FISHERIES BIOLOGY OF EMPERORS (LETHRINIDAE) IN NORTH-WEST AUSTRALIAN COASTAL WATERS

FRDC PROJECT 89/20

FINAL REPORT DECEMBER 30 1993

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SUMMARY

Lethrinid fishes are major components of multi-species demersal fisheries on the continental shelves off the north coast of Western Australia and the northern half of the west coast. There are a number of important species of lethrinids but reports in the literature that *Lethrinus choerorynchus* is the same species as *L. nebulosus* or *L.laticaudis* are shown to be erroneous.

While the adult and juvenile lethrinids are not highly mobile, the larvae have the potential to be carried great distances by currents. Larval mixing between localities is sufficient to maintain genetic homogeneity across the whole Western Australian range of these species. the conclusion from the combined results of our genetic, tagging and otolith microchemistry research is that the management zones in WA are appropriately sized for management of growth overfishing independently in each zone. There may, however, be interdependence between zones in a reproductive sense.

Validation of age determination by tetracycline tagging and comparison of age estimates, between readers and between methods of reading, indicated that ageing using either whole or sectioned otoliths is possible, though with low precision and possibly mediocre accuracy. Using sectioned otoliths, the growth of male and female *Lethrinus nebulosus* was found to be similar but growth varied between regions. Age-structure of males and females was also similar, giving no indication of the widespread sex reversal in adults which was suggested may occur from the existence of protogyny in other lethrinids. Sex reversal may still occur in juveniles. Age structure of populations did vary among regions, with areas that were unexploited until recently having fish up to an estimated 27 years old. Natural mortality was estimated from catch-curves and longevity methods as $M = 0.155$. Fishing mortality in the region of NW Cape estimated from a catch-curve was $F = 0.18$.

L. nebulosus was found to be a spring-summer spawner on the west coast but spawning around NW Cape is a month or two in advance of spawning at the southern end of the species range. Relationships of gonad weight and egg diameter to fish length indicated that reproductive maturity is reached by females around 38cm in length to caudal fork.

The commercial fishery for lethrinids by Australian vessels has expanded greatly in the last decade, alongside the reduction and finally withdrawal of foreign trawling. Line fishing on the west coast is dominated by *L.miniatus,* the sweetlip or red-throat emperor. Trapping on the NW Shelf takes mainly spangled emperor *L.nebulosus*, as does the recreational line fishery in Ningaloo Marine Park. The trawl fishery currently localised off Dampier takes mainly the lesser spangled emperor *L. choerorynchus* which is also common in other areas but has been avoided in the past due to lack of markets. There is potential for greater catches of the smaller lethrinid species. Catch-rates of lethrinids in trap fisheries tend to peak around 120 kg/boat-day then fall to around 40kg over about three years. It appears that the larger species, with a strong habitat dependence, tend to aggregate on small patches of suitable habitat which are soon fished down.

There is cause for concern about the status of the stocks of the large species, *L.nebulosus* and *L. miniatus*, but not for the smaller species of lethrinids. It is possible that the larger lethrinids are the species most vulnerable to overfishing in the multi-species demersal fisheries in northern Western Australian waters. This may be related to their strong habitat dependence and a relatively small area of habitat compared to eastern Australia.

Limited access to the commercial fisheries on the north coast has been introduced as a management measure in 1992, though the west coast is likely to remain open-access. Reduced bag limits have been implemented in Ningaloo for recreational fishers and an increased minimum legal length of 41cm (formerly 28cm) has been recommended for *L. nebulosus*. This should lead to significant increases in yield per recruit and reproductive output per recruit. The most pressing need for future research on Western Australian

lethrinids is on the biology of *L. miniatus*, to determine an appropriate minimum size for that species since it will not receive any protection by limiting of fishing effort on the west coast.

This project has been timely, coinciding with the intensification and expansion of commercial fisheries on lethrinids in Western Australia. The focus of this project on the fisheries has played a large part in the introduction of management measures to some of these fisheries and in the adoption of a much-needed increase in minimum legal length for *L. nebulosus*.

Biology of Emperors (Lethrinidae) in NW Australia

Introduction

The trap fishery which developed on the NW Shelf of Australia in the mid 1980s was dominated by the family Lethrinidae or spangled emperors. Lethrinids made up 40% of the total trap and line catch and the majority of these were *Lethrinus nebulosus* (Moran et al.1988). This study of the biology of lethrinids was undertaken to provide fisheries management information.

The same species were exploited by recreational fishers, especially in Ningaloo Marine Park where *L.nebulosus* was again the main species in the catch and also by commercial fisheries on the west coast as far south as the Abrolhos and on the north coast as far east as the Kimberley. With species taken by a range of different fisheries over such a wide area, stock structure was therefore a priority for research and the methods chosen to study it were genetics, trace elements in otoliths and tagging.

There is some confusion in the taxonomic literature about the status of some lethrinid species. *Lethrinus nebulosus* and *L. choerorynchus* are major species and *L. fraenatus* a minor species in northwest Australian demersal fisheries (species names from Sainsbury et al (1985)). The FAO catalogue by Carpenter and Allen (1989) includes *L. choerorynchus* as a synonym of *L. nebulosus*; it also states that L.laticaudis has often been called *L. fraenatus* but this name is also a junior synonym of *L. nebulosus.* Allen and Swainston (1990), however, list *L. nebulosus* and *L.choerorynchus* as separate species, but state that *L. choerorynchus* is the juvenile stage of *L. laticaudis*. People who work in the fishery have no doubt that there are three separate species, and we sought to verify this genetically.

The legal minimum size in Western Australia applied to the whole of the genus *Lethrinus* and was 28 cm total length. It was thought that this may be below the optimum minimum length for management of the larger species such as *Lethrinus nebulosus*, so studies of age, growth and reproductive biology were initiated to determine the size at first capture which gave the best yield per recruit and also the size at reproductive maturity. The latter was potentially complicated because some lethrinid species had been reported to change sex so that size at maturity could be different between males and females.

The size of the lethrinid stocks and their state of exploitation were unknown so monitoring of abundance through catch per unit effort, calculated from data in fisher's monthly returns, was continued.

Interaction between the project leader and managers of the fisheries on lethrinids occurred throughout the project and results have been used in the management planning for this fishery as they became available.

STOCK STRUCTURE OF LETHRINIDS

Genetic analysis of populations of north-western Australian fish species

Allozyme variation was used to investigate the genetic structure of *Lutjanus sebae*, *Lethrinus nebulosus*, *Lethrinus choerorynchus* and *Epinephelus multinotatus*, which are major species in the demersal fishery off northwestern Australia. Samples of each species were obtained from five or six of the following locations over a distance of 2 000 km: Heywood Shoals; Lacepede Islands; Bedout Island; Lowendal Islands; Ningaloo; Shark Bay and Abrolhos Islands (Fig. 1).

The results of this study have been published (Johnson et al., 1993). Allelic variation was found at 13 to 16 loci in each species. The consistent picture to emerge is one of little genetic subdivision in all four species, with average values of F_{ST} ranging from 0.003 in *L. sebae* to 0.012 in *E. multinotatus*. Although there is statistically significant variation in allelic frequencies in three of the species, there were no clear geographical groupings of populations. With the possible exception of aldehyde oxidase in *E. multinotatus*, all heterogeneity of allelic frequencies is within the range that could easily be due to within-generation effects of selection. Thus, the allozyme data are consistent with the view that there are extensive connections of populations over large distances.

In terms of fisheries management, this is a non-result. It is a feature of genetic studies of this type that if significant differences are found between two populations, that is very powerful evidence that they are completely independent stocks. On the other hand, if no differences are found, it does not differentiate between complete mixing of the two populations on the one hand, and on the other hand a very low level of mixing which is insignificant for fisheries management purposes but sufficient to maintain the genetic similarity. Our conclusion must be that even if the other studies show little or no mixing of adult fish, there remains the possibility of mixing of larval fish between populations.

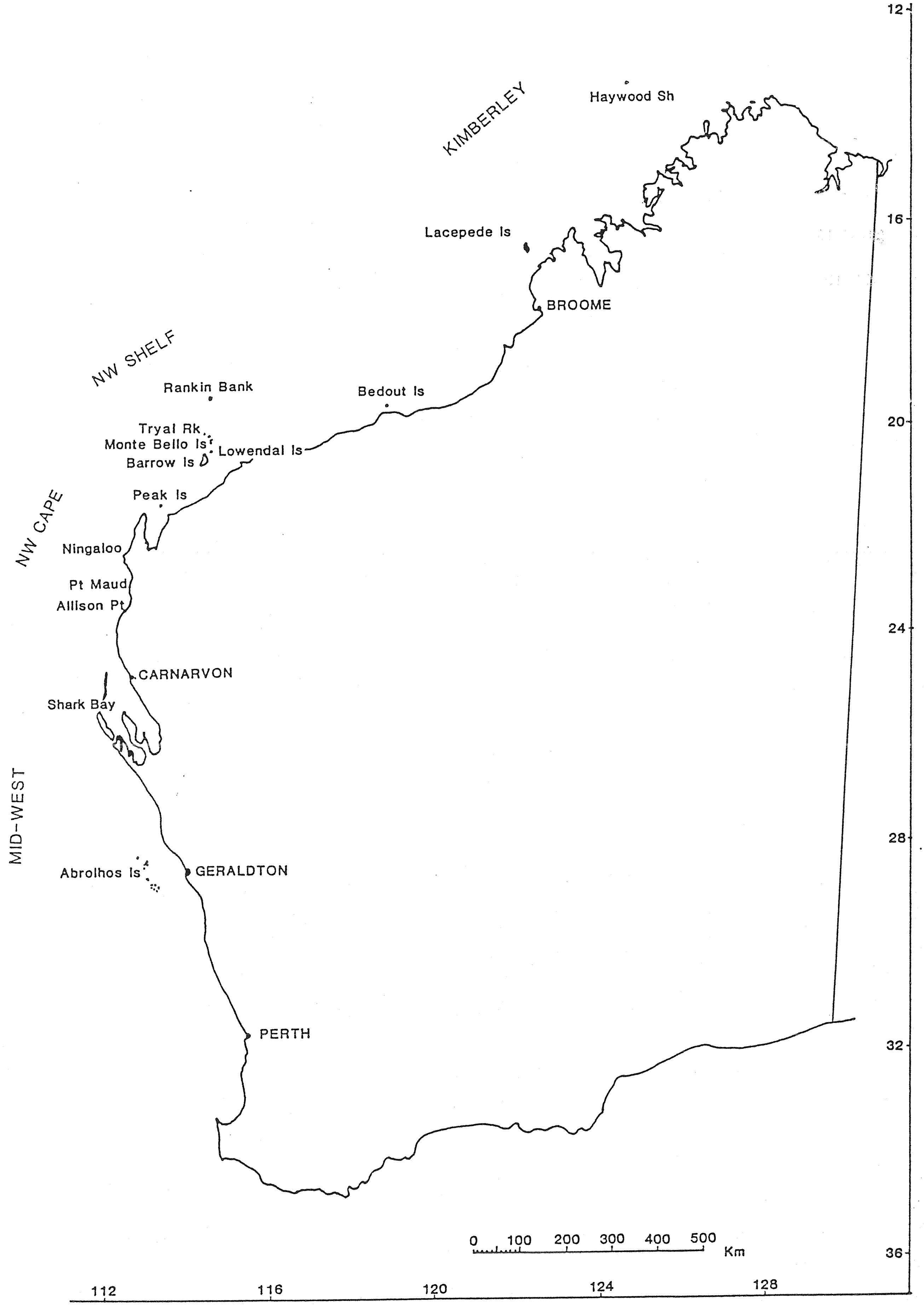


Fig. 1. A map of Western Australian waters showing regions and locations from which fish samples were collected for stock-identification and biological studies.

The electrophoretic study also confirmed that, contrary to suggestions in the literature, *Lethrinus nebulosus*, *L.choerorynchus*, and *L. laticaudis* are reproductively isolated species. Although the genetic similarities between these three species are high, in the range 0.92 to 0.95, each pair of species can be distinguished by two or three diagnostic loci.

Blue-spotted emperor *Lethrinus choerorynchus* and spangled emperor *Lethrinus nebulosus*: population discrimination by elemental analysis of sagittal otoliths

Method was as follows: 1. Sagittal otoliths removed from fish, cleaned (nylon brush and distilled water) and dried. 2. Single otolith dissolved in 10% redistilled nitric acid and analysed for B, K, Mg, Na, P, S, and Sr by ICP-AES, and for Cu, Zn, Cd, Sr, Ba and Pb by ICP-MS. 3. Results of elemental analyses subjected to statistical treatment by canonical discriminant analysis to demonstate differences in chemical composition of otoliths (if they exist) and to maximise separation based on any differences.

Blue-spotted emperor

Initially samples from three locations were analysed, *viz.* 40 fish from each of Maud Anchorage, North-West Allison and Bedout Island. More recently a group of samples from Broome has been chemically analysed, but the results of this analysis have not yet been included in the statistical treatment.

The canonical discriminant analysis was carried out, for various reasons, with a smaller number of elements than the total analysed (see figure 2). Because the concentration of some elements used in the statistical analysis varied with fish size or, more closely, with otolith weight, an adjustment of element concentration to accommodate this variation has been made before the canonical analysis was executed.

Differences based on location were demonstrated for all three sites. This was unexpected as the Maud Anchorage and NW Allison locations are only a few tens of kilometres apart. Separation was greatest though between the Bedout Island and the other two sites reflecting its geographical remoteness.

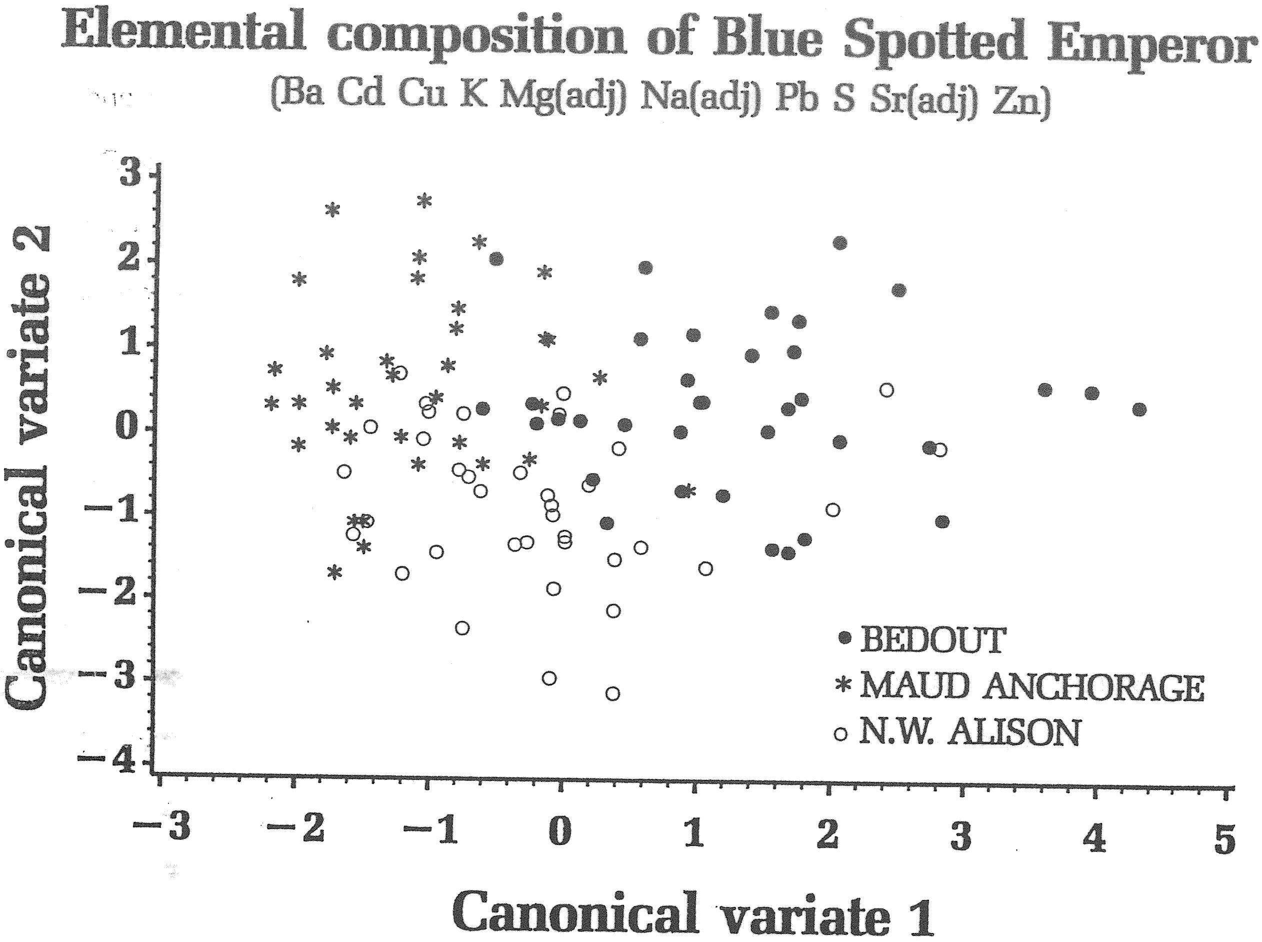


Fig. 2. Canonical Variate Analysis of the elemental composition of the otoliths of the Blue Spotted Emperor Lethrinus choerorynchus, illustrating the separation of the NW Alison sample from the other two on CV2 and the separation of the Maud Anchorage and Bedout Island samples on CV1.

Spangled emperor

Sagittal otoliths from samples of fish (30 from each location) were analysed from the following locations:

Heywood Shoal	15°20' S	124°20' E
Lowendal Is	20°40' S	115°37' E
Maud Anchorage	23°05' S	113°46' E
NW Shelf	19°40' S	116°00' E
N.W. Peak Is	21°32' S	114°27' E
N. Tryall Rocks	20°10' S	115°24' E
W.N.W. Barrow Is	20°35' S	115°12' E
Montebello Is	20°20' S	115°32' E
Abrolhos Is	27°45' S	113°23' E

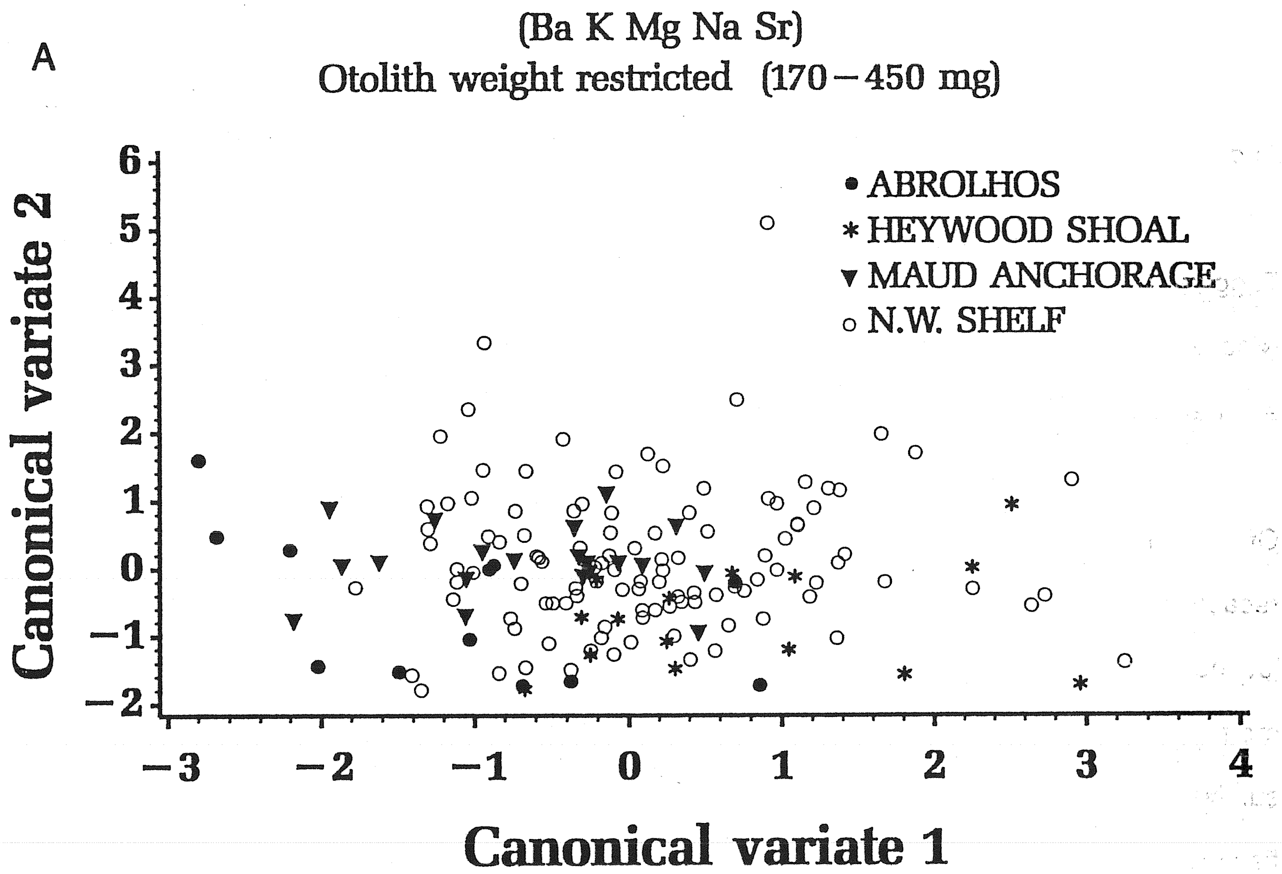
ie a cluster of locations on the NW Shelf, a remote location to the south (Abrolhos), and a remote location to the north (Heywood Shoal) were considered. Subsequently, samples from an additional northern site (Broome) were analysed but, again, these results have not yet been included in a canonical discriminant analysis.

Some elemental concentrations again showed variation with fish size/otolith weight and, because there was considerable differences in the size range of fish sampled at the various locations, this variation was accommodated in two ways in separate canonical analyses. First, the canonical variate analysis was carried out using only those otoliths within the weight range available from all sampling sites (this restricted the amount of data that was usable), and second, the analysis was performed, as for the blue-spotted emperor, using data from all sampled fish after size corrections were made for those elements requiring them.

In the first instance the central cluster of sites was treated in the canonical analysis as if it were a single location, ie three locations were considered - Abrolhos, the central cluster and Heywood Shoal. These three were separated on the scatterplot (see figure) as expected with points for the two remote locations occupying positions on either side of those of the central cluster. The scatterplot thus reflected the geographical distribution of the sampling sites.

The locations in the central cluster were then subjected to a canonical variate analysis with each location (including the not so central Maud Anchorage) considered as a separate site. It was expected that there would be no significant difference between these locations (with the possible exception of Maud Anchorage), ie fish were expected to move and mix freely through the region covered by the central locations. However, the results indicated that although the chemical characteristics of the otoliths were similar for these sites (see figure - means and 95% confidence intervals about the means only are shown) there was enough separation in some cases to indicate that mixing was considerably more limited than was expected. This notion was reinforced by the boron analyses which showed major differences location to location. Results for boron were not included in the original canonical analysis because of uncertainty about their validity. They have subsequently been shown to be correct and the differences they indicate appear to be real.

A



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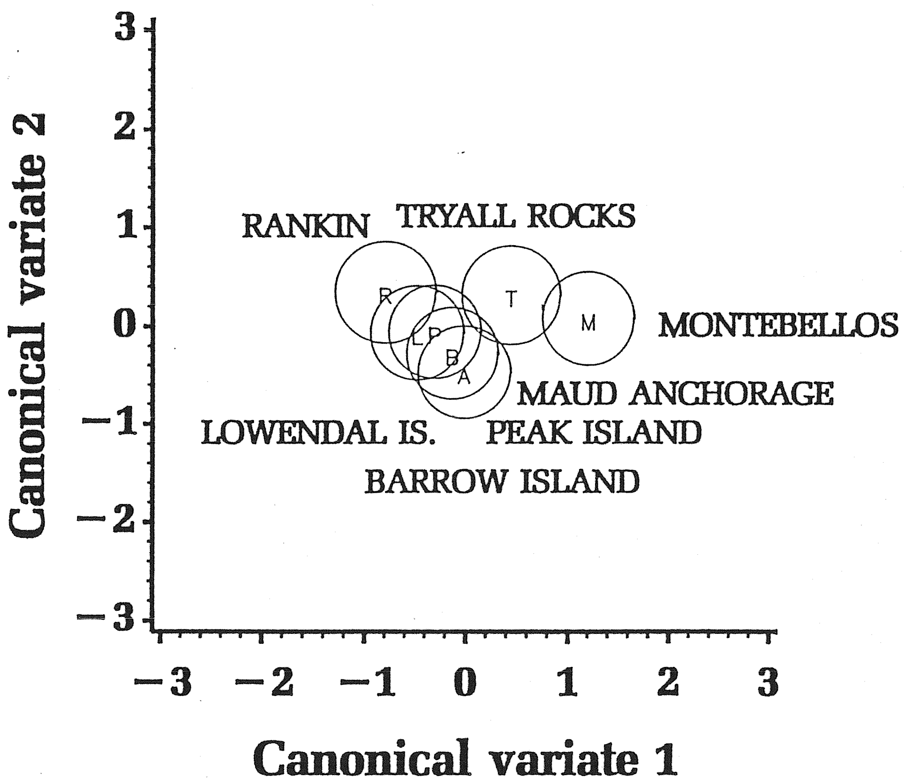

Fig. 3. A) Canonical Variate Analysis of the elemental composition of the otoliths of Spangled Emperor *Lethrinus nebulosus* from four widely spaced locations. The samples from all the NW Shelf locations were pooled for this analysis.

B) Mean and 95% confidence regions of canonical variates 1 and 2 of the elemental composition of *L.nebulosus* otoliths from Maud Anchorage and six closely spaced locations on the NW Shelf. While there is a latitudinal correlation with CV2, the degree of separation of samples does not reflect geographic distance between locations.

Tagging

Tagging of lethrinids was attempted at the Montebello Islands, Dampier Archipelago and Ningaloo Reef but was only really successful at Ningaloo, where reasonable numbers of both adult and juvenile fish could be caught.

Of 1781 lethrinids (*Lethrinus nebulosus* and *L. atkinsoni*) tagged at Ningaloo, there were 60 recaptures with good data on the time and location of recapture. The recaptures dropped to very low numbers by the third year after tagging, and the rate of decline indicated a total exponential mortality rate of Z=1.2, which indicates that 30% of the tagged fish present at any time will survive to one year later. However, analysis of tag loss using the return rates of double-tagged fish with one or both tags indicates that this apparent mortality is mainly due to tag loss. In fact, the expected survival of fish with their tags is 28% which indicates that there was no mortality of the fish at all. This is not a reliable conclusion since the tag-loss rate is based only on a regression of three data points (Fig. 4).

Many of the tagged fish were recaptured close to their release point, two thirds were still within three n.miles even in the third year after tagging. A few fish had moved 60 n.miles within 3 months of release and no fish was recaptured more than 80 n.miles from its release point (Fig. 5a). There was no significant correlation of distance moved with time at liberty ($R=0.17$, 58 d.f., $P>0.05$), nor with the size of fish when released ($R=0.18$, 58 d.f., $P>0.05$). However, the proportion of recaptures which had moved more than 25 n.miles did show a significant increase with time at liberty (Fig. 5b, $R=0.89$, d.f.=3, $P<0.05$). Regression of the proportion more than 25 n.miles from release point against years at liberty indicated that this proportion increased by 10% per year over the first 2.5 years.

The water between the shore and the reef-crest in Ningaloo Marine Park is zoned into sanctuary zones and recreational fishing zones. The sanctuary zones average about 6 n.miles in length so our result that over 60% of the recaptures were taken within 3 miles of the release point indicates

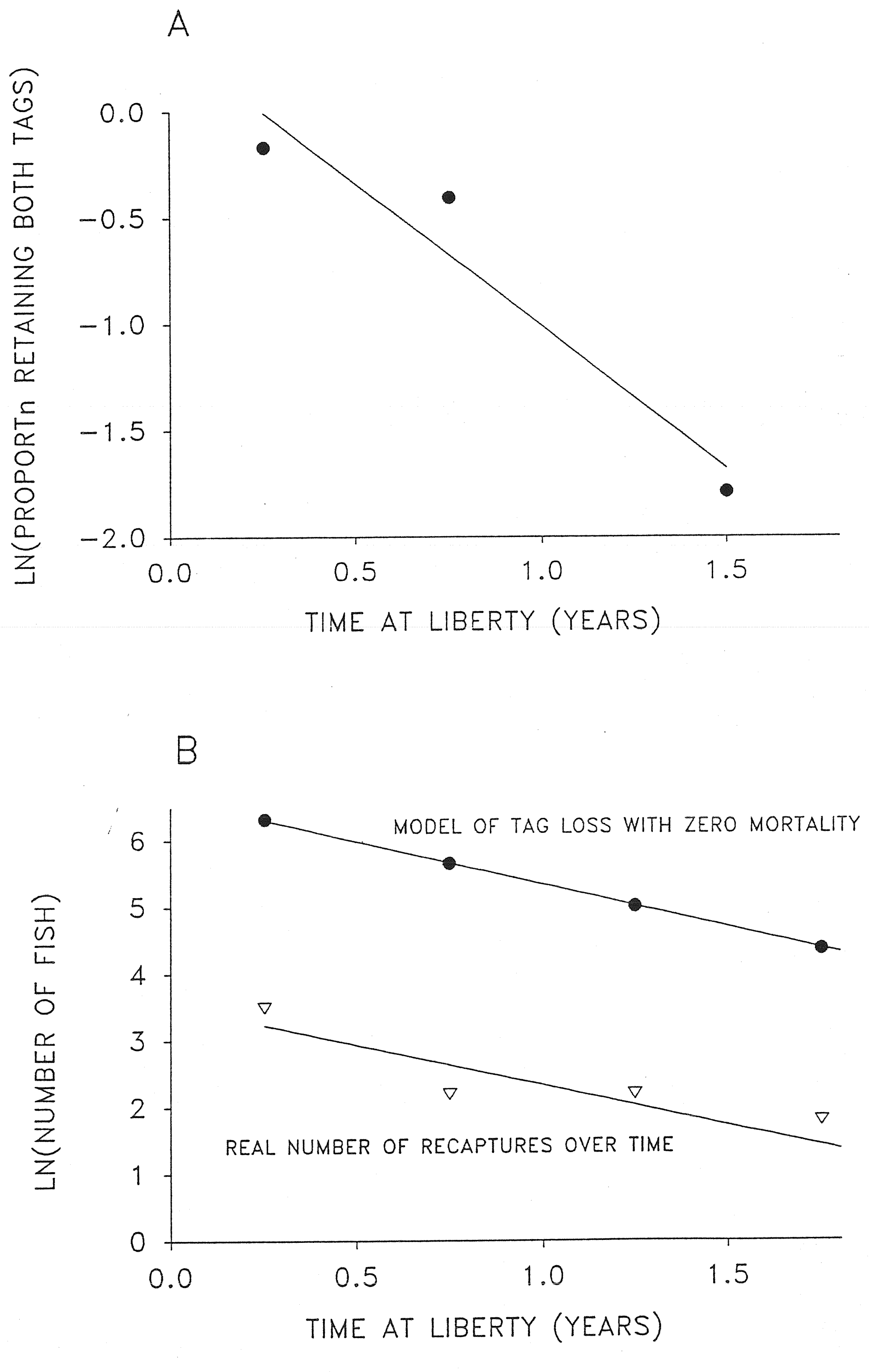

Fig. 4. A) The proportion of double−tagged fish recaptured with only one tag (as natural log) plotted against time at liberty to estimate tag−loss rate. B) A model of the expected number of tagged fish remaining in the water based on the tag−loss rate from A and assuming zero mortality; and the actual reduction in number of recaptured fish with time at liberty, both sets plotted as natural logs.

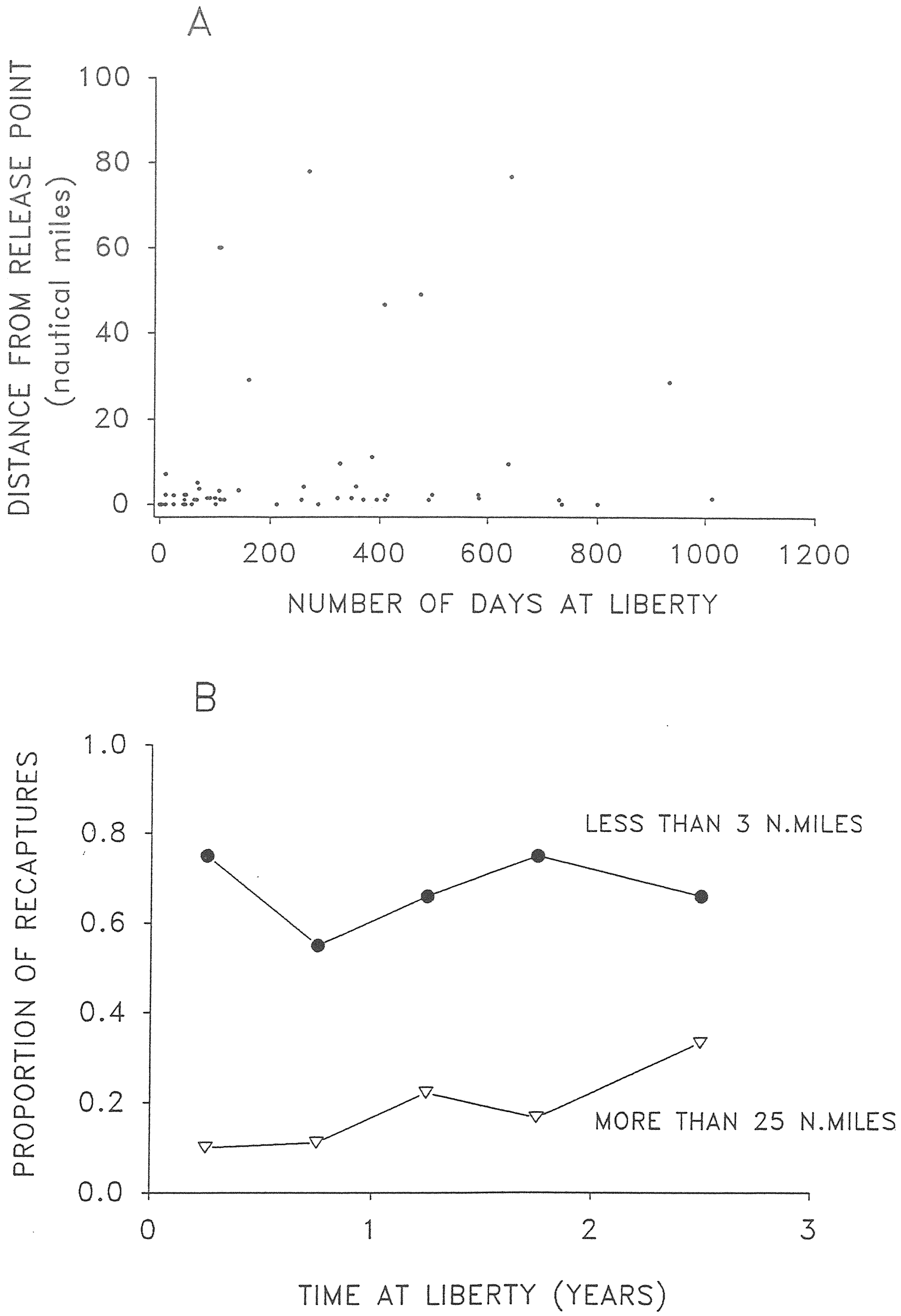

Fig. 5. Movements of tagged lethrinids: A) Distance of each recaptured fish from its release point, plotted against its number of days at liberty; B) The proportion of recaptured fish recaptured less than three n.miles and more than 25 n.miles from their release point, in six-month intervals of time at liberty.

that the lethrinids have a sufficiently low mobility that sanctuary zones of this size are effective in providing some protection to local lethrinid populations, but not total protection.

The management zones for commercial fisheries are on the scale of hundreds of n.miles of coastline. The tagging results indicate that movement between these management zones would be minimal within the size ranges sampled.

Summary of stock-identity results

The retention of the majority of tagged fish within a small distance of the release point helps to explain how significant differences can persist in otolith microchemistry on quite a small scale. All that is required is that the local geology can generate variations in water or sediment chemistry which can be accumulated directly by the fish or through the food chain.

The implications for fisheries management of the combined results of the genetic, tagging and otolith microchemistry research are that management of fishing mortality rates is possible in commercial fisheries management zones of the size used in W.A.

What is still not known is the degree to which recruitment of young fish to a zone comes from its own zone or from other zones. The genetic study indicates that there is a possibility that there is larval transport by ocean currents between management zones. If the genetic study had shown significant genetic differences among populations, we could treat the different zones as totally independent stocks. The conclusion is that the management zones are appropriate in relation to growth overfishing, but not necessarily for recruitment overfishing.

AGE, GROWTH AND MORTALITY OF *L.NEBULOSUS*

Tetracycline tagging for validation of ageing

Otoliths were expected to be the most reliable structure in the fish for age determination, and sectioned otoliths to be more reliable than whole otoliths. We therefore set out to validate the reading of the sectioned otoliths by tagging with tetracycline, which is supposed to leave a mark on calcareous structures at the time of injection. On recapture of the fish, the mark can be seen under UV light. The number of rings outside the tetracycline mark should equal the number of years at liberty if the rings are valid annual rings.

All of the lethrinids tagged for studies of movement were also injected with oxytetracycline at the dose rate of 25mg.Kg^{-1}. Eleven of the sixty recaptured fish were returned with their heads intact and otoliths were extracted. The tetracycline mark was visible on all these otoliths. The otoliths were sectioned through the origin as for normal age-determination and were photographed under normal light and UV light. The positions of the estimated annual rings were measured off the normal photograph and the position of the fluorescent tetracycline mark was measured off the UV photograph. For some fish, the tetracycline mark and supposed annuli could be seen on both the dorsal and ventral sides of the section and measurements were made on both sides.

Two approaches were taken to checking the validity of the annuli: simple counting of rings for comparison with the number expected; and estimation of time at liberty including fractions of a year, by measurement of the marginal increment between the outermost ring and the edge of the section, then expressing this increment as a fraction of the expected distance between the outermost ring and the next one due to form. When two sides of the otolith could be read, the mean of the two estimated times at liberty was calculated. All measurements and calculations were done without knowing any of the details of the fish or its time at liberty.

The actual times at liberty were significantly correlated with estimated times at liberty (Fig. 6, R=0.97, 9 d.f., $P<0.01$). The comparison of expected number of rings, based on actual time at liberty, with the numbers counted outside the tetracycline mark are shown in Table 1.

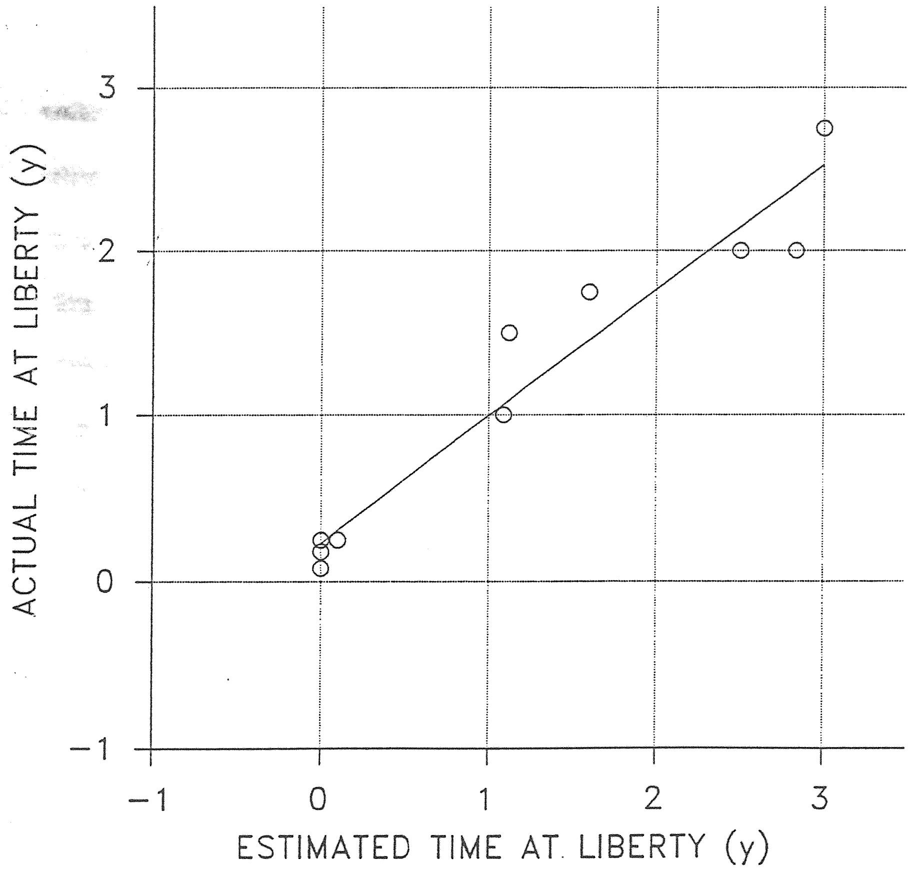

Fig. 6. Comparison of times at liberty estimated from counting rings and measuring increments on otoliths of tetracycline-tagged Lethrinids, with actual time at liberty.

Table 1. The number of rings expected outside the tetracycline mark if rings are annual, and the actual number of rings counted, in tetracycline-tagged lethrinids. When counts were different on the two sides of the otolith, both are shown.

Fish No.	Rings expected based on time at liberty	Rings counted
1	3	3
2	2	2
3	2	1 , 2
4	1	1
5	0	0
6	0	0
7	0	0
8	0	0
9	1	1
10	0	0
11	2	2 , 3

The comparison of actual and estimated numbers of rings and times at liberty is fairly good, but it must be remembered that we had only one fish at liberty for 3 years and three fish for 2 years, two of which gave ambiguous counts.

Comparison of ageing methods, whole and sectioned otoliths and scales for *Lethrinus nebulosus*.

Otoliths from 1476 *L. nebulosus* were extracted. All otoliths were read whole, then embedded in resin, sectioned through the origin and read as sections. In addition, scales of 105 fish were read to compare with otolith ages.

A comparison of ages from scales with those from sectioned otoliths, by the same reader, showed that the scale ages were greater than otolith ages in the younger age groups but less than otolith ages for the older fish (Table 2). The ages from the two methods were comparable around age 7. A regression gave:

scale age = 4.56 + 0.36*otolith age R=0.66

Comparison of ages from whole otoliths with those from sectioned otoliths read by the same person gave much better agreement than the scale-otolith comparison.

whole otolith age = 1.25 + 0.87*section age R=0.94

However the spread was still very great and there was a slight tendency for ages of young fish to be greater from whole otoliths than from sections, and vice versa for the older fish (Table 3). There was perfect agreement on only 28% of the fish and a further 40% were one year different.

The correlation between estimates by two readers for whole otoliths was R=0.96, with perfect agreement on 32% of fish and a further 35% were one year different. For sectioned otoliths, correlation between readers was R=0.97, with agreement on 31% and a further 40% out by one year. The level of agreement between sectioned and whole otoliths is therefore similar to the level of agreement between two readers using the same method. If either method was more reliable than the other, the level of agreement between readers would be expected to be greater for the more reliable method.

While the accuracy of ageing *L.nebulosus* from otoliths is not brilliant, we considered it worthwhile to use the ages from otolith sections to obtain estimates of growth and mortality.

Table 2. Ages estimated for Lethrinus nebulosus: number of fish at each estimated scale age, by estimated age from otolith section. The outlined section indicates equal estimates.

OTOLITH SECTION AGE (y) \ SCALE AGE (y)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1			1																			
2																						
3				3	2	3	1															
4				2	7	6	5	1														
5					4	7	5	8	1													
6					2	5	1	2														
7					1	3	2		2	1												
8					2	3		3	1													
9								2	1	1												
10						1	1															
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21																						
22										1												
23																						
24																						

Table 3. Ages estimated for Lethrinus nebulosus: number of fish at each estimated age from whole otoliths, by estimated age from otolith section. The outline indicates equal estimates.

SECTION AGE (y) \ WHOLE AGE (y)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1	4	4																													
2	3	56	19	1	1																										
3		8	32	40	3	6	4																								
4			15	43	49	29	10	1																							
5			1	26	55	68	17	4	3	1																					
6				6	25	55	38	12	7	1	1			1		1															
7		1	2	2	2	22	38	45	12	4																					
8			1	1	6	9	21	26	22	6	2																				
9			1	1		2	7	13	11	11	6	1		3				1													
10						2	3	2	11	15	10	4	2	2		2															
11					1	1	2	1	1	5	5	7	5	2	1	3		2													
12							2	1	4	5	7	7	4	5	2	1	1	1													
13									1		4	7	2	6	6	3															
14									1			2	4	5	3	2	1														
15							1				3	1	2	6	5	5	5	1	4												
16												2	2	3	5	11	5	3	5												
17										1		2	1	3	6	4	8	2	1	4											
18										1		1		1	6	5	2	4	9	4	4			1	1						
19												2			2		25	2	2	2	1	1		1							
20												1					3	1	1	3	2	2	4			1					
21												1	3		4		2	4	4	2	3	8	3	1	1						
22													1	1		1	5	2	1	12	5	12	6	6	1						
23								1	1							3	2	2	4	5	2	5	3	4	1	2					
24																	2	1	4	1	4	3	1	3	1	1					
25																		2			1	2	4	4	3	3					
26																1			1	1	1	2		2							
27													1		1							3	3	3		2				1	1
28																					1		1		1			1			
29																															

Growth of *Lethrinus nebulosus*: the effects of sex and region.

To determine whether the sexes needed to be treated separately in determining growth-rates, the lengths at estimated age for males and females were plotted separately (Fig. 7) for fish from each of the four main areas from which we took otolith samples, i.e. the Kimberley, NW Shelf, NW Cape and Mid-west (Fig.1). The estimated ages are the means of two readers using sectioned otoliths. The overlap between the sexes in length-at-age is almost total in most cases and the sexes are combined for further analysis of growth.

The mean lengths-at age of the four areas are compared in Fig. 8. The NW Cape and NW Shelf data are clearly very similar but the Mid-west fish are longer than the Kimberley fish at all ages sampled. The NW Cape and adjacent NW Shelf areas were combined into a Northwest group for comparison with the other two areas. Both the Kimberley and Mid-west groups show the same pattern of having greater lengths-at-age than the NW group for the younger fish, but smaller lengths-at-age for the older fish.

The smaller mean lengths-at-age of the older Kimberley and Mid-west fish than the NW fish are likely to be real, but the difference in younger fish is more doubtful. The Kimberley and Mid-west fish were caught by commercial vessels which do not take small *L.nebulosus*. The NW fish were taken both by commercial fishing and research sampling and thus cover a greater range of fish sizes. The Kimberley and Mid-west samples are therefore more prone to bias due to selection of only the largest members of younger age-groups. This bias is likely to be greatly accentuated in our case by errors in age-determination.

While we can reach no reliable conclusion regarding the variation in growth of young fish among areas, we do conclude that the mean maximum length to which this species grows is greatest in the Northwest, then the Mid-west, and least in the Kimberley area. The mean length to caudal fork of the older fish in the Mid-west is 540mm and for the Kimberley fish 506mm. A von Bertalanffy growth curve fitted to the mean lengths-at-age of the NW fish gives an estimate of L-infinity of 568mm (Fig. 9). The rate of growth K is estimated as 0.221 and T-zero as -1.49 years.

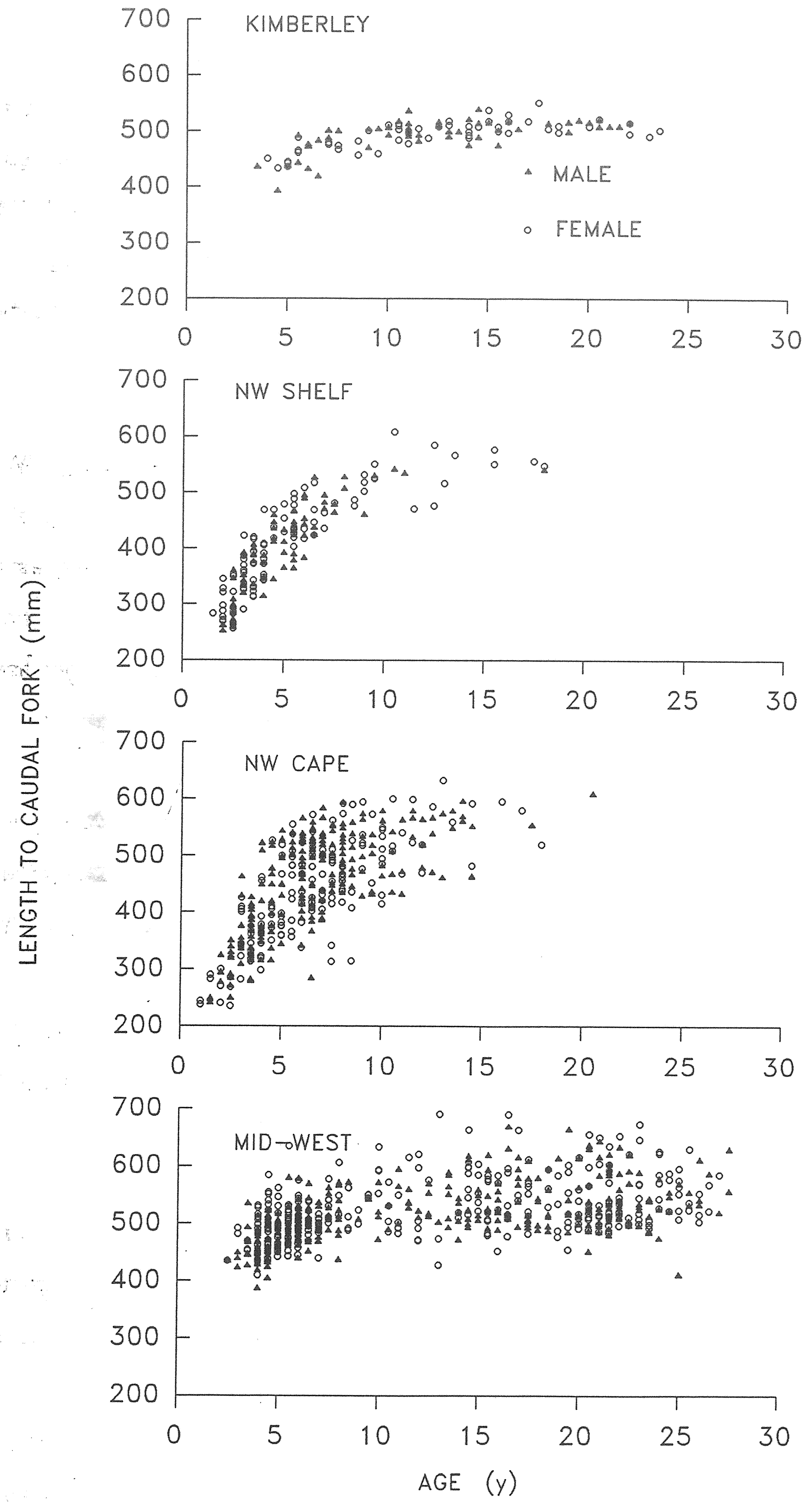


Fig. 7. Length at age for male and female Lethrinus nebulosus from four regions, showing the similarity in growth between the sexes..

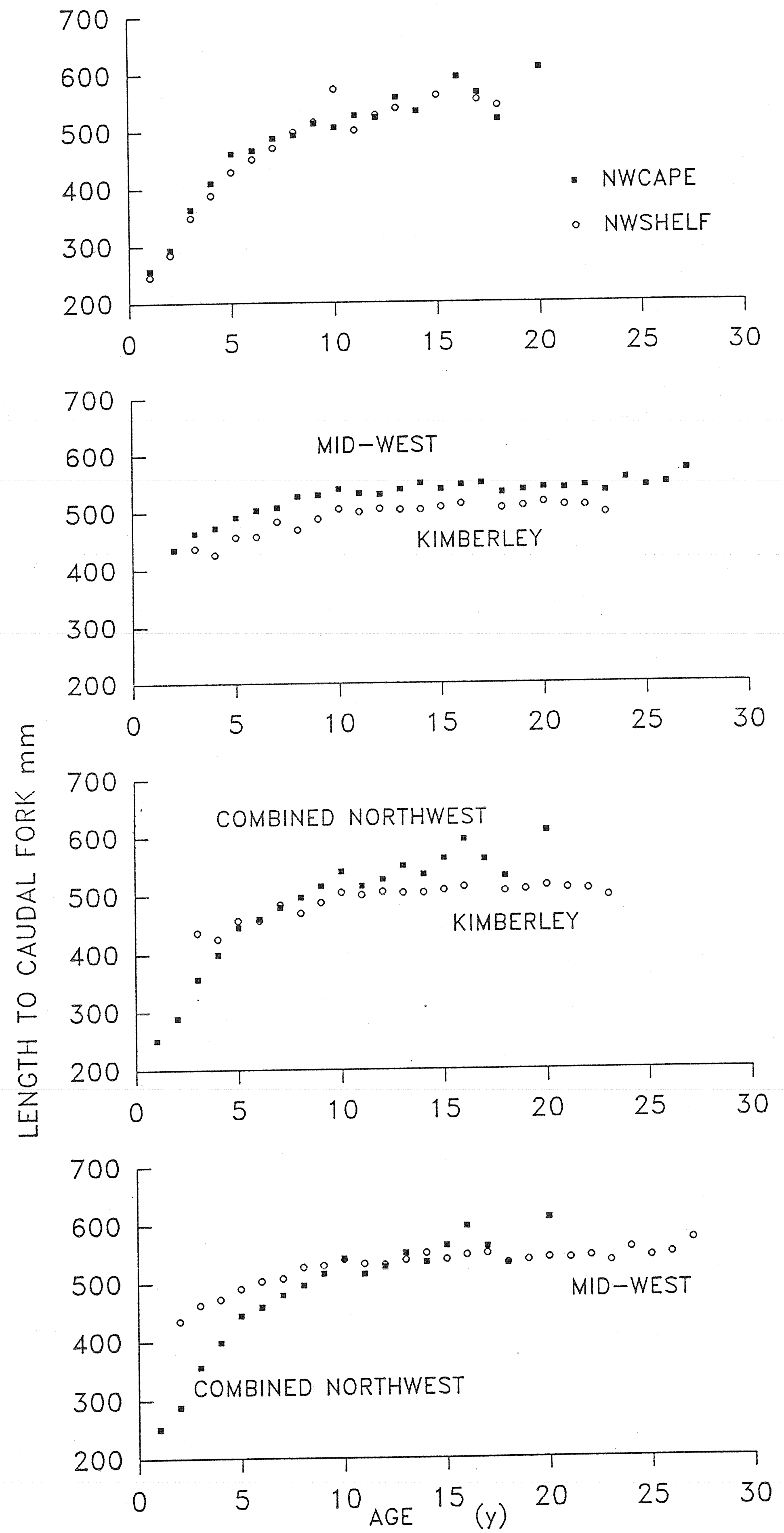


Fig. 8. Comparison of mean length-at age from four areas. Combined Northwest is NW Cape and NW Shelf.

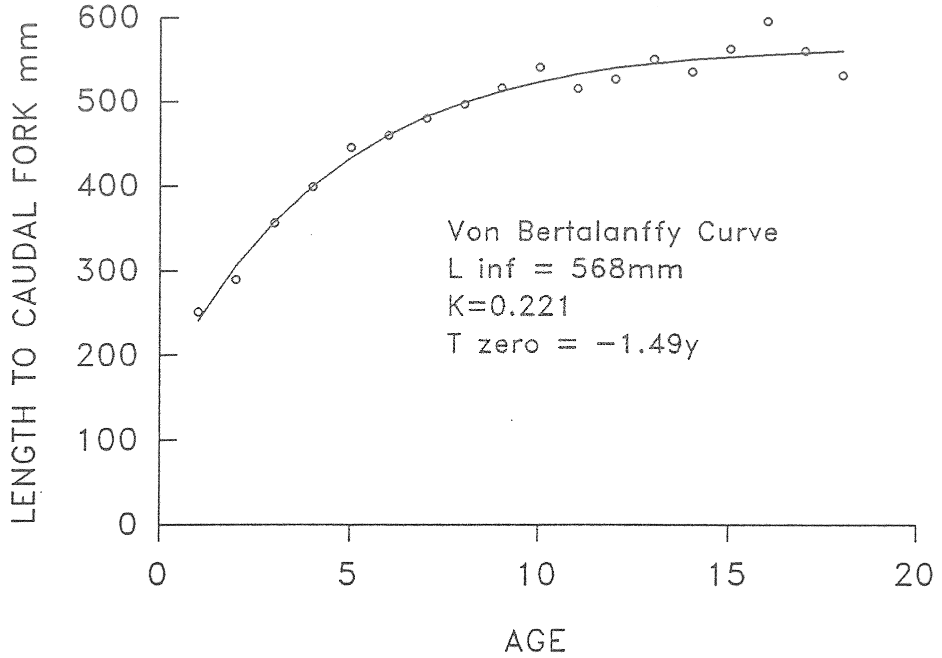


Fig. 9. Von Bertalanffy growth curve, fitted to mean lengths—at age of Lethrinus nebulosus from the combined NW Cape and NW Shelf regions.

Age structure by sex and region, and mortality rates of *Lethrinus nebulosus*

Many fish species change sex at some time in their lives and this phenomenon has been observed in the Lethrinidae (Young & Martin, 1982). Sex change could greatly complicate calculations of optimum minimum legal lengths as effective size at maturity would vary with sex. Under extreme fishing pressure, it is possible that too few fish might survive to become the later sex for adequate spawning, despite an abundance of the earlier sex. At the outset of this research sex reversal was seen as an important feature to investigate.

Lethrinids are reported to be protogynous, i.e. female first then changing to male. We sought evidence for such changes in differences in age-structure between males and females. These age structures are shown by sex for each area in Fig. 10. There is no sign of a general pattern of increasing proportions of males in the older fish. It is possible that sex change occurs before the fish reach sexual maturity as in the pink snapper, *Pagrus auratus* in the related family sparidae (Francis & Pankhurst, 1988), but our conclusion is that sex change is not an important factor in the fisheries population dynamics of *Lethrinus nebulosus*.

The age-structure of the Mid-west sample in particular indicates that the population is subject to variable year-class strength. Errors in age-determination tend to smear such patterns of variable recruitment so it is likely that recruitment to that population is even more variable than appears from the graph (Fig. 10). This population is at the southern end of the species range which would tend to make recruitment more variable than populations nearer the centre of the range.

It is clear that older fish are more common in the Mid-west and Kimberley samples than in the NW Cape and NW Shelf samples. The Mid-west population is not thought to have been exploited at all until two years before this study began, and while the Kimberley population was in the foreign trawl access area, the harder sea-bed areas where the species occurs tended to be avoided by the trawlers. These populations may therefore offer an opportunity to estimate the

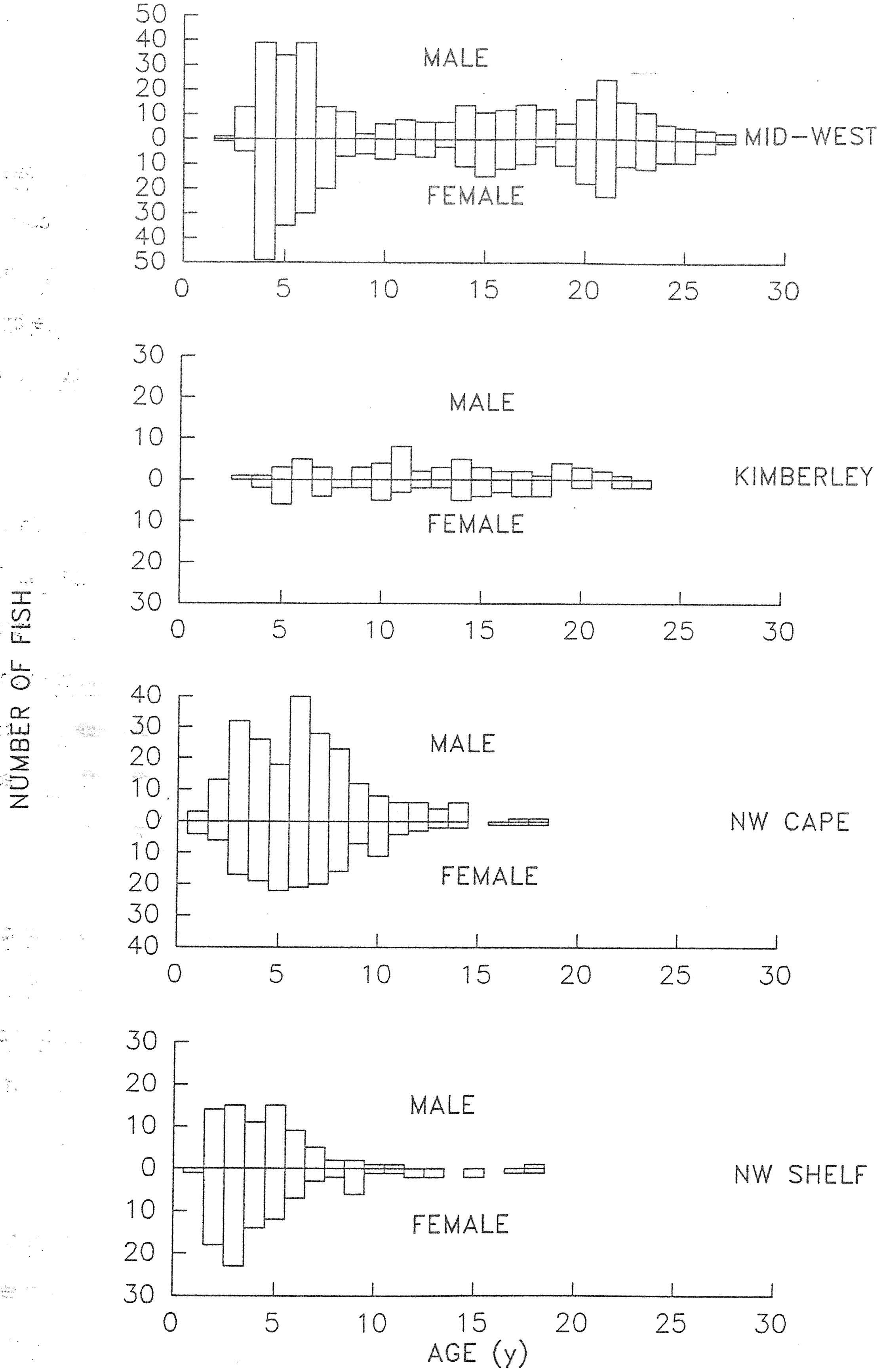


FIG. 10. Age structure of the samples from each area by sex.

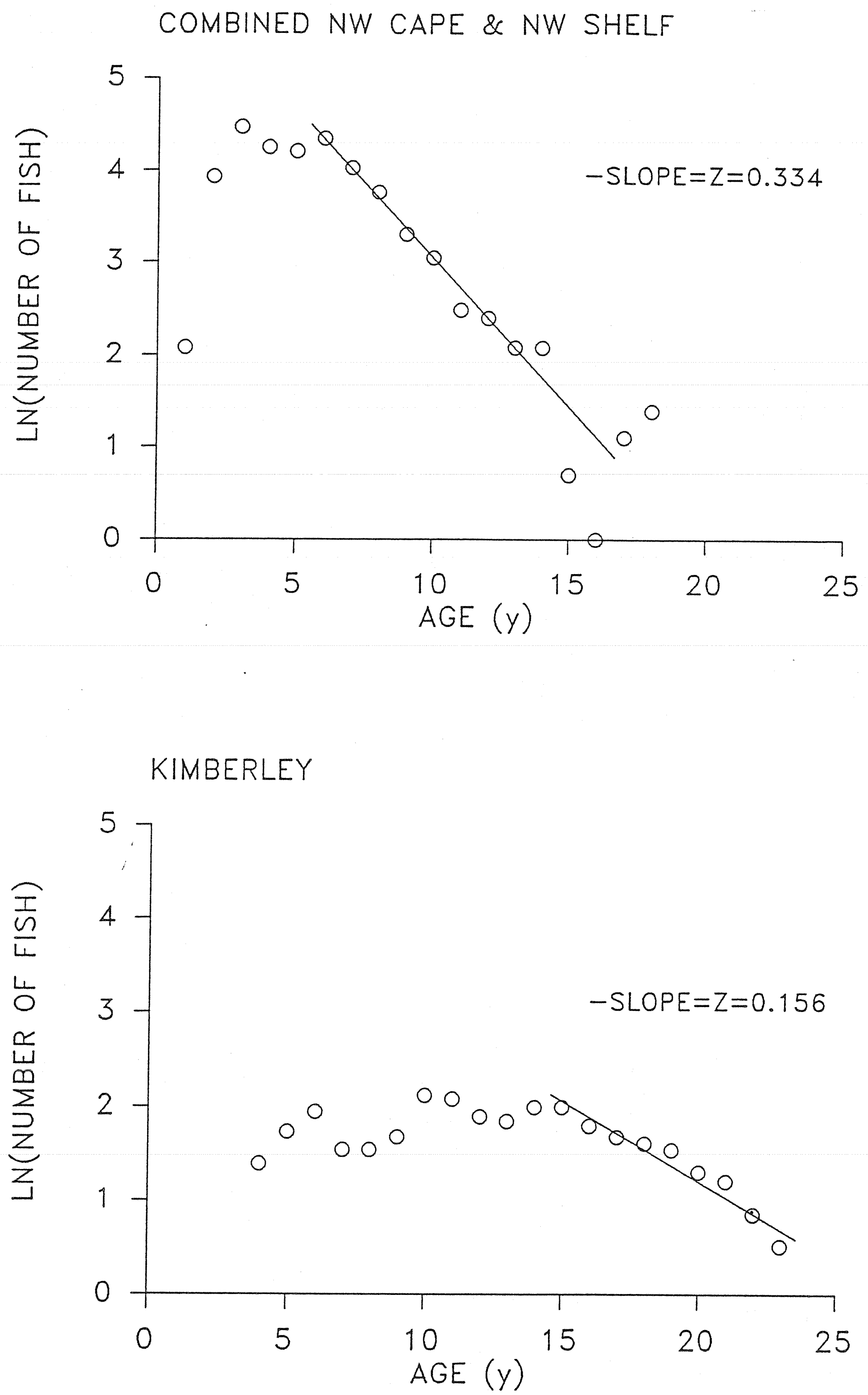


Fig.11. Catch curves for Lethrinus nebulosus from two regions.

rate of natural mortality. The NW Cape and NW Shelf populations, on the other hand, were exploited by line-fishers concentrating on reef areas even before the trap fishery commenced.

The use of catch curves, plotting Ln(number of fish in each age class) against age and estimating the mortality rate from the slope of the right-hand limb of the graph, is not the ideal way to measure mortality, but is often the only means available. Fig. 11 shows catch curves for *L.nebulosus* from the combined NW Shelf and NW Cape populations, and from the Kimberley population. The estimate of the total exponential mortality rate Z from the Kimberley is 0.156, which we will also take as an estimate of the natural mortality rate m. For the Northwest sample, Z = 0.334, subtracting the natural mortality rate of 0.156 gives the rate of fishing mortality F = 0.178.

There is an alternative way of calculating mortality based on the maximum age in the population (Hoenig, 1983) which, for the maximum age of 27 in the Mid-west population, results in an estimate of m = Z = 0.155.

It is encouraging, but undoubtedly fortuitous, that the estimates of m by the two methods are so similar.

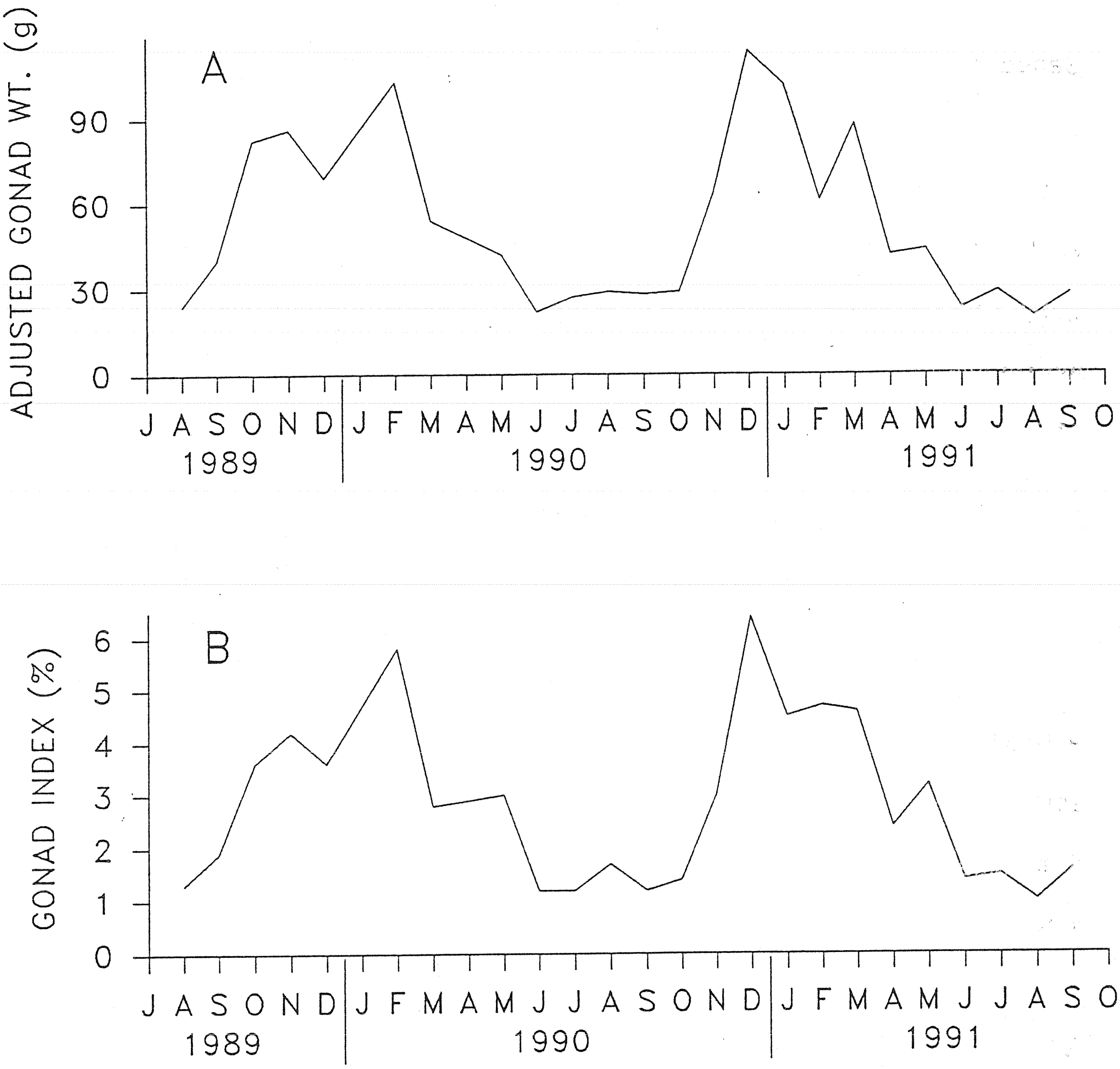


Fig. 12. Female Lethrinus nebulosus from the mid-west region: A) Mean gonad weights adjusted for fish-length and B) Gonad index by month and year of capture.

REPRODUCTIVE BIOLOGY OF L.NEBULOSUS

Seasonality of spawning

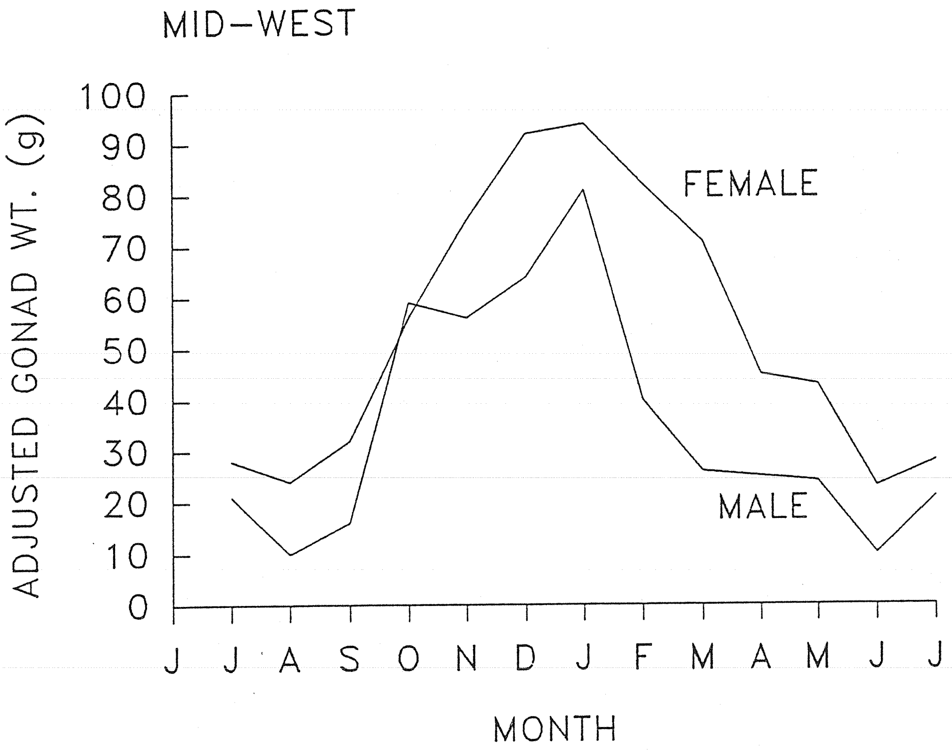
Monthly samples of 30 *L. nebulosus* were obtained when possible from commercial fishermen for each of the Mid-west and NW Cape areas. Due to the vagaries of fishing, no samples could be obtained in some months, particularly for the NW Cape area. Gonad weight and body length and weight (whole and gutted) were recorded. A macroscopic visual estimate was made of the state of the gonad from its external appearance:

stage 0	virgin, immature
stage 1	resting, recovering
stage 2	developing
stage 3	developed, ripe
stage 4	spawning, running ripe
stage 5	spent.

A sub-sample of the fish were also subjected to histological examination of the gonads, using the same developmental stages as the visual stages. Comparison with histological stage showed that visual stages were a poor indication of the state of development of the gonad but gonad index (gonad weight * 100 /gutted weight) was a good indicator, peaking for spawning fish.

Gonad index was found to be positively correlated with fish length, i.e. small mature fish had gonads which were a smaller percentage of their body weight than large mature fish. To ensure that variation in body size from month to month is not distorting the seasonal pattern, both gonad index and gonad size adjusted for fish length (analysis of covariance) are plotted against time of year in Fig. 12 for the Mid-west area.

The pattern is essentially similar for both methods of presentation but the adjusted gonad weight is regarded as the more reliable. The gonads began as small in August 1989, rising to a high level from October to March, then low again from April to October 1990, high again from November to March 1991, low from April to the last sample in September 1991. The graphs are



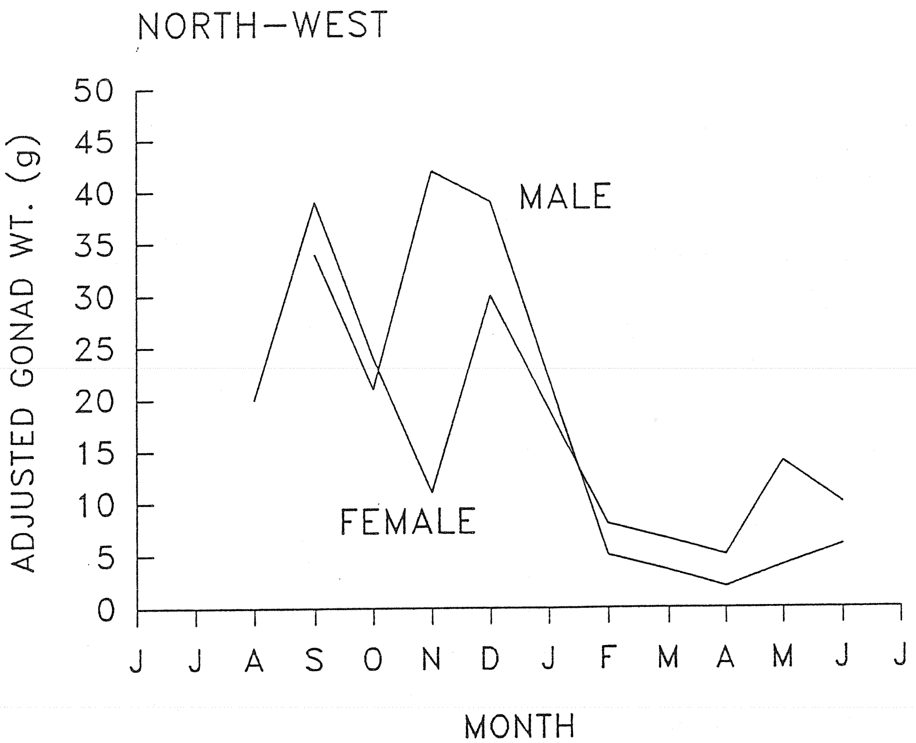


Fig. 13. Monthly variation in gonad weight of Lethrinus nebulosus adjusted for fish length, in male and female fish from the north-west and mid-west regions. Data have been pooled across years.

interpreted as spawning from October 1989 to February 1990, and November 1990 to March 1991, indicating a degree of variability in timing from year to year.

Using data pooled for the two years to compare the timing of spawning in the Mid-west and North-west areas (Fig. 13), it appears that spawning in the more northern area is a month or two in advance of the southern area, possibly reflecting a temperature threshold but perhaps related to other factors. It appears that *L. nebulosus* is a spring-summer spawner on the west coast of Australia as it is in the east. It would be interesting to compare seasonality in the Kimberley population but at the time of sampling, the fishery there was not well developed so regular samples could not be obtained.

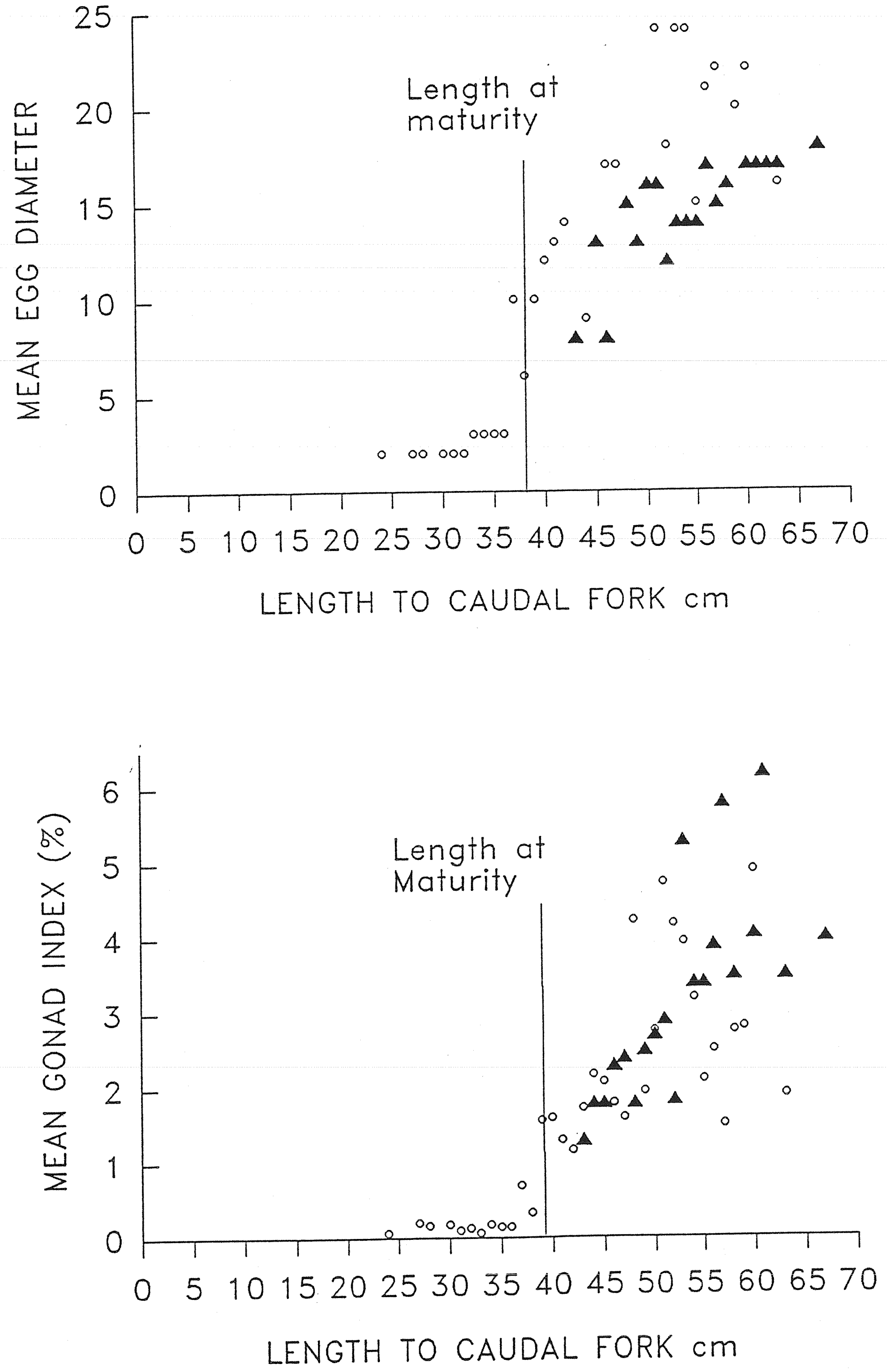


Fig. 14. The length at which female <u>Lethrinus nebulosus</u> reach sexual maturity as shown by A) mean egg diameter, and B) mean gonad index, plotted against fish length. Triangles are mid-west circles are North-west

Size at maturity of *L.nebulosus*

To estimate size at maturity, additional samples were collected in the spawning season in 1990 and 1991 to supplement the samples from the commercial fishery, particularly to obtain smaller fish than were caught commercially. Gonad weight and mean diameter of the 10 largest eggs in a smear of ovary on a slide were recorded and plotted against length of fish to caudal fork (Fig. 14). Both methods show a sharp increase indicating that maturity is reached at a length of approximately 38cm.

No fish smaller than 42 cm could be obtained from the Mid-west area for this aspect of the study but the patterns for the larger fish were similar to those of the North-west fish and there is no reason to suspect a substantially different size at maturity there.

THE COMMERCIAL FISHERY FOR LETHRINIDS

Changes in the geographic distribution of the lethrinid catch

The lethrinids are caught in all marine areas fished in the northern half of Western Australia. Until the mid 1980's they were one of the main target species of line fishers off NW Cape and the islands and reefs of the western Pilbara coast, and a bycatch of line fishers who were mainly targetting pink snapper off Shark Bay and the area south to the Abrolhos Islands. At that time there was a Taiwanese multi-species pair-trawl fishery operating on most of the continental shelf off the north coast of Western Australia but concentrating mainly on the area off Dampier between 116^o and 119^{o}E.

In the mid 1980s trap fishers from the Shark Bay snapper fishery did some fishing around the Montebello Islands following the snapper season. Local fishers from Onslow, Exmouth and, later, Pt Samson saw that the catch rates were much greater than line fishing and many changed over to trapping.

In 1985 there was a huge increase in effort in the Shark Bay snapper fishery, resulting in an increasing catch of the lethrinid bycatch. In 1986 and 1987 the Shark Bay snapper fishery was closed in July as a management measure for that fishery; many of the snapper fishers worked during July in the area off NW Cape immediately north of the snapper boundary at 23^o 30'S, with traps and lines. The late 1980s also saw an increase in line-fishing south of the snapper fishery, where fish trapping is prohibited. Fig.15A shows the distribution of lethrinid catch and the number of boats catching them in 1987. The blocks with the highest catches were.just south of 28^{o}S.around the Abrolhos Islands; the area between 22^{o}S and 24^{o}S south of NW Cape; and the western end of the NW Shelf around the Montebello Islands and the island chain north of Exmouth Gulf.

Following the Taiwanese trawling season in 1986, the area available to that fishery was reduced, with a western boundary being introduced at 116oE. This was moved a few years later to 117o 30'E. The effort by the Taiwanese fleet declined but in 1989 a fleet from mainland China worked the NW Shelf, concentrating on an area off Broome that had received less attention by the Taiwanese. After that the foreign trawlers were denied access to the Australian fishing zone.

In 1990 the domestic fish trawling in the Pilbara began to take off, after some preliminary efforts in the preceding years. Fish trapping in the Kimberley, which had been at a very low level, also intensified. Fishing effort in both these fisheries continued to increase until management restrictions were applied in late 1992.

Comparison of the maps of lethrinid catches in 1987 and 1992 (Fig.15) illustrates the shift from being dominated by line-fishing off Geraldton (28^{o}S) and trap fishing around NW Cape in 1987, to being a much more widespread fishery in 1992 with the biggest catch in a block being taken by the trawl fishery off Pt Samson (116^{o}-118^{o}E) and big catches north of Broome. The distribution of effort on the west coast altered also, with a reduction in the blocks between 22 and 24^{o}S and an increase off Shark Bay. Management rules were changing in most of the fisheries during this time, and new fisheries were opening up, complicating any analysis of catch and effort as an indicator of stock levels.

Methods of capture

Until 1984 the method used to catch most of the lethrinids was hand-line. That has remained the case on the west coast, where trapping is not permitted south of 26^{o}30'S and fish trawling not permitted at all. Drop-lining was popular on the west coast from 1985 to 1987 then went into decline while hand-lining for lethrinids continued to increase. Trapping became important on the north coast and northern part of the west coast in 1985. The fishing strategy was to seek concentrations of fish around rocky reefs, edges and patches of hard bottom; fish them until catch-rates fell, then look for more patches.

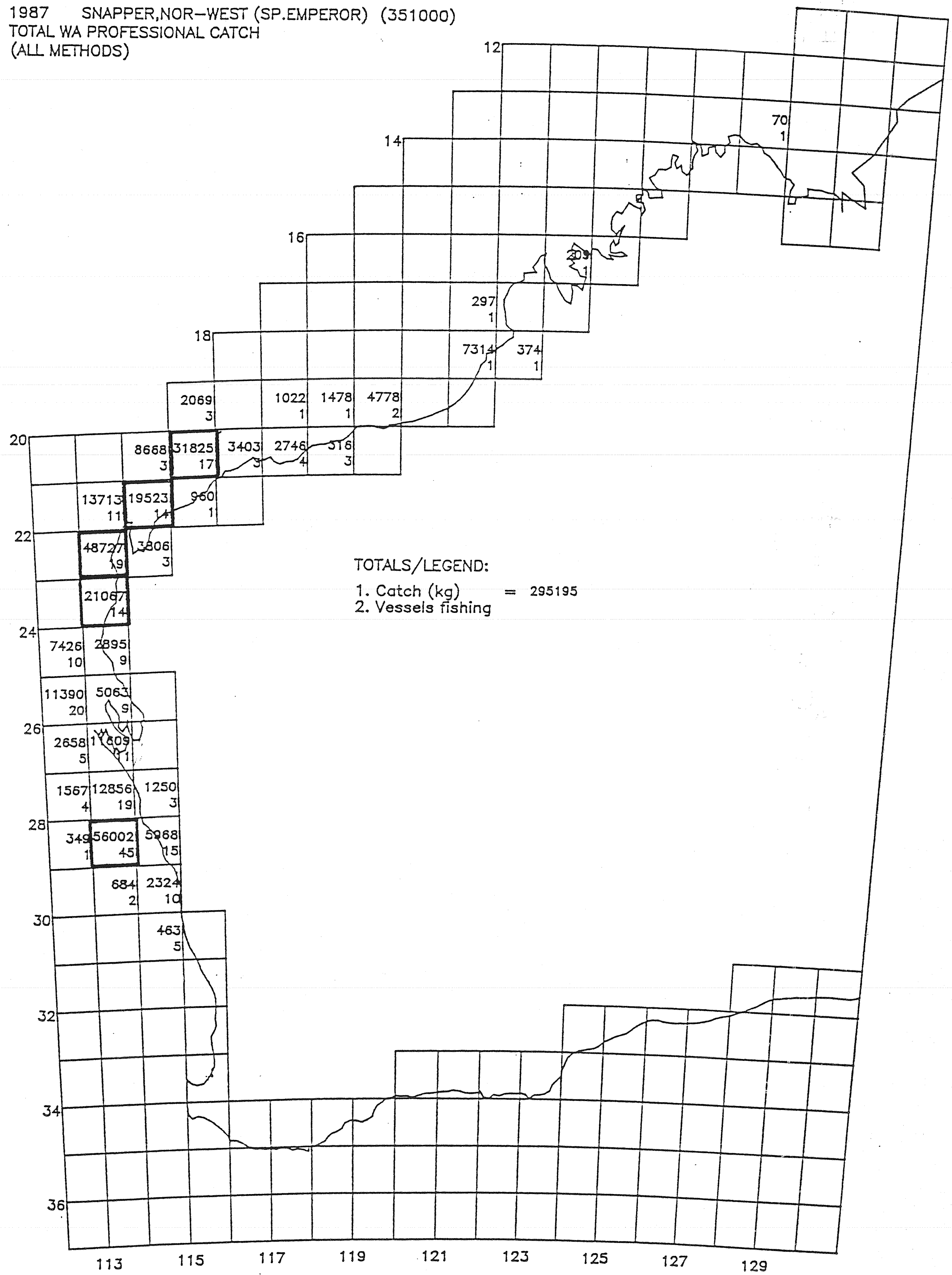


Fig.15 A) The distribution of the commercial lethrinid catch in Western Australian waters in 1987. Blocks with more than 15 tonnes are outlined.

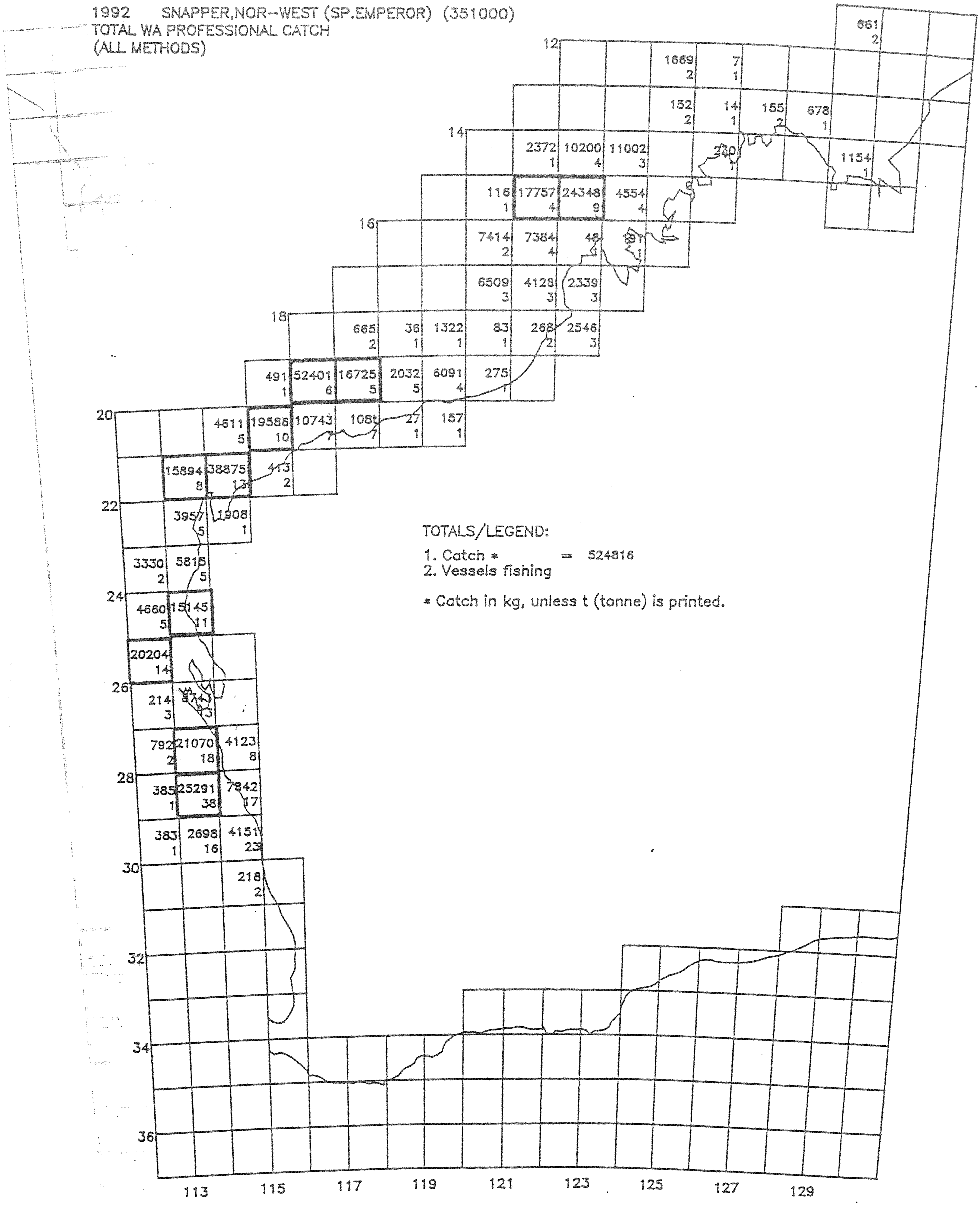


Fig.15 B) The distribution of the commercial lethrinid catch in Western Australian waters in 1992. Blocks with more than 15 tonnes are outlined.

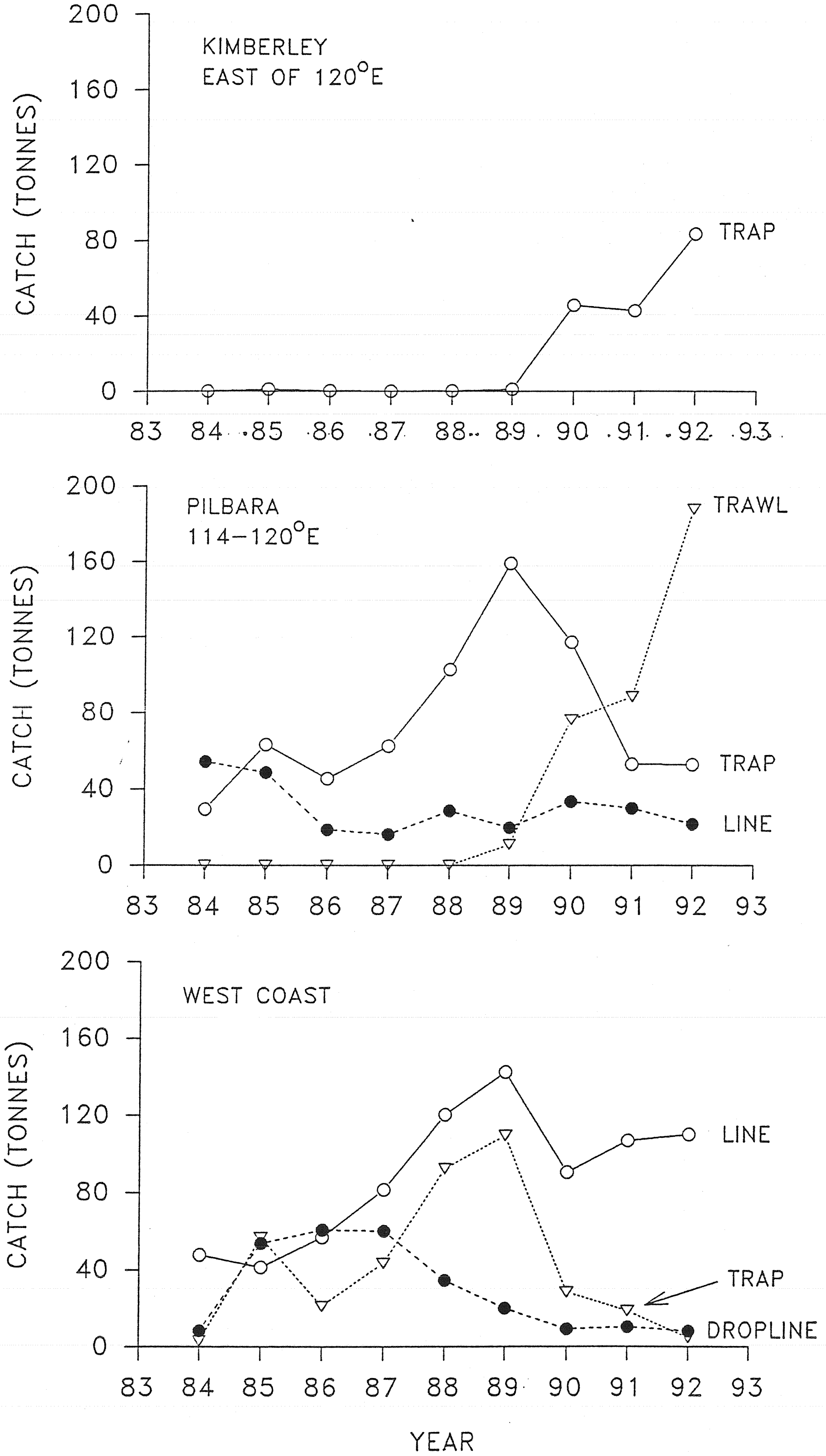


Fig. 16A Catches of Lethrinidae by fishing method in the Kimberley, Pilbara and West Coast regions, 1984 to 1992.

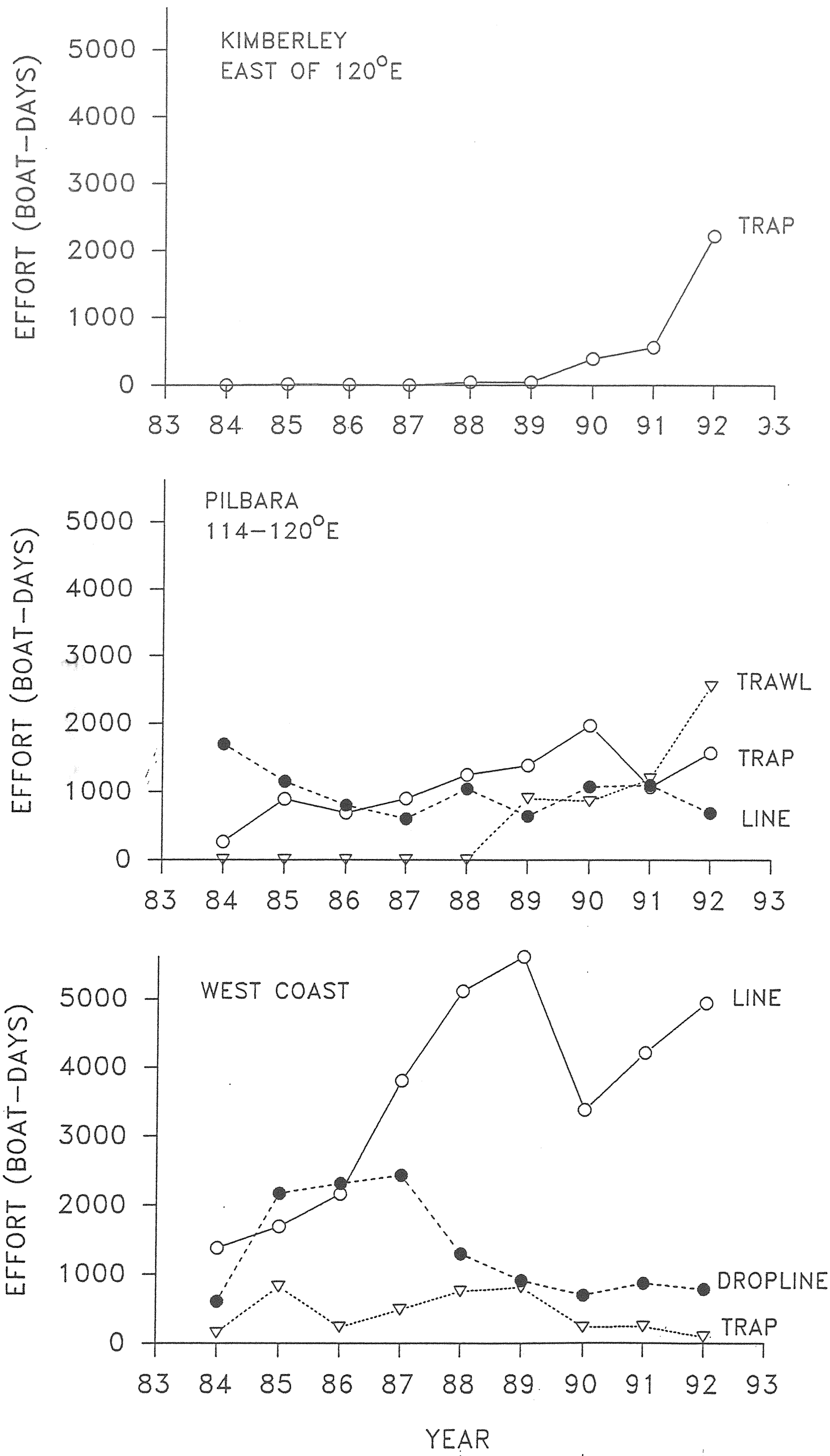


Fig. 16B Fishing effort on Lethrinidae by method in the Kimberley, Pilbara and West Coast regions, 1984 to 1992.

The first attempts at fish trawling by Australians on the north coast were by prawn trawlers from Exmouth Gulf in 1982 during a lean time in the prawn fishery. The nets used were banana prawn nets and the range of species caught very different from the trap and line fishery. When proper fish-trawl nets began being used in the late 1980s, the species composition became much more similar to that in trap catches.

Marketing and discarding/avoidance

The main species of lethrinids originally sought were the large ones, *Lethrinus nebulosus* was the predominant species landed on the north coast and *L. miniatus* on the west coast. While the existence of large numbers of the smaller species, especially *L. choerorynchus*, was well known to fishermen, they avoided these species and discarded them if they caught more than they thought the market could handle. With the advent of the trawl fishery, more determined efforts were made to market the small species and now these are dominant in the trawl catch. There are still smaller species which formed a large part of the Taiwanese catch and are not retained by the larger mesh of the Australian trawlers.

State of stocks

The trend over time of catch per unit effort of lethrinids is shown in Fig.17 by method and region. The most obvious feature of these graphs is the decline in trap catch-rates in all regions since 1989 or 1990. While these are all multi-species fisheries, the large lethrinids were dominant and valuable components of the catch in the mid to late 1980s.

Because of the way that trapping operations have concentrated on hard-bottom features that appear to act as a focus for aggregations of these fish, the least that can be concluded is that these aggregations have been fished down to low levels. It is likely that most of the stock of larger lethrinids is in these aggregations and that the stocks themselves of *L. nebulosus* on the north coast and *L miniatus* on the west coast are seriously depleted.

The trawl catch-rates, based mainly on the smaller species, do not show the same decline. The smaller lethrinids do not have the same habitat dependence as the large ones and are not so aggregated. The stock size was probably larger initially than that of the larger species and, being less marketable and less aggregated, is not so vulnerable to over-depletion.

As part of the management of the trawl and trap fisheries, they are not permitted to work inshore waters which are left to the use of commercial and recreational line fishers. The catch by the commercial line-fishery in the Pilbara has remained low and there is no strong decline in catch-rate by line-fishing evident in the Pilbara. On the west coast, there have been declines in catch rates by line fishers also in some areas, particularly south of the Shark Bay Snapper Fishery in the unmanaged open west coast line fishery. However, these have been balanced by shifts in fishing effort to areas such as the snapper fishery where stocks have been protected as a side effect of the pink snapper fishery management.

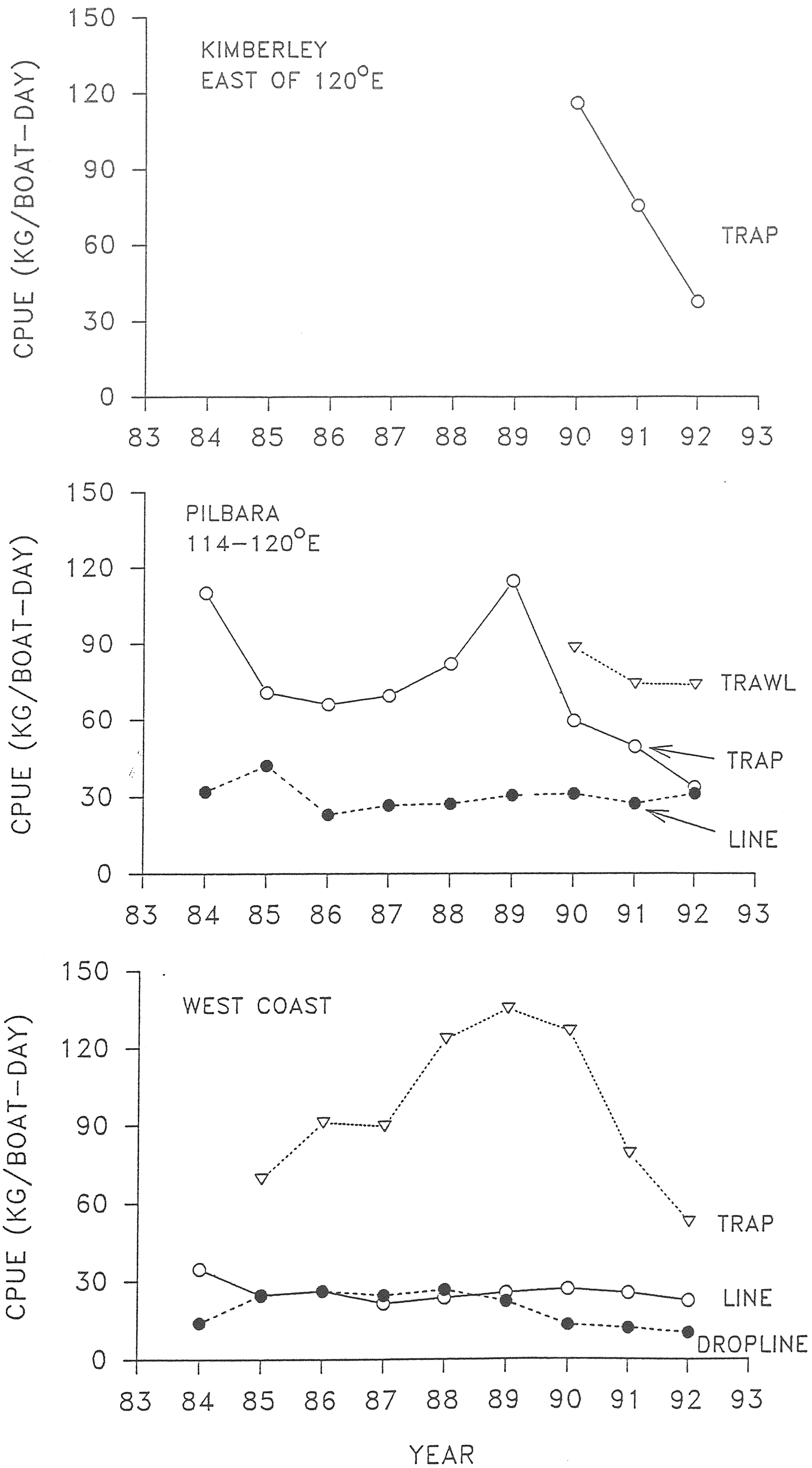


Fig. 17. Catch per unit effort of Lethrinidae by method in the Kimberley, Pilbara and West Coast regions, 1984 to 1992.

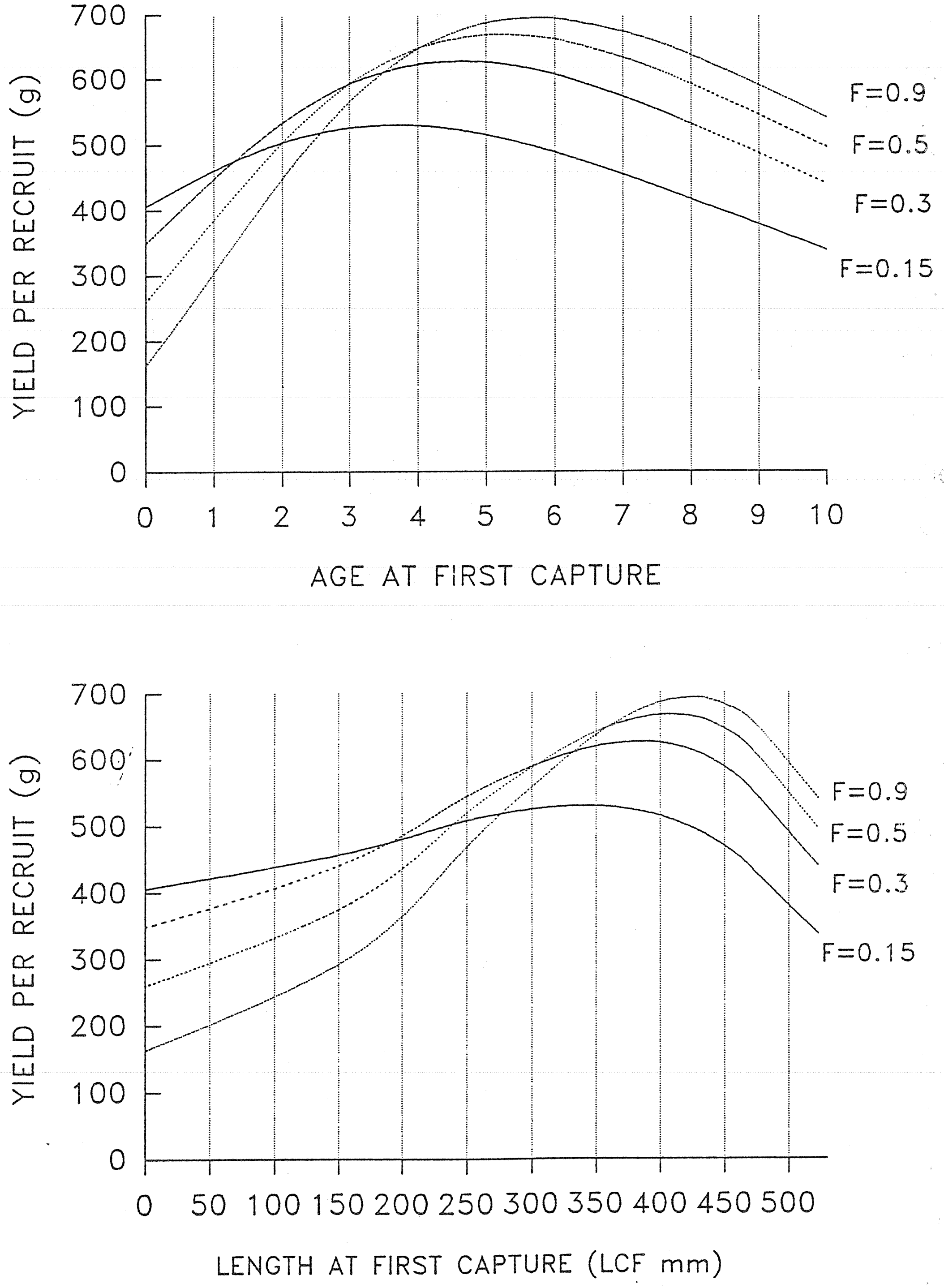


Fig. 18 The effect of age and length at first capture on the yield per recruit of Lethrinus nebulosus, at various levels of fishing mortality F.

There is cause for concern for the status of the stocks of the large species, *L.nebulosus* and *L.miniatus* but not for the smaller species of lethrinids. It is possible that the larger lethrinids are the most vulnerable species in the multi-species demersal fisheries in northern Western Australian waters.

FISHERIES MANAGEMENT

Yield-per-recruit and egg-per-recruit analysis

The family Lethrinidae are all subject to the one minimum length of 28cm total length in Western Australia. When this size limit was introduced, the commercial and recreational fisheries in the north had not developed and few people could tell one species of lethrinid from another. Now that exploitation of these species has increased, and over-exploitation may be occurring, it is appropriate to examine the effect of minimum length of the larger species on the yield and reproductive capacity of the stock.

A yield per recruit analysis was performed for *L. nebulosus* using the parameters for growth and mortality estimated in the biological study. This model indicated that maximum yields that can be obtained per juvenile fish recruiting to the population range from 500 to 700 grams, for ages at first capture from 3.5 to 6 years (Fig.18). The corresponding range of lengths to caudal fork (LCF) is 350 to 430 mm. The optimum length at first capture varies according to the fishing mortality to which the stock is subjected. The higher the fishing mortality is, the greater the benefit of leaving the fish longer before it becomes vulnerable to fishing. At all levels of fishing mortality, greater yields are possible using a LCF at first capture of 350 than 250mm and the increases in yield are more pronounced at higher levels of fishing mortality.

If gonad size is taken as an indicator of the relative reproductive capacity of a fish, an analysis of the effect of length and age at first capture on eggs-per-recruit is possible. Unlike the yield per recruit, these relationships give no optimum size or age which maximises egg production. The longer the fish are left before capture, the greater the egg production (Fig. 19). Many marine populations have stock-recruitment relationships which indicate that maximum recruitment is generated by intermediate levels of egg production, and the rule of thumb is that, in the absence of a known stock-recruitment relationship, egg production should not be allowed to fall below 25% of the maximum produced by an unfished stock.

Under light fishing (F=0.15) this 25% level is achieved by an age of first capture of 1.5 years and LCF of 200mm. Under heavy fishing (F=0.9) it is achieved by an age at first capture of 7 years and 460mm LCF. Obviously there is greater egg production at 350 mm than 250 mm length at first capture for all levels of fishing effort. However, at F=0.15 the increase in egg production is only 30%, at F=0.9 the increase is over 300%.

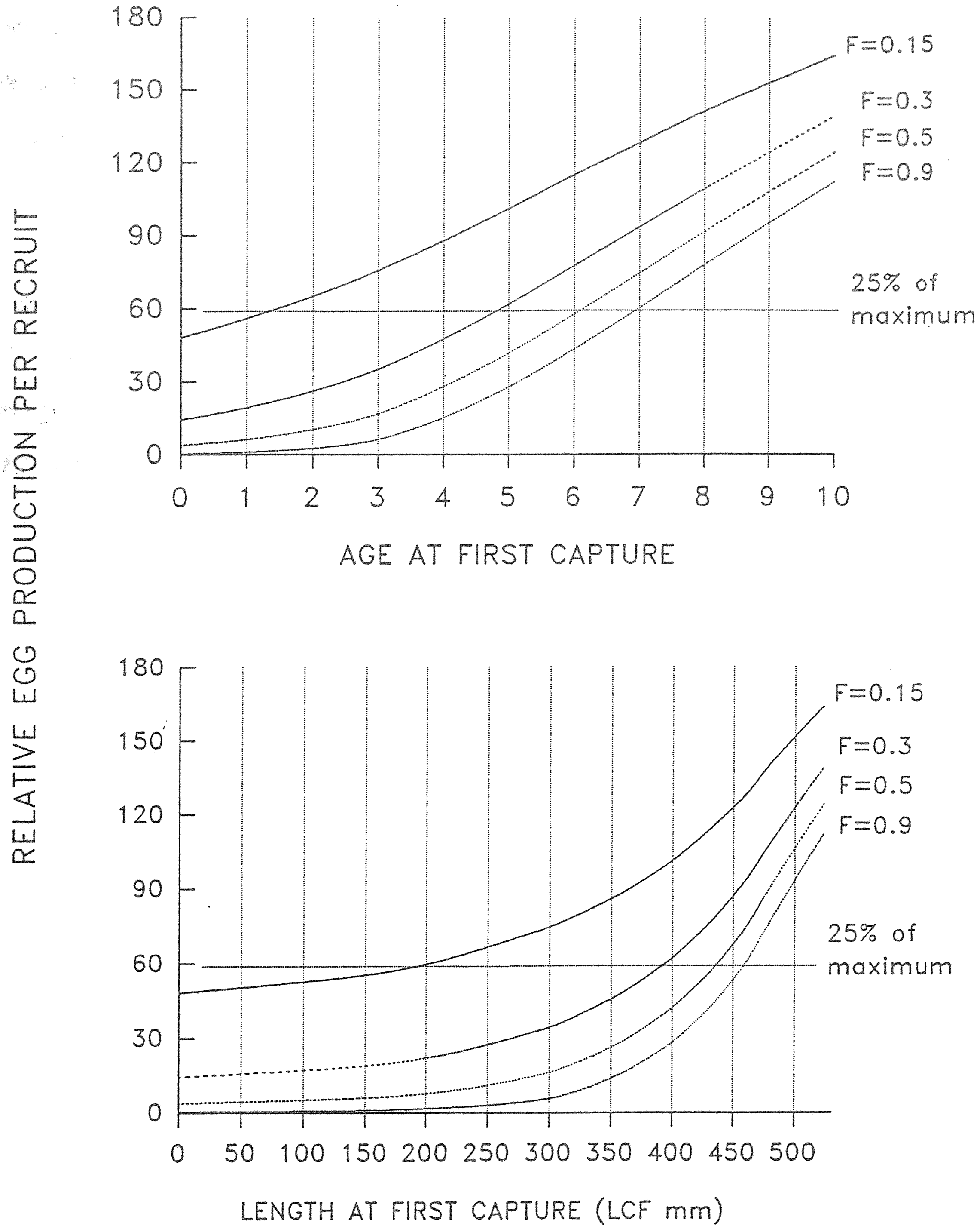


Fig. 19. The effect of age and length at first capture on the eggs per recruit of *Lethrinus nebulosus*, at various levels of fishing mortality F.

Recommended increase in minimum size for *L.nebulosus*

The existing minimum length for *L.nebulosus* of 280mm total length (=250mm LCF) is well below the size at reproductive maturity for the species. Yield per recruit analysis shows that the maximum yield for fishers is obtained by sizes at first capture of 350 to 430mm LCF. Egg per recruit analysis indicates that this range of size at first capture results in egg production of 25% of the maximum at moderate levels of fishing mortality (F=0.3-0.5). An increase in minimum legal length for the species is clearly warranted.

The minimum legal length for two other large species caught together with *L. nebulosus*, pink snapper and red emperor, is 410mm total length. For practical reasons, i.e. making it easier for the public to remember, 410mm would be a good choice for *L.nebulosus* too. This corresponds to 367mm LCF which is close to the length at maturity and within the optimum range for yield per recruit. To achieve 25% of reproductive capacity with this length at first capture, fishing mortality would have to be kept down to less than F=0.3.

An increase in minimum legal length of *L.nebulosus* in Western Australia to 410mm total length has been recommended and will be implemented in 1994.

Limited entry trap fisheries

The Pilbara trap fishery became a limited-entry fishery in May 1992. More boats gained entry to the fishery than it was thought that the fishery could support. The limited-entry licence was made non-transferable for the first three years and transferability would then be reviewed. Performance criteria were specified so that vessels which effectively left the fishery, i.e. did not continue to do a minimum level of fishing, would lose their licences. The number of vessels licensed for the fishery has fallen already and by May 1995 it is hoped that it will have fallen to the level that the fishery can support indefinitely. The other main management measure for this fishery is the restriction to off-shore areas. It is likely that a limit of 20 traps per boat will be implemented in 1994 but this is more than the existing boats use and is mainly for consistency with the Kimberley trap fishery.

The Kimberley trap fishery has been subjected to an interim freeze on the number of vessels licensed until a long-term management plan is formulated. The Kimberley fishery is characterised by a scarcity of ports and some fishing grounds are very remote. There is a limit of 20 traps per boat on the grounds closest to Broome. These closer grounds are thought likely to be overfished if the whole fleet concentrates there. To encourage utilisation of the more remote grounds, the trap limit has been increased to 30, and in the most remote grounds, carrier boats have been allowed on a trial basis to reduce the frequency with which the catching boats need to return to port.

Development fish trawl fishery

The Pilbara Fish Trawl Fishery has the status of a development fishery in which the number of boats is limited but the endorsed boats do not have tenure of access. The effects of trawling on the benthic fauna of sponges, gorgonians and soft corals is being investigated. A research project has begun to measure the fishing mortality of major species in the fishery and relate it to the trawl fishing effort. The management plan for the fishery at the end of the development phase will be based on the results of these projects.

Other lethrinid fisheries

The lethrinids, in particular *L.nebulosus*, are the predominant species in the recreational fishery on Ningaloo Reef. While it is not possible to limit the number of fishers in a recreational fishery as it is in a commercial fishery, special bag-limits have been introduced for Ningaloo Marine Park and these will be periodically reviewed. Commercial fishing is still occurring in the off-shore waters of the Ningaloo Marine Park but this will be slowly phased out.

Commercial line-fishing for lethrinids on the remainder of the west coast is unrestricted apart from the general freeze on fishing boat licences in Western Australia and the policy is that it should remain so. While it is recognised that there are too many line-boats for them all to be viable, there must be an area for those boats to work that did not qualify for any of the managed fisheries. The mechanism by which the number of boats will be reduced in the long-term is a buy-back scheme jointly funded by industry and the government.

Measures are in place to reduce fishing effort where required in the commercial fisheries on lethrinids in Western Australia. The correct level of fishing effort for the lethrinids and the other species in these multi-species fisheries is being researched in only one fishery at present. Research is required to determine optimum effort levels for the other fisheries, and also on the biology of the main west-coast lethrinid, *L. miniatus*, to establish an appropriate minimum length for this species which is not protected by fishing effort controls.

ACKNOWLEDGEMENTS

We thank the many people who helped with the various aspects of this research. Commercial fishers Paul Copeland, the Cassidy family, Mick Manifis and Andy Young provided samples. Fisheries Officers Shane O'Donohue, Eric Laughton and Alan Breeden, skipper Theo Berden and the crew of RV "Flinders", and CALM Officers Barry Cartilage and Steve helped with field work. Mark Rossbach, Rob and Jo Tregonning, Chris Bird, Stuart Blight and Rick Fletcher helped with field and lab work. Dianne Baird, Jenny Moore, Rachel Caldwell, Janus Smajdor, Marie Wapnah, Wilf Lehre and Tina Thorne helped with lab work and data-entry. Karina Bakich and Gabrielle Nowara helped with data analysis, Drs Jim Penn and Rod Lenanton with advice and Kevin Carhart's team with administrative support.

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