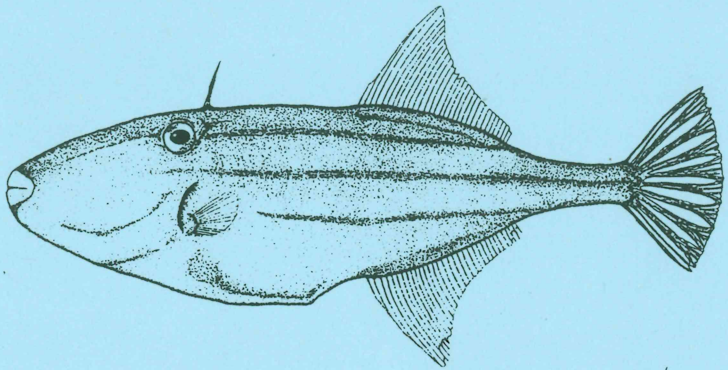
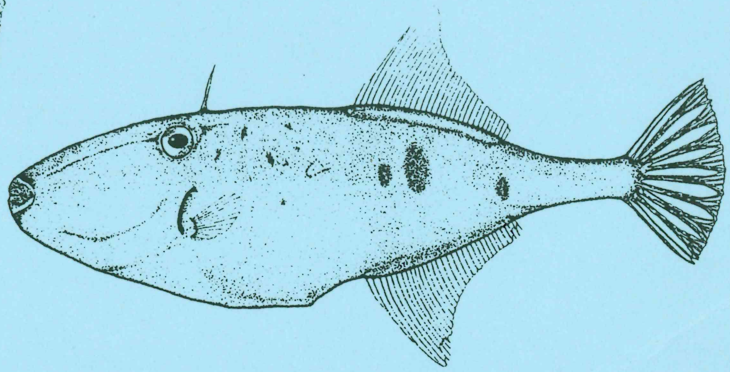
FISHERIES BIOLOGY OF THE OCEAN JACKET (MONACANTHIDAE: *Nelusetta ayraudi*) IN THE EASTERN WATERS OF THE GREAT AUSTRALIAN BIGHT, SOUTH AUSTRALIA





Final Report

to the Fishing Industry Research and Development Council

Grant Number DFS01Z

by

Rodney P. Grove-Jones BSc (Hons)
and
Andrew F. Burnell BSc

SOUTH AUSTRALIAN DEPARTMENT OF FISHERIES

- 1991 -

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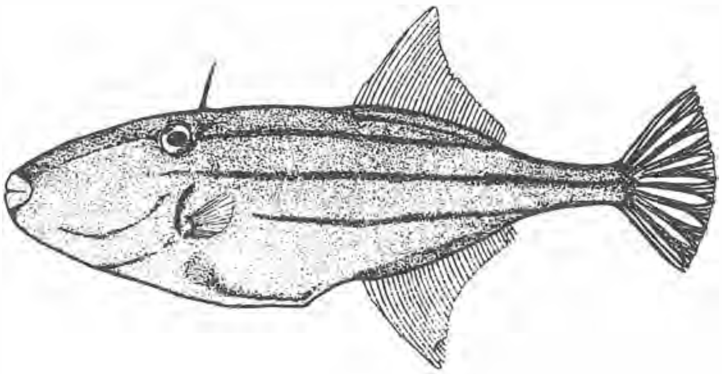

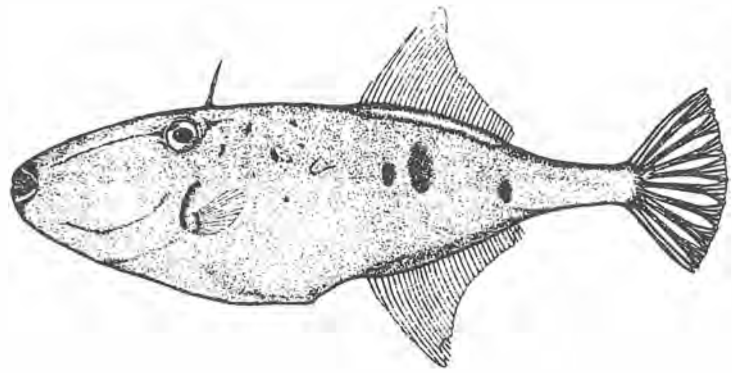

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1. INTRODUCTION

The South Australian commercial fishery for ocean jackets commenced during 1984/85 following the provision of regular refrigerated road transport between the west coast of Eyre Peninsula and markets in Sydney. Catches of approximately 31 tonnes whole weight in 1984/85 rose to 119 tonnes in 1985/86 and reached 916 tonnes by 1989/90.

In view of this rapid increase in catches, the Department of Fisheries, as manager of the resource, moved to gather as much information relevant to its management as possible, while also introducing measures to prevent catches exceeding the long term sustainable yield. A biological research project was initiated and funding obtained from the Fishing Industry Research and Development Council (FIRDC). Its four major objectives were to;

1. determine the life history parameters (reproductive biology, feeding biology, growth and population structure) of the species;

2. determine the catch composition by length, age and reproductive status;

3. analyse catch rates and develop suitable log books; and

4. experimentally evaluate fish trap designs.

This report describes the management of the fishery and the principal findings of that investigation. The project was expanded to include studies of juvenile populations, adult mortality rates and migration patterns. However, feeding biology was not investigated because it had been considered in a previous study by Lindholm (1984). Studies on fish trap designs were summarised in the Department of Fisheries magazine Safish volume 15(1) and are reproduced in appendix 1.

The report is divided into four main sections. The Background and Methods section provides an introduction to the subject matter and describes the way in which the research was conducted. The findings of that research are presented in the main body of the report, the Results and Discussion. This section begins by describing the management regulations that have been introduced since 1984/85. This is followed by a description of the commercial catch using information provided by professional fishers and the results of research surveys. The remainder of the section describes the results of research on the biology of the species as they relate to its exploitation. Management issues with a biological basis are considered in the conclusions and recommendations.

2. BACKGROUND AND METHODS

2.1 Commercial Catch Assessment

2.1.1 Log Books

Licensed marine scalefish and rock lobster fishers are required to supply the South Australian Department of Fisheries with daily catch and effort figures recorded on log books provided by the department. Records detail the weight of the daily catch, the area in which the catch was taken and the method used and effort expended in taking the catch. Catch is recorded as the kilograms of headed, headed and gutted or whole fish, and effort as the number of days that fishing took place. The area fished is determined using a block system.

Existing log books were designed to monitor catch and effort in the multi-species and multi-method marine scalefish fishery but were not ideal for the developing ocean jacket fishery. The shortcomings of the existing log books were that they failed to distinguish between catches of ocean jacket and other leatherjacket species and that the units of effort were inappropriate to a trap fishery. These changes were addressed during 1989 by requiring all commercial fishers to distinguish between catches of ocean jackets and catches of other leatherjacket species and by modifying the log books of marine scalefish fishers, who accounted for most of the catch, to record effort in terms of trap lifts.

Total catches in the fishery were determined from log book data. Prior to 1989/90, commercial fishers were not required to distinguish between catches of ocean jackets and those of other leatherjacket species, and the ocean jacket catch was estimated by assuming all leatherjackets taken in fish traps to be ocean jackets. Fishers generally reported catches in terms of cleaned (headed and gutted) weights and whole weights were then calculated using a conversion factor of 1:2.1 for ocean jackets and 1:1.7 for other leatherjacket species. Whole weights of all leatherjackets (including ocean jackets) caught before 1989 were calculated using the 1:1.7 ratio and are therefore under stated by the department by approximately 19%. This situation was corrected in 1989 and is not thought to have affected the trends in catches before that date to a significant degree.

Fishing effort was defined as the amount of fishing expended to catch fish and the catch rate as the weight of fish caught per unit of fishing effort expended. Effort data were available as boat days, and since 1989/90, as trap lifts. Boat days were defined as the number of days a boat was used to catch a particular species. Trap lifts were defined as the number of times a fish trap was set to catch ocean jackets.

Knowledge of total catches and catch rates is important because of their relationship to the developmental stage of the fishery, the efficiency of each vessel and the abundance of fish (Gulland, 1983). During the early developmental stages of a fishery, total catches are typically low because few fishers are engaged in the fishery but catch rates high because the stock is abundant. Total catches in the fishery tend to increase each year in direct proportion to the number of new fishers entering the fishery. At this stage, the catches and catch rates of individual fishers also tend to increase as they improve their gear, vessels and knowledge of the fishes habits and so become better fishers.

As the fishery develops further however, the stock becomes less abundant as increased fishing pressure means fewer fish survive to old age. The older age classes become increasingly rare and young fish form a much larger proportion of the total catch. Catch rates decline significantly from those experienced during the early stages of the fishery, although this decline can be masked by increases in the efficiency of individual fishers or by the discovery of new stocks. If the stock is fished optimally with respect to the amount of fishing and size at first capture and comes to a steady state equilibrium (when the number of fish recruited to the fishery equals the number lost through fishing and natural causes), total annual catches then tend to stabilise at a level somewhat higher, and catch rates at a level somewhat lower than those taken during the early years of the fishery. If the amount of fishing is excessive, the spawning stock can be reduced to a level where it no longer produces sufficient young to replace itself (recruitment overfishing) or too many fish are caught before they have reached a decent size (growth overfishing), and catch rates decline. Biological collapse is inevitable in a fishery facing recruitment over fishing.

2.1.2 Catch Composition

Monthly surveys of the commercial catch were undertaken at sea aboard commercial vessels between November 1987 and May 1990. During each survey, a random sample of approximately 250 ocean jackets was sexed and measured and used to describe the size composition and sex ratio of the catch. The age composition of the catch was calculated from the size composition data using an age length matrix (Appendix II).

2.1.3 Per Recruit Analysis

Per recruit analyses are typically used in the modelling of fisheries with a small number of age classes, and appeared suitable for analysis of the ocean jacket fishery. They allow fisheries managers to investigate the effects of varying fishing mortality and the age (or size) at first capture, which can often be achieved through altering the level of effort and the mesh size or minimum legal length of capture (Sluczanowski, 1985). They can also indicate the current state of a fishery relative to the optimum (in terms of yield) harvesting situation. They do not indicate whether or not a particular yield is sustainable. A major constraint of yield per recuit models is that they assume steady state conditions and it is unclear whether or not equilibrium has been reached in the ocean jacket fishery. Outputs should therefore be considered as trends rather than the absolute outcomes that may be expected.

(i) Classical

The classical yield per recruit model of Beverton and Holt (1956, 1957) predicts the relative yields that can be expected from a fish stock in a steady state under different levels of fishing and size at first capture. The analysis calculates the equilibrium relationship between biomass added to the stock through growth (using Von Bertalanffy growth parameters) and that subtracted from the stock as mortality (using mortality rate estimates) due to natural causes and fishing. Separate yield per recruit analyses were carried out for male and female ocean jackets using the Beverton and Holt (1956,1957) model as incorporated into the Lotus computer spreadsheet package by Sluczanowski (1985)

(ii) Age Structured

In addition to using the Beverton and Holt yield equations, the data were analysed using an age structured yield model being developed by Sluczanowski (in prep.). The model accepts age structured input parameters and recruitment need not therefore be knife-edged as is assumed in the classical analysis. The model accepts fecundity at age data and can therefore be used to forecast egg production at various levels of fishing effort. Outputs can be used to describe the age structure of the fished population at any level of fishing effort and size at first capture. The principal advantages of the analysis are its age structured inputs and outputs, its interactive nature and capability to visually demonstrate the effects of fishing. The model incorporates an egg per recruit function and therefore provides some insight into sustainable levels of fishing if the appropriate level of egg production needed to sustain catches is known or can be estimated.

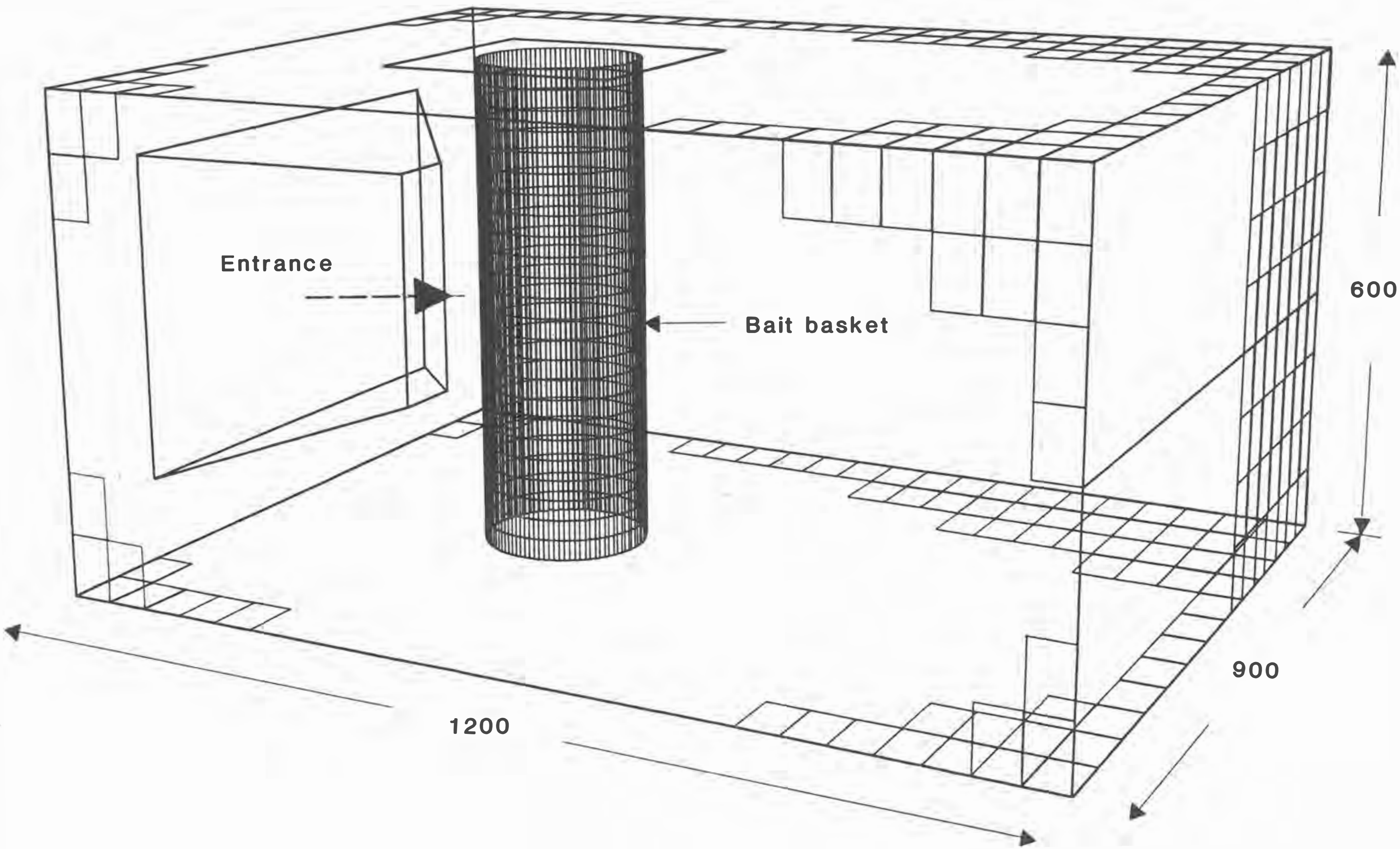


Figure 1: Principal dimensions of an ocean jacket trap (measurements in mm). Mesh dimensions 72 X 48 or 48 X 48mm in external panels and [illegible] X [illegible] in the bait basket.

The age specific length, weight, fecundity and sex ratio data used in the analysis were as determined in sections 3.6.2(iii), 3.4.2(i), 3.5.3 and 3.2.2(iii) respectively. Age specific natural mortality data were not available and the overall female natural mortality rate estimated in section 3.7.5 was utilised. Vulnerability was estimated from knowledge of the habitat of the species and age composition of the catch. For example, the habitat of 0+ and 1+ year old fish (3.3.3) is an area not fished (3.2.1(i)) and these age groups do not appear in the commercial catch (3.2.2(ii)). They were assigned a vulnerability of zero. Fish older than 1+ years were assigned vulnerability ratings on the basis of their proportional representation in the catch (3.2.2(ii)) and the estimated maximum efficiency of a fish trap. Trap efficiency was estimated crudely from film of traps in situ. Traps were assumed to catch all age groups of fish 2+ years and older equally well based on the filmed observations that fish of all sizes present on the fishing grounds entered traps (appendix 1).

2.2 Juvenile Populations

Initial trial sampling for juvenile Nelusetta ayraudi in April 1989 was conducted using a "standard" 1200mm X 900mm X 600mm commercial fish trap (Fig.1) modified by using small 23mm X 23mm mesh in the external panels instead of the 48mm X 48mm or 48mm X 72mm mesh used by commercial fishers. Entrance dimensions were 80mm wide by 200mm high and the opening was set 200mm from the bait basket which measured 500mm deep by 180mm X 180mm. An additional six smaller traps were incorporated into the sampling program in August 1989. These smaller traps measured 600mm X 500mm X 350mm with external panels constructed from 12mm X 12mm mesh and 100mm X 60mm entrances set 110mm from the 250mm X 150mm X 150mm bait pole. Trap caught samples were sometimes supplemented with additional catches taken by line or hand spear.

Traps were baited using southern bluefin tuna (Thunnus maccoyii) offal or whole European carp (Cyprinus carpio), jack mackerel (Trachurus declivis) or tommy ruff (Arripis georgianus) bodies cut into five centimetre steaks. Traps were set during the early morning in southern Boston Bay (Fig.2) at depths of 4-10 metres, usually in the vicinity of Picnic Beach on the eastern side of Boston Island or near Bickers Islands as these areas consistently produced good catches of juveniles. On two occasions, SCUBA equipment was used to photograph and make behavioral observations of juvenile N. ayraudi entering traps and to record the type of substratum. Traps were left for two hours then retrieved, cleared of leatherjacket and other fish and invertebrate species, and rebaited and reset.

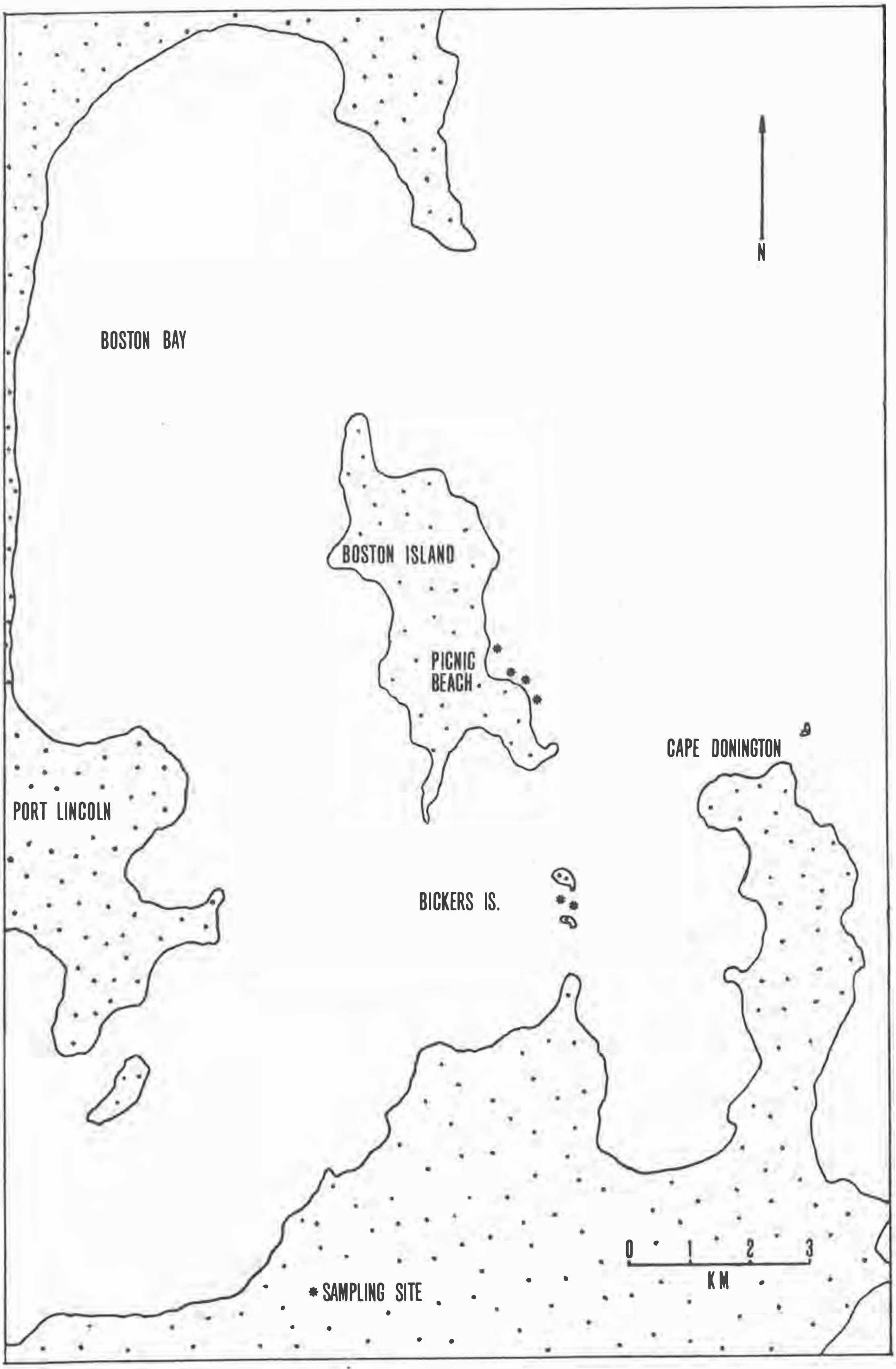


Figure 2: Juvenile sampling locations.

Leatherjacket samples were divided into species groups, and into sexes for species that could be sexed externally. The presence or absence of infestation with the leatherjacket louse Ourzeuktes owenii was also noted.

All leatherjackets were measured to the nearest millimetre from the tip of the snout to the base of the median caudal fin ray (Fig.3) using a fish measuring board (Anderson and Gutreuter, 1983). Length frequency distributions were prepared for juvenile N. ayraudi for each month and growth rates estimated from the rate of increase in the modal length of the population or cohort. The first month during which juvenile N. ayraudi were caught was assumed to represent the timing of early recruitment to the bays and the last month during which juvenile N. ayraudi were caught assumed to represent the timing of the end of the phase of emigration to deeper waters. (Recruitment to the bays was defined as susceptibility to small meshed research traps, not to commercial fish traps). A time series of samples was also available from specimens collected during prawn surveys undertaken in Spencer Gulf and these data were used as an additional independent estimate of growth.

The distribution of juvenile N. ayraudi in South Australia was crudely estimated from reports of sightings of small ocean jackets made by commercial and recreational fishers and departmental staff during their normal field activities. All sightings were verified by interviewing the original observer and, when possible, by obtaining a sample specimen to confirm its identity as a juvenile N. ayraudi.

2.3 Adult Sampling

Length stratified samples of approximately thirty female and thirty male N. ayraudi were used in the determination of monthly changes in the Gonado-Somatic, Hepatic and Condition indices and of length to weight and other morphometric relationships. Samples were collected monthly aboard commercial fish trapping vessels and from the Department of Fisheries' Marine Research Vessel Ngerin between November 1987 and May 1990 inclusive at sampling locations and dates shown in appendix 3. Size categories were <30, 31-32, 33-34, 35-36, 37-38 and >38 centimetres. The first five male and five female fish encountered in each of these size categories were chilled and returned to the laboratory for examination. In some instances samples were frozen prior to examination.

In the laboratory, fish were weighed to the nearest gram whole weight, measured to the nearest millimetre standard length and the gonads and liver removed and weighed to the nearest 0.1g. Each fish was cleaned by

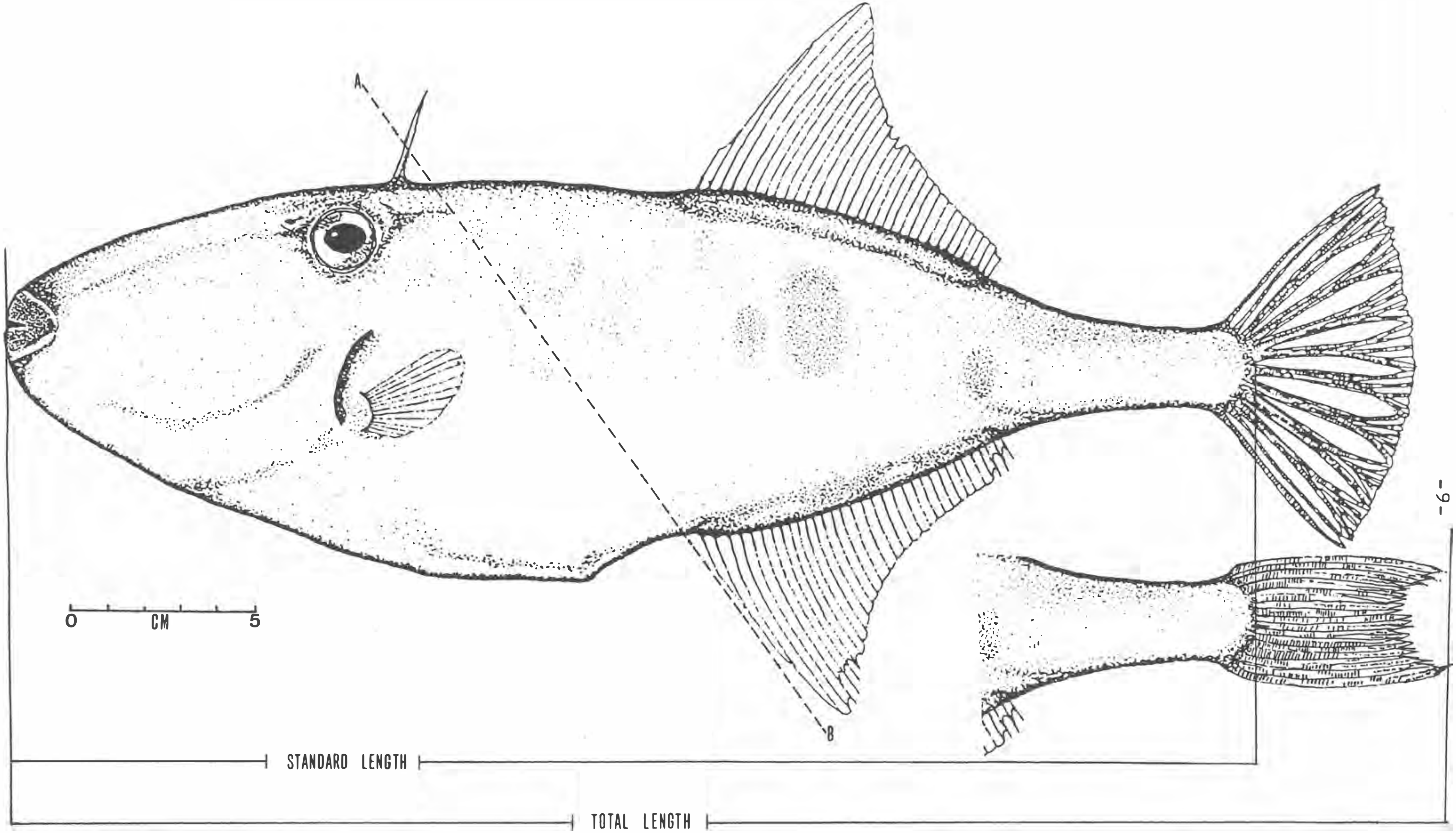


Figure 3: Male ocean jacket showing length measurements and location of cut made during cleaning (A-B).

cutting from behind the dorsal spine to the vent (Fig.3) and the cleaned weight determined. A block of vertebra 4-5cm long was cut from the cleaned portion and frozen for ageing.

Random samples were taken monthly and were used to describe the size composition and sex ratio of the commercial catch. Samples were collected by measuring and sexing the contents of several bins of fish emptied directly from commercial traps until approximately 250 fish had been measured. The age composition of the catch was calculated from size composition data (2.1.2). It was assumed that both size stratified and random samples were representative of the monthly catch.

2.4 Morphometrics

Measurements of fish lengths, weights, length to weight relationships and the length composition of the commercial catch are fundamental to any study of the fisheries biology of a species. Lengths are usually measured from the snout to the tip (total length) or base (standard length) of the caudal or tail fin as shown in figure 3. In this study, standard length was used in preference to total length because damage to the caudal fin affected total length measurements. However, a conversion factor for total length to standard length was determined to allow comparisons to be made with the results of an earlier study (Lindholm, 1984) which used total length measurements. In addition, the relationship between the length of the dorsal fin and standard length was investigated to determine whether standard length could be determined accurately from measurements of cleaned (headed and gutted) fish in port.

Standard length was defined as the shortest distance from the anterior tip of the mouth to the base of the median caudal fin ray (Fig.3). It was measured by laying fish flat on a measuring board (Anderson and Gutreuter, 1983), piercing the base of the median caudal fin ray with a sharp probe and measuring the distance to the tip of the snout. Total length was defined as the shortest distance from the tip of the snout to the tip of the longest caudal fin ray with the dorsoventral lobes of the caudal fin pressed together (Fig.3). Dorsal fin length was defined as the distance from the point of insertion of the first dorsal fin ray to the point of insertion of the most posterior dorsal fin ray measured with vernier callipers.

Length to length relationships were determined from measurements of 199 fish taken over a size range representative of juvenile and adult populations. Length to weight relationships were determined from the combined measurements of 1,347 fish taken monthly between November 1987 and May 1990 and 29 fish from the juvenile sampling program. Shrinkage due to freezing and the weight of cheek muscles relative to the body weight were determined from additional stratified samples representative of the commercial catch. All measurements were rounded down as is the accepted convention in studies of fish stock assessment (Anderson and Gutreuter, 1983). Measurements used in juvenile and tagging studies and in determining length to length and length to weight relationships were rounded down to the nearest millimetre and gram respectively. Fish lengths used in length frequency analysis were reported to the nearest centimetre and all organ weights were measured to within 0.1 grams.

2.5 Reproduction

Reproductive studies were conducted to determine where and when spawning occurred, the minimum size and age at first spawning and the number of eggs produced per female of different size and ages. Additional data were collected on changes in migration patterns and condition indices associated with the spawning cycle.

2.5.1 Spawning Season

Many fish in temperate waters have an annual cycle of reproductive activity with defined spawning and reproductively quiescent periods. For ocean jackets, the time of spawning was determined by examining monthly changes in both the ratio of the weight of the gonads relative to the weight of the fish (the Gonado-Somatic Index or GSI) and also in the maximum size of oocytes or developing eggs (the Maximum Oocyte Diameter or MOD) present in the gonad. Both GSI and MOD values peak immediately prior to the time of spawning and decline after spawning so can be used to identify the onset and approximate duration of the spawning season. The percentage of male fish in the commercial catch producing milt was also recorded as a potential indicator of reproductive activity.

(i) Determined from Gonad Indices

Monthly changes in the Gonado-Somatic Index (GSI) or weight of the reproductive organs relative to whole body weight were determined to estimate the timing and duration of spawning activity. GSI was defined as the weight of the gonads expressed as a percentage of the whole weight.

GSI = 100 X (gonad weight/whole fish weight)

The mean GSI was calculated monthly for all males and females in the stratified sample and the results graphed.

(ii) Determined from Oocyte Diameters

In addition to information from monthly changes in GSI, the timing of spawning activity was further investigated by monitoring monthly changes in the Maximum Oocyte Diameter (MOD). Ovaries dissected from fish in the size stratified sample were fixed in a 10% seawater formalin solution and later examined microscopically and the ten largest oocytes measured. The tissue examined was taken from the centre of a transverse section cut from either ovarian lobe midway along the length of the ovary. This tissue was mounted as a squash preparation and examined at 50 or 80 times magnification. The diameters of the ten largest oocytes were measured and the diameter of the fifth largest oocyte recorded as the MOD for that fish. Using the fifth largest oocyte effectively eliminates the situation in which the largest oocyte is isolated from the rest of the distribution (West, 1990). Mean MODs were then determined for each month and for different size categories within months and graphed.

2.5.2 Fecundity

(i) Sampling

The fecundity of fish in each of six size stratified length categories of <30, 31-32, 33-34, 35-36, 37-38 and >38 centimetres was determined for samples collected 46 nautical miles west (bearing 260^{o}) of Pearson Island (Fig.12) at latitude 34^{o}.07' S, longitude 133^{o}.27' E on 21 April 1990 from a depth of 90 metres. Each fish was measured at sea and its ovaries and a block of vertebrae including the fifth vertebra removed and frozen. Oocytes were than separated from the ovarian tissue and the number present estimated using methods described below. Fecundity estimates were related graphically to gonad weight and the parent weight, length, and age when this could be determined. Fecundity at age data were used in per recruit analyses to determine the effects of fishing on the total egg production of the stock.

(ii) Oocyte removal

Oocytes were separated from the ovarian tissue using chemical and mechanical techniques. Chemical treatment involved immersion in modified (Simpson, 1951) Gilson's Fluid, which separates oocytes from the ovaries. This mixture was further modified to reduce its toxicity by substituting formaldehyde for mercuric chloride which performs a similar fungicidal function (G. West pers. comm.). The mixture used was 100 ml 60% ethanol, 880 ml distilled water, 15 ml 80% nitric acid, 18 ml glacial acetic acid and 20 ml 40% formaldehyde. Treated ovaries were first sectioned longitudinally and then shaken periodically to assist penetration of the chemical treatment. After two weeks, most oocytes had separated from the ovarian tissue and sank to the bottom of their storage jars. Any remaining oocytes were teased free from the surrounding connective tissue using a camel hair brush and finally separated by passing through a one mm mesh sieve. This method was effective in removing oocytes from frozen ovaries but was unsatisfactory for ovaries that had been fixed and stored in 10% seawater formalin solution prior to treatment.

(iii) Counting Oocytes

To estimate the number of oocytes separated from each ovary, the oocytes were suspended in four litres of water and subsampled according to a volumetric method based on that described by Hislop and Hall (1974). The oocytes present in each of three two ml subsamples were counted using an Olympus stereo microscope at 40 times magnification and the mean number of oocytes present in a two ml subsample determined. All oocytes larger than 0.1 mm diameter were counted as they appeared to be undergoing vitellogenesis (accumulating yolk) and it was assumed they would therefore mature during the spawning period in which they were sampled. The number of oocytes present in each ovary was then estimated by multiplying the mean number present in a two ml subsample by 2000. Fish that failed to produce any visible oocyte suspension after the initial chemical treatment were not treated further and were assigned fecundities of zero.

2.6 Seasonal Cycles

In addition to seasonal changes in the relative weight of the reproductive organs which may be clearly related to the spawning cycle, the mean monthly weights of livers relative to whole body weights and the mean monthly condition or weights of whole fish relative to whole weights of "average" fish predicted from length data can also change in a regular manner can be related to seasonal changes in energy availability (food supply) and expenditure (migration and spawning). The liver is an energy storehouse in many fish and its weight has been shown to vary with food ration (Tyler and Dunn, 1976). A high relative liver weight can indicate good feeding conditions while low relative liver weight can indicate poor feeding conditions (Tyler and Dunn, 1976). The utilisation of energy reserves for migration and growth including the production of gametes can also be expected to influence liver weights. Changes in the relative liver and body weights were therefore examined to identify any seasonal trends related to the energy budget of the species.

2.6.1 Hepatic Index

The Hepatic or liver index (HI) was defined as the weight of the liver expressed as a percentage of the whole weight and was determined monthly for male and female fish in the stratified sample. Monthly means results were expressed graphically.

HI = 100 X (liver weight/whole fish weight)

2.6.2 Condition Index

Condition Index (CI) was defined as the ratio of the actual whole weight to the expected whole weight calculated from the standard length. Monthly mean results for males and females were expressed graphically.

CI = whole weight(kg)/(1.4 X 10^{-8} X [standard length(mm)]$^{3.10}$

2.7 Age and Growth

Ocean jackets were aged by counting rings laid down on the face of the fifth vertebra and additionally for juvenile fish, from knowledge of the time of spawning, settlement and growth since settlement. Von Bertalanffy growth parameters were estimated from these data using the non linear least squares FISHPARM computer program (Saila et al, 1988). Growth parameters were also estimated from plots of annual growth rate against mean standard length (Gulland 1969) derived from tag-recapture and modal progression data. An age length matrix (Appendix 2) was constructed from these data assuming length at age was normally distributed about a point predicted by the Von Bertalanffy growth curve. Annual catch curves for 1988 and 1989 were then calculated from length frequency data using the age length matrix.

Ocean jackets were aged directly by counting concentric rings or growth checks laid down on the centra of the fifth vertebra, a technique that had been used previously to age other leatherjacket species in Korea (Park, 1985). Preliminary investigations showed rings also to be present in otoliths and the dorsal spine of N. ayraudi but ageing using these bones was not pursued. The dorsal spine was considered unsuitable because it hollowed with age and the inner rings were obliterated in older specimens. Otoliths were not pursued because ocean jackets are landed with the head removed and future studies may not have ready access to whole fish with otoliths intact. Vertebrae may be extracted from cleaned or whole fish.

Blocks of vertebrae were removed from the backbone in the area immediately posterior to the standard spine to anus cut used to clean the fish (Fig.3). Samples were taken monthly from the commercial catch and opportunistically from juveniles collected inshore, and were frozen intact as this produced better results than storage in alcohol or as air dried specimens. Initial processing involved the thawing of samples, identification and removal of the fifth vertebra and the removal of the cone gel and surrounding muscle and connective tissues using forceps. Various staining procedures previously used in the preparation of tuna (Berry et al, 1977), shark (Davenport and Stevens, 1988) and Korean leatherjacket (Park, 1985) vertebrae were then used to enhance any rings present. These included the protein stains ninhydrin and mercurochrome and calcium stain alizarin. The Korean method of treatment in potassium hydroxide (KOH) solution proved most suitable with slight modification.

Thawed and cleaned vertebrae were boiled in water for five minutes, rinsed and then soaked in 3% KOH solution for 24 hours, then rinsed again, air dried and sectioned along the dorso-ventral axis with a jewellers saw and examined under a dissecting microscope fitted with an ocular micrometer. Ring resolution was further enhanced by the application of oil of cloves to dried vertebrae or by rubbing with a soft 2B pencil which highlighted the ridge and groove structure of the cone face. Another method of enhancement which had the unexpected effect of causing extensive cracking of the cone surface was to apply glycerine to vertebrae that had been soaked briefly in alcohol. The initial cracking sometimes highlighted rings but the general cone surface was soon damaged severely and this procedure was only adopted when other methods had failed.

The vertebral radius was measured across the cut surface of the anterior face in the dorso ventral plane. Rings were assigned ages on the assumption that two minor and one major ring formed during the first and second years and that one minor and one major ring were laid down in subsequent years. The frequency of ring formation was estimated after examining the vertebrae of known age juvenile fish and ring formation in tagged fish injected with oxytetracycline and recaptured approximately one year later.

2.8 Tagging Experiments

Twenty mark-recapture experiments were conducted between March 1988 and March 1990 at sites listed in appendix 4 with the aim of providing estimates of growth, movement and mortality rates. Early trials were concerned with assessing different tag types and developing appropriate handling methodologies since there had been no previous attempts to tag this species.

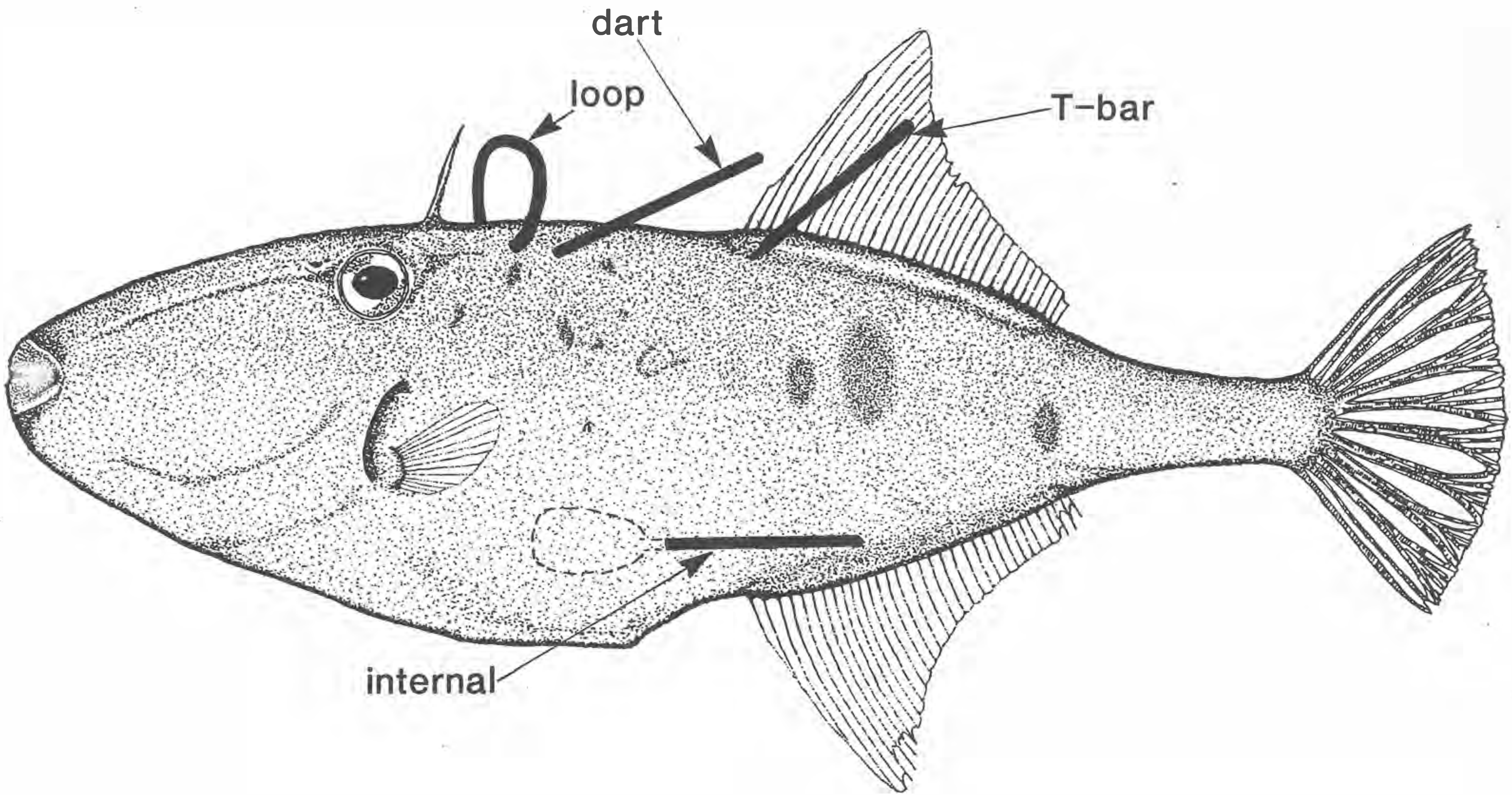


Figure 4: Types of tags used and positions of insertion

Ocean jackets used for tagging were caught from commercial and departmental vessels using typical fish traps (Fig.1). Most fish caught in this manner suffered severe barotrauma during the ascent from 80-120 metres to the surface, resulting in over inflation and distension of the swim bladder causing ocular and anal hernias, damage to the internal organs, and in males, rupture of the subcutaneous capillaries. Attempts to alleviate barotrauma by raising traps slowly to the surface over a period of four hours were unsuccessful. The procedure finally adopted was to retrieve traps as quickly as possible then select one or two fish with no signs of damage from each catch of 50-60. These fish were placed in a 60 litre bin of regularly replenished seawater then measured, tagged and released.

Four tag types were used over the duration of the program. T-bar, loop and dart tags consisted of labelled polypropylene tubing attached to a nylon (T-bar and dart) or wire (loop) shank and were manufactured by Hallprint[1]. Internal tags have been described by Cappo (1987).

Initial fears that tags would be chewed by other fish resulted in the use of internal tags because identification numbers were recorded both inside and outside the fish and would not be lost if the outer part was bitten off. These tags were inserted beneath the skin through a shallow incision made in the vicinity of the gut wall anterior to the vent. T-bar tags were inserted into the flesh between the supporting basal elements of the dorsal fin. Both loop and dart tags were inserted posterior to the dorsal spine, with dart tags entering the left side of the fish at an angle of approximately 30 degrees to the horizontal. The tag types used and their positions of insertion are shown in figure 4.

To assist with subsequent ageing studies, some fish were injected with oxytetracycline (OTC) at the time of tagging. OTC creates a fluorescent mark on calcified structures including the vertebrae, and was used to provide a discrete time reference for subsequent study of the growth of the vertebrae. OTC was injected subcutaneously between a fold of abdominal skin pinched between thumb and forefinger at a dose rate of 25mg/kg using a Phillips automatic livestock vaccinator. The vertebrae of recaptured OTC tagged fish were removed and carefully picked cleaned with forceps but were not subjected to further treatment in boiling water or KOH. They were examined under ultra violet illumination using an NEC 4 watt fluorescent tube mounted in a portable miner's torch (Zelco Industries, Lumifier).

[1]Hallprint, 27 Jacobsen Crescent, Holden Hill, South Australia, 5088.

3. RESULTS AND DISCUSSION

3.1 Management Measures

The amount of fishing has been regulated by controlling the number of licensed commercial fishers and the use of commercial fishing equipment. Conditional access is currently open to holders of a South Australian marine scalefish fishery (MSF) licence with an historic commitment to the fishery, South Australian rock lobster (RL) licence with fish trap endorsement, or Commonwealth Great Australian Bight developmental trawl fishery (GAB) licence. The principal aim of the South Australian controls has been to prevent catches increasing beyond sustainable levels by limiting the fishing power of the commercial fleet. Conditions of access are described below.

3.1.1 Marine Scalefish Sector

As of January 1991 there were 527 active marine scalefish fishery licences, of which 14 had access to the ocean jacket resource. The decision to restrict access to a maximum of 14 marine scalefish fishery licences followed discussions with representatives of the South Australian Fishing Industry Council in January 1989 in which the Department of Fisheries sought to curb the then rapid rate of increase in annual catches. Access was allocated to those marine scalefish fishery licence holders showing an historic commitment to the fishery. This was gauged by the quantity of leatherjackets caught using fish traps in preceding years. Access was granted by means of a condition placed on the licences of all trap endorsed MSF fishery licence holders prohibiting the use of traps in waters deeper than 60 metres. The lack of this condition on the fourteen licences provided access to the deeper waters where the majority of the ocean jacket stock is found.

This licence condition was non-transferable. However, one transfer was provided for as the licence holder provided the Department of Fisheries with supporting information indicating the operation had been developed with the intent of a family member taking over the operation. Following agreement with the department and SAFIC on the original access arrangements, a further agreement dealing with entry to the ocean jacket sector of the fishery by other licence holders in the event of licence transfer by an original entrant was finalised. This provided for a listing of licence holders to which entry would be offered, based on a ranking of historic ocean catches. To date, five such replacements have occurred.

The maximum number of traps that MSF fishery licence holders with the endorsement to use fish traps in waters deeper than 60 metres was reduced from 20 to 15 and the dimensions of such traps were redefined. The overall size of traps permitted was reduced from a maximum dimension of two metres to a maximum volume of one cubic metre calculated by multiplying the three principal external dimensions. Maximum entrance dimensions were increased from 200mm X 60mm to 300mm X 80mm and the maximum number of entrances increased from one to two.

3.1.2 Rock Lobster Sector

The number of rock lobster fishers with access to the ocean jacket resource was not limited following the introduction of measures to curb expansion in the fishery in 1989, but the use of ocean jacket fishing equipment was. Like reducing the number of MSF licence holders with access to the resource, this had the effect of reducing the collective fishing power of the ocean jacket catching fleet. The maximum number of traps was reduced to 15 per licence and their maximum size was limited to one cubic metre with two 300mm X 80mm entrances. All 15 fish traps could be used during the closed rock lobster season but only one could be used (to catch bait) during the open rock lobster season. This restricted the season during which RL licence holders could trap ocean jackets commercially to the closed rock lobster season. The closed rock lobster season extends from May 1 to September 30 inclusive in the Southern Zone (approximating the waters of the south east of South Australia) and from June 1 to 30 October inclusive in the Northern Zone (approximating the waters of Kangaroo Island, lower gulf areas and the west coast of South Australia). The total number of rock lobster vessels with restricted access to the ocean jacket resource as of January 1991 was 280 and comprised 194 from the Southern Zone and 86 from the Northern Zone.

3.1.3 Trawl Sector

The Great Australian Bight developmental trawl fishery operates in part of the waters east of 138°30' in South Australia (Cape Jervis) and west of 115°08' in Western Australia. It exploits deep water (>800 metres) stocks of orange roughy (Hoplostethus atlanticus) and shallow water (<200 metres) stocks of mixed species composition. Leatherjackets are not a sought after component of the shallow water catch and tend to be taken incidentally while fishing for Bight redfish (Centroberyx gerrardi) or flathead (Neoplatycephalus conatus). Leatherjackets are nonetheless a significant component of the catch and ocean jackets (N. ayraudi) are, by weight, the main leatherjacket species caught. The fishery is managed by Commonwealth authorities who have limited access to twelve vessels with an option to allow access to an additional three vessels.

3.2 Commercial Catch Assessment

3.2.1 Log Book Data

(i) Total Catches

Total annual reported catches of leatherjacket taken in the South Australian marine scalefish and rock lobster commercial fishing sectors from 1983/84 to 1989/90 are shown in figure 5. These results clearly show the substantial increase in leatherjacket catches that occurred during that period. This increase has been due almost entirely to increased catches of ocean jackets while catches of other leatherjacket species have remained virtually unchanged (Fig.5). Catches stabilised between 1988/89 and 1989/90 after four consecutive years of increasing catches. This was due to both the effects of the management measures (section 3.1) that prevented new MSF fishers entering the fishery and a perception among licence holders with access to the resource that ocean jacket fishing was not worthwhile. The stabilisation in total catch since 1988/89 is considered unrelated to changes in stock abundance.

Both northern zone rock lobster and marine scalefish fishery sectors took significant catches of ocean jacket during the first few years of the fishery and both were instrumental in its early development, but since 1987/88, the MSF sector has accounted for most of the catch (Table 1). Catches in the southern zone rock lobster and miscellaneous fishery sectors have been insignificant.

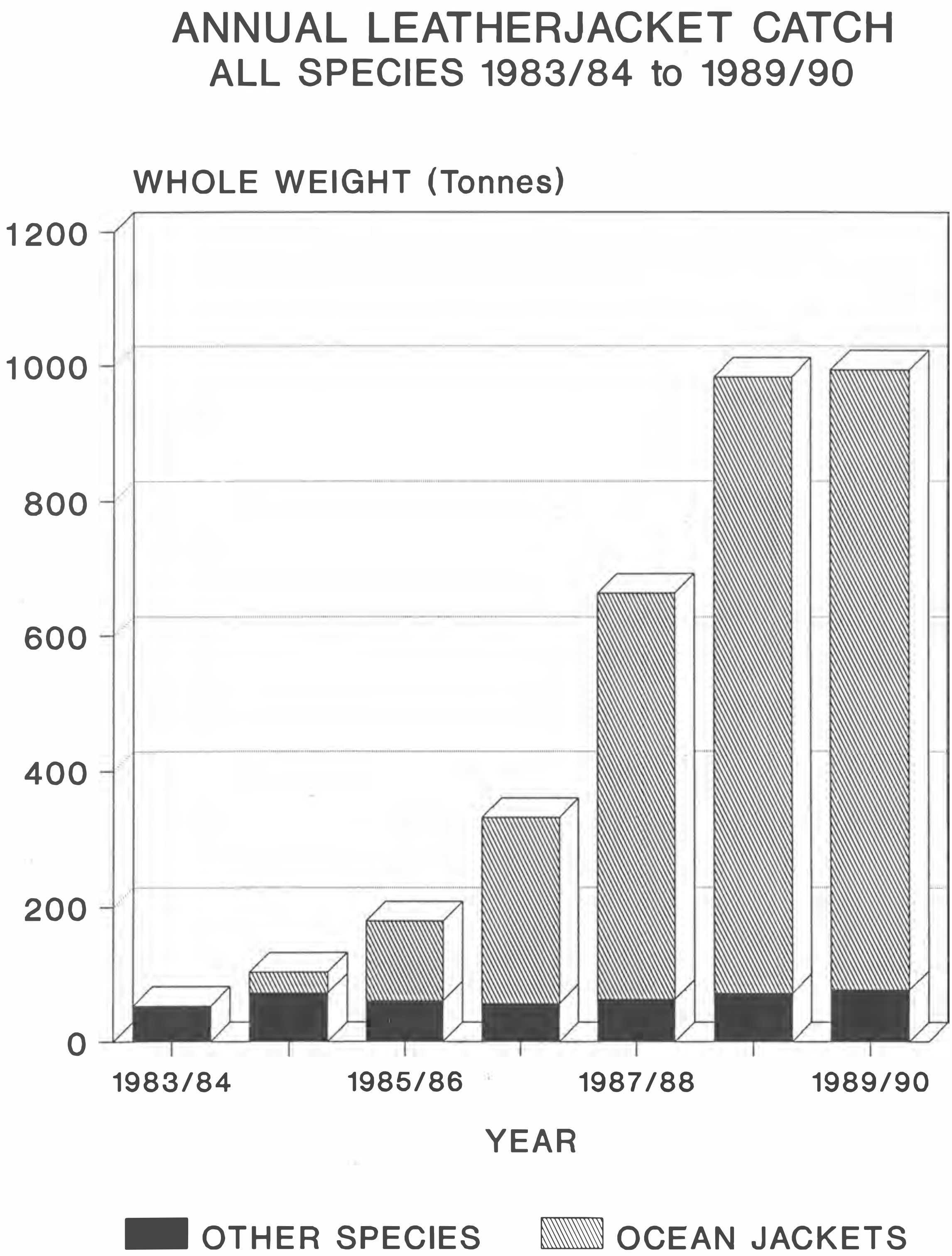


Figure 5. Total annual reported leatherjacket catches.

Table 1 Total reported ocean jacket catch data for marine scalefish (MSF), rock lobster (RL) and miscellaneous (Misc.) fishing sectors 1983/84 to 1989/90 (tonnes whole weight).*

Year	MSF	RL Nthn	RL Sthn	Misc.	Totals (target)	Totals (non target)
1983/84	0	0	0	0	0	
1984/85	18	13	0	0	31	
1985/86	53	65	<1	1	119	
1986/87	194	80	<1	0	274	
1987/88	533	66	<1	<1	600	1.1
1988/89	760	124	<1	26	910	
1989/90	863	49	1	3	916	2.9

*1983/84 to 1988/89 catches are of leatherjackets caught in fish traps. 1989/90 catches are declared ocean jacket catches (see section 2.1).

Closer examination of catches taken in the MSF sector shows a relatively small number of licence holders accounted for most of the catch (Table 2), and that in 1989/90, five MSF sector vessels took 95% of the MSF sector catch, which was 94% of the total catch from all sectors. The other nine MSF sector vessels with access to ocean jackets landed only 5% of the sector catch due to decisions by the fishers involved to restrict their fishing activities or not to fish at all. Fishers have indicated the high costs of catching (bait, steaming and boat operating, labour and interest on borrowed capital) and selling (ice, freight and auction commission) relative to the low prices received in return have made ocean jacket fishing only marginally economic, depending on the circumstances of the individual licence holder. Added to this has been the perception among fishers that the Australian market for ocean jackets is well supplied and exerting downward pressure on prices.

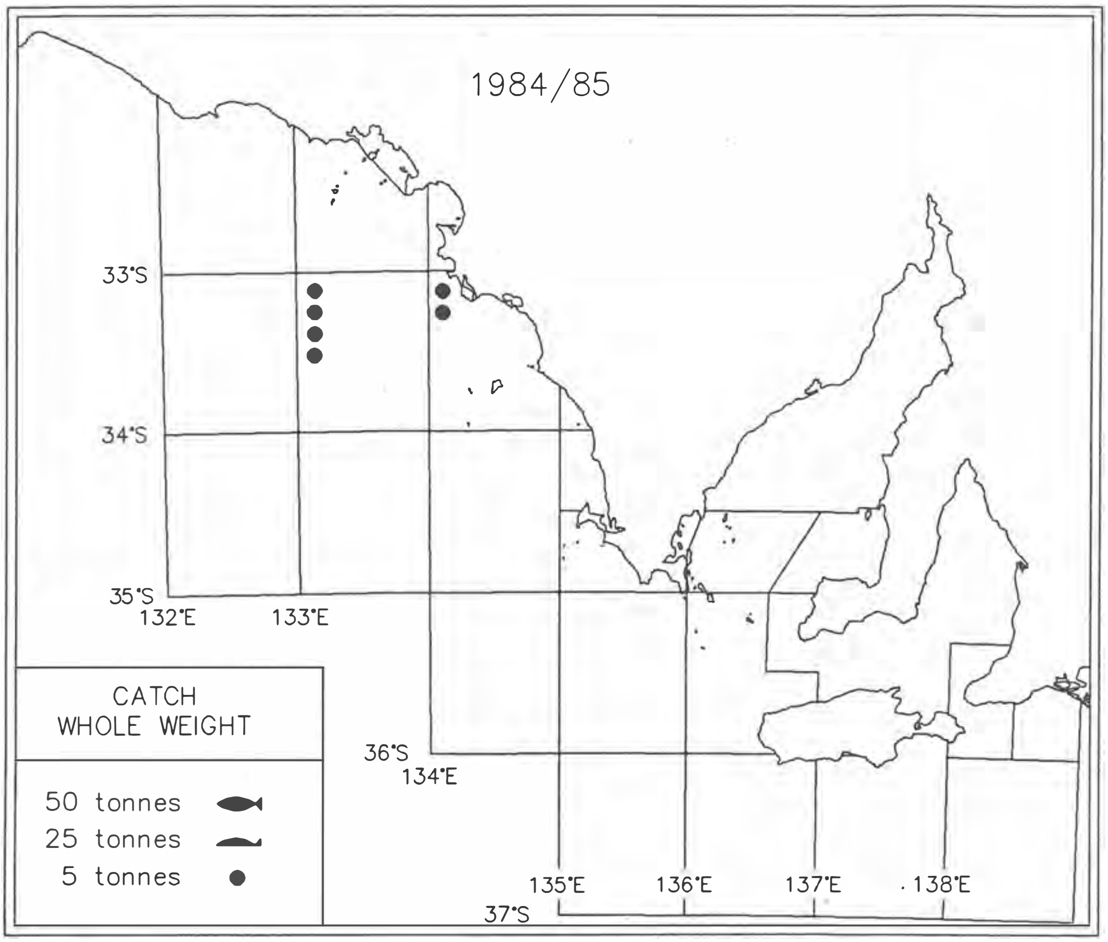
Table 2 Distribution of the ocean jacket catch within the MSF sector.

	Number of licence holders with an annual catch of					
	<1	1-20	20 -100 (tonnes*)	100 -150	>150	Total
1983/84	0	0	0	0	0	0
1984/85	3	1	0	0	0	4
1985/86	2	5	0	0	0	7
1986/87	8	2	6	0	0	16
1987/88	11	8	4	1	1	25
1988/89	17	12	11	0	0	40
1989/90	1	4	0	2	3	10

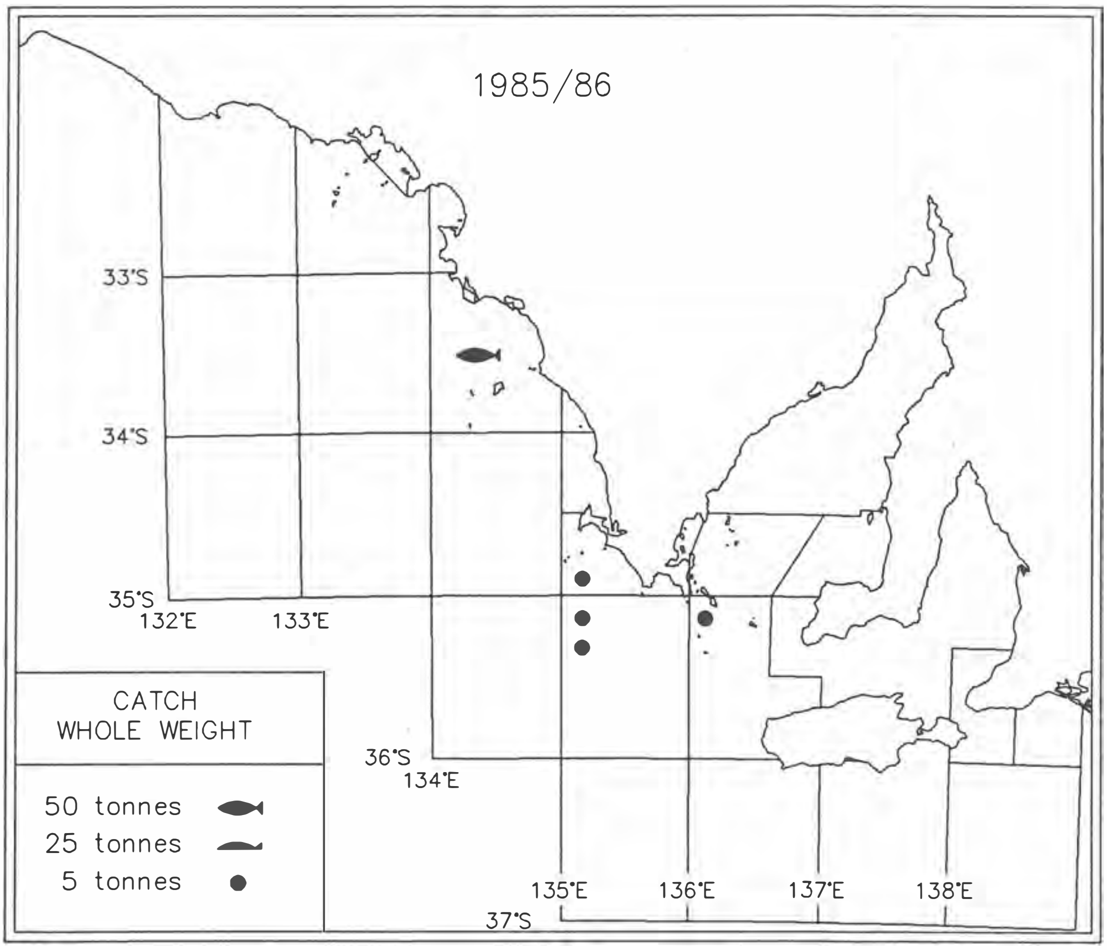
*1983/84 to 1988/89 catches are of leatherjackets caught in fish traps. 1989/90 catches are declared ocean jacket catches (see section 2.1).

The geographic distribution of catches is shown in figure 6 (a-f). These results clearly show the expansion in the area fished that has occurred since 1984/85. The fishery arose in waters off Streaky and Venus bays, then expanded south to the waters near Coffin Bay and Port Lincoln to western Kangaroo Island. More recently, the fishery has expanded into the offshore waters west of Coffin Bay and Pearson Island and into the waters west of Thevenard to Nuyt's Reef. Most of the waters east of 132^0 to Kangaroo Island were fished in 1989/90 but the areas west of 132^0, south of Kangaroo Island and those of the south east have not yet been fished to a significant degree. The quantities of ocean jackets in those areas remains unclear.

In addition to catches taken by the South Australian commercial fishing fleet, catches have also been reported by Commonwealth trawlers operating in waters off both South Australia and Western Australia. Annual leatherjacket catches reported since 1988 are presented in table 3. Catches were relatively low and ranked as the 15th and 12th most important trawl species in terms of weight of catch in 1988 and 1989 respectively (G. Newton, pers. comm.). According to the reported figures, ocean jacket catches were negligible during 1990. Catches of this size are unlikely to impact ocean jacket stocks adversely, however there remains considerable potential for increased catches by this sector. Stock managers should therefore monitor changes in catches by this sector closely.

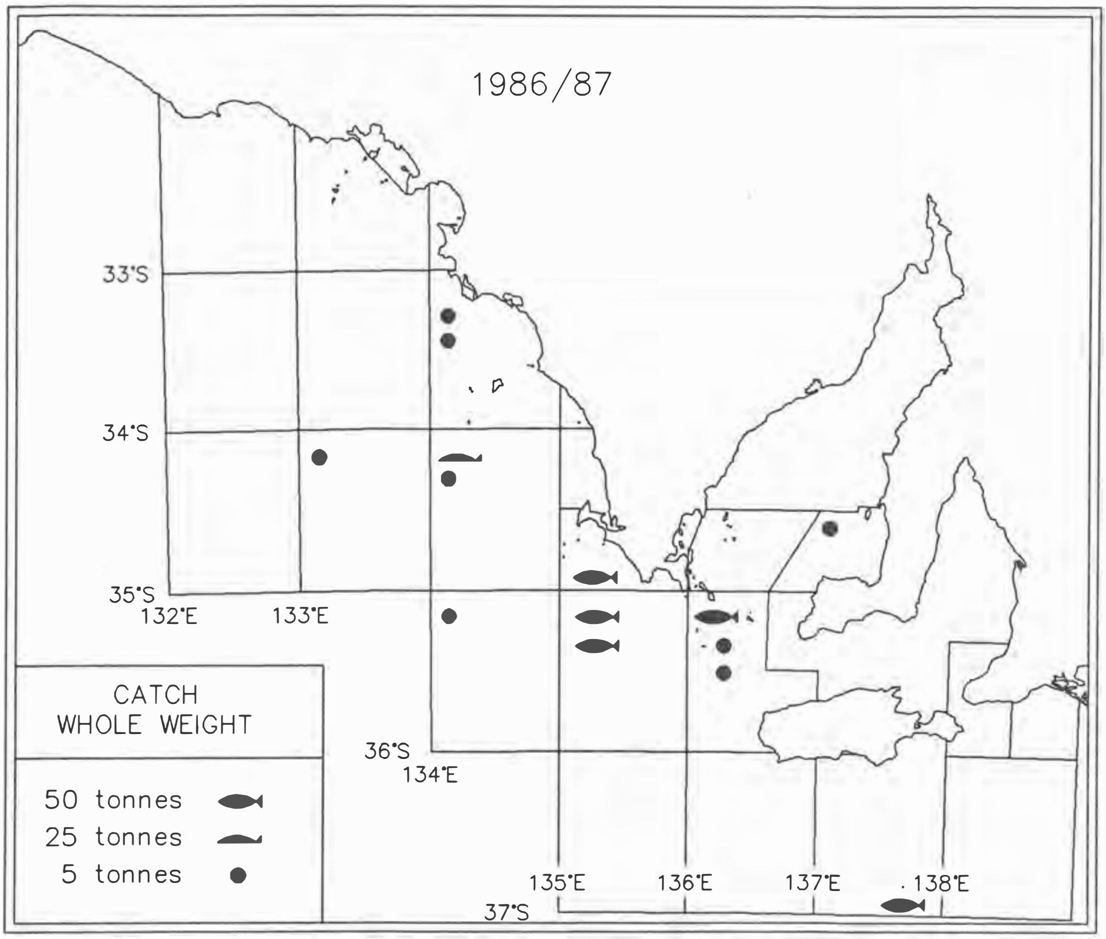


a

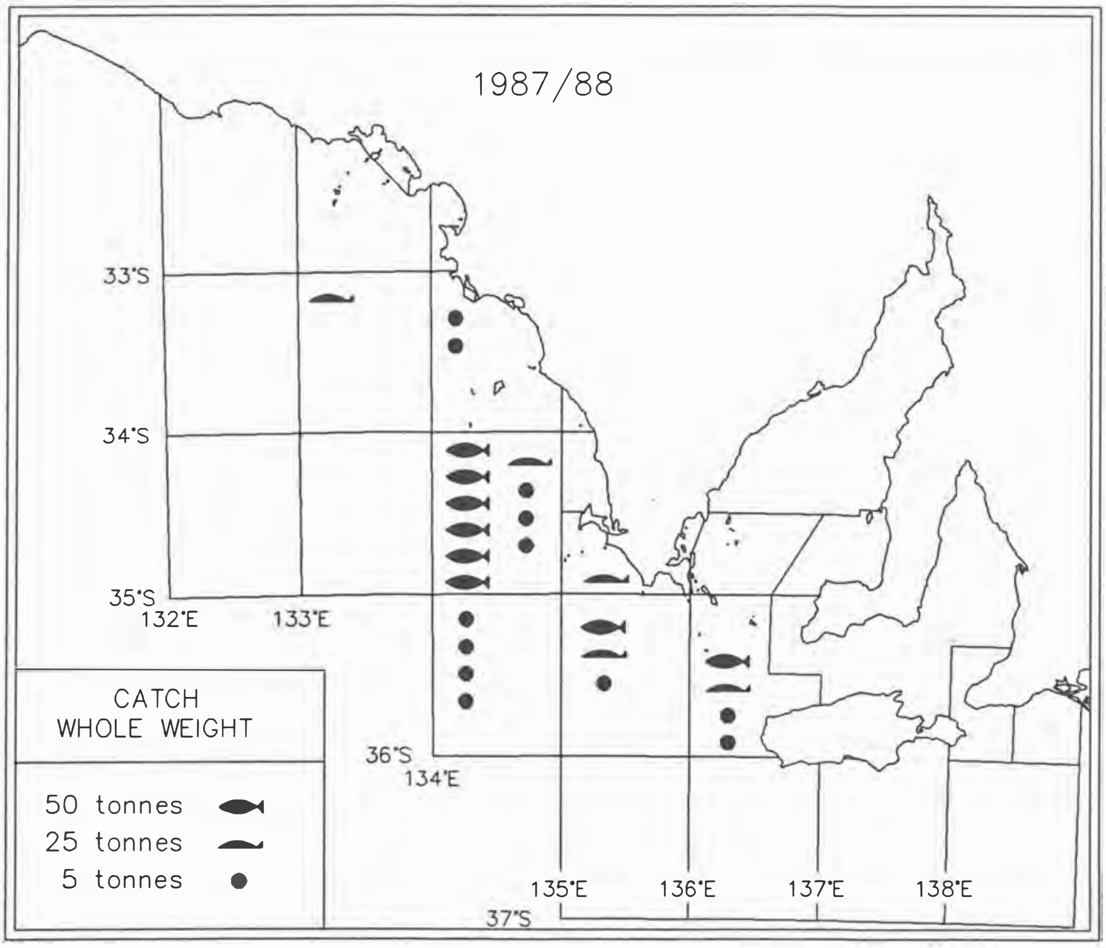


b

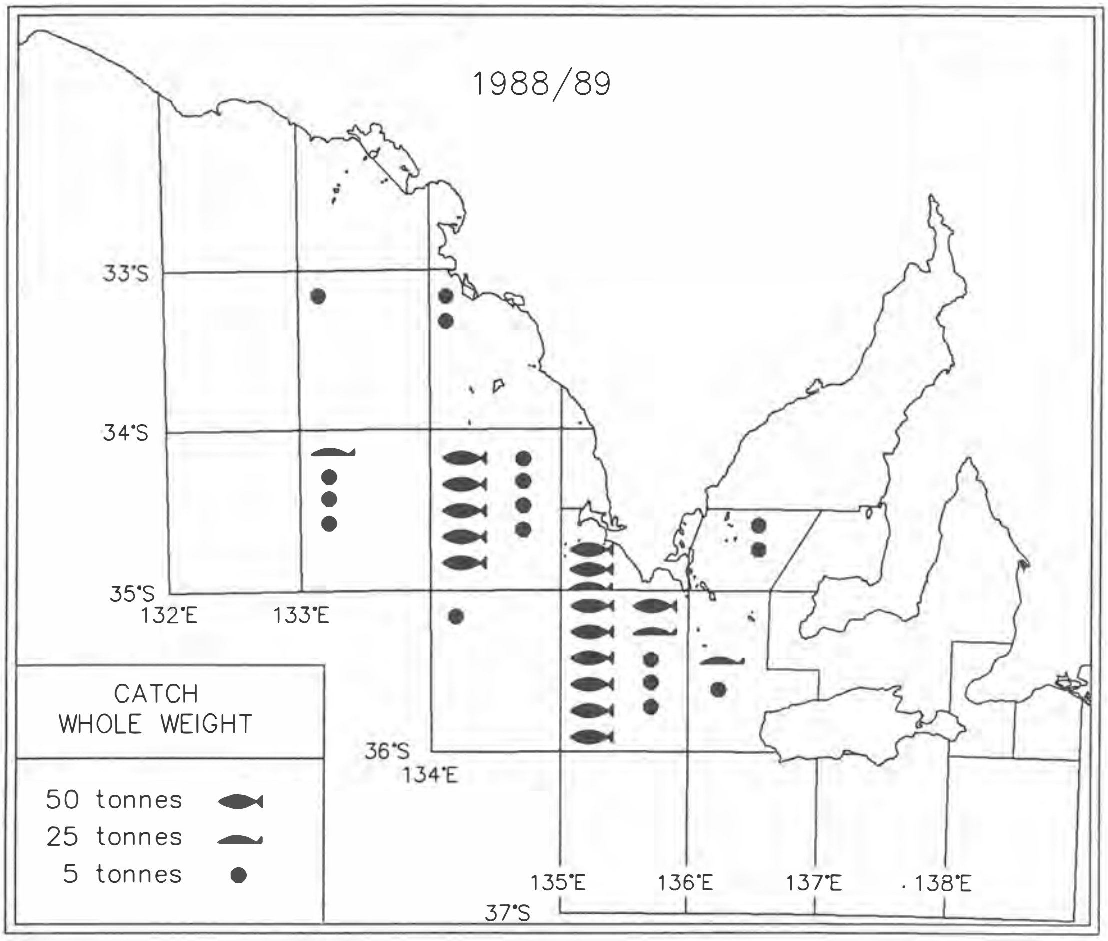
Figure 6. (a-f) Ocean jacket catch by areas, 1984/85 to 1989/90.


1986/87
33°S
34°S
35°S
132°E
133°E
36°S
134°E
135°E
136°E
137°E
138°E
37°S
CATCH
WHOLE WEIGHT
50 tonnes
25 tonnes
5 tonnes

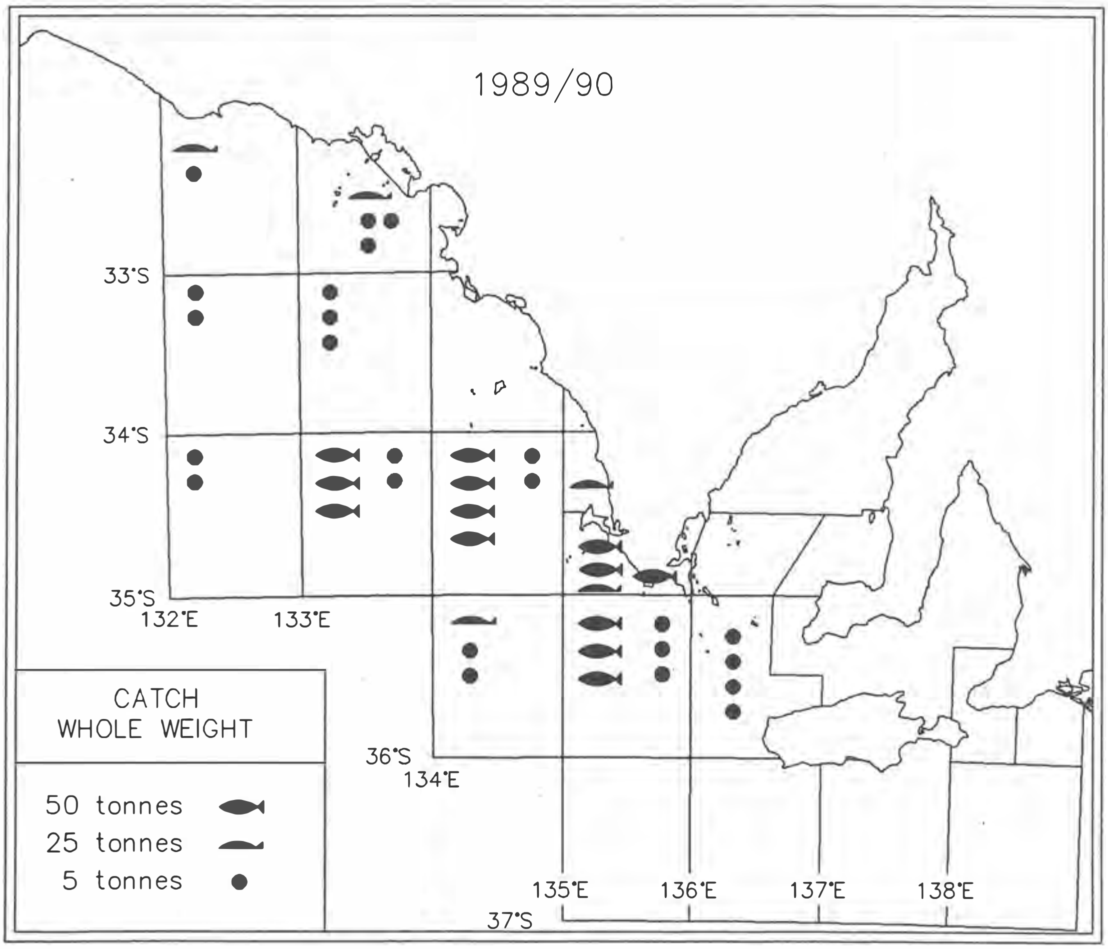
c


1987/88
33°S
34°S
35°S
132°E
133°E
36°S
134°E
135°E
136°E
137°E
138°E
37°S
CATCH
WHOLE WEIGHT
50 tonnes
25 tonnes
5 tonnes

d


1988/89
33°S
34°S
35°S
132°E
133°E
36°S
134°E
135°E
136°E
137°E
138°E
37°S
CATCH
WHOLE WEIGHT
50 tonnes
25 tonnes
5 tonnes

e


1989/90
33°S
34°S
35°S
132°E
133°E
36°S
134°E
135°E
136°E
137°E
138°E
37°S
CATCH
WHOLE WEIGHT
50 tonnes
25 tonnes
5 tonnes

f

Table 3 Annual trawl sector leatherjacket catch. (Calender years, source G. Newton pers. comm. and Newton and McLoughlin, 1991)

	Catch (tonnes cleaned weight)		
	Leatherjacket (ocean)	Leatherjacket (species not specified)	Leatherjacket (all species)
1988	14.1	2.3	16
1989	20.6	15.2	36
1990	2.1	49.9	52

Recreational catches were considered to be insignificant in this fishery and have been ignored. Ocean jackets are not a popular recreational species, although anglers do catch juvenile ocean jackets incidentally to catches of more popular species. Juveniles are caught in shallow water areas of the west coast and Spencer Gulf during summer and autumn (section 3.3). Adults occupy deeper waters (>60m) over sandy or "coral" bottom where they unlikely to be caught by amateur fishers.

(ii) Fishing Effort and Catch Rates

The number of boat days reported to take the total annual ocean catch and calculated catch rates are shown in table 4. Effort increased gradually during the period 1984/85 to 1988/89 but then decreased markedly between 1988/89 and 1989/90 (Table 4). The gradual increase in effort between 1984/85 and 1988/89 was due to expansion in the fishery (increased numbers of fishers and days fished) while the effort reduction between 1988/89 and 1989/90 was due to the restrictions on ocean jacket fishing introduced during 1989.

Table 4 Total catch and target effort expended by the MSF and NZRL fishing sectors catching ocean jackets.

Year	Target Catch (tonnes whole weight)	Target Effort (boat days)	Catch Rate (tonnes whole weight per boat day)
1984/85	31.4	87	0.36
1985/86	118.8	359	0.33
1986/87	273.8	1534	0.18
1987/88	599.7	1786	0.34
1988/89	885.4	2226	0.38
1989/90	913.6	840	1.08

The data in table 4 show no significant change in catch rates between 1984/85 and 1988/89 then a large increase between 1988/89 and 1989/90. These changes were considered to be governed by the efficiency of individual fishers and not the abundance of fish. Catch rates rose markedly between 1988/89 and 1989/90 because licence holders with historically low catches were removed from the fishery in 1989, and this group tended to have low catch rates. The influence of inefficient fishers on catch rates was discounted by considering the data of vessels with at least four years continuous ocean jacket fishing experience as shown in table 5. These data confirm that high catch rates were taken before 1989/90 but were masked by the low catch rates of less efficient operators. The gradual increase in catch rates since 1986/87 is attributed to the increase in the area fished described in section 3.2.1(i) and increased efficiency of individual vessels as described in section 3.3 below.

Table 5 Ocean jacket target catch and effort expended by licence holders with at least four years continuous operation.

Year	Target Catch (tonnes whole weight)	Target Effort (boat days)	Catch Rate (tonnes whole weight per boat day)
1986/87	6.6	178	0.3
1987/88	287.6	265	1.1
1988/89	189.4	140	1.4
1989/90	332.5	226	1.5

(iii) <u>Effort Standardisation</u>

The effort expended by the five principal ocean jacket catching vessels in 1989/90 was 28,966 trap lifts at an average catch rate of 13.4 kg/trap lift cleaned weight or 28.2 kg/trap lift whole weight. These vessels collectively accounted for 90% of the total ocean jacket catch but the relative fishing power of individual vessels varied considerably (Table 6). Some fishers used larger vessels (approx. 60') than other fishers (approx. 45') which allowed them to fish further from port and facilitated the use of the new one cubic metre traps which were 54% larger than the old 1200mm X 900mm X 600mm traps in general use. This demonstrates a capacity for three of the five specialist ocean jacket vessels to increase their efficiency by an amount equivalent to at least one extra vessel in the fishery by upgrading their equipment. In addition, further increases in the efficiency of vessels beyond the 1989/90 fishing power of 1.0 are likely as fishers continue to improve their skills.

Table 6 Relative fishing power of specialist ocean jacket trapping vessels during 1989/90.

Vessel Number	Mean Catch Rate (kg clean weight per trap lift)	Fishing Power Index
1	17.01	1.00
2	16.63	0.98
3	13.29	0.78
4	11.42	0.67
5	10.12	0.59
average	13.71	0.80

It is concluded that catch rates have continued to increase since the inception of the fishery, although this underlying trend has been masked to some degree by the low catch rates reported by non specialist ocean jacket trapping vessels. Catch rates have tended to increase because the efficiency of boats and gear has improved and individual fisher's knowledge of how and where to fish has increased. In addition, new areas not previously fished have come into production and helped to maintain high and increasing catch rates. This situation cannot continue and catch rates must eventually decrease below current levels when most of the older fish have been removed from the population and there are no new fishing grounds to exploit. Catch rates should then stabilise at a level somewhat lower than the current level.

(iv) New South Wales Fishery

Ocean jackets are a popular table species in New South Wales and are exploited using traps and trawlers. Leatherjacket production figures for 1961/62 to 1980/81 are shown in table 7. The figures are assumed to be cleaned weights of mostly ocean jackets which is the dominant leatherjacket species in New South Wales. The results clearly show that catches taken during the early stages of the fishery were not sustainable. Catches continued to fall during the 1980's and were estimated at approximately 70 tonnes in 1989/90 (G. Hendry, pers. comm.), most of which was sold in regional centres and did not reach Sydney market where most of the South Australian catch is sold. These results demonstrate the species can be over fished and that caution should be exercised in exploiting the South Australian stocks. Unfortunately we can learn little more from the experience because New South Wales authorities did not research the fishery.

Table 7 New South Wales leatherjacket production 1961/62-1980/81. 1970/71 and 1971/72 data unavailable.

Year	Reported Catch (kg)	Year	Reported Catch (kg)
1961/62	578,446	1972/73	486,707
1962/63	549,372	1973/74	385,909
1963/64	327,601	1974/75	189,747
1964/65	378,050	1975/76	135,978
1965/66	489,872	1976/77	123,907
1966/67	276,330	1977/78	87,731
1967/68	242,659	1978/79	73,856
1968/89	218,209	1979/80	126,827
1969/70	558,796	1980/81	156,616

3.2.2 Biological Characteristics

(i) Size Composition

Annual length frequency distributions for 1988 and 1989 are shown in figures 7 and 8. Large females were more common than large males and maximum average sizes approximated the 427mm for females and 406mm for males determined by independent growth analyses (3.6). The average sizes of male and female fish in the commercial catch were virtually unchanged between 1988 and 1989 (Figs 7 & 8), indicating that fishing mortality did not influence the size structure of the population significantly during that period.

(ii) Age Composition

Age structures for 1988 and 1989 derived from size distribution data using the age-length matrix in appendix 2 are shown in figure 9 and table 8. These results demonstrate the relative importance of age classes of each sex in determining the total catch.

One year old fish were not caught and two year old fish were poorly represented in the catch. Three year old fish provided approximately one quarter of the catch but were not fully recruited to the fishery. Full recruitment occurred at age four years. Three, four and five year old fish were most important to the fishery and provide approximately 76-82% of the catch.

The dependence of the catch on a relatively small number of age classes means the fishery should

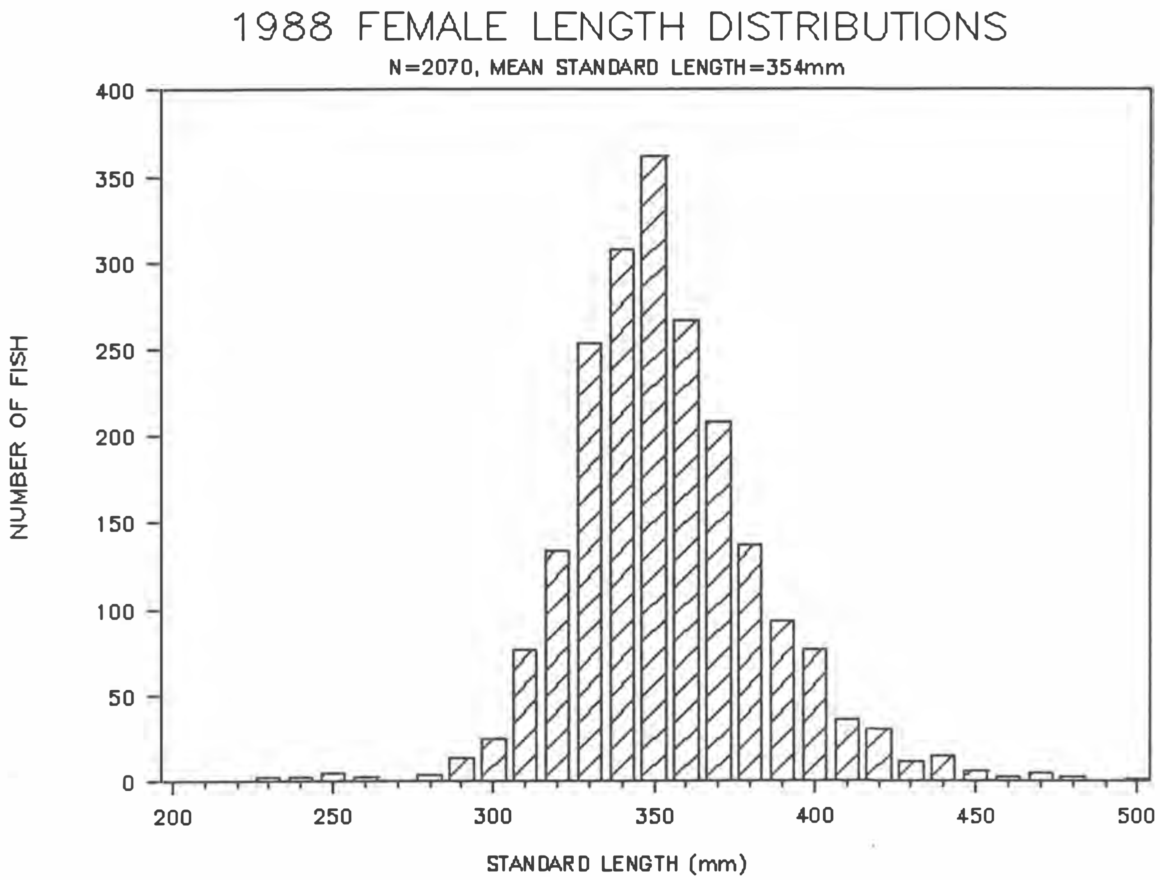


Figure 7 a: Annual size frequency distribution of female ocean jackets in the commercial catch; 1988 and 1989

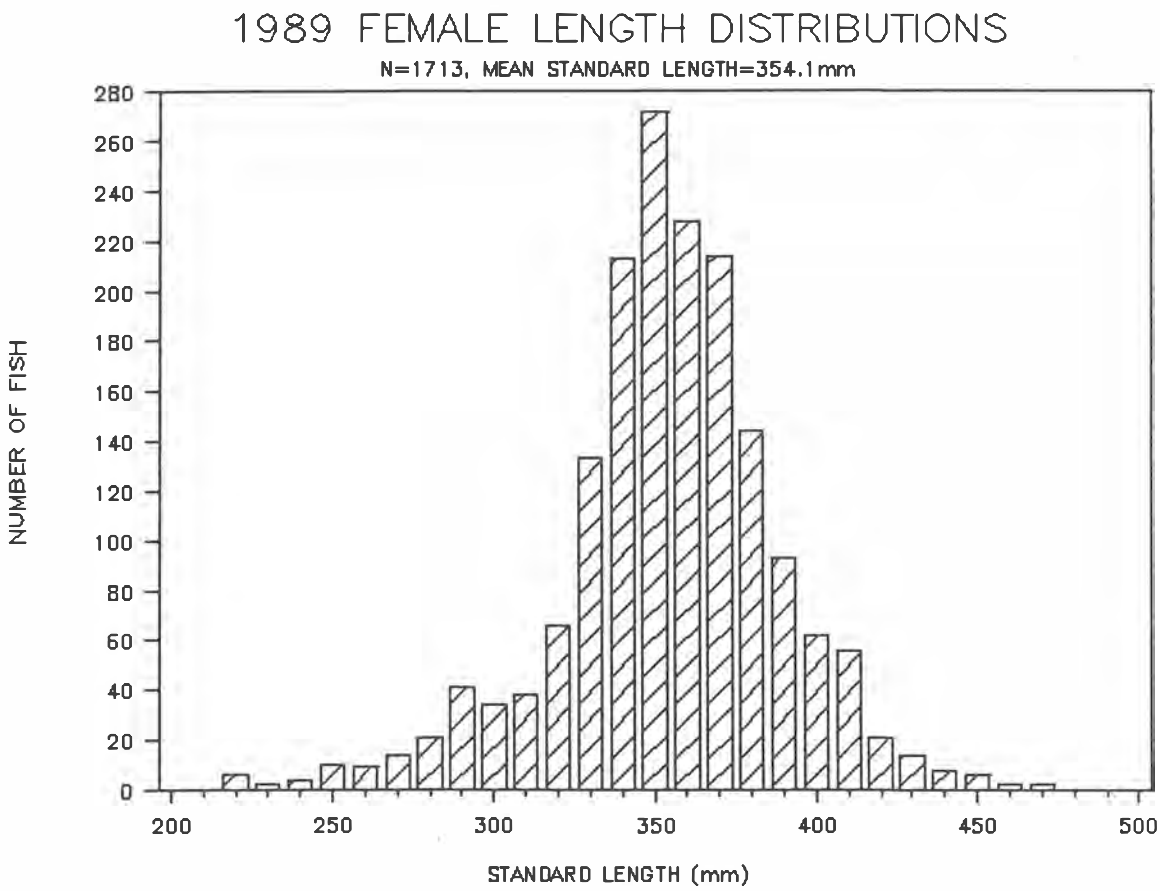


Figure 7b: Annual size fequency distribution of female ocean jackets in the commercial catch; 1988 & 1989

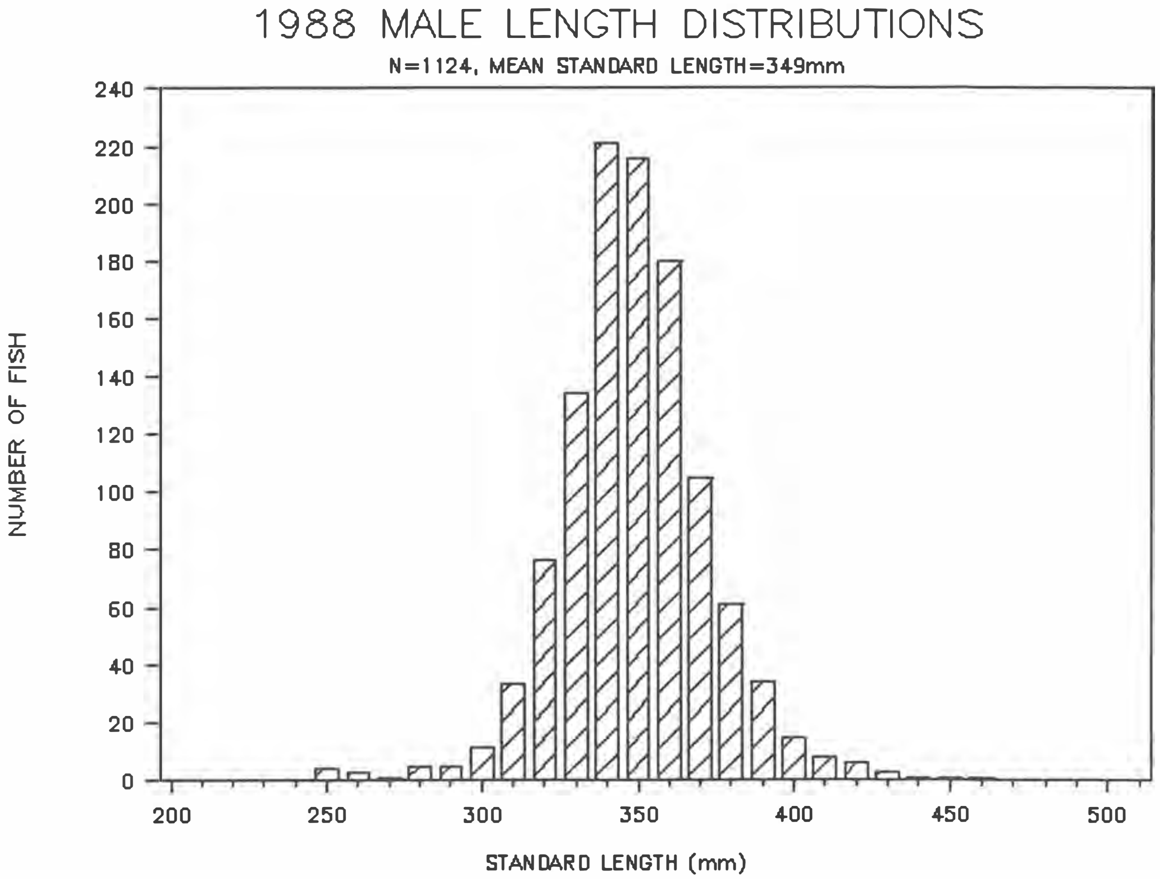


Figure 8a: Annual size frequency distribution of male ocean jackets in the commercial catch; 1988 & 1989

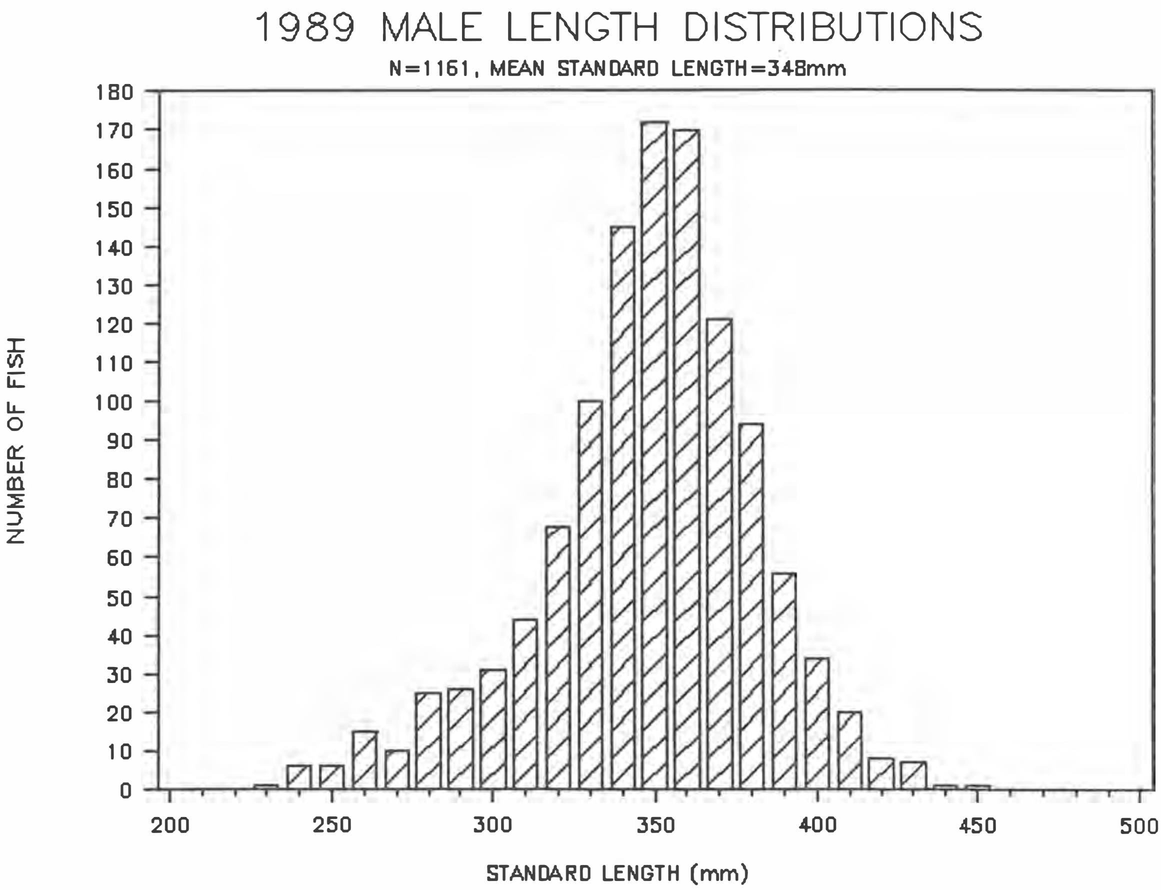


Figure 8b: Annual size frequency distribution of male ocean jackets in the commercial catch; 1988 & 1989

experience significant annual fluctuations in total catches and catch rates once it is fully developed. The magnitude of these fluctuations will depend on the exploitation rate and the extent to which environmental factors influence reproductive success or failure. The effects of reproductive success or failure will be felt in enhanced or reduced catches 3, 4 and 5 years after the event that influenced reproduction.

The effects of excess fishing would also take 3 to 5 years to be translated to reduced commercial catches because it takes that amount of time for the eggs to develop and grow to the size at which they are caught. Resource managers should therefore be aware of this lead time between changes in reproductive success and the subsequent recruitment to the fishery when considering actions which may influence reproduction.

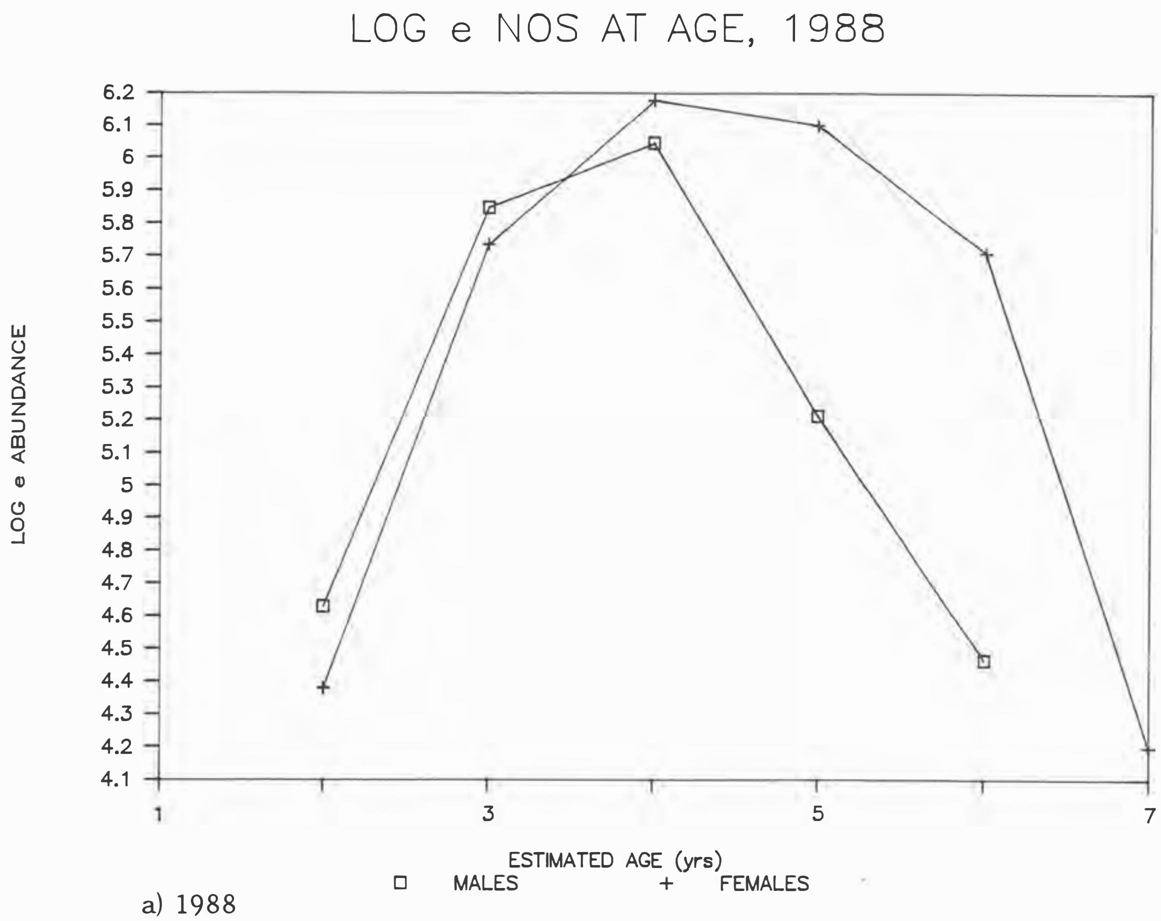
Table 8 Percent occurrence of age classes of each sex in samples of the commercial catch during 1988 and 1989.

	PERCENT OF CATCH					
	1988			1989		
Age	Male	Fem	Total	Male	Fem	Total
1	0	0	0	0	0	0
2	1	1	2	3	3	6
3	12	15	27	12	11	23
4	15	19	34	15	17	32
5	4	17	21	6	15	21
6	1	10	11	3	10	13
>6	1	4	5	1	4	5
Total	34	66	100	40	60	100

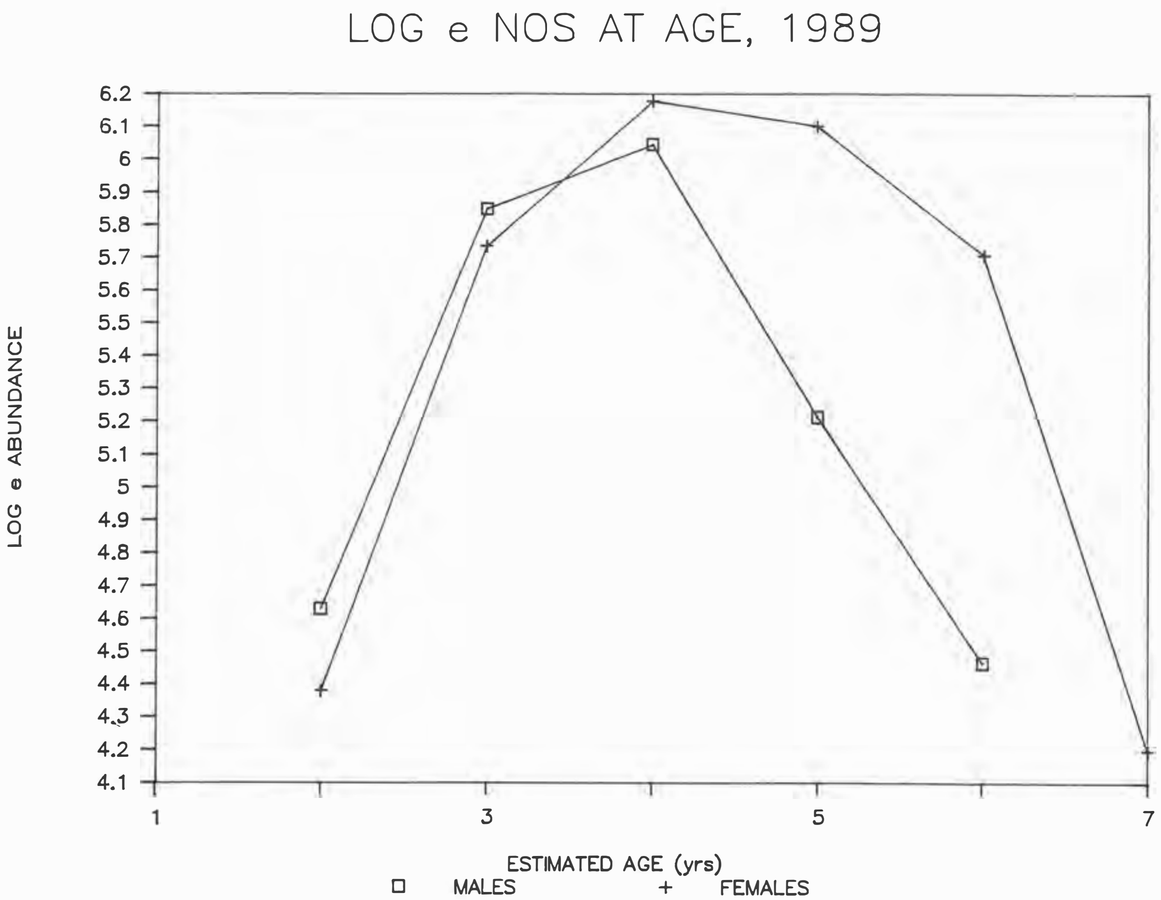
(iii) Sex Ratio

Females comprised 60-66% of the total catch due to their greater abundance in age classes five and six (Table 8 and Fig.10). Numbers of males and females were approximately equal in the two, three and four year classes but males were much less numerous than females in year classes 5, 6 and 7. This was the result of a higher natural mortality rate (3.7.4) and shorter life span (3.6.1) in males than females.

The alternative explanation that older females are more numerous than males of the same age because males changed sex or became less vulnerable to fishing gear due to behavioral changes or migration out of the fishing area were considered unlikely. All tagged male fish were recaptured as males and no gonads in

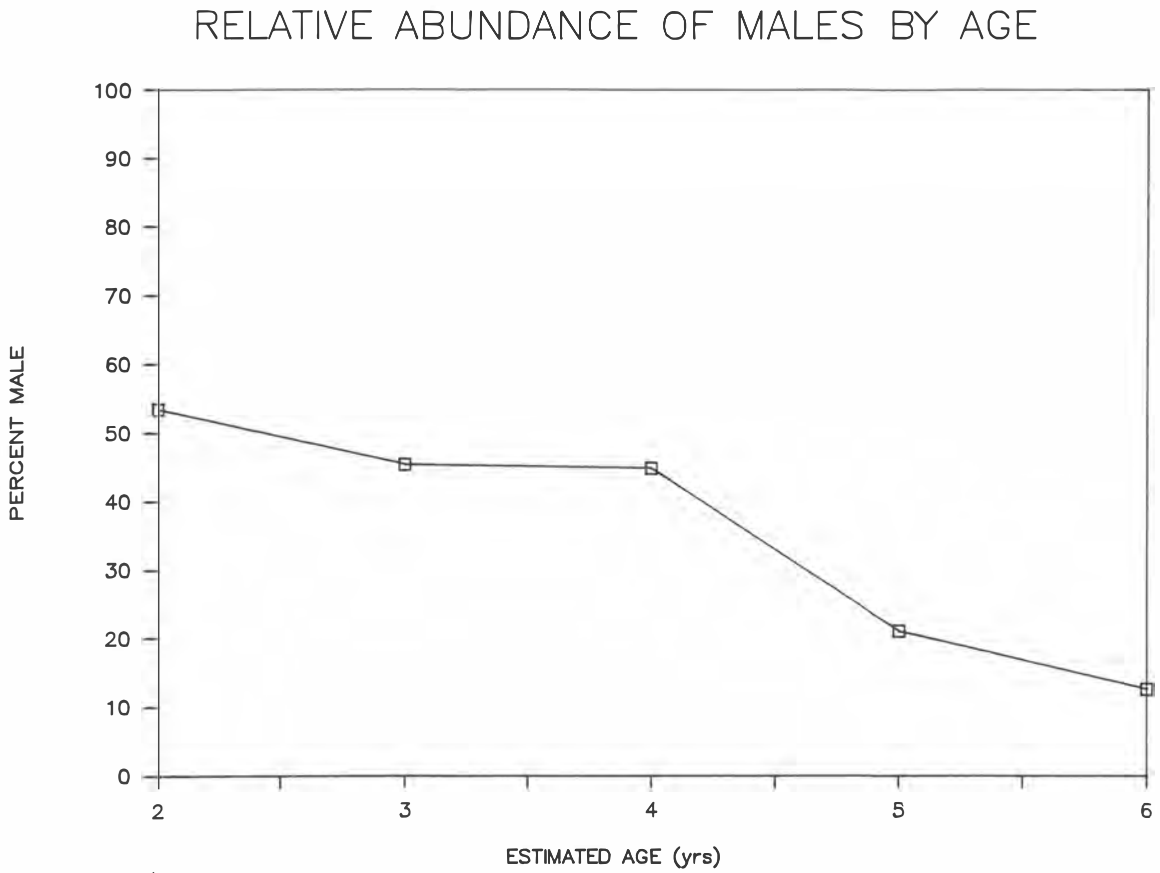


a) 1988

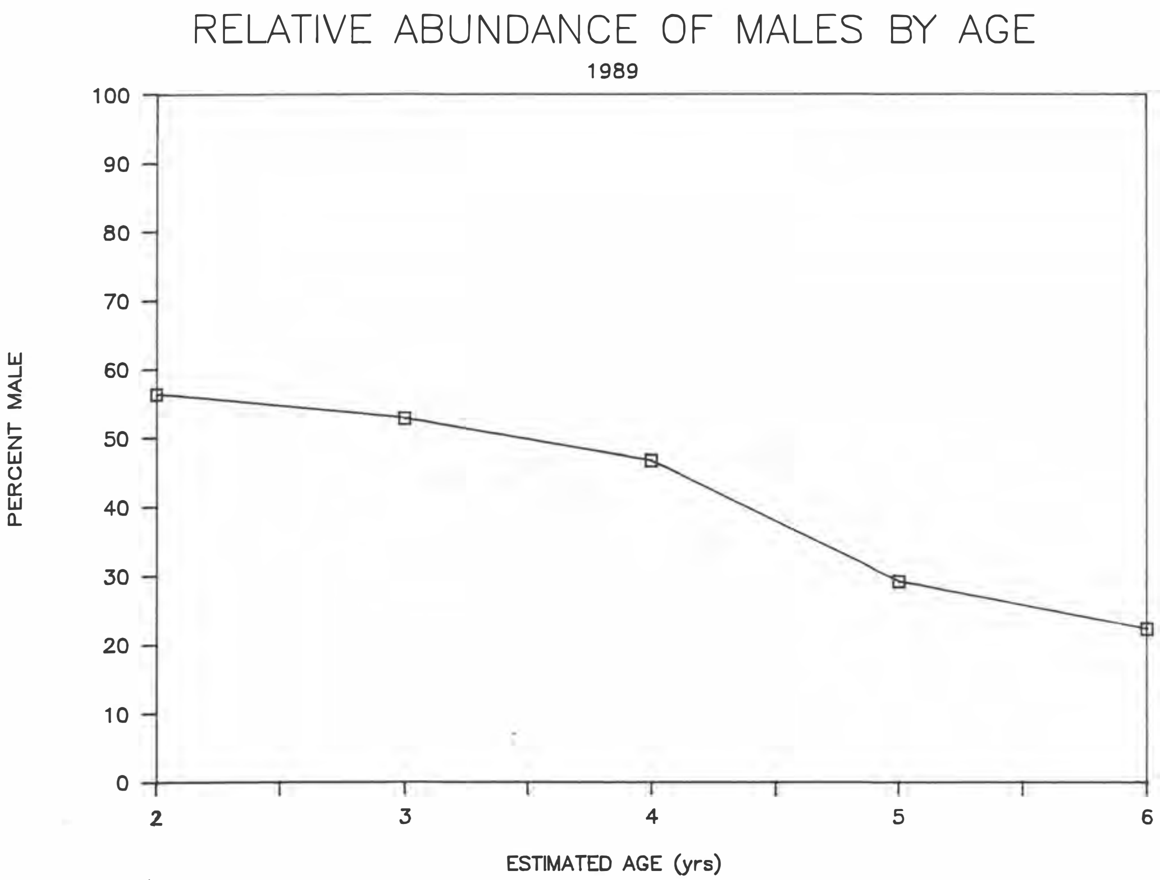


b) 1989

Figure 9: Log_e numbers of fish at age in the commercial catch in a) 1988 and b) 1989



a) 1988



b) 1989

Figure 10: Relative abundance of males by age in a) 1988 and b) 1989

transitionary stages between a male and female form were observed despite hundreds of dissections. Also, similar sex ratios for N. *ayraudi* (33:67 m:f) were reported by Lindholm (1984) using different sampling methods and sampling over a wider area which would not be expected if older males simply avoided traps or migrated out of the fished area.

One consequence of fishery development should be an eventual decrease in the number of large old fish (mostly females) in the catch. This will result in lower catch rates, a smaller average size and proportionally less females in the catch relative to present catches.

(iv) Sub Stocks

Fish populations comprise one homogeneous stock or from two to many sub stocks which may be considered as independent for management purposes. Fisheries comprising more than one stock can be managed separately according to the biological characteristics of each sub stock or zone. At present, there are insufficient data to determine the existence of sub stocks in the Australian ocean jacket population or within the South Australian management zone. Ocean jackets are common in the south east of the state, south of Kangaroo Island, in the eastern, central and western Bight and west at least to Perth. Ocean jackets are also common in New South Wales where they are fished commercially. There are no known physical barriers to migration between these areas and it is not known with certainty whether ocean jackets in each of these areas comprise from a few to several sub stocks with limited mixing between them, or if they comprise one large homogeneous stock. In the South Australian fishery, it would be useful to know the extent to which catches in the south east of the state and Kangaroo Island area are dependent on stocks originating in the eastern Bight, and the extent to which catches in the eastern Bight are dependent on stocks from the central Bight.

Tagging studies demonstrated there was some mixing between the south-east and west coasts of South Australia when two small fish tagged in the eastern Bight were recaptured in the south east (at Robe and Cape Jaffa). All other recaptures were made within the eastern Bight area however, demonstrating that some fish were sedentary and suggesting that movement between regions may be restricted to younger age classes. It is suggested that immature fish aged one to three years (sub-recruits) are highly mobile, undertaking offshore as well as potentially long distance long shore migrations but that mature fish are relatively sedentary, undertaking seasonal spawning migrations while staying within the same general region. Further studies are required to determine the movement patterns of immature fish, and consequently the dependence of catches in one area on reproduction and emigration from other areas. Data are also required to map the presence and extent of spawning grounds and nursery areas in the south-east and determine the extent to which ocean jacket populations in the south-east are dependent on reproduction from the Great Australian Bight.

3.3 Juvenile Populations

Inshore studies of larval and juvenile leatherjackets were undertaken in Boston Bay (Fig.2) between March 1989 and May 1990 inclusive. The primary objective of this aspect of the study was to determine the growth rate of juvenile N. ayraudi using modal progression techniques. Modal progression estimates the average population growth rate from increases in the modal lengths in a time series of fish length samples. It is a particularly useful method for estimating growth rates in young fish. It was assumed that the juveniles sampled were produced during a short spawning period the previous autumn (assigned common birthdays of May 1st) which resulted in length frequency distributions with a single mode corresponding to the lengths of fish produced during the peak of the spawning period and growing at an average rate. It was also assumed that sampling was unbiased with respect to size.

3.3.1 Seasonal Occurrence

In Boston Bay, juvenile N. ayraudi were present in trap samples collected between the months of December and May but absent in those taken between June and November inclusive. This indicates that eggs hatched offshore during late April appeared the following December as seven month old small but fully formed juveniles. Juvenile ocean jackets were absent in samples dabbed from surface floating inshore drift algae, indicating the pre settlement association with drift algae common in some other leatherjacket species (Kingsford and Milicich, 1987; Hutchins and Swainston, 1986) was absent in N. ayraudi. Settled juvenile ocean jackets remained in the inshore nursery area during summer and autumn, before emigrating offshore between May and June at age 12-13 months.

Catches of 0+ year old juveniles were highest during February 1990 (Table 9) then declined during March, April and May. Decreasing catches during this period could indicate a prolonged period of emigration offshore, or, indicate the traps used were more efficient at catching smaller fish of the size most common in February than the larger fish most common during later months. Observations made while diving suggest that juveniles were still abundant during March and April although fewer were caught in research traps.

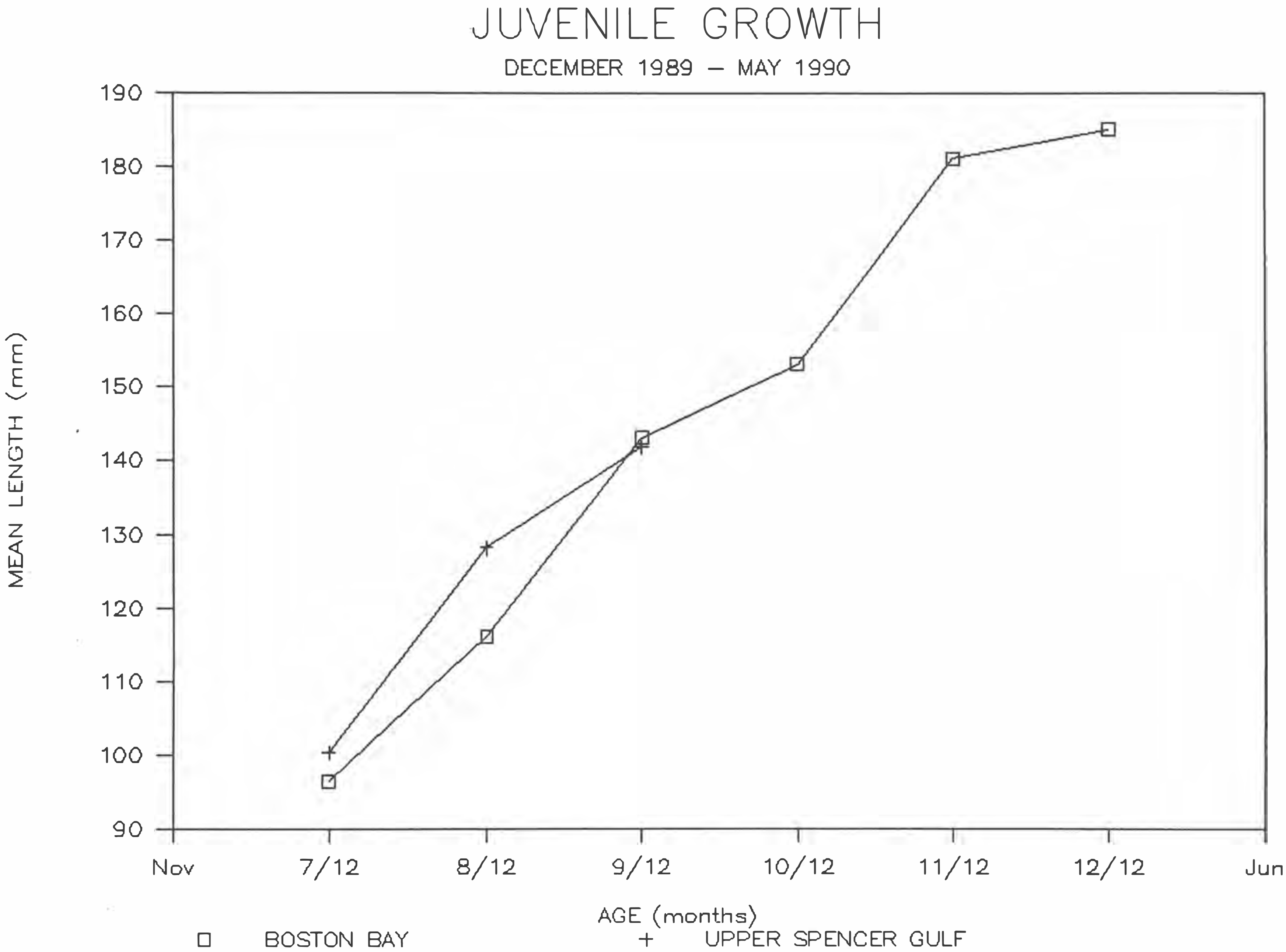


Figure 11: Growth rates of juvemnile ocean jackets

In view of the findings that catch rates in the adult fishery were highly sensitive to trap dimensions (Appendix I), catches of juveniles may be improved in future by similarly varying trap dimensions. It is concluded that the main movement of 0+ year old juvenile fish out of the inshore nursery areas occurs during May at age 12 months.

3.3.2 Growth

The mean length of juveniles sampled in Boston Bay increased from 96.5 mm at age 7 months in December 1989 to 181 mm at age 12 months in May 1990 (Fig.11 and Table 9). By June 1990, 1+ year old juveniles had migrated offshore and were therefore absent in the inshore sampling program. Although generally poorly represented in the commercial catch, significant numbers of juveniles averaging 254 mm standard length were caught in the commercial sample collected in March 1989 and were aged at two years old using the vertebral ring technique. Two one year old juveniles maintained in aquaria for 8 months and 12 months grew at a rate consistent with results obtained using modal progression techniques as did juveniles sampled from Upper Spencer Gulf over three consecutive months (Fig.11). Together these data indicated a rapid growth rate for juvenile N. ayraudi to reach a mean standard length of approximately 180mm at age one year and approximately 250mm at age two years.

3.3.3 Geographic Distribution

(i) 0+ Year Old Fish

Sightings of 0+ year old juveniles smaller than approximately 200mm standard length were reported from Spencer Gulf, western Investigator Strait and the west coast bays (Fig.12), indicating that the western waters of the state are important nursery areas for N. ayraudi juveniles under one year old. The reports suggested that juvenile abundance increased with increasing distance west. For example, prawn trawlers operating near Ceduna and in Anxious Bay reported occasional large catches of juvenile N. ayraudi while they are relatively uncommon in the by-catch of Spencer Gulf prawn trawlers (the small leatherjackets commonly caught in large quantities by Spencer Gulf prawn trawlers are male and female Degen's leatherjacket, Thamnaconus degeni). Juvenile ocean jackets have not been reported from Gulf St. Vincent despite several years of extensive and systematic surveys of prawn and juvenile marine scalefish species conducted by the South Australian Department of Fisheries that should have detected ocean jackets had they been present. The lack of reports of ocean jackets from Gulf St. Vincent suggests the area is not a significant nursery area for 0+ year olds or habitat for 1+ year old juveniles or adults. The nursery status of the inshore waters of the

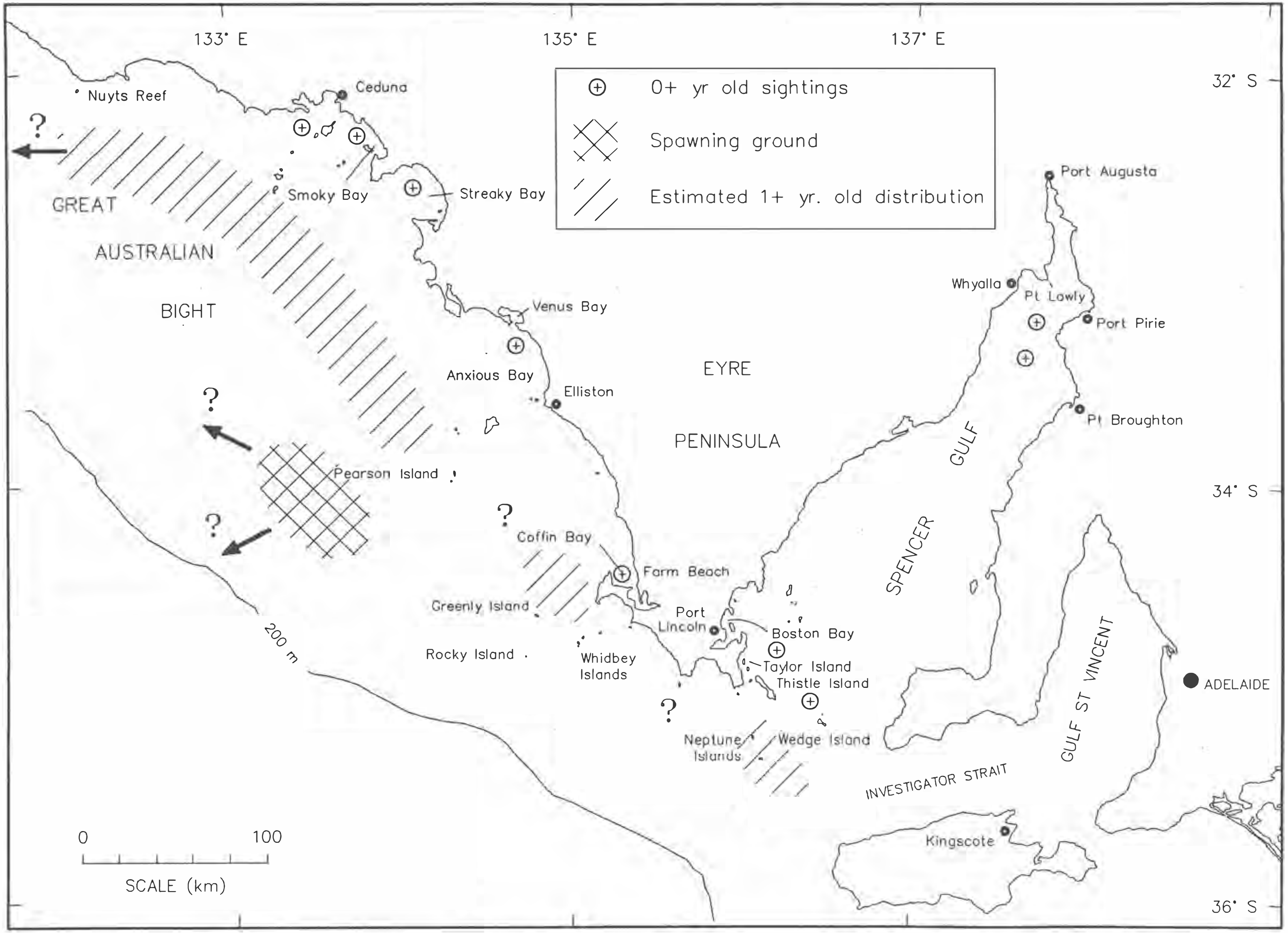


Figure 12: Distribution of juvenile ocean jackets and adult spawning areas.

south east is unclear due to a lack of systematic surveys and reported sightings by fishers, although adult fish are known to occur in offshore waters.

Table 9 Juvenile sampling details

Sample Date	Age (months)	Sample Size	Mean Length (mm)	Size Range (mm)	Standard Deviation (mm)
15/12/89[a]	8	2	96.5	93-100	3.0
12/01/90[a]	9	107	116	85-146	11.2
13/02/90[a]	10	266	143	108-178	11.5
05/03/90[a]	11	54	153	133-185	10.9
11/04/90[a]	12	16	181	126-202	17.1
10/05/90[a]	13	13	185	161-222	15.5
15/03/89[b]	22	49	254	230-300	18.3

[a]; caught in Boston Bay, [b]; caught on commercial fishing grounds.

In addition to 0+ year old juvenile N. ayraudi taken monthly in Boston Bay by the investigators, confirmed sightings (specimens seen) were reported by anglers at Dangerous Reef near Port Lincoln and Farm Beach in Coffin Bay (both sightings in April). Further sightings were reported by prawn fishers in both the central area of upper Spencer Gulf between Port Broughton and Point Lowly during December and February and between Lounds Island and Goat Island near Ceduna in November. Research staff of the Department of Fisheries caught 0+ year old juveniles during April using a Danish seine net in lower Spencer Gulf near Wedge and Thistle islands. Unconfirmed but reliable sightings (specimens not seen but reporter interviewed) of 0+ year old fish were also reported during summer and autumn months by anglers fishing for King George whiting (Sillaginodes punctata) at Farm Beach, Smoky and Streaky bays, and by prawn trawlers operating in Anxious Bay. The location of sightings and assumed distribution of 0+ year old fish is shown in figure 12.

It is concluded that the inshore waters of the eastern Bight are of major importance and the waters of Spencer Gulf and Investigator Strait of minor importance as nursery areas for ocean jackets. Gulf St. Vincent is probably not a nursery area for ocean jackets. The inshore waters of the south east of the state cannot be assigned nursery status with any certainty due to limited observations.

(ii) 1+ Year Old Fish

At the end of their first year, juveniles emigrated out of Spencer Gulf and the west coast bays to the more open waters of the continental shelf. Data on the distribution of 1-2 year olds are incomplete, however commercial fishers (J. Lennell, B. Cuddeford, personal communication) reported large numbers of 180-250 millimetre ocean jackets in waters 40-80 metres deep between Pearson Island and Nuyts reef (Fig.12), suggesting that this age class inhabits waters deeper than the nursery areas of 0+ year old fish but shallower than the commercial fishing grounds. Very few 1-2 year old fish were caught by commercial vessels operating at depths greater than 80 metres. Furthermore, a special trap made with small 15mm X 15mm meshes designed to catch small fish and deployed on the main commercial fishing grounds (ie waters deeper than 80 metres) by the investigators on several separate occasions over several months failed to catch fish less than two years old. These results indicate the general absence of 1-2 year old fish in commercial catches was due to their rarity in the areas fished and not to escapement from large meshed commercial traps.

1+ and 2+ year old fish were thought to represent the main dispersive phase of the life cycle, migrating from the inshore nursery areas toward the offshore adult habitat and also along the coast. Tagging studies revealed the movement of two small fish aged 2+ from waters of the eastern Bight to the waters of the south east near Robe and Cape Jaffa but the extent of juvenile migration patterns remains unclear. Density dependent migrations of juveniles from lightly fished (eg. the central Bight) to fished areas may be important in maintaining high catch rates on the commercial fishing grounds and should be investigated in a juvenile tagging program.

3.4 Morphometrics

3.4.1 Length Measurements

(i) Total Length to Standard Length

The relationship between standard length and total length was found to be strongly linear over the range 230-535mm standard length (Fig.13), the equation being;

Total length(mm) = 1.10 standard length(mm) + 22.48

The regression was calculated from a sample of 199 fish and had a regression coefficient of 0.99 (Fig.13). The reciprocal relationship was;

Standard length(mm) = 0.90 total length(mm) - 17.81.

(ii) Fin Length to Standard Length

The relationship between dorsal fin length and standard length was linear over the range 225-415mm standard length (Fig.13) with a regression coefficient of 0.92. The equation was;

Standard length(mm) = 3.86 dorsal fin length(mm) - 16.30

Standard length measurements calculated from fin length measurements were subject to considerable scatter (Fig.14) despite having a relatively high regression coefficient and were not considered suitable for routine determination of the length frequency composition of the catch.

3.4.2 Weight Relationships

(i) Length to Weight

Monthly samples of approximately 60 fish comprising equal numbers of males and females in <30, 31-32, 33-34, 35-36, 37-38 and >38 cm size classes were weighed and measured routinely on shore. Results (Fig.15) conform to the generalised cubic length to weight relationship with the form;

$W=aL^b$

where W = weight (kg)

and L = standard length (mm)

Parameters a and b were estimated by taking logarithms of both sides of the equation to give the straight line function

$\log W = \log a + b \log L$

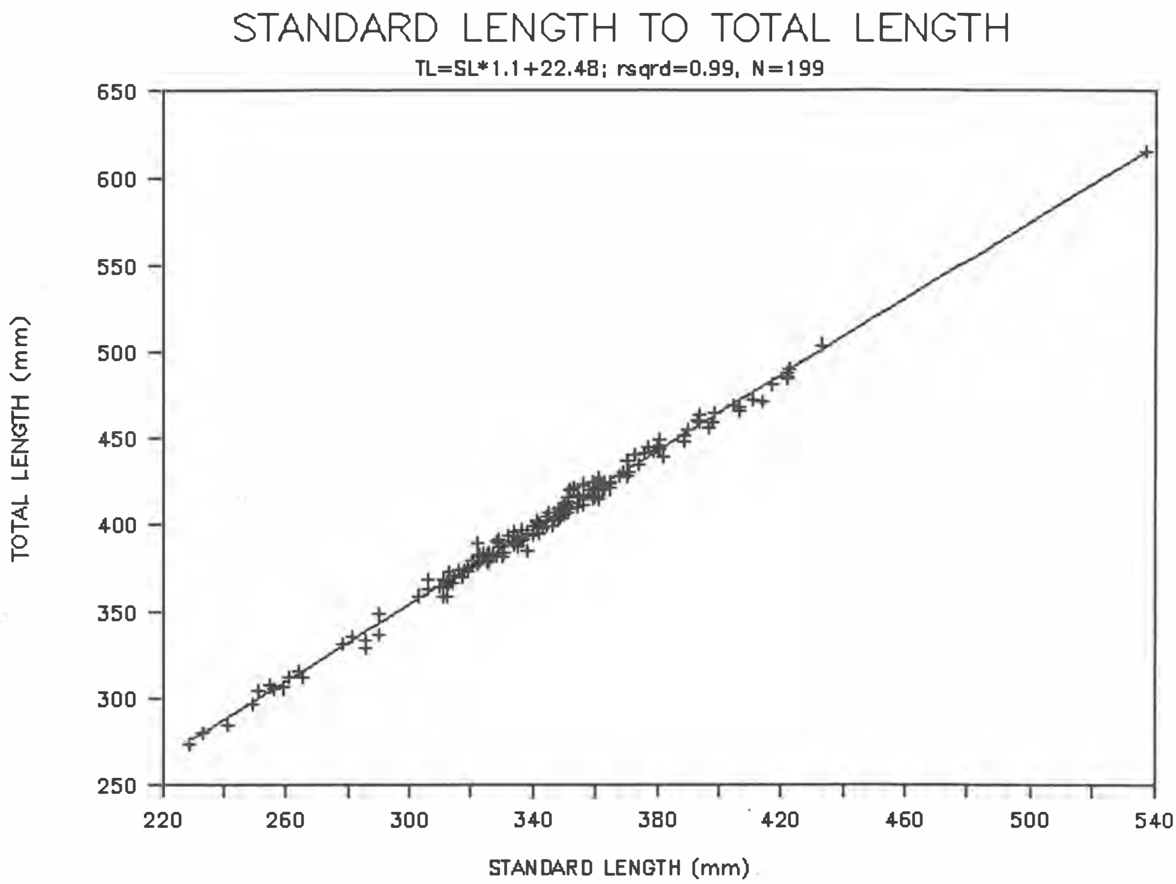


Figure 13: Standard length to total length relationship

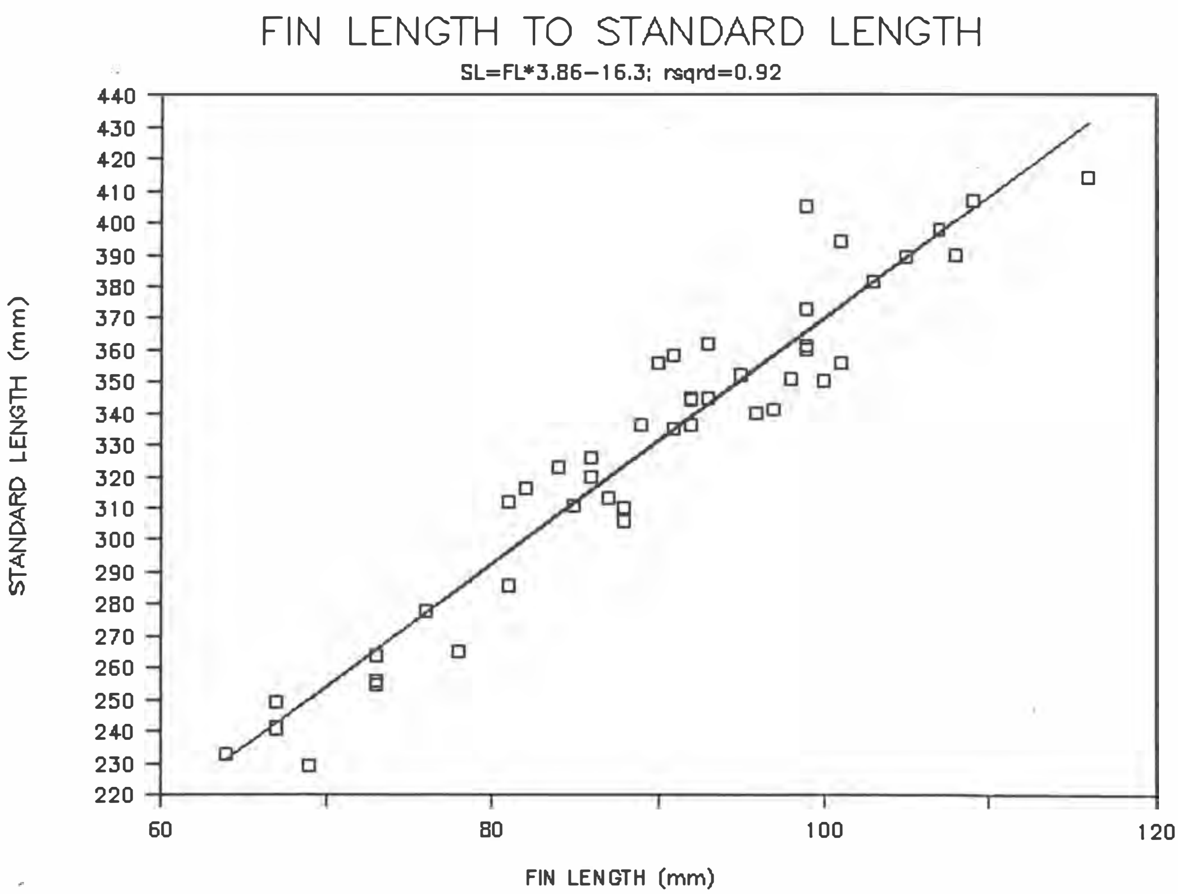


Figure 14: Fin length to standard length relationship

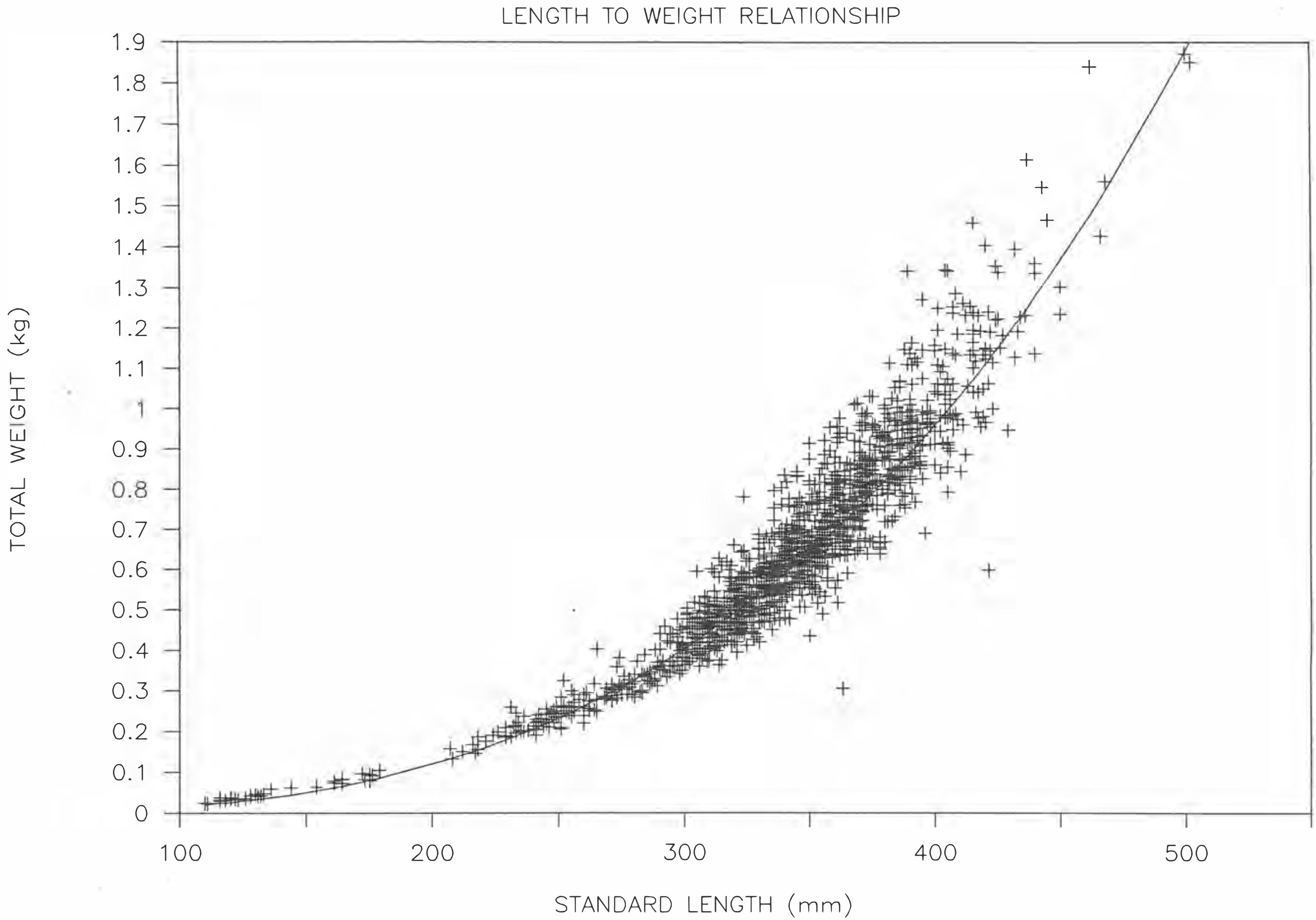


Figure 15: Length to weight relationship

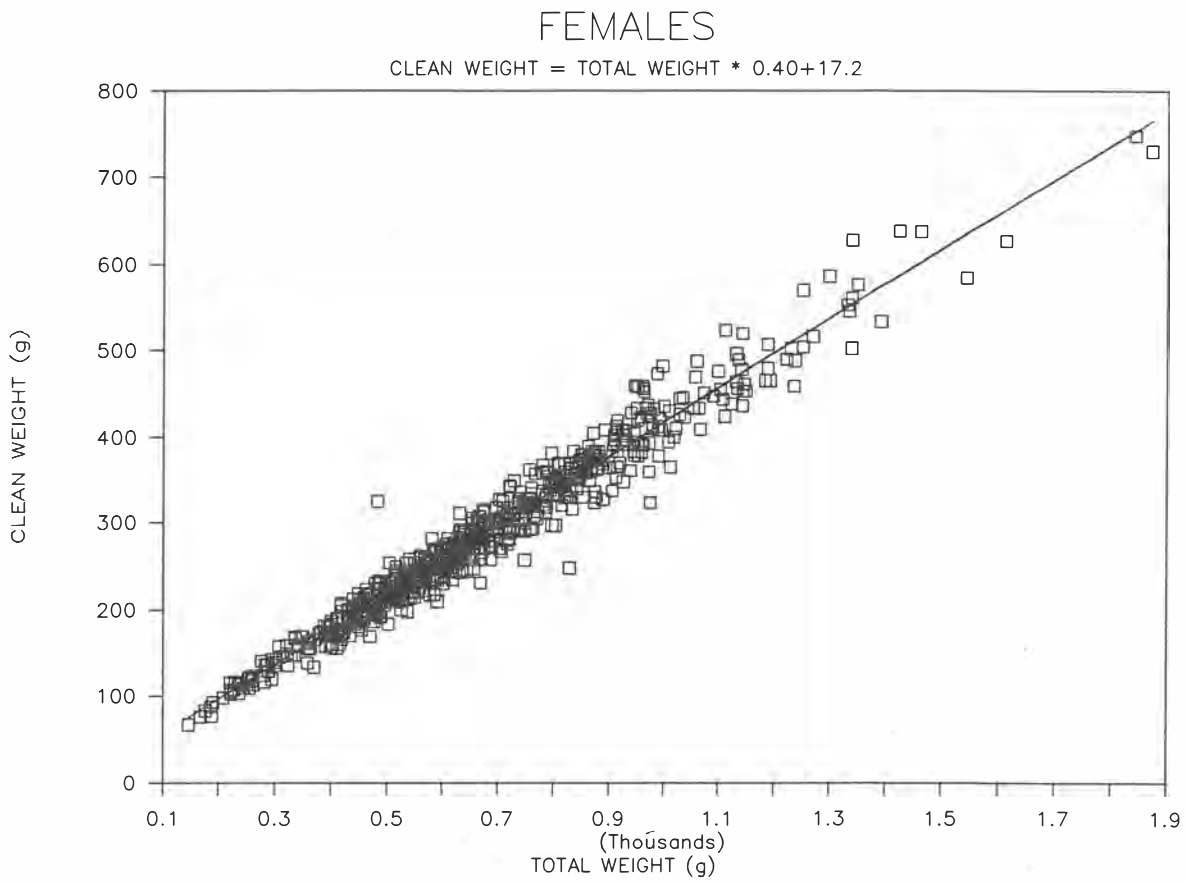


Figure 16: Clean weight to total weight relationship; female ocean jackets

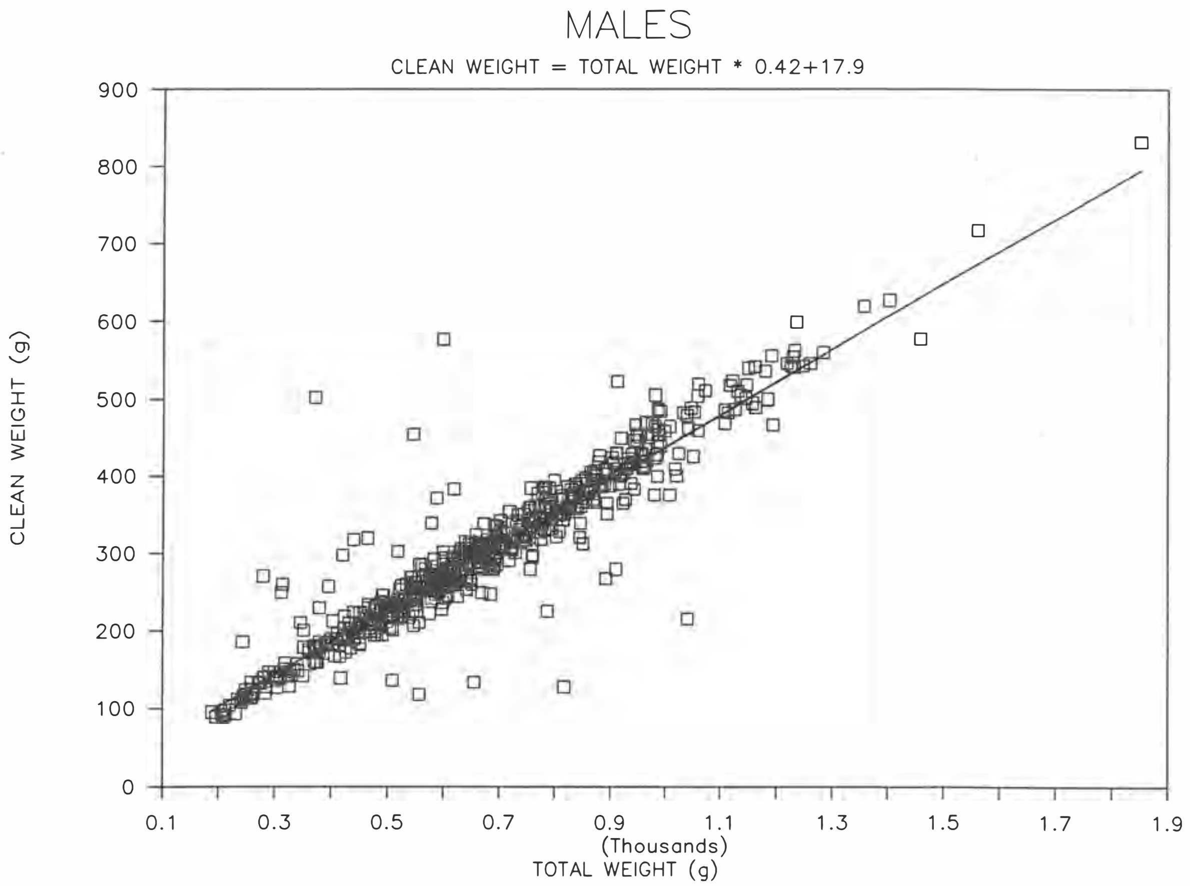


Figure 17: Clean weight to total weight relationship; male ocean jackets

then regressing log W on log L and solving for a (y intercept) and b (slope).

Solutions for a and b are given in table 10 The length to weight relationship was similar for both males and females but different between juveniles and adults. These results are reflected in different b values in juveniles and adults but similar b values between male and female adults. The equation

$$\text{Total weight(kg)} = (1.41 \times 10^{-8}) \times \text{Standard Length(mm)}^{3.01}$$

described the relationship between standard length and total weight for fish longer than 216mm.

Table 10. Length to weight relationships for N. ayraudi. (Weights in kg, standard lengths in mm) [1]Results include juveniles; [2]results exclude juveniles.

	sample size	a ($\times 10^{-8}$)	b	r^2	size range
Juveniles only	52	8.91	2.68	0.99	110-304
Females[1]	731	3.54	2.86	0.97	110-500
Males[1]	697	3.09	2.88	0.97	110-502
Sexes combined[1]	1376	2.82	2.89	0.95	110-502
Males[2]	645	1.28	3.03	0.92	226-502
Females[2]	679	1.42	3.01	0.90	216-500
Sexes Combined[2]	1324	1.41	3.01	0.912	216-502

(ii) Total Weight to Cleaned Weight

Ocean jackets are headed and gutted at sea and sold as trunks with the skin intact. They are not generally filleted because bony swellings of the vertebrae and ribs prevent a clean fillet being taken. Total or whole weight to cleaned weight relationships for 679 females and 643 males are shown in figures 16 and 17. The relationship was similar for both male and female fish and sex can be ignored when converting between cleaned and total weights. The relationship between cleaned weight and total weight for 1322 fish of both sexes was described by the equation:

$$\text{Cleaned Weight(g)} = \text{Total Weight(g)} \times 0.41 + 15.7$$

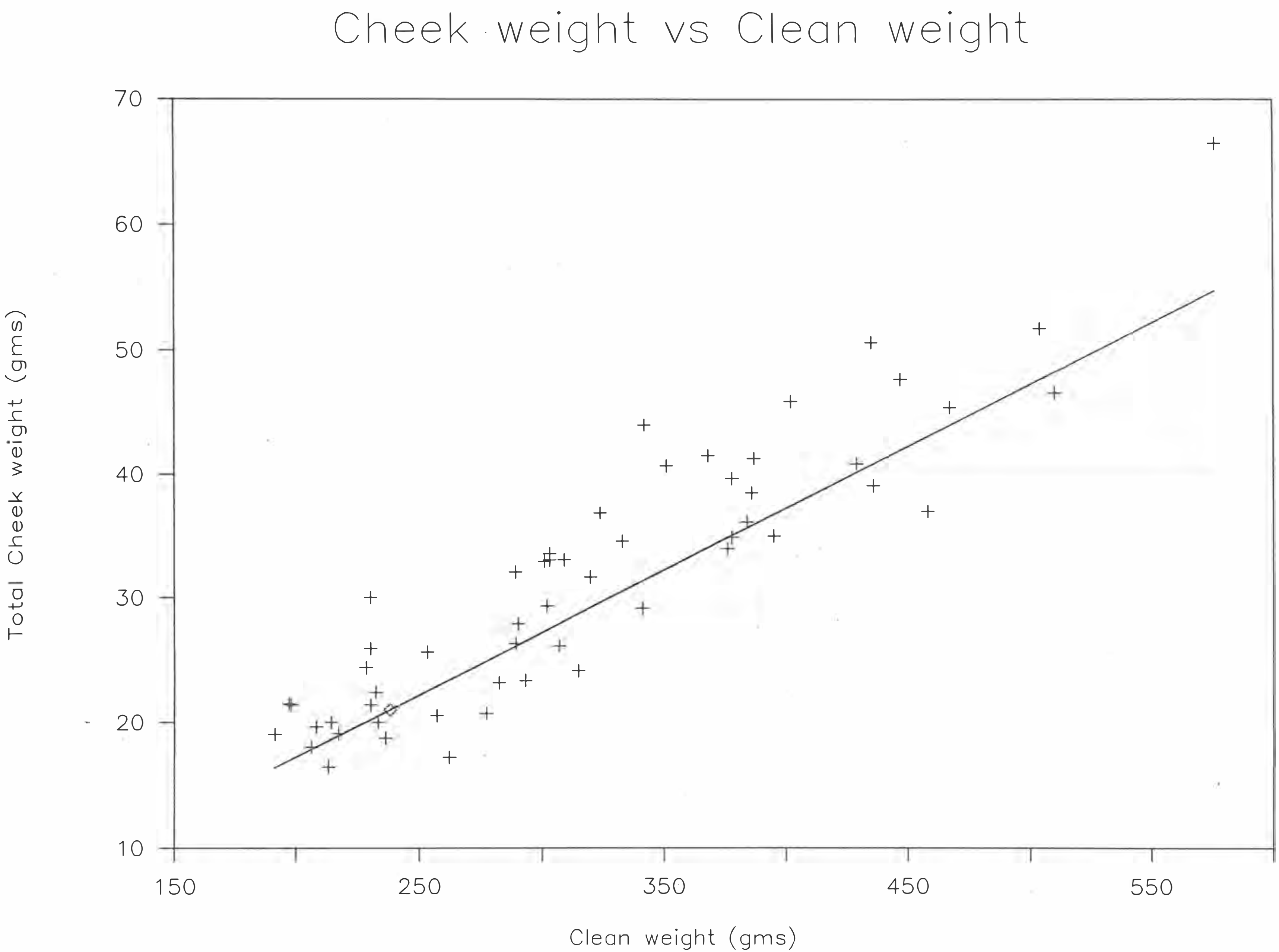


Figure 18: Cleaned weight to cheek weight

The reciprocal relationship was

Total Weight(g) = Cleaned Weight(g) X 2.23 + 15.4

Total weights included the weight of food and bait in the gut and to adjust for this a conversion factor of 1:2.1 was routinely used to convert ocean jacket cleaned weights to total weights. For other leatherjacket species, a conversion factor of 1:1.7 was used to convert cleaned weights to whole weights.

(iii) Cleaned Weight to Cheek Weight

The head and viscera are normally discarded at sea, however the upper jaw muscles are sometimes removed and sold separately to the cleaned trunks. The pair of muscles removed are the adductor mandibulae, attached anteriorly to the premaxillae of the upper jaw and known to fishers as cheeks, cheek fillets or eye fillets. The relationship between cheek weight (both muscles) and cleaned weight is shown in figure 18.

Cheek weights average 10.4% of the cleaned weight or 4.6% of the total weight (46 tonnes cheek weight per 1000 tonnes total weight = approx. 880 kg per week at current catch rates). Cheek meats hold together when cooked because each fillet is a single muscle and preliminary market research conducted by the fishers indicates a potentially high market acceptance. However, cheek meats are not usually kept because of the high labour cost of their recovery.

3.5 Reproductive Studies

3.5.1 Spawning Season

Maximum monthly female GSI values were recorded during April in 1988, 89 and 90 (Fig.19) and indicated *N. ayraudi* spawns during autumn. In 1989 and 1990, female GSI values increased rapidly from March to April then declined rapidly between April and May (Fig.19), indicating a relatively short spawning period with an April peak. MOD values (Fig.22) also indicated spawning occurred during April. Advanced oocytes with diameters greater than 0.5mm and thought to be ripe for ovulation were found only during April (Fig.22). Samples taken during March and May contained only immature oocytes smaller than approximately 0.35mm diameter (Fig.22) and were thought to represent the pre (March) and post (May) spawning conditions respectively.

In 1988, the maximum GSI was significantly lower than maxima recorded in 1989 and 1990 (Fig.19) indicating the 1988 sample was not taken from fully gravid fish. The 1988 sample was collected approximately 20 nautical miles south of Greenly Island (Fig.12), while those of 1989 and 1990 were both collected further into the

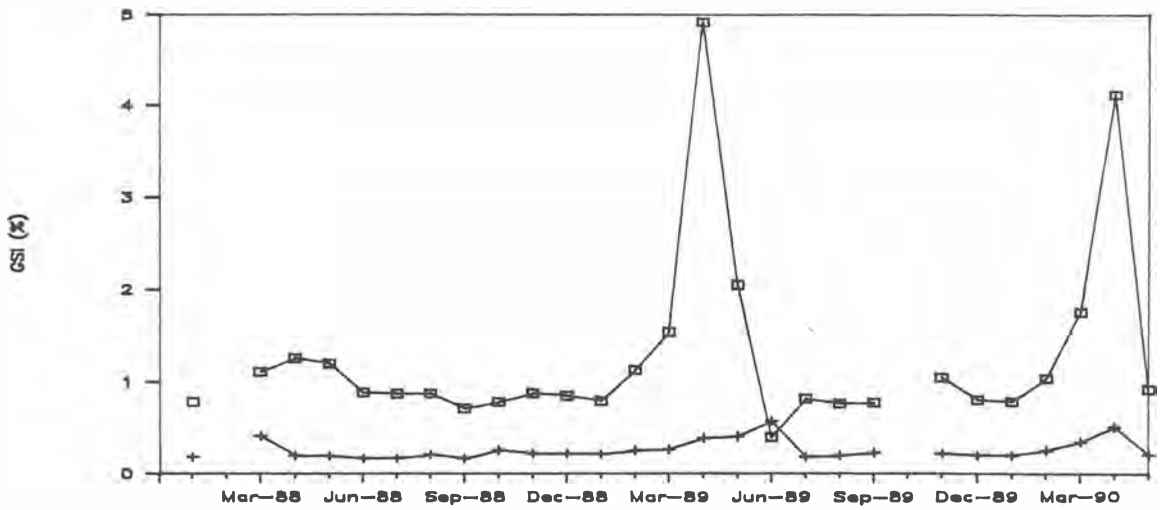
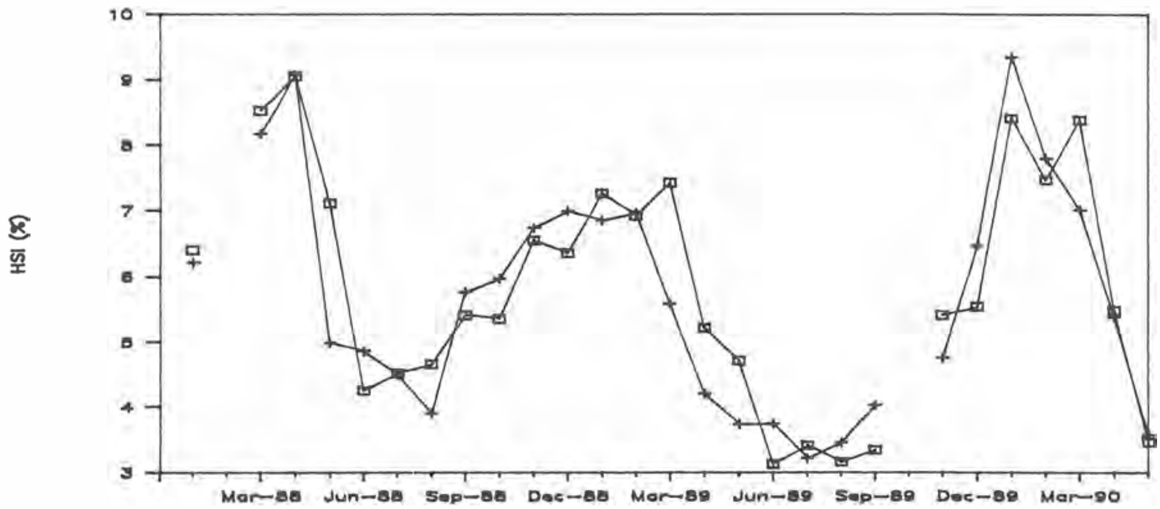


Figure 19: Monthly gonad indices



Figures 20: Monthly hepatic indices

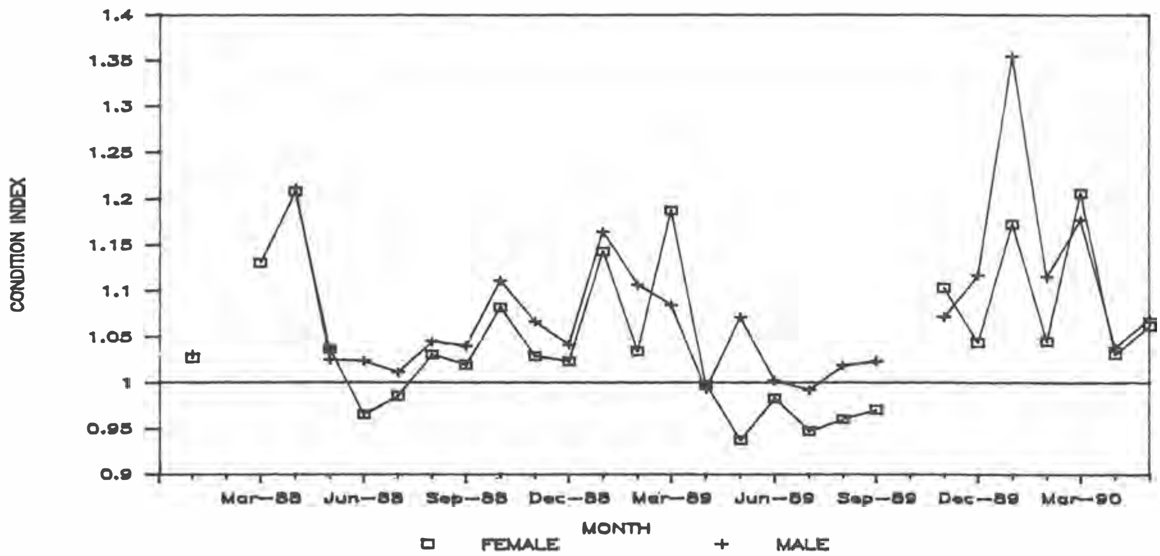


Figure 21: Monthly condition indices

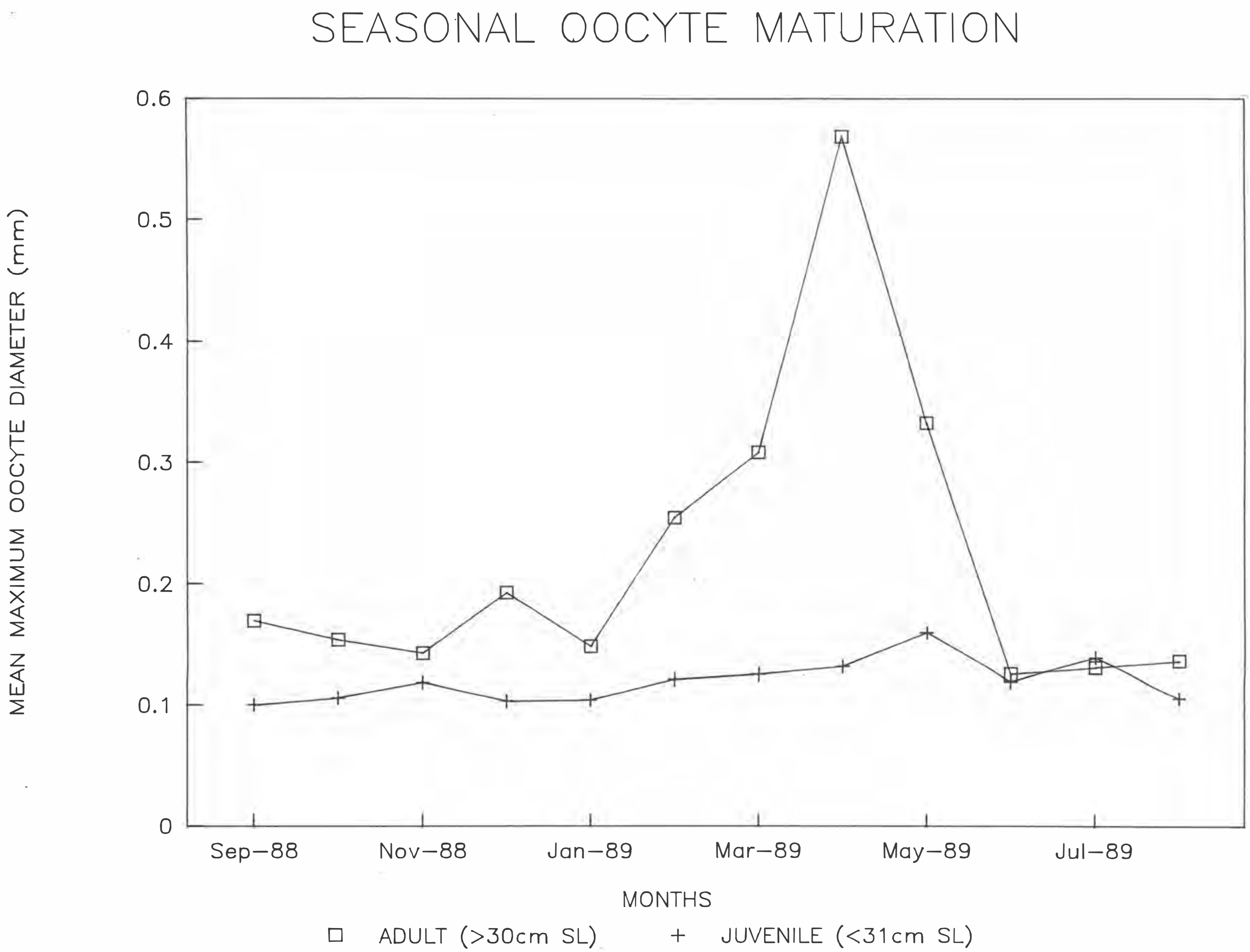


Figure 22: Seasonal oocyte maturation.

Bight over 30nm west of Pearson Island. These data indicate spawning occurs in particular areas at a particular time of year, and specifically that spawning took place during April in the area west of Pearson Island but not in the area south of Greenly Island. The spawning grounds are probably more extensive than these data indicate but further surveys would be required to identify the entire area over which spawning occurs. On the basis of these observations together with those for juvenile distribution and abundance, which appears to increase with increasing distance west of Spencer Gulf, it is suggested that the offshore waters of the Great Australian Bight are the major and possibly only spawning grounds for Nelusetta ayraudi in South Australia.

Male GSI values peaked during autumn in 1988, 1989 and 1990 (Fig.19). The peaks for males occurred one month earlier than that for females in 1988, two months later in 1989 and then coincided exactly with the female peak in 1990. Male GSI values may not therefore be as useful as female GSI values in identifying the exact time of spawning. This may be due to males producing sperm over a longer period than is actually required for spawning purposes. It was concluded that male reproductive studies are of limited use in determining spawning activity in N. ayraudi.

(i) Duration of Spawning

Oocyte size frequencies were examined in three female fish aged two, three and seven years (Fig .23) collected in April 1990 just prior to the anticipated spawning period. Oocyte size frequencies have been used as an indication of the dynamics of maturation in studies of other fish species (Clark, 1934; De Silva, 1973) although use of the technique has been criticised (West, 1990). Multiple modes may suggest multiple spawning, a bimodal distribution synchronous spawning while the presence of oocytes of all sizes may suggest spawning occurs over a protracted period. The pattern found in N. ayraudi (Fig.23) shows oocytes of all sizes were present prior to spawning but that small (<.375mm) oocytes were more common than larger (0.375-0.625mm) ones. These results together with those for the monthly changes in Maximum Oocyte Diameters (Fig.22) and mean Gonado Somatic Indices indicate spawning probably occurred on more than one occasion over a period of less than one month. It was concluded that spawning occurred between mid April and mid May and May 1st was assigned as the average birth date for ageing studies.

(ii) Size and age at First Spawning

The results indicated a minimum size at first spawning of approximately 31cm. The ovaries of most fish smaller than 31cm contained small oocytes that did not increase significantly in mean diameter during the autumn

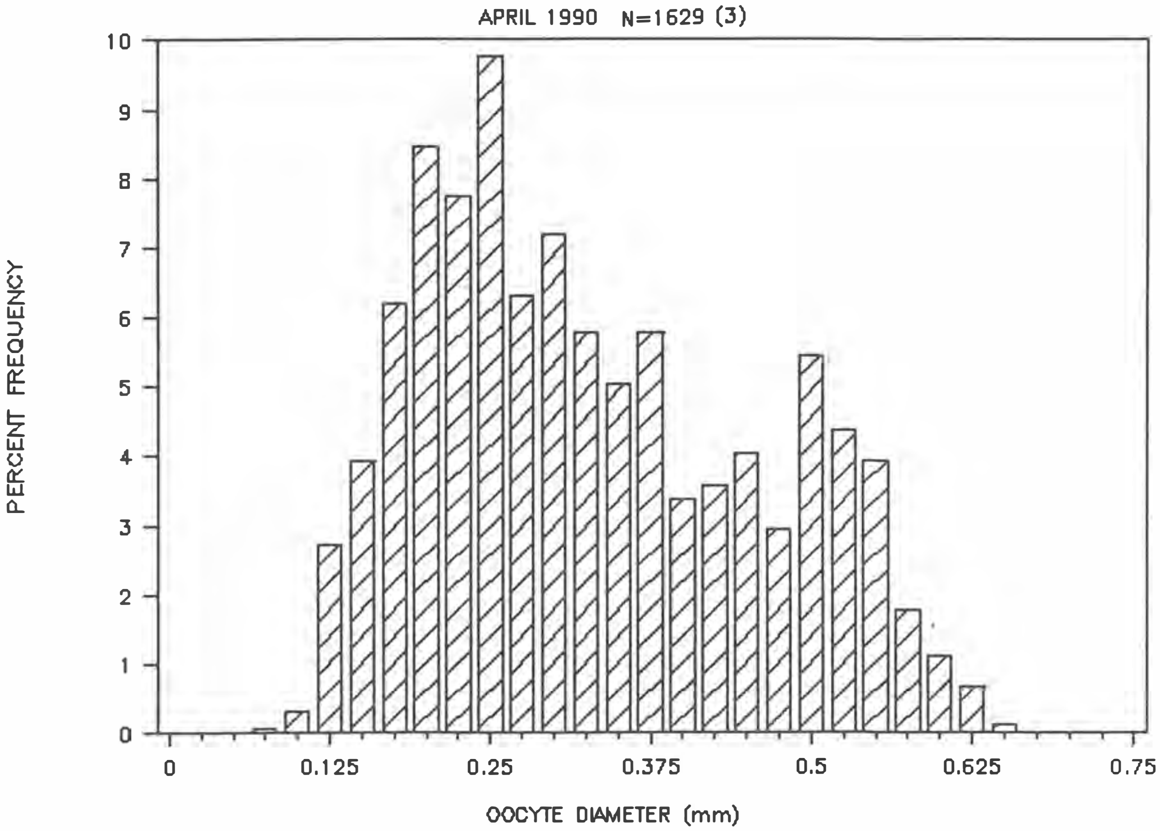


Figure 23: Oocyte size frequency distributions in gravid fish

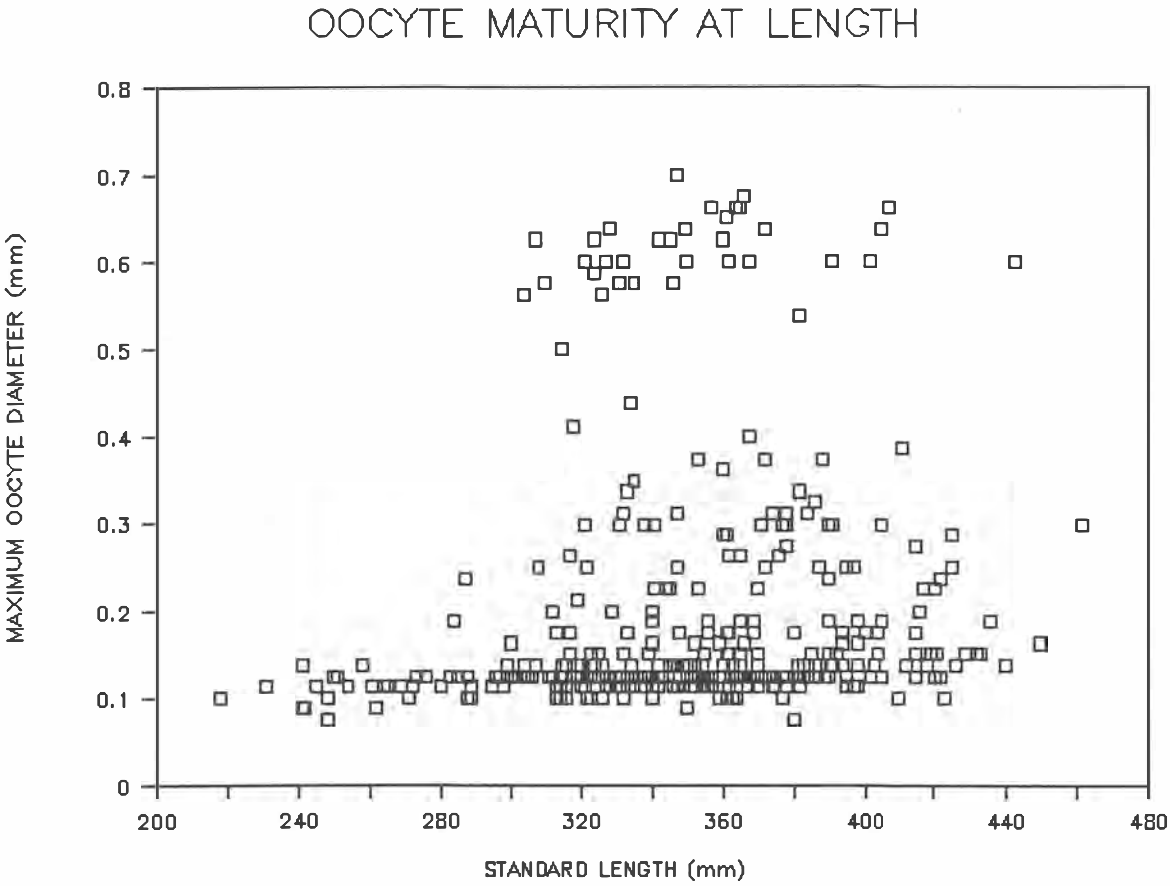
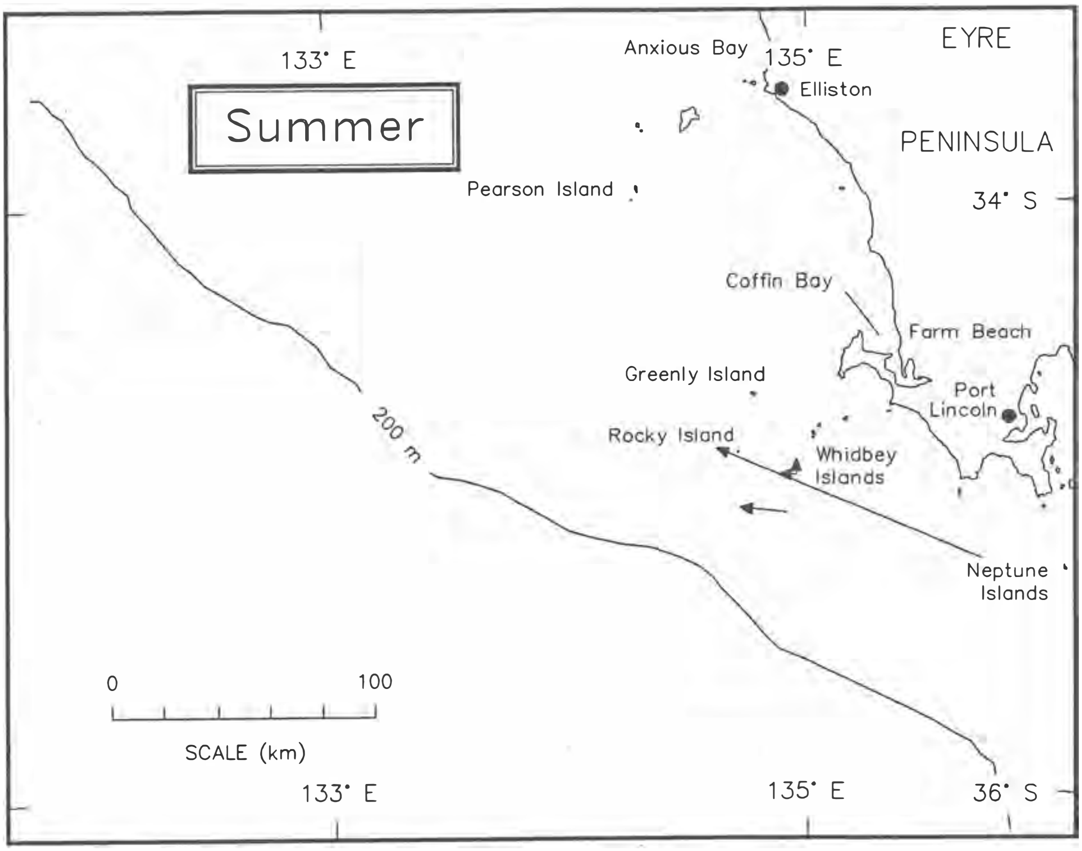
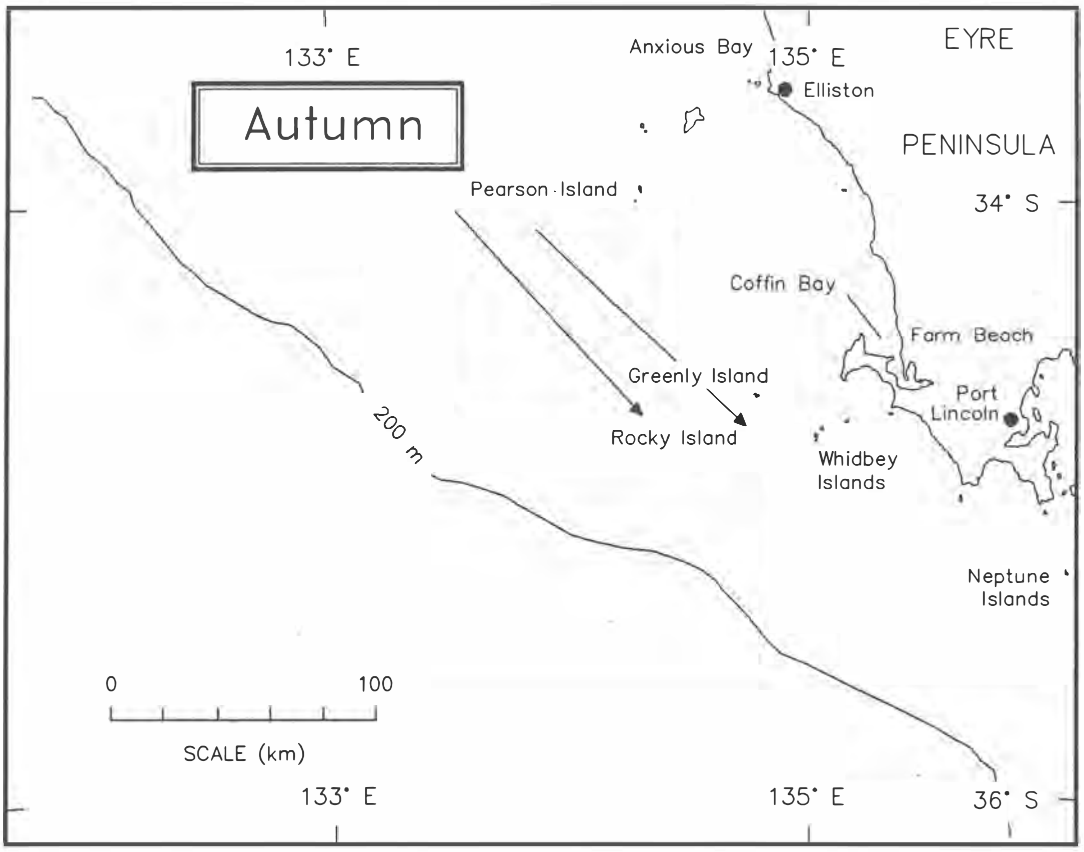


Figure 24: Oocyte maturity at length



a)



b)

Figure 25: Movements of fish tagged and recaptured in the same season, a) Summer and b) Autumn

spawning period (Fig.22). This indicates the oocytes of fish smaller than 31cm did not mature and were not spawned. Conversely, the mean diameter of oocytes in fish 31cm or larger grew significantly during the autumn spawning period and then declined (Fig.22). This indicates the oocytes of larger fish matured and were spawned successfully.

The minimum age at first spawning corresponded to a minimum age at first spawning of approximately 2.5 years, as calculated using the age length relationship described in section 3.5. Using the direct ageing method also described in section 3.5, the youngest fish thought capable of reproducing was aged at 2+ years. 22% of nine two year old fish examined, 83% of six three year old fish and all of the fish aged four years old or older were thought potentially capable of reproducing. These data indicate the proportion of spawning females in the commercial catch increased from ages two to four years at which age 100% of all females were reproductively active.

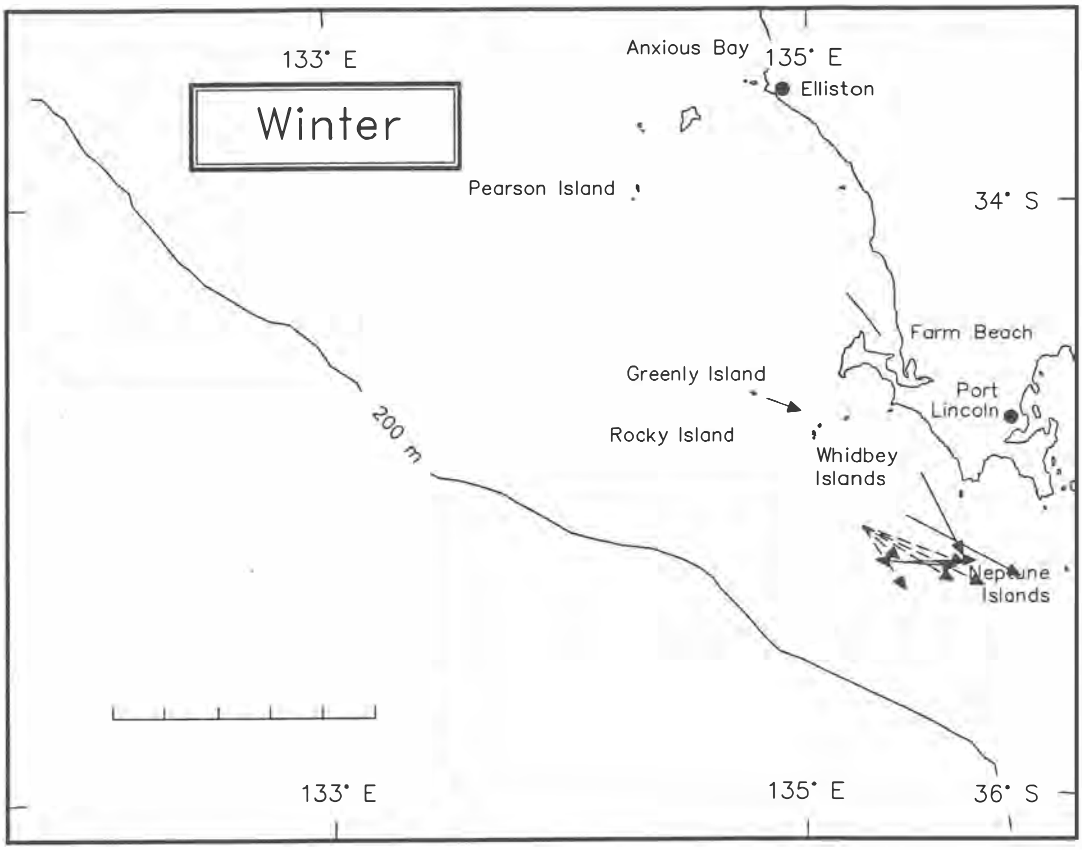
(iii) Spawning Migration

The results of tagging experiments demonstrated that migration patterns were seasonal and appear to be associated with the spawning cycle. Fish tagged during late summer moved rapidly west while those tagged during May, just after spawning, moved rapidly east (Fig.25). Fish tagged during winter continued the easterly movement while those tagged during the spring migrated in a northerly direction (Fig.26). The average distances travelled and swimming speeds of fish tagged and recaptured within one season reached their highest rates of over 40 nautical miles travelled at 3.5 miles/day during autumn spawning period compared to less than 22 nautical miles travelled at less than one mile per day during winter (figures 27 and 28). Examination of individual tag recaptures and knowledge of commercial fishing patterns indicates the westerly (pre-spawning) migration probably commenced during late summer and peaked during March and April. The return (post-spawning) migration occurred during the month of May and was probably of short duration. Seasonal migration patterns represent a fundamental and complex interaction between the fish and its environment and are discussed further below.

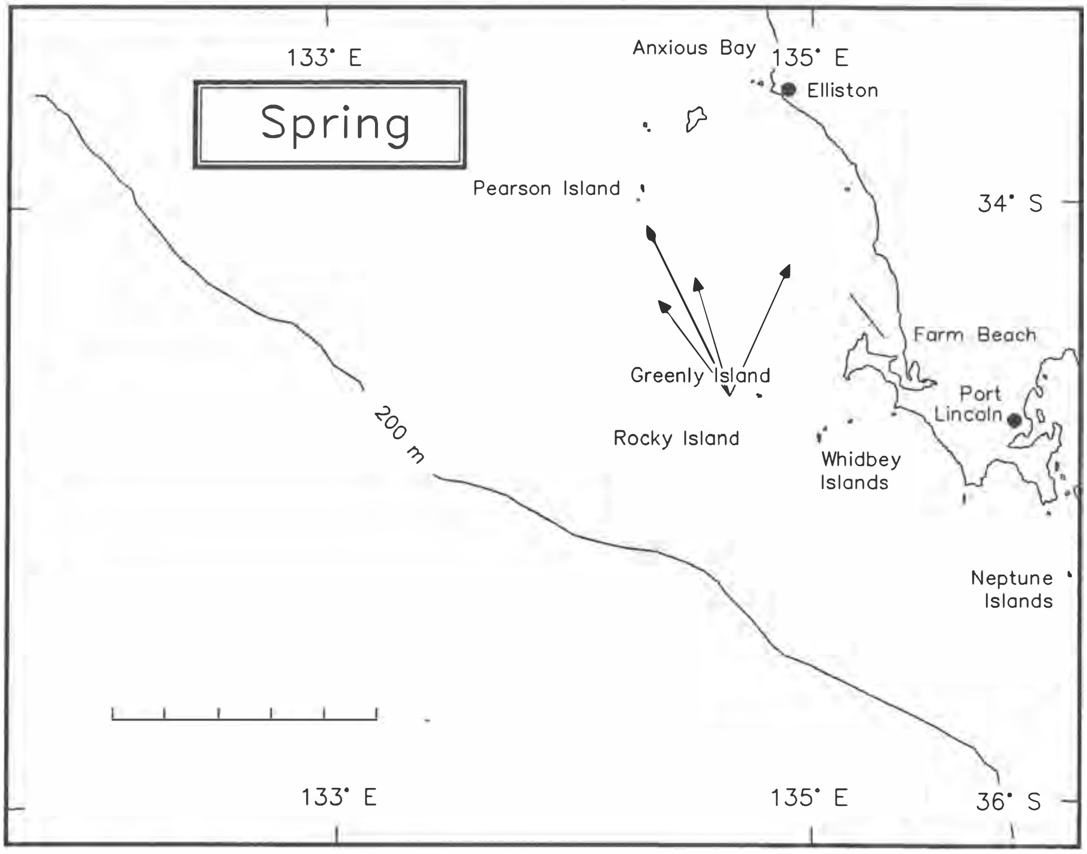
3.5.2 Other Seasonal Changes

(i) Hepatic Index

Liver weights varied from minima of 3-5% of body weight during winter to maxima of 7-9% of body weight during summer and early autumn (Fig.20). The trend was similar for both males and females and repeated over three consecutive summers and two winters. Maxima occurred during summer and early autumn when liver weights were



a)



b)

Figure 26: Movements of fish tagged and recaptured in the same season, a) Winter and b) Spring

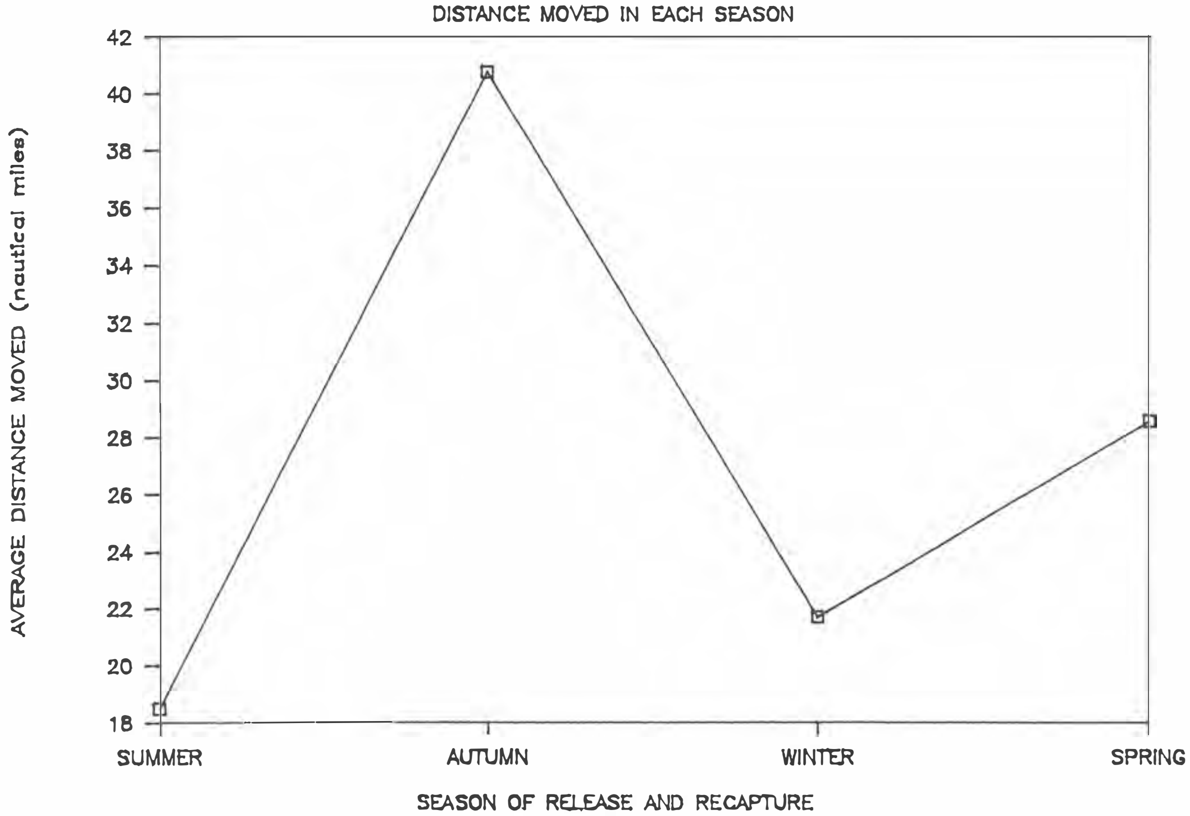


Figure 27: Average distance travelled by fish tagged and recaptured in the same season

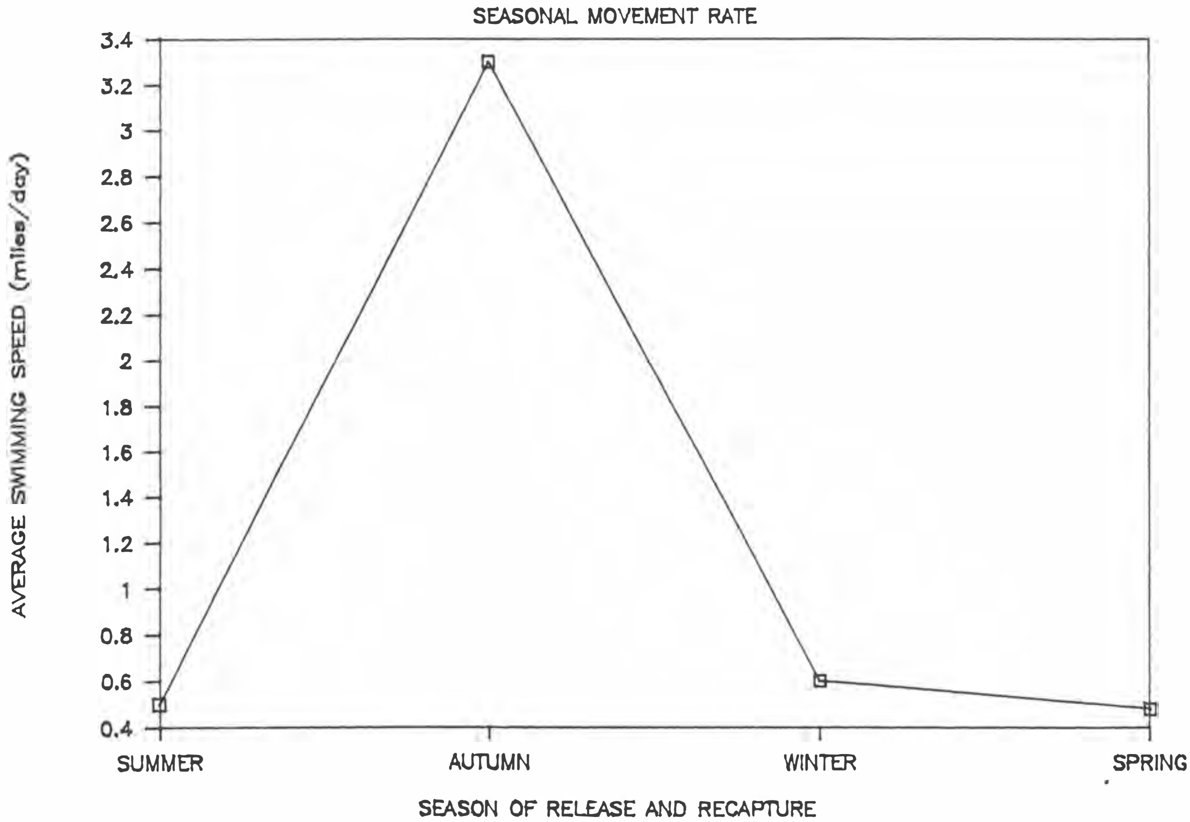


Figure 28: Average swimming speed of fish tagged and recaptured

high but stable and are interpreted as periods when energy stores were full and excess energy was available for growth in gonad and body weight. Data for monthly gonad weights (Fig.19) confirm that ovary weight increases from approximately 1% to 4-5% of body weight during this period. Similarly, body growth is strongly seasonal as demonstrated by the formation of bands on the vertebra showing growth checks and pulses.

Liver weights decreased rapidly during the late autumn and early winter months when energy requirements must have been greater than could be supplied by natural food supplies. Adult ocean jackets were known to spawn and undertake extensive migrations at this time of year. Spawning involves the physiological cost of swimming to the spawning grounds, of possibly exhausting ritualistic behaviour associated with spawning and, in females, the cost of producing yolk and ripening several hundred thousand eggs. It is concluded that relative liver weights were reduced during autumn because the accumulated energy reserves were used in migration and spawning.

Minimum liver weights occurred during early winter and were maintained throughout the winter months (Fig.20) indicating that energy stores depleted by the autumn spawning and associated migration and were not replaced. Low and stable liver weights are interpreted as indicating poor feeding opportunities and insufficient energy for growth. Winter is a period of physiological stress for ocean jackets and may be associated with higher than usual mortality rates and growth checks resulting in the formation of rings on the vertebrae and other calcified structures.

Liver weights increased rapidly during spring and early summer, indicating an excess of energy availability over requirements. This excess was directed into liver and body growth (Figs 20 & 21) and the spring and early summer months are interpreted as periods of recuperation and growth.

(ii) Condition Index

The Condition Index used compared the actual weight of fish with the weight that would be expected in an average fish of that length. Values greater than one indicate heavier than average fish and values less than one indicate lighter than average fish. The Condition Index is similar to the Hepatic Index in that it is an index of well-being that increases when food is plentiful and stress is low and decreases when energy requirements exceed availability. Commercial fishers were aware of the general drop in condition during late autumn and winter as fish become progressively lighter for their length and then remain "skinny" until spring.

The Condition Index varied throughout the year (Fig.21) in a pattern similar to that for changes in the hepatic index (Fig.20). It declined rapidly after spawning in autumn and remained low throughout the winter, resulting in less than average condition at that time of year. Condition improved during spring and relatively high levels were maintained over summer ("fat" fish) with maxima recorded in late summer or early autumn. The recovery of edible flesh per fish of any particular length was therefore lowest during late autumn and winter and highest in summer and early autumn.

In contrast to the hepatic cycle, condition indices for female fish tended to be lower than for males and there was greater variability between months within seasons. The Hepatic Index was therefore considered more useful than the Condition Index for determining physiological condition.

(iii) <u>Colouration</u>

Male ocean jackets developed a distinctively darker tone to the colouring of the skin during April and May. The general body surface became darker and was most noticeable along the dorsal surface and lips, skin surrounding the eyes and between the fin rays. The latter areas were black in good specimens. At other times of year males were grey to steel blue with black blotches on the sides and yellow fins. It is not known why males developed their distinctive colouration at spawning time but it may have been part of a display identifying males in prime spawning condition to other males or to females. Males also appeared to be much more active when caught at this time of year than at any other.

Males also displayed a red tinge that appears to be due to a rupturing of the capillaries in the skin (Hutchins and Swainston, 1986) during ascent although the mechanism of damage is not clear. That this red colouring was an artefact of being brought to the surface was confirmed by the absence of any red tinge in males filmed at depths of 95 metres using artificial light. This effect was not evident in the skin of females but captured specimens of both sexes sometimes had dilated capillaries visible in the eye.

3.5.3 <u>Fecundity</u>

Fecundity was defined as the number of developing eggs (oocytes > 1mm diameter) in the ovary just prior to spawning. Its measurement is of importance in stock assessment studies because it is a key factor affecting the ability of a stock to replace itself.

All fish larger than 31cm were mature and produced approximately half a million to a maximum of two

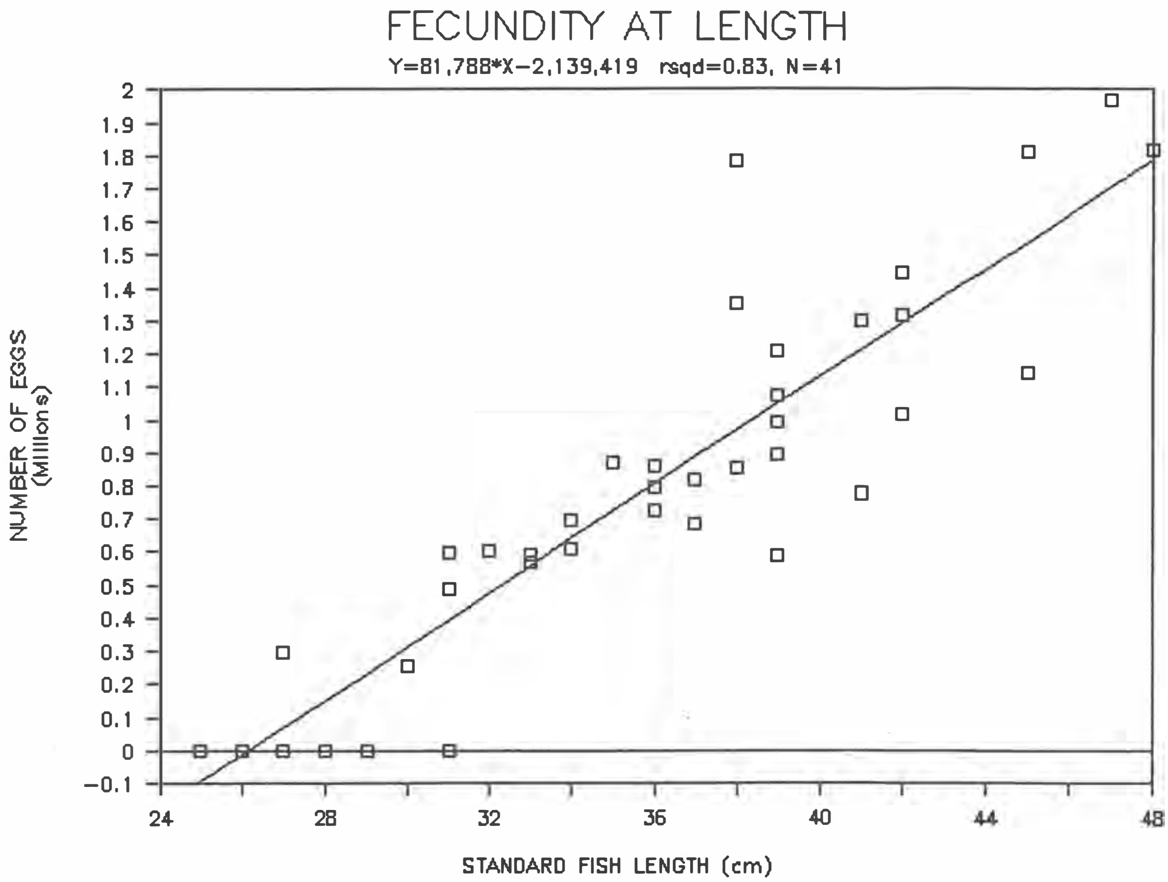


Figure 29: Fecundity at length relationship

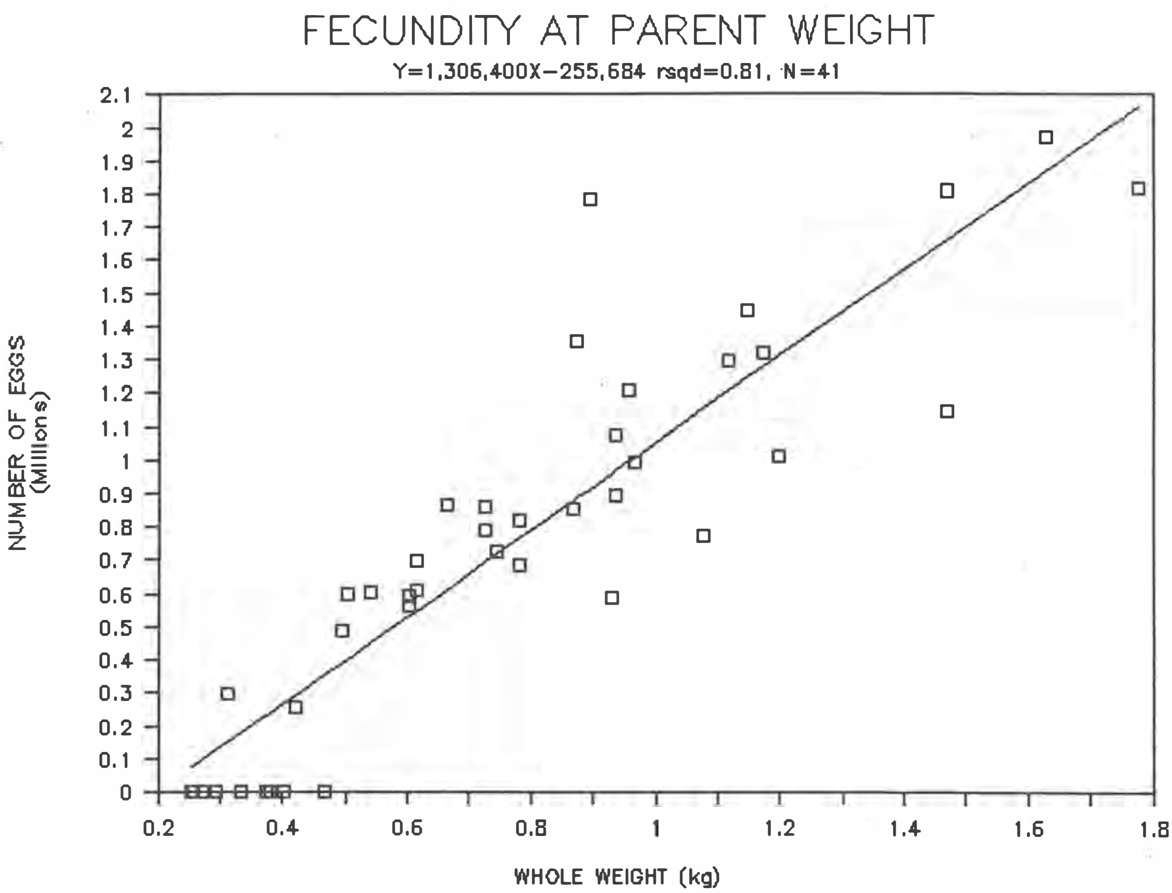


Figure 30: Fecundity at parent weight relationship

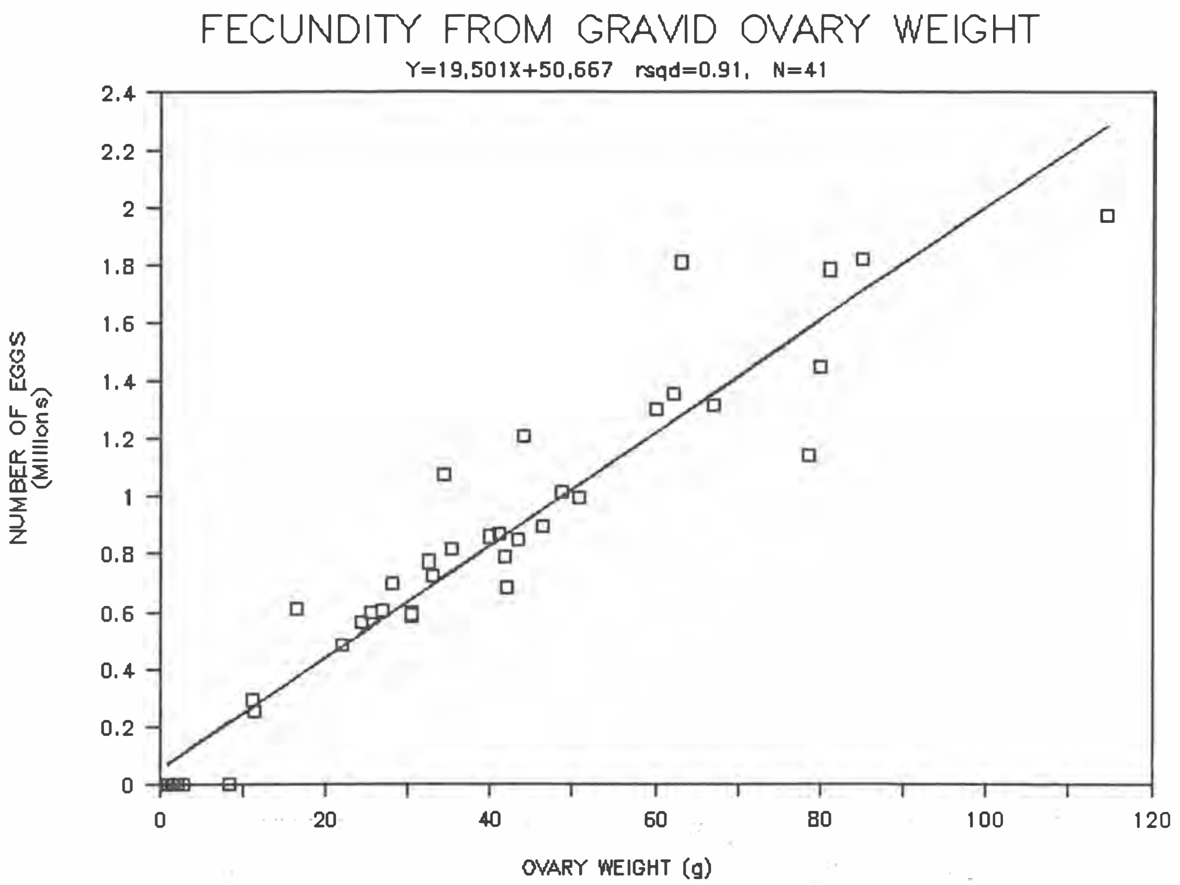


Figure 31: Fecundity at ovary weight relationship

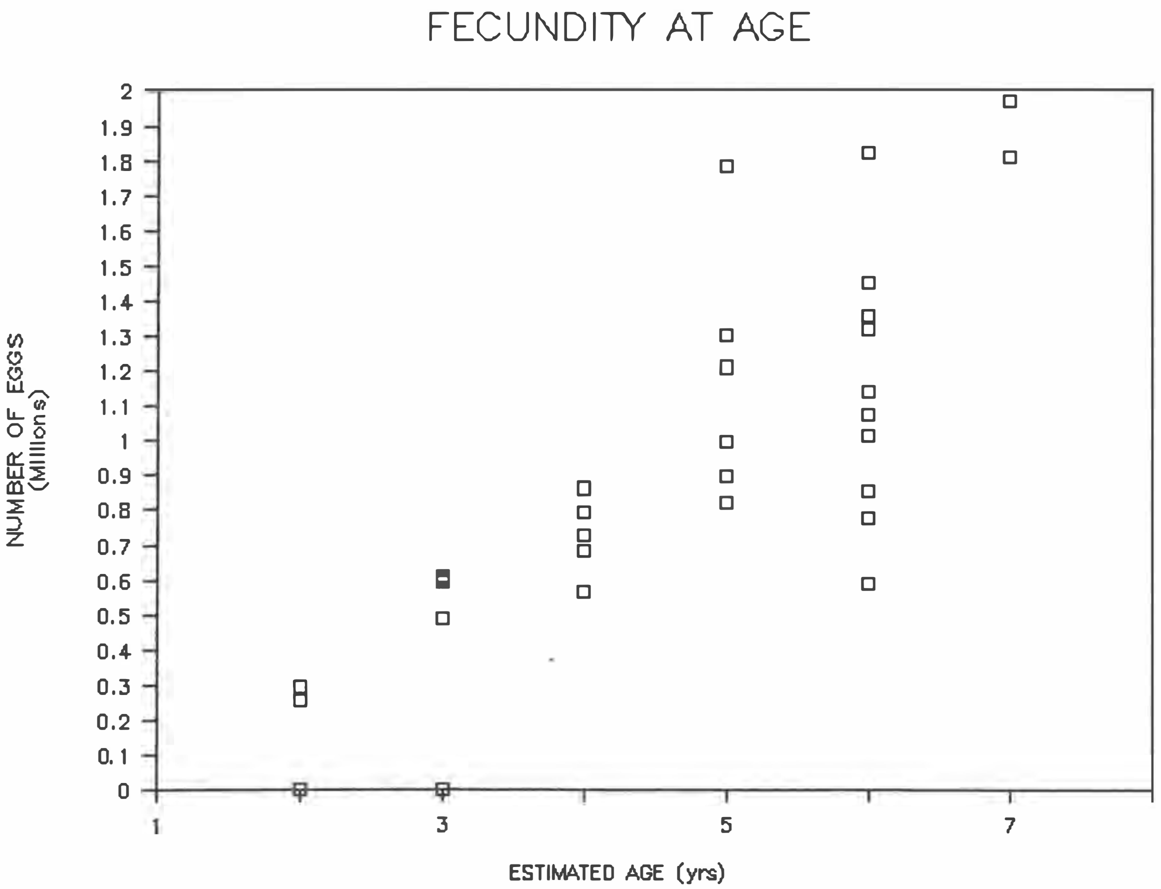


Figure 32: Fecundity at age relationship

million oocytes in very large fish (Fig.29). The 34-36cm size class of female fish most common in the commercial catch (Fig.7) produced approximately 650,000-800,000 oocytes per individual. In contrast, the contribution of small fish to overall reproduction was considered to be minor. Females smaller than 32 cm were relatively uncommon in the catch (Fig.7) and only 22% of those examined were mature. Those that were mature produced approximately 250,000 to 600,000 oocytes (Table 11).

Individual fecundity estimates varied but increased consistently with fish length and weight and gonad weight (Figs 29, 30 & 31). The increase was linear with both length total weight and gonad weight and least squares regression estimates of these relationships were:

Fecundity = standard length(cm) X $8.1*10^4-2.1 \times 10^6$. $r^2=0.83$

Fecundity = whole body weight(kg) X $1.3 \times 10^6-2.5*10^5$. $r^2=0.8$

Fecundity = ovary weight(g) X $1.9 \times 10^4+5 \times 10^4$. $r^2=0.913$

Fecundity at age data (Fig.32 and Table 11) showed a clear increase in the production of oocytes over the range two to five years and a levelling off between the ages of five and six years. Fecundity then appeared to increase between the ages six to seven years old but this may have been a sampling artefact due to the small number of seven year old fish examined. The possibility that fecundity increases throughout life was not disproved but this was considered unlikely and it is concluded that fecundity increased from ages two to five years and then levelled off at an average maximum of approximately 1.1 million oocytes per fish.

Table 11 Fecundity and percent reproductive activity at age for a size stratified sample of 41 female N. ayraudi collected during the 1990 spawning season. [1] does not include fish with zero oocytes. [2] small number of samples.

Age (yr)	(N) (41)	Mean Ln (cm)	Percent repro-ductive	Mean Fecundity	Lower Fecundity Range	Upper Fecundity Range
1	(0)					
2	(9)	28[1]	22	275,000[1,2]	255,333	294,667
3	(6)	33[1]	83	578,266[1]	486,000	610,000
4	(5)	35	100	725,866	566,667	860,667
5	(6)	39	100	1,166,222	819,333	1,782,000
6	(10)	41	100	1,138,333	588,000	1,820,000
7	(2)	46	100	1,890,333[2]	1,810,000	1,970,667
8	(0)					
unknown	(3)					

3.5.4 Artificial Spawning

Artificial spawning was attempted to determine whether fertilised N. ayraudi eggs sink or float and therefore whether surface or bottom water currents influence their subsequent distribution. This is of interest because annual variation in the strength and direction of water circulation patterns in the Great Australian Bight might influence reproductive success and water circulation data could then be used to predict year class strength and future catches in the fishery. A second objective was to raise fertilised eggs through at least the early yolked stages of development and produce diagrams of the larval stages of N. ayraudi. This would allow the identification of N. ayraudi larvae present in plankton samples collected during this project and other offshore ichthyoplanktonic collections made in southern Australia.

The largest oocytes observed were 0.65mm diameter, heavily yolked, and appeared close to ovulation. Attempts were made to artificially fertilise eggs at sea on 21 April 1990 using eggs and sperm stripped from live adults and dry mixed according to the protocol described in appendix 5. This was not successful, probably because the eggs were not fully ripe for spawning. It is suggested that greater success may be achieved in future attempts if the eggs used are fully ripe and that this may be achieved by inducing ovulation by hormonal injection. An alternative strategy would be to collect the spawning animals as close to dusk as possible as many fish species spawn naturally at this time. It should also be considered that ripe (ovulated) eggs will be floating free in the ovarian lumen and would probably be squeezed from the ovaries and lost during ascent as a reduction in ambient pressure causes the swim bladder to press against the internal organs. The yield of ripe eggs by this method would therefore be relatively low.

Since N. ayraudi eggs were not successfully fertilised, it was not possible to determine whether or not fertilised eggs float or sink. However, it is suggested that if the eggs float they would be transported from the offshore spawning grounds to the inshore nursery areas by the net inshore movement of surface waters that predominate during the spawning period. Preliminary studies on the direction and strength of surface water currents in the eastern Great Australian Bight carried out by the Department of Fisheries indicate that south westerly surface currents predominate in the area during late autumn and early winter (P. Petrusevics pers comm). The hypothesis of floating egg and larval stages fits the observations of offshore spawning during autumn, a net inshore autumn and winter movement of surface waters and the occurrence of settled juveniles in inshore habitats during spring. However, the only monacanthid species in which spawning has been studied (Leis and Rennis, 1983; Milicich, 1986 cited in Kingsford and Milicich, 1987) have all produced demersal eggs (associated with the bottom) and would therefore be independent of surface currents. There are no data on the direction and strength of bottom water currents in this area.

Further studies are therefore be required to ascertain the fate of ocean jacket eggs and investigate any potential link between autumn/winter current strength and direction and the numbers of fish recruited to the fishery two to four years later. It is suggested that a better understanding of the oceanography of the Great Australian Bight would be useful in determining recruitment pathways in N. ayraudi and other species.

3.6 Age and Growth

3.6.1 Age

The ages of a total of 147 fish comprising 21 juveniles, 83 females and 43 males were determined by interpreting rings on the centra of the fifth vertebra as described in section 2.3.6.. Ages could be assigned to 57 percent of 257 vertebrae examined but the remainder were considered unusable. Vertebral diameter increased with fish length (Fig.33) over the full size range for the species indicating that vertebrae continued to grow and produce circuli as the fish grew longer.

The oldest female examined was aged 9 years and the oldest male was 7 years old, indicating Nelusetta ayraudi has a short to medium life span. Some

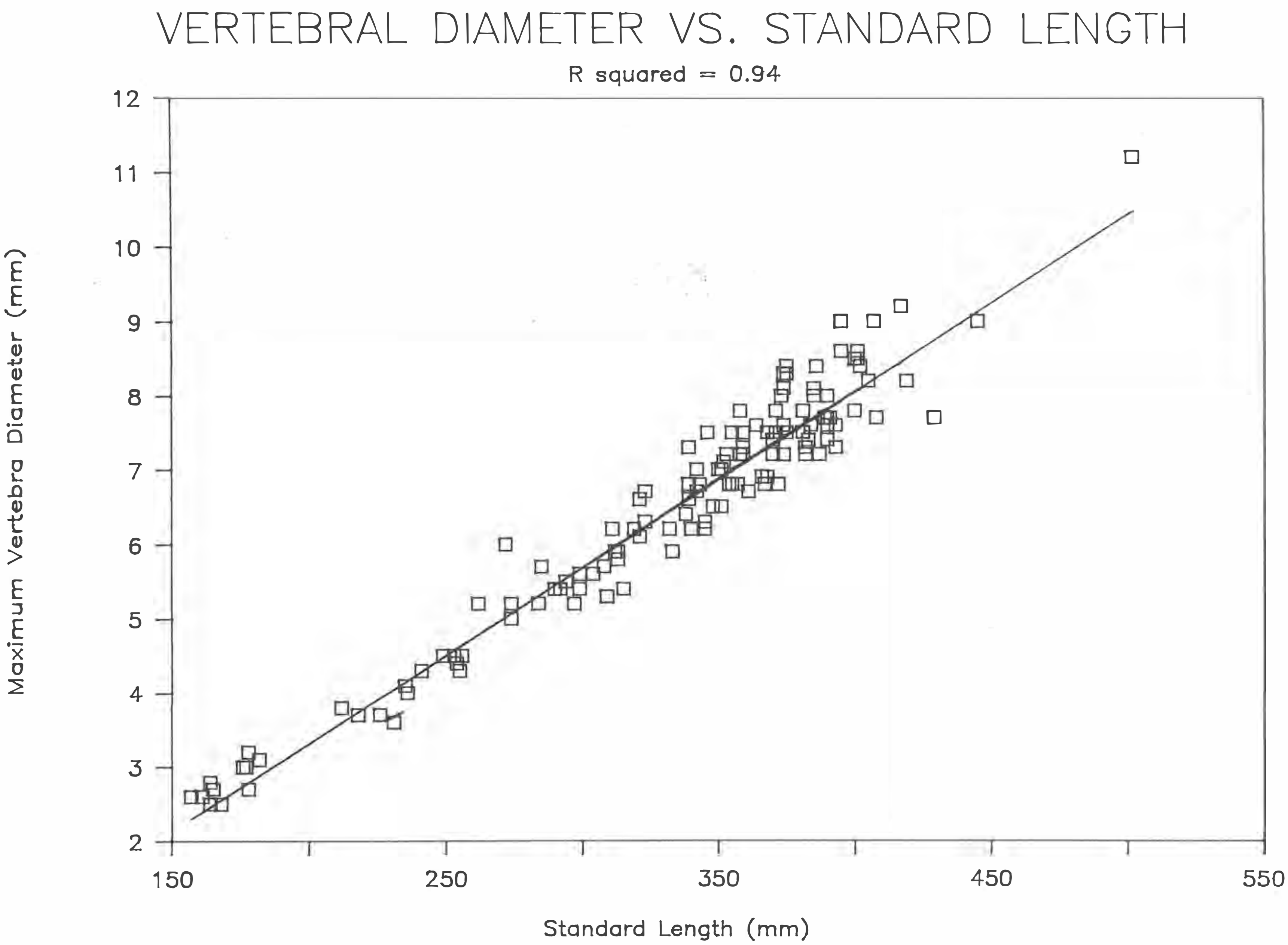


Figure 33: Vertebral diameter to standard length relationship.

individuals may have exceeded the maximum observed age however, because the outer growth rings in large fish were close together and difficult to distinguish from one another.

3.6.2 Growth

(i) Estimated from Direct Ageing

The age data obtained from vertebral ring counts were fitted to the Von Bertalanffy growth model using the non linear least squares FISHPARM computer program (Saila et al, 1988). The Von Bertalanffy growth model is widely used in fisheries research because it generally describes fish growth well and can be incorporated into per recruit and other analyses. It has the form:

$$L_t = Linf\ [1-e^{-k(t-to)}]$$

where:
- L_t = length (standard length) at time t
- Linf= asymptotic length
- k = growth rate coefficient
- t_0 = theoretical age at which length is zero if a juvenile fish displayed adult growth characteristics

The parameters Linf, k and t_0 were derived and are presented in Table 12.

(ii) Estimated from Tagging and Modal Progression

3,153 tagged and measured ocean jackets were released over two years between March 1988 and March 1990. 90 (2.8%) were recaptured and returned to the investigators before September 1 1990. Growth increment generally increased with time at liberty (Fig.34) however not all recaptures were equally useful for determining growth rates. Twelve recaptured fish had been headed and could not therefore be measured or used to determine the amount of growth since release. 46 had grown by less than one centimetre and could not be used because errors introduced in measuring their lengths were similar to the growth increment. 32 fish comprising 17 female and 15 males grew by more than one centimetre and were used in the growth analysis.

Von Bertalanffy growth parameters were estimated using the graphical method described by Gulland (1969) of the plot of growth rate (L2-L1)/(t2-t1) against the mean length between release and recapture (L2+L1)/2

where;
- L1 = length when released,
- L2 = length when recaptured, and
- t2-t1 = the time at liberty.

Accurate estimations require growth rate data for both small and large fish and results from the modal

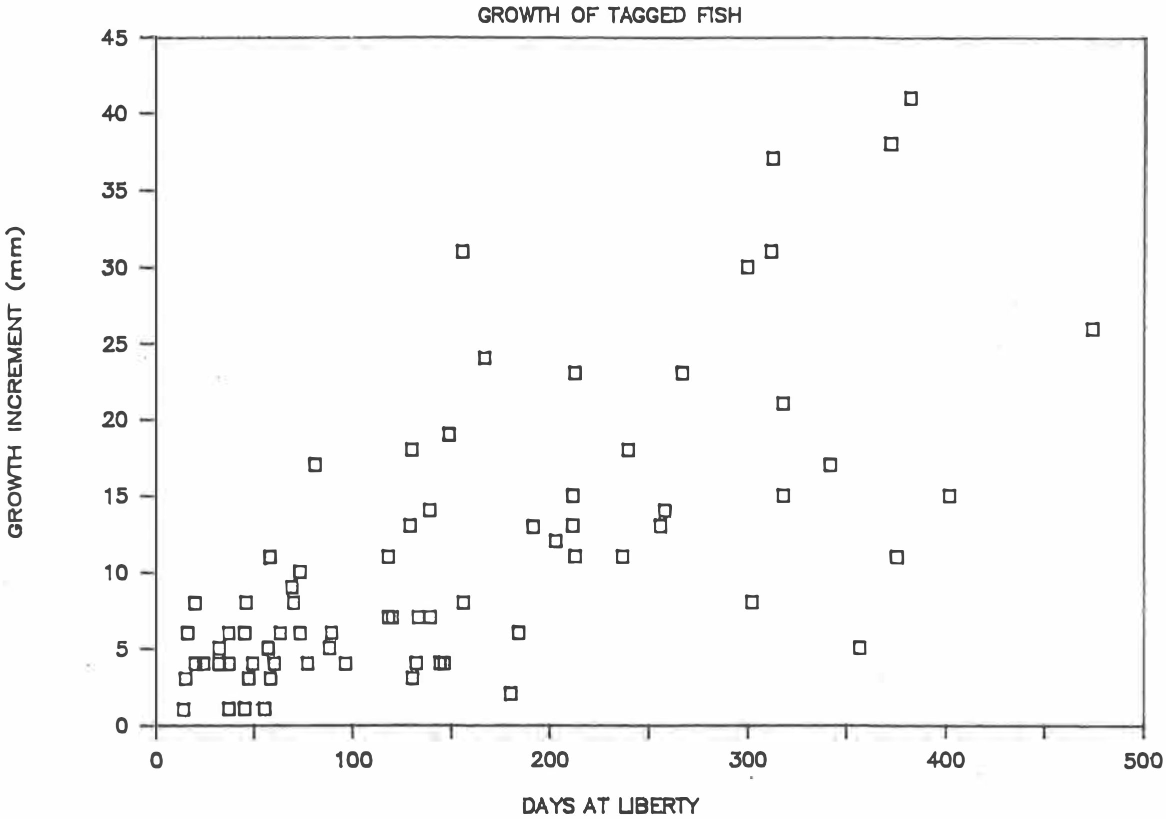


Figure 34: Absolute growth of tagged fish.

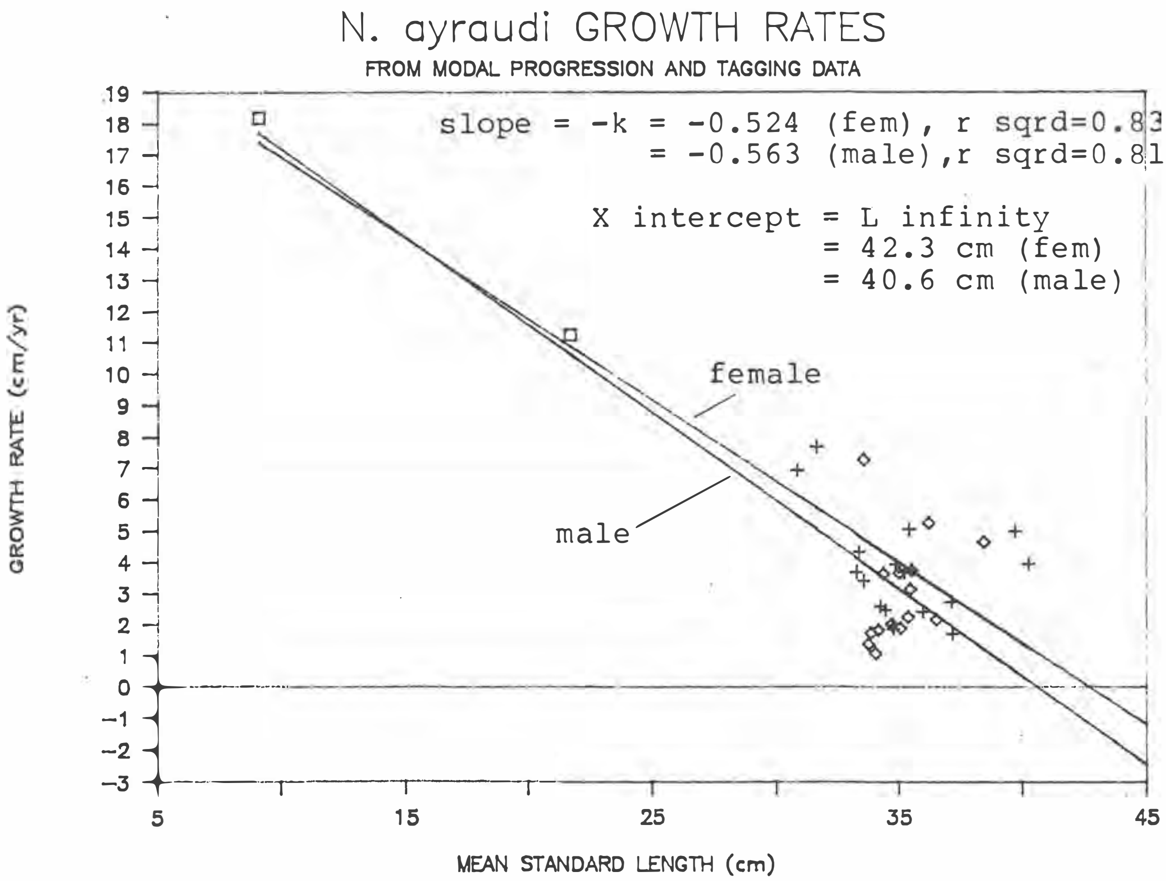


Figure 35: Growth rate at length relationship derived from male (+) and female (◊) tag returns and modal progression (□) data.

progression studies (3.3.2) which concerned small immature fish were combined with results from the tagging studies which dealt mainly with larger mature fish from the commercial catch. The plot (Fig.35) produced the expected negative linear relationship because growth rate slowed with increasing length and had a slope approximating -k and x axis intercept of L infinity (Linf). Estimates of Linf and k derived from this method and direct ageing are summarised in table 12.

Future tagging studies conducted to assess growth rates should aim to tag one year old fish which may be caught in the west coast bays in large numbers during autumn. Tagged one year old fish would grow considerably before recruiting to the fishery as two, three and four year old fish and provide useful growth data. Two year olds may also be tagged in shallow (<80m) waters north west of Flinders Island to Nuyt's Reef (Fig.12). Tagging of fish older than four years would not provide useful growth data but would be of use in refining mortality estimates.

Table 12 Parameter estimates for the Von Bertalanffy growth function derived from direct ageing, tagging studies and modal progression.

	FEMALES			MALES	
	Tag Data[1]	Direct Ageing	Mean	Tag Data[1]	Direct Ageing
k	0.524	0.481	0.503	0.563	0.619
Linf (cm)	42.3	43.05	42.7	40.6	39.77
t0	-0.154	0.013	-0.141	-0.154	+0.138

[1]includes modal progression data

(iii) Growth Curves

Results for the Von Bertalanffy growth parameters derived from direct ageing and combined tagging and modal progression data (Table 12) were used to generate growth curves (Figs 36 & 37) and age-length keys (Table 13) for male and female *Nelusetta ayraudi*. The mean values of results obtained using the two methods were used to generate growth curves for female fish but tag data only were used to generate curves for male fish. This was because there were few males larger than 40cm in the aged sample and it was thought calculations from these data would tend to over estimate k and underestimate Linf.

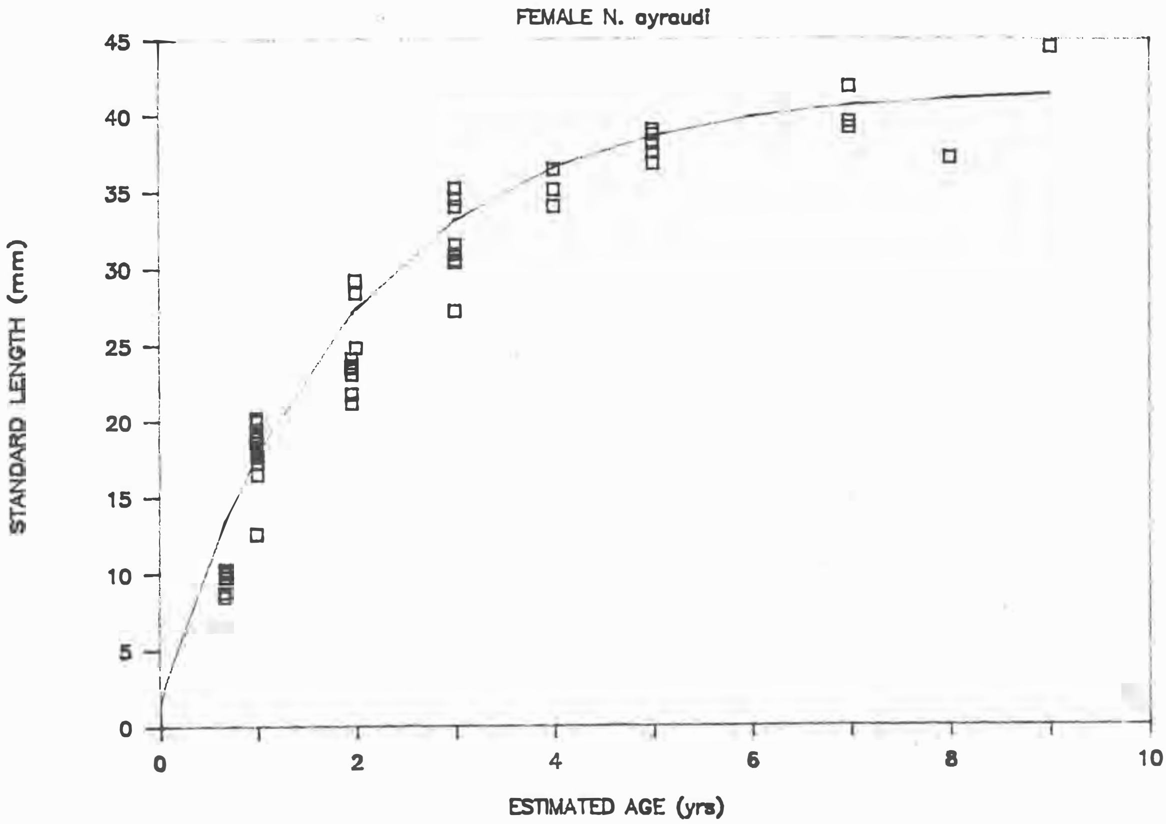


Figure 36: Von Bertalanffy growth curve; female ocean jackets

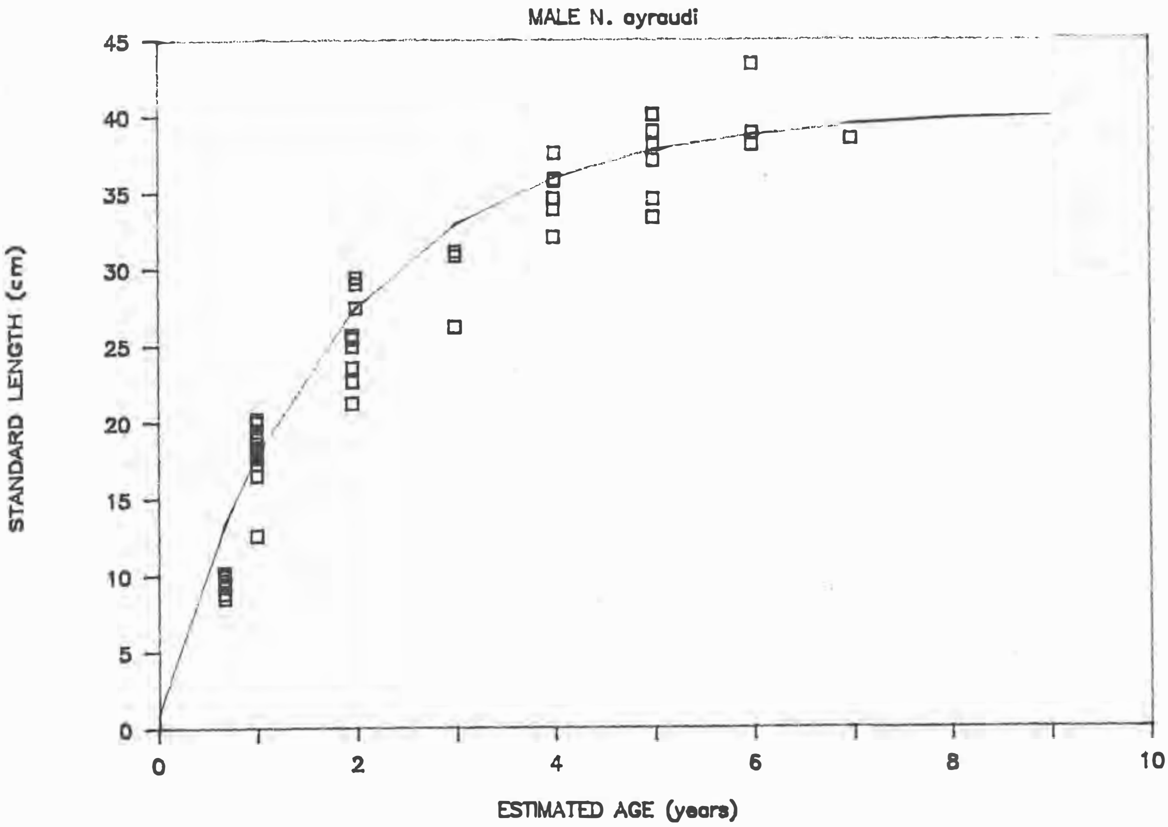


Figure 37: Von Bertalanffy growth curve; male ocean jackets

Table 13 Age-length key for male and female N. ayraudi.

Age (yrs)	Mean Length (cm) Female	Male
1	18.6	19.4
2	28.2	28.5
3	33.9	33.7
4	37.4	36.7
5	39.5	37.6
6	40.8	38.4
7	41.5	39.3
8	42.0	-
9	42.3	-

Von Bertalanffy growth curves provided a good fit to the observed direct ageing data points (Figs 36 & 37) assuming rings to be created three times every year for the first two years and twice every year thereafter. Larger Linf estimates for females than males were consistent with size distributions observed in the commercial catch (Fig.7 & 8). Growth constants (k) in the range 0.48-0.56 were relatively high and indicate a medium to fast growth rate for N. ayraudi. For comparison, k values estimated for other South Australian species are 0.1 for snapper Chrysophrys auratus, 0.25-0.31 for King George whiting Sillaginodes punctata, 0.45 for garfish Hyporhamphus melanochir (Jones et al, 1990) and 0.28 for Australian salmon Arripis truttaceus (Nicholls, 1973). Higher k values recorded for males than females indicated males approach their average maximum size at a rate faster than females.

3.7 Mortality

Information on the rates at which fish die due to both natural causes and deaths due to fishing were required to model the dynamics of the fishery. Natural mortality (M) is the rate of death due to disease, predation and old age, fishing mortality (F) is the rate of death inflicted by fishing effort and total mortality (Z) is the rate of death due to all causes. Mortality rates are expressed as instantaneous rates and are additive, eg. the total mortality is equal to the sum of the natural and fishing mortalities;

$$Z = F + M$$

3.7.1 Estimated from Tagging Data

Both fishing (F) and total (Z) mortalities were estimated from the number of tag returns using the

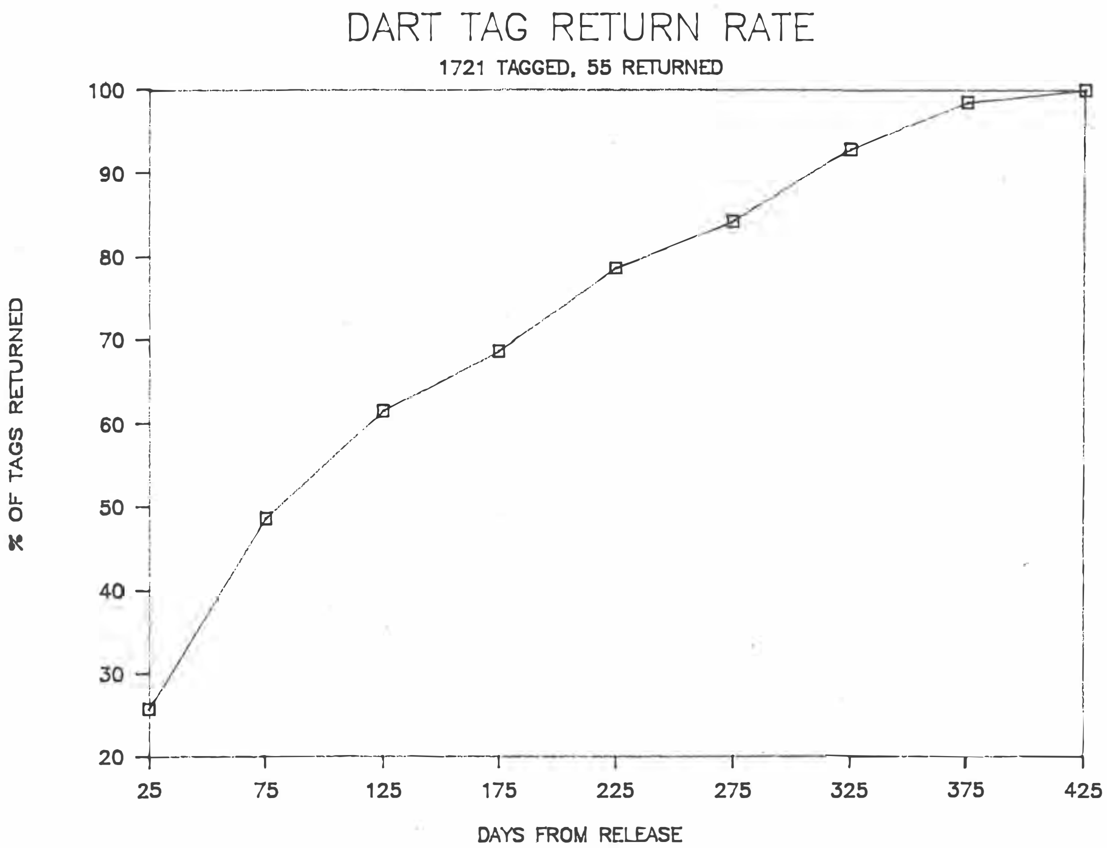


Figure 38: Dart tag return rate

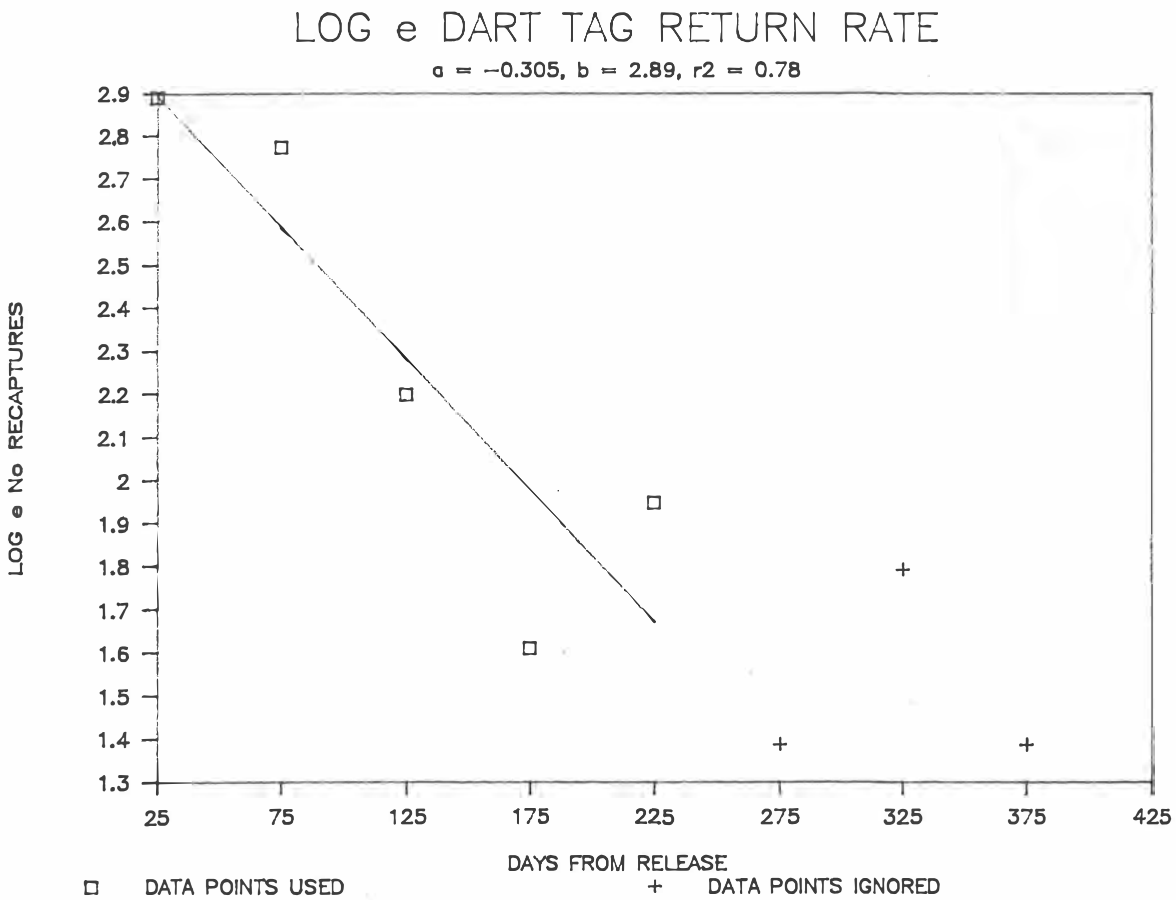


Figure 39: Log dart tag return rate

method described by Gulland (1969). The basic premise of the method is that fishing mortality (F) is proportional to the rate at which tagged fish are recaptured.

Gulland derives the linear equation:

$\log n_r = -(F+X)rT + \log [FNo(1-e^{-(F+X)T})/F+X]$

from the basic mortality equation:

$Nt = No\ e^{-(F+X)t}$

where Nt = the number of tagged fish alive after time t
No = the number tagged
r = one period of time T (first period r = 0)
F = fishing mortality
X = other mortality (natural + tag related and migration)
n_r = the number recaptured during the rth period
nt = the number recaptured after time t

This equation is a straight line with the form:

y = ax + b; where y = loge nr and x = r

When log e nr is plotted against r, the slope is an estimate of total mortality,

a = -ZT
-(F+X)T.

Using this value of (F+X), F can be estimated from the number of returns to time t

$nt=(FNo/F+X)\ X\ [1e^{-F+X)t}]$..........................(i)

The number of recaptures grouped into 50 day recapture periods of fish tagged between December 1988 and March 1989 using dart tags are shown in figure 38 and table 14. Data for all monthly tagging experiments conducted between December 1988 and September 1989 were combined as return rates for individual months were too low to determine mortalities. Results for fish tagged using T bar, internal or loop tags have not been included because of the low numbers of returns using these tag types (Table 15). Results for fish tagged after September 1989 (tagging continued until March 1990) were ignored to allow for a period of at least twelve months for recaptures to be reported. Returns made after September 1 1990 were not included in the mortality analysis.

Table 14 Number of recaptures to September 1 1990 of 1721 fish tagged between December 1988 and September 1989 using dart tags.

Time at liberty (days)	Recapture Period (r)	Number Recaptured (n_r)	$\log_e n_r$
1-50	0	18	2.89
51-100	1	16	2.77
101-150	2	9	2.20
151-200	3	5	1.61
201-250	4	7	1.95
251-300	5	4	1.39
301-350	6	6	1.79
351-400	7	4	1.39
401-450	8	1	0

The data in Table 14 were plotted (Fig.39) giving a slope of -0.305 and y intercept of 2.89. Recaptures made more than 250 days after release were ignored in the calculation of the regression line shown in figure 39 because the variance of the data points increased as the number of recaptures decreased and the assumption made in calculating the regression, that variances were equal for all data points, was violated at low recapture rates.

Solving a = -0.305 = -ZT for at T = 50 days = 0.137 years gave an upper estimate for total mortality of

Z = 2.23

and substituting Z=(F+X) = 2.23 into equation (i) for (nt=) 55 tags returned within (t=) 250 days (0.68 years) after tagging (No=) 1721 fish gave a direct estimate of fishing mortality of

F = 0.327 , and therefore

X = 1.903

3.7.2 Errors in Estimating Mortality Rates from Tagging Data

Mortality estimates made from tagging studies are subject to bias if certain assumptions are violated. The basic assumption of the method described above was that fishing mortality was constant while tagged fish are at liberty. This assumption was broadly satisfied as fishing effort stabilised during the experimental period 3.1.3. Other assumptions were that natural mortality was constant over the whole tagging period, that there were no deaths from tagging or shedding of tags, that there was no net migration of tagged fish out of the fished area, that tagged fish were evenly distributed throughout the fished population and were equally vulnerable to the fishing gear as untagged fish, and that all recaptures were reported to the investigators. The significance of these assumptions in estimating mortality rates in N. ayraudi are discussed in the following two sections and correction factors applied where appropriate.

(i) Fishing Mortality

Fishing Mortality (F) can be under estimated if the initial number of fish tagged and released (No in equation (i)) is reduced by the tagging operation itself (deaths resulting from catching, tagging and releasing), by loss of tags shortly after tagging, or from incomplete reporting of recovered tags rather than by deaths due to fishing and natural causes. Initial mortality due to the rapid pressure reduction from 10 to 1 atmospheres as fish were brought to the surface was thought to be the most significant of these influences and was estimated and compensated for. The initial tag induced mortality rate was estimated at 25% judging from the survival of tagged fish held overnight in an on board pumped seawater holding tank. Applying this initial mortality rate to equation (i) reduced the number of fish tagged by 25% (No X 0.75) and gave a revised estimate for fishing mortality of

$$F = 0.436$$

The estimate for Z was unaffected.

To minimise short term tag loss, all tags were checked to see if they were properly anchored before release and any loose tags rejected. It was assumed that initial tag loss was not a significant influence on mortality estimates.

Incomplete reporting of recovered tags has two components; the recognition of tagged fish by fishers and their reporting that information to the investigators. Recognition was considered to have been higher for dart tags than for T-bar and Internal tags. Each fisher handled over 2400 and cleaned over 1200 fish on a typical day so high visibility tags were essential. One T bar tag was returned by a fish buyer demonstrating that not all T bar tags were noticed by fishers. Recognition of dart tags was facilitated by their bright orange colour and because tags were inserted near the point where fishers make an incision to clean the fish. T bar tags were less likely to be noticed by fishers due to their similar (yellow) colour to female N. ayraudi and because tags were inserted into the basal elements of the dorsal fin several centimetres from the incision made to clean the fish. Similarly, T bar tagged fish "seeded" into the catch at sea were not always found by fishers whereas the more conspicuous dart tags were always noticed.

Internal tags were also inconspicuous because they were inserted in the abdomen where they were less obvious during cleaning operations. Differential recognition of tag types appears to have been reflected in the different return rates for each tag type (Table 15) and returns of T-bar and internal type tags were not used to estimate mortality rates. The single return for a loop tag was considered insignificant and ignored.

Reporting of recovered tags was considered to have been high because a relatively small number of fishers were involved, all of who knew about the tagging program and agreed to supply catch details to the investigators. Fishers reporting tag returns were given details of the growth and movement of that fish and "leatherjacket research" T shirt.

Table 15 Tag Types and their return rates.

TAG TYPE	NUMBER TAGGED	NUMBER RECAPTURED	RECAPTURE RATE(%)
DART	2312	78	3.4
INTERNAL	408	5	1.2
T-BAR	408	6	1.5
LOOP	25	1	4
TOTAL	3153	90	2.9

(ii) Total Mortality

Total Mortality (Z) is over estimated if the number of tagged fish surviving after time T is diminished by means other than fishing and natural mortality. This occurs when tags work loose and fall out, if more tagged fish die than untagged fish due to infection or other debilitating effect of tagging, or if tagged fish migrate out of the fishing area. It was noted that the tags in some recaptured fish had worked loose and the total mortality estimate of 2.23 based on tagging data was therefore over estimated by the quantity X' in the equation;

$$Z = F+M+X'$$

where

Z = total mortality
F = fishing mortality
M = natural mortality
X'= treatment mortality.

Since F=0.436 and M=0.715 (see section 3.7.4 for the estimation of M), the corrected estimate for total mortality is;

$$Z = F+M$$
$$= 0.436 + 0.715$$
$$= 1.15$$

The quantity X' was estimated at 2.23-1.15 = 1.08

It should be noted that separate estimates of F and Z for each sex could not be obtained from current tagging studies. Future studies should aim to obtain separate estimates by increasing tag return rates. Tag shedding and tag induced mortality rates should also be investigated and handling procedures improved to minimise these losses.

3.7.3 Estimated from Age Composition

Total Mortality was also estimated from the slope of the descending limb of the catch curve or plot of the natural logarithm of the number of fish at each age against age (Figure 9). Calculations were based on numbers of males aged 4-6 years and females aged 5-7 years in samples of the 1988 and 1989 commercial catches (Table 13).

Table 16 Relative numbers of fish of different ages in the commercial catch, 1988 and 1989.

	1988		1989	
	Males Log_eNo	Females Log_eNo	Males Log_eNo	Females Log_eNo
Age				
1	-	-	-	-
2	3.67	3.55	4.62	4.37
3	5.95	6.14	5.84	5.73
4	6.19	6.40	6.04	6.17
5	4.96	6.28	5.21	6.09
6	3.86	5.78	4.46	5.70
7	-	4.18	-	4.19
Total Mortality Estimate (yr^{-1})	1.17	1.05	0.79	0.95

Mortality estimates derived from the age structure of fished populations are estimates of the total mortality (=fishing + natural mortalities) but estimates derived from unfished populations are estimates of the natural mortality only. Such estimates are extremely valuable because the opportunity to assess natural mortality directly is lost once the population has been exploited. Any future studies on this species in areas where the stock has not been exploited such as is the current situation in Western Australia should assign the highest priority to natural mortality estimation or at least collect representative samples of vertebrae for later age determination.

3.7.4 Estimated from Growth and Environmental Parameters

Natural mortality rates were estimated indirectly from growth and environmental parameters using the equation described by Pauly (1980). Pauly examined growth, mortality and environmental data in 175 fish stocks and found natural mortality to be related to the Von Bertalanffy growth parameters k and Linf and the mean annual water temperature by the equation;

$$\log M = -0.0066 - 0.279 \log Linf + 0.6543 \log k + 0.4634 \log T$$

Separate estimates of natural mortality for males and females were obtained using growth parameters derived in section 3.5.2 (male k=0.563, Linf=40.6cm and female k=0.503, Linf=42.7cm) and bottom water temperatures (annual mean = 16.39^{0}C; Appendix 3 (ii)). Natural mortality rates estimated by this method were 0.81 for females and 0.88 for males.

A second indirect method for determining natural mortality used by Jones et al (1990) relates natural mortality to the maximum age;

$$M = \ln 100/\text{maximum age}$$

Values of M obtained by this method using maximum ages of nine for female fish and seven for males were 0.51 for females and 0.66 for males.

3.7.5 Summary of Mortality Estimates

Instantaneous total, natural and fishing mortality rate estimates are summarised in table 17. All mortality estimates were subject to error and "best estimates" of Z, M and F were obtained by weighting an estimate according to its assessed accuracy. These estimates were then used in per recruit analyses which predicted the changes in yield that can be expected at different levels of fishing mortality and age at first capture. Natural mortality rates were high, as was expected for a short lived fish and fishing mortality rates were relatively low, as would be expected in a developing fishery.

Mortality rates are more easily understood when expressed in percentages instead of the instantaneous rates used in mathematical computations and in these terms the results in table 17 correspond to an annual death rate of 69% for males and 65% for females. In males, 45% of annual deaths were due to natural causes and 24% due to fishing. In females, 40% were due to natural causes and 24% due to fishing.

Table 17 Summary of instantaneous annual mortality estimates

Sex	Parameter	Catch Curve	Pauly Method	Max. Age	Tagging	Best Estimate (inst.)	Best Estimate (%)
Male	Z	0.79-1.17	-	-	-	1.17	69
	F	-	-	-	-	0.40	24
	M	-	0.88	0.66	-	0.77	45
Female	Z	0.95-1.05	-	-	-	1.05	65
	F	-	-	-	-	0.39	24
	M	-	0.81	0.51	-	0.66	40
Not Spec-ific	Z	-	-	-	1.15		
	F	-	-	-	0.33-0.44		
	M	-	-	-	-		

3.8 Per Recruit Analysis

3.8.1 Classical

Input parameters used in the calculation of yield tables (appendix 6) and yield curves (Figs.40-44) are shown in table 18.

Table 18 Input parameters for Beverton and Holt yield per recruit analysis.

	Von Bertalanffy (b=3) Winf (kg)	Linf (cm)	k	t0	Max age (yr)	Mortalities Ntrl	Fishing mid	Fishing max	Age at 1st capture mid (yr)	Age at 1st capture max (yr)
female	1.17	42.7	.503	-.141	9	0.66	0.8	1.6	2.5	4
male	1.00	40.6	.563	-.154	7	0.77	0.78	1.56	2.5	4

Using these figures but assuming zero fishing, biomass per recruit curves were plotted for male and female ocean jackets and are shown in figure 40. The maximum biomass (Bmax) occurred at relatively young ages for both male and female ocean jackets due to the high rates of natural mortality and growth estimated for the species. Bmax occurred at age 1.92 years (ie 279mm standard length, 329mm total length or 323g whole weight) for males and age 2.22 years for females (ie 296mm standard length, 348mm total length or 387g whole weight). These lengths represent the sizes at which the total biomass of the stock is maximised.

The sensitivity of the estimates of Bmax and the lengths at which they occur to the accuracy of estimates for M are shown in table 19. M values used in the assessment were the means of separate indirect estimates (section 3.6.4). Analyses were sensitive to variation in the estimate for M but still predicted greater yields at fish lengths significantly less than the current average length in the commercial catch of 348mm for males (3.33yrs) and 354mm (3.37yrs) for females. It is recommended that a direct estimate of M be obtained by ageing a sample of vertebrae taken from the very lightly fished population of ocean jackets in Western Australia. The opportunity to obtain a direct estimate of the natural mortality rate will be lost once the Western Australian population has been exploited.

Table 19 Bmax, age and lengths at Bmax for three values of M.

	M ($year^{-1}$)	Bmax	Age at Bmax (yrs)	Length at Bmax (mm)
Females	0.51	0.129	2.59	318
	0.66	0.090	2.22	296
	0.81	0.066	1.95	277
Males	0.66	0.092	2.10	291
	0.77	0.074	1.91	279
	0.88	0.060	1.75	267

Incorporating the age (tc) or length (lc) at first capture and various levels of fishing mortality (F) from 0-1.6 into the analysis indicated the stock was fished sub optimally with respect to yield (Figs 41-44, Appendix 6). The analysis did not include a bio-value component to determine the size at first capture that maximises the value of the catch because current markets do not pay higher prices for fish of a particular size.

For female ocean jackets, the yield was estimated at 52% of Bmax (Fig.41) at 1989 levels of F (=0.4) and an age at first capture of 2.5yrs (=31.4cm standard length). The maximum yield of 93% of Bmax was obtained at F=1.6 and an age at first capture of 2.0yrs (Fig.42). At the 1989 level of F, yield was maximised at 68% of Bmax at an age of first capture of 1.00yrs

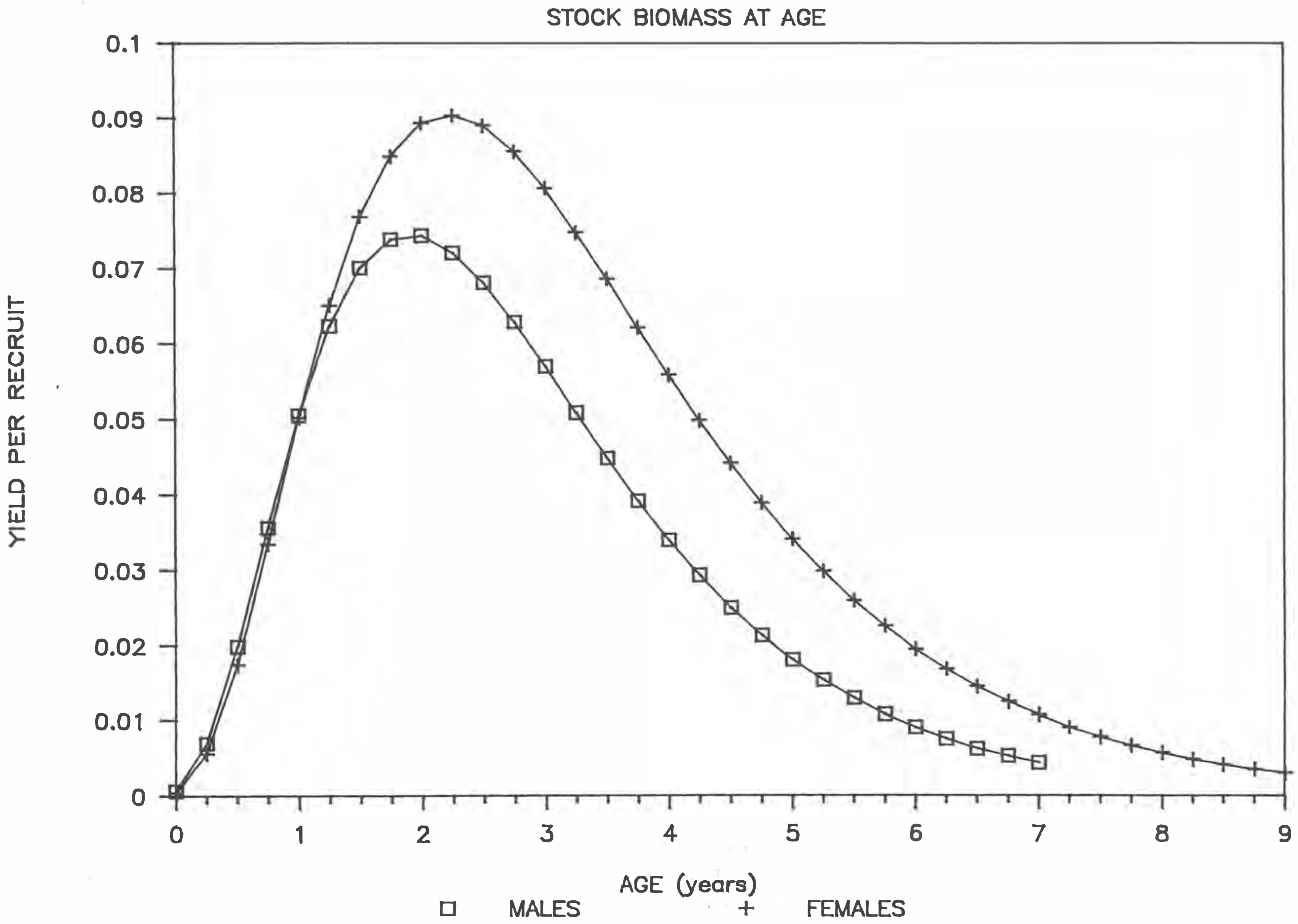


Figure 40: Stock biomass at age (unfinished population)

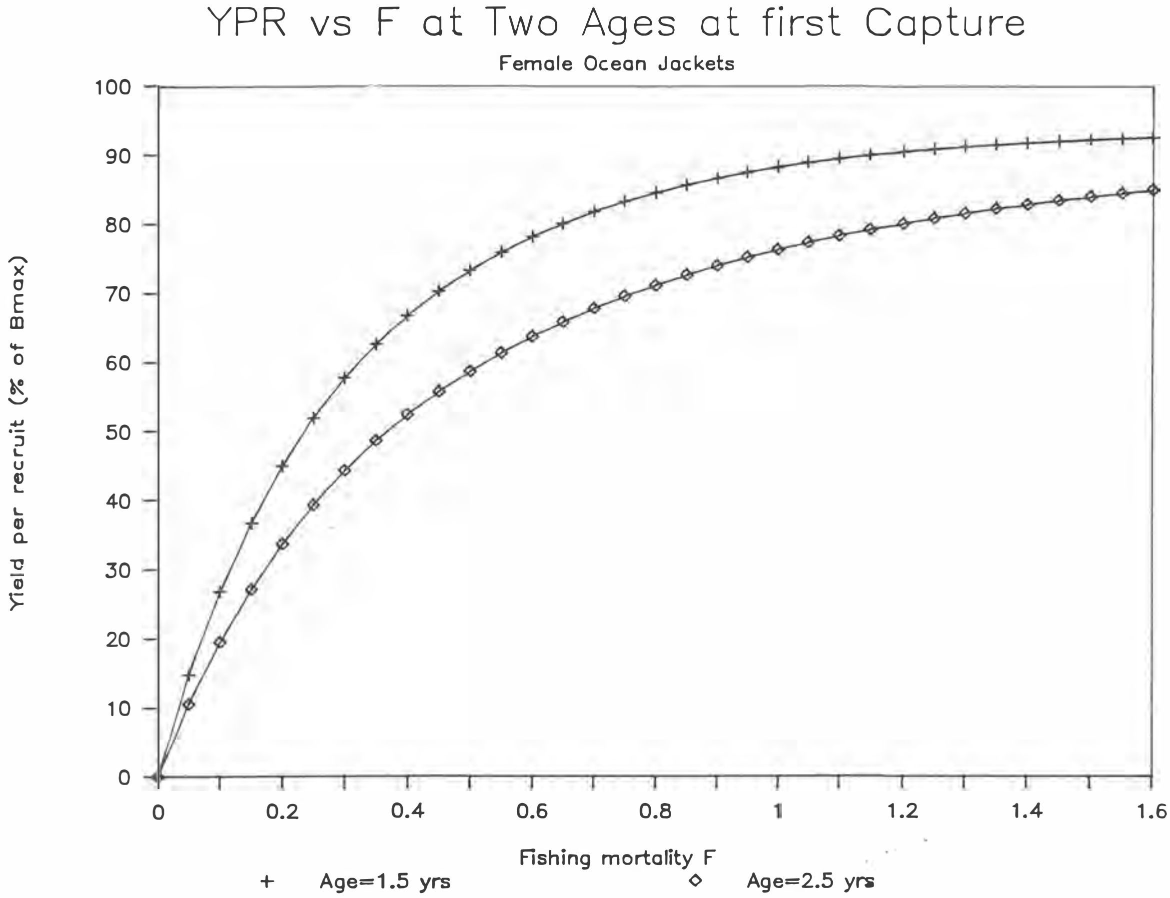


Figure 41: Yield per recruit and fishing mortality relationship at two ages at first capture; female ocean jackets

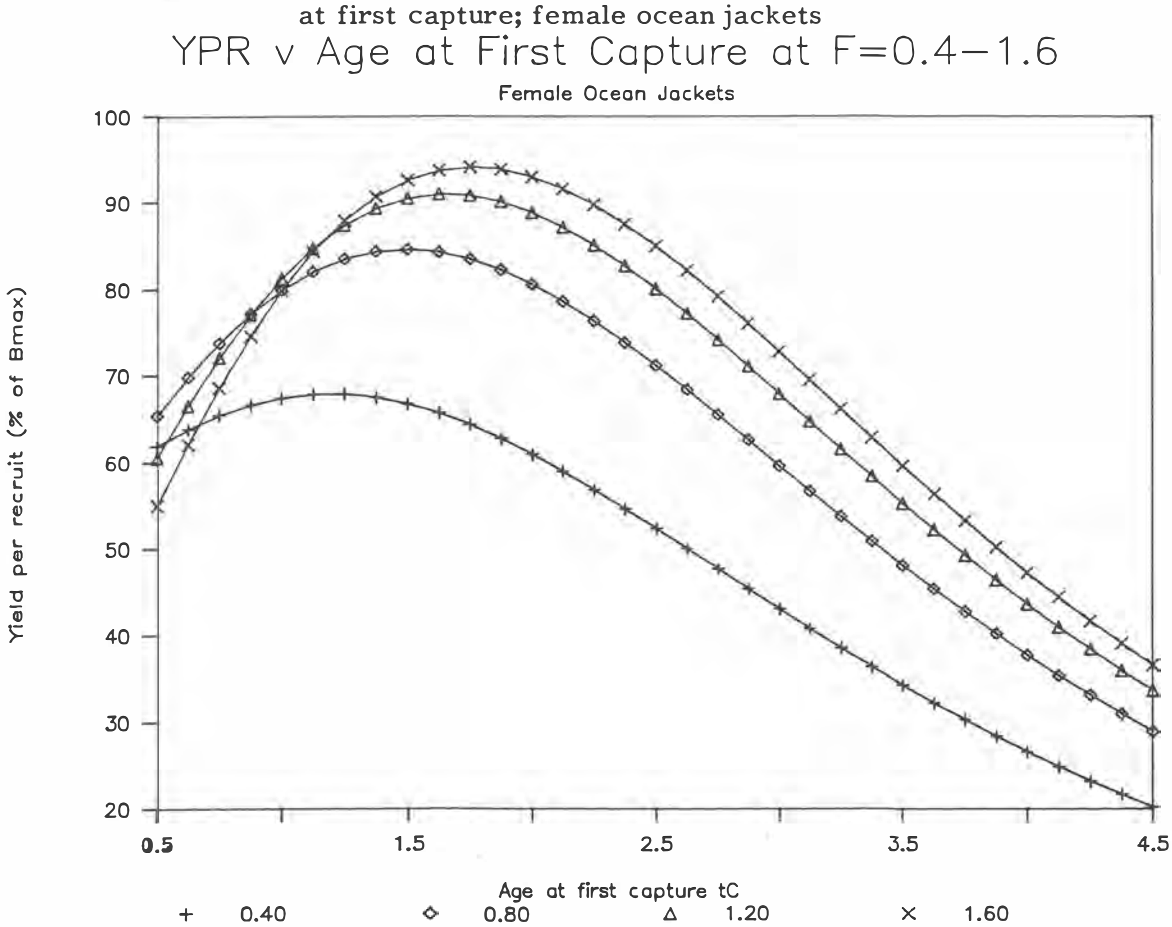


Figure 42: Yield per recruit and age at first capture relationship at four levels of fishing mortality; female ocean jackets

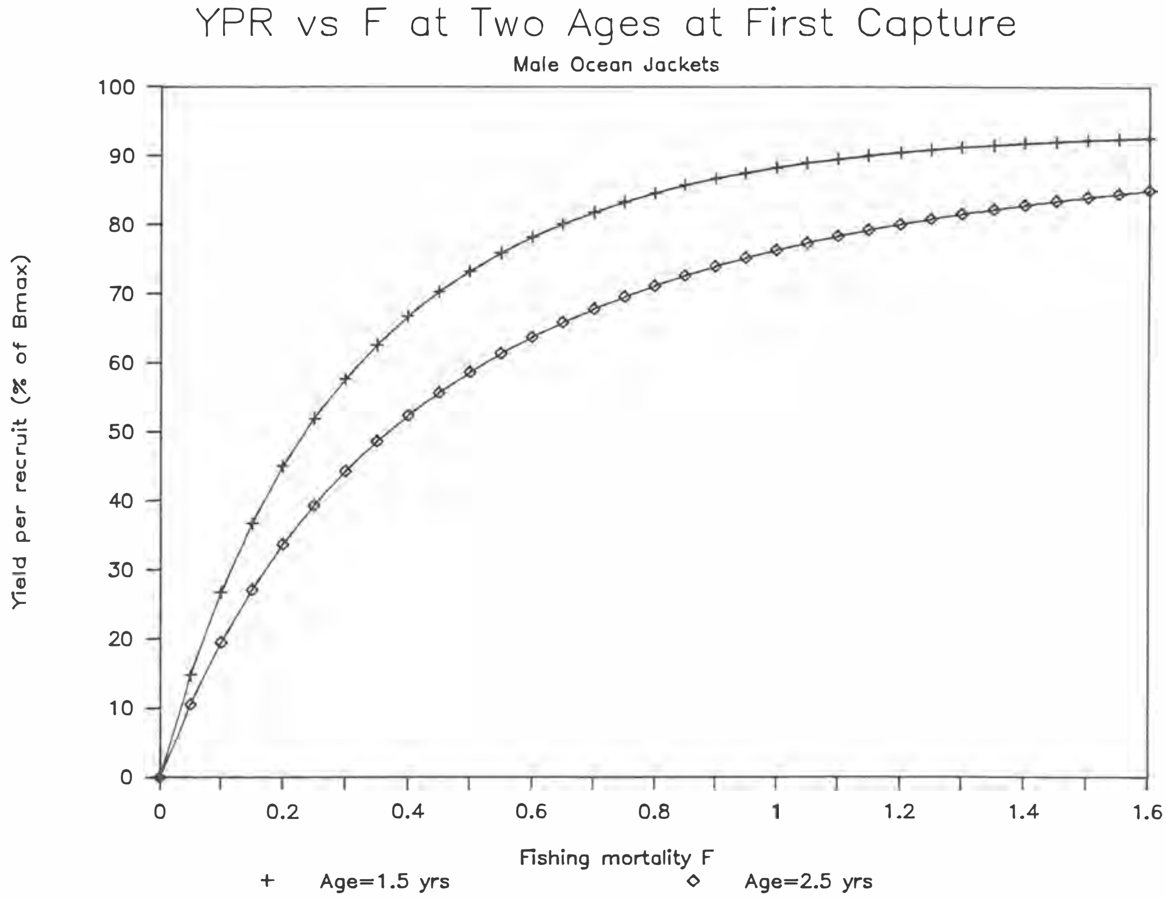


Figure 43: Yield per recruit and fishing mortality relationship at two ages at first capture; male ocean jackets

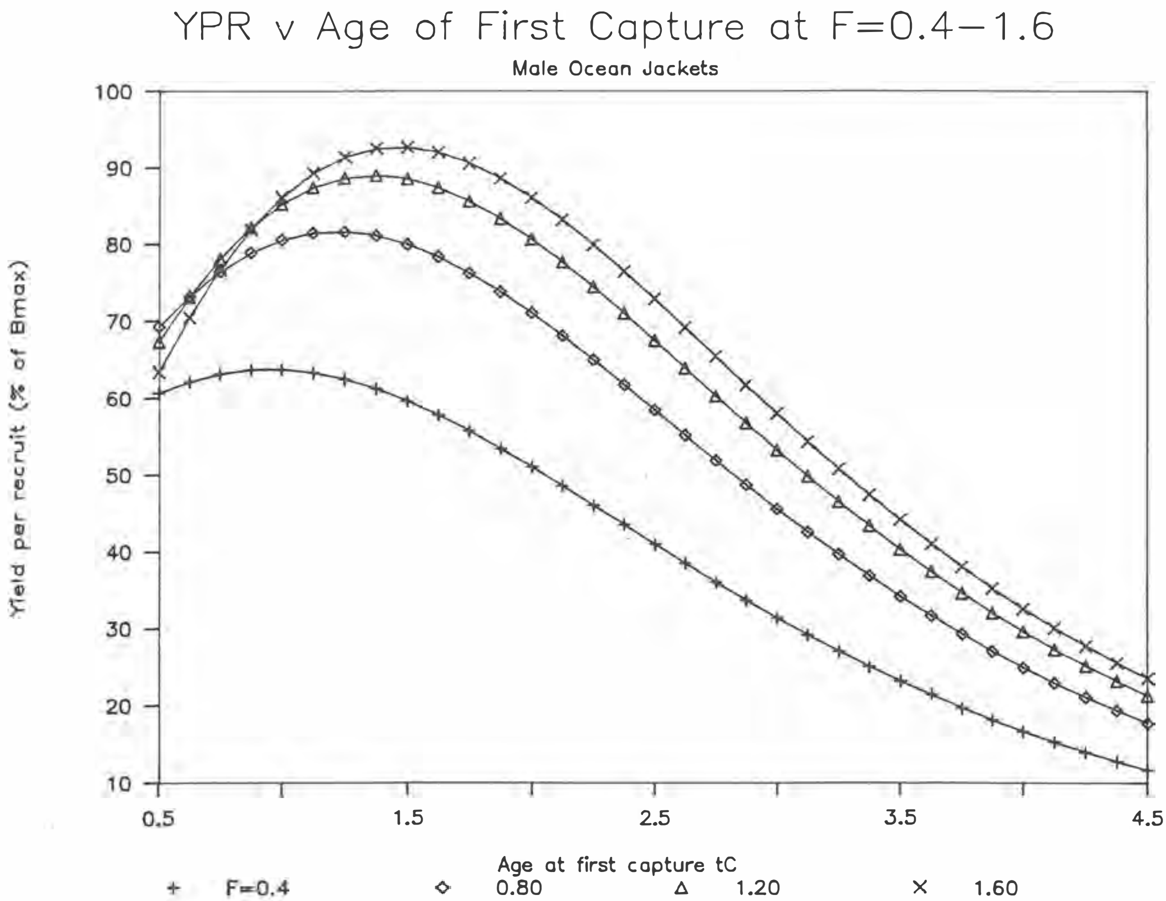


Figure 44: Yield per recruit and age at first capture relationship at four levels of fishing mortality; male ocean jackets

(18.6cm) although yields greater than 60% of Bmax were obtained over the range of ages at first capture of 0.5-2.0. At the current age at first capture, yield continued to increase with increasing fishing mortality over the range F=0.4-1.6, albeit at a reducing rate, to a level of 85% of Bmax at F=1.6.

For male ocean jackets, the yield was estimated at 41% of Bmax (Fig.43) at the 1989 levels of F (0.4) and age at first capture of 2.5yrs (31.5cm). The maximum yield of 93% of Bmax was obtained at F=1.6 and age at first capture of 1.5yrs (24.6cm) (Fig.44). At the 1989 level of F, yield was maximised at 64% of Bmax at an age of first capture of 1.0yrs (19.4cm) although yields greater than 60% of Bmax were obtained over the range of ages at first capture of 0.5-1.5 (=12.5-24.6cm). At the current age at first capture, yield continued to increase with increasing fishing mortality over the range F=0.4-1.6, but at reducing rate, to a level of 73% of Bmax at F=1.6.

These results indicate that increased fishing mortality and a reduction in the size at first capture should result in an increased total catch. This is because the natural mortality and growth rates estimated for the species were both high, and that under these circumstances the harvesting strategy that maximises total catch is to exploit the younger age classes.

Reducing the age at first capture from 2.5 to 1.5 years at the 1989 fishing mortality level of F = 0.4 should result in an increase in yields of approximately 27% in females and 45% in males (Appendix 6). Under this harvesting strategy, the target size would be 18-24cm standard length compared to the current average size 35cm (Figs 7&8), and the number of fish handled would be considerably greater than at present. The target size is less than the size at first spawning, and measures would need to be introduced to prevent recruitment overfishing. The target size would also be less than the size of fish currently sold in Australia and new markets could be required for the larger numbers of small fish produced under this scenario. Suitable markets could exist in Asia where the domestic fisheries are for relatively small leatherjacket species ranging in length from 14-32cm total length in Japan (Kakuda, 1979) and averaging approximately 22cm standard length in Korea (Park, 1985).

This fishing strategy would involve considerable change in the fishery and should not be considered without further research and consultation with industry. The research should identify ways to prevent recruitment overfishing and investigate potential markets for small ocean jackets. A legislated minimum legal size would not be an appropriate way to regulate size at first capture because most undersized fish would die when returned to the water due to the effects of barotrauma as described in section 2.8. However, ocean jackets occur in different habitats at different stages of their life cycle and closed areas could therefore be used to regulate the size at first capture. 1+ year old fish could be targetted by concentrating fishing activity in the 40-80 metre habitat occupied by 1+ year old juveniles.

Classical yield per recruit analysis indicated the fishery is not fully exploited at current levels of effort. This implies that catches should increase if fishing effort is increased but the size at first capture remains unchanged. The yields predicted by the model following a doubling of the fishing effort relative to the predicted 1989 equilibrium levels (Appendix 6) were an increase from 52 to 71% of Bmax for females and from 41 to 58% of Bmax for males. This approximates an increase in total catches above the predicted 1989 equilibrium level of approximately 36-41%. The model assumes the fishery has reached equilibrium (numbers of births = numbers of deaths) but this is not known and the predictions generated must be considered as trends rather than absolute outcomes. It is concluded that catches should increase if effort increases but that the ammount by which catches should increase is unclear.

3.8.2 Age Structured

Input parameters used in the calculation of female age structured yield curves (Figs.45-47) are shown in table 20.

Table 20 Input parameters for age-structured yield analysis (females).

Age (yr)	Ntrl Mort	Std Ln (cm)	Tot Wt (kg)	Fecund-ity (thou)	% mat-ure	Vul-ner-ability	Select ivity
0	0.66	2.9	0.00	0.00	0	0.00	0.00
1	0.66	18.5	0.09	0.00	0	0.00	0.00
2	0.66	28.0	0.32	162.40	22	0.10	1.00
3	0.66	33.8	0.57	489.00	83	0.30	1.00
4	0.66	37.3	0.76	737.20	100	0.68	1.00
5	0.66	39.4	0.90	920.10	100	0.68	1.00
6	0.66	40.7	0.99	1037.7	100	0.68	1.00
7	0.66	41.5	1.05	1116.0	100	0.68	1.00
8	0.66	41.9	1.09	1168.3	100	0.68	1.00
9	0.66	42.2	1.11	1194.4	100	0.68	1.00

Figure 46 shows the relative weight of female ocean jackets in each age class at the 1989 exploitation rate (Fig.46a) and at double that exploitation rate (Fig.46b). From these figures it can be seen that

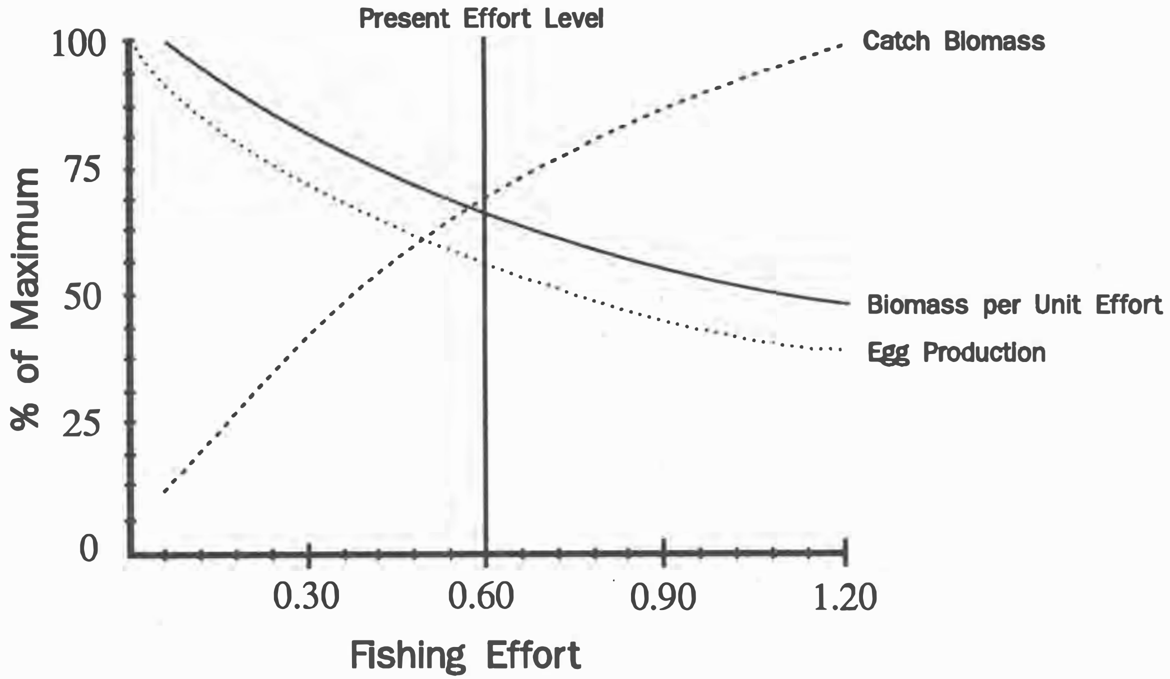
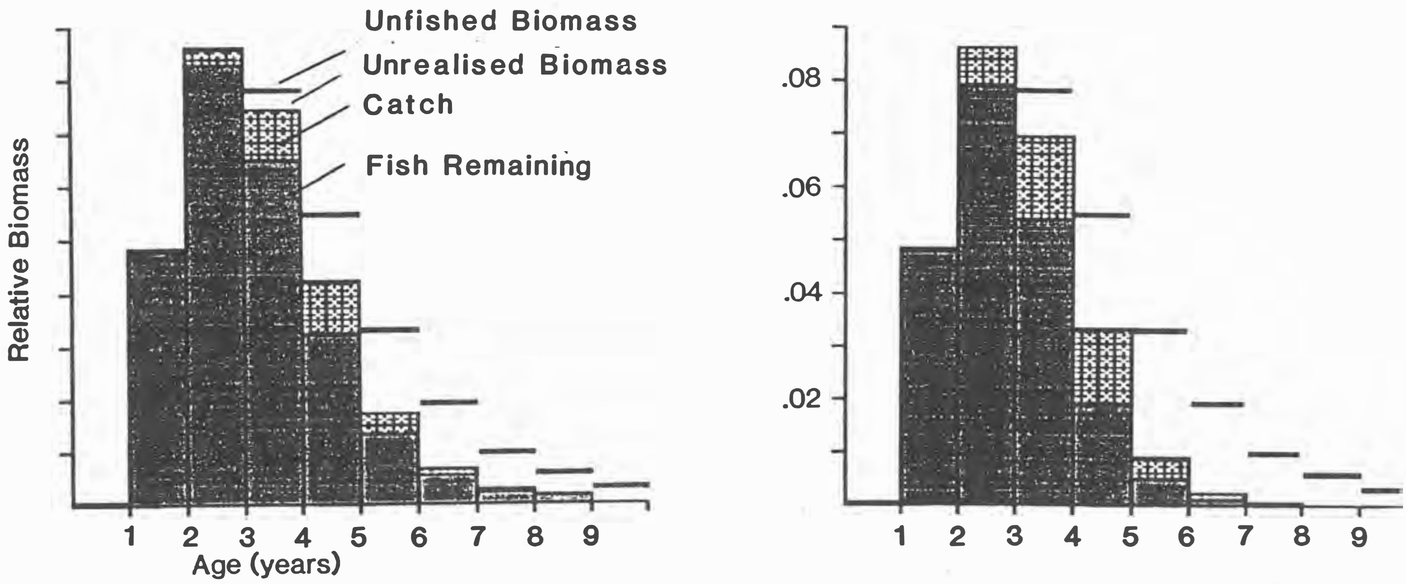
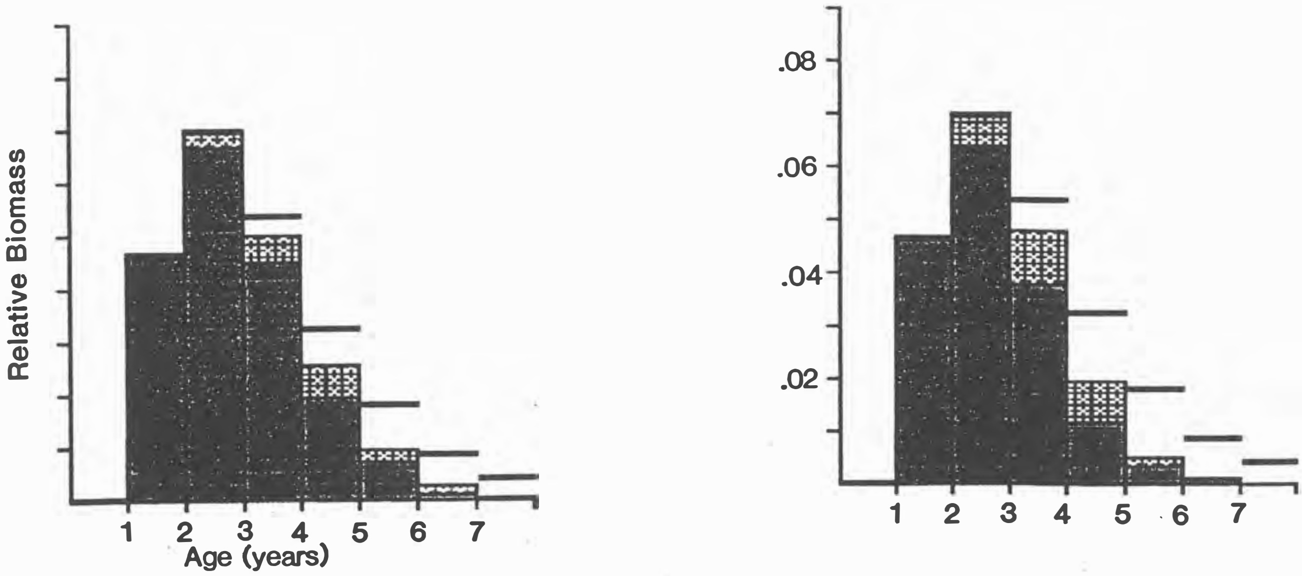


Figure 45: Equilibrium total catch, catch rates and egg production for female ocean jackets predicted by age structured yield modelling at zero to double current fishing effort.



a) b)

Figure 46: Relative weight of female ocean jackets in each age class at a) the current exploitation rate and b) double the current exploitation rate as predicted by age structured yield modelling



a) b)

Figure 47: Relative weight of male ocean jackets in each age class at a) the current exploitation rate and b) double the current exploitation rate as predicted by age structured yield modelling

fishing at the 1989 level would eventually remove most of the nine year old fish from the population and cause seven and eight year old fish to become increasingly rare. Old fish must eventually decline in numbers once those that were present before the stock was fished have been removed because few survive being caught long enough to reach an age of seven or eight. At double the 1989 level of fishing, most eight and nine year old females would eventually disappear and the six and seven year old fish become rare. Male ocean jackets showed similar trends (fig.47 a&b) with the younger age classes forming an increased proportion of the catch at higher levels of effort.

i) Egg Per Recruit

Figure 45 shows the trends in levels of egg production, female catch biomass and catch rates that can be expected over the range from zero fishing effort to twice the 1989 level of fishing effort. Results are expressed as percentages of the maxima obtained over the range of effort prescribed and are not absolute maxima. According to the model, egg production should stabilise at 51.3% of the pre fishing level at the current level of fishing effort. Egg production should drop to 36.5% of the pre-fishing level at double the 1989 level of effort and 24.1% of pre-fishing levels at four times the 1989 level of effort (not shown on graph).

Although the level of egg production that need be maintained in a fishery to sustain continued catches is the subject of discussion among biologists, it would be imprudent to allow egg production to drop below 25% of the pre-fishing level without further information. A more responsible and safer level would be to maintain egg production above 35% of the pre-fishing level. This level of egg production should be maintained by containing fishing mortality below a level of 0.8, or twice the 1989 level.

ii) Catch Rates

The model predicted that at the 1989 level of fishing mortality, catch rates of females (biomass per unit of effort) should eventually drop by approximately 31% of the pre-exploitation level before stabilising (Fig.45). At twice that level of fishing mortality, catch rates should decline by approximately 52% (Fig.45) relative to catch rates that were possible before exploitation before stabilising. A similar trend was predicted for males with an eventual decrease in catch rates of 26% at the 1989 level of fishing mortality and 45% at twice that level. The reason for the predicted decline in catch rates is that most of the old fish will eventually be removed from the population, and catches will be dependent on the numbers of young fish entering the fishery each year.

The accuracy of the prediction is affected by increases in the efficiency of individual fishers and by uncertainty over the state of equilibrium of the fishery. If the fishery is close to equilibrium, the predicted decline in catch rates at current levels of fishing should be low, and may be masked by increases in efficiency. Conversely, decreases in catch rates should be substantial at the current level of fishing if the equilibrium is distant. By comparing the age structure of the catch in 1988 and 1989 (table 8) in which 76-82% of the catch were fish from three age classes with the predicted age structure at equilibrium (Figs 46 & 47), it appears that the fishery may be close to equilibrium. It is concluded that catch rates should not decline significantly at current levels of fishing if the fishery is close to equilibrium.

4. CONCLUSIONS

4.1 General Biology

Ocean jackets reproduced during April and May in offshore waters west of Pearson Island. All females aged four years and older were mature as were a smaller proportion of two and three year old fish. The number of eggs produced per female per year ranged from approximately 250,000 among two year old fish to approximately 1,100,000 in fish aged 5 years. Ocean jackets are concluded to be a highly fecund species with an offshore seasonal breeding cycle.

In contrast to the adult habitat, juveniles were found to be seasonal inhabitants of Spencer Gulf and the shallow bays west of Yorke Peninsula to Nuyt's Reef. Within this range, abundance tended to increase in a westerly direction. The smallest juveniles were detected in November, six months after the May spawning. They grew rapidly to reach a mean length of 18 centimetres the following May at age one year. At age 13 months they migrated out of the inshore bays to occupy more open waters at depths to approximately 60 metres. At age two years they reached a mean length of 28 centimetres and some began to mature. The onset of maturity occurred between ages two and four years and was associated with a migration further offshore where fish became vulnerable to commercial fishing.

The age at maturity coincided with the age of recruitment and the offshore migration into the adult habitat. Full recruitment occurred at age four years and partial recruitment at ages two and three years. Approximately 79% of the catch comprised fish from three year classes (ages 3,4 and 5 years). The effects of any reproductive failure should therefore take 3-5 years to be felt as reduced catches because it takes that period for the young to develop and enter the fishery.

Maximum ages of seven years for males and nine years for females were estimated by counting growth rings on the vertebrae. Total mortality rates were estimated to be high due mainly to natural causes rather than fishing. Total mortality rates were estimated at 65-69% per year, of which 40-45% of deaths were due to natural causes and 24% due to fishing. Ocean jackets are a fast growing short lived species. The rapid growth and short life span determined for ocean jackets indicated the fishery should sustain high fishing pressure and the removal of a relatively high proportion of its biomass annually.

Lower natural mortality rates in females than males resulted in greater longevity in females and therefore more large females than males in the commercial catch. Females outnumbered males considerably in age classes five years and older but were present in approximately equal numbers in the younger age classes. One effect of fishing should therefore be a reduction in the number of old females and consequently a reduction in the ratio of females to males from the current ratio of 2:1.

4.2 State of the Fishery

Total annual catches increased each year between 1983/84 and 1988/89 due mainly to increases in the proportion of the catch taken by a small number of specialist ocean jacket trapping vessels in the marine scalefish sector. Annual catches have stabilised at approximately 900 tonnes whole weight since 1988/89 due mainly to marketing constraints.

Per recruit analyses indicated yields could be increased by reducing the size at first capture and increasing fishing mortality. Decreasing the size at first capture would involve considerable change within the fishery however, and cannot be advocated without support from industry, an assessment of potential markets for small fish, and application of measures to prevent recruitment over-fishing. Increasing the amount of fishing should result in increased total catches but there is uncertainty surrounding the level of fishing that would be sustainable in the long term.

Egg per recruit analysis indicated egg production was relatively high despite the high level of exploitation in the fishery. This was due to the short lifespan and high fecundity attributed to the species. Egg production was estimated at 51% of pre-fishing levels in 1989 and it was predicted this should stabilise at approximately 36% of pre-fishing levels at twice the 1989 level of fishing mortality.

4.3 Capacity for Increased Catches

Per recruit analysis has indicated fishing mortality could be increased above present levels while maintaining a reasonable level of egg production. However, there remains considerable uncertainty concerning the sustainability of higher catches and caution must be advocated when setting target levels of catch. It is recommended that fishing levels be maintained at or below current levels for a period of three years to allow the fishery to come to equilibrium. The level of fishing should be controlled by quota unless managers are confident they can control increases in effort arising from increases in the efficiency of existing operators and an increase in the number of vessels in the fishery. The fishery should be closely monitored during this period to determine changes in the size and age composition of the catch, catch rates and sex ratio. If there are no significant changes in the fishery during the next three years, managers may consider a variation in quotas. Egg per recruit analysis indicated a fishing mortality level of 0.8, corresponding with an estimated annual catch of 1200 tonnes whole weight would result in a level of egg production approximately 36% of the pre-fishing level. There is considerable uncertainty whether or not this is level of catch is sustainable, but it is suggested as a target for managers to work towards subject to the results of the monitoring program.

4.4 Future Research and Monitoring

This research project has succeeded in developing methods for studying leatherjackets and in making first estimates of the fishery parameters. These methods should now be refined and second estimates obtained and used to improve the understanding of the species and the effects of fishing.

Highest priority should be allocated to the determination of the natural mortality rate in the very lightly fished population of ocean jackets in Western Australia using direct ageing methods. The opportunity to assess natural mortality rate directly will be lost once the population there is exploited. Further work is also required on the growth and movement of small (0-2 year old) fish and should include juvenile tagging studies in the west coast bays. The relationships between exploited stocks in the eastern Great Australian Bight and those in the south east, south of Kangaroo Island and central and western Great Australian Bight remain unclear and should be investigated.

Monitoring should include the collection and interpretation of changes in the total catch by weight, size, age and sex ratio, the effort expended to catch the fish in terms of standard trap lifts, and the area fished. Collection of these data would require input from the commercial fishers, a technician, and minor modifications to the fishers compulsory daily logbooks and the SADF data handling and GARFIS computer systems.

4.5 Recommendations

(i) Contain catches in the fishery to current levels for a period of three years by the allocation of a quota of 900 tonnes whole weight (428.5 tonnes clean weight) applicable to all commercial fishing activity in the waters defined by the northern zone of the South Australian rock lobster fishery. An additional exploratory quota of 100 tonnes should be allocated to commercial fishers operating in the waters defined by the southern zone of the South Australian rock lobster fishery.

(ii) Introduce a detailed monitoring program of the South Australian fishery.

(iii) Review quotas in three years subject to the results of the monitoring program.

(iv) Obtain a direct estimate of the natural mortality rate from the Western Australian population of ocean jackets and

(iv) Support studies on marketing small ocean jackets and other leatherjacket species in Asia.

5. Acknowledegements

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Members of the Department of Fisheries assisted in various other aspects of the project and to them we extend our thanks. Kevin Branden completed the difficult task of filming ocean jackets in situ at a depth of 94 metres with assistance from Brian Davies and the crew of the MRV Ngerin. Bob Spriggs, John Omerod, and Keith Evans provided details of juvenile ocean jacket catches taken during departmental surveys of other species. Gavin Wright helped with many of the diagrams, Janine Baker ran the age structured per recruit program, and Keith Jones and John Johnson critically reviewed the manuscript.

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R E S E A R C H

OCEAN JACKET TRAPS
A S S E S S E D

Aspects of the operational performance of fish traps have been assessed as part of the Port Lincoln based research program on ocean jackets *Nelusetta ayraudi.* Researchers varied the entrance widths and distances between entrances and bait containers and measured the catch rate of ocean jackets at the different settings.

Catches were high when the entrance width was set at 80mm and the entrance to bait container distance set at 150–200mm but settings higher or lower than this generally resulted in reduced catches. Trap volume and the interaction between trap volume and soak time were also thought to influence catches but could not be assessed due to logistic difficulties. To help interpret how changes to the traps had influenced catch rates and to better understand the behaviour of ocean jackets near a fish trap, traps were video filmed at depths of 92–95m.

Effect of entrance width

To test the effect of different entrance widths on the catch of ocean jackets a total of seven traps with different entrance widths were used alongside one another and their catch rates compared. One trap had an entrance only 40mm wide and two each of the remaining six traps had entrances 60mm, 80mm and 90mm wide. The distance from the entrance to the bait basket was standardised at 175mm for all traps. The traps were set and retrieved after approximately 2–2.5 hours, then rebaited and reset for a further two to two and one half hours. The number of fish caught and the soak time were recorded for each trap, and the average catch rate for each entrance width setting determined.

Results are summarised in Table 1 and show an increase in the average catch rate as the entrance widths increased from 40mm to 60mm to 80mm; however, little or no increase was recorded between 80mm and 90mm. On the basis of these results 80mm was certainly a better entrance width for catching ocean jackets than the 60mm maximum allowed under the Fisheries Act (1982); but there was no advantage in using entrances wider than 80mm. As a result the regulations governing the use of fish traps are being amended to allow entrances up to 80mm wide for ocean jacket traps.

Position of the bait basket

The second trap setting investigated was the distance between the entrance and bait basket (see FIGURE 1). For this trial a total of four traps with different distances from the bait basket to entrance were used. The distances were 100mm, 150mm, 200mm and 300mm, and the entrance width for all traps was set at 80mm. The traps were set at first light and then pulled and reset a total of five times for each trap. As in the previous trial the number of fish caught and the soak time was recorded for each trap and the average catch rate determined for each of the different settings. Catches were foundto be high using a setting of 150mm or 200mm but were reduced if the bait basket was set closer or further from the entrance (TABLE 2). Note that the catch rates reported in Table 1 cannot be validly compared with those in Table 2 as the respective trials were conducted in different locations and on different days.

Filming traps

To help interpret how changes to the trap settings affected catch rates we decided to film and study the behaviour of ocean jackets in the vicinity of a baited trap. To do this a fish trap was attached to a heavy steel frame which had a video camera with underwater lights fitted at one end and a 35mm camera with 2 flash units mounted to optimise exposure. The 35mm camera was fitted with a wide angle lens, self winding mechanism, and attached to a timing device set to trigger an exposure every three minutes. The video equipment was focused on the trap entrance and filmed continuously from the time it was started on deck, before being lowered to the bottom, until its batteries were drained 90 minutes later.

The film showed that some ocean jackets were able to feed from the bait basket while hovering in the trap entrance, then reverse out and avoid capture. Placing the bait basket too close to the entrance would have encouraged this behaviour and resulted in low catch rates. Fish that entered the trap to feed did not escape and future improvements to trap design should therefore aim to increase the ease of entry to the trap rather than prevent the escape of already trapped fish.

Like other members of the leatherjacket family ocean jackets were found to be extremely manoeuvrable and able to swim forwards, backwards, or hover in one place with little difficulty. They were able to do this by undulating their centre top and bottom (dorsal and anal) fins in unison or in opposition. The tail (caudal) fin and trunk of the body was used mainly to produce a rapid turn of speed from a standing start. This type of swimming behaviour was seen in fish nipped by other members of the school and is probably also used to evade predators or catch fast swimming prey such as pilchards and other small fish which form a part of their diet.

Filming also provided a view of the bottom surface and water movement around the trap and the behaviour of the fish in its natural environment. The bottom surface around each trap was either coarse sand, or sand and silt, and ripple marks were evident at depths of 92–95m. The horizontal back and forth wash of suspended particles (and trapped fish) rather than a steady stream of suspended matter from one side of the screen to the other was evidence of that swell was operating at these depths in two of the three films produced. (There was no water

TABLE 1 Effect of entrance width on the catch rate of ocean jacket *Nelusetta ayraudi* in traps.

ENTRANCE WIDTH (mm)	40	60	80	90
AVERAGE CATCH RATE (#fish/hour)	1.5	11.1	24.0	23.4

TABLE 2 Effect of the position of the bait basket on the catch rate ofocean jacket *Nelusetta ayraudi* in traps.

BAIT BASKET TO ENTRANCE DISTANCE (mm)	100	150	200	300
AVERAGE CATCH RATE (#fish/hour)	4.7	13.8	12.6	2.4

Figure 1 Part A

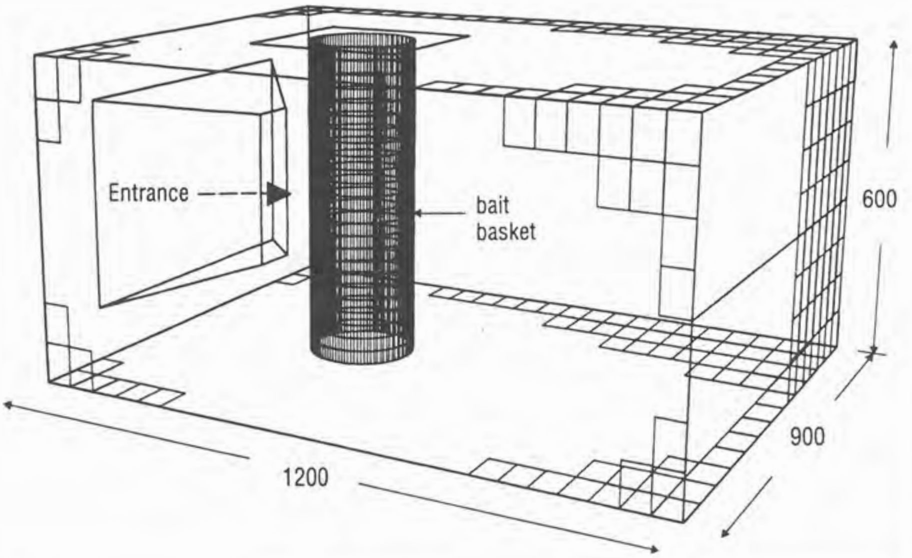
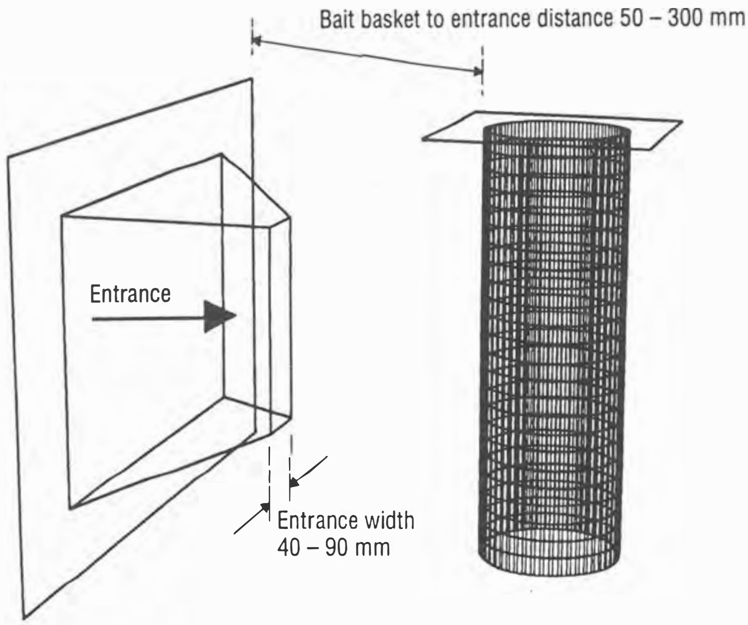


Figure 1 Part B



Top and middle left: *Principal dimensions of an ocean jacket fish trap showing positions of the bait basket and entrance.*

movement in the third film.)

Consequently, fish did not seem to approach the trap from one particular direction as would be have beenexpected if a steady current was streaming past the trap and carrying the scent of bait off in that direction.

Other observations were that ocean jackets appear to form loose and relatively small schools when feeding (comprising dozens rather than thousands of fish). These schools have both males and female members and there is some interaction between individuals (tail biting) that may suggest a social structure to the school, or alternatively may have resulted from competition for the food (bait). When two or more fish were hovering in the trap entrance at the same time it was often a nip from one that encouraged the other to swim into the trap and be caught. Results from our tagging program in which some fish caught and tagged together were recaptured together some months later suggests there is some level of social cohesion within a school.

R. Grove-Jones,
Senior Research Officer

A. Burnell,
Technical Services Officer

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Bottom left: *Ocean jackets* (Nelusetta ayraudi) *approach a fish trap at 92 metres.*

continued from page 9

e) Sex ratio/length relationship: with increasing length of fish the relative number of females increases, till at lengths of 48cm, almost all fish are females.

The department is grateful for the assistance of many fishers collecting information on spawning fish. These include: Larry Edmonds, Chris Johnson, Bob Rutter, Ian King, Bill Jackson, (late) Bert Fooks, and Fisheries Officer Rod Ashenden. The Research Branch welcomes any fishers supplying information on the location, time, and size of spawning whiting or any other fish species. They should contact the branch on (08) 226 0626 or (08) 356 4600 (reverse changes) to register their interest.

For those collecting information for us in the future we have presented the field guide which will aid in the identification of spawning fish (page 9).

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APPENDIX II

(i)

Percent Length at Age Distribution: Males

Standard Length (cm)	Age (years) 2	3	4	5	6
20	100				
21	100				
22	100				
23	100				
24	100				
25	97.7	2.3			
26	95.4	4.6			
27	89.5	10.5			
28	78.3	21.7			
29	60.5	38.9	0.6		
30	38.5	57.9	3.6		
31	20.1	69.6	10.3		
32	8.8	69.2	22.0		
33	3.2	59.4	37.4		
34	1.1	45.8	52.6	0.5	
35	0.4	32.8	63	3.8	
36		20.6	61.3	18.1	
37		10.1	42.7	45.3	1.9
38		3.5	19.3	57.3	19.9
39		1.0	6.4	37.8	54.8
40		0.5	3.3	27.0	69.2
41			3.9	34.8	61.3

APPENDIX II

(ii)

Percent Length at Age Distribution: Female

Standard Length (cm)	Age (years) 2	3	4	5	6	7
24	100					
25	99.3	0.7				
26	96.0	4.0				
27	86.8	13.2				
28	67.2	32.8				
29	40.5	58.8		0.7		
30	19.5	77.7		2.1	0.7	
31	8.7	84.0		5.5	1.8	
32	3.5	79.6	1.3	12.1	3.5	
33	1.2	57.8	12.2	22.4	6.4	
34	0.3	25.4	40.2	26.2	7.9	
35		8.6	58.1	25.3	8.0	
36		3.3	55.7	28.4	12.6	
37		1.5	36.2	39.9	22.4	
38		0.4	11.0	48.9	39.7	
39			1.4	43.6	55.0	
40				19.0	40.4	40.4
41				11.2	44.4	44.4
42				6.2	46.9	46.9
43				2.8	48.6	48.6

APPENDIX III
Sampling Locations

(i)

SIZE STRATIFIED SAMPLES

Date	Latitude (°S)	Longitude (°E)	Depth (m)
26.1.88	34.37	134.29	94
25.3.88	34.40	134.13	111
16.4.88	34.59	134.47	110
29.5.88	34.32	134.37	94
17.6.88	34.38	134.38	96
7.7.88	34.34	134.28	94
29.8.88	35.05	135.33	88
15.9.88	35.26	135.45	121
20.10.88	35.15	135.21	111
1.12.88	35.24	135.44	107
19.12.88	34.57	134.52	104
25.1.89	34.36	134.35	86
2.3.89	34.44	134.32	98
16.3.89	34.39	134.37	100
22.4.89	34.18	133.35	100
6.5.89	34.02	134.11	80
22.6.89	35.08	135.24	102
20.7.89	35.03	135.11	113
24.8.89	34.37	134.38	92
21.9.89	34.39	134.41	95
26.11.89	34.11	134.52	80
14.12.89	34.24	134.45	80
21.1.90	34.40	134.00	109
21.2.90	35.00	134.26	120
30.3.90	34.20	132.55	131
22.4.90	34.05	133.43	91
26.90	34.40	134.45	95

APPENDIX III
Sampling locations
(ii)

WATER TEMPERATURE AND SALINITY SAMPLES

Date	Lat (°)	Long (°E)	Depth (m)	Temperature (C)		Salinity (ppt)	
				Surf	Bottom	Surf	Bottom
16.3.89	34.39	134.37	100	18.25	17.39	35.94	35.71
18.4.89	34.28	133.49	100	19.00	17.20	36.00	36.16
24.5.89	34.41	134.42	95	18.07	17.00	36.42	35.73
21.6.89	35.16	135.26	85	16.10	15.60	35.80	35.81
19.7.89	35.03	134.52	112	15.52	15.60	36.04	35.91
24.8.89	34.37	134.38	92	14.86	14.66	35.93	36.24
21.9.89	34.36	134.40	94	15.46	15.46	36.30	35.90
22.11.89	34.53	134.15	120	17.10	15.95	35.58	35.44
20.1.90	34.38	134.07	106	20.07	18.87	35.67	35.83
21.2.90	35.00	134.26	120	19.86	15.82	35.75	35.69
30.3.90	34.20	132.55	125	19.47	19.07	35.96	35.87

APPENDIX IV
TAG RELEASE DETAILS

(i)

Date	Location	Depth (m)	Tag Type	Number Released	Tag Numbers
24.3.88	34.38 S; 134.13 E	110	Int	65	2750-2814
24.3.88	34.43 S; 134.13 E	111	Int	59	2815-2874
14.4.88	35.02 S; 134.51 E	118	Int	25	2875-2899
15.4.88	34.59 S; 134.47 E	120	Int	50	3000-3049
26.5.88	34.17 S; 134.35 E	94	Int	50	3050-3099
28.5.88	34.37 S; 134.40 E	97	Int	48	4727-4749 + 4801-4825
29.5.88	34.32 S; 134.37 E	94	Int	24	4826-4849
17.6.88	34.38 S; 134.38 E	96	Int	50	3100-3149
23.8.88	35.06 S; 135.56 E	95	T-bar	2	1252-1253
23.8.88	34.58 S; 135.15 E	93	T-bar	16	1281-1282 + 1254-1271
24.8.88	34.40 S; 134.47 E	84	T-bar	5	1272-1280
29.8.88	35.05 S; 135.33 E	88	T-bar	14	1313-1326
14.9.88	35.25 S; 135.45 E	111	T-bar	51	1328-1379
15.9.88	35.26 S; 135.45 E	121	T-bar	62	1380-1445
19.10.88	35.05 S; 135.33 E	90	T-bar	57	2001-2059
20.10.88	35.15 S; 135.21 E	111	T-bar	81	2060-2140
21.10.88	35.15 S; 135.21 E	109	T-bar	58	2143-2200
1.12.88	35.24 S; 135.44 E	107	T-bar	49	2201-2249
2.12.88	35.23 S; 135.43 E	105	T-bar	50	2251-2300
19.12.88	34.57 S; 134.52 E	104	Dart	50	5001-5050
25.1.89	34.36 S; 134.35 E	86	Dart	50	5051-5100
25.1.89	34.36 S; 134.35 E	86	Loop	25	6001-6025
27.2.89	34.57 S; 134.52 E	104	Dart	50	5101-5150
28.2.89	35.02 S; 135.01 E	117	Dart	100	5151-5250
1.3.89	35.00 S; 134.37 E	118	Dart	100	5251-5350
16.3.89	34.39 S; 134.37 E	100	Dart	10	5351-5360
17.3.89	34.31 S; 134.31 E	90	Dart	40	5361-5400
19.4.89	34.29 S; 133.48 E	101	Dart	90	5401-5490
20.4.89	34.29 S; 133.48 E	98	Dart	110	5491-5600
21.4.89	34.18 S; 133.35 E	100	Dart	43	5680-5722
22.4.89	34.18 S; 133.35 E	100	Dart	50	5601-5650
5.5.89	33.45 S; 133.55 E	82	Dart	30	5651-5679
6.5.89	34.02 S; 134.11 E	80	Dart	38	5723-5760
7.5.89	34.02 S; 134.11 E	89	Dart	26	5761-5786
8.5.89	34.10 S; 134.08 E	89	Dart	136	5787-5922

APPENDIX IV
TAG RELEASE DETAILS

(ii)

Date	Location	Depth (m)	Tag Type	Number Released	Tag Numbers
10.5.89	34.10 S; 134.08 E	85	Dart	139	5923-7061
21.6.89	35.01 S; 135.26 E	85	Dart	59	7062-7120
22.6.89	35.08 S; 135.24 E	102	Dart	96	7121-7216
18.7.89	35.16 S; 135.25 E	111	Dart	79	7217-7295
19.7.89	35.03 S; 135.11 E	111	Dart	107	7297-7400
20.7.89	35.03 S; 135.11 E	113	Dart	83	7401-7483
19.9.89	34.39 S; 134.41 E	95	Dart	17	7484-7500
20.9.89	34.39 S; 134.41 E	95	Dart	100	7501-7600
21.9.89	34.39 S; 134.41 E	95	Dart	118	7601-7716
23.10.89	35.04 S; 134.36 E	129	Dart	65	7717-7781
24.10.89	35.03 S; 134.29 E	126	Dart	83	7783-7869
25.10.89	35.01 S; 134.23 E	135	Dart	80	7870-7950
19.1.90	34.40 S; 134.12 E	105	Dart	13	7951-7963
20.1.90	34.38 S; 134.07 E	107	Dart	87	7964-8050
21.1.90	34.40 S; 134.00 E	109	Dart	50	8051-8100
28.3.90	34.23 S; 133.01 E	122	Dart	106	8101-8215
29.3.90	34.19 S; 133.07 E	122	Dart	94	8216-8250 + 8551-8600 + 8501-8510
30.3.90	34.20 S; 132.55 E	131	Dart	13	8511-8523

APPENDIX V

Dry Fertilisation of Ocean Jackets

A. Haywood, R. Grove-Jones

The following general technique (AH) was used (RGJ) to attempt fertilisation of N. *ayraudi* eggs at sea. Successful fertilisation was not achieved because the eggs were not fully ripe but the handling technique was otherwise satisfactory. In any future attempts to fertilise N. *ayraudi* at sea, steps should be taken to ensure the oocytes used are fully ripe (see section on artificial fertilisation).

The protocol assumes N. *ayraudi* eggs and sperm are activated to allow fertilisation when mixed with seawater. Sperm and eggs are extracted from the broodstock into separate clean containers and kept away from seawater until enough gametes are available to attempt fertilisation and everything is ready. Then they are mixed together and left to stand a few minutes before adding seawater, stirring gently and leaving approximately 5 minutes. Excess sperm are then rinsed away and the fertilised eggs left to sit in clean aerated seawater for transport to the laboratory. All receptacles should be cleaned in alcohol prior to use.

1. Lay female fish on its side on a bench covered with a damp towel. Strip eggs by stroking with a finger in an anterior to posterior direction along the belly toward the genital opening. Gentle strokes are sufficient if the fish are ready to spawn. Express the eggs into a clean cup or beaker taking care to avoid contamination with any faeces that may also be voided.

2. Continue to strip eggs until several millilitres have been obtained. Eggs from different fish can be combined if necessary.

3. Express sperm in a similar manner. Draw the sperm suspension directly from the genital opening into a syringe. Collect sperm from several males.

4. Add sperm to the eggs and mix together gently but thoroughly using a glass rod or feather. Do not add seawater at this stage. Leave the egg and sperm mixture for 5 minutes then add 300 ml seawater. Stir gently and leave another 5 minutes.

5. Fertilisation should have occurred by this stage if the gametes were viable. Float a 300 micron (1/2 egg diameter) sieve in a bucket of seawater and pour the egg suspension gently through the sieve. Rinse off the excess sperm but try to avoid pushing the eggs hard against the mesh as they are delicate.

APPENDIX V
(ii)

6. After rinsing off the excess sperm, transfer the sieve and eggs to a larger bucket or bin with lid and aerate gently to keep the eggs in suspension. If aerators are not available half fill the bucket or bin and let the motion of the boat provide the agitation.

7. Transfer eggs to laboratory as soon as possible after reaching port.

APPENDIX VI

YIELD PER RECRUIT TABLES

YPR (% of Bmax) vs Age (tc) or Length (lc) at First Capture and Fishing Effort

Female Ocean Jackets (M=0.66)

		Fishing Mortality F							
		0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6
tc	lc								
0.00	2.92	42.8	52.0	50.6	46.1	41.0	36.2	31.9	28.2
0.50	11.77	46.5	61.9	65.8	65.4	63.2	60.5	57.7	55.0
1.00	18.65	47.5	67.5	76.2	79.9	81.1	81.2	80.7	79.8
1.50	24.00	45.0	66.7	78.1	84.5	88.3	90.5	91.8	92.6
2.00	28.15	40.0	60.9	73.0	80.5	85.4	88.8	91.2	93.0
2.50	31.39	33.7	52.4	63.7	71.1	76.3	80.0	82.8	84.9
3.00	33.90	27.3	43.0	52.9	59.6	64.4	67.9	70.6	72.8
3.50	35.86	21.5	34.2	42.4	48.1	52.2	55.3	57.7	59.6
4.00	37.38	16.5	26.5	33.1	37.7	41.1	43.6	45.6	47.2

Male Ocean Jackets (M=0.77)

		Fishing Mortality F							
		0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6
tc	lc								
0.0	3.37	39.9	51.6	52.6	49.7	45.6	41.3	37.2	33.5
0.50	12.51	43.0	60.7	67.4	69.2	68.8	67.3	65.4	63.4
1.00	19.40	42.6	63.7	74.7	80.6	83.7	85.3	86.0	86.2
1.50	24.60	38.4	59.6	72.2	80.0	85.1	88.6	91.0	92.7
2.00	28.53	32.1	51.1	63.0	71.0	76.6	80.7	83.8	86.1
2.50	31.49	25.3	41.0	51.3	58.4	63.6	67.5	70.5	72.9
3.00	33.72	19.1	31.4	39.7	45.6	49.9	53.3	55.9	58.0
3.50	35.41	14.0	23.2	29.6	34.2	37.7	40.3	42.4	44.2
4.00	36.68	9.9	16.6	21.4	24.9	27.6	29.7	31.3	32.6