next length class, or grow two length classes, or grow into any higher length class, or not grow at all. To model this process, in any given moulting time, each possible growth transition of 0, 1, 2, or more length classes has a given probability. This probability is the fraction of lobsters in that starting length class that grow 0, 1, 2, or more length classes. Probabilities of transition to smaller length classes are considered to be zero. Such a description represents variation in moult increment, though not as a continuously varying quantity.

Here we apply tag-recapture data for South Australian rock lobster to estimate the length-transition probabilities for use in length-structured stock assessment models. Previous models that employed this growth description include those of Sainsbury (1982), Sullivan et al. (1990), Bergh and Johnston (1992), Zheng et al. (1995), and Punt et al. (1997).

Methods

For the growth model length classes were 8 mm-wide bins. Since SA lobsters exhibit a moult increment of about 10 mm or less, particularly for older females, the model allowed moults of 0, 1 or 2 classes from the starting length class. The goal was to estimate the moult transition probabilities, *P0*, *P1* and *P2* of respectively 0 (no moult), 1 (8 mm), or 2 length classes (16 mm) upward from each starting length. Different mean growth curves for males and females (McGarvey et al., in press) prescribed separate estimations for each.

For the model, 11 length classes were defined from a minimum size of 82 mm: 82-90, 90-98, . . ., 162+. Few females were tagged or recaptured in length classes above 140 mm.

It would be possible to estimate each probability as an independent parameter. However, this high number of parameters would likely express much of the variation in the data that is due to sampling and finite sample size, rather than the mean growth of SA rock lobster. To reduce the number of parameters, and make the variation in mean growth with starting length more smooth, the probabilities of transition will be expressed as a two-step function of starting length.

First, the probabilities of growth to each length class were taken as the integrals under one of two continuous probability distributions, either normal or gamma. This approach was implemented by Punt and Kennedy (1997), Zheng et al. (1995), and Bergh and Johnston (1992), employing normal and gamma, gamma, and beta distributions, respectively. Second, the two parameters of the gamma (location and shape) or normal distribution (mean and standard deviation) were themselves set to polynomial functions of starting length. This novel additional level of variation with starting length allows a highly flexible description of both mean growth and individual variation in growth from each given starting length class.

Separate analysis of the SA tag-recapture data set (Ferguson and McGarvey, in prep.) showed that moulting of adult lobsters occurred primarily in two moulting times, mid-summer, late November through February, and over winter. Two moult transition times per year were therefore assumed, January 1 and July 1. Times of mark-release and recapture for each recaptured lobster were assigned to the semi-annual spring and autumn time periods between these dates. Thus time is divided into discrete half-year bins much like carapace length. The data spanned the time from August 1993 through the present, with most tagged lobsters released in the first two years.

Two forms of length-transition matrix estimator were implemented: (1) sum-of-squares, and (2) multinomial likelihood (Punt and Kennedy 1997).

Results

The data sets chosen comprised relatively large sample sizes of recaptures. Northern Southern Zone males (n = 1325) and Southern Southern Zone females (n = 4061) are sub -populations of relatively high growth and relatively low growth respectively.

To present the results graphically, and to allow direct comparison with previous von Bertalanffy fits to the same data sets, 'growth curves' of the classical variety, showing mean length versus age were constructed.

In Figure 7.1 below, the negative relationship between growth rate and length is indicative of the general asymptotic nature of growth, characterising the von Bertalanffy curve, and assumed in most continuous growth models. The graph for females (Figure 7.1.a) shows the asymptote being reached for larger starting sizes, and downward curvature, i.e. slower growth at increasingly larger sizes is evident in all the curves. The moult transition model employed in this analysis includes no a priori asymptotic assumption but appears as a natural fit to data.

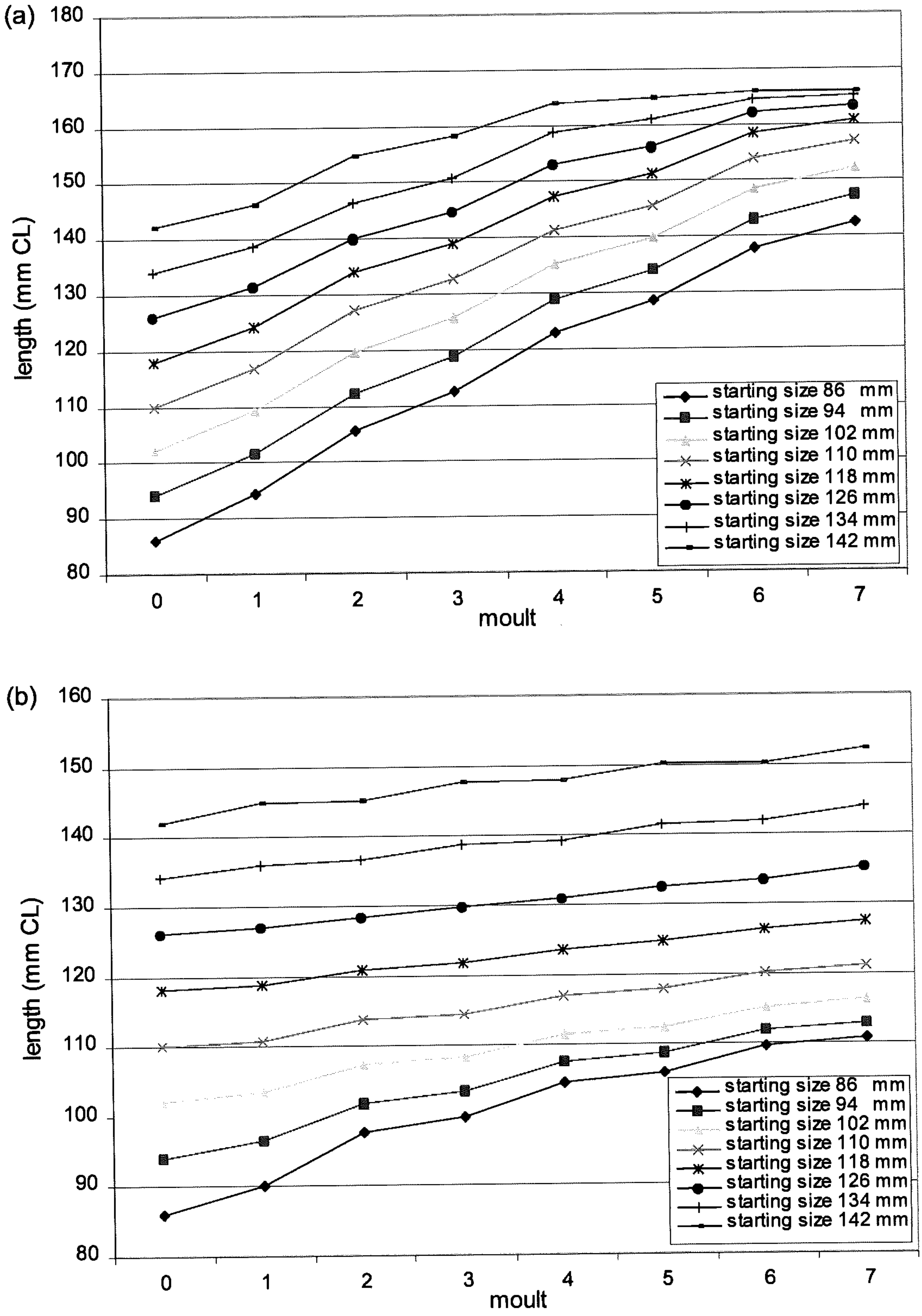

Figure 7.1. Individual growth curves of lobsters from the moult transition estimator starting at each of the first 8 length classes. (a) males, (b) females.

The next set of figures compares the 4 forms of moult transition estimator applied to these two data sets for the 2 forms of objective function that were minimised, namely the sum of squares, and multinomial likelihood, in each case, applied to each of two growth models, one employing the normal distribution and the second employing the gamma distribution to define the moult probabilities (*P*0, *P*1 and *P*2). Comparing the range of estimators allows the identification of any that may exhibit strong bias by differing in prediction from the others. Any trends that characterise these differences may reflect more broadly-based properties of the estimators in question.

In addition to the results of moult probability estimation, two additional growth curves are plotted. The results of the fit of a continuous von Bertalanffy model, estimated from the same tag-recovery data set (McGarvey et al., in press), allow comparison of the moult growth approach with the more traditional form of von Bertalanffy fit to tag data which is currently applied in SA stock assessment. Furthermore, a 'data' growth curve can be calculated directly from the data matrices to which the moult transition model is fitted as the mean growths from each starting length.

The results for males are presented in Figures 7.2 and 7.3. In Figure 7.2, growth begins in the half-year preceding the first moult transition (a summer moult, in January 1993) from the smallest length class (82-90 mm CL).

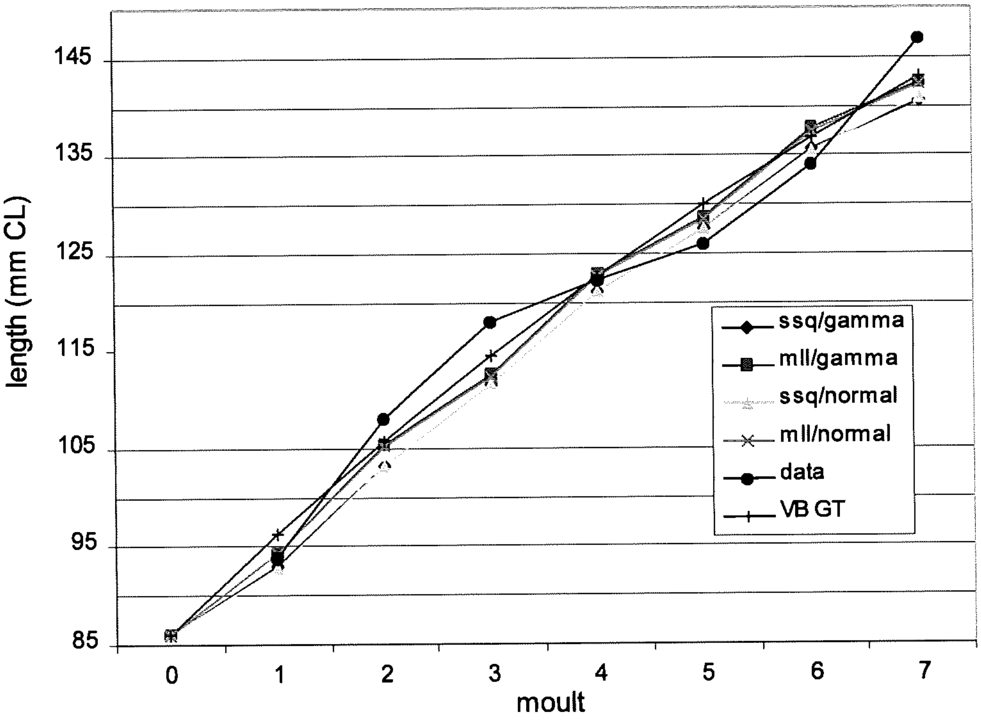

Figure 7.2. Growth curves for males starting at the midpoint of the first length class (82-90 mm CL). Results of mean growth from each of the estimators for each semi-annual moult transition time period. 'mll' is the multinomial log-likelihood; 'ssq' is the sum of squares estimator for the 4 moult probability estimators developed in this chapter. The von Bertalanffy curve 'vb gt' was estimated previously (McGarvey et al., in press) using the GROTAG estimator of Francis (1988).

In Figure 7.3, the growth curves describe male lobsters starting in the 4th length class, (106-114 mm CL).

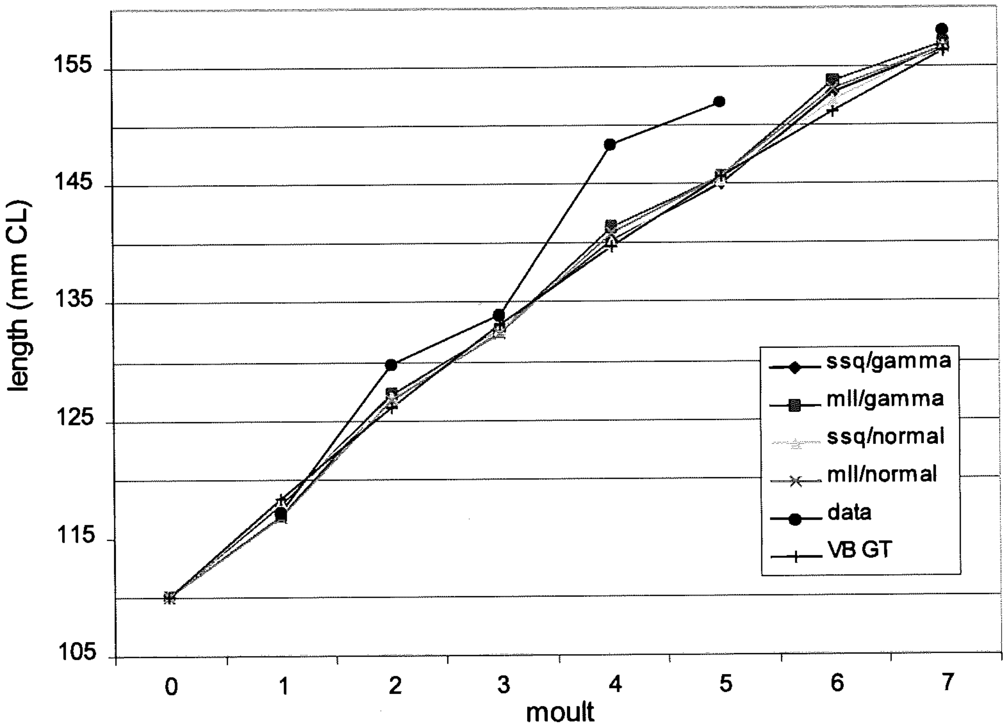

Figure 7.3. Growth curves for males starting at the midpoint of the fourth length class (106-114 mm CL). Abbreviations as described in the caption of Figure 7.2.

The results for males show close agreement among the 5 estimators (4 moult probability and 1 von Bertalanffy GROTAG). Within the levels of uncertainty that characterise inputs and other assumptions in fishery stock assessment modelling, their agreement is very close. The slight tendency downward for odd-numbered moult transitions (in summers), and upward in the even-numbered ones (winters) implies slightly higher moulting mean growth in winter.

The results for females are not as mutually self-consistent. One of the estimators, the normal multinomial, did not converge to a fit. The three remaining moult transition estimators differ more than for males.

The von Bertalanffy fit to these female data sets differed from those obtained using the moult probability estimators indicating possible bias. For smaller females (Figure 7.4), most of which are not mature and are known to grow at a significantly faster rate than mature larger females, the von Bertalanffy curve falls below the moult probability estimated lengths.

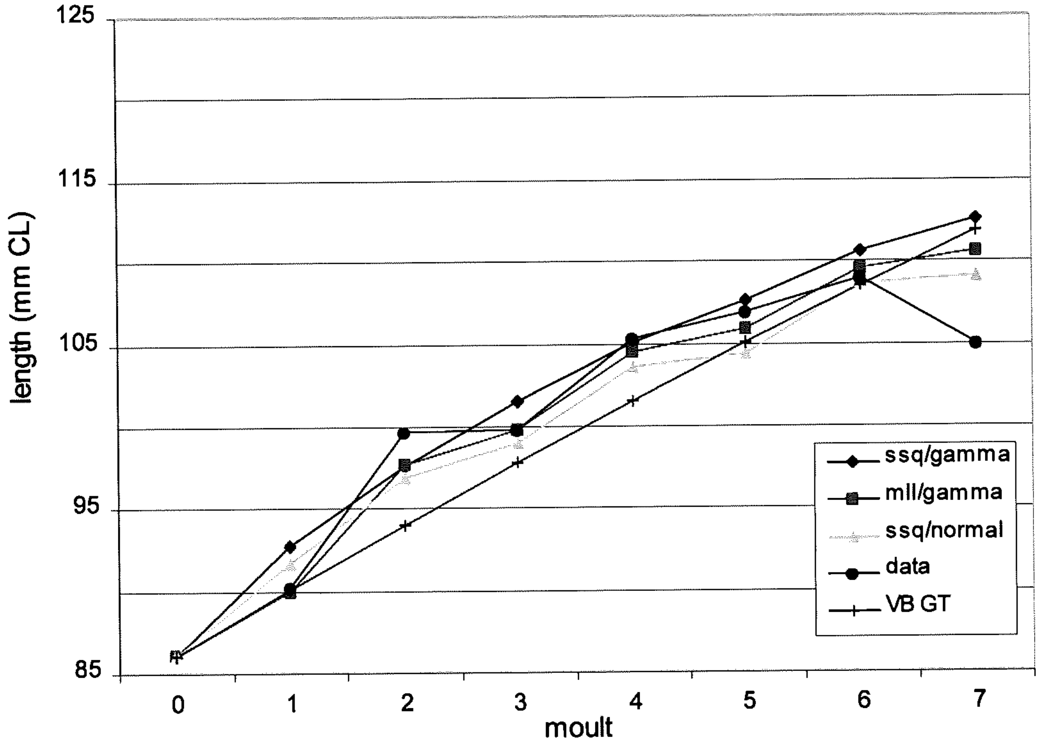

Figure 7.4. Growth curves for females starting at the midpoint of the first length class (82-90 mm CL). Abbreviations as described in the caption of Figure 7.2.

For larger and older, predominantly mature females (Figure 7.5), the von Bertalanffy curve falls above mean growth curves derived using the moult estimators.

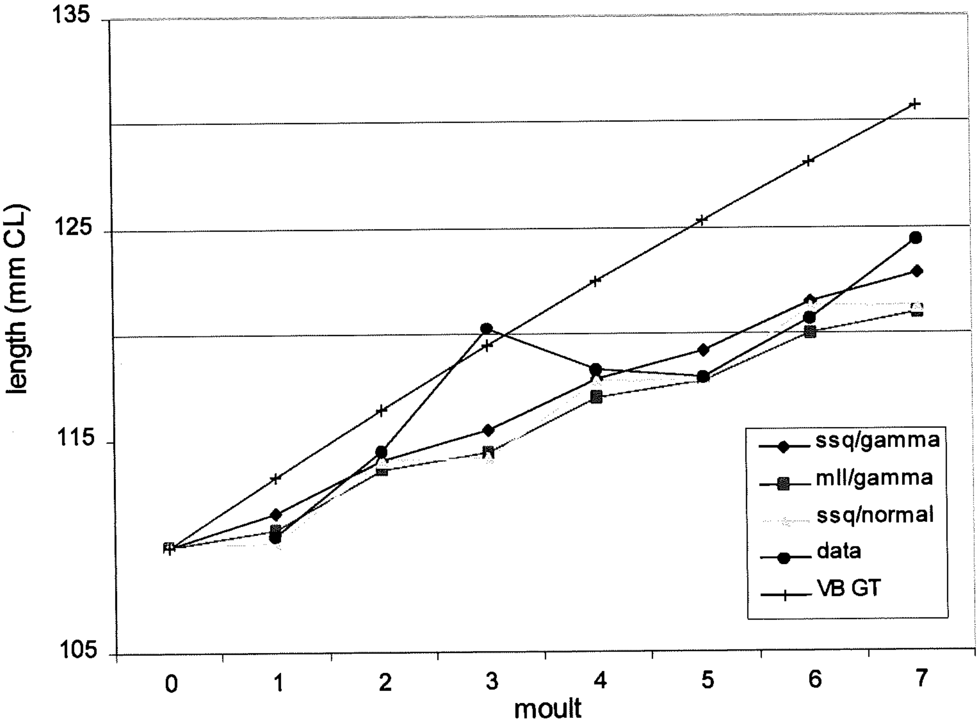

Figure 7.5. Growth curves for females starting at the midpoint of the fourth length class (106–114 mm CL). Abbreviations as described in the caption of Figure 7.2.

Discussion

The non-linear polynomial approach of the moult transition estimators presented in this chapter permits a wider range of non-linear outcomes for mean growth than the von Bertalanffy model, which assumes a constant linear decrease in mean growth increment with starting length. This greater flexibility arises, to a great extent, because the moult estimators employ 9 parameters (4 polynomial coefficients for each normal or gamma probability parameter, and 1 parameter independently estimating the moult transition probability from the 10th to the 11th (highest) length class), compared with the two parameters of the von Bertalanffy curve (K and L_∞). Thus, in general we expect that the differences between von Bertalanffy and the estimators presented here arise from a less accurate description of the simpler von Bertalanffy model.

Taking the lower growth as underestimation by von Bertalanffy for smaller females (Figure 7.4), and the higher growth as overestimation for larger females (Figure 7.5), this trend is consistent with our analysis of the difficulties of describing female growth with a single curve proposed earlier (McGarvey et al., in press). Von Bertalanffy himself (1938) addressed the differing rates of sub- and post-mature female mice by fitting them to separate growth curves. The estimators presented here, because of their relatively flexible form, allow a single description to apply to females of all lengths, while still maintaining a continuous change in predicted moult increment with starting length. The formulation as a series of moult transition probabilities, previously carried out in a number of studies of crustacean growth, makes explicit the variability in the moult increment.

For the case of males, close agreement among different growth models is good evidence of their success at capturing the rates of increase in male lobster carapace length as functions of starting length. Much of this success is due to the rich database of tag recoveries gathered in the previous FRDC program, 93/086 & 93/087. The agreement between the more general model here and von Bertalanffy suggests that the von Bertalanffy model is appropriate for mean growth of male lobsters, and that more complex growth models are not required.

Punt and Kennedy (1997) also found the von Bertalanffy model to produce the best fits for mean growth of the same species, *Jasus edwardsii*, in Tasmanian waters. This corroborates the conclusions of Morgan (1980) that the most adequate description of spiny lobster growth was the von Bertalanffy model. Normality and uniformity of residuals of fits to a von Bertalanffy model for the SA tag-recapture data set (McGarvey et al., in press) also suggested that the model was a good description of growth after times-at-liberty of approximately one or two moults, i.e., after incremental moulting growth was smoothed out by individual growth variation.

Benefits

The principal beneficiary is the commercial SA rock lobster industry. Increasingly stringent requirements for a yearly stock assessment are demanded by the managers under the aegis of the Fisheries Act, by the public in its greater emphasis on environmentally sustainable harvesting, and by industry themselves to allow more considered planning of different strategies for optimising the value of the harvest. Hence, improved methods of assessment for enhanced lobster resource management were sought.

The benefits of the project are directed toward three outcomes: (1) generating better data, (2) more efficient methods of gathering the data for stock assessment, and (3) developing new and superior methods of analysing those data in evaluating the annual status of rock lobster stocks in South Australia.

Further Development

The following recommendations refer to the survey design for length sampling:

1. The most economically and statistically efficient way to improve survey precision and accuracy is to increase the number of fishers participating as volunteers. Efforts to inform fishers of the use of these data and continued feedback about their outcome to encourage wider participation would be an effective use of field researcher time.
2. Option C should be adopted in favour of tested options B and A. (Based on preliminary results, this recommendation was implemented in 97/98 when all volunteer fishers sampled 3 pots per day.)
3. To encourage wider participation, and reduce the workload of all that do contribute their time and effort to voluntary research catch-monitoring, the numbers of pots sampled by each fisher can be reduced. Those wishing to sample 2 pots per sample day, rather than 3, will be inducted and/or continue as participants in the volunteer program.
4. To further reduce volunteer (and on-board researcher) workload, the specification to measure carapace length to the nearest 0.1 mm should be changed to the nearest 1 mm.
5. Subject to discussion among researchers, processors, and fishers, a program of port sampling could be instituted to supplement on-board sampling of non-volunteer licences.

The indicative 10-yr periodic trend in recruitment suggests a similar periodicity in the oceanic currents in and off the Great Australian Bight that might induce a similar trend in yearly settlement success of phyllosoma/pueruli. If the pattern of previous decades continues, then the current relatively strong rising trend of recruitment will peak in the early years of the next decade and fall by the middle of the decade. Should this prediction be confirmed, the search for the environmental cause of these variations would potentially be a research objective of economic value. A clear cyclical trend in the catches would conceivably allow more careful marketing of the product, and allow the potential to devise longer-term marketing strategies to optimise the economic return from the varying harvest.

In future, the question of which of the two model types employing length-frequency data is best at capturing yearly population change remains to be addressed. The most appropriate model choice in the trade off among the advantages of length- versus age-based models will depend on the nature and accuracy of the growth model used. Assessing the relative strengths of these two approaches remains to be done. This would be of direct interest to SA rock lobster, where both length-frequency data models remain an option. Currently Victorian and NSW industry and fisheries scientists are contemplating different approaches to developing or adopting a formal method to assess their lobster stocks. These two length-frequency methods are obvious candidates. The qR method is a more immediately applicable option; its mathematical and data input requirements are considerably less demanding than a full length-frequency fitted model approach.

Conclusion

The goals of the original proposal were achieved. The length-sampling survey is now established in rigorous statistical formulation, and the optimal design identified.

In addition, we have extended the original objectives to make four additions to the tools of yearly stock assessment. The first two, the data simulator and the dynamic qR model, now serve as the basis of yearly stock assessment in SA rock lobster. The second two, the age-based length-frequency model and the moult-probability growth model, await implementation in assessment and management.

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Appendix 1: Intellectual Property

Intellectual property is allocated as per the original FRDC contract, where it is specified that the Corporation's share will be 52%. Section 7 of that contract specifies the details of intellectual property share among contract signatories.

Appendix 2: Staff

Rick McGarvey
Mike Pennington
Janet Matthews
David Fournier
John Feenstra
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Appendix 3: Communications with Fishers

Throughout the project a number of letters and summaries of results of their participation in survey protocol design were sent (or handed out) to all rock lobster fishers. Copies of these written communications comprise this Appendix.

Appendix 3A: Industry Survey Poll Response Form

The following survey form asks you to select the method by which you would like to see pot sampling data collected.

It is very important to have your say. Pot sampling is critical data required every season for stock assessments. There are a number os different options, some will mean volunteer work from every fisher and other options require no work from you, but will then cost more. Please select an option that you think will be the best method of collected the data in a cost-effective and efficient manner. A one-day workshop will be hod on July 4th at West Beach Aquatic Sciences Centre to discuss the results of the survey and select an option to be implemented for the 1996/97 and following seasons.

Enclosed is a survey form - please return it in the self-addressed reply-paid envelope or fax to us no later than 30th June 1996. Sorry for the short time to respond, but we will need your comments for the workshop on July 4th. Further information on the workshop and the survey is also included in this mailing.

For more information or workshop registration, please contact Melissa Lorkin on (086) 830 824 or (086) 830 857 (fax).

POT SAMPLING SURVEY

Pot sampling is simply that – a sample of size, sex and reproductive state of the crays you are catching. Some fishers have been pot sampling on a certain number of their pots for a few seasons now.

We will seek to get a large sample size, perhaps in two surveys, as large as we obtained for the entire year of seven surveys in the past. This could possibly be in November, before the summer moulting period, and in March, after. We would also like to get a large coverage of both zones – this will depend on getting a larger numbers of vessels either participating or having scientists aboard.

The options are:

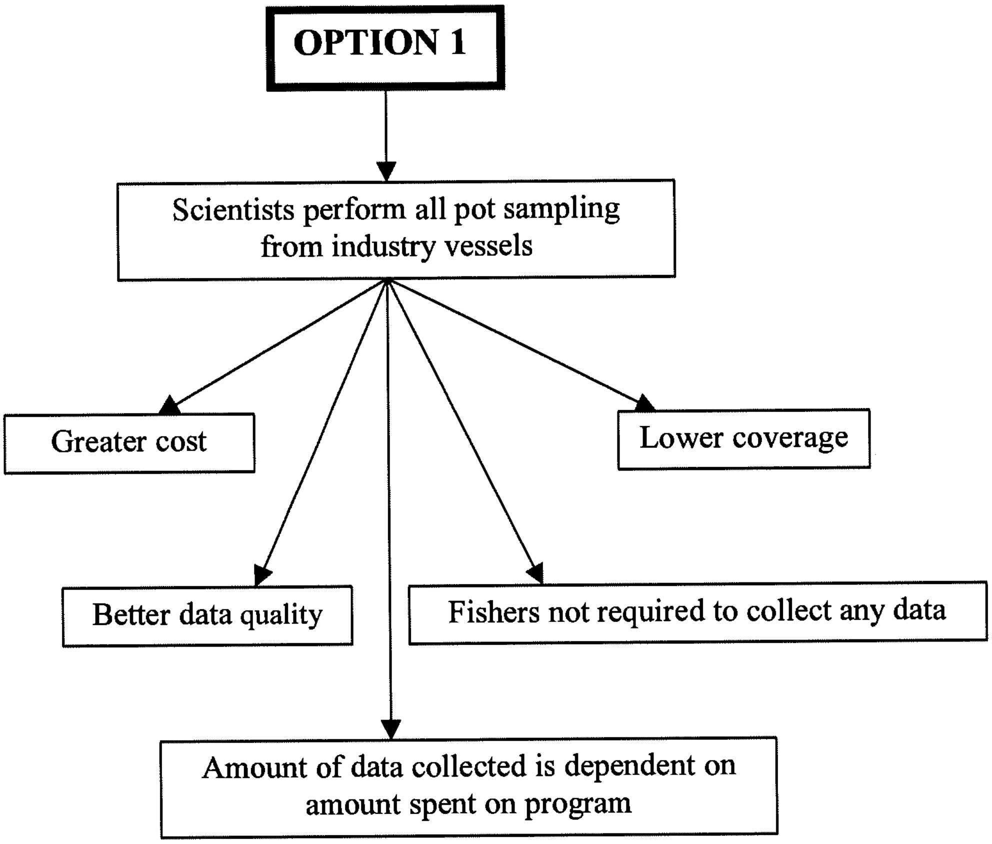
OPTION 1.

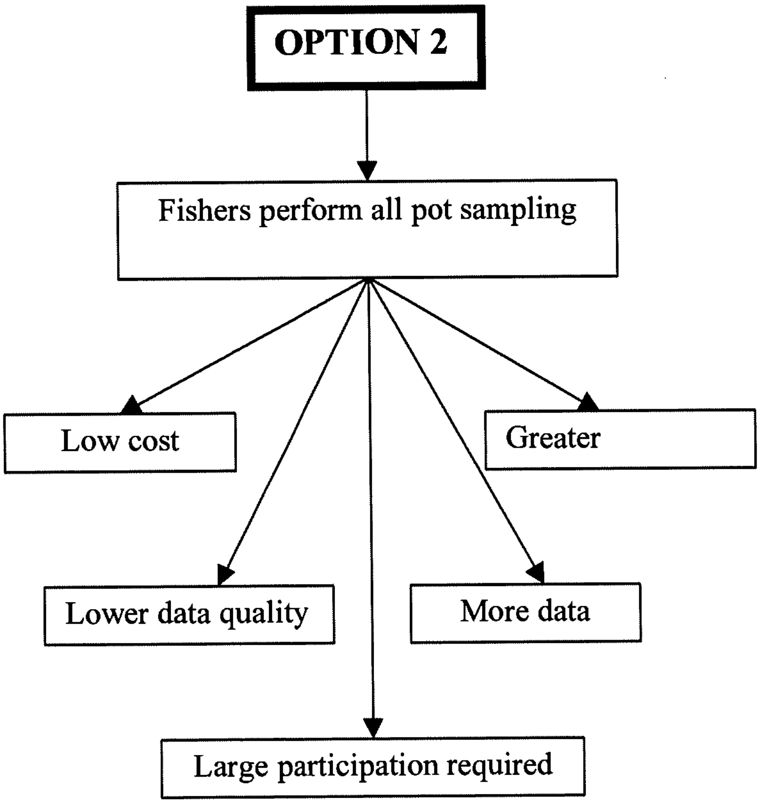
If fishers feel that they do not wish to participate in the data collection, or, that there will not be enough participation by a large number of fishers, the survey work will have to be carried out by scientists on board fishing boats.

Please be aware that employing scientists for this work will be a costly program compared to volunteer work by the fishers. It is also unlikely that scientists would cover the same area that fishers do.

OPTION 2.

The second option involves fishers performing the measurements, assisted by the scientists already employed on the program. This is a more cost effective option than the previous one, but would require a greater level of participation by industry during the two survey periods in November and March, than has occurred monthly in the past.


OPTION 1
Scientists perform all pot sampling from industry vessels
Greater cost
Lower coverage
Better data quality
Fishers not required to collect any data
Amount of data collected is dependent on amount spent on program


OPTION 2
Fishers perform all pot sampling
Low cost
Greater
Lower data quality
More data
Large participation required

SURVEY FORM

Name: ....

Licence Number: ....

Do you prefer:
(Please **tick** preference)

Option 1 Scientists do the pot sampling work from commercial fishing boats, at an additional cost. ☐

Or

Option 2 Fishers do the pot sampling work on a voluntary.basis. ☐

If Option 2 becomes the method for collecting the data:

A Would you be willing to participate in a survey that ran intensively twice a year? ☐
(please answer Yes or No in the box)

B. Do you think more widespread participation should be encouraged amongst all fishers? ☐
(please answer Yes or No in the box)

C. If widespread participation is not possible, and instead a limited number os fishers participate in sampling as in the past five seasons,
Do you support compensating these fishers with

1. A bit of extra quota in the SZ ☐
   (please answer Yes or No, only if you are a SZ fisher)
2. An extra day or two of fishing ☐
   (please answer Yes or No, only if you are a NZ fisher)
3. Some other form of financial compensation ☐

Please specify: ....

....

Please write any comments or suggestions you may have on the back of this form.

Thankyou!

Appendix 3B: Survey Design Questionnaire Results

SURVEY RESULTS

Number of surveys returned:

Northern zone **30%** Southern zone **23%**

Percentage supporting option 1 – scientists collecting survey data:

Northern zone **4%** Southern zone **16%**

Percentage supporting option 2 – fishers collecting survey data

Northern zone **96%** Southern zone **84%**

If option 2 is implemented, the percentage of fishers willing to participate is:

Northern zone **75%** Southern zone **75%**

If option 2 is implemented, the percentage of fishers who would like to see more widespread participation is:

Northern zone **82%** Southern zone **77%**

Of the Southern zone fishers:
59% support compensating with extra quota
23% do not support compensating with quota
9% support some other form of financial compensation

Of the Northern zone fishers:
54% support compensating with extra days
36% do not support compensating with extra days
6% support some other form of financial compensation

SURVEY RESULTS

Number of surveys returned:

Northern zone **30%**	Southern zone **23%**
28/94	44/203
	Total 24% (72/297)

Percentage supporting option 1 – scientists collecting survey data:

Northern zone **4%**	Southern zone **16%**
(1)	(7)
	Total 11%

Percentage supporting option 2 – fishers collecting survey data

Northern zone **96%**	Southern zone **84%**
(27)	(37)
	Total 89%

If option 2 is implemented, the percentage of fishers willing to participate is:

Northern zone **75%**	Southern zone **75%**	Total 75%
No 0% (0)	No 16% (7)	Total 15%
Undecided 25% (7)	Undecided 9% (4)	Total 10%

If option 2 is implemented, the percentage of fishers who would like to see more widespread participation is:

Northern zone **82%**	Southern zone **77%**	Total 79%
No 7% (2)	No 9% (4)	Total 13%
Undecided 11% (3)	Undecided 14% (6)	Total 8%

Of the Southern zone fishers:

59% support compensating with extra quota
23% do not support compensating with quota
9% support some other form of financial compensation
9% undecided

Of the Northern zone fishers:

54% support compensating with extra days
36% do not support compensating with extra days
6% support some other form of financial compensation
4% undecided

Southern zone comments:

- Penalising fishers who don't do research as well as rewarding those that do eg. taking quota from those that don't to pay those that do.
- Only those that have done sampling in the past should be rewarded.
- Please consider weather conditions (eg. Nov) when determining sampling months
- Concerns on data quality for fisher collected data
- Use scientists in strategic areas or where fishers haven't worked.
- Only give extra quota to those fishers without previous convictions or offences

Northern zone comments:

- Stick to proven volunteers for better data quality – should be compensated
- Take into account that often non licence owning skippers are doing work and they need incentive other than the 'good of the fishery'.

Appendix 3C: Survey Design Workshop Announcement

like to reach some consensus among those attending about how this survey should run. Also in attendance will be a fishery survey expert from North America, Dr Mike Pennington, widely regarded as the world leader in this field. Assuming we can decide upon one or two but not more than three options at this workshop, these will be presented to all fishers for final approval in a written ballot by mail. If you wish to attend, please notify Melissa Lorkin at (086) 830 824 or by fax at (086) 830 857 by Thursday June 27. Hope to see you there.

And we wish to thank all fishers who have been doing catch monitoring and tagging, some for as many as five years, nearly all for no additional compensation, in the ongoing length catch monitoring program. This information has already proved to be irreplaceable in both the model and stock assessment of the SA rock lobster fishery.

Rick McGarvey
2 June 1996

Upcoming Survey Design Workshop

Progress on the FRDC Trust Fund project whose goal is to set up an ongoing stock monitoring survey is proceeding on schedule. The most important input to this project is the feedback and, ultimately, the decision of rock lobster fishers about how you want this survey to be undertaken. Scientists serve to assure that whatever options are proposed yield the highest quality of information about the stock. The three fundamental quantities we want to measure annually for managing this resource are (1) recruitment, (2) egg production, and (3) the "exploitation rate", which is the fraction of legal crays being removed from the "fishable stock". This survey will not be a major departure from the catch monitoring of the past five seasons--the goal is to choose one methodology so that the results in all future years are consistent. A second goal is to get as accurate a measure of the numbers of crays captured in each size grouping as is practically feasible. The last goal is to derive the mathematical formulas needed to be able to estimate how precise these estimates of cray numbers are. Discussions with fishers thus far have indicated their sentiment that the time expenditure in measurement at sea is becoming excessive. In meetings with SEPFA, at the Kingston port association, with SANZRLFA, briefly at the NZ IMC, and in discussions with individual fishers, one proposed recommendation has met with general approval:

We plan to reduce the survey frequency from monthly (seven times) to twice per year, ideally around November and March. Large numbers of lobsters would be measured for length, sex, and if female, sexual status. Both scientists and fishers believe this would provide adequate coverage of the catch lengths. By running the survey before and after the summer moulting period, we obtain a snapshot of the stock before and after summer growth and heavy summer fishing. Moreover, what we truly require are large sample sizes. In some past surveys (notably in the SZ 1994/95), large numbers measured for length have allowed us to identify age-peaks, in other words to see visually evident bumps that represent individual age classes. Since we cannot determine the age of an individual lobster, identifying age-class peaks in these length frequency samples is a large bonus in knowledge about the stock.

Two principal options are being considered:

1. We would continue with at-sea measurement as done in the past five seasons, but with intensive participation by scientific on-board staff, and probably employing additional temporary scientific crew to send out with fishing boats during the two periods of intensive length sampling. Boats would be chosen at random, which increases the accuracy of the resulting sample of the fishery overall. During, say, a 6-week survey period, perhaps 60 individual skippers and owners in each zone would be requested to take on board for a day, scientific field staff who would carry out the measuring and recording. Acceptance of this request would be at the discretion of the skipper and/or owner.

2. The second option is that fishers themselves continue to do most of the length sampling as they have done for the past five seasons. There are two general approaches that we can take under this general option:

2.1 Ideally we would get wide participation among a high percentage of vessels in the fishery. This would be best accomplished with a random sample of boats. In practice, it might not be realistic to get everyone, but that would be the goal under this option. This achieves two advantages: a wider coverage of the catch being sampled, and a more fair distribution of the workload.

2.2. If a limited number of individual fishers themselves carry out the work as they have in the past, we could consider providing an economic compensation for their extra work. In the SZ, this could be in the form of quota, as was undertaken in 1994/95. In the NZ, this could be in the form of a day or two of extra fishing. Other forms of compensation, like direct cash payments, could also be considered.

To indicate your choice among these proposed options, you are asked to fill out the attached written survey. Additional comments or suggestions will be welcome.

On Thursday 4 July, there will be a one-day "Survey Design Workshop", at SARDI Aquatic Sciences in Adelaide (West Beach) to which all rock lobster fishers are invited. The goal will be to make preliminary decisions about the way the survey will operate. Ideally we would

1996/1997 SURVEY PROGRAM

ONE DAY WORKSHOP

JULY 4TH 1996, 1.00PM
WEST BEACH AQUATIC SCIENCE CENTRE, ADELAIDE.

You are invited to attend a workshop where we will decide a survey option for future fishing seasons.

The aim of the workshop is to select a pot sampling program that:

- Meets the requirements of a scientific study
- Is the most efficient, economical and practical method of collecting data
- Has a data collection method that is simple and interesting, to encourage participation by industry

To achieve these aims will require input from fishers. Pot sampling is a compulsory section of the research – yearly stock assessments are based on the results. Please help us to find a method that is acceptable to industry as a cost-effective and efficient method of collecting data.

For more information, and to register your interest in attending the workshop, please contact Melissa on the following numbers:

Tel. (086) 830 824   Fax (086) 830 857

REMINDER!

ONE DAY WORKSHOP TO BE HELD AT THE WEST BEACH AQUATIC SCIENCES CENTRE, 4TH JULY 1996 AT 1.00PM.

THE PURPOSE OF THIS WORKSHOP IS TO SELECT A METHOD OF CARRYING OUT THE POT SAMPLING WORK FOR THE 1996/97 SEASON AND ONWARDS FOR THE NORTHERN AND SOUTHERN ZONES.

POT SAMPLING IS COMPULSORY DATA REQUIRED EACH SEASON FOR STOCK ASSESSMENTS.

PLEASE ATTEND THE WORKSHOP AND HELP TO FIND A METHOD WHICH WILL BE ACCEPTABLE TO INDUSTRY AS A COST-EFFECTIVE AND EFFICIENT METHOD OF COLLECTING DATA.

REGISTRATION DETAILS ARE IN THE MAIL!

FOR MORE INFORMATION, PLEASE CONTACT MELISSA LORKIN ON 086 830 824 (PHONE) OR 086 830 857 (FAX).

HOPE TO SEE YOU THERE!

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SURVEY DESIGN WORKSHOP

AGENDA

West Beach Aquatic Sciences Centre
July 4th 1996, 1.00pm

12.30	Lunch at Aquatic Sciences Centre
1.00 – 1.45	Rick McGarvey Why do we need a survey? What we have learned so far. What information we hope to get from semi-annual surveys.
1.45 – 2.00	Questions and discussion about the goals of a monitoring project.
2.00 – 2.20	Mike Pennington How should a survey program be designed? Strategies for getting the best information possible for a given amount of sampling time and cost.
2.20 – 2.30	Questions for Mike.
2.30 – 2.45	Rick McGarvey Overview of the different options discussed in the poll.
2.45 – 3.00	Melissa Lorkin Results of the survey poll.
3.00 – 3.15	Afternoon tea
3.15 – 3.30	Jim Prescott Discussion of the practical advantages and disadvantages of the two overall options.
3.30 – 4.00	General discussion, questions and comments from fishers.
4.00 – 4.30	Decision on the survey design.
4.30 – 5.00	Discussion on logistics of survey design: Sample size Coverage Compensation Bias etc.
5.00 – 5.30	Decision on what to do. Either: 1. Reach consensus and send out ballot for approval. Or 2. Formulate 2, or at most 3, options for mail ballot vote.

Appendix 3D: Survey Design Workshop Summary

SURVEY DESIGN WORKSHOP SUMMARY

The survey design workshop held at West Beach Aquatic Sciences Centre on the 4th July was attended by 15 fishers from the Southern zone and 23 from the Northern zone. Previous meetings of SEPFA, NZ IMC and NZ Management Plan Sub-Committee had also provided opportunities for discussion with fishers on survey design.

Rick McGarvey opened the workshop with a discussion on the reasons for having a survey, what we have learned from previous surveys, and what information we hope to get from semi-annual surveys. Dr Mike Pennington, a survey design specialist, followed with advice on how we could get the best information possible for a given amount of sampling time and cost. Dr Pennington demonstrated how useful widespread participation would be.

The questionnaire results were then presented and discussed. Of the questionnaires sent out, we had replies from 30% of Northern Zone fishers and 23% of Southern Zone fishers. Since then, late returned questionnaires have increased the number of replies to 35% in the NZ and 31% in the SZ. The results were as follows:

OPTIONS	**NZ**	**LATE NZ**	**SZ**	**LATE SZ**
Option 1 – Scientists collecting survey data	4%	3%	16%	15%
Option 2 – Fishers collecting survey data	96%	97%	84%	85%
If option 2 is implemented:				
Fishers willing to participate	75%	82%	75%	73%
Fishers supporting widespread participation	82%	76%	77%	69%
Of the southern zone fishers:				
Support compensating with extra quota			59%	60%
Support other form of financial compensation			9%	8%
Of the northern zone fishers:				
Support compensating with extra day	54%	52%		
Support other form of financial compensation	6%	6%		

NZ, SZ = figures used in workshop.
Late NZ, Late SZ = figures adjusted to include late returned surveys

Although the results from the questionnaire were very conclusive, there was some concern that, due to the low response, every port was not equally represented. Fishers present at the workshop decided to adopt a survey design for which fishers would collect the majority of data. Financial incentives were decided against on the basis of bad data quality. A survey

was then designed to make the workload for volunteer fishers as easy and efficient as possible.
At the end of a very productive workshop the following decisions had been made for both northern and southern zones:

- Survey data will be collected by fishers. This will enable greater coverage, more data, lower costs to fishers, and continuation of fisher involvement in the research.

- There will be no compensation for volunteers: This will prevent some fishers doing a poor job just to get compensation, but will mean that there may not be full participation by industry.

- Sampling would be done twice a season, with volunteers able to choose a combination of days and pots that best suits them to do the survey work.

- Currently employed scientists will be present on vessels during the sampling times, to increase the amount of data collected and to assist on any vessels which have not collected this type of data before.

- Electronic means of data recording will be investigated for the future. This may provide an easier and quicker means of collecting information and will then hopefully encourage greater participation by industry.

The different options for data collection depend on the number of pots you work and the port that you work from, as well as a personal choice in the number of days and pots you would prefer to sample. We have tried to make the amount of work equal across the state, so that those fishers handling large numbers of undersize lobsters in their pots are not therefore required to measure more lobsters!

Another questionnaire is included in this mailing with more details on the different options. Please choose whether you wish to participate in the volunteer survey, and if so, how you would prefer to collect your data.

Thank you to all those that took the time to fill in the surveys and attend the workshop. Your contribution and advice on the survey design were appreciated and valuable.

Appendix 3E: Northern Zone Lobster Sampling Options

NORTHERN ZONE LOBSTER SAMPLING OPTIONS

It was decided at the survey workshop that sampling would be done by volunteer fishers in the Northern Zone. There will be no compensation for the work and it is up to you whether you choose to participate in the sampling work.

The voluntary pot sampling completed by fishers last season was of a very high standard and we thank you for your work. Please try not to let the same fishers take responsibility for the research work each season. We hope that the following options (developed by fishers) will make it easier for you to be able to participate in the survey program without causing too much interruption to your normal fishing operations.

Sampling simply involves measuring and sexing all the lobsters from the survey pots. Sized lobsters are then kept as normal, and undersize and spawnies are thrown back. It will need to be done only twice a year, once in November (or if you really need to, early December) and again in March. There are three choices in the way the work is carried out.
You can:

OPTION A:
Sample ALL your pots for 5 days in November and then ALL your pots for 5 days in March (you choose the days).

The advantage in this method is that you get the work over and done with quickly. The disadvantage is that these will be quite long days once you have measured the lobsters in every pot.

OPTION B:
The second choice is to do 1/5th of your pots for 10 days in November and 10 days in March (you choose the days).

We have divided the number of your pots by 5, and this will be the number of pots you will need to sample each of the 10 days. Each pot will be marked as a research pot and randomly mixed in and set with your other pots.

OPTION C:
Measure all the lobsters from 1/15th of your pots for 30 days in November and 30 days in March.

We have divided the number of pots by 15, and this will be the number of pots you will need to sample each of the 30 days. Each pot will be marked as a research pot and randomly mixed in and set with your other pots.

Options B and C are the preferred options of the scientists as we will get data from a larger area. In total, you will also be measuring fewer pots by this method.

Now, if everything is clear to you please go ahead and fill in your questionnaire. Otherwise, please call Melissa on (08) 8683 2517 or Jim on (08) 8724 2930 for help or more details on any of the options!

Licence No:
No. of Pots:

NORTHERN ZONE LOBSTER QUESTIONAIRE

Please fill in and return the following questionnaire in the self-addressed reply paid envelope, or fax to Melissa on (086) 830 857, if possible by the 23rd August 1996. Any comments or questions can be discussed with Jim at Mt Gambier on (087) 242 930 or Melissa at Pt Lincoln on (086) 830 824.

Please note: This is not a survey - it is intended as a form for you to sign-up for the volunteer 96/97 research program.

Please TICK your preferred option:
(only ONE box should be ticked)

OPTION A. ☐ You would like to sample **ALL** your pots over **5** days in November and **5** days in March.

OR

OPTION B. ☐ You would like to sample 1/5th of your pots over **10** days in November and **10** days in March.
The number of pots you would need to sample is: __________

OR

OPTION C. ☐ You would like to sample 1/15th of your pots over **30** days in November and **30** days in March.
The number of pots you would need to sample is: _________

(Options B & C are the preferred options of the scientists as we will get data from a larger area).

OR

OPTION D. ☐ You would **not** like to participate in the volunteer research this season.

Thank you for filling in the form (yes we know, another form - this will be the last for a while!) Those fishers willing to participate will be contacted with details closer to the start of the season.

Appendix 3F: Southern Zone Lobster Sampling Options

SOUTHERN ZONE LOBSTER SAMPLING OPTIONS

It was decided at the survey workshop that sampling would be done by volunteer fishers in the Southern Zone. There will be no compensation for the work and it is up to you whether you choose to participate in the sampling work.

The voluntary pot sampling completed by fishers last season was of a very high standard and we thank you for your work. Please try not to let the same fishers take responsibility for the research work every season. We hope that you the following options (developed by fishers) will make it easier for you to be able to participate in the survey program without causing too much interruption to your normal fishing operations.

Sampling simply involves measuring and sexing all the lobsters from the survey pots. Sized lobsters are then kept as normal, and undersize and spawnies are thrown back. It will need to be done only twice a year, once in October/November and again in February/March.

If you fish from Kingston, Cape Jaffa or Robe, your options are:

OPTION A:
Sample ALL your pots for 4 days in November and ALL your pots for 4 days in March.

The advantage in this method is that you get the work over and done with quickly. The disadvantage is that these will be quite long days once you have measured the lobsters in every pot. You can pick your days from any time in October/November and February/March. So you can pick nice days when you are not in a hurry to get anywhere!

OPTION B:
The second choice is to sample 1/7th of your pots for 10 days in October/November and 10 days in February/March (you choose the days).

We have divided the number of pots by 7, and this will be the number of pots you will need to sample each of the 10 days. Each pot will be marked as a research pot and randomly mixed in and set with your other pots.

OPTION C:
Measure all the lobsters from 1/21st of your pots for 30 days in October/November and 30 days in February/March.

We have divided the number of pots by 21, and this will be the number os pots you will need to sample each of the 30 days. Each pot will be marked as a research pot and randomly mixed in and set with your other pots.

Options B and C are the preferred options of the scientists as we will get data from a larger area. In total you will also be measuring fewer pots by this method.

If you fish from Beachport, Southend, Port MacDonnell, Carpenter Rocks or Blackfellow Caves, your options are:

OPTION A:
Sample ALL your pots for 3 days in November and ALL your pots for 3 days in March.

The advantage in this method is that you get the work over and done with quickly. The disadvantage is that these will be quite long days once you have measured the lobsters in every pot. You can pick your days from any time in October/November and February/March. So you can pick nice days when you are not in a hurry to get anywhere!

OPTION B:
The second choice is to sample 1/10th of your pots for 10 days in October/November and 10 days in February/March (you choose the days).

We have divided the number of your pots by 10, and this will be the number of pots you will need to sample each of the 10 days. Each pot will be marked as a research pot and randomly mixed in and set with your other pots.

OPTION C:
Measure all the lobsters from 1/30th of your pots for 30 days in October/November and 30 days in February/March.

We have divided the number of your pots by 30, and this will be the number of pots you will need to sample each of the 30 days. Each pot will be marked as a research pot and randomly mixed in and set with your other pots.

Options B and C are the preferred options of the scientists as we will get data from a larger area. In total you will also be measuring fewer pots by this method.

Now, if everything is clear to you please go ahead and fill in your questionnaire. Otherwise, please call Melissa on (08) 8683 2517 for help or more details on any of the options!

Licence No:
No. of Pots:
Port:

SOUTHERN ZONE LOBSTER QUESTIONAIRE

Please fill in and return the following questionnaire in the self-addressed reply paid envelope, or fax to Melissa on (086) 830 857, if possible by the 23rd August 1996. Any comments or questions can be discussed with Jim at Mt Gambier on (087) 242 930 or Melissa at Pt Lincoln on (086) 830 824.

Please note: This is not a survey - it is intended as a form for you to sign-up for the volunteer 96/97 research program.

Please TICK your preferred option:
(only ONE box should be ticked)

OPTION A. ☐ You would like to sample **ALL** your pots over a number of days in Oct/Nov and again Feb/Mar.
The number of days you will need to sample is: __________

OR

OPTION B. ☐ You would like to sample a fraction of your pots over **10** days in Oct/Nov and **10** days in Feb/Mar.
The number of pots you would need to sample is: __________

OR

OPTION C. ☐ You would like to sample a fraction of your pots over **30** days in Oct/Nov and **30** days in Feb/Mar.
The number of pots you would need to sample is: __________

(Options B & C are the preferred options of the scientists as we will get data from a larger area).

OR

OPTION D. ☐ You would **not** like to participate in the volunteer research this season.

Thank you for filling in the form (yes we know, another form - this will be the last for a while!) Those fishers willing to participate will be contacted with details closer to the start of the season.

Appendix 3G: Northern Zone Port Tour Announcement

IMPORTANT NOTICE!

FOR ALL FISHERS PARTICIPATING IN THE VOLUNTEER POT SURVEY PROGRAM, THERE WILL BE SHORT PORT MEETINGS ON THE FOLLOWING DATES:

TUESDAY 8TH OCTOBER

9.30am – 10.30am	**PORT LINCOLN TAFE** **(following the Association meeting)**
7.30pm – 8.30pm	**KINGSCOTE** **Graham Walden's House** **18 Cygnet Rd**

WEDNESDAY 9TH OCTOBER

3.30pm – 4.30pm	**WAROOKA HOTEL**

WE HOPE THAT YOU ARE ABLE TO ATTEND ONE OF THESE MEETINGS. PLEASE LET US KNOW IF THESE TIMES ARE NOT SUITABLE AND WE WILL ARRANGE TO SEND YOUR KIT TO YOU.

Port Lincoln Office Phone Number: (086) 830824

CARE FOR CALLIPERS.....

Please note that the tagging program finishes this season, which means that we will have insufficient funds to provide replacement callipers.

Please take care of the callipers supplied to you!

Appendix 3H: Instructions and examples for Kit A

INSTRUCTIONS:

1. How many lobsters do I measure out of each pot?

You must measure and sex EVERY lobster in EVERY pot. Sometimes this will mean lots of work and other times the pot may be empty and there will be no measuring. If the pot is empty it is still important to record the pot details. Whatever the case, it is very important that you record exactly what is in the pot.

2. How do I fill in the forms?

a. Weather conditions

Indicate what the weather conditions are for that day. Please include top and bottom temperatures if you have a thermometer. Remember to write down the pot number which contains the bottom thermometer. This will give us a location at which the temperature was taken.

b. Pot details

As each research pot comes up, record the pot number and then the position and depth of that pot in this section. Please report any octopus in the pot. Latitude and longitude need only to be recorded to a fraction of a minute.

For example, latitude would be written as 32.58 and longitude 136.24.

- When you have finished entering the details for pot 12 you will have filled up the ‘pot details’ section. Now turn over to a new page. Write down the date but you needn’t write all the weather conditions again. Then start pot 13 in the pot details section and its corresponding lobster details below in the ‘lobster details’ section*

c. **Lobster details**

After recording pot details, you then record the pot number again in this section. Then record the length, sex and maturity (reproductive state) of all lobsters from that pot. Maturity needs only to be recorded for females and is recorded as follows:

SS = short setae – no hairs on pleopods
LS = long setae – hairs present on pleopods
SP = spawny – female with eggs

3. What if I am unsure on any of the details. For example, a dead lobster with broken carapace that I can't measure?

Simply record anything unknown as "U"

4. What if the pot contains a dead lobster?

Record a "D" with the sex. For example, FD for dead female or UD for dead lobster of unknown sex.

5. What if I forget how to measure, sex or tell the reproductive state of a lobster?

Simply read the enclosed instructions and diagrams, or ring the research team on the "help line" numbers.

6. What do I do with the lobsters after measuring?

Just proceed as normal – keep the legal catch and undersize and spawnies can be returned.

7. What if, for some reason, I do not have enough time to sample every pot in one day?

Then you must do as many complete pots as you are able. DO NOT measure a few lobsters in all pots, it is important that you measure everything that comes up in each individual pot.

8. What do I do with the forms when I have finished for the day

Simply put your completed forms in the supplied reply-paid envelope and drop into a mailbox on the way home!

Appendix 3I: Instructions and examples for Kits B & C

1996 / 97 SA ROCK LOBSTER SURVEY PROGRAM

Volunteer Researcher:

………………………………………………………………………

Option:

Number of pots you are sampling:

……………………………………………

Number of days you will be sampling these pots

……………………………………………

Month/s you can choose your sampling days from:

……………………………………………

INFORMATION FORM

Please fill in the following form – we have included this to save you repeating the same information on every form.

Licence Number: ....

What depth units will you be working with?
(metres or fathoms?)

....

Please choose your research pots, mark them as 1, 2, 3 etc.

Do your research pots have escape gaps?
(please tick yes or no box)

	yes	no		yes	no
pot 1	☐	☐	**pot 7**	☐	☐
pot 2	☐	☐	**pot 8**	☐	☐
pot 3	☐	☐	**pot 9**	☐	☐
pot 4	☐	☐	**pot 10**	☐	☐
pot 5	☐	☐	**pot 11**	☐	☐
pot 6	☐	☐	**pot 12**	☐	☐

HELP LINES!

Please don't hesitate to call us with any comments or questions on:

In Mt Gambier:
(087) 242 934 or 242 930
Fax (087) 242 940

In Port Lincoln:
(086) 830 824
Fax (087) 830 857

INSTRUCTIONS:

1. Select your research pots

Decide which pots you would like to use for sampling and mark them in some way that will identify them as research pots. Please number them as 1, 2, 3, etc.

If you have thermometers, please put the bottom thermometer in one of your research pots. This pot number is marked on your forms in the temperature section. This will give us a location at which the temperature was taken

2. How should I set the research pots?

Do not treat the research pots any differently. Just mix them in with your other gear and set as you normally would. It is better if you spread the research pots our amongst your other gear to get information from a larger area.

3. What do I do when I pull a research pot?

When a research pot comes up, you must measure and sex EVERY lobster in that pot. Sometimes this will mean lots of work and other times the pot may be empty and there will be no measuring. If the pot is empty it is still important to record the pot details. Whatever the case, it is very important that you record exactly what is in the pot.

4. How do I fill in the forms?

a. Weather conditions

Indicate what the weather conditions are for that day. Please include top and bottom temperatures if you have a thermometer. Remember to write down the pot number which contains the bottom thermometer.

b. **Pot details**

As each research pot comes up, record the position and depth of that pot in this section. Please report any octopus in the pot. Latitude and longitude need only to be recorded to a fraction of a minute.

For example, latitude would be written as 32.58 and longitude 136.24.

c. **Lobster details**

After recording pot details, you then record the length, sex and maturity (reproductive state) of all lobsters from that pot. Maturity needs only to be recorded for females and is recorded as follows:

SS = short setae – no hairs on pleopods
LS = long setae – hairs present on pleopods
SP = spawny – female with eggs

5. What if I am unsure on any of the details. For example, a dead lobster with broken carapace that I can't measure?

Simply record anything unknown as "U"

6. What if the pot contains a dead lobster?

Record a "D" with the sex. For example, FD for dead female or UD for dead lobster of unknown sex.

7. What if I forget how to measure, sex or tell the reproductive state of a lobster?

Simply read the enclosed instructions and diagrams, or ring the research team on the "help line" numbers.

8. What do I do with the lobsters after measuring?

Just proceed as normal – keep the legal catch and undersize and spawnies can be returned.

9. What do I do with the forms when I have finished for the day?

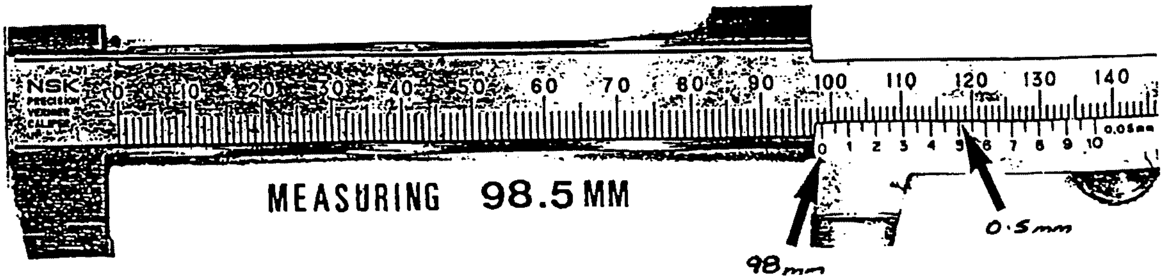
Simply put your completed forms in the post box on the way home!

MEASURING INSTRUCTIONS:

The size of the lobster is measured along the carapace, using the same two places on the shell that you normally use when determining whether a lobster is of legal size. An accurate measurement can only be made when the tapered face of the callipers is used between the antennae, and the antennae are spread apart.

Place the callipers over the lobster and slide the jaws along until they are a firm fit.

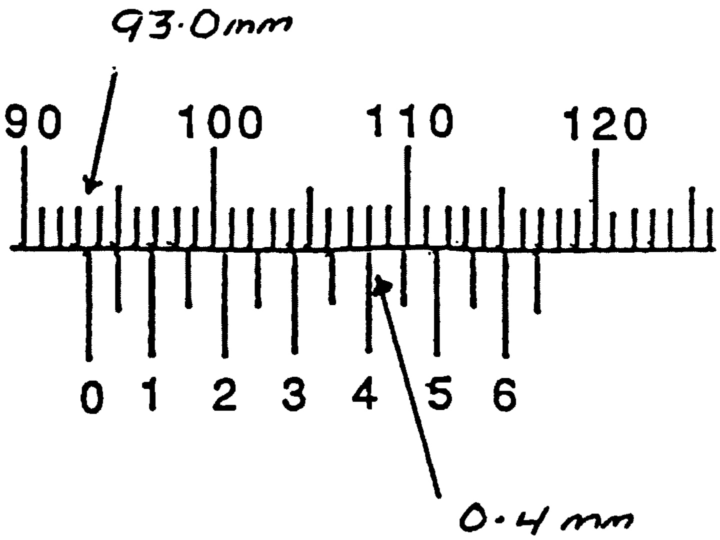
Read the number of millimetres at the "0" reading (<u>not</u> the edge of the sliding part of the calliper). Read the fraction of a millimetre along the bottom scale, where the whole millimetre scale and fractional scale are in line (see below):



In this example, the measurement is 98 millimetres. Then find a mark on the lower scale which aligns with a graduation on the top scale. In the above example, 5 on the lower scale aligns with a

Graduation of the top scale. The number on the lower scale is the decimal part of a millimetre, in this case 0.5 millimetres. The total length measured is 98.5 mm.

Let's look at another example below:



In this example, "4" on the lower scale aligns with a graduation on the top scale. The total length in this example would be recorded as 93.4 mm.

Appendix 4: Volunteer fisher data entry form

This was distributed and used by volunteer fishers for reporting their measurements of subsample of their catch. The form is returned monthly by the volunteer fishers and the information entered into the SA rock lobster fishery catch-monitoring database.

WEATHER DETAILS

17.11.96	Date	NE	Wind direction	14	Bottom Temp.
S017	Licence No.	5	Wind speed	16	Surface Temp.
		NW	Current Direction	46	Temp. pot no.
		0	Swell Height		

POT DETAILS

Pot No.	No. Octopus	Depth	Latitude	Longitude	Escape Gaps?
1	0	15	35 21	136 21	N
2	0	16	35 21	136 21	N
3	0	17	35 22	136 20	N
4	1	14	35 26	136 20	N
5	0	22	35 43	136 20	N
6	0	25	35 42	136 22	N
7	2	27	35 41	136 22	N
8	2	11	35 33	136 23	N
9	0	21	35 39	136 21	N
10	0	15	35 38	136 30	Y
11	1	17	35 38	136 30	Y
12	0	18	35 38	136 31	N
13	0	16	35 38	136 29	N

LOBSTER DETAILS

Pot No.	CL	Sex M/F	Maturity SS/LS/S	CL	Sex M/F	Maturity SS/LS/S	CL	Sex M/F	Maturity SS/LS/SP	CL	Sex M/F	Maturity SS/LS/SP
1	97.7	M		UU	FD	SS	128.	F	LS	97.2	UU	UU
	152.	M		120.	M							
2	NIL											
3	72.9	MD										
4	83.3	F	SS	92.2	F	SS	93.5	F	LS			
5	NIL											
6	NIL											
7	NIL											
8	125.	M		102.	FD	UU						
9	NIL											
10	NIL											
11	72.2	M		81.2	F	SS	119.	F	SP	110.	F	LS
	98.5	F	SP									
12	NIL											
13	112.	M		102.	M							