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RESEARCH FOR ALLOCATION OF NORTH WEST MARINE FINFISH RESOURCES AMONG DIVERSE USER GROUPS.

FRDC PROJECT 91 / 28

FINAL REPORT - December 1995

by
M.Moran
J.Jenke
G.Cassells
G. Nowara

WESTERN AUSTRALIAN MARINE RESEARCH LABORATORIES

INTRODUCTION

The Australian marine finfish industry exploiting demersal scalefish in the north west shelf operated at a very low level, using handline only, until the introduction of trapping in the mid-1980s. Recreational fishing also intensified in the 1980s, being particularly heavy in the Shark Bay and Ningaloo regions and Dampier Archipelago. This period also saw increasing interest in conservation with one marine park declared and several others proposed.

During the 1980s the Taiwanese pair-trawl fishery on the NW Shelf gradually reduced its effort and the area where foreign trawling was permitted was progressively reduced by the Commonwealth Government as Australian interest in using the tropical finfish resource developed. Initially, fish trapping was introduced to the NW Shelf by Shark Bay Snapper fishermen but was soon adopted by local handline fishermen. Subsequently, prawn trawl fishermen on the Pilbara coast saw the potential for fish trawling using modified prawn trawl vessels. Throughout this period, a number of charter boat operations had continued, usually working as commercial handline boats when there were no charters.

Commercial fishing of the Australian North-west Shelf began in the early 1960s with a Japanese stern trawl fishery targeted on lethrinids in the area north of Dampier. The lethrinid stocks were depleted in a few years and the fishery ceased. A Taiwanese pair-trawl fleet began fishing in the early 1970s over a wider area but with the centre of fishing effort again north of Dampier and retaining a much wider range of species (Jernakoff and Sainsbury, 1990). The pair-trawl fishery peaked in both catches and fishing effort in the early 1970s and its access to the grounds was progressively restricted over the period 1986-1990 after which foreign fishing on the NW Shelf ceased.

Australian vessels began trapping on the NW Shelf in 1984 and stern trawling in 1989. The trawl fishery has since expanded rapidly. As the commercial finfish fisheries developed and intensified, the Western Australian Government moved to limit the number of licences for each fishery.

In managing the trap and trawl fisheries, some protection has been given to the inshore areas which are more accessible to recreational, charter and commercial handline fishing through inshore closures. Nevertheless, sources of conflict are generally perceived by the less efficient recreational, charter and commercial handline fishers against the more efficient trap and trawl methods. Concerns that have been expressed include:

- that trap and trawl fishing are over-exploiting species and localities important to recreational fishing;
- that traps and trawls destroy the habitat, and thence the fishing;
- that prawn trawlers catch and trash juveniles of important recreational and commercial species;
- that traps and fish trawls catch juveniles of important species;

The objectives of this project were to provide information to managers for rational allocation of access to the marine finfish resources of NW Australia. The management aims are to minimise conflict between user groups; maximise efficiency and viability of the industry; and ensure sustainablility by limiting the impacts of fishing on the stocks and their supporting environment. Specifically, this project aimed to:

1. Estimate the degree of overlap in resource usage among the diverse commercial and recreational user groups of the north-west marine finfish stocks.

2. Relate the degree of damage sustained by the habitat, to the level of trawling or trapping effort, using standard and "low-impact" gear designs.

3. Investigate the distribution of juveniles of major species, and the vulnerability of juveniles to the various gear types.

The date set for completion of the project was 30 June 1994 and all of the actual data gathering was complete by that time. A number of factors have however affected the time to finalise this report. The research scientist in charge of the project was transferred to a policy position in the Fisheries Department in late June 1994 and has had limited time available to devote to analysis and writing up. Objective 2 required development of new techniques using underwater video in the field and in analysis of the video material back in the laboratory. Development of these techniques has of necessity continued after the end of the project period. Interaction between the project leader and managers of the fisheries involved has, however, occurred throughout the project and results have been used in the management of the fisheries as they became available.

Interim results of this project have led to the timely identification of the need for specific projects on the relationship between fish trawl effort and fishing mortality to enable management to prevent serious overfishing in the Pilbara trawl fishery; and to gather the basic data on the resource in the Kimberley demersal fishery.

This project did not attempt to study the developing Australian shark fishery in the north-west, nor the troll fishery for spanish mackerel and related pelagic species.

It is anticipated that the results of the project will be formally published in full detail as a series of Western Australian Fisheries Department research reports.

OVERLAP IN RESOURCE USAGE AMONG THE DIVERSE COMMERCIAL AND RECREATIONAL USER GROUPS OF THE NORTH-WEST MARINE FINFISH STOCKS

INTRODUCTION

There has been in the past, and continues to be, a perceived overlap in the use of demersal finfish resources in the northern half of Western Australia which the users of the less powerful fishing methods see as being to their detriment. Recreational fishers generally view all commercial fishermen as responsible for catches not being as good as they used to be. They focus especially on trap and trawl fishing which they see as being destructive to habitat as well as taking large quantities of fish, and on prawn trawling which they are aware incidentally takes small fish of a variety of species which they assume are juveniles of their target species. Many commercial line and charter operators share the recreational fishers' views of trapping and trawling.

An objective of this project is to provide factual data on overlap between user groups in terms of species fished and areas fished. We were also seeking evidence of downstream effects, for example one user group taking young fish which, if they were allowed to survive, would form a major part of the catch of another user group.

The methods used were analysis of logbooks and monthly fishing returns of commercial operators; interviews with recreational fishers; and sampling of catches both for species and size composition. The area studied was the extensive coastline between Shark Bay and Broome.

Previous work on the major finfish species had established that, although there was evidence that adults of major species tended to remain in a particular locality, there was no evidence that any of the species was divided into smaller stocks in the genetic sense (Johnson et al. 1993). This means that unless different user groups are actually fishing the same grounds, they are probably not competing directly with each other for adult fish. However, if any group depletes a population of fish to the extent that the reproductive output of that population is seriously reduced, any consequent reduction in recruitment of young fish is likely to affect all users, whether or not they are fishing the same grounds.

The results are presented by region as direct effects of competition for the resource are likely to be confined to within a region. The regions are:

Shark Bay	23°30'S to 26°30'S
Ningaloo	23°30'S to 114°E
West Pilbara	114°E to 116°E
East Pilbara	116°E to 120°E
Kimberley	120°E to 129°E

SHARK BAY REGION

The major demersal finfish resource in the Shark Bay region, 23°30'S to 26°30'S, (Fig. 1.) is the pink snapper, *Pagrus auratus*. A commercial fishery has focussed on this species at least since the 1950s and large catches of snapper are mentioned in the early exploration reports and throughout the written history of Shark Bay. There is an unusual situation whereby the truly marine stock of snapper is a separate breeding stock from the stocks in the inner gulfs of Shark Bay (Johnson et al., 1986). The commercial fishery on the marine stock has been managed as a limited entry fishery since 1987 and the catch limited by partial quota management since 1988. The commercial snapper fishery has been stable since the introduction of quotas with annual catches of 500-530 tonnes.

The snapper fishery began as a seasonal (winter) handline fishery on breeding aggregations close to the mainland and the islands which bound Shark Bay. Trapping for snapper was started by rock lobster fishermen in 1959 and has been controversial for decades. The (non-transferable) permits to trap snapper were limited when the management of the fishery began in 1987 and, with licence transfers, the number of boats permitted to trap has fallen to one. The one boat permitted to trap does not do so, as the premium quality snapper required by the export market cannot be produced by trapping. The commercial fishery is now a mechanised handline fishery.

Other major demersal species taken in the commercial line fishery are lethrinids (sweetlip emperor, *Lethrinus miniatus*; spangled emperor, *L. nebulosus*; and lesser spangled emperor, *L. choerorynchus*); serranids (Estuary cod, *Epinephelus coioides*; and rankin cod, *E. multinotatus*); lutjanids (red emperor, *Lutjanus sebae*) and a variety of carangids (trevally). The recreational and charter fisheries take the same species, in similar proportions. Although they also take mainly pink snapper, there is

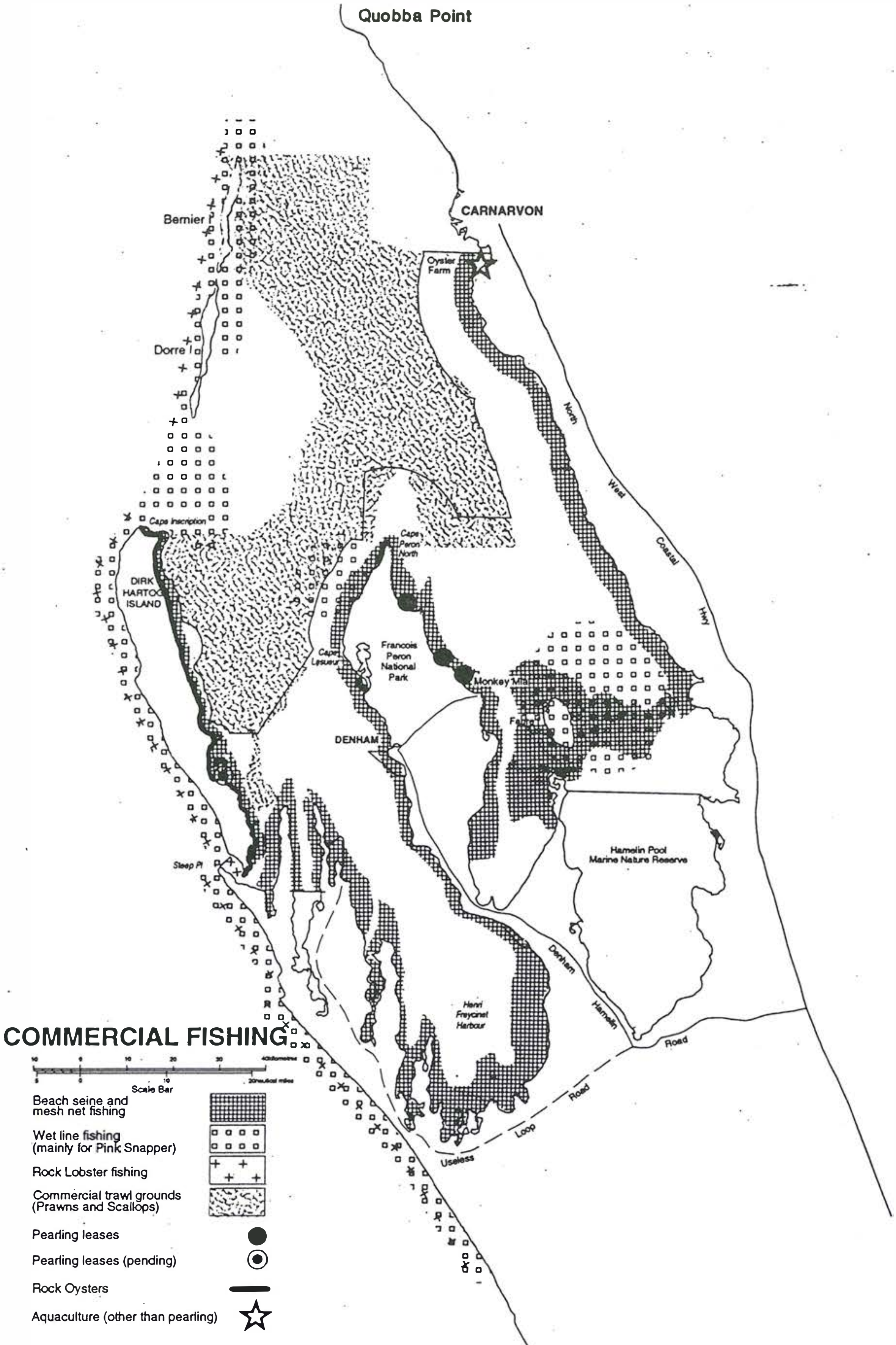

Fig.1. The distribution of various types of commercial fishing in Shark Bay.

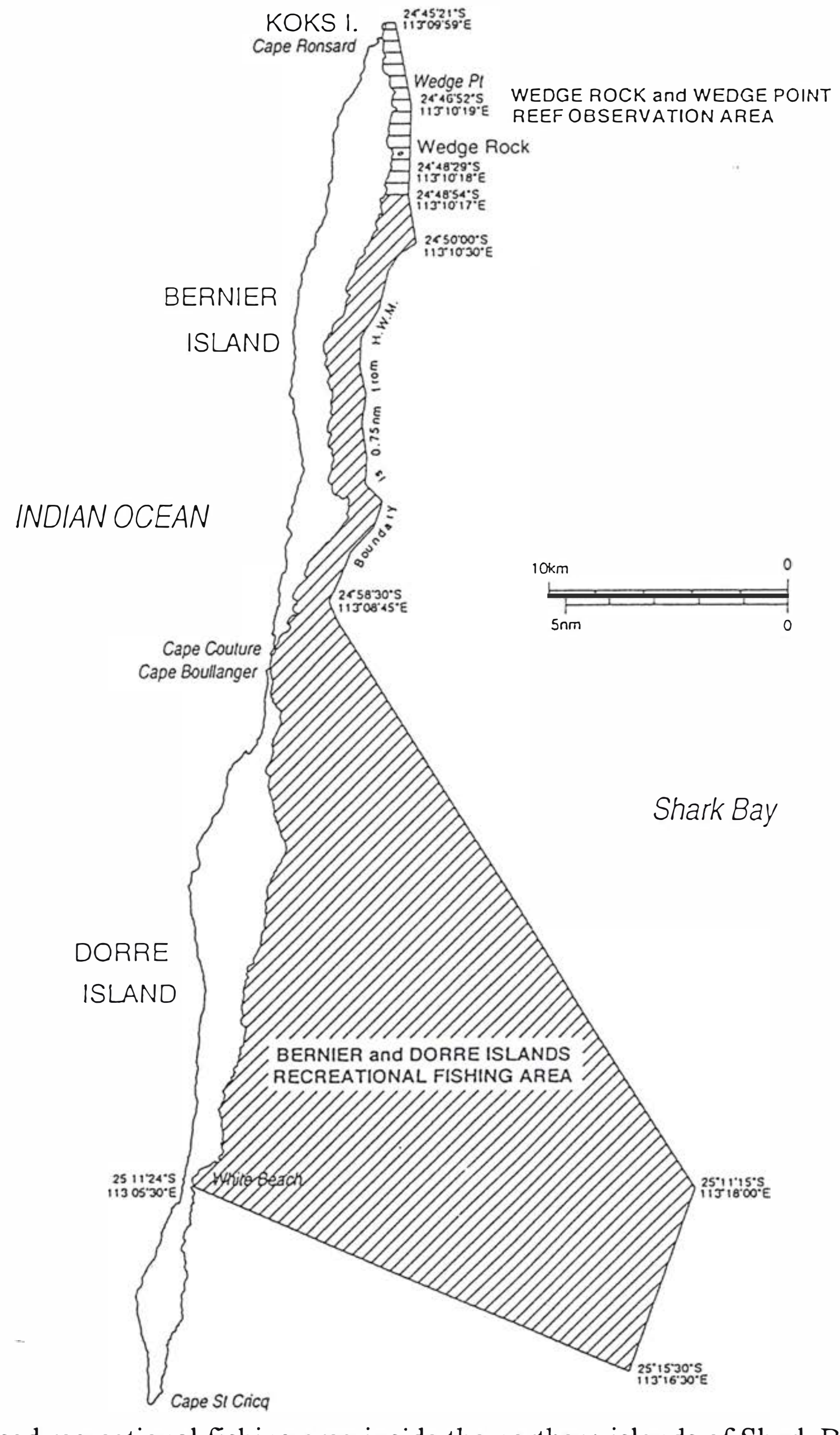

Fig. 2. Proposed recreational fishing area inside the northern islands of Shark Bay

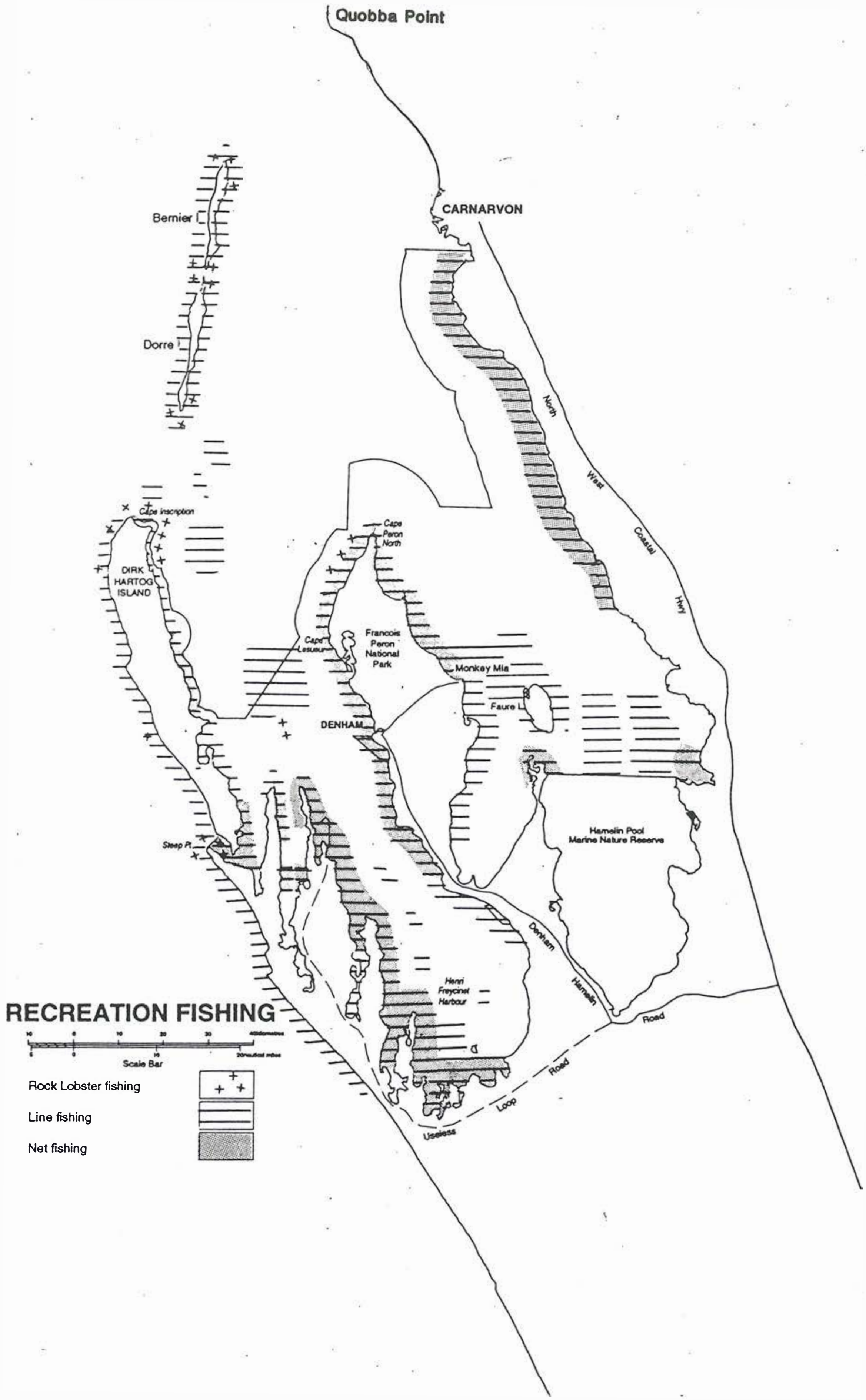

Fig. 3. The distribution of various types of recreational fishing in Shark Bay.

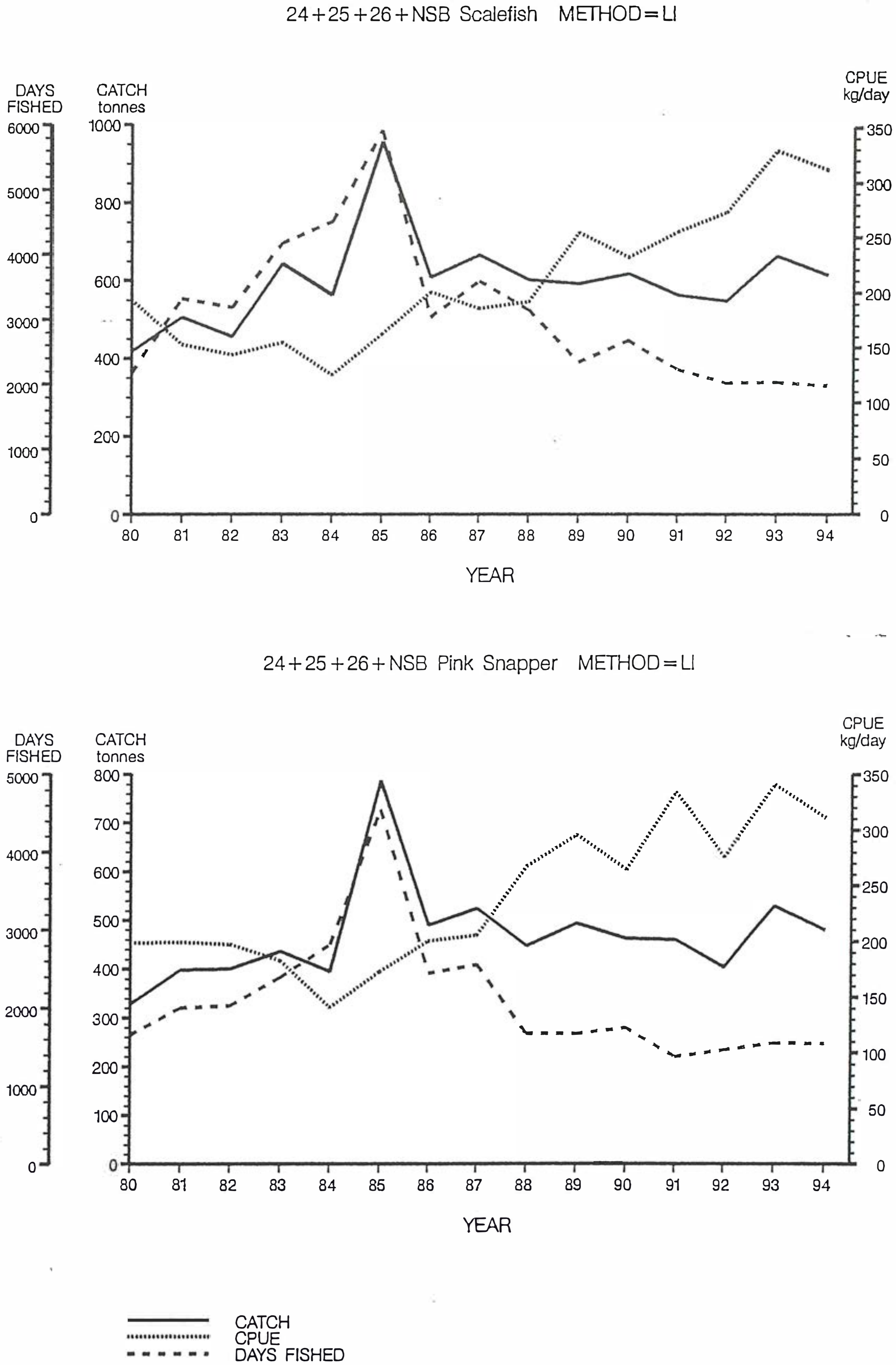

Fig 4. The commercial line fishery in Shark Bay, catches, effort and catch per unit effort by year for all scalefish and for pink snapper.

a bag limit on reef fish (snapper, lethrinids, lutjanids) so that when they have their bag limit of these, recreational fishers will try for a big cod to top off their catch. Recreational fishers also catch a small, numerous serranid, the chinaman cod *Epinephelus rivulatus*.

The best fishing grounds for demersal scalefish are around the islands, 20 to 30 n miles offshore, that bound Shark Bay; though the coastal reefs around Pt Quobba and northwards are also good and worked mainly by recreational fishers. Although there have been no restrictions on commercial fishing areas in the past, the commercial fishermen have always fished more than five miles offshore. The commercial fishermen fish as far as 20 n miles outside the island chain but the recreational and charter boats rarely fish more than 5 miles outside the islands. As part of the World Heritage plan for Shark Bay, the commercial fishermen have voluntarily suggested a recreational fishing only zone inside Dorre and Bernier islands (Fig 2.). The main grounds for marine fishing by commercial line, recreational and charter boats are around Koks Island off Carnarvon, and Turtle Bay off Denham (Figs 1 & 3). Tourism, which in the Shark Bay area is focused largely on recreational fishing, peaks in winter as people go north from southern WA to the warmer weather and also the area tends to be very windy and hot in the summer. The main recreational season therefore straddles the snapper spawning season and the catch-rates from the snapper aggregations on the main fishing grounds are high enough that bag limits are usually caught.

The commercial fishery for the main fish species in the region is conservatively managed and, to date, the fish are sufficiently abundant that there is little direct competition between the linefishing groups for the resource and no indirect competition through depletion of spawning stocks.

One species catchable by traps and lines, the lesser spangled emperor, *Lethrinus choerorynchus,* may be under-exploited in the Shark Bay area. Although in the Pilbara trawl fishery this is a major species, in the trap and line fisheries it is a marginal species considered not worth targeting as the price is generally low, though it is retained if caught incidentally while targeting other species. This may be a good resource in the future if markets improve.

There is currently no fish trawling permitted in the Shark Bay region. There have been a few brief fish trawling ventures in the past. In 1977 "Miss Boomerang" trawled the schools of snapper in the spawning season, taking 30% of the total snapper catch for that year. Although it caught a lot of snapper, the price obtained for the product was low and the costs of running this very large boat were high. In the mid 1980's two prawn trawlers worked the finfish grounds, taking good catches of a range of species.

Although some of the main species taken by the trawlers, pearl perch *Glaucosoma burgeri* and frypan snapper, *Argyrops spinifer*, are rarely taken by trap or line, the fish trawling was prohibited because species important to the line fishery were also taken. These species are a virtually unexploited resource in the area off Shark Bay.

Line fishermen have expressed concern that the prawn and scallop trawlers take juveniles of commercial finfish species. Sampling of prawn trawls has revealed that small quantities of pink snapper are taken in many areas of the grounds. Other commercial species taken are bream, *Acanthopagrus latus*, and lesser spangled emperor which is by far the most abundant commercial or recreational fish species in the trawl bycatch. All these species are taken as 0+ or 1+ juveniles. Much more abundant again than the lesser spangled emperor are other lethrinids of very small species such as *Lethrinus nematacanthus* which have never been of any interest at all to Australian commercial or recreational fishers but formed an important part of the Taiwanese trawl catch on the NW Shelf.

As these small fish have been part of the trawl fishery bycatch for many years, and their abundance in the bycatch is apparently not decreasing, it does not appear that the trawl fishery is affecting the reproductive output of these stocks. Whether the abundance of snapper and bream available for line and seine catches as adults would increase if their juveniles were not taken by the prawn trawlers is unknown.

NINGALOO

The major fishery in the Ningaloo region, 23°30'S to 114°E, (Fig 5) is the recreational fishery. Most of the fishing is done from dinghies and small boats by people holidaying by the marine park or resident in Exmouth. The main species are lethrinids and serranids. The target lethrinid species is generally the large spangled emperor *Lethrinus nebulosus*, however the smaller species *L. choerorynchus*, *L. atkinsoni* and *L. rubrioperculatus* are also frequently taken. The most numerous species are the small chinaman cod, *Epinephelus rivulatus* and the similar black-tipped cod, *E. striatus*. Coral trout, *Plectropomus maculatus*, and tuskfish, *Choerodon spp.* are minor but highly valued components of the catch. Various

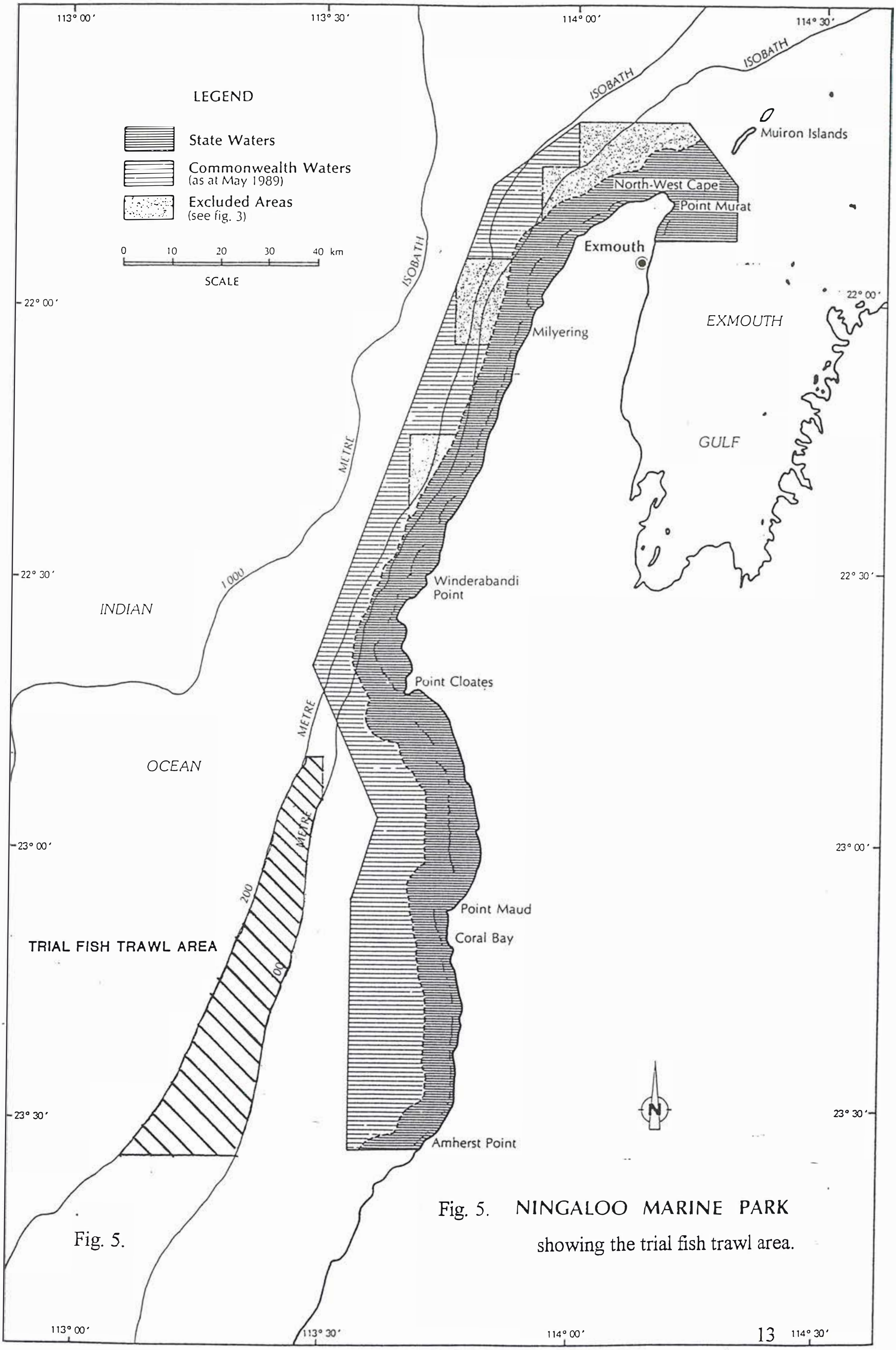

Fig. 5. NINGALOO MARINE PARK
showing the trial fish trawl area.

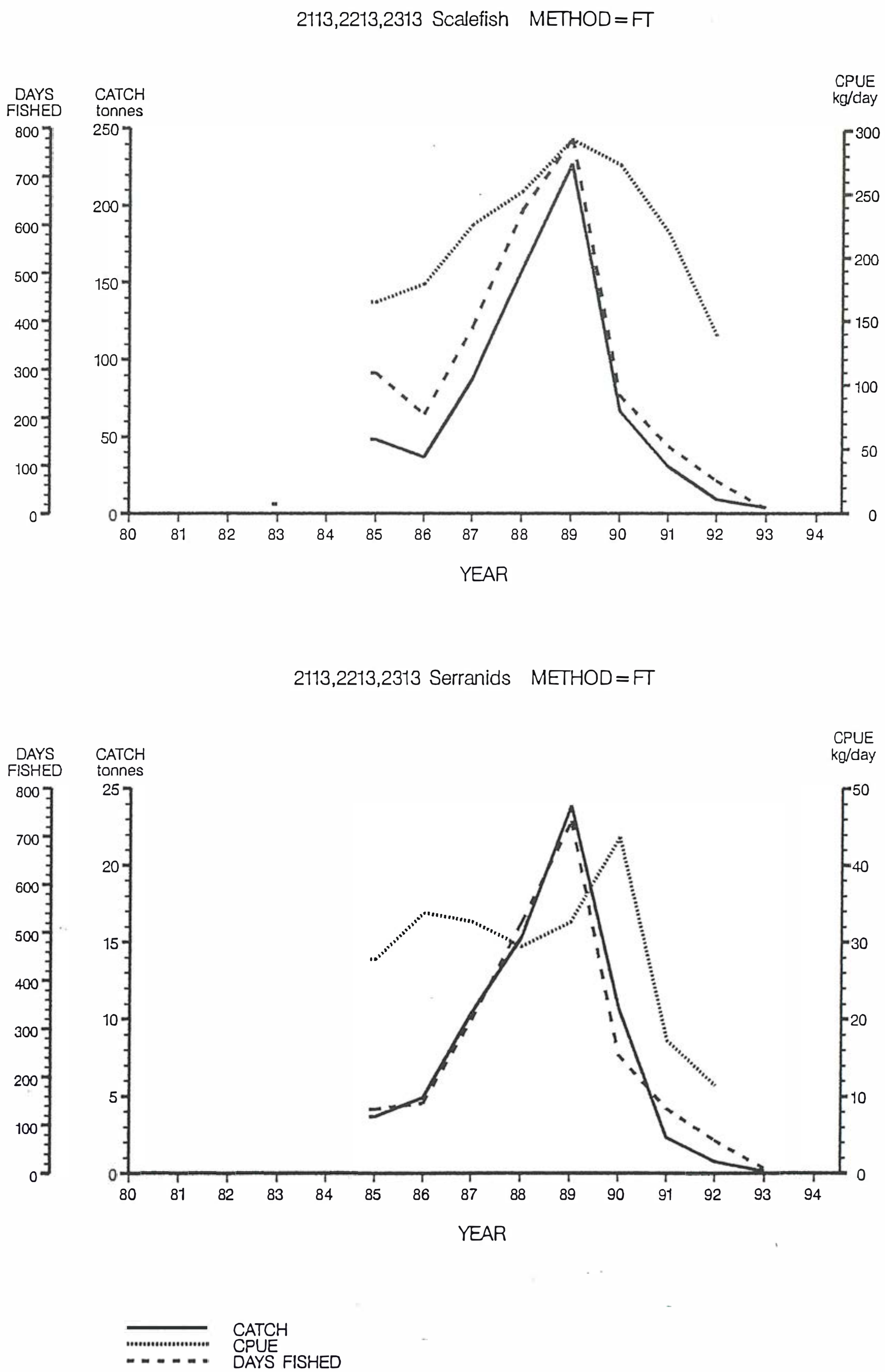

Fig. 6. Time series of catch and effort by fish trap off Ningaloo, all fish and serranids.

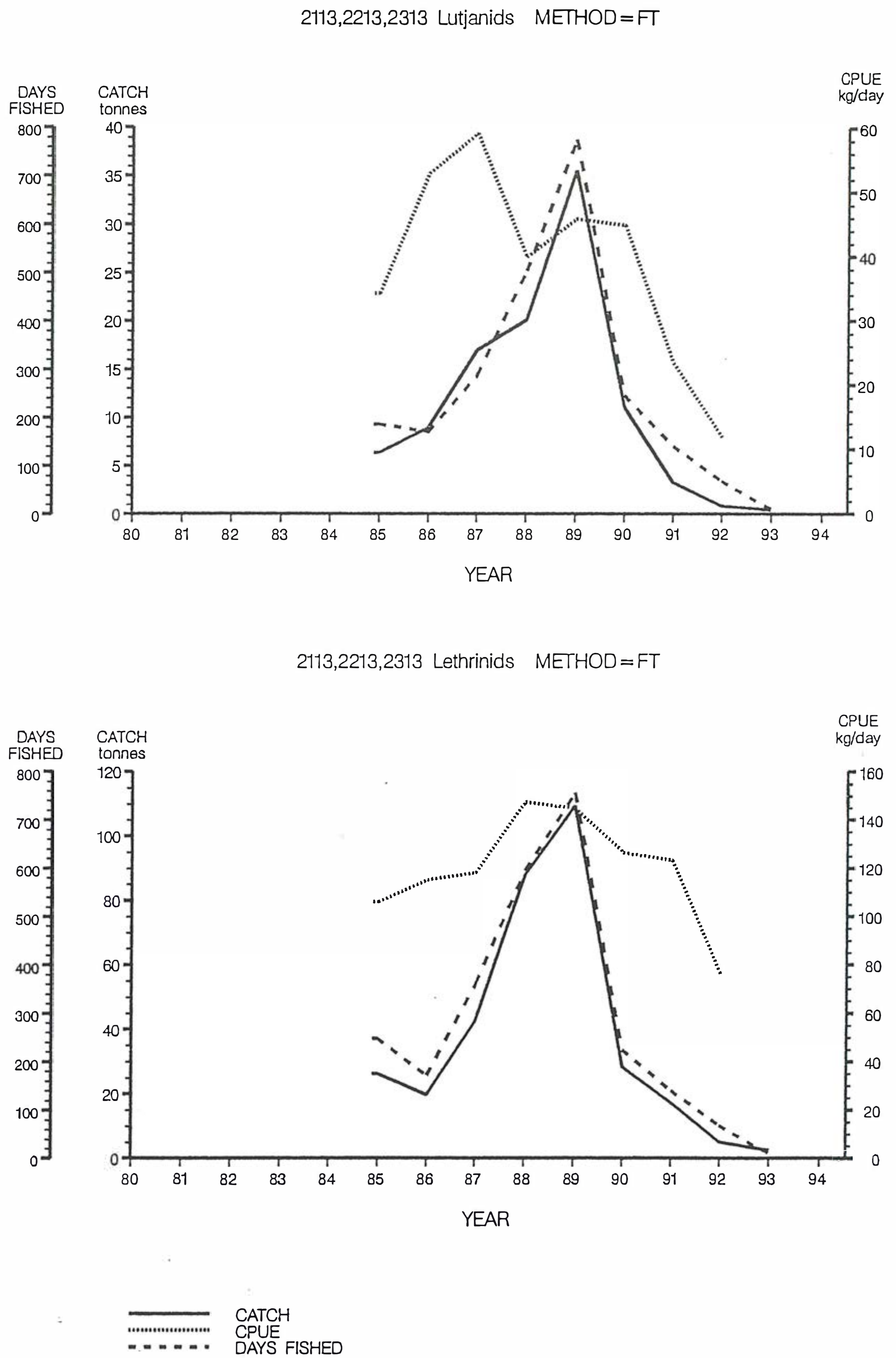

Fig. 7. Catch and effort by fish trap off Ningaloo, lutjanids and lethrinids.

NINGALOO RECREATIONAL FISHING

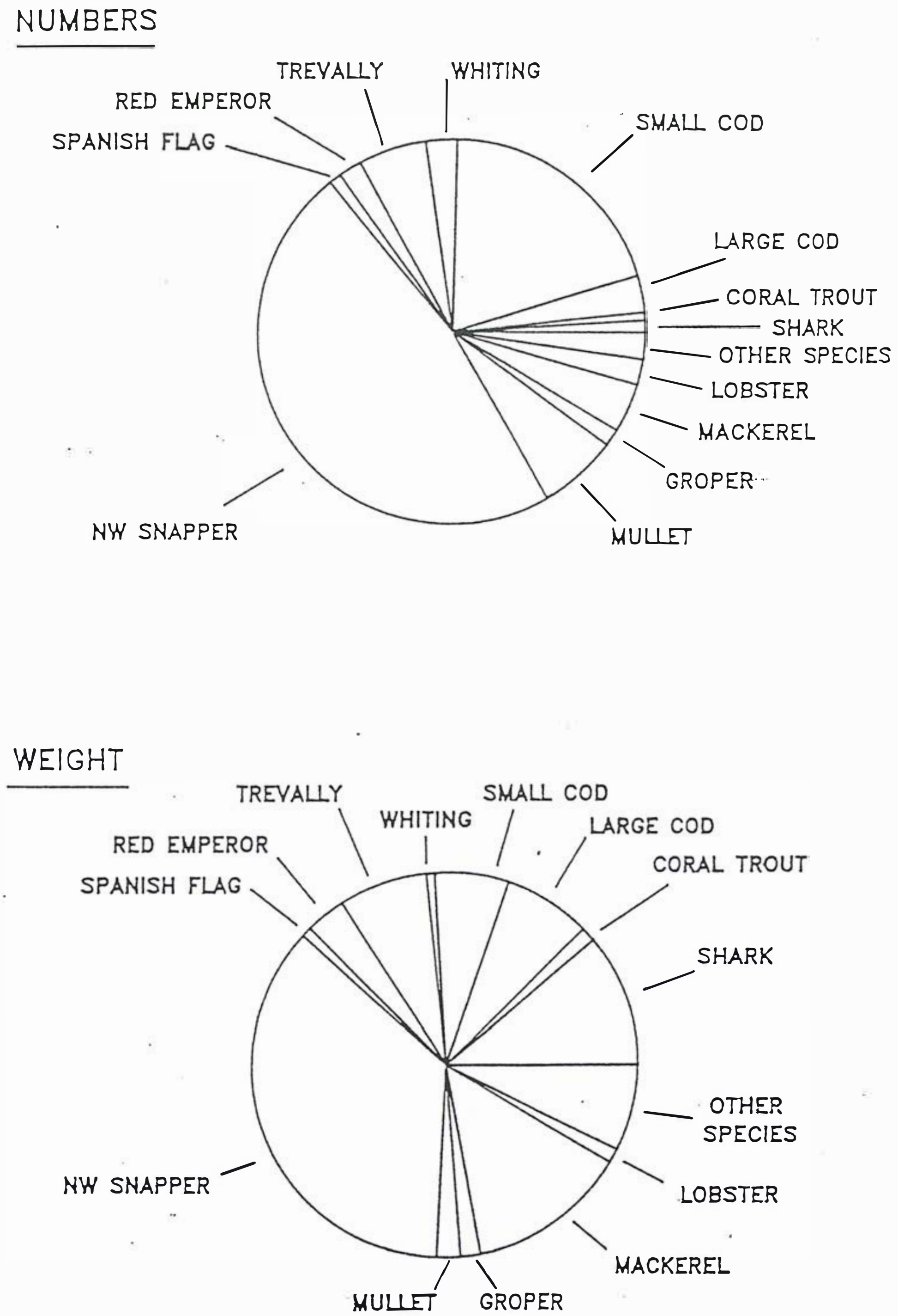

Fig.8 Total catch of the interviewed sample by species–groups: A. numbers of fish, B. weight of fish.

trevally species such as the golden trevally *Gnathanodon speciosus* are also taken in quantities.

A great deal of the recreational fishing is done on or inside the Ningaloo reef line. Charter boats take recreational fishers farther out to sea and other species such as sweetlip emperor *Lethrinus miniatus,* red emperor *Lutjanus sebae* and rankin cod *Epinephelus multinotatus*, are added to the catch.

The charter boats, based at Exmouth and Coral Bay, are the biggest section of the commercial fishery at Ningaloo. They also do charters for divers, viewing tours on whale sharks and commercial line fishing. When line-fishing commercially, they take the same species as the recreational fishers but concentrate on the larger species such as spangled emperor, sweetlip emperor, red emperor, rankin cod and coral trout.

Management of the Ningaloo Marine Park has included more stringent bag limits than elsewhere in the state, and a possession limit which is likely to have a greater effect than the bag limit on fishing mortality in the region from small boat and charter boat recreational fishing. There are also sanctuary areas where no fishing is permitted.

In the mid to late 1980s there was considerable fish trapping in the waters outside Ningaloo reef, mainly because in 1986 and 1987 the Shark Bay snapper fishery was closed for July. Some of the snapper fishermen would work Shark Bay in June, move north to Ningaloo in July, then back to Shark Bay in August. A small number of boats continued for a few years then stopped due to low catch rates. Major species were sweetlip emperor, red emperor and rankin cod.

Recently one fish trawler which operates in the Commonwealth-managed deep water trawl fishery in waters deeper than 200 metres was granted permission on a trial basis to work in an area off Ningaloo, outside of the marine park, in waters between 100 and 200 m depth (Fig 5). While a small part of the trawler's catch is similar in composition to the inshore commercial line and charter boat catch, the bulk of the catch is deep water species such as jobfish (*Pristipomoides* and *Etelis spp*.), frypan snapper and pearl perch.

Of the fisheries in the Ningaloo region, the greatest overlap in species composition and grounds worked is between the recreational charter fishery and the commercial line fishery. The same boats do both types of fishing. The trap fishery would overlap completely with these also if it began to operate again. The fish trawler has little overlap in species with these fisheries and virtually none with the recreational small boat fishery. It has no overlap in terms of area worked. While there is some concern about the trawler from recreational fishers, this is based on misunderstanding at seeing the trawl catch unloaded over the beach at Coral Bay rather than any real source of conflict.

There is plentiful anecdotal evidence that the recreational fishery inside Ningaloo reef is nowhere near as good as it used to be. Apparently a decade or so ago, one could catch a bag limit of large spangled emperor within half an hour on virtually any evening. Now only a small proportion of people take their daily bag limit. However, the recreational fishing there now is still excellent by most standards.

Of greater concern is the possible depletion of the nearshore stocks on the continental shelf outside the reef by fish trapping in the late 1980s. While the evidence for this is not conclusive, it is worth bearing in mind in considering long-term access for fish trapping in this area where the continental shelf is narrower than anywhere else on the WA coast.

WEST PILBARA

The west Pilbara region, 114 - 116° E, contains Zone 1 of the Pilbara Trap Fishery (Fig 9). Trap fishing began in this area in 1984 as an offshoot of the Shark Bay snapper fishery and rapidly took over from commercial line fishing as the major finfish fishery. The trap boats operated in a similar manner to the line boats before them. The skipper would look for promising ground with his echo sounder; this meant hard bottom, preferably a lump or ledge which provided the vertical relief to attract reef fish; he would fish there for a few hours or days until the catch rates fell, then look for another lump.

The area from NW Cape up to Rankin Bank has many lumps and edges and patches of hard ground, but a much greater area of poor ground where aggregations of fish worth line or trap fishing are not found. The trap fishery continued at a steady level through the mid 1980s then saw a big increase in catch and effort for a few years before falling to a low level. Many fishermen virtually stopped fishing or moved on to more easterly regions and generally considered the trapping grounds depleted. The introduction of limited-entry management came after the peak and subsequent decline in trap fishing.

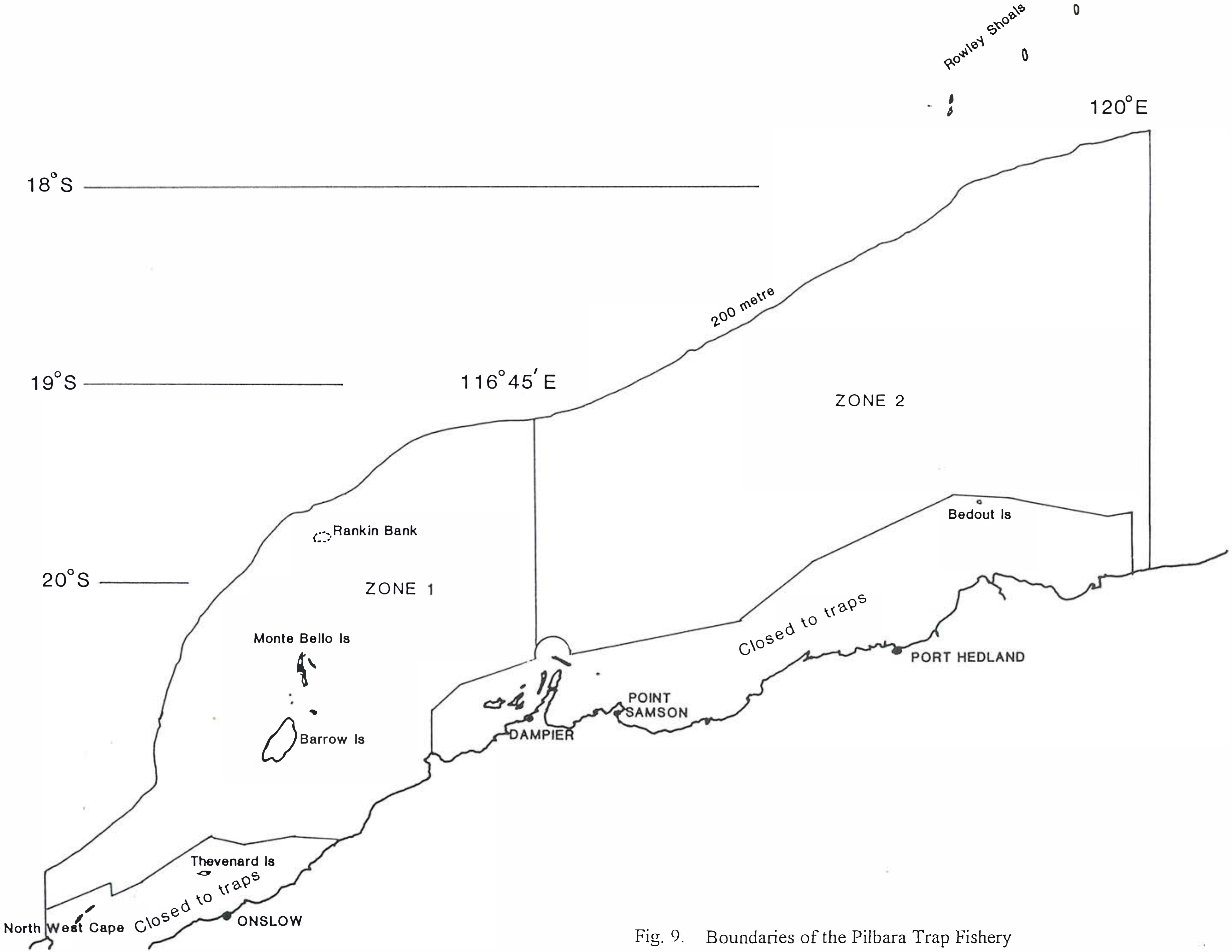

Fig. 9. Boundaries of the Pilbara Trap Fishery

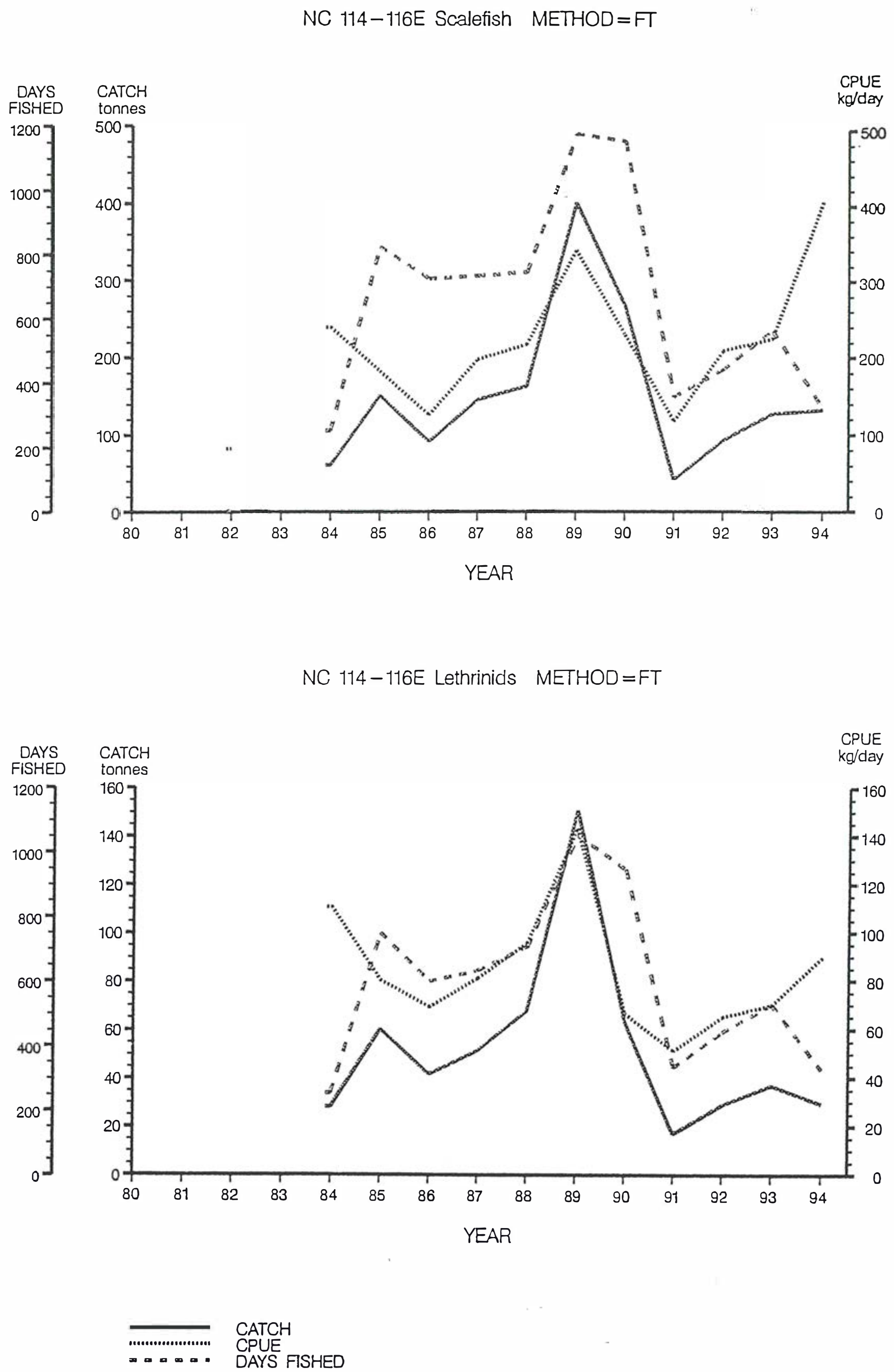

Fig. 10. Time series of catch / effort by fish trap, West Pilbara: all fish and lethrinids

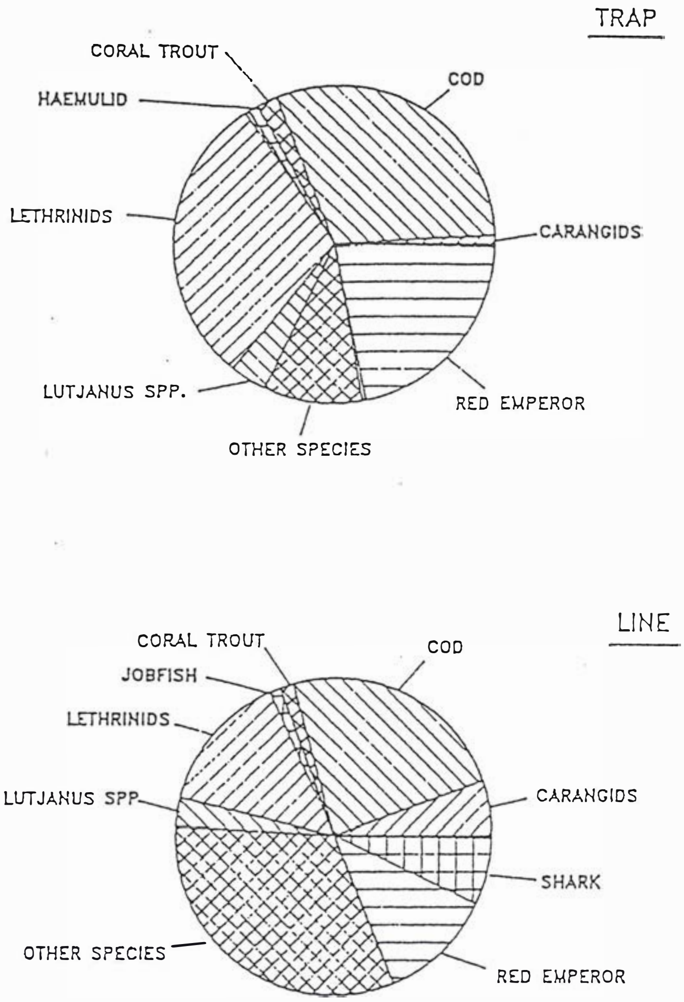

Fig 11. Comparison of species composition of the trap and line catches, West Pilbara, 1990.

PILBARA TRAP 114-116E

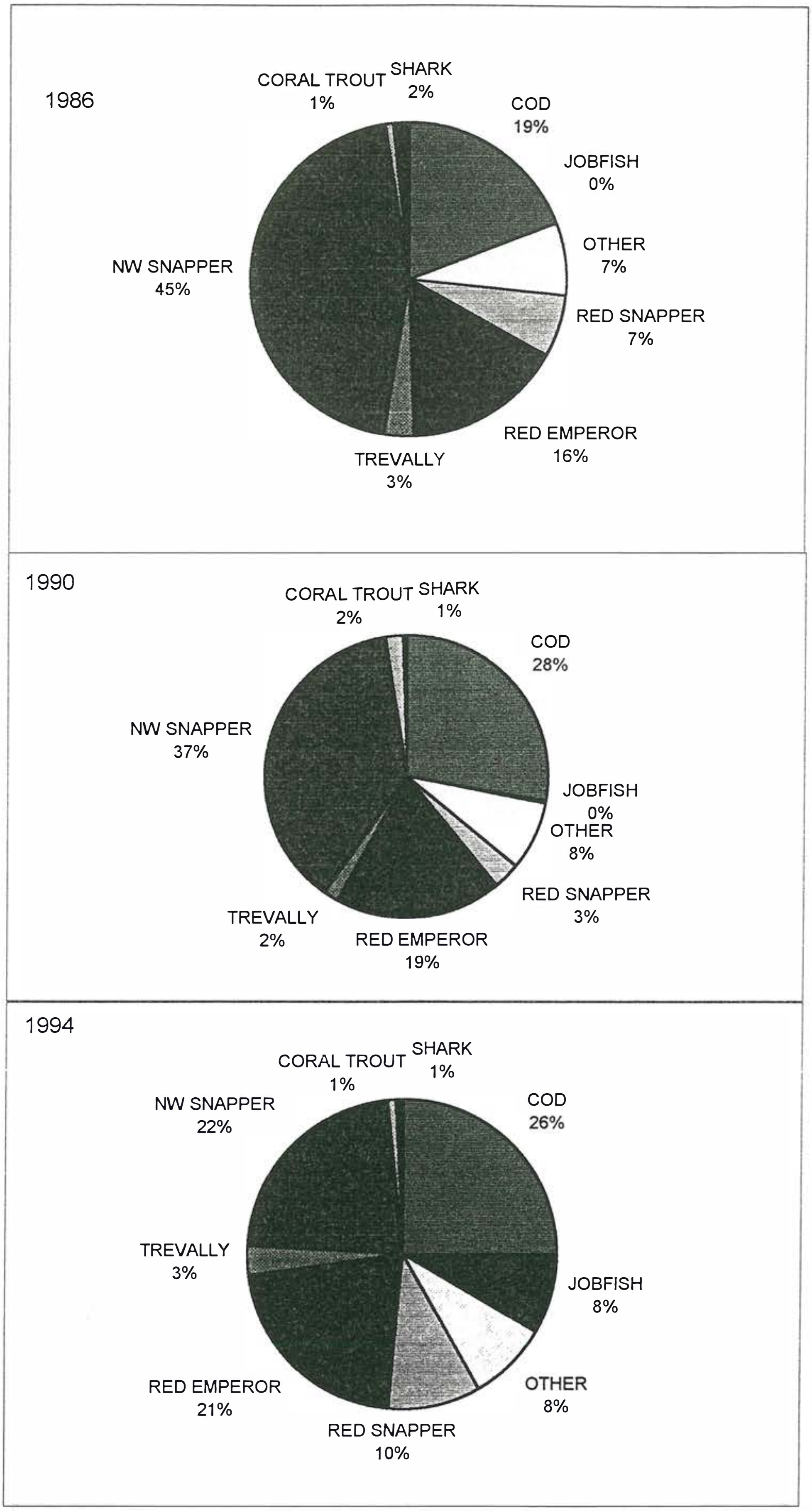

Fig 12. Species changes through time. West Pilbara.

Both Onlsow and Exmouth had trap boats and charter/commercial line boats in the mid to late 1980s, with Onslow being the main trap centre and Exmouth the main charter boat centre. Charter boat owners have generally viewed trap boats as potentially or actually over-depleting the demersal fish resource, though a few charter boats switched to trapping for a time. The two groups fish the same type of ground and take the same species of fish. Now there is little fish trapping out of Exmouth and the grounds between 114 and 115°E are worked mainly by the charter/commercial line boats while the grounds between 115° and 116°E are worked more by trap than charter boats. The main species are large spangled emperor, *Lethrinus nebulosus*, red emperor *Lutjanus sebae* and rankin cod *Epinephelus multinotatus*. Smaller species of lethrinids, lutjanids and serranids are also important in the catch and as in Shark Bay, greater catches of *Lethrinus choerorynchus* could probably be taken if there was sufficient market demand.

There is an inshore closure to trap fishing to protect the line fishers from competition by the trapping boats (Fig 9). Inside this closure are the islands which run in a chain from NW Cape up to Barrow Island. In addition to the charter boats, recreational fishers in small boats fish around these islands from both Onslow and Exmouth, with one island (Thevenard) having a holiday camp where recreational fishers stay. The recreational catch is the same in species composition to the charter and commercial line fishing catch. The trap boats catch the same species but also catch some large lutjanids such as *Lutjanus malabaricus*, *L. erythropterus* and *Pristipomoides multidens* (jobfish).

The trap fishery went through a peak in catch and effort in the late 1980s. This was followed by a number of the fishers leaving to work in other fisheries, such as trapping farther north. There was a change in species composition from the first years of the trap fishery, with *L. nebulosus* becoming much less abundant (Fig 12). It is very likely that there was overfishing for the larger species during this period. The Fisheries Department is currently addressing the issue of excess latent and actual effort in the Pilbara trap fishery. The trap fishers have always combined some trolling for spanish mackerel with their trap fishing. There has been a trend in recent years to also dropline for jobfish in the deeper water as occurs in the Timor Box area in Northern Territory waters.

Fish trawling by Australians on the NW Shelf began in the West Pilbara region. In the early 1980s when the Exmouth Gulf prawn fishery had a depleted tiger prawn stock, the boats in that fishery were encouraged to diversify into fish trawling. The gear used was modified prawn nets and the species composition was dominated by small species such as nemipterids. At that time there was very little overlap between the species composition of fish trawls and that of any other demersal fishing methods. The amount of fish trawling at that time was small and did not persist after 1983.

When fish trawling re-emerged in the late 1980s, one boat was permitted to work the grounds west of 116°E and it was restricted to a narrow longitudinal strip to reduce conflict with the trap fishery (Fig 13). The gear used this time was proper fish trawl nets and a prawn trawler was modified extensively for fish trawling. The species composition had a much greater overlap with that of line and trap fishers than did the early fish trawling attempts, though there were species in the trawl catch such as javelin fish *Pomadasys kaakan* which were not caught by other methods.

There is an intensive prawn trawl fishery in Exmouth Gulf with some stocks extending outside the management boundary to be taken by trawlers from Onslow. Sampling of the trawl bycatch in Exmouth Gulf did not show any significant quantity of commercial fish species important to the commercial or recreational demersal finfish fisheries.

EAST PILBARA

The eastern part of the Pilbara zone of the NW Shelf extends from 116 to 120°E. The major finfish fishery in this area is the Pilbara trawl fishery. There are two full time trawlers and 10 prawn trawlers from the Nickol Bay prawn fishery which currently have six months access per year to the fish trawl fishery. All of these boats are modified for fish trawling with proper fish trawl nets. There is a maximum boat size of 375 boat units and there has been a progressive replacement of the smaller trawlers used in the Nickol Bay prawn fishery with large boats formerly in the Northern Prawn Fishery which are at or close to this size limit.

There is an inshore boundary to fish trawling near the 50 m depth contour, and an inshore boundary to trapping which approximates the 30 metre contour. Thus the inshore area is reserved for commercial and recreational line fishing, the 30 to 50 metre zone for trap and line fishing. The trawl fishery currently works to about 100 metres depth.

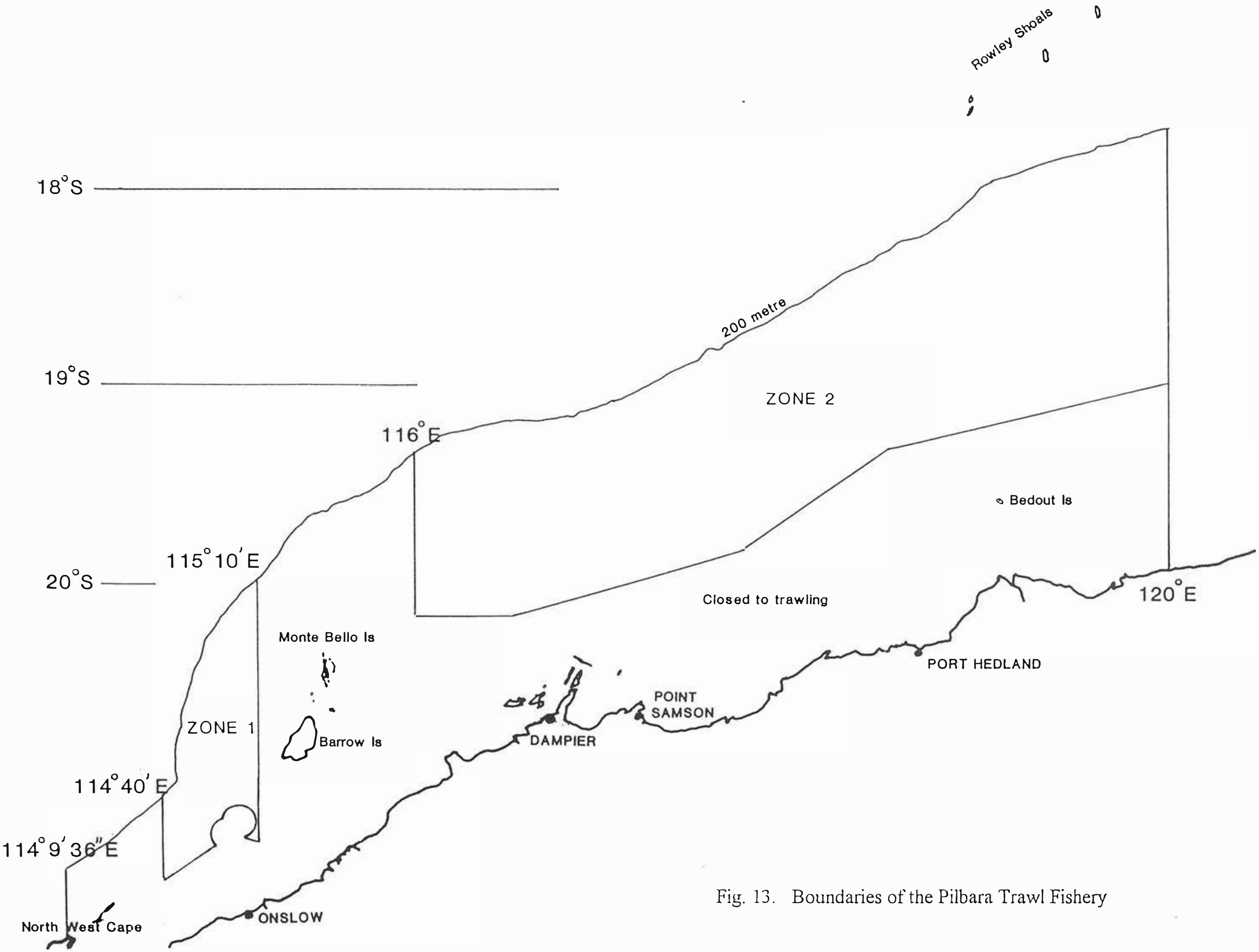

Fig. 13. Boundaries of the Pilbara Trawl Fishery

Table 1. Finfish catches by method on the NW Shelf off the Pilbara and Kimberley coasts, 1985 to 1993.

CATCH (tonnes)

PILBARA (west of 120°E)

YEAR	LINE	TRAP	TRAWL	TOTAL DEMERSAL	SCOMBRIDS (TROLL)
1985	165	170	7	342	132
1986	58	111	8	177	85
1987	58	189	12	259	116
1988	110	274	15	399	74
1989	81	456	133	670	113
1990	147	402	454	1003	208
1991	197	120	795	1112	191
1992	262	148	1355	1757	115
1993	159	122	1591	1872	157

KIMBERLEY (east of 120°E)

YEAR	LINE	TRAP	TRAWL	TOTAL DEMERSAL	SCOMBRIDS (TROLL)
1985	10	4	0	14	99
1986	9	1	0	10	79
1987	29	0	0	29	50
1988	10	11	1	22	116
1989	24	27	4	55	100
1990	6	204	4	214	102
1991	26	318	0	344	231
1992	55	686	0	741	172
1993	31	737	10	778	340

Fig. 14 1993 North West Trawling Catch/Effort of Fleet

	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	41	43
43																	300 133.3	400 71.6	1000 123.7	880 135.3	440 146.6			
44									120 37.8				333 74	415 68.2	1972 91.7	800 145.4	820 118.5	500 90.9	6280 135	6140 165.5	6065 182.4	1060 179.1	315 420	245 98
45				480 160	0 3	1655 239.2	1525 88.4	18430 130.6	26227 142.7	3110 70.8	3035 66.8	16018 147.4	9022 110.4	12510 207.9	11020 91.5	5535 114.1	6605 131.8	16005 136.4	8645 154.3	9835 168.7	2350 202.8			880 364.1
46				770 210	15710 135	32498 142.1	29784 109.4	11439 113.4	52710 82.9	38755 85.1	30202 103.9	63817 137.4	30595 137.5	5065 106.4	8880 111.5	3440 136.6	3780 89.4	4070 108		130 43.3				
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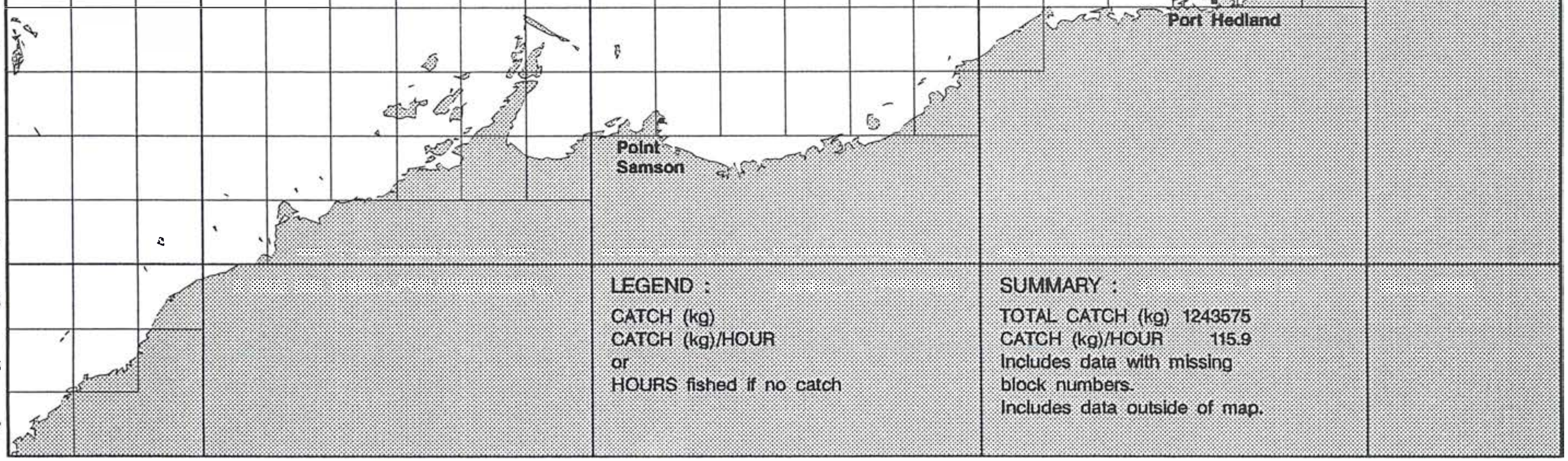
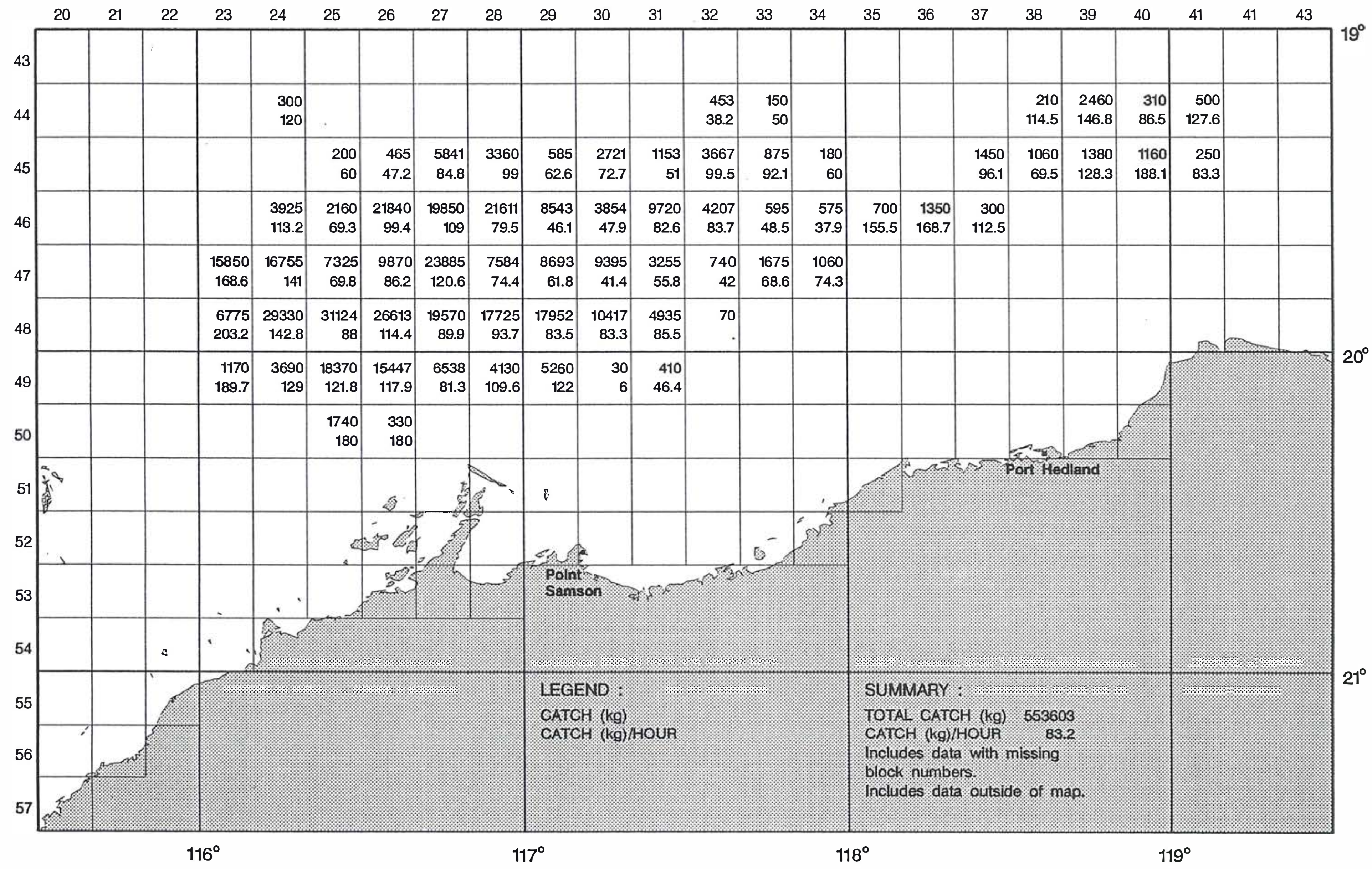


WAMRL 30 MAY 1995

Fig. 15 1992 North West Trawling Catch/Effort of Fleet



WAMRL 26 MAY 1995

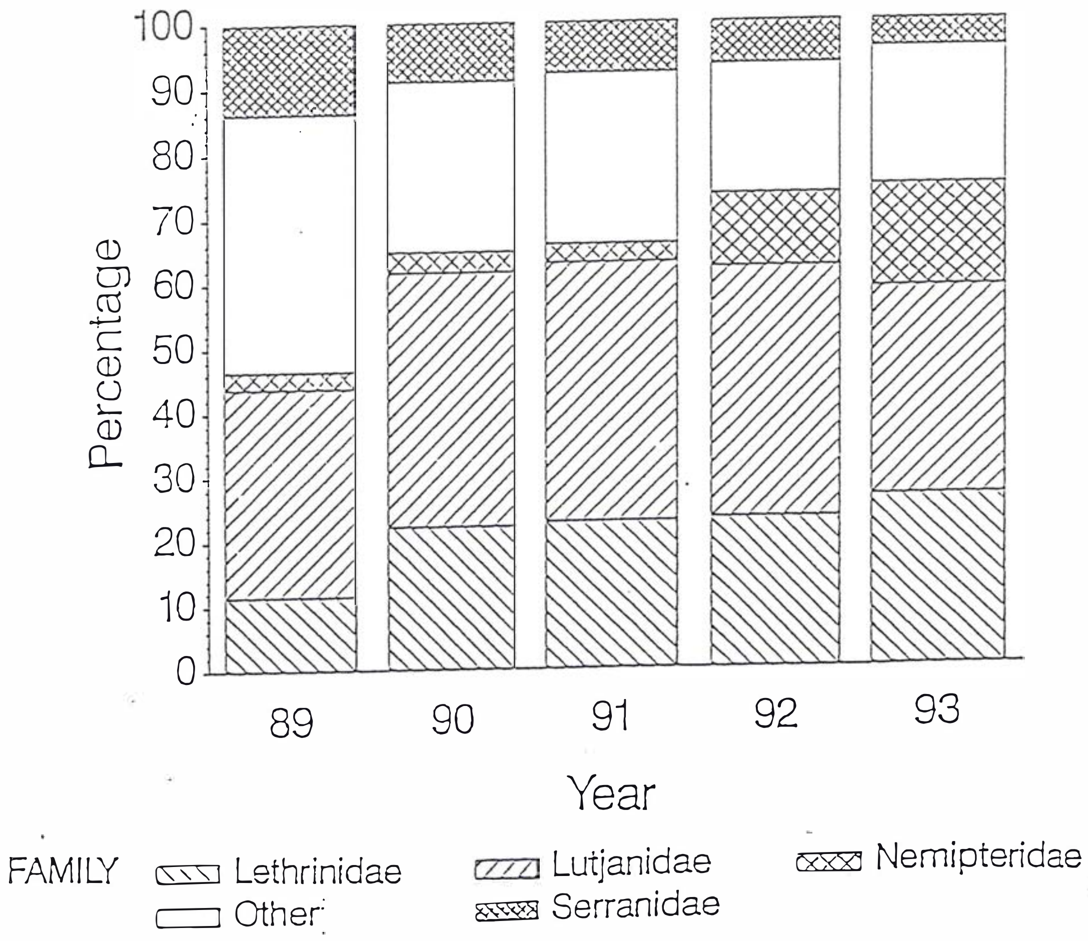
Prior to the development of the trawl fishery there was some fish trapping. A number of the Nickol Bay prawn fleet tried fish trapping but generally found their boats unsuitable and only one trawler persisted. Recently there has been no trapping from Point Samson in the area between 116 and 118°E where the trawl fishery has concentrated but a small number of trap and commercial line boats have worked out of Port Hedland in the area between 118 and 120°E, mainly on grounds near Bedout Island but also on patches of good trapping habitat near the inner boundary of the trawl fishery near the 50 m depth contour.

The fish trawlers take all of the species taken by the trap and line fisheries. In the early years of the Australian trawl fishery the species retained and targeted were almost completely the same as those taken by the trap fishery. In the last few years, however, marketing of the smaller species such as threadfin bream *Nemipterus furcosus* and small species of lethrinids and lutjanids such as *Lethrinus choerorynchus*, *L. lentjan* and *Lutjanus vittus* has improved and the trawl fishery now retains almost all of its catch of these species. The trawl fishery takes much greater quantities than the trap and line fisheries of the species taken by those fisheries. It is very likely that the trawl fishery, with only partial dependence on the reef fish, has out-competed trap and line boats on the grounds trawled most heavily between 116 and 118°E.

The recreational fishery in the Dampier Archipelago is probably one of the most intensive in the north-west. The Dampier-Karratha area is said to have the highest rate of boat ownership in Western Australia. Boats are launched mainly from ramps in Dampier harbour but many are also launched at Point Samson. The many islands and reefs in the area make this region an angler's paradise. As in Shark Bay and Ningaloo, local people provide anecdotal evidence that the fishing was much better a decade or so earlier. The species composition is very varied, dominated by lethrinids, lutjanids and serranids but noticeably different from Ningaloo in having a higher proportion of the prized coral trout *Plectropomus maculatus*. There is a small and variable charter fleet. Probably chartering is less popular than at Exmouth and Shark Bay because this area is less of a tourist destination and the residential fishers have their own boats or a friend with a boat.

The recreational fishery out of Port Hedland is much smaller than that in the Dampier Archipelago and there is no permanent charter boat fleet. Nevertheless, the reefs are highly valued by the local recreational fishing population.

Fig. 16. Changes in species composition of the Pilbara trawl catch through time.



PILBARA TRAP 116-120E

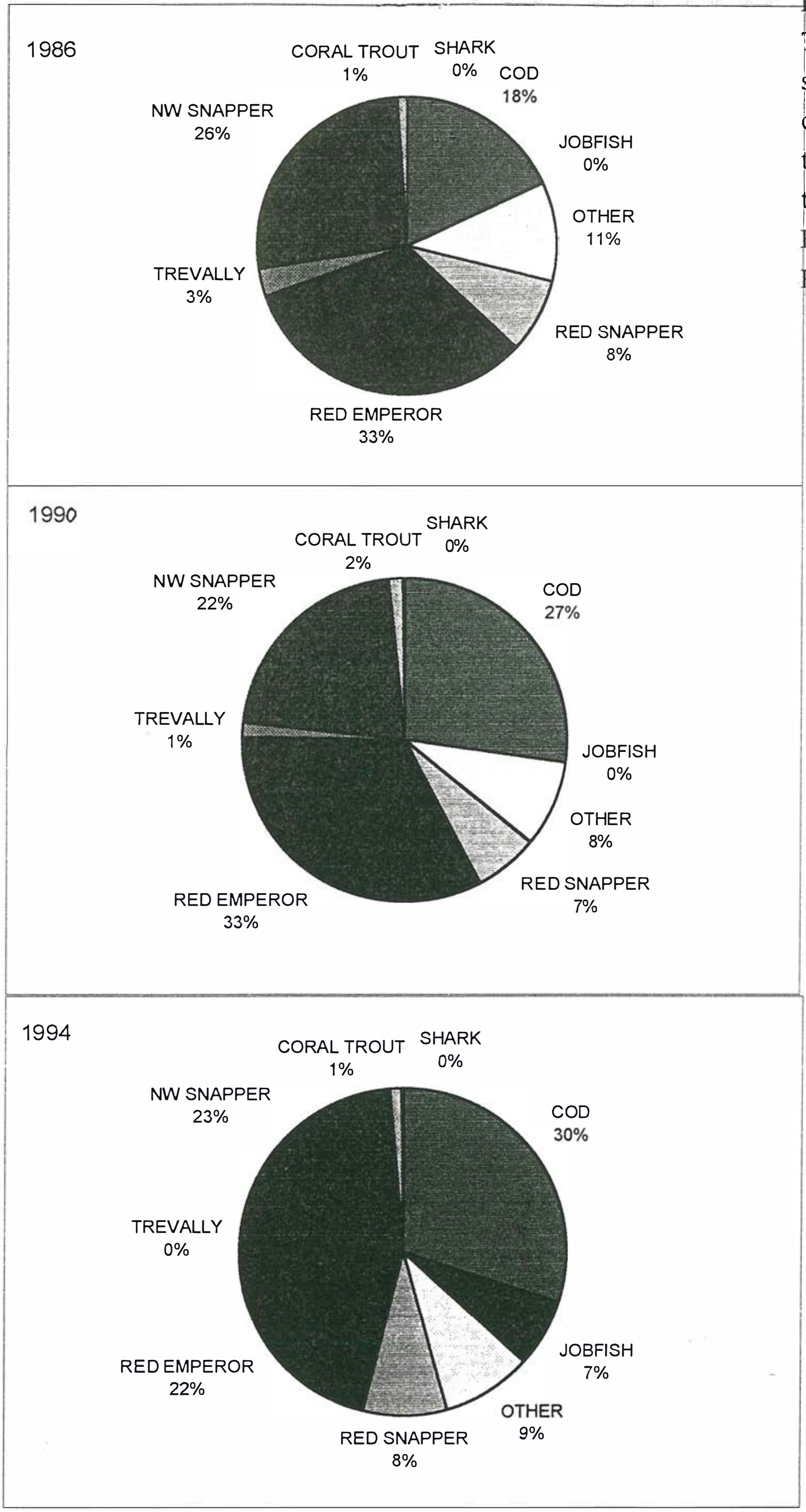


Fig. 17. Trap species changes through time: East Pilbara

In 1994 the trawl fishery was restricted to the area between the Rankin gas pipeline and 117° 30'E for an experimental estimation of the relationship between trawl fishing effort and fishing mortality. While this was the main area worked by the fishery prior to the experiment, the fishing effort in the area increased markedly, probably as a result of the replacement of small with large boats that are more efficient and can spend more days at sea. At the end of the experiment in early 1995, the grounds between 117° 30'E and 120°E were reopened to trawling and the trawl fleet responded by leaving the area it had trawled heavily for a year and worked the newly reopened area.

This markedly increased presence in the eastern area has resulted in complaints from commercial trap and line fishers and recreational fishers that the trawlers are destroying the reefs and taking all the fish.

The prawn fishery in this area is known as the Nickol Bay prawn fishery. While there is a variable banana prawn fishery in Nickol Bay itself, most of the trawling is done at a variety of grounds with suitable prawn habitat along the whole coastline of this area. The most abundant species of commercial finfish in the bycatch of the prawn fishery are juveniles of the large lutjanids *Lutjanus erythropterus* and *L. malabaricus* which are important in both the fish trawl and fish trap fisheries but not the recreational or commercial line fisheries.

KIMBERLEY

The major fishery in the Kimberley region from 120° to 129°E is the trap fishery (Fig 18). This fishery has expanded rapidly since 1990 but has now been contained by a freeze on licences.

While Western Australia controlled trap fishing in the Kimberley prior to 1995, it only controlled fish trawling as far east as 123° 45'E, and did not control line fishing at all outside the 3-mile limit. These methods were under Commonwealth jurisdiction. Although the Commonwealth tried to encourage fish trawling with environmentally friendly trawl gear in the eastern area (Timor Sea), there was not much interest. One long-line vessel was licensed by the Commonwealth to fish the Kimberley waters.

In early 1995 the Commonwealth passed jurisdiction for all demersal scalefish in the Kimberley region to Western Australia. The whole area is now closed to fish trawling but the longline boat is continuing to fish on the basis that its Commonwealth licence has not expired. Line fishing has in 1995 been restricted to certain boats while awaiting formulation of a demersal fishing management plan for the Kimberley.

The recreational fishery and charter fishery in waters close to Broome are growing with the town's increasing popularity as a tourist destination. To protect the recreational fishers from direct competition from the trap boats, the area within the 30 metre depth contour close to Broome has been closed to trapping.

The trap fishery based on Broome began by working close to the town, but for the past few years has worked at increasing distances, up to two days travel northwards. Although the catch-rate has not declined markedly (Fig 19), the increasing distance travelled to fish is indicative of depletion of the closer grounds. A few boats fish from Darwin, sometimes in the area adjacent to the Northern Territory's Timor Box trap and line fishery, and sometimes travelling long distances westwards to the grounds fished by the Broome-based boats. There is a large area of the Timor Sea that these boats cross to reach their westerly grounds, indicating that the Timor sea close to 129°E is not good trapping ground. Ramm (1991, pers comm.) has conducted trawl surveys in that area and calculated that there may be a sustainable yield of large lutjanids on the order of 1000 tonnes per year. This exceeds the current annual catch from the trap fishery in a much bigger area. It is possible that there is a demersal resource in this area which cannot be taken by the current trap and line methods and may only be harvestable by trawling.

While there is probably not a great deal of latent effort in the trap fishery, unless line fishing can be limited adequately, the realisation of latent linefishing effort may result in a total demersal fishing effort too great for the reef fish stock.

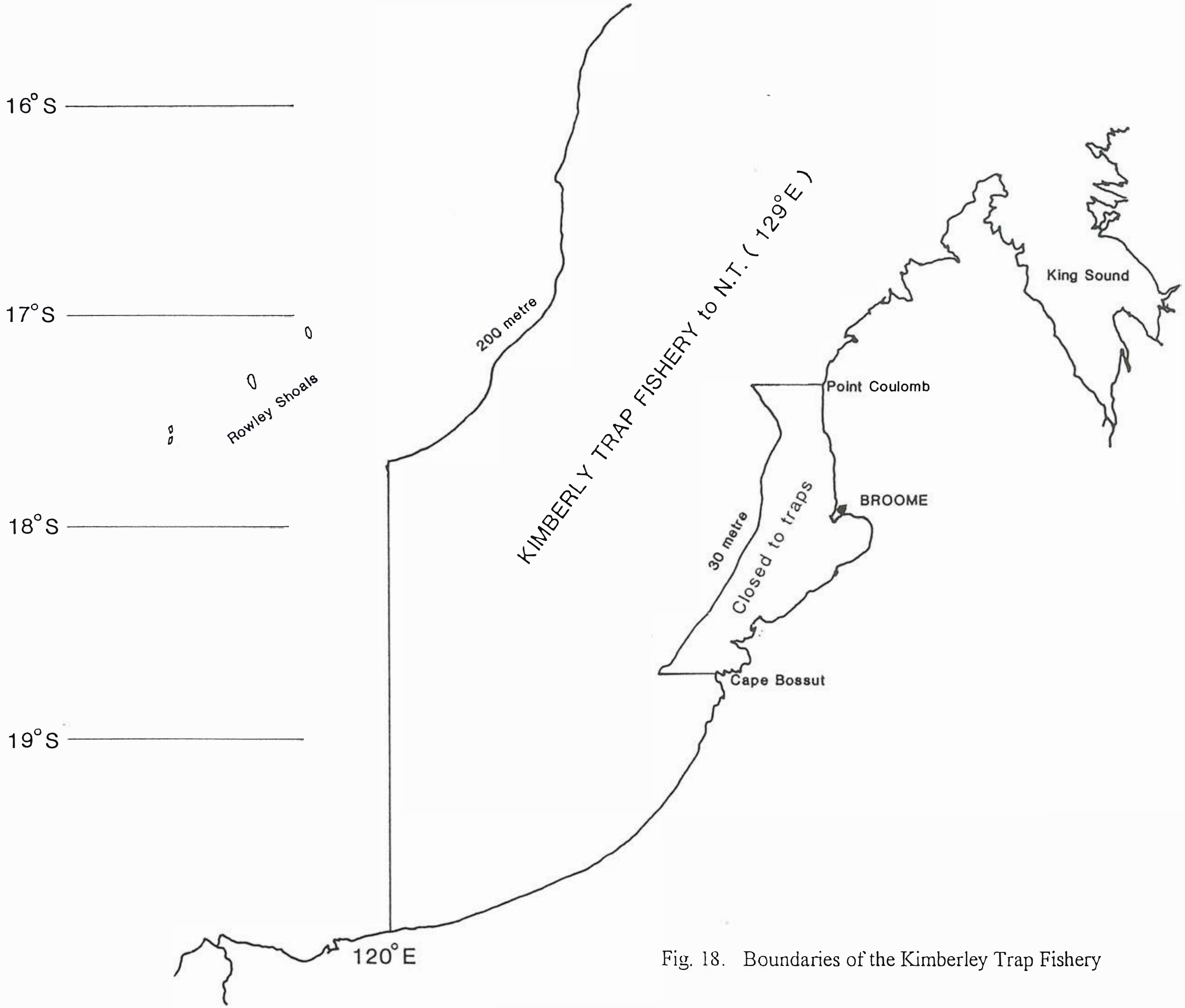


Fig. 18. Boundaries of the Kimberley Trap Fishery

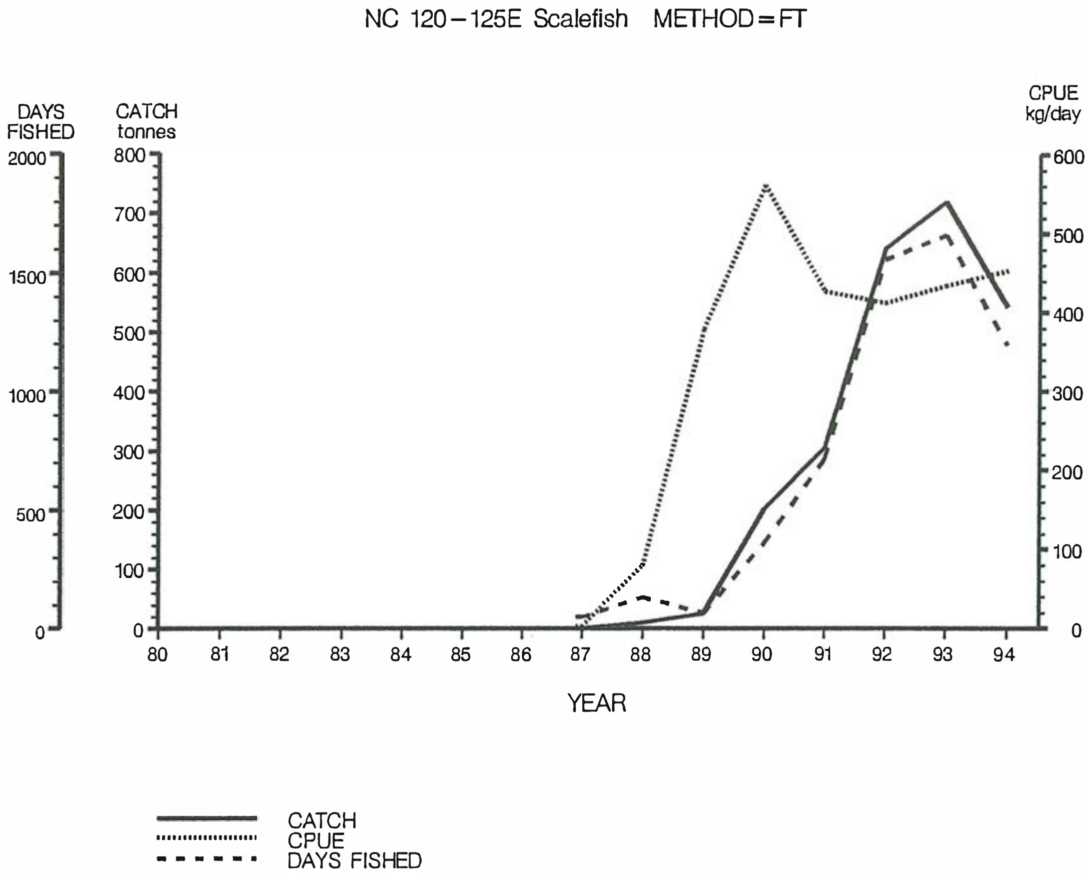


Fig 19. Time series of catch / effort in the Kimberley trap fishery.

EFFECTS OF FISHING GEAR ON THE BENTHIC HABITAT

INTRODUCTION

Commercial fishing of the Australian North-west Shelf began in the early 1960s with a Japanese stern trawl fishery targeted on lethrinids in the area north of Dampier. The lethrinid stocks were depleted in a few years and the fishery ceased. A Taiwanese pair-trawl fleet began fishing in the early 1970s over a wider area but with the centre of fishing effort again north of Dampier and retaining a much wider range of species (Jernakoff and Sainsbury, 1990). The pair-trawl fishery peaked in both catches and fishing effort in the early 1970s and its access to the grounds was progressively restricted over the period 1986-1989 after which foreign fishing on the NW Shelf ceased. Australian vessels began trapping on the NW Shelf in 1984 and stern trawling in 1989. The trawl fishery has expanded rapidly since then.

There were a number of research trawl surveys by various nations over this period, culminating in CSIRO surveys when the Australian Fishing Zone was declared in 1979. Sainsbury et al.(in press) found that the catches of sponges and other macrobenthos declined markedly in the fishing area over the duration of the pair-trawl fishery. Investigating the change in species-composition of research vessel trawl catches from dominance by lutjanids and lethrinids to dominance by saurids and nemipterids, Sainsbury examined a number of hypotheses and concluded that the most likely was that the habitat had been modified by the pair trawling such that the large macrobenthos habitat preferred by lethrinids and lutjanids had been replaced by a sparse macrobenthos habitat which favoured the saurids and nemipterids. This raised the possibility that if the habitat was allowed to return to its former state, the fish stocks may be more profitably exploited by a trap fishery on lethrinids and lutjanids than by a trawl fishery.

Stern trawling is likely to be very different from pair trawling in its effects on macrobenthos, though large quantities of sponges, etc can be caught in stern trawls. Sainsbury et al (in press) have estimated that a demersal otter trawl could detach 89% of the benthic organisms in the path of the net. They did not estimate the additional effects of the sweeps in detaching benthos. Mounsey and Ramm (1991) developed and tested a semi-pelagic trawl net, called the Julie-Anne trawl, and found that in the waters off the Northern Territory, the new net could catch similar quantities of fish to a standard demersal trawl while taking much less benthos. The high fish catches of the

Julie-Anne trawl were partly due to its better manoeuvrability which enabled better targeting and repeated shots through schools of red snapper, Lutjanus malabaricus.

Fish trapping has also been alleged to cause damage to macrobenthos. These allegations usually come from commercial or recreational line fishers. Moran & Jenke (1989) used underwater video to study grounds near Shark Bay which had been intensively trapped and found these grounds appeared to have at least as dense and varied a macrobenthic community as nearby grounds which had been subjected only to line fishing. They also observed the motion at the sea bed of traps being set and pulled, and found the motion to be gentle and unlikely to damage most benthos.

The major objective of the research to be reported here was to investigate the level of destruction of macrobenthos by a standard demersal trawl, as used by Australian trawlers on the NW Shelf.

The semi-pelagic trawl was found by Mounsey & Ramm to catch only around 3% of the quantity of benthos caught by a demersal trawl. This relates only to the damage to benthos done by the net itself. Fish trawl nets have on each side of the net long sweeps which brush the sea bed, raising a curtain of suspended sediment which is thought to herd the fish into the net. If damage to the benthos is being caused by the sweeps, the evidence would not show up in the net. Also, a semi-pelagic net requires more careful tuning than a demersal net to ensure that it is high enough above the sea bed so that it is not destroying benthos but it is not so high that it allows a high proportion of fish to escape beneath the foot-rope. The semi-pelagic net can be fished hard on the bottom as though it was a demersal net. We aimed to examine the effects on the benthos of a well-tuned semi-pelagic net, including effects of the sweeps, and to study the effects of tuning the net on fish and benthos catches.

The evidence against significant trap-caused benthic habitat damage obtained by Moran & Jenke (1989) was circumstantial and the view that traps do cause damage is still held by many line fishers. As part of this work, therefore, trap-caused damage to benthos was also estimated experimentally.

METHODS

The overall approach for estimating benthos mortality due to fishing was to mark out an area of sea-bed, fish it repeatedly (4 times), and survey the benthos abundance quantitatively before and after each fishing event.

Block marking and position fixing

Marking an area of seabed for repeated fishing has been done by Joll & Penn (1990) to measure trawl catchability of scallops and prawns in Shark Bay and Exmouth Gulf. Decca positioning technology was used to position the trawler within metres. Shark Bay and Exmouth Gulf are well suited to this technique as they have long islands or peninsulas close to the trawl grounds on which to position well spaced Decca transmitters. We did not have this technology available to us in the open sea on the NW Shelf.

Global Positioning Systems (GPS) are now common on fishing and other vessels for position fixing. While this technology has the capacity for very accurate fixes, the signals from the satellites are deliberately subjected to a precision-reducing error by the operators of the system. As a result, positions are only known with an accuracy that for most of the time, is within about 30 metres. This accuracy can be improved to within a few metres by using differential GPS, ie. a GPS at a fixed point of known position can be used as a reference point to calculate and subtract the deliberate error. Commercial differential GPS was not available on the NW Shelf at the time of this experiment. A high quality differential GPS system was beyond the resources of the project so a cheap system was purchased. This failed in the field and the experiment had to be done using the lower accuracy of standard GPS.

Blocks to be fished were marked on the research vessel's position plotter screen, as were the passes through the block with trawling or video survey gear. The vessel was effectively steered through the block according to its track on the plotter screen. At the rare times when the GPS connected to the plotter failed briefly to give a position, a second GPS system, using a different set of satellites, always gave a reasonable position which enabled the pass to be continued.

Development of a quantitative benthic survey method

Underwater video offers an opportunity to see and count items such as sponges on the sea bed. However, drifting a camera over the sea bed cannot be used for quantitative estimates of density of sponges because the size of the area in view is not known, similarly there are no reference points against which the size of objects can be measured.

On a perfectly flat sea bed, a camera mounted in a sled at a fixed height above and angle to the sea bed would have a constant-sized field of view. The image of a ruler held horizontally on the sea bed a fixed distance ahead of the camera would always be the same size and position on the video screen. If a line the same size and position as the image of the ruler was painted permanently on the screen, objects could be counted as their images crossed the line, resulting in a fixed width transect. If the transect was also of known length, a quantitative estimate of the density of the objects could be made. Similarly if an image of a vertical ruler connected to the horizontal ruler was painted on the screen, the heights of objects could be estimated.

We achieved the same as having the above lines painted on a video screen by taking video footage of the vertical and horizontal ruler, showing the image on a computer screen, and using software to draw the appropriate lines on the screen. The underwater video survey tapes were then shown on the computer screen and macrobenthos measured and counted by clicking on the top of the object with a mouse as the base of the object crossed the horizontal line. A specially written program calculated the height of the object by reference to the image of the ruler and accumulated the number of objects in each height category found in the transect. It then used the length and width of the transect to convert the numbers to densities.

One problem encountered was that the visibility varied with sea conditions, eg spring tides result in very low visibility due to suspension of fine sediment. Although video work on days with the worst visibility was avoided, the combination of the resolution of the camera and the poor visibility meant that objects smaller than 20cm could not always be identified reliably, eg is it a standing sponge, a broken-off sponge, or a rock?. Rather than risk biasing the results through misidentification, we decided to only count benthos estimated to be 20 cm or higher.

Another potential problem with this technique is that when the seabed is not flat, eg when there are large ripples in the sediment, the angle of the camera to the sea bed will vary as the camera climbs the ripples and descends into the troughs. This would mean that the width of the transect and height of objects would not be estimated accurately using the lines on the computer screen. Fortunately the area we chose to work was fairly flat and we do not consider this to be a serious problem with our results. A more serious problem found in developing this technique was keeping the sled which housed the video camera flat on the bottom. There are numerous forces acting to interfere with the level position of the sled and we consider attention to sled design and operation to be of vital importance in this kind of work.

Underwater Sled

A stable towable video platform (underwater sled) was developed. The underwater sled was designed and built in-house by the project's technical officer and the laboratories' workshop. The design incorporates two depressors, stabilising fins, adjustable video camera mount, adjustable bridle and rear-view mirror (Figs 20, 21).

The sled's main frame was constructed from 19 mm galvanised water pipe with an additional 40 mm × 5 mm flat bar for the skids, bridle, adjustment plates, camera mounting plates and the rear view mirror mount. The stabilising tail was constructed out of 40 mm square section tube with two plates welded to the top of the rear end at 45° to the vertical centre line to facilitate the attachment of the marine ply tail fins. The complete tail fin unit had plates welded to the front and towards its middle and then bolted to the top of the sled at the sled's cross braces as a separate unit to facilitate easier transport and storage. The top of the anterior end of the tail fin unit had a D shackle welded to it and this was used to attach a lazy line so that the sled could be retrieved over the rear of the boat after being detached from its towing weight.

The high mounting of the tail fin unit on the sled has the effect of making the sled self righting as long as a forward motion is maintained and the sled can be slightly lifted off the bottom. The sled will only ever end up on its side if the towing vessel turns too tightly causing the sled to stop and then taking up the slack when it is past right angles to the sled or if the video cable is shorter than the towing wire or becomes entangled in the sled.

The forward sloping front to the runners at 55°, together with the sled's light weight is such that the sled has been able to ride over all obstacles so far encountered, some of which were higher than the sled itself. The inward camber of 20° assists in sled stability and bridle guidance.

The bridle is solidly attached to the rear end of the sled and passes through a very small break-off shackle approximately halfway along the sled before terminating at a swivel in front of the sled. This break-off shackle point acts as the sled's balance point and controls its stability whilst also doubling up as a safety weak point should the sled hook up. Should this misfortune occur, the small shackle should break, the sled flip and tow out backwards. The sled's bridle attachment points were kept low so as not to pull the sled on its nose.

Sled balance and stability through the water and on the bottom is adjusted by moving the bridle backward or forward along the balance attachment point on the balance bar.

The large depressor in the centre of the sled provided the major down thrust and also provided the sled with its gliding capability. The posterior positioning in the frame prevents interference should the camera be mounted in a vertical position. The depressor was hinged at the front on a cross brace and its angle adjusted from the top by chain links at the rear and then tied down to a cross bar underneath. The depressor angle was kept at $< 15°$. Cross braces beneath the depressor can be used to lash additional weight to the sled should they be required.

The small depressor at the top and towards the front of the sled added to the total depressor area and was mainly used for fine tuning. This was attached to the front cross brace by U bolts and adjusted to not more than 15°.

A small curved automotive rear view mirror 30 mm × 50 mm was added to the upper right front of the sled and positioned in the cameras view such that it appears in the top right corner of the monitor when the sled is in the water. The mirror views the left skid from just above the lower front bend to where it disappears under the main depressor and allows a check on the sled's contact with the bottom.

General sled tuning can be aided by keeping the sled motionless on a flat bottom for a short time and taking note of where the horizon appears on the monitor. This horizon position should then be approximated while the sled is in motion by its various adjustments.

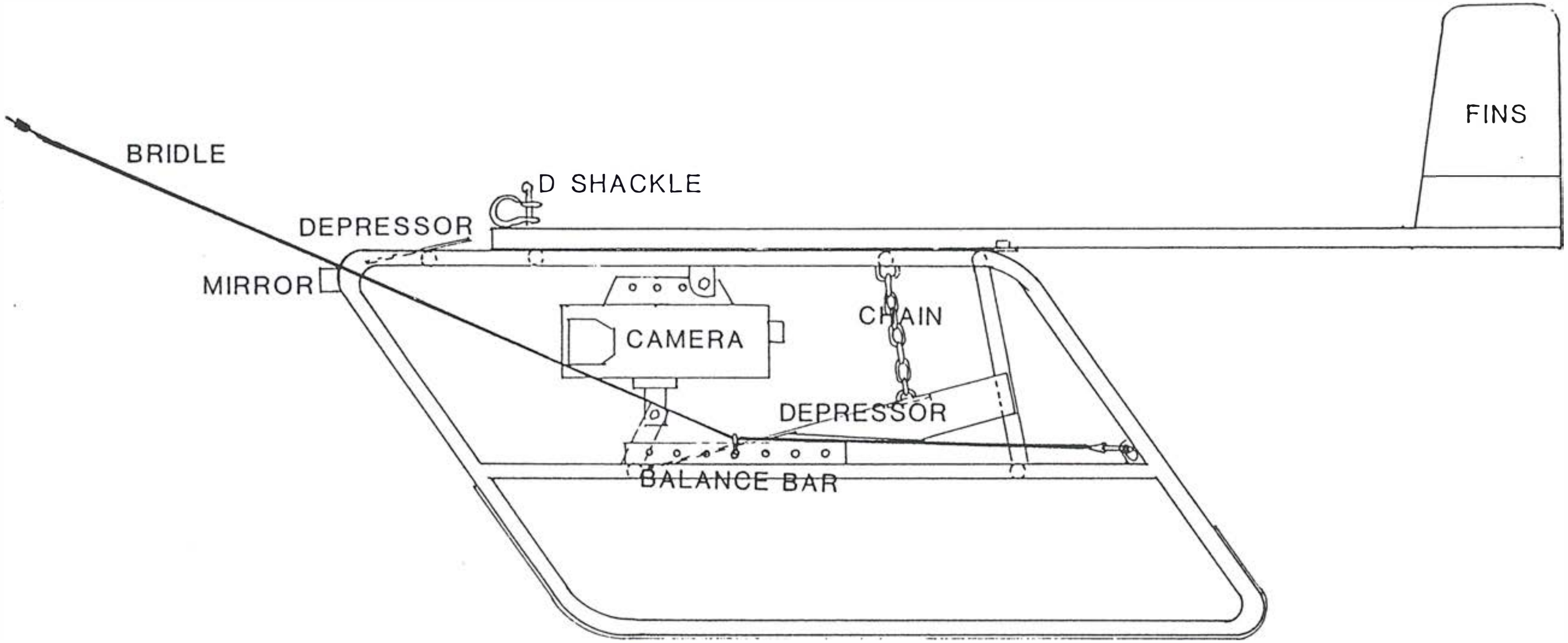


Fig.20. The arrangement of the underwater sled and TV camera

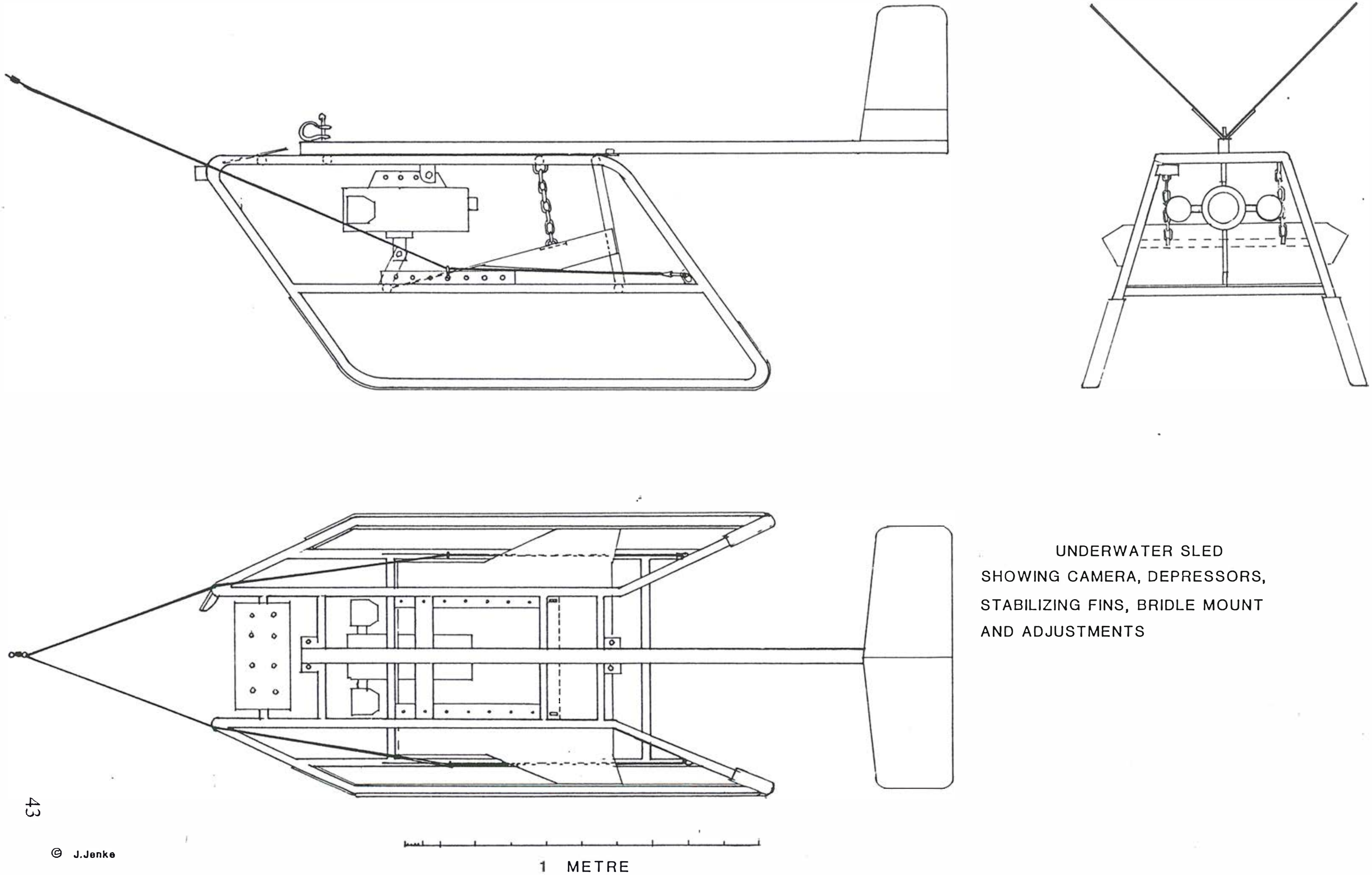


Fig. 21. Side, front and top views of the underwater sled

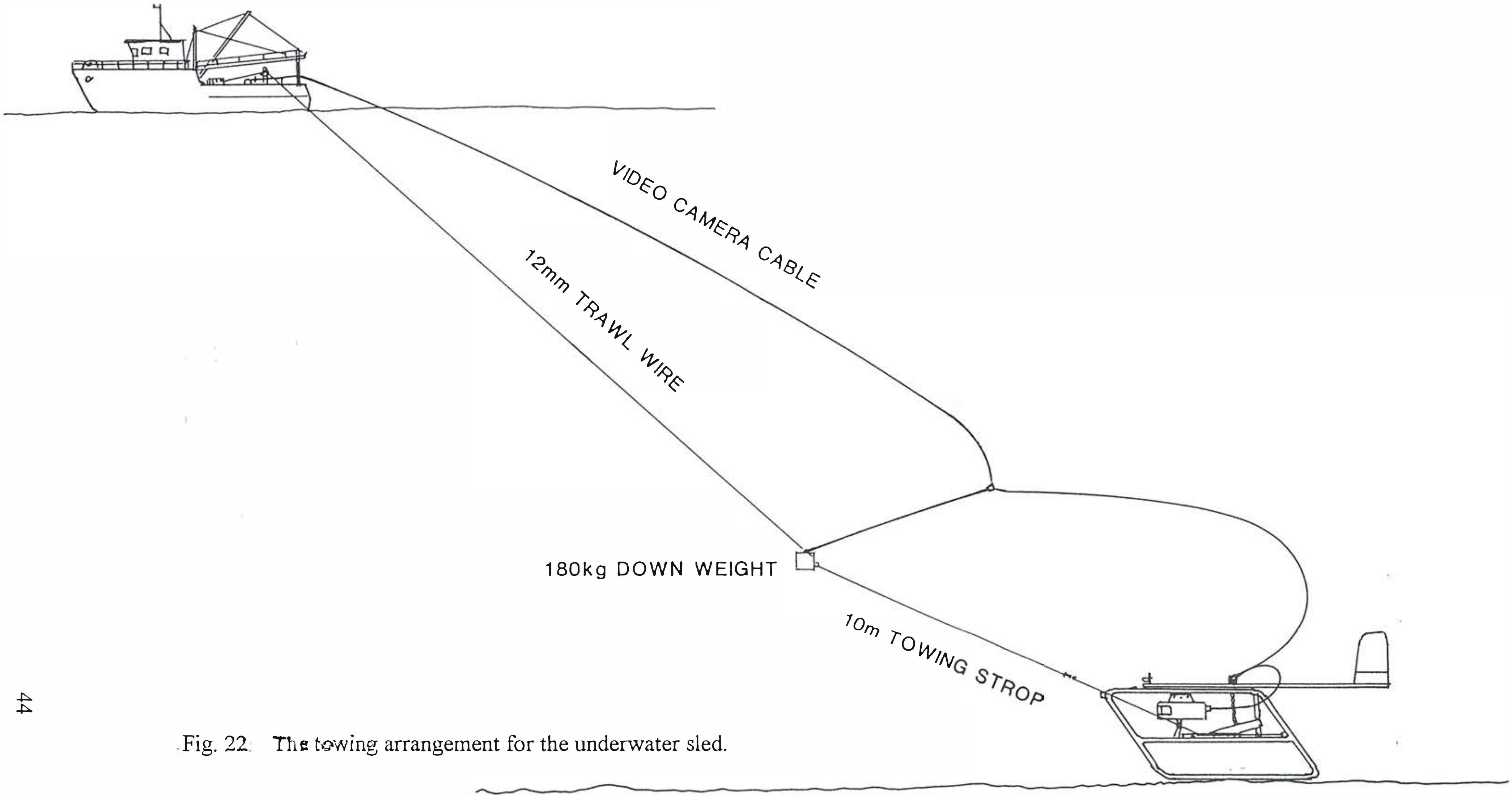


Fig. 22. The towing arrangement for the underwater sled.

Towing was achieved by attaching a 180 kg weight to the end of the research vessel's trawl wire and adding a 10 metre towing strop between the weight and the sled's bridle swivel.

The video cable was easily handled by letting it stream separately behind and away from the towing wire, usually by 2 to 2.5 times the depth. This system has so far been used successfully to 100 metres.

The camera used was a JVC TK-1280E with a FUJINON DF6B-SND4-1 lens. The scenery was recorded on a super VHS recorder Panasonic model NV-FS90A. The data was later analysed by measuring the height of all corals and sponges on a AMIGA 2000 using a specially written BASIC program.

Fishing gear

The demersal trawl and semi-pelagic trawl were designed and made by gear technologist Helmut Bauer, to suit the towing power of the research vessel "Flinders". The design of the semi-pelagic trawl is similar to the Julie-Anne trawl developed by Mounsey & Ramm (1989) and the demersal trawl similar to nets made by Mr Bauer for the commercial trawl fishery on the NW Shelf. The net designs are shown in figures 23 & 24, together with details of the towing warps, sweeps and bridles. The trawling depth was just over 50 metres and a warp to depth ratio of 3:1 was used.

The fish traps were standard round traps as used in the Shark Bay snapper fishery and the Pilbara trap fishery (Moran & Jenke, 1989).

Study area

The fish-trawl fishery on the NW Shelf operates mainly in depths of 50-100m. To enable effective estimation of the effects of fishing on the benthos, an area with substantial densities of macrobenthos was required. In the initial design, a differential GPS was to be used for vessel position fixing so proximity to a land site for the known-location component was another important factor. An area north of the Monte Bello Islands outside of the 50 metre depth contour was found which met all requirements. This area is closed to the Australian trawl fishery and, since it is within 12 nautical miles (nm) of the islands, should not have been trawled by the Taiwanese pair trawl fishery either.

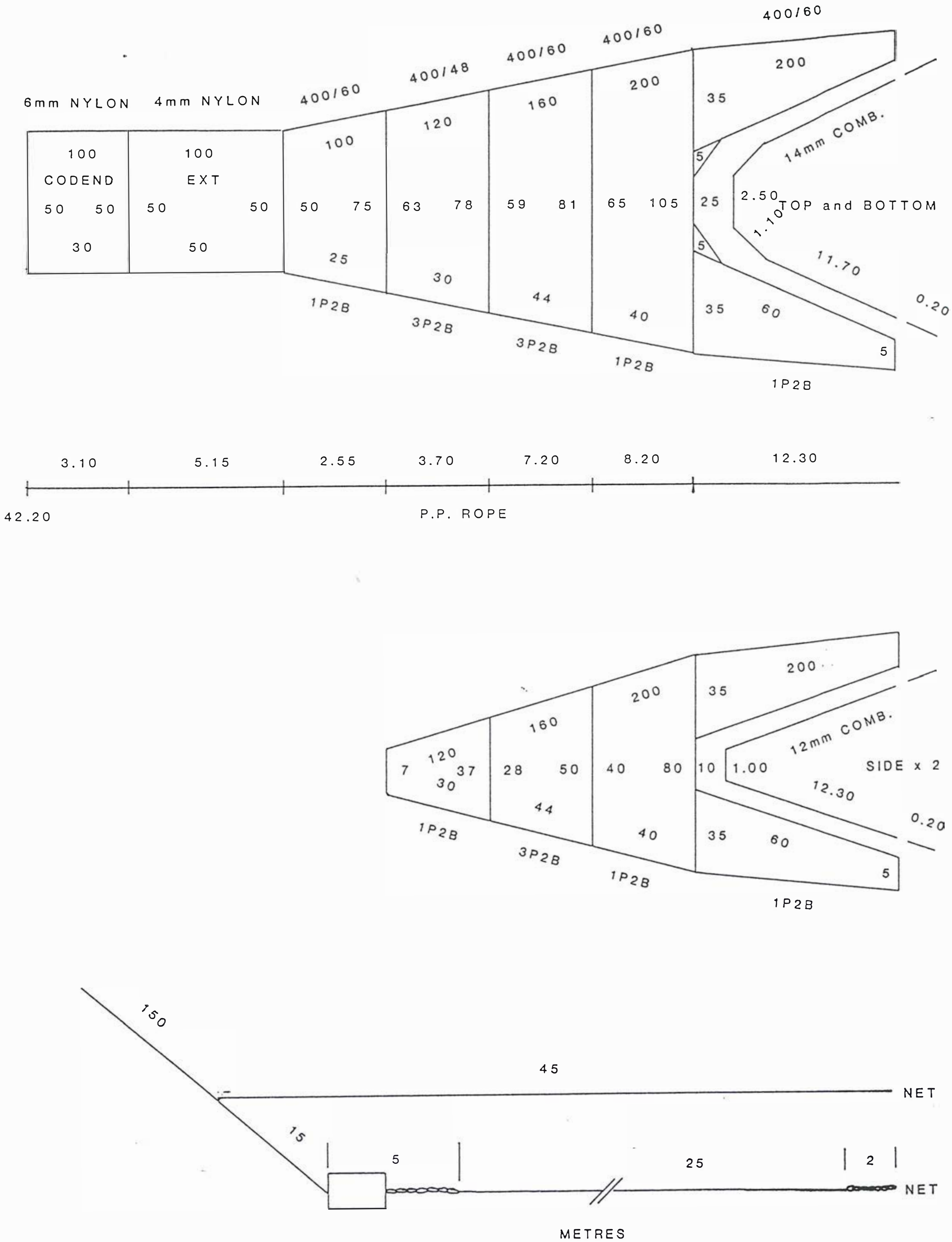


Fig. 23. Net diagram and towing arrangement of the semi-pelagic trawl.

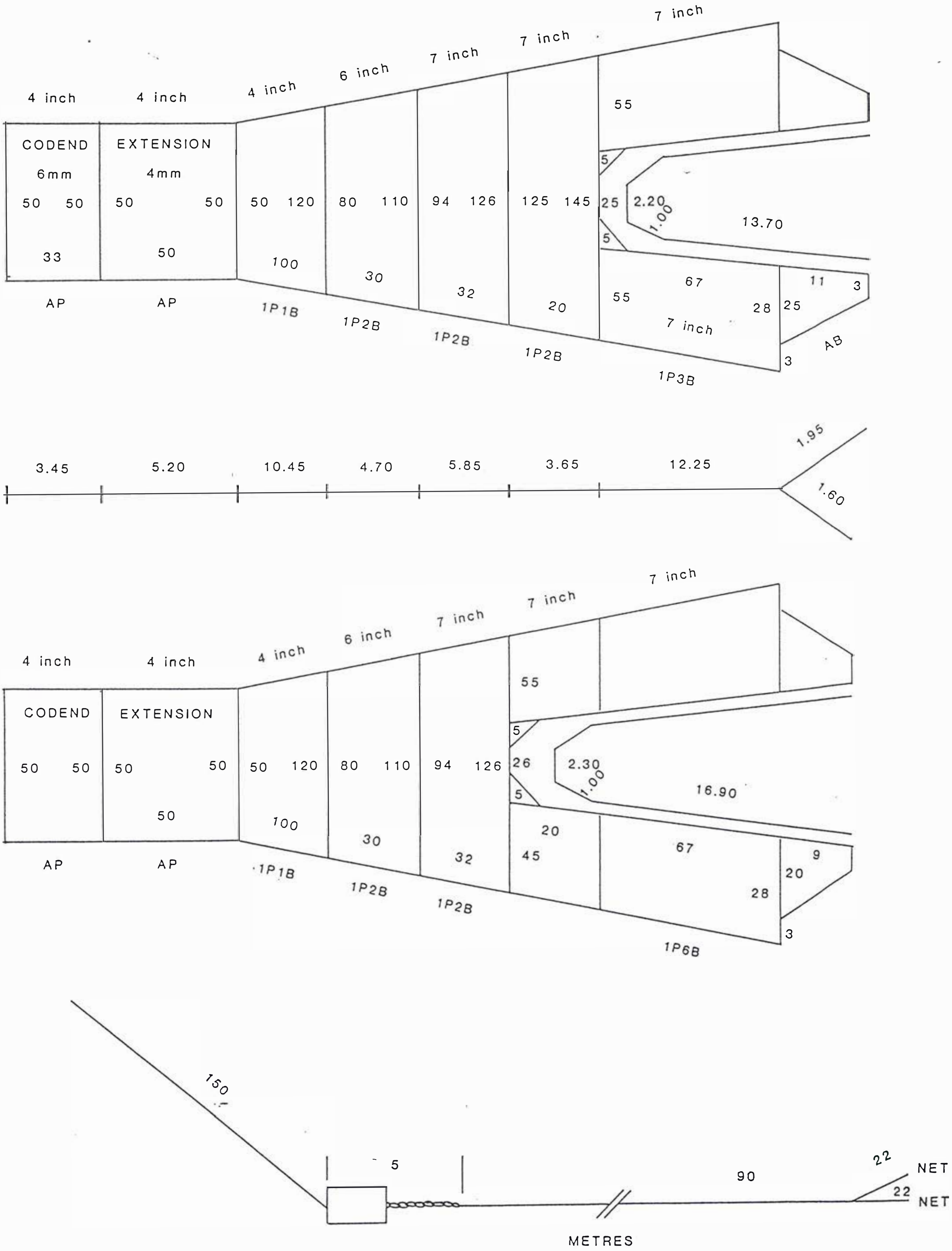


Fig. 24. Net diagram and towing arrangement of the demersal trawl.

Procedure for estimating fishing damage

Blocks were marked on the GPS plotter 0.2 nautical miles (nm) wide x 0.5nm long, in locations observed in a preliminary survey to have high benthos densities. These blocks were oriented with their long axis NW-SE, parallel to the main direction of tidal flow. The number of trawl-widths required to cover the width of the block was calculated and that number of shots were done parallel to the long axis to try to completely cover the block. One set of trawl shots done in this way is referred to as one trawl pass.

In practice the net is shot away on the first approach to the block boundary so that on the skipper's estimation, it will reach the sea bed as it crosses the boundary. At this point the boat will be about 140 metres into the block. Similarly, on leaving the block, winching-up begins when the trawl is estimated to be crossing the block boundary. Instead of winching up completely, just sufficient warp wire is winched in to allow the boat to make a U turn without upsetting the trawl, eg crossing the otter boards. The next shot is made in the opposite direction to the first and so on until the required number have been completed. Trawl speed over the ground varied according to the direction of the shot relative to the current, but averaged about three knots.

The shots are positioned so that, according to the tracks on the plotter screen, the block has been covered evenly by equally-spaced parallel shots. In reality, the plotter tracks are not quite straight or parallel, and often cross. This is expected with the variation in position fixing generated by the deliberate error in the GPS signals. Although the ideal adjacent parallel shots giving a complete, once only, coverage of the block is probably never achieved, the right amount of trawling for complete coverage has been done and an attempt made to spread it evenly. This problem would be greatly reduced with differential GPS and, for this experiment, is a source of random experimental error which would reduce the power of the experiment to detect significant differences between treatments.

The block surveyed by means of the video transects is located in the centre of each trawled block. The video block is 0.1nm wide x 0.3nm long. This is to ensure that the video transects are actually done inside the trawled area and not, as a result of a GPS error, outside the trawl block. Again, allowance is made for the distance the boat is ahead of the camera when entering and leaving the block. Four video transects in each video block make one set. An attempt was made to space the transects evenly and parallel but the GPS error introduces a randomising factor to the transect positions.

One set of video transects was done in each block before trawling and after each trawl pass.

Trapping blocks were done in the same way as trawling blocks except that traps were repeatedly dropped throughout the block and pulled to the surface for dropping again in the same manner as a commercial operation except that the traps were not left for a time to fish. As the objective was to estimate the impact of the dropping and pulling operations, the number of drops in a time period was maximised (65 drops). The positions of the drops were noted by marking the position of each drop on a GPS plotter and spread as evenly as possible through the blocks .

Control blocks were not fished at all but a set of video transects were done on the controls every time they were done on the fished blocks. It is possible that the camera sled itself does a small but detectable amount of damage to the benthos. The width of the sled is about 0.5% of the width of a video block; the width of the actual runners is of course much less.

Two replicate blocks were used for each of the treatments. The four treatments were: standard demersal trawl; semi pelagic trawl; fish trap; and unfished control. The two trawl treatments were each fished four times and surveyed five times; the control was surveyed five times and the trap blocks were fished three times and surveyed four times. The original design involved more times fished for each treatment but this was all that could be achieved with finite field time and time lost due to bad weather, spring tides, and gear and vessel breakdowns.

Trawl catches

When the net was brought aboard at the end of a trawl pass, all commercial fish were measured to the nearest cm and lengths recorded by species group. Some species groups were one species, such as *Lethrinus nebulosus* and *L. choerorynchus*, other groups were a number of related species, such as all lethrinids other than the two species above. All types of macrobenthos were measured and their lengths recorded as one group, regardless of whether they were sponges, soft corals, gorgonians or other taxa.

All items caught were retained on board until the end of the day's fishing. When disposing of the catch, care was taken to dump them into the sea at least 5 nm from the study area, in a direction where they would not be carried back by tidal currents into the study area to be caught again later.

It required several days trawling trials to tune the nets properly. The height that various parts of the semi-pelagic net were above the sea bed was measured by the polish on lengths of rusted chain suspended from the footrope. When all parts of the net were 15 cm above the sea bed, the net caught little or no benthos. This was the setting used to test the effect of the net on macrobenthos in the video experiment. The tuning trial trawls were used to examine the relationship between a net's ability to catch fish and its ability to catch benthos.

RESULTS

Relationship between benthos and fish catches

The records of commercial fish and benthos catches from six trawls with the semi-pelagic net set at various distances above the sea bed show a strong and significant positive correlation between the numbers of benthos and fish caught (Fig. 25, $r=0.94$, 4df, $P<0.05$). The standard demersal net, fished in a similar area, showed only a weak and non-significant negative correlation ($r=-0.26$). the semi-pelagic net caught similar quantities of fish and benthos to the standard demersal trawl when it was fished hard on the bottom, and caught much less of both when fished above the bottom. In effect, when the net was fished in such a manner that it did not catch much benthos, it did not catch much fish either.

Effects of various fishing gears on mortality of macrobenthos

The densities of benthos higher than 20 cm were estimated from the video transects before fishing and after each of four trawl passes, with corresponding estimates on the control blocks and after each of three fishing sessions in the case of the trap blocks. The most appropriate method of estimating the mortality of benthos in a single fishing event is a regression of the natural logarithm of benthos density against the number of times fished. The slope of the regression line would then be an estimate of the instantaneous rate of fishing mortality and the exponent of the slope would be an estimate of the proportion of the benthos which survive a single fishing event.

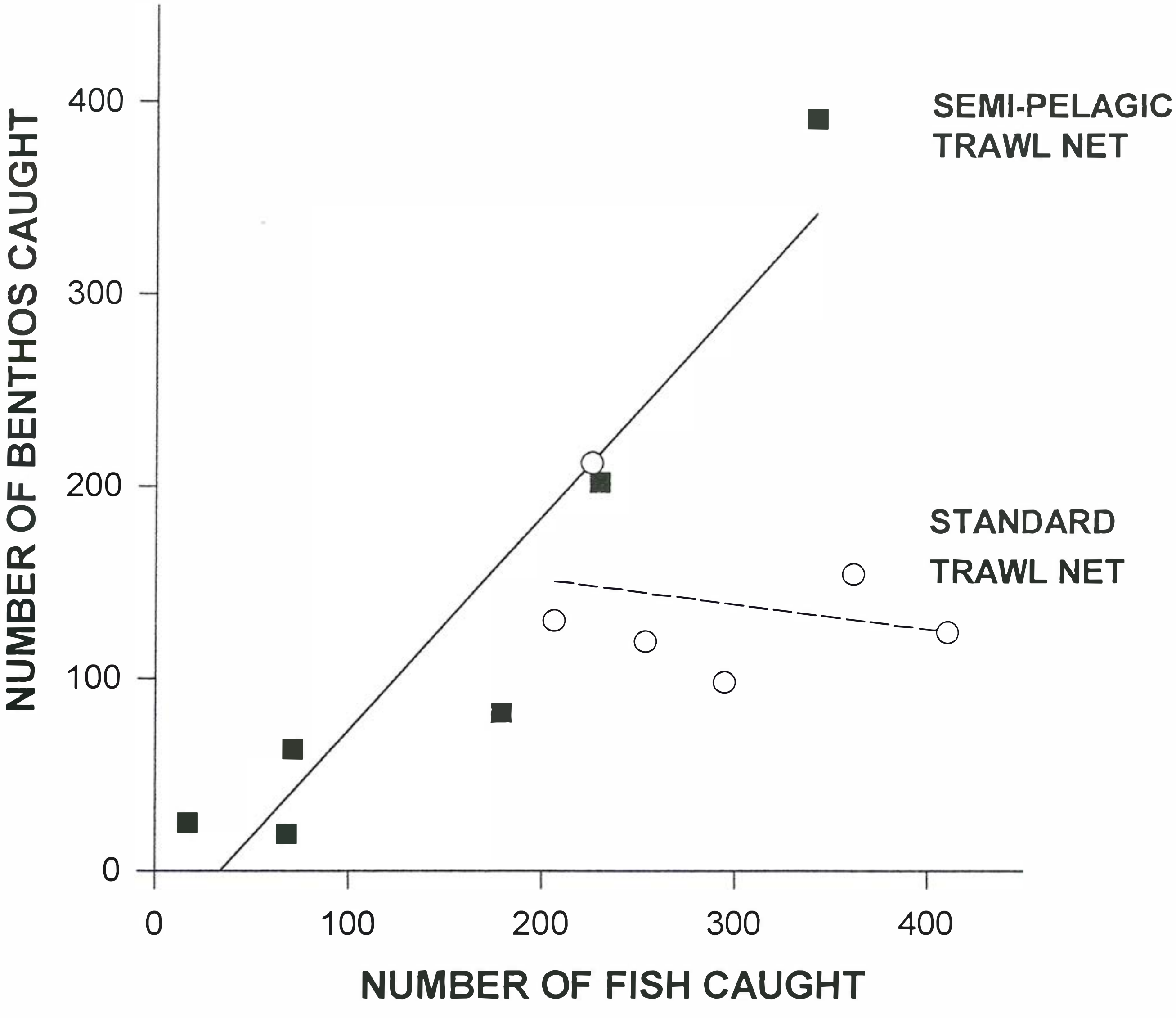


Fig. 25. The relationship between the number of benthos and the number of fish caught by a trawl net: standard demersal trawl and semi pelagic trawl.

These regressions were calculated for each treatment and are shown in Fig. 27. Only for the standard demersal trawl treatment is the slope of the regression significantly different from zero. That is, only the standard trawl has been shown by this experiment to inflict a detectable mortality on the benthos. The calculated slopes of the regressions, the proportion of benthos surviving one fishing event (survivorship) and the proportion of the observed variance in benthos density which can be explained by the treatment (R^2) are shown for each treatment in the table below.

	Standard trawl	Semi - pelagic	Fish trap	Unfished control
SLOPE	-0.167	-0.034	0.003	-0.024
SURVIVORSHIP	0.845	0.97	1.0	0.975
R^2	0.944	0.501	0.0006	0.067

The effect of the demersal trawl on benthos of various sizes

The height-frequency distribution of benthos higher than 20cm estimated from the video transects before trawling in the blocks used for demersal trawling are shown in Fig. 26. with the actual height-frequency distribution measured from all the benthos retained by the demersal net for comparison. Clearly there is a greater representation of the larger sized benthos in the catch data compared with the video data. This may be due to the net picking up more of the larger sponges it detaches than the small ones as would be expected. It may also be partly due to a bias in the size of sponges as estimated by the video method. We do not have information at this stage to decide between these alternative explanations but both of them are interesting possibilities and worthy of further investigation by anybody doing this kind of research.

The regressions of Ln(density of benthos) against number of times trawled for benthos in the estimated size ranges 20-30cm, 31-50cm and taller than 50cm, (Fig.28) do not show any differences in the mortality rates of the three size ranges due to trawling.

The regressions of Ln(number of benthos caught) with the demersal trawl against trawl pass number for benthos in various size ranges (Fig. 29) also do not show any differences in the trend in catch rates for the different benthos sizes. The regression for the largest benthos size (>75cm) appears to have a negative slope which would

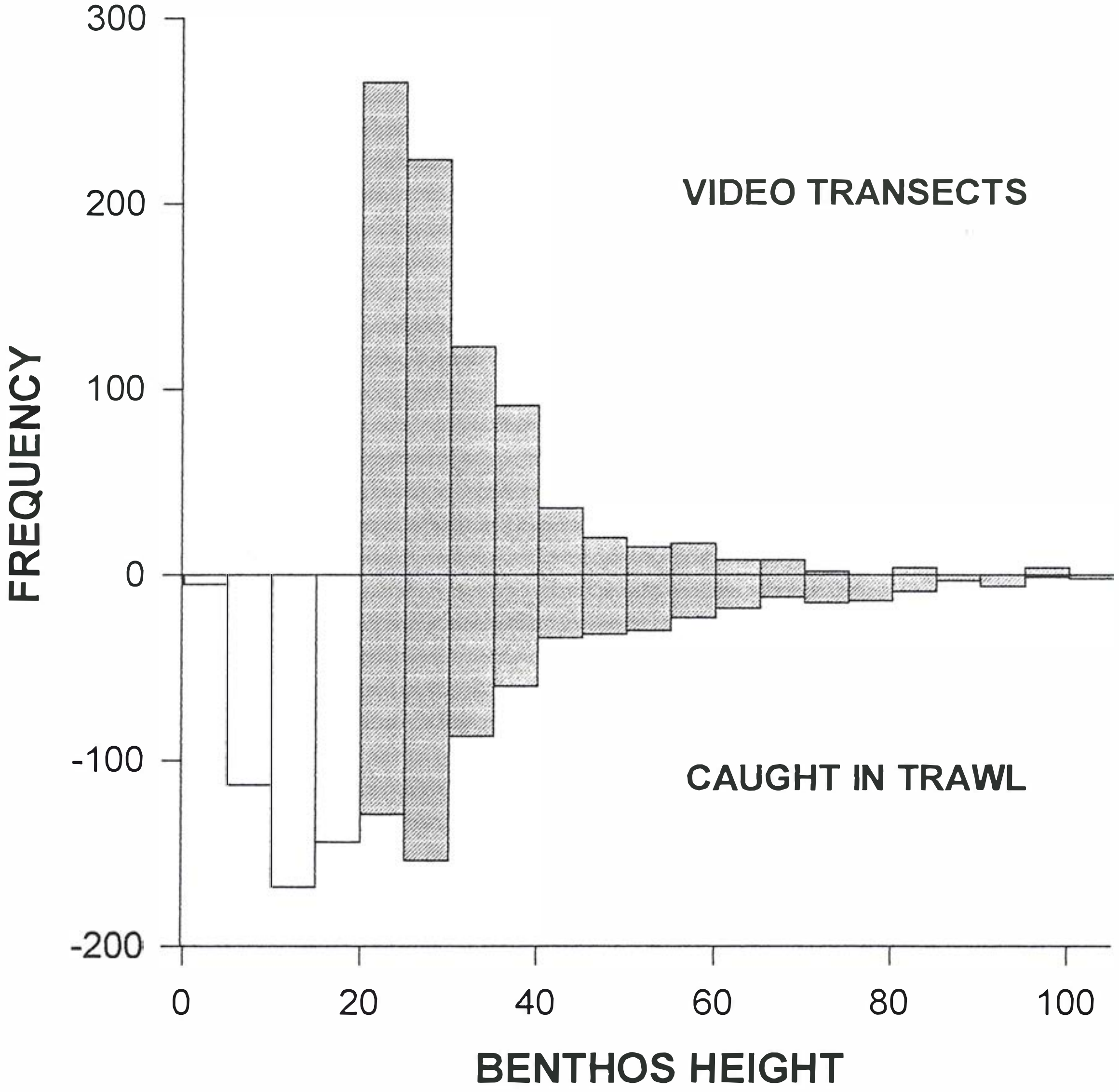


Fig. 26. The height frequencies of benthos bigger than 20 cm estimated from the video transects, compared with the height frequency of benthos actually caught in the demersal trawl on the same grounds.

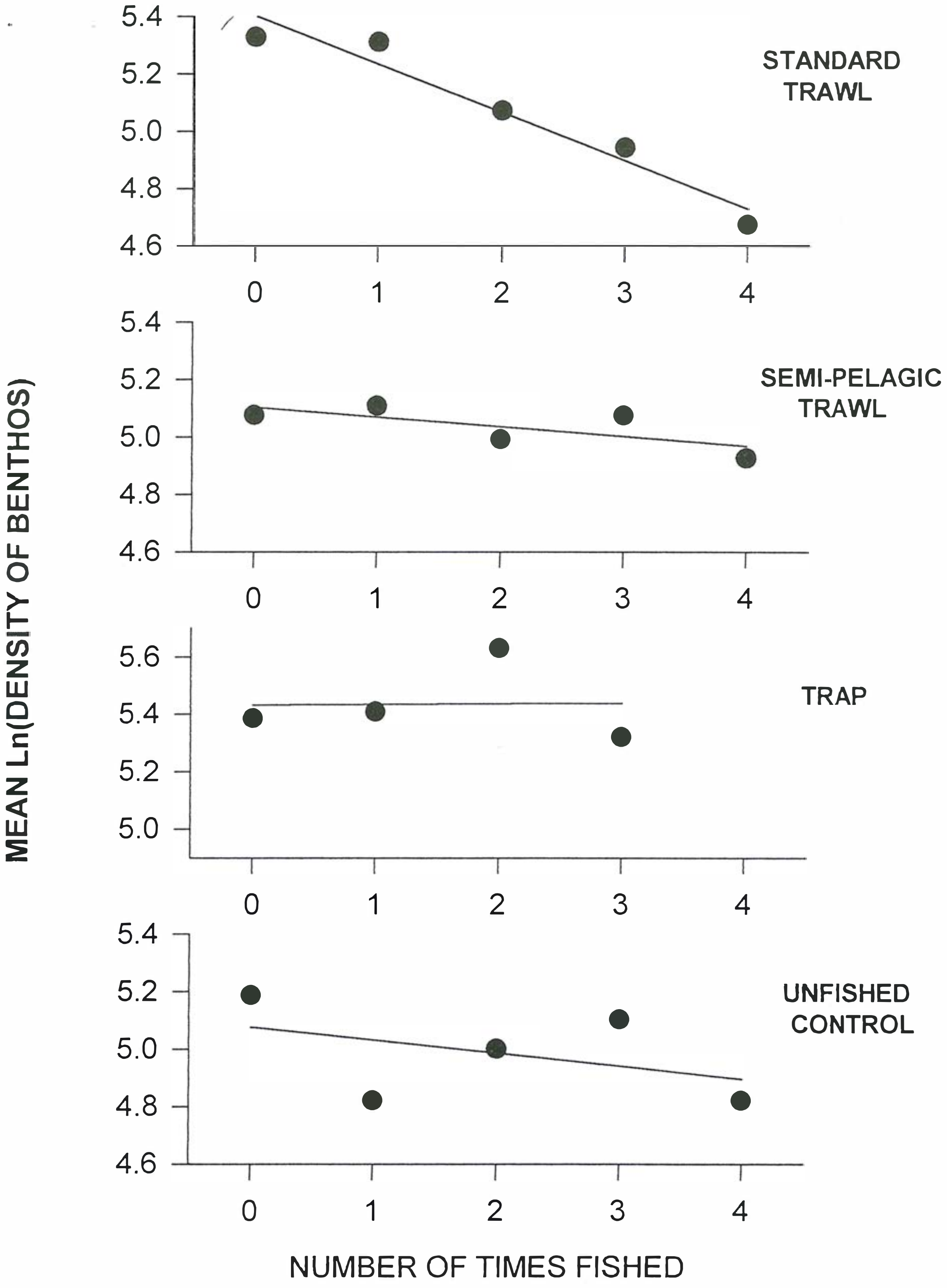


Fig 27 Plots of the natural log of benthos density, as estimated from video transects, against the number of times fished by standard trawl net, semi-pelagic trawl net or fish trap, compared with an unfished control. The slope of the regression line is used to calculate the survivorship of the benthos.

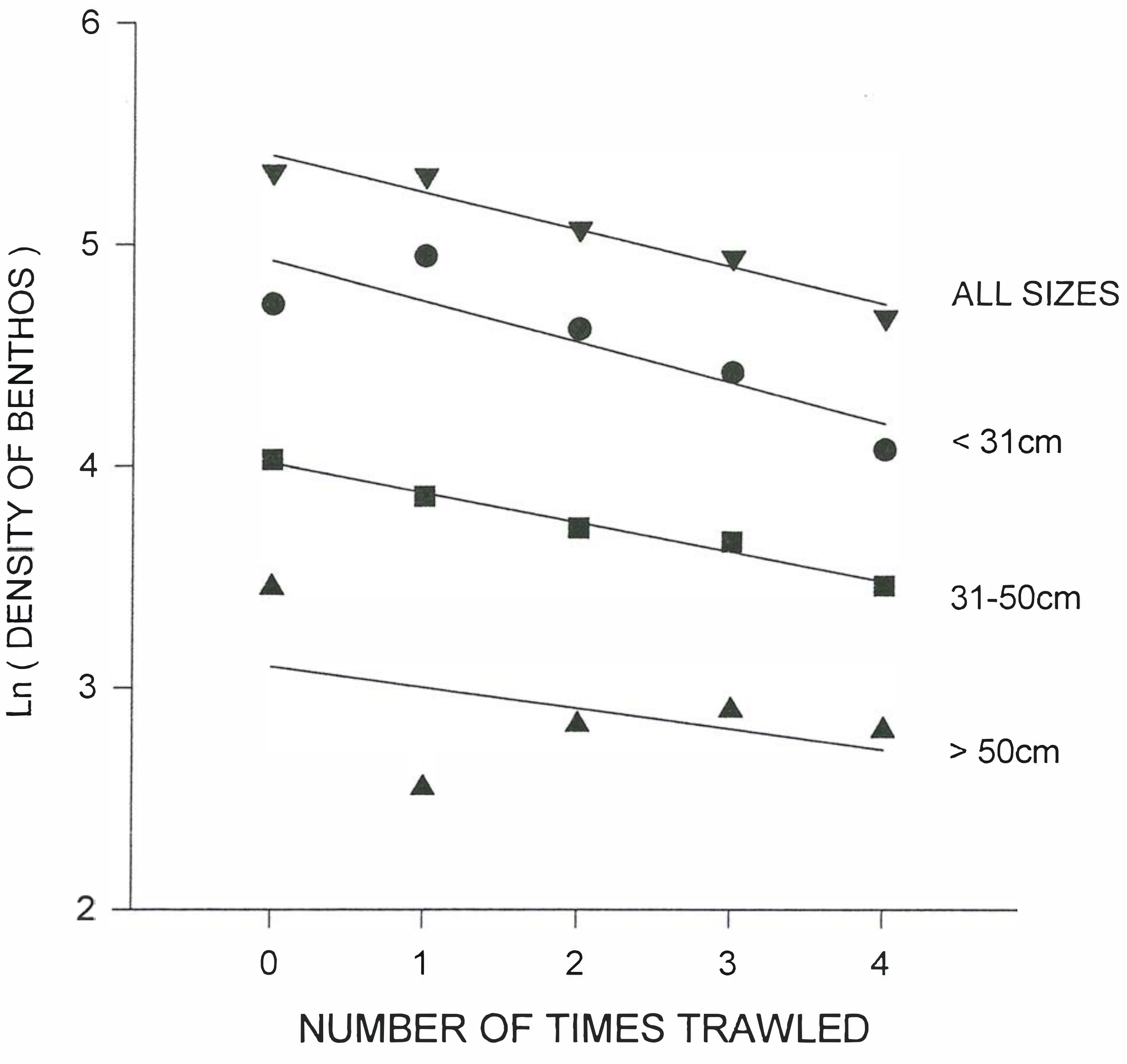


Fig. 28. Regressions of the natural log of benthos density, as estimated from the video transects, versus the number of times the area had been trawled, for various size categories of benthos.

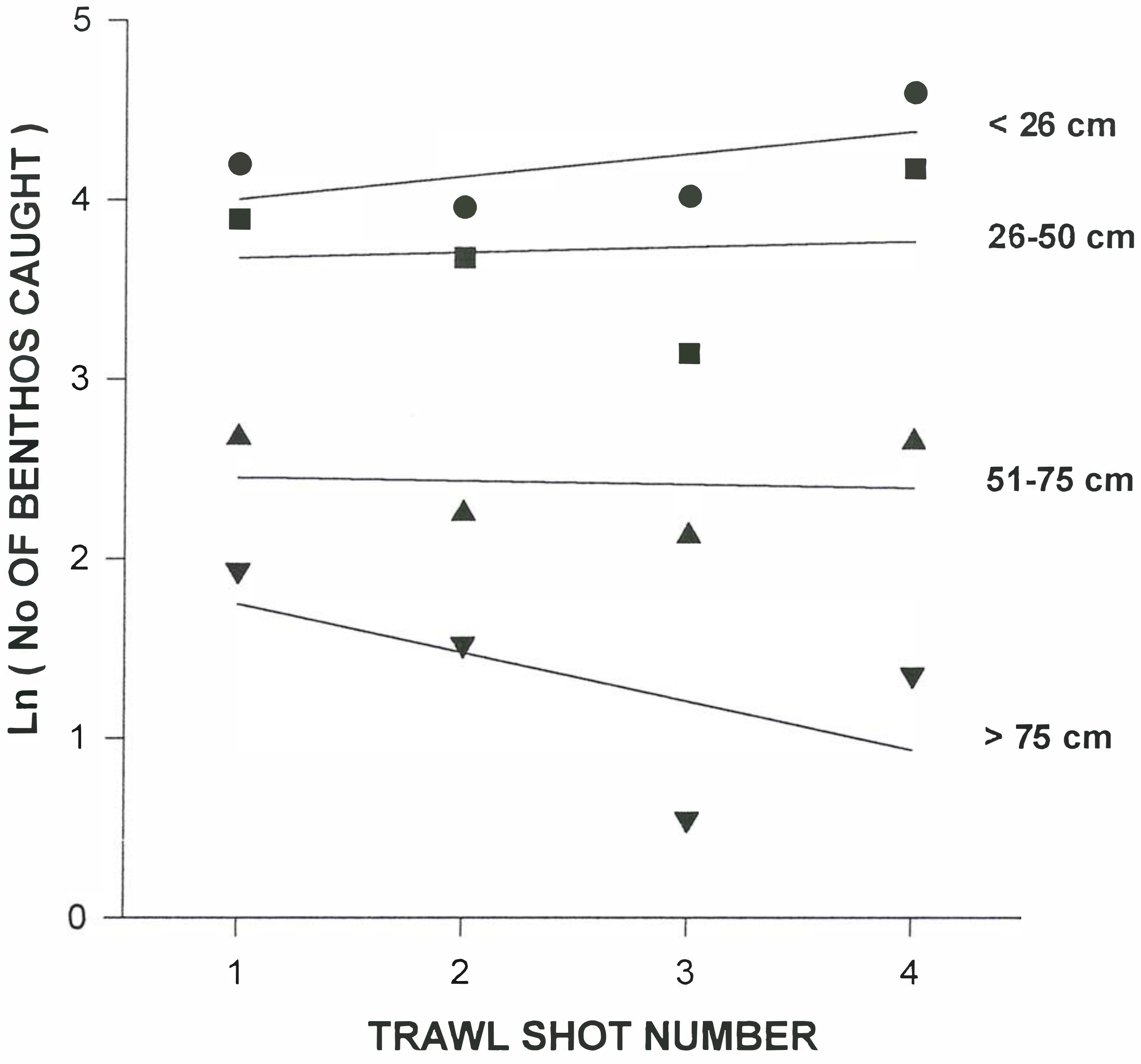


Fig.29. Regressions of the natural log of the number of benthos caught in the demersal trawl, versus the number of the trawl shot over the area, for different size categories of benthos.

indicate that this size group is removed from the grounds at a greater rate than the smaller sizes. However this slope, like those for the smaller benthos, is not significantly different from zero.

The lack of a significant trend in benthos catches with number of times trawled indicates that the sponges seen in the trawl are an undetectably small fraction of those present on the grounds. Extrapolation (the y intercept of the regression) from the densities estimated from the video transect indicates that there were in the vicinity of 60,000 benthos items larger than 20 cm in the whole of the trawled block at the beginning of the experiment. The four trawl passes reduced this by about half. The number of benthos items retained by the trawl in the whole four passes was 1925; 1244 were 20 cm or bigger. This means that only about 2% of the larger benthos items present in the block or 4% of the number detached by the trawl, were actually taken in the trawl net over the whole four passes. On these figures it is not surprising that there was no detectable reduction in number of benthos caught with increasing number of times trawled.

DISCUSSION OF EFFECTS OF FISHING ON BENTHOS

A demersal trawl was estimated to destroy 15.5% of the benthos (>20cm) in its path in a single pass. The experiment gave no information on benthos <20cm.

Fish traps and a semi-pelagic trawl were estimated to inflict no measurable damage to the benthos. When the semi-pelagic net was rigged so that it did not catch benthos, it also took low catches of fish. This differs from the findings of Mounsey and Ramm (1991) in Northern Territory waters where a semi-pelagic net took a similar amount of fish to a standard demersal trawl, while catching much less benthos. This difference could be due in part to the targeted fishing of schools of *Lutjanus malabaricus* in the Northern Territory study. Our experiment, by its nature, did not permit targeting schools. In this, however, it was similar to the commercial trawling on the NW Shelf where *Lutjanus malabaricus* are much rarer and fishermen target productive areas rather than fish schools. It is our view that while it is possible to legislate, as the Commonwealth has in its northern trawl fishery, to force fishermen to use semi-pelagic nets, if these nets only catch well when rigged to fished hard on the bottom, then that is how fishermen will use them. It is not possible to police how a net is rigged on a vessel far out to sea. On the NW Shelf, in the absence of large schools of high-value fish that could be target-trawled, the semi-pelagic net is unlikely to solve the problem of damage to benthos.

THE VULNERABILITY OF JUVENILE FISH TO DIFFERENT GEAR TYPES

EFFICIENCY AND SELECTIVITY OF A DEMERSAL TRAWL

Selectivity of trawling gear is generally measured as mesh-selectivity by counting and measuring fish which have escaped through the net into a codend cover or small mesh bags placed on the outside of the net. The proportion of the fish in a particular size group that has been retained by the net is then calculated by comparing the numbers in the net with the numbers in the codend cover and bags. Liu et al. (1985) calculated mesh selectivity in this way for many of the major species groups taken by the Taiwanese pair-trawl fishery on the NW Shelf.

There are other ways that a trawl can operate to selectively catch one group of fish more efficiently than another. For example, different species or sizes of fish may vary in their susceptibility to being herded by the sweeps, or their ability to escape the net over the headrope or beneath the footrope. Ramm (1992, pers comm.) has recently investigated the effect of sweep length on herding various tropical trawl fish.

The experiment on benthos mortality, with its repeated trawling of a marked area, provided an opportunity to attempt another approach to measuring the efficiency of a demersal trawl in catching various sizes of fish. This repeated fishing approach is not generally used to measure gear efficiency for finfish in the open sea, though Joll and Penn(1990) have used it effectively for the less mobile scallops and prawns. An advantage of this approach is that it measures efficiency overall, combining the effects of mesh selection, herding etc.

Using the commercial fish catches from the repeated trawling of the two blocks with the demersal trawl as described in the section on benthos mortality, the numbers of fish in various size categories retained in the first, second, third and fourth trawl passes were recorded. Unfortunately sufficient fish of individual species were not obtained to measure efficiency and selectivity for each species. However, pooled data from the whole multi-species catch can still be useful.

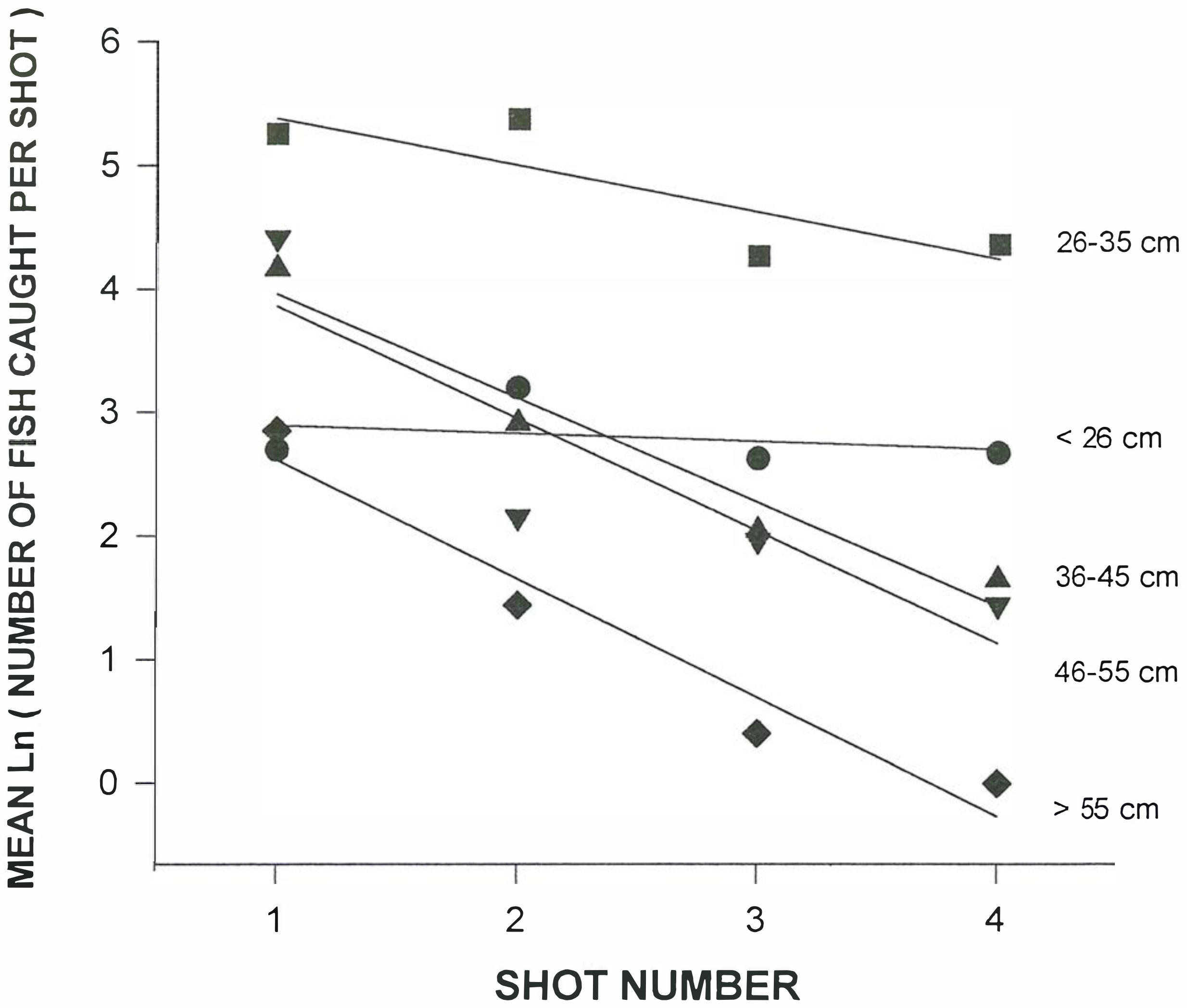


Fig.30. Regressions of the natural log of the number of fish caught in the demersal trawl, versus the number of the trawl shot over the area, for different size categories of fish.

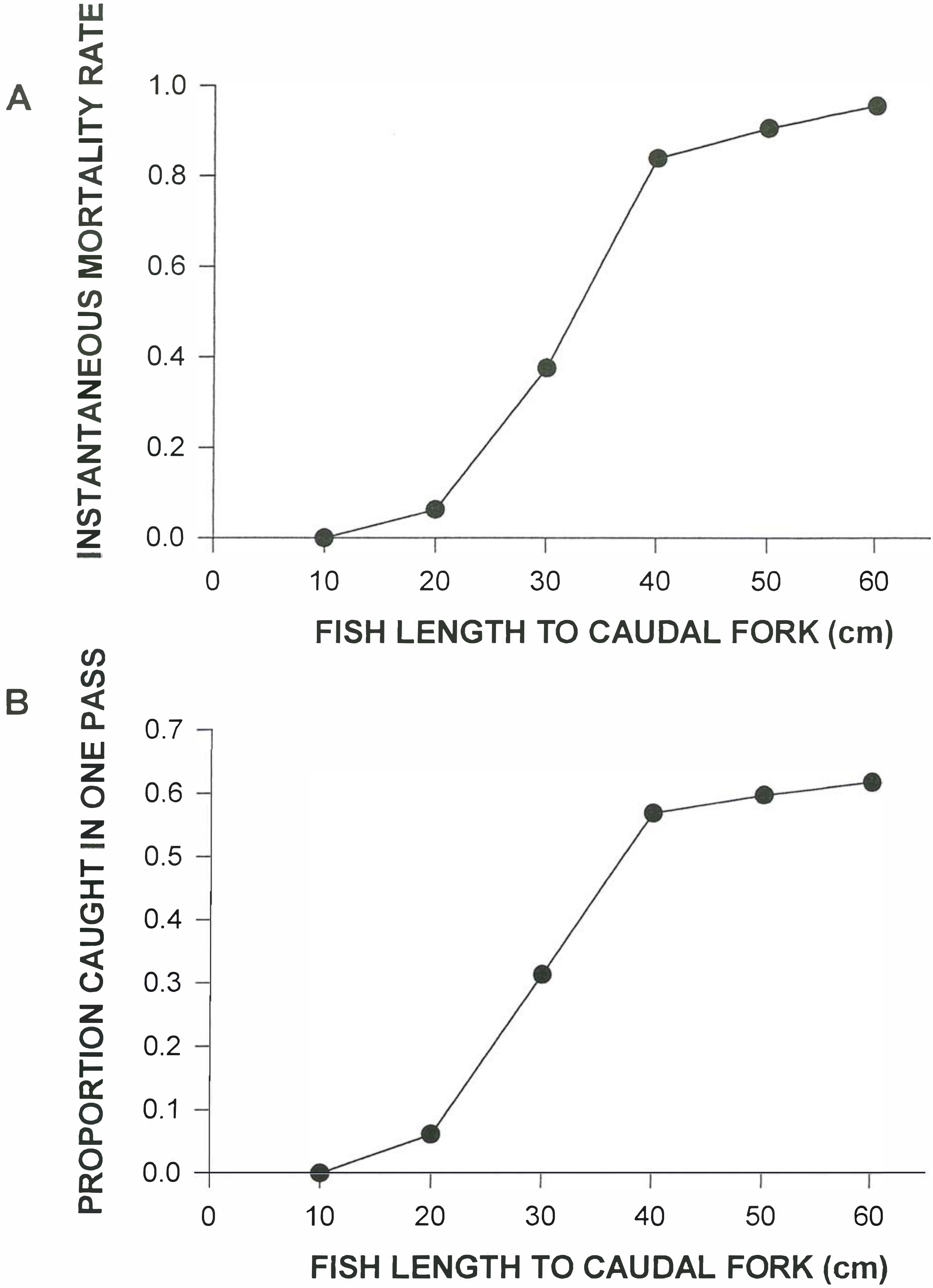


Fig. 31. Selectivity of a demersal trawl: A, the instantaneous mortality rate; and B, the proportion caught in one trawl pass, for fish of different sizes.

If it can be assumed that there is negligible nett movement of fish into or out of the marked area, the mortality rate per trawl pass for a fish size group can be estimated from the slope of a regression of the natural logarithm of the number of fish caught in a trawl pass, against the pass number (1 to 4).

These regressions were done for fish in the size groups (length to caudal fork) <26cm, 26-35cm, 36-45cm, 46-55cm and >55 cm (Fig 30). The three larger size groups had similar large slopes, the 26-35cm group an intermediate slope and the smallest group a very low slope. The instantaneous mortality rate per trawl pass for each size group is shown in Fig 31A, and, in Fig. 31 B, the proportion of fish caught in one trawl pass for each size group.

For the fish larger than 35 cm, the proportion of fish in the area caught by a single pass is around 0.6. For the 26-35 cm group, which is the most abundant group, the proportion falls to 0.3, while for the small fish less than 26cm the proportion is less than 0.1.

As for the benthos, this result can be extrapolated from this small block to the whole area of the fishery, to give estimates of fishing mortality for the various size groups of fish.

The important point from this study is that the susceptibility of fish larger than 35 cm to being caught in a demersal trawl is double that of the fish in the 26-35 cm group. In a single-species fishery this would be a very acceptable state of affairs. However, in this fishery it means that the large species such as *Lutjanus sebae, Epinephelus multinotatus*, and *Lethrinus nebulosus* are subjected, if fishing is random, to double the fishing mortality of the smaller species such as the common small lethrinids such as *L. choerorynchus* and lutjanids such as *L. vittus* .

If the larger species are targeted by concentrating fishing in areas where they are known to be more plentiful, the difference in fishing mortality rates will be even greater. While the biology of these species is not well known, it is possible that the larger species have lower natural mortality and recruitment rates and are thus more susceptible to overfishing.

To maximise sustainable yield from a multi species fishery, all species should ideally be fished at a level of fishing mortality that maximises yield for that species. This ideal is of course unattainable. However, having the larger species more heavily exploited than the smaller ones in this fishery is likely to leave the small species under-exploited while the large species are over-exploited.

We believe that this is a serious problem and that research should be initiated to find a solution. It may be that a type of gear could be introduced which evens out the selectivity or reverses it, or the solution may be to seasonally close the areas favoured by the large species. Research into this imbalance of fishing mortalities should be a high priority.

SIZES OF FISH TAKEN BY DIFFERENT GEAR TYPES

Length-frequencies of many species taken by the various gear types were collected to determine if any had significant numbers of juvenile fish. Although fish trawling has the physical ability to retain juveniles of the larger species, in fact juveniles of most species are rare in the catches. This is probably because the juveniles are living in a different area. CSIRO trawl surveys on the NW Shelf found that for most species examined, size increased with depth. This may mean that the juveniles of some of the species are inshore of the inner boundary of the trawling area.

Two species of which juveniles are moderately common in trawl catches are the coral trout, *Plectropomus maculatus*, and the red emperor, *Lutjanus sebae*. While the red emperor juveniles flap vigorously on deck when spilled from the codend and seem as though they would have a good chance of survival when returned to the water, the coral trout are dead or appear moribund. Coral trout do not make up a major part of the trawl catch and it is possible that when more information becomes available on their distribution, they may be seen to be localised in areas which could be avoided by the trawl fleet. The minimum legal length of red emperor is 41 cm and for coral trout it is 45 cm.

Juvenile coral trout are also taken in Dampier Archipelago by recreational line fishers, but the water is generally shallow enough to give them a good chance of survival when returned to the water.

Pink snapper, *Pagrus auratus*, are taken as undersize (<41 cm) fish by both recreational and commercial line fishing. The snapper tend to be segregated to some extent by size. Inside Shark Bay the juveniles older than one year are usually found in shallow areas where, although they are frequently caught by recreational fishers, they .

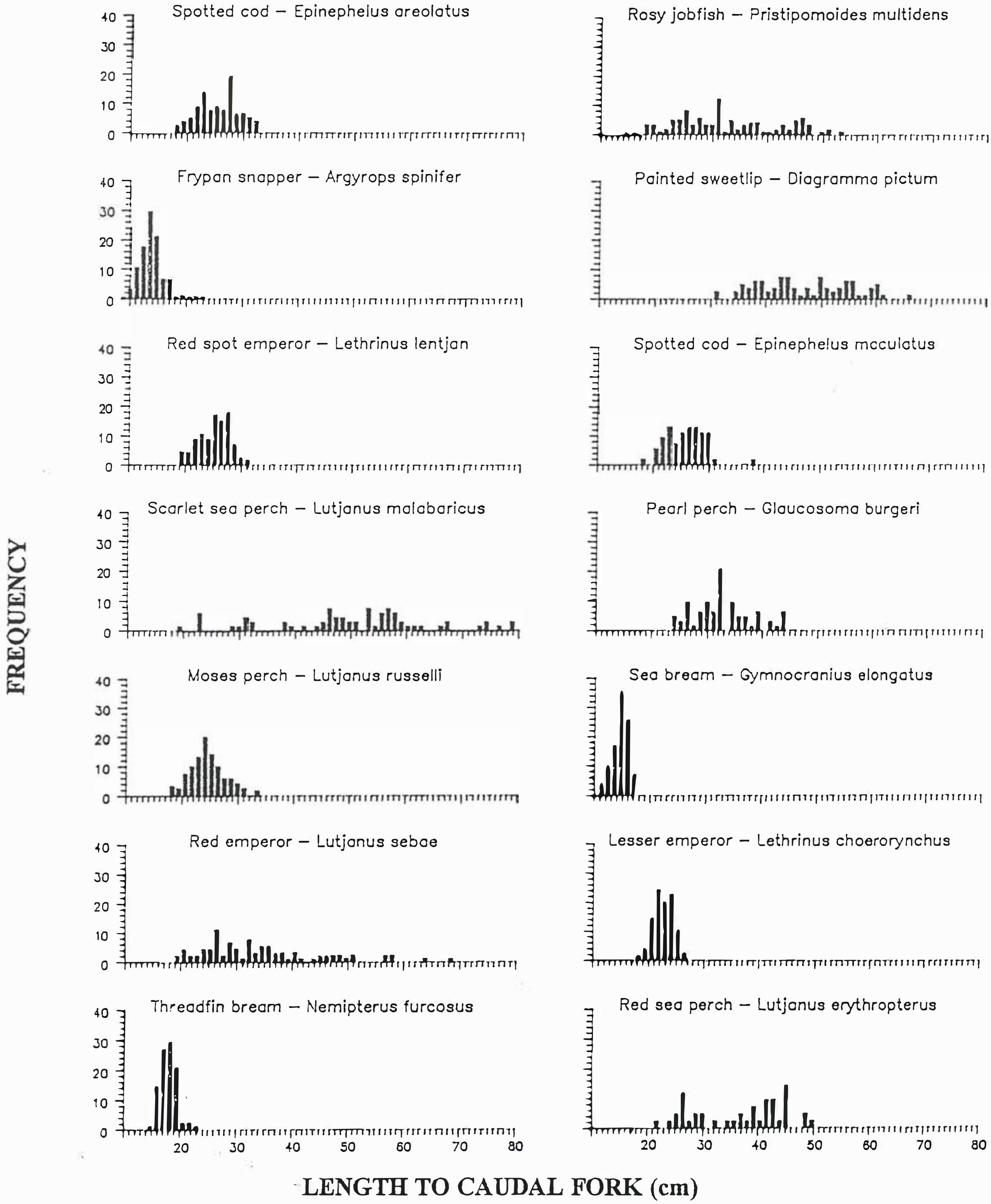


Fig.32. Length-frequencies of samples of trawl fish of various species in the retained catch from Australian NW shelf fish trawlers.

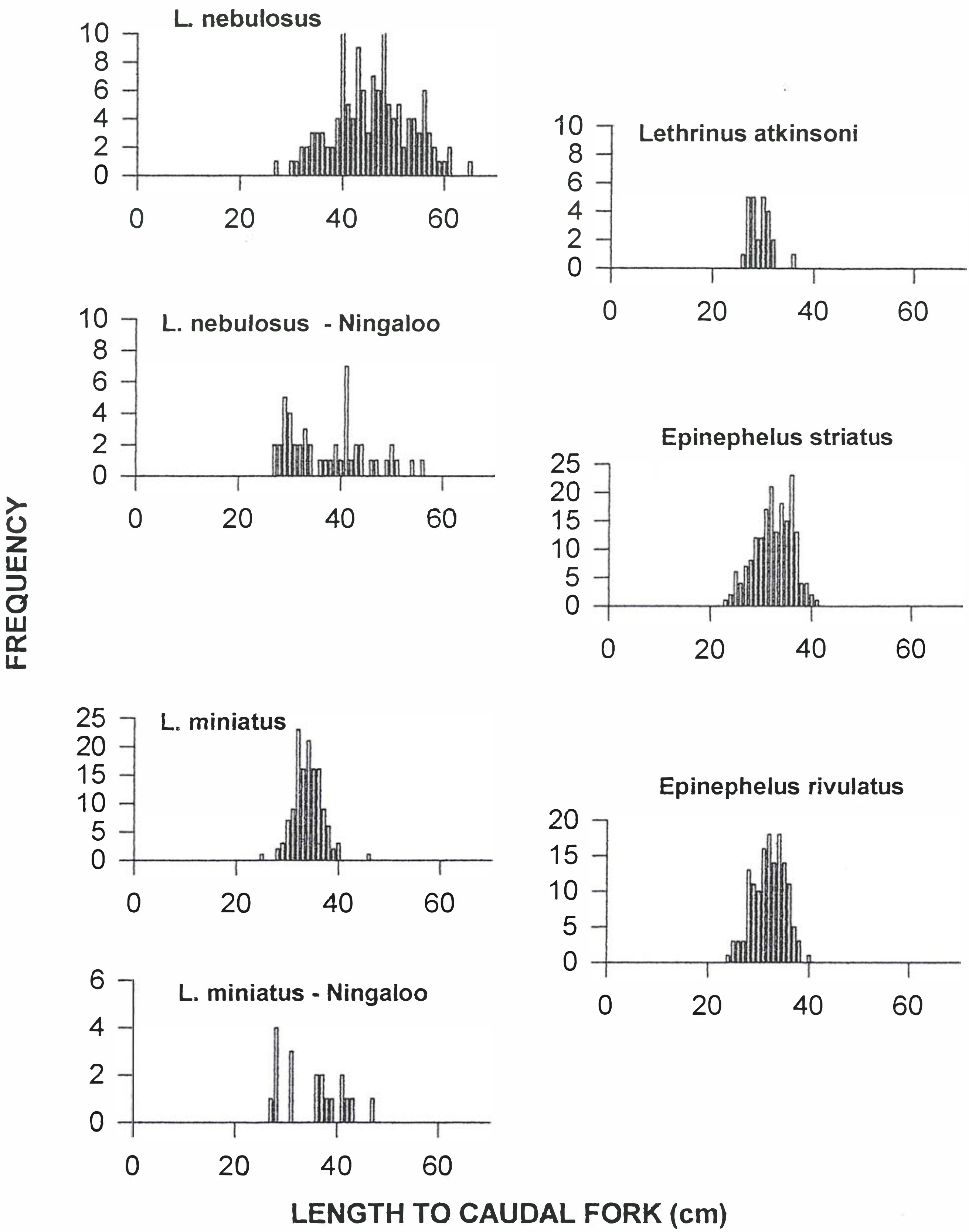


Fig. 33. Length frequency distributions of some recreational catches. All were taken in the west Pilbara region except where marked Ningaloo. Note the smaller *Lethrinus nebulosus* which are caught inside the reef at Ningaloo.

have a high chance of survival on return to the water. Outside Shark Bay where the commercial fishery occurs, the smaller fish in the peak fishing season are in deeper water and the commercial fishers and charter skippers know their distribution well enough to avoid them.

The large spangled emperor *Lethrinus nebulosus* is rarely taken as a small fish in commercial fishing by any method. Inside the reef at Ningaloo, however, small ones less than the minimum length of 41 cm are often taken by recreational line fishing. However, in this shallow water the fish have an excellent chance of survival when returned to the water.

Although we have no data to support it, we have been told by trap fishermen that before the inshore closure to trapping was introduced, juvenile rankin cod *Epinephelus multinotatus*, could be caught by trap in the shallow waters of the eastern Pilbara. Although small species of cod are frequently caught by trap and fish trawl, juvenile rankin cod are rare in the commercial catches.

While the very young juveniles (less than one year old) of all species are probably vulnerable to capture by prawn trawls, most of the commercial and recreational species appear to have a juvenile distribution away from the prawn grounds. Exceptions are pink snapper and lesser spangled emperor, *Lethrinus choerorynchus*, in Shark Bay and the lutjanids *Lutjanus malabaricus* and *L. erythropterus* in the Pilbara. The effects that capture of these juveniles have on the overall population dynamics are unknown. Pink snapper and the lesser spangled emperor are known to have other nursery habitat away from the prawn grounds.

DISCUSSION

A major finding of this work is the estimate of mortality of benthic fauna such as sponges, soft corals and gorgonians in the path of a fish trawl. Our findings, which include the effects of the sweeps as well as the net, support those of Mounsey & Ramm (1991) that semi-pelagic trawls, fished with the foot-rope above the sea-bed, are much less damaging to benthos than demersal trawls. However, a semi pelagic net, fished just above the sea-bed, catches much less fish than a demersal net.

Mounsey & Ramm (1991) found in the Arafura Sea that fish catches in a demersal net were of similar weight to those of a semi pelagic net. The high catch rate of the semi-pelagic net was largely due to the fact that it could be used to target schools of *Lutjanus malabaricus* because the net was more manoeuvrable than a demersal net and the boat could quickly turn to make repeated passes through the school. Our difference from Mounsey & Ramm's (1991) result is probably due to the absence of large schools of *Lutjanus malabaricus* on the NW Shelf, in contrast to the Arafura sea.

There is no practical way to ensure that fishermen will tune their nets to fish 15 cm above the seabed. As they would naturally operate the net at a height to maximise catches, we do not believe that semi-pelagic trawls are a solution to habitat damage on the NW Shelf as they are in the Arafura Sea where schools of large lutjanids occur. If standard demersal trawls continue to be used on the NW Shelf, the level of effort could be limited so that each piece of sea bed was only trawled rarely enough to be sustainable depending on benthos regeneration rates. The problem is that the regeneration rates of these benthic organisms are unknown. Sainsbury et al (in press) estimate that the time for recovery is well in excess of ten years.

While fish trawling is much more damaging environmentally than the other methods of catching demersal scalefish, it takes species which are not taken by other means, such as the threadfin bream, pearl perch and frypan snapper. Prohibiting trawling in an area is very likely to leave a valuable resource such as this unexploited. On the NW Shelf a practical compromise may be to limit trawl fishing to the area currently worked between 116° and 120°E. An exception could be made in areas where the habitat is completely sand or mud as may be the case in some of the grounds between 127° and 129°E. Environmental surveys should certainly be a prerequisite to opening up more trawl areas. The interactions of the fish populations with the benthic fauna are unknown, although Sainsbury's work indicates that a change in the benthos due to

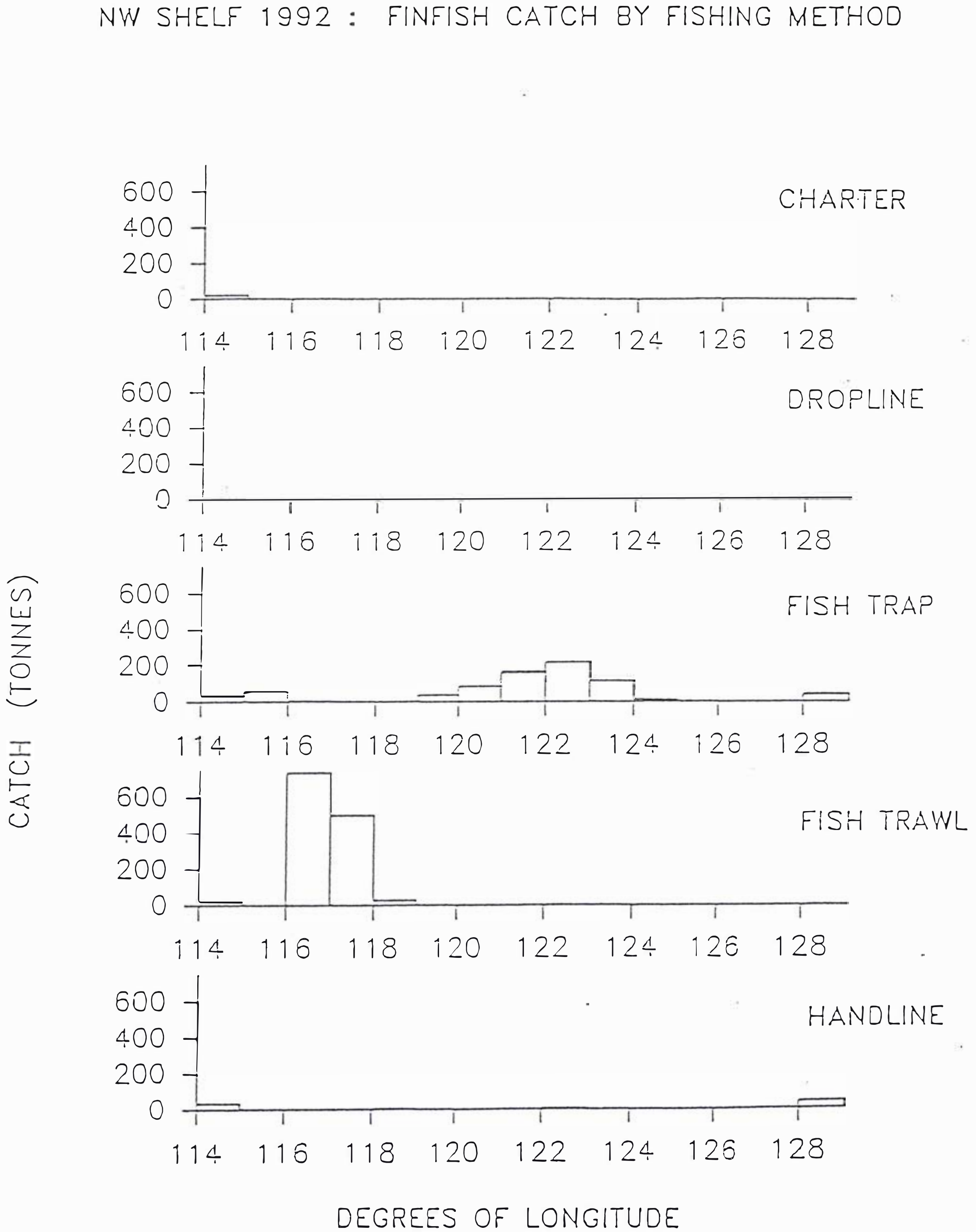


Fig.34. The distribution of the 1992 finfish catch on the NW Shelf by fishing method and longitude. Trapping and trawling are clearly the methods taking the greatest catches, with trapping centred on Broome (122°E) and trawling on Pt. Samson (117°E). CAESS data.

the decades of Taiwanese pair trawling could have caused major changes in the fish community.

In the Shark Bay region, the demersal fish stocks of the oceanic part of the region are in a healthy state. There is little impact of the recreational and commercial fisheries on each other despite a large overlap in both species taken and area fished. The commercial fishery for the major species, pink snapper, is tightly constrained by quota management. There is potential for increased effort by commercial fishermen who do not have snapper quota and by charter operators unless these are limited in some way. There is a certainty of increasing recreational effort as the population increases and a method of constraining the catches of the recreational sector must be found in the future to prevent overfishing to the detriment of both the commercial and recreational sectors. A number of species in this region are likely to be currently under-exploited. These include the lesser spangled emperor, pearl perch, frypan snapper and trevally. There is potential for exploiting some currently unexploited species in the deeper water (more than 150 metres) by trawling without impacting the linefishing species.

Ningaloo is predominantly a recreational fishing area. The Fisheries Department's policy is to phase out commercial fishing in the marine park in consultation with the licence holders. As tourism grows, so will recreational fishing effort. There is anecdotal evidence that recreational fishing on inshore stocks of species such as spangled emperor has already caused depletion in the area inside the reef. Bag and possession limits should be reviewed at intervals of about five years to prevent serious overexploitation. Means of reducing the dependence of the charter boats on the commercial linefishing part of their business should be sought, as the income from chartering provides a better economic return for the fish caught. Commercial linefishing at some level is still desirable as there will always be a need for fresh-caught local fish in the tourist/restaurant trade. The best overall solution may be a limited number of charter boats in the region with some or all of them having the ability to fish commercially for local needs.

Fish trapping in the inner shelf waters outside Ningaloo reef had a peak in catch and effort in the late 1980s and has now dwindled to nothing as a result of depletion of stocks to unattractive levels. Since fish trapping both in Shark Bay and Ningaloo has wound down of its own accord, it is an opportune time to extend the area currently closed for fish trapping on the west coast by moving its northern boundary from 26° 30'S (below Shark Bay) to 114°E (North West Cape).

The fish trawler in the deep water (100 to 200 metres) outside Ningaloo Marine Park, while not affecting other user groups, should be monitored to detect any overfishing in its prescribed area. No additional trawlers should be permitted in this area until its productive capacity and the status of the benthos are known.

In the western Pilbara, the area directly to the north of Exmouth Gulf is no longer a major commercial trap fishing area and could be excised from the commercial trap fishery. As Ningaloo bag and possession limits already apply in this area and will be subject to future reviews, the area could, for fishing purposes, become part of the marine park as a recreational and charter fishing area with a small amount of commercial linefishing.

The western zone of the Pilbara Trap Fishery has persisted as a fishery though many of the licensees have moved north to the Kimberley or simply ceased to fish. Catches have consequently declined to a low level. The main problem in this fishery is that too many licences were granted in the limited-entry fishery for the trappable fish resource. A lesser problem was the permission given to a fish trawler to operate in part of the trapping grounds to the west of Barrow Island, where there is a substantial species overlap between the trawl and trap catches.

The small fish-trawling area west of Barrow Island was granted initially because the base of the trawler was Exmouth and packing the trawl fish was important to the factory there. There is a significant overlap in trawl species composition with the trap fishery in the same area. Since the trawler no longer works from Exmouth, the justification for trawl access to this area no longer exists. If the area were removed from the trawl fishery, it would be to the benefit mainly of the trap fishery and to a lesser extent the recreational fishery.

The rapid increase in catch and effort in the Pilbara Trawl Fishery has led to concern about sustainability of the fish stocks. A separate research programme is calculating the appropriate level of effort in this fishery. There is some conflict between the trawl fishers and other commercial fishers (trap and line) and recreational fishers in the eastern Pilbara. There are a number of patches of reef at about 50 metres depth which the trap and line fishers believe should not be trawled but the trawl fishers consider should be within their area. Trap fishing in the eastern Pilbara has virtually ceased as the trawl fishery developed. Although trawling over the rough bottom which favours trap and line fishing should be minimal to prevent net damage, it does occur and the trawl fishery catches all the trap and line species very efficiently. It cannot be proven that the trawl fishery has made trap and line fishing unprofitable but on circumstantial evidence it appears very likely.

In Dampier Archipelago, fish trawling and trapping are prohibited, and although commercial linefishing is permitted it does not currently occur. The archipelago is primarily a recreational fishing area and anecdotal evidence indicates that the stocks of demersal fish have become greatly depleted during the last two decades. A higher order of management of recreational fishing in this area is probably justified. There is currently conflict between commercial and recreational rock lobster fishermen in the Dampier region and an increase in commercial linefishing would be very likely to lead to conflict over demersal fish also.

The closure to trapping around Broome has been adequate to prevent conflict between commercial and recreational fishers to date. However, charter fishing from Broome is growing with the development of tourism in the town and, if commercial linefishing in the area intensifies, it may be appropriate to change the trapping closure to a general commercial demersal fishing closure to prevent over-depletion of the area.

Latent effort from linefishing is probably the main future problem for management of the fish stocks on the NW Shelf outside of the fish trawl area. The Western Australian fishing industry has a policy that linefishing generally should not be restricted. Even though hand-line fishing is generally less efficient than trapping or trawling, mechanised lines can be just as or more effective than trapping. Management of a demersal resource should encompass all methods capable of taking that resource and limit the total fishing effort from the combined methods to a sustainable level. Currently, except for the Kimberley, there are no limits on commercial linefishing anywhere and any licensed Western Australian fishing boat can fish with any type of line.

The fish trawl fishery is the subject of a current research program to determine an appropriate level of fishing effort. The growth of effort in that fishery has been rapid and may be cause for serious concern, both in terms of the stocks of the larger species and the benthos. Future growth of this fishery should be directed at the smaller species such as threadfin bream which are probably being under-exploited while the larger species are being over-exploited. Research into a fishing gear solution to this problem may be productive.

The incidental take of juveniles of commercially and recreationally important finfish species by prawn trawlers is not known to be having a serious impact on any of the demersal finfish user groups. While it is straightforward to measure the abundance of juveniles of important species in the trawl bycatch, the reduction this causes on availability of fish for exploitation as adults is very difficult to determine. In Shark Bay, snapper and bream are a small but significant part of the bycatch which is nearly all non-commercial species. In Exmouth Gulf, commercially and recreationally important species were not significant in the bycatch and in the Pilbara the main commercial bycatch species are juvenile *Lutjanus malabaricus* and *L. erythropterus*. These two species are important to the fish trawl fishery and were a major component of the trap fishery in the eastern Pilbara when it was active. While the juvenile mortality due to prawn trawling cannot be proven to be having adverse effects on the finfish fisheries, clearly it should be minimised if possible. As the technology of fish escape panels for prawn trawls improves, they may provide a solution to this aspect of prawn trawl fisheries.

ACKNOWLEDGMENTS

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