Assessment of the Victorian rock lobster fishery

Final report to

The Fisheries Research & Development Corporation

by

D.K. Hobday, T.J. Ryan, D.R. Thomson and R.J.Treble

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FISHERIES RESEARCH & DEVELOPMENT CORPORATION

PROJECT 92 / 104

MARINE & FRESHWATER RESOURCES INSTITUTE

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Project 92 / 104

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NON TECHNICAL SUMMARY

92/104	Assessment of the Victorian rock lobster fishery

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OBJECTIVES:

1. To obtain biological information on southern rock lobsters across Victoria, particularly size at maturity, size/age specific fecundity, growth and migration patterns.
2. To evaluate methods for estimating the size of southern rock lobster populations.
3. To determine the recreational impact on the resource.
4. To assess the current status of the fishery for southern rock lobster in Victoria.
5. To determine biological and population characteristics of rock lobster off Apollo Bay region, Victoria.

NON TECHNICAL SUMMARY:

The southern rock lobster (*Jasus edwardsii*) is fished commercially in south-eastern Australia and New Zealand. The Victorian annual catch is currently 458 tonnes with a landed value of $14.5 million representing 10.6% of total rock lobster landings in south east Australia (ABARE 1997). Over eighty percent of Victoria's catch is taken in the Western Management Zone (from the South Australian border to Apollo Bay).

Catch rates in the Victorian fishery have shown a steady decline from 2.5 kg/potlift in the 1950's to 0.47 kg/potlift in 1996/93 (Anon 1997). Since this time, the Western Zone catch rates have stabilised at around 0.5 kg/potlift (Anon 1997). The Eastern Zone catch rate declined steadily until 1992/93, and has shown some stabilisation over the past two years and is currently around 0.3 kg/potlift (Anon 1997).

Investigation of the biology of the species in Victoria highlighted the differences between the two management zones particularly with respect to size composition of the commercial catch, size at onset of sexual maturity (SOM), movement and growth.

Female lobsters were found to reach maturity at a smaller length in the Western Zone. SOM was estimated at 90 mm and 112 mm in the Western and Eastern fishing Zones respectively, and in the Apollo Bay area (at the eastern limits of the Western Zone), SOM was estimated around 96 mm. SOM, fecundity and commercial catch length frequency were used to estimate the relative reproductive potential of various size classes. In the Western Zone 75% of the reproductive potential came from the 105 and 110 mm size classes close to the legal minimum length. In contrast, maximum reproductive potential (40%) in the Eastern Zone was from the length classes between 125 and 135 mm.

The current level of egg production estimate in the Western Zone of 14% of the virgin, unfished stock, is well below the management target of 25%. Options for achieving a higher egg production from the Victorian component of the fishery include reduction of fishing mortality and increasing the LML. Reducing fishing mortality would in time increase the mean size of individuals in the population, resulting in higher egg production. Increasing the female LML from 105 to 110 mm (equivalent to male LML), would increase egg production particularly in the Western Zone where the maximum relative reproductive potential currently occurs at the present LML. However, this would place the LML 20 mm higher than the SOM which may be over-cautious in the long term. Such an increase in LML in the Eastern Zone would have less effect on overall egg production because of the low reproductive potential of animals at the current LML and the smaller size of the fishery compared with the Western Zone. However, an increase in LML in this Zone is necessary given the low percent mature at the current LML. A major concern of this study is the need for review of the legal minimum length in the Eastern Zone where the size at onset of sexual maturity is 113 mm CL (Hobday and Ryan, 1997) or 8 mm above the legal minimum length. Assuming an average growth of 3.0 mm/yr at 115 mm CL (Table 4), many females would be vulnerable to capture for in excess of 2 years before breeding.

Subjective measurement of the softness and degree of fouling of the carapace by polychaetes were found to be useful indicators of the moult state of *J. edwardsii* in the Apollo Bay area. These carapace condition data showed that there were strong sex-, size-, and reproductive state-specific moult timing patterns for *J. edwardsii* in the Apollo Bay area. Small and medium size males moulted asynchronously from August to April, in contrast to large males that moulted once per year around October. Mature females moulted once per year in late autumn to winter, just before mating and egg bearing. Larger mature females moulted earlier than smaller mature females.

A total of 10,297 lobsters were tagged during the study. Co-operation between MAFRI and commercial fishers was high. All tags were released from commercial vessels with fishers providing sea time to project staff at no cost. Fishers were also encouraged to tag and their involvement contributed to 40% of the total releases during the study. The majority lobsters were released in the Western Zone west of Cape Otway (7,030) and by the end of March 1996, 1,307 (13%) lobsters had been recaptured. Recapture rates decreased from the west to the east of the state, with the highest being from the South Australian border to Warrnambool (16%).

Tagging suggested that many medium size males (approximately legal-size) moulted twice per year, with annual growth of about 20 mm carapace length. Larger males moulted only once annually, probably with slightly smaller moult increments. Females grew at a slower rate than males, and immature females had higher growth rates than mature females. Average growth rates for both sexes were slightly higher in the Eastern Zone.

Movements of tagged lobsters while at liberty were mostly localised with 94% being recaptured within 10 km, and 65% within 500 metres of the original release position. Differences in the frequency of larger movements were more apparent between zones with 7% of Eastern Zone and only 1% of Western Zone recaptures moving more than 30 km. In the Eastern Zone, 15 females and 6 males moved more than 30 km, averaging 85 km. The mean time at liberty for these large movements was 289 days for females and 439 days for males, resulting in overall movement rates of 0.45 and 0.25 km/day respectively. The Eastern Zone movements generally followed the coastline between Barwon Heads and Cape Otway in a south westerly direction, with a mean distance moved of 35 km for females and 23 km for males. Of particular interest were the recaptures of several of these lobsters near King Island in Tasmanian waters, travelling 60 - 100 km. Unsetose females comprised the majority (79%)

of movements, generally moving to deeper water when recaptured. Setose and berried females were generally recaptured at the same depth as release.

Western Zone movements were less directional than in the Eastern Zone with movements greater than 50 km only observed by males. Most females moved in a south westerly direction representing travel to deeper water. This movement to deeper water was most noticeable among immature (unsetose) females that showed a mean distance of 21 km compared with setose (15 km) and berried (7 km). Movements of males were mostly in an easterly direction along the coast at similar depth contours.

The recreational SCUBA catch of rock lobster was estimated for 1995/96 using catch rate data from a random survey of dive shops, and biological data from Fisheries and Wildlife Officer interviews. The estimated Eastern Zone catch of 11,609 kg was approximately 20% of the commercial catch from all depths and 46% of the commercial catch shallower than 20 metres. The estimated recreational SCUBA rock lobster catch for 1995/96 in the Western Zone of 9,700 kg was 2.3% of the commercial catch at all depths and 15.5% of the commercial catch shallower than 20 metres.

Investigation of the change-in-ratio method of abundance estimation in the Apollo Bay region showed that only the precision of the female estimates was adequate for stock assessment. Precision was higher for females because the change in proportion of the catch that was of legal-size (effect size) was higher for this sex. Bootstrap re-sampling showed that the distributions of abundance and exploitation rate estimates were skewed (especially for males), so that confidence limits based on normal probability theory should not be used.

CPUE data from the 9 and 11 Mile Reef area during 1994-95 and from commercial fisher's logbooks were utilised in the Leslie method to obtain estimates of abundance and exploitation rate for legal-size lobsters in the Apollo Bay area. This method produced unrealistic, inconsistent and sometimes nonsensical results because its assumption of constant catchability was violated, and because of recruitment of males to legal-size during the fishing season.

Underwater visual census of inshore reefs around Apollo Bay by SCUBA divers was used to successfully estimate the density of *J. edwardsii*. These surveys showed that lobster density varied between sites, probably because of differences in the availability of suitable crevice habitat.

The Victorian stock is considered to be fully exploited with concerns over the level of egg production and the level of fishing effort. Stock assessment incorporated a range of models including biomass dynamic, yield per recruit and preliminary age structured. These included increases in fishing effort due to technological improvements, adjustment of fishing effort to summer equivalent, and a weighting for recreational catch. Results showed that too much effort is being expended in both fishing Zones resulting in reduced yield and lower egg production. The biomass dynamics (production) assessment models in the Western Zone estimated that the reduction in commercial effort needed to maximise yield was 22-29%. In the Eastern Zone fishing effort reductions of 26% and 34% were necessary to maximise yield assuming a recreational catch of 12 and 20 tonnes and increases in fishing power of 0 and 1% per year respectively.

Future research in Victoria should be directed towards more intensive biological sampling and tagging to further refine growth, exploitation rates and reproductive biology. Modelling of the fishery would then be best undertaken using existing models developed recently in the adjacent fisheries of South Australia (McGarvey, Matthews and Prescott 1997) and Tasmania (Punt and Kennedy 1997).

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KEYWORDS:

Southern rock lobster; Jasus edwardsii; abundance estimation; size at maturity; fecundity; recreational catch; stock assessment; growth; tagging.

Background to the project

The southern rock lobster (*Jasus edwardsii*) is found in the southern waters from south-west Western Australia to southern New South Wales, including the waters around and between Tasmania and New Zealand. An overlap occurs at the extremes of the Australian distribution in the west with the western rock lobster (*Panulirus cygnus*) and in the east with the eastern rock lobster (*Jasus verreauxi*). The major fishery for southern rock lobster occurs in the three south-eastern states of South Australia ($71.4 million), Victoria ($14.5 million) and Tasmania ($51.8 million) where in 1996/97 4,752 tonnes were landed, valued at $138 million (ABARE 1997). During the 1996/97 season, the Victorian component of this catch was 458 tonnes or 9.6% of the south eastern fishery catch (ABARE 1997).

Research into southern rock lobster fisheries is well advanced in the Tasmanian and South Australian fisheries and this project aimed to establish a research program to investigate basic biological parameters and assess the state of the Victorian component of the fishery.

This project evolved from the amalgamation of two applications to FRDC, one from the Department of Conservation and Environment to assess the status of the Victorian Southern Rock Lobster Fishery, and another from The University of Melbourne aimed at the evaluation of abundance estimation methods and investigation of biological parameters in the Apollo Bay region.

Need

Prior to this study, the status of the fishery in Victoria was uncertain. Catches and catch rates in both the eastern and western components of the Victorian fishery have fallen steadily since the 1970's prompting concerns about the long term viability of the fishery. An added uncertainty was the lack of information on the catch from the recreational fishery and its impact on the resource.

Some biological information was available for southern rock lobster in Victoria, but key parameters such as size at first maturity, size specific fecundity and recruitment processes were unknown, al of which are critical inputs to effective management of the resource.

The lack of detailed knowledge of the biology and dynamics of southern rock lobster in Victoria also impacts on the understanding of interactions across the south-eastern states, particularly in relation to recruitment processes.

Objectives

Objective 1: To obtain biological information on southern rock lobsters across Victoria, particularly size at maturity, size/age specific fecundity, growth and movement patterns.

Objective 2: To evaluate methods for estimating the size of southern rock lobster populations.

Objective 3: To determine the recreational impact on the resource.

Objective 4: To assess the current status of the fishery for southern rock lobster in Victoria.

Objective 5: To determine biological and population characteristics of rock lobster off Apollo Bay region, Victoria.

Methods

General biology - fecundity and size at onset of maturity

Fecundity was estimated from egg masses collected from 98 mature females of various sizes collected between Portland and Walkerville held in MAFRI aquaria. Eggs were stored in ethanol until ready for counting when they were dried at 40°C for at least 24 hours. The total dry weight was determined and three 0.04g samples were taken and the number of eggs in each was counted twice under a dissecting microscope. Fecundity was then estimated for each sample by simple proportion and the fecundity relationship fitted to all estimates using SAS non-linear model procedure

Size at onset of sexual maturity (SOM) was estimated from commercial catch sampling data and analysed to determine the smallest size class at which 50% of females were carrying eggs or possessed ovigerose setae.

SOM estimates, fecundity and commercial catch length frequency were used to estimate the relative reproductive potential of each 5 mm size class under current exploitation rates.

A detailed description of the methods used to determine *size at maturity and size specific fecundity* are documented in Appendix 3 - "Contrasting size at sexual maturity of southern rock lobster *(Jasus edwardsii)* in the two Victorian fishing zones: implications for total egg production and management" - D.K. Hobday and T.R. Ryan.

General biology - movement, growth and larval settlement

Data collection was conducted during at-sea observations aboard commercial rock lobster vessels operating out of major Victorian fishing ports (Fig. 1) between February 1994 and April 1997. Commercial fishers took project staff on board their vessels as observers during their normal fishing activities. The carapace length of all captured rock lobsters was measured and recorded along with details of the sex, size, shell state, and reproductive state of females (Table 1). All undersize lobsters, berried females and out of season females were tagged and released. Lobsters were tagged on the ventral surface of the first abdominal segment using Hallprint T-bar tags (50mm long with 23mm green identification section containing a unique 5-digit number and the lettering "MSL VIC"). All licensed Victorian commercial rock lobster fishers were provided with a tag return booklet containing 20 reply paid cards to record tag capture details including date, name and address, vessel, tag number, capture depth and position, carapace length, sex, shell colour and hardness, female reproductive state, injuries and if applicable, re-release position. These tag return booklets were also distributed to recreational SCUBA dive clubs and all coastal Fisheries and Wildlife Officers. Midway through the project, commercial fishers were encouraged to tag lobsters which they normally returned to the water. Approximately 40 fishers were trained by project staff to tag lobsters and supplied with a tagging kit comprising tags, tagging gun, release data sheets, recapture reporting cards and plastic callipers.

Moult timing and reproductive changes were investigated by (1) examining the proportion of soft shelled males and females and unsetose/setose/berried females in the commercial catch sampling data, and (2) observing changes in tag recaptures. Lobsters which grew or showed a reproductive change whilst at liberty for less than 100 days were given an equal probability of the change happening across each of the days at liberty. These daily probabilities were summed by month and expressed as a percentage of the monthly probabilities of lobsters where no change was observed.

Parameters describing growth rate from tagging data (time at liberty and lengths at release and recapture) were estimated using GROTAG, a program developed by Chris Francis (NIWA, Wellington, New Zealand) following methods described in Francis (1988).

The distance moved between tag release and recapture positions was calculated by:

Distance (km) = (arcos(cos(ab)cos(ac)+sin(ab)sin(ac)cos(bc))3969.665x1609.344)/1000

where: ab=((90 -release latitude)π)/180

ac=((90 -capture latitude)π)/180

bc=abs(((release longitude-capture longitude)π)/180)

Direction moved between tag release and recapture was calculated using the method described in Treble (1996). Fishers returning tag recapture information were sent details of the particular tag including distance and direction travelled, time at liberty and growth. The movement information given to fishers was rounded to the nearest 5km and eight compass point categories to protect confidentiality of release positions.

Larval settlement monitoring sites were established at Point Nepean, Ocean Grove, Barwon Heads, Lorne, Apollo Bay harbour, Marengo Reef (Apollo Bay) and Port Campbell (Fig. 1). Criteria for selection of these sites included proximity to reefs known to contain juvenile lobsters (established by consultation with commercial fishers), accessibility and ease of servicing in poor weather. At each site, crevice type puerulus collectors similar to those described by Booth and Tarring (1986) were used. Crevice collectors are used in Tasmania, South Australia, and New Zealand, and use of this collector for this study was based on a need to maintain consistency of collector types and larval collection methods across the distribution of *Jasus edwardsii.* Collector heads were constructed from marine grade plywood (8 sheets, 400 x 400 x 9 mm) enclosed in a galvanised iron frame with a single craypot anode. Collector heads were labelled using a plastic cow tags so that the history of individual collectors could be traced. Collector bases consisted of used car tyres filled with concrete with a 400 mm vertical galvanised pole on which the collector head was fixed by a removable stainless steel pin. At Port Campbell collectors were arranged in triangular groups with each connected by galvanised iron pipes to prevent movement in high seas.

Sites were serviced monthly by divers as close to the day of full moon as possible. During servicing, collector heads were covered with a fine meshed bag to prevent escape of puerulii during retrieval, removed from the base and winched aboard the boat where they were checked for pueruli. Information was recorded on the collector identification number, the number and stage (according to Booth 1979) of captured puerulii, number of crabs, shrimp and gobies, degree of fouling and the carapace length of any juvenile lobsters. Before returning collectors to the site, the crevices and outside surfaces were cleaned with a wire brush to maintain a constant settlement surface.

Abundance estimation and biological and population characteristics in the Apollo Bay region.

This component of the study was conducted in the Apollo Bay Region. Abundance of southern rock lobster (*Jasus edwardsii*) populations was estimated using the "change-in-ratio" and the Leslie methods, the latter of which can be used to estimate stock abundance from within-season trends in catch and effort data. These two methods were also used to estimate exploitation rates in the Apollo Bay area. Underwater visual census by SCUBA divers was used to estimate the number of lobsters per unit area (lobster "density").

A detailed description of the methods used to determine *the biological and population characteristics of rock lobster off Apollo Bay region, Victoria* , and for *estimating the size of southern rock lobster populations* are documented in Appendix 4 - "To evaluate methods for estimating the size of southern rock lobster populations" - R.J. Treble.

Recreational fishing

The recreational lobster catch was estimated using data from a SCUBA airfill survey conducted during 1993/94, a random monthly survey of divers obtaining airfills at dive shop outlets, and Fisheries and Wildlife Officer interviews. The airfill survey was used as an estimate of the SCUBA diving effort, dive shop survey gave an estimate of the number of lobsters caught and proportion of dives in each. The Fisheries and Wildlife Officer interviews were used to determine the length composition and sex ratio of the recreational catch.

A detailed description of the methods used to determine *the recreational impact on the resource* are documented in Appendix 5 - "The recreational catch and effort estimates for southern rock lobster in Victoria", - T.J. Ryan and D.K. Hobday.

Stock assessment

Fishery (Stock) Assessment Groups were formed to undertake annual assessments of Victoria's major fisheries and harvested stocks. Each assessment is conducted with reference to the stated management objectives for the fishery and the implications of the assessment for management of the fishery is a major outcome. The Groups were also established to ensure formal communication between fishery managers, scientists, industry and other client groups.

The 1996 assessment used preliminary results from this study including growth (not separated by zone), fecundity, and fishing mortality estimates. Catch and effort data was examined from 1951 to the present with data for the period 1978 to 1993 examined in detail. Length frequency data for the three periods 1963-67, 1980-86, 1990-96 from Portland were examined using length-converted catch curve analysis to estimate total mortality. Yield- and egg-per-recruit analyses were conducted using estimates of growth, mortality and fecundity derived from the current research program. These analyses were used to investigate the effect on yield from reductions in fishing effort and to estimate the current level of egg production. Two types of biomass dynamic models were applied separately to a set of catch and effort data for the Western Zone and Eastern Zone. Effort was adjusted to summer (November-April) equivalent and various scenarios were examined using a cumulative weighting of effort between 1978 and 1993 of 0%, 1.5% and 3.0% for technological improvements or increased fishing power.

A detailed description of the methods used to assess *the current status of the fishery for southern rock lobster in Victoria* are detailed in Appendix 6 - "Victorian Fisheries Assessment Report - Rock Lobster 1996" - D.K. Hobday and D.C. Smith.

The stock assessment was repeated in October 1997 using the methods outlined above and using the more recent results obtained from this study separating growth, size at onset of maturity, egg production and mortality estimates by Zone (Appendix 7).

Results

The following is a summary of the of the major results for each of the project objectives. A more detailed account of the results and discussion of their importance are provided in the relevant appendices.

General biology - fecundity and size at onset of maturity

Fecundity of *Jasus edwardsii* from Victorian waters was found to be related to carapace length (CL) by the equation: $F = 0.0316 \times CL^{3.359}$ ($r^2 = 0.8539$; n=571).

The Eastern Zone commercial catch sample contained a higher proportion of larger lobsters than from the Western Zone. SOM was estimated from commercial catch sampling (n = 3,891) and analysed to determine the smallest size class at which 50% of females were carrying eggs or possessed ovigerose setae. SOM in the Western fishing Zone (90 mm) was lower than in the Eastern fishing Zone (112 mm).

SOM estimates, fecundity and commercial catch length frequency were used to estimate the relative reproductive potential of each 5 mm size class. The maximum reproductive potential (75%) in the Western Zone was attributed to the size classes of 105 and 110 mm. In contrast, maximum reproductive potential(40%) the Eastern Zone was from the length classes between 125 and 135 mm. The results from this work indicated that the current legal minimum size limits need to be re-assessed and also that consideration be given to separate management strategies in each zone.

General biology - movement, growth and larval settlement

A total of 15,047 lobsters were examined during the study with 9,751 measured by on-board observers during commercial catch sampling and the remainder by commercial fishers when releasing or recapturing tagged lobsters. The Eastern Zone commercial catch sample contained a higher proportion of larger lobsters than from the Western Zone with males larger than 150mm and females larger than 120mm more abundant in the Eastern Zone (Figure 2). Sex ratio was similar for both zones with the proportion of females highest (61%) at start of the fishing season (November and December). The proportions of each sex were equal from January to April with males more common in the catch during May (66%), June (59%) and July (62%).

Occurrence of soft shelled lobsters in the catch was low, reflecting the shelter-seeking behaviour of recently moulted lobsters whilst the new shell is hardening. From the commercial catch data, the months with the highest percentage of soft shelled lobsters (4%) were March for females and June for males (Table 2). Analysis of tagging data for recaptures at liberty for less than 100 days at liberty, showed that the months with the highest summed probabilities of females moulting were April and June (Figure 3), and October to March and July for males (Figure 3). The mean length of tagged lobsters which moulted was higher for females between August and November and for males between October and December (Figure 3). Similarly, the highest summed probabilities for shell changing from hard to soft whilst at liberty were June / July for females and September for males (Figure 4).

The proportion berried females was highest in the commercial catch from July to October (Table 2). Consequently, these months showed the lowest percentage of setose females representing non-breeding or later breeding females (Table 2). Tagging data showed that females were most likely to undergo a maturing reproductive change (ie from unsetose to setose or berried, or from setose to berried) during March and April (Figure 5).

Movement

A total of 10,297 lobsters were tagged during the study with the majority released in the Western Zone west of Cape Otway (7,030) (Table 3). The tagging program was well supported by commercial fishers who tagged or re-released 4,534 lobsters or 44% of the total releases. The length distributions of the releases of females (Figure 6) reflected the distribution in the commercial catch (Figure 2) but the number of tagged males above the legal minimum length was proportionally lower because of the lack of seasonal closures for males during the fishing season thus biasing the releases to undersize males which must be returned to the water (Figure 6). Almost all of the males tagged above the legal minimum length were captured in pots supplied by project staff and set from commercial vessels during commercial catch sampling. By the end of March 1996, 1,307 lobsters or 13% of tagged lobsters had been recaptured (Table 3). Recreational divers reported 4 tag recaptures, 38 were recovered by lobster processors and the remainder were reported by commercial rock lobster fishers. Recapture rates decreased from the west to the east of the state, with the highest (16%) from the South Australian border to Warrnambool which was twice that from Wilson's Promontory to the New South Wales border (Table 3).

Movements of lobsters while at liberty were localised with 94% recaptured within 10 km, and 65% within 500 metres of their original release position. Small differences were observed in distances between the sexes for recaptures over larger distances with 2.9% of females and 2.4% of males moving more than 30 km. Differences in the frequency of larger movements were more apparent between zones with 7% of Eastern Zone and only 1% of Western Zone recaptures travelling more than 30 km. In the Eastern Zone, 15 females and 6 males moved more than 30 km (average 85 km), with most recaptured during November and December and several of these recaptured in Tasmanian waters to the northwest of King Island. The mean time at liberty for these large movements was 289 days for females and 439 days for males or 0.45 and 0.25 km/day respectively. Recaptures greater than 50 km from release were only observed by males in the Western Zone whereas similar movements of females occurred in both zones (Figure 7). For recaptures within 10 km of release, movements of females and males were similar within each zone (Figure 8) but the mean distance travelled was 1.2 km and 0.7 km in the Eastern and Western Zones respectively.

In the Eastern Zone, most movements followed the coastline between Barwon Heads and Cape Otway in a south westerly direction (Figure 9), generally following the coastal reefs in the area (mean distance females 35 km, males 23 km). Recaptures which travelled in a north westerly or south easterly direction represented inshore and offshore movements respectively (Figure 10). Unsetose females at release comprised the majority (79%) of movements, generally moving to deeper water when recaptured. Setose and berried females were generally recaptured at the same depth as release. The mean distance of males travelling in a north easterly direction, against the general direction in the zone, was much higher than for females (Figure 9).

Western Zone recaptures were less directional than observed in the Eastern Zone (Figure 10). Most females moved in a south westerly direction representing travel to deeper water (Figure 11). These movements to deeper water were most noticeable among immature (unsetose) females with a mean distance of 21 km compared with setose (15 km) and berried (7 km). Female lobsters travelling in an east-south-easterly and north-north-westerly direction were relatively frequent and represented movement along similar depth contours (Figure 11). Recaptures of males were mostly in an easterly direction showing movement along the coast at similar depth contours. However, two lobsters were recaptured over 100 km having moved in an east-south-easterly direction. Movements of males in northerly and southerly directions were less frequent in indicated inshore and offshore travel (Figure 11).

Growth

The majority of recaptured lobsters showed no growth while at liberty (Figure 12) but of those which did, the most frequent increments in carapace length category were 5 and 10 mm for females and males respectively (Figure 12). The GROTAG analysis estimated that the growth rate constant (K) was higher in the Western Zone for both sexes and L infinity values were higher in the Eastern Zone (Table 4). This was more noticeable in the results for females and probably caused by biases in tag releases towards smaller females in the Western Zone and large females in the Eastern Zone (Figure 6). In contrast, the estimated average growth rates (g_α g_β) for selected lengths showed faster growth in the Eastern Zone (Table 4). At 90 mm, the average growth rate for males (17.5 mm/yr, Table 4) was nearly three times that of females (5.9 mm/yr, Table 4). For larger lobsters, males (140 mm CL, Table 4) grew on average 7.4 mm/yr, more than twice that of females (3.5 mm/yr at 115 mm CL, Table 4). Males of 140 mm CL grew much faster in the Eastern Zone (8.1 mm/yr, Table 4) compared with the Western Zone (4.8 mm/yr, Table 4). Similarly, females grew faster in the Eastern Zone with an average rate of 3.0 mm/yr compared with 2.0 mm/yr in the West (Table 4).

Larval settlement

Larval collector sites were established at Apollo Bay and Marengo Reef in March 1994, Point Nepean in October 1995, Lorne Jetty in April 1995, Ocean Grove in June 1995 and at Port Campbell in August 1996 (Table 5). The Lorne site was discontinued in July owing to high surge and access problems, and the Point Nepean site was abandoned in September 1995 as a result of unstable substrate - neither of these sites recorded any puerulus settlement (Table 5). The highest and most consistent puerulus settlement was observed at the Apollo Bay harbour site where a general pattern of a relatively low settlement was observed from January to April with maximum settlement during August. The highest settlement of 3.17 puerulus / collector was recorded at Apollo Bay harbour during August 1995 (Table 5, Figure 13). Settlement at the nearby Marengo Reef collector site was initially similar to Apollo Bay harbour, but thereafter showed very low or no settlement (Table 5, Figure 13). Similarly, settlement at Ocean Grove was low and only occurred during two months since the site was established in 1995. The most recently established site at Port Campbell has shown a low level of settlement (0.17 - 0.25 puerulus/collector) in three of the eight months which it has been serviced (Table 5, Figure 13).

Abundance estimation and biological and population characteristics in the Apollo Bay region.

The following is a summary of the main results of the University of Melbourne component of the study. More extensive results are provide in Appendix 4.

This project evaluated various stock assessment methods that could in theory be used to estimate absolute abundance and exploitation rates of populations of the southern rock lobster, *Jasus edwardsii* in the Apollo Bay area of the Victorian lobster fishery. Data analysis concentrated on three types of information: data collected on board lobster fishing vessels, archived data from the Marine and Freshwater Resources Institute, and data from SCUBA surveys. Observations on lobster biology, catch composition, catch rates, and fishing strategy were collected during 100 days spent on board commercial fishing vessels operating out of Apollo Bay. Lobsters were tagged, and experiments conducted to determine the size-selectivity of lobster pots with escape-gaps. These data were used apply stock assessment methods to populations of *J. edwardsii* in the Apollo Bay area, and to evaluate the assumptions of these methods. Data to determine biological and fishery-related information (e.g., size at onset of reproduction) that are useful for assessment of the Victorian southern rock lobster fishery were collected in this project as well, and are presented here.

Subjective measurement of the softness and degree of fouling of the carapace by polychaetes were found to be useful indicators of the moult state of *J. edwardsii* in the Apollo Bay area. These carapace condition data showed that there were strong sex-, size-, and reproductive state-specific moult timing patterns for *J. edwardsii* in the Apollo Bay area. Small and medium size male *J. edwardsii* moulted asynchronously from August to April, in contrast to large males that moulted once per year around October. Mature female *J. edwardsii* moulted once per year in late autumn to winter, just before mating and egg bearing. Larger mature female *J. edwardsii* moulted earlier than smaller mature females. Immature females probably moulted more than once per year, one moult being after the moult period of mature females. There was significant recruitment to the fishery during the main summer fishing season, as a result of moulting to legal-size by males. A much lower level of moulting to legal-size by females was observed during the main fishing season.

Egg-bearing began around June in the Apollo Bay area, and females carried eggs from then until the main egg hatching period in September to November. Some smaller mature females did not have eggs during August to September, the peak of the egg bearing period. Large mature female *J. edwardsii* reproduced earlier than smaller mature females, matching the observed size-specific trend in moult timing. Size at onset of maturity (*SOM*) and size at onset of breeding (*SOB*) were calculated using observations on whether females had ovigerose setae (*SOM*) or if they were carrying eggs during the peak of the egg bearing season (*SOB*). Results from these two analyses were close: *SOM* was calculated as 96.3 to 96.8 mm carapace length, *SOB* was estimated as 98.7 mm carapace length. There was also some evidence that *SOM* varies between areas at Apollo Bay.

Tagging suggested that many medium size males (approximately legal-size) moulted twice per year, with annual growth of about 20 mm carapace length. Larger males moulted only once annually, probably with slightly smaller moult increments. Female *J. edwardsii* grew at a slower rate than males, and immature female *J. edwardsii* had higher growth rates than mature females. Tagging showed that most *J. edwardsii* moved little, although a very small proportion of lobsters moved significant distances offshore to the southwest in the Apollo Bay area. Low movement rates meant that stock assessment methods were not biased from emigration or immigration during sampling. Loss of Hallprint "t-bar" tags was virtually negligible, although loss of western rock lobster "toggle" tags was much higher because of loss of the tag's sheath. Some under-reporting of recaptured tagged lobsters by fishers was evident. Dorsally inserted t-bar tags were more conspicuous to fishermen, had no tag loss, were easier to insert, and may have resulted in less damage to lobsters.

On-board measuring showed that there were consistent differences in the size of *J. edwardsii* in catches from various areas around Apollo Bay. A comparison of 1969-76 and 1992-95 size-frequency (pooled over all areas and samples) showed that the size of legal-size *J. edwardsii* in commercial catches in the Apollo Bay area has shifted only slightly toward smaller lobsters.

Field experiments showed that escape-gaps in lobster pots let undersize *J. edwardsii* escape from pots while on the sea floor. Size-selectivity curves for pots with different size escape-gaps were calculated from (1) carapace depth and carapace length measurements and from (2) analysis of the experimental data. These data showed that the size of escape-gaps has a large effect on the sizes of *J. edwardsii* retained in pots, and that the current escape-gap size of 60 mm is optimum for the legal minimum lengths in the Victorian fishery. Nonetheless, there is potential for soft, postecdysial lobsters just above the legal minimum length to escape from pots with 60-mm escape-gaps. The was no evidence to support the hypothesis that escape-gaps enhance CPUE of legal-size *J. edwardsii*.

The most intensive catch data were collected on board one vessel that consistently fished one of the major fishing grounds (the 9 and 11 Mile Reef area) over one fishing season (1994-95). These data were used to estimate abundance and exploitation rates of *J. edwardsii* using the change-in-ratio method. Because sampling was with pots with escape-gaps, size-selectivity curves were used to adjust these data to obtain abundance of undersize lobsters. A new way to apply the change-in-ratio method is presented, utilising linear regression of the proportion of the catch that was of legal-size on each day of fishing versus cumulative catch. The estimates for abundance of legal-size *J. edwardsii* were approximately 2,000 for females and 2,300 for males. Exploitation rates were high, about 0.80 for females and between 0.45 and 0.57 (depending on statistical estimator used) for males over a 3 month period of exploitation (probably close to annual rates of exploitation). The higher estimate of exploitation for females could reflect the fact that the sex ratio of the catch was skewed toward females. However data from carapace condition and tagging showed that for males, recruitment to the legal-size component of the stock was significant, suggesting that exploitation of males was underestimated compared to females.

Bootstrap re-sampling was used to calculate confidence limits for the estimates of abundance and exploitation rate from the change-in-ratio method. These showed that the precision of the female estimates was adequate, but for males the precision was not adequate for stock assessment. Precision was higher for females because the change in proportion of the catch that was of legal-size (effect size) was higher for this sex. Bootstrap re-sampling showed that the distributions of abundance and exploitation rate estimates were skewed (especially for males), so that confidence limits based on normal probability theory should not be used.

CPUE data from the 9 and 11 Mile Reef area during 1994-95 (above) and from commercial fisher's logbooks were utilised in the Leslie method to obtain estimates of abundance and exploitation rate for legal-size lobsters in the Apollo Bay area. This method produced unrealistic, inconsistent and sometimes nonsensical results because its assumption of constant catchability was violated, and because of recruitment of males to legal-size during the fishing season.

Underwater visual census of inshore reefs around Apollo Bay by SCUBA divers was used to successfully estimate the density of *J. edwardsii*. These surveys showed that lobster density varied between sites, probably because of differences in the availability of suitable crevice habitat.

Recreational fishing

This research was the first attempt to quantify the recreational SCUBA catch of southern rock lobster in Victoria. The recreational catch component of marine fisheries resources is an issue of increasing concern, particularly for heavily exploited resources such as the southern rock lobster. The recreational diving community in Victoria is difficult to sample due to the lack of a structured recreational licence database in the state. Unlike states such as Tasmania and Western Australia, recreational divers are not required to apply for a specific rock lobster or abalone licence and are not required to register a name and address. It was therefore necessary for this research to utilise techniques which included a questionnaire distributed randomly in dive shops and Fisheries and Wildlife Officer (FWO) interviews conducted during regular coastal patrols. The dive shop questionnaires were used to calculate the catch rates of southern rock lobster which were then scaled up according to the total number of airfills for Victoria, as determined by an air-fill survey conducted during 1993/94. FWO interview information was also used to characterise the length distribution of the recreational catch sex so the numbers of lobsters determined in the dive shop survey could be converted to weight.

Dive shop survey

A total of 351 dive shop questionnaires were returned between November 1995 and September 1996, representing 2,135 SCUBA dives in the state. The following are the main findings of the survey:

- Different diving patterns were detected for each zone, but overall 48% of recorded dives were from the shore
- 78% of the respondents belonged to a dive club
- 45% of the total diving activity occurred in central Victoria between Torquay and Wonthaggi
- 61% of divers indicated that they targeted rock lobster and of these divers 44% also targeted abalone.
- In the Eastern Zone, a total of 195 rock lobster were caught during 1,463 dives giving a mean catch rate of 0.20 lobsters per dive.
- In the Western Zone 248 rock lobster were caught in 672 dives yielding a mean catch rate of 0.39 lobsters per dive.
- The catch rate of divers targeting rock lobster was approximately twice the overall catch rate for all divers in each zone, while catch rates appeared to increase for divers with more than 10 years experience.
- Catch rates varied between months throughout the course of the survey, with the highest in March and August 96 in the western and Eastern Zones respectively.

Fisheries and Wildlife Officer survey

A total of 246 interviews were conducted during the 1995/96 fishing season and a summary of the results follow:

- The main capture method was SCUBA (46%), followed by snorkel (33%) and hookah (12%).
- The average carapace length of males from the FWO survey was 136.7 mm, and the average carapace length of females was 116.0 mm, which converted to average weights of 1.36 kg and 0.84 kg for males and females respectively.
- The catch rates of the divers interviewed in this survey were higher than those estimated from the dive shop questionnaire which is believed to be due to the selective sampling of the survey.
- The FWO interviews indicated that only 9% of all divers interviewed caught 40% of the total recreational catch and that catch rates for the hookah divers in the Western Zone were much higher than for the other methods.

The total recreation catch in Victoria for 1995/96 was estimated as 18,241 kg or 3.9% of the commercial catch at all depths and 20.8% of the commercial catch in waters shallower than 20 metres. The total recreational rock lobster catch in the Eastern Zone (11,609 kg) was approximately 20.7% of the commercial catch at all depths and 46% of the commercial catch in water shallower than 20 metres. The total recreational rock lobster catch for 1995/96 in the Western Zone (9,700 kg) was 2.3% of the commercial catch at all depths and 15.5% of the commercial catch in water shallower than 20 metres. These estimates indicate the significant level of the recreational catch and the need for its inclusion in stock assessment.

Stock assessment

Catch rates in the Victorian fishery have shown a steady decline from 2.5 kg/potlift in the 1950's to 0.48 kg/potlift in 1992/93. Since this time, the Western Zone catch rates have stabilised at around 0.5 kg/potlift. The Eastern Zone catch rate declined steadily until 1992/93, showing some stabilisation over the past two years (confirmed by examination of catch rates of the more experienced fishers), and is currently around 0.3 kg/potlift.

Recent advances in technology such as colour sounders satellite navigation and planing hulls have increased fishing power and effort particularly in the Western Zone on the more distant fishing grounds, by enabling accurate and repeatable positioning on reefs.

The 1996 stock assessment incorporated a range of increases in fishing effort due to technological improvements and a weighting in the Eastern Zone for recreational catch. Results of the biomass dynamics (production) assessment models in the Western Zone estimated that the reduction in effort needed to maximise yield was 10%, 29% and 37% with corresponding increases in fishing power of 0, 1.5 and 3% per year.

The Eastern Zone production model estimated maximum yield with effort reductions of 36, 45 and 50% using effort standardised for winter fishing, a 7 tonne recreational catch and increases in fishing power of 0, 1.5 and 3% per year respectively. Effort reductions of 39, 45 and 51% would be required to maximise yield if a recreational catch of 14 tonnes is assumed.

Yield per-recruit models predicted that a small gain in yield of 8% could be achieved by reducing fishing mortality. Egg per recruit analysis estimated that the current Victorian egg production between 6 and 19% of the virgin, unfished stock (depending on the level of natural mortality used). This estimate is less than the management target of 25% of the virgin egg production, and is a cause for concern.

The 1997 stock assessment, conducted in October 1997, was able for the first time to estimate fishing mortality, yield and egg per recruit by fishing Zone. Fishing mortality was estimated at 0.1-0.2 in the Eastern Zone for both sexes, and 0.3 and 0.4-0.5 for males and females respectively in the Western Zone. These estimates of fishing mortality are consistent with tag recapture rates. Current egg production, expressed as a percentage of unfished egg production was 17-32% in the Eastern Zone and 14% in the Western Zone. These results were more optimistic than the previous assessment (Appendix 6) primarily because of the revised estimates of fishing mortality particularly in the Eastern Zone (Appendix 7).

The Gulland production model was fitted to catch and effort data for the period 1964/65 to 1996/97. The Fox model, however, could only be fitted with the addition of data from 1951/52 to 1963/64. As there are considerable uncertainties about the quality these data, results from the Fox model were not considered. The maximum yield and corresponding effort was estimated using the following effort weightings (for technological advances) determined after discussion with Industry participants at the Stock Assessment Workshop:

Eastern Zone 0% and 1.0%
Western Zone 0.5%, 1.25% and 2.0%

In addition the model was run using data adjusted for recreational catches of 0, 11.6 and 20 tonnes in the Eastern Zone, and 0, 9.7 and 20 tonnes Western Zone. Results for the Gulland model in the Eastern Zone showed that the reduction in commercial effort needed to meet effort at MSY were between 26.4% and 34.1% depending on the level of recreational catch and the effort weighting used (Appendix 7). This estimate was less than the previous assessment because of the partitioning of the reduction between commercial and recrational sectors. Results for effort reductions in the Western Zone were unchanged from the previous assessment and ranged from 22.2% to 24.3% effort reduction depending on the level of recreational catch and the effort weighting used (Appendix 7).

Discussion

The results of this work have provided important parameters for assessment of the fishery. Of major importance have been the differences in growth, movement and reproduction found between the two management zones and the need to consider these differences in future management.

The fecundity estimate for *J. edwardsii* in Victoria is similar to that by other workers in the region (Hobday and Ryan in press). Because of this similarity, further spatial refinement of the fecundity relationship would not seem necessary. This study has provided a preliminary picture of SOM in Victoria's two fishing zones, however, as SOM for *J. edwardsii* has been found to vary geographically (Annala et al. 1980), estimation of SOM at a finer geographical resolution within each fishing zone needs to be investigated in Victoria.

The current egg production estimate in the Western Zone of 14% of the virgin, unfished stock (Appendix 7), is well below the management target of 25%. The effect of local recruitment resulting from Victorian egg production is unknown, but until recruitment processes are defined, each of the States in the south-east fishery (South Australia, Victoria and Tasmania) should aim to maintain suitable levels of egg production. Options for achieving a higher egg production from the Victorian component of the fishery include reduction of fishing mortality and increasing the LML. Reducing fishing mortality would in time increase the mean size of individuals in the population, resulting in higher egg production. Increasing the female LML from 105 to 110 mm (equivalent to male LML), would increase egg production particularly in the Western Zone where the maximum relative reproductive potential currently occurs at the present LML. However, this would place the LML 20 mm higher than the SOM which may be over-cautious in the long term. Such an increase in LML in the Eastern Zone would have less effect on overall egg production because of the low reproductive potential of animals at the current LML and the smaller size of the fishery compared with the Western Zone. However, an increase in LML in this Zone is necessary given the low percent mature at the current LML. A major concern of this study is the need for review of the legal minimum length in the Eastern Zone where the size at onset of sexual maturity is 113 mm CL (Hobday and Ryan, in press) or 8 mm above the legal minimum length. Assuming an average growth of 3.0 mm/yr at 115 mm CL (Table 4), many females would be vulnerable to capture for in excess of 2 years before breeding.

Winstanley (1975) found that females moulted from mid May to mid June prior to mating and that males moulted later during October and November. The present study confirmed Treble's (1996) results which showed a much longer moult period for males with the larger males moulting around October but with moult activity occurring between August and April. Treble (1996) also found that the main period of female moulting was autumn to early winter with larger individuals moulting earlier. The results from this study showed that smaller females were moulting during autumn-winter, and larger females during September-October. This spring moult of larger females was also observed during the course of the study in captive lobsters held as part of the reproductive investigations of the project.

Movements of lobsters in this study were consistent with other workers (eg. Annala and Bycroft 1993, Treble 1996) with the majority of tag recaptures showing little movement. Similar patterns of offshore movement of maturing females observed by Winstanley (1975) were also seen. The most interesting results from the present study were from tagged lobsters which moved more than 30km from release. The majority of such movements occurred in the Eastern Zone from releases of females between Barwon Heads and Apollo Bay and then recaptured during November and December to the south west towards King Island. Tagging studies in South Australia have also shown little movement overall with a small component of recaptures moving larger distances but in contrast to this study, without any single area of destination (J. Prescott pers. Comm.). Annala and Bycroft (1993) found that long distance movements of *J. edwardsii* in southern New Zealand were usually highly directional in opposition to the prevailing current system. It is possible that some of the Eastern Zone (Bass Strait) females move in the direction of the continental shelf adjacent to the Southern Ocean to breed, but until the dynamics of larval dispersion in the region are known and more tagging is conducted, this cannot be substantiated.

The assessment of growth rates by zone differed according to whether the von Bertalanffy growth parameters (K, L_∞) or the mean growth at arbitrary lengths (g_α, g_β, Francis 1988) were used. There has been much concern about the use of von Bertalanffy growth parameters to describe the discontinuous growth of crustaceans. In this study, the results of the GROTAG analysis, namely faster growth in the Eastern Zone, explain the observed bias in length frequency distribution towards larger animals in this Zone. Similar results have been found in South Australia where growth is slower in areas of high catch rates and presumably high recruitment, possibly because of density dependant factors (J. Prescott pers. Comm.).

The establishment of larval collection sites in Victoria as part of this study has been important in terms of building a long term monitoring program in South East Australia in order to understand larval recruitment processes in the region. The important feature of the data collected to date is the variability between sites and the subsequent difficulty in comparing absolute settlement rates on a wider scale. As an example, the Apollo Bay Harbour site showed the highest settlement rates but these were not reflected in the Morengo Reef site less than 5 km away. Settlement rates from Apollo Bay Harbour were consistent with those from South Australia and Tasmania as was the peak settlement observed during 1995 at many sites in south east Australia (Frusher, Prescott and Hobday 1997). The main operational problems with the larval collection were the expense of servicing, accessibility and exposure to extreme weather. Continuation of the monitoring is critical at sites such as Apollo Bay Harbour and less productive sites may need to be relocated. Establishment of larval collector sites in western Victoria is a high priority and because of more extreme sea conditions may require some structural modification as was necessary at the Port Campbell site.

The estimates of exploitation (exploitation rate (u) = $1-e^{-F}$, where F is fishing mortality) and abundance from the study produced varying results and highlighted the need for further work in this area. Treble's (1996) use of the change in ratio and Leslie methods in two reefs west of Apollo Bay were not conclusive. The change in ratio method produced very high estimates of exploitation rate for females (0.8, F=1.6), and a large range for males (0.04 - 0.75, 95% CI). The low precision for males was mainly because of the smaller decrease in the proportion of legal-size in the population during the fishing season. The change-in-ratio method is more efficient in fisheries where a large proportion of the stock is taken out in a short time, because in such cases the "closed population" assumptions of the method are less likely to be violated, and the precision of the method is highest. However, a high exploitation fishery is often contrary to management objectives. Hence reductions in exploitation rate through management changes may make the change-in-ratio method less precise and not as useful. The Leslie method gave much lower estimates of exploitation, 0.49 (F=0.65) for females and 0.07 (F=0.07) for males and for the latter was not reliable probably because of changes in catchability during a season. There is probably scope for using the existing extensive CPUE data sets with biological and environmental data to understand the causes of changes in catchability of *J. edwardsii*. Mean annual CPUE is probably a more reasonable way of utilising CPUE data for stock assessment. However this only provides an index of abundance. Techniques such as the change-in-ratio method are needed to obtain estimates of absolute abundance and exploitation rates of *J. edwardsii* stocks. Winstanley et al. (1982), and Powell (1977b) published estimates of fishing mortality in the Victorian fishery ranging from F of 0.2 to 0.64. In the present study Hobday and Smith (1996) using length converted catch curves, estimated fishing mortality in the Western Zone between 0.28 and 0.45, which were more consistent with Treble's tag recapture rate of 30% (Treble 1996) suggesting that exploitation was only about 30% (F=0.36) in the area. More recent estimates of fishing mortality from the 1997 stock assessment were similar for the Western Zone but much lower in the Eastern Zone (Appendix 7). In addition, size-frequency distributions of lobsters in the Treble's work were quite broad (Treble 1996), i.e., many lobsters managed to grow to be much larger than the legal minimum lengths, the opposite expected under a high exploitation rate. Therefore the size-frequency data also suggest that the estimates of exploitation rate produced by the change-in-ratio method, especially for females, could be too high.

SCUBA surveys for the estimation of abundance were easily applied to stocks of *J. edwardsii* in Victoria (Treble 1996). However, such underwater visual census techniques are only applicable to inshore stocks, and they cannot be used to assess the main stocks of *J. edwardsii* inhabiting areas deeper than 20-30 m. In addition, there is still the problem of scale, because density estimated on the larger scale of a fishing ground is likely to be different to density estimated from diver surveys. A standard survey over time could be used as an index of abundance, and used to monitor the "health" of lobster stocks.

With the growing national diving population, the pressure on marine resources will undoubtedly increase. An important component of stock assessment therefore is recreational catch and effort data, particularly in the Eastern Zone where divers and commercial fishers both utilise the same inshore reefs. The survey of dive shops showed that in the more popular recreational lobster diver locations, the proportion of the recreational catch caught by SCUBA may have more impact on inshore populations than the commercial fishery in the same area. The estimated catch from this survey represented a lower limit as they did not include capture methods such as hookah which were found in the Fisheries and Wildlife Officer survey to comprise 12% of the interviews and resulted in a higher catch rate than for SCUBA. These results emphasise the need for a better licensing system for recreational lobster fishers which would enable random surveys to be conducted annually across all capture methods to better estimate catch rates for inclusion in stock assessment.

The current stock assessment highlighted the need for effort reductions which are required to achieve sustainable yields, and concerns about the current level of egg production in the

Western Zone. The effect of local recruitment resulting from Victorian egg production is unknown, but the South East Australian fishery must be considered as a whole and each State should be responsible for maintaining suitable levels of egg production. Effort reductions would provide benefits to the Victorian fishery by increasing egg production, increasing long term yield, and improving the economics of fishing. Similar results have been found in South Australia's southern Zone where the same yield could be expected with less effort if rates of fishing mortality were reduced (Prescott et. al 1997)

Examination of CPUE in the Western Zone indicated that the fishery has stabilised in recent years. The management target of a 25% reduction in effort remains appropriate. In the Eastern Zone, CPUE appears to have also stabilised. The revised estimates for the percentage reduction in effort of 26-34% to achieve maximum yield, require a review of the management target in the Eastern Zone. It is important however, that any reduction in effort in both zones must be applied to both the commercial and recreational fisheries.

A high priority should be given to further improve the spacial resolution of the biological and fishery parameters for the Victorian fishery. This study has been successful in resolving these to the level of fishing zone but more data will be required in order to model the fishery using models developed in South Australia (McGarvey 1997) and Tasmania (Punt and Kennedy 1997.

Benefits

This project provided a much needed assessment of the biology and fishery parameters for the Victorian Southern Rock Lobster Fishery. It has helped form the basis for continuing monitoring of the resource and identified directions for future research. The community has benefited by annual assessments of the state of Victoria's southern rock lobster resource which are key inputs to the management of the fishery. The results of the study have been used extensively in the management of the fishery by the Rock Lobster Committee of the Fisheries Co-management Council.

Further Development

The highest priority for future research is collection of more detailed biological information. This should be conducted in conjunction with commercial fishers as an on-board measuring and tagging program. The resulting data would be used to estimate parameters such as SOM, growth, movement and exploitation rates at a finer resolution, and provide data for length-based population modelling.

The data base established as part of this study will continue to be maintained and data from tagged lobsters currently at liberty analysed. Liaison with commercial and recreational fishers will be on-going to maintain the high level of tag reporting established in this study.

Monitoring of puerulus and pre-recruits as an index of recruitment variability should be continued, particularly in light of increasing research effort investigating the dynamics of pelagic stages of the larval cycle prior to settlement.

Monitoring of the recreational catch should be continued. This should be based on a licensing system which would require an endorsement to take lobsters, enabling assessment of the catch by all capture methods using a random survey of recreational lobster licence holders.

There is a need for a more sophisticated analysis of commercial catch and effort data to provide estimates of changes in fleet dynamics, including fishing power and gear competition.

Conclusion

All of the objectives set in the original proposal were successfully completed.

Objective 1: To obtain biological information across Victoria, particularly size at maturity, size/age specific fecundity, growth and movement patterns.

Extensive biological data on southern rock lobsters was collected during the study with the main outcomes as follows:

- A fecundity / carapace length relationship was determined.
- Size at onset of maturity was determined by fishing zone and also at a finer spatial resolution in the Apollo Bay region.
- Growth relationships were determined for each sex by fishing zone from tagging data.
- Movement patterns were examined an showed a marked difference between the two fishing zones with movements in the Eastern Zone on average larger and more directional than in the West.
- Reproductive patterns and moult cycles were defined.

Objective 2: To evaluate methods for estimating the size of southern rock lobster populations.

- The Change in Ratio and Leslie methods were used to estimate population size in the Apollo Bay region but the results were generally not reliable.
- Underwater SCUBA visual surveys were more successful but would be difficult to extend to waters deeper than 20-30 metres.

Objective 3: To determine the recreational impact on the resource.

- The recreational SCUBA catch was estimated by fishing zone for the 1995/96 fishing season and compared to the total commercial catch and the commercial inshore catch.

Objective 4: To assess the current status of the fishery for southern rock lobster in Victoria.

- A range of models were used to assess the fishery including biomass dynamic, yield per recruit and age structured.
- Various scenarios accounting for changes in fishing power and inclusion of recreational catch during the time series of catch and effort data were examined and included in the models.
- Effort reductions required to achieve maximum sustainable yield were estimated for each fishing zone.

Objective 5: To determine biological and population characteristics of rock lobster off Apollo Bay region, Victoria.

Extensive data was collected in the Apollo Bay region defining reproductive and moult cycles along with growth and movement patterns.

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Tables

Table 1. Observations recorded during at-sea observations aboard commercial fishing vessels.

Observation	Details recorded
Fishing unit	Vessel name and Registration
	Skipper and crew
Position	Latitude, longitude from vessel's GPS
	Depth
	Date
Tag number	Tag number when used
Pot number	Number of pot retrieved
Lobster size	Carapace length to the nearest 0.1mm.
Sex	Male or female
Shell colour	Red
	Speckled
	White
Shell hardness	Very soft (indicating recent moult)
	Soft / Flexible
	Hard
Female reproductive state	Unsetose
	Short setae
	Setose
	Berried
Injuries	External damage
Other	Number of dead lobsters
	Number of octopus

Table 2. Occurrence of soft shelled lobsters and reproductive state of females from commercial catch sampling data between February 1994 and April 1997.

	Female					**Male**	
Month	Number measured	Percent soft shelled	Percent unsetose	Percent setose	Percent berried	Number measured	Percent soft shelled
January	457	0%	21%	77%	3%	337	0%
February	426	0%	35%	64%	0%	465	0%
March	342	4%	23%	77%	0%	401	1%
April	241	1%	13%	86%	0%	234	1%
May	607	0%	15%	85%	0%	1174	0%
June	36	0%	22%	78%	0%	53	4%
July	281	2%	37%	4%	59%	462	1%
August	620	2%	42%	6%	53%	686	1%
September	305	0%	52%	14%	34%	218	0%
October	307	1%	14%	24%	62%	74	0%
November	840	0%	13%	76%	12%	466	0%
December	454	0%	8%	89%	3%	239	1%

Table 3. Number of tags released and recaptured by broad area between February 1994 and April 1997.
(Tags released by R. Treble omitted)

Area	Number released	Number recaptured	Percent recaptured
South Australian border to Warrnambool	4,379	691	16%
Warrnambool to Cape Otway	2,651	349	13%
Cape Otway to Queenscliff	2,080	178	9%
Queenscliff to Wilson's Promontory	560	40	7%
Wilson's Promontory to New South Wales border	627	49	8%
Total	10,297	1,307	13%

Table 4. Results of growth parameter estimation from tagging data using Grotag model.

Parameters		Male			Female		
		Western Zone	Eastern Zone	Both Zones	Western Zone	Eastern Zone	Both Zones
Mean growth	$g_{(cl)}$ (mm/year)	$17.7_{(90)}$	$16.7_{(90)}$	$17.5_{(90)}$	$6.6_{(90)}$	$7.7_{(90)}$	$5.9_{(90)}$
	$g_{(cl)}$ (mm/year)	$4.8_{(140)}$	$8.1_{(140)}$	$7.4_{(140)}$	$2.0_{(115)}$	$3.0_{(115)}$	$3.5_{(115)}$
Seasonal variation	u	0*	0.92	0*	0.90	0*	0.0
	w	0*	0.90	0*	0.90	0*	0.0
Growth variability	v	0.11	1.02	0.50	0*	1.09	0.75
	t	0*	0*	0*	0*	0*	0*
Measurement error	s (mm)	4.3	4.3	4.3	2.2	0.9	1.2
Outliers	p	0.15	0.02	0.01	0.10	0.08	0.06
Number	n	481	118	598	770	190	886
Asymptotic length	L_∞ (cl, mm)	172.2	187.8	177.0	126.4	161.2	151.7
Growth constant	K	0.24	0.19	0.22	0.20	0.10	0.10

Table 5. Number of puerulus collectors serviced (top) and mean number of puerulii per collector (in brackets) for all sites from March 1994 to April 1997. *Collectors serviced twice in July 96 as two full moons occurred in the month. Dots indicate months when sites were not serviced, crosses discontinued sites.

1994

Month	1	2	3	4	5	6	7	8	9	10	11	12
Apollo Bay Harbour (number/collector)			6 (1.33)	6 (0.50)	6 (0.00)	6 (0.00)	6 (0.50)	. .	6 (1.67)	6 (0.17)	. .	. .
Marengo Reef			6 (0.00)	6 (0.33)	. .	6 (0.60)	6 (1.00)	. .	6 (0.00)	6 (0.00)	. .	. .
Point Nepean										6 (0.00)	. .	. .

1995

Month	1	2	3	4	5	6	7	8	9	10	11	12
Apollo Bay Harbour	. .	6 (0.00)	. .	6 (0.00)	6 0.83	6 (2.50)	6 (1.17)	6 (3.17)	6 (1.33)	6 (1.00)	6 (0.83)	6 (0.67)
Marengo Reef	6 (0.00)	3 (0.00)	. .	6 (0.00)	2 (0.00)	5 (0.00)	6 (0.17)	6 (0.00)	. .	6 (0.00)	6 (0.00)	2 (0.00)
Ocean Grove						3 (0.00)	3 (0.00)	2 (0.00)	. .	2 (0.00)	. .	6 (0.00)
Lorne Jetty				6 (0.00)	6 (0.00)	6 (0.00)	6 (0.00)	X	X	X	X	X
Point Nepean	6 (0.00)	6 (0.00)	6 (0.00)	6 (0.00)	6 (0.00)	6 (0.00)	6 (0.00)	6 (0.00)	X	X	X	X

1996

Month	1	2	3	4	5	6	7-1*	7-2*	8	9	10	11	12
Apollo Bay Harbour	6 (0.50)	6 (0.50)	6 0.83	6 (0.17)	6 (0.00)	6 (0.00)	6 (1.00)	6 .83	6 1.83	6 0.83	6 0.67	6 (0.17)	6 (0.00)
Marengo Reef	6 (0.00)	6 (0.00)	6 (0.00)	6 (0.00)	6 (0.00)	6 (0.00)	6 (0.00)	6 (0.00)	6 (0.00)	6 (0.00)	6 0.20	6 (0.17)	6 (0.17)
Ocean Grove	6 (0.00)	6 (0.17)	6 (0.17)	6 (0.00)	6 (0.00)	6 (0.00)	6 (0.00)	6 (0.00)	6 (0.00)	. .	6 (0.00)	6 (0.00)	6 (0.00)
Port Campbell									6 (0.17)	6 (0.00)	6 (0.00)	6 (0.00)	6 (0.25)

1997

Month	1	2	3	4
Apollo Bay Harbour	6 (0.33)	6 (0.33)	6 0.83	6 (0.33)
Marengo Reef	6 (0.00)	6 (0.00)	6 (0.00)	6 (0.00)
Ocean Grove	6 (0.00)	6 (0.00)	6 (0.00)	12 (0.00)
Port Campbell	6 (0.20)	. .	6 (0.00)	6 (0.00)

Figures

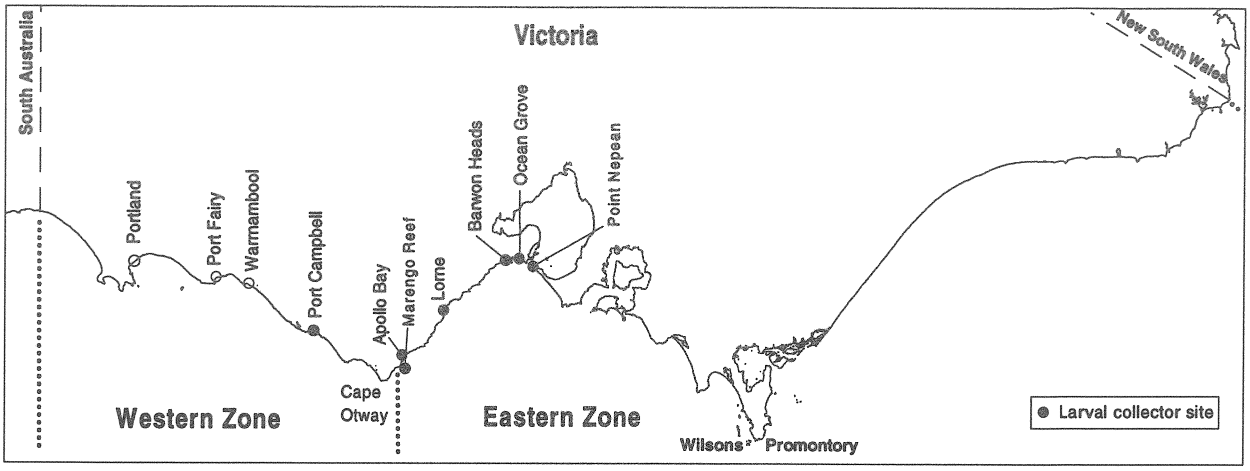
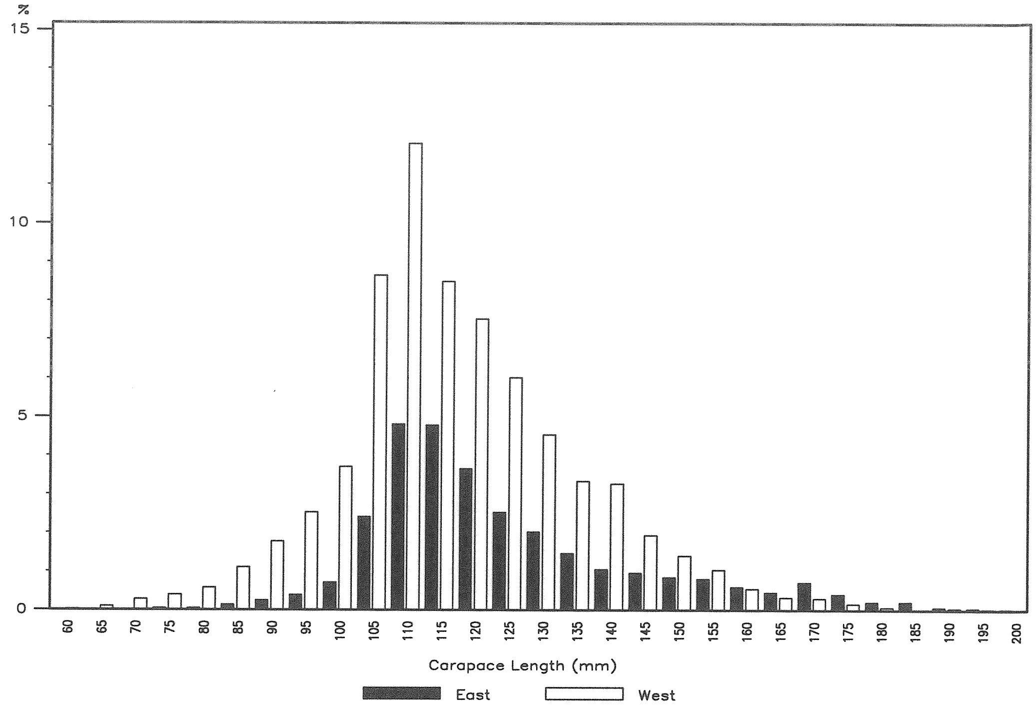


Figure 1. Map of study area showing main Victorian rock lobster fishing ports, fishing Zones and larval collection sites.

Male



Female

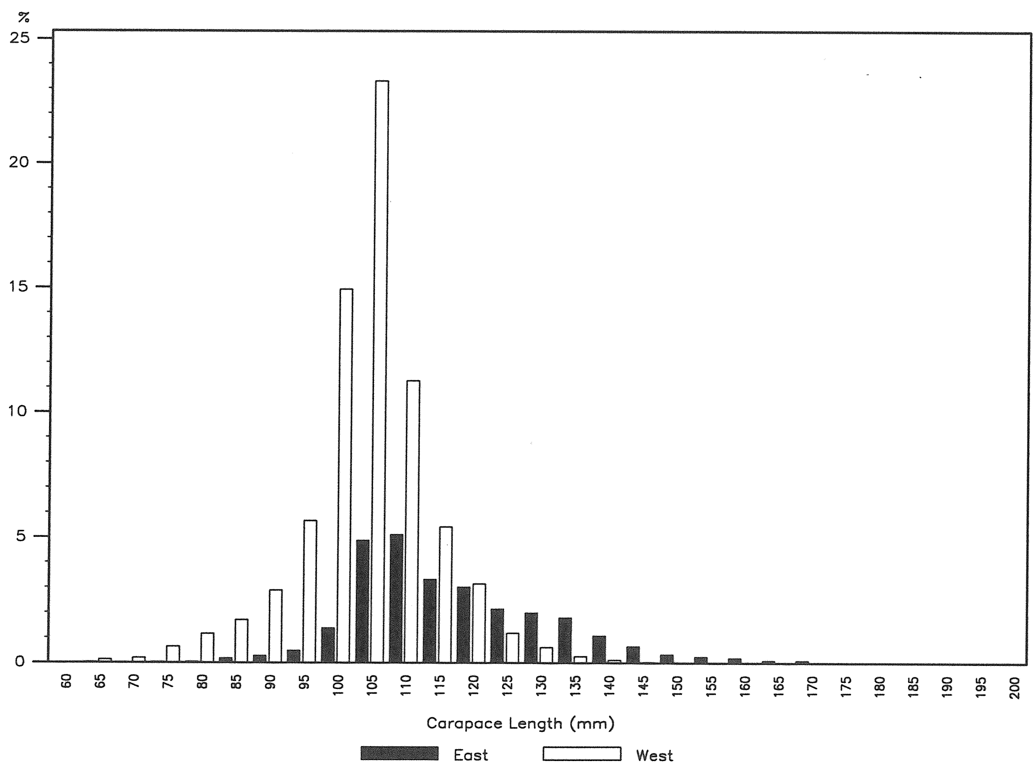


Figure 2. Length frequency for male (top, n=4,818) and female (bottom, n=4,933) lobsters measured by on-board observers during commercial catch sampling (February 1994 - April 1997).

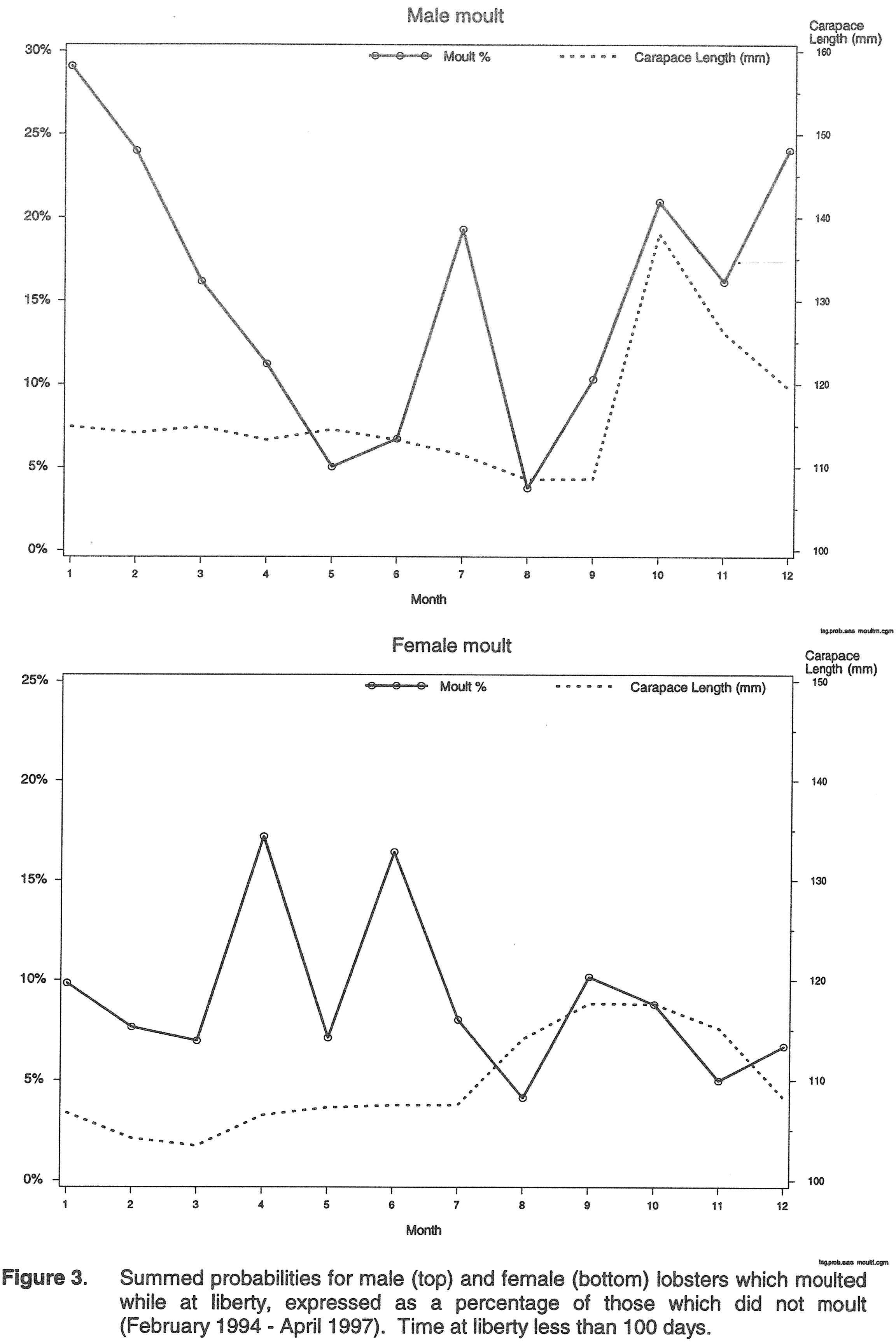


Figure 3. Summed probabilities for male (top) and female (bottom) lobsters which moulted while at liberty, expressed as a percentage of those which did not moult (February 1994 - April 1997). Time at liberty less than 100 days.

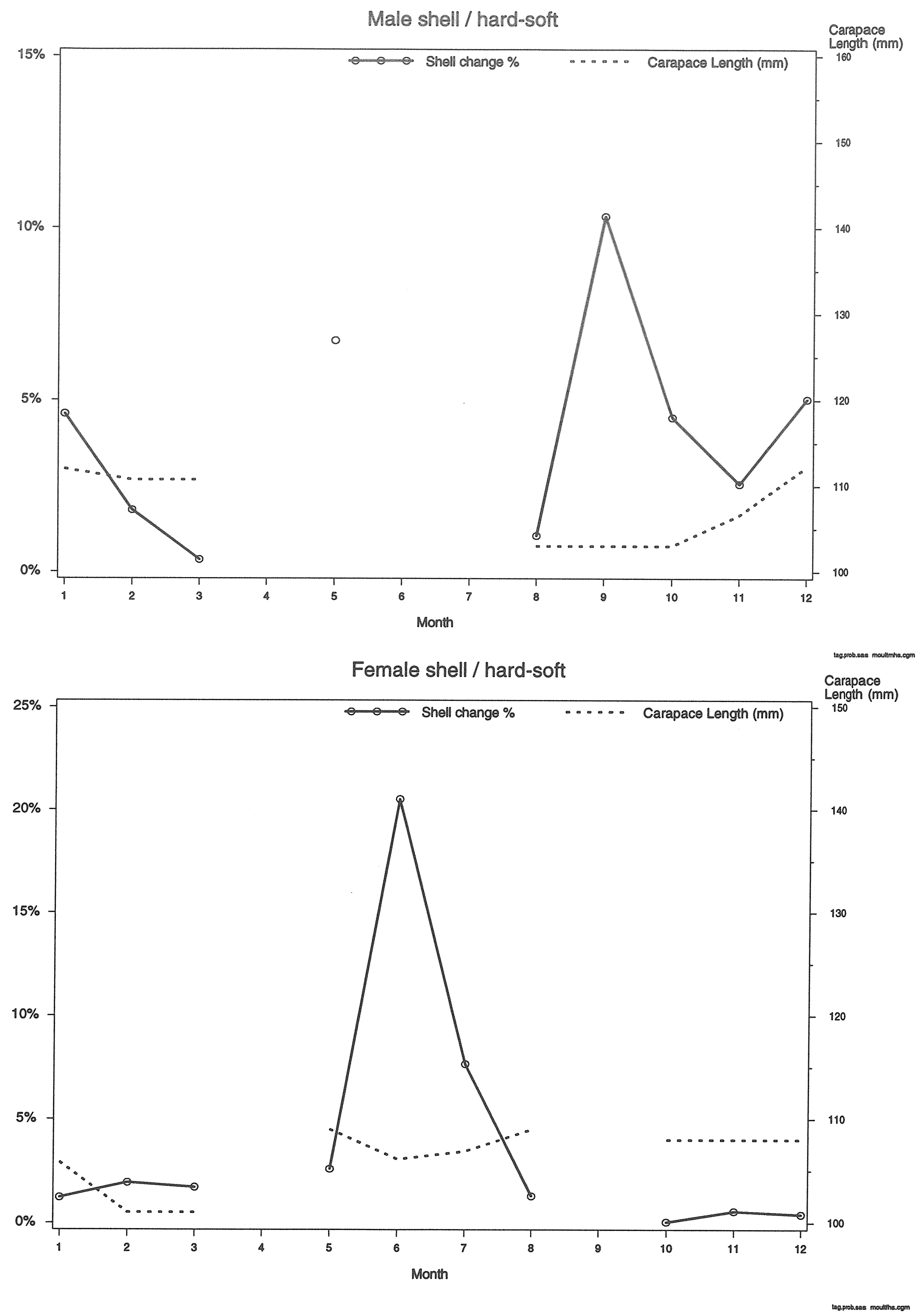


Figure 4. Summed probabilities for male (top) and female (bottom) lobsters where shell changed from hard to soft during time at liberty (less than 100 days), expressed as a percentage of those in which shell condition did not change (February 1994 - April 1997).

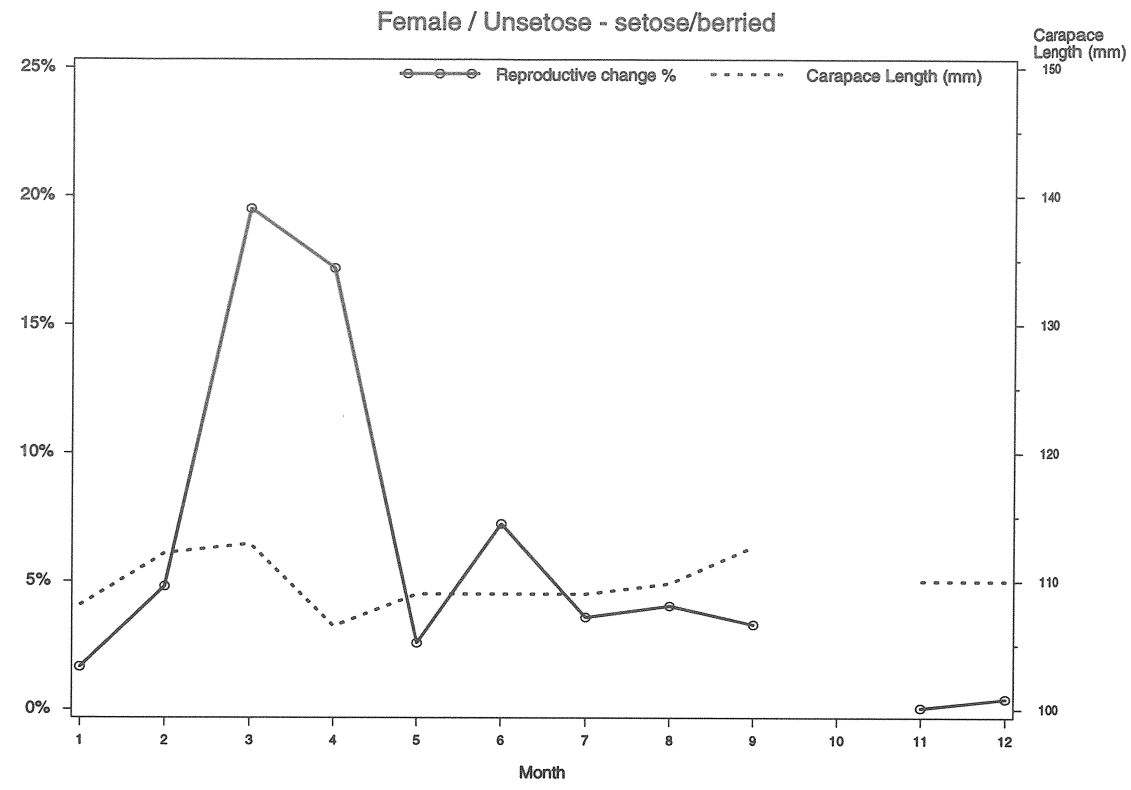


Figure 5. Summed probabilities for lobsters which changed from unsetose to setose or from setose to berried while at liberty, expressed as a percentage of those which did not moult (February 1994 - April 1997). Time at liberty less than 100 days.

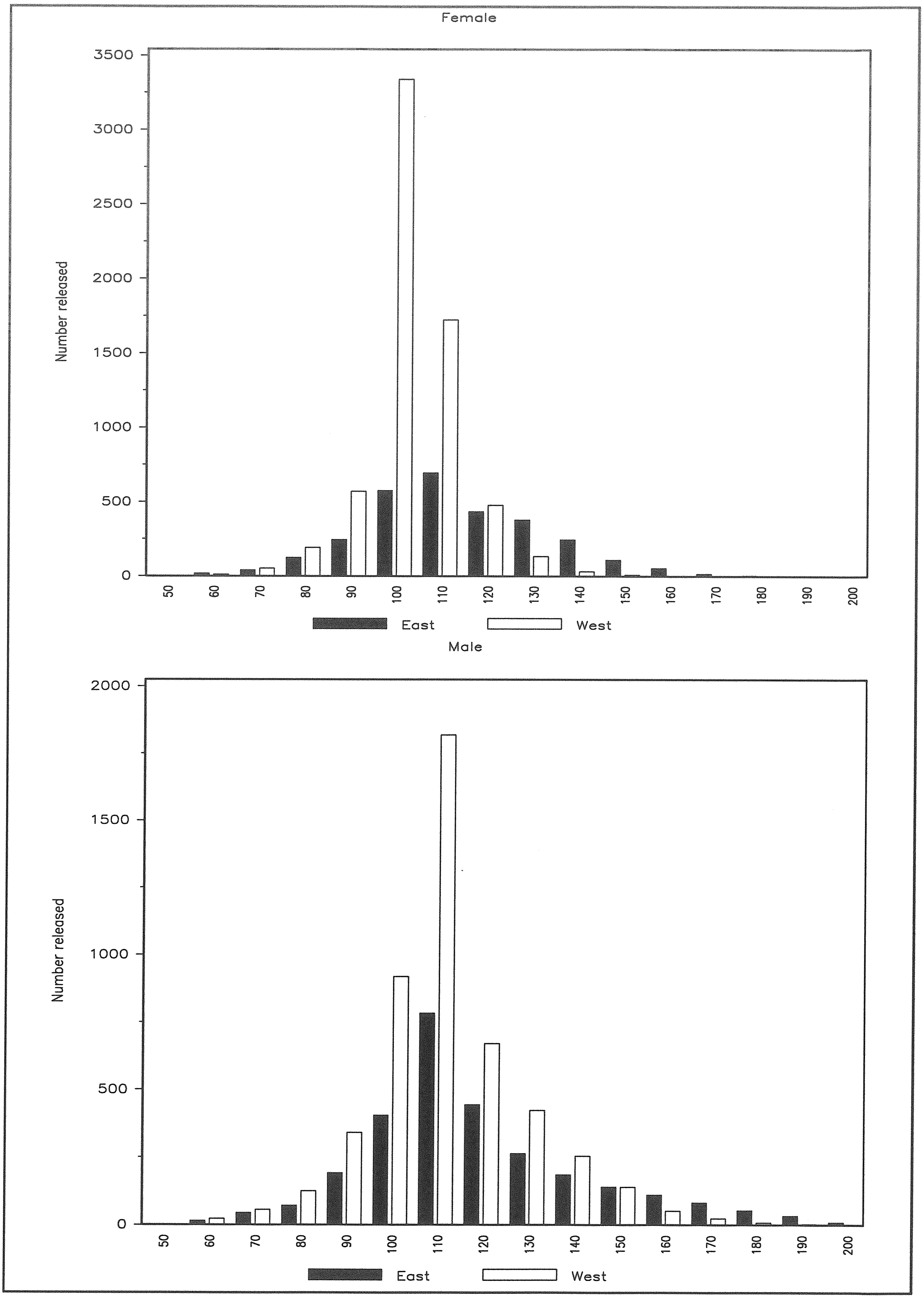


Figure 6. Length frequency distributions of tagged female (top) and male (bottom) lobsters by Victorian management zone (February 1994 - April 1997).

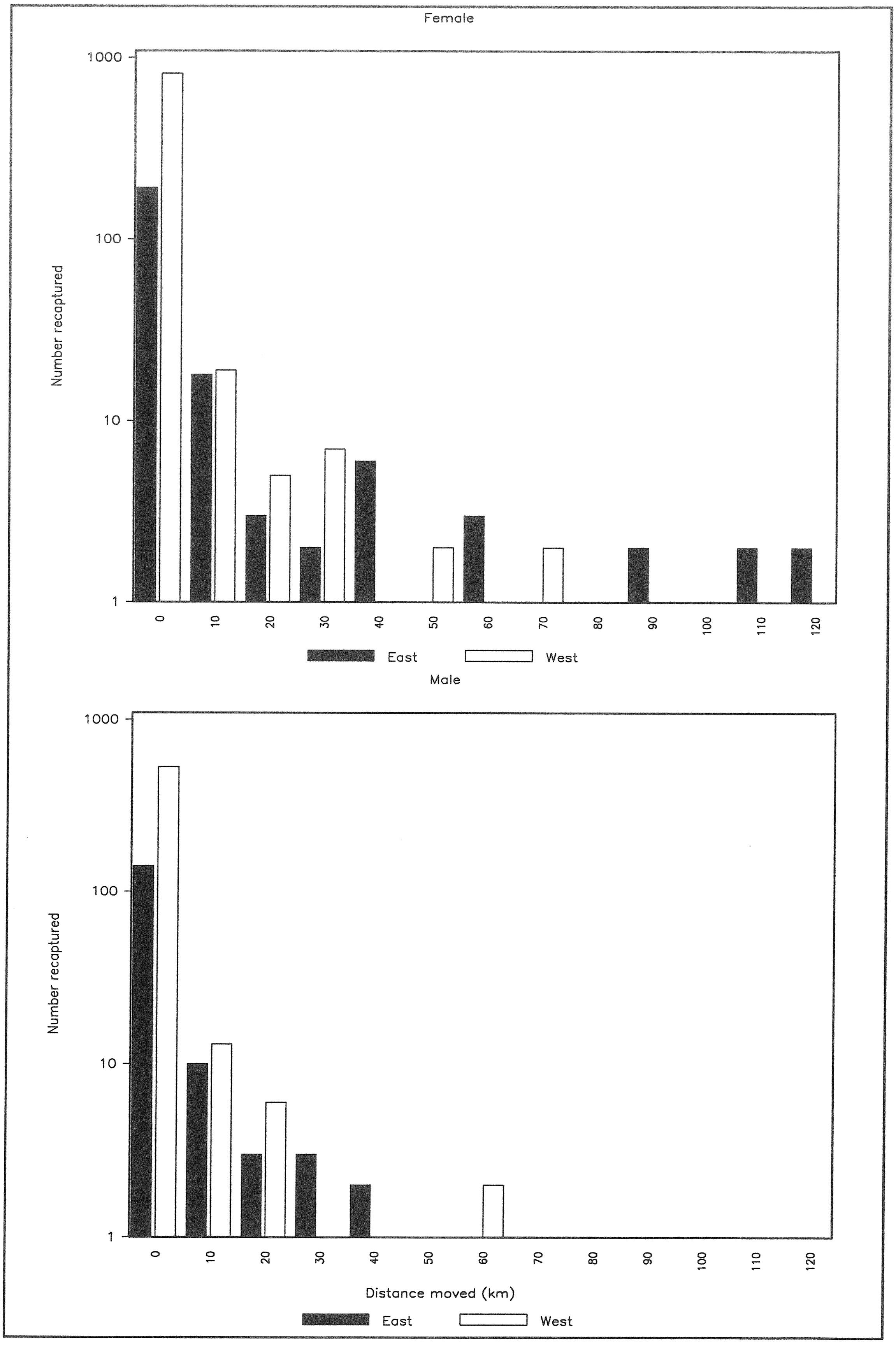


Figure 7. Frequency of larger scale movements (up to 120 km) for recaptured female (top) and male lobsters (bottom) by management zone (February 1994 - April 1997). Note logarithmic scale of vertical axis.

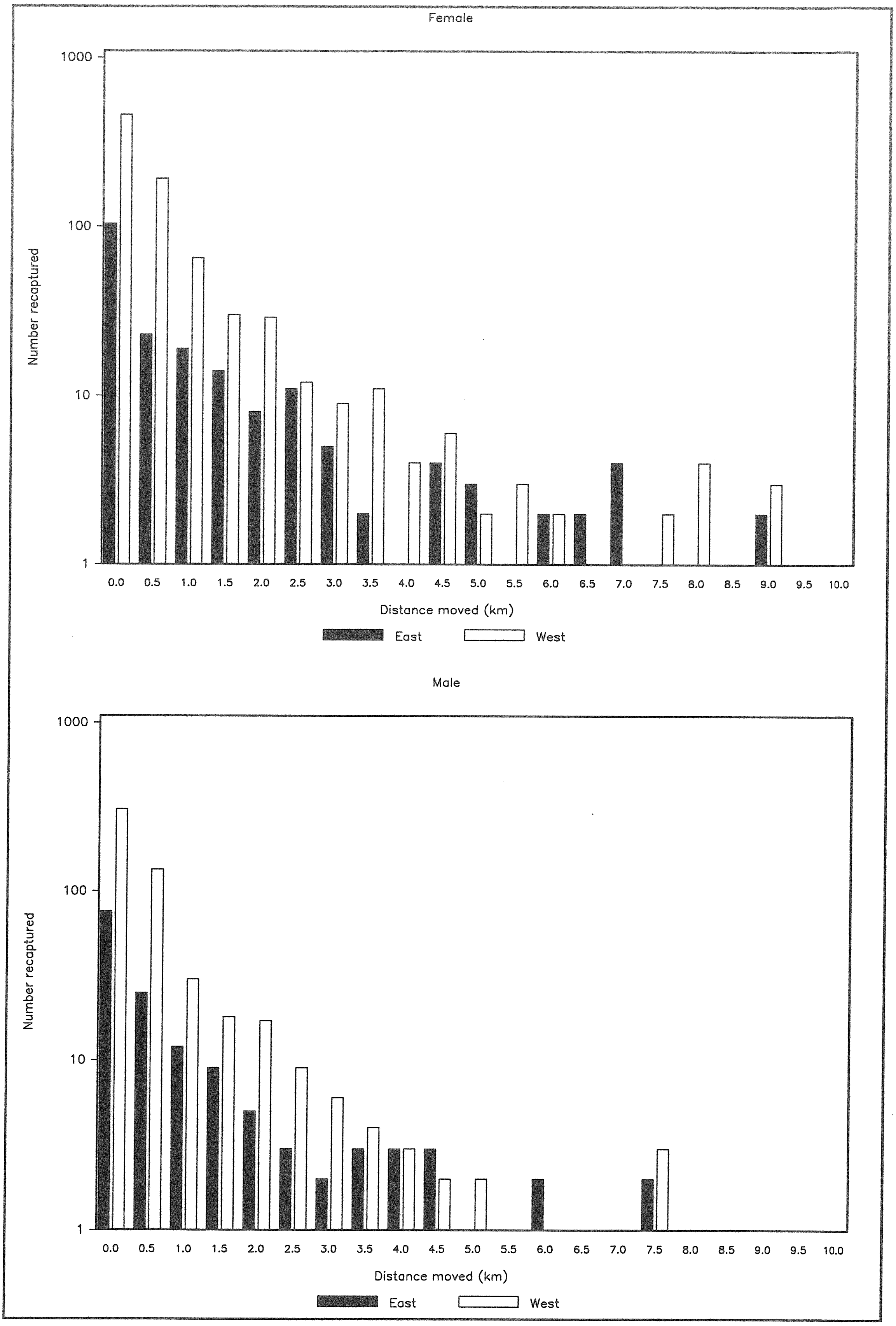


Figure 8. Frequency of smaller scale movements (less than 10 km) for recaptured female (top) and male lobsters (bottom) by management zone (February 1994 - April 1997).
Note logarithmic scale of vertical axis.

Eastern Zone

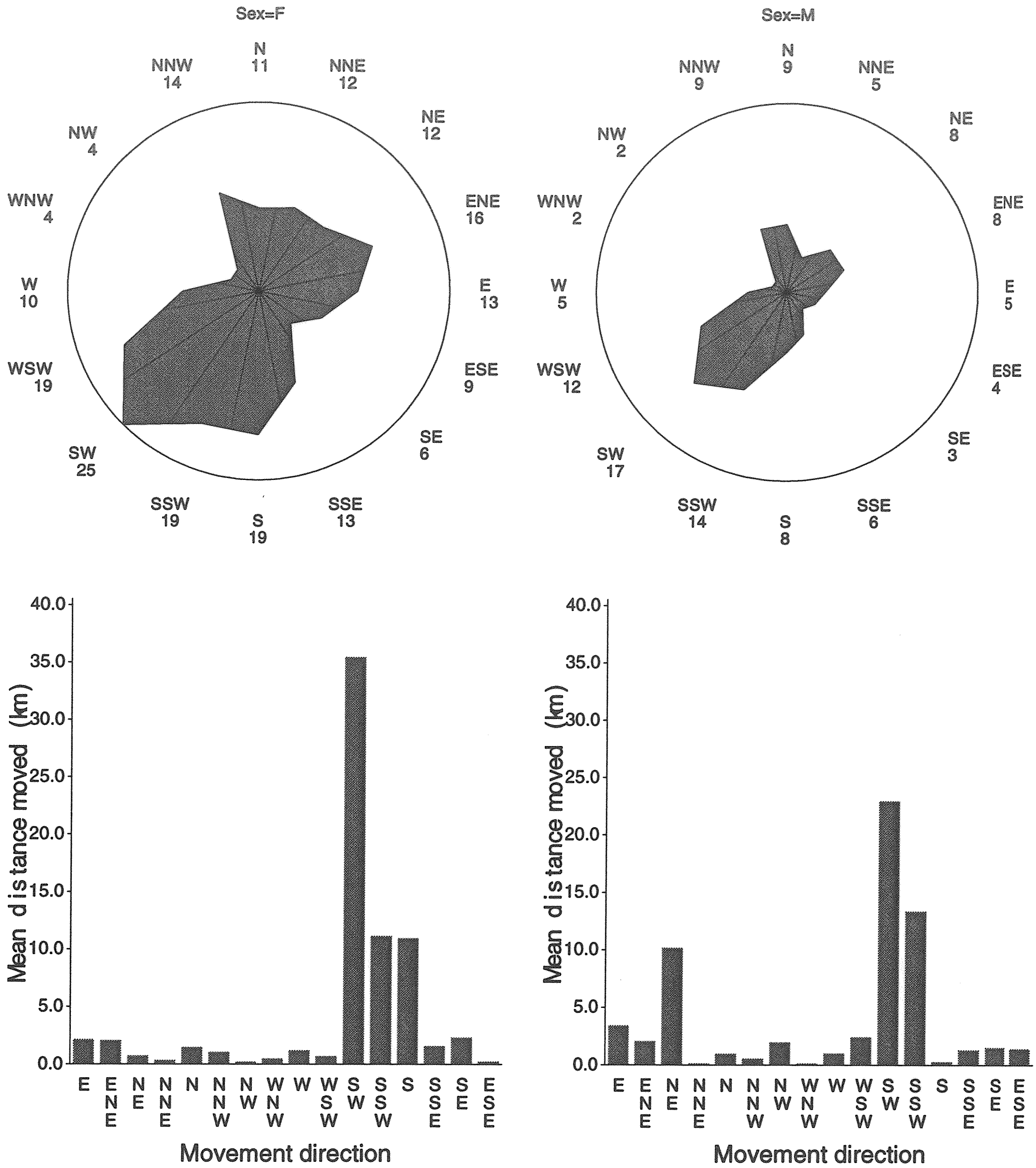


Figure 9. Movement direction frequency (top) and mean distance travelled (bottom) for Eastern Zone tag recaptures of females (left) and males (right) (February 1994 - April 1997). Numbers below direction in top figures are the number of recaptures for that direction.

Western Zone

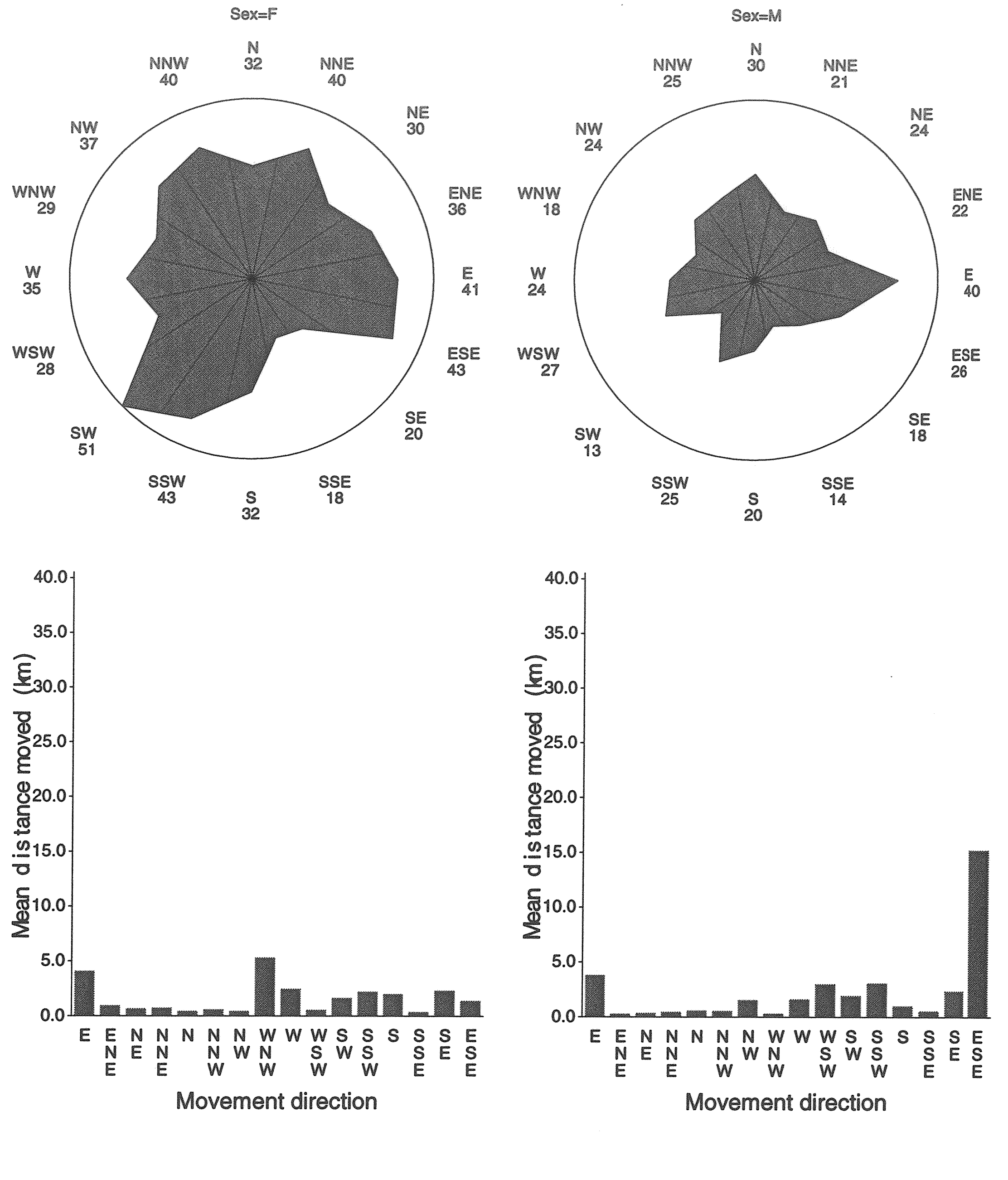


Figure 10. Movement direction frequency (top) and mean distance travelled (bottom) for Western Zone tag recaptures of females (left) and males (right) (February 1994 - April 1997). Numbers below direction in top figures are the number of recaptures for that direction.

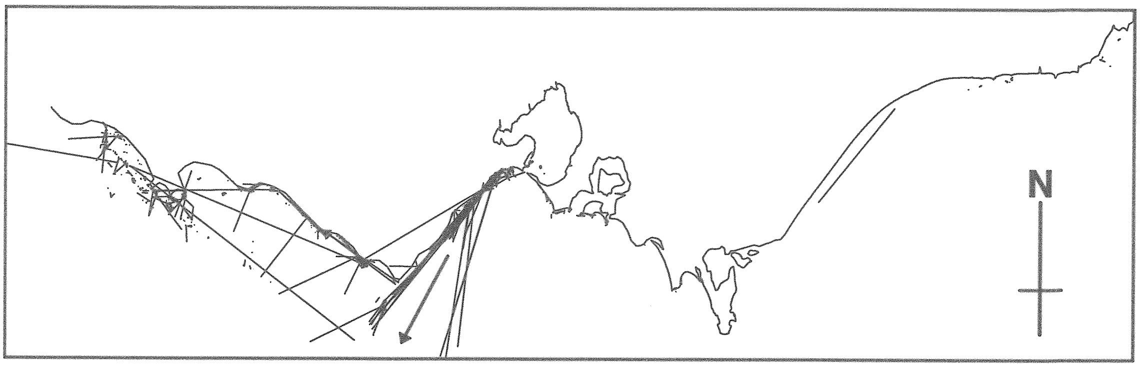


Figure 11. Large scale movements of tagged rock lobsters (February 1994 - April 1997). Arrow shows general south west movement of large scale movements of releases from central Victoria.

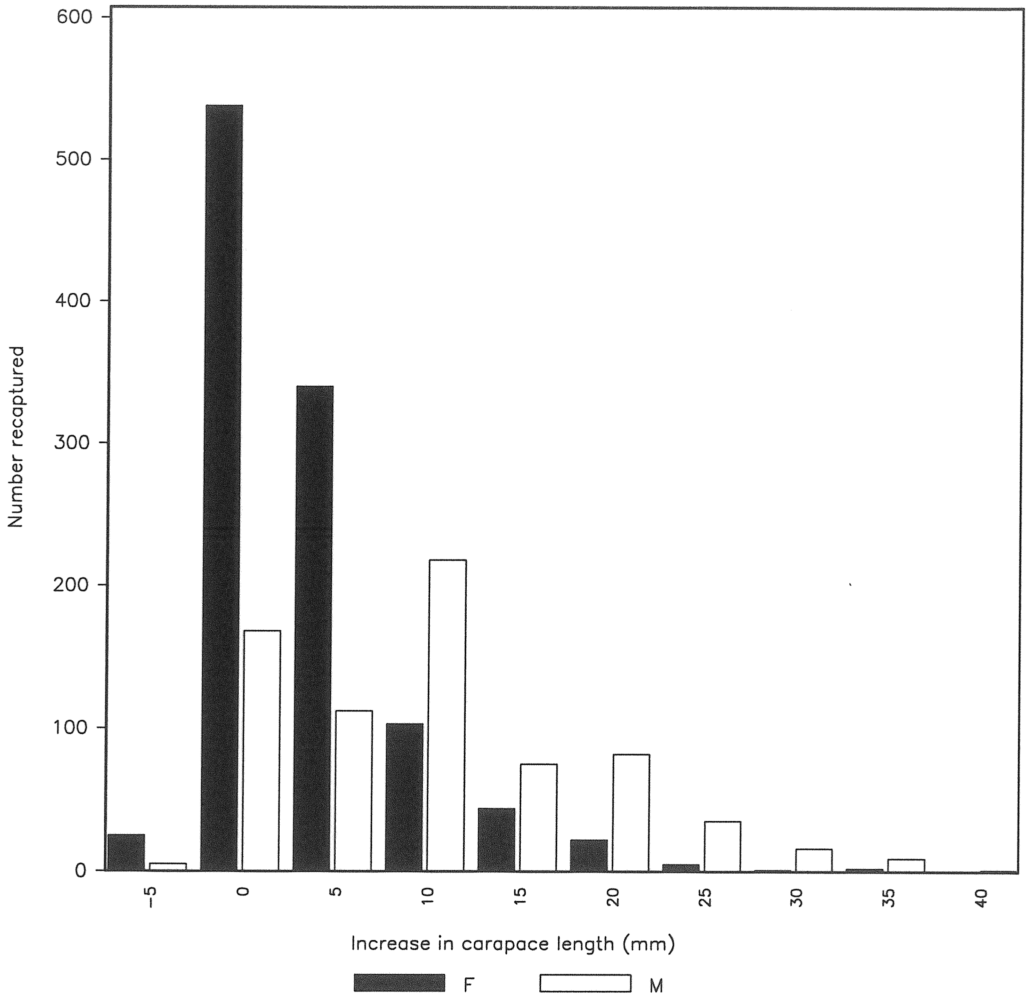


Figure 12. Frequency of growth increments by sex for all recaptures (February 1994 - April 1997).

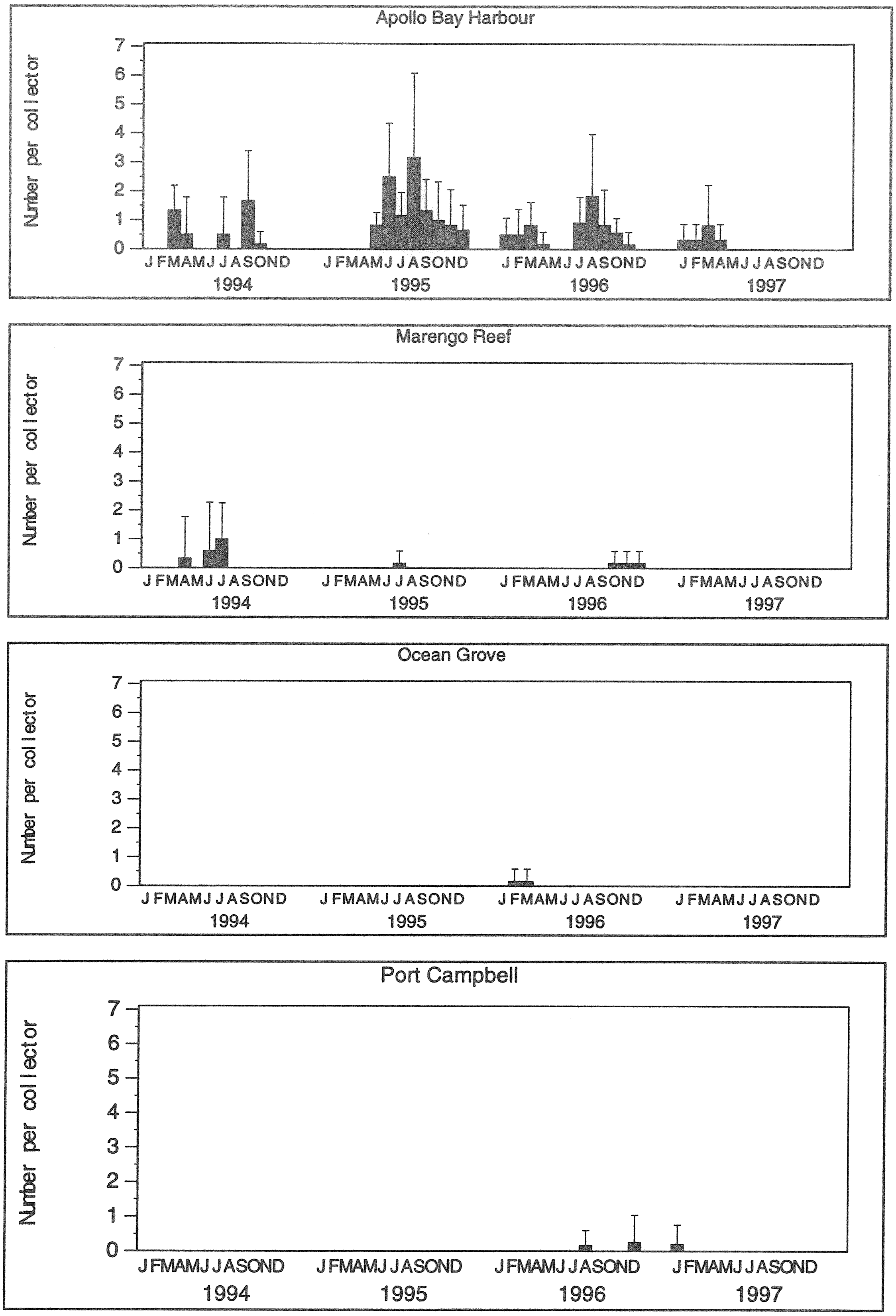


Figure 13. Mean larval settlement (number of puerulus per collector) at Apollo Bay harbour, Marengo Reef, Ocean Grove and Port Campbell.

Appendix 1

Intellectual Property

Intellectual ownership of data collected during the study will be shared between the parties. Due acknowledgement of funding agencies will be given in any publications.

Appendix 2

Staff

David Hobday	Project leader	October 94, continuing
Patrick Coutin	Project leader	July 93 to October 94
Tom Ryan	Scientist	February 95 to March 97
Cynthia Elliott	Scientist	February 94 to January 95
Dale Thomson	Technical Assistant	February 94 to July 97
Rodney Treble	Ph.D. Student	January 93 to April 96
David Lucas	On-board observer	Casual, February 94, continuing

APPENDIX 3

Objective 1 - "To obtain biological information on southern rock lobsters across Victoria, particularly size at maturity, size/age specific fecundity, growth and movement patterns.

Contrasting size at sexual maturity of southern rock lobster (*Jasus edwardsii*) in the two Victorian fishing zones: implications for total egg production and management.

D.K Hobday and T. J. Ryan

Mar. Freshwater Res., 1977, 48, 1009-1014

Paper presented at the Fifth International Conference and Workshop on Lobster Biology and Management, Queenstown, New Zealand, February 1997

MARINE & FRESHWATER RESOURCES INSTITUTE

FISHERIES RESEARCH & DEVELOPMENT CORPORATION

Project 92 / 104

Contrasting size at sexual maturity of southern rock lobster (*Jasus edwardsii*) in the two Victorian fishing zones: implications for total egg production and management.

D. K. Hobday* and T. J. Ryan
E.
Mar. Freshwater Res., 1977,48, 1001-1008

Marine and Freshwater Resources Institute,
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Abstract. Fecundity of *Jasus edwardsii* Hutton (Decapoda: Palinuridae) from Victorian waters was estimated from egg masses collected from 98 mature females of various sizes (97.0-164.2 mm CL) from Victorian waters. Fecundity (F) was found to be related to carapace length (CL) by the equation: $F = 0.0316 \times CL^{3.359}$ ($r^2 = 0.8539$; n=571).

Size at onset of sexual maturity (SOM) was estimated from commercial catch sampling (n = 3,891) and analysed to determine the smallest size class at which 50% of females were carrying eggs or possessed ovigerose setae. SOM in the Western fishing Zone (90 mm) was lower than in the Eastern fishing Zone (112 mm).

SOM estimates, fecundity and commercial catch length frequency were used to estimate the relative reproductive potential of each 5 mm size class. The maximum reproductive potential (75%) in the Western Zone was attributed to the size classes of 105 and 110 mm. In contrast, maximum reproductive potential(40%) the Eastern Zone was from the length classes between 125 and 135 mm.

The results from this work indicate that the current legal minimum size limits need to be re-assessed and also that consideration be given to separate management strategies in each zone.

Introduction

The current Victorian annual commercial catch of *J. edwardsii* is currently around 500 tonnes representing 10% of the South-east Australian fishery. The Victorian fishery is divided into an Eastern and Western Zone (Fig. 1) with over eighty percent of the catch being taken in the latter. Current management of the Victorian commercial fishery is based on input controls with limited entry licensing and pot numbers, closed seasons, minimum legal lengths (110 mm and 105 mm for male and female respectively) and escape gaps (Anon 1994), however a recommendation to move towards a quota management system was recently announced (Anon 1996). Catch rates in the fishery have shown a steady decline from 2.5 kg/potlift in the 1950's to current levels of 0.5 and 0.3 kg/potlift in the Western and Eastern Zones respectively (Hobday and Smith, 1996).

A current management objective in Victoria is to maintain at least 25% of the virgin egg production. Size at onset of sexual maturity (SOM) and fecundity are key biological parameters used to assess egg production and the applicability of size limits in a fishery. However no fecundity estimates have been published for *J. edwardsii* in Australian waters, and the only estimate of SOM (96.3 mm) from Victorian waters comes from a small area west of Apollo Bay (Treble, 1996), situated near the boundary of Victoria's two fishing zones (Fig. 1).

Characteristics used to establish sexual maturity of lobsters include changes in morphometric relationships, dimorphism of pleopods, condition of ovaries, presence of eggs, presence of a spermatophoric mass, and changes in sternal plates (Aiken and Waddy 1980). Presence of ovigerose setae on the pleopods of female *J. edwardsii* have been shown to have a strong correlation with mature ovaries (Annala et al. 1980; MacDiarmid 1989a). Most maturity measurements of *J. edwardsii* have used the presence of ovigerose setae or eggs carried by females to establish size related estimates. Throughout this paper, estimates of SOM refer to the size class having 50 % of females mature determined by presence of ovigerose setae or eggs as described in Wenner et al. 1974.

SOM is thought to vary due to a number of influences including temperature, growth rate, age, metabolic rate, population density, food availability, and other environmental factors (Annala et al. 1980). Temperature has been implicated as major influence on SOM of localised populations of *J. edwardsii* (Bradstock 1950; Street 1969; Annala et al. 1980), with larger estimates of SOM in warmer areas with faster growth rates compared with relatively colder environments.

SOM of *J. edwardsii* varies geographically across the species distribution. For example female southern rock lobster reach sexual maturity between 90 and 95 mm carapace length in south-eastern South Australia, while in western South Australia, sexual maturity occurs between 112 and 114 mm carapace length (J. Prescott, SARDI, pers. comm.). In New Zealand SOM has been found to vary in different areas by over 30 mm from 72 mm near Gisborne, to 90 mm at Tauroa Point, 107 mm at Stewart Island, and 121 mm at eastern Foveaux Strait (Annala et al. 1980). Similarly, estimates of SOM in Tasmania have shown a marked variation from 112.4 mm in the warmer northern population near King Island to 41.3 mm in the colder south-west waters (R. Kennedy pers. comm.).

Size limits are often set to ensure that lobsters are able to breed at least once prior to recruitment into the fishery (Annala et al., 1980). The legal minimum length (LML) for females in Victoria (105 mm, CL) should ensure reproductive opportunities prior to recruitment into the fishery. However, the proportion of eggs produced by the smaller length classes can be effected by their lower fecundity and lower proportion mature . In this paper, the relationships between fecundity and size, and SOM are presented. These data greatly refine previous estimates of egg production and have implications for management of the fishery in Victoria.

Methods

Fecundity

A total of 124 females (97.0 - 164.2 mm CL) carrying eggs were collected from western and central Victoria between September 1994 and July 1996 (Fig. 1, Table 1). Sampling was conducted to obtain a wide size range of females. As in previous work (Annala and Bycroft 1987), variability due to location was not considered important. As a result, most of the smaller females were caught in the Western Zone and the larger in the Eastern Zone (Table 1), reflecting the length composition of the catch in each zone (see Results, Size at Onset of Sexual Maturity). The majority of egg samples were collected during July while the eggs were in an early-mid stage of development to ensure minimal egg loss. An ice bath was used to pacify the females while the eggs were stripped from the pleopods using a sharp scalpel to cut the setae. Females were then placed in tanks to recover, and within several weeks were tagged and returned to the fishing grounds. The carapace length and weight were recorded at the time of egg removal. Egg samples were placed in 98% ethanol and stored away from light. Eggs were prepared for counting first by filtering excess liquid and then drying in an oven at 40 °C for at least 24 hours. A 7 micron sieve was used to remove foreign matter and to separate egg clumps. The total dry weight was determined and three 0.04g samples were taken and the number of eggs in each was counted twice under a dissecting microscope. Each sample was ranked from 1 to 3 according to the following criteria:

1. Samples consisting of well separated, whole eggs,
2. Samples containing small clusters of eggs which could be counted and contained a low proportion (less than 20%) of ruptured eggs,
3. Samples containing large egg clusters which were difficult to count and had a large proportion (more than 20%) of ruptured eggs.

Fecundity (F) was estimated from all samples with rankings 1 and 2 (N = 98) according to the following equation

$$F = (\text{Total weight} / \text{Sample weight}) \times \text{Sample count}$$

The data from all subsample estimates was then fitted using SAS non-linear model procedure to the following relationship:

$F = a \times (CL)^b$, where CL is the carapace length (mm); and a and b are constants (Kensler 1968; Annala et al. 1980; MacDiarmid 1989b).

Table 1: Locations and dates of lobster fecundity samples. (Sampling locations shown in Figure 1).

Date	Sampling Location	Fishing Zone	Carapace length range (mm)	N
05/09/94	Queenscliff	East	117.9 - 138.7	7
28/10/94	Port Fairy	West	101.3 - 101.6	2
07/07/95	Moonlight Head	West	97.0 - 123.3	46
09/07/95	Walkerville	East	110.6 - 164.2	15
10/07/95	San Remo	East	104.5 - 159.1	10
21/08/95	Flinders	East	115.0 - 139.3	10
28/08/95	Port Campbell	West	104.7 - 116.9	3
16/10/95	Lorne	East	119.1 - 146.2	5
28/11/95	Portland	West	100.0 - 105.1	4
23/07/96	Flinders	East	103.3 - 147.1	17
26/07/96	San Remo	East	120.4 - 127.8	5

Size at Onset of Sexual Maturity (SOM)

Data used for SOM analysis was collected by observers aboard Victorian commercial rock lobster fishing vessels from January 1994 to October 1996. On these trips biological data was collected on the vessel's entire catch with undersize and out-of-season female lobsters being tagged and returned to the water. Victorian rock lobster pots are required to contain escape gaps which are effective in reducing the proportion of undersize animals in the catch (Treble et al., submitted) and therefore in order to sample undersize lobsters a small number of pots without escape gaps were used under permit. The information collected on these trips relevant to this study included carapace length (to the nearest 0.1 mm); sex (male or female), sexual condition of females (berried - carrying eggs, setae - ovigerous setae present, non-setae - ovigerous setae not present).

The data were divided into the two fishing zones (Fig. 1) and the carapace length into 5 mm length classes (eg. 105 mm length class contain animals greater than or equal to 102.5 mm and less than 107.5 mm). The pecentage of mature females (either berried or with ovigerose setae present) in each length class was determined. The percentage maturity was then fitted to the following logistic model using SAS non-linear model procedure:

$$P\% = 1/(1 + e^{(-C \times CL - L_{50})})$$

where P% is the percentage of mature females at the midpoint of the length class; C is the parameter controlling the slope of the curve at the inflection point; CL is the carapace length (mm); and L_{50} is the length at which 50% are mature (SOM).

Relative Reproductive Potential

Morgan (1972) calculated the relative reproductive potential for *Panulirus cygnus* in Western Australia by combining the fecundity of individuals of different carapace lengths with their corresponding relative numbers in the population. In this paper, Morgan's calculation is modified by including the proportion of individuals in the size classes above LML which are mature using the following relationship:

$$E_i = C_i \times M_i \times F_i;$$

where E_i is the relative egg production or reproductive potential; C_i is the proportion in the commercial catch; M_i is the percent mature; and F_i is the fecundity; for each length class i above LML.

Results

Fecundity

Fecundity was estimated from replicate counts (N = 571) from the 98 samples with ranks 1 and 2 and found to vary non-linearly with carapace length (Fig. 2) according to the relationship:

$$F = 0.0316 \times CL^{3.359} \quad (R^2 = 0.8539; N = 571).$$

The maximum number of eggs ranged from 152,450 for a 97 mm female to 682,544 eggs for a 149.7 mm female.

Size at Onset of Sexual Maturity (SOM)

Eastern Zone 1,430 female lobsters were measured in the Eastern Zone. The length frequency distribution of the commercial catch showed that as expected the proportion of catch increased substantially at the 105 mm LML for female rock lobster in Victoria (Fig. 3). The size distribution of females in the Eastern Zone is quite broad with size classes from 105 - 135 mm CL well represented in samples.

No ovigerous setae were observed in females smaller than and including the 85 mm size class. The smallest female observed with ovigerous setae was 88.9 mm CL. The percentage mature increased rapidly between 105 mm and 120 mm with all females larger than 145 mm CL containing ovigerous setae and considered mature (Fig.3). The fitting of the logistic model to the proportion mature for each 5 mm size class in the Eastern Zone data estimated the SOM (50% maturity) at 112.4 mm CL($R^2 = 0.998$; n = 23 size classes)(Fig. 3).

Western Zone In the Western Zone, 2,461 females were measured. The length frequency distribution of the Western Zone was distinctly different to that of the Eastern Zone, with the highest frequencies occurring in the 105 and 110 mm size classes and lobsters larger than 120 mm poorly represented in all samples (Fig. 4).

The proportion of mature females was observed to increase earlier than in the Eastern Zone with the smallest female possessing ovigerous setae being 75.3 mm CL. At the LML of 105 mm more than 90% were mature (Fig. 4), with the SOM (50% maturity) estimated at 89.7 mm ($R^2 = 0.995$; n = 17 size classes)(Fig. 4).

Relative Reproductive Potential

The relative reproductive potential characteristics were distinctly different for Victoria's Eastern and the Western fishing zones. The Eastern Zone relative reproductive potential was characterised by significant contributions from larger size classes, while the Western Zone's relative reproductive potential came predominantly from the smaller size classes above LML.

Eastern Zone The size class with the highest relative reproductive potential in the Eastern Zone was 135 mm CL (Fig. 5), resulting from the large SOM and high proportion of large females in the catch. More than 50% of the female commercial catch is equal to or below 115 mm but the relative reproductive potential for these size classes is only 20% (Fig. 5).
Western Zone The relative reproductive potential in the Western Zone followed the commercial catch length distribution (Fig. 6). The 105 mm length class contains more than 45 % of the total commercial catch and approximately 75% of the female catch is taken over the two size classes 105 - 110 mm. More than 60% of the potential egg production in this zone comes from the two length classes 105 - 110 mm, with more than 37% from the 105 mm length class alone.

Discussion

Although fecundity relationships for *J. edwardsii* have varied according to specific studies (Table 2), possibly due to factors such as food availability (Melville-Smith et al., 1995), population density (Chittleborough 1979; Beyers and Goosen 1987; MacDiarmid, 1989b), and water temperature (Annala and Bycroft 1987), no significant correlations have been found within studies relating fecundity to locality or any broad-scale biological or environmental variables (e.g. Annala and Bycroft 1987).

Table 2: Summary of fecundity studies of J. edwardsii

Study	Fecundity relationship	Estimated fecundity at CL 104 and 120 mm	Estimation method	Sampling area
Hickman (1946)	Geometric Relationship		2g wet subsample	Wedge Bay, Tasmania
Kensler (1968)	$F = 0.6921 \times CL^{2.69}$	184,497 and 271,123	2g wet subsample	Chatham Islands, New Zealand
MacDiarmid (1989b)	$F = 0.169 \times CL^{3.0091}$	198,309 and 305,036	Bycroft (1986)	North east New Zealand
Annala and Bycroft (1987)				
Highest	$F = 9.2999 \times CL^{2.11}$	166,378 and 225,023	Bycroft (1986)	Various sites around New Zealand
Lowest	$F = 0.0050 \times CL^{3.75}$	183,166 and 313,256		
The current study	$F= 0.0316 \times CL^{3.359}$	188,322 and 304,549	Dry subsample	Western and central Victoria

The fecundity estimate for *J. edwardsii* in Victoria is similar to that by other workers in the region (Table 2). Because of this similarity, further refinement of the fecundity relationship by fishing zone in Victoria would not seem necessary. The consistency in the fecundity relationship suggests that environmental conditions are not important in determining the number of eggs produced by a female. Because eggs are adhered to setae, fecundity could be determined by the physical limitation of pleopod size. As such, individuals from areas with higher growth rates would have larger pleopods enabling them to carry a larger number of eggs according to the fecundity relationship.

Some authors argue that the presence of setae on a female is not an absolute guarantee that it will produce eggs that season (Booth 1984; MacDiarmid 1989b) and as a result the SOM estimates may provide under-estimates of egg production. SOM may also over-estimate egg production because setae may be lost during a late spring /summer moult (October to December) and therefore an otherwise mature female may be recorded as immature based on the absence of ovigerose setae (Fielder 1964; Annala et al. 1980; MacDiarmid 1989b). Because smaller females are more likely to moult during late spring/summer the SOM could ultimately be biased to a larger length classes.

This study has provided a preliminary picture of SOM in Victoria's two fishing zones. Treble's (1996) SOM estimate of 96.3 mm is consistent with the findings of this paper, as it was from an area near the eastern limit of the Western Zone, and falls between the zone estimates of this paper (89.7 mm Western Zone, 112.5 mm Eastern Zone). However, as SOM for *J. edwardsii* has been found to vary geographically (Annala et al. 1980), estimation of SOM at a finer geographical resolution within each fishing zone needs to be investigated in Victoria.

Egg per recruit analysis has estimated the current Victorian egg production for both fishing zones at 6 - 20% of the virgin, unfished stock (Hobday and Smith, 1996), which is well below the management target of 25%. The effect of local recruitment resulting from Victorian egg production is unknown, but until recruitment processes are defined, each of the States in the south-east fishery (South Australia, Victoria and Tasmania) should aim to maintain suitable levels of egg production.

Options for achieving a higher egg production from the Victorian component of the fishery include reduction of fishing mortality and increasing the LML. Reducing fishing mortality would in time increase the mean size of individuals in the population, resulting in higher egg production. Protection of setose females as practiced in Western Australia may not be appropriate in Victoria because the long closed female season (June to November) which spans the main reproductive period. Increasing the female LML from 105 to 110 mm (equivalent to male LML), would increase egg production particularly in the Western Zone where the maximum relative reproductive potential currently occurs at the present LML. However, this would place the LML 20 mm higher than the SOM which may be over-cautious in the long term. Such an increase in LML in the Eastern Zone would have less effect on overall egg production because of the low reproductive potential of animals at the current LML and the smaller size of the fishery compared with the Western Zone. However, an increase in LML in this Zone is necessary given the low percent mature at the current LML. Consideration of the introduction of a legal maximum length may be more appropriate in the Eastern Zone where the relative reproductive potential for the size classes of 145 mm and greater is 17% representing only 6% of the catch (Fig 7). However such a strategy may not be beneficial owing to likely increased exploitation of the remaining legal sized females which if high enough, could prevent sufficient numbers reaching the maximum legal size.

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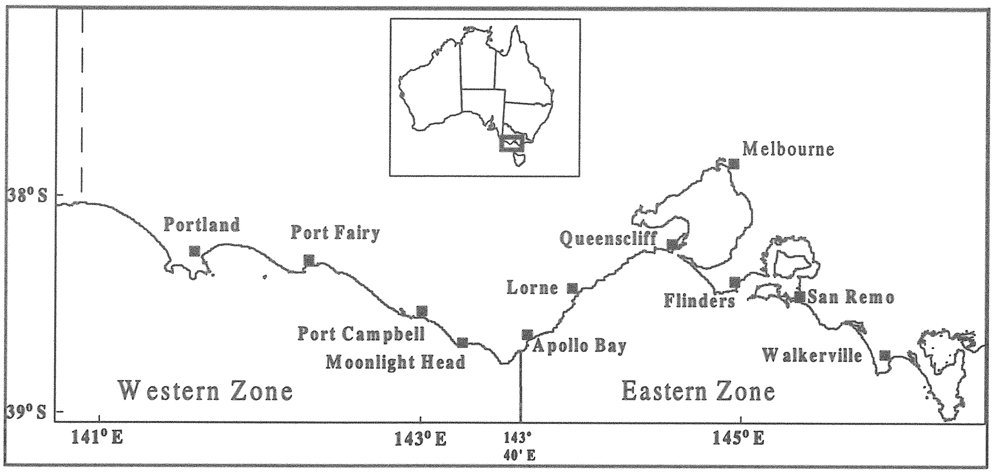

Fig. 1. Commercial fishing Zones and major fishing ports mentioned in text.

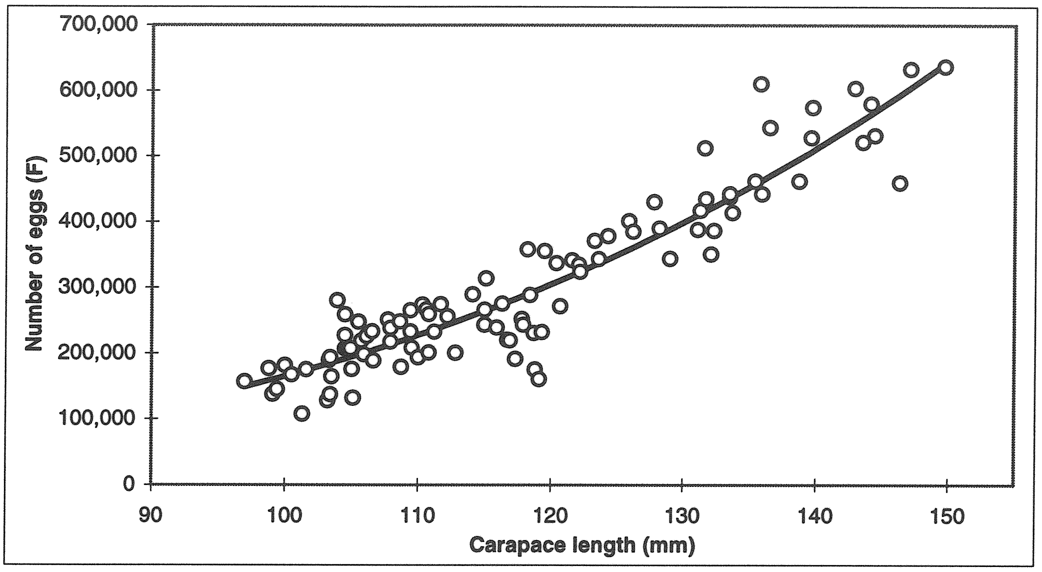

Fig. 2. The relationship between female lobster size (mm CL) and the number of eggs carried (rank 1 and 2, n = 98 females). Fitted line, $F = 0.0316 \times L^{3.359}$ ($R^2 = 0.8539$; N = 571 individual counts from 98 samples).

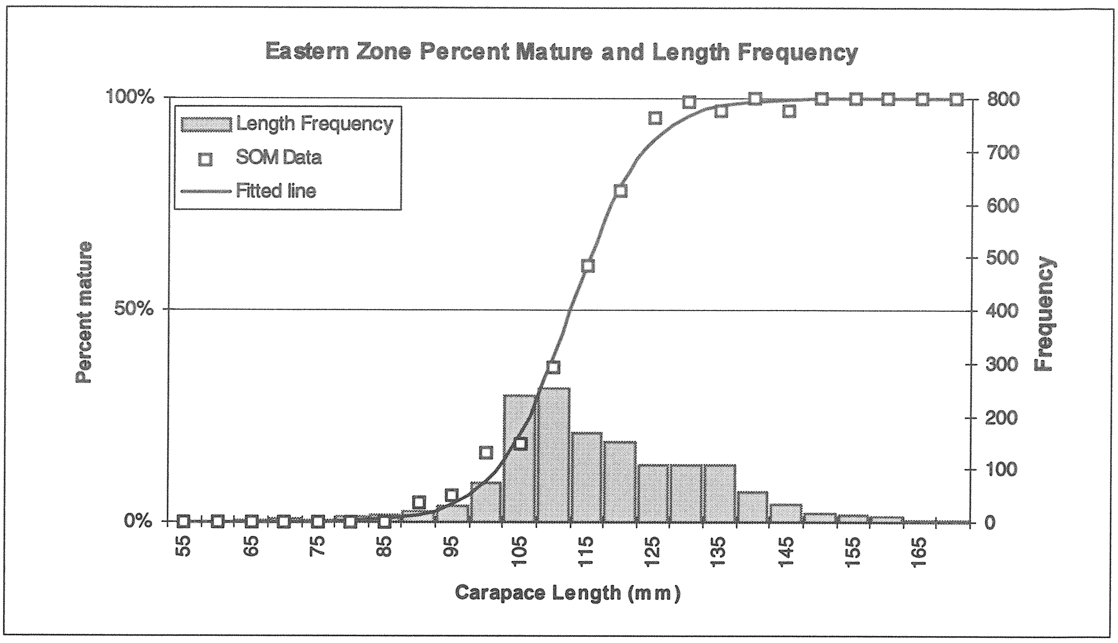

Fig. 3. SOM and length frequency of commercial catch samples for the Eastern Zone. Fitted line, Percent mature = $1/(1 + e^{(-0.18 \times CL - 112.4)})$

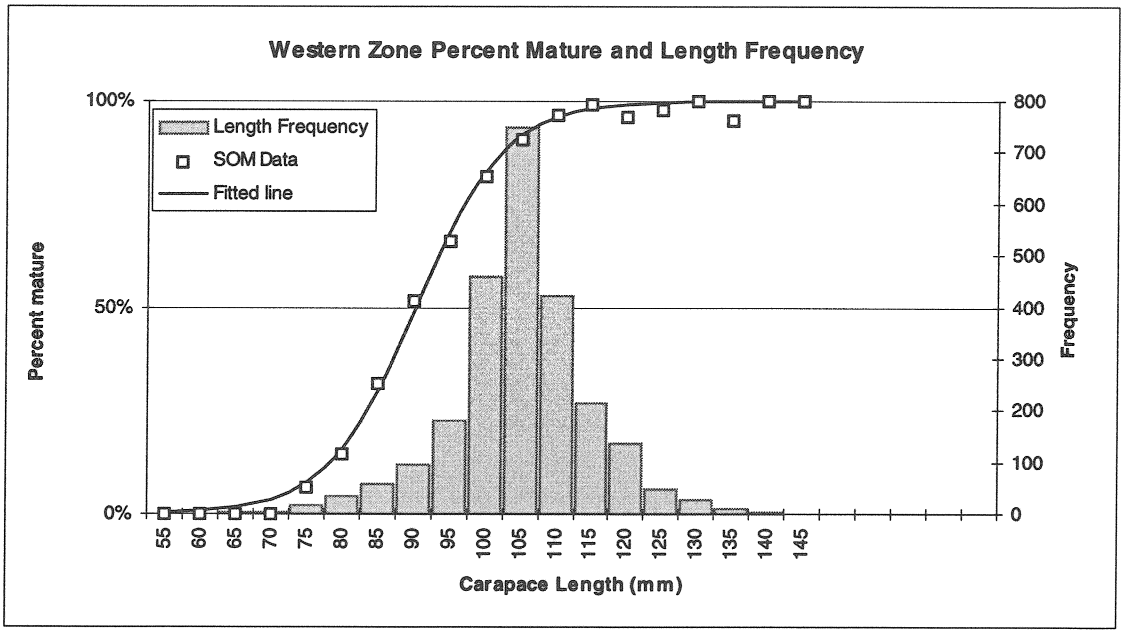

Fig. 4. SOM and length frequency of commercial catch samples for the Western Zone. Fitted line, Percent mature = $1/(1 + e^{(-0.17 \times CL - 89.7)})$

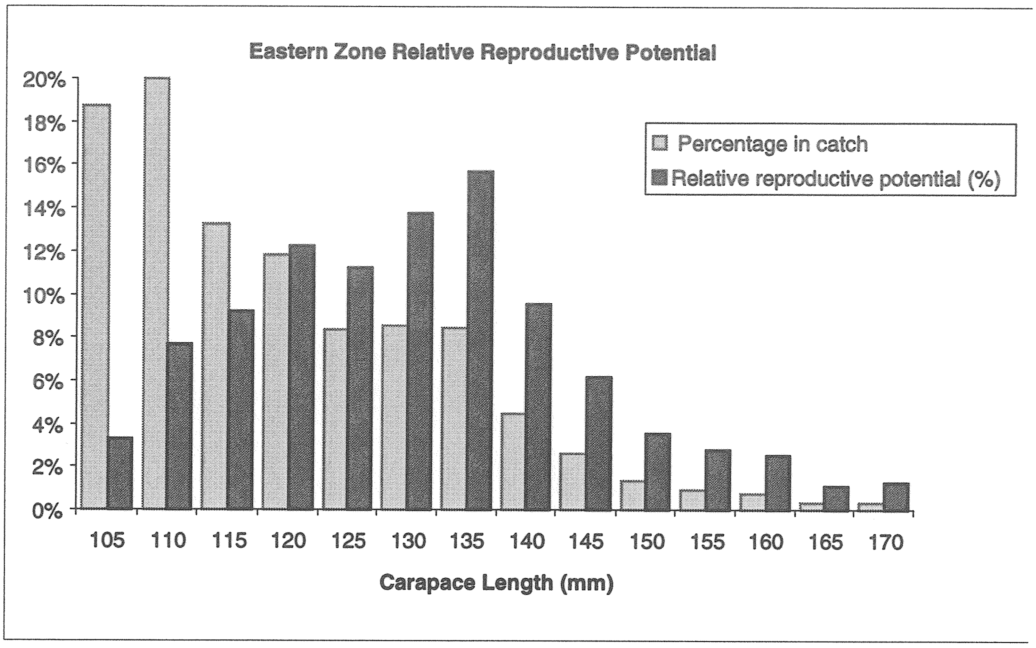

Fig. 5. Eastern Zone relative reproductive potential and percent in the catch sample by 5 mm size classes over LML.

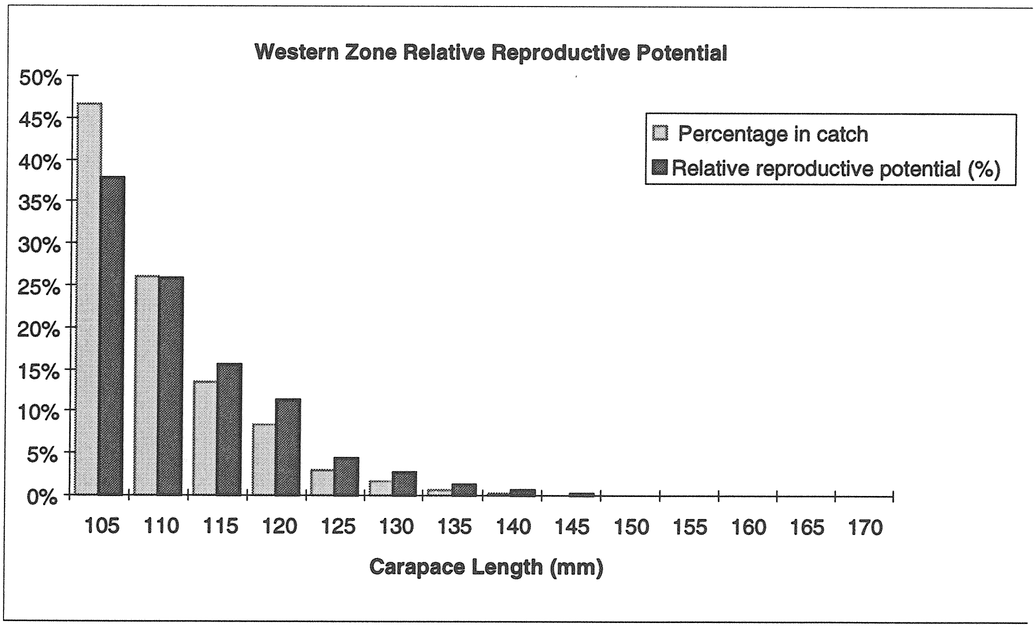

Fig. 6. Western Zone relative reproductive potential and percent in the catch sample by 5 mm size classes over LML.

APPENDIX 4

Objective 2 - "To evaluate methods for estimating the size of southern rock lobster populations."

Evaluation of methods for estimating the size of southern rock lobster populations

R.J Treble

Extract from Ph.D. Thesis, "The southern rock lobster *(Jasus edwardsii)*: Fisheries biology and abundance estimation", The University of Melbourne, Victoria, August 1996.

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Objective 2. To evaluate methods for estimating the size of southern rock lobster populations

Extract from Ph.D. Thesis, "The southern rock lobster *(Jasus edwardsii)*: Fisheries biology and abundance estimation",
R.J. Treble,
The University of Melbourne, Victoria, August 1996.

General methods

We concentrated our efforts on a method that seemed well suited to estimate the abundance of southern rock lobster (*Jasus edwardsii*) populations, the "change-in-ratio" method. We also investigated the Leslie method, which can be used to estimate stock abundance from within-season trends in catch and effort data. In addition, underwater visual census by SCUBA divers was used to estimate the number of lobsters per unit area (lobster "density"). In addition to estimating abundance, we calculated exploitation rates using the change-in-ratio and Leslie methods. Exploitation rate estimation was a new aspect of this study that was not included in the original application. We have discussed these three methods separately below.

The change-in-ratio method

Methods

Because there is a size limit for lobsters (*J. edwardsii*) caught in Victorian waters, legal-size lobsters that are caught are removed from the population, and undersize lobsters are returned to the sea. Therefore the ratio of legal-size to undersize lobsters in the population should decrease during a fishing season. By measuring this "change in ratio" of legal-size to undersize lobsters, exploitation rate (proportion of the stock removed by fishing within a given period) can be estimated, although the number of legal-size lobsters that have been removed by fishing during the sample period needs to be known to estimate abundance (Paulik and Robson 1969; Seber 1982; Udevitz and Pollock 1992).

In this project, data on the proportion of the catch that is of legal-size were obtained from measuring the sex and carapace length of all lobsters caught during sampling on-board commercial fishing vessels operating out of Apollo Bay, Victoria, Australia. Data were collected during 100 days of fishing from August 1992 to April 1995. Due to the opportunistic nature of sampling, and because fishers tend to move their gear between fishing grounds, data could only be collected for different areas at different times of the season. Due to the differences in size-frequency (and thus legal-size to undersize ratios) between these areas (see Chapter 6 in Treble 1996), most data were not suitable for direct application of the change-in-ratio method to the whole of the Apollo Bay area. However, these data were very valuable for determination of the biological characteristics of rock lobsters in the Apollo Bay area, such as moult timing patterns, size at onset of maturity of females, and size-frequency patterns (see Treble 1996). Sampling on board lobster vessels also meant that tagging, and experiments on the size-selectivity of lobster pots with escape-gaps could be achieved (see Treble 1996).

Not withstanding the lack of suitability of most data collected, data for application of the change-in-ratio method were obtained from 32 days of observations on board the FV *Lindy* during normal fishing operations in the 9 and 11 Mile Reef area (Figure 1), between November 1994 and April 1995 (the main annual fishing season). Commercial lobster pots with standard 60-mm escape-gaps were used during fishing.

The cumulative number of legal-size lobsters removed from the 9 and 11 Mile Reef area by each day of fishing during the 1994-95 season was determined from observations made on board the *Lindy*, and from interviews made with the skippers of two other vessels fishing in this area. Data on the number of lobsters removed were also obtained from the skipper of the *Lindy* for the few days in the 1994-95 season when on-board sampling could not take place. As skippers do not record the sex of the catch, trends in the observed sex ratio of the catch from on-board observations (see Figure 10) were used to estimate the number of legal-size males and females removed from the 9 and 11 Mile Reef area.

Abundance and exploitation rates were estimated separately for male and female lobsters. Regressions of the proportion of the catch that was of legal-size on each day versus the cumulative number of legal-size lobsters removed *before* that day of fishing, were used to obtain estimates of the proportion of legal-size lobsters in the catch at the start and end of the 1994-95 season in the 9 and 11 Mile Reef area. Separate regressions were done for males and females. Estimates of abundance and exploitation of legal-size lobsters were obtained using the initial and final proportions legal-size from the regressions, and the total number of legal-size lobsters removed between the first and last day of sampling, in the normal two-sample change-in-ratio method equations (e.g., from Paulik and Robson 1969; Seber 1982).

Because data were collected separately for each pot, the proportion of the catch that was of legal-size on each day of sampling was calculated in two ways, using "pooled" and "average" estimators (Seber 1982). The pooled estimator pools the data over all pots hauled on each day of fishing, to calculate the estimate of the proportion of catch that is of legal-size on each day. The average estimator calculates the proportion of the catch that is of legal-size for each individual pot on a day, and then calculates the mean of these estimates, as the estimate of the proportion legal-size on a day. In addition to using lobsters of all sizes in the change-in-ratio method analyses, an extra analysis was done with a truncated data set (after Frusher et al. in prep.), using intervals 10 mm above and below the legal minimum length for males, and 5 mm above and below the legal minimum length for females, to investigate the effect of size-specific dominance.

We used the 'bootstrap' technique (e.g., Efron and Tibshirani 1993) to estimate 90% confidence limits of the estimates of abundance and exploitation rate of legal-size lobsters. Bootstrapping was not used for the truncated data analysis (i.e., size categories just above and below the legal minimum lengths). A total of 10,000 bootstrap estimates of abundance and exploitation were generated by randomly selecting pots, with replacement, from each day's data, and recalculating the analysis after each iteration. Confidence limits were obtained by using the bias-corrected percentile method outlined in Dixon (1993).

Results

Fishing and sampling in the 9 and 11 Mile Reef area on board the FV *Lindy* was between 18 November 1994 and 14 April 1995. Most data were collected by mid-February though, as no fishing was done in this area between late February and the last two days spent sampling fishing in April. Hence this area was fished for about 3 months. During the 32 days of on-board sampling, 2,367 lobsters were measured from 1,526 potlifts. Between the first and last days of fishing, more legal-size females (1,611) than males (1,326) were removed from the study area. Pots were hauled after 1 day for 23 days of fishing, but for some days pots had soak times of 2 (n = 5), 3 (n = 3) and 4 days (n = 1).

Although there was some day to day variation, the proportion of legal-size lobsters in the catch decreased during the fishing season, as more and more legal-size lobsters were removed (Figure 2). The change in the proportion of the catch that was of legal-size over the period of sampling was higher for females than for males (Figure 2). Due to a larger slope, regressions of proportion legal-size versus cumulative catch were more precise for females than males (Tables 1 and 2). For legal-size female *J. edwardsii*, estimates of abundance and exploitation rate were remarkably similar when using the pooled and average estimators (Table 1). Abundance of legal-size females at the start of the 1994-95 season in the 9 and 11 Mile Reef area was estimated at about 2,000 lobsters, with estimates of the exploitation rate of legal-size females centered at around 0.78 (i.e., 78% of legal-size females were removed by fishing during the 1994-95 season) (Table 1). Use of two different estimators resulted in different estimates of abundance and exploitation rate for legal-size males, in contrast to the analysis of the female data (Table 2). Abundance was estimated as 2,300 legal-size males for the average estimator and about 3,000 for the pooled estimator data (Table 2). Exploitation rates for males were around 0.44 for the pooled estimator data, and 0.57 when using the average estimator (Table 2).

Truncating the data set to just above and just below the legal minimum lengths produced similar results to the above analyses when all sizes of lobster were used, although the truncated data showed more error around the regression line because of the reduced sample size (Figures 2 and 3). Only estimates of exploitation rate were calculated from the truncated data set, and apply only to the "post-recruit" size-classes. Nonetheless, these estimates of exploitation were similar to those obtained when all sizes of lobsters were used in the analysis (Tables 1 and 2).

The bootstrap analyses showed that the distributions of the estimates of abundance and exploitation are skewed (Figures 4 and 5). Hence the confidence limits surrounding the estimates are asymmetrical (Table 3). Confidence limits of abundance and exploitation rate estimates for legal-size males are much wider compared to those calculated for females (Table 3). For males, estimates of abundance and exploitation calculated were more precise when using the average estimator compared to the pooled estimator, in contrast to the female data where little difference was seen in precision between the two estimators (Table 3).

Discussion

New variation on the change-in-ratio method

The regression approach used here is a novel way of using the change-in-ratio method to estimate abundance and exploitation rates. Usually two samples of the population are obtained before and after a period of exploitation, using special research surveys (e.g., Frusher et al. in prep.). With our method, samples were obtained on board commercial fishing vessels during normal fishing operations.

As shown here, estimates of abundance and exploitation rate of *legal-size* lobsters can be obtained using the change-in-ratio method, even if pots with escape-gaps are used to sample the population. Estimation of undersize abundance would need to use pots without escape-gaps, or use size-selectivity curves to adjust the data from pots with escape-gaps (as done in Treble 1996). Thus a cost effective way of using the change-in-ratio method, may be to use voluntary logbooks filled out by fishers, as sampling can take place while fishing is taking place, using normal fishing gear, i.e., pots with escape-gaps. This would only work for a fish-down of an area though.

The on-board sampling in this study showed that the size of lobsters is different between the main fishing grounds around Apollo Bay (see Treble 1996). That is, the proportion of legal-size lobsters in the catch varies between areas, even at the same time of year. Thus a change in the proportion of legal-size lobsters in a fisher's catch will occur simply from the movement of his boat from one fishing ground to another. If the change-in-ratio method were applied to data collected from within a study area that was too large and comprised different fishing grounds with different size structures (e.g., the whole of the Apollo Bay fishing grounds), significant bias in the method could result simply from changes in the spatial patterns of fishing effort within the study area. Thus the change-in-ratio method needs to be applied to relatively small areas that are homogenous with respect to lobsters size, e.g., as done here in the 9 and 11 Mile Reef area.

Precision and confidence limits

Paulik and Robson (1969) and Conner et al. (1986) have shown that larger changes in proportion produce more precise estimates of abundance and exploitation from the change-in-ratio method. Our study confirms this, as the decrease in the of proportion legal-size lobsters in the catch was much higher for females than for males, and the precision of the estimates of abundance and exploitation was much higher for females compared to males. Only the female estimates of abundance and exploitation rate are of adequate precision for use in monitoring of the stocks of *J. edwardsii*; the male estimates are too imprecise to be useful.

Although the estimate of exploitation for males was reasonably high, it was not high enough to obtain adequate precision from the change-in-ratio method, as the change in proportion legal-size was too low. A change in proportion legal-size around 0.10 is considered borderline for use of the change-in-ratio method, due to its low power at this level (Paulik and Robson 1969). Thus the change-in-ratio method should only be used in fisheries where the changes in proportion legal-size are reasonable (e.g., about 0.25 as for females in our study). However, this only occurs in fisheries with very high exploitation rates, i.e., where a large amount of the available stock is removed by fishing. It is obvious that improvements to the precision of the change-in-ratio method are needed.

Frusher et al. (in prep.) stated that in Tasmania, two samples of 100 potlifts (before and after the fishery) were sufficient to estimate exploitation rates of *J. edwardsii* in a small area with adequate precision using the change-in-ratio method. In our study, over 1,500 potlifts were sampled, much more than Frusher et al. (in prep.) recommended. Nonetheless, only the female estimates of exploitation and abundance from our study are of adequate precision. Less sampling effort was needed in the Tasmanian surveys, because the changes in proportion legal-size and catch rates were much higher than observed at Apollo Bay. Hence the actual amount of effort (number of potlifts) required to use the change-in-ratio method with required precision on the southern rock lobster populations will be area-specific, as it will depend on the catch rate and the magnitude of the change in proportion legal-size.

The skewed bootstrap distributions of the estimates of abundance and exploitation rate presented here are actually a characteristic of the change-in-ratio method, as seen by Frusher et al. (in prep.) and Chen et al. (in prep.). Confidence limits for estimates of abundance or exploitation rate obtained from the change-in-ratio method have been assumed to be symmetrical (e.g., Paulik and Robson 1969; Seber 1982). However, our study, in addition to Udevitz (1989) (in Udevitz and Pollock 1992) and Frusher et al. (in prep.), has shown that such symmetrical confidence limits are not valid, as the distributions of abundance and exploitation are skewed (i.e., asymmetrical). Our study shows that asymmetrical confidence limits should be calculated, e.g., using bootstrapping.

For female *J. edwardsii*, there were no differences in precision when using different estimators of proportion legal-size (i.e., pooled versus average). However, a large increase in the precision of the change-in-ratio method was observed for males when the average estimator was used, compared to when the pooled estimator was used. Hart and Gorfine (1996) also found that the average estimator resulted in higher precision than the pooled estimator when using the change-in-ratio method on abalone (*Haliotis rubra*) in Victoria. It is worth noting that for females the difference in the change in proportion legal-size between pooled and average estimators was only about 0.004, but for males the change in proportion legal-size was higher for the average estimator (0.140) than for the pooled estimator (0.097). It is because of these differences in the change in proportion legal-size that both the estimates, and the precision of the estimates, are different between the two estimators for male lobsters. The change-in-ratio method is very sensitive to bias when the change in proportion legal-size is around 0.10 (Paulik and Robson 1969), hence it could be due to this phenomenon that the male data are sensitive to which estimator is used. More comparisons of the pooled and average estimators are needed to resolve the question of whether there is an advantage in using the average estimator over the pooled estimator with the change-in-ratio method.

Effect of using narrow size categories with the change-in-ratio method

Anon. (1958) and Winstanley (1977) stated that larger lobsters may exclude smaller lobsters from entering pots because of size-related dominance hierarchies (Fielder 1965a). If this hypothesis is correct, then as legal-size lobsters are removed from an area, the catchability of undersize lobsters relative to legal-size lobsters should increase. This would mean that the ratio of legal-size to undersize lobsters caught in pots would decrease at a greater rate over a period of exploitation than in the actual population, causing the change-in-ratio method to underestimate abundance and overestimate exploitation. However, it seems that there was little bias from size-related dominance in our data, as using a narrow range of sizes above and below legal-size did not make a great difference to the exploitation rates obtained from the change-in-ratio method analyses. It may have been that the number of lobsters caught in pots was so low (see Treble 1996) that interactions between lobsters inside and outside the pot were too infrequent for dominance or catchability effects to appear. Hence there seems to be little reason to lower the power of the change-in-ratio method analysis by truncating the data set. This result also means that the change-in-ratio method is well suited to a voluntary logbook program, because only classification of lobsters as male or female, and legal-size or undersize, need be recorded.

Previous estimates of abundance of Jasus edwardsii

Apart from our study, abundance of *J. edwardsii* has only been estimated using the change-in-ratio method in New Zealand (Paul Breen, National Institute for Water and Atmospheric Research, P.O. Box 14-901, Kilbirnie, Wellington, 6003, New Zealand, personal communication). Frusher et al (in prep.) have used the change-in-ratio method on *J. edwardsii* in Tasmania, but only to estimate exploitation rates, not abundance, as total removals of legal-size lobsters that are need to estimate abundance were not monitored in their study. Estimates of absolute abundance or density of *J. edwardsii* populations have been obtained using SCUBA surveys or using the Leslie method (e.g., MacDiarmid and Breen 1993; see below in this report). However, SCUBA surveys are only useful in shallow water (less than 30 m), and estimates of absolute abundance obtained using the Leslie method are probably biased (Treble 1996), most likely due to changes in catchability within a fishing season (Miller and Mohn 1993).

From SCUBA surveys conducted in shallow lobster habitat in the Apollo Bay area, the mean density of legal-size lobsters (males and females pooled) was estimated as 0.0074 lobsters m^{-2} (see below). The density of legal-size lobsters (males and females combined) calculated from the change-in-ratio method analysis is approximately 0.0008 lobsters m^{-2}, assuming a 6.3 km^2 area was sampled (Figure 1). Thus the SCUBA survey and change-in-ratio method estimates of legal-size *J. edwardsii* density are markedly different. Because the methods were applied in different areas, these differences could be real. The different estimates could also be due to bias in either one or both methods. It is possible that the SCUBA survey estimates are overestimates of lobster density on the scale of the change-in-ratio method sampling, if the SCUBA surveys targeted lobster habitat within areas the size of the 9 and 11 Mile Reef area. Conversely, it is possible that the change-in-ratio method presented here underestimates abundance (and overestimates exploitation). If there was a component of the population of *J. edwardsii* that remained un-catchable by traps during the change-in-ratio method survey, this would result in such a bias. Alternatively, an increase in catchability of undersize compared to legal-size lobsters over the period of the change-in-ratio method survey would have produced such a bias.

Previous estimates of the exploitation rate of Jasus edwardsii

Although most of the change-in-ratio method survey was over a three month period (i.e., mainly from mid-November to late-February), the exploitation rates obtained are that expected on an annual basis, because the 9 and 11 Mile Reef area is seldom fished outside this time of the year. We found, in contrast to Winstanley et al. (1982), that exploitation rates were higher for females than for males. This may be because more legal-size females than males were removed by fishing from the study area. However, the estimate of exploitation for male *J. edwardsii* calculated here may be lower than the female estimate because of a higher rate of moulting of undersize males to legal-size during the sampling period (see below).

Powell (1977) stated that exploitation rates in the Victorian southern rock lobster fishery were between 0.26 and 0.39. Winstanley et al. (1982), using tagging data and an assumed rate of natural mortality of 0.2 yr^{-1}, calculated exploitation rates of 0.5 for males and 0.4 for females for fishing grounds less than 45 m deep off Portland, Victoria. Our estimates of exploitation rate for *J. edwardsii* in Victoria using the change-in-ratio method are somewhat higher than the above estimates, but this is not unexpected as fishing effort and fishing power are probably higher now than during these earlier studies (Hobday and Smith 1996; Treble 1996). Hobday and Smith (1996) calculated annual rates of exploitation of between 0.33 and 0.45 for the *J. edwardsii* fishery across the whole of Victoria, i.e., also lower than the change-in-ratio method estimates presented here.

Similar estimates of exploitation to those presented here have been reported in other *J. edwardsii* fisheries in southern Australia and New Zealand. Frusher et al. (in prep.) estimated exploitation rates over a similar period (November to March) to our study, and reported exploitation rates of *J. edwardsii* just above legal-size of between 0.41 to 0.90 for males and 0.43 to 0.86 for females, using both the change-in-ratio and index-removal methods. Recent analyses have estimated exploitation rates in the Southern Zone of South Australia of between 0.3 and 0.4, and lower values for the Northern Zone (Richard McGarvey, SARDI Aquatic Sciences, P.O. Box 120, Henly Beach, South Australia, 5022, Australia, personal communication). Breen and Kendrick (1995) estimated exploitation as between 0.50 and 0.96 for legal-size males and between 0.09 and 0.81 for legal-size females (modified from their Z estimates using M = 0.1), although the estimates of total mortality for *J. edwardsii* were quite variable between regions and years. Using the change-in-ratio method, exploitation rates were estimated as between 0.55 and 0.83 for legal-size *J. edwardsii* in the Gisborne area of New Zealand (Paul Breen, National Institute for Water and Atmospheric Research., P.O. Box 14-901, Kilbirnie, Wellington, 6003, New Zealand, personal communication).

Bias from moulting to legal-size (recruitment) during change-in-ratio sampling

Using observations on carapace softness and fouling, a significant number of lobsters just above legal-size were classified as recently moulted in the 9 and 11 Mile Reef area during the 1994-95 fishing season, suggesting that there was some growth of undersize lobsters to legal-size during sampling (Figures 6 and 7). Tagging of undersize lobsters also showed that there was a lot of recruitment through growth of males from pre-recruit carapace length-classes to legal-size during the 1994-95 season in the study area, although for females little such recruitment occurred (Table 4). Such recruitment to legal-size would result in overestimates of abundance and underestimates of exploitation.

Thus these data suggest that exploitation rates of males are underestimated compared to females, and abundance of males is overestimated compared to females. If we consider that the estimates of abundance for legal-size males are overestimates compared to female estimates because of recruitment, this brings the estimated sex ratio of legal-size *J. edwardsii* is closer to 1:1, which could be more realistic. Frusher et al. (in prep.) also found significant moulting to legal-size by male *J. edwardsii* in Tasmanian waters during their change-in-ratio method surveys, resulting in underestimates of exploitation of between 6 and 15% for males.

Adjustment to the change-in-ratio method to account for moulting to legal-size can be done using tagging data (e.g., as in Frusher et al., in prep.). Due to the relatively low number of recaptures of tagged lobsters during the 1994-95 season (see Table 4), we did not attempt to adjust the change-in-ratio method for recruitment using the tagging data.

Detailed data on moult state (carapace softness and carapace fouling by polychaetes) of *J. edwardsii* were collected during on board sampling (Figures 6 and 7). However, because of: (1) the subjective nature of the carapace condition data, (2) the unavoidably arbitrary way of classifying lobsters as recently moulted, and (3) possible size-specific variation in the time taken to reach full carapace hardness after ecdysis (see Treble 1996), quantitative use of this information to calculate moulting probabilities and adjust the change-in-ratio method has not been attempted here.

Influence of fishing patterns and depth on change-in-ratio method estimates

The skipper of the *Lindy* stated that although we were fishing in the one general area for about 3 months, small sub-areas in the 9 and 11 Mile Reef area were fished only about 3 or 4 times. Thus the data shown here do not represent a perfect progressive 'fish-down' of the whole study site. Some of the error associated with the proportion legal-size versus cumulative catch regressions is probably associated with non-random pot placements, and this cyclic pattern of exploitation. In addition, the depth of substrate in the 9 and 11 Mile Reef area is not the same, and in deeper areas the proportion of lobsters that were of legal-size is higher (Figure 8). Fishing was not at random with respect to depth during the change-in-ratio survey (Figure 9). Such non-random placement of pots with respect to depth probably explains some of the error in the data, which in turn would tend to lower the precision of the change-in-ratio method estimates presented here. There was a slight trend toward shallow ground toward the end of sampling (Figure 9), but the slope of a linear regression of mean depth versus day of fishing was not significantly different from zero ($n = 32$, slope = -0.040, $R^2 = 0.012$, $p = 0.396$). Hence it is unlikely that the estimates of abundance or exploitation rates are biased to any great extent from this factor. In addition, analyses within depth strata (not shown) showed similar declines in proportion legal-size through the season as when depths were not pooled. The use of fixed, randomly-selected stations for change-in-ratio method surveys might increase the precision of the change-in-ratio method (Chen et al. 1995). However, this would not be possible if commercial catch sampling or voluntary logbook data were being used, since fixed pot placements are not a feature of normal lobster fishing practice.

Other possible sources of bias

Tagging showed that little movement of lobsters (*J. edwardsii*) occurs in the Apollo Bay area, and that little immigration into or emigration out of the study area occurred during sampling (see Chapter 5 in Treble 1996). Thus movement patterns of *J. edwardsii* should not have biased the results obtained. Soak times were mostly 1 day, but on some days pots had been hauled after longer periods (see Results). Soak time probably altered the proportions legal-size, but excluding pots with soak times longer than 1 day did not affect the estimates as the longer soak time samples were reasonably evenly spread through the season. Nevertheless, inclusion of the longer soak time data could have decreased the precision of the estimates.

Changes in the relative catchability of undersize and legal-size lobsters during the course of the survey would bias the change-in-ratio method. Anon. (1958) and Winstanley (1977) stated that larger lobsters (*J. edwardsii*) sometimes prevent smaller lobsters from entering traps. Removal of larger, dominant legal-size lobsters by fishing could increase the rate of entry of undersize lobsters into pots toward the end of the season (e.g., Miller 1979, 1990; Addison 1995), thus altering the catchability of undersize lobsters relative to legal-size lobsters. This change in relative catchability would result in underestimation of abundance using the change-in-ratio method. However, due to the low catch rates of lobsters in the change-in-ratio method survey, interactions between lobsters inside and outside of the pot are probably low and such affects unlikely to be present. Nevertheless, CPUE of undersize lobsters did increase during sampling in the 9 and 11 Mile Reef area in 1994-95 (see Figure 13), suggesting an increase in the absolute catchability of undersize lobsters. However, these data do not suggest a change in the *relative catchability* of legal-size versus undersize lobsters, i.e., the catchability of legal-size lobsters in the 9 and 11 Mile Reef area could have increased at the same time as this increase in undersize catchability. Nevertheless, such a change in relative catchability of legal-size versus undersize lobsters was not tested in our analysis, and is an area that should be investigated, possibly by using more intense tagging of legal-size lobsters than were conducted at Apollo Bay.

The Leslie method

Methods

In a situation where animals are being removed by exploitation, and there is no recruitment to the stock, Leslie and Davis (1939) showed that under certain assumptions, there will be a linear relationship between catch per unit effort (CPUE) and the cumulative catch (animals removed). Thus if catch and effort can be measured during a period of fishing, absolute abundance and exploitation rates can be obtained from a regression of CPUE versus cumulative catch (Seber 1982).

One set of data used in the Leslie method, was from on-board sampling in the 9 and 11 Mile Reef area in the 1994-95 main fishing season (i.e., the data used in the change-in-ratio method analysis described above). This Leslie analysis used CPUE of legal-size lobsters (number per potlift) instead of the proportion of the catch that was of legal-size. Data on the number of legal-size lobsters removed before each day of fishing in the 9 and 11 Mile Reef area in this period were those used for the change-in-ratio method.

Archived catch and effort data from commercial fisher's compulsory logbooks for the Apollo Bay area were also used in the Leslie method. The commercial logbook data were made available in the form of monthly summaries of the number of legal-size lobsters landed and fishing effort (potlifts), for 16 seasons from 1978-79 to 1993-94, in depth range and statistical area categories in the Apollo Bay area.

For the on-board sampling data from the 9 and 11 Mile Reef area, abundance and exploitation rates were estimated separately for males and females. Regressions of mean daily CPUE (legal-size lobsters per potlift) on each day of sampling ($n = 32$ days) versus the cumulative number of legal-size lobsters removed before that day of sampling were done. Estimates of abundance of legal-size lobsters at the start of the season were calculated from the "x-intercepts" of the regressions. Exploitation rates were calculated by dividing the total catch in the season by the estimate of abundance. Because the data from the on-board sampling were recorded on a "per pot" basis (i.e., independent sampling units), bootstrapping was used to calculate the confidence limits of the estimates of abundance and exploitation rate obtained (as done for the change-in-ratio method analysis).

For the commercial logbook Leslie analysis, data were pooled over all statistical areas and depth categories. Thus estimates of abundance and exploitation were for the whole of the Apollo Bay area. Fishers do not record the sex of lobsters retained in their logbooks, so the estimates of abundance and exploitation obtained from the Leslie analyses of the commercial logbook data are for males and females combined. For the commercial logbook data, mean CPUE of legal-size lobsters for each month from November to March for each season were regressed on cumulative catch at the mid point of the month. Commercial logbook data after March were not used, because data on the sex ratio of the commercial catch (Figure 10) show that a significant drop in catchability is observed for females above the legal minimum length at this time, probably because of the onset of the moulting and reproductive season for mature females. We felt that exclusion of this data, and restriction to a shorter period would increase the accuracy of the Leslie method as applied to the logbook data. In addition, females are not landed after June 1 (closed season), so the female component of the catch that is returned to the sea is not recorded in commercial logbooks. Hence June, July and August data were not used in the Leslie analyses.

On-board observations showed that some mature females were still in berry at the start of the season in November and are still caught at low levels in December and January (Figure 11; see also Chapter 4 in Treble 1996). Thus the logbook data for the first few months of the season were adjusted to take into account the proportion of the legal-size catch that was in berry and returned to the sea (i.e., not recorded in logbooks).

Bootstrapping (the best way of calculating confidence limits) could not be used to estimate confidence limits from the Leslie analyses of the commercial logbook data because of the lack of independent replicates.

Results

On-board sampling - 9 and 11 Mile Reef area data

For both sexes, CPUE of legal-size *J. edwardsii* varied markedly on a day to day basis (Figure 12). CPUE of legal-size females decreased over the period of sampling, but CPUE of legal-size males showed a much smaller decline during the 1994-95 fishing season (Figure 12). The CPUE of undersize lobsters showed marked day to day variation (mostly due to low sample sizes), but actually increased over the sampling period (Figure 13).

There was little overlap in the distributions of abundance obtained from the Leslie and change-in-ratio methods for the 9 and 11 Mile Reef area from the 1994-95 season (Figures 14 and 15). That is, the Leslie and change-in-ratio method produced quite different estimates of abundance and exploitation from the same data set. The Leslie estimates of abundance are much larger than those calculated using the change-in-ratio method, especially for males (Figures 14 and 15; Table 5). Leslie estimates of abundance and exploitation of legal-size *J. edwardsii* are skewed, markedly so for males (Figures 14 and 15). The 90% confidence limits of the estimates of abundance obtained using the Leslie method are much wider than those produced by the change-in-ratio method, the estimates for males being ridiculously wide (Table 5). In fact the lower 90% confidence limits for abundance and exploitation obtained for males using the Leslie method are negative (Table 5)! The confidence limits for the exploitation rate estimates are actually wider from use of the change-in-ratio method (Table 5). However, this is probably because the sometimes excessively high estimates of abundance using the Leslie method result in low estimate of exploitation rate, which are not as variable on an absolute scale.

Commercial logbook data

For each year's data, except 1986-87, there was an overall decrease in the CPUE of legal-size *J. edwardsii* (adjusted for unreported catches of legal-size berried females) though the November to March period (Figure 16). However, in some seasons the relationship between CPUE and cumulative catch was sometimes far from linear, with CPUE sometimes higher than in the previous month (Figure 16). This suggests that either the population was not closed, or that the catchability of legal-size lobsters was not constant, violating assumptions of the Leslie method. Estimates of abundance and exploitation rate for legal-size *J. edwardsii* obtained from the Leslie analyses showed marked variability from year to year (Figure 17). In fact, CPUE increased from November 1986 to March 1987, which resulted in a negative estimate of abundance and exploitation rate for the 1986-87 season - an impossible result!

Discussion

Leslie analyses of the commercial logbook data

All lobster populations fluctuate in abundance from year to year (Cobb and Wang 1985), e.g., because of recruitment fluctuations (Chittleborough and Phillips 1975; Pringle 1986; Addison et al. 1995; Polovina et al. 1995). However, the amount of year to year variation in the estimates of abundance obtained from the Leslie analyses of the commercial logbook data are probably too high to be accounted for by natural variation in recruitment. The negative result obtained for the 1986-87 season definitely shows that the Leslie method is producing inaccurate results.

Leslie analysis of the 9 and 11 Mile Reef area data

The markedly skewed sex ratio for legal-size lobsters obtained using the Leslie method (i.e., 7 males to 1 female - see Table 5) for the 9 and 11 Mile Reef area also suggests this method is biased, because the sex ratio of lobsters is probably closer to unity (Fielder and Olsen 1967; Cobb and Wang 1985).

The estimate of exploitation rate of 0.07 for legal-size male southern rock lobsters in the 9 and 11 Mile Reef area over 3 months is much lower than all other estimates of exploitation in the fishery (see above), probably because of a severe overestimation of abundance from the Leslie method for males. This also suggests that the method is biased.

The confidence limits of the estimates of abundance obtained from the Leslie method are much wider than those produced by the change-in-ratio method, and include negative values. This further reduces the attractiveness of using the Leslie method to estimate abundance of *J. edwardsii* - the estimates are too imprecise to be useful for serious stock assessment, especially for males.

Factors that may have biased the Leslie method

Even for a small homogenous area (i.e., the 9 and 11 Mile Reef area), the Leslie method did not work well at all. Thus the Leslie method seems to be biased by factors irrespective of the spatial scale that the data are collected on, and collection or analysis of data on smaller spatial scales did not seem to improve the accuracy of the method.

Tagging has shown that *J. edwardsii* in the Apollo Bay area move little (Treble 1996), so changes in the actual abundance of *J. edwardsii* on particular fishing grounds because of immigration or emigration of lobsters cannot explain why the method seems biased.

The Leslie method as applied here assumes that the catchability of lobsters is constant through a fishing season (e.g., Braaten 1969; Miller and Mohn 1993). Slight variations in catchability though time (i.e., through a season) can result in large errors in the estimates of abundance and exploitation when using this method (Miller and Mohn 1993). Miller and Mohn (1993) stated that the Leslie method has never been shown to produce valid estimates of abundance for crustacean fisheries, because the assumption of constant catchability can rarely be met in commercial trap-based lobster and crab fisheries (Morgan 1980; Miller 1990).

Changes in the catchability of lobsters in pots may be present because of changes in lobster behaviour and feeding rates associated with moulting or reproduction, octopus predation and the presence of dead lobsters in the pot, water temperature and salinity, soak time, weather patterns such as sea swell height and wind strength, tidal flow rates, water turbidity, lunar cycles, and the amount, type and freshness of bait (McLeese and Wilder 1958; Fielder 1965b; Heydorn 1969; Chittleborough 1970; Morgan 1974b; Zoutendyk 1988; Miller 1990; Addison et al. 1995). Violation of this constant catchability assumption is probably the main reason why the Leslie method was inaccurate when applied to the data from Apollo Bay, possibly due to any of these factors.

If catchability was constant, CPUE of undersize *J. edwardsii* should show no trend with time, or a slight decrease over time if discard mortality was present. However, the CPUE of undersize lobsters *increased* during sampling in the 9 and 11 Mile Reef area, suggesting that the CPUE of legal-size lobsters also increased over this period. Such an increase in catchability of legal-size *J. edwardsii* over the main period of sampling probably explains why the Leslie method overestimates abundance and underestimates exploitation rate compared to the change-in-ratio method, because the change-in-ratio method only assumes constant *relative* catchability between undersize and legal-size lobsters.

The Leslie method assumes the population is closed during the fishing period. However, there is significant recruitment of male *J. edwardsii* to legal-size during the main summer fishing season in the Apollo Bay area because of moulting of undersize males (see Figure 6; Table 4; Treble 1996). This would tend to maintain the CPUE of males at higher levels than expected if the population was closed. Thus like the change-in-ratio method, recruitment into the male stock of legal-size lobsters, may have biased the Leslie estimates of abundance and exploitation obtained for males. This would explain why male abundance was overestimated compared to females when using the Leslie method on the 9 and 11 Mile Reef area data, and why the Leslie estimate of exploitation for males was low.

Application of the Leslie method to Jasus edwardsii *populations in other areas*

The Leslie method may not always yield different results to the change-in-ratio method, when applied to stocks of southern rock lobster (*J. edwardsii*). The removal method uses CPUE data in a technique analogous to the Leslie method, and in contrast to our findings, the removal and change-in-ratio methods yield similar estimates of exploitation when applied in Tasmania (Frusher et al., in prep.). Lobster densities in southern Tasmania are much higher than that seen at Apollo Bay, which is why CPUE methods such as the removal method seems to be unbiased in Tasmania (Stuart Frusher, Department of Primary Industries and Fisheries, G.P.O. Box 192B, Hobart, Tasmania, 7001, Australia, personal communication). Thus Frusher et al.'s data suggest that the Leslie method may work better in areas where *J. edwardsii* occurs in high densities.

SCUBA surveys

Methods

Underwater visual census has been used extensively to estimate the density of *Jasus edwardsii* in New Zealand (e.g., MacDiarmid 1991; MacDiarmid and Breen 1993). We used SCUBA surveys similar to those used in New Zealand to estimate the density of *J. edwardsii* in the Apollo Bay area of the Victorian southern rock lobster fishery. Surveys were conducted by Mr. Daryl Joiner and Ms. Dora Novak (Faculty of Resource Science and Management, Southern Cross University, Lismore, New South Wales, 2480, Australia) between December 1994 and February 1995.

Six sites were chosen on the coast around Apollo Bay for the SCUBA surveys: Little Henty Reef, the "Rifle Butts", Blanket Bay, "Mushroom" Reef, "Ryan's Den", and the "Football Ground" (Figure 18). Lobsters (*J. edwardsii*) above approximately 25 mm carapace length (smallest lobster observed) were counted within quadrats placed haphazardly in reef habitat. Only shallow habitat near the shore was surveyed.

Two quadrat sizes were used: 10 x 10 m and 20 x 20 m. The 10 x 10 m quadrat was used most of the time. The 20 x 20 m quadrat was difficult to deploy in the field, and only used twice. However, when the 20 x 20 m quadrat was used, the numbers of lobsters in each 10 x 10 m quarter of the quadrat were noted separately. A 30 m long by 4 m wide belt transect was used on a few occasions as well.

During the initial SCUBA surveys, it became obvious that the number of lobsters observed within a quadrat was dependent on the amount of suitable habitat in that quadrat, i.e., the amount of crevice and macroalgal cover. During later surveys, a subjective index of the amount of lobster crevice in each quadrat was noted. This index was recorded as four levels, from 1 = no crevice or unsuitable crevice, to 4 = abundant suitable crevice. The percentage cover of the dominant macroalgal groups (*Phyllospora comosa*, *Durvillea potatorum*, *Ecklonia radiata*), of "other" macroalgal species, and of bare rock or sand, and the type of rock and whether it was made up of ledges or boulders (or neither), were recorded for each quadrat during later dives as well. Quantitative habitat data were collected for only three sites (Little Henty Reef, Rifle Butts, and Ryan's Den), because of its late introduction into the SCUBA survey program.

Where possible, the sex and carapace length of lobsters seen within quadrats were recorded. Carapace length was usually estimated visually (e.g., as in MacDiarmid 1991 or Andrew and MacDiarmid 1991), although only to the nearest 10 mm. Sometimes the lobster was caught by hand and its carapace length measured accurately using vernier calipers. However, the divers could not estimate the size of every lobster, because some were too far inside crevices to see clearly, and lobsters were captured only occasionally because we wanted to minimise disturbance to lobsters in the survey areas. Some lobsters were only classified as undersize or legal-size.

Results

Lobster density by site

Over 16 days of diving, 132 "quadrats" were surveyed. "Quadrats" include the belt transects (n = 13), and the corners of the 20 x 20 m quadrat (n = 2) counted as replicate 10 x 10 m quadrats. Depths of the quadrats ranged from 2 to 9 m (mean depth = 4.8 m). The density of *J. edwardsii* was variable, ranging from 0 to 11 lobsters per 100 m^2 quadrat (Figure 19). The data were highly skewed toward low lobster densities, because divers saw no lobsters in quadrats most frequently (Figure 19). There were significant differences in lobster density between sites (Welch ANOVA robust to unequal variances, $W = 2.87$, df = 40.45, $p < 0.025$) (Figure 20). Mushroom Reef and the Football Ground have higher densities of lobsters than the other four sites (Figure 20).

Habitat and lobster density

There was a positive association between lobster density and both the crevice index and the percentage cover of *Phyllospora comosa* (cray weed), i.e., lobster densities were higher if there was more suitable crevice or a higher percentage of *P. comosa*. There was also a negative association between lobster density and the percentage cover of *Durvillea potatorum* (bull kelp) (Figure 21).

Lobster size data

Using either estimated size, actual size or undersize/legal-size classification, about 173 undersize and 99 legal-size lobsters were seen during the SCUBA surveys (proportion undersize = 0.636; proportion legal-size = 0.364). The mean lobster density from all sites pooled is 0.020 lobsters m^{-2}. Thus the estimate of density for legal-size lobsters from the SCUBA surveys is 0.364 x 0.020 = 0.0074 lobsters m^{-2}.

Discussion

Habitat and density

The quantitative habitat data collected suggest that the amount of habitat has a large influence on the density of *J. edwardsii* within a site. Edmunds (1995) also found that *J. edwardsii* greater than 60 mm carapace length tended to be confined to areas of reef that had a relatively abundant crevice. Conversely, MacDiarmid and Breen (1993) concluded that lobster densities were low at Poor Knights Island in New Zealand compared to adjacent areas because of the paucity of suitable habitat for juvenile lobsters.

Within a site, lobster density is variable and depends on the amount of crevice habitat, so stratification by the amount of suitable habitat (e.g., by crevice index) could be used to increase the power and thus efficiency of the SCUBA surveys used here. More effort should be expended in areas where high lobster variance is expected, i.e., relatively high density areas.

Differences in density between sites

The sites surveyed in the Apollo Bay area differed in lobster (*J. edwardsii*) density. Differences in *J. edwardsii* density have also been observed between localities in New Zealand and Tasmania (MacDiarmid and Breen 1993; Edmunds 1995). There are two obvious explanations for the differences observed at Apollo Bay. They are, that fishing effort differed between sites, and that the amount of suitable lobster habitat varied between sites. Qualitative descriptions of substrate and habitat obtained from Daryl and Dora showed that the type and amount of habitat differed between sites. The available evidence from diving surveys in New Zealand and Tasmania suggests that fishing pressure does modify lobster density. For example, MacDiarmid and Breen (1993) observed that cessation of fishing has resulted in a large increase in lobster density and biomass in the Leigh Marine Reserve. Differences in lobster density between sites at Apollo Bay are probably because of differences in the amount of habitat at each site, perhaps moderated by the amount of fishing effort at each site.

The percentage cover of *P. comosa*, and perhaps the percentage cover of *D. potatorum* were also important determinants of lobster density. *P. comosa* is known colloquially as "cray weed", because fishers and SCUBA divers have long observed its association with the presence of lobsters on an area. Thus it is not suprising to find a correlation between the percentage cover of *P. comosa* and lobster density. *P. comosa* may give *J. edwardsii* extra amounts of shelter. The slight negative association between *D. potatorum* ("bull kelp") and lobsters may be because they dislike physical contact with heavy kelp fronds during the strong swell induced surges and tidal currents that are characteristic of the Apollo Bay coast.

Possible bias in lobster densities using the SCUBA survey technique

Even though the quadrats were placed haphazardly, they were placed within areas where lobster habitat was relatively abundant. Thus the densities presented here are probably only for rocky areas, so if extrapolated to larger spatial scales, densities of *J. edwardsii* would be much lower than those presented here. This apparent, unintentional targeting of reef habitat may explain why the density of legal-size lobsters calculated using SCUBA was much higher than the density of legal-size lobsters calculated using the change-in-ratio method (see above in change-in-ratio method section).

On a small scale, estimates of lobster density obtained from the SCUBA surveys presented here are probably underestimates, because it is unlikely that 100% efficiency was achieved in observing lobsters in crevices, especially at sites with large amounts of deep, interconnected crevice habitat, and because small *J. edwardsii* (< 30 mm carapace length) were probably not seen by the divers.

General discussion

The estimates of exploitation and abundance for males using the change-in-ratio method were of low precision, in contrast to the female estimates, which were probably precise enough for stock assessment. Low precision for males was mainly because of the smaller decrease in the proportion of legal-size in the population during the fishing season (i.e., a smaller "effect size"). Modelling of the change-in-ratio method data using auxiliary variables (e.g., depth) that may affect the sizes of *J. edwardsii* in pots could be used to increase the precision of the estimates presented here. The change-in-ratio method is more efficient in fisheries where a large proportion of the stock is taken out in a short time, because in such cases the "closed population" assumptions of the method are less likely to be violated, and the precision of the method is highest. However, a high exploitation fishery is often contrary to management objectives. Hence reductions in exploitation rate through management changes may make the change-in-ratio method less precise and not as useful.

We have shown that use of lobster CPUE data in the Leslie method is not a very good way of estimating abundance and exploitation rates of *J. edwardsii* populations, probably because of changes in catchability during a season. The change-in-ratio method does not suffer from the same bias, because it only assumes that the *relative* catchability of legal-size and undersize lobsters is constant over time. It may still be that the change-in-ratio method is biased (see below). There is probably scope for using the existing extensive CPUE data sets with biological and environmental data to understand the causes of changes in catchability of *J. edwardsii*. Mean annual CPUE is probably a more reasonable way of utilising CPUE data for stock assessment. However this only provides an index of abundance. Techniques such as the change-in-ratio method are needed to obtain estimates of absolute abundance and exploitation rates of *J. edwardsii* stocks.

We have presented in this report, estimates of exploitation rate for the Victorian rock lobster fishery, from use of the change-in-ratio method and the Leslie method. Winstanley et al. (1982), Powell (1977b), and Hobday and Smith (1996) have also published estimates of fishing mortality (exploitation rate) in the Victorian southern rock lobster fishery. Application of the change-in-ratio method in the 9 and 11 Mile Reef area resulted in estimates of exploitation of 0.80 for females and between 0.45 and 0.57 (depending on the statistical estimator used) for males. These estimates were over a 3 month period of exploitation, and are probably close to annual rates of exploitation. Ninety percent confidence limits obtained from bootstrapping are between 0.64 and 0.91 for females and 0.04 and 0.75 for males. Thus for males, the estimates are far too wide to be useful, although the female data still suggests that exploitation in the fishery is high.

When the Leslie method was applied to the same data set from the 9 and 11 Mile Reef area, much lower estimates of exploitation resulted: 0.49 for females and 0.07 for males. Because of an increase in catchability thorough the season, these estimates of exploitation are probably underestimates, although other sources of bias could be present as well. Data on abundance for males and females estimated from the Leslie suggest that the sex ratio of legal-size lobsters is markedly different from 1:1 in the 9 and 11 Mile Reef area. This apparent skewed sex ratio was probably because of a severe overestimation of male abundance, and thus a severe underestimation of exploitation when using the Leslie method. Estimates of exploitation rate for the Leslie analyses of the commercial CPUE data were not very consistent from year to year, possibly due to changes in catchability through a season that were not equal from year to year.

Recapture rates of legal-size lobsters tagged in the 9 and 11 Mile Reef area in September 1994 were only about 30% during the change-in-ratio method survey of this area in November 1994 to April 1995 (Treble 1996). This suggests that exploitation was only about 30% in the area. Estimates of the density of legal-size lobsters using SCUBA and the change-in-ratio method were markedly different (CIR estimate only ~ 10% of SCUBA estimate). If we assume that the change-in-ratio method is underestimating abundance compared to the SCUBA surveys, we must assume that it is overestimating the rate of exploitation. Both these comparisons suggest that the change-in-ratio method is underestimating the exploitation rate of *J. edwardsii*. However, the tagging data is based on few recaptures, and the analysis presented here assumes negligible mortality (natural and tagging-induced). In addition, the SCUBA surveys were in different areas to the change-in-ratio method survey, and were on a smaller spatial scale, so that the surveys could have been "targeting" lobster habitat. In addition, size-frequency distributions of lobsters in the 9 and 11 Mile Reef area are quite broad (see Chapter 6 of Treble 1996), i.e., many lobsters manage to grow to be much larger than the legal minimum lengths, the opposite expected if high exploitation rate are present in the area. Therefore the size-frequency data also suggest that the estimates of exploitation rate produced by the change-in-ratio method, especially for females, could be too high. The only other recent estimate of exploitation in the Victorian southern rock lobster fishery is from Hobday and Smith (1996), who did use length-converted catch curves to estimate fishing mortality in the southern rock lobster fishery in Victoria. They estimated an exploitation rate of between 0.33 and 0.45 for the fishery, i.e., lower than the change-in-ratio method estimate as well.

We have shown that SCUBA surveys are easily applied to stocks of *J. edwardsii* in Victoria. However, SCUBA divers are restricted to depths less than about 30 m, so underwater visual census techniques are only good for inshore stocks, and they cannot be used to assess the main stocks of *J. edwardsii* that inhabit areas deeper than 30 m. In addition, there is still the problem of scale, because density estimated on the scale of a fishing ground is likely to be different to density estimated from diver surveys. A standard survey over time could still be used as an index of abundance, and used to monitor the "health" of lobster stocks.

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Table 1. Results of using the change-in-ratio regression method to calculate abundance and exploitation rates of legal-size female lobsters (*Jasus edwardsii*) in the 9 and 11 Mile reef area. Abundance was not calculated where lobsters one increment above and below legal-size were used. The estimate of the total number of legal-size females removed from the 9 and 11 Mile Reef area between the first and last days of sampling was 1,611.

Carapace length-classes used	Estimator type	Regression: p-value	R^2	Legal-size abundance	Exploitation rate
All	Pooled	< 0.001	0.462	2,039	0.790
All	Average	< 0.001	0.518	1,991	0.809
Legal-size +/- 5 mm	Pooled	0.003	0.261	-	0.694

Table 2. Results of using the change-in-ratio regression method to calculate abundance and exploitation rates of legal-size male lobsters (*Jasus edwardsii*) in the 9 and 11 Mile reef area. Abundance was not calculated where lobsters one increment above and below legal-size were used. The estimate of the total number of legal-size males removed from the 9 and 11 Mile Reef area between the first and last days of sampling was 1,326.

Carapace length-classes used	Estimator type	Regression: p-value	R^2	Legal-size abundance	Exploitation rate
All	Pooled	0.043	0.130	2,991	0.443
All	Average	0.004	0.246	2,347	0.565
Legal-size +/- 10 mm	Pooled	0.082	0.098	-	0.474

Table 3. Observed value and 90% bias-corrected confidence limits of (a) abundance of legal-size lobsters at start of season and (b) exploitation rates of legal-size lobsters in the 9 and 11 Mile area during the 1994 to 1995 fishing season. Estimates made for males and females are shown separately.

(a) Abundance

Sex	Data type	Observed value	90% confidence Lower limit	Upper limit	Interval
Female	Pooled	2,039	1,787	2,450	663
Female	Average	1,991	1,766	2,453	687
Male	Pooled	2,991	2,007	10,404	8,397
Male	Average	2,347	1,772	4,614	2,842

(b) Exploitation rates

Sex	Data type	Observed value	90% confidence Lower limit	Upper limit	Interval
Female	Pooled	0.790	0.638	0.890	0.252
Female	Average	0.809	0.656	0.912	0.256
Male	Pooled	0.443	0.178	0.698	0.520
Male	Average	0.565	0.299	0.754	0.455

Table 4. Approximate recruitment rates (moulting to legal-size) for lobsters (*Jasus edwardsii*) in the Apollo Bay area during the 1994-95 season. Data are for pre-recruit lobsters (less than 10 mm carapace length below legal-size for males, and less than 5 mm carapace length below legal-size for females) released and recaptured in the period November 1994 to April 1995. The mean number of days at liberty for each category are in brackets. For females, most (35 out of 38) of the tagged lobsters shown were mature.

Sex	n	Moulted to legal-size	Did not moult to legal-size	% moulted to legal-size
Male	16	5 (90)	11 (54)	31%
Female	38	1 (67)	37 (44)	3%

Table 5. Observed value and 90% confidence limits* of (a) abundance of legal-size lobsters at start of season and (b) exploitation rates of legal-size lobsters in the 9 and 11 Mile Reef area during the 1994-95 fishing season, calculated using the Leslie and change-in-ratio methods. The estimates for the change-in-ratio method are those calculated when using the pooled estimator.

(a) Abundance of legal-size lobsters

		Observed	90% confidence		
Sex	**Analysis**	**value**	**Lower limit**	**Upper limit**	**Interval**
Female	Leslie	3,280	2,783	4,088	1,304
Female	Change-in-ratio	2,039	1,787	2,450	663
Male	Leslie	23,112	-62,961	67,874	130,836
Male	Change-in-ratio	2,991	2,007	10,404	8,397

(b) Exploitation rates of legal-size lobsters

		Observed	90% confidence		
Sex	**Analysis**	**value**	**Lower limit**	**Upper limit**	**Interval**
Female	Leslie	0.491	0.394	0.579	0.185
Female	Change-in-ratio	0.790	0.638	0.890	0.252
Male	Leslie	0.070	-0.145	0.256	0.402
Male	Change-in-ratio	0.443	0.178	0.698	0.520

* Bias-corrected percentile confidence limits (Dixon 1993) were used for the change-in-ratio method. However, for the Leslie method, percentile confidence limits were calculated and presented here because nonsensical results were obtained for males when using the bias-corrected method, e.g., a *lower* 90% confidence limit that was *above* than the median value.

Figure 1. Map of Australasia showing the change-in-ratio method study site. The 3rd expansion map shows the release and recapture positions of tagged lobsters in the 9 and 11 Mile Reef area during November 1994 to April 1995. A approximate estimate of the area fished using these positions is 6.3 km^2.

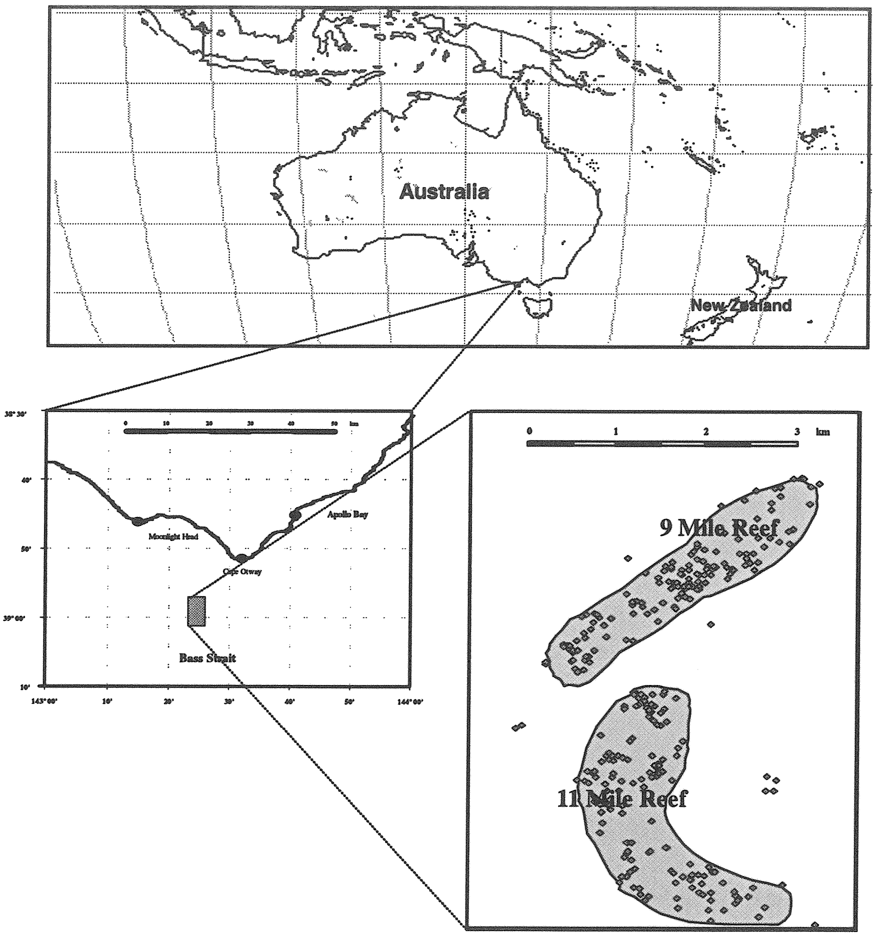
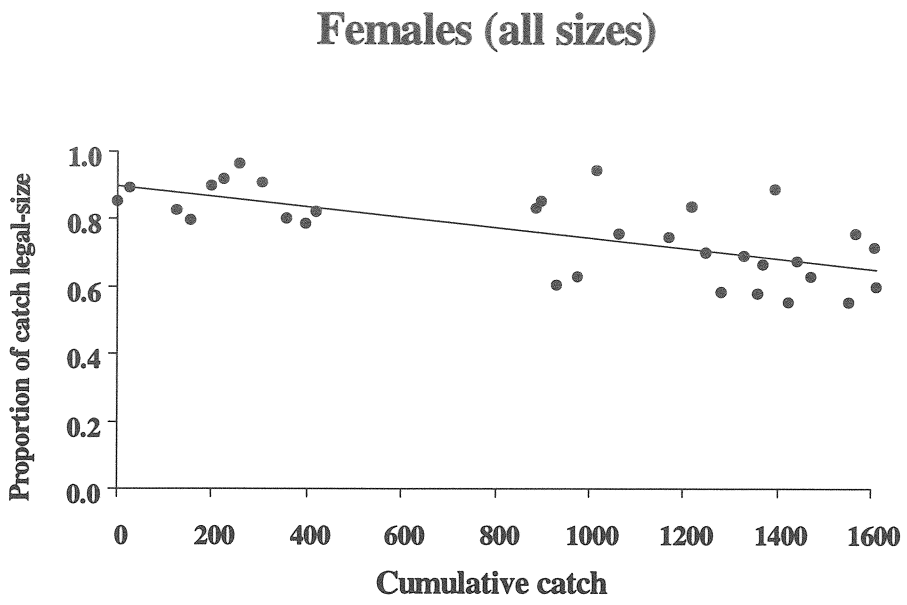


Figure 2. Proportion of female and male lobsters (*Jasus edwardsii*) in the catch that were of legal-size (≥ 105 mm carapace length for females, ≥ 110 mm carapace length for males) on each day of sampling in the 9 and 11 Mile Reef area during November 1994 to April 1995, plotted against cumulative catch (number of legal-size lobsters removed before that day of sampling). A linear regression line is fitted to the data for each sex. Proportions calculated using the pooled estimator.



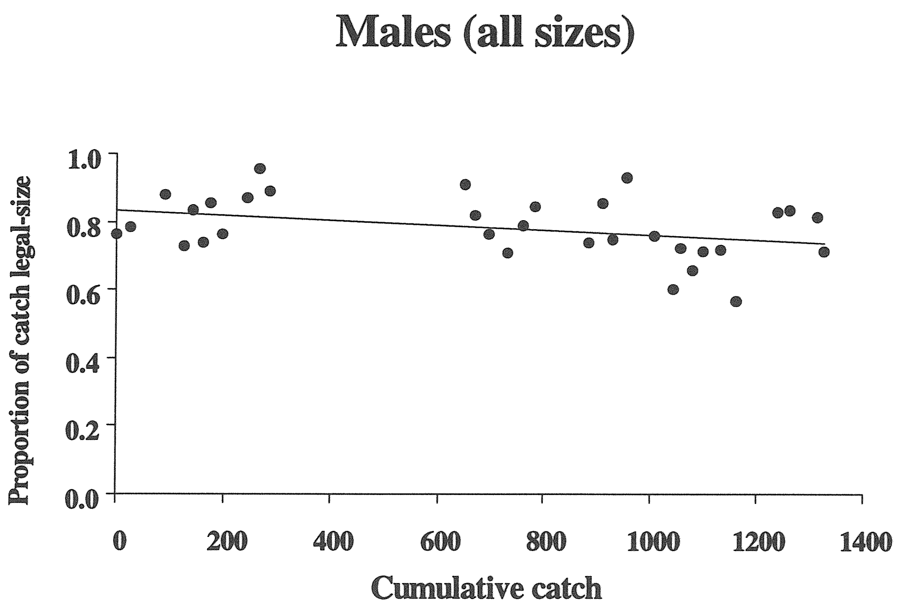
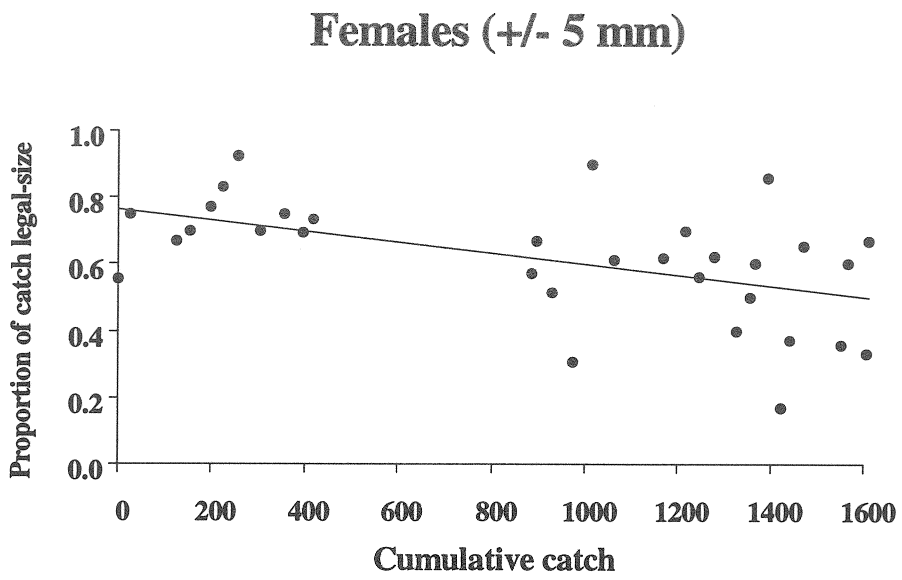


Figure 3. Plot of the proportion of female and male lobsters (*Jasus edwardsii*) that were of "legal-size" on each day of sampling versus the cumulative catch of legal-size lobsters in the 9 and 11 Mile Reef area during November 1994 to April 1995. In this figure, "legal-size" is 10 mm above the legal minimum length for males and 5 mm above the legal minimum length for females. "Undersize" is defined as 10 and 5 mm below the legal minimum lengths for males and females respectively. Linear regression lines are fitted to the data for each sex. Proportions calculated using the pooled estimator.



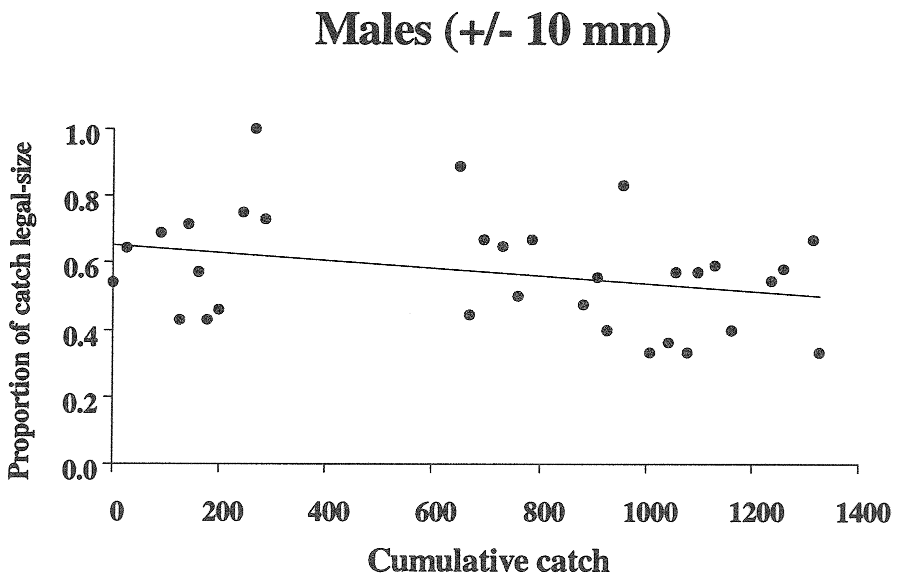


Figure 4. Bootstrap distributions of the estimates of abundance and exploitation rate for legal-size female lobsters (*Jasus edwardsii*) in the 9 and 11 Mile Reef area, obtained using the change-in-ratio method. Part (a) shows the distributions of the number of legal-size female lobsters present in the 9 and 11 Mile Reef area at the start of the 1994-95 season. Part (b) shows the distributions of exploitation rate of legal-size female lobsters during the 1994-95 season in the 9 and 11 Mile Reef area. Results from using pooled and average estimators are shown separately.

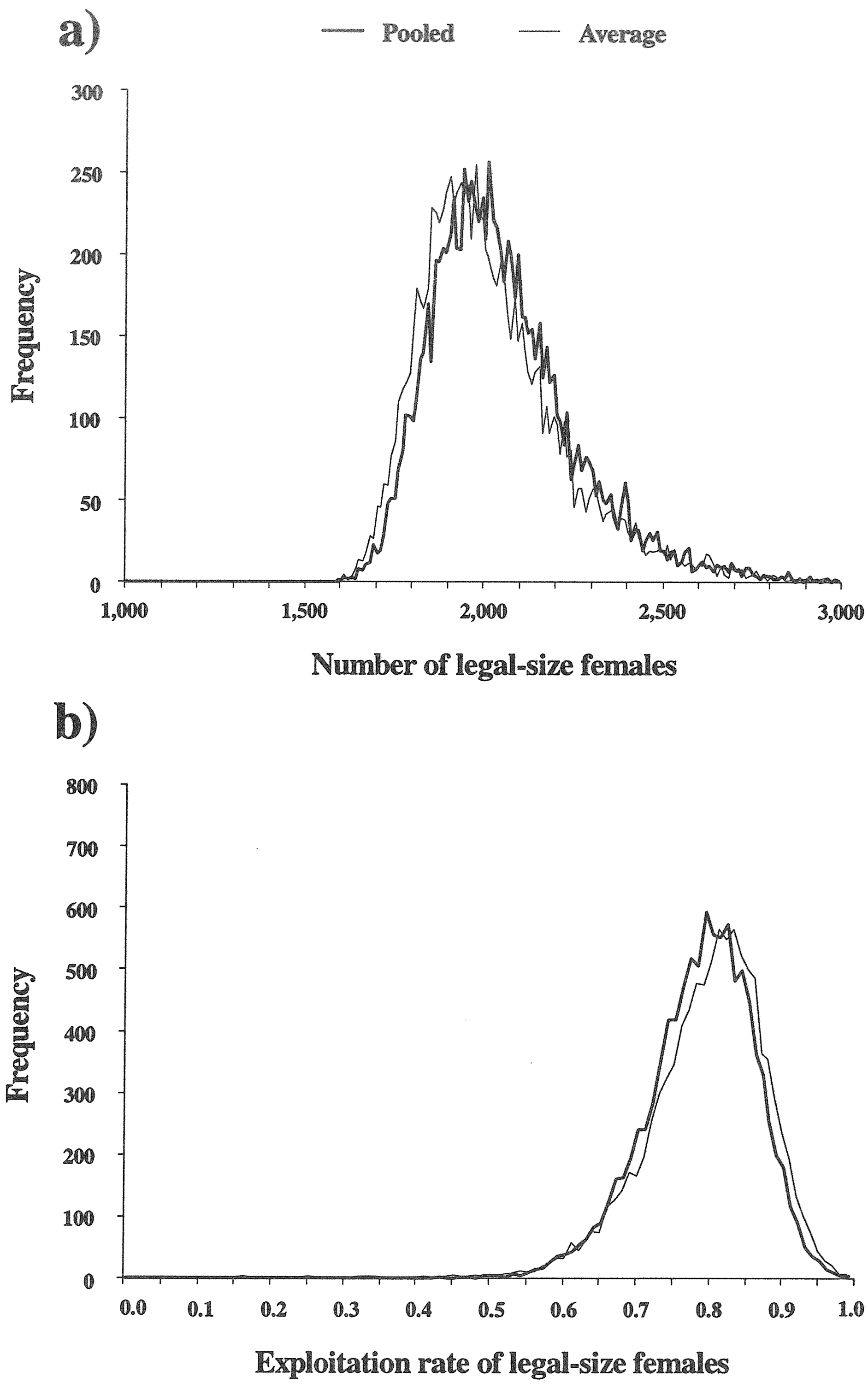


Figure 5. Bootstrap distributions of the estimates of abundance and exploitation rate for legal-size male lobsters (*Jasus edwardsii*) in the 9 and 11 Mile Reef area, obtained using the change-in-ratio method. Part (a) shows the number of legal-size male lobsters present in the 9 and 11 Mile Reef area at the start of the 1994-95 season. Part (b) shows the distributions of exploitation rate of legal-size male lobsters during the 1994-95 season in the 9 and 11 Mile Reef area. Results from using pooled and average estimators are shown separately. Some iterations produced negative values of abundance and exploitation rate, and some iterations produced abundance estimates greater than 10,000, but these have not been shown for simplicity.

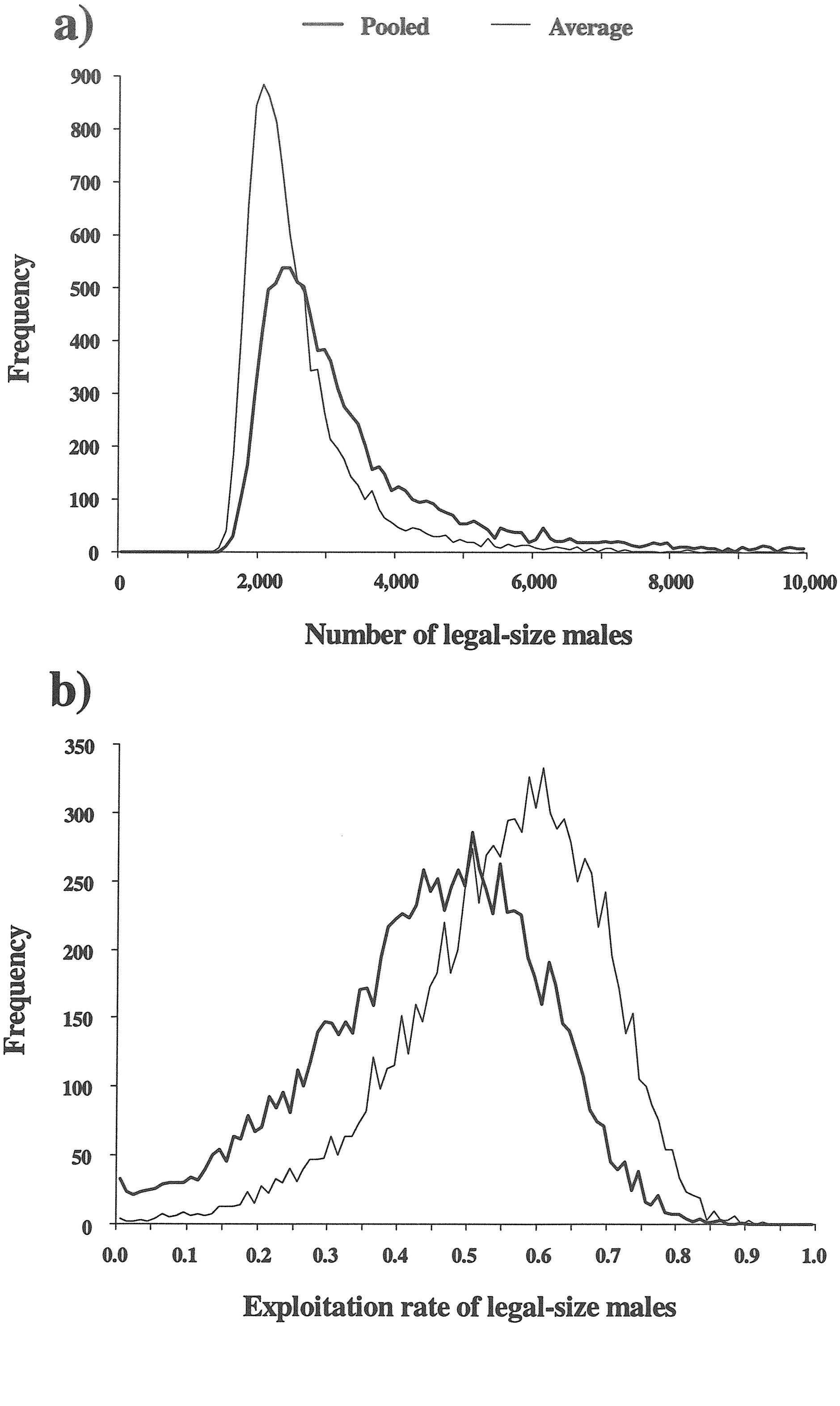


Figure 6. Carapace condition data for male lobsters (*Jasus edwardsii*) caught in the 9 and 11 Mile Reef area during change-in-ratio method sampling in the 1994-95 fishing season. Lobsters had observations made on their carapace softness and degree of fouling by polychaetes. Lobsters have been classified as soft-clean, hard-clean, or hard-fouled (see Treble 1996 for more details). Soft-clean lobsters are considered to have molted recently. Numbers above each bar are the number of lobsters in that carapace length-class caught in that period.

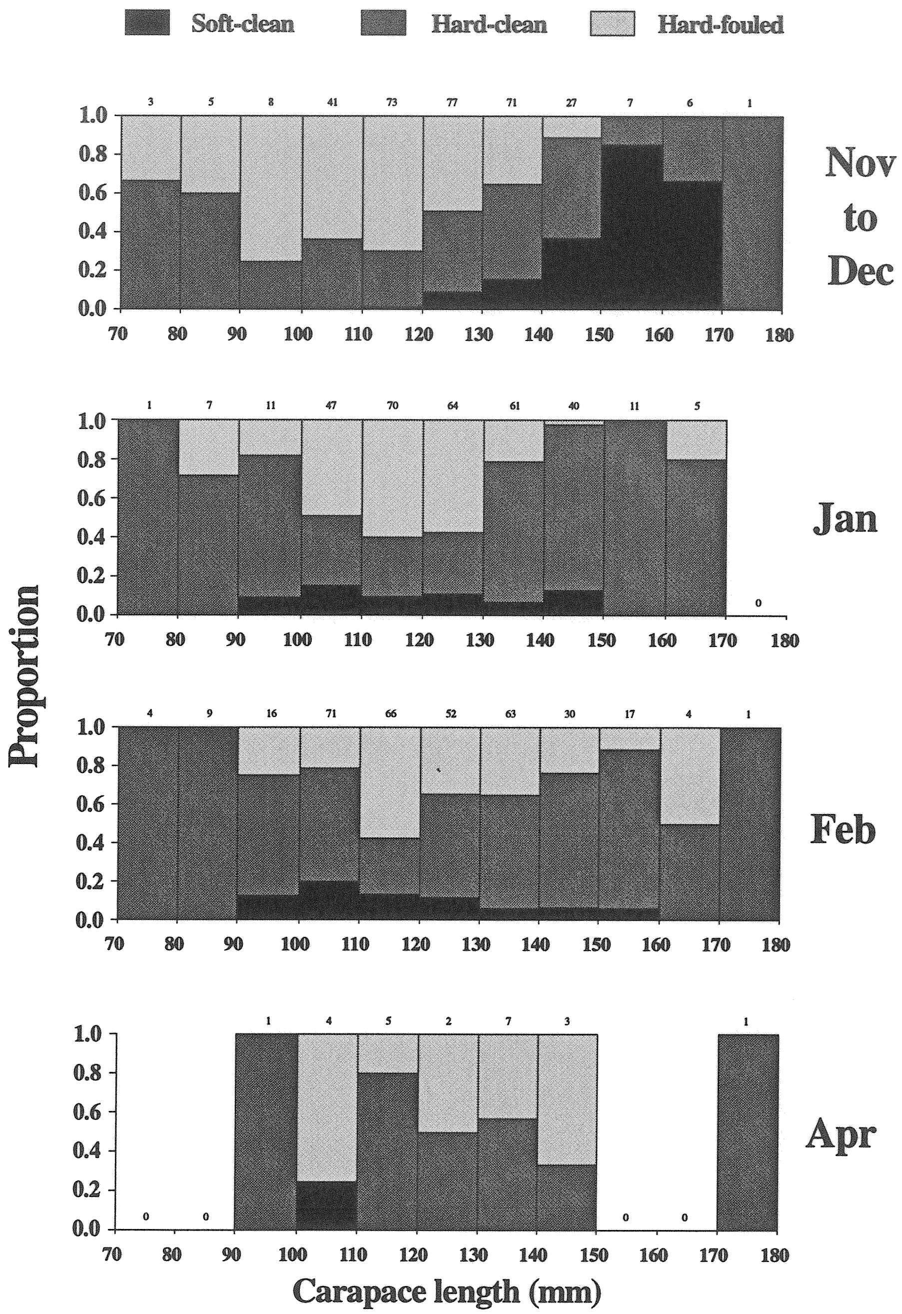


Figure 7. Carapace condition data for female lobsters (*Jasus edwardsii*) caught in the 9 and 11 Mile Reef area during change-in-ratio method sampling in the 1994-95 fishing season. Lobsters had observations made on their carapace softness and degree of fouling by polychaetes. Lobsters have been classified as soft-clean, hard-clean, or hard-fouled (see Treble 1996 for more details). Soft-clean lobsters are considered to have recently molted recently. Numbers above each bar are the number of lobsters in that carapace length-class caught in that period. Immature and mature females have been pooled.

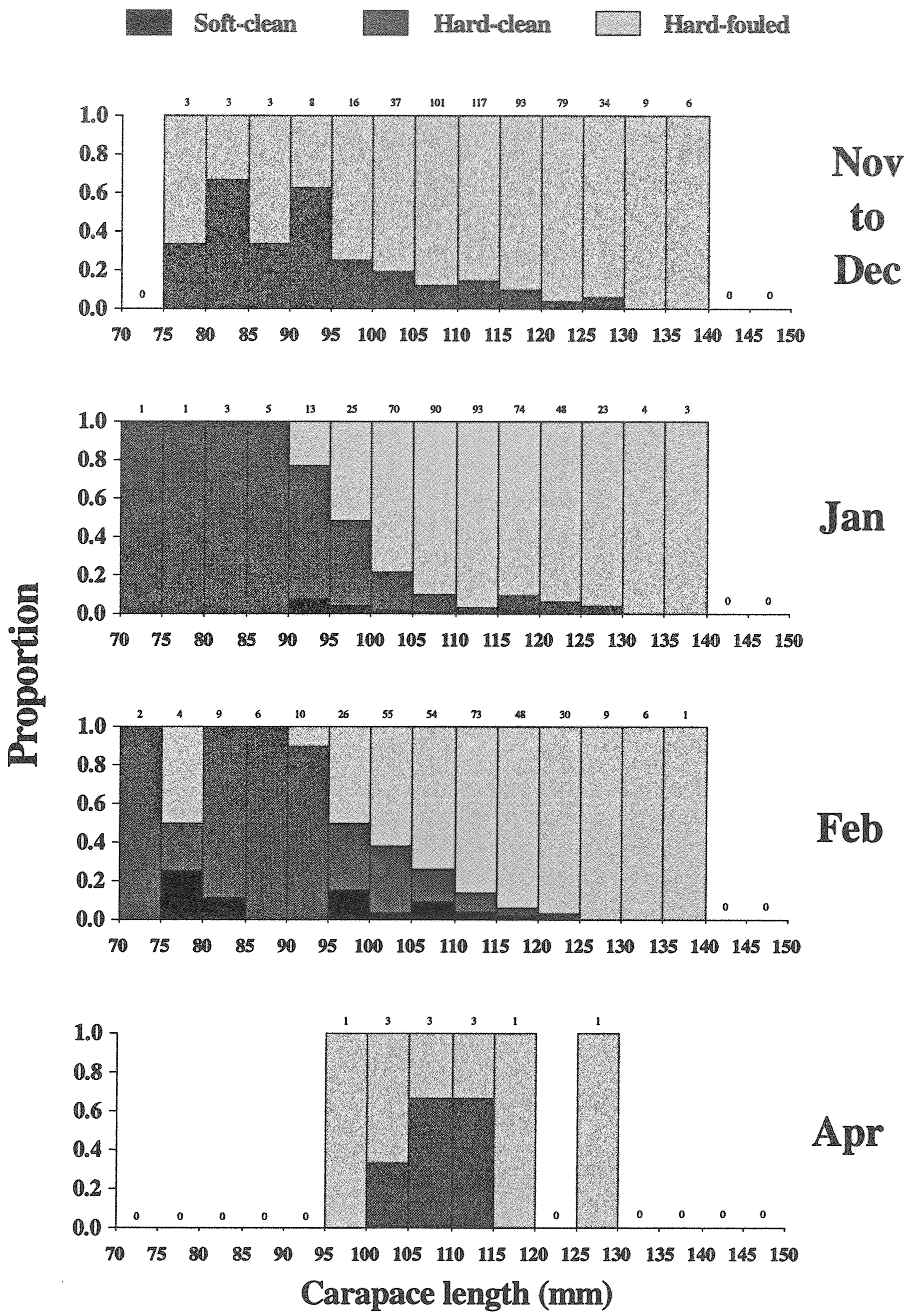
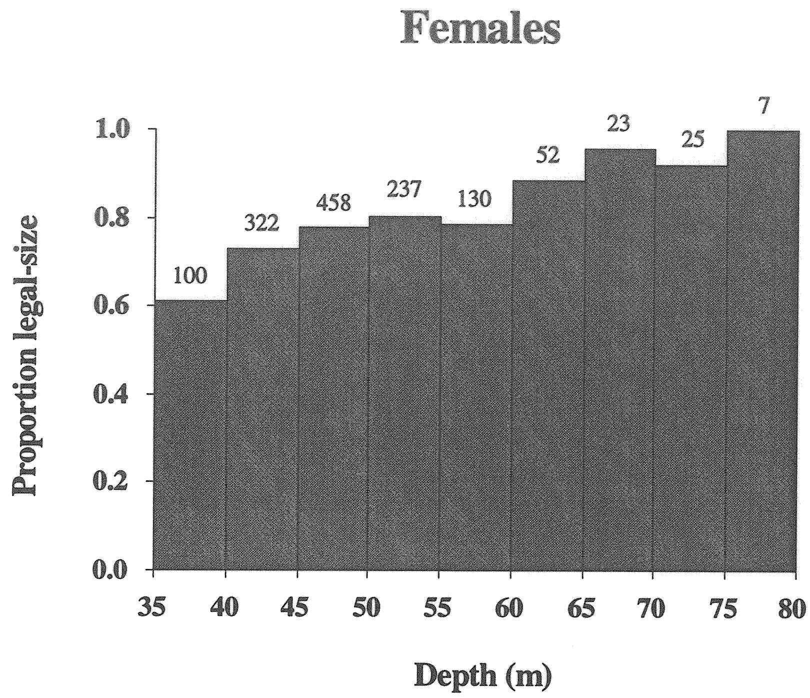


Figure 8. Plot of proportion of the catch that was of legal-size (females and males shown separately) for 5 m depth categories, in the 9 and 11 Mile Reef area during November 1994 to April 1995. Numbers above bars are the number of lobsters caught in each depth category.



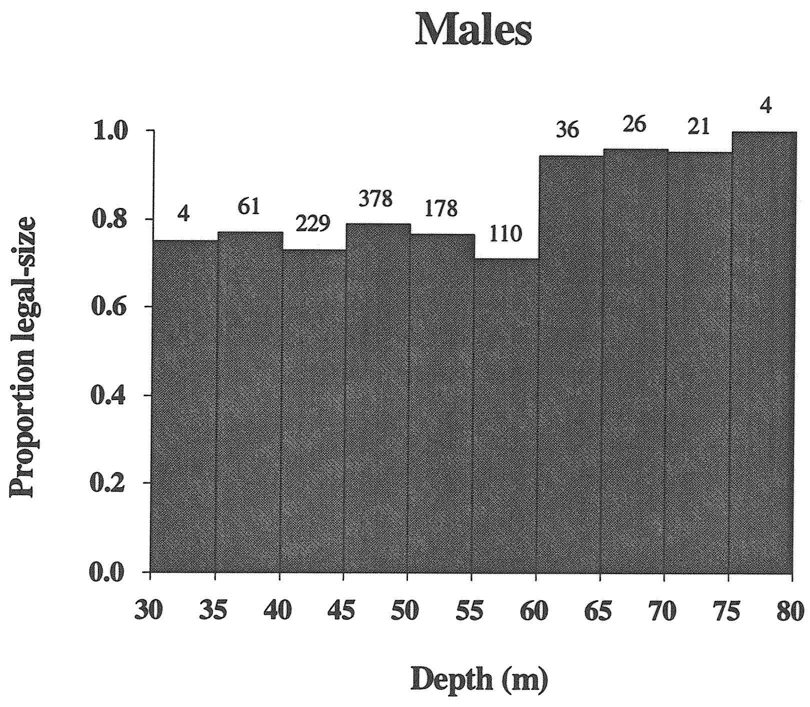


Figure 9. Mean depth that pots were fished on each day of sampling in the 9 and 11 Mile Reef area during November 1994 to April 1995.

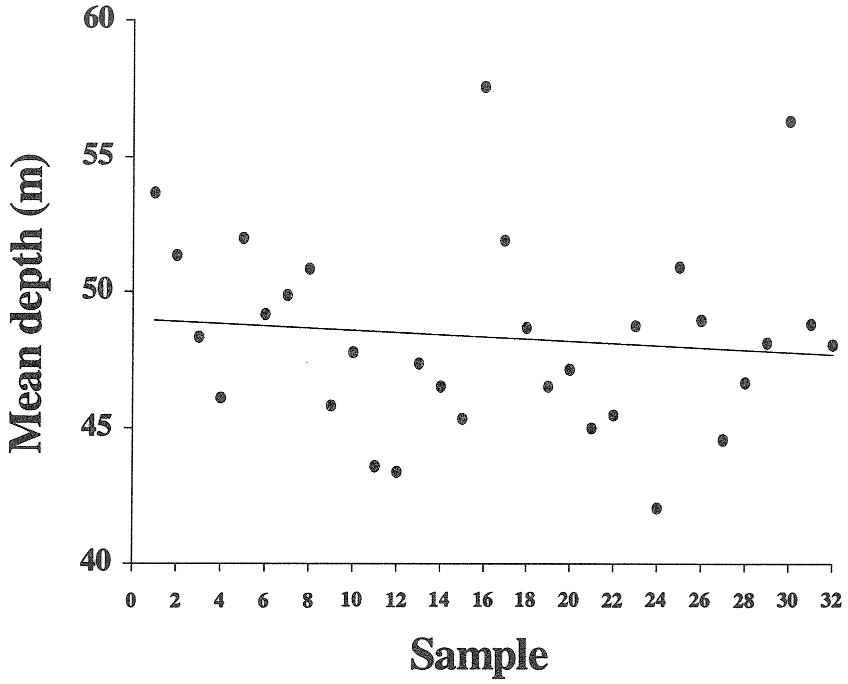


Figure 10. Sex ratio of legal-size lobsters (*Jasus edwardsii*) by month for commercial catches in the Apollo Bay area during August to May. Sex ratio data are presented as the proportion of the legal-size catch that is female in each month. Data for 1969-76 are from the Apollo Bay Fishermen's Co-operative during 1969 to 1976 (obtained from archives at the Marine and Freshwater Resources Institute). For 1969-76, only sex ratio data between November and May are shown, because of the closed season for females from June 1 to November 15. Data for 1992-95 are from on-board observations made during this project at Apollo Bay, although some lobster measuring was done at the Apollo Bay Fishermen's Co-operative. Error bars around each proportion are standard errors, assuming the data are binomially distributed.

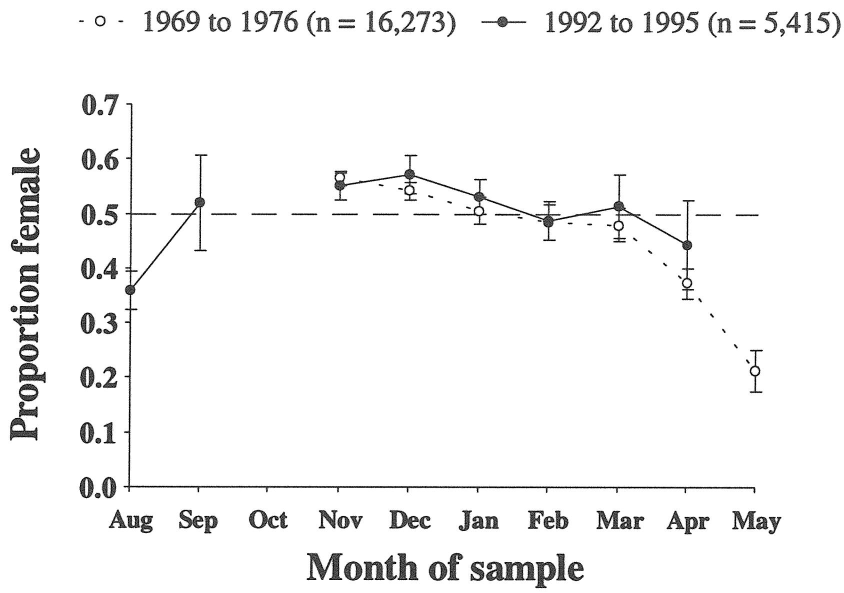


Figure 11. Plot of the proportion of the catch of legal-size lobsters (*Jasus edwardsii*) that were berried females versus the number of days since the start of the fishing season (15 November) in the Apollo Bay area. Data obtained from on-board observations. Data are for all years and sites pooled. The line shown is a quadratic regression.

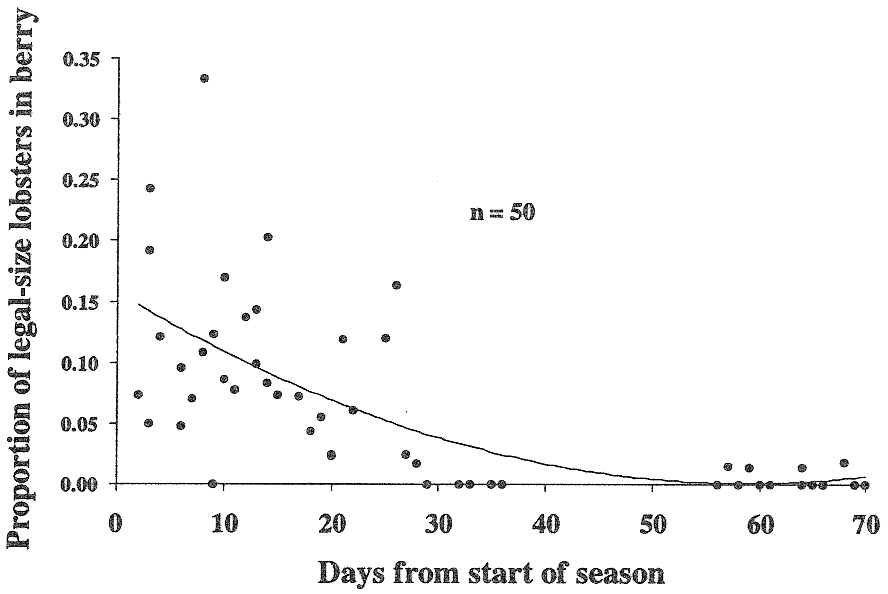
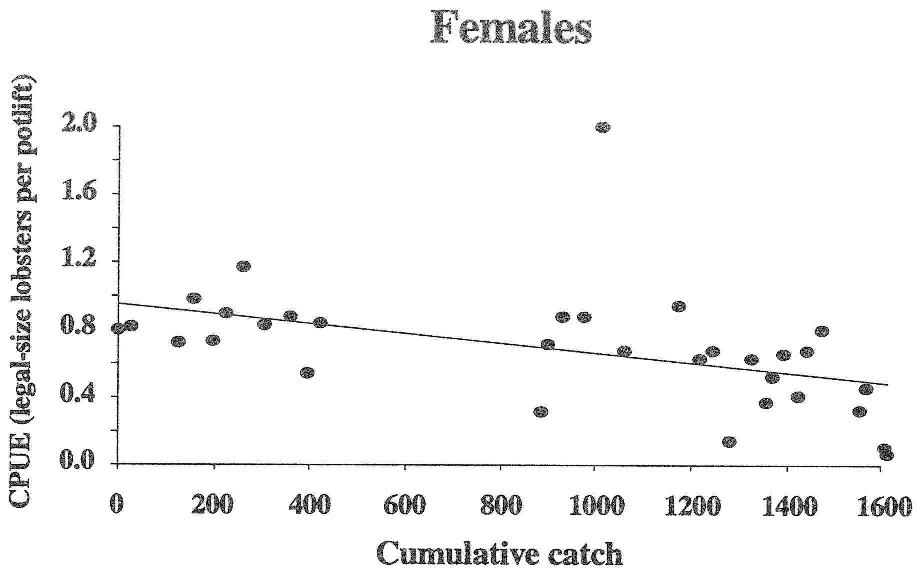


Figure 12. Plot of CPUE of legal-size lobsters (*Jasus edwardsii*) versus cumulative catch on each day of fishing (n = 32) in the 9 and 11 Mile Reef area during November 1994 to April 1995. Data for males and females are shown separately.



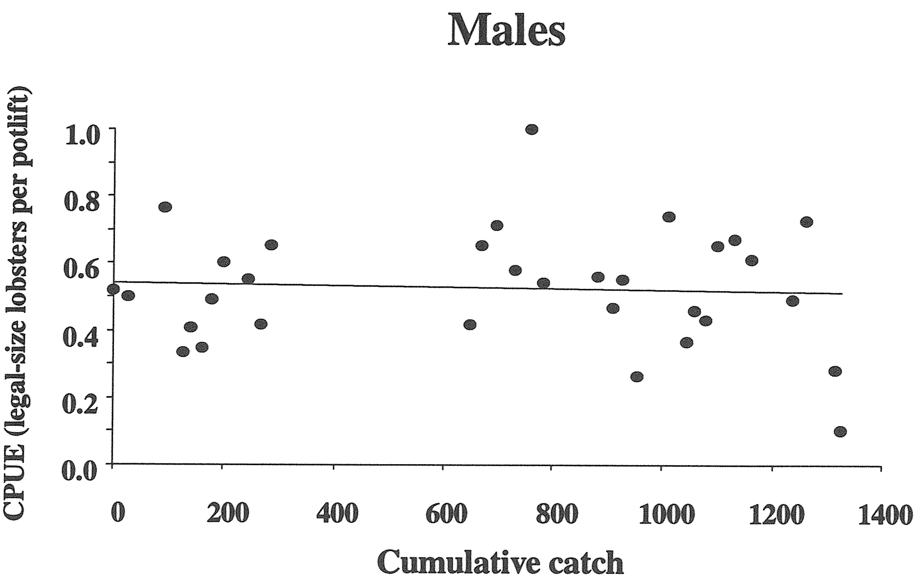


Figure 13. Mean CPUE of undersize lobsters (*Jasus edwardsii*) on each day sampled in the 9 and 11 Mile Reef area during November 1994 to April 1995. Data for females and males shown separately.

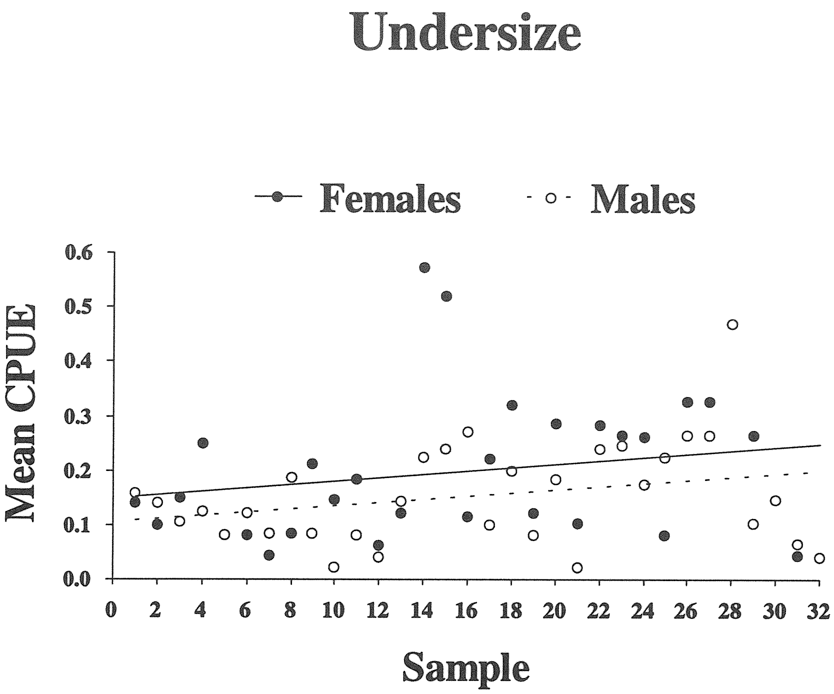


Figure 14. Bootstrap distributions of estimates of (a) abundance and (b) exploitation rate for legal-size **female** lobsters (*Jasus edwardsii*) in the 9 and 11 Mile Reef area at the start of the 1994-95 season, obtained from the Leslie and change-in-ratio (CIR) methods. Change-in-ratio method results are from the analyses using the pooled estimator. A few (39 out of 10,000) bootstrap iterations produced abundance estimates greater than 5,000 with the Leslie method, but these have not been shown for simplicity.

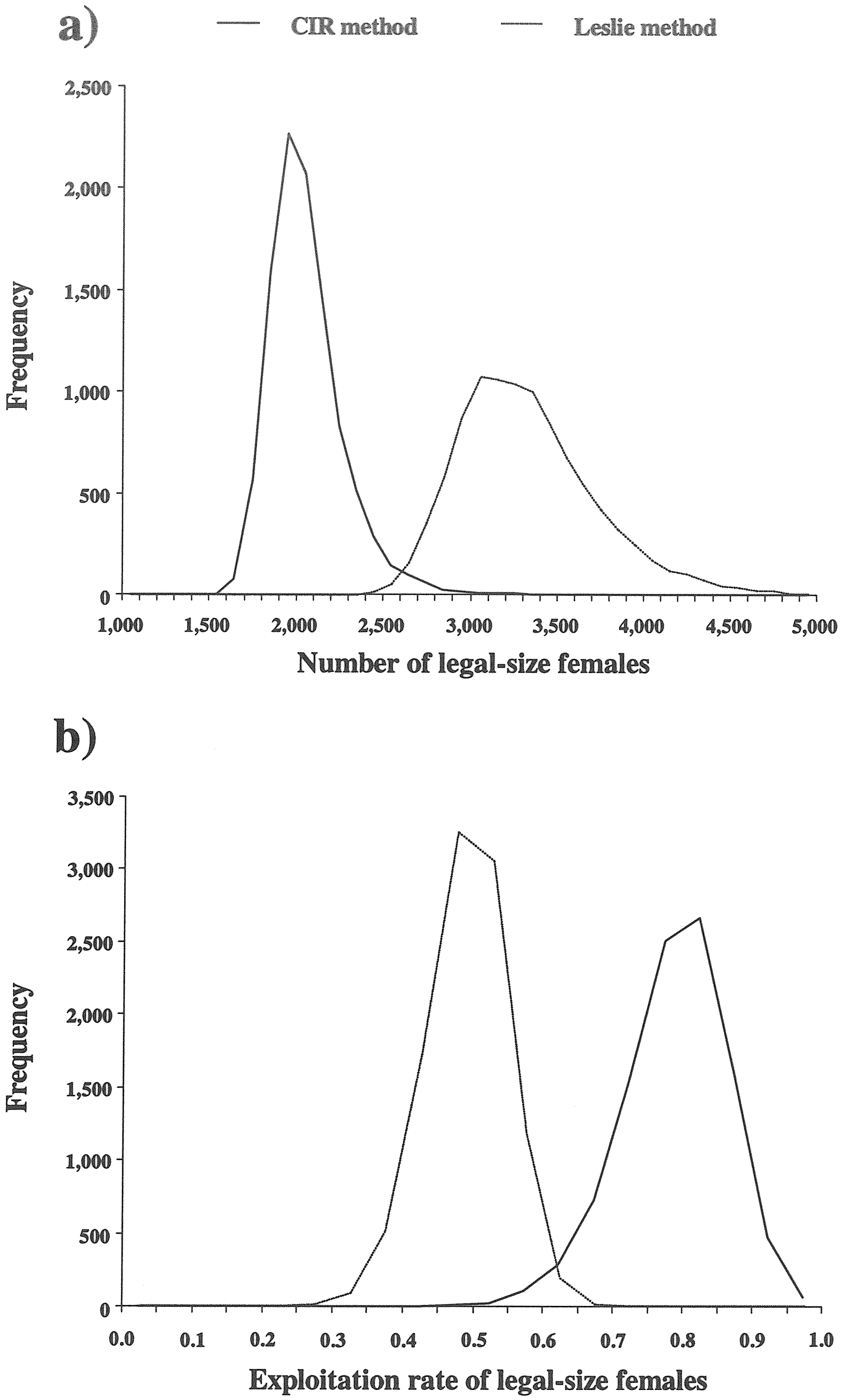


Figure 15. Bootstrap distributions of estimates of (a) abundance and (b) exploitation rate for legal-size **male** lobsters (*Jasus edwardsii*) in the 9 and 11 Mile Reef area at the start of the 1994-95 season, obtained from the Leslie and change-in-ratio (CIR) methods. Change-in-ratio method results are from the analyses using the pooled estimator. Many (27.5%) of the bootstrap iterations resulted in negative values of abundance and exploitation rate from the Leslie method, and some iterations produced abundance estimates greater than 50,000, but these two regions of the distributions have not been shown for simplicity.

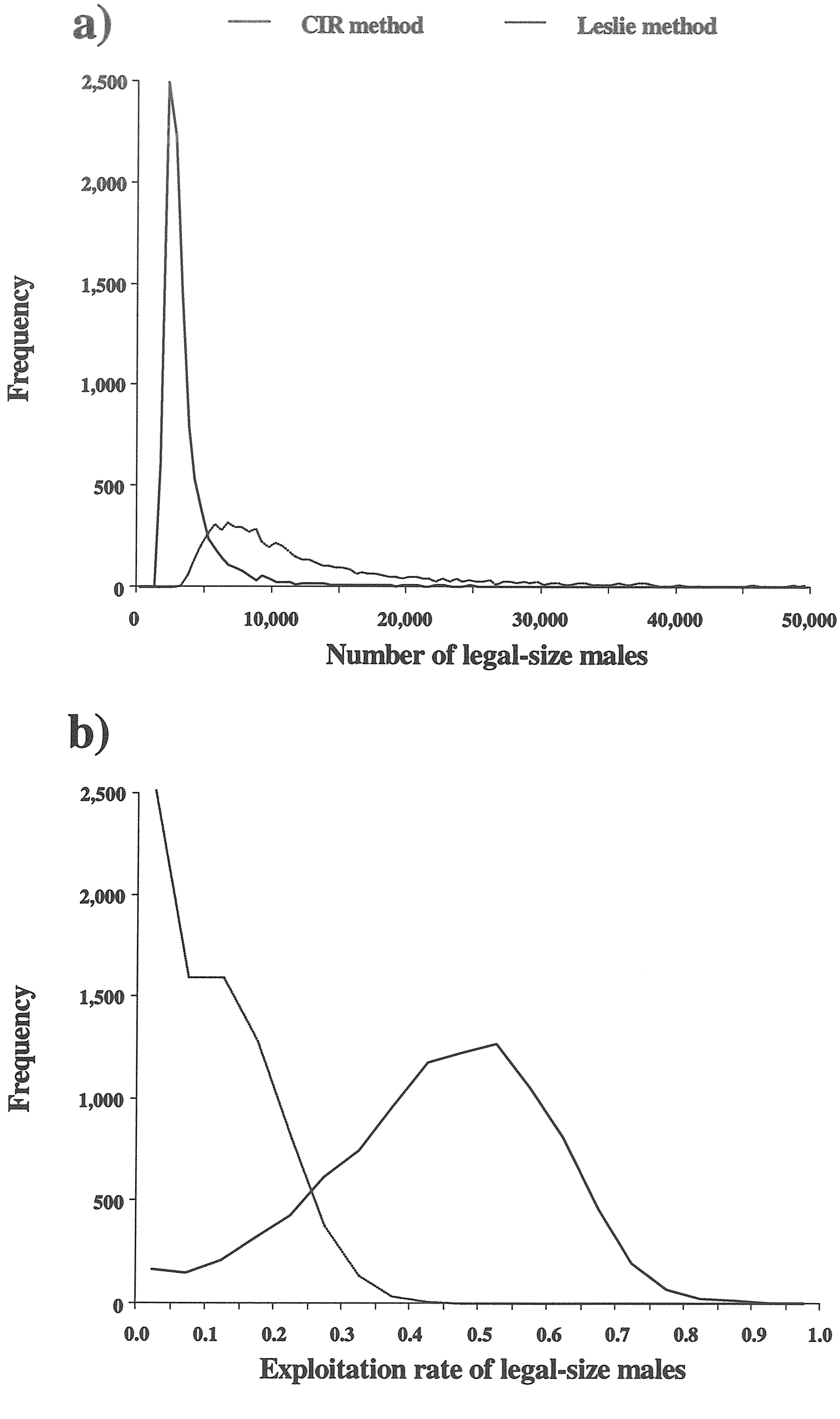


Figure 16. Leslie analyses of the commercial logbook data from Apollo Bay. Plots of CPUE (legal-size lobsters per potlift) for November, December, January, February and March versus the cumulative catch to the "middle" of each month are shown for each fishing season from 1978-79 to 1993-94. CPUE data were adjusted for unreported catches of legal-size berried females at the start of the main fishing season.

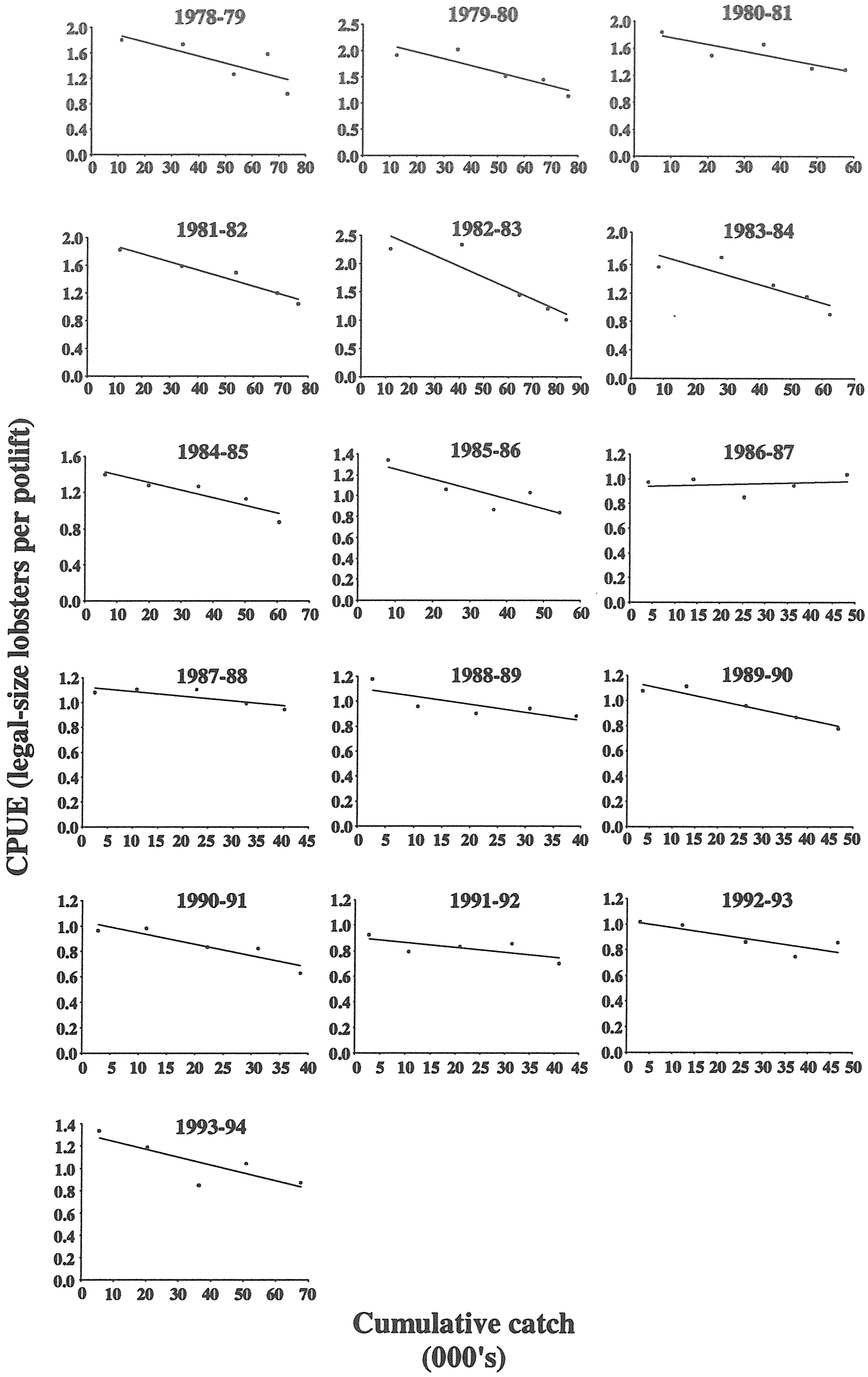


Figure 17. Estimates of abundance at the start of the main fishing season and average exploitation rate for legal-size lobsters (*Jasus edwardsii*) in the Apollo Bay area for each fishing season from 1978-79 to 1993-94, obtained from Leslie analyses of the commercial logbook CPUE data (Figure 16). Estimates for the 1986-87 season are negative and are off the scale of the graph.

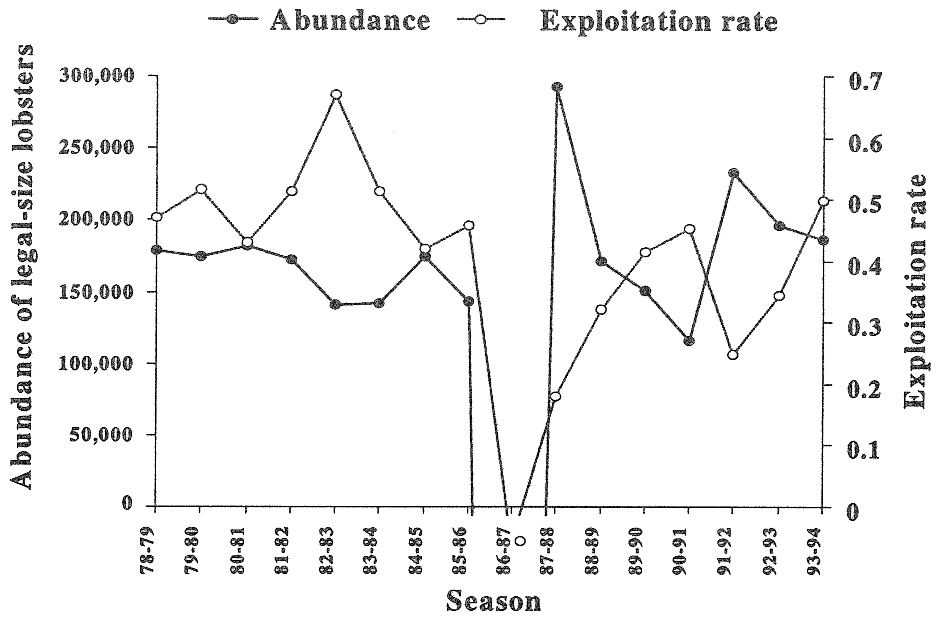
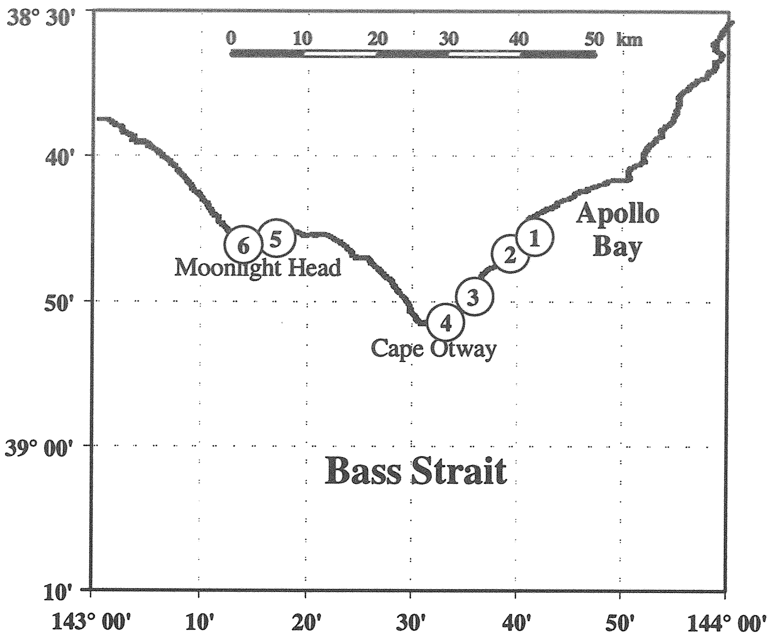


Figure 18. Map of the Apollo Bay region showing the six sites where SCUBA surveys to estimate lobster (*Jasus edwardsii*) density were conducted.



1) Little Henty Reef

2) Rifle Butts

3) Blanket Bay

4) Mushroom Reef

5) Ryan's Den

6) Football Ground

Figure 19. Distribution of lobster (*Jasus edwardsii*) density obtained from the SCUBA surveys at Apollo Bay. Data have been pooled over all sites surveyed. Mean density (all sizes) = 0.020 lobsters m^{-2}. Figure includes data from 30 x 4 m belt transects, and 20 x 20 m quadrats treated as four independent 10 x 10 m quadrats (because data for each quarter of the 20 x 20 quadrat were noted separately).

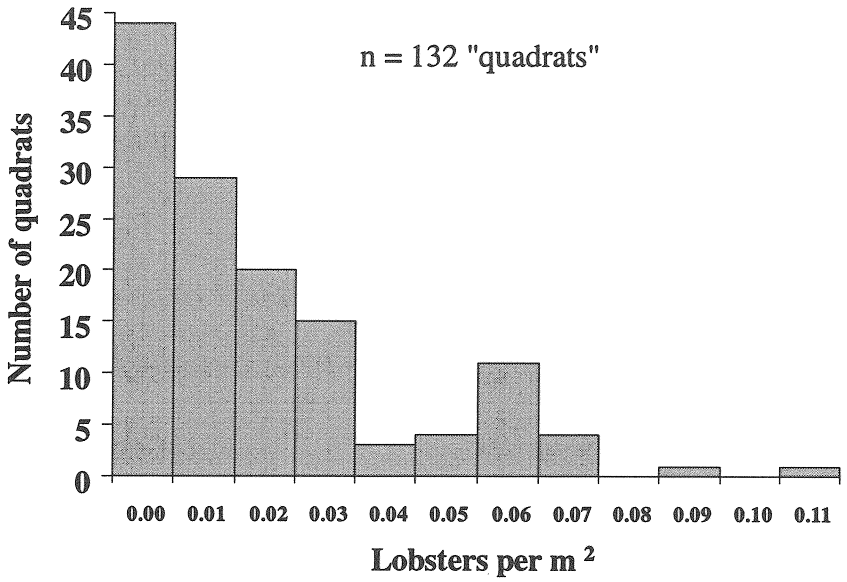
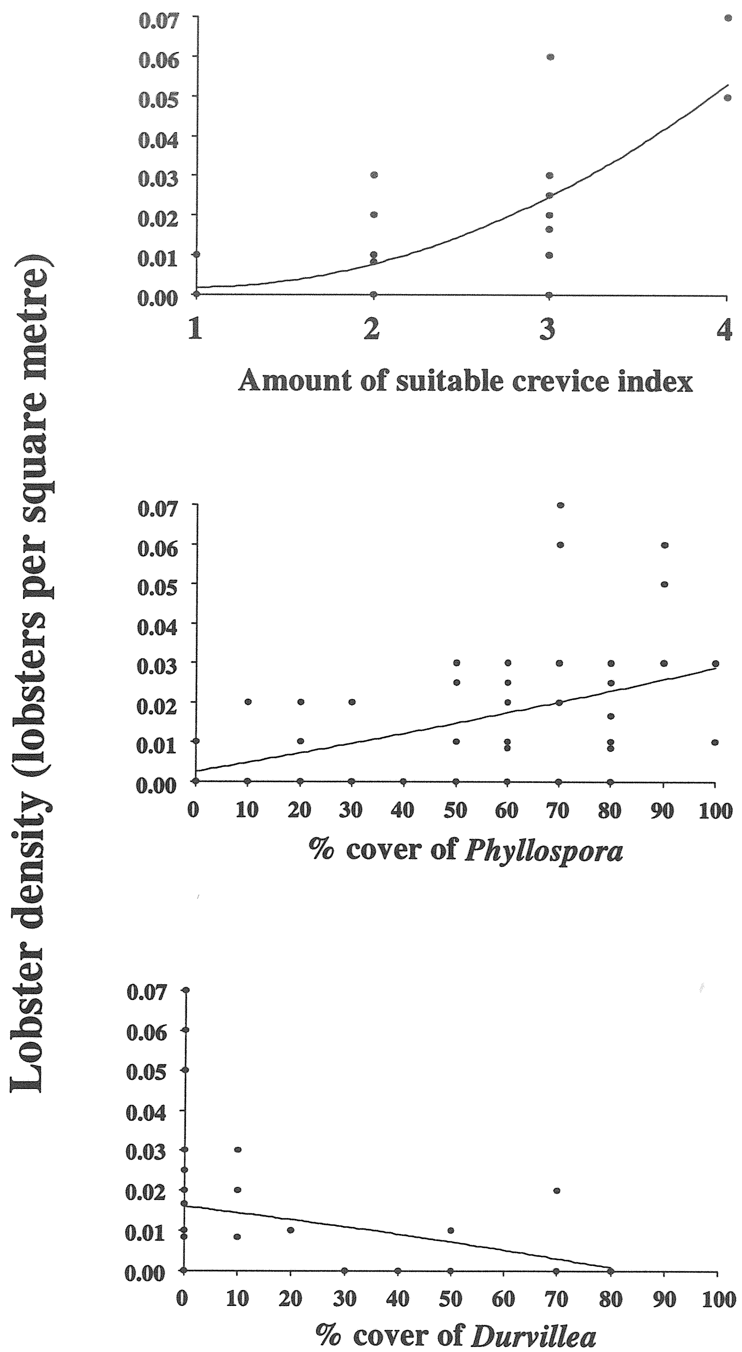


Figure 20. "Box plot" of lobster density versus site (n = 132 "quadrats" in total) for the SCUBA surveys undertaken at Apollo Bay. Numbers above each "box" are the number of quadrats surveyed at each site. Data includes 30 x 4 m belt transects, and 20 x 20 m quadrats treated as four independent 10 x 10 m quadrats (because data for each quarter of the 20 x 20 m quadrats were noted separately).

Figure 21. Mean lobster (*Jasus edwardsii*) density versus the amount of suitable crevice index, percentage cover of the macroalgae *Phyllospora comosa*, and the percentage cover of *Durvillea potatorum*. Data are for 62 "quadrats" from the three sites (Little Henty, Rifle Butts, Ryan's Den) where quantitative substrate data were collected. Data have been pooled over the three sites. Shown on each graph are fitted quadratic regression lines.



APPENDIX 5

Objective 3 - "To determine the recreational impact on the resource"

The recreational catch and effort estimates for southern rock lobster in Victoria

T.J. Ryan and D.K. Hobday

MaFRI Technical Report, 1997.

MARINE & FRESHWATER RESOURCES INSTITUTE

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1.0 Introduction

The decline in the Victorian commercial southern rock lobster catch rates (Hobday and Smith 1996) is also reflected by anecdotal reports from long-term amateur rock lobster fishers. The majority of amateur rock lobster fishers are divers, but there is a small number of amateur hoop net fishers, most of whom fish the inshore waters of the Western Management Zone (west of Apollo Bay). Divers frequently report a relatively recent (3-4 year) decline of inshore populations from previously productive habitat. Few dive locations now remain where the experienced rock lobster diver can catch the bag limit of four rock lobsters.

The recreational catch of rock lobster may have significant impact on specific inshore populations which may be important breeding populations. Most amateur fishers are aware of their responsibility for the long term management of the resource. Unlike the commercial fishery, there is no historical data on the recreational rock lobster fishery which can be used to gauge potential impacts. This survey is the first attempt to quantify the magnitude of the Victorian recreational southern rock lobster catch.

Currently, a recreational rock lobster fisher must hold an Inland Amateur Fishing Licence (AFL), which can be obtained at a large range of retail outlets. In 1993/94 an estimated 100,000 licences were sold, decreasing to 87,000 in 1995/96, however details of where and to whom these licences were sold are not maintained.

There are approximately 100 dive clubs and 40 dive shop outlets throughout the state, with most of the latter associated with a club. Most dive clubs are members of a diving association for insurance benefits and for the support and information that these associations can provide. Additionally, diving club members are represented on the newly established Recreational Peak Body by nominees from the Scuba Divers Federation of Victoria and the Australian Underwater Federation of Victoria on issues such as fishing regulations.

The options available for recreational diver surveys can target people at three different levels (Figure 1.1). The first level is the Victorian population as a whole from which an estimate of the number of divers in the state and the proportion who target rock lobster can be obtained. In the absence of a recreational fisher database, a phone poll of the Victorian population would be necessary to establish such an estimate of the number of divers in the state. Such a phone poll would be expensive due to the large number of interviews that would be required. The second level targets recreational divers by collecting information at dive shops and from dive charter operators. At this level it is possible to collect catch and effort data that is representative of most scuba divers in Victoria if dive shops are selected randomly. The third level targets the private recreational rock lobster divers using a volunteer log book system. This approach is best used when a database of recreational divers is available from which volunteers can be randomly selected to maintain logbooks. This study concentrated at this second level, utilising techniques which include a questionnaire of randomly selected dive shops, Fisheries and Wildlife Officer interviews of regular coastal patrols and charter boat volunteer log books.

SURVEY METHODS

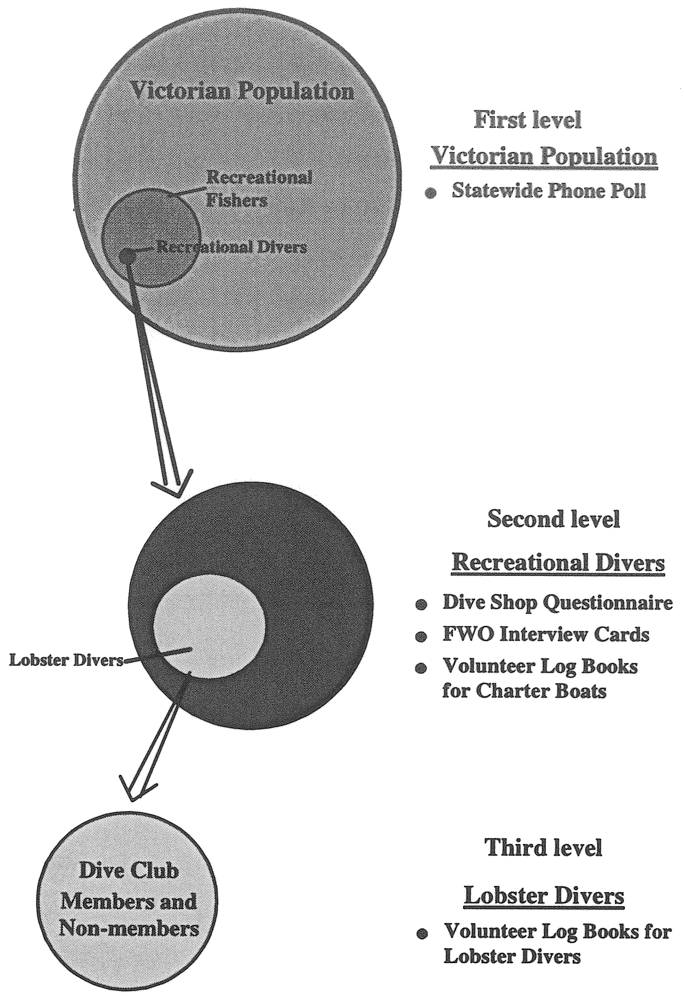

Figure 1.1 Stratification of the Victorian diving community and the corresponding survey method required to sample each.

Each survey used in this study had intrinsic differences in the types of information collected (Table 1.1). The random dive shop questionnaire is most likely to represent the Victorian SCUBA diving community, whereas the Fisheries and Wildlife Interviews and volunteer log books are not random but can be used to provide data on catch composition including length frequency and sex ratios.

Survey method	Dive shop questionnaires	FWO diver interview cards	Volunteer diver log books
No. people surveyed	- 1 per questionnaire	- 1 per card	- 1 to 30 per column
Effort estimates	- monthly number of dives - average dive duration - % effort targeting lobster	- number in group - dive purpose - dive duration	- number in group - dive purpose - dive duration - % effort targeting lobster

Catch estimates	- number caught - number seen	- size, sex and number caught	- size, sex and number caught - number seen and depth
Catch efficiency	- diver experience - lobster diver experience	- diving conditions - diver experience	- diving conditions - diver experience
Dive location and habitat	- site, access and depth of lobster habitat dives	- site and access of lobster habitat	- site, access and depth of lobster habitat dives
Abalone	- % time targeting abalone - monthly catch by species - years diving for abalone	- number and size by species per diver	
Extra information	- dive number in 1994/95 - dive seasonality 1994/95 - dive method/site access - club membership	- club membership - regulation understanding - possession of Amateur Fishing License (AFL)	- % divers targeting lobster - anecdotal information

Table 1.1 The characteristics of information collected by the dive shop questionnaires, FWO interview cards and the volunteer dive log books.

1.1 Other recreational diver surveys

Assessment of the recreational catch is an increasing concern in the management of rock lobster fisheries. In New Zealand the recreational catch is assessed by a random phone survey of 3% of the population to select fishers to maintain a voluntary diary system with boat ramp surveys to verify the results of the surveys (Teirney 1994). The diary survey results from 1991 and 1992 for the southern region of New Zealand indicated that recreational rock lobster fishers represented 14% of all fishers surveyed and their catch estimate was 102 tonne (Teirney 1994).

In Tasmania, a recreational rock lobster survey was conducted during 1995/96, randomly sampled approximately 8% of the 10,000 amateur rock lobster licence holders endorsed for diving and/or for the use of rock lobster pots and traps (J. Lyle, DPIF, Tasmania, pers. comm.). This survey, estimated that 105,000 lobster were caught from December 1995 to June 1996 with the majority caught by amateur pots and traps, with 20% taken by hookah divers and 13% by other divers (J. Lyle, DPIF, Tasmania, pers. comm.).

Current estimates of the recreational catch of western rock lobster in Western Australia are based on annual mail surveys of 25% of the recreational rock lobster licence holders. Total catches reported by respondents to this survey were corrected for recall bias by using catch rates obtained from Fisheries and Wildlife Officer surveys. Between 1986/87 and 1990/91, the recreational catch varied between 3.0% (350 tonnes) and 4.3% (470 tonnes) of the commercial catch (Chubb and Meville-Smith 1996). In 1991/92 and 1992/93, 5.9% (720 tonnes) and 6.5% (800 tonnes) of the commercial catch was taken by recreational fishers, reflecting an increase in the number of recreational rock lobster licences issued. The recreational catch in heavily populated coastal areas such as Fremantle and Geraldton was estimated to represent 20 to 25% of the landings of the commercial fishers in those areas (Chubb and Meville-Smith 1996).

In South Africa, approximately 60,000 recreational fishers are licensed to take rock lobster by the use of hoop-nets or by snorkel (capture by SCUBA is prohibited). A fortnightly phone poll is used to assess the catch of the previous two weeks. Current estimates of the recreational catch are about 20% (400 tonnes) of the commercial catch (Van de Elst and Penney 1994). The proportion of the recreational catch in South Africa has increased from 5% to 20% of the commercial fishery in less than ten years (Meville-Smith 1996).

2.0 Methodology

2.1 Dive shop questionnaire

The dive shop survey was conducted using a random questionnaire (Appendix 1) of divers obtaining airfills at dive shop outlets in Victoria. It aimed to provide tangible information on the recreational diving methods, locations, patterns and catch success along the Victorian coastline (Table 1.1).

The dive shop questionnaire was randomly distributed among twelve dive shops each month where it was given to customers receiving SCUBA airfills for the ten months of the 1995/96 rock lobster season (November 1995 - August 1996). All shop managers were supportive of the survey and agreed to participate. Shops were divided into three groups based on:

1. Popularity (size of club, turnover, reputation);
2. Location - sampling a high proportion of divers diving in important sections of the coast; and
3. Value - value of shop location and need to sample in different areas (eg. if only one shop existed in Ballarat it would be given a higher priority than if there were two).

The scores calculated from these criteria provided an averaged value for each of the shops from Class I to Class III. Class I shops were considered the most important shops to sample, while Class II and Class III were respectively considered intermediate and least important. Thirteen Class I shops, sixteen Class II shops, and eleven Class III shops were sampled. In every month of the survey six Class I shops, four Class II shops and two Class III shops were sampled (Appendix 2).

Recreational catch rates rarely have normal distributions and should not be analysed using parametric techniques (Crone and Malvestuto, 1991). A Bootstrap re-sampling technique first developed by Efron (1982) and subsequently modified by Gason and Conron (1996) was used to obtain mean catch rates and confidence limits.

Dive shop managers and staff were instructed to hand out the questionnaire to all divers requesting an airfill, irrespective of whether the diver intended to target rock lobster. By surveying those divers requesting an airfill the information obtained by the Dive Victoria study of 1993/94 (McDonald 1994) could be used as an estimate of the total possible diving effort in a year. The monthly diving catch per unit effort (CPUE) was determined by :

$$\text{CPUE} = \left(\sum Ci\right) / \left(\sum Ei\right);$$

where CPUE is the monthly catch per unit of effort (number of lobster per dive);
Ci is monthly catch of a diver (number of lobster); and
Ei is the monthly effort of a diver (number of dives).

2.2 Fisheries and Wildlife Officer interviews

The FWO interviews cards were first introduced in the Colac region of the Department of Natural Resources and Environment (DNRE) in 1992 covering the area from Lorne to the Bay of Islands. The Colac DNRE region aimed to sample all divers engaged in underwater activities on a survey day rather than targeting particular groups. Such a random sample of divers was not always achieved in other DNRE regions.

The interview card for this study, was designed to accommodate both the FWO and the Rock Lobster Research Program information requirements (Appendix 3). FWO interview cards were distributed to all DNRE coastal offices, with detailed instructions for their use when divers and hoop net fishers were interviewed during regular coastal patrols.

The FWO interview information was also used in this study to establish, sex ratio and average size by sex of southern rock lobster in the recreational catch (Section 2.4).

2.3 Volunteer log book

A volunteer log book system was piloted as an alternative source of information collection. A total of 62 charter boat operators and representatives from dive clubs were supplied with log books (Appendix 4) and asked to complete a column in the log book for each dive. Information was requested on the number of people diving, the dive location and depth and information on any rock lobster seen or caught during the dive. For the purposes of this survey, diving activity from charter boats was divided into four categories: passive diving; diver training; rock lobster dives and diving for other purposes. Additional information was asked on the effort, catch and relative experience of each diver (Table 1.1). Log books were also established with 22 individual volunteers not affiliated with a dive club or organisation. Follow-up letters were circulated to encourage participation and regular returns.

2.4 Catch and effort estimation

Only the catch rates from the dive shop questionnaire were used in the total SCUBA catch estimation. The estimate of total diving effort for the period of the dive shop survey (1995/96) was determined by the extrapolation of the most recent (1993/94) estimate of the total number of airfills in Victoria (McDonald, 1994). By using this estimate in the catch calculation, it was assumed that the number of airfills directly related to the number of dives completed. The calculation also assumed that additional sources of airfills (privately and unregistered compressors) are not significant compared to the total obtained from legitimate airfill suppliers. It is also important to note that this estimate ignores the catch and effort of divers with alternative capture methods such as hookah and snorkel.

2.4.1 Estimation of statewide number of dives

McDonald (1994) estimated that 80,000 SCUBA airfills were made during 1993/94. The number of airfills /dives for subsequent years was based on a phone survey of twenty randomly selected dive shops in Victoria which indicated that overall business and the total number of airfills was lower than in 1993/94. Increased periods of unfavourable weather conditions was provided by shop managers as the major contributing factor to this decline. The combined change in diving activity from the twenty dive shops indicated that the total number of airfills dropped 12.0% in 1994/95 and a further 4.6% in 1995/96. The number of airfills for Victoria in the 1993/94 survey were adjusted accordingly to 70,375 in 1994/95 and 67,125 in 1995/96 (Figure 2.1). The 1995/96 estimate of 67,125 was used in the calculations to determine the total catch of recreational divers (Section 3.4.1).

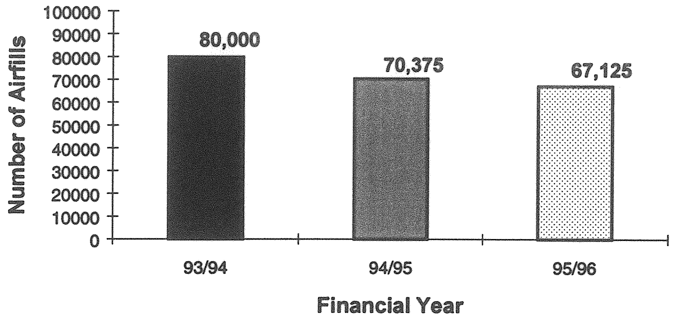

Figure 2.1 The projection of the number of Victorian dives based on the 1993\94 Dive Victoria airfill survey estimate and a survey of twenty randomly selected dive shops.

2.4.2 Total catch estimation

The total catch weight calculation was based on:

1. The number of dives from the McDonald (1994) airfill survey adjusted to reflect decrease in Victorian dive activity.
2. Catch rate and dive location information from the dive shop survey.
3. Sex ratio and average length data from the FWO Survey (Fig 2.2).

Diving location from the dive shop survey was used to attribute dives into the eastern or western commercial rock lobster fishing zones. The proportion of diving activity in each zone was used to apportion the number of dives from the airfill survey into each zone.

The total number of lobster caught in each zone was estimated by multiplying the number of dives and the catch rate (number of rock lobster caught per dive). The sex ratio of the recreational catch from the FWO interview survey was used to convert the catch to the number of male and female rock lobster caught (Figure 2.2) and to provide mean lengths of the male and female rock lobster in the catch. The weight of the recreational catch was then estimated by converting the average length to average weight for each sex (Male weight = $0.000285 \times CL^{3.115}$; Female weight = $0.000271 \times CL^{3.135}$ (B. Kennedy, DPIF, Tasmania, pers. comm.)) and multiplying by the number caught for each sex.

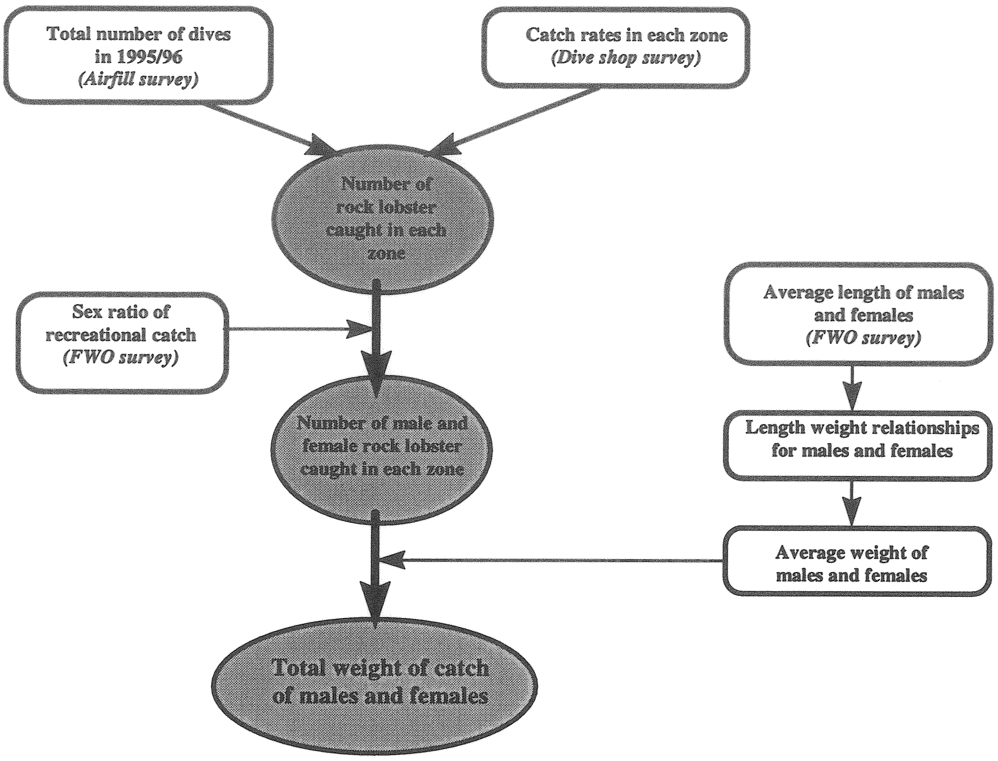

Figure 2.2 Flow chart for the calculation of the total recreational rock lobster catch.

3.0 Results

3.1 Dive shop questionnaire

Three hundred and fifty one questionnaires were returned from dive shops during the ten months from November 1995 to August 1996 (Figure 3.1). Response rates declined during the season, reflecting deteriorating weather conditions (Fig 3.1). The low number of returns during January and February was explained by most dive shop proprietors as a result of poor weather during this period.

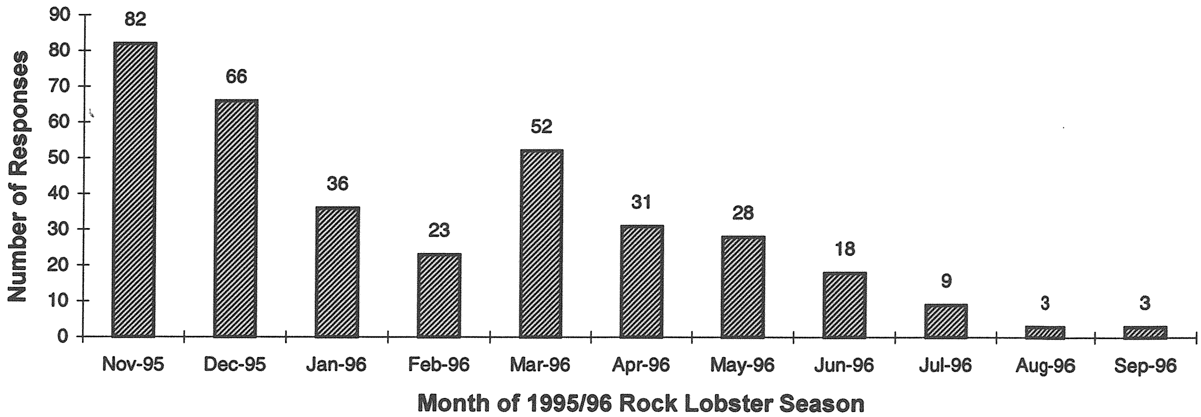

Figure 3.1 Number of dive shop questionnaires completed for each month of the 1995/96 survey period

As the survey proceeded, many divers took the questionnaire away from the shop and mailed the response. It was therefore necessary to assess the return rate of these questionnaires by dividing the number of completed questionnaires by the number of questionnaires distributed (number supplied minus the number remaining at end of month). The methodology of the survey is similar to that of a mail survey, in that it was distributed randomly with little or no prompts and encouragement. Non-response biases are the biggest disadvantage of mail survey (Brown 1991). Non-response biases of mail surveys are typically in the range of 40-60% to members of the general public and in the range of 60-75% for specific targeted audiences (Brown 1991). The response rates varied from 6% to 90% (Table 3.1), and were generally above 60% except for the poor weather months of January and February and the winter months from June onwards.

Month of survey	Number supplied *	Number of unused questionnaires	Number distributed	Number completed	Response rate
November	360	250	110	82	75 %
December	360	264	96	66	69 %
January	360	285	75	36	48 %
February	360	316	44	23	52 %
March	240	166	74	52	70 %
April	240	196	44	31	70 %
May	240	209	31	28	90 %
June	240	195	45	18	40 %
July	240	218	22	9	41 %
August	240	187	53	3	6 %
September	240	222	18	3	17 %

Table 3.1 Monthly questionnaire distribution and response rate information. * Twelve shops were supplied with 30 questionnaires initially each month reducing to 20 questionnaires from March 1996 .

3.1.1 Diving patterns

The mean number of dives made during the previous (94/95) season was 29.5 ± 5.0 (95% CI). Divers in the Western Zone (west of Apollo Bay) made an average of 30.0 dives (± 11.5, 95% CI), while Eastern Zone divers averaged 31.5 dives (± 8.0, 95% CI).

The most popular diving periods in 1994/95 were on weekends and holidays (71%) (Figure 3.2). The proportion of weekday dives was much higher in the Western Zone (41%) compared with 20% in the Eastern Zone.

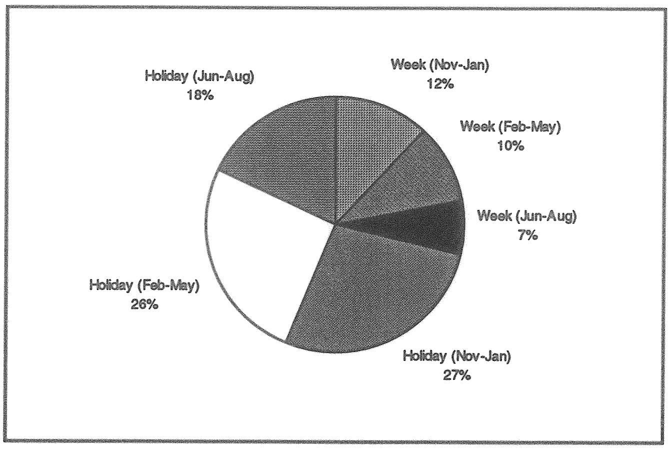

Figure 3.2 Most popular dive periods for the previous (1994/95) rock lobster season (holiday periods in figure include weekend dives, week periods represent dives during a normal working week).

For both zones combined, the proportion of dives conducted from the shore (48%) was similar to those from a boat (52%). The proportion of charter boat dives was higher in the Eastern Zone (35%) compared with the Western Zone (21%) (Figure 3.3), and is probably associated with the greater number of dive charter boats operating out of ports in the vicinity of Melbourne.

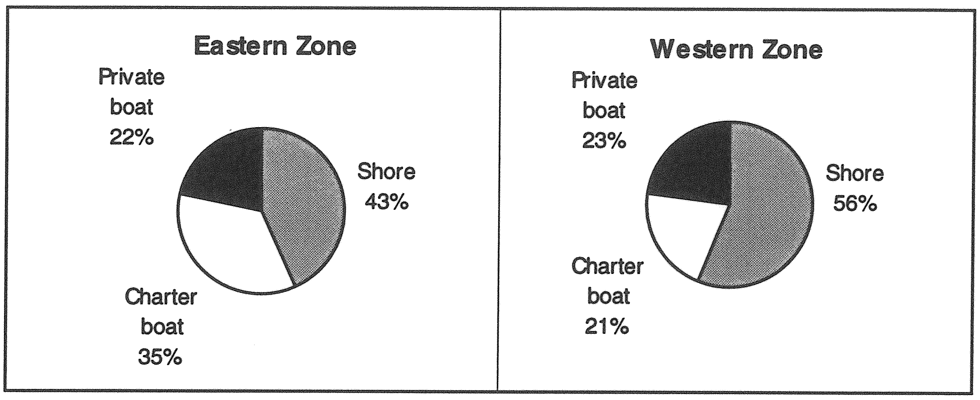

Figure 3.3 The proportion of dives from private boats, charter boats and the shore in each zone for the 1995/96 dive shop questionnaire.

3.1.2 Dive duration

The dive duration ranged between 40 and 54 minutes, with an average of 47 minutes. The dive duration varied by month and would be influenced by a number of factors including tank volume, dive purpose, diver experience, diver fitness, water temperature and the overall diving conditions. While a dive time of 47 minutes would be sufficient for most leisure diving activities, it may limit less experienced divers targeting rock lobsters.

3.1.3 Club membership

Approximately 66% of the divers surveyed by the dive shop questionnaire belonged to a dive club. This was a relatively high membership rate reflecting the location of the questionnaires within dive shops. Dive club membership was significantly different in each zone, with a 78% membership in the Eastern Zone and a 58% membership in the Western Zone. This is not surprising given that more than 70% of the 46 dive clubs that were identified are based in the Eastern Zone.

3.1.4 Diver experience

The proportion of divers by experience category were 32% for those with less than two years, 24% for those with two to five years, 19% for those with six to nine years and 25% for divers with more than ten years diving experience.

The experience categories were also compared to the club membership of respondents. The overall proportion of club membership for divers with less than two years experience (72%) was higher than divers with two to five years experience (66%), six to ten years experience (59%) and divers with more than ten years experience (65%). This trend reflects the closer association of less experienced divers to clubs, and again the proportions of around 60% and over are indicative of the diving population visiting dive shops in Victoria.

3.1.5 Dive locations

A small proportion of questionnaires did not contain sufficient information to identify specific dive locations but enabled allocation of dives into either of the zones. The resulting overall distribution of dives was 30% in the western and 70% in the Eastern Zones. Of the reported dives which could be allocated to a specific section of the coast within the two zones the majority occurred between Wonthaggi and Torquay (45%), which is consistent with the regional distribution of the Victorian population (Figure 3.4). The next most popular section of coast was between Apollo Bay and Warrnambool (31.5%) and a further 8.5% of the diving activity occurred between the eastern sector from Wilsons Promontory to Wonthaggi (Figure 3.4). The section of coast between Torquay and Apollo Bay received only 5% of the recreational diving activity detected by the survey, which appeared lower than the apparent diving popularity of the area might suggest. The lack of representation of this section and sections to the east of Wilsons Promontory and west of Warrnambool may be a reflection of the lower proportion of dive clubs and divers in these areas.

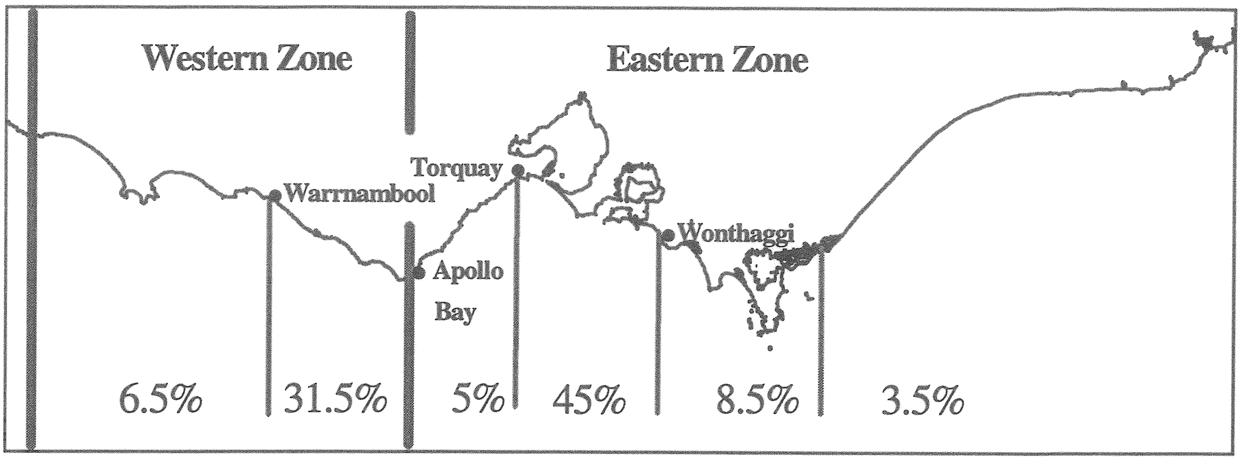

Figure 3.4 The spatial distribution of diving activity expressed as the percentage of the total number of dives in the 1995/96 dive shop questionnaire (based on questionnaires where dive sites were nominated).

3.1.6 Divers targeting rock lobster and abalone

Approximately 61% of all divers in the survey indicated that they targeted rock lobster. Of these divers, 56% stated that they were rock lobster divers only, while the remaining 44% also targeted abalone. Discussions with divers indicated that abalone is often targeted as a secondary species particularly if no rock lobster have been caught during a dive.

Divers in the Western Zone generally dived specifically to collect rock lobster and abalone, whereas in the Eastern Zone, there was a greater variety of diving activities including photography, diver training and ecologically based educational dives.

Of the divers targeting rock lobster and/or abalone, 62% belonged to a dive club which was slightly lower than the club membership of all respondents (66%). These divers also showed a higher usage of private boats (25%) for access to dive sites, compared with 20% for all respondents.

3.1.7 Catch rates of all respondents

In the Eastern Zone, 151 out of 169 failed to catch a lobster while 56 out of 77 divers in the Western Zone reported no catch. The catch frequency distribution for the dive shop questionnaire (Figure 3.5) highlights that the majority (84%) of respondents reported not catching rock lobsters on a dive.

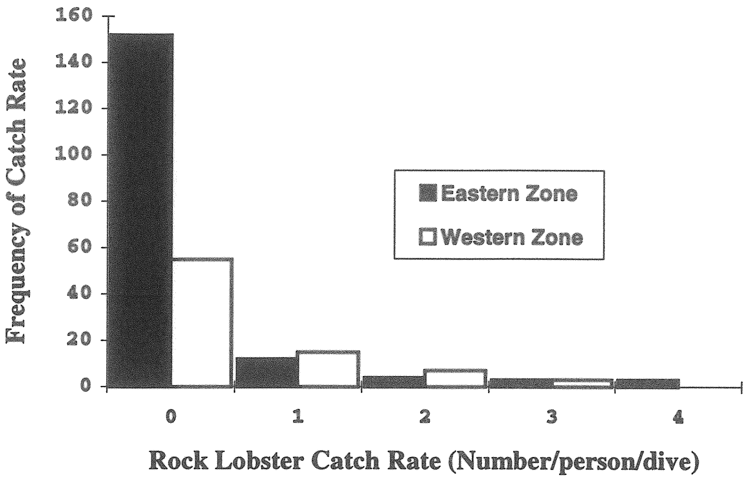

Figure 3.5 Frequency distribution of the number of rock lobster caught for all respondents to the 1995/96 dive shop questionnaire.

3.1.7.1 Catch rates in the Eastern Zone

From the 1463 Eastern Zone dives reported during the 1995/96 survey a total of 195 rock lobster were caught, resulting in a mean catch rate of 0.20 lobsters per dive (n = 169, 0.08 to 0.32, 95% CI;).

The mean catch rate for divers targeting rock lobster in the Eastern Zone was 0.40 lobsters per dive (n = 109, 0.10 to 0.70, 95% CI). Although the variation within this catch rate for the rock lobster targeting divers was high, the overall catch rate of this group was much higher than the catch rate of all divers combined. Analysis of catch rates among Eastern Zone rock lobster divers of different experience levels was undertaken to determine if diving experience was a significant influence on the catch (Table 3.2). The catch rate for divers with less than two years diving experience was much lower than for the more experienced categories of two to five years and more than ten years experience (Table 3.2). However, here was no distinct pattern of increasing catch rate with increasing experience.

Experience category	< 2 yrs	2 to 5 yrs	6 to 10 yrs	> 10 yrs
Number of divers	24	24	26	35
Mean catch rate (number/dive)	0.10	0.44	0.11	0.31
80% Confidence limits	0.03 - 0.17	0.10 - 0.78	0.02 - 0.20	0.14 - 0.47

Table 3.2 Catch rates by experience categories for Eastern Zone dive shop questionnaire respondents.

The monthly catch rates for the Eastern Zone varied greatly, with higher catch rates during January, April, June, July and August (Figure 3.6). The number of returns for June, July and August were low, therefore little emphasis should be placed on the increasing trend of these catch rates in the Eastern Zone towards the end of the 1996 season.

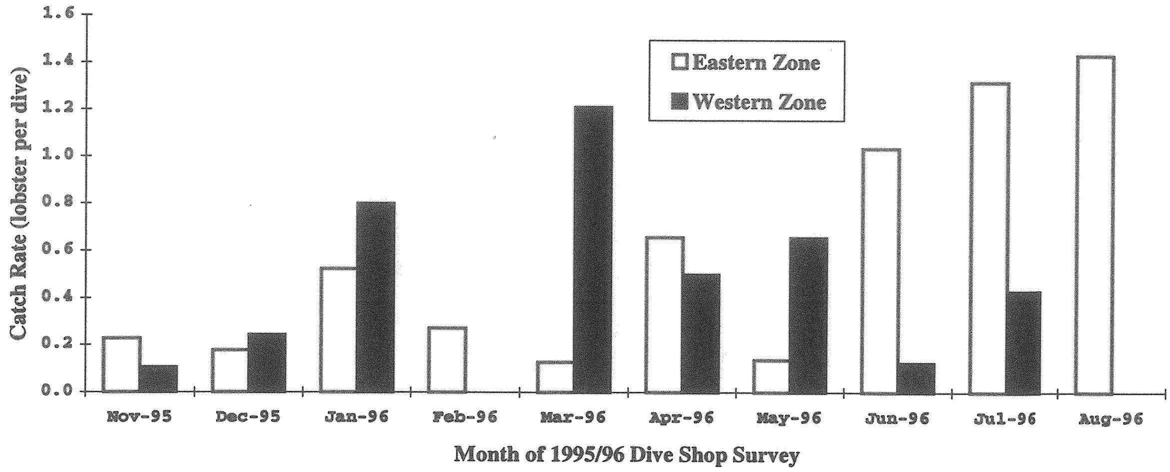

Figure 3.6 Mean monthly catch rates for respondents to the 1995/96 dive shop questionnaire in the eastern and the Western Zones.

3.1.7.2 Catch rates in the Western Zone

From the 672 Western Zone dives reported during the 1995/96 survey a total of 248 rock lobster were caught resulting in a mean catch rate of 0.39 lobsters per dive (n =77, 0.18 to 0.60, 95% CI).

The mean catch rate for divers targeting rock lobster in the Western Zone was 0.68 lobsters per dive (n = 58, 0.33 to 1.03, 95% CI) again reflecting the higher success rate of divers targeting rock lobster. Analysis of the catch rates among Western Zone rock lobster divers with different experience levels demonstrated a lower catch rate for divers with less than two years experience than the other categories (Table 3.3). The mean catch rates show that divers with two to five years experience were twice as successful at catching lobsters while divers with more than ten years experience were around five times more successful than divers with less than two years experience. Again the variation of the catch rate estimates was large, but there appears to be a trend of greater catch rates with diver experience in the Western Zone.

The monthly catch rates for the Western Zone varied with the highest occurring in March 1996 with higher catch rates than the Eastern Zone during January, March and May (Figure 3.6). Estimates for February and August are not available because no Western Zone dives were reported on the questionnaires during these months.

Experience category	< 2 yrs	2 to 5 yrs	6 to 10 yrs	> 10 yrs
Number of divers	16	14	11	17
Mean catch rate	0.15	0.31	0.73	0.79
80% Confidence limits	0.00 - 0.30	0.11 - 0.51	0.10 - 1.35	0.20 - 1.38

Table 3.3 Catch rates by experience categories for Western Zone dive shop questionnaire respondents.

3. 2 Fisheries and Wildlife Officer interviews

The information provided in this section contains results from FWO interviews conducted in Victorian coastal regions. Comparisons are made between the results for the period from July 1995 to June 1996 with the results detailed in Millar (1996) from the period of October 1994 to April 1995 in the Colac Region. A total 328 FWO interview cards were returned for analysis from surveys dating back to October 1994, however only data from the 246 FWO interview cards collected during the 1995/96 rock lobster season was used in this analysis.

3.2.1 General information

Among the divers interviewed by Fisheries and Wildlife Officers, only 26% were club members, which is much lower than the overall membership of 66% obtained from the dive shop questionnaire, but higher than the 18% determined in the Colac region by Millar (1996).

Approximately 80% of interviewed divers during the 1995-1996 period possessed an amateur fishing licence (AFL), compared with 98% in the previous survey (Millar 1996).

The compliance level for regulations in the 1995/1996 FWO survey for the Colac region was better than 90% except for the compliance with under size abalone, which was lower at around 84%. Millar (1996) also found that diver compliance was relatively high at over 97% for most regulations regarding the collection of rock lobster and abalone including size limits, prohibited equipment, bag limits and the protected soft shell and berried rock lobsters.

Comparison of diving methods showed that SCUBA diving represented 46%, snorkel diving 33% and hookah diving 12% of amateur diver effort (Figure 3.8). Millar (1996) established diving method proportions of 42%, 42% and 13% for SCUBA, snorkel and hookah respectively, consistent to the results of the present study.

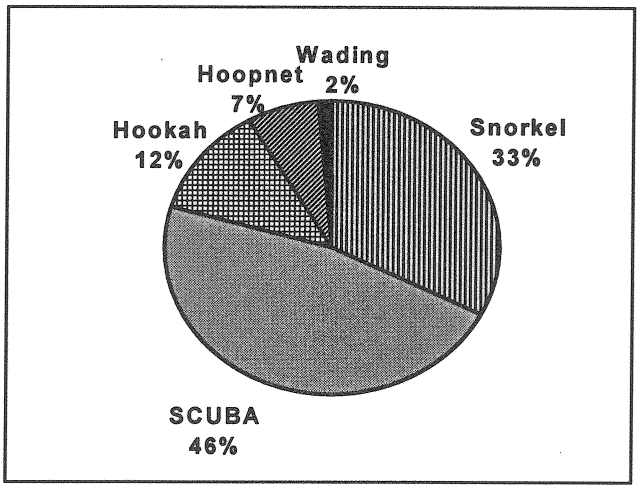

Figure 3.8 Capture methods employed by divers interviewed in the FWO survey from July 1995 to June 1996.

3.2.2 Length frequency and sex ratio of rock lobster catch

The FWO interviews provided length frequency measurements of the recreational catch (Figure 3.9). Many divers target the largest rock lobster available resulting in a catch distribution with a relatively high proportion of large lobsters compared with the commercial catch (Hobday and Smith, 1996). A greater proportion of males are taken at a 3.2:1 male to female ratio. The average carapace lengths of males and females caught in the FWO survey was 136.7 mm and 116.0 mm respectively which converted to mean weights of 1.36 kg and 0.84 kg for males and females respectively.

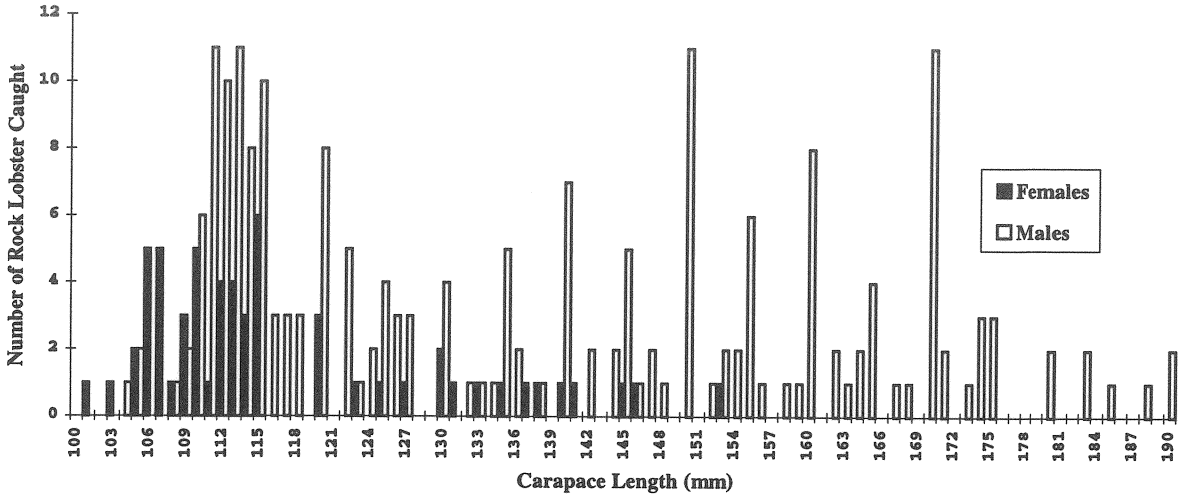

Figure 3.9 Length frequency distribution of the recreational catch of male and female rock lobster from the FWO interviews during 1995/96.

3.2.3 Rock lobster catch rate

The number of rock lobster caught per interviewed diver showed that there was a high proportion of divers with no catch (56%) (Figure 3.10). It is important to note that the 9% of divers interviewed with a catch of four rock lobsters took 40% of the catch in the survey. There was also a small proportion of the catch (4%) taken illegally by divers with a bag of more than four rock lobster.

The complete FWO interview data (Oct 1994 to May 1996) was used to compare catch rates by diving method and fishing zone (Table 3.4). All interviews where more than 8 rock lobster were caught were excluded as in Millar (1996) because these limits were defined to be commercial quantities and not considered part of the normal recreational catch. The catch rates established for the SCUBA divers from the FWO interview method (Table 3.4) were over four times higher for the Eastern Zone and three times higher for the Western Zone than the estimates from the dive shop questionnaire.

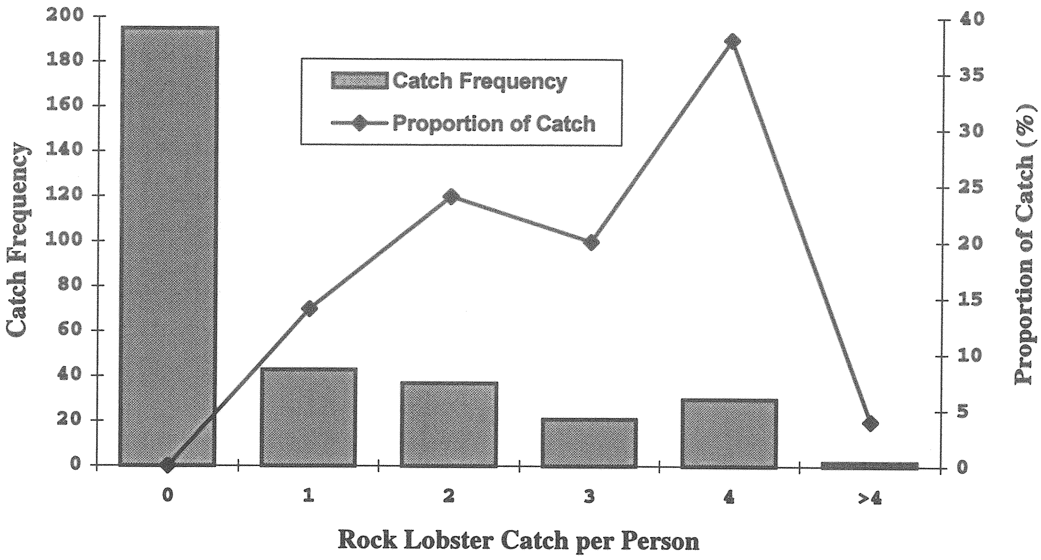

Figure 3.10 **Catch frequency distribution per diver and the corresponding proportion of the total recreational catch.**

Zone	Method	Sample number	Mean catch rate (number/dive)	80% Confidence limits (80% unless specified)
East	All	20	0.74	0.10 - 1.38 (95% CI)
West	All	98	1.29	0.88 - 1.70 (95% CI)
East	SCUBA	14	0.93	0.29 - 1.57
West	SCUBA	48	1.16	0.80 - 1.52
West	Hookah	14	2.68	1.81 - 3.55
West	Hoop net	12	0.83	0.43 - 1.26
West	Snorkel	24	0.72	0.26 - 1.18

Table 3.4 **Catch rate of rock lobster by diving method and fishing zone from the FWO survey during 1995/96.**

The number of FWO interviews in the Western Zone was higher than in the Eastern Zone because the of a greater priority given to marine creel data collection in the Western Zone DNRE regions. As a consequence, analyses of hookah and snorkel divers and hoop net fishers in the Eastern Zone were not possible due to small sample sizes. The catch rate for all diving methods combined were higher in the Western Zone (Table 3.4), and was probably due to a larger occurrence of hookah divers in this region. The catch rate of SCUBA divers in each zone are similar, despite the greater variance in the catch rate distribution for the Eastern Zone.

3.3 Volunteer log books

Volunteer log books were used as an alternative method to collect recreational rock lobster catch and effort information. The return rate was low and maintaining the interest of participants was difficult. Individual divers were generally more responsive than charter operators. Returns were received from 8 charter boat operators and 7 individual divers resulting in a total of 59 charter boat operator and 12 individual log book sheets. Each log sheet had a potential to record eight separate dives and in the case of charter boat operators, each separate dive can involve up to 30 divers.

The majority (45%) of dives on charter boat operations were passive ie. diving to observe the habitat and marine biota, with only 26% of the dives targeting rock lobster (Figure 3.13). A further 24% of dives were for training purposes and the remaining 5% of dives targeted other marine species or involved other diving activities (Figure 3.13).

Total catch for all charter boat dives was 118 rock lobster from 3,917 dives (0.03 lobster per dive) and for the divers targeting rock lobster, the catch was 88 rock lobster from 938 dives (0.09 lobster per dive). It is important to note that these results were not conclusive. Some charter boat operators not sampled in this survey may have targeted rock lobster for a greater proportion of time and may have substantially higher catch rates than the participating operators.

Total catch from individual divers was 60 lobster from 277 dives, resulting in a catch rate of 0.22 rock lobster per dive. The majority (90%) of the volunteer individual log book respondents dived in the Eastern Zone and all were keen rock lobster divers. It was therefore surprising that the catch rate of this group of divers was not substantially greater than the overall Eastern Zone catch rate established by the dive shop questionnaire (0.20 rock lobster per dive).

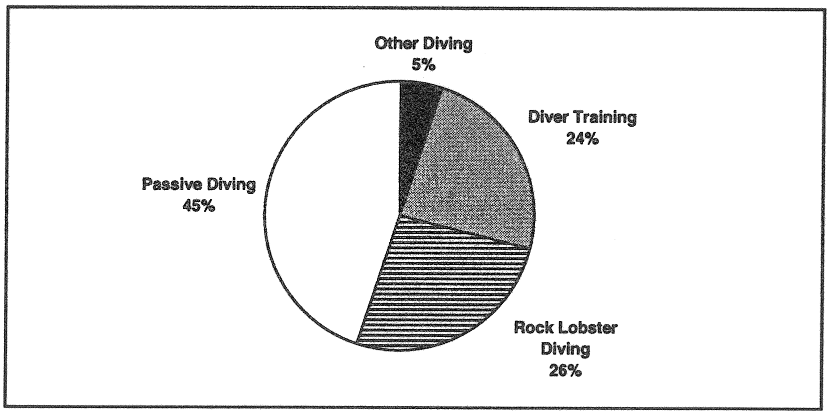

Figure 3.13 Proportion of recreational diving activity established from charter boat volunteer log book survey.

3.4 Recreational catch estimation

3.4.1 Rock lobster catch estimation from dive shop questionnaire

The estimated total catch for both zones from the dive shop questionnaire was 18,241 kg with 11,609 kg caught in the Eastern and 9,700 in the Western Zones respectively (Table 3.6). The greater number of dives in the Eastern Zone resulted in a higher catch despite a catch rate approximately half that in the Western Zone.

Total catch estimation using the combined catch rate for all respondents (18,241 kg) is lower than the combined estimate of the eastern and Western Zones (21,309 kg). These two estimates, however provide a useful range of the recreational catch to be used for comparison in future years of the survey. It is important to note that these estimates do not include the catch of hookah and snorkel divers and also hoop-net fishers.

Zone	Catch rate (lobsters per dive)	No. of dives for 1995/96	Estimated number of lobster caught	Estimated female catch weight (Kg)	Estimated male catch weight (Kg)	Total catch weight (Kg)
Eastern	0.20 (Mean)	46,988 (70%)	9,398	1,895	9,714	11,609
Western	0.39 (Mean)	20,137 (30%)	7,853	1,583	8,117	9,700
All	0.22 (Mean)	67,125 (100%)	14,768	2,977	15,264	18,241

* Average weight of the recreational catch female and male rock lobster

Table 3.6 Estimated total catch number and weight of rock lobster from the 1995/96 dive shop questionnaire.

Assuming that most of the recreational diving activity occurs in water less than twenty metres, a better comparison can be made with the commercial catch taken below twenty metres. The estimated total recreational SCUBA catches in each zone, established from the dive shop questionnaire, were compared to the total commercial catch from all depths and also from water less than 20 metres (Table 3.7). The total recreational catch in Victoria was 3.9% of the commercial catch at all depths and 20.8% in waters shallower than 20 metres. The results indicated a greater recreational component of the total catch in the Eastern Zone than in the Western Zone. The difference is primarily due to the greater commercial effort and the substantially lower recreational diving effort in the Western Zone. The Eastern Zone recreational sector was approximately 20.7% of the commercial catch from all depths and 46% of the commercial catch from water shallower than 20 metres (Table 3.7). In the Western Zone the proportion of the total commercial catch was comparatively low (2.3%), however, the proportion of the commercial catch shallower than 20 metres was significant (15.5%).

Zone	Commercial catch from all depths (kg)	Commercial catch from < 20 m (kg)	Recreational Catch (kg)	Percentage of total commercial catch from all depths	Percentage of commercial catch from <20 m
Eastern	56,029	25,084	11,609	20.7%	46.3%
Western	417,061	62,699	9,700	2.3%	15.5%
Both Zones	473,090	87,783	18,241	3.9%	20.8%

Table 3.7 Comparison of the recreational catch from the dive shop survey with the commercial rock lobster catch from all depths and from less than 20 metres for the 1995/96 fishing season.

4.0 Discussion

With the growing national diving population, the pressure on marine resources will undoubtedly increase. This research was initiated by a necessity to quantify the recreational rock lobster catch for stock assessment analysis and provides the first estimate of the recreational SCUBA catch of southern rock lobster in Victoria.

The dive shop survey was similar to a mail survey, in that it was distributed randomly with little or no prompts. Non-response biases are the biggest disadvantage of mail survey (Brown 1991) and are typically in the range of 40-60% to members of the general public and in the range of 60-75% for specific targeted audiences (Brown 1991). Response rates to the all questions in the questionnaire varied from month to month, and were acceptable for all months except the last two months of the 1995/96 survey.

The FWO was haphazard and opportunistic in the selection of participants, with a bias towards favourable diving conditions and location (Millar 1996) and therefore may not represent the Victorian diving population as a whole. Biases also existed between the different regions in which the FWO's work, and the variations in budget priorities and staffing allocations. The catch rates established from the FWO interviews (Table 3.4) were higher than those from the dive shop questionnaire reflecting the targeting of this survey to those divers engaged in diving at popular diving locations.

4.1 Recreational catch of rock lobster

The dive shop questionnaire did not sample recreational lobster fishers not relying on dive shops for SCUBA airfills, such as hookah and snorkel divers and those divers with access to private or club owned compressors and therefore, the total catch from the dive shop questionnaire may be an under-estimate. Hookah divers made up 12 % of the FWO interviews (Figure 3.8) and their catch rates were much higher than SCUBA divers (Table 3.4). This difference reflects the advantages of hookah diving which include minimal dive time restrictions and better access to lobster habitat without bulky SCUBA tanks.

The recreational catch is significant compared with the commercial fishery, particularly in water shallower than 20 metres and should be included in stock assessments. A similar comparison has been made in Tasmania where the amateur catch has been estimated at 18% of the commercial catch from waters shallower than 20 metres and 5% of the total commercial catch for the period between December 1995 and June 1996 (J. Lyle, DPIF, Tasmania, pers. Comm.). In the more popular recreational lobster diver locations, the proportion of the recreational catch may have more impact on inshore populations than the commercial fishery.

4.3 Future research requirements

The most important information required to obtain a more confident estimation of the recreational impact is a definitive estimate of the total Victorian recreational diving effort, which can only be achieved via randomly sampling the recreational fishing population of Victoria.

The dive shop questionnaire has been established for 1995/96 and is continuing to record information on the number of divers targeting rock lobster and the number of dives and the catch each month. The dive shop survey is continuing in the 1996/97 fishing season and has been modified by reducing the number of questions asked and by providing a small discount on an air fill if the questionnaire is completed.

The main requirement for future assessments of the recreational catch is a reliable estimate of the total number of divers and dives in Victoria. Recreational catch estimation in Victoria is difficult due to the lack of a structured recreational licensing system with associated electronic database. Future recreational research should have the minimal requirement of a database of all amateur fishers endorsed for capture of marine species. Establishment of such a recreational fisher database would enable the relevant catch and effort information to be determined by a phone survey of registered fishers. Western Australia and Tasmania have specific amateur rock lobster licences which enable them to rapidly, accurately and cost effectively assess the recreational catch and effort by a phone poll. Until a similar approach is adopted in Victoria, the accuracy of catch and effort assessment cannot be confirmed. Such an approach would include capture by all methods, thus allowing assessment of the hookah catch.

The results from the volunteer diver log books were inconclusive due to the low response rate. However, there is merit in this form of survey when a recreational database has been established and fishers can be allocated a log book after being randomly selected during a state-wide phone poll.

Roving Boat Ramp surveys are not practical in Victoria due to sparse and variable diving localities and activities. The most appropriate way to collect continuous direct diver information is by the continuing use of the FWO interviews. In the absence of a recreational fisher database, the dive shop questionnaire should continue but methods other than the 1993/94 airfill survey need to be developed for the estimation of dive effort.

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The assistance and enthusiasm of managers and staff of all participating dive shops was greatly appreciated as were the efforts of those charter boat operators and personal log book participants who made the effort to provide regular catch and effort information.

We also wish to thank the Fisheries and Wildlife Officers of the various coastal regions in Victoria, particularly Paul Millar at Colac and Graham Hanel and Ian Westhorpe at Warrnambool, for their knowledge and continued enthusiasm for the collection of the recreational diving information under increasingly tighter budget constraints.

The other members of the Rock Lobster Research Group must also be thanked for their assistance throughout the period of the project. Thanks to Paula Baker, Rhonda Flint and Dale Thomson for your hard work and commitment to the research objectives and thanks to Dave Lucas for providing additional field support.

Appendix 1: Format of 1995/96 Dive Shop Questionnaire

ROCK LOBSTER SURVEY

ALL DIVERS ARE ASKED TO COMPLETE THIS FORM BUT ARE REQUESTED NOT TO COMPLETE MORE THAN ONE PER MONTH.

This survey will remain confidential and will be used solely for Rock Lobster research.

1. In the 1994/95 Rock Lobster season (Nov.'94 - Aug.'95) how many dives did you make ? ☐

2. For the 1994/ 95 season how many dives did you make in the following periods ?

	Nov - Jan	Feb - May	Jun - Aug
Weekday			
Weekend or Holiday			

3. Are you a member of a dive and/or fishing club ? Yes ☐ No ☐

If yes, please list

....

....

4. How many years have you been diving ? <2 ☐ 2-5 ☐ 5-10 ☐ >10 ☐

5. In the last month how many dives did you make from shore or boat ? Shore ☐ Charter Boat ☐ Private Boat ☐

6. Estimate your average dive time. ☐ minutes

7. When diving do you actively search for Rock Lobster ? Yes ☐ No ☐

If yes, can you estimate the percentage of your dives that you actively search for Rock Lobster ? ☐ %

8. When diving do you actively search for Abalone ? Yes ☐ No ☐

If yes, can you estimate the percentage of your dives that you actively search for Abalone ? ☐ %

9. In the last month how many Rock Lobster have you seen and caught ? Seen ☐ Caught ☐

10. In the last month how many Abalone have you taken ? G.lip ☐ B.lip ☐

11. How many years have you been diving for Rock Lobster and/or Abalone ? Lobster ☐ Abalone ☐

12. Where do you usually dive for Rock Lobster ?

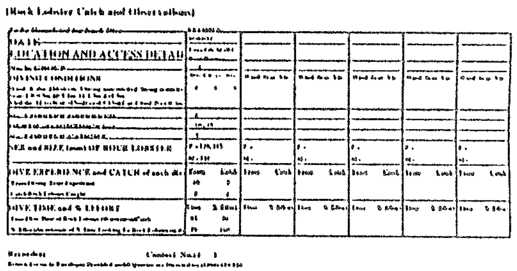
Location	Access method and location	Depth (m)

Thankyou for filling in this questionnaire.

Would you like to become more involved in Rock Lobster research by providing regular catch information ?

If so, please ring 1800-659 528 (toll free) and provide your name, address and phone number. You will receive a log book which can be used to record catch information (format demonstrated in diagram below).

PERSONAL DIVER LOG SAMPLE ONLY



Additional information about the Rock Lobster Assessment Project can be obtained from :

ROCK LOBSTER ASSESSMENT PROJECT
VICTORIAN FISHERIES RESEARCH INSTITUTE
P. O. BOX 114
QUEENSCLIFF 3225

Ph. (052) 580111 Fax. (052) 580270

Appendix 2: Schedule for the 1995/96 dive shop questionnaire.

NOVEMBER	Aqua Blue Scuba Instruction.	Associated Divers	Bay City Scuba	Dive Experience	Southern Cross Divers	Springvale Dive Centre	Dive Experience Dive Centre	Diver Instruction Services (Portsea)	Diving Headquarters	Professional Diving Services	Melbourne Diving Services (Portsea)	Rye Scuba Centre
DECEMBER	Aqua Blue Scuba Instruction.	Dive Experience	Australian Scuba Centre-Dive Line	Paradise Divers	Peninsula Diving Instruction	Schomberg Diving Services	Australian Scuba Centre-Dive Line	Adventure Down Under	Duck Dive Scuba	Melbourne Diving Services (Heidelberg)	Dive Under	Ocean Divers
JANUARY	J & K Cross Diving Services	Bay City Scuba	Australian Scuba Centre-Dive Line	Schomberg Diving Services	Warnambool Diving Services	Peninsula Diving Instruction	Take 2 Diving	Diver Instruction Services (Doncaster)	Diving Headquarters	Skin, Ski and Surf	Peninsula Diving Instruction (Flinders)	Western Diving
FEBRUARY	Aqua Blue Scuba Instruction.	Southern Cross Divers	Bay City Scuba	Warnambool Diving Services	Peninsula Diving Instruction	Paradise Divers	Diving Headquarters	Seal Diving Services	Take 2 Diving	Australian Scuba Centre-Dive Line	John's Diveshop	Geelong Dive and Outdoor Centre
MARCH	Dive Under	Southern Cross Divers	Schomberg Diving Services	Dive Experience	Seal Diving Services	Associated Divers	Diver Instruction Services (Portsea)	Ballarat Skin, Ski and Surf	Skin, Ski and Surf	Duck Dive Scuba	John's Diveshop	Interdive
APRIL	Schomberg Diving Services	Paradise Divers	Aqua Blue Scuba Instruction	Associated Divers	Bay City Scuba	Dive Experience	Dive and Dive	Dive Experience Dive Centre	Geelong Dive and Outdoor Centre	Professional Diving Services	Interdive	Rye Scuba Centre
MAY	Southern Cross Divers	Peninsula Diving Instruction	J & K Cross Diving Services	Schomberg Diving Services	Warnambool Diving Services	Paradise Divers	Dive and Dive	Duck Dive Scuba	Dive Experience Dive Centre	Skin, Ski and Surf	Ocean Divers	Ballarat Skin, Ski and Surf
JUNE	J & K Cross Diving Services	Bay City Scuba	Associated Divers	Springvale Dive Centre	Peninsula Diving Instruction	Southern Cross Divers	Paradise Divers	Wetsports	Ballarat Skin, Ski and Surf	Australian Scuba Centre-Dive Line	Skin and Scuba Sports	Rye Scuba Centre
JULY	J & K Cross Diving Services	Southern Cross Divers	Peninsula Diving Instruction	Dive Experience	Aqua Blue Scuba Instruction.	Warnambool Diving Services	Geelong Dive & Outdoor	Diver Instruction Services (Portsea)	Melbourne Diving Services (Portsea)	Seal Diving Services	Ocean Divers	Interdive
AUGUST	Dive Experience	Warnambool Diving Services	Paradise Divers	Schomberg Diving Services	Springvale Dive Centre	Associated Divers	Wetsports	Melbourne Diving Services (Heidelberg)	Diving Headquarters	Deep Down Diver Education	Melbourne Diving Services (Portsea)	Ocean Divers
SEPTEMBER	Paradise Divers	Aqua Blue Scuba Instruction.	Bay City Scuba	Associated Divers	Springvale Dive Centre	Peninsula Diving Instruction	Adventure Down Under	Professional Diving Services	Deep Down Diver Education	Dive Experience Dive Centre	Dive Under	Rye Scuba Centre
OCTOBER	Southern Cross Divers	Aqua Blue Scuba Instruction.	J & K Cross Diving Services	Warnambool Diving Services	Schomberg Diving Services	Bay City Scuba	Dive Experience Dive Centre	Diving Headquarters	Dive and Dive	Ballarat Skin, Ski and Surf	Skin and Scuba Sports	Western Diving

Appendix 3: Format of the Fisheries and Wildlife Officer Interview Cards (Front & Back)

ROCK LOBSTER - Recreational Interview (Capt: Divr)

Date__/__/__ Officer(s): .... Office: ....
Time: __:__ Location: .... Person __ of __ in Group

Diving Conditions: Seas ☐ Wind ☐ Visibility ☐
((1) - Rough / Strong / Poor (2) - Moderate (3) - Flat / Calm / Good)

Diver origin: .... Access: Boat ☐ Shore ☐

Method: SCUBA ☐ Hookah ☐ Dive Club: Yes ☐ No ☐
Hoopnet ☐ Snorkel ☐ AFL holder: Yes ☐ No ☐
Other .... Diver Experience: .... (Yrs)

Dive Purpose and catch:
☐ RL No. ☐ No. u/s ☐ Offence ☐
☐ Abs No. ☐ No. u/s ☐ ☐
☐ Other .... ☐

Knowledge: RL size ☐ RL closure ☐ Ab size ☐ G/lip closure ☐

Dive Period: ...... (Minutes) Lobster Research Diver: No ☐ Yes ☐

ABALONE cm	B/lip	G/lip
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		
shucked		
Total		

ROCK LOBSTER mm	Male	Female
105		
106		
107		
108		
109		
110		
111		
112		
113		
114		
115		
Total		

Name: ....
Address: ....
....
....
Ph. ( )

Comments ____________________

PERSONAL DIVER LOG

(Rock Lobster Catch and Observations)

Recreational Survey
Victorian Fisheries Research Institute
Rock Lobster Assessment Program

To be Completed for Each Dive EXAMPLE

	EXAMPLE				
DATE	06/04/94				
LOCATION AND ACCESS DETAILS	Lonsdale Wall Boat-Portsea				
No. in GROUP	6				
DIVE PURPOSE (P-Passive, T-Training, R-Rock Lobster, D-Diving for other species, O-Other)	Purpose Divers P 2 T 2 R/D 2	Purpose Divers	Purpose Divers	Purpose Divers	Purpose Divers

To be Completed if Rock Lobsters Observed and/or Caught.

	EXAMPLE				
DIVING CONDITIONS Wind: 1.Calm 2.Moderate 3.Strong-unrestrictive 4. Strong-restrictive Seas: 1. 0-0.5m 2.0.5-1m 3.1-1.5m 4.>1.5m Visibility: 1.Excellent >15m 2.Good 9-15m 3.Fair 4-8m 4. Poor 0-3m	Wind Seas Vis. 2 3 2	Wind Seas Vis.	Wind Seas Vis.	Wind Seas Vis.	Wind Seas Vis.
No. LOBSTER OBSERVED	4				
DEPTH of SIGHTINGS (m)	10 - 15				
No. LOBSTER CAUGHT	3				
SEX and SIZE (mm) OF ROCK LOBSTER	F - 120, 115 M - 121	F - M -	F - M -	F - M -	F - M -
DIVE TIME, % EFFORT, EXPERIENCE and CATCH of each diver. Time: Dive Time of Rock Lobster Catch (minutes) %: An estimate of % Time Looking for Rock Lobster on this Dive Years: Diving Years Experience Catch: Rock Lobster Caught	Time % Years Catch 85 50 10 2 70 100 3 1	Time % Years Catch	Time % Years Catch	Time % Years Catch	Time % Years Catch

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APPENDIX 6

Objective 4 - "To assess the current status of the fishery for southern rock lobster in Victoria"

Victorian Fisheries Assessment Report - Rock Lobster 1996

Compiled by Rock Lobster Fishery Assessment Group,

D.K.Hobday and D.C. Smith (eds).

MARINE & FRESHWATER RESOURCES INSTITUTE

FISHERIES RESEARCH & DEVELOPMENT CORPORATION

Project 92 / 104

VICTORIAN FISHERIES ASSESSMENT REPORT

ROCK LOBSTER 1996

Compiled by the

Rock Lobster Fishery Assessment Group

Edited by

David Hobday and David Smith
Marine and Freshwater Resources Institute

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This series of Fishery Assessment Reports provide general fishery assessments dealt with by the Stock Assessment Groups established by Victorian Fisheries. The documents are not intended as definitive statements but rather as progress reports about ongoing assessments, research and monitoring.

Contents **Page**

Summary

- The southern rock lobster (*Jasus edwardsii*) is fished commercially in south-eastern Australia and New Zealand. The Victorian annual catch is currently around 500 tonnes with a landed value of $15.6 million representing 10% of the Southeast Australian fishery. Over eighty percent of Victoria's catch is taken in the western management zone from the South Australian border to Apollo Bay.
- Catch rates in the Victorian fishery have shown a steady decline from 2.5 kg/potlift in the 1950's to 0.48 kg/potlift in 1992/93. The Western Zone catch rates have stabilised at around 0.5 kg/potlift. The Eastern Zone catch rate has declined steadily but has shown some stabilisation over the past two years (confirmed by examination of catch rates of the more experienced fishers), and is currently around 0.3 kg/potlift.
- Recent advances in technology such as colour sounders, satellite navigation and planing hulls have increased fishing power and effort on the more distant fishing grounds, by enabling accurate and repeatable positioning on reefs.
- This stock assessment aimed to refine the 1995 assessment in four ways:-
  1. Update the assessment with data from the 1994/5 fishing season.
  2. Use results of recent research to provide Victorian specific growth, fecundity and fishing mortality estimates as inputs to the assessment models.
  3. To provide, for the first time, an estimate of the recreational SCUBA diver catch in each management zone.
  4. Investigate the relationship between fisher experience and catch rates.
- The assessment incorporated a range of increases in fishing effort due to technological improvements and a weighting in the Eastern Zone for recreational catch.
- The recreational SCUBA catch for the 1995/96 season to the end of April was estimated to be 7.1 tonnes (10% of commercial catch) in the Eastern Zone, and 9.2 tonnes (2% of commercial catch) in the Western Zone. These estimates were agreed to be minimum values as they did not include hookah divers and illegal activities.
- Results of the biomass dynamics (production) assessment models in the Western Zone estimated that the reduction in effort needed to maximise yield was estimated at 10%, 29% and 37% with corresponding increases in fishing power of 0, 1.5 and 3% per year, with no allowance for recreational catch. These estimates were slightly higher than estimated in the 1995 assessment.
- The Eastern Zone production model estimated maximum yield with effort reductions of 36, 45 and 50% using effort standardised for winter fishing, a 7 tonne recreational catch and increases in fishing power of 0, 1.5 and 3% per year respectively. Effort reductions of 39, 45 and 51% would be required to maximise yield if a recreational catch of 14 tonnes is assumed. These estimates were unchanged from the 1995 assessment.
- Yield and egg per-recruit models predicted that a small gain in yield of 8% could be achieved by reducing fishing mortality.
- Egg per recruit analysis estimated that the current Victorian egg production is between 6 and 19% of the virgin, unfished stock (depending on the level of natural and fishing mortalities used). This estimate is less than the management target of 25% of the virgin egg production.
- Preliminary age structured modelling using Western Zone data showed that a reduction in effort by 30% over 5 years, would initially reduce catch by about 20%, but would stabilise at around 400 tonnes.
- High priorities for future research are further refinement of the estimation of the recreational catch and its continued monitoring. Other areas of high priority are more detailed analysis of catch and effort data at a finer resolution than the current management zones, and estimation of fishing mortality and growth parameters by zone.

Acknowledgments

This report was prepared by the Rock Lobster Fishery Assessment Group of Victoria from discussions and a compilation of contributions by members and non-members of the Group. Participants at the fishery assessment workshop held over three days during 11 - 13th June 1996 are listed as follows:

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Mr Glenn Pettigrove	Rock lobster fisher, Queenscliff	VFIF Eastern Zone Representative
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Introduction

The Fishery (Stock) Assessment Groups were formed to undertake annual assessments of Victoria's major fisheries and harvested stocks. Each assessment is conducted with reference to the stated management objectives for the fishery and the implications of the assessment for management of the fishery is a major outcome. The Groups were also established to ensure formal communication between fishery managers, scientists, industry and other client groups.

Each report contains a summary of the assessment for each fishery. The format and contents of each report and summary are standardised across each fishery. This ensures that both known information and inadequate or missing data are highlighted for discussion. Research needs are addressed and prioritised.

Management goals, objectives and targets were provided by the Fisheries Branch, Department of Natural Resources and Environment.

Management Goals, Objectives and Strategies

Goals

1. Ensure the sustainability of the resource.
2. Ensure the optimum utilisation of the resource.
3. Ensure a prosperous commercial fishery.
4. Provide recreational opportunities and ensure that recreational fishers have an appropriate and equitable allocation of the rock lobster resource.
5. Ensure that management arrangements are effectively implemented, monitored and reviewed.
6. Ensure co-operative and participative management with clients.

Objectives

1. Ensure adequate recruitment from the Victorian component of the rock lobster fishery by allowing the spawning stock to rebuild.
2. Improve the yield from the fishery, by reducing growth overfishing.
3. Improve the economic viability of operators in the fishery by reducing fleet fishing costs, encouraging the rationalisation of the number of boats in the fishery and maximising the value of the catch.
4. Rebuild the inshore rock lobster stocks to assist with conservation of the resource and provide improved recreational opportunities in the long term.
5. Ensure that management arrangements are cost effective and focused on the resource.
6. Ensure that management arrangements for the fishery are enforceable, and that an appropriate enforcement strategy is developed on an annual basis.
7. Provide education and extension services to commercial and recreational rock lobster fishers.
8. Implement monitoring programs for regular assessment.
9. Establish appropriate mechanisms to ensure effective consultation and communication with commercial and recreational fishers, and other groups.

Strategies

1. Maintain a spawning biomass in all major areas of the fishery in Victoria that will achieve a level of egg production that is at least 25% of the egg production from the unexploited stock.
2. Reduce fishing effort in the fishery. Stock assessment has indicated that yield could be maximised with effort reductions of 25% in the Western Zone and 50% in the Eastern Zone.
3. Reduce recreational catch, and the commercial catch from inshore areas.
4. Implement the research and monitoring strategy.
5. Implement the education and extension strategy.
6. Develop and implement an enforcement strategy for the fishery each year.
7. Review annually the state of the resource and management of the fishery with the commercial and recreational fishers.

Stock Structure and Life History

Boundaries, stocks and areas

The southern rock lobster (*Jasus edwardsii*) is found in the southern waters from the south-west Western Australian coast to southern New South Wales, including the waters around Tasmania and New Zealand. An overlap occurs in the western and eastern boundaries of the Australian distribution with the western rock lobster (*Panulirus cygnus*) and the eastern rock lobster (*Jasus verreauxi*).

There is a distinct lack of genetic variation in *J. edwardsii* across Australasia (Ovenden et al. 1992), which is primarily thought to be due to its long pelagic larval life and wide larval distribution across Australasia (Phillips et al. 1994). The discovery of a sub-species of *J. edwardsii* in 1995 on a deep seamount in the eastern South Pacific Ocean, 4,500 km west of Juan Fernandez Islands (Webber and Booth 1995), is the only known exception to the uniformity of speciation and reflects the changes associated with an isolated population. Geographic variations have lead to the classification of populations according to factors such as antennae banding, size of maturity of females, migratory behaviour, phyllosoma abundance and puerulus settlements (Phillips et al. 1994).

Biology and population parameters

Growth

Female southern rock lobster moult around mid May to mid June (Winstanley 1975) prior to mating and spawning. Male southern rock lobster moult 6 months out of phase from the females, around October - November, to ensure a hard shell for courtship and mating (Winstanley 1975). Moult frequency of the southern rock lobster decreases with age from 5 per year for post puerulus to 1 per year for large adults (McCoy & Esterman 1981; Winstanley 1977). The large adults also appear to moult more synchronously, while the smaller southern rock lobster may moult later in the season (MacDiarmid 1989, Treble 1996). In favourable conditions some adult populations may grow rapidly, requiring 2 yearly moults e.g. at Apollo Bay (Treble 1996).

Larval Development

Within hours of hatching, the naupliosoma larvae moult into phyllosoma in which form they undergo numerous moult stages. During this period larvae can travel large distances, with little control of movement apart from a diurnal migration (shallower at night and deeper during the day) (Booth 1989). Larval rock lobster in New Zealand can spend 12 to 24 months offshore (Booth & Phillips 1994). In Victoria, larvae could potentially be offshore for as little as 5 months. Larval rock lobster have been found in large expanses of water such as the Tasman Sea and are subject to prevailing current flows such as the west to east current across southern Australia (Ovenden et al. 1992).

Lesser (1978) described 11 phyllosoma stages collected from plankton samples, from the east coast of the North Island of New Zealand. From this work, phyllosoma were observed to grow from approximately 2 mm (total body length) at Stage I to approximately 25 mm (total body length) at around Stage IX in 12 months. Growth then accelerated to increase total body length to approximately 45 mm by Stage XI after six months. During this development a gradual progression from shallow to deeper water was observed. Stage XI is the longest phyllosoma stage, which may have the potential to delay metamorphosis to the puerulus stage until conditions are suitable. The mortality of the phyllosoma life stages appears to be very high, at around 98% from Stage I to Stage XI (Lesser 1978).

When the phyllosoma moult into the puerulus stage, they adopt the typical rock lobster appearance representing the longer benthic life stage. Pueruli are capable of a directional swimming motion using the pleopods and a rapid backwards motion by flexing the abdomen. After settling in water generally less than 40 metres depth, puerulus pigmentation and hardening adjustments see four post-puerulus moult stages before the juvenile stage.

Reproduction
The sexual age of maturity varies geographically. For example, female southern rock lobster reach sexual maturity (50% mature) at 90-95 mm carapace length (CL) in south-east SA, while western SA the sexual age of maturity (50% mature) is 112 - 114 mm CL (J. Prescott, SARDI, pers. comm.). The sexual age of maturity for females is believed to be 95 mm CL (50% mature) in western Victoria (Treble 1996).

The competitive nature of male crayfish ensures that in an unexploited population only the large lobsters (greater than 140 mm CL) successfully mate with females (MacDiarmid). The male deposits a spermatophore on the ventral side of the females. Shortly after mating the female exudes, fertilises and then incubates the eggs on specially adapted swimmerets under the tail for 3 to 4 months (MacDiarmid 1988; McKoy 1979). Females are generally in berry from June to November depending on geographic location and water temperature. The reproductive potential of females increases substantially with size with as many as 600,000 eggs being carried by the larger females.

The Fishery

Main Features

	Western Zone	Eastern Zone	Total
Catch (94/95)	434 tonnes	72 tonnes	516 tonnes
Value (94/95)	$13.4 M	$2.2 M	$15.6 M
Fleet	96 Licences	76 Licences	172 Licences
By-catch	Nil	Nil	
Discards	Lobsters killed by octopus	Lobsters killed by octopus	

Brief History

Commercial fishing for rock lobsters in Victorian waters dates back more than 100 years. During the early decades, the fishery was based on the use of baited hoopnets (cray-rings) in shallow coastal waters and the commercial use of hoopnets did not cease until the 1950s. Around the turn of the century, when the initial impact of commercial fishing of the inshore stocks was being reflected in lower catches by hoopnets, the rock lobster pot was introduced. At first, pots were set in shallow waters without buoylines and were retrieved by long boathooks.

Until the 1950s, the rock lobster fishers were also responsible for most of the landings of sharks and scale-fish from Victorian coastal waters, fishing seasonally for barracouta, Australian salmon, edible sharks and other species. However, after the Second World War, the rapid expansion of the overseas markets for rock lobsters, the growth of the Danish seine fishery off eastern Victoria, and progressive impacts of new technology, particularly in the location of grounds and the hauling of pots, had a major influence on the fishery. During the 1970s, declining barracouta catches and restrictions on the landing of school sharks in Victoria led to many fishers fishing full-time for rock lobster.

During the late 1980's falling inshore catch rates saw extension of the fishing grounds in western Victoria into deeper water and further from home ports. A new fishery for giant crabs developed between Apollo Bay and Portland along with new fishing methods and gear to work the deeper water along the edge of the continental shelf. As the giant crabs are distributed over a different habitat of soft muddy substrates, fishermen are able to directly target rock lobsters at depths less than 100 m, or giant crabs at depths exceeding 100 m using electronic fish finding and navigation equipment. Giant crab pots are generally set for four days before being hauled compared to an average soak time of one day for lobsters.

Over 80% of the catch of the Victorian rock lobster fishery is taken west of Cape Otway, where extensive rocky reef habitat occurs from the shore to depths of 180 m, up to 30 n miles from shore. Between Cape Otway and Wilsons Promontory, suitable habitat is confined to a narrow strip from the shore to depths of 50 m, generally up to 5 n miles from the shore. East of Wilsons Promontory to the New South Wales border, there are discrete patches of rocky reef habitat.

The major port for the Victorian fishery is Portland. Other major ports are Port MacDonnell (in South Australia), Port Fairy, Warrnambool, Port Campbell, Apollo Bay, Queenscliff, Newhaven, San Remo, Port Welshpool and Lakes Entrance. In recent years many licences have been transferred to Port Mac Donnell (SA) reducing the number of boats in Apollo Bay, Port Campbell and Portland. Some boats from ports between Portland and Lakes Entrance operate in the Tasmanian fishery, in particular around the Furneaux Islands and King Island.

Anecdotal information suggests that the recreational fishery has expanded in concert with the increase in SCUBA diving as a recreational activity. This activity is concentrated on inshore reefs particularly in central Victoria adjacent to high population areas.

History of management strategies adopted for the rock lobster fishery in Victoria.

1958 or earlier	The following regulations applicable to both amateur and commercial harvesters have been in force since at least 1958:- The commercial fishery was open to all licenced Master Fishermen. Legal minimum lengths (LML), of 105 mm for females and 110 mm for males. The **female closed season** from the first day of June in each year to the thirty-first day of October. The **male close season** from the first day of October in each year to the thirty-first day of October.
1968	The number of boats operating in the fishery was fixed under a system of limited entry. The maximum number of pots a boat could use was set at one pot per foot of boat length, plus 20 pots if the fisher worked alone or 40 pots if he employed crew. The fishery was also divided into two zones, east and west of Longitude 143° 40' East, and boats were licenced to operate in a specified zone.
1971	An amateur bag limit of four per person per day introduced
1982	The pot entitlements of all western zone licences were reduced, based on a sliding scale:- Entitlements of 10 - 40 pots were reduced by 5%, Entitlements of 46 - 65 pots were reduced by 10%, Entitlements over 66 pots were reduced by 15%. Pots became transferable between licences within each zone. In both zones a 20% forfeiture of pots transferred between licences was introduced.
1985	A 5% pot forfeiture at each transfer of a licence
1986	The closed season was extended to include the period from 1 to 15 November each year.
1987	The **closed season** was extended to include the month of September. The closed seasons being from 1 June to 15 November for females, and from 1 September to 15 November for males.
1990	Escape gaps became compulsory in all lobster pots.

Current management of the commercial fishery is based on limited licensing and pot numbers, closed seasons, minimum legal lengths and escape gaps (Anon 1994). There are 172 licence holders (76 in the Eastern Zone with the loss of 1 licence since last assessment of the fishery, and 96 in the Western Zone). The pot entitlements range from less than 10 to more than 100. There are 2,636 (average 34 per boat) and 5,537 (average 57 per boat) pots in the Eastern and Western Zones, respectively. The closed season for females is from 1st June to 15th November, and for males from 1st September until November 15th both inclusively. The legal minimum carapace lengths are 105 mm for females and 110 mm for males.

The recreational fishery is managed using the same closed seasons and legal minimum lengths as the commercial fishery. In addition, recreational fishers must hold an amateur fishing licence which entitles them to take 4 rock lobsters per day, by hand or using a maximum of two hoop nets. The use of spears and snares to take rock lobsters is prohibited.

Current Situation

Currently about 5,000 tonnes of southern rock lobster valued at $140 million is landed in south-eastern Australia. The Victorian component of this catch is around 500 tonnes valued at $15.6 million.

Victorian catch rates have fallen significantly in recent years. The catch rate in the Western Zone appears to have stabilised at about 0.5 kg/potlift, but in the Eastern Zone is continuing to decline and is currently about 0.3 kg/potlift.

The development of the giant crab fishery in the Western Zone has seen some effort being directed away from lobsters in 1992/93. Landings of giant crabs increased rapidly to 204 tonnes in 1992-93 due to an increase in effort in depths over 100 m. However, following the introduction of a legal minimum length for giant crabs, the effort at depths over 100 m declined and the catch in 1993-94 was 113 tonnes. Improvement in landed prices for southern rock lobster in recent years has resulted in higher levels of lobster fishing activity in periods of lower catch rates such as the late-autumn and winter months.

Post harvest processing and marketing considerably enhance the value of the fishery. Approximately 50% of the rock lobster catch is exported to Japan, Taiwan and the USA. The remainder is sold on interstate and local markets. Over the five years since 1990, peak prices (August) have risen by 63%.Eastern ZoneWestern Zone

Previous Assessments

There have been few formal stock assessments of the Victorian rock lobster fishery. Yield-per-recruit (YPR) analyses conducted in the 1970s, and reported in 1977 (Anon. 1977), indicated that little increase in yield would be achieved by changing the current legal minimum lengths. The results of preliminary surplus production modelling, also reported in 1977, argued that the fleet at that time had the capacity to exert more fishing effort than was necessary to take the estimated maximum sustainable catch of 600 tonnes (Anon. 1977). More recently, tagging experiments conducted between 1976-79 were analysed to provide growth and mortality parameters. Preliminary YPR analyses and surplus production modelling were conducted by the Rock Lobster Fishery Assessment Group in 1994. YPR analyses showed that there would be little increase in yield from increased effort. These surplus production models indicated that current levels of effort are greater than that necessary to achieve the maximum catch. A more exhaustive assessment was conducted in 1995 addressing concerns of industry that catch rates were artificially depressed because of increased winter effort when catch rates are lower on average, and inclusion of giant crab effort ie. >100 m (see below) in the assessment.

Economic surveys of the fishery have been conducted in the 1960s, 70s, 80s and in 1996. The latter showed that economic performance was unsatisfactory, especially in the Eastern Zone, and that a considerable proportion of fishers were making negative returns to capital. The 1988 study indicated that the operating surplus in the Western Zone was increasing faster than in the Eastern Zone. The most recent study by Read and Sturgess (1996) found that fishing activity involved relatively large amounts of capital investment and labour costs in the Western Zone compared to the Eastern Zone. Fishing time has increased over the past 6 years by some 16% in the Western Zone while the Eastern Zone has remained static. The Western Zone fishes around 55% more than the Eastern Zone. The average investment on net equity was around $500,00 for the Western Zone compared to $160,000 for the Eastern Zone. The average level of debt for the Western Zone was approximately 24% in the West compared to 17% in the East. The average level of boat profit for both zones decreased over the period 93/94 to 94/95 by 37% to $49,000 in the West while the East showed a decline of 140% over the same period to a loss of $9,000. Since 1987/88 the West has increased its profits per pot by around 50% (114% increase in price, and 11% increase in kg/pot.) to an average of $790 per pot. While the East has decreased its loss per pot by around 30% (114% increase in price, and 38% decrease in kg/pot.) to an average of $ minus 254 per pot. The return on capital for the West was approximately 8% (down from 11% in 1987/88) while the East had a return of -4.8% (up from -15% in 1987/88. (94/95). In summary, Read Sturgess (1996)found that the gap in boat profit between the two zones was widening and this was reflected in the prices for pot entitlements. Over the 6 year period the price for pot entitlements has increased by over 270% in the West compared to only 100% in the East. The difference in fish abundance and fishing technology (as reflected in catch per potlift) play a large part in explaining the difference and also contribute to the greater latent effort apparent in the Eastern Zone.

1996 Assessment

Recent Developments

This assessment uses preliminary results from the present Victorian study including growth (not separated by zone), fecundity, and fishing mortality estimates.

Methods

Data

Commercial Catch and Effort data

Catch and effort data are available from 1951 to the present. Before 1978 this data was reported as monthly catch and number of potlifts, and since has been reported on a daily basis. Data for the period 1978 to 1993 were examined in detail as part of this assessment. The effect of fisher experience on catch rates was examined in detail as part of this assessment, and the following three adjustments to the commercial catch and effort data were made and the results used in the stock assessment models :-

1. Giant crab effort. Until recently, rock lobster fishers involved in catching giant crabs, did not report separate efforts directed to crabs and rock lobsters. The distribution of catch of southern rock lobster and giant crab and reported total effort (1978-1994) were analysed by depth and zone. For the Western Zone, effort was removed from the data when more than 30% of a fisher's daily catch by weight consisted of giant crab (effort not targeted on rock lobster). This method produced effort figures comparable to those used in the 1995 assessment by omitting effort at depths greater than 100 m.
2. Seasonal shift in effort. The implications of a shift in effort to late autumn / winter were examined in the 1995 assessment. Catch and effort data for the entire fishing season were compared to the November - April data. Winter effort data were standardised to equivalent "summer" (November-April) effort when used in the biomass production models. Equivalent Summer effort for the fishing season = (Total season catch / Summer catch) x Summer effort)
3. Increase in fishing power. An adjustment was made to effort (potlifts) to account for a range of possible increases in fishing power. In WA and SA a 3% per year increase in fishing effort has been used to account for technological improvements. For the Victorian data, arbitrary values of 0, 1.5 and 3.0% were applied to the biomass dynamic models. It is recognised that increases in fishing power tend to be stepwise as new technology is introduced and this is a factor that needs to be addressed in later assessments.
4. The relationship between commercial fisher experience and catch statistics was investigated to see if decreases in catch rates could be due to an increased proportion of less experienced fishers in later years. Experience of fishers was calculated from the catch and effort data as the number of days fished since daily data was recorded in 1978. Participants at the workshop helped to estimate relative experiences of fishers at the commencement of the data in 1978.

Recreational Catch and Effort data

The 1995 Stock Assessment presented some preliminary, unsubstantiated estimates of the recreational catch. The recreational catch and effort data presented in the current assessment is based on information obtained from surveys conducted during the 1995-96 fishing season. Models for the Eastern Zone were run with a recreational component, however the Western Zone models were run without a recreational component as the estimated recreational catch was only a small proportion of the total catch.

Commercial Length Frequency and Growth Data
Length frequency data has been collected at Portland since 1963 and this data was available for analysis. Data for several other Victorian ports has been collected on an ad hoc basis since the mid 60's but is not yet available in an electronic form for analysis.

Data Quality
Commercial catch and effort data used for this assessment (1978-95) varies in quality. Since the last stock assessment workshop, much effort has been directed to checking this data for errors in key punching and for gross errors in the data by running various range and ratio checks (e.g. average weights). This data validation process has been completed for the 1994-95 season back to 1986-87 and is continuing. The majority of errors detected have occurred in the interpretation of the return, mistakes in key punching or calculations prior to key punching. These errors are more likely to be a problem when the data is used at a high resolution rather than the yearly summaries by zone used in this assessment.

Analytical techniques
Recreational diving surveys
Three different approaches have been taken to assess the amateur catch of southern rock lobster in Victoria:

1. Dive shop questionnaire.
2. Charter boat / dive club and personal log books.
3. Fisheries and Wildlife Officer (FWO) interview cards.

The dive shop questionnaire was conducted as a random survey of SCUBA airfill outlets in Victoria. The information collected was used to represent the recreational SCUBA activity throughout the state. The charter boat and dive club log books weredesigned to obtain volunteer amateur catch and effort information over a long period. The interview cards (collected by the Fisheries and Wildlife Officers) were obtained from several Department of Natural Resources and Environment (DNRE) coastal regions. These interviews were site specific and targeted divers involved in the harvest of rock lobsters or abalone (Millar 1996). This survey included data on illegal activities not represented in either of the other surveys. Each survey method collected data on effort, catch, diver experience and dive locations (Table 3). For the purposes of this assessment only the information collected from the dive shop questionnaire and the FWO interviews were used to estimate the recreational catch. The other surveys will be used in analysis of longer term trends and were not random and could not be related to available SCUBA air fill data.

Dive Shop Questionnaire

The primary aim of the dive shop questionnaire (Appendix A) was to analyse the relative numbers of divers targeting southern rock lobster (or abalone) and to obtain an estimate of the respective catch per unit of effort of divers in Victoria. It provides tangible information on the methods, locations, diving patterns and catch success along the Victorian coastline. The survey was structured to enable direct comparison with commercial catch and effort information.

The questionnaire was distributed at random to twelve dive shops per month during the 1995-96 fishing season (results presented from November 1995 to April 1996). All shop managers (Total of 41) were in support of the survey and agreed to participate. Shops were divided into three distinct groups based on:

1. Popularity (size of club, turnover, reputation).
2. Location - sampling a high proportion of divers at key sections of the coast.
3. Value - value of shop location and need to sample in different areas (e.g. if only one shop in Ballarat it would be given a higher priority then if there were two).

The combination of these three classifications provided an averaged value for each of the shops from one to three. The highest ranking shops were sampled more regularly and weighted accordingly.

Appendix B shows the schedule designed for the shop selection with the shop name and the corresponding month of selection.

The managers and staff of the dive shop were instructed to hand out the questionnaire to all divers requesting an airfill irrespective of the dive purpose (ie. targeting rock lobster or not). By targeting those divers requesting an air fill the information obtained by a Dive Victoria study of 1993-94 could be incorporated to estimate the total possible diving effort in a year.

FWO interview cards

A small interview card (Appendix C) was re-designed from previous cards developed by DNRE Colac and distributed to accommodate both the enforcement and research information requirements. FWO interview cards were distributed to all coastal DNRE Offices for use on regular patrols for divers and/or hoop-netters exiting the water. Interviews were random and as such contained biases that prevent extrapolation to the whole of the Victorian population. The FWO interviews provide information on the catch of the unaffiliated (and also the illegal) sector of amateur rock lobster fishers. Due to the enforcement nature of the FWO interviews, the results obtained are expected to represent the maximum potential catch rate of the amateur fishery. This information is being used to monitor the intensity and location of diving, hoop netting and hookah fishing effort at popular dive locations. Collection of this information over an extended period will provide valuable length frequency and catch success information for all methods of amateur rock lobster fishing as well as identifying any changes in preferred fishing methods.

Growth

Preliminary growth estimates were obtained from the present tagging study as well as the 1976-79 tagging experiments using Fabens (1965) method of fitting the von Bertalanffy growth curve with SAS non-linear estimation software.

Mortality

Length frequency data for the three periods 1963-67, 1980-86, 1990-96 from Portland were examined using length-converted catch curve analysis (Pauly 1983, 1984a, 1984b) to estimate total mortality.

Fecundity

During the 1995 egg-bearing season 150 egg samples were collected from berried females, dried, and counted by sub-sampling. Fecundity estimates were transformed using natural logarithm and a linear regression applied to the data to estimate the carapace length / fecundity relationship.

Per recruit analysis

Yield- and egg-per-recruit analyses were conducted using estimates of growth, mortality and fecundity derived from the current research program. These analyses were used to investigate the effect on yield from reductions in fishing effort and to estimate the current level of egg production. These analyses were performed using a spread-sheet (Excel Version 5) applying three values of natural mortality (0.10, 0.15 and 0.20). The previous assessment (Hobday and Smith, 1995) used a natural mortality value of 0.2 which may be too high given results from Tasmanian research where a value of 0.1 has been used in this type of analysis (Kennedy 1992).

Biomass dynamics models

Two types of biomass dynamic models, the Integrated Fox (Fox 1970) and Gulland (Gulland 1965) models, were applied separately to a set of catch and effort data for the Western Zone and Eastern Zone. Effort was adjusted to summer equivalent. Various scenarios were examined using a cumulative weighting of effort between 1978 and 1993 of 0%, 1.5% and 3.0% for technological improvements or increased fishing power. To account for recreational diving, the Eastern Zone recreational catch was increased over the past 10 years from zero to the values estimated in the recreational survey (see recreational survey results) and added to the commercial catch. The commercial effort was increased proportionally each year by adding the equivalent commercial effort required for the recreational catch. The equivalent commercial effort was obtained by dividing the recreational catch for a year by the commercial CPUE for that year. The catch and effort data used in the models therefore represented the combined commercial and recreational fishery.

Age structured model
A preliminary age-structured model was used to assess the outcome of changes in fishing effort in the Western Zone. Since the last assessment, this model has been improved by the incorporation of Victorian growth and fecundity parameters and by separation of the sexes in the calculations.

Results

Industry Perspectives
Commercial
There was a general concern from the commercial sector regarding the state of the stocks of Southern Rock Lobster in Victoria. The trends of declining catch with increasing effort (declining CPUE) were supported along with the need to fish more distant grounds. The technical efficiency of fishers has increased with the introduction of black and white sounders and radar during the 50's and 60's, bottom locked sounders in the mid 70's, colour sounders and satellite navigation in the early to mid 80's, global positioning systems (GPS) in the late 80's, and GPS plotters in the late 80's to early 90's. The advances in sounder technology have enabled fishers to locate new fishing grounds and the significant improvements in position fixing by GPS have made returning to a particular fishing location possible and repeatable. There has been a trend, particularly in the Western Zone to bigger and faster boats and a shift to operating out of ports further to the west. Increased effort in the Western Zone was initially directed into new grounds and initially allowed time for areas to rebuild between fishing. More recently, further expansion of grounds has been limited and the increased effort has been directed to repeated fishing of grounds, resulting in decreasing size range in the catch because the localised populations do not have time to rebuild. The introduction of escape gaps has been effective in reducing the number of undersize lobsters in pots. The economic pressure on fishers needing to service loans has increased effort in the fishery, particularly among new fishers who have had to borrow to buy into the fishery. The higher effort and lower catch of the inexperienced fishers are influencing the catch and effort trends, particularly in the Eastern Zone. Uncertainty in management direction, including the possibility of quota, have led to the potential of some fishers to change the way the catch and effort information has been supplied.

The impact of recreational fishers, particularly in the Eastern Zone, is believed to have increased in the last 10 to 20 years. Concerns were also expressed for the lack of consideration of other potentially damaging impacts of agricultural and industrial waste on near shore lobster stocks.

Recreational
Recreational divers generally support the observations from the commercial sector of a decline in rock lobster populations to the extent that many consider seeing a crayfish on a dive to be fortuitous, rather than normal as in earlier days. Although the number of qualified divers is high, the number of skilled divers is limited, with a very high turnover of participants. Recreational divers can be divided into three groups, firstly those who are not interested in catching lobsters at all and dive for other reasons; secondly, those who used to seek lobsters but now don't because the low catch rates do not justify the effort; and thirdly divers actively seeking lobsters. The third group find that they need to expend more effort and dive further afield in order to catch lobsters, and generally expect to fail to catch the daily bag limit of 4 lobsters. Fisheries and Wildlife Officers suggest that many divers are still taking their bag limits and are now willing to take more risks to do so. The recreational divers sampled by Fisheries and Wildlife Officers may not represent the majority, but they appear to be more successful and are therefore representing the serious divers with the sole purpose of catching rock lobster.

Commercial Catch and Effort data

Western Zone

In the Western Zone, the number of days fished per fishing season was relatively constant between 1978-79 and 1988-89. The number of days increased until 1992-93 and has since stabilised (Figure 1). The increase in the number of days fished in the late 1980's was initially directed to depths of less than 20 fathoms and more recently also in 20-40 fathoms (Figure 2). The maximum Western Zone catch of 534 tonnes was recorded during the 1979-80 fishing season (Figure 3, Table 1). Following this, effort and subsequent catch declined over 3 years stabilising until 1988-90, after which effort increased steadily to around 780,000 potlifts with catch failing to increase and has stabilised over the past three years at around 430 tonnes. The average weight of lobsters in the Western Zone prior to the mid 80's was around 1 kg but since then, increasing effort has driven the average weight below this level (Figure 3). The distribution of effort by month in recent years shows a small decrease in the percentage of the year's potlifts in December - February and a large increase from May - August (Figure 7).

Eastern Zone

The number of days fished per fishing season in the Eastern Zone showed a decline until 1987-88 and then increased between 1993-94 and 1994-95 (Figure 1). The increase in the number of days fished since the late 1980's was initially in 10-20 fathoms depth followed two years later by an increase in depths less than 10 fathoms (Figure 4). The average weight of lobsters caught in the Eastern Zone has been greater than 1 kg except for several years in the late 80's when large numbers around the legal minimum length have been reported anecdotally (Figure 5). The maximum Eastern Zone catch of around 130 tonnes was recorded during the 1978-79 fishing season and has declined to around 70 tonnes (Figure 5, Table 2). Effort increased until 1982-83 and then declined until 1987-88 possibly reflecting effort diverted to other fisheries such as shark during this period. Effort has since increased steadily without a corresponding increase in catch and has shown some sign of stabilising during the past 2 years at around 250,000 potlifts. Little change has been seen in the proportion of winter effort prior to the early 1980's, but in recent years effort during April - July has doubled, and August effort has also increased (Figure 9).

CPUE

Catch per unit effort (CPUE, kg/potlift) in the Victorian lobster fishery has shown a steady decline from 2.5 kg/potlift in the 1950's (Hobday and Smith, 1995) to a relatively stable level around 0.8 and 0.7 kg/potlift in the late 70's and early 80's in the Western and Eastern Zones respectively (Figure 6). CPUE then declined steadily in both zones until 1990-91 stabilising in the Western Zone at around 0.55 kg/potlift. The Eastern Zone CPUE continued to decline until 1992-93 and appears to have stabilised around 0.3 kg/potlift over the past three years. Monthly Western Zone catch rates are very similar to those in 1985-88 with the exception of August when CPUE has been reduced by half (Figure 8). In contrast, Eastern Zone monthly catch rates have been reduced by 30 - 50% in all months (Figure 10).

Effect of experience

The distribution of experience (days fished since 1978) was markedly different in the two zones. The Western Zone fishing was dominated by the more experienced categories with newer entrants to the fishery a minority (Figure 11a). In contrast most fishers in the Eastern Zone belonged to the less experienced categories (Figure 11a), probably reflecting the lower entry cost to this fishery.

The average number of potlifts generally increased with experience category in both zones, with more variation in the Eastern Zone of high experience categories (Figure 11b). The average individual total catch in the Western Zone for the <200 day experience category was much lower than the remainder of fishers, reflecting the fewer number of potlifts by this group (Figure 11c). In the Eastern Zone, the average catch in the <1000 day experience categories were similar, with the most experienced category higher and more variable, reflecting the more part-time nature of some fishers in the Eastern Zone (Figure 11c).

Catch per unit effort of the top 3 experience categories in the Western Zone has shown no trend over the past 5 seasons whereas the Eastern Zone CPUE declined between 1990-91 and 1992-3 and then stabilised during the past 3 season (Figure 12).

Recreational Catch and Effort data

Dive Shop Questionnaire

A total of 283 questionnaires were received from November 1995 to April 1996. The information from these questionnaires was used to estimate the catch rate of divers determined by averaging of the summed catch per dive for every diver.

The number of rock lobster seen by divers, in any particular month, exceed those caught by a magnitude of 4 to 15 times (Figure 13). The pattern of sightings of rock lobsters increased in December and January, decreased in February, and again increased in March and April.

The recreational catch and effort analysis was divided into the same zones as the commercial fishery. The proportion of dives conducted in the eastern and Western Zones was calculated according to the dive locations listed on the questionnaire returns. The number of dives reported by the dive shop questionnaires for the Eastern Zone was 71% of all dives, while the remaining 29% of dives were conducted in the Western Zone.

The dive shop questionnaire information was linked to an estimate of the number of SCUBA airfills in Victoria conducted by Dive Victoria (affiliated to Dive Australia). A figure of 80,000 dives was established for the 1993/94 financial year (W. MacDonald, Dive Victoria pers. comm.). There have been no subsequent SCUBA airfill estimates since this study. We conducted a survey of 20 major dive shops and clubs in the state which indicated that diving activity had declined since 1993/94 and estimates of SCUBA airfills for subsequent years were adjusted accordingly from the 1993/94 airfill survey to 70,940 in 1994/95 and 67,880 in 1995/96. The catch per zone was calculated using the proportion of dives in each, the catch rate in each zone and the projected total number of dives for 1995/96 (Figure 15).

Size and sex data from the recreational catch recorded by the FWO interviews were analysed to determine the length frequency and average lengths of recreational catch (Figure 14). The results clearly indicated that divers target larger rock lobster which invariably result in the capture of large males. The catch of male rock lobster represented 76% of the recreational catch in the FWO interviews.

The majority of female rock lobster caught were relatively small (106 to 116 mm CL), while the males captured are from a larger size range with a higher average weight. The average weight of females caught was 0.840 kg and the average weight of males caught was 1.360 kg. To calculate the weight of the recreational catch by sex and by zone, the number of rock lobster caught was multiplied by the proportion of expected catch of males to females (76% : 24%) and the average weight of males and females (1.36 kg, 0.84 kg) (Figure 15).

The catch rate determined for the Western Zone was 0.38 lobsters per dive while the catch rate for the Eastern Zone was 0.12 lobster per dive. The surveys have shown that divers in the Western Zone are generally more experienced and target rock lobster to a greater degree whereas diving activity in the Eastern Zone has a larger emphasis on passive diving activity and contains a greater proportion of inexperienced divers. The resulting catch for males, and females was larger in the Western Zone despite the much lower proportion of dives (Table 4). The total recreational catch in the Western Zone of 9.2 tonnes represents approximately 2% of the commercial catch, while the total recreational catch for the Eastern Zone of 7.1 tonnes represents 10% of the commercial catch (Table 4).

Fisheries and Wildlife Officer interview survey
The catch estimated from the dive shop questionnaire may represent minimal values because private compressor owners, snorkel divers, hookah divers and illegal operators were not sampled (this view was not supported by the Recreational sector). The FWO interviews sample actual recreational diving activity and may therefore be used to provide another estimate of the recreational catch rate which would include a sample of the illegal catch. The FWO catch rate for the Western Zone was derived primarily by the Fisheries and Wildlife Officers of the Colac region, and contains interviews of amateur fishers exiting the water from Apollo Bay to Peterborough during enforcement activities.

The FWO catch rate for the Eastern Zone was calculated by assuming the same comparative increase in catch rate from the expected minimal catch rate determined by the questionnaire (i.e. 1.8 times the minimum catch rate). The estimated catch per dive was 0.22 and 0.70 lobsters per dive in the Eastern and Western zones respectively (Table 5). Preliminary results from FWO interviews conducted in the Eastern Zone suggest that a catch rate of 0.22 lobster per dive would not be excessive. Further work will continue to obtain definitive estimates of the FWO catch rate for the Eastern Zone which can be used as an estimate of the actual catch rate.

Commercial Length Frequency Data
Length frequency data showed a marked shift to relatively smaller lobsters for males in the Portland catch. During the period between 1964 and 1976, the proportion of lobsters greater than 170 mm CL was reduced (Figure 16). Since 1976, there has been a depletion of individuals greater than 155 mm CL and a reduction in the proportion greater than 135 mm CL (Figure 16).

Analysis of Portland length frequency data using length converted catch curves estimated fishing mortality for males to be constant, and decreasing for females since the 60's (Table 6). These estimates are much lower compared with those around Cape Otway using the Change-in-ratio method (R. Treble, Appendix D), and the decreasing estimates for females and constant estimates for males over time do not fit current expectations of increasing fishing mortality over time. This analysis is sensitive to growth parameters and variation in size frequency between areas fished (e.g. Treble 96). More work needs to be directed towards this analysis before the next assessment.

Growth Data
Estimates of growth for each sex varied widely by zone and between the present and 1970's tagging studies (Table 7). It is expected that these differences will be reduced as more recaptures are received from the present tagging study. For this assessment, an average growth curve for each sex was fitted by eye to the various growth estimates, and these were used in the yield, egg per recruit and age structured model assessments (Figure 17).

Fecundity
Fecundity was found to increase non-linearly with carapace length according to the relationship:-

$N = 17051 \times e(0.023 \times CL)$. N = number of eggs

Within the range of females most commonly caught, this relationship agreed well with similar work in Tasmania (Figure 18, Kennedy 1992), but was higher for larger lobsters. More samples will be taken this winter to better define the relationship in larger females.

Stock Assessment Analysis

Biomass dynamics models
The Integrated Fox model was investigated in this assessment as it provides a more realistic fit at higher levels of fishing effort than the Gulland model. However, it failed to fit the Victorian data for either zone. The Gulland model (Gulland, 1965) provided a better fit to the Western Zone data (R^2 0.6 - 0.8)

than for the Eastern Zone (R^2 0.5 - 0.7) (Table 8). The maximum sustainable yield (MSY) for the Western Zone was estimated at 419 - 437 tonnes with a corresponding effort of 562 - 603,000 potlifts depending on the weighting of effort for increases in fishing power due to technological improvements. Similarly, the Eastern Zone MSY ranged from 114 - 123 tonnes at efforts of 155 - 183,000 potlifts assuming a recreational catch of 7 tonnes, and 116 - 183 tonnes (161 - 196,000 potlifts) with a recreational catch of 14 tonnes. The reduction in current effort required to maximise yield in the Western Zone was estimated as 10, 29 or 37% assuming a fishing power increase of 0, 1.5 and 3% per annum over the last 10 years respectively (Table 8). In the Eastern Zone reductions in current effort to obtain maximum yield were estimated at 36, 45 or 50% (Table 8) with 0, 1.5 and 3% effort weighting respectively and a 7 tonne recreational catch. Similarly, Eastern Zone effort reductions assuming a 14 tonne recreational catch were 39, 45 and 51%. These estimates were slightly higher for the Western Zone and unchanged in the Eastern Zone compared with those reported in the 1995 assessment.

Per recruit analysis

The yield per recruit analyses estimated that maximum yield would be achieved at a fishing mortality between 0.2 and 0.3 for females, and 0.1 to 0.2 for males (Figure 19). The yield of males for a given fishing mortality was greater than that for females because of the difference in growth rates between the sexes. If the current level of fishing mortality is conservatively assumed to be 0.4, the maximum gain in yield by reducing effort could be around 10%.

The theoretical egg production for a fishing mortality of 0.4 was estimated to be 6%, 11% and 19% of that of the virgin population for natural mortalities of 0.1, 0.15 and 0.2 respectively. These estimates all fall below the management target of 25% of virgin egg production and are cause for concern. If fishing mortality was reduced from 0.4 to 0.3 (assuming a natural mortality of 0.15), a 21% rise in egg production would result increasing the percent of virgin egg production from 11% to 14%. These estimates use a size at onset of maturity (SOM) determined for Apollo Bay (Treble 1992, 1996) and uncertain values of fishing mortality and require further refinement.

Age structured model

Since the last assessment, this model has been improved by using Victorian growth and fecundity parameters and by separation of the sexes. This improved the fit of the model to historic Western Zone catch data, but predicted catches were much higher than the reported during 1968-72 and 1989-94 (Figure 21). The model showed that a reduction in Western Zone effort of 30% over 5 years would initially reduce catch by about 20%, but it would then stabilise at around 420 tonnes per annum.

Uncertainties

The growth parameters used in yield- / egg-per-recruit and age-structured models are derived from ongoing research and will be further refined by the next assessment with the aim of providing parameters separated by zone. There is also a lot of uncertainty about natural mortality and the current levels of fishing mortality.

The models are sensitive to the effort statistics used, and the rate at which fishing power has increased in recent years is difficult to quantify. It is also not known whether excessive commercial and recreational effort, particularly in the Eastern Zone and inshore Western Zone, is causing competition between gear and/or between the recreational and commercial fisheries.

Management Implications

The current results are similar to the 1995 assessment with respect to predictions concerning effort reductions required to achieve maximum sustainable yield, but are much more pessimistic concerning the current level of egg production. The effect of local recruitment resulting from Victorian egg production is unknown, but the south east fishery must be considered as a whole and each state should be responsible for maintaining suitable levels of egg production. Effort reductions would provide benefits to the Victorian fishery by increasing egg production, increasing long term yield, and improving the economics of fishing. The principal behind these benefits is that with less effort, a proportion of the lobsters that are currently caught would not be removed from the population and may moult to a larger size before being caught. Reducing fishing mortality would provide the potential to increase total yield by 8% and egg production would increase.

Estimates of CPUE in the Western Zone indicate that the fishery has stabilised in recent years. The management target of a 25% reduction in effort remains appropriate given the similarity of the estimates to the previous assessment and the reduction of the upper limit from 51 to 37%. The age-structured model suggests that following the targeted reduction in effort, once the fishery has stabilised, catches close to current levels could be maintained.

CPUE appears to have stabilised in the Eastern Zone. The revised estimates for the percentage reduction in effort to achieve maximum catch, 36-50% are consistent with the 50% management target. There may be some scope for a downward revision of this target given the stabilisation of CPUE, but given the poorer fit of the Eastern Zone data to the biomass production model, it would be wise to remain at the higher limit of the predicted reduction. It is important however, that any reduction in effort in both zones must be applied to both the commercial and recreational fisheries.

Future assessment of the recreational fishery is complicated by the unlimited and unregistered access of divers in the fishery. Currently the only requirement of a recreational rock lobster fisher is an Amateur Fishing License (AFL), which can be obtained at a large range of retail outlets. In 1993-94 an estimated 100,000 licenses were sold, with no detail of where or to whom. The number of rock lobster amateur fishers could be estimated generously at around 10,000. Any attempt to obtain recreational catch information from such a small range people in the total Victorian population would be difficult. A statewide phone poll or the introduction of a rock lobster endorsement on the AFL are two of the most promising options that may provide the data required.

Research Needs

- More detailed biological information and estimates of population parameters across Victoria are necessary to reduce uncertainty in the assessments. Expansion of current on-board measuring by MaFRI and commercial fishers is of high priority to provide data for future length - based modelling.
- Monitoring of puerulus and pre-recruits as an index of recruitment variability should be continued.
- The stock structure of southern rock lobsters is unknown although they are currently managed as if the resources of each state were separate stocks. The implications of this are for recruitment; particularly whether the South Australian and Tasmanian fisheries could impact on recruitment to Victoria.
- A high priority for research is to continue monitoring of the recreational catch.
- There is a need for a more sophisticated analysis of catch and effort data to provide estimates of changes in fleet dynamics, including fishing power and gear competition. The spatial changes in the fishery should be analysed using GIS methods.
- Further work is required to reduce uncertainty in the models.

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Table 1 Catch, effort (giant crab effort not included) and CPUE data for the Western Zone for fishing seasons (year commencing November) between 1978 and 1994 for the complete season and for summer (November - April).

Western Zone

year*	Entire Season Catch (kg)	Entire Season Effort (potlifts)	Entire Season CPUE	Summer Catch (kg)	Summer Effort (potlifts)	Summer CPUE
78-79	477853	612852	0.78	414092	476714	0.87
79-80	445356	558639	0.80	377796	415589	0.91
80-81	534572	665851	0.80	473565	524559	0.90
81-82	479035	613768	0.78	415840	477289	0.87
82-83	452125	587425	0.77	389994	440873	0.88
83-84	415406	538814	0.77	365226	431600	0.85
84-85	390032	543110	0.72	345274	424480	0.81
85-86	344886	545999	0.63	286267	406118	0.70
86-87	335244	568240	0.59	291830	439551	0.66
87-88	332452	531340	0.63	297080	427006	0.70
88-89	285139	538426	0.53	243074	407319	0.60
89-90	321028	625096	0.51	280241	457688	0.61
90-91	312026	639474	0.49	255192	452665	0.56
91-92	403556	696757	0.58	335599	498398	0.67
92-93	399426	755234	0.53	327413	524356	0.62
93-94	444079	741846	0.60	371550	509393	0.73
94-95	433478	778784	0.56	353599	513352	0.69

*Years begin November

Table 2 Catch, effort and CPUE data for the Eastern Zone for fishing seasons (year commencing November) between 1978 and 1994 for the complete season and for summer (November - April).

Eastern Zone

year*	Entire Season Catch (kg)	Entire Season Effort (potlifts)	Entire Season CPUE	Summer Catch (kg)	Summer Effort (potlifts)	Summer CPUE
78-79	134840	186407	0.72	106108	137730	0.77
79-80	109820	157772	0.70	88802	117854	0.75
80-81	121655	171208	0.71	99289	127640	0.78
81-82	124395	180836	0.69	103121	136710	0.75
82-83	133526	198951	0.67	104019	138527	0.75
83-84	125526	209691	0.60	100882	151586	0.67
84-85	104404	183720	0.57	90775	145232	0.63
85-86	89418	167626	0.53	74574	128039	0.58
86-87	78912	143206	0.55	63974	110324	0.58
87-88	67754	124781	0.54	60047	99165	0.61
88-89	64091	143972	0.45	52692	106895	0.49
89-90	85369	191267	0.45	71432	147524	0.48
90-91	70848	164101	0.43	56303	123168	0.46
91-92	65127	173940	0.37	51809	123916	0.42
92-93	66486	212530	0.31	50341	139763	0.36
93-94	79120	253948	0.31	64295	178935	0.36
94-95	71695	244794	0.29	57484	176961	0.32

*Years begin November

Table 3 The information characteristics of each of the three survey types (Data from Nov. '95 - April '96)

INFORMATION COLLECTED	SURVEY Shop questionnaire	METHOD Volunteer log book	EMPLOYED FWO interview cards
Number of people surveyed	- 1 per form - 283 forms	- 1-30 per dive - 63 returns (up to 8 dives per return)	- 1-5 per card - 202 cards from 10/94.
Effort Estimates	- monthly number of dives - average dive time - % of dives targeting rock lobster	- no. in group - dive purpose - dive time - % effort on RL	- no. in group - dive purpose - dive time
Catch Estimates	- no. RL catch - no. RL sightings	- size, sex and no. of RL - no. and depth of sightings	- size, sex and no. of RL
Catch Efficiency	- diver experience - no. years diving for RL	- weather/diving conditions - diver experience	- weather/diving conditions - diver experience
Dive Location	- site, access and depth of RL habitat dives	- site, access and depth of RL habitat dives	- site and access of RL habitat
Abalone	- % dive time - Green and Blacklip catch - years diving for abalone	None	- catch and size of Greenlip/ Blacklip
Additional Information	- no. dives in 1994/95 - seasonality in 1994/95 - dive method/site access -club membership - personal log recruitment - anecdotal information	- % divers targeting RL	- dive method/site access -club membership - personal log recruitment - regulation knowledge - possession of AFL

Table 4 Recreational catch estimates using Dive Shop Survey data.

CATCH RATE (lobsters per dive)			CATCH			Proportion of commercial catch
			Number of Lobster	Weight of males (Kg)	Weight of females (Kg)	
Dive Shop Estimate	East	0.12	5783	5977	1166	~10%
	West	0.38	7480	7732	1508	~2%

Table 5 Recreational catch estimates using FWO interview data.

CATCH RATE (lobsters per dive)			CATCH			Proportion of commercial catch
			Number of Lobster	Weight of males (Kg)	Weight of females (Kg)	
FWO Estimate	East	0.22	10603	10671	2138	~18%
	West	0.70	13780	14243	2778	~4%

Table 6 Results of length converted catch curve analysis, providing estimates of fishing mortality at Portland for three time periods. (Natural mortality assumed to be 0.1)

Portland	1963-67			1980-86			1990-96		
Sex	F	Std Error	R square	F	Std Error	R square	F	Std Error	R square
Male	0.44	0.03	0.89	0.44	0.01	0.96	0.44	0.05	0.73
Female	0.46	0.04	0.89	0.41	0.02	0.97	0.32	0.02	0.97

Table 7 Results of Von Bertalanffy parameter estimation where time at liberty > 10 days and growth increase > -3 mm.

Tagging Study	Sex	Western Zone		Eastern Zone	
		L_∞	K	L_∞	K
1990's	Male	159.86 ± 3.99	0.298 ± 0.034	162.80 ± 11.12	0.297 ± 0.103
1970's	Male	179.46 ± 1.96	0.200 ± 0.011	192.92 ± 11.73	0.180 ± 0.030
Both studies	Male	203.30 ± 6.95	0.145 ± 0.012	192.30 ± 10.81	0.180 ± 0.020
1990's	Female	159.50 ± 13.42	0.102 ± 0.028	142.29 ± 3.790	0.185 ± 0.024
1970's	Female	117.68 ± 0.950	0.307 ± 0.019	123.22 ± 1.130	0.226 ± 0.013
Both studies	Female	120.00 ± 0.256	0.282 ± 0.009	119.77 ± 0.163	0.258 ± 0.007

Table 8 Results of biomass dynamics modelling of Victorian Southern Rock Lobster during 1964/65 - 1994/95

Methods: Gulland.

Symbols: E = effort , r = stock growth rate, q = catchability, B = Biomass, MSY = maximum sustainable yield, E_{MSY}.= effort required for MSY, $E_{(1993)}$ = effort in 1994-95.

Assumptions: During 1973/74-1977/78 missing data substituted with catch = 403 tonnes and annual CPUE = 0.8 pa.

Effort: Standardised as commercial equivalent Nov-Apr effort.

Commercial effort weighted 1% pa during 1978/79-1993/94 in Eastern Zone for recreational diving.

Weighted 0%, 1.5% & 3.0% pa (Wt E) during 1978/79-1993/94 for technological improvements.

Western Zone

Results	Commercial Nov-Apr & No Recreational catch				Summer Equiv Effort				
Adjusted R sq	**Effort Weight Technology%**	**qB**	**+/- se**	**q^2/r**	**+/- se**	**MSY Tonnes**	**E(MSY)**	**E(1994)**	**% Reduction #**
0.63	0	1.489912	0.094007	-0.00132	0.000183	419	562	629	**10.7%**
0.76	1.5	1.506243	0.076027	-0.00134	0.000135	425	564	790	**28.6%**
0.82	3	1.448769	0.063463	-0.0012	0.000104	437	603	950	**36.5%**

Eastern Zone

Results	**7 tonne REC Catch**								
Adjusted R sq	**Effort Weight Technology%**	**qB**	**+/- se**	**q^2/r**	**+/- se**	**MSY Tonnes**	**E(MSY)**	**E(1994)**	**% Reduction #**
0.50	0	1.4653996	0.135026	-0.004728	0.000851	114	155	242	**36.0%**
0.63	1.5	1.4222172	0.104494	-0.004283	0.000597	118	166	304	**45.4%**
0.67	3	1.3422313	0.088281	-0.003659	0.000458	123	183	366	**50.0%**
	14 tonne REC Catch								
Adjusted R sq	**Effort Weight Technology%**	**qB**	**+/- se**	**q^2/r**	**+/- se**	**MSY Tonnes**	**E(MSY)**	**E(1994)**	**% Reduction #**
0.55	0	1.4406585	0.11911	-0.004478	0.000733	116	161	264	**39.0%**
0.62	1.5	1.3978484	0.101265	-0.004102	0.000581	119	170	309	**45.0%**
0.67	3	1.2891059	0.082653	-0.003285	0.000415	126	196	398	**50.8%**

Reduction in current effort required to maximise yield.
Note for the Eastern Zone, the standardised effort includes a recreational component.

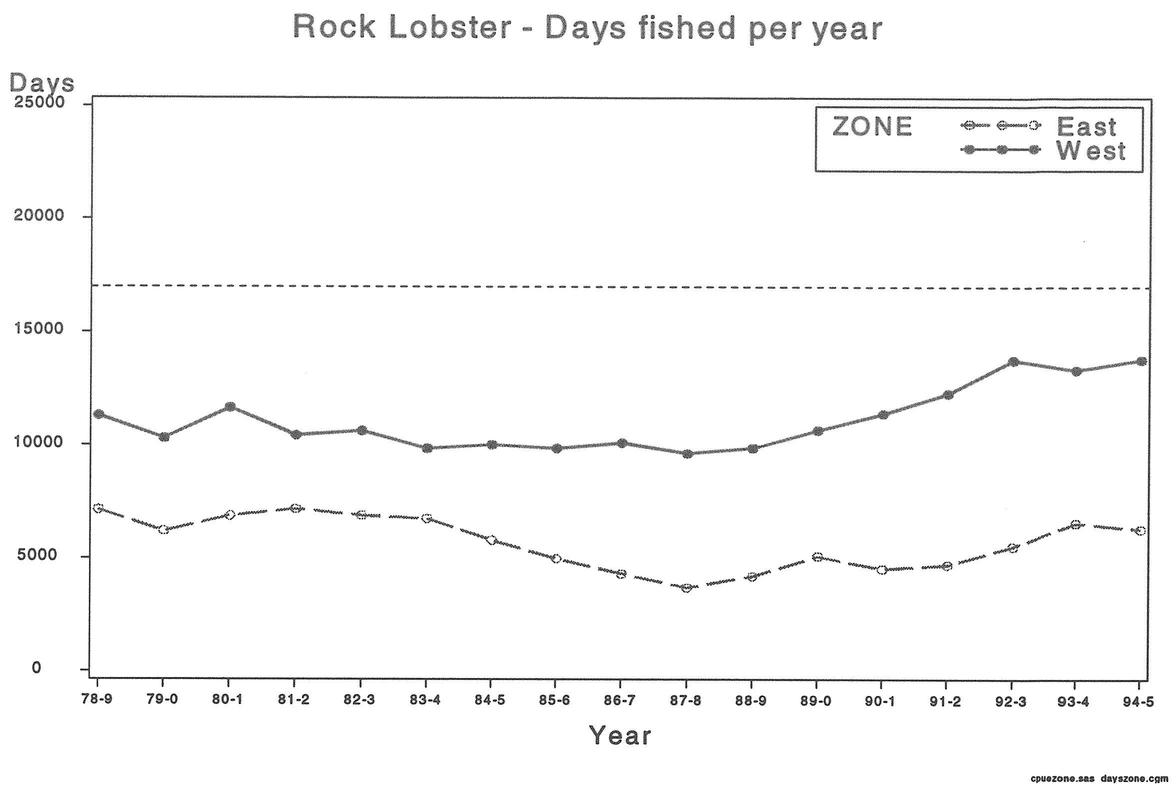


Figure 1 Distribution of effort (days fished) by zone for the fishing seasons (year commencing November) between 1978 and 1994. Dotted line represents maximum possible days in the Western Zone assuming 60% of days in season fishable.

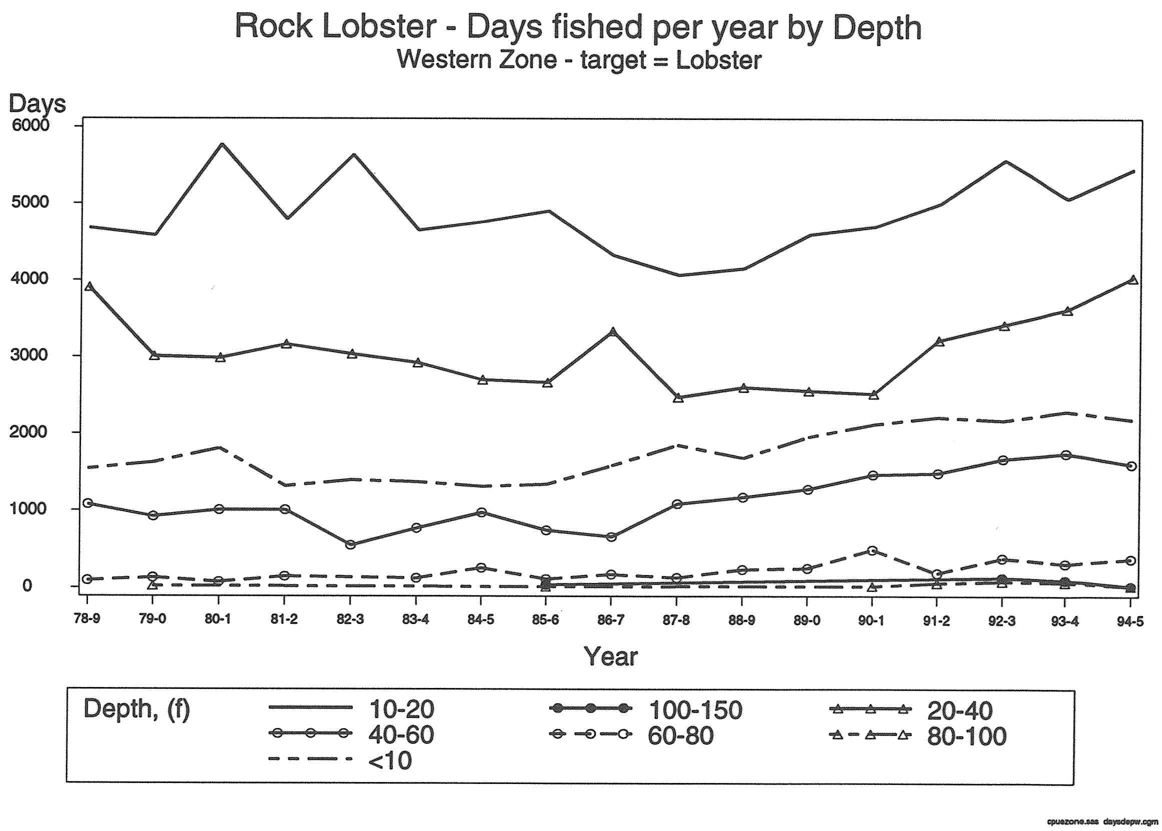


Figure 2 Distribution of effort (days fished) by depth (fathoms) in the Western Zone for the fishing seasons (year commencing November) between 1978 and 1994.

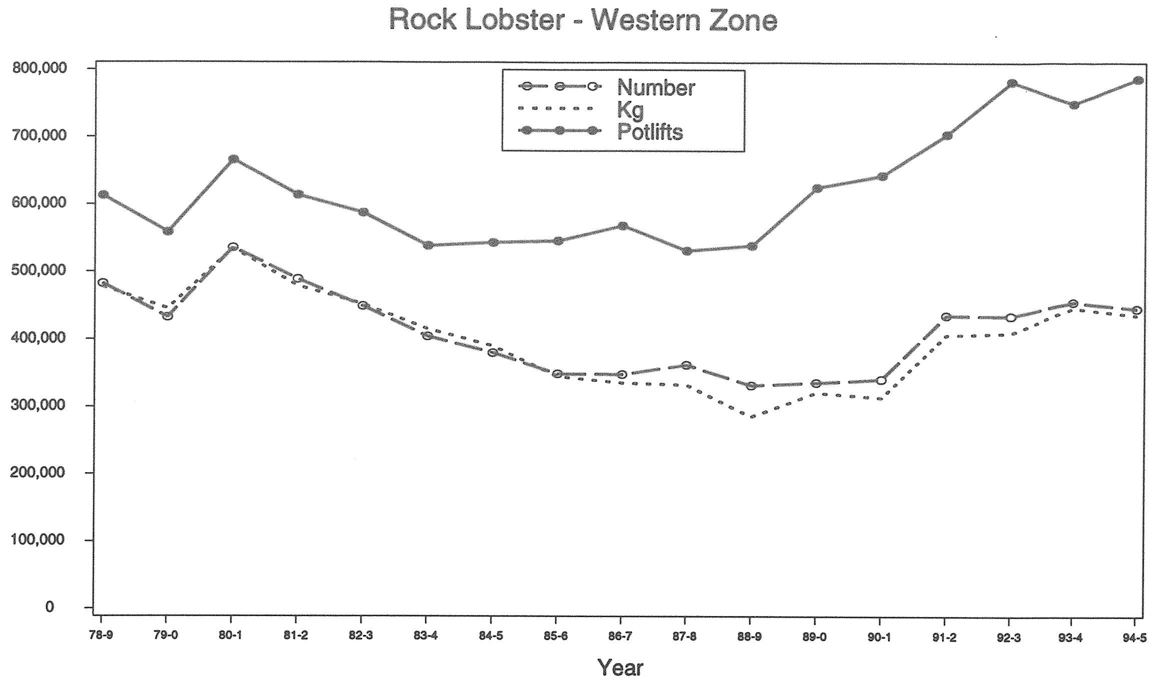


Figure 3 Catch and effort (excluding giant crab effort) in the Western Zone for entire fishing seasons (year commencing November) between 1978 and 1994.

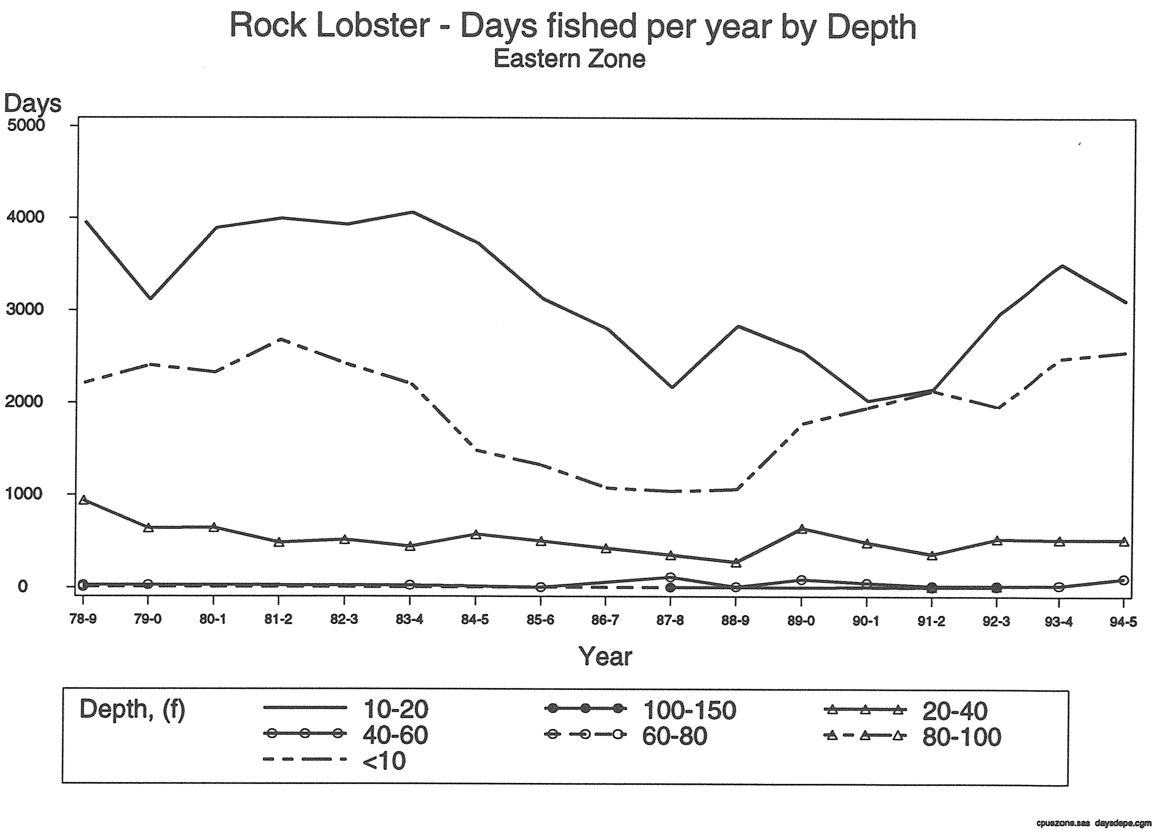


Figure 4 Distribution of effort (days fished) by depth in the Eastern Zone for the fishing seasons (year commencing November) between 1978 and 1994.

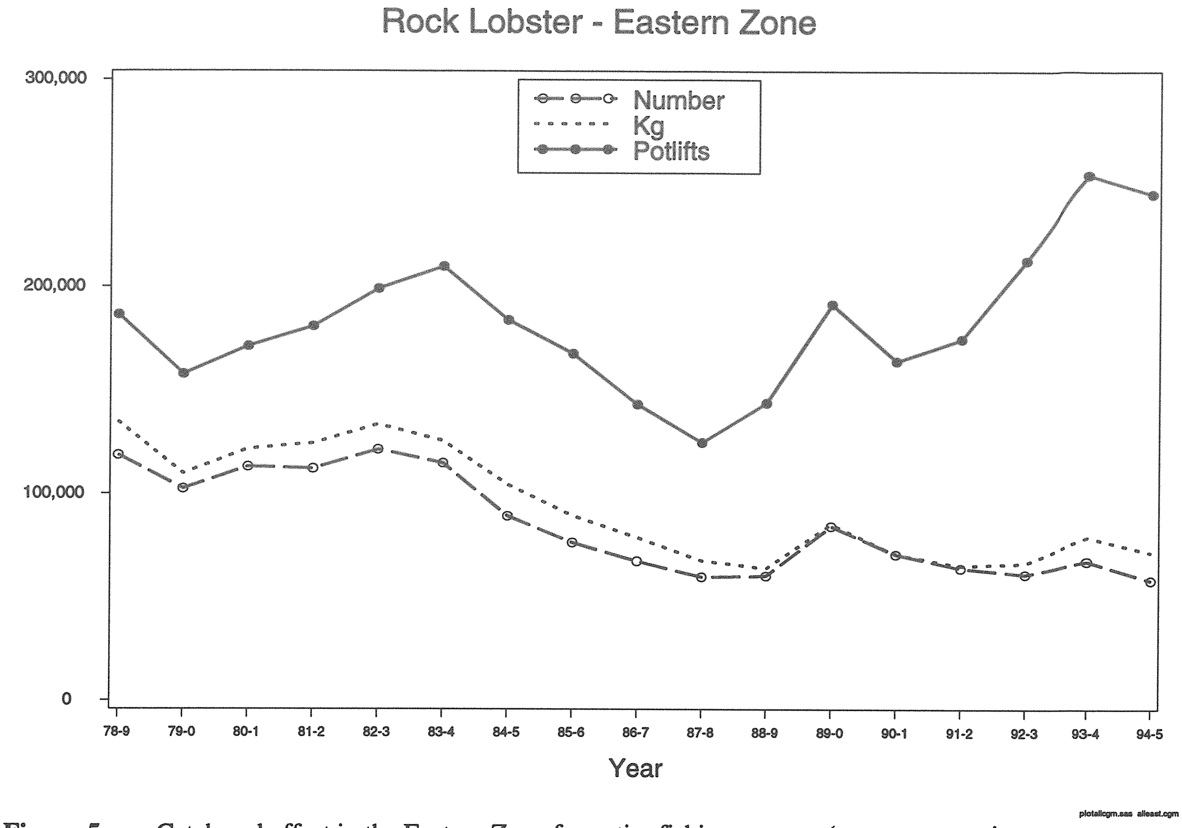


Figure 5 Catch and effort in the Eastern Zone for entire fishing seasons (year commencing November) between 1978 and 1994.

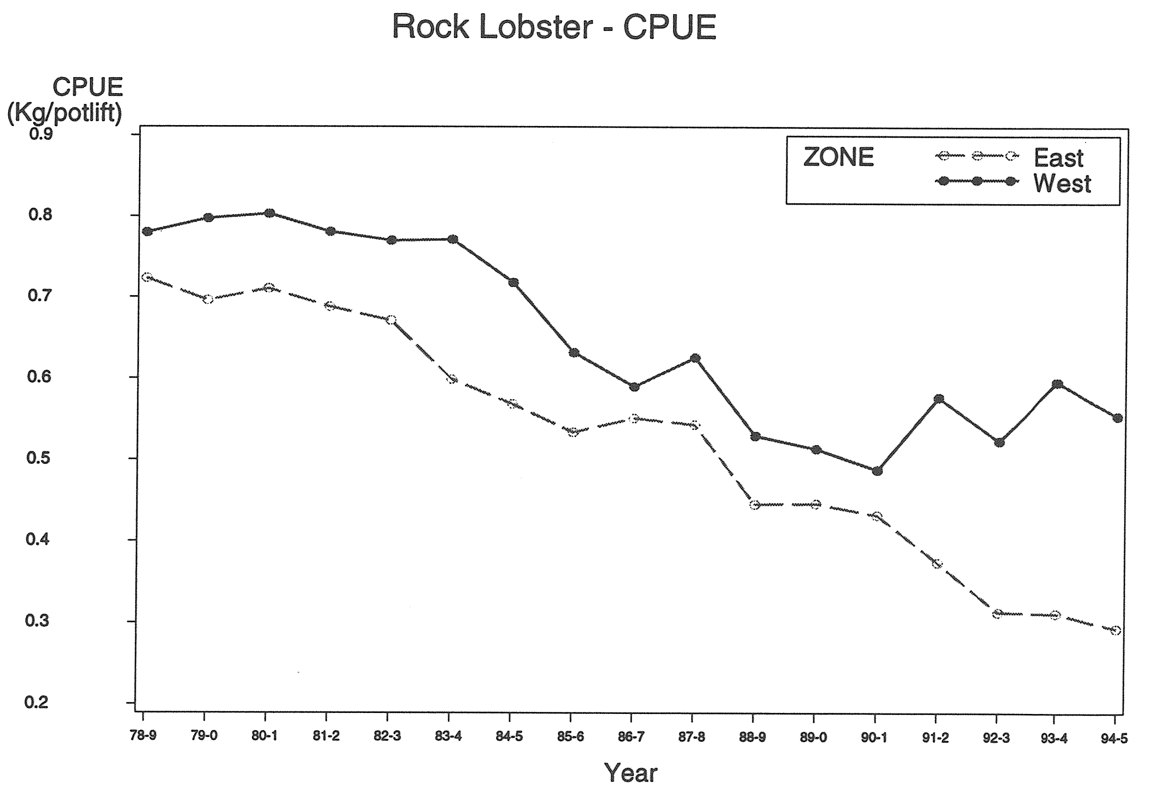


Figure 6 Catch per unit effort data for the western and Eastern Zones for fishing seasons (year commencing November) between 1978 and 1994.

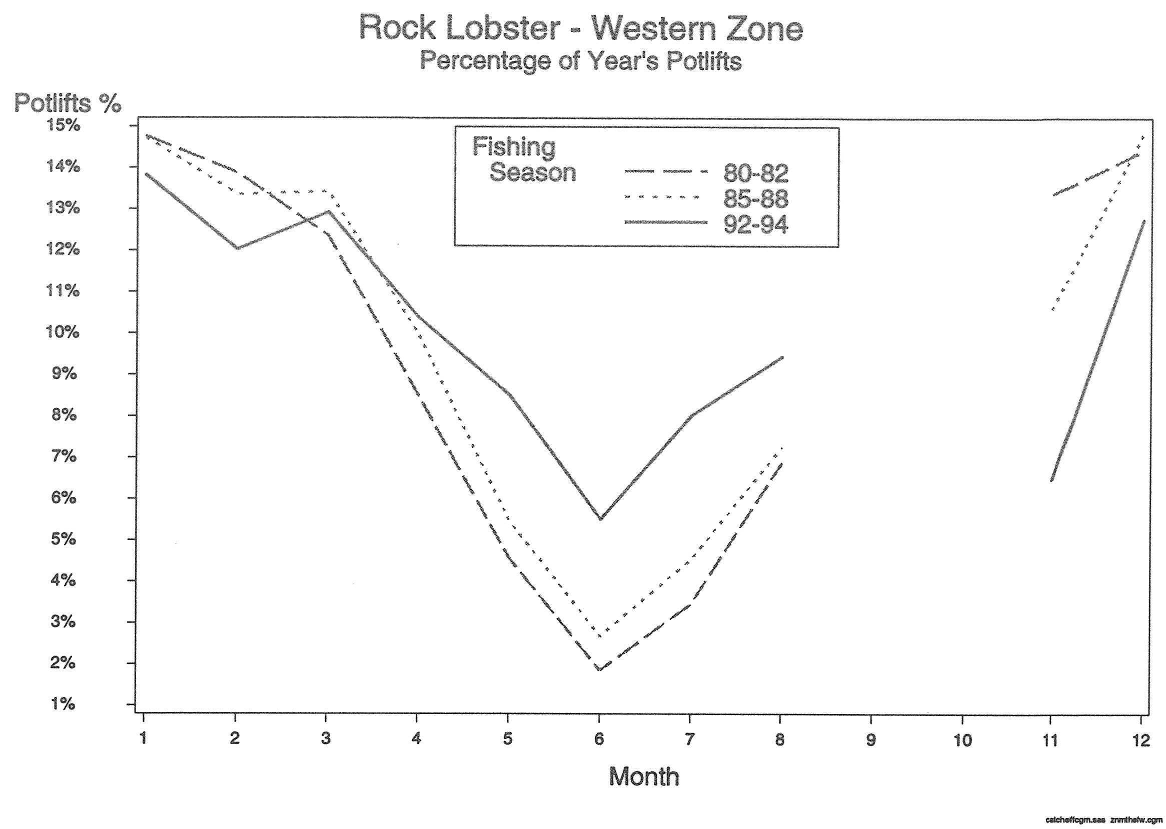


Figure 7 Percentage of the years potlifts in the Western Zone by month for three time periods, 1980-82, 1985-88 and 1992-94.

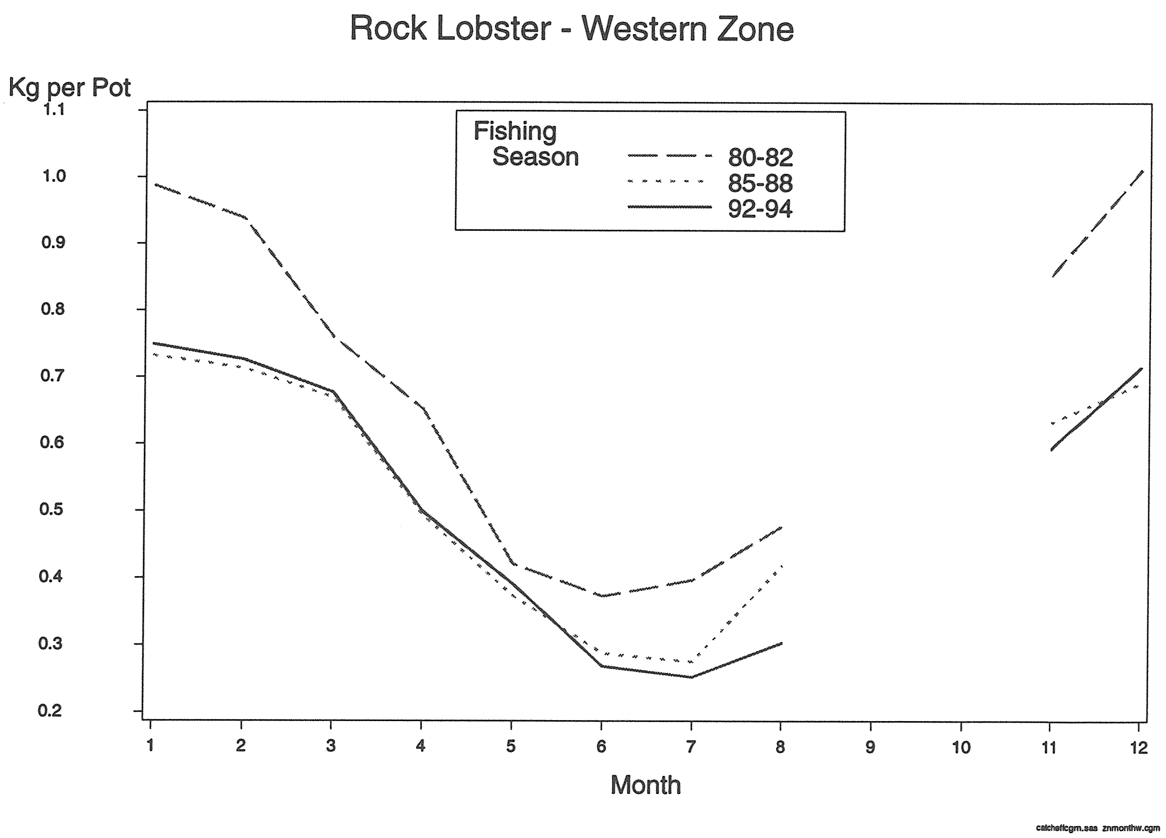


Figure 8 Western Zone CPUE (kg/potlift) by month for three time periods, 1980-82, 1985-88 and 1992-94.

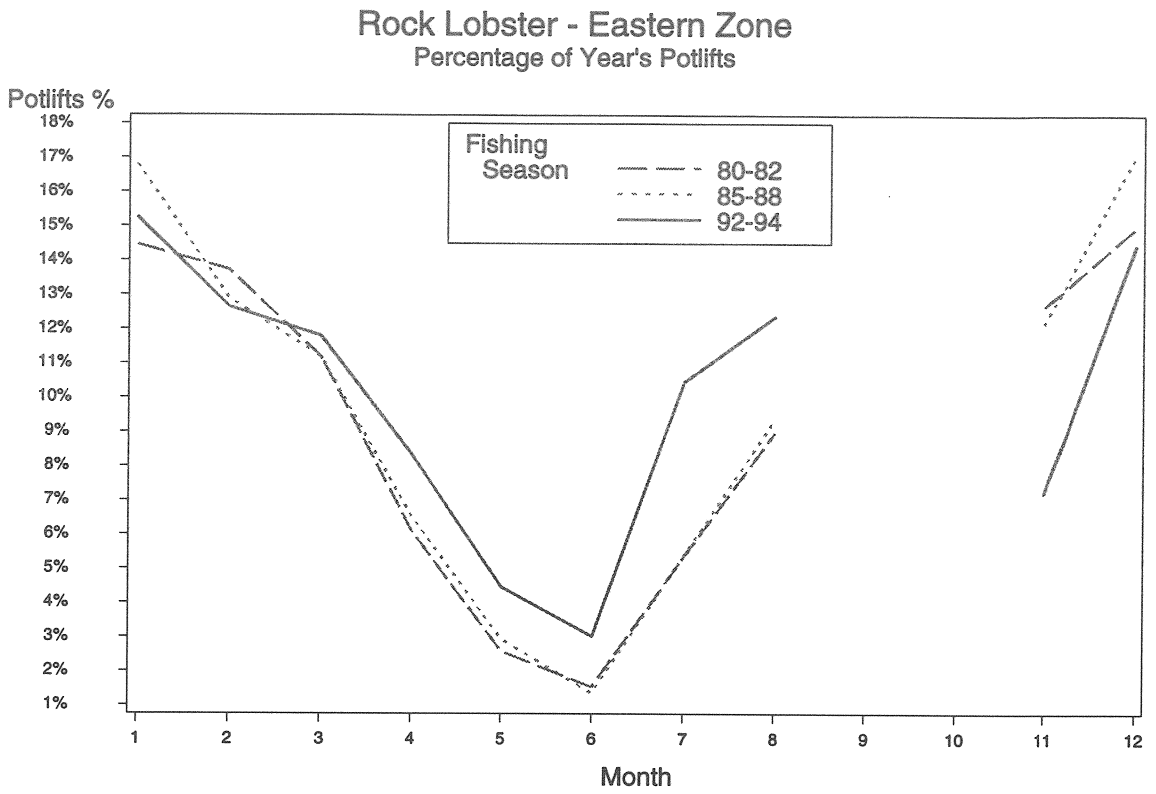


Figure 9 Percentage of the years potlifts in the Eastern Zone by month for three time periods, 1980-82, 1985-88 and 1992-94.

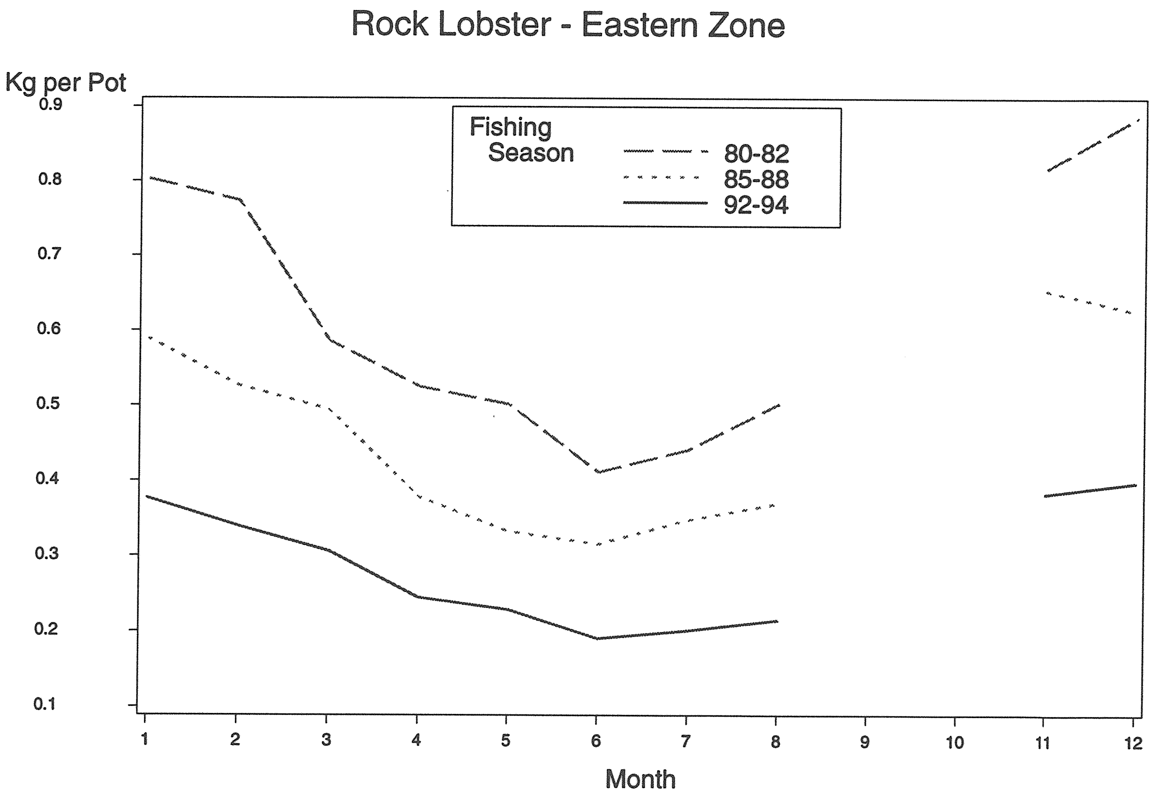
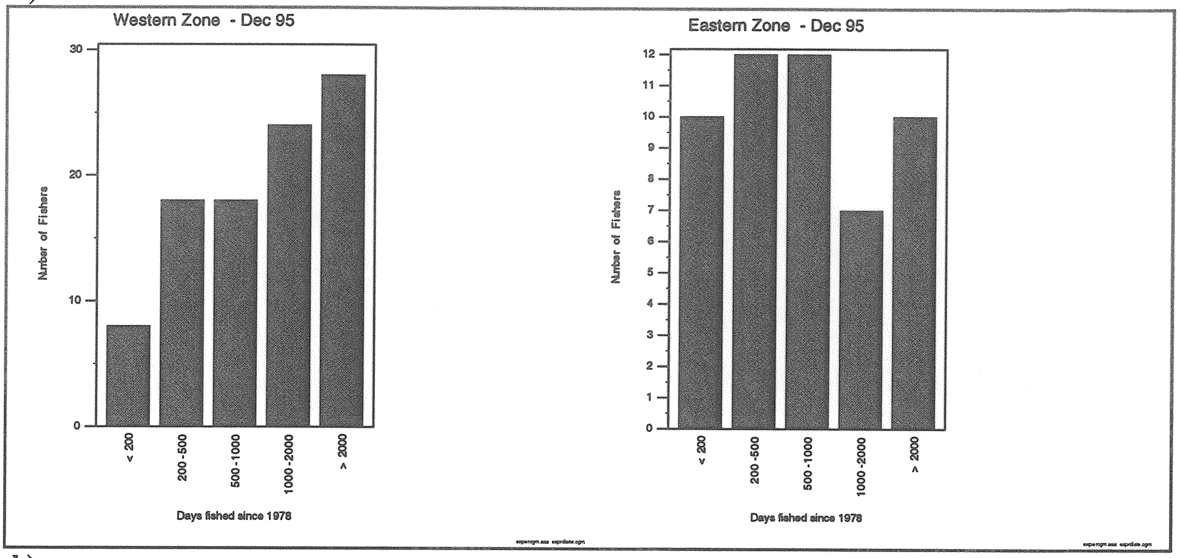
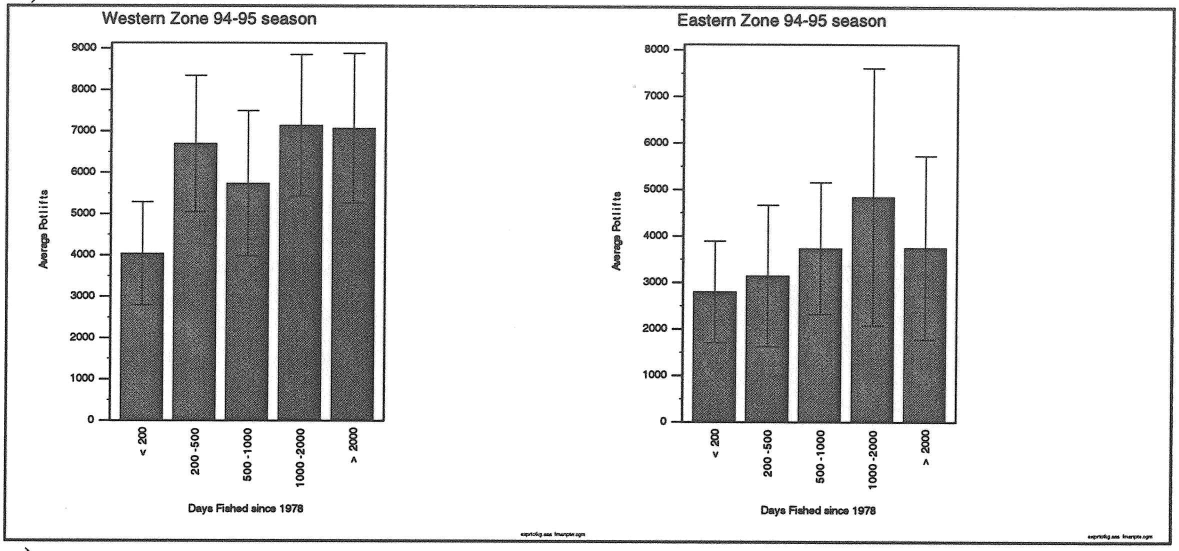


Figure 10 Eastern Zone CPUE (kg/potlift) by month for three time periods, 1980-82, 1985-88 and 1992-94.

a)



b)



c)

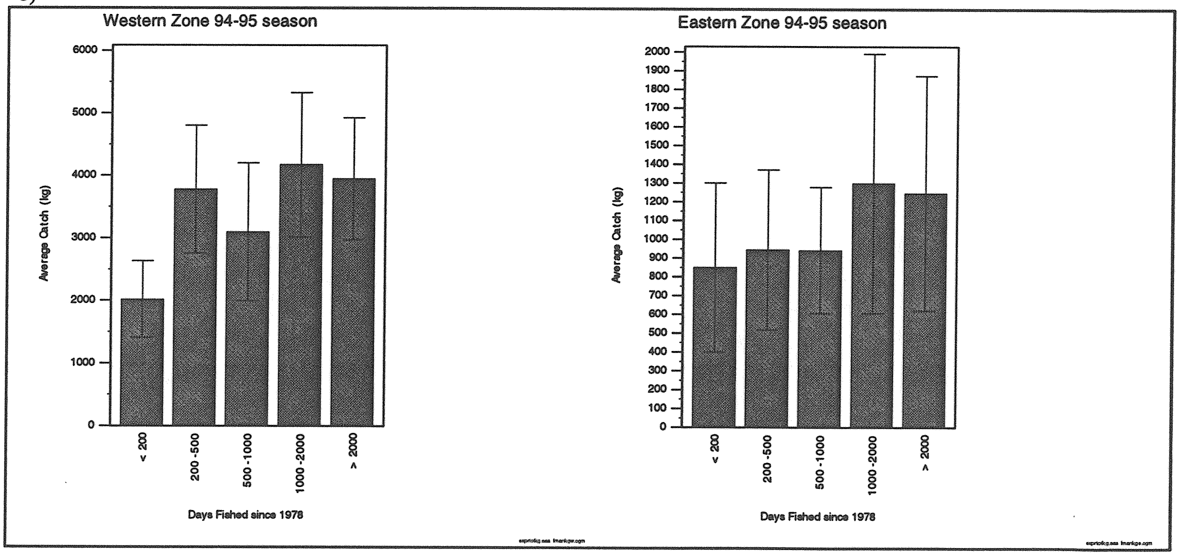
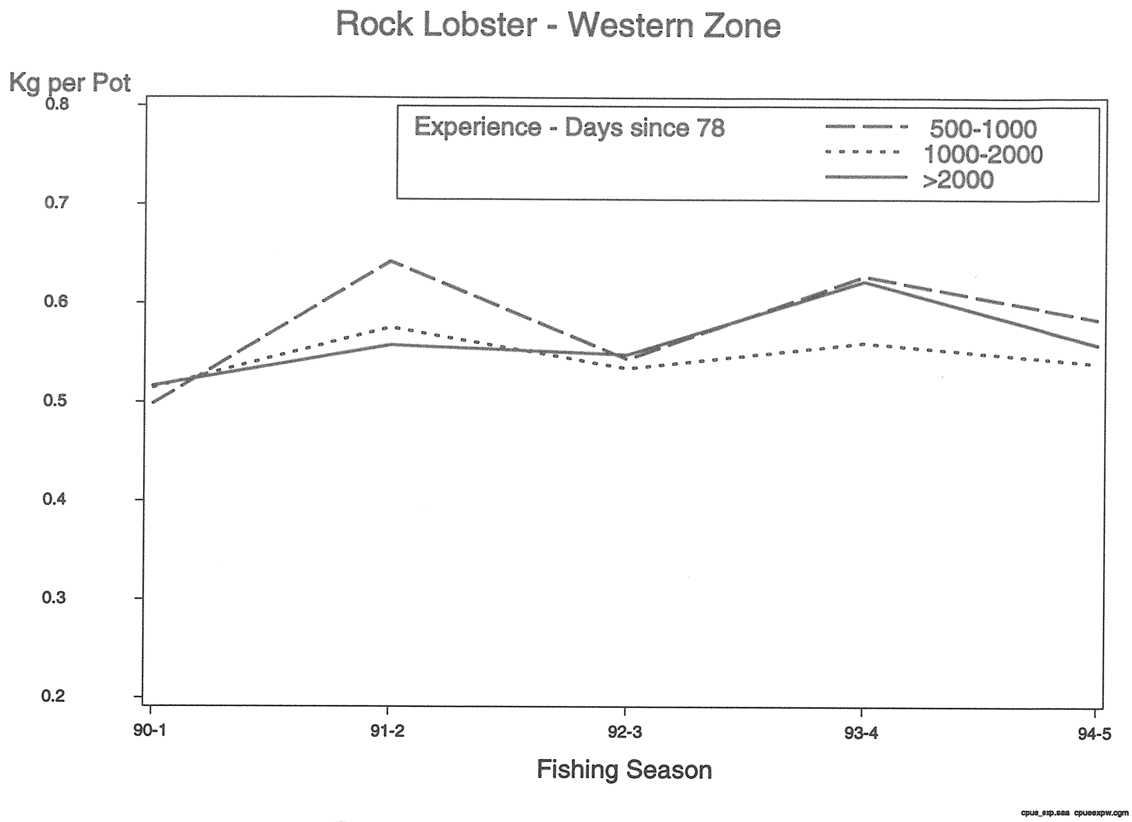


Figure 11 Number of rock lobster fishers, average effort (potlifts), and average catch per fisher (kg) for each zone and experience category during the 1994-95 fishing season.
Error bars represent 95% confidence limits.



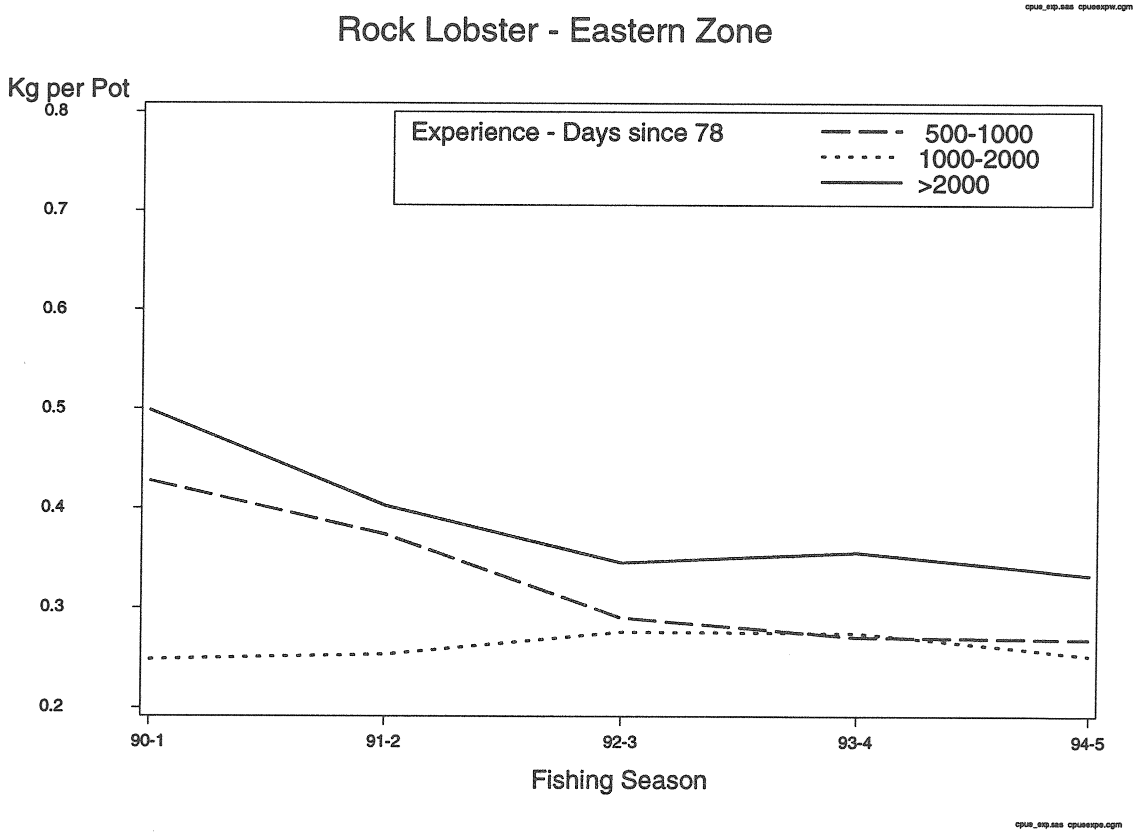


Figure 12 Average catch per potlift by experience category for the past five fishing seasons for the western (top) and eastern (bottom) zones.

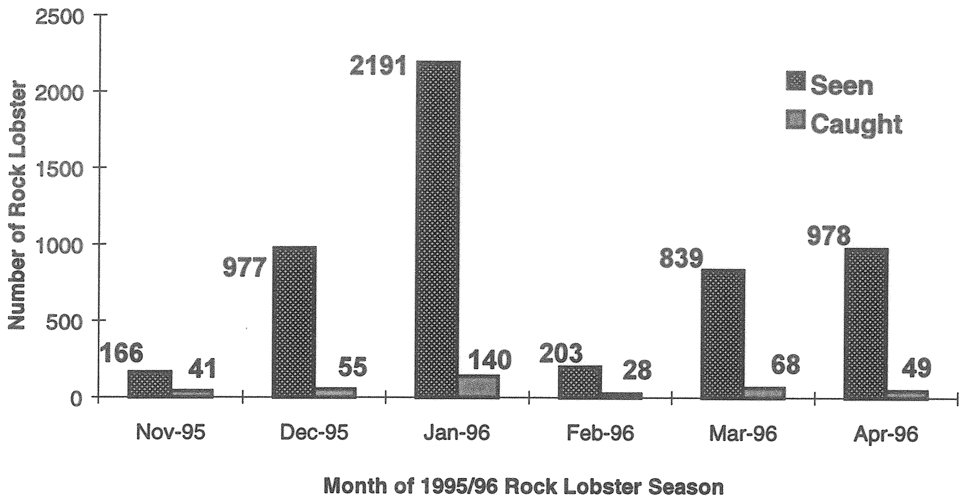


Figure 13 Number of rock lobster seen and caught by recreational divers as reported from the dive shop questionnaire (Nov. '95 - April '96)

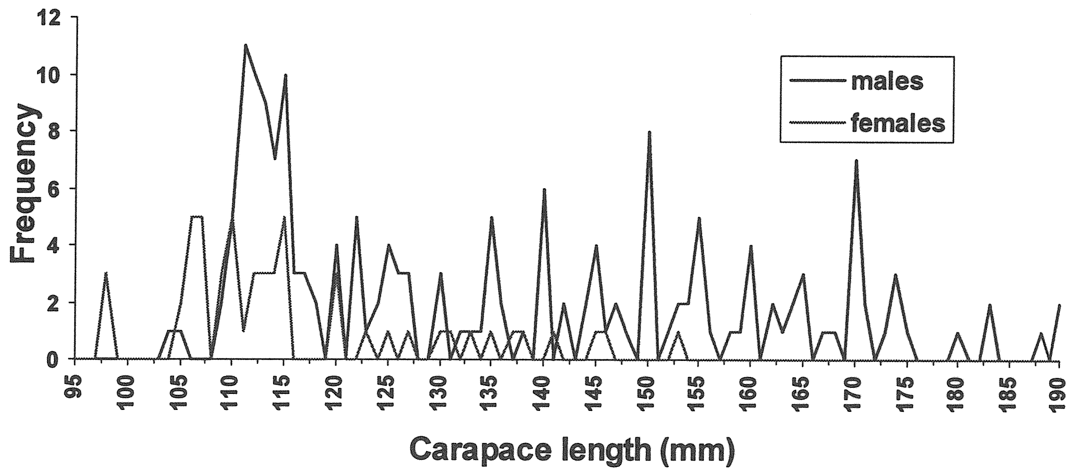


Figure 14 Length frequency distribution of rock lobster caught by recreational divers

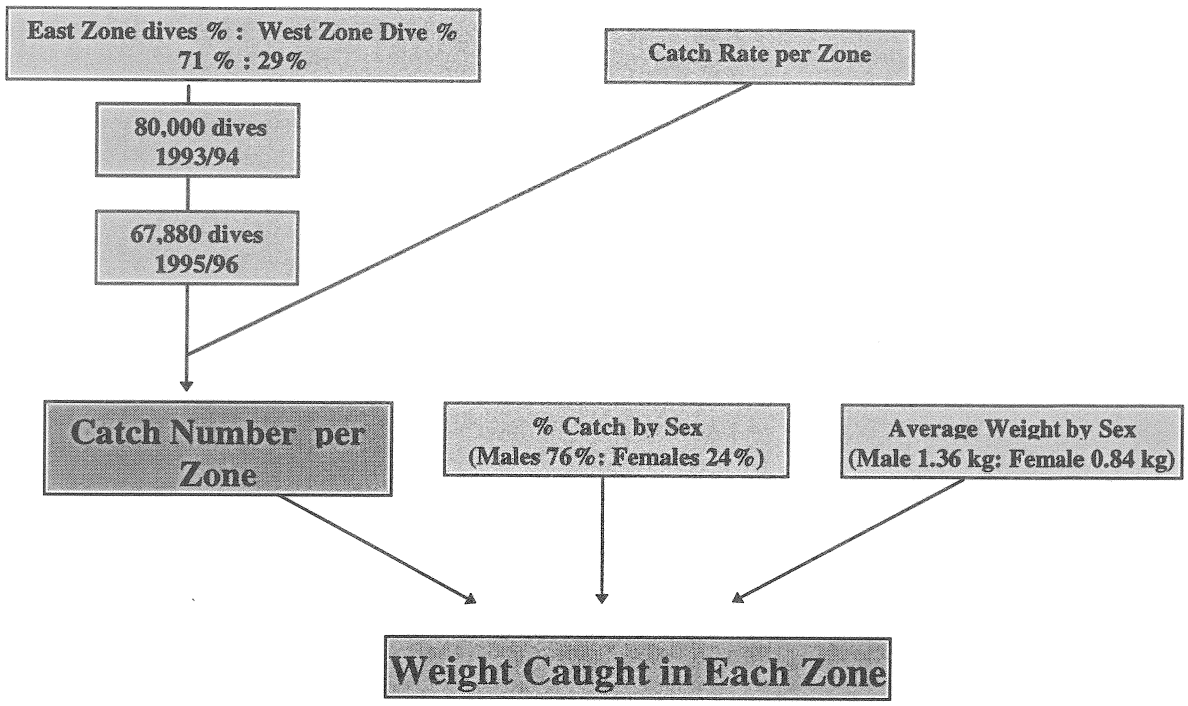


Figure 15 Calculation of the total recreational catch per zone.

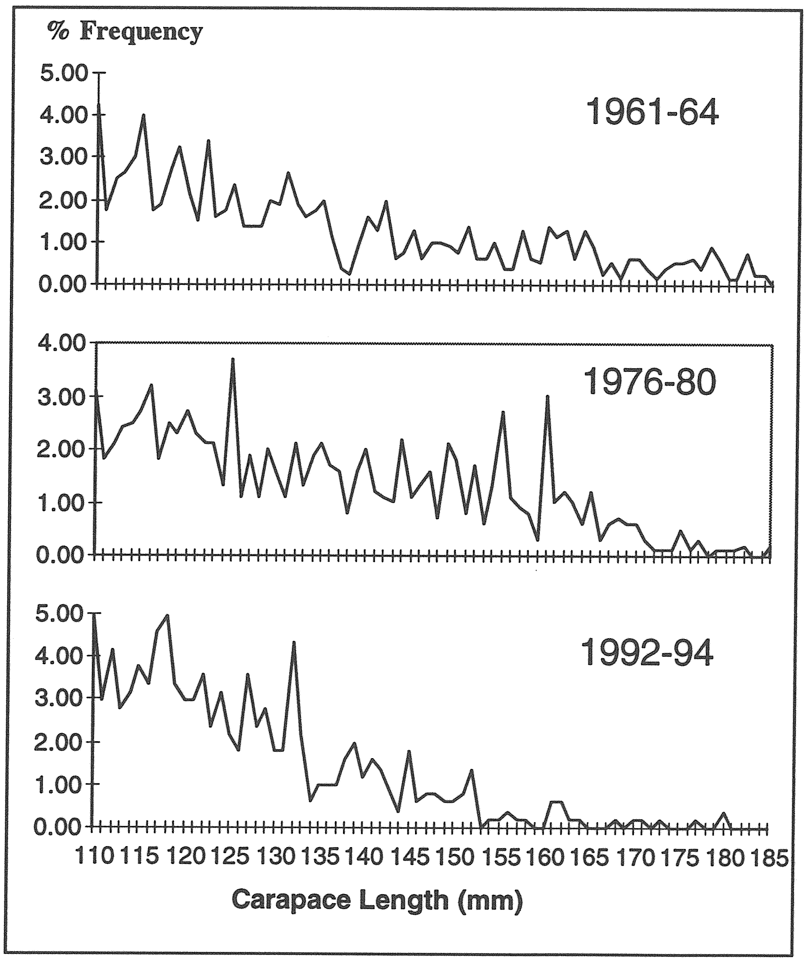


Figure 16 Length frequency for male rock lobsters sampled at Portland during three time periods.

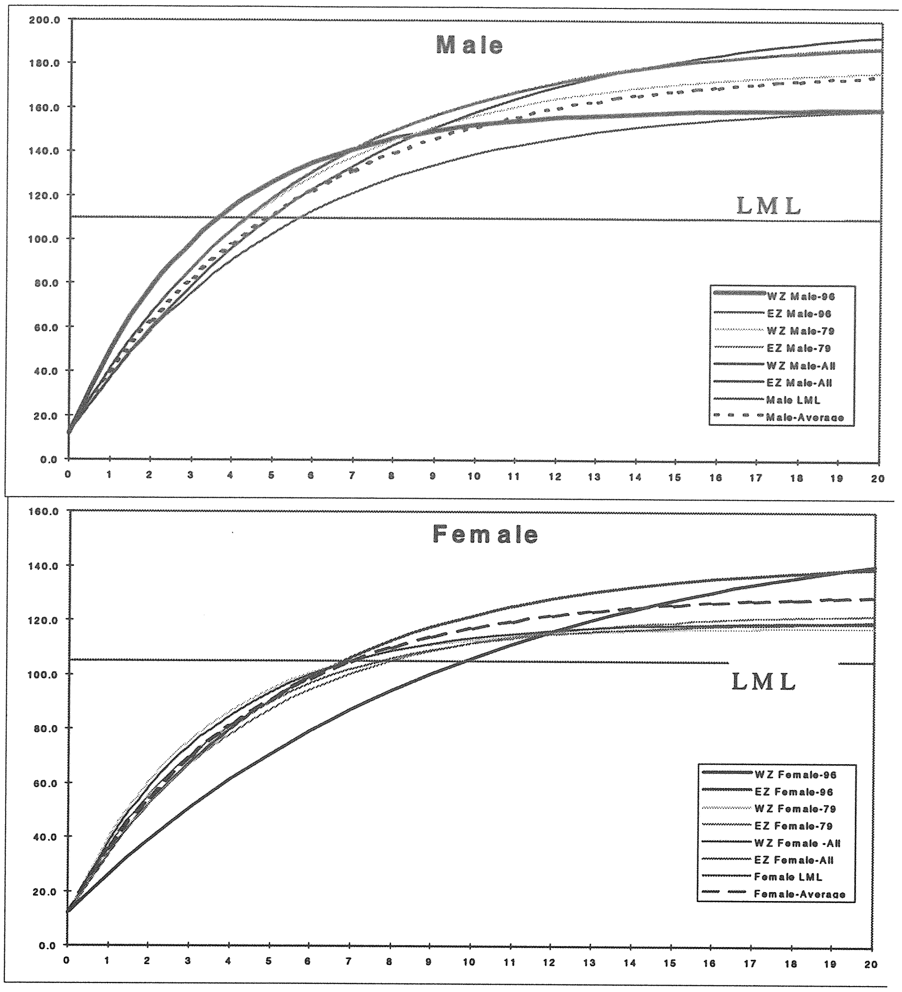


Figure 17 Results of growth estimation from tagging data. Dotted lines represent the average curve used in models.

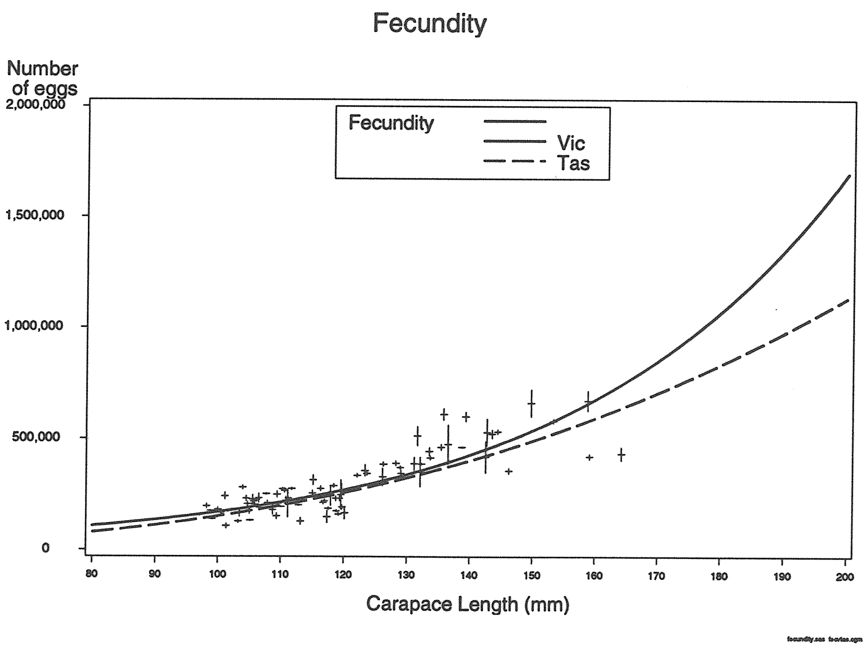


Figure 18 Individual egg counts and the fitted fecundity relationship for Victorian and Tasmanian (Kennedy, 1992) rock lobsters.

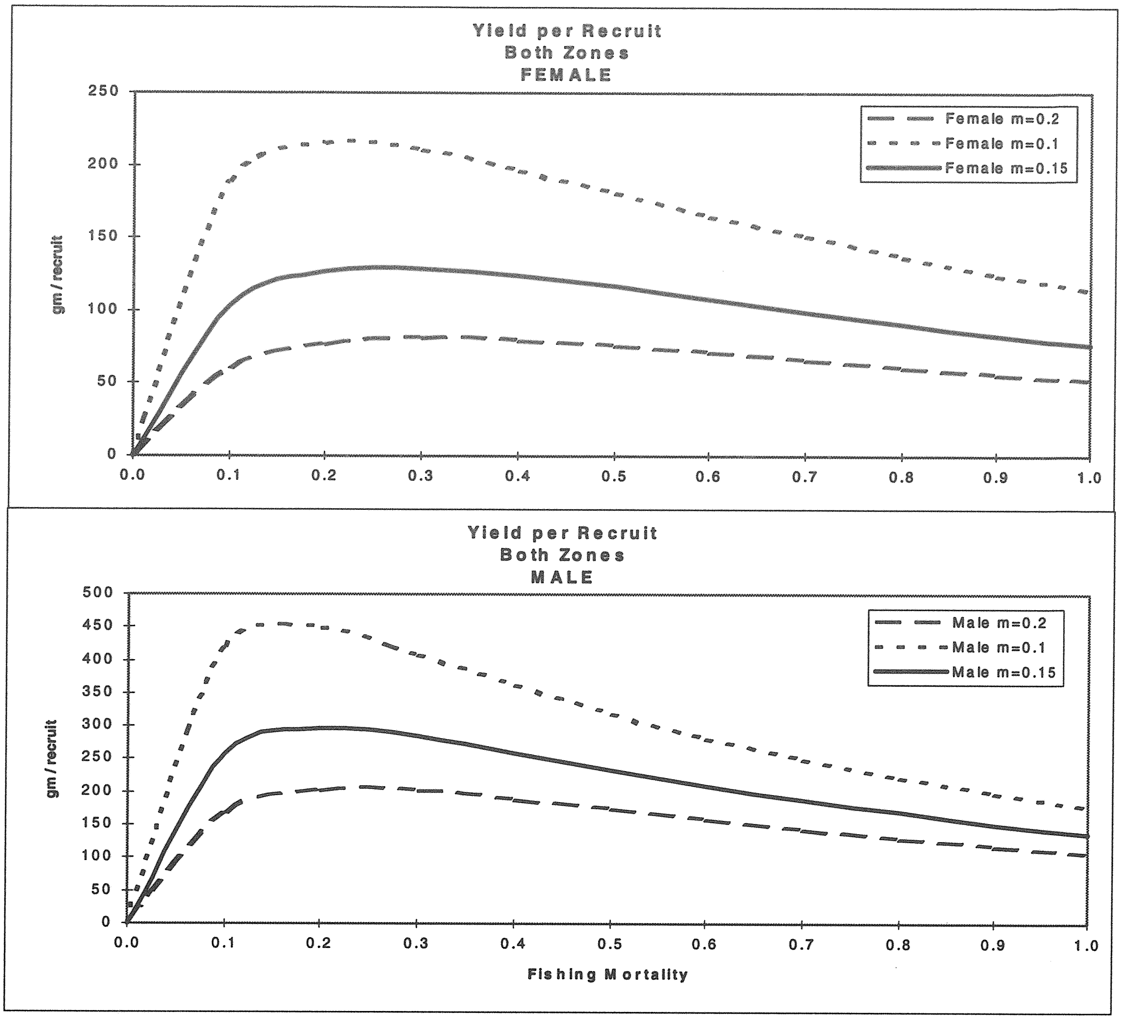


Figure 19 Yield per recruit (gm / recruit) for male and female rock lobsters at various fishing mortalities and natural mortalities (m) for both zones combined. (Males, K= 0.18, L_∞=179, Lc= 110; Females K= 0.22, L_∞=130, Lc= 105)

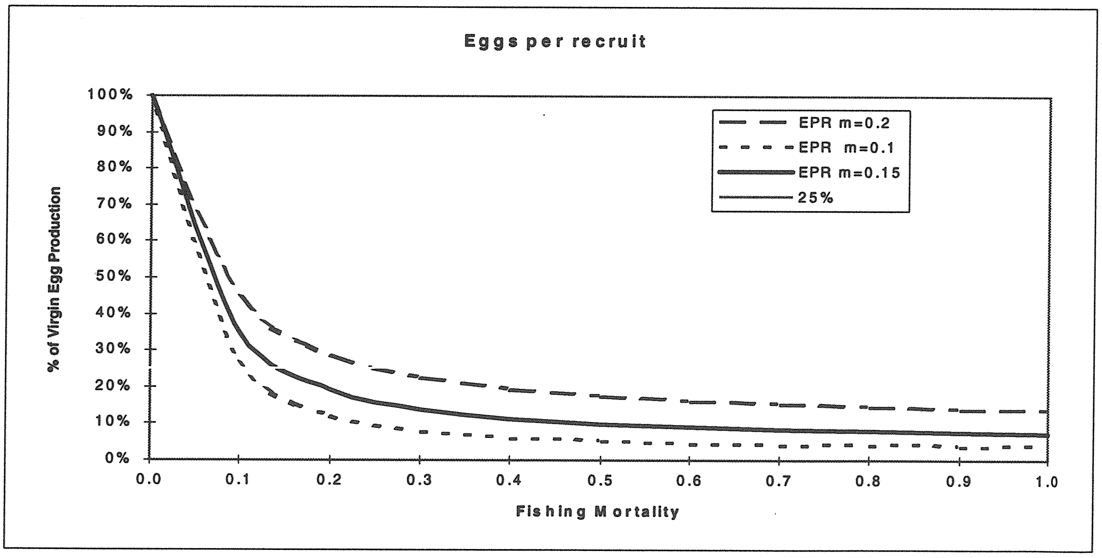


Figure 20 Egg per recruit (gm / recruit) for male and female rock lobsters at various fishing mortalities and natural mortalities (m) for both zones combined. (Males, K= 0.18, L_∞=179, Lc= 110; Females K= 0.22, L_∞=130, Lc= 105)

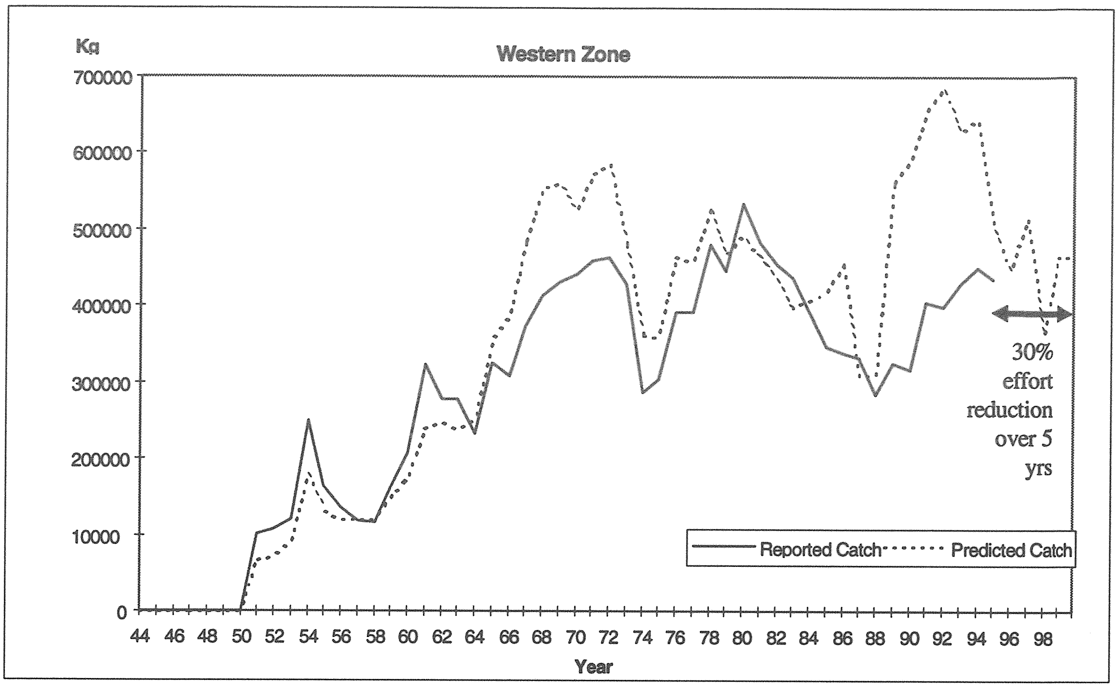


Figure 21 Preliminary, combined sex, age structured model for the Western Zone.

Appendix 1: Format of 1995/96 Dive Shop Questionnaire

ROCK LOBSTER SURVEY

ALL DIVERS ARE ASKED TO COMPLETE THIS FORM BUT ARE REQUESTED NOT TO COMPLETE MORE THAN ONE PER MONTH.

This survey will remain confidential and will be used solely for Rock Lobster research.

1. In the 1994/95 Rock Lobster season (Nov.'94 - Aug.'95) how many dives did you make ? ☐

2. For the 1994/ 95 season how many dives did you make in the following periods ?

	Nov - Jan	Feb - May	Jun - Aug
Weekday			
Weekend or Holiday			

3. Are you a member of a dive and/or fishing club ? Yes ☐ No ☐

   If yes, please list

   ....

   ....

4. How many years have you been diving ? <2 ☐ 2-5 ☐ 5-10 ☐ >10 ☐

5. In the last month how many dives did you make from shore or boat ? Shore ☐ Charter Boat ☐ Private Boat ☐

6. Estimate your average dive time. ☐ minutes

7. When diving do you actively search for Rock Lobster ? Yes ☐ No ☐

   If yes, can you estimate the percentage of your dives that you actively search for Rock Lobster ? ☐ %

8. When diving do you actively search for Abalone ? Yes ☐ No ☐

   If yes, can you estimate the percentage of your dives that you actively search for Abalone ? ☐ %

9. In the last month how many Rock Lobster have you seen and caught ? Seen ☐ Caught ☐

10. In the last month how many Abalone have you taken ? G.lip ☐ B.lip ☐

11. How many years have you been diving for Rock Lobster and/or Abalone ? Lobster ☐ Abalone ☐

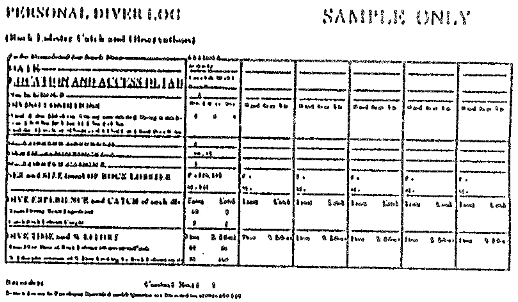
12. Where do you usually dive for Rock Lobster ?

Location	Access method and location	Depth (m)

Thankyou for filling in this questionnaire.

Would you like to become more involved in Rock Lobster research by providing regular catch information ?

If so, please ring 1800-659 528 (toll free) and provide your name, address and phone number. You will receive a log book which can be used to record catch information (format demonstrated in diagram below).



Additional information about the Rock Lobster Assessment Project can be obtained from :

ROCK LOBSTER ASSESSMENT PROJECT
VICTORIAN FISHERIES RESEARCH INSTITUTE
P. O. BOX 114
QUEENSCLIFF 3225

Ph. (052) 580111 Fax. (052) 580270

Appendix 2: Schedule for the 1995/96 dive shop questionnaire.

NOVEMBER	Aqua Blue Scuba Instruction.	Associated Divers	Bay City Scuba	Dive Experience	Southern Cross Divers	Springvale Dive Centre	Dive Experience Dive Centre	Diver Instruction Services (Portsea)	Diving Headquarters	Professional Diving Services	Melbourne Diving Services (Portsea)	Rye Scuba Centre
DECEMBER	Aqua Blue Scuba Instruction.	Dive Experience	Australian Scuba Centre-Dive Line	Paradise Divers	Peninsula Diving Instruction	Schomberg Diving Services	Australian Scuba Centre-Dive Line	Adventure Down Under	Duck Dive Scuba	Melbourne Diving Services (Heidelberg)	Dive Under	Ocean Divers
JANUARY	J & K Cross Diving Services	Bay City Scuba	Australian Scuba Centre-Dive Line	Schomberg Diving Services	Warrnambool Diving Services	Peninsula Diving Instruction	Take 2 Diving	Diver Instruction Services (Doncaster)	Diving Headquarters	Skin, Ski and Surf	Peninsula Diving Instruction (Flinders)	Western Diving
FEBRUARY	Aqua Blue Scuba Instruction.	Southern Cross Divers	Bay City Scuba	Warrnambool Diving Services	Peninsula Diving Instruction	Paradise Divers	Diving Headquarters	Seal Diving Services	Take 2 Diving	Australian Scuba Centre-Dive Line	John's Diveshop	Geelong Dive and Outdoor Centre
MARCH	Dive Under	Southern Cross Divers	Schomberg Diving Services	Dive Experience	Seal Diving Services	Associated Divers	Diver Instruction Services (Portsea)	Ballarat Skin, Ski and Surf	Skin, Ski and Surf	Duck Dive Scuba	John's Diveshop	Interdive
APRIL	Schomberg Diving Services	Paradise Divers	Aqua Blue Scuba Instruction	Associated Divers	Bay City Scuba	Dive Experience	Dive and Dive	Dive Experience Dive Centre	Geelong Dive and Outdoor Centre	Professional Diving Services	Interdive	Rye Scuba Centre
MAY	Southern Cross Divers	Peninsula Diving Instruction	J & K Cross Diving Services	Schomberg Diving Services	Warrnambool Diving Services	Paradise Divers	Dive and Dive	Duck Dive Scuba	Dive Experience Dive Centre	Skin, Ski and Surf	Ocean Divers	Ballarat Skin, Ski and Surf
JUNE	J & K Cross Diving Services	Bay City Scuba	Associated Divers	Springvale Dive Centre	Peninsula Diving Instruction	Southern Cross Divers	Paradise Divers	Wetsports	Ballarat Skin, Ski and Surf	Australian Scuba Centre-Dive Line	Skin and Scuba Sports	Rye Scuba Centre
JULY	J & K Cross Diving Services	Southern Cross Divers	Peninsula Diving Instruction	Dive Experience	Aqua Blue Scuba Instruction.	Warrnambool Diving Services	Geelong Dive & Outdoor	Diver Instruction Services (Portsea)	Melbourne Diving Services (Portsea)	Seal Diving Services	Ocean Divers	Interdive
AUGUST	Dive Experience	Warrnambool Diving Services	Paradise Divers	Schomberg Diving Services	Springvale Dive Centre	Associated Divers	Wetsports	Melbourne Diving Services (Heidelberg)	Diving Headquarters	Deep Down Diver Education	Melbourne Diving Services (Portsea)	Ocean Divers
SEPTEMBER	Paradise Divers	Aqua Blue Scuba Instruction.	Bay City Scuba	Associated Divers	Springvale Dive Centre	Peninsula Diving Instruction	Adventure Down Under	Professional Diving Services	Deep Down Diver Education	Dive Experience Dive Centre	Dive Under	Rye Scuba Centre
OCTOBER	Southern Cross Divers	Aqua Blue Scuba Instruction.	J & K Cross Diving Services	Warrnambool Diving Services	Schomberg Diving Services	Bay City Scuba	Dive Experience Dive Centre	Diving Headquarters	Dive and Dive	Ballarat Skin, Ski and Surf	Skin and Scuba Sports	Western Diving

Appendix C Fisheries and Wildlife Officer interview card (front and back).

ROCK LOBSTER - Recreational Interview (Camp: Dive:)

Date __/__/__ Officer(s): .... Office: ....

Time: __:__ Location: .... Person __ of __ in Group

Diving Conditions: Seas ☐ Wind ☐ Visibility ☐

((1) - Rough / Strong / Poor (2) - Moderate (3) - Flat / Calm / Good)

Diver origin: .... Access: Boat ☐ Shore ☐

Method: SCUBA ☐ Hookah ☐ Dive Club: Yes ☐ No ☐

Hoopnet ☐ Snorkel ☐ AFL holder: Yes ☐ No ☐

Other .... Diver Experience: .... (Yrs)

Dive Purpose ☐ RL No. ☐ No. u/s ☐ Offence ☐

and catch: ☐ Abs No. ☐ No. u/s ☐ ☐

☐ Other .... ☐

Knowledge: RL size ☐ RL closure ☐ Ab size ☐ G/lp closure ☐

Dive Period: ...... (Minutes) Lobster Research Diver: No ☐ Yes ☐

ABALONE cm	B/lip	G/lip	ROCK LOBSTER mm	Male	Female
7					
8					
9					
10			105		
11			106		
12			107		
13			108		
14			109		
15			110		
16			111		
17			112		
18			113		
19			114		
20			115		
shucked					
Total			Total		

Name: ....

Address: ....

....

....

Ph. ( )

Comments ______________________

____

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Appendix D Summary of presentation at the workshop by Rod Treble, Department of Zoology,The University of Melbourne.

The southern rock lobster (*Jasus edwardsii*): Fisheries biology and abundance estimation.

Summary

Various stock assessment methods were applied empirically to assess the stocks of lobsters (*Jasus edwardsii*) in the Apollo Bay area of the Victorian southern rock lobster fishery. Strong sex-, size-, and reproductive state-specific moult timing and reproductive patterns, and high growth was observed for *J. edwardsii* in this area. Tagging showed that most *J. edwardsii* moved very little, although some moved quite significant distances toward the southwest from the Apollo Bay area. There were consistent differences in the size of *J. edwardsii* in catches from different areas. Mean carapace length of legal-size *J. edwardsii* was slightly lower in 1992-95 compared to 1969-76. Size-selectivity curves showed that the current escape-gap size of 60 mm is optimum for the legal minimum lengths in the fishery. The change-in-ratio method was used to estimate abundance and exploitation rates of legal-size *J. edwardsii* at one site. Abundance of legal-size *J. edwardsii* in this area was about 2,000 for females and 2,300 for males in this 6 km^2 area. Observed exploitation rates were 0.80 for females and 0.57 for males (approximately annual rates of exploitation). Bootstrap re-sampling showed that the precision of the female change-in-ratio method estimates was adequate, although too low for males. Significant recruitment of males to the legal-size stock took place during the fishing season, so the exploitation rate for males is considered low. The Leslie method produced inconsistent and sometimes nonsensical estimates of abundance and exploitation because it's assumption of constant catchability was violated. Visual census using SCUBA divers successfully estimated density of *J. edwardsii.*

APPENDIX 7

Objective 4 - "To assess the current status of the fishery for southern rock lobster in Victoria"

Victorian Fisheries Assessment Report - Rock Lobster 1997

SUMMARY

Compiled by Rock Lobster Fishery Assessment Group,

D.K. Hobday and D.C. Smith (eds).

MARINE & FRESHWATER RESOURCES INSTITUTE

FISHERIES RESEARCH & DEVELOPMENT CORPORATION

Project 92 / 104

VICTORIAN FISHERIES ASSESSMENT REPORT

ROCK LOBSTER 1997

SUMMARY

Compiled by the

Rock Lobster Fishery Assessment Group

Edited by

David Hobday and David Smith
Marine and Freshwater Resources Institute

ISBN

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PO Box 114
QUEENSCLIFF VIC 3225

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This series of Fishery Assessment Reports provide general fishery assessments dealt with by the Stock Assessment Groups established by Victorian Fisheries. The documents are not intended as definitive statements but rather as progress reports about ongoing assessments, research and monitoring.

Southern Rock Lobster Fishery Assessment Group
1997 Assessment Report DRAFT Summary

Fisheries Victoria's Management Goals, Objectives and Strategies

Goals

1. Ensure the sustainability of the resource.
2. Ensure the optimum utilisation of the resource.
3. Ensure a prosperous commercial fishery.
4. Provide recreational opportunities and ensure that recreational fishers have an appropriate and equitable allocation of the rock lobster resource.
5. Ensure that management arrangements are effectively implemented, monitored and reviewed.
6. Ensure co-operative and participative management with clients.

Objectives

1. Ensure adequate recruitment from the Victorian component of the rock lobster fishery by allowing the spawning stock to rebuild.
2. Improve the yield from the fishery, by reducing growth overfishing.
3. Improve the economic viability of operators in the fishery by reducing fleet fishing costs, encouraging the rationalisation of the number of boats in the fishery and maximising the value of the catch.
4. Rebuild the inshore rock lobster stocks to assist with conservation of the resource and provide improved recreational opportunities in the long term.
5. Ensure that management arrangements are cost effective and focused on the resource.
6. Ensure that management arrangements for the fishery are enforceable, and that an appropriate enforcement strategy is developed on an annual basis.
7. Provide education and extension services to commercial and recreational rock lobster fishers.
8. Implement monitoring programs for regular assessment.
9. Establish appropriate mechanisms to ensure effective consultation and communication with commercial and recreational fishers, and other groups.

Strategies

1. Maintain a spawning biomass in all major areas of the fishery in Victoria that will achieve a level of egg production that is at least 25% of the egg production from the unexploited stock.
2. Reduce fishing effort in the fishery. Previous stock assessments had indicated that yield could be maximised with effort reductions of 25% in the Western Zone and 50% in the Eastern Zone.
3. Reduce recreational catch, and the commercial catch from inshore areas.
4. Implement the research and monitoring strategy.
5. Implement the education and extension strategy.
6. Develop and implement an enforcement strategy for the fishery each year.
7. Review annually the state of the resource and management of the fishery with the commercial and recreational fishers.

Note: target effort reductions may change as a result of the current assessment.

Stock Structure and Life History

The southern rock lobster (*Jasus edwardsii*) is found in the southern waters from the south-west Western Australian coast to southern New South Wales, including the waters around Tasmania and New Zealand. An overlap occurs in the western and eastern boundaries of the Australian distribution with the western rock lobster (*Panulirus cygnus*) and the eastern rock lobster (*Jasus verreauxi*). The relationships between southern rock lobsters found off south-eastern Australia are unknown.

Female southern rock lobster moult around mid May to mid June prior to mating and spawning. Males moult 6 months out of phase from the females, around October - November. Moult frequency of the southern rock lobster decreases with age from 5 per year for post puerulus to 1 per year for large. The large adults also appear to moult more synchronously, while the smaller southern rock lobster may moult later in the season. In favourable conditions some adult populations may grow rapidly, requiring 2 yearly.

The age of maturity varies geographically. For example, female southern rock lobster reach sexual maturity (50% mature) at 90-95 mm carapace length (CL) in south-east SA, while western SA the sexual age of maturity (50% mature) is 112 - 114 mm CL. The sexual age of maturity for females is believed to be 95 mm CL (50% mature) in western Victoria. The male deposits a spermatophore on the ventral side of the females. Shortly after mating the female exudes, fertilises and then incubates the eggs on specially adapted swimmerets under the tail for 3 to 4 months. Females are generally in berry from June to November depending on geographic location and water temperature. The reproductive potential of females increases substantially with size with as many as 600,000 eggs being carried by larger females.

Within hours of hatching, the naupliosoma larvae moult into phyllosoma in which form they undergo numerous moult stages. During this period larvae can travel large distances, with little control of movement apart from a diurnal migration (shallower at night and deeper during the day). Larval rock lobster in New Zealand can spend 12 to 24 months offshore. Larval rock lobster have been found in large expanses of water such as the Tasman Sea and are subject to prevailing current flows such as the west to east current across southern Australia. When the phyllosoma moult into the puerulus stage, they adopt the typical rock lobster appearance representing the longer benthic life stage. After settling in water generally less than 40 metres depth, puerulus pigmentation and hardening adjustments see four post-puerulus moult stages before the juvenile stage.

The Fishery

Main Features

	Western Zone	Eastern Zone	Total
Catch (96/97)	403 tonnes	61 tonnes	464 tonnes
Value (96/97)	$12.9 M	$2.1 M	$15.0 M
Fleet	96 Licences	76 Licences	172 Licences
By-catch	Nil	Nil	
Discards	Lobsters killed by octopus	Lobsters killed by octopus	

Current Situation

Currently about 5,000 tonnes of southern rock lobster valued at $140 million is landed in south-eastern Australia. The Victorian component of this catch in 1996/97 was 464 tonnes valued at $15.0 million.

Improvement in landed prices for southern rock lobster in recent years has resulted in higher levels of lobster fishing activity in periods of lower catch rates such as the late-autumn and winter months. Post harvest processing and marketing considerably enhance the value of the fishery. Approximately 50% of the rock lobster catch is exported to Japan, Taiwan and the USA. The remainder is sold on interstate and local markets.

Industry Perspectives

There was a general concern from the commercial sector regarding the state of the stocks of southern rock lobster in Victoria. However, Eastern Zone industry participants at the Fishery Assessment Workshop, believe that the conclusions of the 1996 assessment exaggerated the severity of the decline. They were particularly concerned with the figures used for technological change (ie increased fishing power due to improved equipment). Industry believes that in the East the nature of the fishing grounds is such that, although more sophisticated electronic equipment is used, it has had little impact on fishing practices except, perhaps for new entrants to the fishery. The extremely low current egg production estimated in 1996 was also of concern and didn't accord with their observations of the number and size of spawning females.

In the Western Zone, Industry accepts that there has been technology "creep" but argue that the upper limit (3%) used in the assessments was to high and that 2% per year may be closer to the true situation. The quality of catch and effort data in the South Australia border area was raised and their potential impact on the assessment models need to be examined. Fishermen from both zones criticised the compounding nature of an annual percentage increase and suggested that occasional surveys are conducted of industry to better document technological change.

There were suggestions that the 1996/97 season was unusual with a lower proportion of berried females in catches. The question of environmental variability on lobster abundance/availability needed to be addressed.

Previous Assessments

Yield-per-recruit (YPR) analyses and preliminary surplus production modelling were conducted in the 1970s,. Tagging experiments were conducted between 1976-79 were analysed to provide growth and mortality parameters. Preliminary YPR analyses and surplus production modelling were conducted by the Rock Lobster Fishery Assessment Group in 1994. YPR analyses showed that there would be little increase in yield from increased effort. Surplus production models indicated that the current levels of effort were greater than that necessary to achieve the maximum catch. A more exhaustive assessment was conducted in 1995 addressing concerns of industry that catch rates were artificially depressed because of increased winter effort when catch rates are lower on average, and inclusion of giant crab effort ie. >100 m in the assessment.

The 1996 assessment refined the 1995 assessment including updating the assessment with data from the 1994/5 fishing season; using results of recent research to provide Victorian specific growth, fecundity and fishing mortality estimates as inputs to the assessment models; providing, for the first time, an estimate of the recreational SCUBA diver catch in each management zone; and investigating the relationship between fisher experience and catch rates. Major results were:

- The recreational SCUBA catch for the 1995/96 season to the end of April was estimated to be 7.1 tonnes (10% of commercial catch) in the Eastern Zone, and 9.2 tonnes (2% of commercial catch) in the Western Zone. These estimates were agreed to be minimum values as they did not include hookah divers and illegal activities.
- Results of the biomass dynamics (production) assessment models in the Western Zone estimated that the reduction in effort needed to maximise yield was estimated at 10%, 29% and 37% with corresponding increases in fishing power of 0, 1.5 and 3% per year, with no allowance for recreational catch. These estimates were slightly higher than estimated in the 1995 assessment.
- The Eastern Zone production model estimated maximum yield with effort reductions of 36, 45 and 50% using effort standardised for winter fishing, a 7 tonne recreational catch and increases in fishing power of 0, 1.5 and 3% per year respectively. Effort reductions of 39, 45 and 51% would be required to maximise yield if a recreational catch of 14 tonnes is assumed.
- Egg per recruit analysis estimated that the current Victorian egg production is between 6 and 19% of the virgin, unfished stock (depending on the level of natural and fishing mortalities used). This estimate is less than the management target of 25% of the virgin egg production.
- Preliminary age structured modelling using Western Zone data showed that a reduction in effort by 30% over 5 years, would initially reduce catch by about 20%, but would stabilise at around 400 tonnes.

Economic surveys of the fishery have been conducted in the 1960s, 70s, 80s and in 1996. The latter showed that economic performance was unsatisfactory, especially in the Eastern Zone, and that a considerable proportion of fishers were making negative returns to capital.

1997 Assessment

Recent Developments

This assessment uses results from the present Victorian study including growth, fecundity, size at maturity and fishing mortality estimates, by zone. Commercial catch and effort statistics were updated to include 1995/96 and 1996/97 data. Data were available for the recreational SCUBA catch during 1995/96. A fishery assessment workshop was held at MAFRI, Queenscliff on 29-31 October 1997.

Data and Methods

Commercial catch and effort data by and within zone for the period 1978/79 to 1996/97 were examined. Catch and effort data from the South Australian border area and the possible effects of misreporting on model outputs were evaluated.

The recreational SCUBA catch for the 1995/96 season was estimated using data from a dive shop survey, DNRE's Fisheries and Wildlife Officer (FWO) interview cards. The dive shop questionnaire was conducted as a random survey of SCUBA airfill outlets in Victoria. The information collected was used to represent the recreational SCUBA activity throughout the state. The interview cards (collected by the Fisheries and Wildlife Officers) were obtained from several Department of Natural Resources and Environment (DNRE) coastal regions. These interviews were site specific and targeted divers involved in the harvest of rock lobsters or abalone. These data provided basic biological information including sex and length.

Fecundity by length and the size at 50% maturity in each zone were estimated. Results of MAFRI and Industry tagging were used to assess movement and determine growth rates.

Larval settlement was assessed by monthly sampling of puerulus from collectors at a number of sites.

Length frequency distributions for each zone were converted into age frequencies using the appropriate growth curves. Total mortality was estimated via catch curves and fishing mortality calculated from $F = Z - M$. These estimates together with growth parameters were used to assess the current level of egg production, assuming constant or stable recruitment.

Maximum yield was estimated using Gulland and Fox surplus production models.

Results

The Western Zone catch showed a small decline to 402 tonnes during the 1996-7 fishing season, down from 419 tonnes during 1995-6. The number of potlifts increased from 749 thousand in 1995/96 to 778 thousand in 1996/97. Although there was a small decline in catch rate from 0.56 to 0.52 kg/potlift over the two fishing seasons, catch rates appear to have stabilised. Catch rates west of Port Fairy were lower than those to the east between Port Fairy and Apollo Bay.

Catch and effort data for the area adjacent to the South Australian border was examined comparing single (Victorian) and dual (South Australian /Victorian) licence holders. The results showed that dual licence catch and effort was much lower than for single licence holders, and that their catch rates although slightly higher, were still within the range observed throughout the zone.

In the Eastern Zone, the catch increased from 57 tonnes in 1995/96 to 61 tonnes in 1996/97 with similar effort in both seasons, resulting in an increased catch rate from 0.26 to 0.28 kg/potlift over the two fishing seasons. Catch rates between Apollo Bay and Queenscliff were generally lower than those from Queenscliff and Cape Liptrap, with those east of Cape Liptrap the highest.

The majority of the recreational diving effort (45%) occurred between Torquay and Inverloch in the Eastern Zone while 32% of dives were reported between Port Fairy and Apollo Bay.

The results of the 1995/96 and 1996/97 recreational dive survey are as follows:

Zone	Year	Mean Catch rate (no per dive)	No. of dives for 1995/96	Estimated no of lobster caught	Estimated female catch weight (Kg)	Estimated male catch weight (Kg)	Total catch weight (Kg)
Eastern	95/96	0.20	46,988	9,398	1,895	9,714	11,609
	96/97	0.21					
Western	95/96	0.39	20,137	7,853	1,583	8,117	9,700
	96/97	0.39					

These estimates should be seen as a minimum because the dive survey estimates did not include recreational catches by hookah, snorkel and hoop net.

The 1995/96 recreational SCUBA catch from the dive shop survey was compared with the commercial rock lobster catch during the same year:

Zone	Commercial catch from all depths (kg)	Commercial catch (95/6) from < 20 m (kg)	Recreational Catch (kg)	% of total commercial catch from all depths	% of commercial catch from <20 m
Eastern	56,029	25,084	11,609	20.7%	46.3%
Western	417,061	62,699	9,700	2.3%	15.5%
Both Zones	473,090	87,783	18,241	3.9%	20.8%

The recreational SCUBA catch was 21% and 2.3% of the commercial catch in the Eastern and Western Zones respectively. However it was 46% and 21% of the commercial catch in water less than 20 m.

11,000 lobsters have been tagged with 1,888 recaptures (17%). Recapture rates were highest in the Western Zone (21-24%) compared to the Eastern Zone (6-10%). The majority of recaptures occurred within 10 km of release. Movements in the Eastern Zone were larger and more directional than in the Western Zone.

Puerulus settlement at Apollo Bay Harbour was highest during July - September however the settlement rates during the past two years were lower than that observed in 1995. Settlement at other sites continued to be lower and more variable than at Apollo Bay Harbour.

A fecundity - carapace length relationship was determined for use in egg per recruit modelling. Female lobsters reached maturity (50% mature) at 89.7mm and 112.5mm in the Western and Eastern Zones respectively.

Length frequency distributions for female and male lobsters landed in each zone were distinctly different. In 1996/97, the modal length of females in the Western Zone was 105 mm with the recorded maximum length at 130 mm. Males ranged in length from 110 mm to 165 mm with the mode at 115 mm. In the Eastern Zone, females ranged in length from 105 mm to 160 mm with a mode at 115 mm and a second mode at 130 mm. Males ranged in length from 105 mm to 195 mm with the mode at 110-115 mm but a greater proportion of lobsters were in the 130-160 mm size classes compared to the Western Zone.

Fishing mortality, assuming natural mortality at 0.1, was estimated at 0.1-0.2 in the Eastern Zone for both sexes, and 0.3 and 0.4-0.5 for males and females respectively in the Western Zone. Current egg production, expressed as a percentage of unfished egg production was 17-32% in the Eastern Zone and 14% in the Western Zone.

The Gulland production model was fitted to catch and effort data for the period 1964/65 to 1996/97. The Fox model, however, could only be fitted with the addition of data from 1951/52 to 1963/64. As there are considerable uncertainties about the quality of this earlier data results from the Fox model are not presented.

The maximum yield and corresponding effort was estimated using different effort weightings (for technological advances) agreed to by Workshop participants:

- Eastern Zone 0% and 1.0%
- Western Zone 0.5%, 1.25% and 2.0%

In addition the model for each zone was also run using data adjusted for recreational catches:

- Eastern Zone 0, 11.6 and 20 tonnes
- Western Zone 0, 9.7 and 20 tonnes

Note: 20 tonnes was the best estimate of the total recreational catch including catches by hookah, snorkel and hoop net.

Results for the Gulland model are shown below. Reductions in effort (pot lifts) needed to meet E(MSY) were calculated. Because recreational catches and effort (in summer equivalent pot lifts) were included in the estimation, the reductions attributable to the commercial sector were also calculated.

- Eastern Zone production (Gulland) model results

Results	1964-96/7 Data					Effort reductions	
Adjusted R sq	Effort Weight%	Rec Tonnes	MSY Tonnes	seE(MSY)	seE(1996/7)	Total	Comm
0.486138	0	0	109	144	196	26.4%	26.4%
0.62	1	0	113	150	233	35.6%	35.6%
0.626326	0	11.6	115	154	235	34.2%	28.6%
0.698015	1	11.6	119	167	279	40.2%	33.6%
0.681234	0	20	119	165	262	37.0%	34.1%
0.724203	1	20	124	181	312	42.0%	31.4%

Western Zone production (Gulland) model results

Results	1964-96/7 Data					% Reduction	
Adjusted R sq	Effort Weight%	Rec Tonnes	MSY Tonnes	seE(MSY)	seE(1996/7)	Total	Comm
0.636758	1	0.00001	410	586	754	22.2%	22.2%
0.66	1.25	0	412	592	784	24.5%	24.5%
0.700975	2	0	418	613	874	29.9%	29.9%
0.644948	1	9.7	415	597	772	22.6%	22.1%
0.663467	1.25	9.7	417	603	803	24.9%	24.3%
0.70521	2	9.7	423	626	895	30.1%	29.4%
0.652001	1	20	420	610	792	23.0%	21.9%
0.669467	1.25	20	422	616	823	25.2%	24.0%
0.70871	2	20	428	640	918	30.3%	28.9%

Uncertainties

There are distinct differences between the two zones both in the performance of the fishery and also in life history parameters. Greater spatial resolution is required to enhance assessment models. There is considerable uncertainty about natural mortality and the current levels of fishing mortality in both zones. Fishing mortality is likely to vary considerably spatially.

The models are sensitive to the effort statistics used, and the rate at which fishing power has increased in recent years is difficult to quantify. It is also not known whether excessive commercial and recreational effort, particularly in the Eastern Zone and inshore Western Zone, is causing competition between gear and/or between the recreational and commercial fisheries.

Management Implications

The current results provide a slightly more optimistic picture of the fishery, particularly in the Eastern Zone, than those in previous reports. The differences are primarily due to refined analyses with life history parameters estimated for each zone and to the lower values applied to fishing effort to weight the effort statistics for technological improvements. In previous assessments the values used were based on the Western Australia fishery. Advice from industry is that the values used previously are to high and that there are significant difference between zones. An additional refinement is the apportioning of effort reduction to each sector.

The Western Zone catch showed a small decline to 402 tonnes during the 1996-7 fishing season, down from 419 tonnes during 1995-6. The number of potlifts increased from 749 thousand in 95-6 to 778 thousand in 1996-7. Although there was a small decline in catch rate from 0.56 to 0.52 kg/potlift over the two fishing seasons, catch rates appear to have stabilised.. The reductions in commercial fishing effort necessary to maximise yield ranged from 22 to 30% depending on the size of the recreational catch and the effort weighting used in the models. It appears therefore, that the management target of a 25% reduction in effort remains appropriate.

In the Eastern Zone, the catch increased from 57 tonnes in 1995-6 to 61 tonnes in 1996-7 with similar effort in both seasons resulting in an increased catch rate from 0.26 to 0.28 kg/potlift over the two fishing seasons. CPUE appears to have stabilised in the Eastern Zone. The revised estimates for the percentage reduction in effort to achieve maximum catch of 26 to 36% are considerably lower than the 50% management target. Therefore, it is suggested that the current management target in the Eastern Zone be reconsidered.

The current level of egg production, assuming constant or stable recruitment, was estimated separately for each zone for the first time. In the Eastern Zone it was estimated at 17-32% and in the Western Zone at 14%. Estimates are sensitive to the estimated current fishing mortality. In the 1996 assessment, egg production was estimated at 6-19% across both zones assuming a fishing mortality of 0.4. The differences reflect the better estimates of fishing mortality used in 1997. The lower overall fishing mortalities (0.1-0.2) estimated in the Eastern Zone are more consistent with the greater proportion of large lobsters seen in catches.

The recreational fishery, particularly in the Eastern Zone, contributes a significant proportion of the total catch from inshore waters. Future assessment of the recreational fishery is complicated by the unlimited and unregistered access of divers in the fishery. Currently the only requirement of a recreational rock lobster fisher is an Amateur Fishing License (AFL), which can be obtained at a large range of retail outlets. In 1993-94 an estimated 100,000 licenses were sold, with no detail of where or to whom. The number of rock lobster amateur fishers could be estimated generously at around 10,000. Any attempt to obtain recreational catch information from such a small range people in the total Victorian population would be difficult. A statewide phone poll or the introduction of a rock lobster endorsement on the AFL are two of the most promising options that may provide the data required.

The relationships of southern rock lobsters in Victoria, Tasmania and South Australia are unknown as in the relative contribution of each fishery to recruitment.

Research Needs

- More detailed biological information and estimates of population parameters across Victoria are necessary to reduce uncertainty in the assessments. Expansion of current on-board measuring and tag and release by MAFRI and commercial fishers is of high priority to provide data for future modelling. A joint MAFRI/Industry length measuring and tagging program should be developed.
- Monitoring of puerulus and pre-recruits as an index of recruitment variability should be continued.
- The stock structure of southern rock lobsters is unknown although they are currently managed as if the resources of each state were separate stocks. The implications of this are for recruitment; particularly whether the South Australian and Tasmanian fisheries could impact on recruitment to Victoria.
- A high priority for research is to continue monitoring of the recreational catch.
- There is a need for a more sophisticated analysis of catch and effort data to provide estimates of changes in fleet dynamics, including fishing power and gear competition. The spatial changes in the fishery should be analysed using GIS methods.
- Periodic surveys of industry to better document technological change should be implemented.
- Almost nothing is known of the environmental effects on availability and/or abundance, and recruitment of southern rock lobsters.