ADAPTIVE MANAGEMENT OF THE PILBARA TRAWL FISHERY

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96/133 Adaptive Management of the Pilbara Trawl Fishery

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OBJECTIVES:

1. To assess the size and age at maturity and reproductive capacity of Rankin cod, and lesser spangled emperor, the two species for which no information is available elsewhere.
2. To develop a more cost effective and accurate method for monitoring the level and distribution of catch and effort of the ten most valuable species in the Pilbara trawl fishery.
3. To investigate fish movement patterns, and the periodicity of otolith growth rings by tagging key species and monitoring tag returns.
4. To use the age structure of the 5 key species over time to assist in the evaluation of the effectiveness of management strategies.
5. To confirm whether otolith growth rings are annual for the 5 key species, using marginal increment analysis.
6. To refine and improve modeling techniques using biological, ageing, and tagging information.

NON-TECHNICAL SUMMARY:

The Pilbara trawl fishery expanded rapidly in the early 1990's creating the need for a rapid assessment of the impact of trawling on the fish stocks. In a three year collaborative project with industry, commencing in 1993, an experimental approach was used to determine the fishing mortality of five key species in the Pilbara trawl fishery. This experiment determined that at the 1994 level of fishing effort, a long-lived and valuable species in the fishery, red emperor (*Lutjanus sebae*), was over-exploited although other more abundant but less vulnerable short lived species were under-exploited.

To bring fishing mortality of red emperor to the agreed reference point of F = 0.1, and to maximise the catch of the species less vulnerable to over-fishing, a management plan was instigated which divided the fishery into discrete management areas with effort quota being allocated in each area. Fishing effort was reduced in areas of high red emperor abundance

(including an area closure) and redirected into lightly fished areas and areas where short lived species were abundant. The effort quota was enforced with a Vessel Monitoring System.

The principal purpose of this project was to improve the stock assessment of species in the Pilbara trawl fishery by incorporating biological information, catch and catch rate data, and age structure into an age structured model and to refine the mortality model of the previous FRDC project using current catch and effort information.

The age structured model indicated that the red emperor stock in area 1 (116°E to 116°49'E) was rapidly declining to a low level and the blue spot emperor stock was declining at the 1998 effort level. This was expected as high effort quotas were allocated in area 1 to increase the catches of the short lived species. The combined stock of red emperor in areas 1 to 3 (116°E to 118°E) continued to be over-exploited up to 1998. However with the area 3 closure and the lower 1999 effort levels maintained (possibly with adjustments for efficiency increases) the red emperor stock in these areas should recover to sustainable levels over the next 4 years. Across the whole fishery these effort reductions are expected to protect Rankin cod as it is less vulnerable to over-exploitation than red emperor, but the short lived species like blue spot emperor, flagfish and rosy threadfin bream are expected to be under-exploited. The mortality model, updated for the west Pilbara (116°E to 118°E) using recent effort and catch rate data, indicated that the fishing mortality of red emperor had been reduced from F = 0.26 in 1996 to 0.09 in 1999 when calculated with nominal effort. When calculated with a 7.5% efficiency increase after 1994, the fishing mortality in 1999 was slightly above 0.1.

Both the mortality model and the age structured model developed and refined in this project have provided the research information needed to develop effort quotas for the Pilbara trawl fishery. This is the first fishery in Western Australia to operate with VMS monitored effort quotas and it has proved highly successful ensuring the stocks of this multi-species fishery are fished at sustainable levels.

1 BACKGROUND

The Pilbara trawl fishery (Figure 1) is a multi-species tropical fishery with a long history of trawl fishing over the last 40 years. From 1959 to 1963, a Japanese trawl fleet produced a catch of 16 700 tonnes. In 1972, a Taiwanese pair trawl fleet commenced operation and it's catch peaked at 37 000 tonnes in 1973 but subsequently the catch and effort declined until the fishery was closed to foreign fishing in 1987 (Sainsbury, 1991).

In 1987, a domestic trawl fishery commenced operation with an initial catch in that year of 12 tonnes. The fishery rapidly expanded, and the 1992 catch was 1400 tonnes (Fisheries WA, 1998). Prior to this time, the Northern Fisheries Assessment Group supplied yield estimates for the NW Shelf generally based on Taiwanese logbook data and some biological data (Jernakoff & Sainsbury, 1990). However Fisheries WA considered there was a need for an alternative assessment of the sustainable effort in the Pilbara trawl fishery relative to the Australian fleet operating in the 1990's.

During 1993 and 1994, the FRDC Project 93/25 entitled 'Relating Fishing Mortality to Trawl Effort' was conducted in the Pilbara trawl fishery to determine the relationship between trawl effort and fishing mortality for five significant scalefish species. This experiment estimated that at the 1994 level of effort, two long lived species (red emperor and Rankin cod) were over-exploited and three short lived species (flagfish, blue-spot emperor, and rosy threadfin bream) were under-exploited (Stephenson, 1999).

Red emperor (*Lutjanus sebae* (Cuvier 1828)) is a valuable species in the trawl fishery, but it is more long-lived than most species and therefore may be more vulnerable to over-exploitation. In 1997 the fishing licence holders agreed to reduce trawl effort to a level that would limit fishing mortality of red emperor to 0.1 or less. This corresponds to a removal of less than 10% of the stock each year. To achieve this objective, an Interim Management Plan for the Pilbara trawl fishery was gazetted on 23 December 1997 to commence operation on January 1, 1998. The Interim Management Plan established two Zones in the fishery (Zone 1 and Zone 2; Figure 1). Fish trawling is restricted to Zone 2 only, and within this zone, 6 management areas have been determined (Figure 1). The Interim Management Plan allocated trawl access (VMS hours) to the fleet to the areas 1, 2, 4 and 5 with areas 3 and 6 closed in order to bring about the objectives of the Interim Management Plan during 1998. The closure in Area 3 was aimed at reducing fishing mortality on red emperor and Rankin cod and the large effort allocation in Area 1 aimed to maximize the catches of the small species. Controlled access to Area 6 was granted for research purposes only. The Minister for Fisheries amended the interim management plan, reducing the level of access by the trawl fleet to some areas on 30 December 1998 to commence operation on 1 January 1999.

- The results of FRDC Project 93/25 have provided a sound basis for establishment of remedial management strategies, however considerable uncertainty still remains. Further research is required to reduce this uncertainty, by assessing the ongoing responses of the stocks to predicted model outcomes. The current project has gathered additional critical biological information, completed the validation of ageing and has gathered ongoing age composition data to facilitate the further development and refinement of the models, and assesses their outcomes against the observed levels and distribution of catch and effort. This additional information will enable evaluation of the ongoing responses of the stocks to the established management strategies.

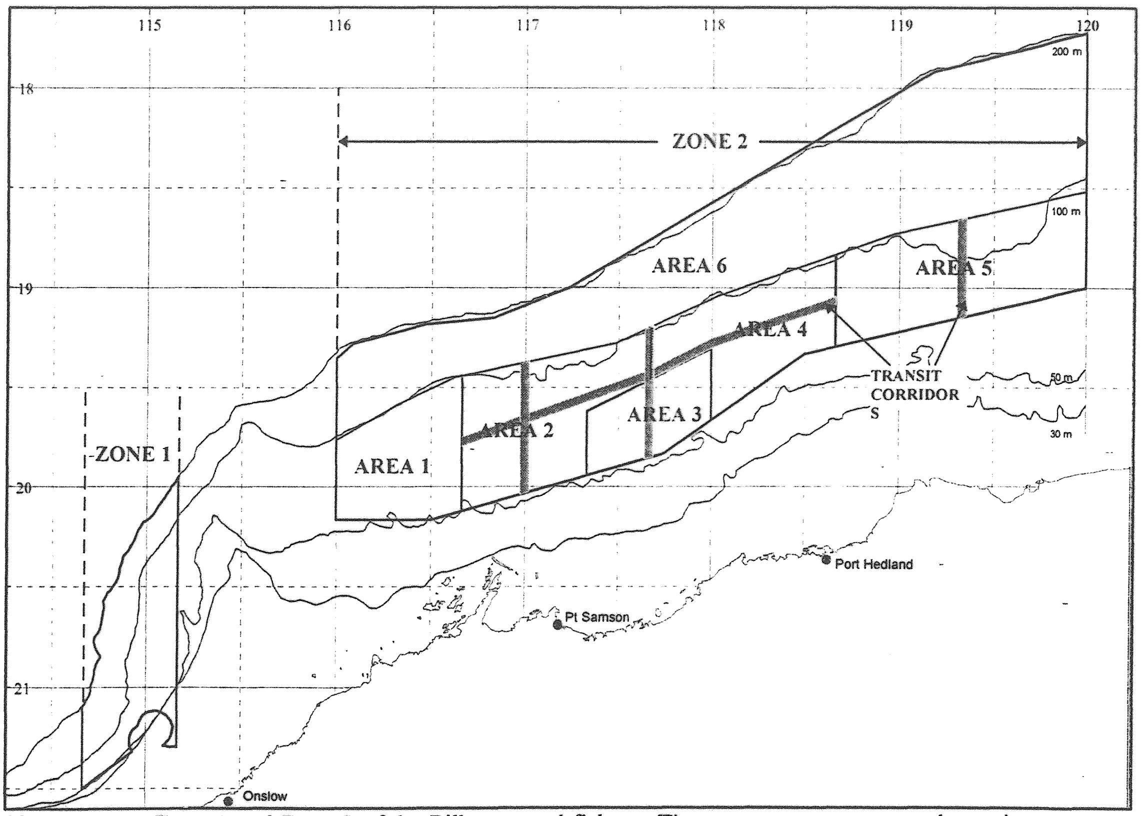


Figure 1. Zone 1 and Zone 2 of the Pilbara trawl fishery. The management areas and transit corridors of Zone 2 are shown.

2 NEED

The stocks of some long lived species in the Pilbara trawl fishery are over-exploited, and the most abundant, short-lived species range from under-exploited in some areas to over-exploited in other areas. This situation necessitates a system of control over both the level and distribution of effort, if production from the fishery is to be sustained. A management plan to address these problems was introduced on 1 January 1998. Given the state of the key species in the fishery, it is vitally important that additional research is undertaken to continue to assess the ongoing status of each of the major stocks as the fishery expands into the full fishing area. Secondly, this project was needed to develop a cost effective ongoing monitoring regime to service the fishery in the long term.

3 OBJECTIVES

The objectives of the current project are;

1. To assess the size and age at maturity and reproductive capacity of Rankin cod, and blue spot emperor, the two species for which no information is available elsewhere.
2. To develop a more cost effective and accurate method for monitoring the level and distribution of catch and effort of the ten most valuable species.
3. To investigate fish movement patterns, and the periodicity of otolith growth rings by tagging key species and monitoring tag returns.
4. To use the age structure of the 5 key species over time to assist in the evaluation of the effectiveness of management strategies.
5. To confirm that otolith growth rings are annual for the 5 key species, using marginal increment analysis.
6. To refine and improve modeling techniques using biological, ageing, and tagging information.

4 METHODS

4.1 Monitoring catch and effort (Objective 2)

4.1.1 Introduction of vessel monitoring system

The vessel monitoring system (VMS) was introduced by Fisheries WA on 1 January 1998 and enabled effort quotas to be allocated to the licensees in the Pilbara trawl fishery. The system successfully monitors the time vessels operate in each area of the fishery and also enables enforcement of area closures. Masters of vessels in the Pilbara trawl fishery are required to contact Fisheries WA when leaving port to enter the fishery, and when leaving the fishery. While in the fishery, the GPS on the vessel is interrogated and the vessel's location and speed is transferred to the Fisheries WA monitoring facility via VMS.

Summaries of time used by each vessel, referred to as 'VMS effort' were regularly sent to fishing licence holders to enable them to plan their time usage and to Fisheries WA Research Division for stock assessment. The VMS effort summaries and logbook data were used to determine the ratio of logbook effort (time that the net is on the sea bed) to VMS effort to enable the determination of the VMS effort on fish stocks (Stephenson 1999).

4.1.2 Voluntary logbook program

A voluntary logbook program has been running in the Pilbara trawl fishery since 1991. All skippers in the Pilbara trawl fishery complete a voluntary logbook (with varying diligence) containing the time and location of each trawl shot as well as the catch in kg (estimated by volume of fish) of the major species. In 1998, Fisheries WA revised the format of the logbooks to increase the number of species recorded from 10 to 14 and improve the layout. All skippers in the Pilbara trawl fishery are currently using the updated version of the logbook.

To provide vessel owners and skippers some feedback and to encourage skippers to supply accurate logbook data in the future, a summary of logbook information for each vessel and a summary of logbook information for the whole trawl fleet was provided to the respective license holders and skippers of each vessel in the Pilbara trawl fishery. Skippers are frequently contacted by a researcher at Fisheries WA to encourage the supply of logbook information.

Since 1996, one skipper in the fishery has been entering logbook information directly into an Excel 6.0 spreadsheet (created by Fisheries WA) in lieu of the paper log sheet.

4.1.3 Real time catch reporting

The objective of instigating the transfer of logbook catches via satellite to the shore base station has not been achieved. After discussion with scientists from other countries at the International Conference on Satelite Technology in Fisheries held in Cairns in 1999, it appears that sending a typed email message of the catch each shot is the extent of international progress in this area. There appears to be no great barriers to sending compressed data files via satellite but this has not been done in any fisheries at the present time. A considerable amount of work has been done at the Northwest Fisheries Science Centre in Seattle to design an electronic logbook system with compressed data which can be sent via the internet by email (Murray 1999). A system of using an "Access" database and transfer of data via satellite is being constructed by Dr Lynne Purchase at Marine Resources Assessment Group Limited, in London.

At Fisheries WA, there continues to be a commitment to instigate catch reporting via satellite when it becomes economically feasible and practical.

4.1.4 Analysis of catch and effort data

The unloaded catch is weighed at the processing factory and compiled into a compulsory monthly catch and effort summary (CAES). Six of the nine trawl vessel licensees give the catches by species and trip on their monthly return. The monthly return provides accurate unloaded catch and the logbooks provide the accurate information on location and duration of shots and a skipper's estimate of the species catch. The logbook data is useful for verifying the CAES data. The trawl fishery catch is calculated by multiplying up the skipper's estimated catch for each shot according to the CAES catch data for each trip. Where logbook data is missing, VMS time is used to determine the expected logbook effort and the CAES catch is substituted. However, before the implementation of the VMS, the product of CAES time (days) and the average logbook time per day (based on the whole fleet) was used to determine the expected logbook effort and the CAES catch was substituted. The trawl fishery catches and effort are summarized each year (1991 to 1998) into 10 minute by 10 minute blocks (Figure 2) and reported in Stephenson & Mant (in prep.).

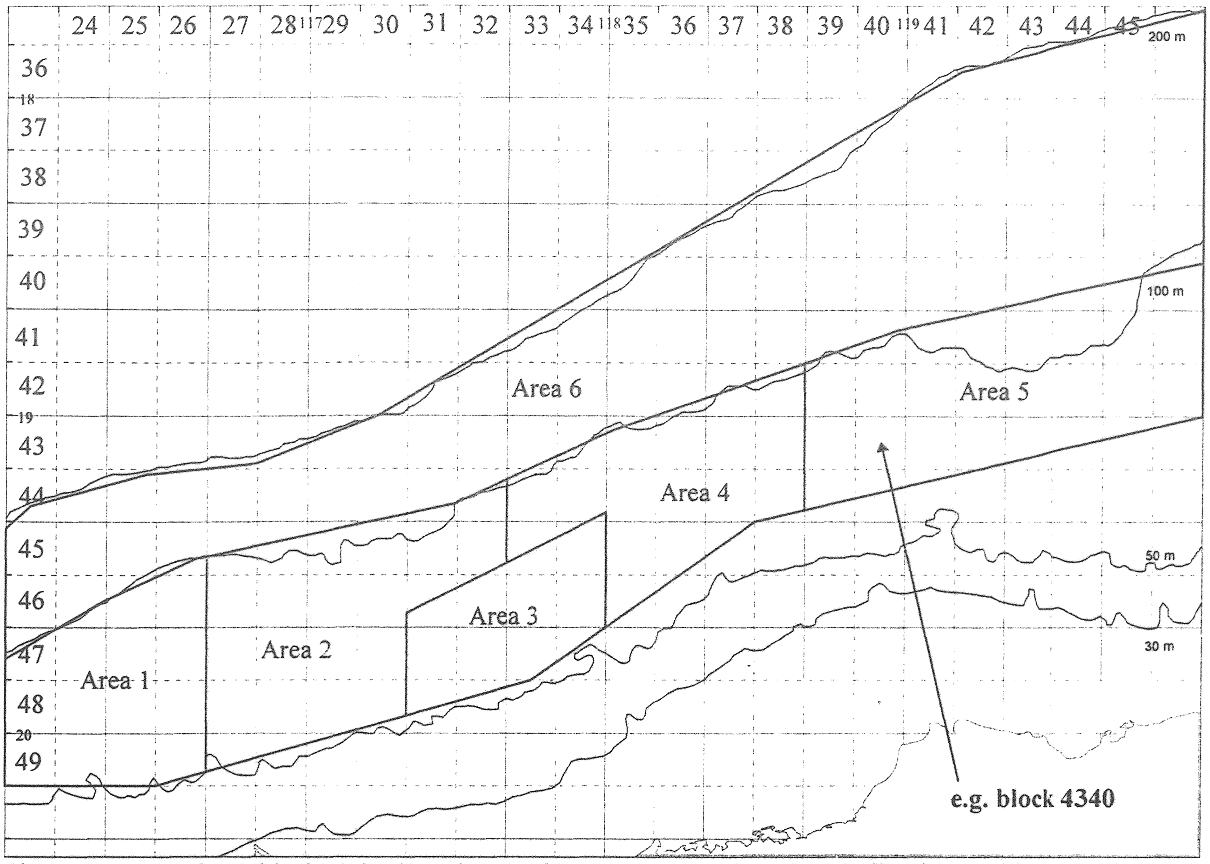


Figure 2. Logbook blocks (10 minute by 10 minute) used to pool catch and effort in the Pilbara trawl fishery.

4.1.5 Catch rates

For each shot in the logbook database, where catch by species, location, and trawl time were recorded, the catch rate (kg/2.5hour) was determined. No allowance was made for different efficiency of skippers, or for vessel, gear or skipper improvement in catching power over time. In order to illustrate the catch rates, the catch and effort was summarized into 10 minute by 10 minute blocks before calculating the catch rate. The catch rates from 1991 to 1998 for 10 species are reported in Stephenson & Mant (in prep.).

4.1.6 Fisheries WA surveys

During 1993 and 1994, extensive surveys were conducted on chartered commercial vessels from the Pilbara trawl fishery (Stephenson & Dunk 1996). The surveys were conducted with 18 fathom nets with an average shot duration of 2.5 hours. The catch rates of 10 species (kg/2.5 hour trawl) in each 10 minute by 10 minute grid for each survey is reported in Stephenson & Mant (in prep.).

4.1.7 CSIRO surveys

During 1982/83 and on annual trips from 1986 to 1991, CSIRO conducted surveys in the Pilbara. The catch rates for 10 species were summarized by 10 minute by 10 minute grids and pooled into two time periods 1982/83 and 1991-1996. The catch rates were adjusted for comparison to match the head rope length and trawl duration of Fisheries WA survey data. The maps of the CSIRO data are reported in Stephenson & Mant (in prep.).

4.2 Biological studies

4.2.1 Species studied

Of the many species caught in the Pilbara trawl fishery, five of the major species in the catch were used in this study. The key species selected were two long-lived species, red emperor, *Lutjanus sebae*, and Rankin cod, *Epinephelus multinotatus*, together with three shorter lived species, flagfish, *Lutjanus vitta*, blue-spot emperor, *Lethrinus* sp. (*L. choerorynchus* in Sainsbury *et. al.*, 1984 and FRDC report 93/25), and rosy threadfin bream, *Nemipterus furcosus*.

4.2.2 Data collection

During 1994 and 1995, research staff collected biological samples from commercial catches at the market. Each fish was measured for caudal fork length (lcf) and total length (tl) and weighed to the nearest 1 millimeter and 1 gram respectively. Where possible, the sex of each red emperor and Rankin cod was determined by macroscopic examination of the gonads and each of the gonads were weighed to the nearest 0.01g. Both of the sagittal otoliths of each fish were removed, cleaned in fresh water, dried on paper towel and stored in paper envelopes labelled with collection number, date of capture, and fork length.

During the period August 1996 to December 1998, research staff embarked on field trips of five to seven days aboard commercial trawlers at approximately 8 week intervals. For each shot during daylight hours, all red emperor and Rankin cod were sampled. The smaller species blue-spot emperor, flagfish, and rosy threadfin bream were collected in lots of 15-25 from random shots during daylight hours depending on availability in the catch to make up approximately 150 fish of each of these species per trip. Each fish was measured for caudal fork length (lcf) to the nearest 1 millimeter. Where possible, the sex of each fish was determined by macroscopic examination of the gonads and if necessary microscopic examination of the gonads. Both of the sagittal otoliths of each fish were removed, cleaned in fresh water, dried on paper towel and stored in paper envelopes labelled with collection number, location, date, and fork length. The otoliths of Rankin cod and flagfish were fragile and in some cases one otolith was broken and unusable. The number of otoliths collected in each year of the study are shown in Table 1.

Table 1. Number of fish measured and otoliths collected on commercial trawl vessels during the period August 1996 to December 1998.

	Number of otoliths collected		
	1996	1997	1998
Flagfish	450	1371	1000
Blue-spot emperor	453	1314	1000
Threadfin bream	450	1337	1000
Red emperor	353	1109	858
Rankin cod	187	466	273
Total	1893	5597	4131

4.2.3 Age and growth

4.2.3.1 Length-weight

The relationship between weight and length for the 5 key species was determined from market sampling of commercial catches during 1994 and 1995. As the variance of the weight increases with length, a logarithmic transformation of the data was carried out and estimates of the parameters *d*, and *e* of the relationship $\ln(weight) = d + \ln(length) \times e$ were obtained using "AD model builder", the equation between length of fish and weight being:

$$weight = \exp(d) * length^{e} \qquad (1)$$

where weight (live weight) is in kilograms (kg) and length (caudal fork length) is in millimeters (mm).

4.2.3.2 Sex ratios

To identify how the sex ratio varied with size and age for each of the key species, length frequency distributions and age frequency distributions were plotted by sex for each species. The data were pooled for the years 1996 to 1998.

4.2.3.3 Otolith preparation and analysis

Both sagittal otoliths were weighed on a Mettler AG245 balance (to 0.00001 g) and the results transferred electronically to an Excel 6.0 spreadsheet linked to the balance. For each fish the estimated mean otolith weight was determined for otolith pairs with no chips or very small chips (< 2% chip) for the analysis. If one otolith was largely chipped, broken or missing, single otolith weight was used. If one otolith was largely chipped, broken or missing and the other had a very small chip (< 2% chip), single otolith weight was estimated by adding 2% to give the approximation in Table 2. If both otoliths were chipped, broken or missing the weight was rejected.

Table 2. Percentage of fish where either both otoliths were good (whole or small chip <2%), one only good, weight approximated or no weight determined.

	Percentage of fish sampled for otoliths											
	Both good			One good			Approximation			Neither good		
	96	97	98	96	97	98	96	97	98	96	97	98
Flagfish	86.8	92.9	91.9	11.4	6.3	6.5	0.7	0.5	1.3	1.1	0.2	0.3
Blue spot emperor	86.3	87.7	84.4	10.6	6.4	9.6	1.8	4.4	5.1	1.3	1.4	0.9
Threadfin bream	82.4	84.3	86.0	13.8	12.9	7.9	0.4	0.5	3.4	3.3	2.3	2.7
Red emperor	94.9	92.2	95.1	2.8	6.4	3.5	0.0	0.5	0.7	2.3	0.9	0.7
Rankin cod	81.3	84.3	92.7	13.4	8.6	4.0	0.0	0.2	0.4	5.3	6.9	2.9

One otolith per fish (left otolith where possible) was encased in clear casting resin and a thin transverse section (0.3 - 0.5 mm) was made through the core of the otolith using a Buehler Isomet low-speed saw with a 100 mm by 0.1 mm diamond tipped saw blade. The sections were then ground using 9 μ lapping film and mounted on 76 mm by 25 mm glass slides using clear casting resin and covered with glass cover slips. Each slide contained between 4 and 6 sectioned otoliths, depending on otolith size. Otoliths were viewed under transmitted light using a dissection microscope.

4.2.3.4 Age determination (Objective 4)

The growth rings on otoliths appeared as series of wide, dark opaque bands separated by narrow translucent bands which appeared light. The dark wide bands were very noticeable for older fish whereas for young fish the dark coloration was often absent. The number of dark bands on each otolith section were counted by two readers and most discrepancies between readers were reconciled. If agreement could not be reached, the first authors age allocation was used. In order to allocate ages, fish were assigned birth dates in each calendar year. The birth date was taken as the time of formation of a new opaque band. The age of the fish in years was determined by;

$$age = r + (t - b) \qquad (2)$$

where r is the number of rings, t is the date of capture, b is the birth date.

4.2.3.5 Age-length

Growth of the five key species was represented by the von-Bertalanffy growth equation (Equation 3)

$$L_t = L_{\infty}\left\{1 - \exp\left[-K\left(t - t_o\right)\right]\right\} \quad (3)$$

where the growth parameters L_{∞} (theoretical maximum or asymptotic length that the species would reach if it lived indefinitely), K (growth coefficient which measures the rate at which maximum size is reached) and t_o (theoretical age at length zero). The von-Bertalanffy growth parameters were estimated using data collected from the Pilbara trawl fishery during 1996 to 1998. For each of the key species except *N. furcosus*, immature fish collected from the nearby prawn fishery have also been included in the von-Bertalanffy analysis because the smaller fish were not abundant in the Pilbara trawl fishery catches. The small fish were weighted to a factor of three in the von-Bertalanffy growth model because of their small numbers. *E. multinotatus* changes sex from female to male and all data was combined for determination of the growth coefficients. For the other 4 species, it was anticipated that there may be different growth rates between sexes for each species therefore the growth calculations were classified according to gender. Due to the much higher exploitation rates in the west than in the east of the fishery, it was anticipated that there may also be different growth rates in the two areas of the fishery, therefore samples were also classified by area as coming from the west (116°E - 118°E) or east (118°E - 120°E) of the fishery. If it was appropriate to pool fish on area, growth parameters for each sex for the whole fishery were determined. An age - length key was established to allocate ages according to fish length.

4.2.3.6 Age validation (Objective 5)

Age validation was achieved using marginal increment analysis of monthly samples collected from the markets during 1993 and 1994 for *L. vitta, Lethrinus* sp., *N. furcosus* and *L. sebae* (Stephenson in prep.). The marginal increments for *E. multinotatus* was not successful due to the poor definition of the outermost rings.

4.2.4 Reproductive biology

4.2.4.1 Gonadosomatic indices

Gonadosomatic indices (GSI's) were determined from Equation 4 (Laevastu, 1965). For red emperor and Rankin cod, GSI's were determined from gonad samples collected at monthly intervals from the markets during the period April 1994 to May 1995. For blue-spot emperor, GSI's were determined from gonad samples collected from the Pilbara trawl fishery during the period August 1996 to October 1998. The pattern of change shown by the mean monthly values for the GSI was used as an indication of the peak spawning period for each species.

$$WG \,/\, WF * 100 \qquad (4)$$

where WG = weight of the gonad and WF = total weight of fish.

4.2.4.2 Length and age at first maturity (Objective 1)

Ovaries of female red emperor, Rankin cod and blue-spot emperor collected during the peak spawning period were stored in buffered formalin and subsequently sent to Agriculture Western Australia for histological slide preparation. Each ovarian section was classified as being either immature or mature based on the absence (immature) or presence (mature) of yolk - globules in the oocytes. The mean length at which 50% of the females of each species were sexually mature was then calculated using the logistic function (Equation 5).

$$length = \frac{length^{c}}{b^{c} + length^{c}} \qquad (5)$$

Lengths were converted to age using the inverse of the von-bertalanffy growth equation (Equation 6) and the mean age at which 50% of the females of each species were sexually mature was then calculated using the logistic function (Equation 7).

$$t = t_{o} - \frac{\ln(1 - \frac{L}{L_{\infty}})}{K} \qquad (6)$$

$$age = \frac{age^{c}}{b^{c} + age^{c}} \qquad (7)$$

4.2.5 Natural mortality

FRDC Project 93/25 (Stephenson & Dunk, 1996) determined the instantaneous rate of natural mortality, M (year^{-1}) for the 5 key species. Estimates of M for each species, assumed constant over the age classes, are based on longevity using Equation 8 (after Hoenig, 1983). For each species, the maximum age was determined from the age of the oldest fish observed from samples in the Pilbara trawl fishery multiplied by 1.2 as this is an exploited population and much larger fish than in our samples have been observed.

$$\ln(Z) = 1.46 - 1.01\ln(t_{max}) \qquad (8)$$

where $Z = M$ as maximum age is the only available data.

4.3 Tagging studies (Objective 3)

During the periods 27 April - 5 May 1997 and 12 - 22 May 1998, tagging of key species was undertaken aboard Fisheries WA's research vessel 'RV Flinders' in the waters off north west Australia to investigate fish movement patterns and the periodicity of otolith growth rings of the key species. Fish traps were used to capture fish for tagging. The locations where trapping and tagging was undertaken during 1997 and 1998 are shown in Figure 3. These areas were selected due to the relatively high abundance of *L. sebae* and *E. multinotatus* and the relatively shallow depths in these areas. It was anticipated that commercial trap fishers would recapture tagged individuals. A total of 155 traps during 1997 and 250 traps during 1998 were set during daylight hours in depths ranging from 24 to 112m (1997) and 39 to 79m (1998). All fish which were considered to be in good condition after capture were tagged using either dart tags (of two different sizes) or the smaller t-bar anchor tags, depending on the size of the fish. Generally, two tags were applied to each fish and the swim bladder was pierced to overcome the problem of embolism. All tagged fish were injected with tetracycline at 50mg kg^{-1} body weight before being released.

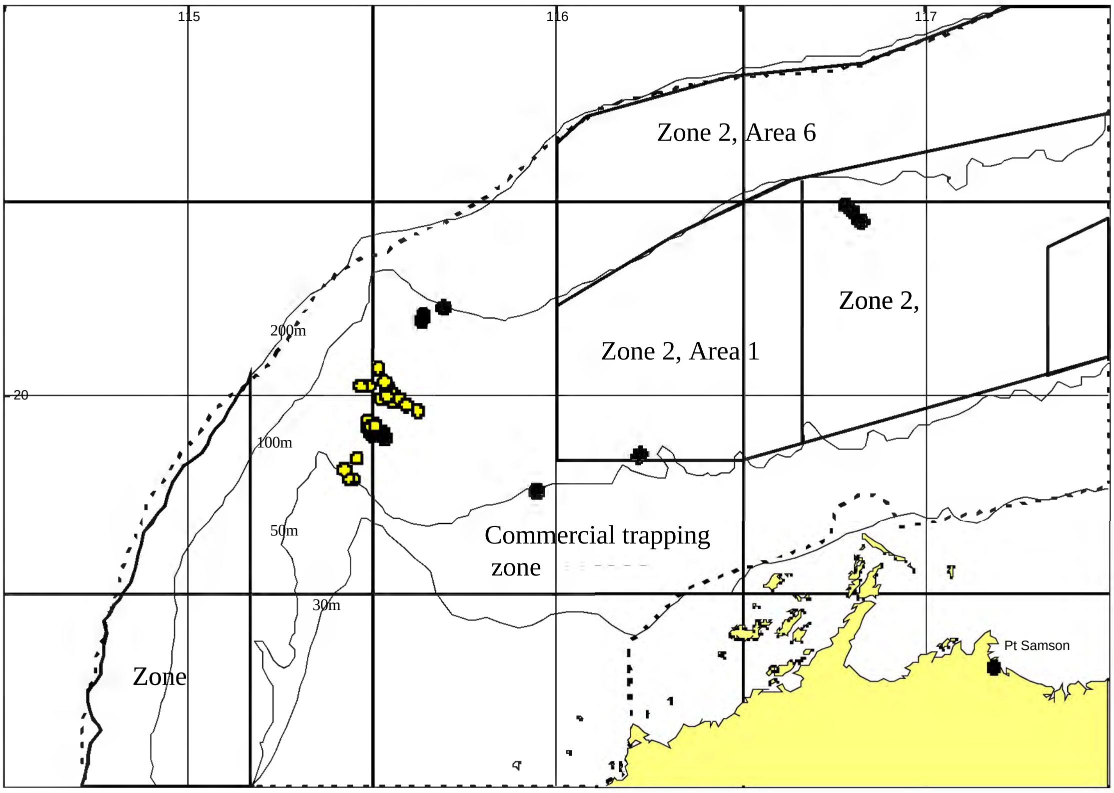


Figure 3. General areas where trapping and tagging was undertaken during 1997 (black circles) and 1998 (grey circles).

4.4 Age structure of key species (Objective 4)

4.4.1 Relationship between otolith weight and age

The use of otolith weight to determine ages was considered only for the three short lived species *L. vitta*, *Lethrinus* sp. and *N. furcosus*. The large number of age classes for *L. sebae* and *E. multinotatus* would result in small frequencies in the age-length key, and consequently otolith weight was not used to allocate ages for these two species.

To determine if the relationship between otolith weight and age was different between samples from the west Pilbara (116°E to 118°E) and east Pilbara (118°E to 120°E) the differences in the slope and then the intercept between sites "east" and "west" were tested using analysis of covariance separately for female and male. If the regression lines were not significantly different between west and east then differences between sexes were tested.

The allocated decimal ages (4.2.3.4 Equation 2) were converted to integer ages to enable a otolith age - weight key to be generated. The birth date was assumed to be September 15 and fish collected before this date were allocated an age of integer(age)+1 and those collected after September 15 were allocated an age of integer(age). For example a fish collected on August 4, 1997 with age 6.9 would be allocated a 1997 age of 7 and a fish collected in November 13, 1997 with an age of 3.18 would be allocated an age of 3.

The otolith weight was converted to adjusted otolith weight, O_{adj}, according to

$$O_{adj} = \begin{cases} O + slope(\text{int}\,eger(age+1) - age) & \text{if collected before September 16} \\ O + slope(\text{int}\,eger(age) - age) & \text{if collected after September 16} \end{cases} \quad (9)$$

where O is the otolith weight corresponding to age, O_{adj} is the adjusted otolith weight corresponding to the integer value of the age, and *slope* is the slope of the regression line.

4.4.2 Otolith weight - age key

The 1996-97 data was split chronologically into two halves with equal numbers of fish and an otolith weight-age key constructed for the first half of the data. For the second half of the data, predicted ages were determined for female and male fish in west Pilbara (116°E to 118°E) and east Pilbara (118°E to 120°E) using otolith weights and the otolith weight-age key. A contingency table was constructed for the observed and predicted age frequencies for the second group of 1996-97 data with data pooled for small and large ages to ensure the frequencies were ≥ 5. A Chi square test was used to determine if there were significant differences between the observed and predicted frequencies.

4.4.3 Age frequency distributions

Due to different levels of fishing effort in the west and east of the fishery, it was expected that there would be different age distributions in the west and east of the fishery. For the five species *L. vitta*, *Lethrinus* sp., *N. furcosus*, *L. sebae*, *and E. multinotatus*, separate age frequency distributions were determined for each sex in west Pilbara (116°E to 118°E) and east Pilbara (118°E to 120°E) for the 1996-97 data using ages from reading sectioned otoliths. For 1998, to save time in reading otoliths, ages were obtained for each sex in east and west using otolith weights and the otolith weight-age key for the three small species *L. vitta*, *Lethrinus* sp. and *N. furcosus* and using ages from sectioned otoliths for *L. sebae*, *and E. multinotatus.*

Age frequency data in each of the management areas was determined to enable stock assessments to be made in each area. The areas used for representing the age frequency data and for the stock assessment were those defined by the extension of the vertical boundary line of areas 1 to 5 out to the 200 m depth contour (Figure 1). That is

Area 1: 116°E to 116°40'E, Area 2: 116°40'E to 117°20'E,
Area 3: 117°20'E to 118°E, Area 4: 118°E to 118°40'E, and
Area 5: 118°40'E to 120°E.

The area closure in January 1998 resulted in small samples from area 3 defined above for the age structure and modeling.

4.4.4 Catch curves

Catch curves for each species were obtained by plotting age against ln(frequency) for female and male in the west and east Pilbara for 1996-97 and also for 1998. The total mortality for each species in each area is estimated as the negative of the slope of the right-hand arm of the catch curve.

4.5 Population modeling (Objective 6)

4.5.1 Age structured model

An age structured model was developed using the software "A D Model Builder" (Otter Research) to assess the red emperor and blue spot emperor stock in the western portion of the Pilbara trawl fishery (116°E to 118°E.). The model incorporated;

1. Biological information
    - length-age relationship
    - length weight relationship
    - selectivity of each age class (probability of being captured by the fishing gear)

proportion of each female age class being sexually mature

natural mortality

2. Age structure of each species in areas 1, 2, and 3 of the trawl fishery.
3. Catch of these species by trap, trawl and line from 1989 to 1998. 1999 catch data was multiplied up according to the proportion of data available.
4. Catch rate from trawl logbook data (1993 to 1999).

The parameters estimated in the model were the number of fish present at the beginning of 1989 and catchability (common for all age classes, and areas).

The model projected catches and spawning biomass into the future by fixing the effort at the 1999 level without efficiency increase. The chosen biological reference point (25% of the 1989 spawning biomass) was used to assess the effectiveness of the effort reduction and redistribution put in place with the 1998 plan, and the adjusted plan for 1999. The 1989 biomass is not the virgin level, as considerable fishing took place in the 1970's and so the biological reference point is not conservative, especially for the long lived species.

4.5.2 Mortality model

The mortality model developed in the previous FRDC project (Stephenson & Dunk, 1996) was updated with 1997, 1998, and 1999 effort levels and catch rates. The model was used to determine fishing mortality of red emperor in the west of the trawl fishery (116°E to 118°E) using the raw logbook effort and effort with a 7.5% efficiency increase after 1994. The efficiency increase was estimated from the age structured model developed in the current project. The estimates of fishing mortality were compared to the previously agreed biological reference point $F_{0.1} = 0.1$.

5 RESULTS AND DISCUSSION

5.1 Monitoring catch and effort

Maps of the spatial distribution of the catch and catch rates of each of the major species (10 species) as well as the total catch and effort in the Pilbara trawl fishery for the years 1991 to 1998 (184 maps), the catch rates of 5 species from surveys conducted in 1993 and 1994 (10 maps) the catch rates of 5 species from CSIRO surveys conducted in 1982/83 and 1986 - 1991 (10 maps) have been prepared and will be published in Stephenson & Mant (in prep.).

5.2 Biological studies

5.2.1 *Lutjanus sebae* (red emperor)

5.2.1.1 Age and growth

The parameters of the relationship between caudal fork length, lcf (mm) and weight (kg) determined from 177 *L. sebae* is shown in Appendix 1 and illustrated in Figure 4.

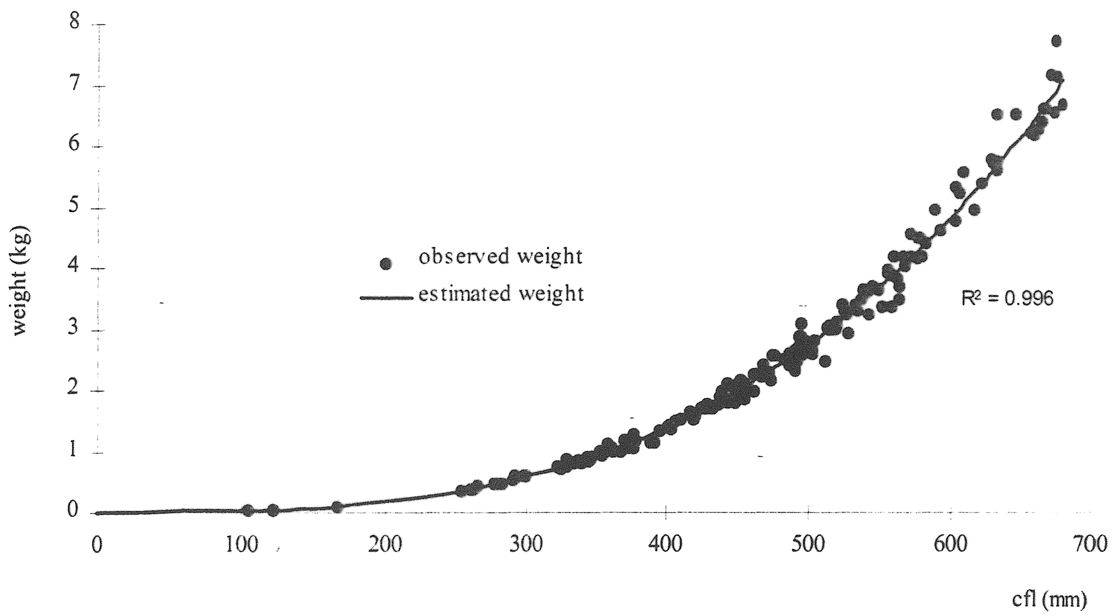


Figure 4. Caudal fork length (mm) and weight (kg) of 177 *L. sebae* together with the length-weight relationship $Weight = 1.312 \times 10^{-8} \cdot length^{3.0841}$.

L. sebae showed size-related differences in sex ratio with males predominating at larger sizes (Figure 5). There appears to be no difference in age-related differences in sex ratio (Figure 6).

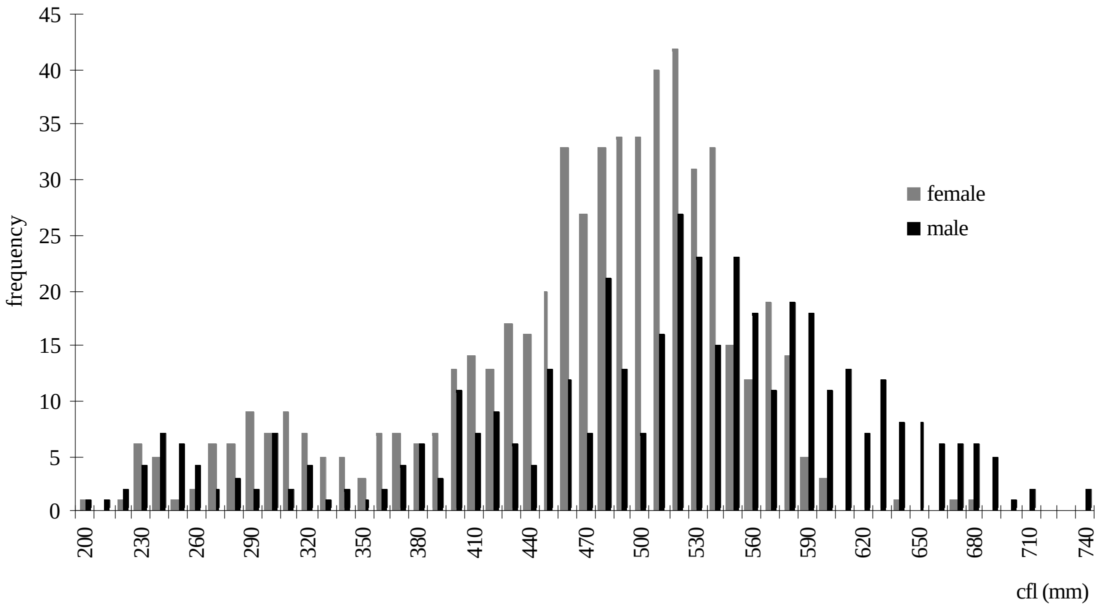


Figure 5. Frequency distribution for caudal fork length (mm) of male and female *L. sebae* sampled during 1996 to 1998 (lengths indicate initial points of 10mm size classes).

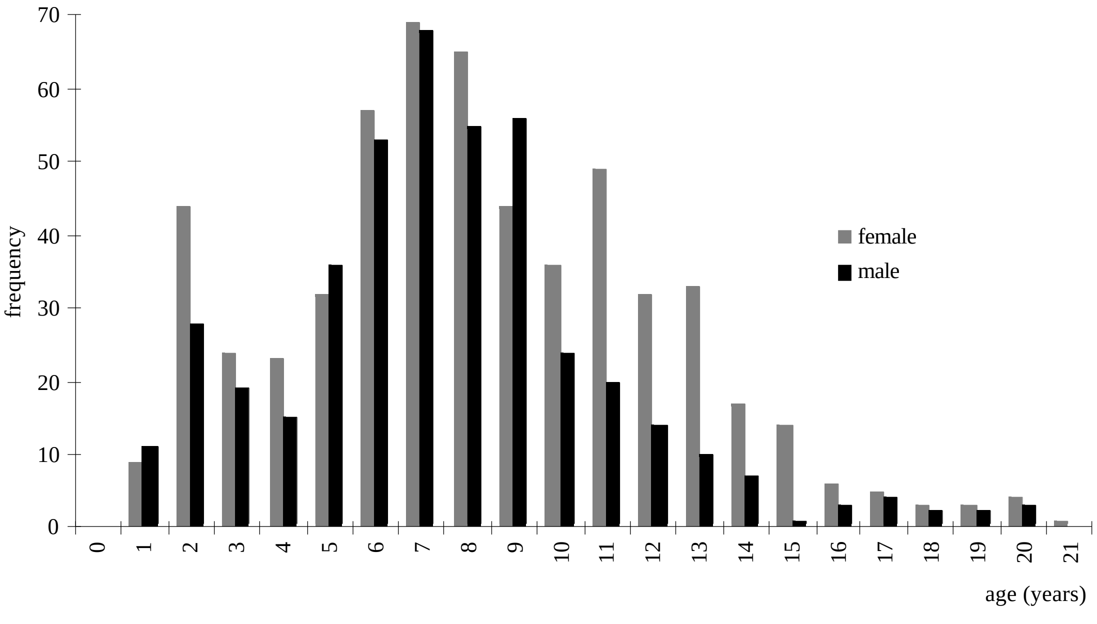


Figure 6. Frequency distribution for age (years) of male and female *L. sebae* sampled during 1996 to 1998.

The caudal fork length (mm) and ages from sectioned otoliths from 433 male, 572 female and 25 immature *L. sebae* otoliths are shown in Figures 7 and 8. The von Bertalanffy growth parameters and their 95% confidence limits for male and female *L. sebae* are provided in Table 3.

Table 3. Growth parameters (with 95% confidence limits) for the von Bertalanffy relationship between length and age for male and female *L. sebae* (L_∞ asymptotic length, K growth coefficient, t_0 hypothetical age at which fish would have zero length; N sample size).

	von Bertanaffy			
	L_∞	K	t_0	N
Male	698.9±32.1	0.165±0.02	-1.496±0.30	433
Female	548.9±12.3	0.235±0.03	-1.570±0.31	572

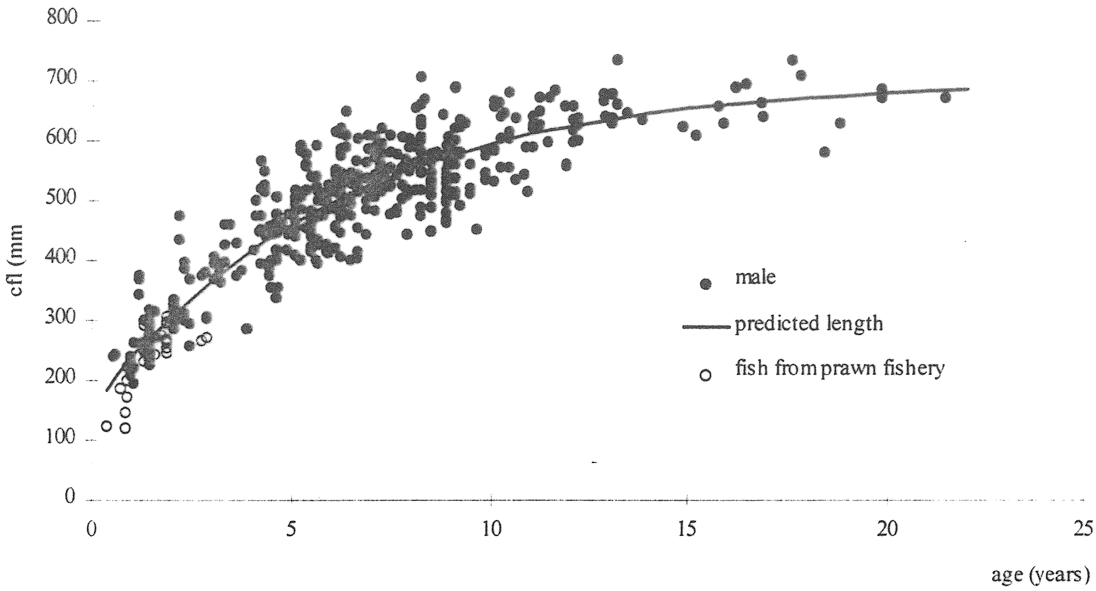


Figure 7. Von Bertalanffy growth curve fitted to observed length-at-age data derived from sagittal otoliths of male *L. sebae*.

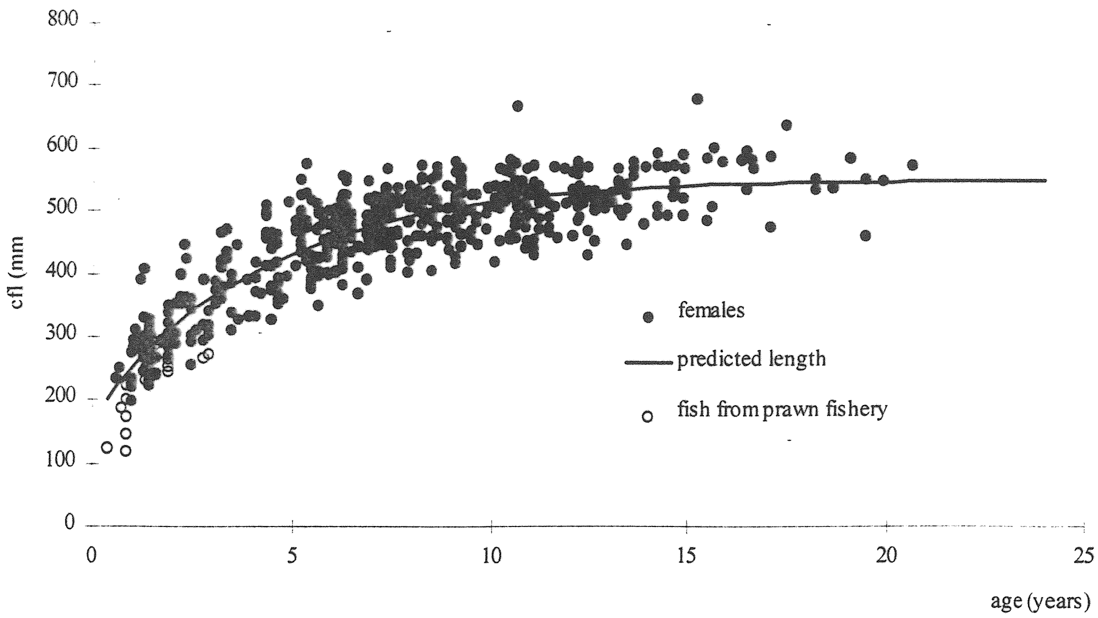


Figure 8. Von Bertalanffy growth curve fitted to length-at-age data derived from sagittal otoliths of female *L. sebae*.

5.2.1.2 Reproductive biology

The mean monthly GSI's of female *L. sebae* increased sharply from 0.7 in August to 2.3 in October (Figure 9). They subsequently fell to 1.0 in January and 0.2 in April. The pattern of change in mean monthly values for the GSI's suggests the peak spawning time for *L. sebae* occurs between September and December.

During the peak spawning period in the Pilbara (September to December), the age and lcf at which 50% of female *L. sebae* are mature is 3.8 years and 392 mm (Figure 10). The lcf of 392 mm corresponds to a total length of 419mm, slightly larger than the current legal size of 410 mm total length for red emperor in Western Australia.

By comparison, McPherson *et. al.* (1992) reported that the duration of the spawning period for *L. sebae* was determined as 7 months during spring and summer in the Great Barrier Reef region.

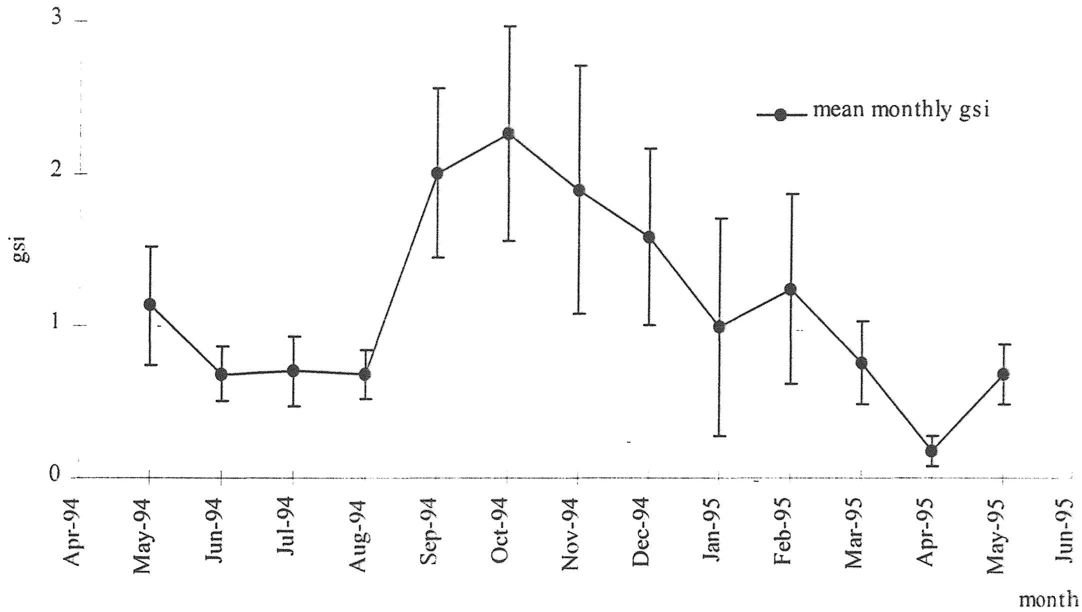


Figure 9. Mean monthly values of gonadosomatic indices ± 95% confidence limits for mature female *L. sebae*.

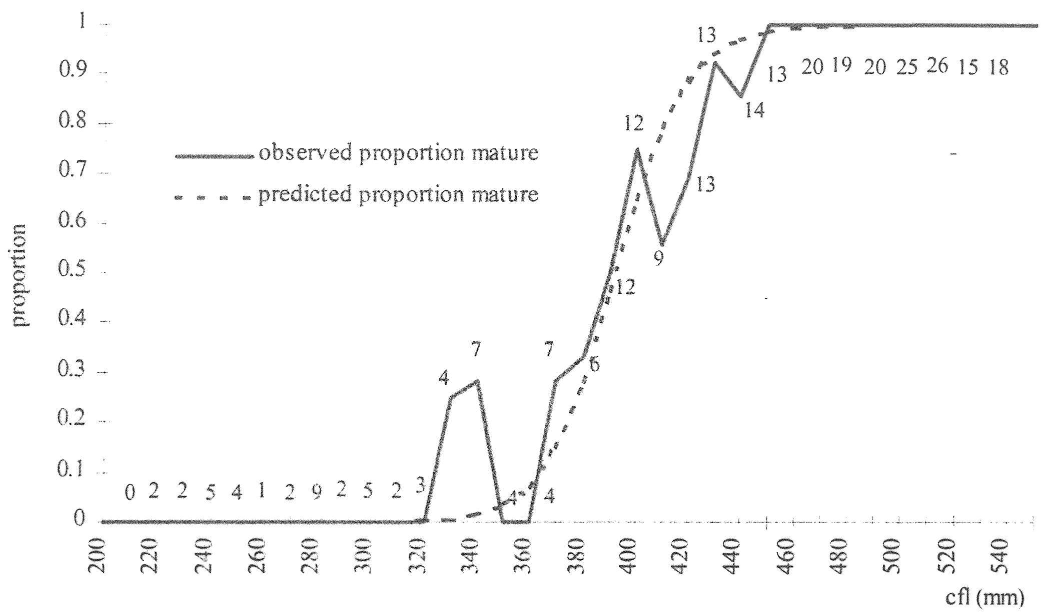


Figure 10. Logistic curve derived from the proportions of observed mature gonads for each 10mm length class of female *L. sebae*.

5.2.1.3 Natural Mortality

The oldest red emperor from sampling on commercial vessels in the Pilbara trawl fishery was 33 years and the maximum age is taken as $33 \times 1.2 = 40$. The maximum age and corresponding value of natural mortality M (see Hoenig, 1983) for *L. sebae* are shown in Table 4.

Table 4. Maximum age and estimate of natural mortality M for *L. sebae*.

Maximum age	M
40	0.10

5.2.2 *Epinephelus multinotatus* (Rankin cod)

5.2.2.1 Age and growth

The parameters of the relationship between caudal fork length, lcf (mm) and weight (kg) determined from 132 *E. multinotatus* is shown in Appendix 1 and illustrated in Figure 11.

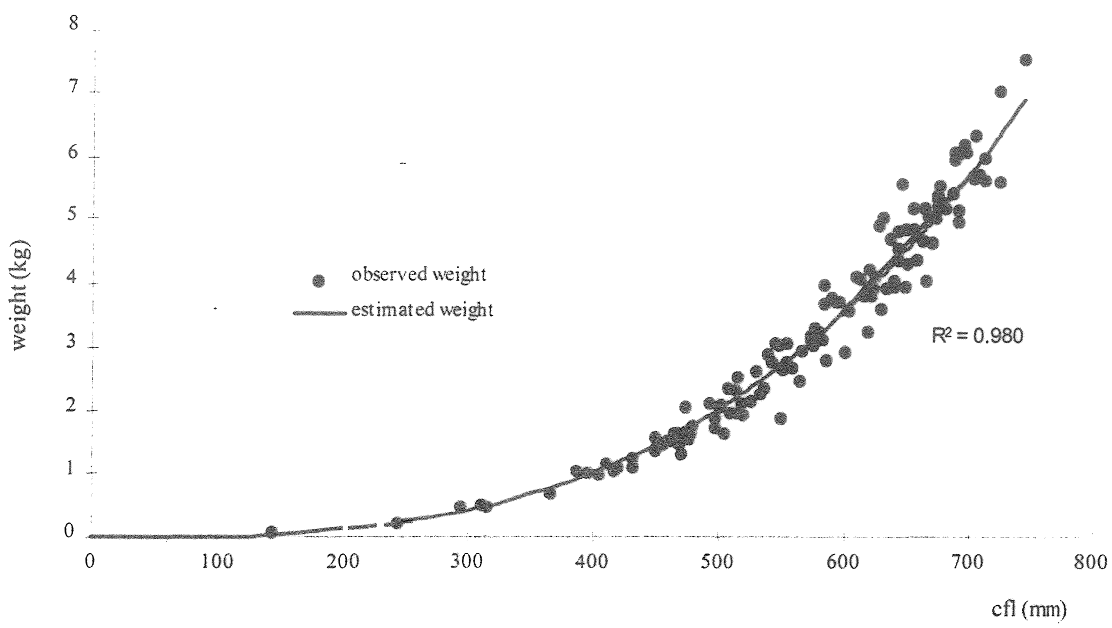


Figure 11. Caudal fork length (mm) and weight (kg) of 132 *E. multinotatus* together with the length - weight relationship $Weight = 0.932 \times 10^{-8} \cdot length^{3.0924}$.

E. multinotatus showed size-related differences in sex ratio with males occurring at larger sizes (Figure 12) and ages (Figure 13). The skew in sex ratio for *E. multinotatus* is due to protogynous hermaphroditism (see section 5.2.4.2) therefore the calculations for growth rates are made on pooled data i.e., males and females combined.

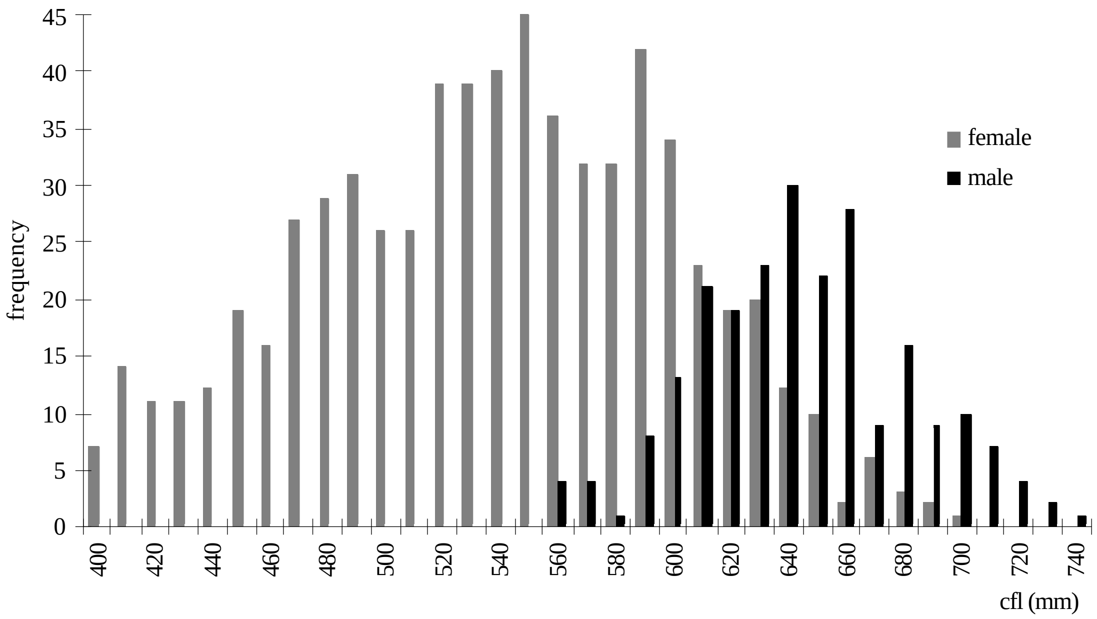


Figure 12. Frequency distribution for caudal fork length (mm) of male and female *E. multinotatus* sampled during 1996 to 1998 (lengths indicate initial points of 10mm size classes).

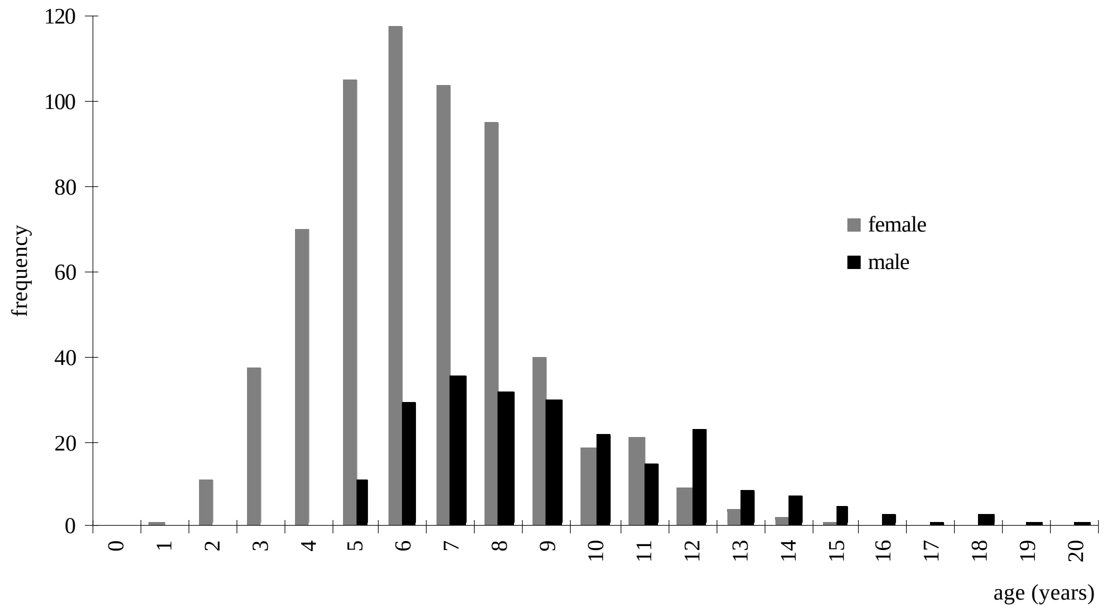


Figure 13. Frequency distribution for age (years) of male and female *E. multinotatus* sampled during 1996 to 1998.

The caudal fork length (mm) and ages from sectioned otoliths from 223 male, 643 female and 6 immature *E. multinotatus* otoliths are shown in Figure 14. The numbers of immature *E. multinotatus* is very low as small fish rarely occur in the Pilbara trawl fishery or adjacent prawn fisheries. The von Bertalanffy growth parameters for *E. multinotatus* are provided in Table 5.

Table 5. Growth parameters (with 95% confidence limits) for the von Bertalanffy relationship between length and age for *E. multinotatus* (L_∞ asymptotic length, K growth coefficient, t_0 hypothetical age at which fish would have zero length; N sample size).

	von Bertanaffy			
	L_∞	K	t_0	N
Both sexes	666.4±21.0	0.221±0.04	-1.835±0.65	872

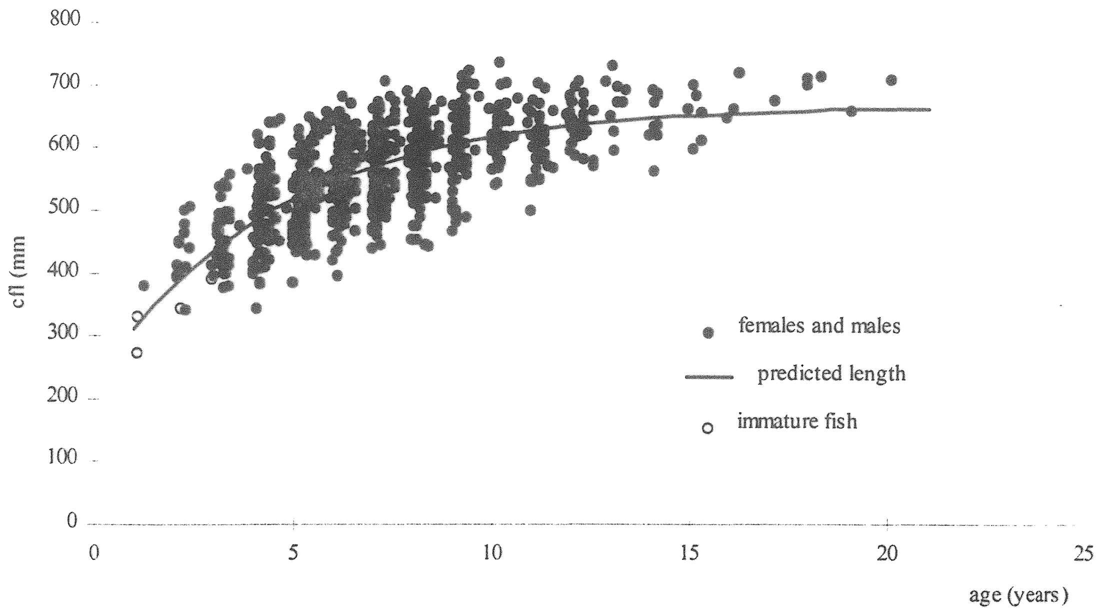


Figure 14. Von Bertalanffy growth curve fitted to length at age data derived from sagittal otoliths of male and female *E. multinotatus*.

5.2.4.2 Reproductive biology

The mean monthly GSI's of female *E. multinotatus* increased sharply from 1.0 in July to 3.5 in August, before rising to 4.3 in October (Figure 15). They subsequently fell precipitously to 1.7 in November and then more gradually to a minimum of 0.2 in April. The pattern of change in mean monthly values for the GSI's suggests the peak spawning time for *E. multinotatus* occurs between August and October.

During the peak spawning period, considerable effort was used to find immature fish. However the number of immature fish encountered during the peak spawning period was very low. Based on the little data available, the age and lcf at which 50% of female *E. multinotatus* are mature is 2.2 years and 391mm (Figure 16).

The serranid fishes are among the best known and most diverse groups of hermaphroditic species (Sadovy & Colin, 1995).*E. multinotatus* are protogynous hermaphrodites, i.e. individuals develop into sexually mature females and then later change to males. Based on the proportion of male and female fish at each length class, the mean length at which 50% of females change sex is 626mm.

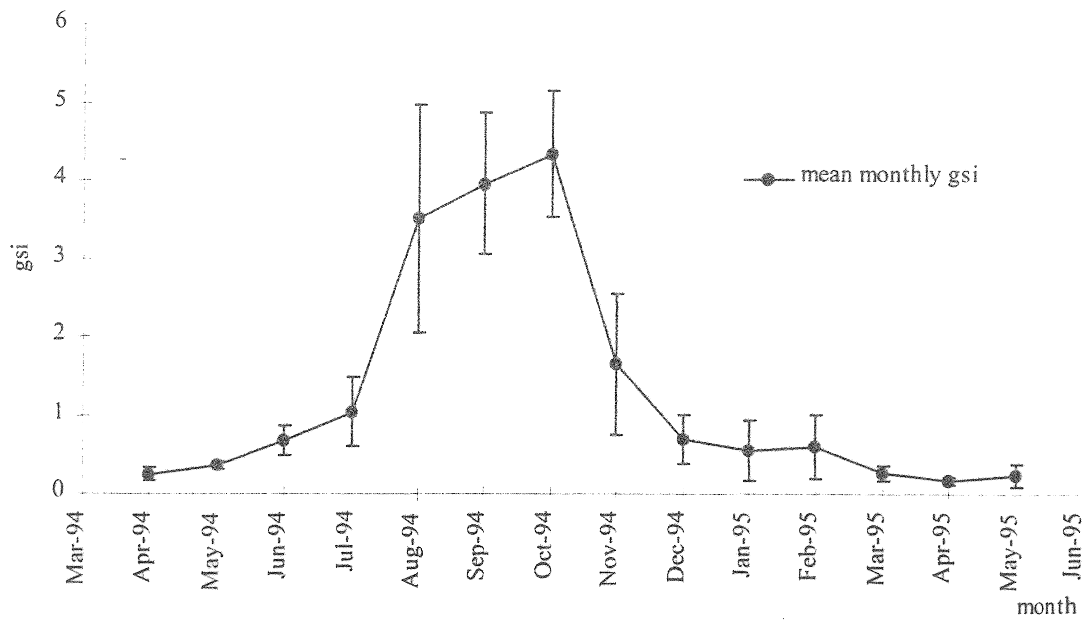


Figure 15. Mean monthly values of gonadosmomatic indices ±95% confidence limits for mature female *E. multinotatus*.

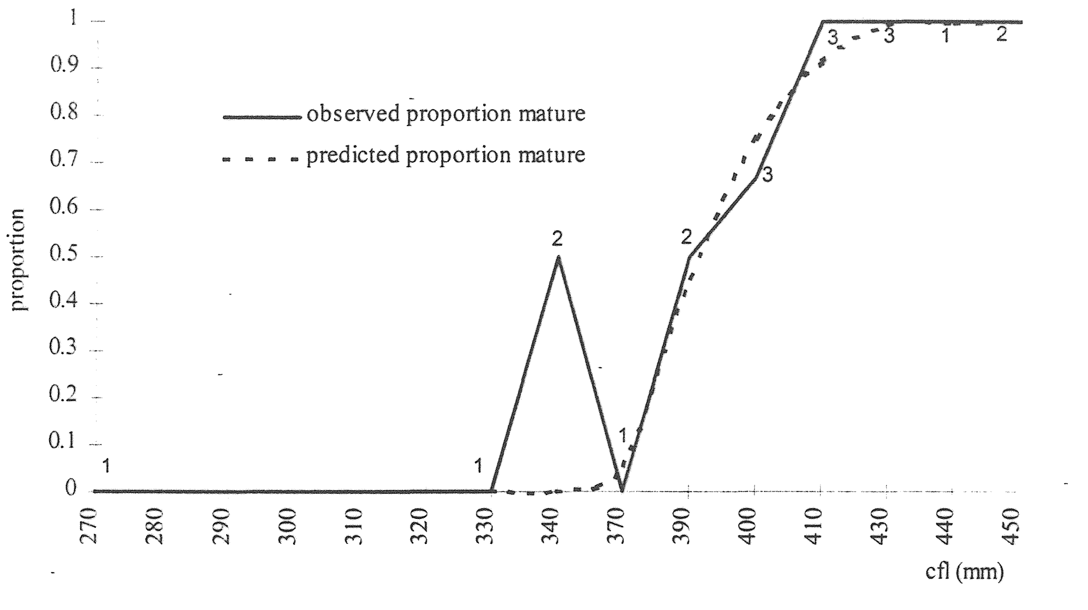


Figure 16. Logistic curve derived from the proportions of observed mature gonads for each 10mm length class of female *E. multinotatus*.

5.2.4.3 Natural Mortality

The oldest Rankin cod from sampling on commercial vessels in the Pilbara trawl fishery was 19 years and the maximum age is taken as $19 \times 1.2 = 23$. The maximum age and corresponding value of natural mortality *M* (see Hoenig, 1983) for *E. multinotatus* are shown in Table 6.

Table 6. Maximum age and corresponding estimate of natural mortality *M* for *E. multinotatus*.

Maximum age	*M*
23	0.18

5.2.3 *Lethrinus* sp. (blue-spot emperor)

5.2.3.1 Age and growth

The parameters of the relationship between caudal fork length, lcf (mm) and weight (kg) determined from 318 *Lethrinus* sp. is shown in Appendix 1 and illustrated in Figure 17.

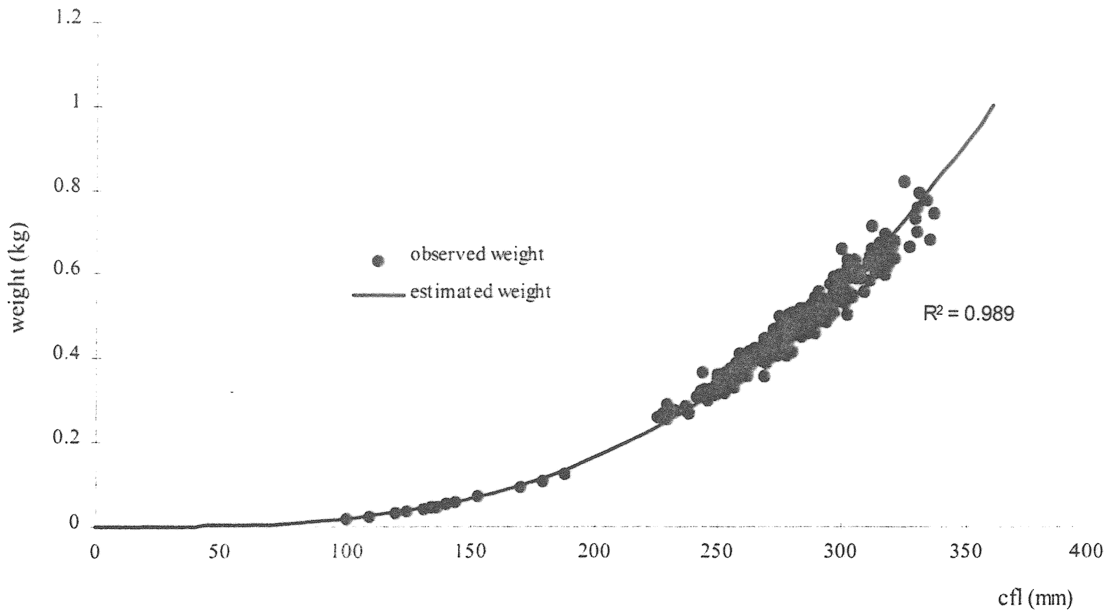


Figure 17. Caudal fork length (mm) and weight (kg) of 318 *Lethrinus* sp. together with the length - weight relationship $Weight = 1.287 \times 10^{-8} \cdot length^{3.0881}$.

Lethrinus sp. showed size-related differences in sex ratio with males occurring at larger sizes only (Figure 18). There appears to be no difference in age-related differences in sex ratio (Figure 19).

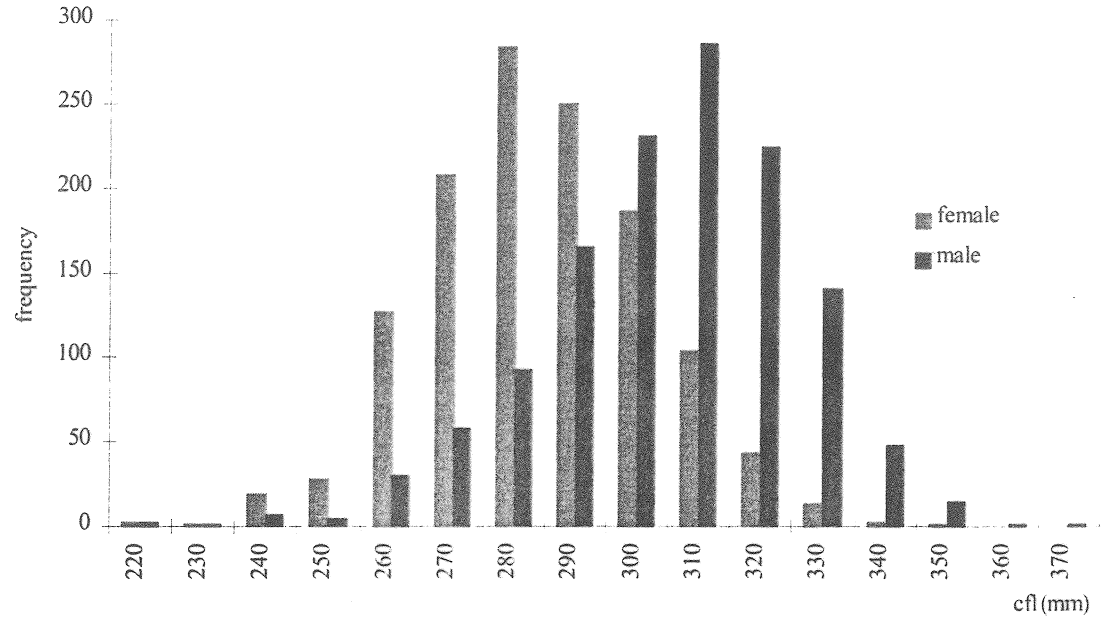


Figure 18. Frequency distribution for caudal fork length (mm) of male and female *Lethrinus* sp. sampled during 1996 to 1998 (lengths indicate initial points of 10mm size classes).

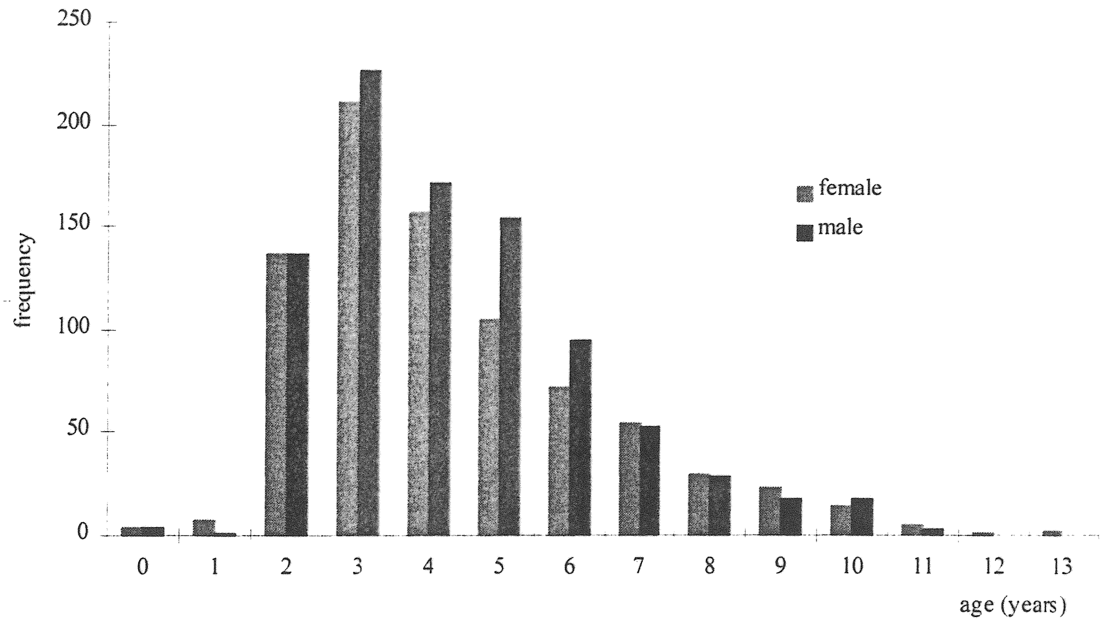


Figure 19. Frequency distribution for age (years) of male and female *Lethrinus* sp. sampled during 1996 to 1998.

The caudal fork length (mm) and ages from sectioned otoliths from 898 male, 815 female and 20 immature *Lethrinus* sp. otoliths are shown in Figures 20 and 21. The numbers of immature *Lethrinus* sp. is low as small fish rarely occur in the Pilbara trawl fishery. The von Bertalanffy growth parameters for male and female *Lethrinus* sp. are provided in Table 7.

Table 7. Growth parameters (with 95% confidence limits) for the von Bertalanffy relationship between length and age for male and female *Lethrinus* sp. (L_∞ asymptotic length, K growth coeficient, t_0 hypothetical age at which fish would have zero length; N sample size).

	von Bertanaffy			
	L_∞	K	t_0	N
Male	315.2±2.44	0.716±0.07	-0.472±0.22	898
Female	293.1±2.33	0.742±0.07	-0.471±0.17	815

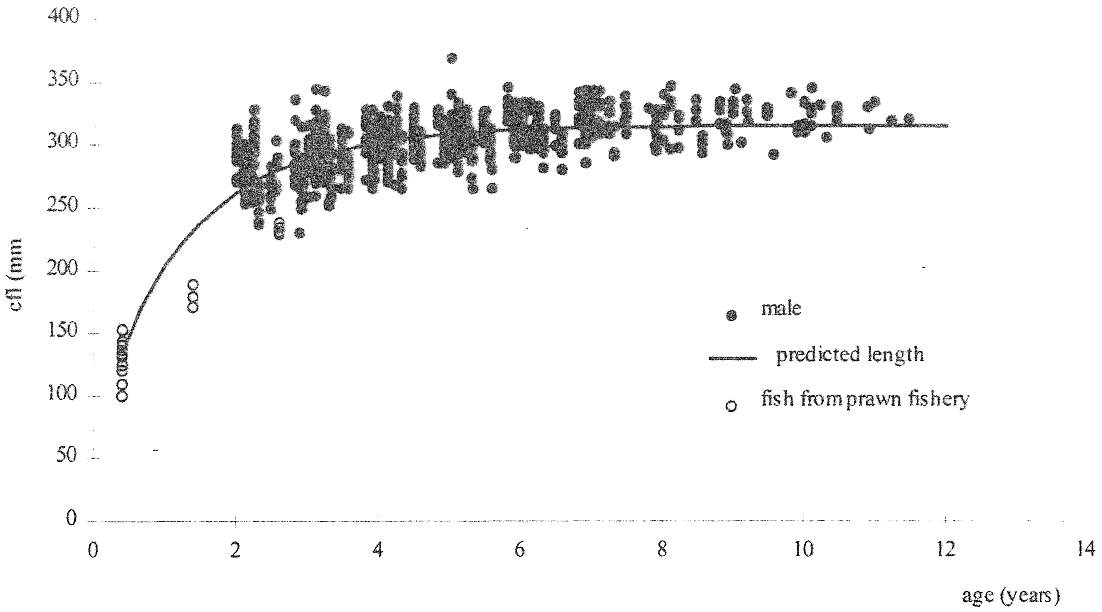


Figure 20. Von Bertalanffy growth curve fitted to observed length-at-age data derived from sagittal otoliths of male *Lethrinus* sp.

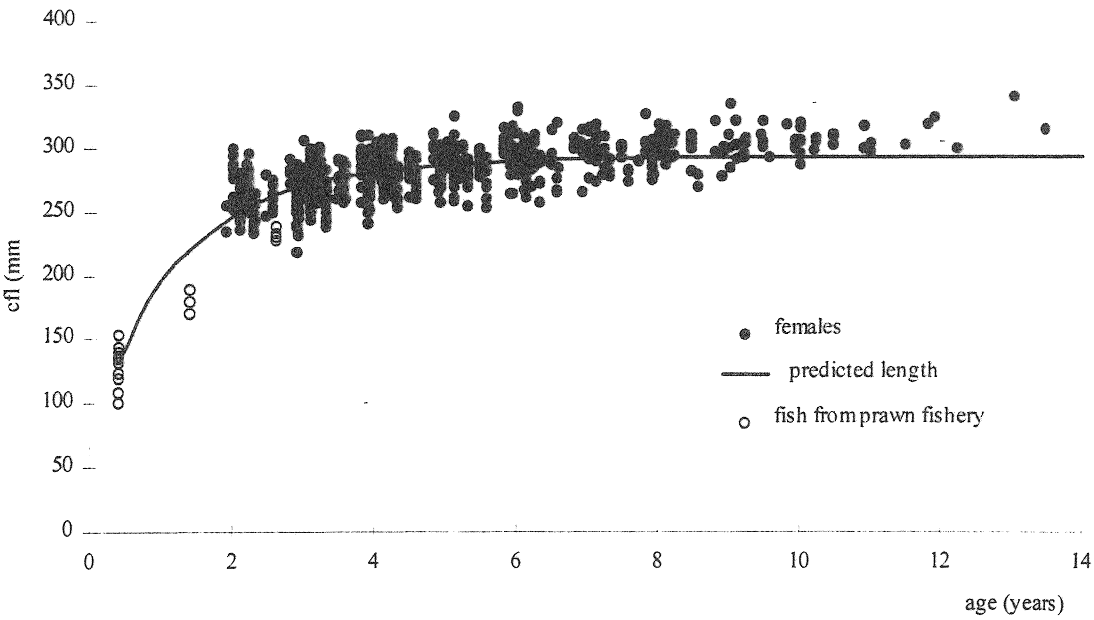


Figure 21. Von Bertalanffy growth curve fitted to observed length-at-age data derived from sagittal otoliths of female *Lethrinus* sp..

5.2.3.2 Reproductive biology

The mean monthly GSI's of female *Lethrinus* sp. peaked at 6.6, 4.6 and 6.4 in August 1996, September 1997 and September 1998 respectively (Figure 22). The pattern of change in mean monthly values for the GSI's suggests that *Lethrinus* sp. has a relatively short spawning season which occurs annually in September.

During the peak spawning period (September), the age and lcf at which 50% of female *Lethrinus* sp. are mature is 1.8 years and 240 mm (Figure 23). The lcf of 240 mm corresponds to a total length of 274 mm, slightly smaller than the current legal size of 280 mm total length for blue spot emperor in Western Australia.

Protogynous hermaphroditism is thought to be the typical mode of sexuality in lethrinid fishes (Young & Martin, 1982). However, sex reversal in *Lethrinus nebulosus* may be difficult to detect (Moran *et al.*, 1993) because it generally occurs before maturity, or at an early adult stage (Ebisawa, 1990). Figure 18 and Figure 19 suggest that if sex reversal in *Lethrinus* sp. occurs, it would occur at a small size, generally before the fish are recruited into the Pilbara trawl fishery.

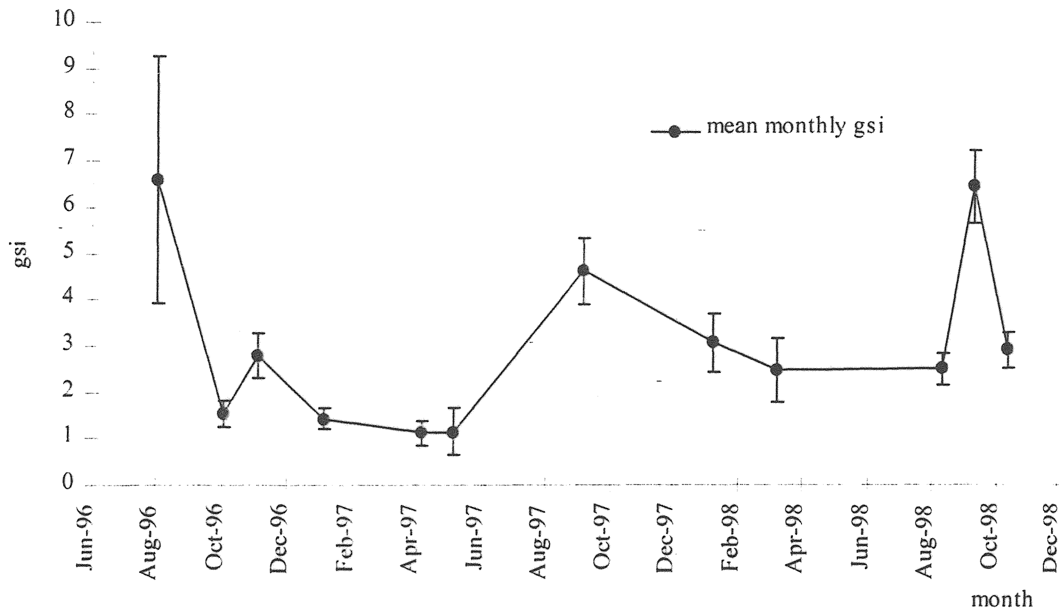


Figure 22. Mean monthly values of gonadosomatic indices ±95% confidence limits for mature female *L.* sp..

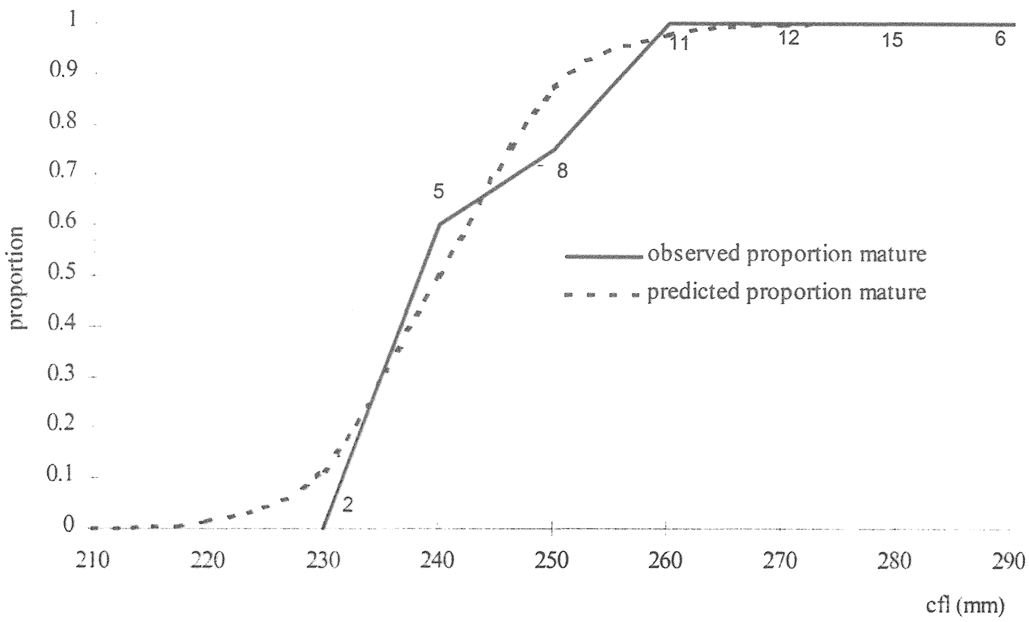


Figure 23. Logistic curve derived from the proportions of observed mature gonads for each 10mm length class of female *L.* sp..

5.2.3.3 Natural Mortality

The oldest blue spot emperor from sampling on commercial vessels in the Pilbara trawl fishery was 12 years and the maximum age is taken as $12 \times 1.2 = 14$. The maximum age and corresponding value of natural mortality M (see Hoenig, 1983) for *Lethrinus* sp. are shown in Table 8.

Table 8. Maximum age and corresponding estimate of natural mortality M for *L.* sp..

Maximum age	M
14	0.30

5.2.4 *Lutjanus vitta* (flagfish)

5.2.4.1 Age and growth

The parameters of the relationship between caudal fork length, lcf (mm) and weight (kg) determined from 334 *L. vitta* is shown in Appendix 1 and illustrated in Figure 24.

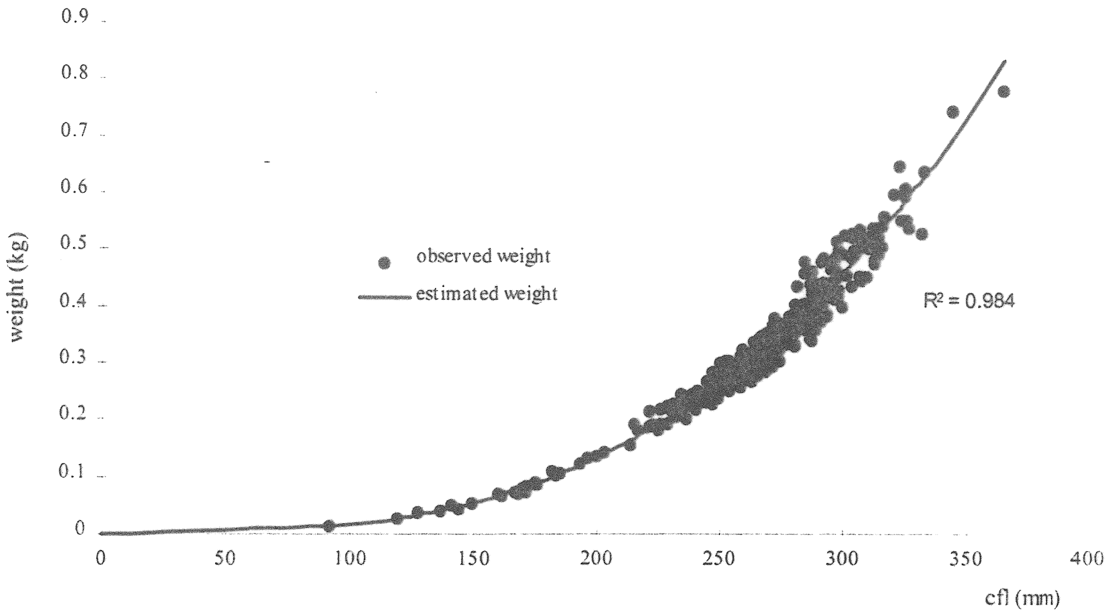


Figure 24. Caudal fork length (mm) and weight (kg) of 334 *L. vitta* together with the length-weight relationship $Weight = 1.185 \times 10^{-8} \cdot length^{3.0645}$.

L. vitta showed size-related differences in sex ratio with males predominating at larger sizes (Figure 25). There was no significant difference in age-related differences in sex ratio (Figure 26).

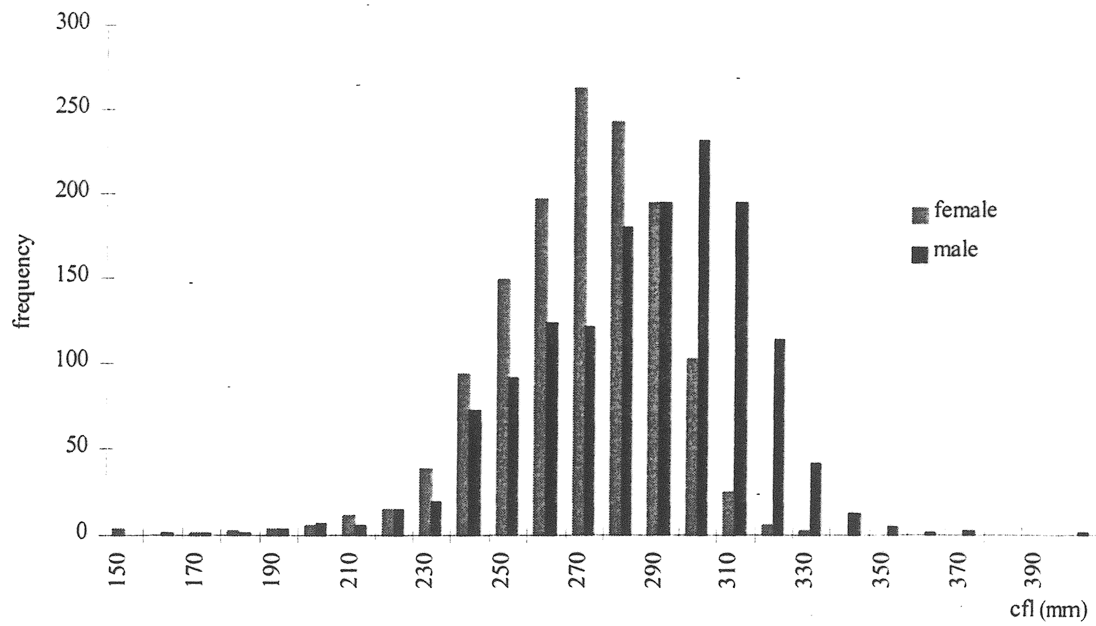


Figure 25. Frequency distribution for caudal fork length (mm) of male and female *L. vitta* sampled during 1996 to 1998 (lengths indicate initial points of 10mm size class).

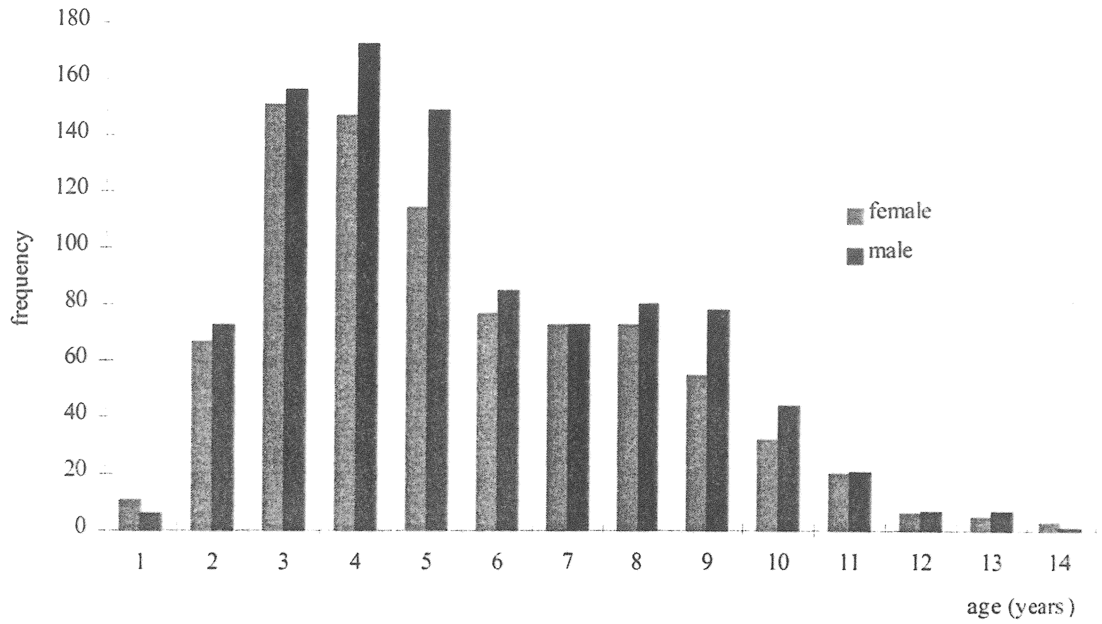


Figure 26. Frequency distribution for age (years) of male and female *L. vitta* sampled during 1996 to 1998.

The caudal fork length (mm) and ages from sectioned otoliths from 952 male, 834 female and 22 immature *L .vitta* are shown in Figures 27 and 28. The von Bertalanffy growth parameters for male and female *L. vitta* are provided in Table 9.

Table 9. Growth parameters (with 95% confidence limits) for the von Bertalanffy relationship between length and age for male and female *L. vitta* (L_∞ asymptotic length, K growth coeficient, t_0 hypothetical age at which fish would have zero length; N sample size).

	von Bertanaffy			
	L_∞	K	t_0	N
Male	301.9±2.26	0.706±0.05	-0.333±0.09	952
Female	282.9±4.00	0.661±0.19	-0.801±0.69	834

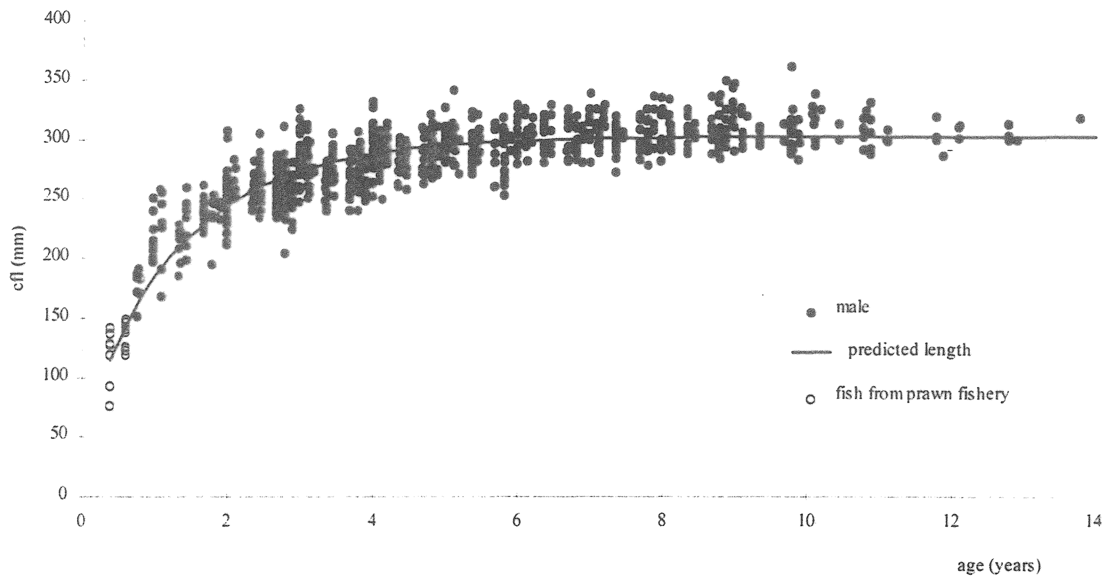


Figure 27. Von Bertalanffy growth curve fitted to observed length-at-age data derived from sagittal otoliths of male *L. vitta*.

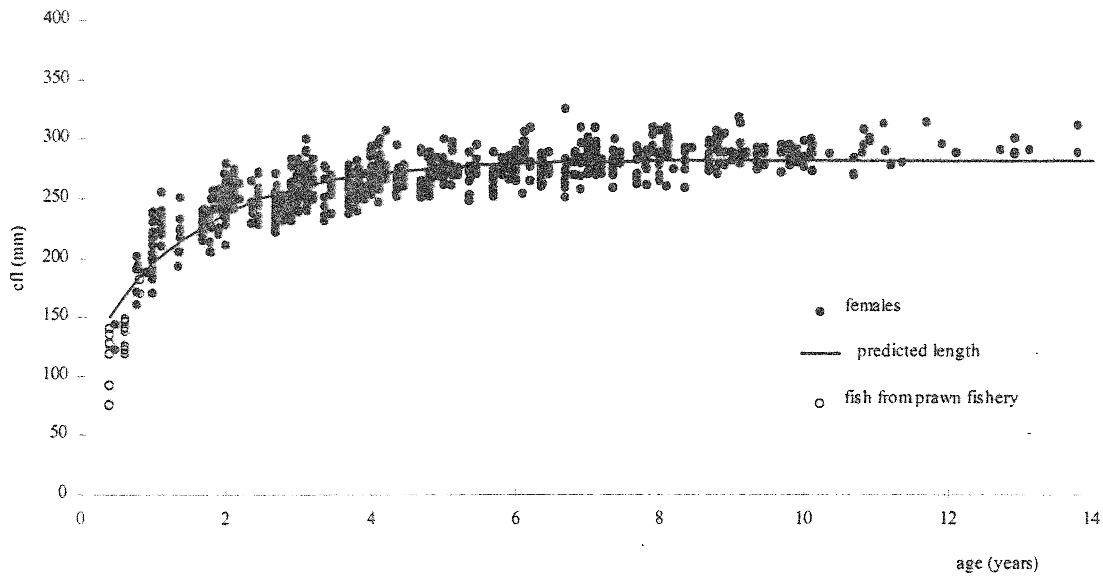


Figure 28. Von Bertalanffy growth curve fitted to observed length-at-age data derived from sagittal otoliths of female *L. vitta*.

5.2.4.2 Reproductive biology

An investigation of the reproductive biology of *L. vitta* was not an objective in this project. For information on the reproductive biology of *L. vitta* see Davis & West (1993).

5.2.4.3 Natural Mortality

The oldest flagfish from sampling on commercial vessels in the Pilbara trawl fishery was 12 years and the maximum age is taken as $12 \times 1.2 = 14$. The maximum age and corresponding value of natural mortality M (see Hoenig, 1983) for *L. vitta*. are shown in Table 10.

Table 10. Maximum age and corresponding estimate of natural mortality *M* for *L. vitta*.

Maximum age	*M*
14	0.30

5.2.5 *Nemipterus furcosus* (rosy threadfin bream)

5.2.5.1 Age and growth

The parameters of the relationship between caudal fork length, lcf (mm) and weight (kg) determined from 328 *N. furcosus* is shown in Appendix 1 and illustrated in Figure 29.

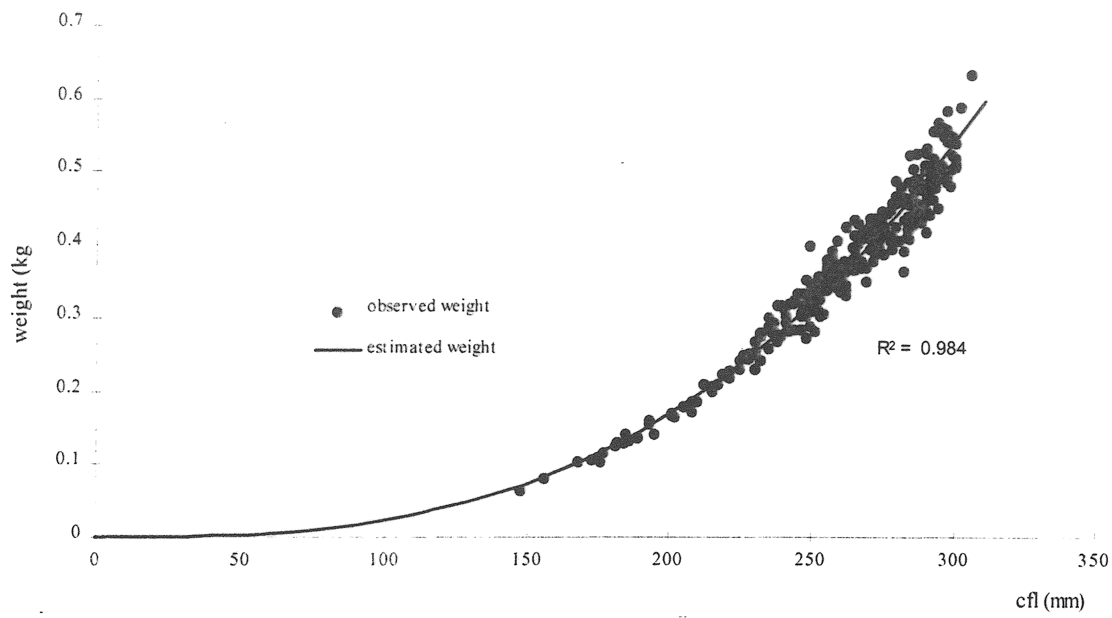


Figure 29. Caudal fork length (mm) and weight (kg) of 328 *N. furcosus* together with the length - weight relationship $Weight = 3.397 \times 10^{-8} \cdot length^{2.8826}$.

N. furcosus showed size-related differences in sex ratio with males predominating at larger sizes (Figure 30). There was no significant difference in age-related differences in sex ratio (Figure 31). Size - related differences in sex ratio have previously been examined for *N. furcosus* on the North West Shelf with males predominating at larger sizes (Young & Martin, 1985; Sainsbury & Whitelaw, 1984). Histological examination of the gonads identified a hermaphroditic *N. furcosus* individual, which shows some evidence for hermaphroditism in *N. furcosus* (Young & Martin, 1985). Sainsbury & Whitelaw (1984) identified a hermaphroditic *N. furcosus* individual, however they concluded that a more detailed study is needed to determine whether sex reversal or hermaphroditism is usual among *N. furcosus* on the North West Shelf.

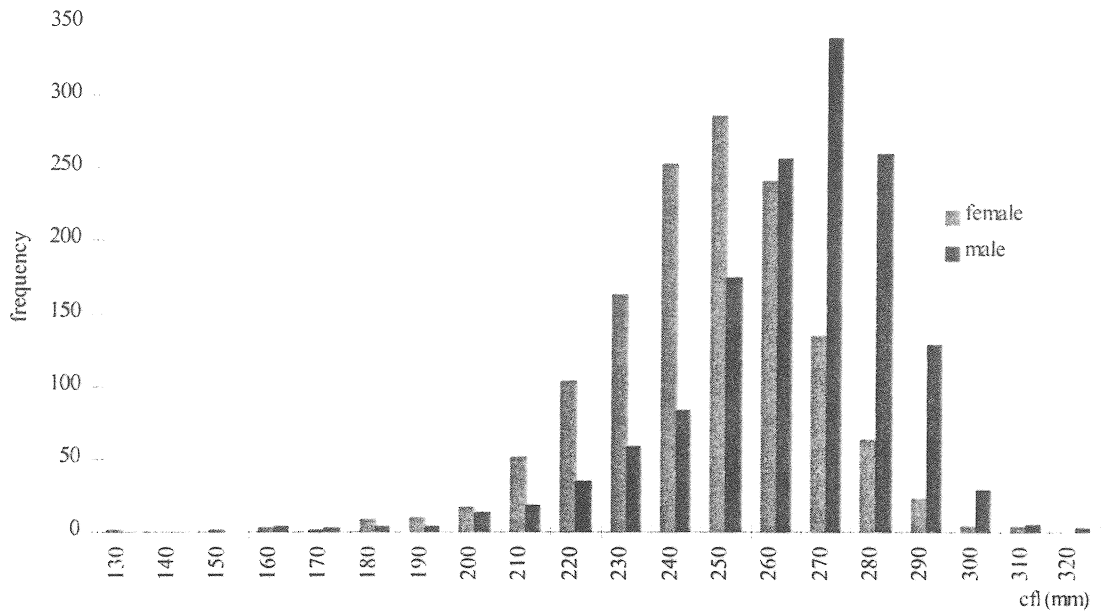


Figure 30. Frequency distribution for caudal fork length (mm) of male and female *N. furcosus* sampled during 1996 to 1998 (lengths indicate initial points of 10mm size class).

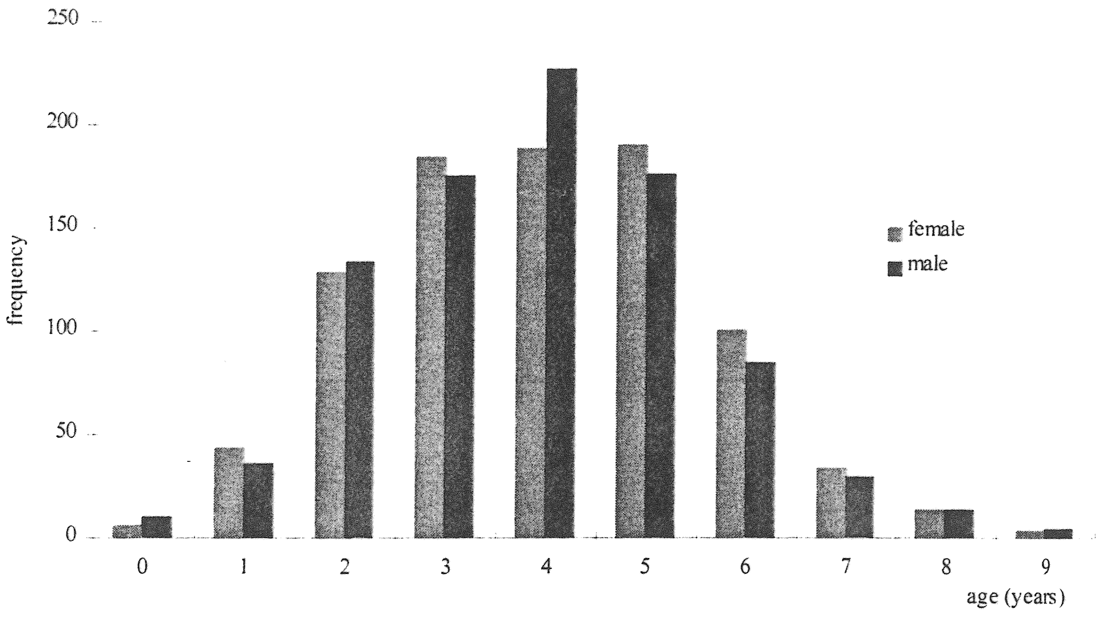


Figure 31. Frequency distribution for age (years) of male and female *N. furcosus* sampled during 1996 to 1998.

The caudal fork length (mm) and ages from sectioned otoliths from 877 male and 881 female *N. furcosus* are shown in Figures 32 and 33. No immature *N. furcosus* were identified from samples collected from the Pilbara trawl fishery or adjacent prawn fisheries. The von Bertalanffy growth parameters and their 95% confidence limits for male and female *N. furcosus* are provided in Table 11.

Table 11. Growth parameters (with 95% confidence limits) for the von Bertalanffy relationship between length and age for male and female *N. furcosus* (L_∞ asymptotic length, K growth coeficient, t_o hypothetical age at which fish would have zero length; N sample size).

	Von Bertanaffy			
	L_∞	K	t_o	N
Male	271.6±3.44	0.475±0.003	-2.00±0.00	877
Female	254.0±3.12	0.483±0.03	-2.00±0.00	881

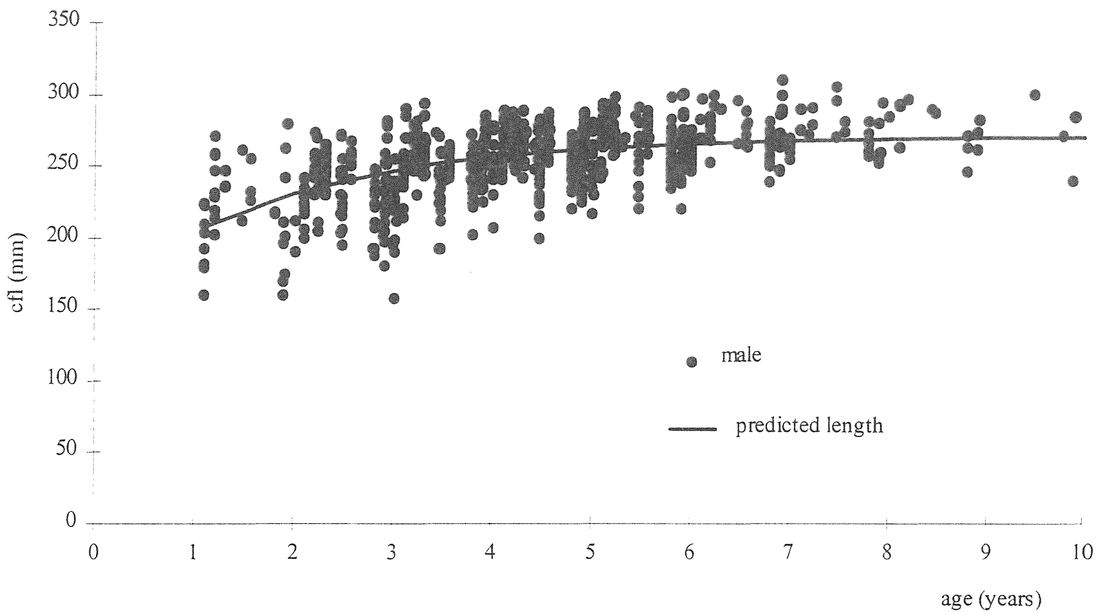


Figure 32. Von Bertalanffy growth curve (with upper and lower 95% confidence limits) fitted to observed length-at-age data derived from sagittal otoliths of male *N. furcosus*.

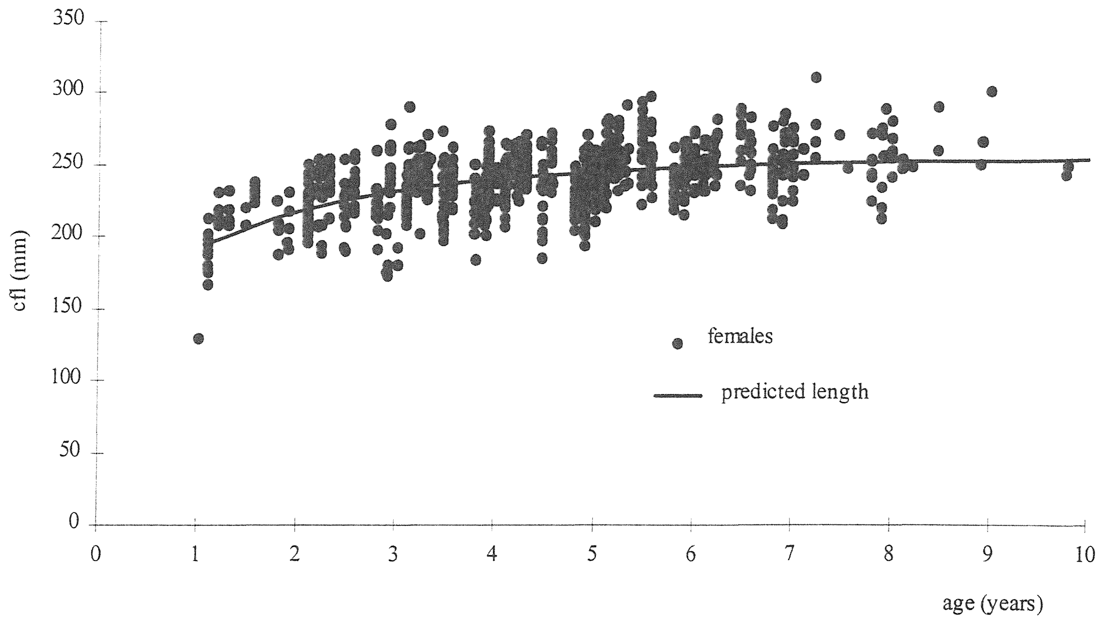


Figure 33. Von Bertalanffy growth curve (with upper and lower 95% confidence limits) fitted to observed length-at-age data derived from sagittal otoliths of female *N. furcosus*.

5.2.5.2 Reproductive biology

The reproductive biology of *N. furcosus* did not form part of this project. For information on the reproductive biology of Nemipterid fishes from coastal waters around northern Australia see Wu *et. al.* (1986), Young & Martin (1985) and Sainsbury & Whitelaw (1984).

5.2.5.3 Natural Mortality

The oldest rosy threadfin bream from sampling on commercial vessels in the Pilbara trawl fishery was 10 years and the maximum age is taken as $10 \times 1.2 = 12$. The maximum age and corresponding value of natural mortality M (see Hoenig, 1983) for *N. furcosus* are shown in Table 12.

Table 12. Maximum age and corresponding estimate of natural mortality M for *N. furcosus*.

Maximum age	M
12	0.35

5.3 Tagging studies

A total of 1116 fish were successfully tagged and released during the 1997/98 tagging program. The numbers of each species tagged and released during each year is provided in Table 13.

Table 13. Numbers of each species tagged during 1997 and 1998.

	Year	
Species	1997	1998
Red emperor	163	155
Rankin cod	64	28
Blue-spot emperor	178	62
Flagfish	35	12
Rosy threadfin bream	42	77
Other fish	230	70
Total	712	404

Unfortunately no tagged fish have yet been recaptured therefore no indication of fish movement patterns or the periodicity of otolith growth rings is available from the tagging studies. If and when a tagged individual is recaptured, the number of rings deposited on the otolith between known dates for the individual will be determined and used to validate the periodicity of growth rings and information on movement shall become available.

5.4 Age structures of key species

5.4.1 *Lutjanus sebae* (red emperor)

The red emperor age structure in west (116°E to 118°E) and east (118°E to 120°E) Pilbara in 1996-97 and 1998 (from sectioned otoliths) is shown in Table 14. In 1998, in the west Pilbara, there is a noticeable change in the age structure with few fish older than 16 years appearing in the sample.

Table 14. Age frequency for *L. sebae* in west and east Pilbara from commercial vessels in 1996-97 and 1998.

	age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	total
1996-7	west	2	15	16	34	78	99	82	65	50	29	40	24	20	14	19	4	6	8	5	4	3	1	2	620
1996-7	east	1	4	5	12	17	26	37	22	14	21	12	8	7	4	1	4	2	3	1	1	0	0	0	202
1998	west	11	36	22	15	28	39	21	20	15	6	18	7	4	4	2	2	4	0	0	1	1	1	0	257
1998	east	13	46	23	19	26	48	92	83	62	45	38	36	32	17	5	4	3	3	3	2	1	0	0	601

Catch curves for *L. sebae* in the west and east Pilbara (sexes pooled) for 1996-97 and 1998 are shown in Figure 34. The estimate of total mortality from the catch curve showed similar mortality levels in the west and east in 1996-97 and in 1998.

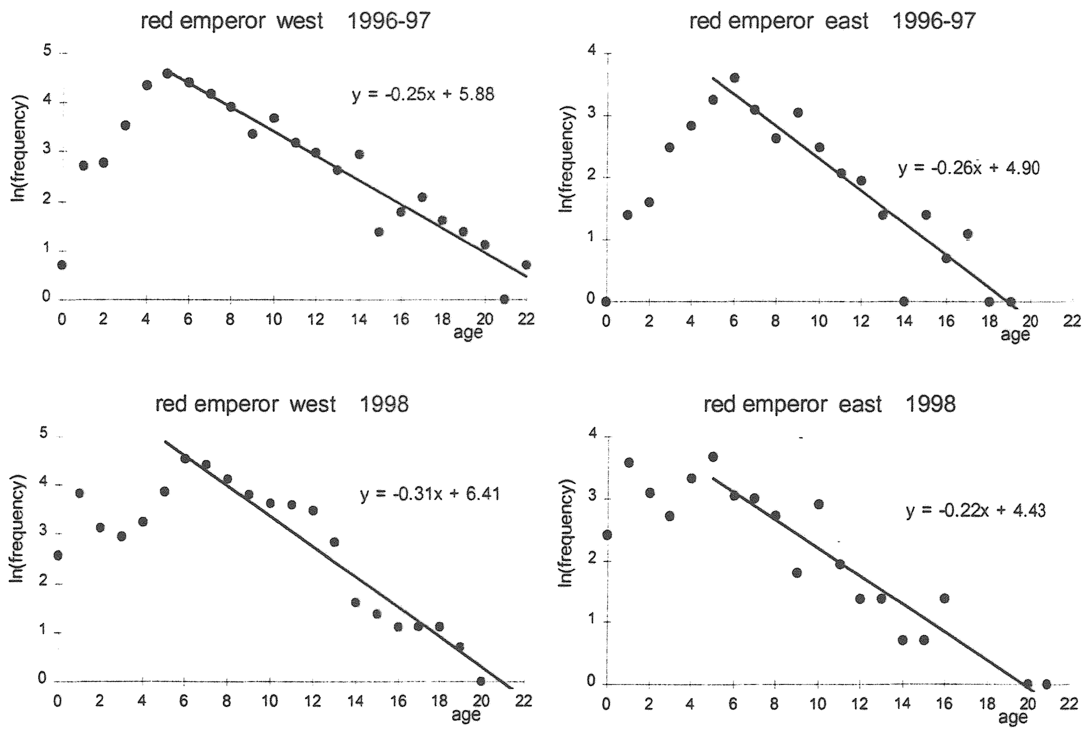


Figure 34. Catch curve and total mortality estimates (- slope) for *L. sebae* in the west and east Pilbara in 1996-97 and 1998.

It is surprising that the total mortality was not lower in the east than in the west, because the effort has been much lower in the east Pilbara than in the west. This could be an indication that the stock is mixing on this geographical scale and/or that the trap operators which target this species in the east Pilbara may be having an impact on the red emperor stocks.

The age structure for *L. sebae* in areas 1 to 5 of the Pilbara trawl fishery are shown in Table 15 and illustrated in Figure 35. The age structure in area 1 shows the disappearance of animals over 16 years due to heavy fishing effort. In areas 3 to 5, the modal age class is 6 to 7 years compared to 4 to 5 years in areas 1 and 2 and this has remained unchanged throughout the duration of the fishery.

Table 15. Age structure for *L. sebae* in areas 1 to 5 of the Pilbara trawl fishery from commercial vessels for 1996 to 1998.

	age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	total
1996	1	0	3	3	5	19	19	15	10	8	4	10	13	2	4	3	3	0	3	2	0	0	0	0	0	0	126
1996	2	0	1	6	12	27	31	16	12	6	6	8	2	3	3	4	0	1	3	1	0	1	1	1	0	0	145
1996	3	0	3	1	2	2	7	17	16	6	6	7	7	6	2	0	0	0	0	0	0	0	0	0	0	0	82
1997	1	1	2	3	5	16	16	12	5	4	2	7	1	4	1	5	2	2	1	1	0	1	0	0	0	0	91
1997	2	0	5	1	10	13	22	13	9	9	5	4	0	2	1	4	0	0	2	1	0	0	0	0	0	0	101
1997	3	2	1	1	1	1	6	9	13	16	6	4	1	3	3	3	0	1	0	0	4	0	0	0	0	0	75
1997	4	1	4	5	11	16	25	36	20	14	21	12	8	7	3	1	3	2	3	1	0	0	0	0	0	0	193
1997	5	0	0	0	1	1	1	1	2	0	0	0	0	0	1	0	1	0	0	0	1	0	0	0	0	0	9
1998	1	8	20	15	10	23	27	13	14	10	5	14	5	2	3	0	1	2	0	0	0	0	0	0	0	0	172
1998	2	0	2	2	2	3	5	1	0	2	1	2	2	0	1	1	1	1	0	0	1	0	1	0	0	1	29
1998	3	3	14	5	3	2	7	7	6	3	0	2	0	2	0	1	0	1	0	0	0	0	0	0	0	0	56
1998	4	1	42	19	14	23	37	68	66	48	33	24	25	20	11	4	3	2	3	2	2	1	0	0	0	0	448
1998	5	12	4	4	5	3	11	24	17	14	12	14	11	12	6	1	1	1	0	1	0	0	0	0	0	0	153

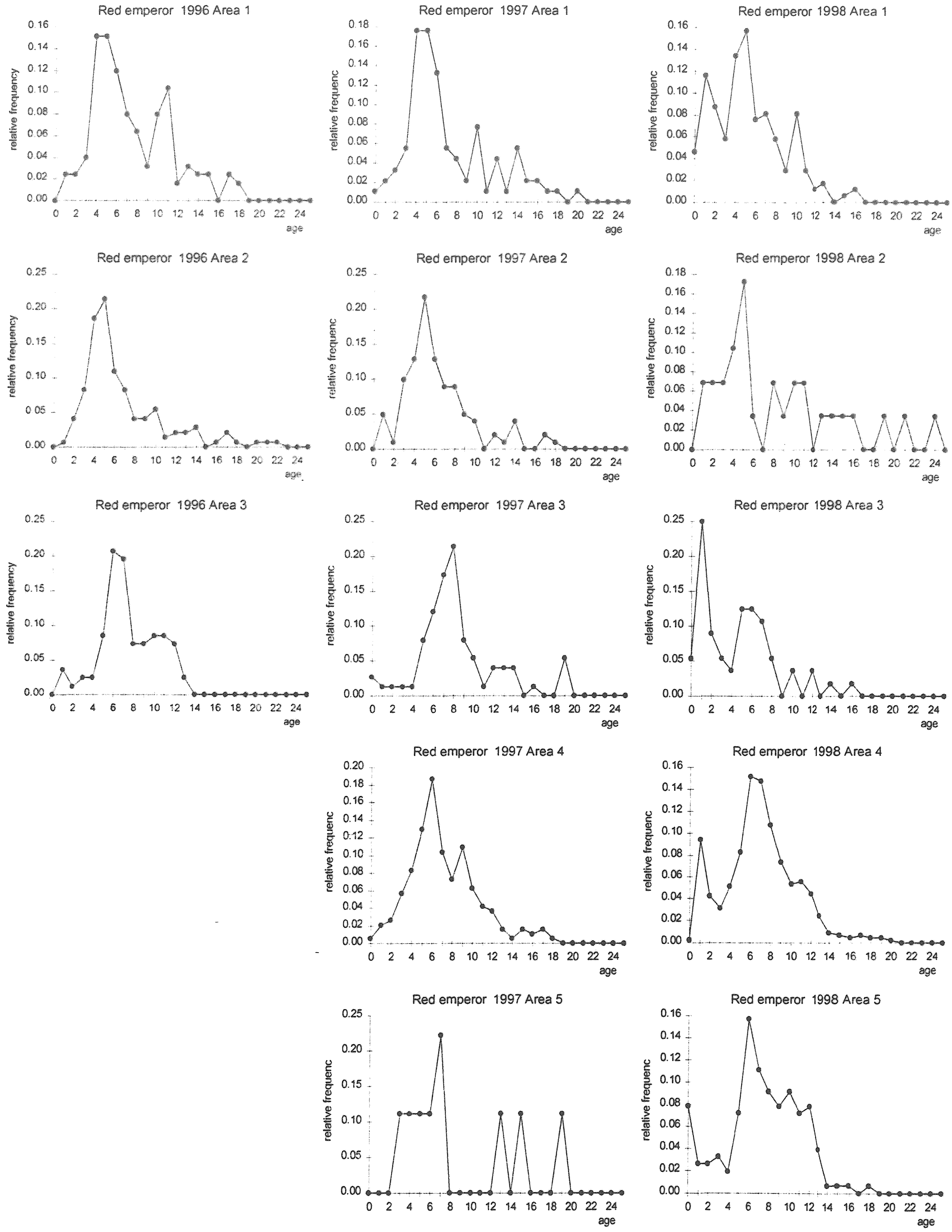


Figure 35. The relative frequency distribution of ages for *L.sebae* in areas 1 to 5 of the Pilbara trawl fishery. The ages are derived from sectioned otoliths collected during 1996 to 1998.

5.4.2 *Epinephelus multinotatus* (Rankin cod)

The Rankin cod age structure in west and east Pilbara in1996-97 and 1998 (from sectioned otoliths) is shown in Table 16. In 1998, in the west Pilbara, there were no fish with ages greater than 11.

Table 16. Age frequency for *E.multinotatus* in west and east Pilbara from commercial vessels in 1996-97 and 1998.

	age	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	total
1996-7	west	0	2	24	36	61	52	51	39	25	13	15	7	6	4	1	0	1	1	338
1996-7	east	2	7	10	22	23	47	38	46	24	21	21	18	3	5	5	1	1	3	297
1998	west	0	0	2	3	12	13	10	4	2	2	2	0	0	0	0	0	0	0	50
1998	east	1	8	12	19	36	45	41	28	12	8	1	3	0	0	0	2	0	0	216

Catch curves for *E. multinotatus* in the west and east Pilbara (sexes pooled) for 1996-97 and also for 1998 are shown in Figure 36. The estimate of total mortality from the catch curve showed slightly lower mortality levels in the west than in the east in 1996-97 and 1998. All the mortalities are high for a species of this longevity. The high mortalities in the east Pilbara, where trawl effort is low, could be an indication that the trap sector operating in the east Pilbara could be having an appreciable impact on Rankin cod stocks.

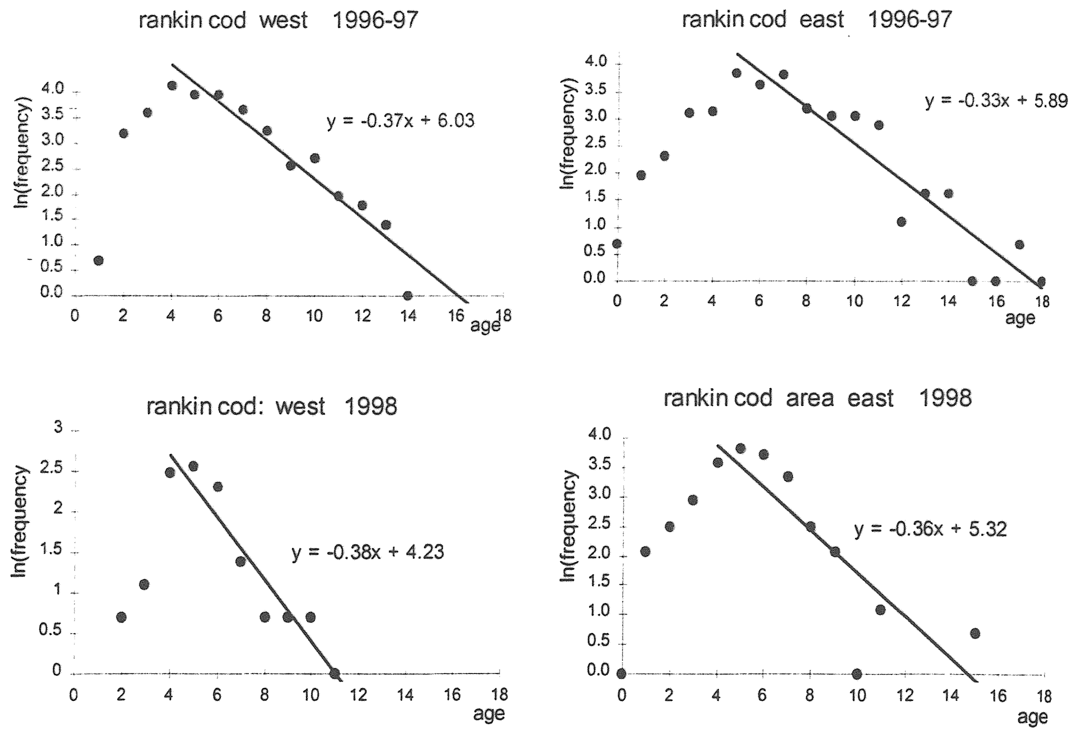


Figure 36. Catch curve and total mortality estimates (- slope) for *E. multinotatus* in west and east Pilbara in 1996-97 and 1998.

The age structure for *E. multinotatus* in areas 1 to 5 of the Pilbara trawl fishery are shown in Table 17 and illustrated in Figure 37. The maximum age of this species in area 1 and 2 in 1998 is 11 years with older fish appearing in samples from the easterly areas especially area 5 in 1997 however there doesn't appear to be any real decline in modal age with time.

Table 17. Age structure for *E. multinotatus* in areas 1 to 5 of the Pilbara trawl fishery from commercial vessels for 1996 to 1998.

	age	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	total
1996	1	0	0	12	11	15	9	14	6	7	2	2	3	3	0	0	0	0	1	0	85
1996	2	0	0	1	5	14	8	4	4	2	2	2	1	0	0	0	0	0	0	0	43
1996	3	0	0	2	9	5	7	7	11	2	3	3	1	2	2	0	0	0	0	0	54
1997	1	0	0	1	4	11	12	3	5	2	2	2	0	0	0	0	0	0	0	0	42
1997	2	0	1	6	7	8	8	5	6	5	0	1	1	1	0	0	0	0	0	0	49
1997	3	0	1	2	0	8	8	18	7	7	4	5	1	0	2	1	0	1	0	0	65
1997	4	0	0	3	8	8	12	8	8	2	4	5	10	0	0	0	0	0	0	0	68
1997	5	2	7	7	14	15	35	30	38	22	17	16	8	3	5	5	1	1	2	1	229
1998	1	0	0	2	3	8	9	8	3	2	1	2	0	0	0	0	0	0	0	0	38
1998	2	0	0	0	0	3	4	0	0	0	1	0	0	0	0	0	0	0	0	0	8
1998	3	0	0	0	0	1	0	2	1	0	0	0	0	0	0	0	0	0	0	0	4
1998	4	1	4	8	10	20	36	27	18	6	6	0	1	0	0	0	1	0	0	0	138
1998	5	0	4	4	9	16	9	14	10	6	2	1	2	0	0	0	1	0	0	0	78

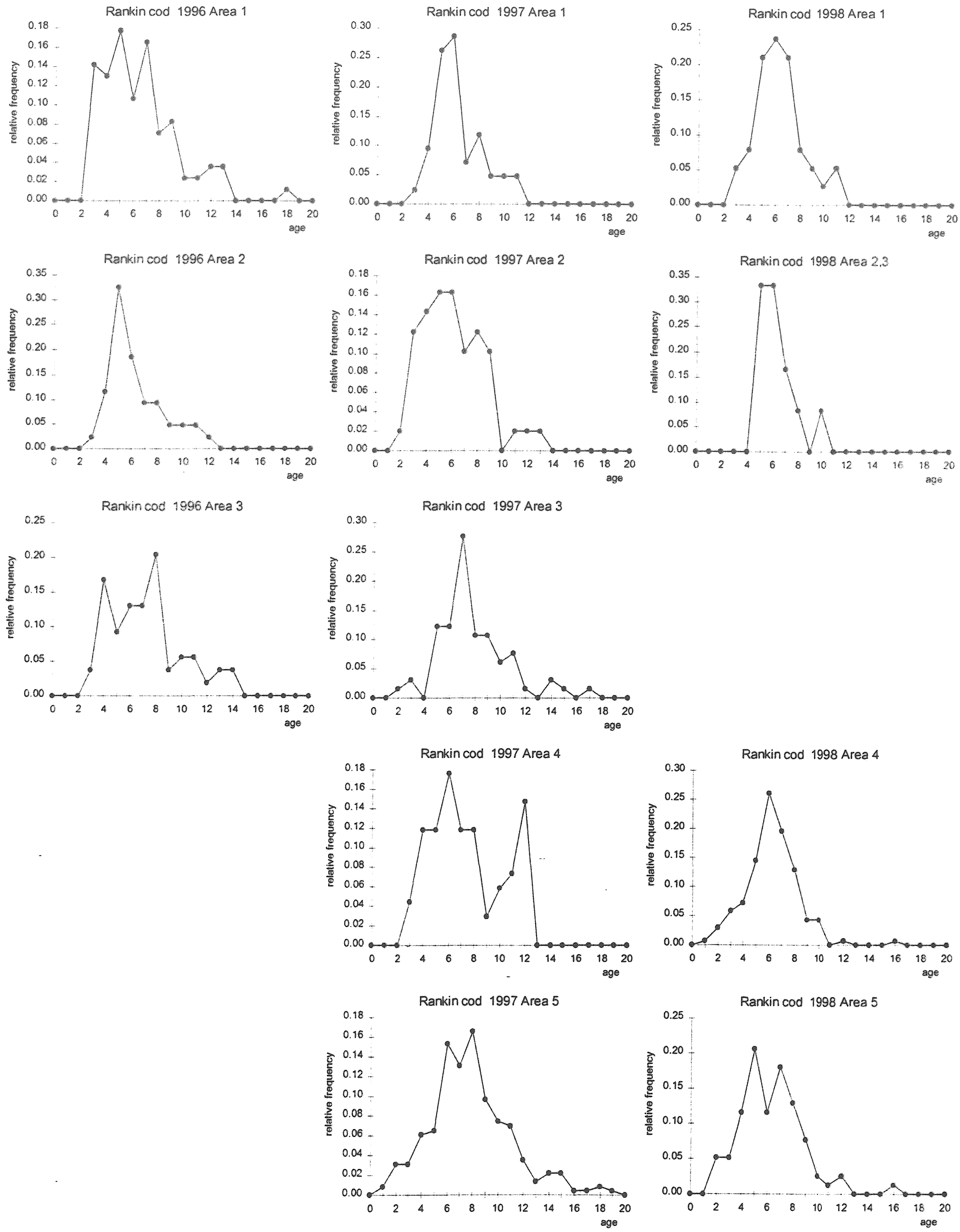


Figure 37. The relative frequency distribution of ages for *E. multinotatus* in areas 1 to 5 of the Pilbara trawl fishery. The ages are derived from sectioned otoliths collected during 1996 to 1998.

5.4.3 *Lethrinus* sp. (blue-spot emperor)

The plots of age vs otolith weight (Figure 38) illustrate the linear relationship.
For fish of age > 1, there was no difference between the slopes of the linear relationship between sites for females (F = 0.01, n=821, P=0.98), nor the intercepts (F=3.12, n=821, P=0.08). For males there was no significant differences between the slopes between sites "west" and "east" (F = 0.95, n=906, P=0.33), but there was a significant difference between the intercepts (F=10.6, n=906, P < 0.001), but this only contributed 0.3% to the sum of squares. As there was no practical difference between the predicted age for male fish between the west and the east, data were pooled.

There was a significant difference between the slopes of the of the regression lines between females and males (F = 17.06, n = 1728, P < 0.001) and thus data was not pooled over the sexes. The slope of the regression lines is greater for male than female indicating that the otolith weight, like body length and weight, increases more rapidly in males than females.

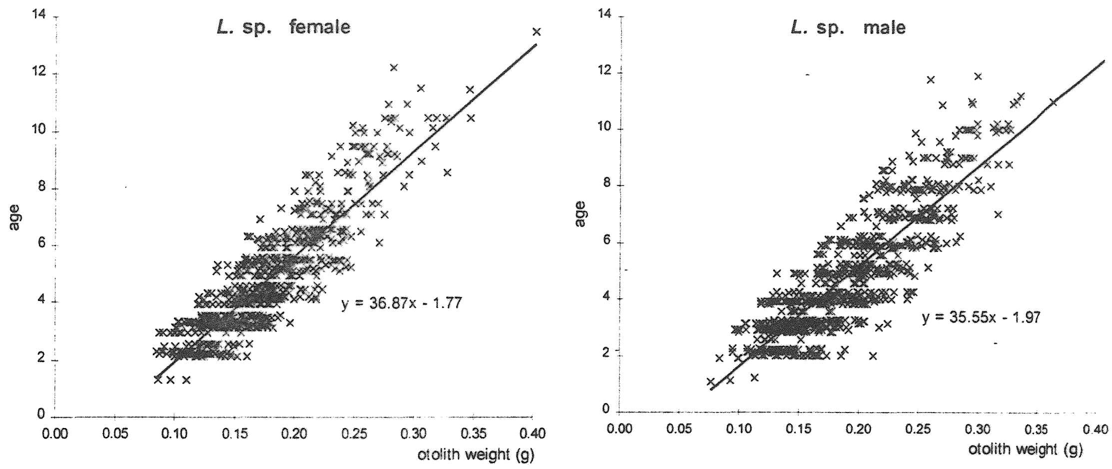


Figure 38. Otolith weight vs age for female and male *L.* sp. with fitted lines.

For *L.* sp., with ages ≥ 2, the linear relationship is

$$age = 36.87 \cdot otolith\ weight - 1.77 \text{ for females}$$

$$age = 35.55 \cdot otolith\ weight - 1.97 \text{ for males.}$$

The age and otolith weight data were pooled on area and otolith weight-age keys were constructed for each sex for the second group of data from 1996-97. The observed ages (from reading sectioned otoliths) and the predicted ages (from otoliths and an otolith weight-age key) for females and males are illustrated in Figure 39.

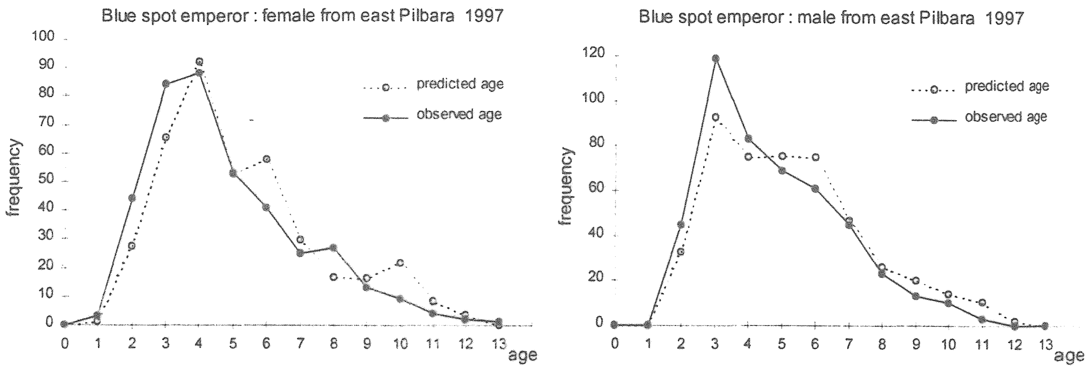


Figure 39. Frequency distribution of ages for *L.* sp. from otoliths in the second group collected in 1996-97. The observed age is from sectioned otoliths and the predicted age from otolith weight.

The Chi-square test determined that there was no significant difference between the observed and predicted age distributions for female nor for male *L.* sp.

Female $\chi^2 = 14.2$ which is less than $\chi^2_{0.05,9} = 18.3$

Male $\chi^2 = 15.5$ which is less than $\chi^2_{0.05,9} = 18.3$

An otolith weight-age key, pooled on area, was generated for each sex for all the 1996-97 data (Table 18 for females and Table 19 for males). The age frequency distributions for each sex in west and east Pilbara for 1996-97 (using sectioned otoliths) and for 1998 (using the otolith weight-age keys are shown in Table 20.

Table 18. The otolith weight-age key for female *Lethrinus* sp. with otolith weight (g) in the left column and age (years) in the top row.

	Age														
otwt.	0	1	2	3	4	5	6	7	8	9	10	11	12	13	total
0.06	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.07	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
0.08	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.09	0	1	3	2	0	0	0	0	0	0	0	0	0	0	6
0.1	0	0	9	11	0	0	0	0	0	0	0	0	0	0	20
0.11	0	1	15	8	0	0	0	0	0	0	0	0	0	0	24
0.12	0	0	22	17	11	0	0	0	0	0	0	0	0	0	50
0.13	0	0	14	30	21	2	0	0	0	0	0	0	0	0	67
0.14	0	0	4	34	21	1	0	0	0	0	0	0	0	0	60
0.15	0	0	7	18	34	10	1	0	0	0	0	0	0	0	70
0.16	0	0	3	21	30	12	1	0	0	0	0	0	0	0	67
0.17	0	0	0	10	29	22	15	1	0	0	0	0	0	0	77
0.18	0	0	0	2	25	20	20	2	0	0	0	0	0	0	69
0.19	0	0	0	1	14	18	18	0	0	0	0	0	0	0	51
0.2	0	0	0	0	8	19	18	4	1	0	0	0	0	0	50
0.21	0	0	0	0	4	7	19	4	6	0	0	0	0	0	40
0.22	0	0	0	0	2	4	6	6	11	2	0	0	0	0	31
0.23	0	0	0	0	0	2	9	18	5	6	0	0	0	0	40
0.24	0	0	0	0	1	2	1	3	5	2	1	0	0	0	15
0.25	0	0	0	0	0	0	2	5	5	1	2	0	0	0	15
0.26	0	0	0	0	0	0	3	6	7	4	2	0	1	0	23
0.27	0	0	0	0	0	0	0	1	2	4	2	1	0	0	10
0.28	0	0	0	0	0	0	0	1	0	4	4	0	1	0	10
0.29	0	0	0	0	0	0	0	0	1	2	2	3	0	0	8
0.3	0	0	0	0	0	0	0	0	0	0	2	1	1	0	4
0.31	0	0	0	0	0	0	0	0	0	1	2	0	0	0	3
0.32	0	0	0	0	0	0	0	0	0	0	2	2	1	0	5
0.33	0	0	0	0	0	0	0	0	0	0	1	2	0	0	3
0.34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 19. The otolith weight-age key for male *Lethrinus* sp. with otolith weight (g) in the left column and age (years) in the top row.

	Age														
ot wt.	0	1	2	3	4	5	6	7	8	9	10	11	12	13	total
0.06	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.07	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.08	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
0.09	0	0	2	0	0	0	0	0	0	0	0	0	0	0	2
0.1	0	0	2	4	0	0	0	0	0	0	0	0	0	0	6
0.11	0	0	7	7	0	0	0	0	0	0	0	0	0	0	14
0.12	0	0	8	13	3	0	0	0	0	0	0	0	0	0	24
0.13	0	0	7	33	12	0	0	0	0	0	0	0	0	0	52
0.14	0	0	14	28	10	0	0	0	0	0	0	0	0	0	52
0.15	0	0	7	30	19	3	0	0	0	0	0	0	0	0	59
0.16	0	0	11	37	26	3	0	0	0	0	0	0	0	0	77
0.17	0	0	2	24	21	15	6	0	0	0	0	0	0	0	68
0.18	0	0	1	19	30	18	4	0	0	0	0	0	0	0	72
0.19	0	0	1	2	27	19	12	4	0	0	0	0	0	0	65
0.2	0	0	0	5	15	27	15	3	1	0	0	0	0	0	66
0.21	0	0	1	0	12	22	29	4	0	0	0	0	0	0	68
0.22	0	0	0	2	6	19	12	10	4	0	0	0	0	0	53
0.23	0	0	0	0	1	12	12	15	2	0	0	0	0	0	42
0.24	0	0	0	0	4	6	19	11	6	1	0	0	0	0	47
0.25	0	0	0	0	0	1	10	13	7	3	2	0	0	0	36
0.26	0	0	0	0	0	1	5	11	4	5	2	0	0	0	28
0.27	0	0	0	0	0	0	5	5	5	5	1	0	0	0	21
0.28	0	0	0	0	0	0	2	4	5	2	0	1	0	0	14
0.29	0	0	0	0	0	0	0	0	2	5	5	2	0	0	14
0.3	0	0	0	0	0	0	0	0	2	1	1	1	0	0	5
0.31	0	0	0	0	0	0	0	0	1	1	3	0	0	0	5
0.32	0	0	0	0	0	0	0	0	0	2	1	1	0	0	4
0.33	0	0	0	0	0	0	0	0	0	1	1	2	0	0	4
0.34	0	0	0	0	0	0	0	0	0	0	1	1	0	0	2
0.36	0	0	0	0	0	0	0	0	0	0	0	2	1	0	3
0.39	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2

Table 20. Age frequency for *Lethrinus* sp. for females in west and east Pilbara (F W and F E) and males in the west and east (M W and M E) from commercial vessels for 1996-97 and 1998.

	age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	total
F W	1996/7	0	2	51	110	154	86	75	32	28	16	9	2	3	1	569
F W	1998	0	0.8	24.6	47.3	57.9	33.9	33.4	15.5	14.5	7.0	5.3	1.5	1.3	1	244
F E	1996/7	0	1	26	44	46	33	38	19	15	11	11	5	1	1	251
F E	1998	0	0.2	15.2	46.2	73.3	45.9	39.1	18.0	16.8	10.6	8.3	2.6	1.0	1.0	278
M W	1996/7	0	0	38	119	148	94	67	44	18	15	8	7	1	0	559
M W	1998	0	0	19.9	55.6	46.8	37.8	31.9	18.5	6.6	3.2	2.5	1.1	1	0.5	225
M E	1996/7	0	0	7.8	37.4	49	47.1	42.7	28.7	16	9.3	7.1	4.2	1	1	345
M E	1998	0	0	7.87	37.4	49	47.1	42.7	28.7	16	9.3	7.1	4.2	1	1	252

Catch curves for *Lethrinus* sp. in the west and east Pilbara for 1996-97 and also for 1998 are shown for females in Figure 40 and males in Figure 41. The estimate of total mortality from the catch curve showed mortality levels considerably higher in the west Pilbara where fishing effort is higher (Z=0.53, 0.48 for females and Z = 0.55 and 0.59 for males) than in the east (Z = 0.40 and 0.44 for females and 0.44 and 0.40 for males) where effort is lower. The mean total mortality in the east Pilbara (Z = 0.42) is expected to be an over-estimate of natural mortality as there was some fishing in the east Pilbara from 1995 to 1998. The difference between the mean total mortality in the west (Z = 0.54) and east is an under-estimate of the fishing mortality for the species in the west (F = 0.54 - 0.42 = 0.12)

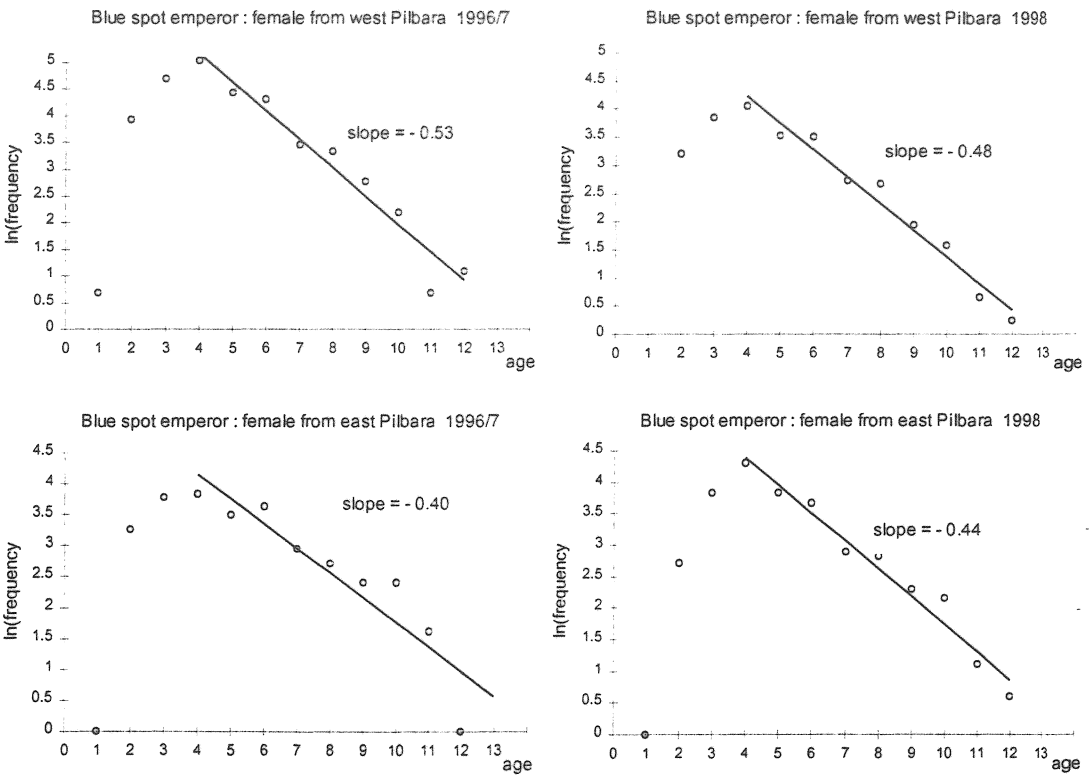
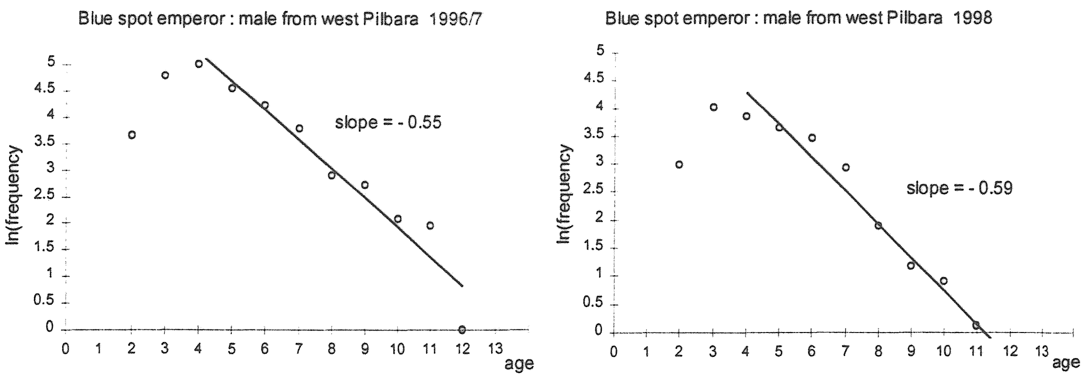


Figure 40. Catch curve and total mortality estimates (- slope) for female *Lethrinus* sp. from west and east Pilbara in 1996-97 and in 1998.



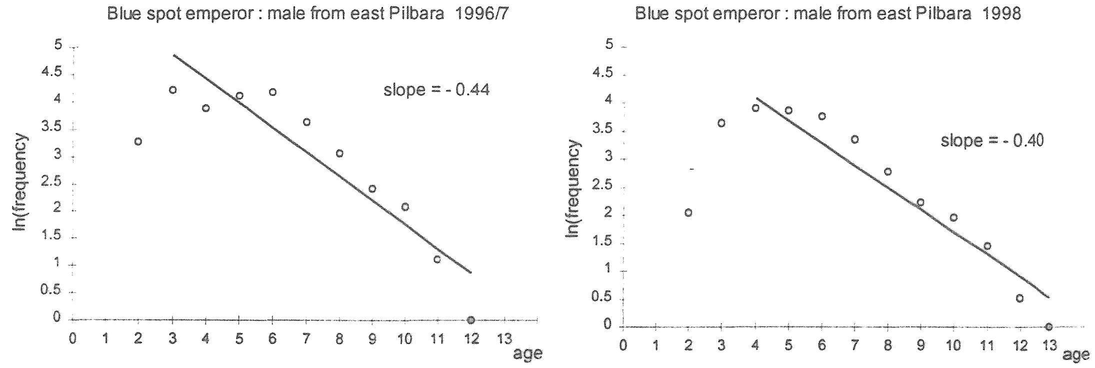


Figure 41. Catch curve and total mortality estimates (- slope) for male *Lethrinus* sp. from west and east Pilbara in 1996-97 and in 1998.

The age structure for *Lethrinus* sp. in areas 1 to 5 of the Pilbara trawl fishery are shown in Table 21 and illustrated in Figure 42. There appears to be little difference in the age structure over time or between areas.

Table 21. Age structure for *Lethrinus* sp. in areas 1 to 5 of the Pilbara trawl fishery from commercial vessels for 1996 to 1998.

	age	1	2	3	4	5	6	7	8	9	10	11	12	13	total
1996	1	0	31	49	59	33	26	5	5	5	2	2	1	0	218
1996	2	0	6	22	40	21	13	2	2	6	4	0	0	0	116
1996	3	0	12	22	18	11	10	11	3	2	2	0	0	0	91
1997	1	1	22	56	49	46	31	18	7	9	2	0	0	0	241
1997	2	0	7	24	57	32	34	18	10	1	0	2	1	0	186
1997	3	1	11	56	79	37	28	22	19	8	7	5	2	1	276
1997	4	1	12	39	37	46	54	24	13	7	5	2	1	0	241
1997	5	0	40	72	57	47	48	32	23	15	14	6	0	1	355
1998	1	1	46	89	70	60	45	34	18	11	7	2	0	1	384
1998	2	0	1	6	9	10	8	5	3	2	1	0	0	0	45
1998	3	0	4	11	9	6	3	2	1	1	2	1	0	0	40
1998	4	0	15	52	67	60	47	35	23	16	14	3	2	0	335
1998	5	0	8	34	44	36	25	18	10	7	9	1	0	0	191

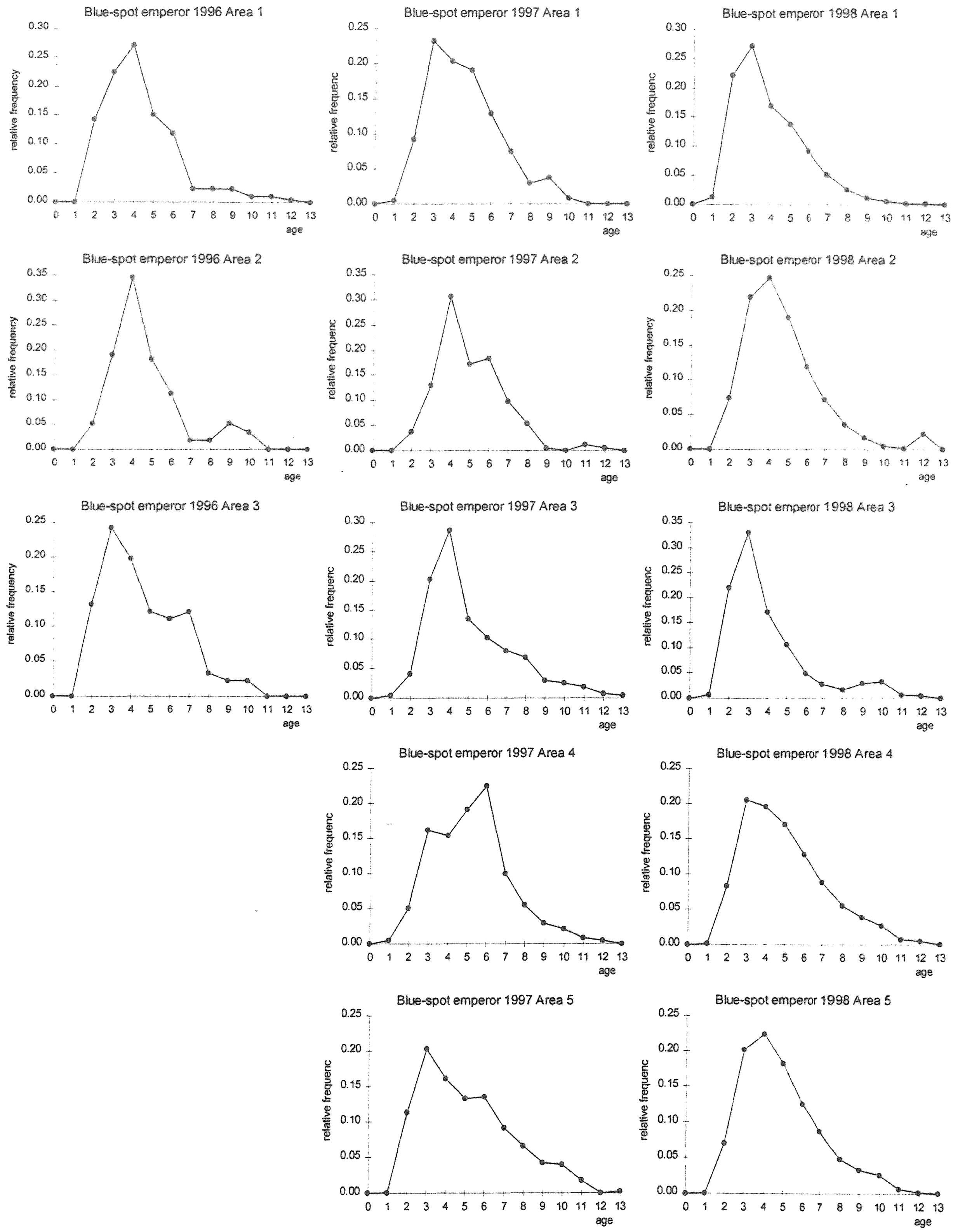


Figure 42. The relative frequency distribution of ages for *Lethrinus* sp. In areas 1 to 5 of the Pilbara trawl fishery. The ages are derived from sectioned otoliths collected during 1996 and 1997 and from otolith weights collected in 1998.

5.4.4 *Lutjanus vitta* (flagfish)

For flagfish there was no difference in the slopes of the linear relationship of age and otolith weight presumably between sites "west" or "east" for females (F = 0.82, n=829, P=0.49), nor the intercepts (F=0.82, n=829, P=0.36). For males there was a significant difference in slope between the sites "west" and "east (F = 5.9, n=942, P=0.017), but site contributed only 0.1% of the sum of squares (compared to 84% for otolith weight) and the slopes were considered equal. There was a significant difference between the intercepts (F=24.2, n=942, P < 0.001), but this only contributed 0.4% to the sum of squares and as there was no practical difference between the predicted age for male fish between the west and the east, data was pooled.

There was a significant difference between the slopes of the of the regression lines between females and males (F = 25.6, n = 1772, P < 0.001) and thus data was not pooled over the sexes.

The age and otoliths weight, with the fitted lines for female *L. vitta* are shown in Figure 43. The slopes of the regression equations indicate that otolith weights, like body weight, increases more rapidly with age in males than females.

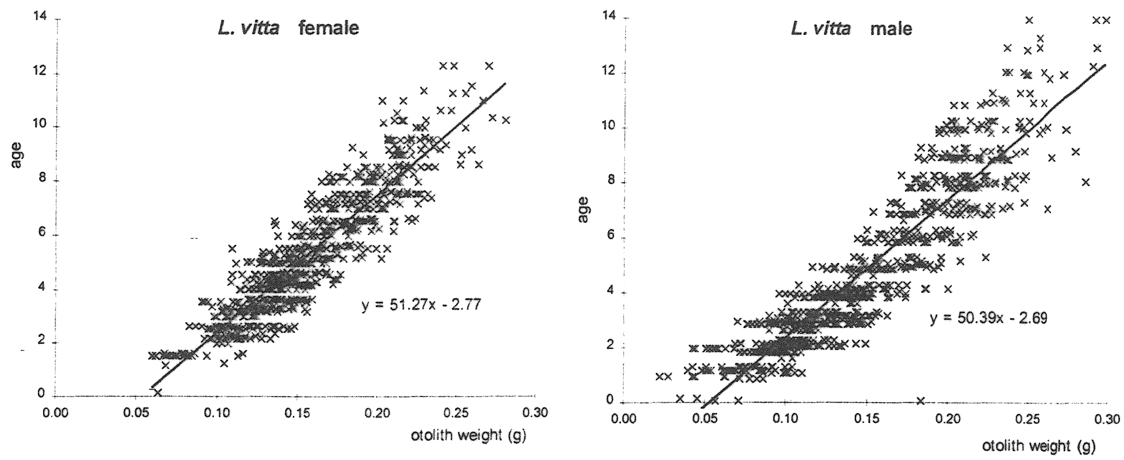


Figure 43. Age vs otolith weight for female and male *L. vitta* with fitted lines.

For flagfish, the linear relationship is

$age = 51.27 \cdot otolith\ weight - 2.77$ for females, and

$age = 50.39 \cdot otolith\ weight - 2.69$ for males.

The observed ages from reading sectioned otoliths (observed) and the ages determined from the otolith- age key (predicted) for females and males are shown in Figure 44.

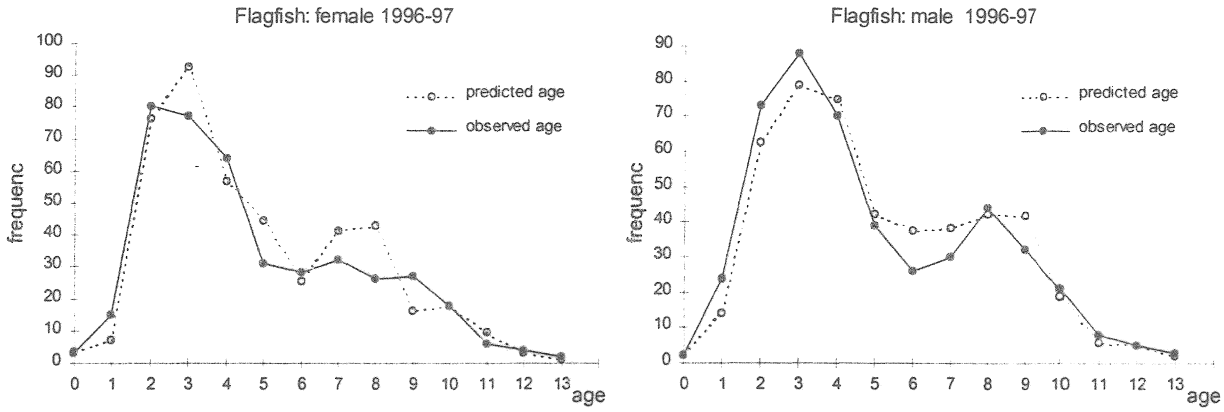


Figure 44. Frequency distribution of ages for *L.vitta* from otoliths in the second group collected in 1996/7. The observed age is from sectioned otoliths and the predicted age from otolith weight-age key.

A Chi-square test determined that there was no significant difference between the observed and predicted age distributions for female nor for male *L. vitta*.

Female $\chi^2 = 12.3$ which is less than $\chi^2_{0.05,8} = 18.3$

Male $\chi^2 = 7.01$ which is less than $\chi^2_{0.05,8} = 18.3$

An otolith weight-age key, pooled on area, was generated for each sex for all the 1996-97 data (Table 22 for females and Table 23 for males). The age frequency distributions for each sex in west and east Pilbara for the 1996-97 (using sectioned otoliths) and for the 1998 (using the otolith weight-age keys are shown in Table 24.

Table 22. The otolith weight-age key for female *L. vitta.* with otolith weight (g) in the left column and age (years) in the top row.

	Age														
ot.wt	0	1	2	3	4	5	6	7	8	9	10	11	12	13	total
0.015	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
0.025	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
0.035	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
0.045	1	2	0	0	0	0	0	0	0	0	0	0	0	0	3
0.055	0	3	2	0	0	0	0	0	0	0	0	0	0	0	5
0.065	2	7	2	0	0	0	0	0	0	0	0	0	0	0	11
0.075	1	9	4	0	0	0	0	0	0	0	0	0	0	0	14
0.085	0	6	8	5	0	0	0	0	0	0	0	0	0	0	19
0.095	0	3	24	10	0	0	0	0	0	0	0	0	0	0	37
0.105	0	4	36	21	6	0	0	0	0	0	0	0	0	0	67
0.115	0	2	20	36	6	1	0	0	0	0	0	0	0	0	65
0.125	0	0	6	44	23	7	1	0	0	0	0	0	0	0	81
0.135	0	0	5	12	33	13	0	0	0	0	0	0	0	0	63
0.145	0	0	0	6	37	21	2	1	0	0	0	0	0	0	67
0.155	0	0	0	6	20	24	7	4	0	0	0	0	0	0	61
0.165	0	0	0	0	7	14	20	10	1	0	0	0	0	0	52
0.175	0	0	0	0	3	4	18	19	7	0	0	0	0	0	51
0.185	0	0	0	0	0	8	10	23	15	2	0	0	0	0	58
0.195	0	0	0	0	0	2	4	8	12	5	0	0	0	0	31
0.205	0	0	0	0	0	2	2	8	11	10	7	1	0	0	41
0.215	0	0	0	0	0	0	2	5	15	9	10	2	0	0	43
0.225	0	0	0	0	0	0	0	3	6	8	7	4	0	0	28
0.235	0	0	0	0	0	0	0	0	0	5	3	1	1	0	10
0.245	0	0	0	0	0	0	0	0	1	1	4	1	2	0	9
0.255	0	0	0	0	0	0	0	0	0	0	2	1	1	2	6
0.265	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
0.275	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2
0.285	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2
0.295	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
0.305	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
0.315	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1

Table 23. The otolith weight-age key for female *L. vitta* with otolith weight (g) in the left column and age (years) in the top row.

	Age														
ot.wt	0	1	2	3	4	5	6	7	8	9	10	11	12	13	total
0.015	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
0.025	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
0.035	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
0.045	0	1	1	0	0	0	0	0	0	0	0	0	0	0	2
0.055	0	3	1	0	0	0	0	0	0	0	0	0	0	0	4
0.065	0	4	2	0	0	0	0	0	0	0	0	0	0	0	6
0.075	0	5	5	1	0	0	0	0	0	0	0	0	0	0	11
0.085	0	4	11	0	0	0	0	0	0	0	0	0	0	0	15
0.095	0	5	24	4	0	0	0	0	0	0	0	0	0	0	33
0.105	0	4	34	15	4	0	0	0	0	0	0	0	0	0	57
0.115	0	0	17	29	5	0	0	0	0	0	0	0	0	0	51
0.125	0	0	5	33	10	1	0	0	0	0	0	0	0	0	49
0.135	0	0	3	39	42	9	0	0	0	0	0	0	0	0	93
0.145	0	0	1	22	48	16	2	0	0	0	0	0	0	0	89
0.155	0	0	1	17	34	17	9	0	0	0	0	0	0	0	78
0.165	0	0	0	2	23	25	7	2	0	0	0	0	0	0	59
0.175	0	0	0	0	6	24	14	3	1	0	0	0	0	0	48
0.185	1	0	0	0	3	10	17	6	3	1	0	0	0	0	41
0.195	0	0	0	0	0	6	12	18	12	1	0	0	0	0	49
0.205	0	0	0	0	1	1	8	17	19	4	5	0	0	0	55
0.215	0	0	0	0	0	1	8	11	17	19	3	0	0	0	59
0.225	0	0	0	0	0	1	0	6	13	12	7	1	0	0	40
0.235	0	0	0	0	0	0	0	8	12	8	6	3	0	0	37
0.245	0	0	0	0	0	0	0	2	9	10	5	2	2	1	31
0.255	0	0	0	0	0	0	0	0	0	2	4	4	2	0	12
0.265	0	0	0	0	0	0	0	1	0	2	4	1	0	1	9
0.275	0	0	0	0	0	0	0	0	0	2	0	1	2	0	5
0.285	0	0	0	0	0	0	0	0	0	1	2	1	0	0	4
0.295	0	0	0	0	0	0	0	0	1	0	0	0	1	1	3
0.305	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
0.315	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1

Table 24. Age frequency for *L. vitta.* in females in west and east Pilbara (F W and F E) and males in the west and east (M W and M E) from commercial vessels for 1996/7 and 1998.

	age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	total
F W	1996/7	2	15	56	104	114	72	40	54	49	22	19	6	3	1	557
F W	1998	0.1	5.4	32.2	47.3	57.4	36.9	17.3	17.6	12.1	8.6	6.6	2.2	3.0	0.3	247
F E	1996/7	2	23	51	36	22	24	26	27	19	18	14	4	4	2	273
F E	1998	0.3	5.9	32.6	55.5	49.0	31.0	16.4	21.0	20.7	15.4	11.7	4.2	3.3	2.0	269
M W	1996/7	1	16	59	116	134	85	53	45	44	29	12	5	2	0	426
M W	1998	0.39	3.04	30.3	54.1	43.9	31.2	19.6	11.2	11.3	8.53	5.48	2.34	1.25	1.48	224
M E	1996/7	1	10	46	46	43	26	24	29	43	33	24	8	5	4	342
M E	1998	0.37	4.4	34.47	48.7	42	30.2	22.2	18.3	21.3	17.4	8.82	3.73	1.82	1.37	255

Catch curves for *L vitta.* in west and east Pilbara for 1996-97 and also for 1998 are shown in Figure 45 for females and Figure 46 for males. The estimate of total mortality from the catch curve showed mortality levels considerably higher in the west Pilbara where fishing effort was high (Z =0.47 in 1996-97 and 0.47 in 1998 for females and Z = 0.48 and 0.41 for males) than in the east (Z = 0.30 and 0.31 for females and 0.22 and 0.35 for males) where effort is lower. The mean total mortality in the east Pilbara (Z = 0.30) is expected to be an over-estimate of natural mortality as there was some fishing in the east Pilbara from 1995 to 1998. The difference between the mean total mortality in the west and the east is an under-estimate of the fishing mortality for this species in the west (F = 0.47 - 0.30 = 0.17)

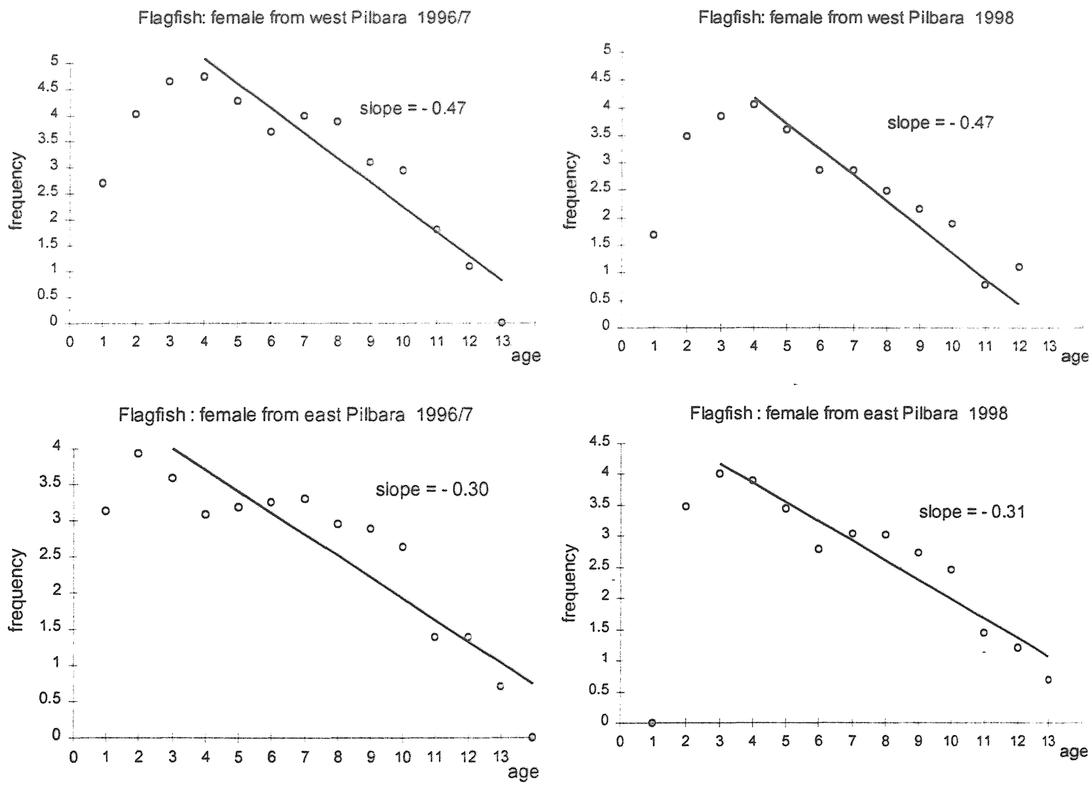
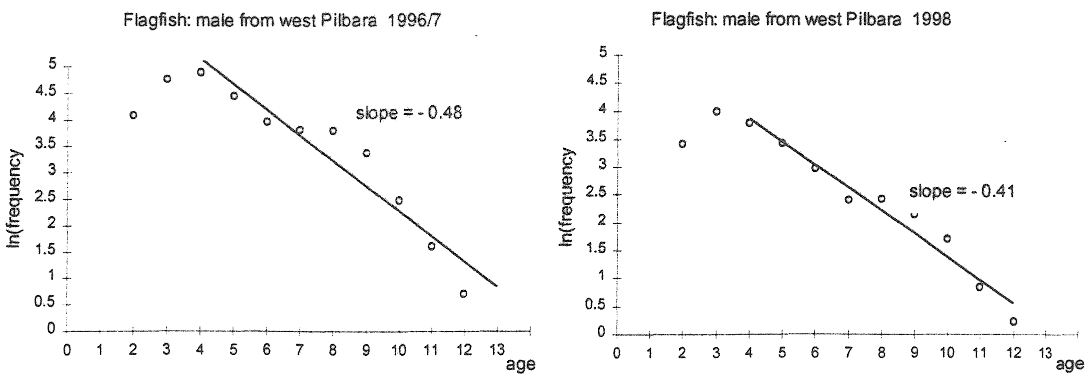


Figure 45. Catch curve and total mortality estimates (- slope) for female *L. vitta* from west and east Pilbara in 1996-97 and in 1998.



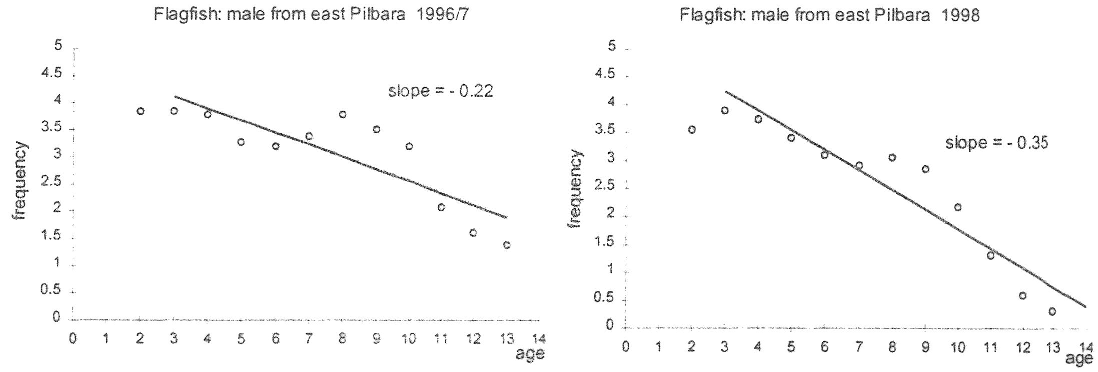


Figure 46. Catch curve and total mortality estimates (- slope) for male *L. vitta* from west and east Pilbara in 1996-97 and in 1998.

The age structures for *L. vitta* in areas 1 to 5 of the Pilbara trawl fishery are shown in Table 25 and illustrated in Figure 47. There appears to be little change in the age structure over time.

Table 25. Age structure for *L. vitta* in areas 1 to 5 of the Pilbara trawl fishery from commercial vessels for 1996 to 1998.

	age	1	2	3	4	5	6	7	8	9	10	11	12	13	total
1996	1	0	31	49	59	33	26	5	5	5	2	2	1	0	218
1996	2	0	6	22	40	21	13	2	2	6	4	0	0	0	116
1996	3	0	12	22	18	11	10	11	3	2	2	0	0	0	91
1997	1	1	22	56	49	46	31	18	7	9	2	0	0	0	241
1997	2	0	7	24	57	32	34	18	10	1	0	2	1	0	186
1997	3	1	11	56	79	37	28	22	19	8	7	5	2	1	276
1997	4	1	12	39	37	46	54	24	13	7	5	2	1	0	241
1997	5	0	40	72	57	47	48	32	23	15	14	6	0	1	355
1998	1	0	12	59	90	80	59	42	24	16	11	4	1	0	397
1998	2														0
1998	3	0	2	16	25	20	16	12	7	4	4	2	0	0	108
1998	4	1	11	56	92	85	80	70	51	43	20	7	2	0	519
1998	5	0	9	42	58	44	28	19	12	9	11	2	0	0	234

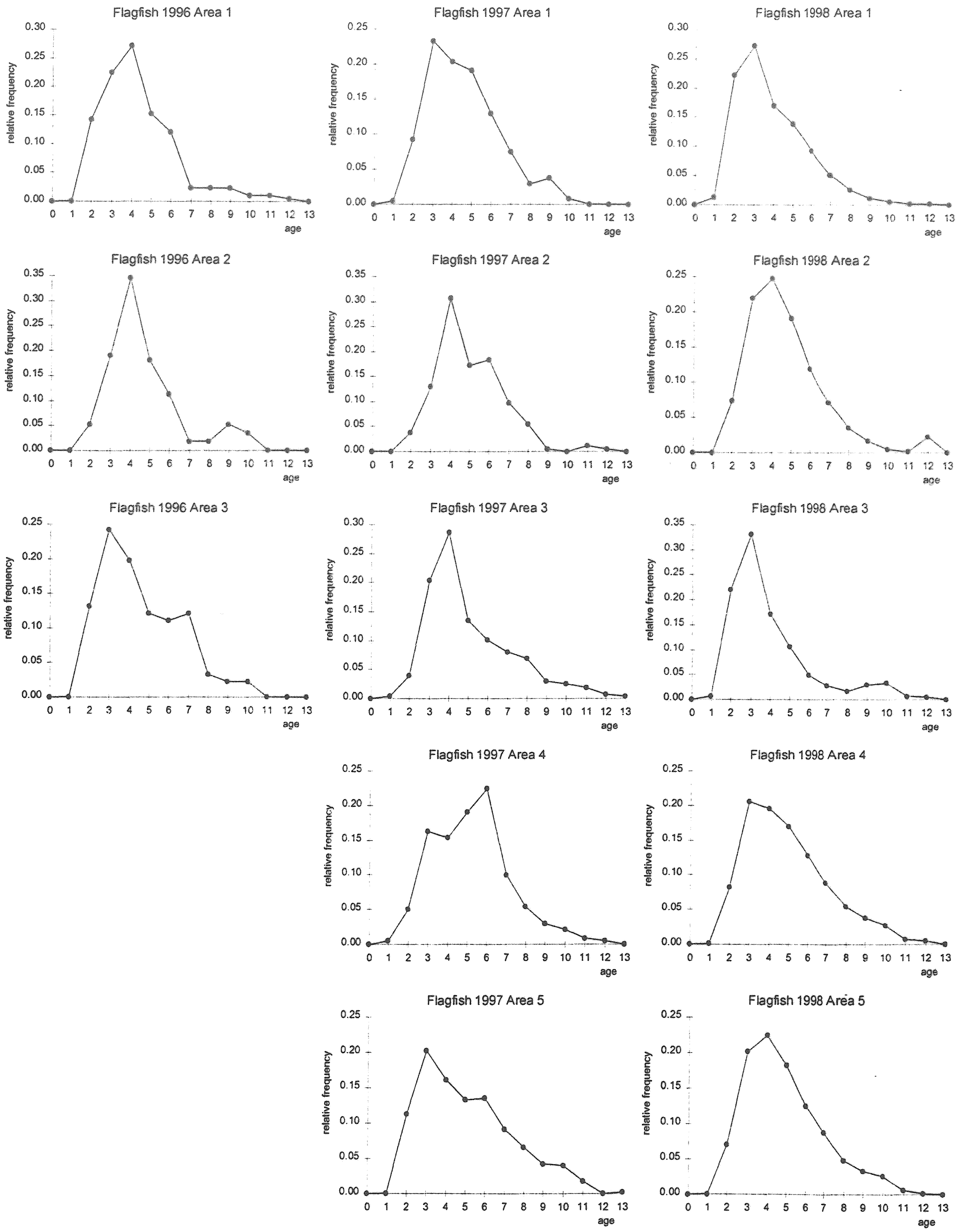


Figure 47. The relative frequency distribution of ages for *L. vitta* in areas 1 to 5 of the Pilbara trawl fishery. The ages are derived from sectioned otoliths collected during 1996 and 1997 and from otolith weights collected in 1998.

5.4.5 *Nemipterus furcosus* (rosy threadfin bream)

The plots of age vs otolith weight (Figure 48) illustrate the large variation in otolith weight for this species and otolith weight explained less variance (43%) for this species than for *L. vitta* (84%) and *L.* sp. (75%). There was no difference between the slopes of the linear relationship between sites for female *N. furcosus* ($F = 1.19$, $n=859$, $P=0.30$), but the intercepts were different ($F=43.0$, $n=859$, $P=0.001$). For males there was no significant differences between the slopes between sites "west" and "east ($F = 0.09$, $n=853$, $P=0.91$), but there was a significant difference between the intercepts ($F=34.4$, $n=853$, $P < 0.001$). The difference between intercepts explained only 4% of the sum of squares, and as there was no practical difference between the predicted age for male fish between the west and the east, data were pooled.

There was a significant difference between the slopes of the of the regression lines between females and males ($F = 3.84$, $n = 1713$, $P = 0.05$) and the intercepts ($F = 17.35$, $n = 1713$, $P =< 0.001$) and thus data were not pooled over the sexes. The slopes of the regression lines is greater for male and female indicating slightly more rapid growth in otolith weight in males than females.

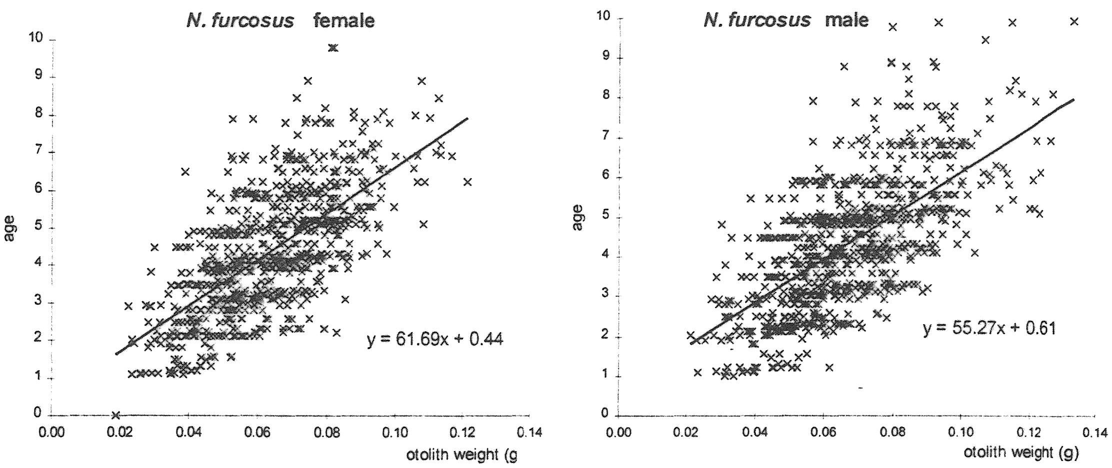


Figure 48. Otolith weight and age for female and male *N. furcosus* with fitted lines.

For *N.* furcosus, the linear relationship between age and otolith weight is

$age = 35.55 \cdot otolith\ weight - 1.97$ for females and

$age = 35.55 \cdot otolith\ weight - 1.97$ for males.

The *N. furcosus* age and otolith weight data were pooled on area and otolith weight-age keys were constructed for each sex for the second group of data from 1996-97. The observed ages (from reading sectioned otoliths) and the predicted ages (from otoliths and an otolith weight-age key) for females and males are illustrated in Figure 49.

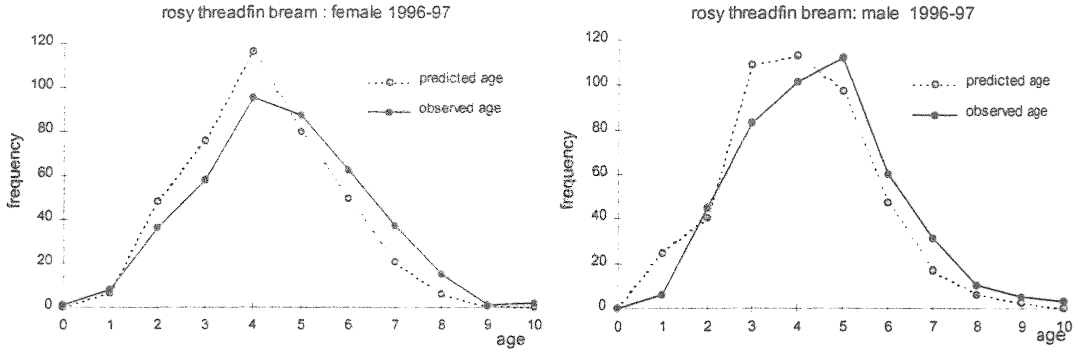


Figure 49. Frequency distribution of ages for *N. furcosus* from otoliths in the latter group collected in 1996/7. The observed age is from sectioned otoliths and the predicted age from otolith weight.

A Chi-square test determined that there was no significant difference between the observed and predicted age distributions for female nor for male *N. furcosus*.

Female $\chi^2 = 16.8$ which is less than $\chi^2_{0.05,8} = 16.9$

Male $\chi^2 = 13.6$ which is less than $\chi^2_{0.05,7} = 14.1$

An otolith weight-age key, pooled on area, was generated for each sex for all the 1996-97 data (Table 26 for females and Table 27 for males). The age frequency distributions for each sex in west and east Pilbara for the 1996-97 (using sectioned otoliths) and for the 1998 (using the otolith weight-age keys are shown in Table 28.

Table 26. The otolith weight-age key for female *N. furcosus* with otolith weight (g) in the left column and age (years) in the top row.

	Age										
ot.wt	1	2	3	4	5	6	7	8	9	10	total
0.017	1	0	0	0	0	0	0	0	0	0	1
0.021	0	1	0	0	0	0	0	0	0	0	1
0.025	0	1	1	1	0	0	0	0	0	0	3
0.029	0	2	3	1	0	0	0	0	0	0	6
0.033	0	2	6	5	1	0	0	0	0	0	14
0.037	0	4	10	2	0	1	0	0	0	0	17
0.041	0	5	12	4	5	2	0	0	0	0	28
0.045	0	3	10	9	10	5	1	0	0	0	38
0.049	0	0	12	18	21	7	1	0	0	0	59
0.053	0	0	9	17	28	14	2	1	0	0	71
0.057	0	0	7	27	25	12	9	5	1	0	86
0.061	0	0	5	30	16	13	13	0	1	0	78
0.065	0	0	0	7	25	12	9	2	0	0	55
0.069	0	0	1	14	24	15	8	4	0	0	66
0.073	0	0	0	7	16	17	16	10	1	0	67
0.077	0	0	0	4	16	16	13	7	3	2	61
0.081	0	0	0	2	9	32	12	4	3	0	62
0.085	0	0	0	3	7	20	15	4	2	2	53
0.089	0	0	0	0	4	6	8	8	2	0	28
0.093	0	0	0	0	0	5	7	9	1	0	22
0.097	0	0	0	0	0	3	10	3	3	0	19
0.101	0	0	0	0	0	1	1	3	1	0	6
0.105	0	0	0	0	0	1	1	2	0	0	4
0.109	0	0	0	0	0	1	2	2	1	1	7
0.113	0	0	0	0	0	0	0	2	1	0	3
0.117	0	0	0	0	0	0	0	0	1	1	2
0.121	0	0	0	0	0	0	0	0	1	1	2
0.125	0	0	0	0	0	0	0	0	1	1	2
0.129	0	0	0	0	0	0	0	0	0	1	1
0.133	0	0	0	0	0	0	0	0	0	0	0
0.137	0	0	0	0	0	0	0	0	0	0	0

Table 27. The otolith weight-age key for male *N. furcosus* with otolith weight (g) in the left column and age (years) in the top row.

	Age											
ot.wt	0	1	2	3	4	5	6	7	8	9	10	freq
0.017	0	1	0	0	0	0	0	0	0	0	0	1
0.021	0	1	0	0	0	0	0	0	0	0	0	1
0.025	0	2	2	0	0	0	0	0	0	0	0	4
0.029	0	1	2	1	0	0	0	0	0	0	0	4
0.033	0	3	2	3	2	1	0	0	0	0	0	11
0.037	0	3	4	7	0	1	0	0	0	0	0	15
0.041	0	6	5	4	2	0	0	0	0	0	0	17
0.045	0	2	11	8	3	1	1	0	0	0	0	26
0.049	0	1	19	8	10	9	1	0	0	0	0	48
0.053	0	2	10	15	17	13	4	0	0	0	0	61
0.057	0	0	6	22	16	12	6	0	0	0	0	62
0.061	0	0	6	25	19	19	7	1	1	0	0	78
0.065	0	0	2	13	32	23	5	1	0	0	0	76
0.069	0	0	0	16	20	17	8	1	1	0	0	63
0.073	0	0	1	16	17	22	6	3	1	0	0	66
0.077	0	0	0	5	18	19	14	3	1	0	0	60
0.081	0	0	0	8	15	22	10	4	2	0	0	61
0.085	0	0	0	3	10	10	10	7	3	1	0	44
0.089	0	0	0	2	9	13	8	5	1	1	0	39
0.093	0	0	0	0	5	11	8	5	1	1	0	31
0.097	0	0	0	0	1	10	7	7	1	1	0	27
0.101	0	0	0	0	0	6	5	9	4	0	0	24
0.105	0	0	0	0	1	1	3	4	1	0	0	10
0.109	0	0	0	0	0	0	3	1	1	0	0	5
0.113	0	0	0	0	0	0	3	2	3	1	0	9
0.117	0	0	0	0	0	0	1	1	1	1	0	4
0.121	0	0	0	0	0	0	0	2	1	1	0	4
0.125	0	0	0	0	0	0	2	1	1	1	0	5
0.129	0	0	0	0	0	0	0	0	1	1	1	3
0.133	0	0	0	0	0	0	0	0	0	1	1	2
0.137	0	0	0	0	0	0	0	0	0	1	1	2

Table 28. Age frequency for *N. furcosus* in females in west and east Pilbara (F W and F E) and males in the west and east (M W and M E) from commercial vessels for 1996-97 and 1998.

	age	0	1	2	3	4	5	6	7	8	9	10	total
F W	1996/7	0	17	56	114	138	130	85	37	12	2	1	592
F W	1998	0	0.5	7.0	28.6	49.4	55.4	47.7	34.8	13.0	5.0	0.5	242
F E	1996/7	1	3	18	36	70	54	43	32	8	2	1	268
F E	1998	0	3.6	9.7	35.3	52.3	45.9	37.1	18.4	5.5	1.8	0.5	210
M W	1996/7	0	18	36	92	117	123	69	36	14	4	2	511
M W	1998	0	0.9	10.8	30.9	50.3	60	43.2	27.9	13.5	5.3	0.3	243
M E	1996/7	0	3	33	64	81	92	43	16	7	3	3	345
M E	1998	0	3.4	11.0	44.9	66.8	74.4	39.6	19.2	7.1	2.2	0.5	269

Catch curves for *N. furcosus* in the west and east Pilbara for 1996-97 and also for 1998 are shown for females in Figure 50 and males in Figure 51. The estimate of total mortality from the catch curve showed mortality levels slightly higher in the west Pilbara where fishing effort is higher (Z = 0.90, 0.89 for females and Z = 0.86 and 0.94 for males) than in the east (Z = 0.75 and 0.80 for females and 0.74 for males) where effort is lower. In the east Pilbara in 1998, the total mortality of 0.98 is unexpectedly high. The mean total mortality in the east Pilbara, Z = 0.82 is expected to be an slight over-estimate of natural mortality as there was some fishing in the east Pilbara from 1995 to 1998. The difference between the mean total mortality in the west and east is an under-estimate of the fishing mortality for the species in the west (F = 0.90 - 0.82 = 0.08)

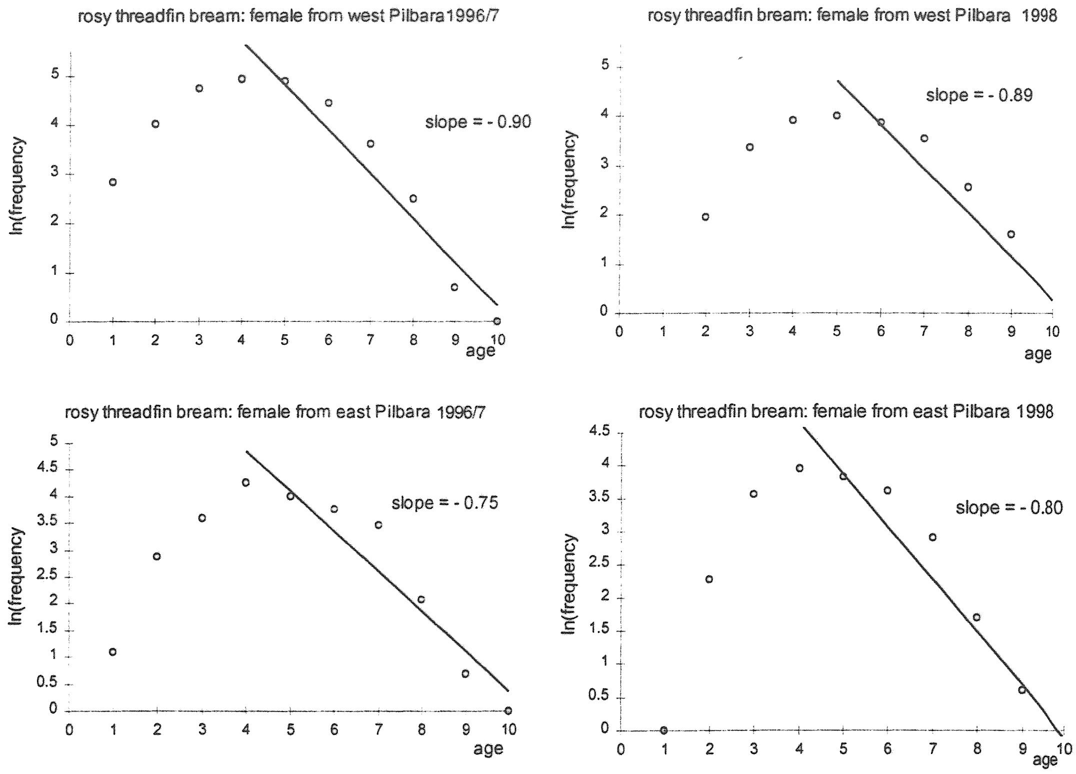


Figure 50. Catch curve and total mortality estimates (- slope) for female *N. furcosus* from west and east Pilbara in 1996/7 and in 1998.

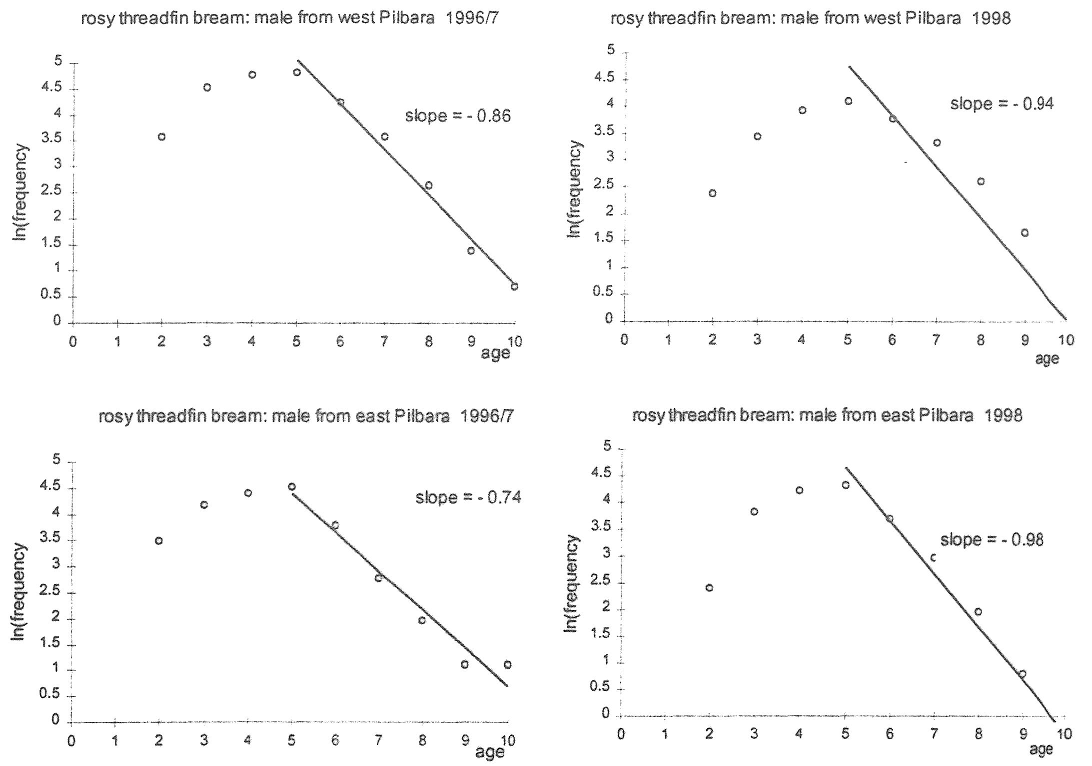


Figure 51. Catch curve and total mortality estimates (- slope) for male *N furcosus.* from west and east Pilbara in 1996/7 and in 1998.

The age structure for *N. furcosus* in areas 1 to 5 of the Pilbara trawl fishery are shown in Table 29 and illustrated in Figure 52. There is no apparent change in the age structure over time or between areas.

Table 29. Age structure for *N. furcosus* in areas 1 to 5 of the Pilbara trawl fishery from commercial vessels for 1996 to 1998.

	age	0	1	2	3	4	5	6	7	8	9	10	total
1996	1	0	5	18	32	42	46	19	9	5	2	0	178
1996	2	0	12	13	20	35	43	22	9	4	0	1	159
1996	3	0	7	12	22	30	15	6	1	0	0	0	93
1997	1	0	1	17	44	46	65	49	21	3	0	0	246
1997	2	0	3	10	42	44	28	7	2	1	0	0	137
1997	3	0	7	22	46	57	56	51	30	13	4	2	288
1997	4	0	3	28	48	66	66	48	24	11	4	3	301
1997	5	1	3	24	52	83	80	38	24	4	1	1	311
1998	1	0	1	9	40	72	91	81	58	26	9	3	389
1998	2	0	0	4	12	18	17	11	6	3	0	0	72
1998	3	0	0	1	3	6	6	4	2	0	0	0	24
1998	4	0	6	14	49	71	71	45	22	8	3	1	289
1998	5	0	1	7	32	49	51	33	17	5	1	0	197

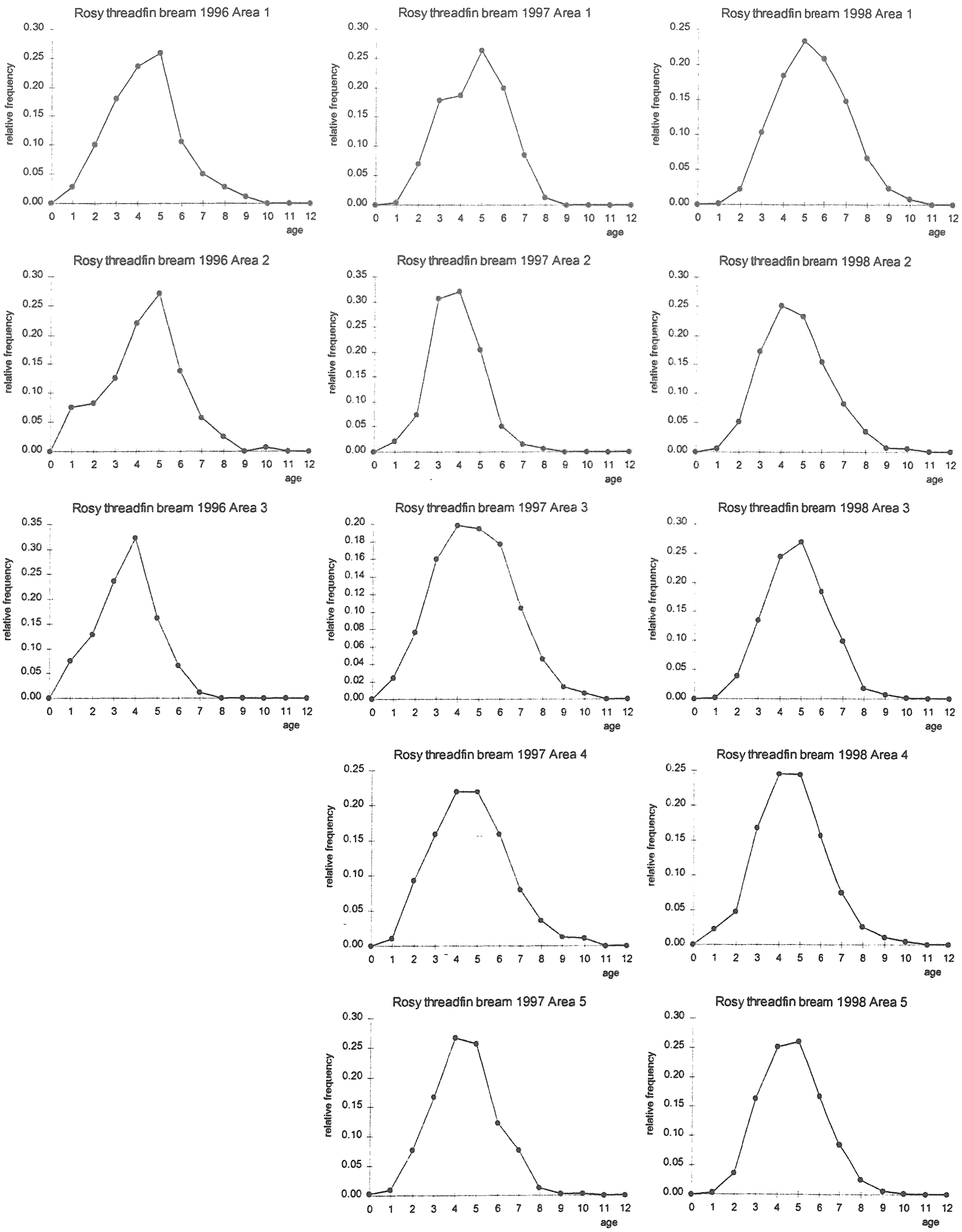


Figure 52. The relative frequency distribution of ages for *N. furcosus* in areas 1 to 5 of the Pilbara trawl fishery. The ages are derived from sectioned otoliths collected during 1996 and 1997 and from otolith weights collected in 1998.

5.5 Population modeling

5.5.1 *Lutjanus sebae* (Red emperor)

The results of the population modeling of red emperor (Stephenson in prep(2)) showed that the catch rate of red emperor declined in areas 1, 2, and 3 from 1994 to 1999, especially in area 1 where the effort was highest. The model indicated that the 1998 spawning biomass was 17%, 21% and 22% of the 1989 level in areas 1, 2, and 3 respectively and by the end of 2003 it is expected to be 15%, 22% and 41% of the 1989 level. The spawning biomass combined for areas 1 to 3 was predicted by the model to be 20% of the 1989 level in 1998 and rising to 26% by the end of 2003. The biological reference point of 25% of the 1989 level indicates that the over - exploitation could be reversed by the end of 2003.

The mortality model (Stephenson and Dunk 1995), when updated for red emperor in the west Pilbara (116°E to 118°E) using recent effort and catch rate data, indicated that the fishing mortality of red emperor had been reduced from $F = 0.26$ in 1996 to 0.09 in 1999 when calculated with nominal effort. When calculated with a 7.5% efficiency increase after 1994, the fishing mortality in 1999 was slightly above 0.1. These results are similar to those from the catch curves in 1996/97, $Z = 0.25$.

5.5.2 *Lethrinus* sp. (Blue-spot emperor)

The results of the population modeling of blue spot emperor (Stephenson in prep(2)) showed that catch rate of blue spot emperor declined in area 1 in 1997, 1998 and 1999 but was stable in areas 2 and 3. The model indicated that the 1998 spawning biomass was 71%, 74% and 74% of the 1989 level in area 1, 2, and 3 and by the end of 2003 it is expected to be 73%, 85% and 90% of the 1989 level. The spawning biomass combined for areas 1 to 3 was predicted by the model to be 72% of the 1989 level in 1998 and rising to 79% by the end of 2003.

5.6 General Discussion

5.6.1 Biological studies

This study found very different length frequency distributions for the five species studies due to differential growth rates for red emperor, blue spot emperor, flagfish, rosy threadfin bream, and due to sex change for Rankin cod. The age frequency distribution of Rankin cod expectedly showed the older fish being predominantly males but for the other five species the age frequency distributions of males and females were similar. These results indicate that the weight of females is considerably less than males of the same age and it is important to include sex differentiation into population modeling of these species.

The legal size of red emperor (total length = 410 mm) is less than the size at 50% maturity (total length = 419). The small discrepancy between the current legal size of red emperor and the length at 50% maturity does not warrant changes to the current legal size for red emepror. The legal size of blue spot emperor in Western Australia (total length =280 mm) is slightly larger than the size at 50% maturity (total length = 274). The current legal size of blue spot emperor is therefore appropriate.

The peak spawning period of the three species in this study is around August to October. There are no increased trap or trawl catches and catch rates of these species at this time of year which are sometimes indicative of targeting spawning aggregations.

5.6.2 Natural mortality

For the small species, the total mortality estimate, which is the negative of the slope of the catch curve, was lower in the east Pilbara than the in the west. The trawl fishery has only operated in the east Pilbara in the last few years and the trap fishery does not target these species. The natural mortality estimate from the east Pilbara catch curve and the estimate from Hoenig (1983) indicated similar results for flagfish, the former being higher for blue spot emperor, and much higher for rosy threadfin bream. For red emperor and Rankin cod, the mortality from the catch curve was twice that from longevity. Either the natural mortality is considerably higher than expected from longevity or that the trap fishery in the east Pilbara has had considerable impact on the stocks of these species, which is unlikely for threadfin bream and blue spot emperor

5.6.3 Otolith weight

An otolith weight-age key was found to be an accurate and economical method of assigning ages to the short lived species. For longer lived species, the large number of age classes and the smaller samples makes this method more problematic.

5.6.4 Age structure

The catch curves indicated higher total mortality in the west of the fishery than the east for blue spot emperor and flagfish but the overall results were inconsistent, indicating that the slope of the catch curve gives some indication of fishing and natural mortality but should be used in conjunction with other estimates of mortality. The values of natural mortality determined from longevity estimates were lower than the values suggested by the catch curve for red emperor and Rankin cod in the little trawled east Pilbara. The extensive trap operations in the east could well account for high total mortalities indicated by the catch curves for red emperor and Rankin cod. The trap catch makes up 30% and 50% of the Pilbara red emperor and Rankin cod catch respectively.

The age structure of blue spot emperor appears to have been affected by fishing effort with less fish in the larger age classes. With the high effort, large catches, and declining catch rate of blue spot emperor in the west of the fishery, otoliths collected from market samples could prove to be a cost efficient method of monitoring the age structure of this species in the future.

There was considerable change in the age structure of red emperor in area 1 with all age classes above 16 disappearing in 1998 but little change in the other areas. Rankin cod shows changes in the age structure with few older fish in the west of the fishery, especially in 1998. It is important that determination of the age structure of red emperor and Rankin cod be conducted in the future (in about 3-4 years) to ensure that the age structure is not further altered due to fishing in areas 2, 4, and 5 as has occurred in area 1. For red emperor and Rankin cod the small catches, scattered distribution, increased time necessary to measure the fish and remove otoliths, and high value would make market sampling impractical and on vessel sampling a more suitable proposition.

These age structures of each species in area 1 to 3 of the trawl fishery formed an important component of the age-structured model. The model determines parameter estimates consistent with the catch rates, which are a measure of abundance, and the age structure as an indicator of the rate at which each age class is being depleted by fishing. For example for red emperor, in area 1, the model will estimate parameters consistent with the biomass in 1999 being one quarter of that in 1994 (the catch rate is one quarter) and all fish older than 16 years disappearing from the stock.

5.6.5 Population modeling

The age structured model indicated that the effort reduction and redistribution in the management plan of 1998 and the revised plan of 1999 would probably be effective in causing a stock recovery of red emperor in the next few years provided there are not significant efficiency increases. The blue spot emperor stock appears not to be over-exploited in the fishery as a whole although there are decreasing catch rates and some local depletion in area 1. The blue spot emperor stock appears not to be over - exploited in the west of the fishery as the spawning biomass is >70% of the 1989 level.

The age structured model developed for this project and the fishing mortality model developed in the previous project (Stephenson & Dunk 1996) will be re-run annually incorporating new catch and catch rate data.

5.6.6 Future research

The present FRDC project has set the groundwork for monitoring of the Pilbara trawl fishery. Continuation of the present logbook system to establish the spatial distribution and the VMS system to monitor effort will provide input for annual evaluation of the state of the stock of red emperor and blue spot emperor using the age structured model. Collection of otoliths at regular intervals, if resources were available, would enable incorporation of age structure.

The opening of area 3 after 4-5 years of closure (with closure of another area) and collection of catch, effort and age structure data would enable evaluation of recovery of the stocks due to the closure.

6 CONCLUSIONS

For the five species studied, there were size related differences in the sex ratio, males generally predominating in the large fish. The sex ratio in age classes was 1:1 for red emperor, flagfish, threadfin bream, and blue spot emperor but Rankin cod males predominated in the older fish. For Rankin cod this is due to protogynous hermaphroditism (fish mature as females and later change to males). For the two lutjanid species, red emperor and flagfish, the predominance of males in the large fish is due to different growth rates, as females expend more resources on reproduction than males. Some Lethrinid species appear to change sex, but this could not be determined for blue spot emperor due to the difficulty in finding samples of fish around the size at sexual maturity. It is unknown if threadfin bream change sex.

The size at which 50% of the females are sexually mature was

391 mm caudal fork length (391 mm total length) for Rankin cod

392 mm caudal fork length (419 mm total length) for red emperor

240 mm caudal fork length (274 mm total length) for red emperor

The legal total length of 410 mm for red emperor is slightly low and 280 mm for blue spot emperor is appropriate.

The age structure in 1996, 1997 of five species was determined from ageing sectioned otoliths. The 1998 age structure was determined using otolith weights for the three short lived species flagfish, blue spot emperor, and threadfin bream, and from sectioned otoliths for the long lived species red emperor and Rankin cod. The use of otolith weight proved to be a cost effective alternative to counting growth rings on sectioned otoliths for short lived species.

An age structured model was developed incorporating

biological information

age structure data

catch and catch rates from trawl logbook data from 1993 to 1998.

The agreed limit reference point was 25% of 1989 spawning biomass. In 1997 and 1998, the model estimate of the spawning biomass of red emperor was below the limit reference point. Effort reduction and area closures are expected to result in the recovery of the red emperor stock in the next 5 years. The spawning biomass of blue spot emperor was declining in the west of the fishery, but is expected to stabalise at a level well above the limit level. Theadfin bream and flagfish appear to under-exploited.

The annual addition of catch and catch rate data to the age structured model for red emperor and blue spot emperor will enable the continuation of annual stock assessments in the Pilbara trawl fishery and adjustments to the management arrangements if necessary.

There is scope for further work to improve the stock assessments of the key commercial species in the Pilbara trawl fishery. For example, more information on fish migration to account for movements between management areas and information on habitat distribution and recovery to enable better evaluation of the role of area closures.

7 BENEFITS

The beneficiaries of this research are the commercial fishers on Australia's North West Shelf, the sustainability of their fishery being the primary benefit. These benefits and beneficiaries are the same as those in the original application.

8 FURTHER DEVELOPMENT

The results of this study will be presented to fishers and incorporated in management arrangements for the Pilbara trawl fishery.

9 INTELLECTUAL PROPERTY

No saleable intellectual property is expected from this project.

10 STAFF

Staff employed by the project:
Mr Peter Stephenson
Mr Jason Mant
Mr Iain Dunk
Mrs Jan St Quintin
Mrs Debbie Stephenson

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Appendix 1.

Constants for the weight-length relationship ln (weight) = d + ln (length) * e with 95% confidence intervals (weight in kg and length in mm). Number of observations, n, and a the coefficient in the relationship $Weight = a * Length^{e}$.

	Both sexes			
Species	n	d	e	a
red emperor	177	-18.154 ± 0.1874	3.0841 ± 0.0306	1.312×10^{-8}
blue-spot emperor	318	-18.173 ± 0.1980	3.0881 ± 0.0353	1.287×10^{-8}
rankin cod	132	-18.520 ± 0.4767	3.0924 ± 0.0754	0.932×10^{-8}
flagfish	334	-18.258 ± 0.2360	3.0645 ± 0.0424	1.185×10^{-8}
rosy threadfin bream	328	-17.055 ± 0.3123	2.8826 ± 0.0562	3.397×10^{-8}