Assessment of the outer-shelf fishery resources off the Pilbara coast of tropical Western Australia.

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Objectives

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To provide industry and management with a range of options for sustainable exploitation of the deeper water fish resources of the Pilbara.

Non Technical Summary

Surveys of the 100-200 metre depth zone off the Pilbara coast of Western Australia were undertaken using commercial fishing industry vessels and observers from Fisheries Western Australia. Commercial catch rates in the 100-200 m depth zone off the Pilbara coast were generally low. The commercial viability of this zone appears to be restricted to the shallower depths less than 140 m. The fish fauna was found to be diverse with a number of species of commercial importance present. Catch rates of commercially important fish were higher in the shallower waters of the survey area where hard bottom communities and sponges were more abundant. Fish of the Family Lutjanidae (tropical snappers or seaperches) were found to be the most dominant and commercially important fish landed during the survey. The demersal fish resource in the 100-200 m depth zone was somewhat similar to that of the 50-100 m depth zone although the key species were different.

Juveniles and adults of *G. buergeri* (pearl perch), *L. malabaricus* (scarlet seaperch), *P. multidens* (goldband snapper) and *P. typus* (sharptooth snapper) all appear to be present in depths of 100-200 m, while the juveniles and sub-adults of *L. russelli* (Moses perch) were not caught. The possibility exists that sub-adult or adult *L. russelli* undertake cross-shelf migrations to deeper offshore waters.

The key species (*G. buergeri*, *L. malabaricus*, *L. russelli*, *P. multidens* and *P. typus*) examined in this study are, in general, slow growing, long lived fishes which have low rates of natural mortality. These life history characteristics have important management implications. Their slow growth, protracted longevity and low rate of natural mortality imply that these fish have a low production potential and they will be vulnerable to over-exploitation. Setting harvest strategies below the limit reference point F_{limit} (F_{limit} = 2/3 M) is recommended in order to maintain the spawning stock biomass and prevent stock collapse. A limit reference point represents a state of a fishery resource which is considered to be undesirable and which management action should avoid. Estimates of F_{limit} from this study indicate that less that 10% of the available stock biomass can be harvested on an annual basis in order to achieve sustainability objectives. Fishers often encounter and target large schools of fish, in particular schooling species such as *P. multidens* and *P. typus*. It is difficult for fishers to reconcile and accept that for each fish taken a large number of fish must be left in the water.

Evidence from this study indicates that the exploitation of *P. multidens* off the Pilbara coast exceeds optimum levels, while the harvest rate of the closely related *P. typus* is approaching the limit reference point. Areas closed to fishing (harvest refugia) are recommended to preserve the spawning stock biomass of these fishes. Future stock assessments should also consider the use of otolith weight as a proxy for fish age. Otolith weight is likely to be a reliable and cost effective method of providing age estimates for the species examined in this study.

Precautionary fishery management strategies are recommended in order to facilitate the sustainable development of the demersal fish resources in the 100-200 m depth zone off the Pilbara coast. The complex habitats present in depths of 100-140 metres off the Pilbara coast contain benthic communities which are considered to have had only minimal impact from commercial fishing operations, and therefore these communities remain relatively undisturbed. These complex habitats need to be conserved as part of future fishery management plans. A number of management options are presented for the 100-200 m depth zone off the Pilbara coast.

KEYWORDS: Pilbara, 100-200 metre depth zone, Distribution, Abundance, Scarlet sea-perch, *Lutjanus malabaricus*, Moses perch, *Lutjanus russelli*, Pearl perch, *Glaucosoma buergeri*, Goldband snapper, *Pristipomoides multidens*, Sharptooth snapper, *Pristipomoides typus*, Otoliths, Age, Growth, Mortality, Commercial catch, Non-commercial catch, By-catch, Fisheries management.

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Background

The managed continental shelf finfish fisheries off the Pilbara coast of Western Australia comprise a trap fishery and a fish trawl fishery in the region from 114°E-120°E. A line fishery is also present in these waters but it is presently part of the open access fisheries of Western Australia. The fish trawl fishery dominates with the trap fishery, in general, only persisting in the areas closed to fish trawling (shallower than 50m and west of 116°E), although trapping is undertaken in offshore waters (> 100 m depth). Research on the fish trawl fishery (FRDC Project 93/25) has found that within the boundaries of the fishery the more vulnerable long-lived species such as red emperor (*Lutjanus sebae*) and rankin cod (*Epinephelus multinotatus*) are over-exploited, while the smaller species which make up the bulk of the catch are under-exploited. Management of the trawl fishery is, as a result of this research, aimed at reducing fishing effort and redistributing it away from the areas of highest concentrations of vulnerable species.

Both the trawl and the trap/line fisheries in the Pilbara have been concentrated on the inner continental shelf (<100 m), largely as a result of the previous experience of the operators in inshore waters, the suitability of the boats (ex shallow water prawn trawlers and rock lobster boats) and the greater ease of working in shallower waters. The former foreign vessel fishing fleets operating on the North West Shelf also limited their activities to grounds shallower than 100 m. The landed value of catches from the inner continental shelf waters of the Pilbara is in excess of $10 million annually. During recent years, the trawl, trap and line boats have begun to extend their operations to the outer-shelf waters deeper than 100 m. The grounds between 100 and 200 m depth in the Pilbara region are similar in area to the grounds between 50 and 100 m.

The demersal fish assemblage on the outer-shelf (> 100m) was expected to consist primarily of eteline lutjanids and therefore represent a somewhat different fish community from the one in the 50-100 m depth zone. The results of research conducted in the inner continental shelf region are therefore likely to have little relevance to the outer-shelf. There is currently no information available on which to base management decisions regarding access to the resource in the 100 to 200 m depth zone in this region. The results of this project will be relevant to the inshore zone (50-100 m) as the main species identified in this project are also important in the inshore zone.

Nominal fishing effort in the Pilbara region is restricted to 5 trap licences and 3 trawlers with full-time access, and 8 trawlers with 6 months/yr access. Although currently unrestricted line fishing is in the process of being brought under stricter management. Previous research in the 50-100 m zone found that the larger, longer-lived species such as red emperor and rankin cod were being subjected to about double the sustainable level of fishing mortality. The redistribution of fishing effort in this zone is helping to overcome this problem. However, as this fleet moves into deeper outer-shelf waters, it is very likely to have the capacity to overfish less sustainable, longer lived species such as goldband snapper (*Pristipomoides multidens*) in the 100 to 200 m zone.

The fishing industry is aware of the vulnerability of the deep water species and has sought to work cooperatively with Fisheries WA to ensure that exploitation of the outer-shelf fish resource occurs in a sustainable manner and so that appropriate management measures can be implemented.

Need

Managers need to be provided with information that will ensure that fishing mortalities remain below the appropriate biological reference points for the key species. To provide this information, knowledge of the distribution and abundance of the resource and the demographic parameters of the key species is required. The fish in the 100-200 m depth zone are considered vulnerable to overfishing as many are schooling species and commercial effort will naturally be targeted on schools. Studies throughout the Indo-Pacific suggest that deep slope reef fishes are extremely vulnerable to exploitation pressure.

Objectives

To document the distribution and abundance of adults and juveniles of major finfish species in the 100 to 200m depth zone off the Pilbara coast.

To provide industry and management with a range of options for sustainable exploitation of the deeper water fish resources of the Pilbara.

Methods

1. *Survey area and design*

The survey area of this project comprised the offshore 100-200 m depth zone (known to commercial fishers as Area 6) of the Pilbara Fish Trawl Fishery, off the Pilbara coast of tropical Western Australia (see detailed figures in Appendix 4). The 100-200 m depth zone encompasses an area of approx. 24, 580 km^2 and is bounded to the north and south by a series of lines which generally conform to the 100 and 200 m bathymetric contours (perimeter is approx. 1048 km in length). The 116°E and 120°E meridians form the western and eastern boundaries of the survey area.

The survey area was divided into smaller sub-units (blocks) for allocation to fishers (see detailed spatial maps in Appendix 4) and for comparative purposes. The initial survey proposed 720 eight-mile trawl shots within a six month period, giving 30 shots for each 10 minutes of longitude (block areas) between 116°E and 120°E. A total of 72 blocks were allocated to vessels licensed for the Pilbara Fish Trawl Fishery. Trawl shots were random with some targeted shots undertaken on areas of productive bottom.

All trawls were of approx. two hours duration with 8 trawls initially allocated per block in the smaller Western Zone (116°E to 118°E) and 12 trawls initially allocated per block in the larger Eastern Zone (118°E to 120°E). The additional trawls in the Eastern Zone were designed to incorporate the significantly larger area within each of the trawl blocks in this zone.

Trawl vessels were required at all times to carry two FWA observers in order to monitor catches and vessel movements and to guide survey operations. Trawls were undertaken under normal commercial fishing conditions and all commercial product landed was retained by industry vessels. Vessel movements were additionally monitored by the Fisheries WA Vessel Monitoring System to ensure boundary compliance.

The generally poor catch rates in the 100-200 m depth zone in comparison to the inner-shelf (50-100 m) fishing zone resulted in a reluctance on the part of fishers to complete the initial survey and only approx. 33% of the proposed survey trawls were completed. This project reports on those trawls and the population parameters of the key species in the 100-200 m depth zone.

2 . *Vessel and gear specifications*

Six vessels were used in the survey, each with a relatively similar design (described below). All vessels were based on the northern Australian steel prawn trawler design with modifications to enable fish trawl operations. Vessels were used near-shore for prawn fishing at various times of the year. The general fish trawl configuration was a 'six-pack' design (three twin cabins) stern trawler (trawl warps re-directed off booms when prawn trawling). All vessels were approx. 15-20 years old, of steel plate construction (LOA 23m, breadth 6.5 m). Vessels were powered by a single main 400 Hp diesel engine with two auxiliary engines powering 240V generators, hydraulic pumps and refrigeration compressors. The wheel-house is forward and one level above the work deck, with a short foredeck forward of the wheel-house. Crew quarters lie below the wheel-house and foredeck, with the cold room/freezer hold below crew quarters.

2.1 *Navigation and communications*

All vessels were equipped with GPS units interfaced with a colour plotter (typically Furuno GD 180), monochrome radar, colour echo-sounder, Automatic Location Communicator (ACL) with data terminal for Vessel Monitoring System (VMS), communication equipment including HF and VHF radio, satellite phone/fax and cellular mobile phone.

2.2 *Work deck*

Divided into three main areas. Stern area with split net drum mounted on 'A' frame gantry and net ramp, cod-end spill bay below. Net drum usually with two nets separated by central flange, with one net in operation, the other held as a spare. Central section with above-deck brine tanks banked either side of midships line. Forward section under cover of overhang and housing main winches, ice machine, hatch to freezer hold, wash-up station and dry deck-store.

2.3 *Catch holding facilities*

Several deck-mounted brine tanks with a combined capacity of 4-7 tonnes. Brines usually cooled to 0-1° C by refrigerated coils and/or addition of ice. Below-deck 20-tonne capacity cold room (hold) for post-brine product storage at ~1° C. Shelved blast-freezer cabinet(s) present but employed only when prawning.

2.4 *Crew and accommodation*

Crew complement 4-5 comprising skipper, mate and 2-3 deckhands. Quarters typically arranged to a 6-pack design where 3 twin-berth cabins, a galley, dry food store and bathroom/toilet are arranged to owner preference using non-structural partitions within a standard frame. Some vessels with separate skipper's bunk or quarters in or attached to wheel-house. Wheel-house quarters air-conditioned.

2.5 *Trawl gear*

Single fish trawl usually of 'cutaway' design (not full wings) with 18-fathom headrope, several 8" submersible floats attached. Wing mesh 225-250mm (9-10"), codend mesh 100mm (4"). Steel-cored ground rope threaded with small (2") rubber bobbins interspaced at regular intervals with larger (8") bobbins. Net towed with 14mm warp wires and spread with 20-fathom bridles attached to steel 'V' doors.

Trawl warps controlled by two large hydraulic winches set forward on the workdeck either side of the vessel near the gunwales and directed slightly outboard. Warps directed overboard through a pulley-block projected outboard on retractable boomlets attached to each side of gantry. Warp wire spooled on winches by hand-controlled hydraulic spooling bar. Warp wires physically marked to indicate amount payed-out. Trawl retrieval time (from 150m) approximately 25 minutes.

3. *Trawling procedure*

Most trips were fully dedicated to survey operations although occasionally some inshore fish trawls were undertaken on the way back to port to augment poor survey catches. Trip duration was governed by shelf life of fish and was typically eight days. At least four days of each trip were spent fishing with the remaining time involved in transit between blocks and to and from the home port of Point Samson. An average of five trawls a day were completed and most (88%) were set between 0500 and 2200 hrs. Skippers were generally reluctant to trawl late in the night preferring to rest crews and concentrate effort in crepuscular and daylight periods which they believed produced the best catches.

Prior to fishing, trawl block coordinates were entered into the vessel's colour plotter so that trawl tracks could be viewed in relation to each other and set so as to provide even effort distribution within each block. The skipper decided the order in which the required two-hour trawls were completed. An initial sounder-survey was occasionally undertaken to assess the trawl-ability of the bottom in some blocks.

The first trawl within a block would begin near the point of entry into the block which was planned to be either at the top or bottom to allow the series to progress up or down within the block most efficiently. After following a selected depth roughly along a NE-SE contour for two hours the trawl would then be retrieved and the vessel turned around to shoot away again in a direction parallel to the previous track but at different depth. All trawls were required to be spaced at least one nautical mile apart to avoid repetition.

4. *Catch handling*

Upon retrieval trawls were spilled through the unlaced cod-end onto the deck and usually reset immediately while the crew and observers commenced catch sorting. The commercial component was first picked out by hand and sorted into individual species, if abundant, otherwise into mixed groups of similar species. Sorted fish were placed in slotted lug baskets and immersed in chilled brine tanks above deck as soon as possible to rapidly reduce core body temperatures. After at least two hours the baskets were removed and carried below to the cold room where fish were repacked dry in lidded plastic fish bins with plastic bag liners and stored at 0° to -1° C until unloaded.

5. *Catch sampling*

Catch composition recording was a priority for observers but other sampling was undertaken opportunistically including length frequency measurements and biological sampling from the key commercial species and non-commercial (by-catch) specimen collection for identification.

Project observers recorded all retained or discarded species from every trawl and quantified catches of each by number and weight estimates. Crews also kept a tally of commercial species for the vessel's log. Vessels were not equipped with sea-going balances and crews always estimated catch weights based on known average weights (~35 kg) and numbers of lug baskets filled. Estimates were adjusted where necessary to compensate for significant differences in fish size and packing density. Observers regularly compared commercial weight estimates with crews for consistency and additional checks were undertaken against accurate landed weights. This confirmed the estimated weights as being reasonably accurate.

The commercial component was always processed first and with haste to minimise product exposure to the tropical heat. By-catch was left on deck until the crew finished sorting and cleared the area. Observers first sorted the discards into species or family groups, then counted individuals and estimated an average individual weight for each category. Where a species was too abundant to make counting practical the number that would fill a basket was recorded and multiplied by the number of baskets subsequently filled.

Where practical during commercial catch sorting by crew members, observers measured the fork lengths of as many individuals as time allowed from the key commercial species. Sampling included measurement of total, fork and standard lengths and dissection to determine sex and maturity stage, and gonad and otolith removal. Gonads were frozen in plastic bags to be taken ashore for accurate weighing and otoliths were washed, dried and stored in envelopes for laboratory analysis. During sampling observers were careful to minimise damage to fish which were returned to the crew intact, save gills and viscera, for storage.

Many by-catch species could not be readily identified and were retained for later examination by the WA Museum and CSIRO. Wherever possible a size range of unidentified specimens was collected for this purpose and fish in the best condition were selected. Specimens were placed in plastic bags and frozen.

Results

1. Distribution and abundance of commercial and by-catch species including benthos

1.1 *Distribution of trawl survey effort*

Fish trawl surveys commenced in February 1998 and 182 trawls (79% of total effort) were completed by the end of April 1998, with the remaining trawls completed by November 1998. Survey trawls were undertaken on nine separate trips involving six vessels. On average, 26 trawls were completed per trip. Survey effort was relatively widespread with 49 (68%) of the 72 survey blocks having at least one trawl completed therein. The distribution of the 23 non-surveyed blocks was scattered across the survey area (Appendix 4, Fig. 3). The majority of trawls (114 or 54%) were undertaken in the shallower blocks (A3, B3 etc) closest to the boundary of the inshore zone of the Pilbara Fish Trawl Fishery (Fig. 1.7). Effort in this area was concentrated on known hard bottom areas near the 100 m bathymetric contour. Trawl effort was much reduced (19%) in the outer blocks (A1, B1 etc), furthest from the inshore zone of the trawl fishery and where the bottom substrate was predominantly sand or mud with little hard bottom (see Appendix 4). Trawl effort in the eastern zone (118° E to 120° E) was slightly greater (124 trawls) than in the western zone (116° E to 118° E, 106 trawls, Fig. 1.2). Most trawl effort (65%) was concentrated in the central survey area.

1.2 *Commercial catch*

Ninety-three percent (214) of the 230 completed survey trawls yielded some fish of commercial value. The majority of trawls (79%) were deployed in depths less than 140 m (Fig. 1.7) where bottom features and fish schools were in the main more abundant and hence these depths were the main target interest for commercial fishers. A total of 36.7 tonnes of commercial fish were landed from the survey at an average of only 4.2 tonnes per vessel trip. This was much lower than comparative catches of approx. 10-20 tonnes for a 4-5 day fishing period in the inshore (50-100 m) zone of the trawl fishery. The commercial catch was represented by 123 species or family groups and comprised 66% of the total biomass landed. Bottomfish were represented by 30 families and accounted for 91% of the total commercial catch weight. Most of the remainder comprised sharks and rays (8 families), with whaler sharks (Carcharhinidae) the dominant component (4.2% of total commercial catch) and a small catch component (< 0.1%) of crustaceans and cephalopods.

The bony-fish families of commercial importance were dominated both by weight and abundance by the Lutjanidae which was represented by 13 species and accounted for 72.1% of the bony-fish catch. Priacanthids (6.5%), Carangids (3.6%), Lethrinids (2.8%), Glaucosomatids (2.7%), Sparids (2.4%) and Sciaenids (2.3%) were also well represented in the catch. The remaining 25 families recorded comprised only 7.7% of the catch. Summaries of the relative abundance of the most common species or species groups are listed in Table 1.1. Five key species (*G. buergeri*, *L. malabaricus*, *L. russelli*, *P. multidens* and *P. typus*) of commercial importance were selected for detailed study. All are significant commercial species in the inshore zone (50-100 m) of the fishery and are known to extend to the outer-shelf, particularly the eteline lutjanids, *P. multidens* and *P. typus*.

The total catch of all finfish (bony-fish and cartilaginous fish) was highest in the mid-Eastern sector of the survey area (Fig. 1.1), while catch rates were relatively similar across all fishing sectors (Fig. 1.3). The concentration of fishing effort in depths shallower than 140 m (Fig. 1.7) corresponded to higher catches being recorded in these depths (Fig. 1.6). The spatial distribution of the catches and catch rates of the total catch, commercial fish, non-commercial fish, benthos, sponges, key species and species groups across the survey area are shown in Appendix 4.

A provisional species list of all species recorded, their common names and CAAB codes are detailed in Appendix 5. The occurrence of species and species groups by depth strata are listed in Appendix 6.

1.3 *Catch of key commercial species*

The key species, *G. buergeri*, *L. malabaricus*, *L. russelli*, *P. multidens* and *P. typus* were prominent in the commercial catch and represented 53% of the total commercial catch by weight. Common names and synonyms of the key species are detailed in Appendix 3. *Lutjanus malabaricus* and *P. multidens* were the most abundant (Fig. 1.5) of the 5 species and accounted for 40% of the total catch by weight (Fig. 1.4). The catch of red snapper, *Lutjanus erythropterus* was also relatively high. This species tends to form mixed species schools with *L. malabaricus*. *Pristipomoides multidens* was the most abundant of the key species in terms of the numbers of fish caught, with *L. malabaricus* the next most abundant, followed by *L. russelli*, *P. typus* and *G. buergeri* (Table 1.1, see also Fig. 1.5). The observed CPUE of *L. malabaricus* was higher than the other key species (Fig. 1.5). *Lutjanus malabaricus* had the highest average weight (2.45 kg), while *L. russelli* had the lowest (0.43 kg). The catch and catch rates of the key species were concentrated in depths generally shallower than 140 m (Figs. 1.8-1.13).

1.4 *Non-commercial catch or by-catch*

All trawls returned some level of by-catch, with a total of 18.9 tonnes (34% of total catch) discarded during the survey. The magnitude and composition of the by-catch was recorded as accurately as possible within the logistical constraints of the project. A total of 279 species or species groups were recorded. The magnitude of the benthos retained in the trawl net was also recorded as accurately as was practicable. Difficulties were experienced with recording species such as fan corals, sponges and cephalopods which had a tendency to be retained in the upper trawl meshes of the trawl wings. The size and species composition of the by-catch should provide baseline information on the distribution of fish of non-commercial importance within the survey area and document to some extent the magnitude of fish discards in the Pilbara Fish Trawl Fishery.

The by-catch was dominated by cartilaginous fish (sharks and rays; 48.3% by weight) and bony-fish (41.4% by weight). The actual numbers of sharks and rays were low, but most had a high average weight with the weight data biased by several large sharks and rays (>400 kg). The benthos category included echinoderms and comprised 8.1% of the catch (by weight) with other invertebrate species accounting for the remainder.

The by-catch was very diversified and characterised by numerous small species. Of the bony-fish only 12 species had estimated average weights of more than 1 kg, with pufferfish (Tetraodontidae) the most common large fish in the by-catch. Lizardfishes (Synodontidae) were abundant and widespread in the by-catch (33% of total bony-fish by-catch by weight). Eight species of Synodontids were recorded, with *Saurida filamentosus* and *S. undosquamis* most common (recorded from ca. 90% of trawls).

Summaries of the relative abundance of the most common bony-fish species or species groups are listed in Table 1.2. A relatively high catch of *Lutjanus quinquelineatus* was obtained primarily from 2 trawls in a similar area. In contrast to most other lutjanids this species has little commercial value due to its small size. The inclusion of other commercial species, such as *Glaucosoma buergeri*, in the by-catch list reflects the discarding of small individuals below marketable size. Due to logistical constraints some species were grouped into families, such as the Carangidae and the Synodontidae. However, the white-fin trevally, *Carangoides equula* constituted approx. 50% of the Carangidae by-catch, while *Saurida filamentosa* dominated the Synodontidae by-catch.

1.4.1 *Benthos*

Four groups of organisms were recorded from trawl catches and included in the benthos category. Estimates of the weight and abundance of benthos items in most cases are considered conservative. Benthos groups recorded included the Phyla Porifera (sponges) and Echinodermata (sea urchins, feather stars, starfish), and the Orders

Alcyonacea (gorgonians, soft corals, sea whips) and Antipatharia (black corals). These groups were chosen for their sessile nature and affinity with hard substrates.

The alcyonaceans and sponges comprise 87% of the benthos catch with sponges alone comprising over 60%. Weight estimates are considered conservative due to difficulties associated with quantifying specimens that were either damaged or partially lost during the trawl process. The alcyonaceans and gorgonian fan corals were most common in trawl catches but were difficult to quantify as specimens often became enmeshed in upper meshes of the trawl wings.

Throughout the survey area high relative catches of sponges and fan corals were usually characterised by large and presumably old specimens (10+ kg cup-sponges were not uncommon). This observation suggests that previous trawling in deeper water has been minimal and is in stark contrast to the catch of similar but much smaller benthos observed from the inshore fishery grounds where levels of fishing effort have been much higher.

The benthos catch data was not sufficient for detailed analysis, but did provide some confirmation of substrate type evidenced by echosounder readings and catch records. The spatial distribution of CPUE for sponges (see Appendix 4, Fig. 14) and for all the benthos (see Appendix 4, Fig. 12) indicates that most of the benthos is present in the innermost trawl blocks where hard ground was abundant. This was also the area targeted by commercial fishers and where commercial catches and catch rates were highest (see Appendix 4). The inshore blocks had the highest benthos catches and also yielded the highest catch of commercial fish.

The innermost blocks (eg. D3) accounted for 83% of the total benthos catch (Appendix 4, Fig. 11). The most productive blocks in terms of benthos were also characterised by a serried rocky bank or ridge which loosely followed the 100 m bathymetric contour. The low benthos catches in the middle and outer blocks was associated with lower commercial catches and supported indications from echosounder observations and trawl door scrapings that those blocks contained softer substrates of sand or mud.

Table 1.1: Summary of the abundance of commercial fish species retained in fish trawl catches in the 100-200 m depth survey area off the Pilbara coast (species are listed in order of abundance, weight is kg, n > 100; * = selected for more detailed study).

Species (by no.)	**No.**	**Species (by weight)**	**Wt.**	**Av. Wt.**
Priacanthus spp.	4131	* *Lutjanus malabaricus*	8789	2.1
* *Pristipomoides multidens*	3861	* *Pristipomoides multidens*	5941	1.5
* *Lutjanus malabaricus*	3590	*Lutjanus erythropterus*	3603	1.0
* *Lutjanus russelli*	2958	* *Pristipomoides typus*	2451	0.8
Lutjanus vitta	2372	* *Lutjanus russelli*	1276	0.5
Priacanthus macracanthus	2283	*Priacanthus spp.*	1134	0.5
Lutjanus erythropterus	2276	*Carangidae spp.*	959	0.4
Priacanthus hamrur	1805	*Lutjanus sebae*	934	0.5
* *Pristipomoides typus*	1752	* *Glaucosoma buergeri*	917	0.5
Argyrops spinifer	1283	*Gymnocranius grandoculis*	826	0.6
Hapalogenys kishinouyei	1276	*Lutjanus vitta*	784	0.6
Carangidae spp.	1264	*Protonibea diacanthus*	763	0.6
Gymnocranius grandoculis	1132	*Argyrops spinifer*	727	0.6
Nemipterus bathybius	1092	*Hapalogenys kishinouyei*	513	0.5
* *Glaucosoma buergeri*	978	*Priacanthus macracanthus*	511	0.5
Nemipterus virgatus	861	*Netuma thalassinus*	488	0.6
Protonibea diacanthus	534	*Priacanthus hamrur*	448	0.8
Lutjanus sebae	531	*Lutjanus argentimaculatus*	369	0.7
Parupeneus heptacanthus	512	*Trichiurus lepturus*	219	0.4
Netuma thalassinus	482	*Nemipterus bathybius*	168	0.3
Priacanthus tayenus	401	*Nemipterus virgatus*	155	0.4
Ariomma indica	382	*Epinephelus areolatus*	100	0.3
Psenopsis humerosa	379	*Parupeneus heptacanthus*	91	0.2
Carangoides equula	347	*Priacanthus tayenus*	83	0.2
Lutjanus quinquelineatus	320	*Psenopsis humerosa*	82	0.3
Epinephelus areolatus	305	*Lutjanus quinquelineatus*	71	0.2
Trichiurus lepturus	267	*Dentex tumifrons*	63	0.2
Dentex tumifrons	230	*Ariomma indica*	55	0.2
Lutjanus argentimaculatus	179	*Carangoides equula*	54	0.3
Sphyraena spp.	150	*Branchiostegus sawakinensis*	52	0.3
Branchiostegus sawakinensis	136	*Parupeneus chrysopleuron*	33	0.2
Parupeneus chrysopleuron	103	*Sphyraena spp.*	29	0.3
Nemipterus celebicus	102	*Nemipterus celebicus*	17	0.2

Table 1.2: Summary of the abundance of non-commercial or by-catch fish species retained in fish trawl catches in the 100-200 m depth survey area off the Pilbara coast (species are listed in order of abundance, weight is kg, n > 200; * = selected for more detailed study).

Species (by no.)	**No.**	**Species (by wt.)**	**Wt.**	**Avg. wt.**
Saurida filamentosa	5822	*Saurida filamentosa*	1230	0.21
Saurida undosquamis	4003	*Lutjanus quinquelineatus*	942	0.45
Nemipterus bathybius	3797	*Saurida undosquamis*	855	0.21
Upeneus moluccensis	3465	*Saurida spp.*	516	0.26
Monocentris japonica	3032	*Bycatch spp. UID*	336	n/a
Carangoides equula	2618	*Nemipterus bathybius*	293	0.08
Leiognathus bindus	2567	*Carangoides equula*	224	0.09
Pentaprion longimanus	2534	*Monocentris japonica*	221	0.07
Acropoma japonicum	2395	*Sargocentron rubrum*	215	0.13
Lutjanus quinquelineatus	2090	*Carangidae spp.*	201	0.13
Saurida spp.	1978	*Lagocephalus spadiceus*	162	0.64
Sargocentron rubrum	1667	*Ariomma indica*	157	0.11
Carangidae spp.	1603	*Upeneus moluccensis*	153	0.04
Ariomma indica	1402	*Psenopsis humerosa*	144	0.12
Psenopsis humerosa	1197	*Abalistes stellaris*	142	0.38
Antigonia rhomboidea	1106	*Lagocephalus lunaris*	138	0.81
Trixiphichthys weberi	1000	*Fistularia petimba*	121	0.18
Satyrichthys rieffeli	980	*Trichiurus lepturus*	112	0.29
Lepidotrigla sp. 2 (Sainsbury)	743	*Pentaprion longimanus*	87	0.03
Lepidotrigla grandis	678	*Satyrichthys rieffeli*	79	0.08
Fistularia petimba	657	*Hapalogenys kishinouyei*	68	0.18
* *Glaucosoma buergeri*	510	*Trixiphichthys weberi*	68	0.07
Chaetodon modestus	400	*Acropoma japonicum*	67	0.03
Zenopsis nebulosus	400	*Zenopsis nebulosus*	63	0.16
Trichiurus lepturus	389	*Ostichthys japonicus*	58	0.72
Hapalogenys kishinouyei	385	*Antigonia rhomboidea*	53	0.05
Abalistes stellaris	377	* *Glaucosoma buergeri*	52	0.10
Lepidotrigla spp.	309	*Lagocephalus sceleratus*	51	1.41
Champsodon longipinnis	296	*Priacanthus macracanthus*	48	0.19
Carangoides talamparoides	284	*Chaetodon modestus*	37	0.09
Velifer hypselopterus	278	*Cyclichthys spilostylus*	35	1.06
Lagocephalus spadiceus	254	*Priacanthus spp.*	35	0.19
Priacanthus macracanthus	249	*Nemipterus virgatus*	34	0.14
Thamnaconus hypargyreus	243	*Leiognathus bindus*	33	0.01
Nemipterus virgatus	232	*Velifer hypselopterus*	32	0.11
Lutjanus vitta	201	*Chaetodontoplus personifer*	27	0.23

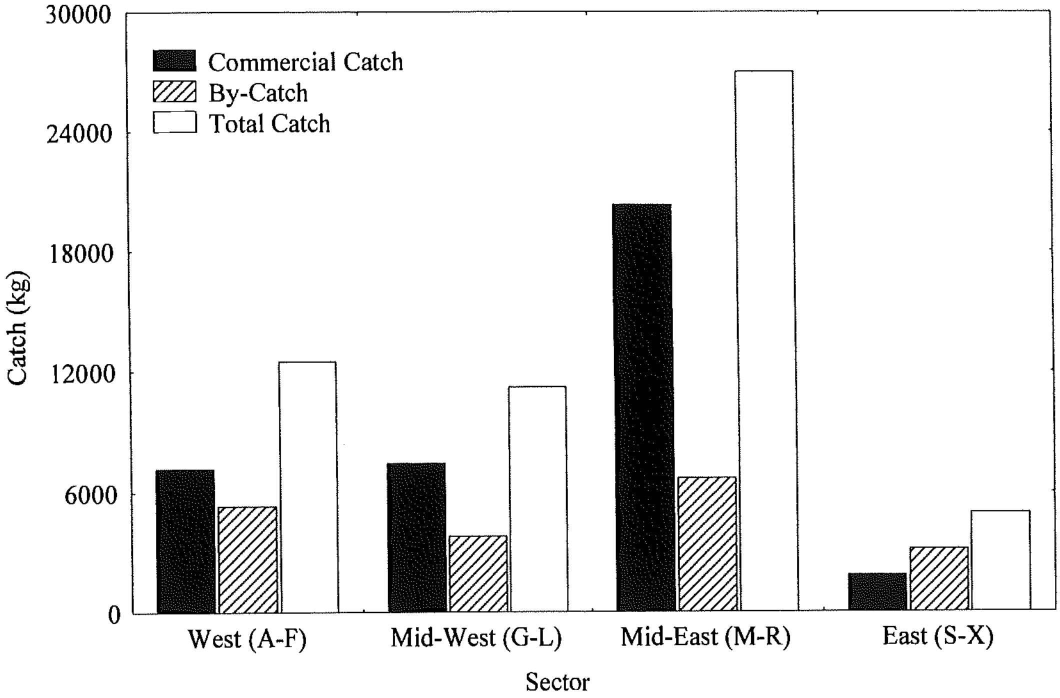

Figure 1.1: Total trawl catch per fishing sector in the survey area off the Pilbara coast.

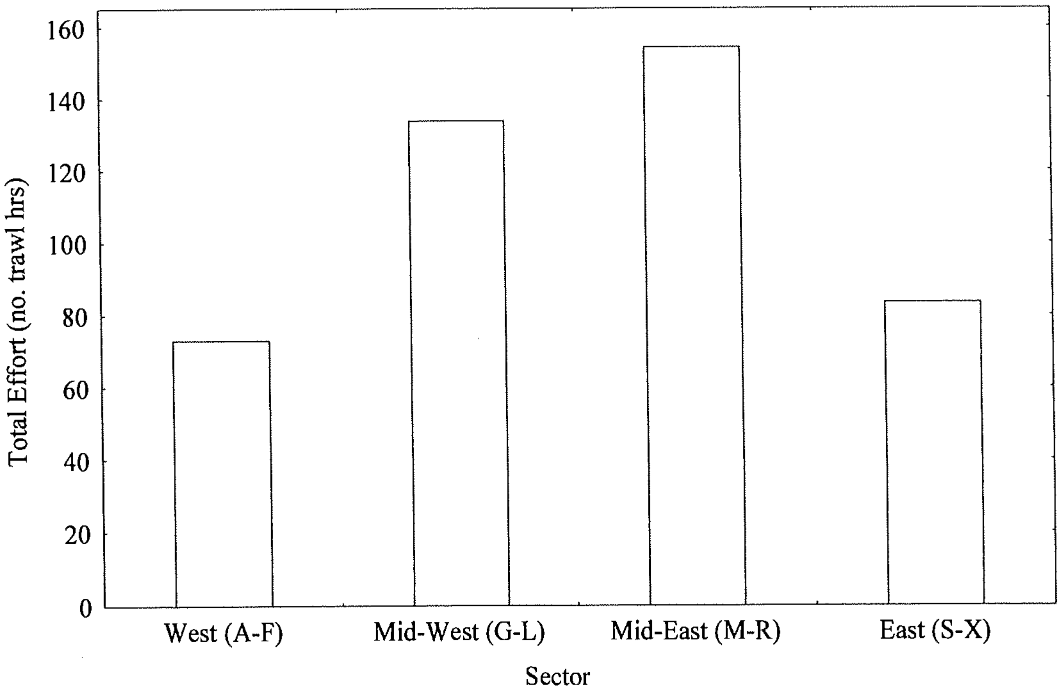

Figure 1.2: Total number of trawl hours per fishing sector in the survey area off the Pilbara coast.

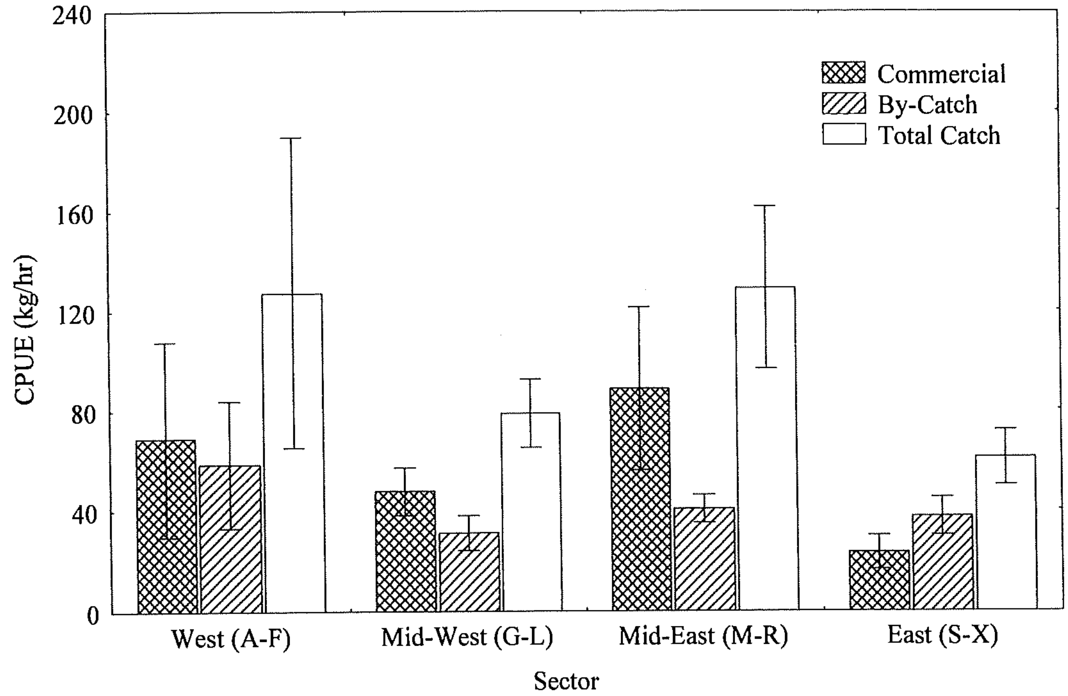

Figure 1.3: Mean catch rate (± SE) per fishing sector in the survey area off the Pilbara coast.

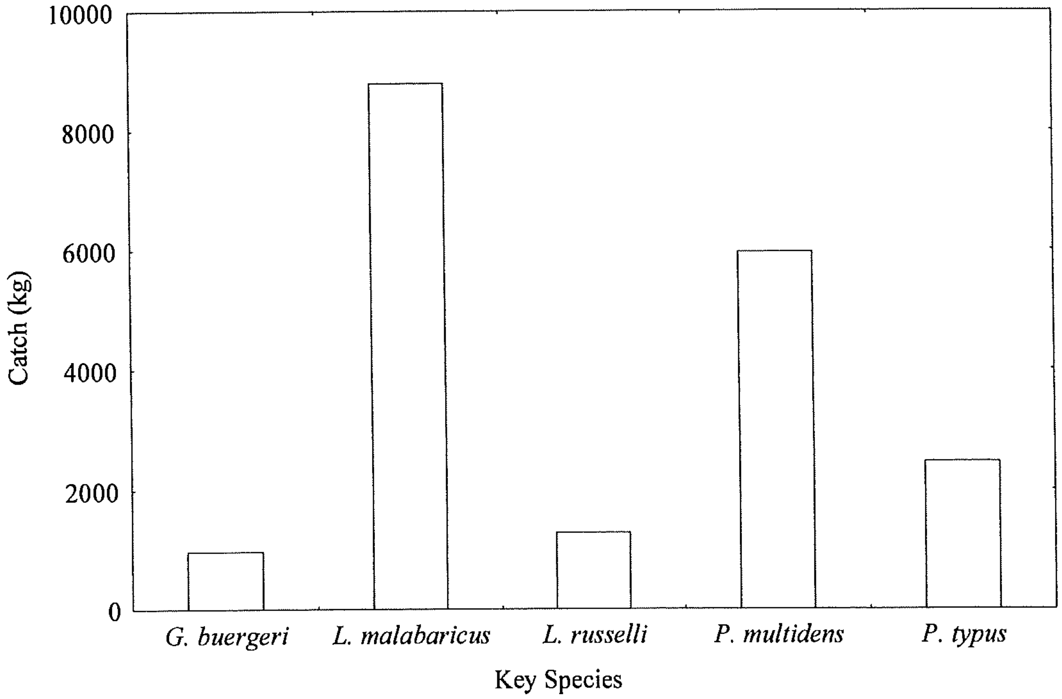

Figure 1.4: Total catch of each of the five key species in the survey area off the Pilbara coast.

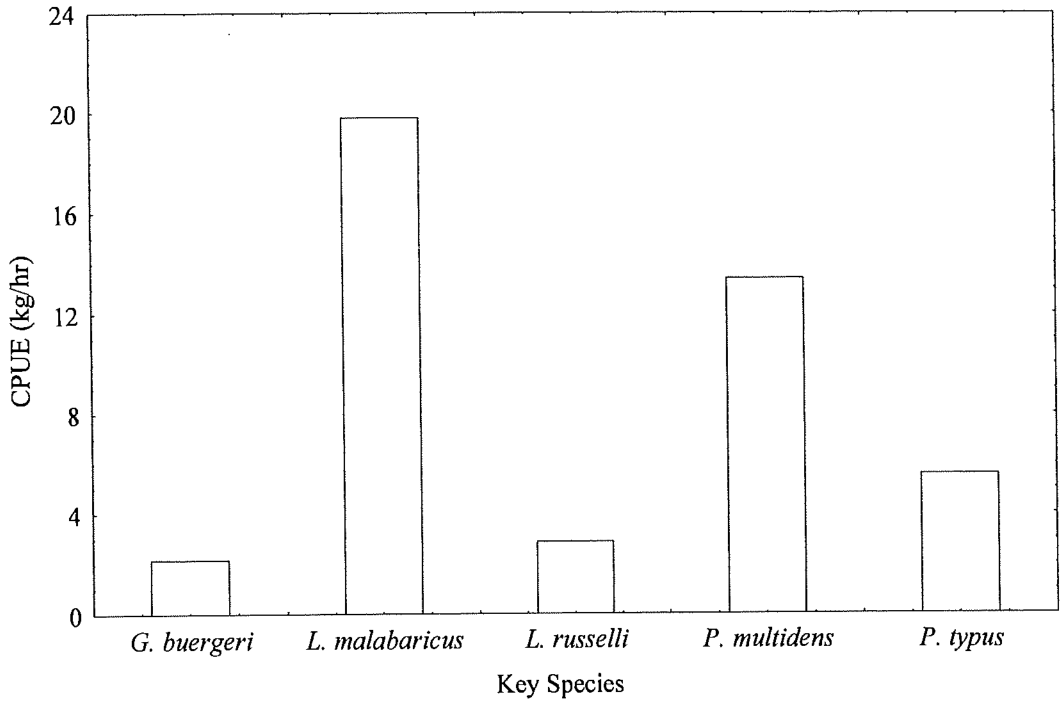

Figure 1.5: Mean catch rates of each of the five key species in the survey area off the Pilbara coast.

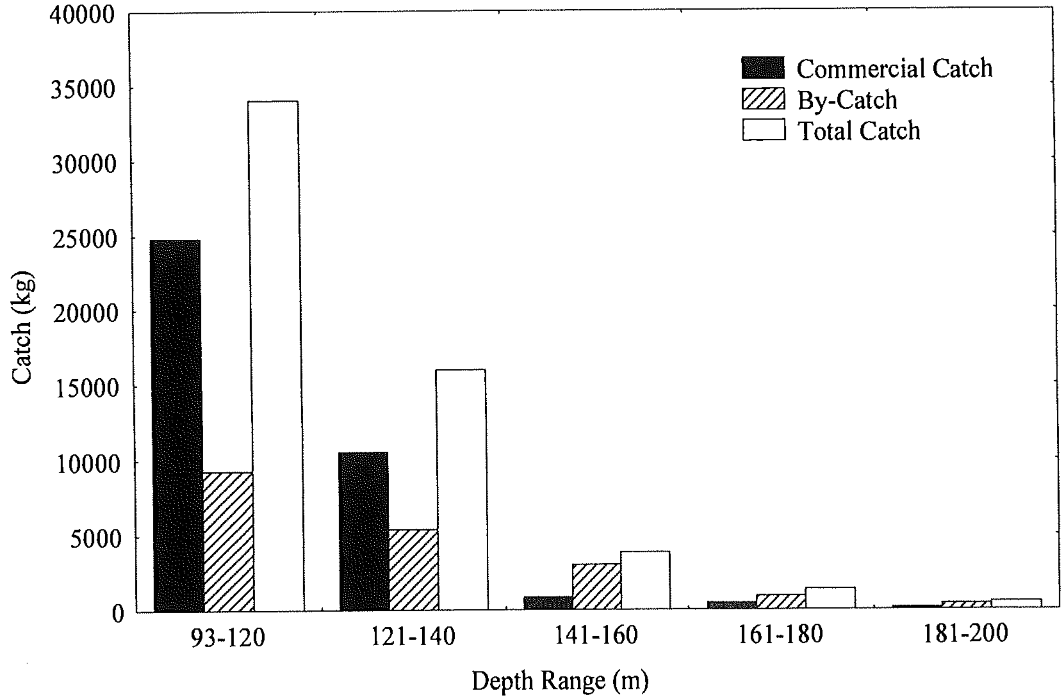

Figure 1.6: Total trawl catch per depth stratum in the survey area off the Pilbara coast.

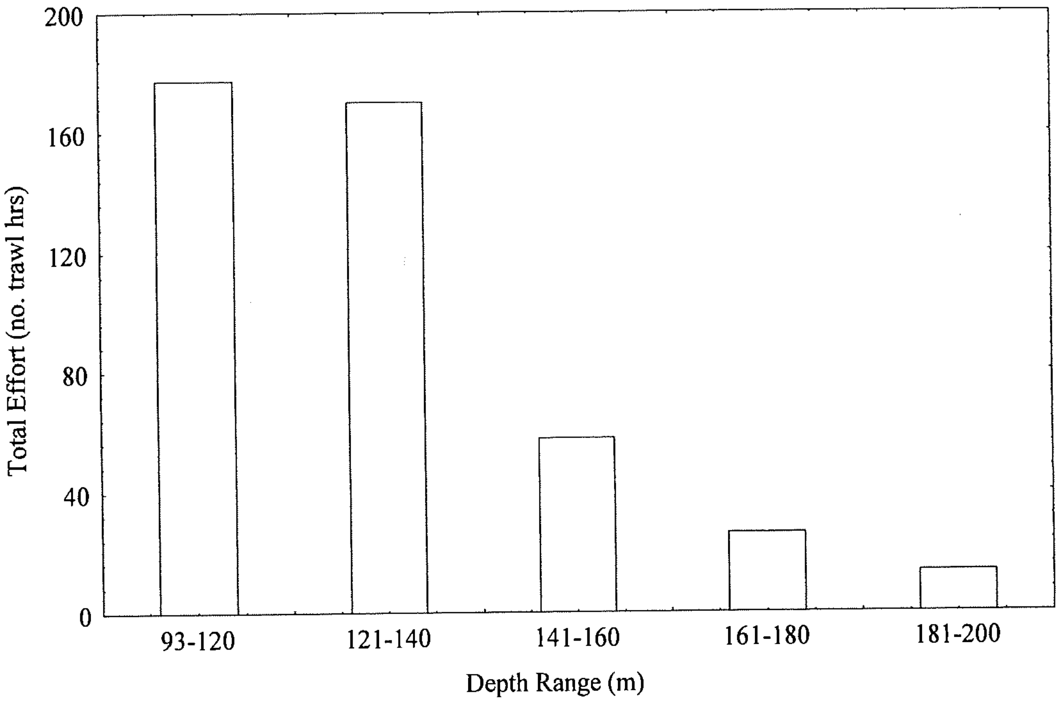

Figure 1.7: Total number of trawl hours within each depth stratum in the survey area off the Pilbara coast.

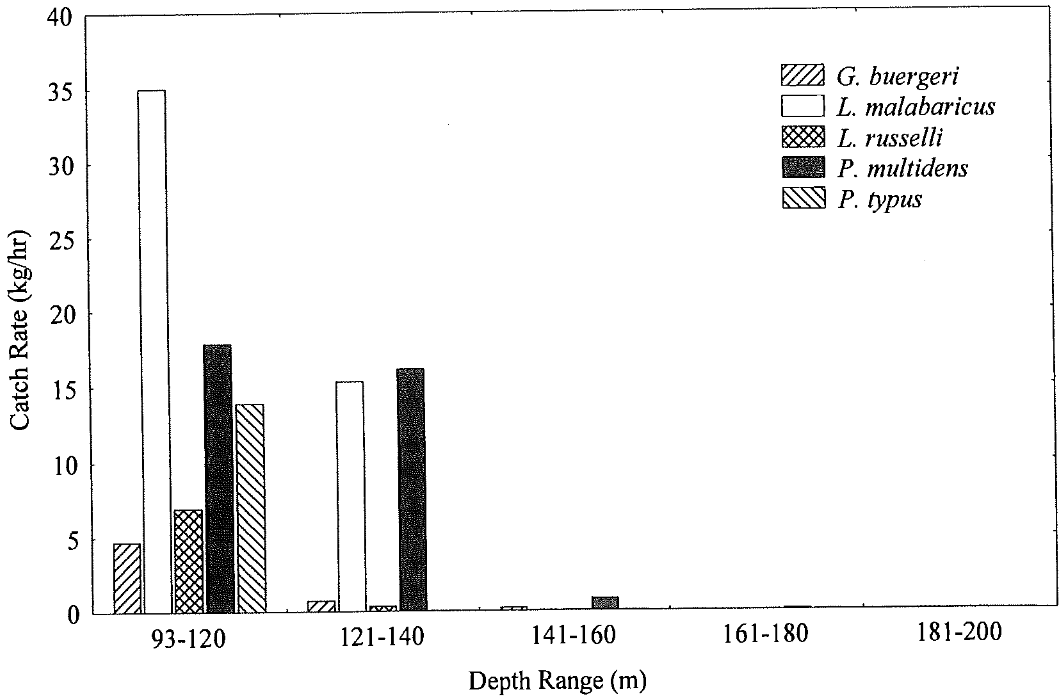

Figure 1.8: Mean catch rates of each of the five key species per depth stratum in the survey area off the Pilbara coast.

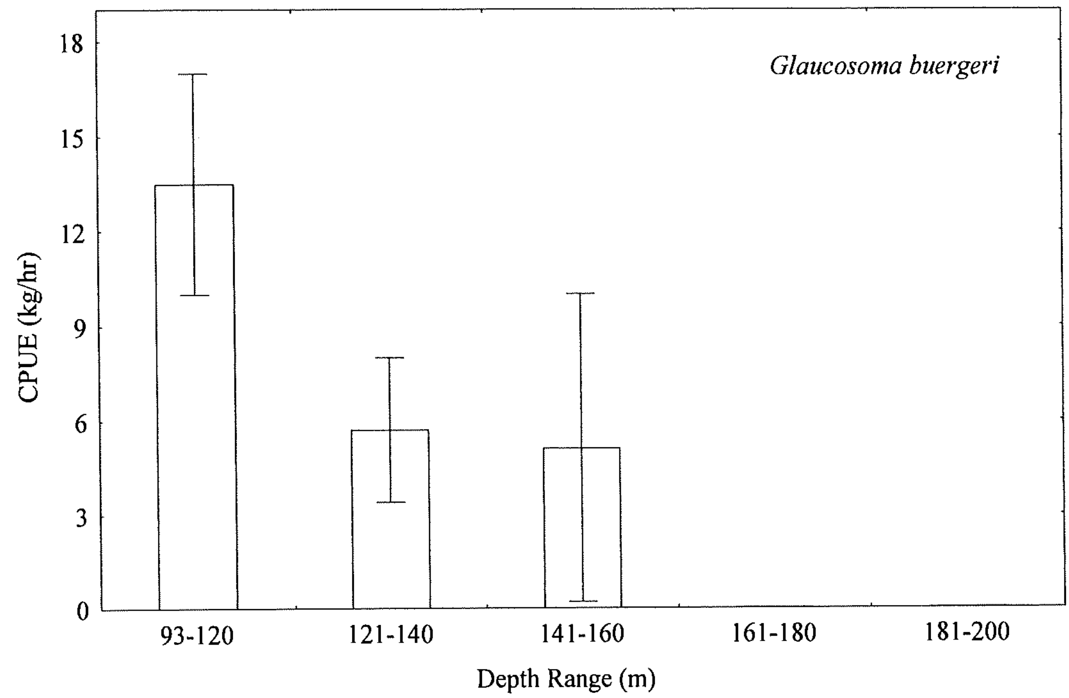

Figure 1.9: Mean catch rate (± SE) of *Glaucosoma buergeri* by depth stratum in the survey area off the Pilbara coast.

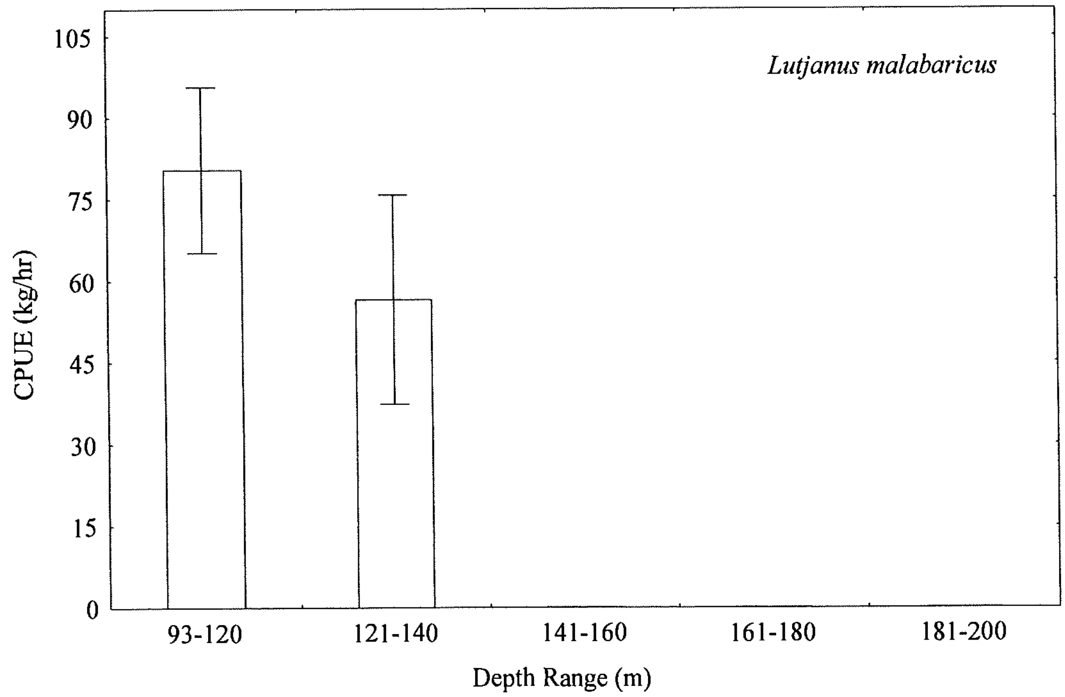

Figure 1.10: Mean catch rate (± SE) of *Lutjanus malabaricus* by depth stratum in the survey area off the Pilbara coast.

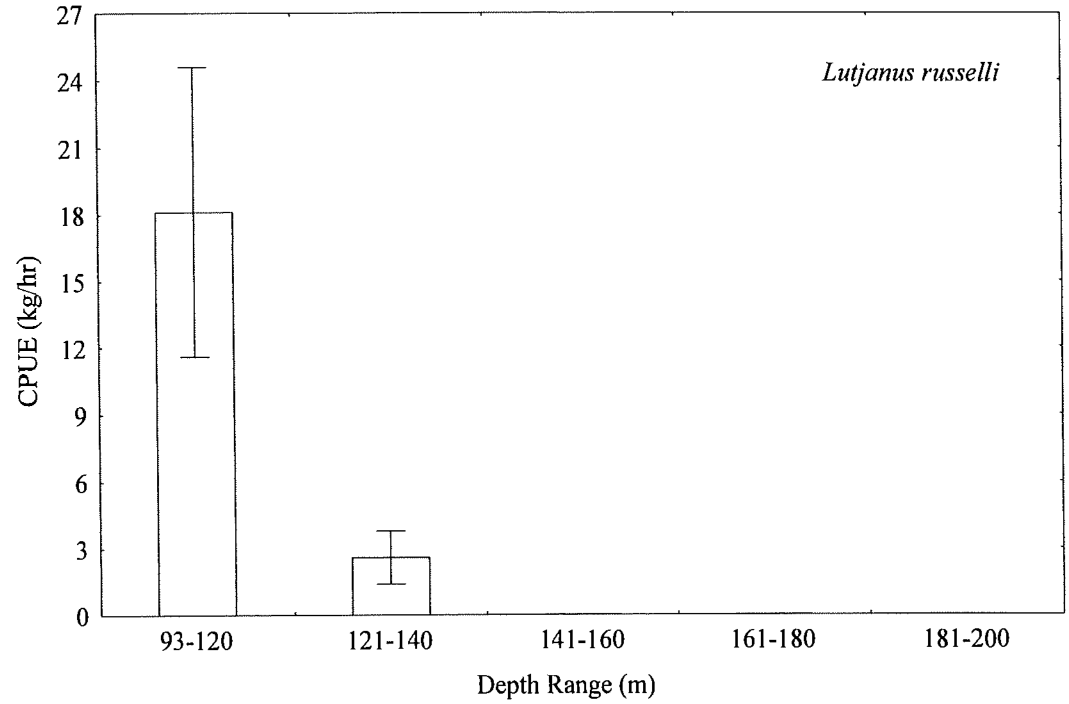

Figure 1.11: Mean catch rate (± SE) of *Lutjanus russelli* by depth stratum in the survey area off the Pilbara coast.

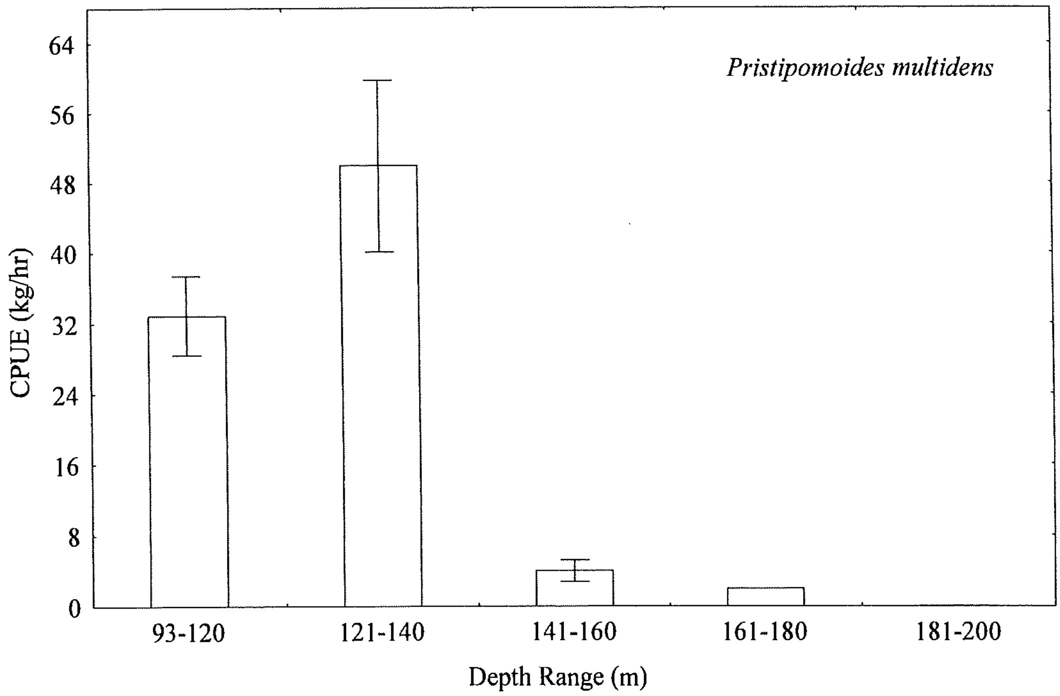

Figure 1.12: Mean catch rate (± SE) of *Pristipomoides multidens* by depth stratum in the survey area off the Pilbara coast.

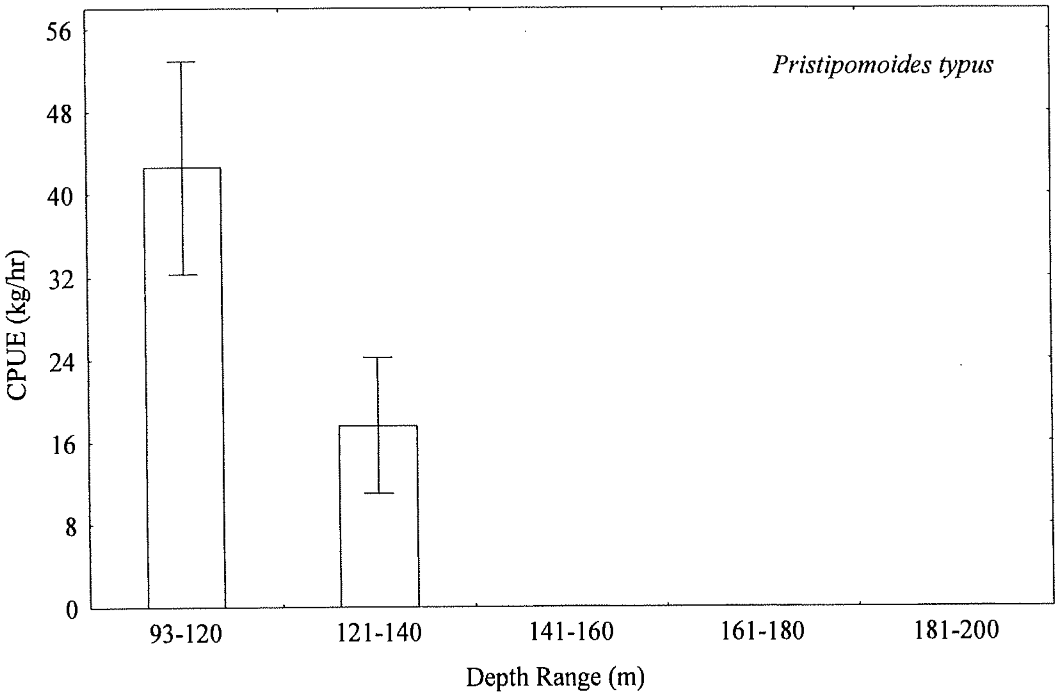

Figure 1.13: Mean catch rate (± SE) of *Pristipomoides typus* by depth stratum in the survey area off the Pilbara coast.

2. Length distribution of the key species among depths.

A similar size range of *G. buergeri* were sampled across their available depth range (93-140 m) during the survey (Fig. 2.1). No trends were evident in the distribution of *G. buergeri* among depths. Individuals greater than 200 mm FL were sampled across their available depth range (Fig. 2.1), while individuals less than 200 mm FL (sub-adult or juvenile fish) were more abundant in the deeper waters (> 110 m, Fig. 2.1).

A similar size range of *L. malabaricus* were sampled across their available depth range (93-138 m) during the survey (Fig. 2.2). No trends were evident in the distribution of *L. malabaricus* among depths. Individuals greater than 400 mm FL were more common in depths of 106-135 m (Fig. 2.2). Individuals less than 400 mm FL were more abundant in depths less than 120 m. However, the smallest individuals collected were from depths of 125-130 m (Fig. 2.2).

No trends were evident in the distribution of *L. russelli* among depths, with individuals obtained from 95-139 m during the survey (Fig. 2.3). Individuals less than 200 mm FL were not caught during this study (Fig. 2.3).

A similar size range of *P. multidens* were sampled across their available depth range (95-147 m) during the survey (Fig. 2.4). No trends were evident in the distribution of *P. multidens* among depths.

A similar size range of *P. typus* were sampled across their available depth range (96-137 m) during the survey (Fig. 2.5). No trends were evident in the distribution of *P. typus* among depths. The smallest *P. typus* sampled were obtained from the deepest section of their sampled depth range.

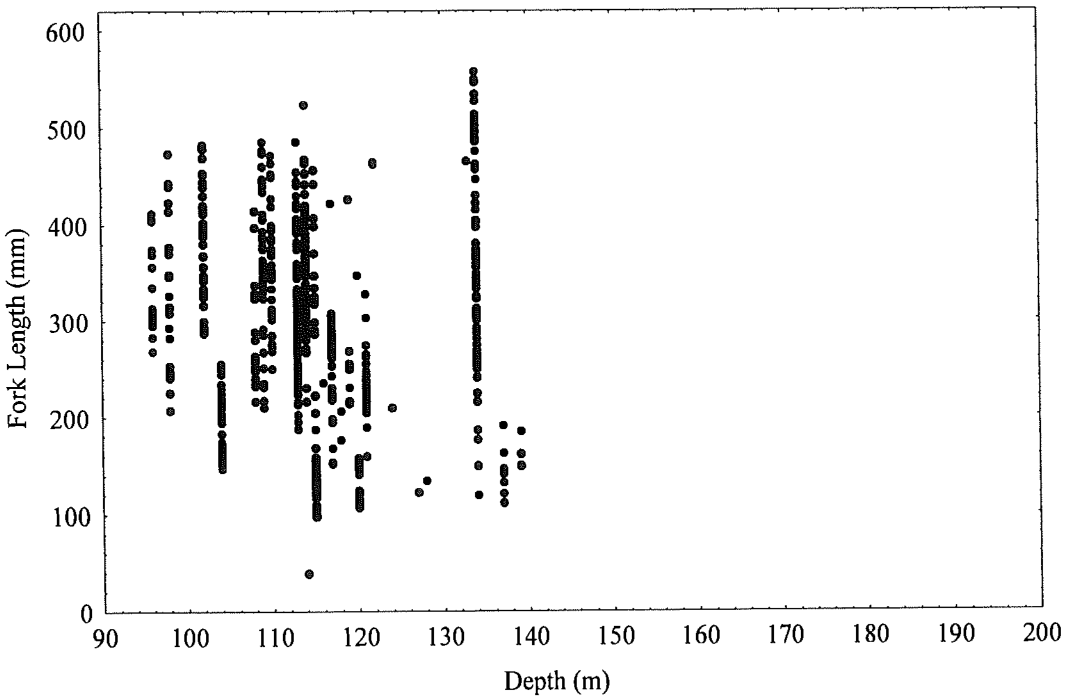

Figure 2.1: Length distribution (FL) of *Glaucosoma buergeri* among depths in the survey area off the Pilbara coast (n = 726).

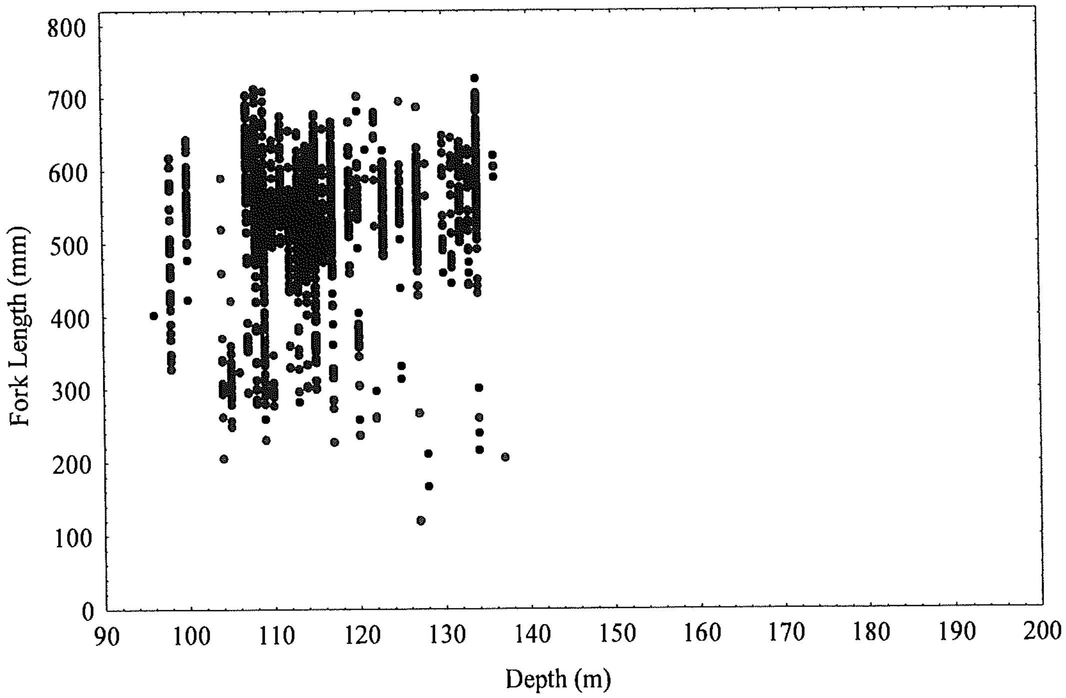

Figure 2.2: Length distribution (FL) of *Lutjanus malabaricus* among depths in the survey area off the Pilbara coast (n = 1905).

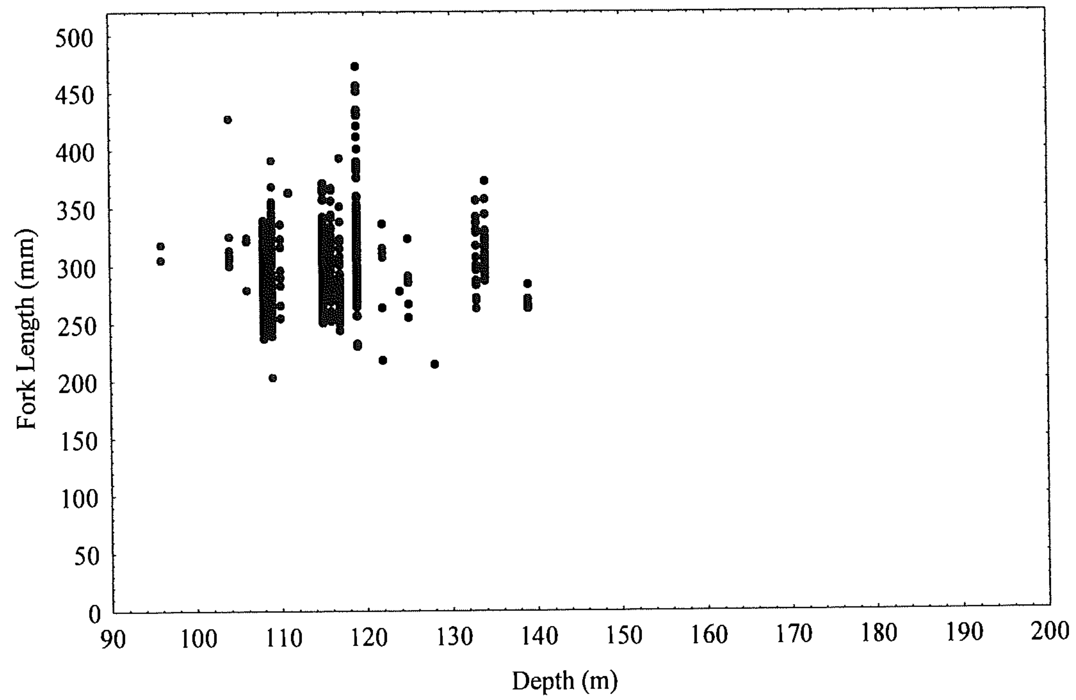

Figure 2.3: Length distribution (FL) of *Lutjanus russelli* among depths in the survey area off the Pilbara coast (n = 716).

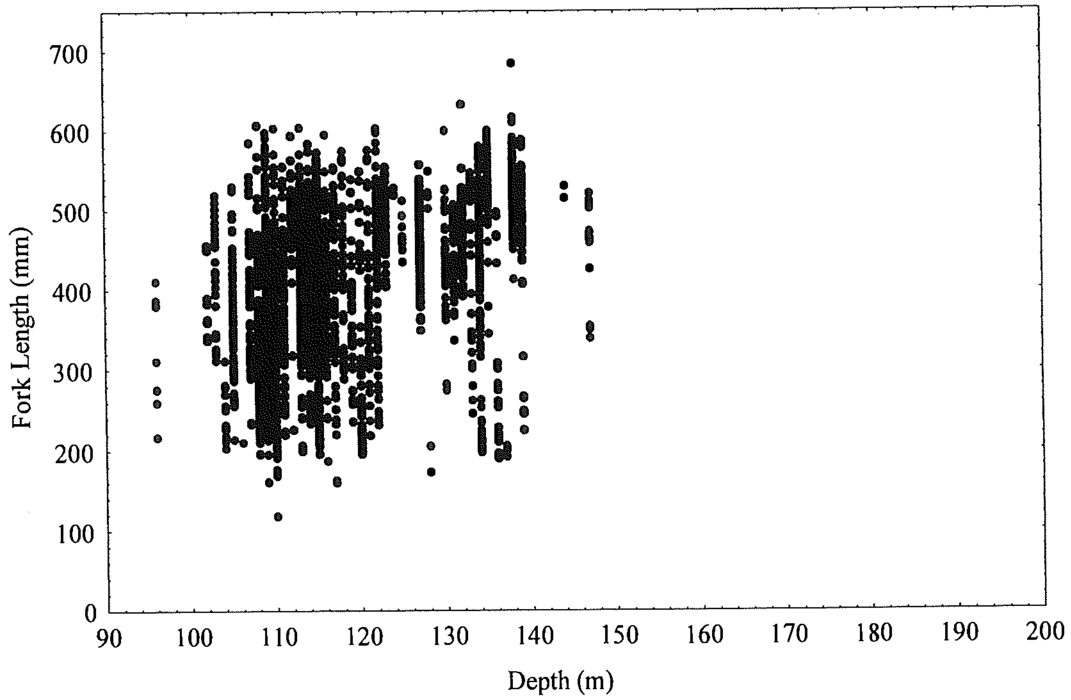

Figure 2.4: Length distribution (FL) of *Pristipomoides multidens* among depths in the survey area off the Pilbara coast (n = 2993).

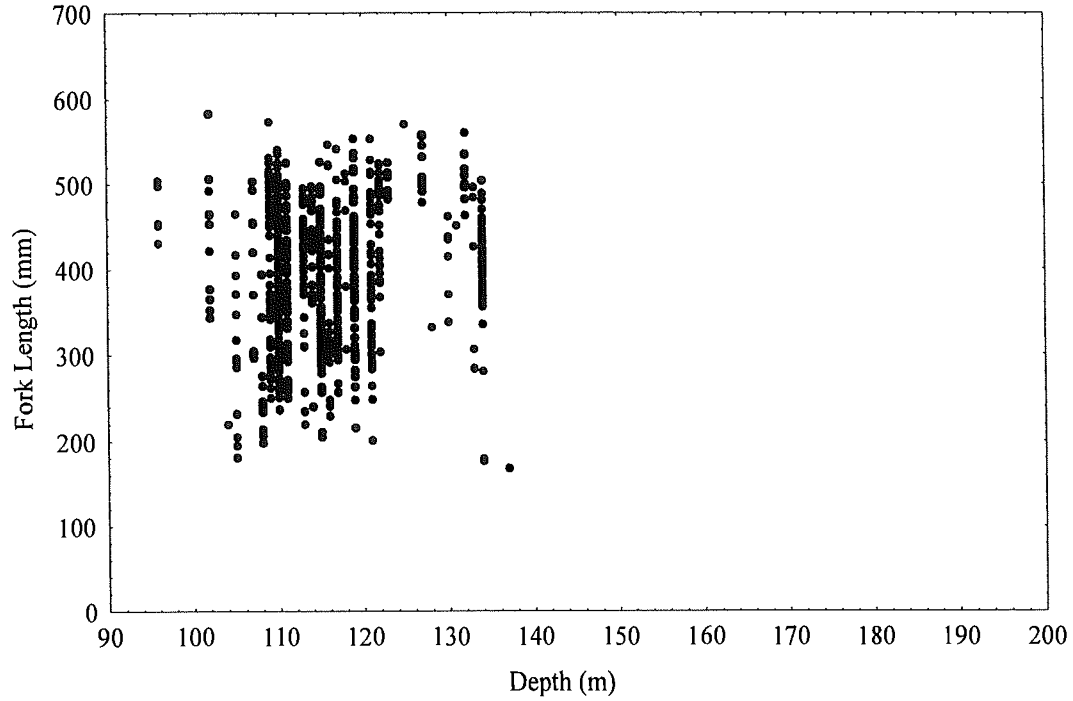

Figure 2.5: Length distribution (FL) of *Pristipomoides typus* among depths in the survey area off the Pilbara coast (n = 851).

3. Length frequency distributions of the key commercial species in the inshore (50-100 m) and offshore (100-200 m) zones of the Pilbara Fish Trawl Fishery.

Length frequency (FL, mm) data for each of the key species collected from the survey area (100-200 m) was compared against length frequency data collected from the inshore zone (50-100 m) of the Pilbara Fish Trawl Fishery. The length frequency data collected from the inshore zone was obtained from fish markets in Perth not directly from trawl boats. A range of parametric and non-parametric tests were used to compare the length frequency distributions among zones. The parametric tests (t-test and F-test) assume a normal distribution. Since the size distributions are not normal, non-parametric methods, Wilcoxon rank sum test and the Kolmogorov-Smirnov test were also used to test whether samples were obtained from a similar distribution. If the length frequency data of samples from the inshore zone and the offshore zone were obtained from the same distribution then they should satisfy all 4 statistical tests.

The means and variances of the length frequency distributions are listed in Table 3.1 along with the size range compared among zones. Figures 3.1 to 3.10 show the length frequency distributions of all species sampled from each depth zone. Results of the parametric tests are not considered to be as robust as the non-parametric tests due to bias associated with the assumption of a common normal distribution to the data (see Figs. 3.1-3.10).

The length frequency distributions of all species were significantly different among the inshore and offshore zones (Table 3.2). These results need to be interpreted with caution due to the small sample size collected from the inshore zone and possible bias associated with the lengths of these fish due to varying market conditions. More robust results will be obtained from future studies which can obtain length data directly from trawl vessels before the landed catch is broken up for market sale.

Table 3.1: Summary of the length distribution data collected from the inshore (50-100 m) zone and the offshore zone (100-200 m) of the Pilbara Fish Trawl Fishery (range is the length range compared).

Species	**Mean**		**Variance**		**No. of observations**		
	inshore	offshore	inshore	offshore	inshore	offshore	range (mm)
G. buergeri	334.29	327.67	5169.17	5233.30	293	552	220-515
L. malabaricus	537.69	548.17	7779.46	3675.42	271	1747	367-726
L. russelli	303.92	293.56	890.05	892.08	264	700	232-393
P .multidens	445.45	432.23	4060.02	5757.29	246	2632	278-589
P. typus	436.98	404.46	2621.74	5034.07	283	786	275-560

Table 3.2: Summary of results of the parametric and non-parametric tests used to compare the length frequency distributions of each of the key species.

Species	**P-value (Two tailed t-test)**	**P-value (F-test)**	**P-value (Wilcoxon rank-sum test)**	**P-value (Kolmogorov-Smirnov test)**
G. buergeri	0.21	0.92	0.19	0.00
L. malabaricus	0.01	0.00	0.05	0.00
L. russelli	0.00	0.99	0.00	0.00
P. multidens	0.01	0.00	0.03	0.00
P. typus	0.00	0.00	0.00	0.00

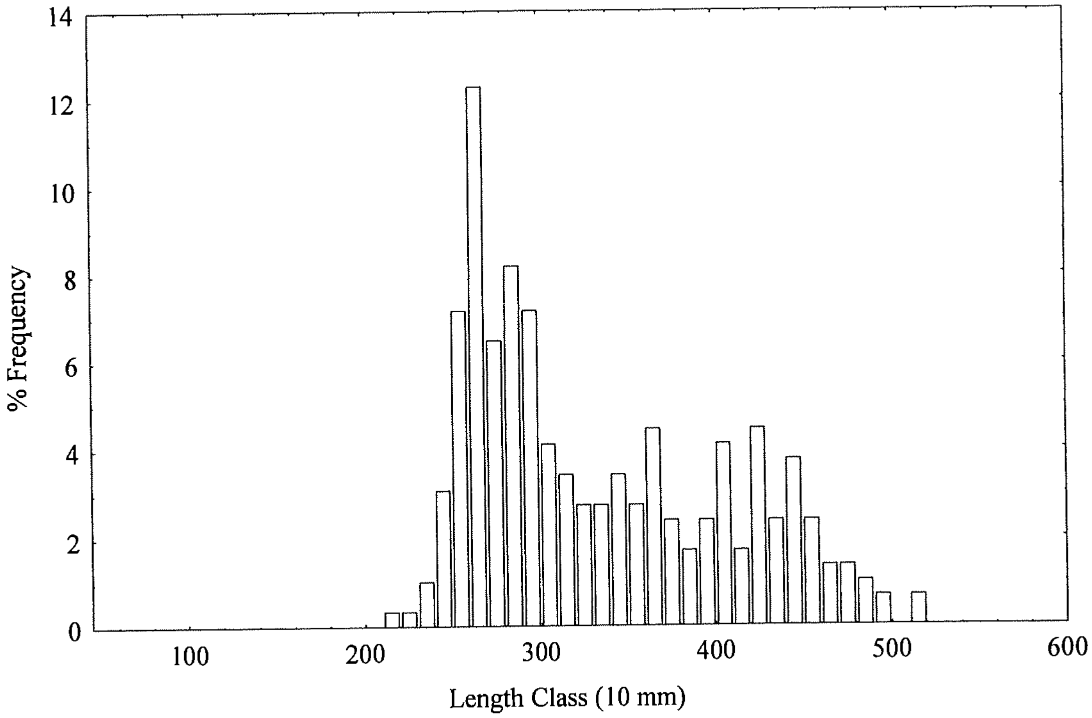

Figure 3.1: Length frequency (FL) distribution of *Glaucosoma buergeri* in the 50-100 m depth zone off the Pilbara coast.

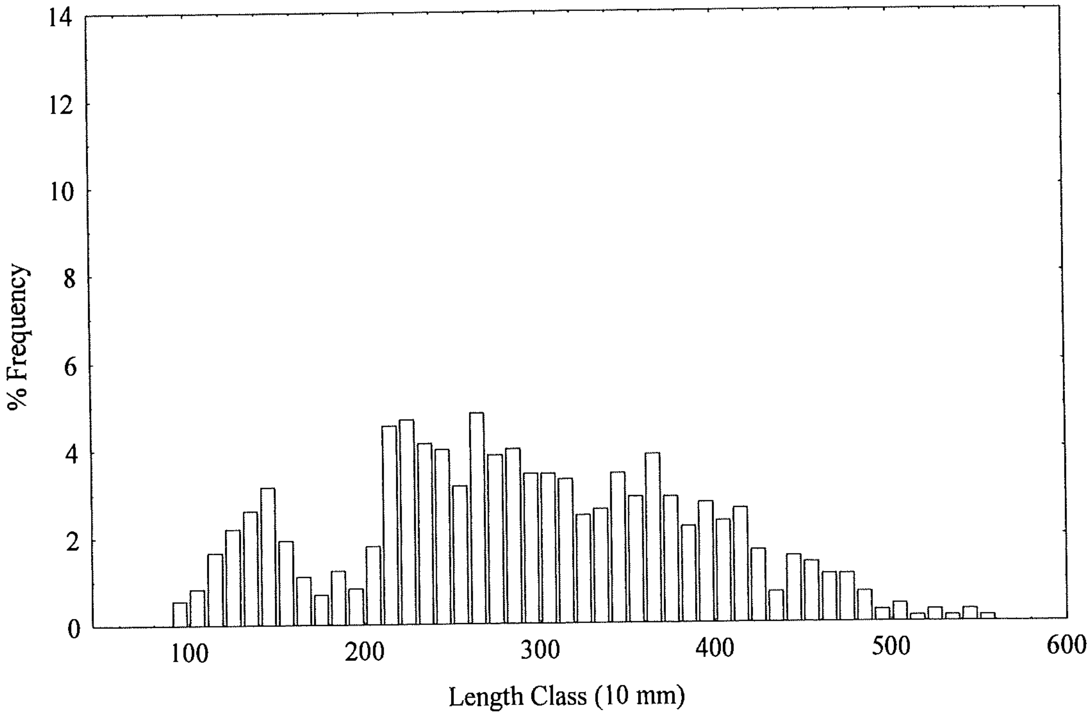

Figure 3.2: Length frequency (FL) distribution of *Glaucosoma buergeri* in the 100-200 m depth zone off the Pilbara coast.

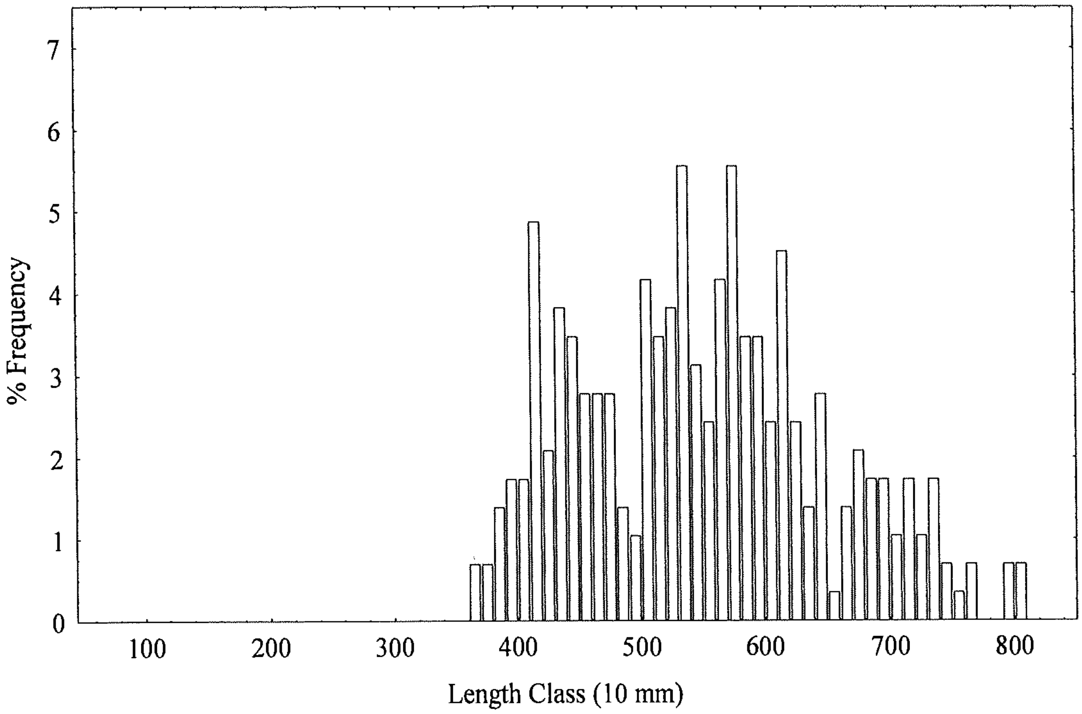

Figure 3.3: Length frequency (FL) distribution of *Lutjanus malabaricus* in the 50-100 m depth zone off the Pilbara coast.

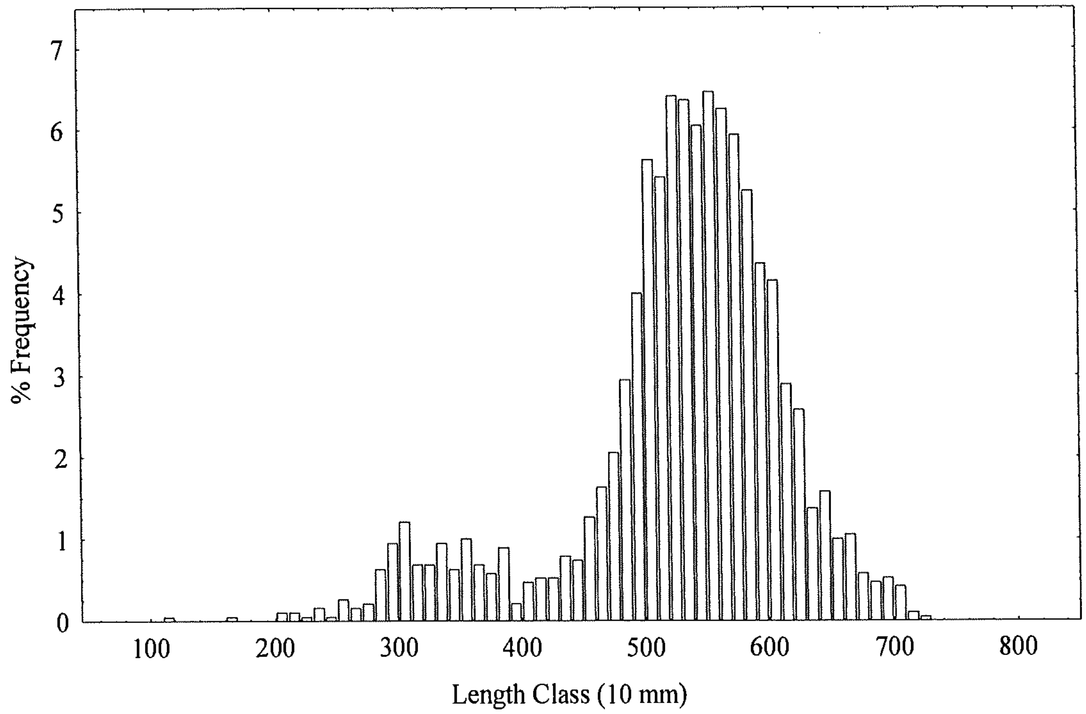

Figure 3.4: Length frequency (FL) distribution of *Lutjanus malabaricus* in the 100-200 m depth zone off the Pilbara coast.

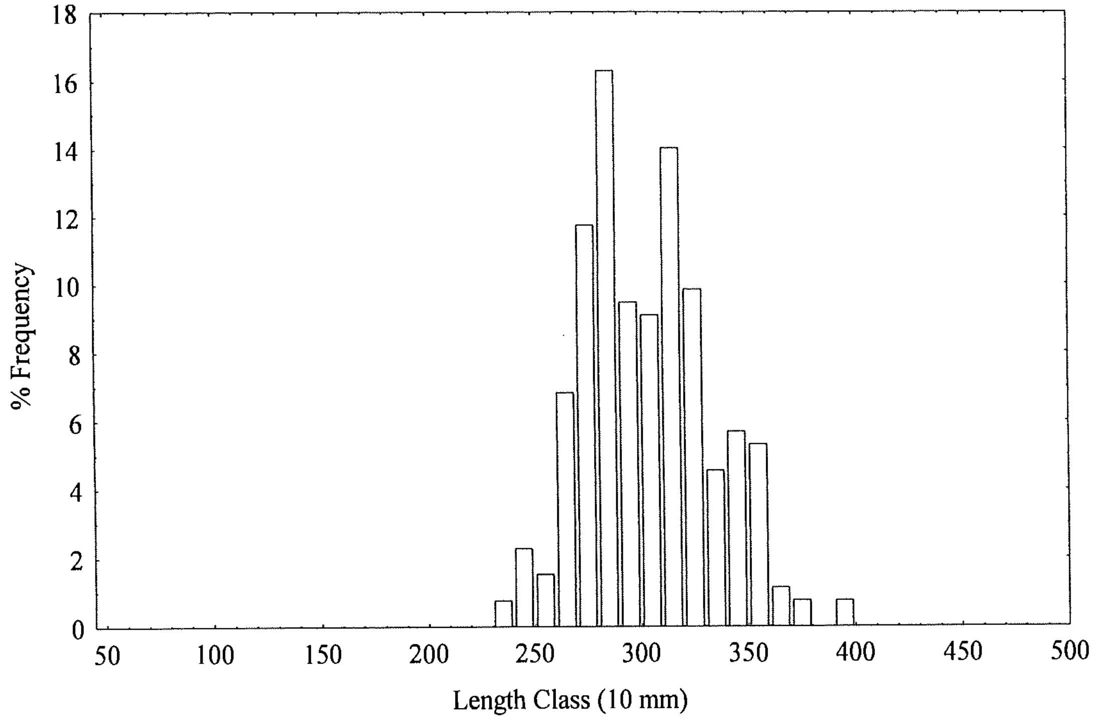

Figure 3.5: Length frequency (FL) distribution of *Lutjanus russelli* in the 50-100 m depth zone off the Pilbara coast.

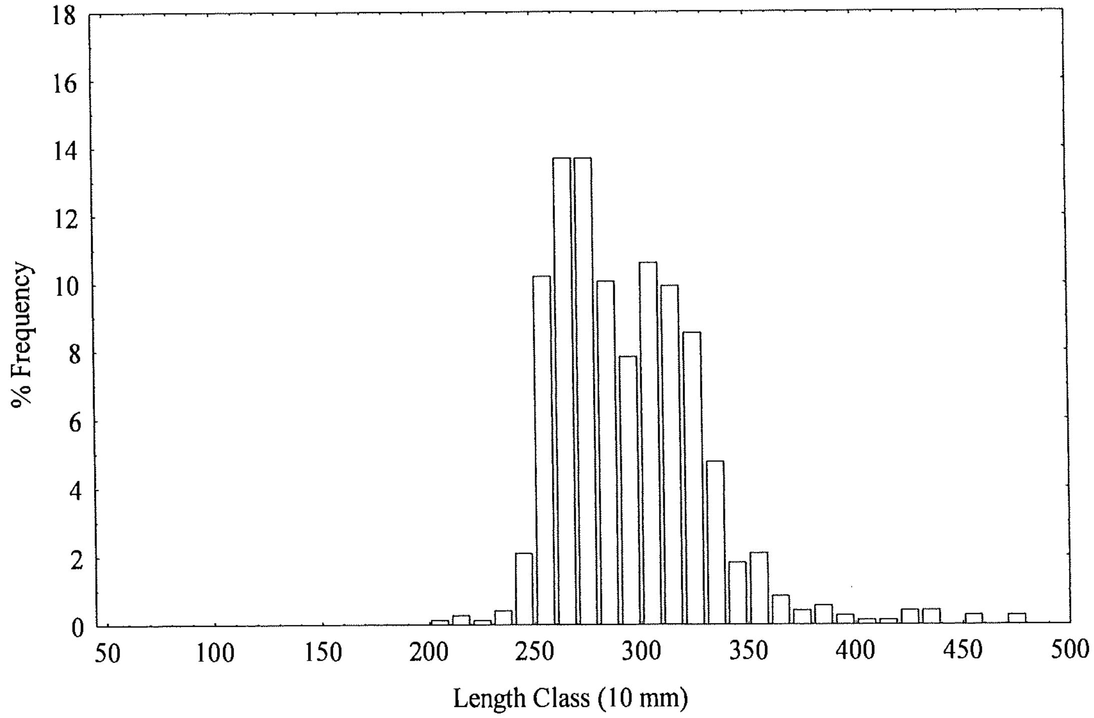

Figure 3.6: Length frequency (FL) distribution of *Lutjanus russelli* in the 100-200 m depth zone off the Pilbara coast.

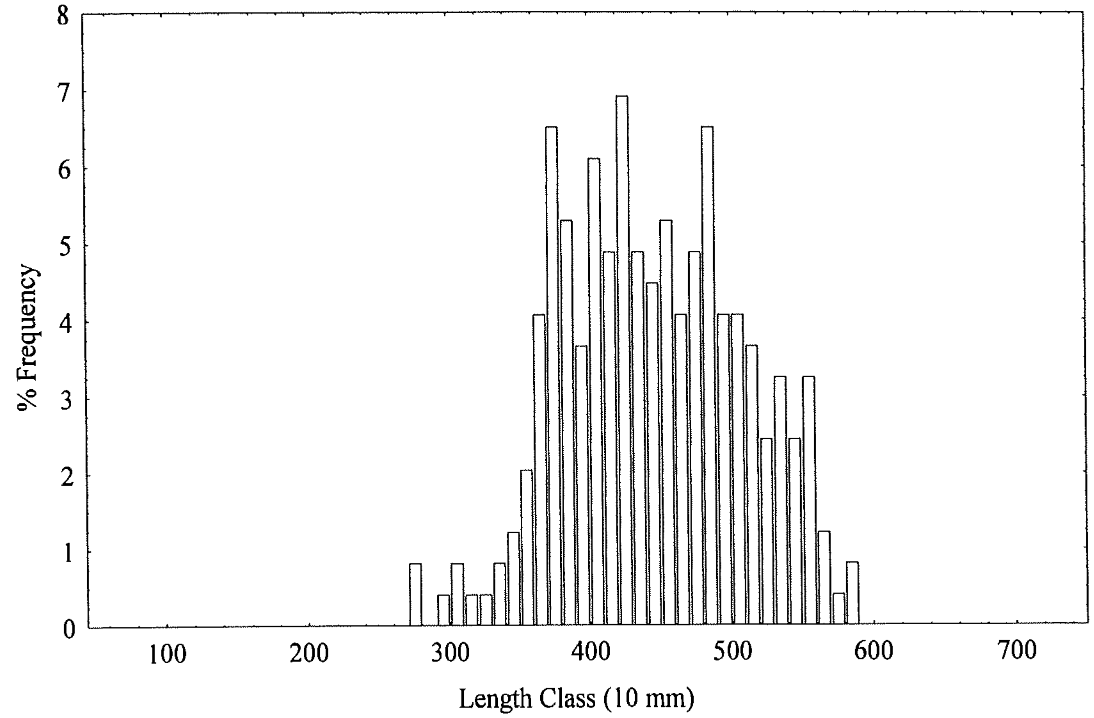

Figure 3.7: Length frequency (FL) distribution of *Pristipomoides multidens* in the 50-100 m depth zone off the Pilbara coast.

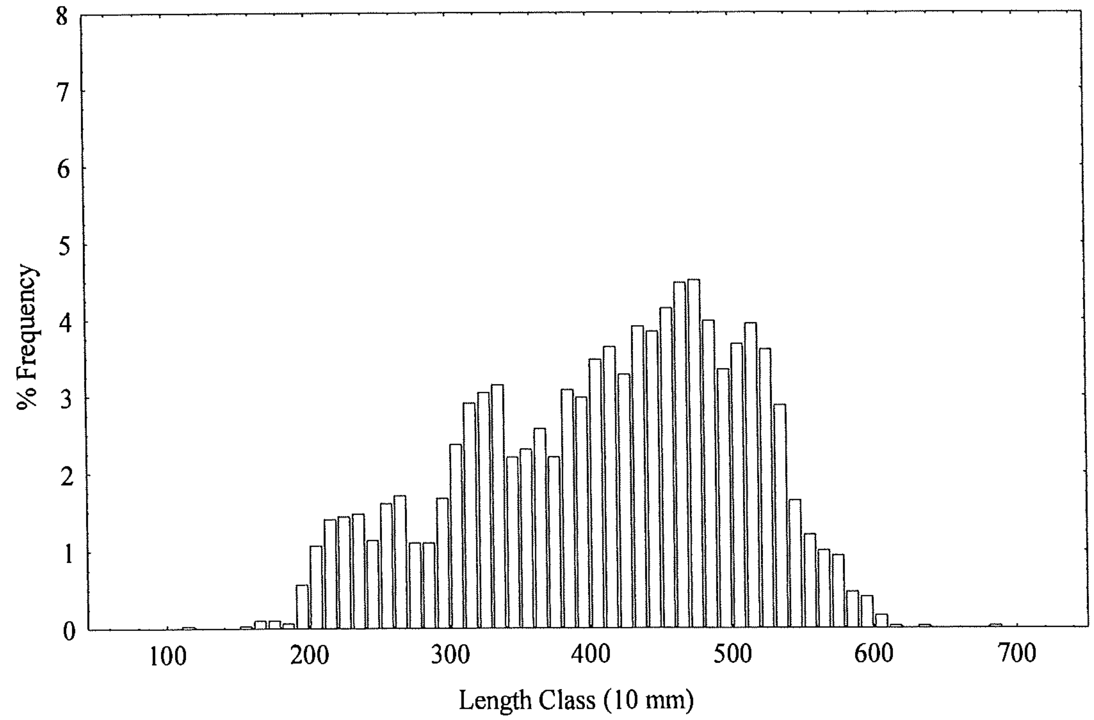

Figure 3.8: Length frequency (FL) distribution of *Pristipomoides multidens* in the 100-200 m depth zone off the Pilbara coast.

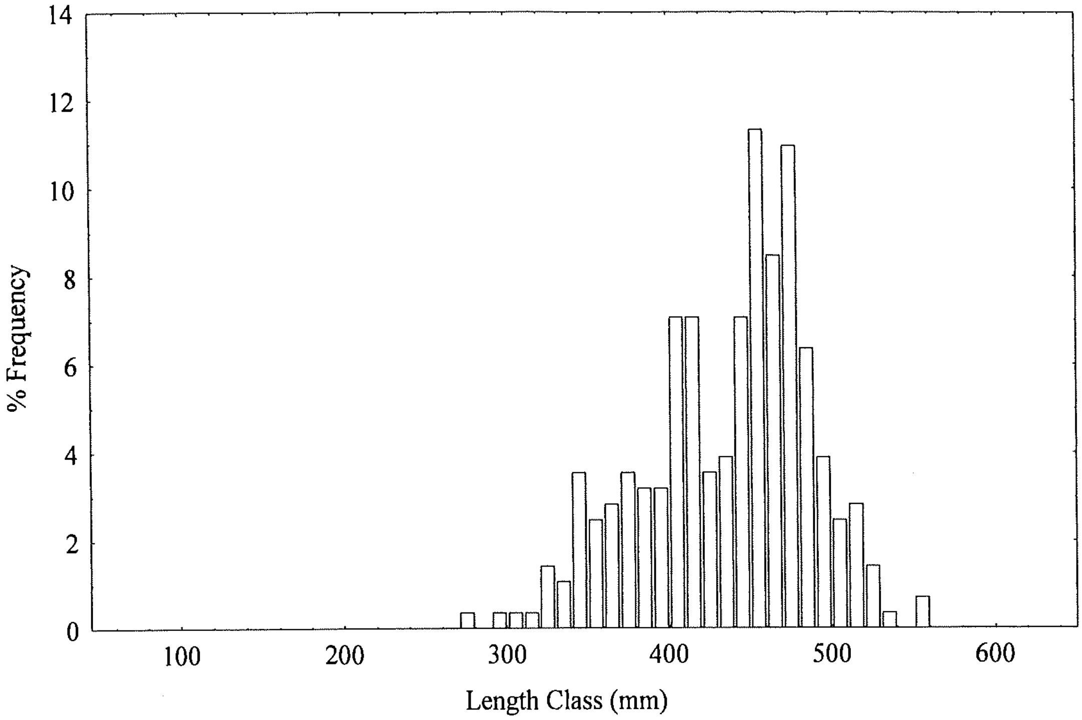

Figure 3.9: Length frequency (FL) distribution of *Pristipomoides typus* in the 50-100 m depth zone off the Pilbara coast.

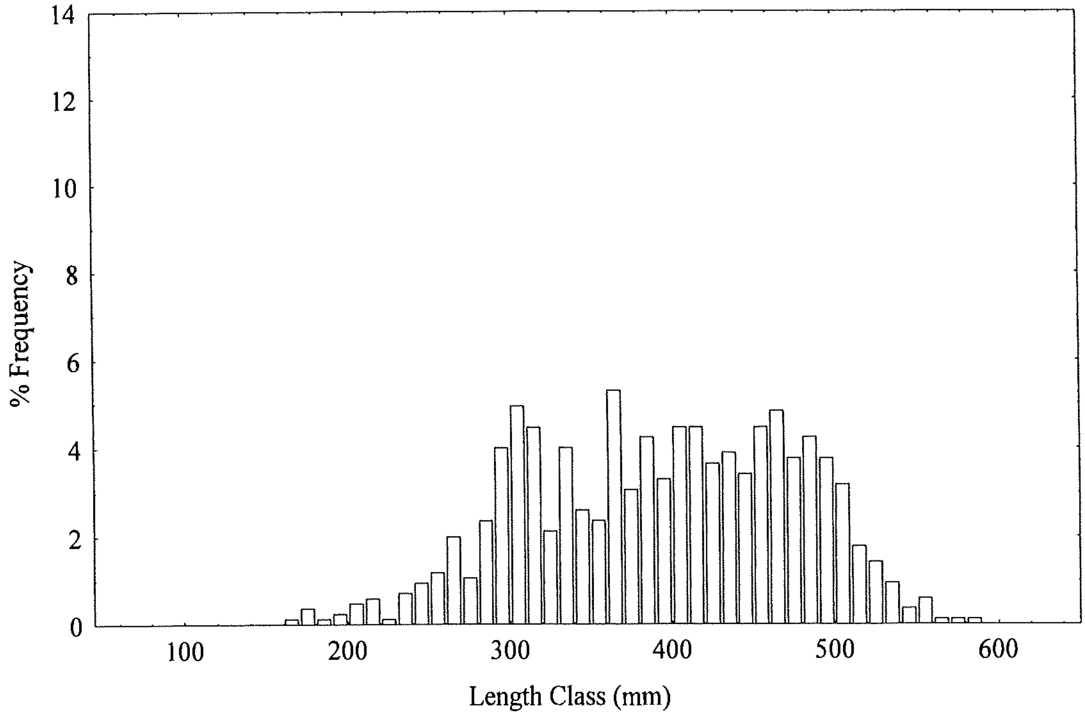

Figure 3.10: Length frequency (FL) distribution of *Pristipomoides typus* in the 100-200 m depth zone off the Pilbara coast.

4. Adults and juveniles of the key species, where are they ?

A wide size range of *G. buergeri* (66-560 mm FL) *L. malabaricus* (167-703 mm FL), *P. multidens* (135-607 mm FL) and *P. typus* (164-570 mm FL) individuals were sampled in the 100-200 m depth zone during the survey period suggesting that both adults and juveniles of these species are located within the survey area.

Individual *L. russelli* less than 200 mm FL were not recorded in any of the trawl catches in the 100-200 m depth zone during the survey. *Lutjanus russelli* less than 200 mm FL were also not observed in the sampled catches of fish trawlers in depths of 50-100 m, although small fish may not have been retained as they have little commercial value. Juvenile *L. russelli* are known to frequent near-shore coastal habitats such as mangrove estuaries, headlands and rocky shores (Newman and Williams 1996, Sheaves 1995). Furthermore, Sheaves (1995) reports that estuarine populations of *L. russelli* consist entirely of reproductively immature fish and that (reproductively) mature fish were only sampled from offshore waters well away from estuaries. Given the available data, it is feasible that juvenile *L. russelli* do not recruit in large numbers in the deepwater (> 100 m) continental shelf waters off the Pilbara coast. The population size of *L. russelli* in offshore waters of the continental shelf may be dependent upon cross-shelf movements of sub-adult or adult *L. russelli*.

In summary, small juvenile and/or sub-adult individuals of *G. buergeri*, *L. malabaricus*, *P. multidens* and *P. typus* were obtained from fish trawl catches in depths of 100-200 m during the survey period, while small juvenile and/or sub-adult *L. russelli* were not present. However, with the exception of *G. buergeri*, few fish less than 100 mm FL were captured. The presence of small individuals of *G. buergeri*, *L. malabaricus*, *P. multidens* and *P. typus* in fish trawl catches in depths of 100-200 m suggests that these species are recruiting in depths greater than 100 metres. The lack of small *L. russelli* is therefore not considered to be a reflection of the selectivity of the trawl gear, but is due to a lack of availability. This suggests that cross-shelf movements of sub-adult or adult *L. russelli* are possible.

5. Age, Growth and Mortality of the Key Species in the 100-200 metre Depth Zone off the Pilbara coast of Western Australia.

5.1 *General introduction*

The five key demersal fish species chosen for study in the offshore waters of the Pilbara coast of Western Australia are *Glaucosoma buergeri*, *Lutjanus malabaricus*, *Lutjanus russelli*, *Pristipomoides multidens* and *Pristipomoides typus*.

Pearl perch or northern pearl perch, *Glaucosoma buergeri* Richardson (1845), (Glaucosomatidae) is distributed along the west coast of Western Australia from Shark Bay in the south to the Timor Sea in the far north of the State (Newman, unpublished data; McKay, 1997). Worldwide, *G. buergeri* is found only from southern Japan, south along the north China coast to Taiwan and Vietnam, throughout Indonesia and north-western Australia (McKay, 1997). It is found in moderate depths (80-150 m) along the continental shelf and is often associated with hard bottom, vertical relief or epibenthic communities. *G. buergeri* is primarily of commercial importance to the fish trawl fisheries of Western Australia with annual landings in 1996-1997 of more than 55,487 kg in WA (Fisheries WA, 1999). *G. buergeri* is only an incidental component of the catch of the commercial trap and line fishers of Western Australia.

Tropical snappers (Lutjanidae), are widely distributed throughout the tropical and subtropical seas of the world (Allen 1985). The scarlet seaperch or saddletail seaperch, *Lutjanus malabaricus* Schneider (1801), (Lutjanidae) is widespread throughout the Indo-Pacific region from the Fiji Islands to the Persian Gulf, and from Australia to southern Japan (Allen, 1985). Within Western Australia, *L. malabaricus* is found from Shark Bay (25°S) northwards. It is found along the continental shelf associated with both coastal and offshore reef areas, shoal grounds and areas of flat bottom with occasional epibenthos, or vertical relief in depths to at least 140 metres. Juveniles are often associated with seagrass beds and are found in the by-catch of prawn trawlers working nearshore. *L. malabaricus* is of major commercial importance to the trap, line and fish trawl fisheries of Western Australia, with landings in 1996-1997 of more than 168,175 kg (Fisheries WA, 1999). *L. malabaricus* also forms a common component of the catch of recreational fishers and is considered to be a valuable angling species although the magnitude of the recreational catch within Western Australia is not presently known. In Queensland, tropical snappers accounted for 4% of the recreational fishing catch in 1997 with an estimated 1.84 million (± 4% s.e.) fish caught (Higgs, 1999).

The Moses perch, *Lutjanus russelli* (Bleeker, 1849) Indian Ocean variety, (Lutjanidae) is widespread throughout the Indo-West Pacific region from the Fiji Islands to East Africa, and from Australia to southern Japan (Allen, 1985). Within Western Australia, *L. russelli* is found from Shark Bay (25°S) northwards. It is found along the continental shelf associated with both coastal and offshore reef areas and shoal grounds in depths to at least 140 metres. Juveniles frequent mangrove estuaries, nearshore rocky reef areas and are sometimes found near seagrass beds. *L. russelli* is presently of modest commercial importance to the trap, line and fish trawl fisheries of Western Australia, with landings in 1996-1997 of more than 65,854 kg (Fisheries WA, 1999). *L. russelli* also forms a common component of the catch of recreational fishers and is considered to be a valuable angling species although the magnitude of the recreational catch within Western Australia is not presently known. Value-adding by commercial fishers has increased the representation of many of the smaller lutjanid species in the commercial catch.

The Goldband snapper, *Pristipomoides multidens* (Day, 1870), (Lutjanidae) is widely distributed throughout the Indo-Pacific region from Samoa to the Red Sea, and from Australia to southern Japan (Allen, 1985). Within Western Australia, *P. multidens* is found as far south as Cape Pasley (34°S), however, commercial quantities are only found north of Shark Bay (25°S). It is found along the continental shelf at moderate depths from 70 to 210 metres, associated with offshore reef areas, shoal grounds and areas of flat hard bottom with occasional epibenthos, or vertical relief. *P. multidens* is the dominant species in the jobfish species complex which is of major commercial importance to the trap, line and fish trawl fisheries of Western Australia, with total landings in 1996-1997 of more than 443,878 kg (Fisheries WA, 1999). Presently, *P. multidens* is not targeted by recreational fishers, but may form a small component of the catch of charter boat fishers in more offshore waters.

The Sharptooth snapper, *Pristipomoides typus* Bleeker (1852), (Lutjanidae) is distributed throughout the tropical Western Pacific and Eastern Indian Ocean region from New Guinea to Sumatra, and from Australia to southern Japan (Allen, 1985). Within Western Australia, *P. multidens* is found as far south as Albany (35°S), however, commercial quantities are only found north of Shark Bay (25°S). It is found along the continental shelf at moderate depths from 70 to 150 metres, associated with offshore reef areas and is often found in association with *P. multidens*. *P. typus* is the second most dominant species (after *P. multidens*) in the jobfish species complex. Presently, *P. typus* is not targeted by recreational fishers, but may form a small component of the catch of charter boat fishers in more offshore waters.

The determination of fish age is the key to estimating rates of growth and mortality. Estimation of the rates of growth and mortality of fish are essential to the understanding of the population dynamics, and to the assessment of potential yields, both of which are needed for the management of fisheries resources. While fish ages can sometimes be derived indirectly from length frequency data and tag-release experiments, the use of hard parts of fish are generally considered as the best method of determining age. Fish otoliths provide reliable estimates of age because they are not subject to resorption, remodelling or regeneration (Secor et al. 1995).

The validation of annuli in otoliths from the direct observation of individuals that have been injected with oxytetracycline and recaptured after annulus deposition has recently been demonstrated for many *Lutjanus* species from the Great Barrier Reef (Newman et al. 1996, Cappo et al. 2000). These studies have also indicated that there is a functional linear relationship between otolith weight and age, independent of fish size, suggesting that otolith weight can be used as a non-subjective method for age determination (Worthington et at. 1995a, 1995b).

Studies of the age, growth and mortality rates of *G. buergeri*, *L. malabaricus*, *L. russelli*, *P. multidens* and *P. typus* have not previously been undertaken off the Pilbara coast of Western Australia. Knowledge of the demographic parameters of these species will assist in the development of models to determine the sustainable exploitation of these species. The objectives of this part of the project were to determine the age, rates of growth, and mortality of *G. buergeri*, *L. malabaricus*, *L. russelli*, *P. multidens* and *P. typus* off the Pilbara coast of Western Australia.

5.2 *General materials and methods*

All fish were measured to the nearest mm total length (TL), fork length (FL) and standard length (SL). All individuals were measured on the left side, with the body flattened and the jaw closed. Weight-length relationships were obtained from market sampling where all fish were weighed to the nearest g total weight (TW). Where possible, the sex was determined by macroscopic examination of the gonads. The sagittal otoliths were removed by opening the otic bulla from under the operculum. Otoliths were then washed in freshwater and stored in envelopes prior to processing.

5.2.1 *Length-weight models*

The relationship between length and weight was described by the power relationship :

$$W = aL^b$$

where W is total weight (g) and L is fork length (mm). The relationship between length and weight was fitted to a log-transformed set of data, and the parameters were back-transformed (with correction for bias) to the above form. Measurements of fish length (TL, FL, SL) were used to derive length conversion equations: TL = a + b (FL), FL = a + b (TL), FL = a = b (SL) and SL = a + b (FL).

Analysis of covariance ($\alpha = 0.05$) was used to determine if there were significant differences in the total weight-at-length (FL) relationships between sexes for each species. Length and weight data were transformed to a natural logarithm function ($\log_e x$) to satisfy assumptions of normality and homogeneity. Multiple comparisons were performed using Tukey's honestly significant difference (HSD) test. One-way analysis of variance ($\alpha = 0.05$) was used to compare mean age, size and weight between sexes of each species (Underwood 1981).

5.2.2 *Otolith preparation and age determination*

Left and right sagittae, were weighed (to 0.01 mg) and measured along three axes (total length, breadth and height through the central core of the otolith) to the nearest 0.01 millimetre using digital callipers. These dimensions were related to the length and age of the fish using linear regression techniques.

All aging work was based on the analysis of transverse sections of otoliths. One sagitta per fish was randomly selected and embedded in epoxy resin. Both sagittae were similar in their marking pattern and counts between sectioned otoliths from the same fish were identical. A thin transverse section (250 - 400 μm) was made through the core of the otolith from the dorsal apex to the ventral apex with a Buehler Isomet low-speed jewellery saw. These sections were then examined under a dissecting microscope at 20-50× magnification on a black background with reflected light.

Ages were assigned based on counts of annuli (alternating opaque and translucent bands) from sectioned otoliths. Alternating opaque and translucent bands (annuli) in sectioned otoliths of tropical fishes have been shown to be formed once per year by direct (eg. tetracycline labeling) and indirect (marginal increment analysis) age validation techniques (eg. Ferreira and Russ 1992, 1994; Fowler and Doherty 1992, Cappo et al., 2000).

To establish the level of confidence that can be placed in the interpretation of the otolith structure, the precision of counts from the sectioned otoliths of each species was assessed. Each otolith was examined on 3 occasions. All counts were made by one reader (SJN) to ensure consistency. A number of fish had different annuli counts from each of the three readings. For those fish whose counts differed, the final count was used for analysis of age and growth, since by this time considerably more experience had been gained in the interpretation of the structure of the otoliths of these species. The counts were compared and the precision of age estimates calculated using the Index of Average Percent Error (IAPE) of Beamish and Fournier (1981). Greater precision is indicated by lower IAPE.

5.2.3 *Growth and mortality models*

Observed lengths-at-age for all species displayed asymptotic growth. The von Bertalanffy growth function (VBGF) was chosen as the best empirical assessment of growth for each species and was fitted to estimates of length-at-age using nonlinear least squares estimation procedures. The VBGF is defined by the equation:

$$L_t = L_\infty \{ 1 - \exp [- K (t - t_0)] \}$$

where L_t = length at age t; L_∞ = asymptotic length; K = Brody growth coefficient and defines the growth rate towards L_∞; t = age of the fish; and t_o = the hypothetical age at which fish would have zero length if it had always grown in a manner described by the equation. Minimum, maximum and mean lengths and ages were also recorded for each species from the Pilbara populations. A modified analysis of the residual sum of squares (ARSS) was used to compare VBGF's between sexes (Chen et al. 1992). The hypothesis being tested is that there is a single underlying growth curve between each sex.

Estimates of the instantaneous rate of total mortality (Z) were obtained using the age based catch curve method of Beverton and Holt (1957) and Ricker (1975). The natural logarithm of the number of fish in each age class (N_t) was plotted against their corresponding age (t) and Z estimated from the descending slope, b. Estimates of the survival rate of each species (S) were then calculated by $S = e^{-Z}$ (Ricker 1975). The use of catch curves implies a relatively constant mortality rate across time periods when fish age from t to $t + 1$ and is used here as all species display asymptotic growth patterns.

The samples of three species, *G. buergeri*, *L. malabaricus* and *L. russelli* obtained from the 100-200 metre depth zone off the Pilbara coast were considered to represent a relatively unfished stock as fishing activity for these species in this zone has been minimal and they are somewhat remote from the inshore fishing grounds. The catch curve for these species was therefore considered to provide a good estimate of M. Samples of the other two species, *P. multidens* and *P. typus*, were not considered to represent an unfished stock as these two species have been actively targeted by trap, line and trawl fishers throughout the region.

Estimates of instantaneous natural mortality rates (M) for each species were also obtained using the general regression equation of Hoenig (1983) for fish, where: $\log_e Z = 1.46 - 1.01 \log_e t_{max}$ (t_{max} is the maximum age in years); and Pauly (1980) based on parameters of the VBGF and mean water temperature (in °C), where: $\log_{10} M = -0.0066 - 0.279 \log_{10} L_\infty + 0.6543 \log_{10} K + 0.4634 \log_{10} T$, and the mean annual water temperature for the Pilbara coast (116°E-120°E) is 26.93°C.

5.2.4. *Estimation of a limit reference point*

A target reference point (TRP) represents a condition or status of a fishery resource which is considered to be desirable and at which management action, whether during development or stock rebuilding, should aim (Caddy and Mahon, 1995). In contrast, a limit reference point (LRP) represents a condition or status of a fishery resource which is considered to be undesirable, and which management action should avoid (Caddy and Mahon, 1995).

Populations of lutjanids and serranids of commercial fishing significance have been shown to have a low productive capacity and hence are vulnerable to overfishing as a consequence of slow growth, extended longevity, late maturity and low rates of natural mortality (Polovina and Ralston, 1987). Furthermore, the ability of harvest strategies to effectively reduce excessive exploitation is often constrained by recreational and commercial fishery lobby groups attempting to avoid the costs associated with effort reduction. Therefore, the conservative LRP of F_{limit} (Patterson, 1992) has been adopted to ensure adequate egg production and hence the maintenance of recruitment for each species such that the development of the demersal fish populations off the Pilbara coast should not compromise the ability of future generations to sustainably harvest the resource. Furthermore, Patterson (1992) reports that exploitation rates above F_{limit} have been associated with stock declines, whereas exploitation rates below this level have resulted in stock recovery.

The LRP of F_{limit} was calculated for each species. Calculation of F_{limit} requires an estimate of the natural mortality (M) of each species, since $F_{limit} = 2/3$ M (Patterson, 1992; Walters, pers. comm.).

5.3 *Results*

Samples of *G. buergeri* (n = 256), *L. malabaricus* (n = 214), *L. russelli* (n = 136), *P. multidens* (n = 365) and *P. typus* (n = 186) were obtained between July 1997 and September 1999 from the FRDC funded fish trawl research program (Project No. 97/138) off the Pilbara coast of Western Australia (116°E-120°E) in depths from 100-200 metres. Weight-length information was obtained, and additional samples also collected from the commercial fish trawl fishery off the Pilbara coast in depths of 50-100 m, as weights could not be determined at sea. As individual *L. russelli* less than 23 cm fork length (FL) were not available or vulnerable to fish trawl fishing, none were able to be obtained from this project for inclusion in this analysis.

5.3.1 *Glaucosoma buergeri* - Pearl Perch

5.3.1.1 *Length-weight models*

Length-weight relationships were calculated separately for males, females and for both sexes combined (Table 5.1). ANCOVA of weight-at-length was not significantly different between sexes for *G. buergeri* ($F = 1.03$; df: 1,302; $p > 0.05$). The relationship between total weight and fork length is presented in Figure 5.1. Length conversion equations were derived for total length, fork length and standard length (Table 5.2).

Mean weight (TW) of *G. buergeri* sampled differed significantly between sexes ($p < 0.01$), with males larger than females. However, mean ages and mean lengths (FL) were not significantly different between sexes (both $p > 0.5$).

5.3.1.2 *Otolith morphology, interpretation and otolith growth*

The sagittae of *G. buergeri* are laterally compressed, elliptical structures, with a slightly concave distal surface, a slightly pointed rostrum and postrostrum and a pointed posterior projection on the dorsal surface. A curved sulcus crosses the proximal surface longitudinally. The depth of the sulcal groove increases with fish age. Annuli were usually counted in the region from the primordium to the proximal surface along the ventral margin of the sulcus acousticus. Annuli in this region were usually well defined and more readily interpreted.

The precision of otolith readings of *G. buergeri* was intermediate to high, with the Index Average Percent Error (IAPE), 8.80%. The lower the IAPE, the higher the level of precision. Otoliths were interpreted in a similar manner on each occasion.

Otolith length and breadth were better predictors of fish length in *G. buergeri* than otolith weight and height, although all variables accounted for more than 90% of the variability (Table 5.3). In contrast, otolith length and breadth were poor predictors of age for *G. buergeri* (Table 5.3). Otolith weight and height were both good predictors of fish age, accounting for 91.2% and 90.6% of the variability in age of *G. buergeri* (Table 5.3). The relationship of otolith weight to fish age for *G. buergeri* (Fig. 5.2) is considered more robust than the otolith height - fish age relationship as there is a reduced chance of incurring measurement error.

5.3.1.3 *Growth and mortality models*

All samples of *G. buergeri* were obtained from fish trawl catches, which selected against individuals less than 1+ years of age and less than 90 mm FL (Figs. 5.3, 5.4). While few fish were retained in the 0+ age class, a large number of individuals were caught which were less than 200 mm and were represented in the 1+, 2+ and 3+ year classes (Fig. 5.3, 5.4).

The von Bertalanffy growth curve was fitted to lengths-at-age for all *G. buergeri* (Fig. 5.5), and separately for each sex (Table 5.4). The VBGF indicates that the rate of growth of *G. buergeri* decreases slowly with increasing age. Growth of *G. buergeri* is slow, with growth in length of age classes beyond 10+ much reduced. Length-at-age of *G. buergeri* was not significantly different between sexes ($p > 0.05$; Fig. 5.5).

Glaucosoma buergeri less than 2+ years of age were not fully recruited to the sampled population (ie. 1+ individuals, Fig. 5.3) and were excluded from the mortality estimates derived from catch curves (Fig. 5.6). The estimated M of the Pilbara population of *G. buergeri* in the 100-220 m depth zone was 0.113 ($r^2 = 0.63$), representing an annual survivorship of ca. 89% yr^{-1} (Table 5.5). Individuals in the 8+ and 9+ age classes were not well represented in the catch and do not appear to be recruited in similar numbers to other cohorts (the equilibrium assumption). However, the descending right hand limb of the catch curve is similar across most ages and hence M is assumed to be constant.

Estimates of M from the equation of Hoenig (1983) were slightly higher than those derived from catch curves and therefore predict a slightly lower survivorship rate (Table 5.5). Estimates of M from the equation of Pauly (1980) were much higher than those derived from either catch curves or the Hoenig equation and suggest a lower rate of survivorship (Table 5.5).

5.3.1.4. *Limit reference point estimation*

The LRP F_{limit} for *G. buergeri* is estimated to be 0.0755 (Table 5.5). An F_{limit} of 0.0755 indicates that only 7.27 % of the available stock of *G. buergeri* can be harvested each year.

5.3.2 *Lutjanus malabaricus* - Scarlet Seaperch

5.3.2.1 *Length-weight models*

Length-weight relationships were calculated separately for males, females and for both sexes combined (Table 5.1). ANCOVA of weight-at-length was significantly different between sexes for *L. malabaricus* (F = 18.57; df: 1,265; $p < 0.0001$), with males larger than females. The relationship between total weight and fork length is presented in Figure 5.7. Length conversion equations were derived for total length, fork length and standard length (Table 5.2).

Mean weight (TW) and mean lengths (FL) of *L. malabaricus* sampled all differed significantly between sexes ($p < 0.001$ and $p < 0.01$, respectively), with males larger than females. Mean ages were also significantly different between sexes ($p < 0.05$), however, females were on average older than males.

5.3.2.2 *Otolith morphology, interpretation and otolith growth*

The sagittae of *L. malabaricus* are laterally compressed, elliptical structures, with a concave distal surface, and a slightly pointed rostrum and postrostrum. A curved sulcus crosses the proximal surface longitudinally. The depth of the sulcal groove increases with age. Annuli were usually counted in the region from the primordium to the proximal surface along the ventral margin of the sulcus acousticus. Annuli in this region were usually well defined and more readily interpreted.

The precision of otolith readings of *L. malabaricus* was relatively high, with the Index Average Percent Error (IAPE), 4.32%. This reflects a relatively high level of precision among otolith readings and indicates that otoliths were interpreted in a similar manner on each occasion.

Otolith length and breadth were good predictors of fish length in *L. malabaricus*, accounting for more than 91% of the variability (Table 5.3). In contrast, otolith weight and height were poor predictors of fish length (Table 5.3). Otolith weight was the best predictor of fish age for *L. malabaricus*, accounting for 91.7% of the variability in age (Table 5.3, Fig. 5.8). Otolith length, breadth and height were poor predictors of age for *L. malabaricus* (Table 5.3).

5.3.2.3 *Growth and mortality models*

All samples of *L. malabaricus* were obtained from fish trawl catches, which selected against individuals less than 2+ years of age and less than 150 mm FL (Figs. 5.9, 5.10). While few fish were retained in the 0+ and 1+ age classes, a number of individuals were caught from 150-450 mm (Fig. 5.10). Hence, fish less than 10+ years of age were not well represented in the catch (Fig. 5.9). A few large individuals (> 700 mm FL) were obtained from the fish trawl fishery in depths of 50-100 m.

The von Bertalanffy growth curve was fitted to lengths-at-age for all *L. malabaricus* (Fig. 5.11), and separately for each sex (Table 5.4). The VBGF indicates that the rate of growth of *L. malabaricus* decreases with increasing age. Growth of *L. malabaricus* is slow, with growth in length much reduced beyond the 10+ age classes. The growth curves of *L. malabaricus* were significantly different between sexes ($p < 0.05$), with males reaching a larger size-at-age than females (Fig. 5.11). Differences between sexes were observed in values of L_∞, K and t_0 (Table 5.4).

Lutjanus malabaricus less than 11+ years of age were not fully recruited to the sampled population and were excluded from the mortality estimates derived from catch curves (Fig. 5.12). The estimated M of the Pilbara population of *L. malabaricus* in the 100-200 m depth zone was 0.115 ($r^2 = 0.90$), representing an annual survivorship of ca. 89% yr^{-1} (Table 5.5). Individuals in age classes 3+ through to 9+ do not appear to have declined at the same rate as individuals in the 11+ through to the 26+ age classes (fish hatched between 1972 and 1987). This data suggests that the numbers of fish in the 2+ to 10+ age classes are not what might be expected, and further suggest that the numbers of younger fish (< 10+ years of age) may be less than what was present in the 1970's and 1980's.

Estimates of M from the equation of Hoenig (1983) were slightly higher than those derived from catch curves and therefore predict a slightly lower survivorship rate (Table 5.5). Estimates of M from the equation of Pauly (1980) were much higher than those derived from either catch curves or the Hoenig equation and suggest a lower rate of survivorship (Table 5.5).

5.3.2.4. *Limit reference point estimation*

The LRP F_{limit} for *L. malabaricus* is estimated to be 0.0769 (Table 5.6). An F_{limit} of 0.0769 indicates that only 7.40 % of the available stock of *L. malabaricus* can be harvested each year.

5.3.3 *Lutjanus russelli* (Indian Ocean variety) - Moses Perch

5.3.3.1 *Length-weight models*

Length-weight relationships were calculated separately for males, females and for both sexes combined (Table 5.1). ANCOVA of weight-at-length was not significantly different between sexes for *L. russelli* ($F = 0.269$; df: 1,265; $p > 0.5$). The relationship between total weight and fork length is presented in Figure 5.13. Length conversion equations were derived for total length, fork length and standard length (Table 5.2).

Mean weight (TW), mean lengths (FL) and mean ages of *L. russelli* sampled all differed significantly between sexes ($p < 0.01$, $p < 0.01$ and $p < 0.05$, respectively) with males larger than females.

5.3.3.2 *Otolith morphology, interpretation and otolith growth*

The sagittae of *L. russelli* are laterally compressed, elliptical structures, with a concave distal surface, a pointed rostrum and a curved postrostrum. A curved sulcus crosses the proximal surface longitudinally. The depth of the sulcal groove increases with the increasing age. Annuli were usually counted in the region from the primordium to the proximal surface along the ventral margin of the sulcus acousticus. Annuli in this region were usually well defined and more readily interpreted.

The precision of otolith readings of *L. russelli* was relatively high, with the Index Average Percent Error (IAPE), 5.96%. This reflects a relatively high level of precision among otolith readings and indicates that otoliths were interpreted in a similar manner on each occasion.

Otolith length was a good predictor of fish length in *L. russelli*, accounting for more than 83% of the variability (Table 5.3). In contrast, otolith breadth, weight and in particular otolith height were poor predictors of fish length (Table 5.3). Otolith weight was the best predictor of fish age for *L. russelli*, accounting for 92.6% of the variability in age (Table 5.3, Fig. 5.14). Otolith length, breadth and height were poor predictors of age for *L. russelli* (Table 5.3).

5.3.3.3 *Growth and mortality models*

All samples of *L. russelli* were obtained from fish trawl catches, individuals less than 4+ years of age and less than 250 mm FL were caught during the survey (Figs. 5.15, 5.16). No fish in the 0+, 1+ and 2+ age classes were able to be obtained for analysis. Lengths-at-age for the 1+ and 2+ age classes were established by back-calculating lengths-at-age of fish in the 3+ and 4+ age classes (Fig. 5.17). Back-calculation of lengths-at-age in the 1+ and 2+ age classes was undertaken in order to provide robust estimates of parameters of the Von Bertalanffy growth curve. The back-calculated fork lengths-at-age were obtained from fork length-otolith radius regressions.

The von Bertalanffy growth curve was fitted to lengths-at-age for all *L. russelli* (Fig. 5.17), and separately for each sex (Table 5.4). The VBGF indicates that the rate of growth of *L. russelli* decreases rapidly with increasing age. Growth of *L. russelli* is rapid to age 5, with growth in length much reduced beyond the 5+ age classes. Length-at-age of *L. russelli* was not significantly different between sexes ($p > 0.05$; Fig. 5.17).

Lutjanus russelli less than 6+ years of age were not fully recruited to the sampled population and were excluded from the mortality estimates derived from catch curves (Fig. 5.18). The estimated M of the Pilbara population of *L. russelli* in the 100-200 m depth zone was 0.142 ($r^2 = 0.69$), representing an annual survivorship of ca. 87% yr^{-1} (Table 5.5). Individuals in some age classes (eg. 8+) were not well represented in the catch and do not appear to be recruited in similar numbers to other cohorts (the equilibrium assumption). However, the descending right hand limb of the catch curve is similar across most ages and hence M is assumed to be constant.

Estimates of M from the equation of Hoenig (1983) were slightly higher than those derived from catch curves and therefore predict a slightly lower survivorship rate (Table 5.5). Estimates of M from the equation of Pauly (1980) were substantially higher than those derived from either catch curves or the Hoenig equation and suggest a lower rate of survivorship (Table 5.5).

5.3.3.4. *Limit reference point estimation*

The LRP F_{limit} for *L. russelli* is estimated to be 0.0945 (Table 5.5). An F_{limit} of 0.0945 indicates that only 9.01 % of the available stock of *L. russelli* can be harvested each year.

5.3.4 *Pristipomoides multidens* - Goldband Snapper

5.3.4.1 *Length-weight models*

Length-weight relationships were calculated separately for males, females and for both sexes combined (Table 5.1). ANCOVA of weight-at-length was not significantly different between sexes for *P. multidens* ($F = 0.508$; df: 1,255; $p > 0.4$.). The relationship between total weight and fork length is presented in Figure 5.19. Length conversion equations were derived for total length, fork length and standard length (Table 5.2).

Mean weight (TW), mean lengths (FL) and mean ages of *P. multidens* sampled were not significantly different between sexes ($p > 0.05$ for each variable).

5.3.4.2 *Otolith morphology, interpretation and otolith growth*

The sagittae of *P. multidens* are laterally compressed, elliptical structures, with a concave distal surface, a pointed rostrum and postrostrum and are characterised by variable growth reticulations along the dorsal edge of the sagitta from the postrostrum to the antirostrum and along the ventral edge of the sagitta from the postrostrum to the rostrum. A curved sulcus crosses the proximal surface longitudinally. The depth of the sulcal groove increases with the increasing age. Annuli were usually counted in the region from the primordium to the proximal surface along the ventral margin of the sulcus acousticus. Annuli in this region were usually well defined and more readily interpreted.

The precision of otolith readings of *P. multidens* was relatively high, with the Index Average Percent Error (IAPE), 5.00%. This reflects a relatively high level of precision among otolith readings and indicates that otoliths were interpreted in a similar manner on each occasion.

Otolith length and breadth were good predictors of fish length in *P. multidens*, accounting for more than 96% of the variability (Table 5.3). In contrast, otolith weight and height were poor predictors of fish length (Table 5.3). Otolith weight was the best predictor of fish age for *P. multidens*, accounting for 94.4% of the variability in age (Table 5.3, Fig. 5.20). Otolith height was also a good predictor of fish age, accounting for 89.2% of the variability in age, but was not as accurate as otolith weight (Table 5.3). In contrast, otolith length and breadth were poor predictors of age for *P. multidens* (Table 5.3).

5.3.4.3 *Growth and mortality models*

All samples of *P. multidens* were obtained from fish trawl catches, which selected against individuals less than 1+ years of age and less than 150 mm FL (Figs. 5.21, 5.22). A large number of small fish ranging in length from 150-450 mm, representing fish in the 1+, 2+, 3+, 4+ and 5+ age classes, were obtained from fish trawl catches for age and growth analysis. Individuals larger than 600 mm FL were not well represented in the catch.

The von Bertalanffy growth curve was fitted to lengths-at-age for all *P. multidens* (Fig. 5.23), and separately for each sex (Table 5.4). The VBGF indicates that the rate of growth of *P. multidens* decreases with increasing age. Growth of *P. multidens* is slow to age 7, with growth in length much reduced beyond the 7+ age classes. Length-at-age of *P. multidens* was not significantly different between sexes ($p > 0.05$; Fig. 5.23).

Pristipomoides multidens less than 6+ years of age were not fully recruited to the sampled population and were excluded from the mortality estimates derived from catch curves (Fig. 5.24). The estimated Z of the Pilbara population of *P. multidens* in the 100-200 m depth zone was 0.291 ($r^2 = 0.86$), representing an annual survivorship of only ca. 75% yr^{-1} (Table 5.5). The descending right hand limb of the catch curve is similar across all age classes and Z is assumed to be constant.

Estimates of M were derived from the equation of Hoenig (1983) based on the maximum observed age of 29 years for *P. multidens* in the nearby Kimberley population (Newman, unpublished data). The estimated M of the Pilbara population of *P. multidens* in the 100-200 m depth zone was therefore assumed to be ca. 0.139 which represents unfished survivorship rate of ca. 87% (Table 5.5). Estimates of M from the equation of Pauly (1980) were substantially higher than that derived from the Hoenig equation and also exceeded the estimate of Z derived from catch curves (Table 5.5).

5.3.4.4. *Limit reference point estimation*

The LRP F_{limit} for *P. multidens* is estimated to be 0.0925 (Table 5.5). An F_{limit} of 0.0925 indicates that only 8.83 % of the available stock of *P. multidens* can be harvested each year.

5.3.5 *Pristipomoides typus* - Sharptooth Snapper

5.3.5.1 *Length-weight models*

Length-weight relationships were calculated separately for males, females and for both sexes combined (Table 5.1). ANCOVA of weight-at-length was not significantly different between sexes for *P. typus* (F = 0.041; df: 1,281; $p > 0.8$). The relationship between total weight and fork length is presented in Figure 5.25. Length conversion equations were derived for total length, fork length and standard length (Table 5.2).

Mean weight (TW), mean lengths (FL) and mean ages of *P. typus* sampled were not significantly different between sexes ($p > 0.05$ for each variable).

5.3.5.2 *Otolith morphology, interpretation and otolith growth*

The sagittae of *P. typus* are laterally compressed, elliptical structures, with a concave distal surface, a pointed rostrum and a curved postrostrum. Variable growth reticulations are present along the dorsal edge of the sagitta from the postrostrum to the antirostrum and also along the ventral edge of the sagitta forward of the position marked by the antirostrum on the dorsal surface. A curved sulcus crosses the proximal surface longitudinally. The depth of the sulcal groove increases with the increasing age. Annuli were usually counted in the region from the primordium to the proximal surface along the ventral margin of the sulcus acousticus. Annuli in this region were usually well defined and more readily interpreted.

The precision of otolith readings of *P. typus* was relatively high, with the Index Average Percent Error (IAPE), 6.16%. This reflects a relatively high level of precision among otolith readings and indicates that otoliths were interpreted in a similar manner on each occasion.

Otolith length and breadth were good predictors of fish length in *P. typus*, accounting for more than 93% of the variability (Table 5.3). In contrast, otolith weight and height were poor predictors of fish length (Table 5.3). Otolith weight was the best predictor of fish age for *P. typus*, accounting for 93.4% of the variability in age (Table 5.3, Fig. 5.26). Otolith height was also a good predictor of fish age, accounting for 89.4% of the variability in age, but was not as accurate as otolith weight (Table 5.3). In contrast, otolith length and breadth were poor predictors of age for *P. typus* (Table 5.3).

5.3.5.3 *Growth and mortality models*

All samples of *P. typus* were obtained from fish trawl catches, which selected against individuals less than 3+ years of age and less than 350 mm FL (Figs. 5.27, 5.28). A large number of small fish ranging in length from 150-350 mm, representing fish in the 1+, 2+, 3+ and 4+ age classes, were obtained from fish trawl catches for age and growth analysis. Individuals larger than 560 mm FL were not well represented in the catch.

The von Bertalanffy growth curve was fitted to lengths-at-age for all *P. typus* (Fig. 5.29), and separately for each sex (Table 5.4). The VBGF indicates that the rate of growth of *P. typus* decreases with increasing age. Growth of *P. typus* is slow to age 6, with growth in length much reduced beyond the 6+ age classes. Length-at-age of *P. typus* was not significantly different between sexes ($p > 0.05$; Fig. 5.29).

Pristipomoides typus less than 5+ years of age were not fully represented in the sampled population and were excluded from the mortality estimates derived from catch curves (Fig. 5.30). The estimated Z of the Pilbara population of *P. typus* in the 100-200 m depth zone was 0.213 ($r^2 = 0.82$), representing an annual survivorship of only ca. 81% yr^{-1} (Table 5.5). The descending right hand limb of the catch curve is similar across all age classes and Z is assumed to be constant.

No estimates of M in unfished populations are available for *P. typus*. Therefore, it has been assumed that the M for *P. typus* is most likely to be related to that of *P. multidens* as both species are closely related and share similar growth rates (Table 5.5). Estimates of M were derived from the equation of Hoenig (1983) based on the maximum observed age of 29 years for *P. multidens* in the nearby Kimberley region (Newman, unpublished data). The estimated M of the Pilbara population of *P. typus* in the 100-200 m depth zone was therefore assumed to be ca. 0.139 which represents unfished survivorship rate of ca. 87% (Table 5.5). Estimates of M from the equation of Pauly (1980) were substantially higher than that derived from the Hoenig equation and also exceeded the estimate of Z derived from catch curves (Table 5.5).

5.3.5.4. *Limit reference point estimation*

The LRP F_{limit} for *P. typus* is estimated to be 0.0925 (Table 5.5). An F_{limit} of 0.0925 indicates that only 8.83 % of the available stock of *P. typus* can be harvested each year.

5.4 *Discussion*

Demographic parameters of *G. buergeri*, *L. malabaricus*, *L. russelli*, *P. multidens* and *P. typus* have not previously been established using sectioned otoliths from populations of these fish in Western Australia and this study is the first to establish the demographic parameters of age, growth rate and mortality of *G. buergeri* and the Indian Ocean variety of *L. russelli.*

5.4.1 *Otolith analysis and interpretation*

Sagittae of all five species were found to have a distinct pattern of alternating translucent and opaque (annuli) bands. A number of smaller rings could be seen within the observed bands in sagittae of *G. buergeri.* These smaller rings may represent monthly growth bands. Observed annuli in *G. buergeri* were wider and more distinct than these smaller rings. Under reflected light on a black background annuli appear opaque in contrast to surrounding translucent areas in all five species. The first few annuli in all species are usually broad and diffuse, with subsequent annuli becoming progressively more compact towards the edge of the otolith.

While the otoliths of *G. buergeri* are interpretable, there is a large amount of individual variability among otoliths and some otoliths were difficult to assess. Hence, the precision of counts of annuli in *G. buergeri* is low when compared to the other species investigated in this study. Otoliths of *L. malabaricus* and *L. russelli* were readily interpretable, with a high level of precision among replicate counts of annuli. A large amount of intra-specific variability was observed among otoliths of *P. multidens* and *P. typus*. However, otoliths were interpretable in a similar manner on each occasion, with a high level of precision among replicate counts of annuli.

5.4.2 *Age estimation and longevity*

Evidence of the annual basis of ring formation is important in any age and growth study using calcareous structures such as otoliths to determine age. The presence of annuli in the key species in this study has not been directly validated. The haphazard manner in which industry undertook the survey component of this study precluded validation by indirect methods such as marginal increment validation. However, a large amount of literature has largely confirmed the hypothesis of annuli in otoliths of both temperate and tropical fishes (eg. Secor et al., 1995; Fowler, 1995) and it has been clearly demonstrated that the alternating bands of opaque and translucent zones found in the sectioned otoliths of fish sampled in similar latitudes represent annuli (Fowler and Doherty, 1992; Ferreira and Russ, 1992; 1994; Newman et al. 1996; Hart and Russ, 1996; Choat and Axe, 1996; Cappo et al., 2000). Direct validation involving tetracycline labelling of tagged fishes has confirmed the presence of annuli in sectioned otoliths of *L. malabaricus* and *L. russelli* (Pacific Ocean variety) sampled in similar latitudes on the Great Barrier Reef (Cappo et al. 2000, Sheaves 1995). In contrast, Milton et al. (1995) argued that the increments observed in the sectioned otoliths of *L. malabaricus* may not be annuli. This conclusion was based on radiometric techniques using disequilibria of Pb^{210}: Ra^{226} ratios of pooled otoliths. West and Gauldie (1994) reviewed the assumptions, biases and procedures underpinning radiometric techniques and concluded that the radiometric disequilibrium method is presently not sufficient to validate fish ages. Further evidence of the annual nature of growth increments in *L. russelli* (Pacific Ocean variety) came from growth rates obtained from tag-release-recapture programs (Sheaves 1995). Newman (unpublished data) has confirmed the presence of annuli in sectioned otoliths of *P. multidens* in the Kimberley region of Western Australia using marginal increment analysis. There appears to have been no studies that have clearly demonstrated that growth rings in sectioned otoliths are not annuli.

Furthermore, evidence of the presence of annuli can be assessed by a number of criteria (Fowler and Doherty, 1992). Otoliths must display an internal structure of increments. Otoliths must grow throughout the lives of the fish at a perceptible rate and there must be a positive relationship between the size of fish caught and the size of the otoliths. The internal structure of increments must be formed periodically on a regular time scale (eg. once per year). Several observations confirm the use of sectioned otoliths to age the key species in this study. Transverse sections of sagittae showed a pattern of alternating translucent and opaque zones in all species. The alternating bands of opaque and translucent zones considered as annuli in this study are analogous to those reported as annuli by Fowler and Doherty (1992), Ferreira and Russ (1994), Newman et al. (1996), Hart and Russ (1996), Choat and Axe (1996) and Cappo et al. (2000). There was also a strong correlation between otolith weight and estimated fish age in all species and the length-at-age of fish increased as the number of rings (age) increased in all species. The high correlation obtained between otolith weight and fish age further supports the suggestion that the bands reported for each species in this study are formed on an annual basis.

Otoliths continue to accumulate mass with increasing age independent of fish growth. The use of otolith weight as a proxy for age may provide an inexpensive, reliable and robust method of assessing age and hence determining growth and mortality of these fishes for fishery monitoring purposes (Worthington et at. 1995a, 1995b).

The oldest *G. buergeri* sampled in this study was a female 26 years of age, and reflects the maximum observed longevity estimated by this study. However, as the sample size is relatively small (< 300 fish sampled), it is feasible that this species may live longer, possibly to at least 30 years. The oldest *L. malabaricus* sampled in this study was a male 31 years of age, and reflects the maximum observed longevity estimated by this study. Similarly, Mansour (1982) estimated a maximum age of 32 years from the sectioned otoliths of *L. malabaricus* sampled in Kuwait. The sample size is this study is relatively small (ca. 200 fish sampled and few fish over 800 mm were obtained), whereas the maximum length of *L. malabaricus* is reported to be 1000 mm (Allen, 1985), it is feasible that fish may live longer, possibly to 40+ years. Mathews and Samuel (1985) reported a maximum observed age of 46 years *for L. malabaricus* from the sectioned otoliths of fish sampled in Kuwait. A number of different methods have been used to estimate the age of *L. malabaricus*, including analysis of whole otoliths (McPherson et al. 1988, McPherson and Squire 1992), scales (Druzhinin, 1970), vertebrae (Lai and Liu 1974, 1979; Edwards 1985) and length frequency analysis (Yeh and Chen 1986, Ambak et al. 1987). These studies have reported longevities in the range of 6-11 years, much less than those reported from studies involving analysis of sectioned otoliths. Sectioned otoliths provide the most reliable estimates of age in long lived fish (eg. Newman et al. 2000).

The oldest *L. russelli* sampled in this study was a male 21 years of age, and reflects the maximum observed longevity estimated by this study. Similarly, Sheaves (1995) estimated a maximum age of 17 years for the Pacific Ocean variety of *L. russelli* from similar latitudes on the Great Barrier Reef. The sample size is this study is relatively small (< 150 fish sampled and few fish over 330 mm were obtained). The maximum reported length of *L. russelli* is 450 mm (Allen, 1985), it is feasible that fish may live longer. Estimates of age of *L. russelli* have also been obtained by analysis of scales (Ye and Tang 1996, Chen 1997). These studies have reported longevities of only 6 years for *L. russelli*.

The oldest *P. multidens* sampled from the Pilbara population was only 19 years of age, much less than the maximum observed longevity of 29 years for *P. multidens* in the adjacent Kimberley region of Western Australia (Newman unpublished data). Given that *P. multidens* has been sampled from fished populations within Western Australia, it is likely that the longevity may exceed 30 years. Estimates of age of *P. multidens* have previously been obtained by analysis of otolith daily rings (Richards 1987), vertebrae and scales (Edwards 1985) and length frequency analysis (Mohsin and Ambak 1996). These studies have reported longevities of only 5-14 years for *P. multidens*.

The oldest *P. typus* sampled from the Pilbara population was only 21 years of age. Given that the sample of *P. typus* was considered to be from a fished population, it is expected that the longevity of this species will be similar to that observed for *P. multidens*, and hence may exceed 30 years. The only previous estimates of longevity of *P. typus* were obtained by analysis vertebrae and scales (Edwards 1985), with a reported longevity of only 11 years.

The lack of a relationship between the age and length frequency distributions of all species, emphasises the problems that will be associated with using length frequency analysis to identify age cohorts. Many age classes tend to accumulate within a narrow size range. For example, *L. russelli* were sampled from a relatively small size range (232-387 mm), yet the observed ages incorporated within this sample ranged from 3-21 years of age. Mohsin and Ambak (1996) used length frequency analysis to estimate demographic parameters of *P. multidens* in Malaysian waters suggesting that they were short-lived (only 5 age cohorts were identified). Length frequency analysis produces biased estimates of the demographic parameters of long-lived reef fishes. Estimates of demographic parameters derived from length frequency analysis of these species will be grossly biased and caution must be applied if they are to be used for fishery management purposes.

5.4.3 *Growth*

Growth of *G. buergeri* is slow (K = 0.138) throughout their life-history. Approximately 40% of linear growth to L_∞ is accomplished within the first 3 years of the lifespan, with ca. 75% of linear growth to L_∞ accomplished within the first 9 years of the lifespan. Growth in length is much reduced after 12 years of age. The range of fish size and age used in age and growth studies may influence estimates of the von Bertalanffy growth equation if they are not representative of the population. This growth study was considered comprehensive because specimens were obtained across the entire size range, with large quantities of small fish (< 200 mm) collected from trawl catches.

Growth of *L. malabaricus* in this study is moderately slow (K = 0.225 from generalised growth curve). Approximately 50% of linear growth to L_∞ is accomplished within the first 3 years of the lifespan, with ca. 75% of linear growth to L_∞ accomplished within the first 6 years of the lifespan. Growth in length is much reduced after 10 years of age. The K observed in this study is similar to that derived by McPherson and Squire (1992, whole otoliths); Yeh (1988, length frequency) and Chen et al. (1984, otolith sections). The observed K is higher than that estimated by Lai and Liu (1974; 1979) and Druzhinin (1970) which ranged from 0.12-0.15 using vertebrae and scales, respectively. The asymptotic FL is similar to that estimated by Mansour (1982).

Differential growth between sexes in *L. malabaricus* was observed in this study, with males significantly longer than females of a similar age. This was evident only from age class 9 onwards. This pattern of size differentiation between sexes within the *Lutjanus* genus on the Great Barrier Reef is consistent with all studies to date indicating that males reach a larger size-at-age than females (McPherson *et al.* 1988; McPherson and Squire 1992; Newman et al. 1996, Newman et al. 2000). Faster growth of males over females in older age classes has also been reported for *L. vitta* on the North West

Shelf of Western Australia (Davis and West 1992, Stephenson and Mant unpublished data).

The absence of small fish in the sampled population of *L. russelli* required back calculation of growth rates to determine length-at-age for 1 and 2 year old fish. Back-calculation of growth based on otoliths has the potential to underestimate length-at-age (Campana 1990). Hence, the growth rates derived from this study can be considered conservative. Growth of *L. russelli* is rapid ($K = 0.347$) during the first 3 years of life and the growth curve is relatively 'square'. Approximately 68% of linear growth to L_∞ is accomplished within the first 3 years of the lifespan, with growth in length much reduced after 5 years of age. The K observed in this study is higher than the K of 0.243 reported by both Ye and Tang (1996) and Chen (1997). Sheaves (1995) did not report parameters of the VBGF, but observed length-at-age was similar to that reported in this study.

Growth of *P. multidens* is slow ($K = 0.25$). Approximately 58% of linear growth to L_∞ is accomplished within the first 3 years of the lifespan, with ca. 81% of linear growth to L_∞ accomplished within the first 6 years of the lifespan. After 10 years of age, ca. 93% of linear growth to L_∞ is accomplished with growth in length much reduced beyond age 10. The K observed in this study is similar to that derived by Edwards (1985, vertebrae/scales) and Brouard and Grandperrin (1985, length frequency). The observed K is higher than the K of 0.188 estimated by Richards (1987) and Ralston (1987, pers. comm.) from daily rings in the otolith microstructure. The asymptotic FL in this study is similar to that estimated by Edwards (1985, $L_\infty = 59.1$) and is lower than that derived by Brouard and Grandperrin (1985, $L_\infty = 65.0$), Richards (1987, $L_\infty = 73.6$) and Ralston (1987, $L_\infty = 73.6$). The reduced L_∞ is a reflection of the sharp truncation of the length distribution beyond 550 mm.

Growth of *P. typus* is slow ($K = 0.25$). Approximately 62% of linear growth to L_∞ is accomplished within the first 3 years of the lifespan, with ca. 83% of linear growth to L_∞ accomplished within the first 6 years of the lifespan. After 10 years of age, ca. 94% of linear growth to L_∞ is accomplished with growth in length much reduced beyond age 10. The K and asymptotic FL observed in this study are similar to that derived by Edwards (1985) from analysis of vertebrae and scales (0.254 and 515.4, respectively).

5.4.4 *Mortality*

Estimating mortality using age-based catch curves involves a number of assumptions. These include the assumptions of constant recruitment and constant mortality for each age class. The steady state or equilibrium assumption of constant recruitment is likely to be violated for most species as recruitment is generally extremely variable and inconsistent (eg. Doherty and Fowler, 1994). However, catch curves are reliable and robust if a large number of age classes are included within the sample. The catch curve of each species suggests that the mortality rate across each age class is constant and therefore the natural mortality rate estimated from the catch curve of each species are likely to be robust. *G. buergeri* were fully recruited to the fish trawl fishery by age 2, and the instantaneous rate of natural mortality (M) is low (estimated to be 0.113). Low rates of natural mortality were expected given the long life span of *G. buergeri*. *Lutjanus russelli* were fully recruited to the fish trawl fishery by age 6, and the instantaneous rate of natural mortality (M) is low (estimated to be 0.142). *Lutjanus malabaricus* were fully recruited to the fish trawl fishery by age 11, and the instantaneous rate of natural mortality (M) is low (estimated to be 0.115).

The abundance of *L. malabaricus* in age classes 2-10 is less than might be expected from the backward projection of the age structure of the sampled population. If we assume that *L. malabaricus* is philopatric and cross-shelf movement negligible then this data infers that the numbers of younger fish (< 10+ years of age) may now be much less than was present in the 1970's and 1980's. The abundance of 'red snappers' (*L. malabaricus* is one of the three red snapper species) rapidly declined in the North-West Shelf area in the 1970's and 1980's as a consequence of high foreign fishing effort (Sainsbury 1987, Ramm 1994). Initial catches of 'red snappers' were much higher than estimates of sustainable yield obtained from production models (Sainsbury 1987, Ramm 1994). Furthermore, 'red snappers' were one of the key species groups targeted by foreign fishing vessels in the mid to late 1980's (Sainsbury 1987, Ramm 1994). The decline in the abundance of valuable commercial fishes on the North-West Shelf and changes in community structure have also been linked with habitat modification and loss caused by fish trawlers (Sainsbury, 1987; Sainsbury et al. 1997). The low abundance of fish in the 2-10+ age classes therefore indirectly suggests that current levels of recruitment (and possibly stock levels) across the Pilbara are possibly much less than historical levels prior to the resource being heavily exploited by both foreign and domestic trawl based fisheries. Alternatively, if cross-shelf movements are a common component of the life history pattern of *L. malabaricus*, then fish in the 2-10 year age classes are likely to occur in more inshore waters.

The *P. multidens* age composition data show a strong peak of younger fish (ages 2-5), with apparent very rapid disappearance of fish over the age range 7-10. If we assume that all fish greater than age 7 are equally vulnerable to fishing then this pattern would indicate a high fishing mortality rate and is likely to reflect a smaller sustainable yield than the current level of catch. The stock of *P. multidens* has been harvested at high rates from the late-70's first by foreign trawlers (Sainsbury 1987) and by domestic fishers over the last 10 years (Stephenson unpublished data). We have assumed in this case that there is similar vulnerability of all the older age classes. The catch curve of *P. multidens* reflects a relatively constant mortality rate across each exploited age class. *P. multidens* were fully recruited to the fish trawl fishery by age 6, and the instantaneous rate of total mortality (Z) estimated to be 0.291. Furthermore, *P. multidens* aged 1-5+ are vulnerable to capture by the fish trawl fishery.

The *P. typus* age composition data show a strong peak of young fish (age 5+), with apparent very rapid disappearance of fish over the age range 6-14. If we assume that all fish greater than age 5 are equally vulnerable to fishing then this pattern would indicate a high fishing mortality rate and is likely to reflect a smaller sustainable yield than the current level of catch. The stock of *P. typus* has been harvested (as part of the *Pristipomoides* spp. complex) at high rates from the late-70's first by foreign trawlers (Sainsbury 1987) and subsequently by domestic fishers over the last 10 years (Stephenson unpublished data). We have assumed in this case that there is similar vulnerability of all the older age classes. The catch curve of *P. typus* reflects a relatively constant mortality rate across each exploited age class. *P. typus* were fully recruited to the fish trawl fishery by age 5, and the instantaneous rate of total mortality (Z) estimated to be 0.213. Furthermore, *P. typus* aged 1-4+ are vulnerable to capture by the fish trawl fishery.

Instantaneous natural mortality rates derived from the age structure of *G. buergeri*, *L .malabaricus* and *L. russelli* were compared to those derived from the empirical regression techniques of Hoenig (1983) and Pauly (1980). Hoenig's empirical equation, based on maximum observed age provided similar estimates of M to those derived from catch curves for each species. The estimates of M obtained from the regression equation of Pauly (1980) provided a gross overestimate of M for these fishes and hence substantially underestimated survivorship.

The estimates of M obtained from the regression equation of Pauly (1980) provided a gross overestimate of M for *P. multidens* and *P. typus* (exceeds Z estimated from catch curves for both species). Errors in estimates of M have profound fisheries management implications as yield and production models all require estimates of M. Overestimates of M will provide overestimates of the potential yield of fish stocks and may lead to over-exploitation and ultimately recruitment overfishing. The Hoenig (1983) equation has been shown to be a reliable and robust method of estimating M in unfished populations, particularly if larger older individuals (near maximum age) can be sampled from within a population (eg. Newman et al. 1996, 2000).

We have assumed that the M derived from the maximum observed age in the adjacent Kimberley population of *P. multidens* using the Hoenig (1983) equation is a more pragmatic reflection of the M for this species. Given that the longevity of *P. multidens* is likely to exceed 30 years, an assumed M of 0.139 is incautious. The F of 0.152 (ie. 0.291-0.139) exceeds the LRP F_{limit} of 0.0925 derived for this species and indicates that the exploitation of *P. multidens* in the Pilbara region is not sustainable. Stephenson (unpublished data) has shown the catch and catch per unit effort of *Pristipomoides* species across the Pilbara Fish Trawl Fishery has been in decline over the last 5 years The F derived from the catch curve is further evidence of the over-exploitation of *P. multidens.*

Furthermore, we have assumed that the M of *P. multidens* (derived above) is representative of the M for *P. typus*. If the longevity of *P. typus* exceeds 30 years, an assumed M of 0.139 would be incautious. The F of 0.074 is in the vicinity of the LRP F_{limit} of 0.092 derived for this species and indicates that the exploitation of *P. typus* in the Pilbara region may be sustainable. The capture of sub-adult and juvenile fish by fish trawl nets also results in a reduction of the available yield to the fishery for this species.

5.4.5 *Summary*

During the sampling period juvenile and sub-adult individuals of *G. buergeri*, *L. malabaricus*, *P. multidens* and *P. typus* were obtained from trawl catches. Few juvenile *L. russelli*, less than 4 years of age were caught by fish trawls, and no fish less than 3 years of age were obtained for analysis. Juvenile *L. russelli* (Pacific Ocean variety) are known to frequent nearshore coastal habitats such as mangrove estuaries, headland areas and rocky shores (Newman and Williams 1996, Sheaves 1995). Furthermore, Sheaves (1995) reports that estuarine populations of *L. russelli* consist entirely of reproductively immature fish and that reproductively mature fish were only sampled from offshore waters well away from estuaries. It is likely therefore that juvenile *L. russelli* do not settle in the deeper (> 100 m) continental shelf waters off the Pilbara coast, rather the population size in more offshore waters is dependent upon cross-shelf movements of sub-adult *L. russelli* from coastal nursery areas.

The key species examined in this study off the Pilbara coast of Western Australia are all long-lived (up to 31 years of age), slow growing fish (except *L. russelli*), with low rates of natural mortality. Hence, these fish have a low production potential and are vulnerable to overfishing. Furthermore, the vulnerability of juvenile and sub-adult fish of each species to capture by fish trawl nets results in a reduction of the available yield to the fishery for these species.

The apparent reduced abundance of *L. malabaricus* in age classes less than 10 years of age needs to be investigated. Fishing pressure by both foreign and domestic fleets (eg.) in nearshore waters may have substantially reduced the spawning stock biomass of *L. malabaricus*, resulting in reduced recruitment of fish in the 100-200 m depth zone. Furthermore, there is also the possibility that habitat loss as a consequence of fish trawl activities is also impacting upon recruitment.

Lutjanus russelli exhibit rapid growth towards asymptotic length, hence their growth curve is relatively square. Length frequency analysis of species characterised by square growth curves (rapid growth to maximum size and then little growth for the rest of their long lives) may provide misleading impressions of the population dynamics of these fishes. Given the importance of *L. russelli* and other long-lived fish to both commercial fishers and recreational anglers, consideration should be given to cross-shelf spatial closures for protection of recruitment sources and the spawning stock biomass for these species.

The sustainable harvest rates of long-lived species rarely exceed the natural mortality rate and are more likely to be in the order of 0.4-0.6 times the natural loss rate or natural mortality rate (Patterson 1992, Walters pers. comm.). Therefore, for most long lived species the annual harvest rate should not exceed approximately 10% per year of the available stock, as evidenced by this study.

Furthermore, *P. multidens*, *P. typus* and *L. malabaricus* are schooling species that often occur in large aggregations that can be easily located by fishing vessels using colour depth-sounders and sonar. This dynamic aggregation process makes these species especially vulnerable to capture in fisheries involving active targeting of schools (eg. trap and line fishing methods), as fishing could proceed with high, stable CPUE (the numbers of schools are likely to decrease with fishing pressure but catch rates once a school is found are likely to remain stable) long after declines in overall population abundance have occurred. This hyperstability in catch rates has serious implications for management of these species. The demographic parameters of these species in association with their schooling behaviour, indicates that they are especially vulnerable to overfishing.

It is important that a large standing stock of these fish is conserved as part of the management plan for the demersal fish resources off the Pilbara coast of Western Australia. In order to increase yields to the fishery the application of additional fishery management control measures, such as the implementation of legal minimum size limits is not recommended. The survivorship of these fish upon release from capture in depths of 60-150 m is negligible due to the over-expansion (and eruption) of the swim bladder. Large spatial area closures (harvest refugia) for protection of both spawning stock biomass and areas of high juvenile recruitment are recommended for these species.

Table 5.1: Length weight relationships of *G. buergeri*, *L. malabaricus*, *L. russelli*, *P. multidens* and *P. typus* from the Pilbara coast of Western Australia. For each species estimates were obtained of the parameters *a* and *b* of the relationship $W = aL^b$, the sample size (*n*) and the regression r^2 value (lengths used are FL in mm and the weight is TW in g).

Species	*a*	*b*	*n*	r^2
G. buergeri	7.797×10^{-5}	2.7633	356	0.9976
G. buergeri (male)	7.652×10^{-5}	2.7677	216	0.9981
G. buergeri (female)	8.519×10^{-5}	2.7471	191	0.9980
L. malabaricus	2.348×10^{-5}	2.9279	289	0.9908
L. malabaricus (male)	2.516×10^{-5}	2.9156	128	0.9942
L. malabaricus (female)	2.507×10^{-5}	2.9187	183	0.9902
L. russelli	1.867×10^{-5}	2.9730	268	0.9696
L. russelli (male)	2.100×10^{-5}	2.9525	140	0.9714
L. russelli(female)	1.605×10^{-5}	2.9996	128	0.9656
P. multidens	3.051×10^{-5}	2.9137	280	0.9948
P. multidens (male)	3.112×10^{-5}	2.9099	168	0.9963
P. multidens (female)	2.933×10^{-5}	2.9207	135	0.9965
P. typus	8.486×10^{-5}	2.7360	285	0.9783
P. typus (male)	8.210×10^{-5}	2.7414	149	0.9782
P. typus (female)	6.592×10^{-5}	2.7777	137	0.9810

Table 5.2: Length conversion relationships of *G. buergeri*, *L. malabaricus*, *L. russelli*, *P. multidens*, and *P. typus* from the Pilbara coast of Western Australia. For each species estimates were obtained of the parameters *a* and *b* of the length-length relationships, sample size (*n*) and regression r^2 value (all lengths are in mm).

Species	*n*	r^2
G. buergeri		
TL = -2.7106446 + (1.05748687 × FL)	257	0.9996
FL = 2.68375820 + (0.945242271 × TL)	257	0.9996
FL = 7.99686541 + (1.24764485 × SL)	257	0.9977
SL = -5.8714858 + (0.799656468 × FL)	257	0.9977
L. malabaricus		
TL = -2.5837700 + (1.03988241 × FL)	214	0.9993
FL = 2.85164134 + (0.960940791 × TL)	214	0.9993
FL = 16.2781754 + (1.19890058 × SL)	214	0.9940
SL = -11.055256 + (0.829073473 × FL)	214	0.9940
L. russelli		
TL = 3.35972057 + (1.06751442 × FL)	124	0.9953
FL = -1.7084800 + (0.932354429 × TL)	124	0.9953
FL = 22.8618923 + (1.13682278 × SL)	124	0.9752
SL = -13.486599 + (0.857790447 × FL)	124	0.9752
P. multidens		
TL = 21.7580222 + (1.12147697 × FL)	317	0.9986
FL = -18.784717 + (0.890429830 × TL)	317	0.9986
FL = 9.59243030 + (1.11024968 × SL)	317	0.9961
SL = -7.1640813 + (0.897183445 × FL)	317	0.9961
P. typus		
TL = 60.7392492 + (1.06689770 × FL)	187	0.9950
FL = -54.606146 + (0.932595097 × TL)	187	0.9950
FL = 7.40237970 + (1.12083021 × SL)	187	0.9947
SL = -4.6661034 + (0.887427130 × FL)	187	0.9947

Table 5.3: Comparison between otolith dimensions and length and age of *G. buergeri*, *L. malabaricus*, *L. russelli*, *P. multidens* and *P. typus*. The predictive equations are of the simple linear regression form $y = a + bx$ (codes for the independent variables are described in the text). For regression analyses fish length (FL) and age were used as the dependent variables (all regressions were significant at $p < 0.001$). The standard error (SE) of the estimate is a measure of the dispersion of the observed values about the regression line.

G. buergeri

Dep. Var.	Ind. Var.	Sample Size	Equation	r^2	SE of Estimate
FL	OW	253	$FL = 130.628 + (299.426 \times OW)$	0.922	34.805
FL	OL	252	$FL = -74.1738 + (24.5582 \times OL)$	0.985	15.445
FL	OB	257	$FL = -176.717 + (43.731 \times OB)$	0.944	29.530
FL	OH	257	$FL = -105.695 + (136.163 \times OH)$	0.907	37.876
Age	OW	252	$Age = 0.12311 + (13.61728 \times OW)$	0.912	1.7010
Age	OL	251	$Age = -8.02928 + (1.03894 \times OL)$	0.840	2.2888
Age	OB	256	$Age = -11.9042 + (1.8074 \times OB)$	0.767	2.7566
Age	OH	256	$Age = -10.7452 + (6.2380 \times OH)$	0.906	1.7526

L. malabaricus

Dep. Var.	Ind. Var.	Sample Size	Equation	r^2	SE of Estimate
FL	OW	213	$FL = 301.3059 + (208.8818 \times OW)$	0.785	58.222
FL	OL	213	$FL = -52.3823 + (27.6065 \times OL)$	0.942	30.149
FL	OB	214	$FL = -140.986 + (49.990 \times OB)$	0.919	35.743
FL	OH	214	$FL = 63.3324 + (135.7595 \times OH)$	0.753	62.244
Age	OW	213	$Age = -0.47201 + (11.13266 \times OW)$	0.917	1.7846
Age	OL	213	$Age = -13.4429 + (1.1784 \times OL)$	0.706	3.3542
Age	OB	214	$Age = -18.1064 + (2.2017 \times OB)$	0.734	3.1859
Age	OH	214	$Age = -12.7391 + (7.1030 \times OH)$	0.849	2.3998

L. russelli

Dep. Var.	Ind. Var.	Sample Size	Equation	r^2	SE of Estimate
FL	OW	120	$FL = 222.1050 + (475.5419 \times OW)$	0.755	15.781
FL	OL	120	$FL = 20.32441 + (23.44762 \times OL)$	0.833	13.036
FL	OB	124	$FL = 12.60850 + (45.02500 \times OB)$	0.786	14.557
FL	OH	124	$FL = 177.1198 + (71.2793 \times OH)$	0.464	23.056
Age	OW	119	$Age = -3.56039 + (75.11332 \times OW)$	0.926	1.2169
Age	OL	119	$Age = -29.0261 + (3.1683 \times OL)$	0.768	2.1506
Age	OB	123	$Age = -31.9368 + (6.3783 \times OB)$	0.784	2.0813
Age	OH	123	$Age = -12.9051 + (12.5286 \times OH)$	0.700	2.4493

Table 5.3 continued: Comparison between otolith dimensions and length and age of *G. buergeri*, *L. malabaricus*, *L. russelli*, *P. multidens* and *P. typus*. The predictive equations are of the simple linear regression form $y = a + bx$ (codes for the independent variables are described in the text). For regression analyses fish length (FL) and age were used as the dependent variables (all regressions were significant at $p < 0.001$). The standard error (SE) of the estimate is a measure of the dispersion of the observed values about the regression line.

P. multidens

Dep. Var.	Ind. Var.	Sample Size	Equation	r^2	SE of Estimate
FL	OW	255	$FL = 204.4661 + (548.5425 \times OW)$	0.869	47.964
FL	OL	262	$FL = -95.0307 + (32.1698 \times OL)$	0.973	21.853
FL	OB	360	$FL = -127.613 + (49.884 \times OB)$	0.968	21.735
FL	OH	367	$FL = -60.9802 + (203.2304 \times OH)$	0.837	49.111
Age	OW	255	$Age = -0.54586 + (18.12517 \times OW)$	0.944	0.9981
Age	OL	260	$Age = -7.66877 + (0.88964 \times OL)$	0.736	2.1611
Age	OB	359	$Age = -8.24561 + (1.32416 \times OB)$	0.699	2.0948
Age	OH	365	$Age = -9.27287 + (6.56986 \times OH)$	0.892	1.2591

P. typus

Dep. Var.	Ind. Var.	Sample Size	Equation	r^2	SE of Estimate
FL	OW	161	$FL = 251.8118 + (376.1665 \times OW)$	0.814	35.783
FL	OL	163	$FL = -83.7171 + (31.6576 \times OL)$	0.954	17.628
FL	OB	186	$FL = -96.3867 + (46.0470 \times OB)$	0.939	20.625
FL	OH	186	$FL = 51.2908 + (128.5395 \times OH)$	0.806	36.732
Age	OW	161	$Age = -1.05690 + (19.34950 \times OW)$	0.934	1.0241
Age	OL	163	$Age = -12.8190 + (1.2759 \times OL)$	0.671	2.2752
Age	OB	185	$Age = -13.0705 + (1.8249 \times OB)$	0.678	2.2056
Age	OH	185	$Age = -10.6392 + (6.3401 \times OH)$	0.894	1.2660

Table 5.4: Growth parameters and asymptotic standard errors (ASE) calculated from the von Bertalanffy growth function ($L_t = L_\infty\{1-\exp[-K(t-t_0)]\}$) and means, minima and maxima of fork length and age, where the length is FL (mm) and age (t) is in years for *G. buergeri*, *L. malabaricus*, *L. russelli*, *P. multidens* and *P. typus* from the Pilbara coast of Western Australia (*n* = sample size).

Parameters	*G. buergeri*			*L. malabaricus*			*L. russelli*			*P. multidens*			*P. typus*		
	Male	Female	Total	Male	Female	Total	Male	Female	Total	Male	Female	Total	Male	Female	Total
n	179	143	256	108	100	214	85	64	136	225	182	365	101	92	186
L_∞	499.2	472.8	488.6	686.4	565.8	622.8	332.8	323.3	330.1	566.1	583.4	571.2	507.3	514.1	509.0
(ASE)	14.30	17.19	12.57	12.55	5.399	7.347	3.249	5.233	3.013	6.798	8.289	5.318	7.615	7.966	5.424
K	0.138	0.138	0.138	0.180	0.262	0.225	0.351	0.371	0.347	0.259	0.238	0.254	0.272	0.248	0.267
(ASE)	0.012	0.016	0.011	0.015	0.016	0.015	0.021	0.032	0.020	0.012	0.012	0.009	0.018	0.018	0.014
t_0	-0.82	-1.03	-0.96	-0.33	-0.09	-0.09	-0.21	-0.19	-0.27	-0.40	-0.50	-0.43	-0.67	-0.75	-0.61
(ASE)	0.169	0.236	0.187	0.224	0.175	0.209	0.107	0.138	0.120	0.079	0.089	0.070	0.157	0.183	0.141
r^2	0.938	0.913	0.909	0.935	0.939	0.869	0.946	0.919	0.900	0.954	0.957	0.945	0.929	0.932	0.915
n	111	76	257	94	86	214	73	51	124	184	141	367	95	85	187
FL_{mean}	351.9	332.9	290.3	568.6	490.9	502.1	308.8	294.9	303.1	452.8	449.1	423.1	409.3	421.1	406.5
FL_{min}	146	146	66	214	286	167	239	232	232	187	196	135	214	231	164
FL_{max}	533	560	560	802	617	802	379	387	387	598	683	683	531	570	570
n	111	75	256	94	86	214	72	51	123	183	140	365	94	85	186
t_{mean}	9.40	9.59	7.39	11.61	11.22	10.22	9.71	8.45	9.17	7.15	6.87	6.38	6.54	7.66	6.84
t_{min}	1	2	0.7	2	3	1	3	3	3	1	1	1	2	2	1
t_{max}	22	26	26	31	26	31	21	20	21	19	19	19	21	19	21

Table 5.5: Estimates of total mortality (Z), natural mortality (M) and survivorship (S) derived from catch curves based on ages determined from sectioned otoliths and from the empirical regression equations of Hoenig (1983) and Pauly (1980). Fishing mortality (F) is derived where appropriate from the equation $F = (Z-M)$. The limit reference point, F_{limit} (Patterson, 1992) is derived for each species based on estimates of M derived from either catch curves or the equation of Hoenig (1983).

Species	Parameter	Catch Curve	Hoenig Estimate	Pauly Estimate
G. buergeri	M	0.113	0.160	0.222
	S	89.3%	85.2%	80.1%
	F_{limit}	0.076 (based on catch curve estimate of M)		
L. malabaricus	M	0.115	0.134	0.286
	S	89.1%	87.4%	75.1%
	F_{limit}	0.077 (based on catch curve estimate of M)		
L. russelli	M	0.142	0.199	0.454
	S	86.8%	82.0%	63.5%
	F_{limit}	0.094 (based on catch curve estimate of M)		
P. multidens	Z	0.291	--	--
	S	74.8%	--	--
	M	--	0.139	0.317
	S	--	87.0%	72.8%
	F	0.152	--	--
	F_{limit}	0.092 (based on Hoenig estimate of M)		
P. typus	Z	0.213	--	--
	S	80.8%	--	--
	M	--	0.139	0.339
	S	--	87.0%	71.3%
	F	0.074	--	--
	F_{limit}	0.092 (based on Hoenig estimate of M)		

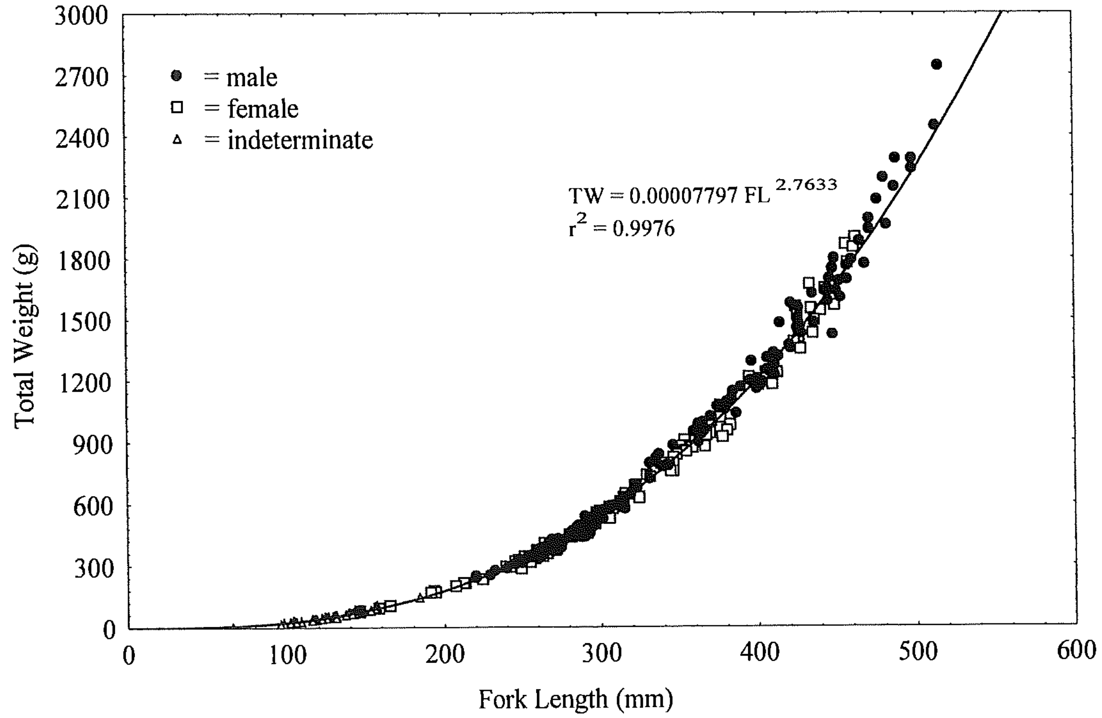

Fig. 5.1: Length-weight relationships for *G. buergeri* off the Pilbara coast of Western Australia.

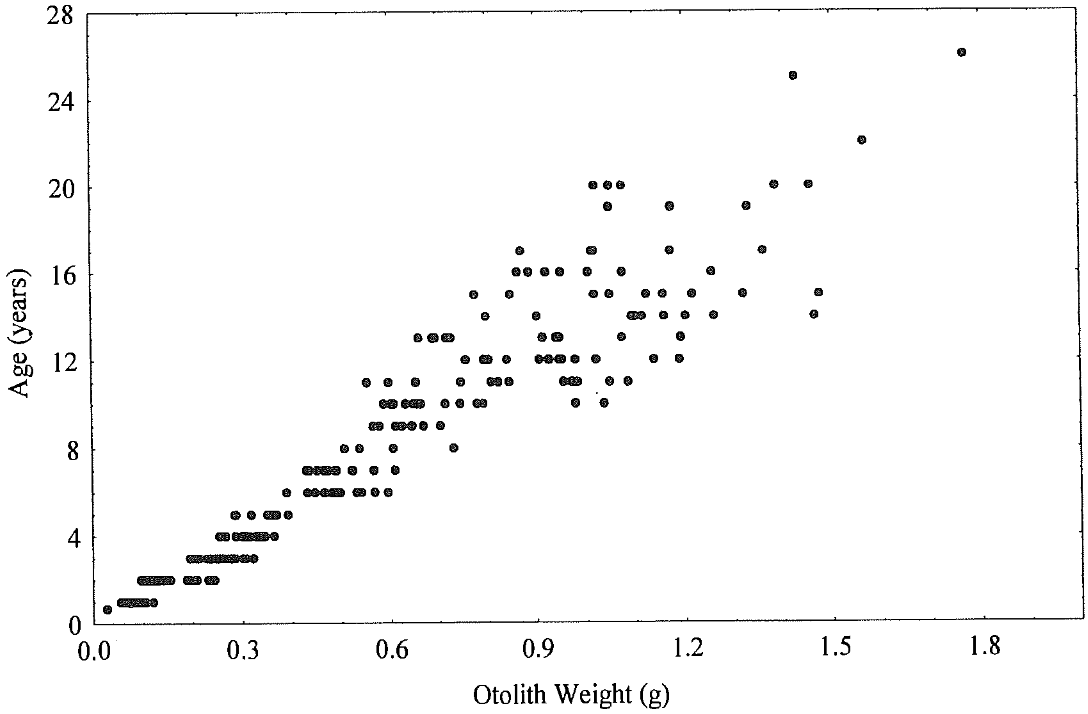

Fig. 5.2: Relationship of fish age to otolith weight (g) for *G. buergeri* off the Pilbara coast of Western Australia.

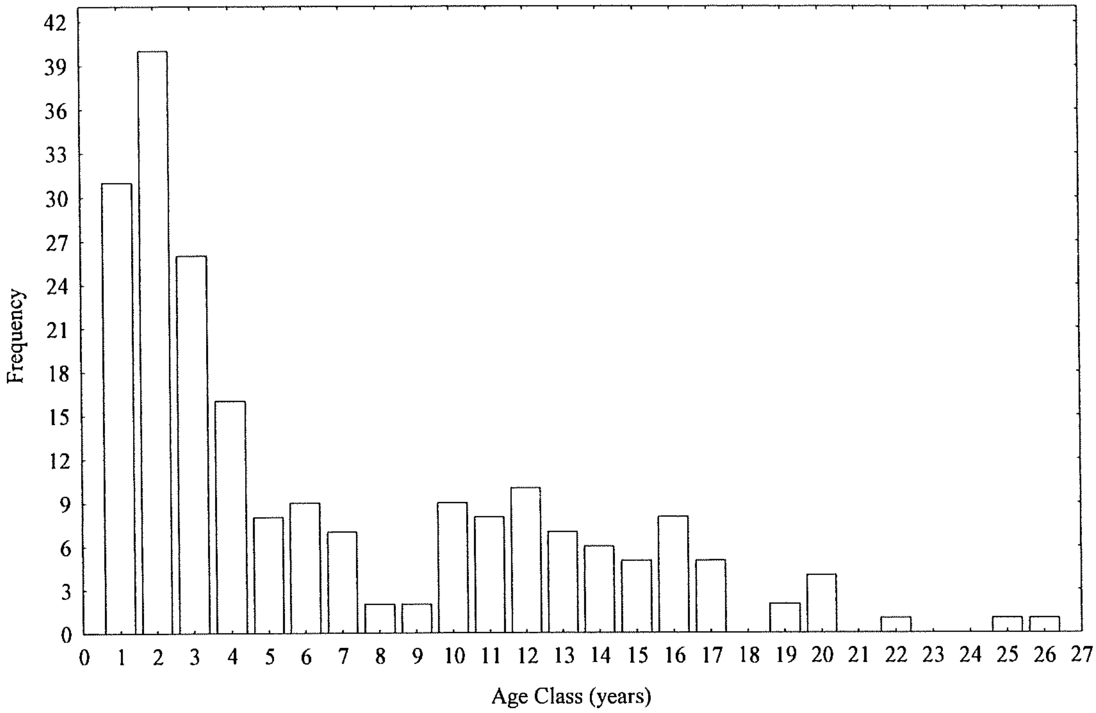

Fig. 5.3: Age frequency distribution of *G. buergeri* in the 100-200 metre depth zone off the Pilbara coast of Western Australia.

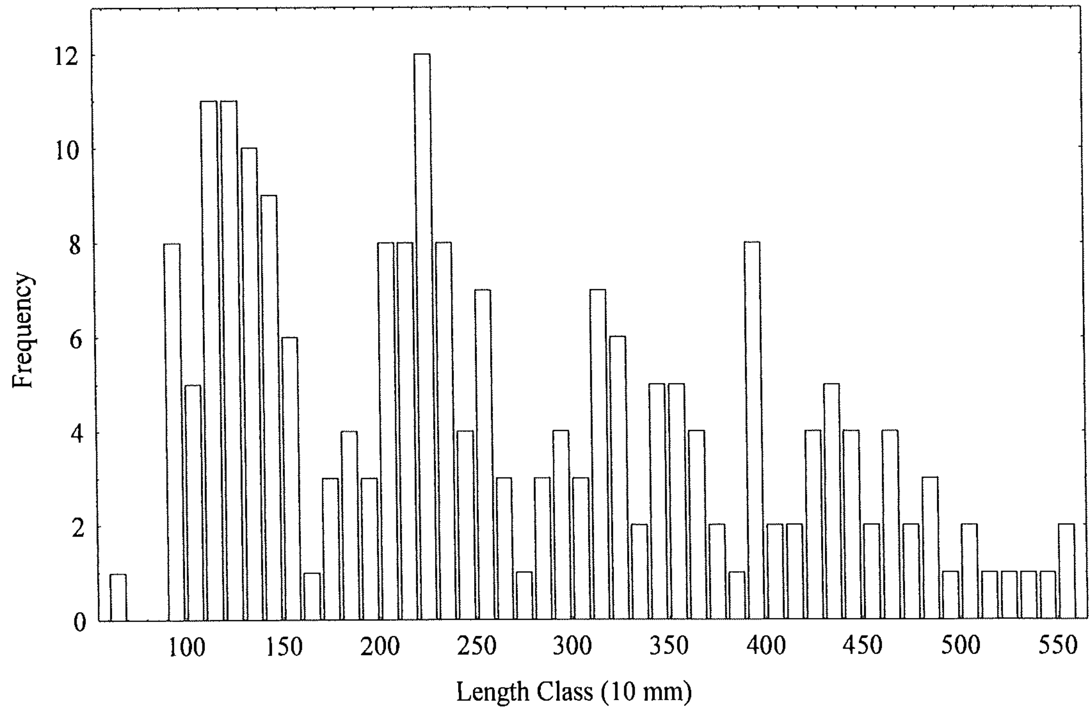

Fig. 5.4: Length frequency distribution of *G. buergeri* sampled for age determination (10 mm length classes).

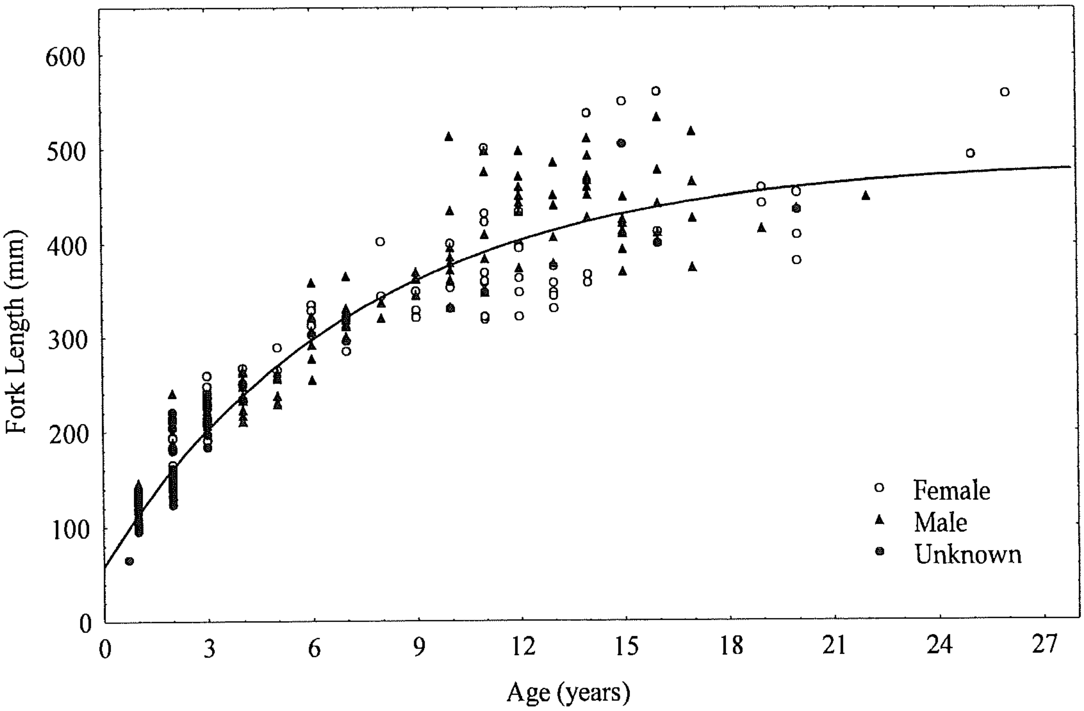

Fig. 5.5: von Bertalanffy length-at-age growth curve for *G. buergeri* off the Pilbara coast of Western Australia.

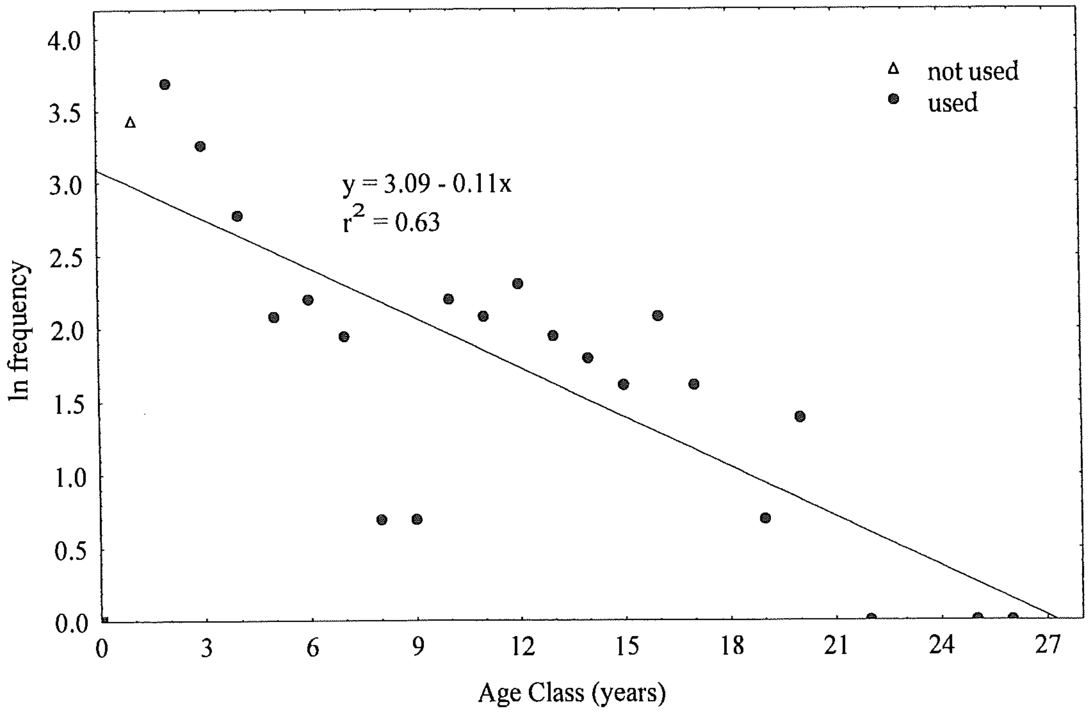

Fig. 5.6: Catch-curve for *G. buergeri* in the 100-200 metre depth zone off the Pilbara coast of Western Australia based on counts of annuli in sectioned otoliths (sagittae).

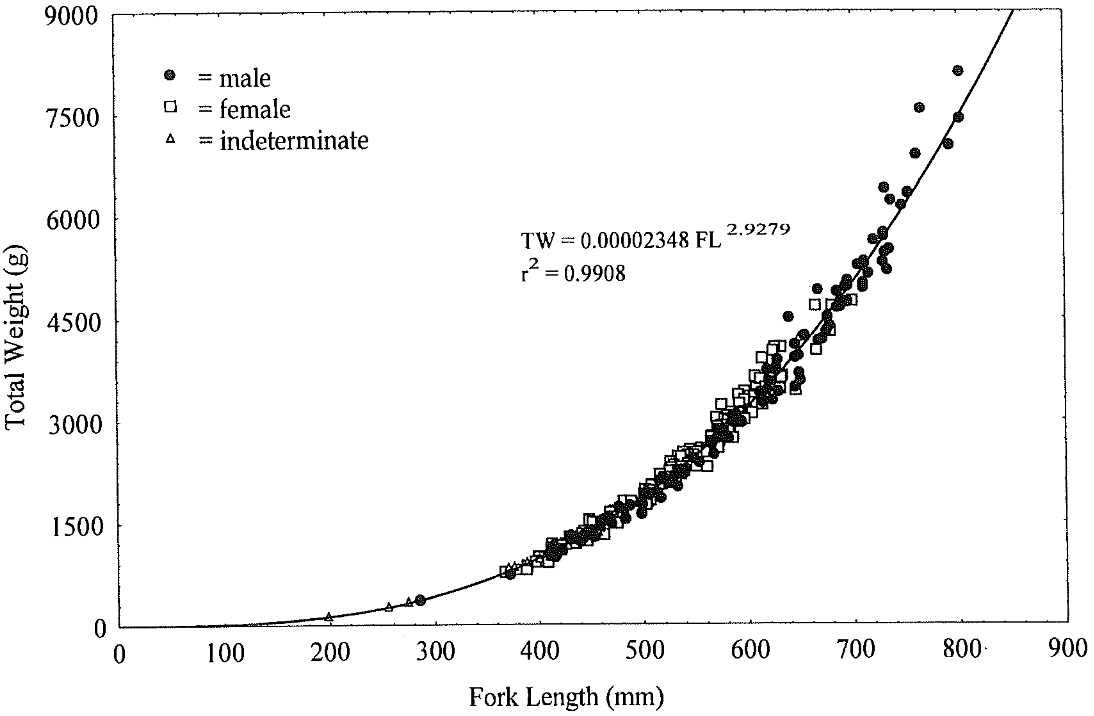

Fig. 5.7: Length-weight relationships for *L. malabaricus* off the Pilbara coast of Western Australia.

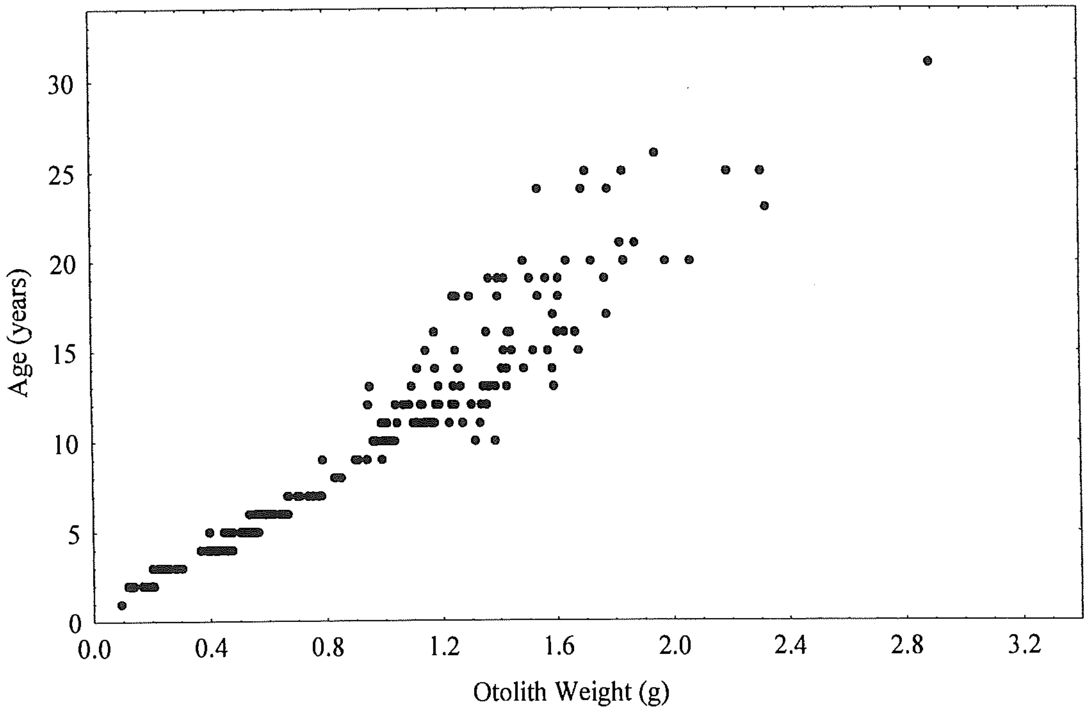

Fig. 5.8: Relationship of fish age to otolith weight (g) for *L. malabaricus* off the Pilbara coast of Western Australia.

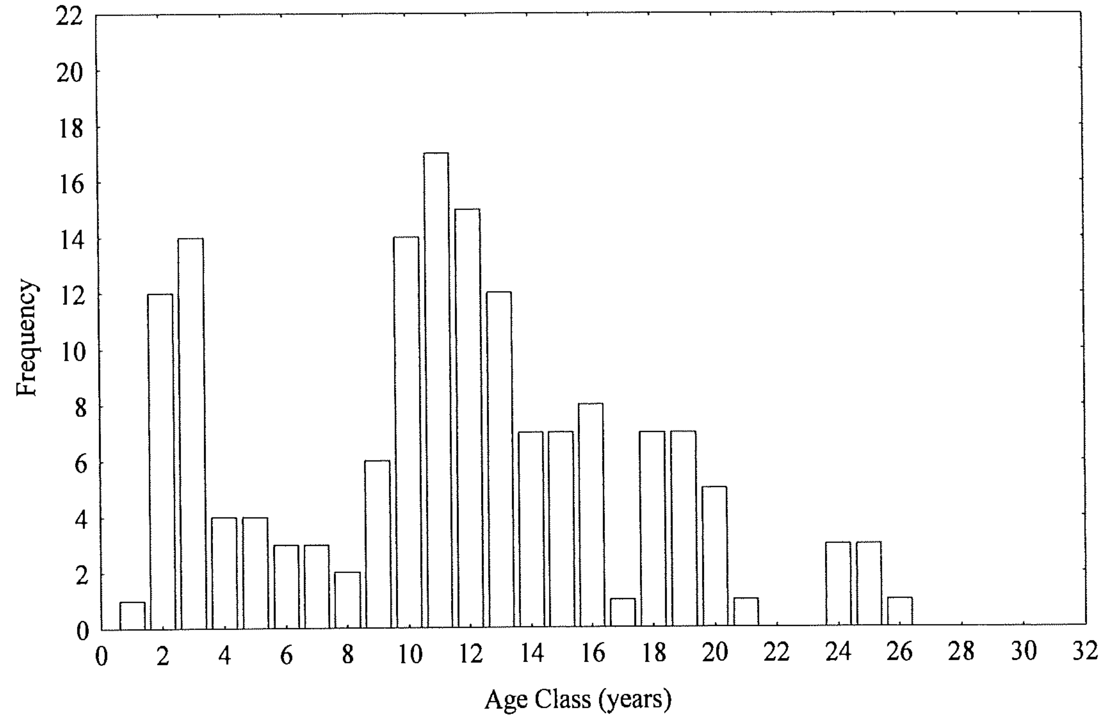

Fig. 5.9: Age frequency distribution of *L. malabaricus* in the 100-200 metre depth zone off the Pilbara coast of Western Australia.

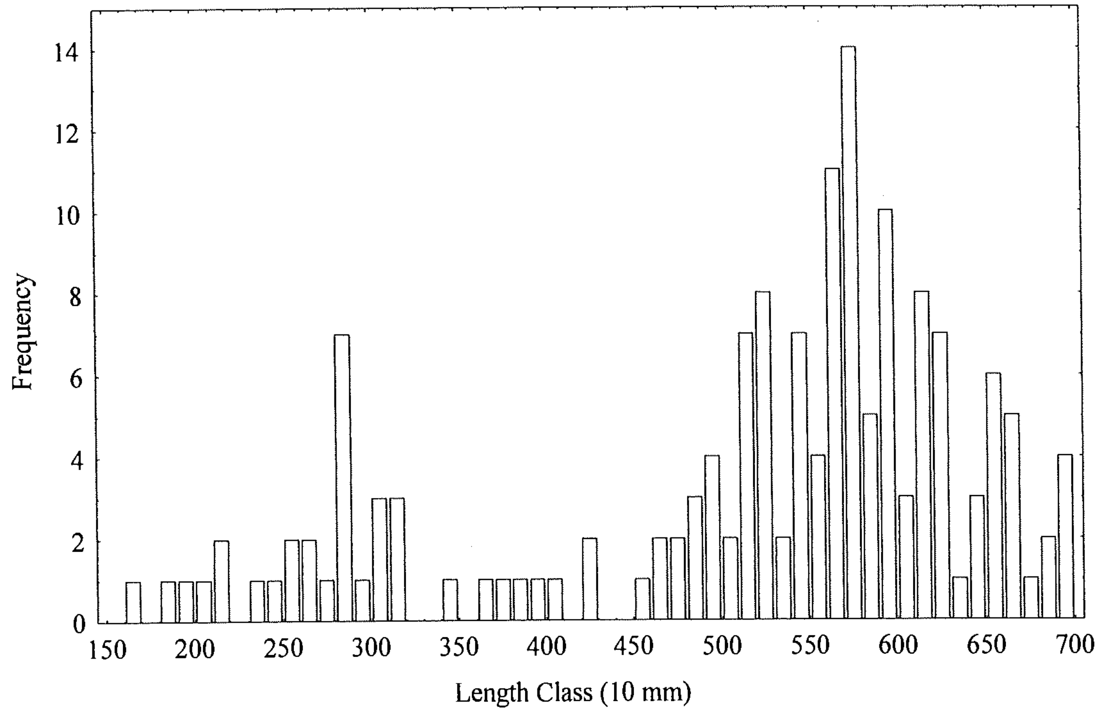

Fig. 5.10: Length frequency distribution of *L. malabaricus* sampled for age determination (10 mm length classes).

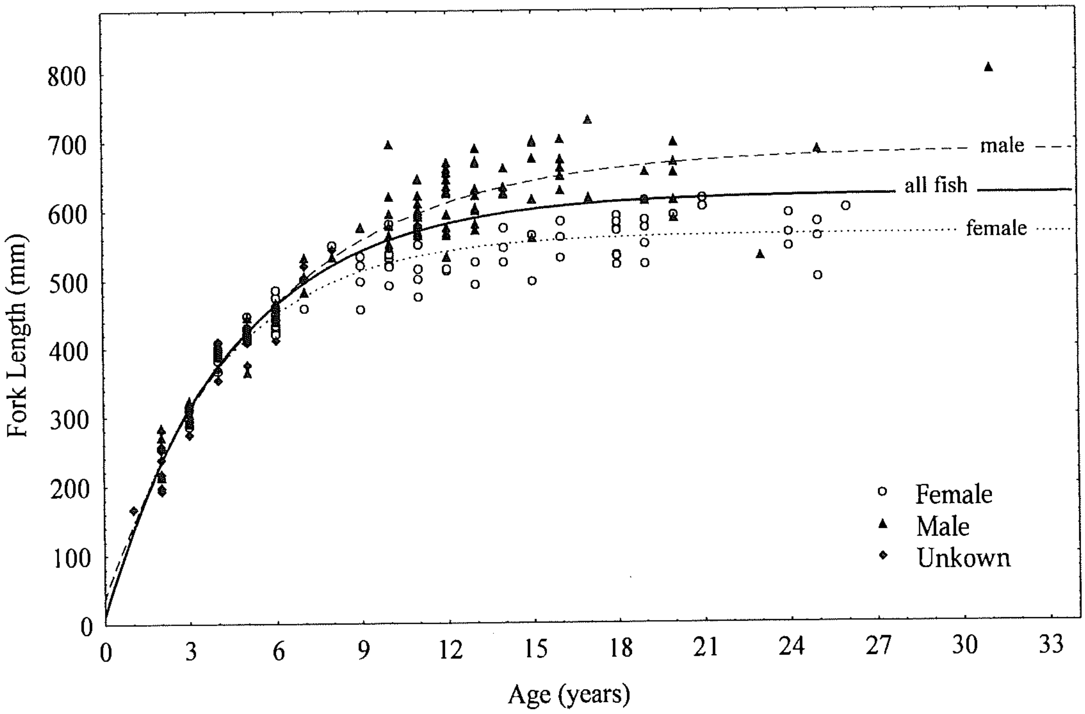

Fig. 5.11: von Bertalanffy length-at-age growth curve for *L. malabaricus* off the Pilbara coast of Western Australia.

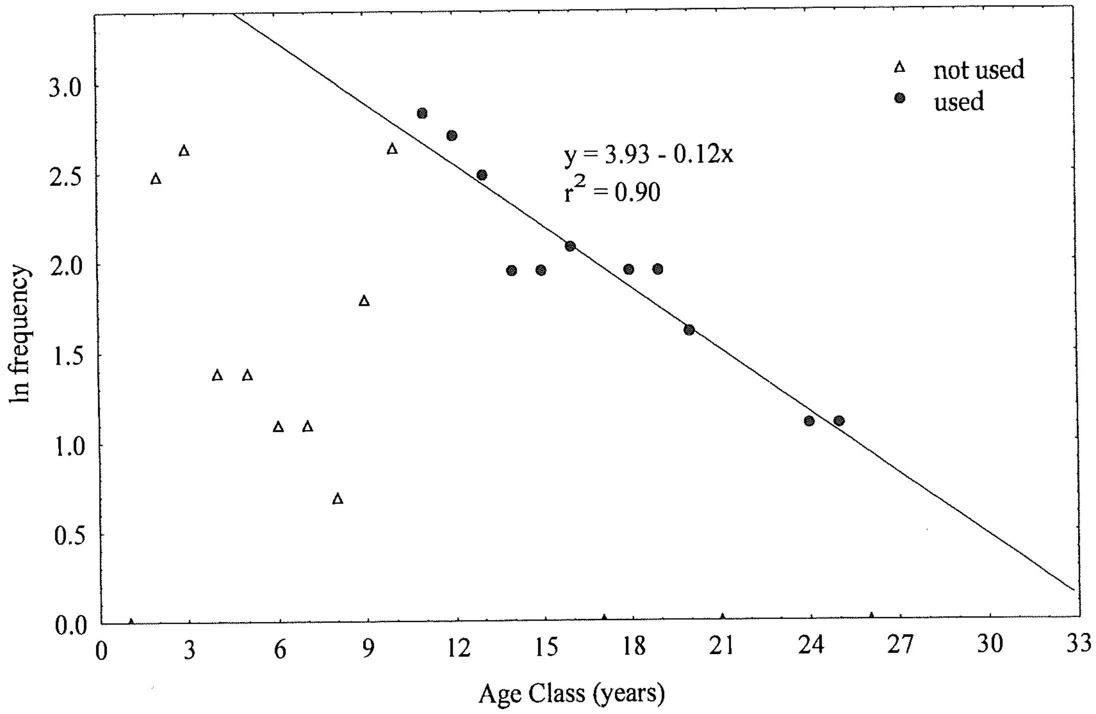

Fig. 5.12: Catch-curve for *L. malabaricus* in the 100-200 metre depth zone off the Pilbara coast of Western Australia based on counts of annuli in sectioned otoliths (sagittae).

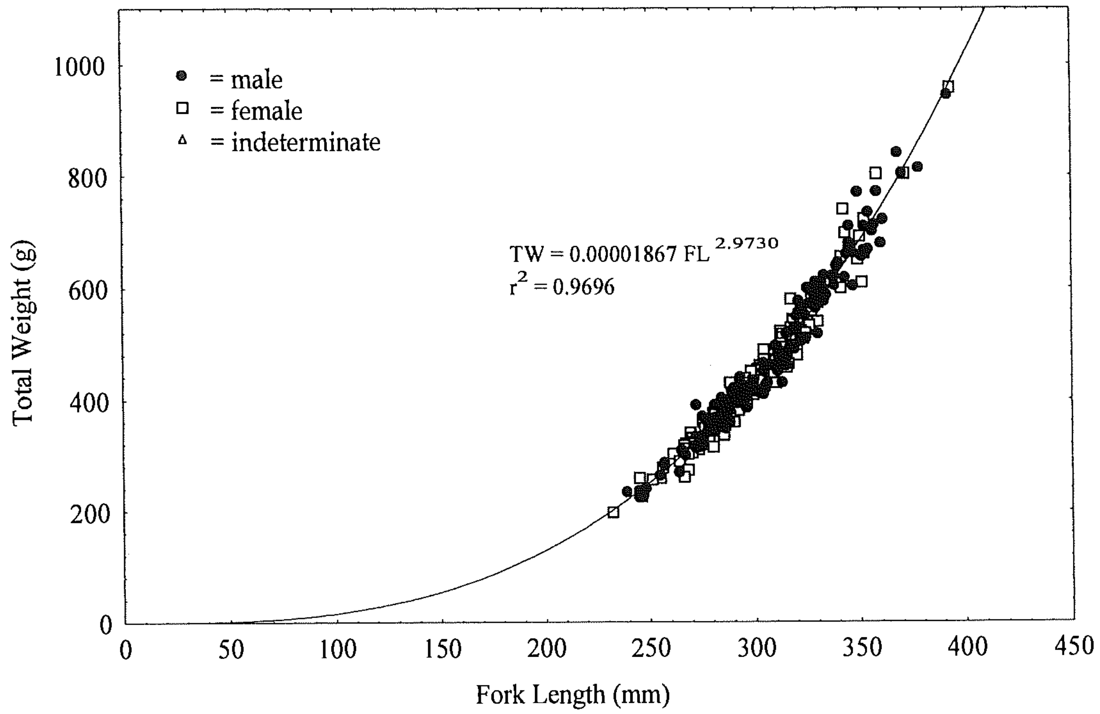

Fig. 5.13: Length-weight relationships for *L. russelli* off the Pilbara coast of Western Australia.

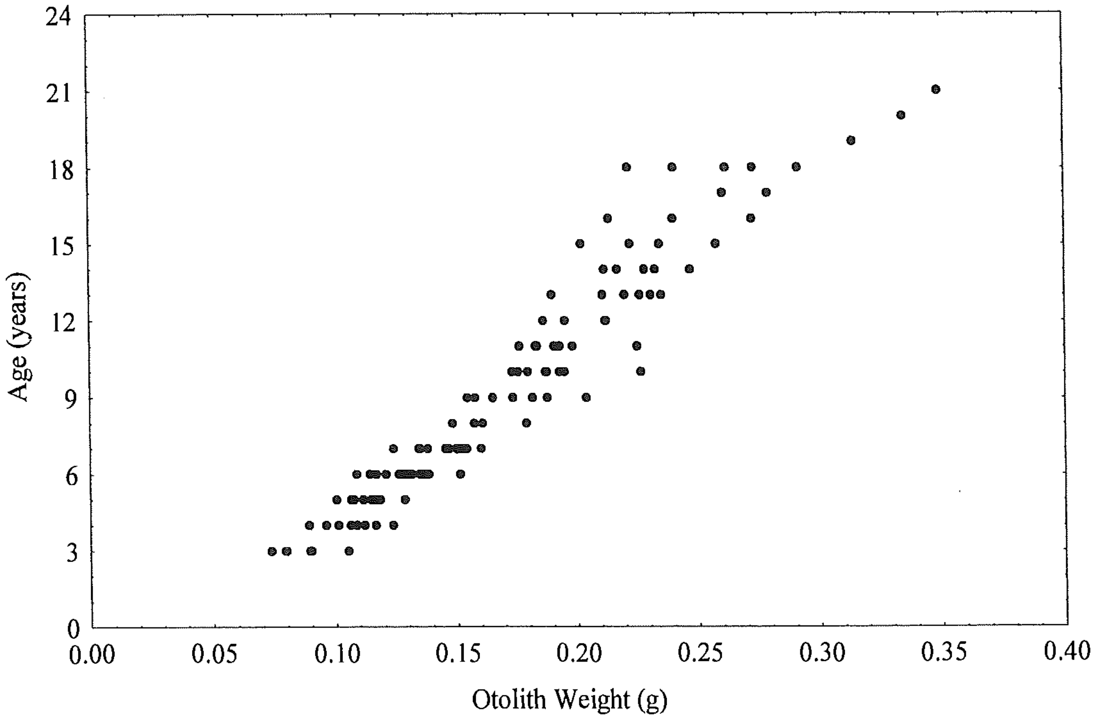

Fig. 5.14: Relationship of fish age to otolith weight (g) for *L. russelli* off the Pilbara coast of Western Australia.

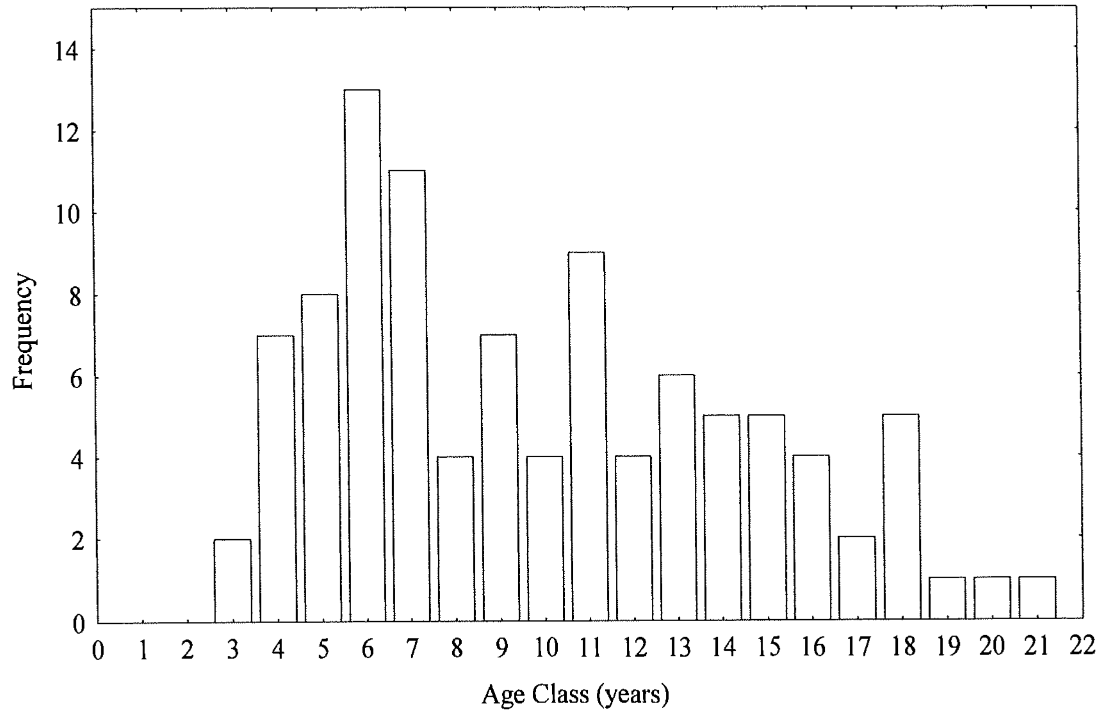

Fig. 5.15: Age frequency distribution of *L. russelli* in the 100-200 metre depth zone off the Pilbara coast of Western Australia.

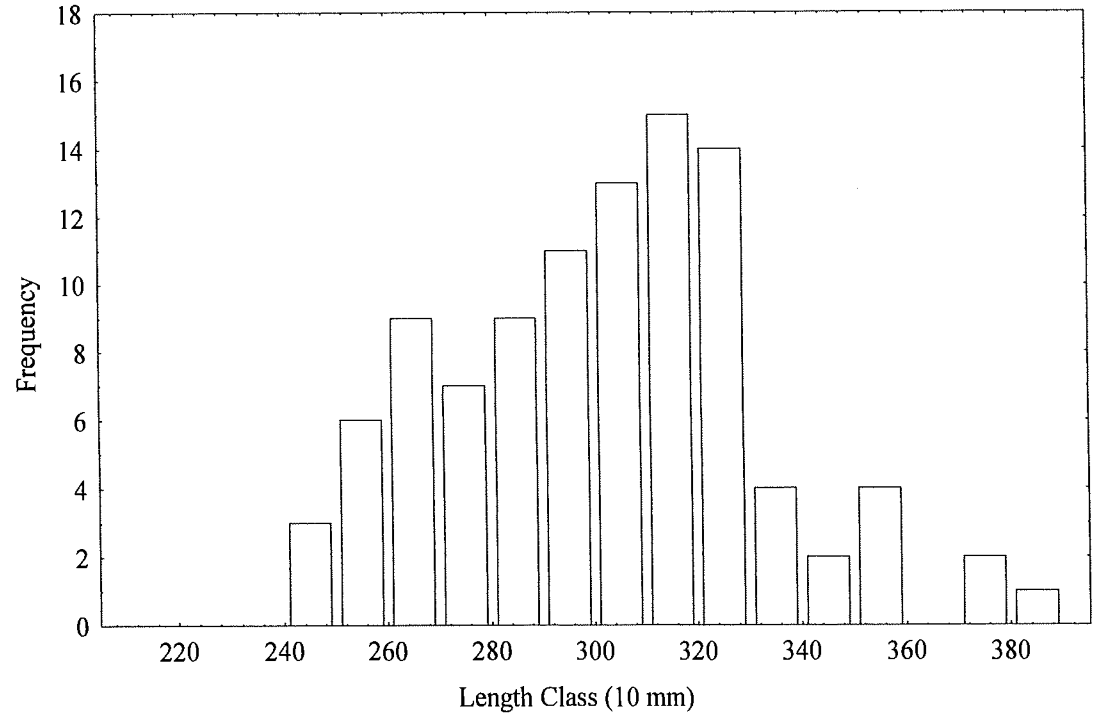

Fig. 5.16: Length frequency distribution of *L. russelli* sampled for age determination (10 mm length classes).

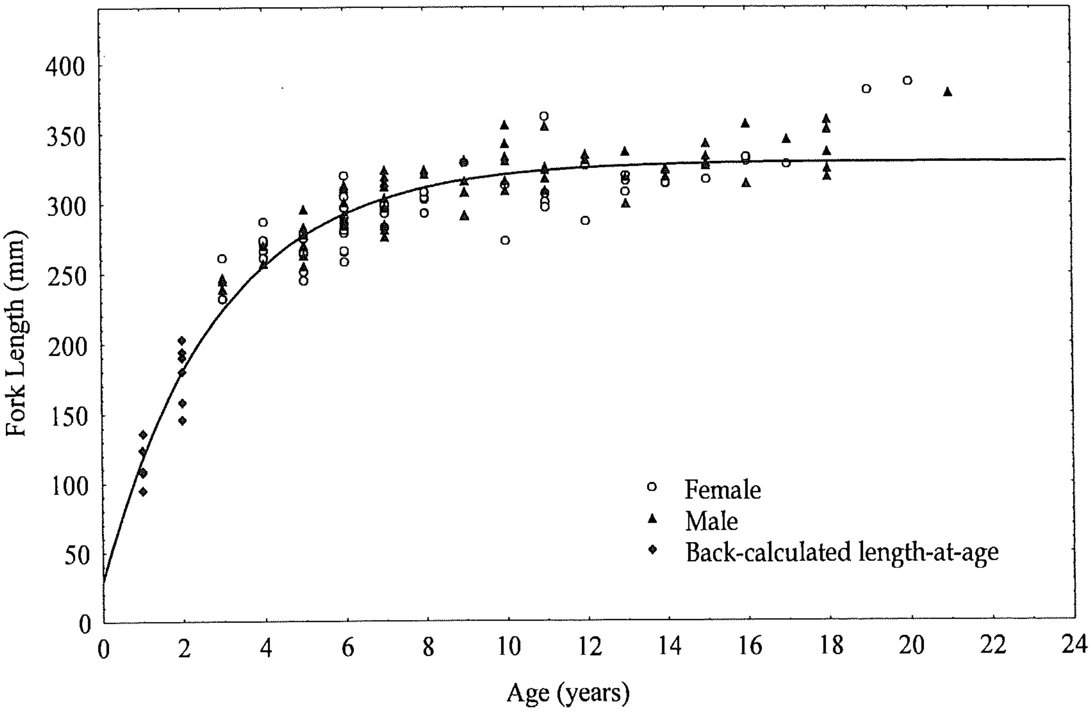

Fig. 5.17: von Bertalanffy length-at-age growth curve for *L. russelli* off the Pilbara coast of Western Australia.

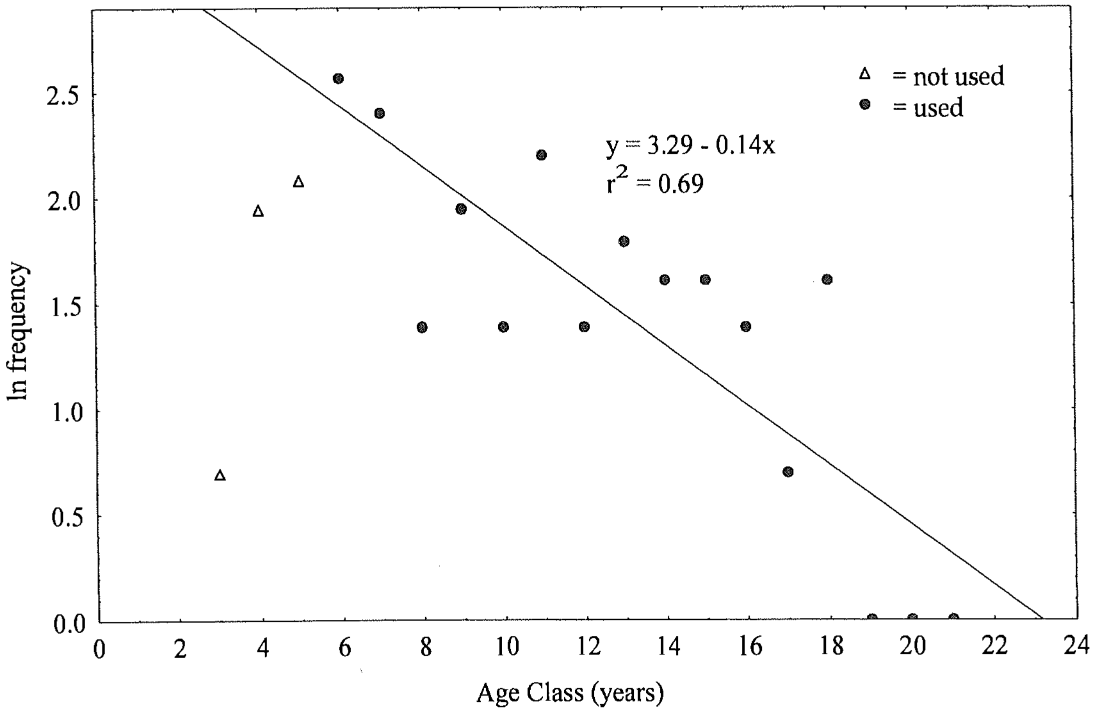

Fig. 5.18: Catch-curve for *L. russelli* in the 100-200 metre depth zone off the Pilbara coast of Western Australia based on counts of annuli in sectioned otoliths (sagittae).

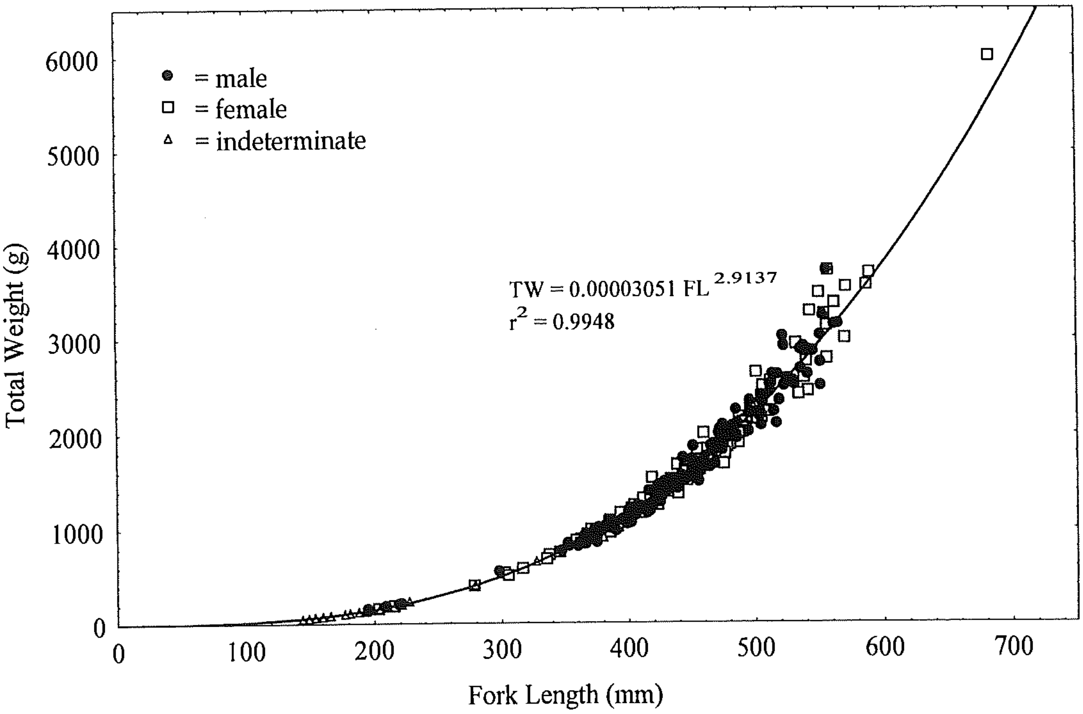

Fig. 5.19: Length-weight relationships for *P. multidens* off the Pilbara coast of Western Australia.

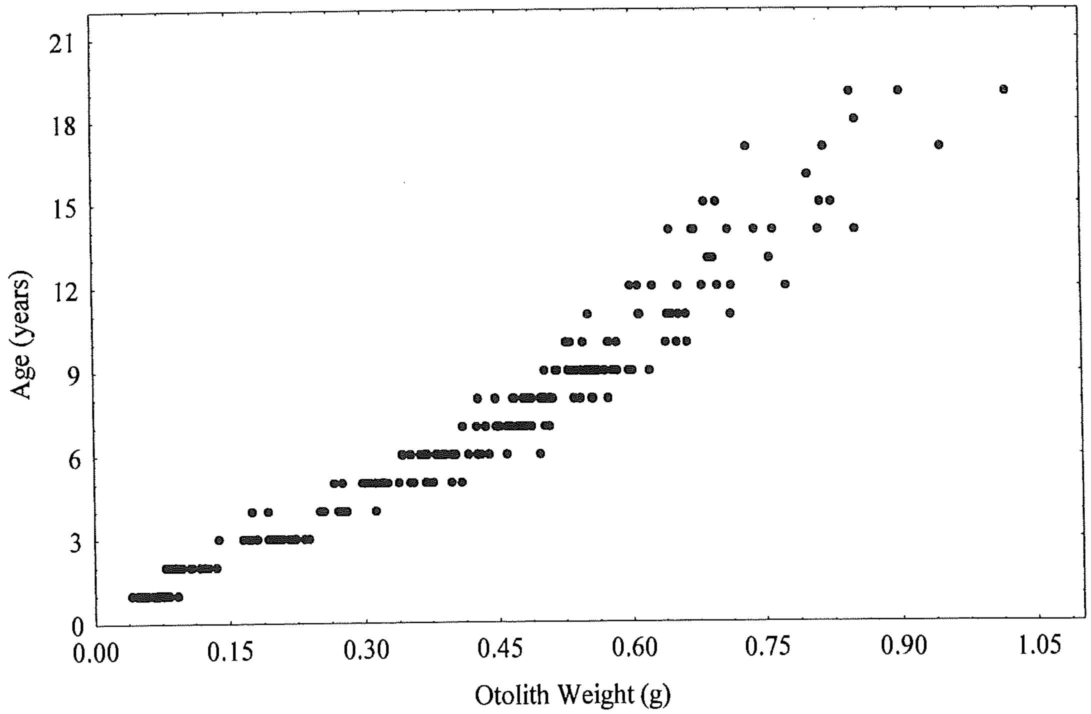

Fig. 5.20: Relationship of fish age to otolith weight (g) for *P. multidens* off the Pilbara coast of Western Australia.

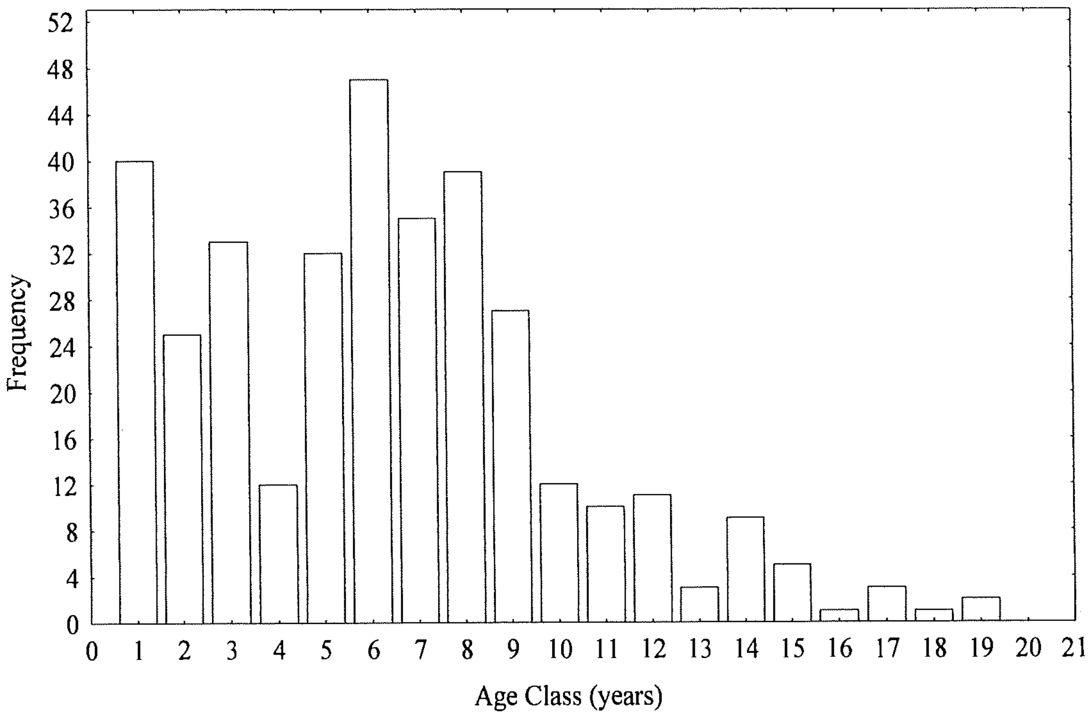

Fig. 5.21: Age frequency distribution of *P. multidens* in the 100-200 metre depth zone off the Pilbara coast of Western Australia.

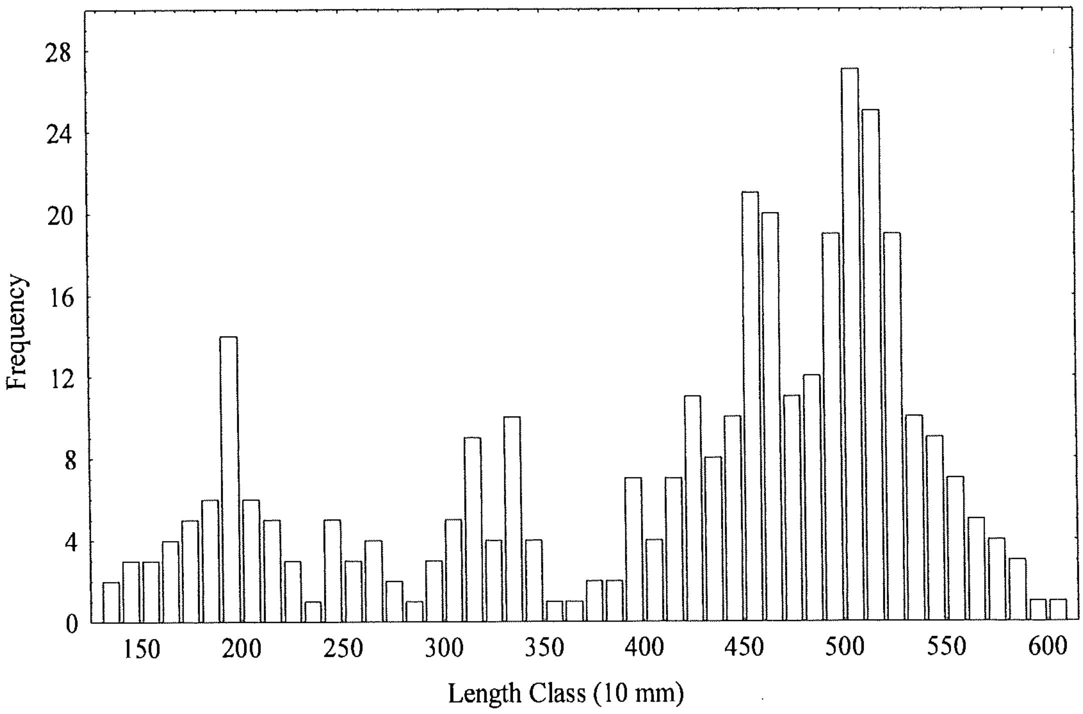

Fig. 5.22: Length frequency distribution of *P. multidens* sampled for age determination (10 mm length classes).

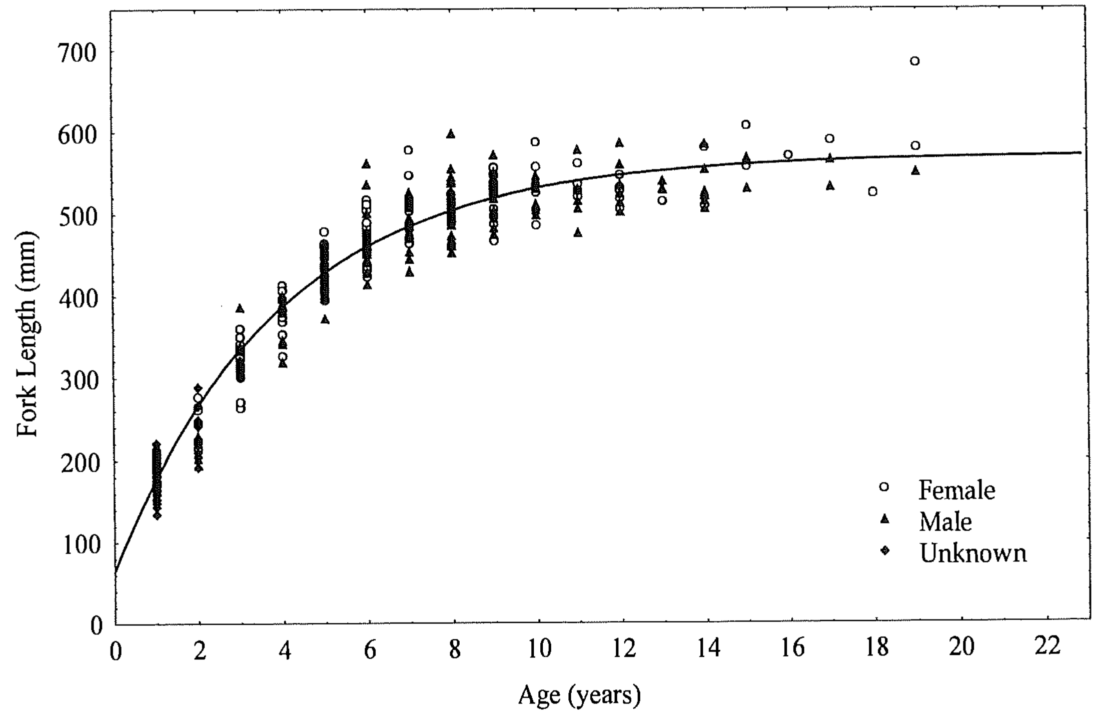

Fig. 5.23: von Bertalanffy length-at-age growth curve for *P. multidens* off the Pilbara coast of Western Australia.

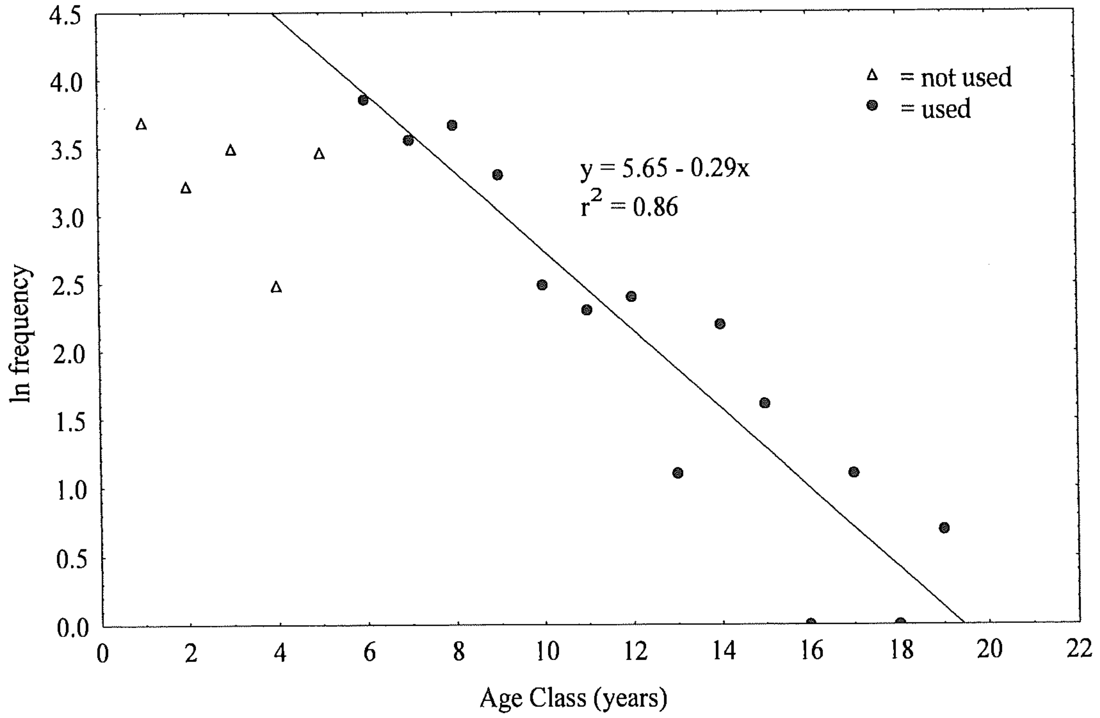

Fig. 5.24: Catch-curve for *P. multidens* in the 100-200 metre depth zone off the Pilbara coast of Western Australia based on counts of annuli in sectioned otoliths (sagittae).

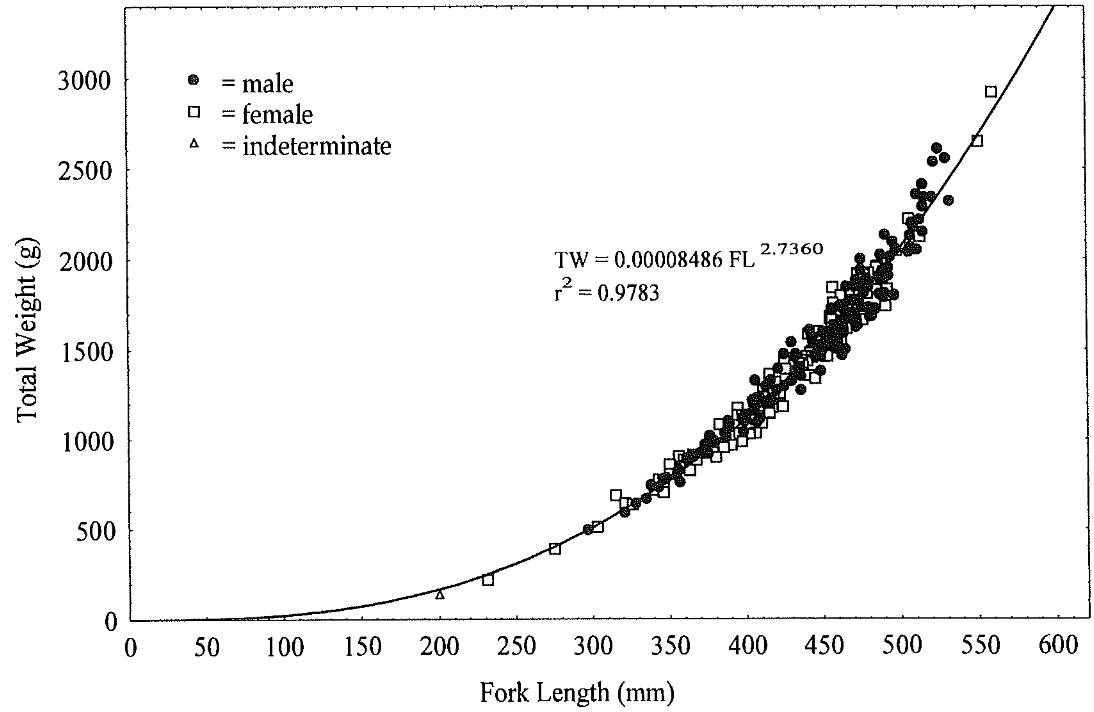

Fig. 5.25: Length-weight relationships for *P. typus* off the Pilbara coast of Western Australia.

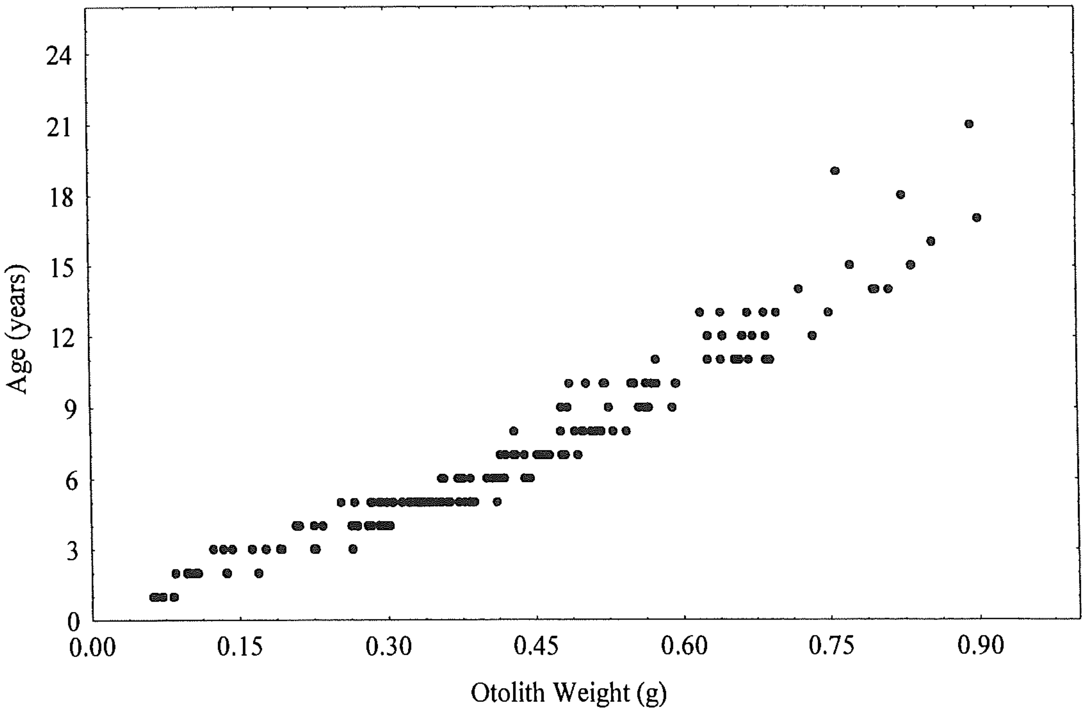

Fig. 5.26: Relationship of fish age to otolith weight (g) for *P. typus* off the Pilbara coast of Western Australia.

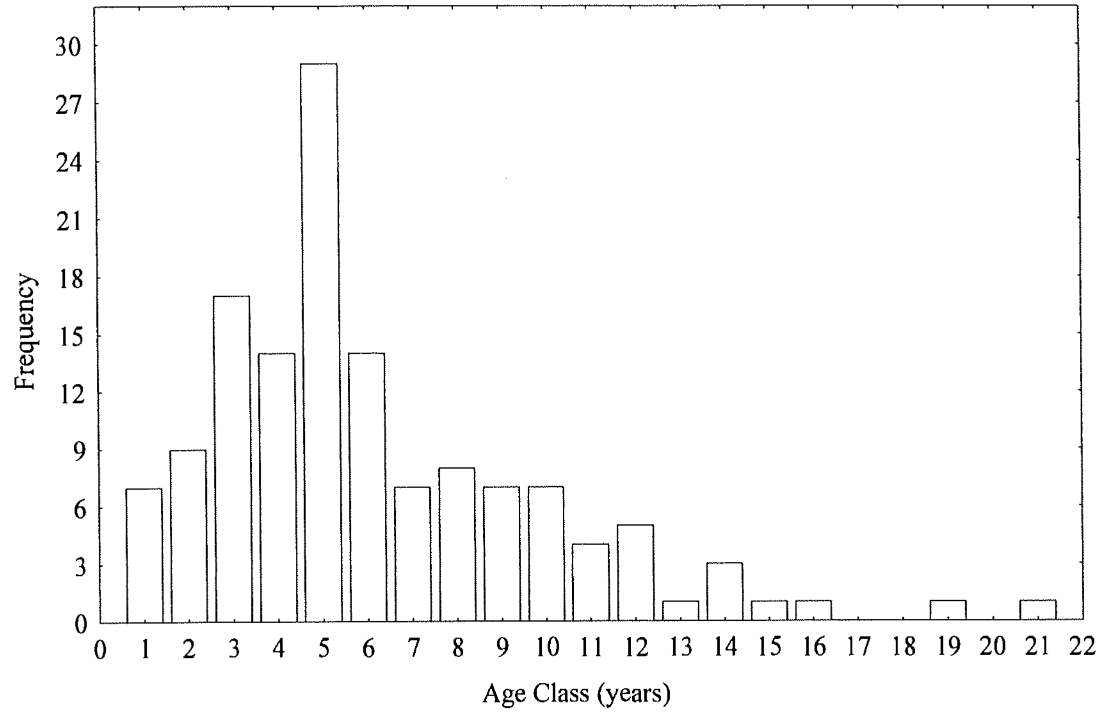

Fig. 5.27: Age frequency distribution of *P. typus* in the 100-200 metre depth zone off the Pilbara coast of Western Australia.

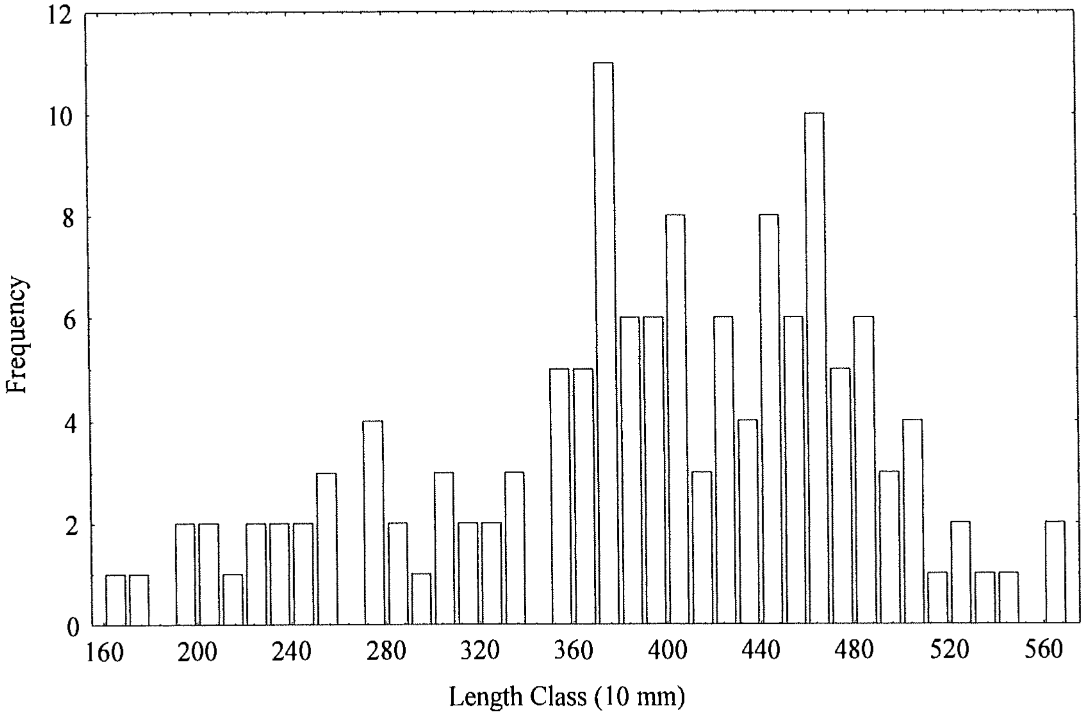

Fig. 5.28: Length frequency distribution of *P. typus* sampled for age determination (10 mm length classes).

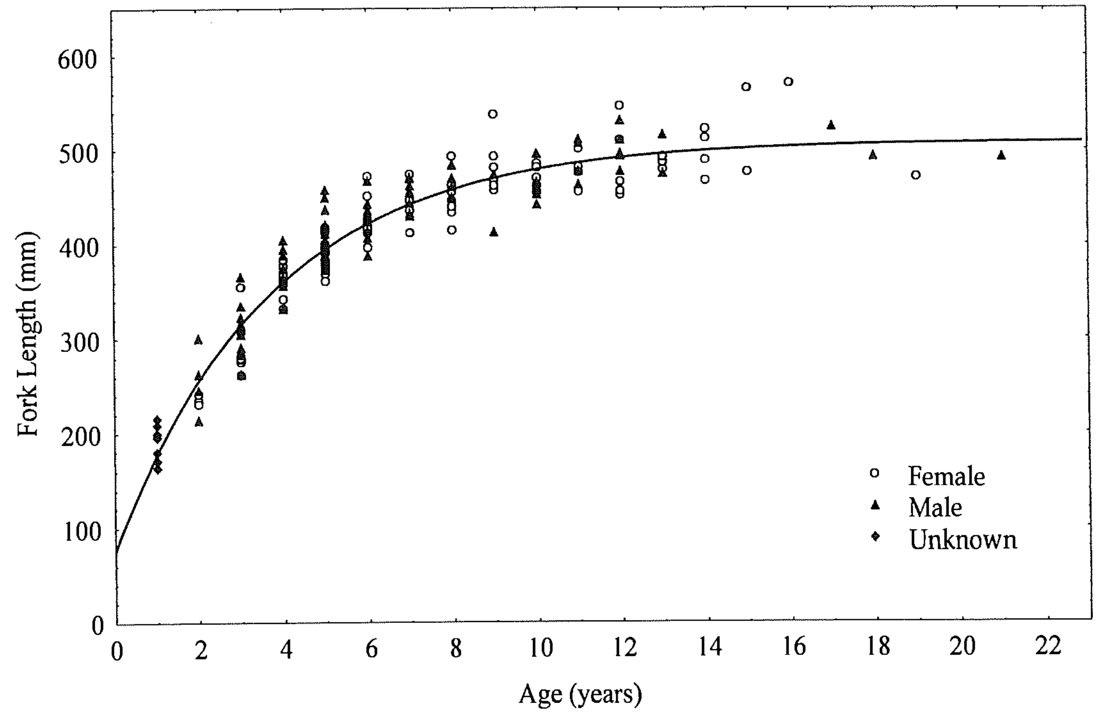

Fig. 5.29: von Bertalanffy length-at-age growth curve for *P. typus* off the Pilbara coast of Western Australia.

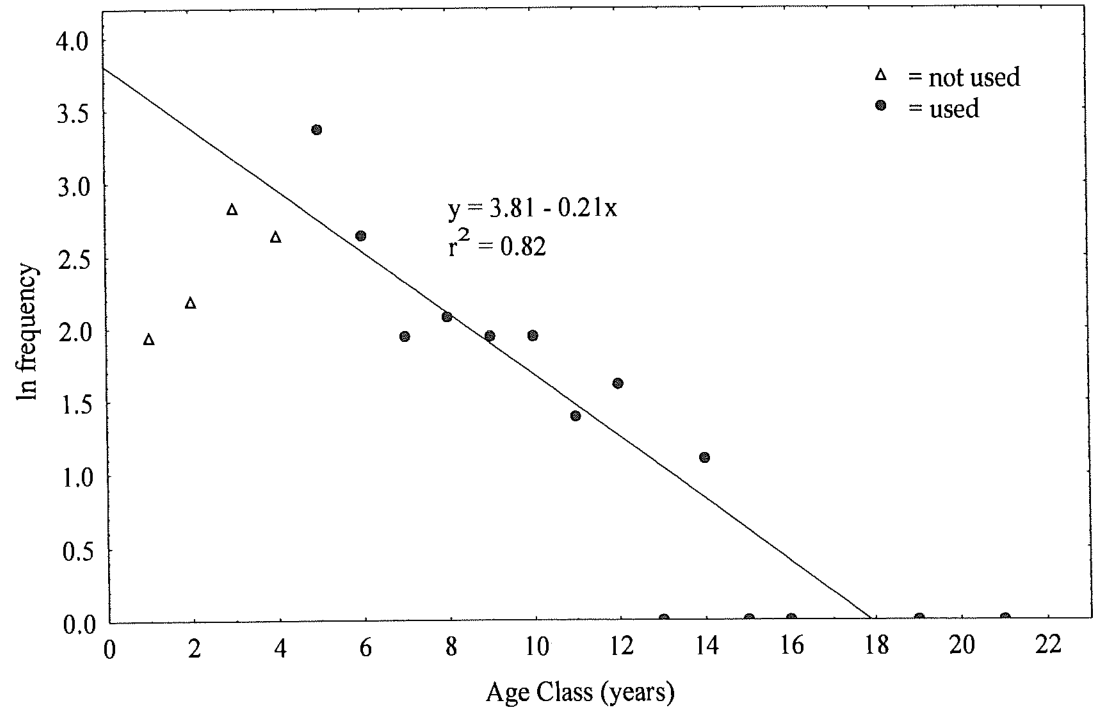

Fig. 5.30: Catch-curve for *P. typus* in the 100-200 metre depth zone off the Pilbara coast of Western Australia based on counts of annuli in sectioned otoliths (sagittae).

Discussion

A number of vessels were used to undertake the survey and the completion of survey trawls was variable throughout the year. Consequently, the catchability of demersal fish may have been variable throughout the survey. Catchability of demersal fish by fish trawl methods is affected by both the availability and vulnerability of demersal fish to capture.

The availability of demersal fish is affected principally by the distribution and abundance of demersal fish species, natural mortality and fishing mortality. The distribution and abundance of demersal fish species at any point in time is affected by the species behaviour (eg. schooling and spawning behaviour, feeding and hence the distribution of food) and seasonal factors (eg. cyclical changes in biological or environmental conditions on a temporal [daily or yearly] scale). Whereas, the vulnerability of demersal fish to capture is affected principally by the performance of the fishing gear. The performance of the fishing gear is directly affected by selectivity of the gear (escapement and avoidance), the vessel type and speed, the experience of the skipper and the ocean conditions. The selectivity of the fishing gear is also affected by the size and dimensions of the gear itself, such as the mesh size, net size, head-rope length and configuration.

The fishing gear used among vessels in this survey is restricted by management controls and therefore is relatively similar. Hence it was assumed that the vulnerability of fish to capture was relatively constant across all the vessels used in the survey. Further, most of the survey trawls were completed within a few months and any variation introduced by seasonal factors is considered to be limited. Although the trawl surveys are likely to underestimate the absolute abundance of demersal fish in each survey block, they provide comparative estimates or indices of abundance to compare among blocks across the survey area. The poor catch rates observed in many of the blocks in this study directly contributed to the project failing to complete the entire survey as originally proposed. However, a large amount of information relevant to the future management of this resource was obtained.

Paxton et al. (1989) have described the offshore waters of Western Australia as being virtually unsampled from an ichthyological perspective. A recent study by Williams et al. (1996) described the demersal ichthyofauna of the continental slope off Western Australia from 20-35°S. No similar studies have been undertaken in the waters of Western Australia north of 20°S. This study has provided a profile of the demersal ichthyofauna of the upper continental shelf region off the Pilbara coast.

The demersal ichthyofauna in the 100-200 m depth zone is diverse and further sampling with a variety of gears is likely to increase the number of species recorded. The trawl gear used in this survey is unlikely to have sampled small and/or cryptic species in a robust manner. The demersal ichthyofauna in this zone was characterised by species of the Lutjanidae.

The demersal fish resources in the survey area are not as uniformly distributed as those on the inner continental shelf. The demersal fish resource is valuable, consisting primarily of highly prized lutjanid fish species. However, their distribution is concentrated in waters less than 140 m and these species, in particular the eteline lutjanids, *P. multidens* and *P. typus* often form large schools. Management of these fish resources can be problematic. Large catches can be taken by fish trawlers over a short period of time and species which form aggregations or aggregate at certain times of the year are highly vulnerable to these fishing operations. Industry's perception of such situations is that there is huge stock of fish and that a large part of the aggregation can be sustainably taken. The low production potential of these demersal fish indicates that these perceptions are unfounded.

The vulnerability of small and juvenile fish to fish trawl operations, in particular small individuals of the key species, directly results in loss of yield to the fishery by the capture of fish before they have reached optimum size. This problem is unlikely to be addressed by changes in the size of the meshes trawled, as a number of the smaller species directly contribute to the successful viability of commercial fish trawl operations. Fishery managers should give consideration to spatial area closures as a management tool for preservation of recruitment grounds within the fishery should these be identified.

A large amount of the total catch (approx. one-third) consisted of discarded fish by-catch or benthos. Little is known about the biology of many of the discarded species and whether they are likely to be impacted by fishing activities. Fishers currently try to value-add by marketing as many of the smaller species as is practicable. Of more concern to fishers is the likelihood of trawl induced modification of the benthic habitats upon which many commercially important species may depend.

Benthic communities are modified as a result of broad-scale habitat disturbance such as that resulting from fish trawl operations. Increased fishing effort has recently been shown to lower species diversity and reduce the numbers of large and long-lived animals in benthic communities (Thrush et al. 1998). Thrush et al. (1998) also directly linked loss of complex habitat structure with increased fishing pressure. The effect of habitat modification on demersal fish assemblages in deep water fisheries requires more detailed study. Furthermore, the benthic communities present in depths of 100-140 metres off the Pilbara coast are considered to have had only minimal impact from commercial fish trawl operations and remain relatively undisturbed. These habitats need to be conserved as part of future fishery management plans.

The exploitation of deeper continental shelf waters is increasing in importance and there is a need to further expand our knowledge of deeper water fish assemblages and the processes which underpin their productivity. This study has provided a description of the fish assemblages of the outer-continental shelf off the Pilbara coast of Western Australia. However, one of the key problems associated with surveys of this type which are dependent upon industry funding and support is the high cost associated with survey work when catches fail to cover costs. As was evidenced in this study, financial loss resulting from survey trips rapidly resulted in the fishing industry abandoning the project and not completing the original survey design (this arrangement was found to be unsatisfactory and needs to be considered in future projects).

There is a need to determine the relationship between the observed fishing mortality and the level of fishing effort. This was one of the objectives in the original proposed project and was not achieved as the objectives of the project were modified due the lack of viability of trawling operations in the 100-200 m zone. It is an area of potential future research work. A number of management options for the demersal fish resources in the 100-200 m depth zone off the Pilbara coast of Western Australia are proposed. This area needs to be managed in its entirety through modification of the existing Pilbara Fish Trawl and Pilbara Fish Trap management plans.

Option 1. The most parsimonious, conservative and cost-effective management strategy would be to close the 100-200 zone to all forms of commercial fishing. The 100-200 metre depth zone would represent a harvest refuge for the demersal fish species in the area. The potential benefits of closed areas (harvest refugia) include: protection of the spawning stock biomass; providing a recruitment source to surrounding fished areas; supplemental restocking of fished areas through possible emigration of adult fishes; maintenance of natural population age structure; maintenance of species diversity, genetic diversity (specifically protection of intraspecific genetic diversity) and abundance; increased size and frequency of reproductions; protects some stock from the possibility of fishery collapse (ie. insurance against fishery collapse); provides insurance against management failure in fished areas; elimination of by-catch and hence preservation of by-catch species; equitable effect on all fishers; capacity to be used in the future as scientific control sites in order to understand anthropogenic impacts (eg. effects of fishing); simplified compliance and reduced enforcement requirements (especially since all vessels are monitored by VMS); preservation of essential fish habitat; maintenance of areas of undisturbed habitat and/or critical habitats; reduced data collection needs; ease of public understanding and acceptance of the management arrangements.

The key commercial species of demersal fish in the 100-200 metre depth zone have a low production potential as a consequence of their long life, slow growth and low rates of natural mortality. Given the capacity of the current fleet of vessels in the Pilbara Fish Trawl Fishery to rapidly over-exploit the demersal fish resources of the inner-continental shelf region, any rational management plan for the demersal fish resources of the 100-200 metre depth zone must be conservative.

This option is a precautionary management strategy. However, the formation of a large closed area has the potential to provide benefits to fishers in the inner continental shelf area of the Pilbara fishery by providing a recruitment source to the shallower fished area and possibly supplemental restocking of these fished areas through emigration of adult fishes, although this remains to be tested.

Option 2. Implementation of an adaptive management policy for the 100-200 metre depth zone off the Pilbara coast that seeks to make 25 % of the area available to fishers whilst leaving the remaining 75% of the area closed to fishing. For reasons of equity the area to be opened in this instance should include both productive and non-productive areas. For this option the area from 117°E to 118°E has been selected to be open to commercial fishing.

The level of access allocated should run for the next quinquennium (5 year period) to allow the examination of the benefits of the closed zones in protecting a significant level of the spawning stock biomass of exploitable fishes. Approximately 200 hours of fish trawl effort should be allocated in the open area, in the first instance. This access needs to be divided equitably among all licence holders. The catch in the open zones can be monitored via a logbook program in order to evaluate the catch trends and identify any depletion effects. The large size of the closed area may reduce the possibility of leakage (spill-over or boundary effects) and may constrain the potential movement of post-settlement fishes across the boundary into an area open to fishing (due to increased size of the closure area).

There is a cost associated with data collection for the purposes of fishery monitoring. Cost levels will be dependent on what type of information fishery managers require on an on-going basis. For example, a low cost strategy would be to use commercial CPUE data in order to monitor the fishery. Although, this is not recommended in isolation, any proposed strategy involving the use of age structure data for fishery monitoring purposes will increase costs substantially. The minimum costs associated with the implementation of this management strategy include; the requirements for a log book program, monitoring of vessels through the use of the VMS, costs associated with conducting research trawls in the area closed to fishing to record both relative catch rates and age structure data for the key species, and the cost associated with processing hard parts such as otoliths for age determination. Potential benefits of this option include the following; it reflects a precautionary management approach, a large portion of the resource (75%) is protected, stock collapse in this instance is unlikely as less than 50% of the spawning stock in the 100-200 m zone is likely to be exposed to fishing, natural community structure will be maintained and areas of undisturbed habitat and/or critical fish habitats preserved in the area closed to fishing, and demersal fish will be supplied to the markets allowing the community access to fish.

Option 3. Implementation of an adaptive management strategy for the rational exploitation of the deepwater demersal fishery resources in the 100-200 metre depth zone. This strategy would involve having 50% of the area open to fishing and 50% of the area closed to fishing. To facilitate this, the 100-200 m depth zone has been divided into a minimum of 4 areas, each of which measures 60 minutes of longitude (approx. 60 nautical miles) in the east-west direction and is bordered North and South by the existing boundaries which generally follow the 100 m and 200 m bathymetric contours. The areas are defined by the following longitudinal zones; Area 1: 116°E to 117°E; Area 2: 117°E to 118°E; Area 3: 118°E to 119°E, Area 4: 119°E to 120°E. It is proposed that 2 of the areas be closed to fishing and that 2 areas are opened to fishing. The objective of this strategy is to try and protect a minimum of 30-40% of the available spawning stock biomass of exploitable fishes in this zone. Of the 2 areas, which are to be closed to fishing, it is desirable that one of these areas be located on the eastern boundary, which separates the Pilbara and Kimberley demersal fisheries. To achieve this, it is proposed that Areas 3 and 4 be closed to fishing activities and that Areas 1 and 2 be opened to fishing. These areas also represent areas of relatively similar productive potential from available research data.

The proposal for closed and open areas allows the opportunity to evaluate the effectiveness of protecting a substantial proportion of the exploitable biomass of deep-water demersal fishes in the 100-200 metre depth zone. The level of access allocated should run for the next quinquennium (5 year period) to allow the examination of the benefits of the closed zones in protecting a significant level of the spawning stock biomass of exploitable fishes, to maintain natural community structure and preserve fish habitats (research trawls may be undertaken on a yearly basis in the closed zones to determine levels of relative abundance). The catch in the open zones would be monitored via a logbook program in order to evaluate the catch trends and identify any depletion effects.

However, it should be noted that low levels of effective fishing effort resulted in the depletion of the demersal fish resources in the 100-200 metre depth zone off Ningaloo within a 3 year period (Newman, unpublished report). Approximately 200 hours of fish trawl effort should be allocated in each area open to fishing (a total of 400 hours of effort), in the first instance. This access needs to be divided equitably among all licence holders. Similar to Option 2 above, the minimum costs associated with the implementation of this management strategy include, the requirements for a log book program, monitoring of vessels through the use of the VMS, costs associated with conducting research trawls in the area closed to fishing to record both relative catch rates and age structure data for the key species, and the cost associated with processing hard parts such as otoliths for age determination. Potential benefits of this option include the following; it reflects an adaptive management approach, 50% of the resource is protected providing some insurance against stock collapse, demersal fish are being supplied to the markets allowing the community access to fish, maintenance of some areas of undisturbed habitat and/or critical fish habitats.

Option 4. To extend the zones of the inner continental shelf in the Pilbara region out to the 120 metre bathymetric contour and close the area from 120-200 m. This proposal would result in a larger fishable area being available to fishers with the current effort limitations to remain in effect. This strategy would expose the areas of high fish abundance to commercial fishing pressure. This management option is unlikely to be sustainable in the long term given the low production potential of the demersal fish in this depth zone. Further, areas of undisturbed habitat and/or critical fish habitats would be exposed to fishing pressure.

Benefits

The primary beneficiaries of this project will be the commercial fishers of the Pilbara region. However, the demographic parameters derived for the two *Lutjanus* species also have application to the management of these two important recreational fish species. This project will facilitate the sustainable development of the outer-shelf fishery resources of the Pilbara region. The direct benefit to fishers will be the sustainability of their fishery.

Further Development

The utility of otolith weight-age relationships and their application to stock assessment will be further assessed. The management options presented in this report will be presented to both industry and fishery managers for their consideration.

Conclusions

The commercial catch rates in this survey were generally low. The commercial viability of this zone appears to be restricted to the shallower depths less than 140 m. The fish fauna was found to be diverse with a number of species of commercial importance present. Catch rates of commercially important fish were higher in the shallower waters of the survey area where hard bottom communities and sponges were more abundant.

The juveniles and adults of *G. buergeri*, *L. malabaricus*, *P. multidens* and *P. typus* all appear to be present in depths of 100-200 m, while the juveniles and sub-adults of *L. russelli* were not present. The possibility exists that sub-adult *L. russelli* undertake cross-shelf migrations to deeper offshore waters.

The relationship of otolith height to fish age was expected to reflect age in a robust manner as the otolith height (thickness) attempted to measure the increasing depth of the sulcal groove. However, this relationship was not as robust as the otolith weight-fish age relationship and this is probably attributable to measurement error. Furthermore, collection of otolith weights is more cost effective than undertaking the difficult and time consuming task of measuring otoliths. Otolith weight increases with increasing age in all species and may provide a cost effective method of age determination for fishery management purposes.

The key species examined in this study are, in general, slow growing, long lived fishes which have low rates of natural mortality. These life history characteristics have important management implications. Their slow growth, protracted longevity and low rate of natural mortality imply that these fish have a low production potential and they will be vulnerable to over-exploitation.

The sustainable harvest rates of long-lived species rarely exceed the natural mortality rate and are more likely to be in the order of 0.4-0.6 times the natural loss rate or natural mortality rate (Patterson 1992, Walters pers. comm.). Therefore, for most long lived species the annual harvest rate should not exceed approximately 10% per year of the available stock.

Setting harvest strategies at or near F_{limit} is recommended in order to maintain the spawning stock biomass and prevent stock collapse. Estimates of F_{limit} from this study indicate that less that 10% of the available stock biomass can be harvested on an annual basis in order to achieve sustainability objectives. Fishers often encounter and target large schools of fish, in particular schooling species such as *P. multidens* and *P. typus*. Consequently, it is difficult for fishers to reconcile and accept that for each fish taken a large number of fish must be left in the water.

Evidence from this study indicates that the exploitation of *P. multidens* is above optimum levels, while the harvest rate of the closely related *P. typus* is approaching the limit reference point. Areas closed to fishing (harvest refugia) are recommended to preserve the spawning stock biomass of these fishes. Precautionary fishery management strategies are recommended in order to facilitate the sustainable development of the demersal fish resources in the 100-200 m depth zone off the Pilbara coast.

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Appendix 1: Intellectual Property

Nil.

Appendix 2: Staff

Dr. S. Newman
Mr. D. Evans
Mr. R. Ashworth
Mr. B. Smith

Appendix 3: Key species common names and synonyms.

1. *Glaucosoma buergeri* - Pearl Perch

Other common names: Deepsea jewfish, North-west jewfish, North-west pearl perch, Northern pearl perch, Grey bigmouth bream.

Common synonyms: *Glaucosoma burgeri* (Sainsbury et al., 1985).

2. *Lutjanus malabaricus* - Scarlet Seaperch

Other common names: Ruby emperor, Saddletail seaperch, Large mouth nannygai, Red jew, , Malabar blood snapper.

Common synonyms: *L. erythropterus* (Masuda et al., 1984; Shen, 1984 - in part), *L. sanguineus* (Fischer and Whitehead, 1974; Masuda et al., 1980) and is usually referred to as *L. coccineus* in the Kuwaiti literature. It is also sometimes referred to as *L. longmani.*

3. *Lutjanus russelli* (Indian Ocean variety) - Moses Perch

Other common names: Russell's snapper, Fingermark bream, Red bream.

Common synonyms: none known.

The colouration of the Pacific Ocean variety of *L. russelli* differs from the Indian Ocean variety of *L. russelli* in having yellow pectoral, pelvic and anal fins rather than the reddish pink or translucent colour of the Indian Ocean variety. The Indian Ocean and Pacific Ocean varieties of *L. russelli* are genetically different (Peter Last, CSIRO pers. comm.). The taxonomy of *L. russelli* needs to be resolved, in particular, which of these varieties is the true *L. russelli* as both varieties have been lumped under the one name (Yearsley et al. 1999).

4. *Pristipomoides multidens* - Goldband Snapper

Other common names: Goldbanded jobfish, Large-scaled jobfish.

Common synonyms: none known.

5. *Pristipomoides typus* - Sharptooth Snapper

Other common names: Sharptooth jobfish, Goldband snapper.

Common synonyms: none known.

Appendix 4: Location of the survey area off the north-west coast of Western Australia and the spatial distribution of survey trawls, catches and catch rates of the key species and species groups.

Figure 1: Location of the fish trawl survey area in depths of 100-200 metres off the Pilbara coast (North-West Shelf) of Western Australia.

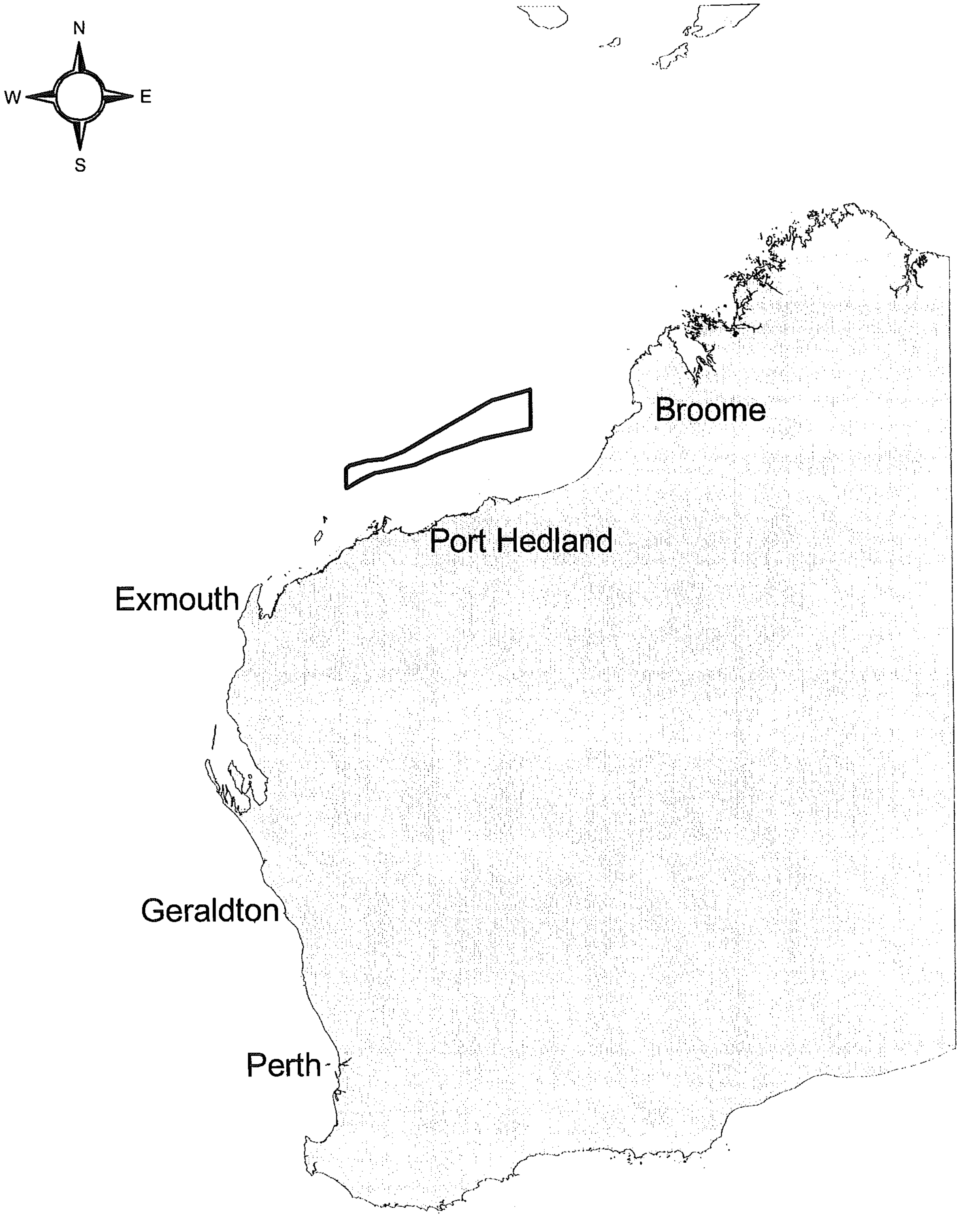

N
W
E
S
Broome
Port Hedland
Exmouth
Geraldton
Perth

Figure 2: Location of the survey blocks within the fish trawl survey area in depths of 100-200 metres off the Pilbara coast of Western Australia.

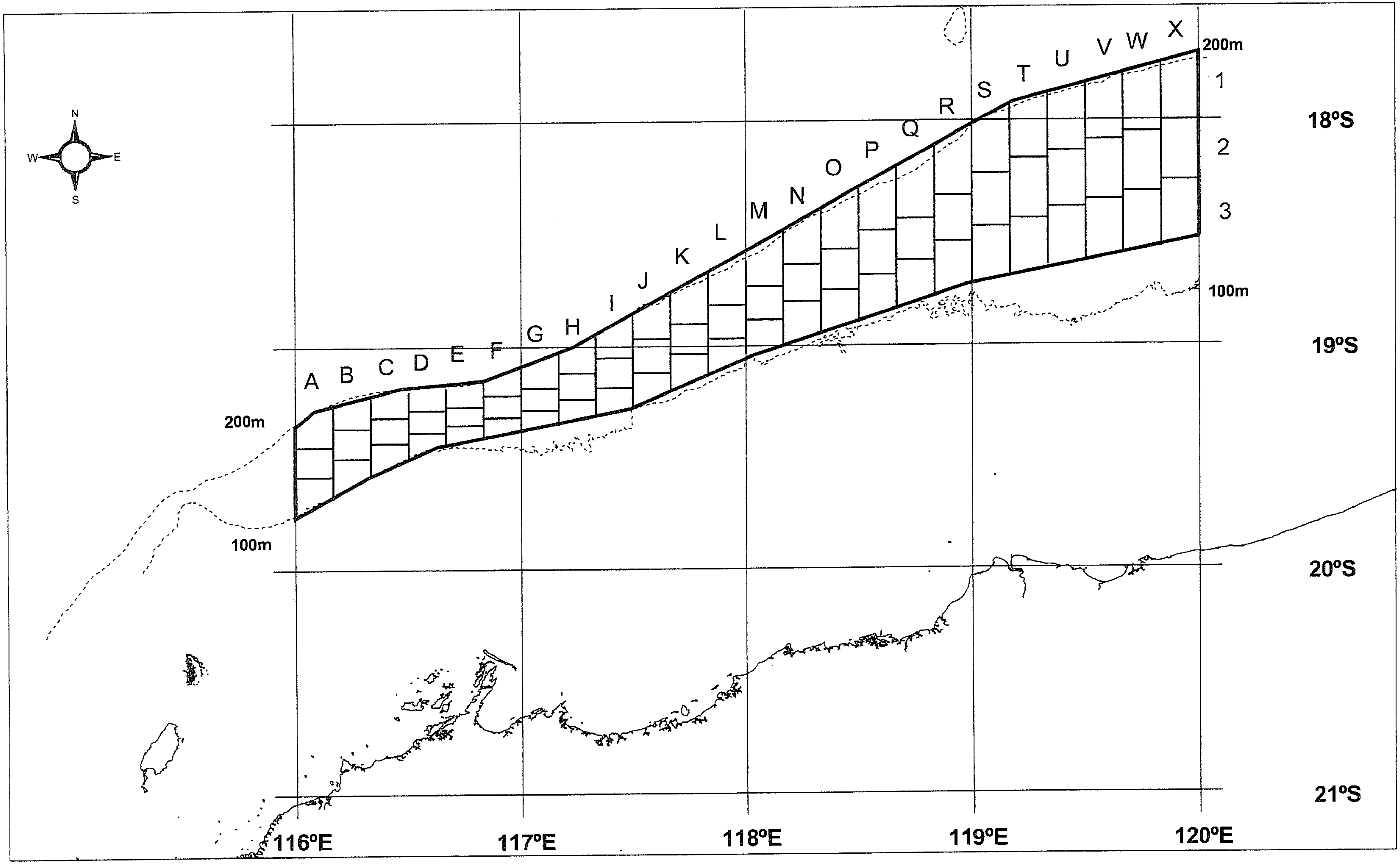

N
W
E
S
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
200m
1
2
3
100m
200m
100m
18ºS
19ºS
20ºS
21ºS
116ºE
117ºE
118ºE
119ºE
120ºE

Figure 3: Spatial distribution of the trawl shots undertaken per block in the fish trawl survey area off the Pilbara coast

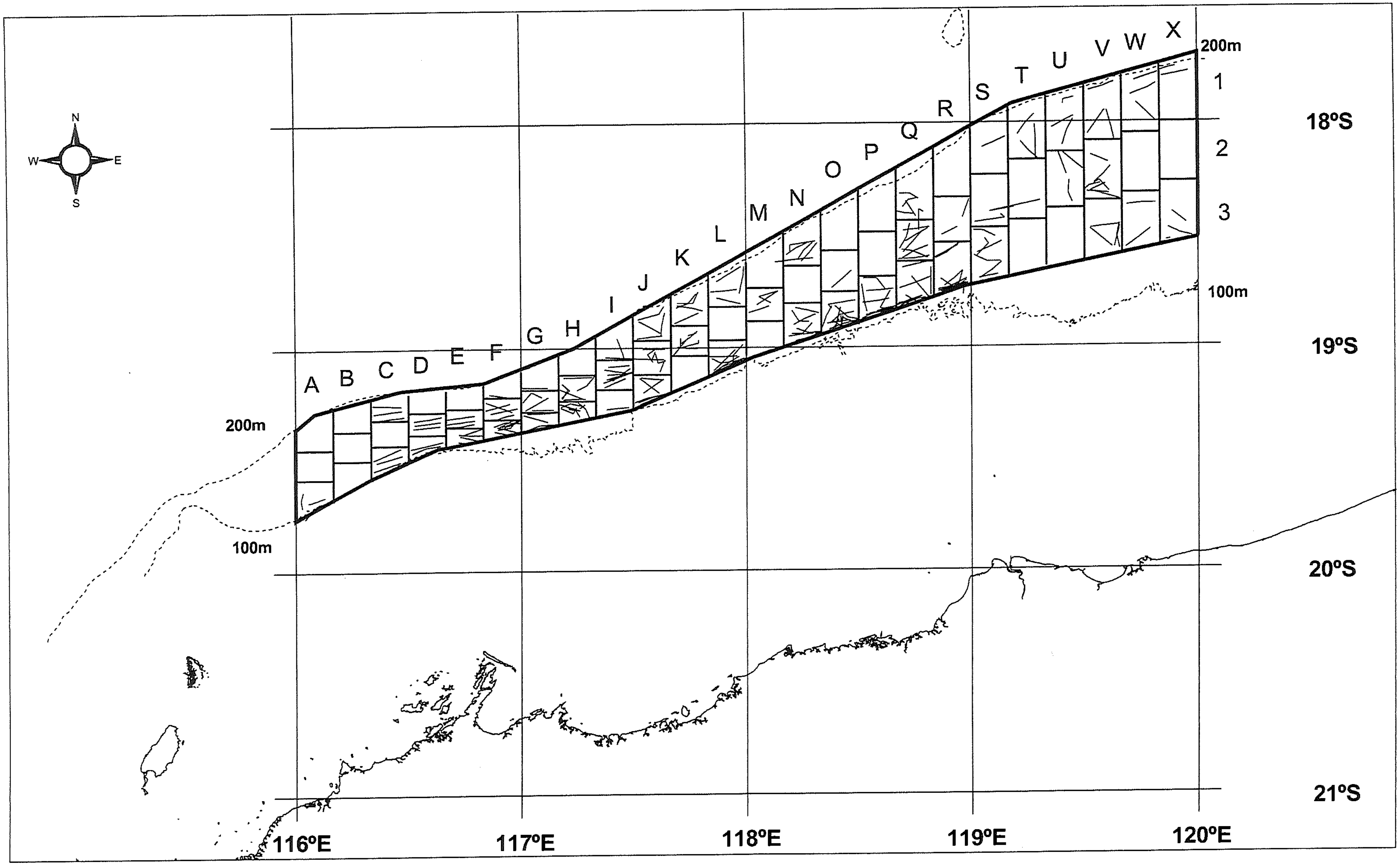

N
W
E
S
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
200m
1
2
3
18ºS
100m
19ºS
200m
100m
20ºS
21ºS
116ºE
117ºE
118ºE
119ºE
120ºE

Figure 4: Spatial distribution of trawl effort (hours) per block in the fish trawl survey area off the Pilbara coast.

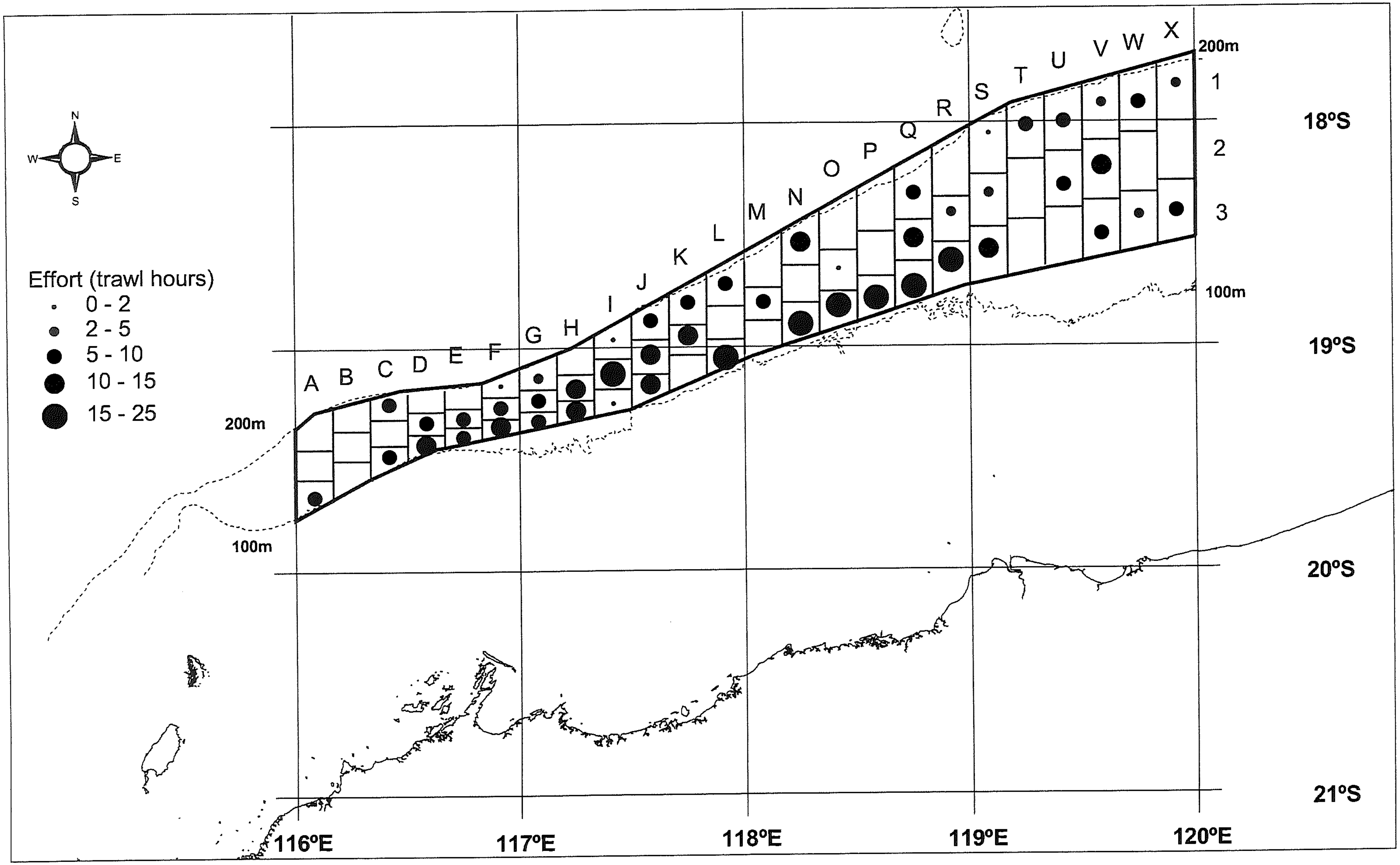

N
W
E
S
Effort (trawl hours)
0 - 2
2 - 5
5 - 10
10 - 15
15 - 25
200m
100m
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
200m
1
2
3
100m
18ºS
19ºS
20ºS
21ºS
116ºE
117ºE
118ºE
119ºE
120ºE

Figure 5: Spatial distribution of the total catch (kg) of all fish per block in the fish trawl survey area off the Pilbara coast.

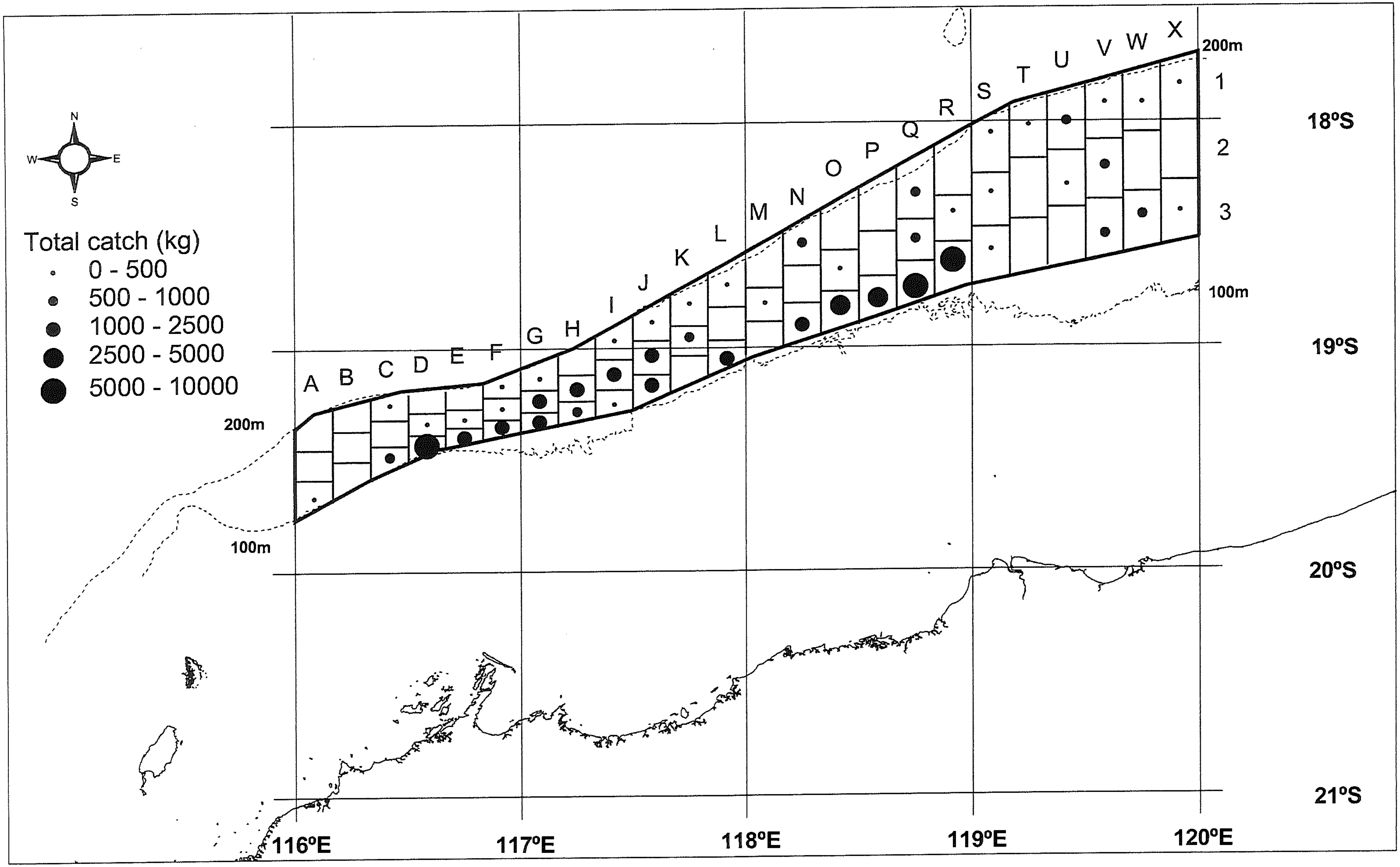

N
W
E
S
Total catch (kg)
0 - 500
500 - 1000
1000 - 2500
2500 - 5000
5000 - 10000
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
1
2
3
200m
100m
200m
100m
18ºS
19ºS
20ºS
21ºS
116ºE
117ºE
118ºE
119ºE
120ºE

Figure 6: Spatial distribution of the CPUE (kg trawl hour^{-1}) of all fish per block in the fish trawl survey area off the Pilbara coast.

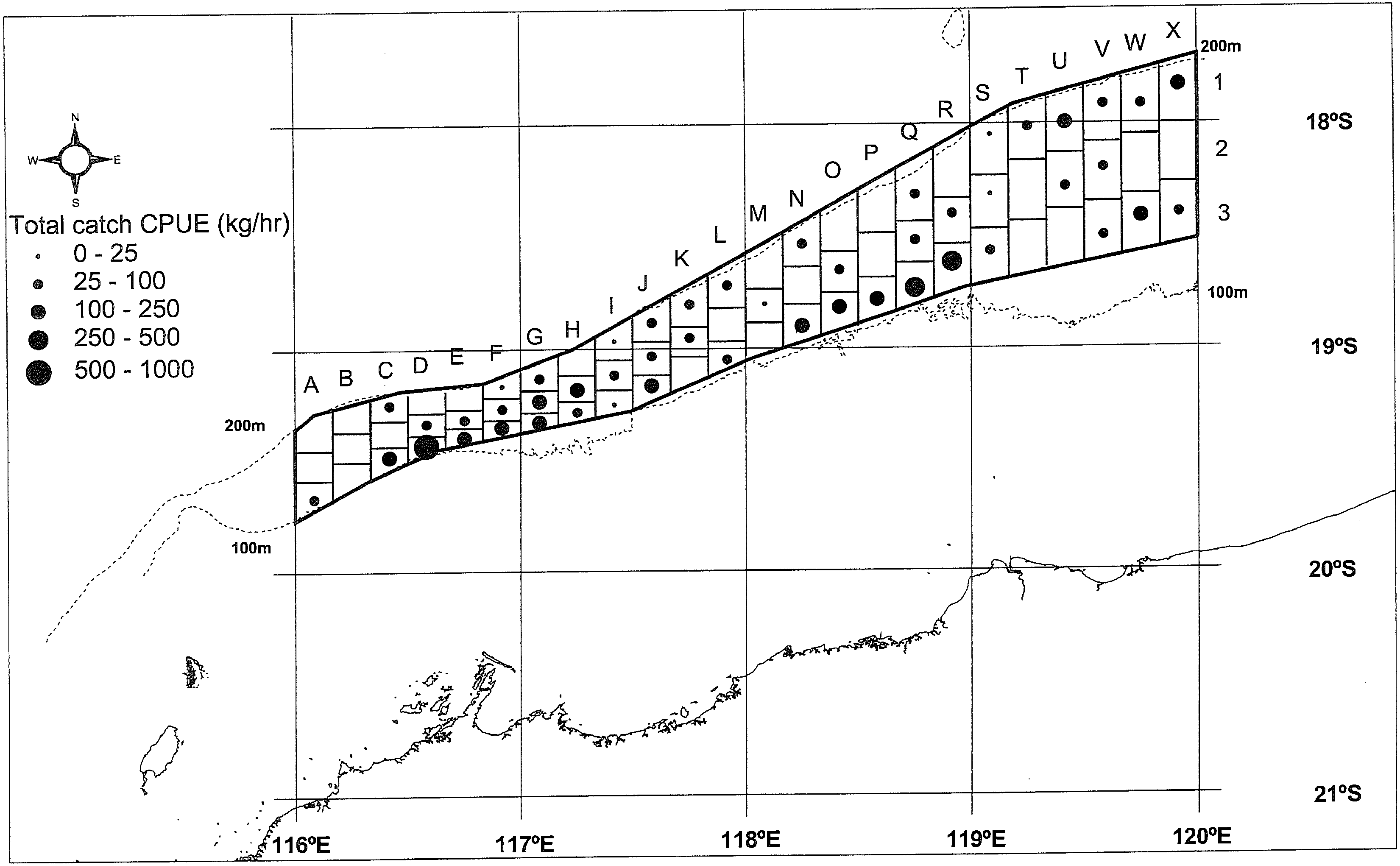

N
W
E
S
Total catch CPUE (kg/hr)
0 - 25
25 - 100
100 - 250
250 - 500
500 - 1000
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
1
2
3
200m
100m
200m
100m
18ºS
19ºS
20ºS
21ºS
116ºE
117ºE
118ºE
119ºE
120ºE

Figure 7: Spatial distribution of the total catch (kg) of fish of commercial importance per block in the fish trawl survey area off the Pilbara coast. total commercial catch (kg)

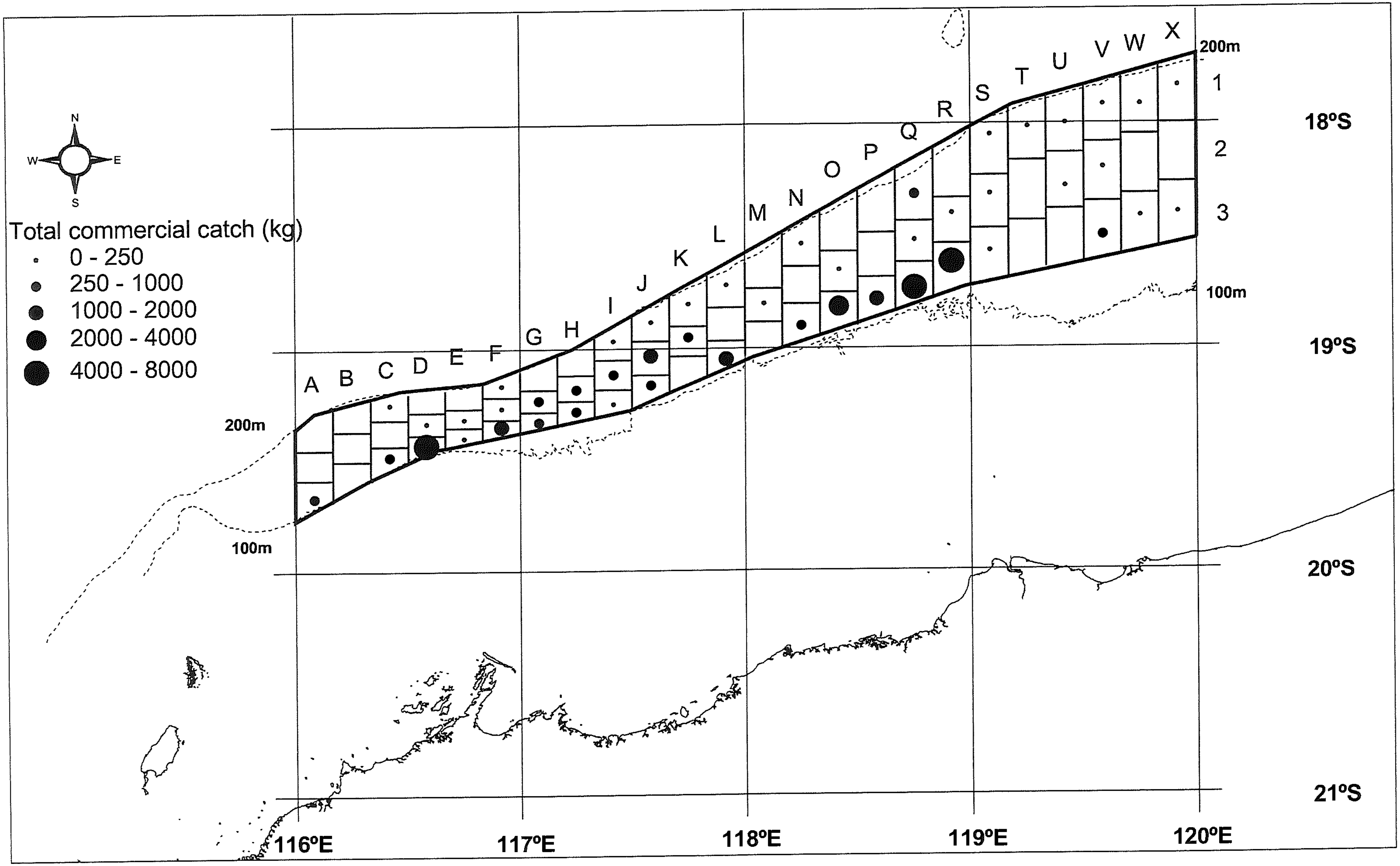

N
W
E
S
Total commercial catch (kg)
0 - 250
250 - 1000
1000 - 2000
2000 - 4000
4000 - 8000
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
1
2
3
200m
100m
200m
100m
18ºS
19ºS
20ºS
21ºS
116ºE
117ºE
118ºE
119ºE
120ºE

Figure 8: Spatial distribution of the CPUE (kg trawl hour^{-1}) of fish of commercial importance per block in the fish trawl survey area off the Pilbara coast.

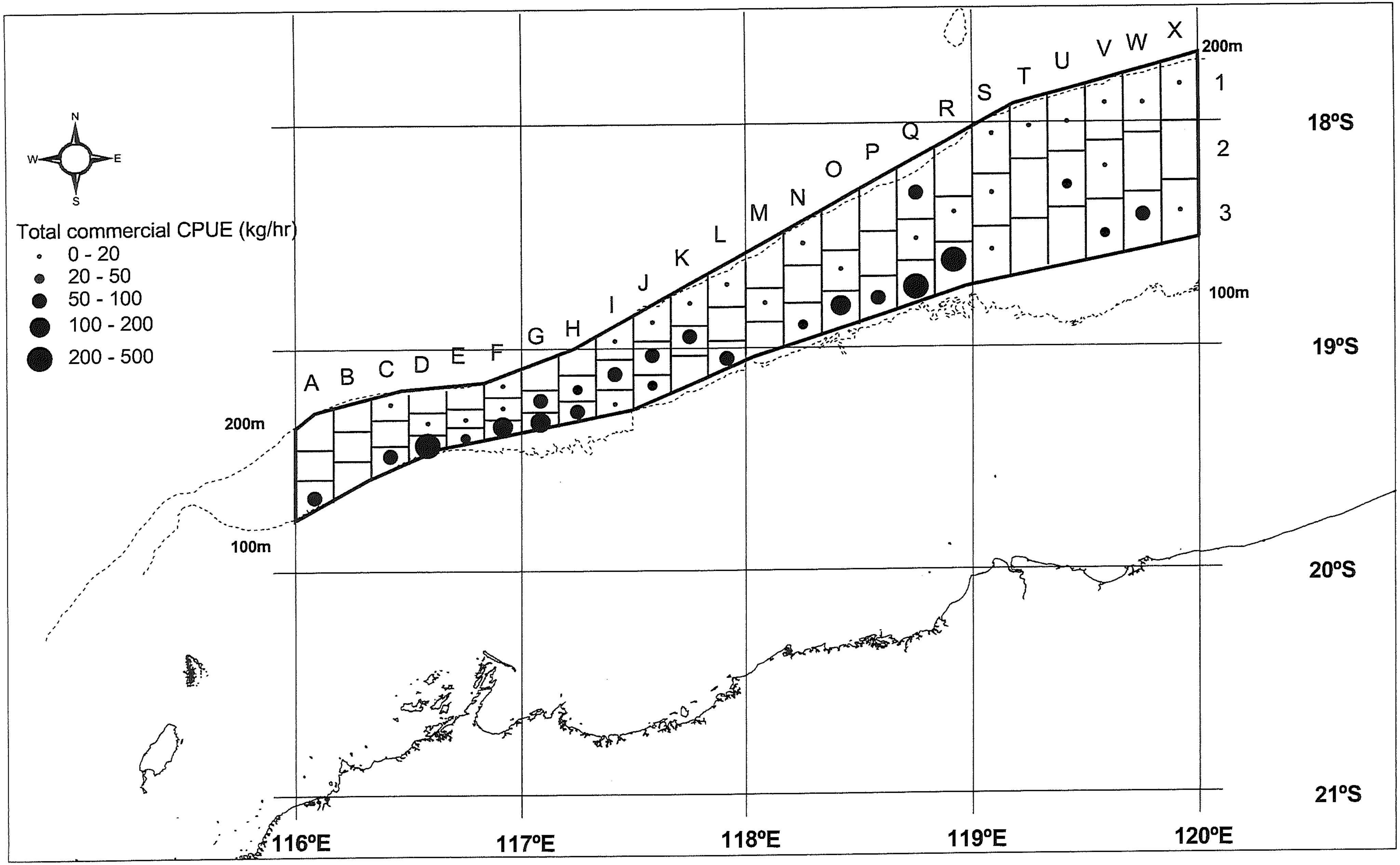

N
W
E
S
Total commercial CPUE (kg/hr)
0 - 20
20 - 50
50 - 100
100 - 200
200 - 500
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
1
2
3
200m
100m
200m
100m
18ºS
19ºS
20ºS
21ºS
116ºE
117ºE
118ºE
119ºE
120ºE

Figure 9: Spatial distribution of the total catch (kg) of non-commercial fish per block in the fish trawl survey area off the Pilbara coast.

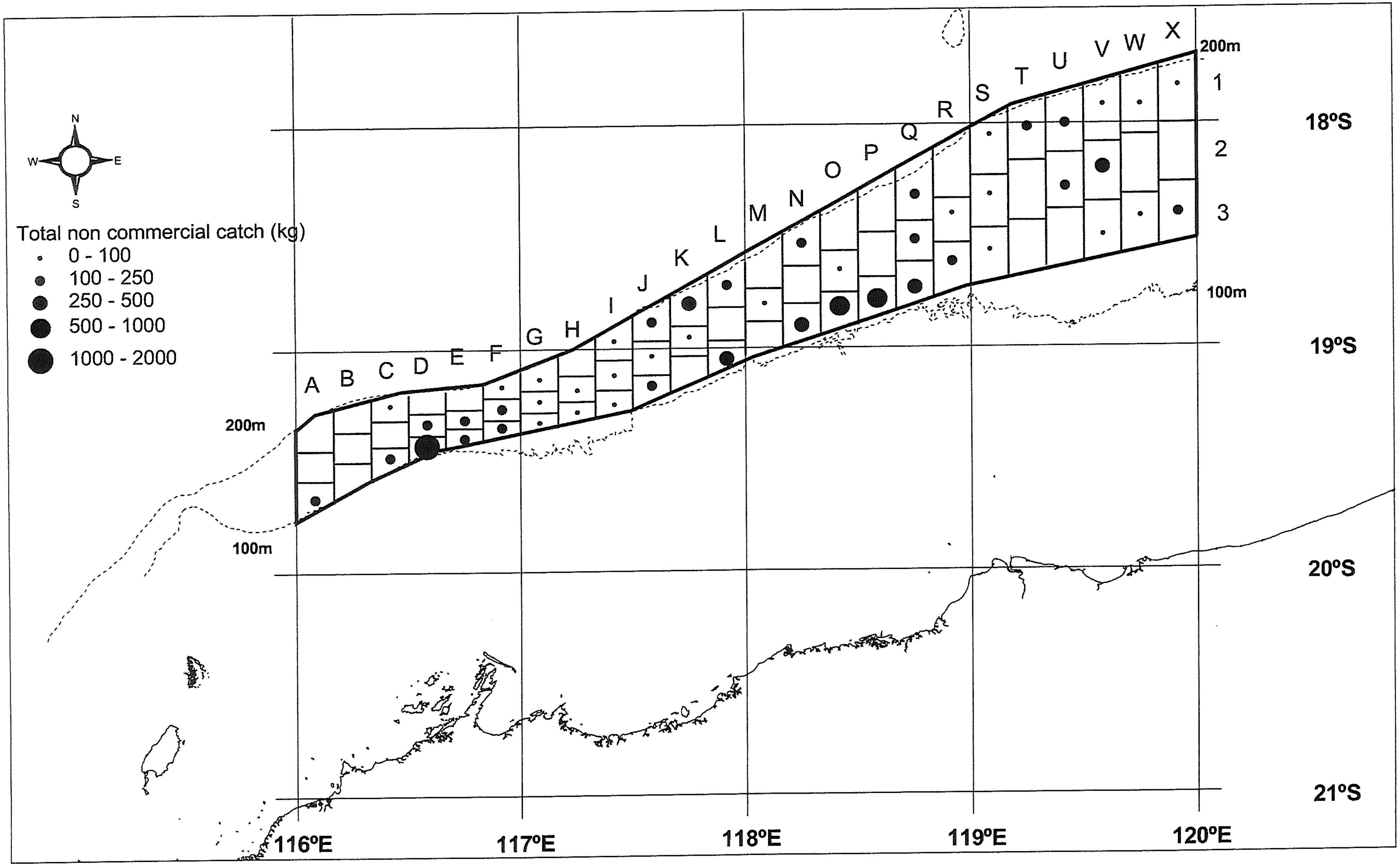

N
W
E
S
Total non commercial catch (kg)
0 - 100
100 - 250
250 - 500
500 - 1000
1000 - 2000
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
1
2
3
200m
100m
200m
100m
18ºS
19ºS
20ºS
21ºS
116ºE
117ºE
118ºE
119ºE
120ºE

Figure 10: Spatial distribution of the CPUE (kg trawl hour^{-1}) of non-commercial fish per block in the fish trawl survey area off the Pilbara coast.

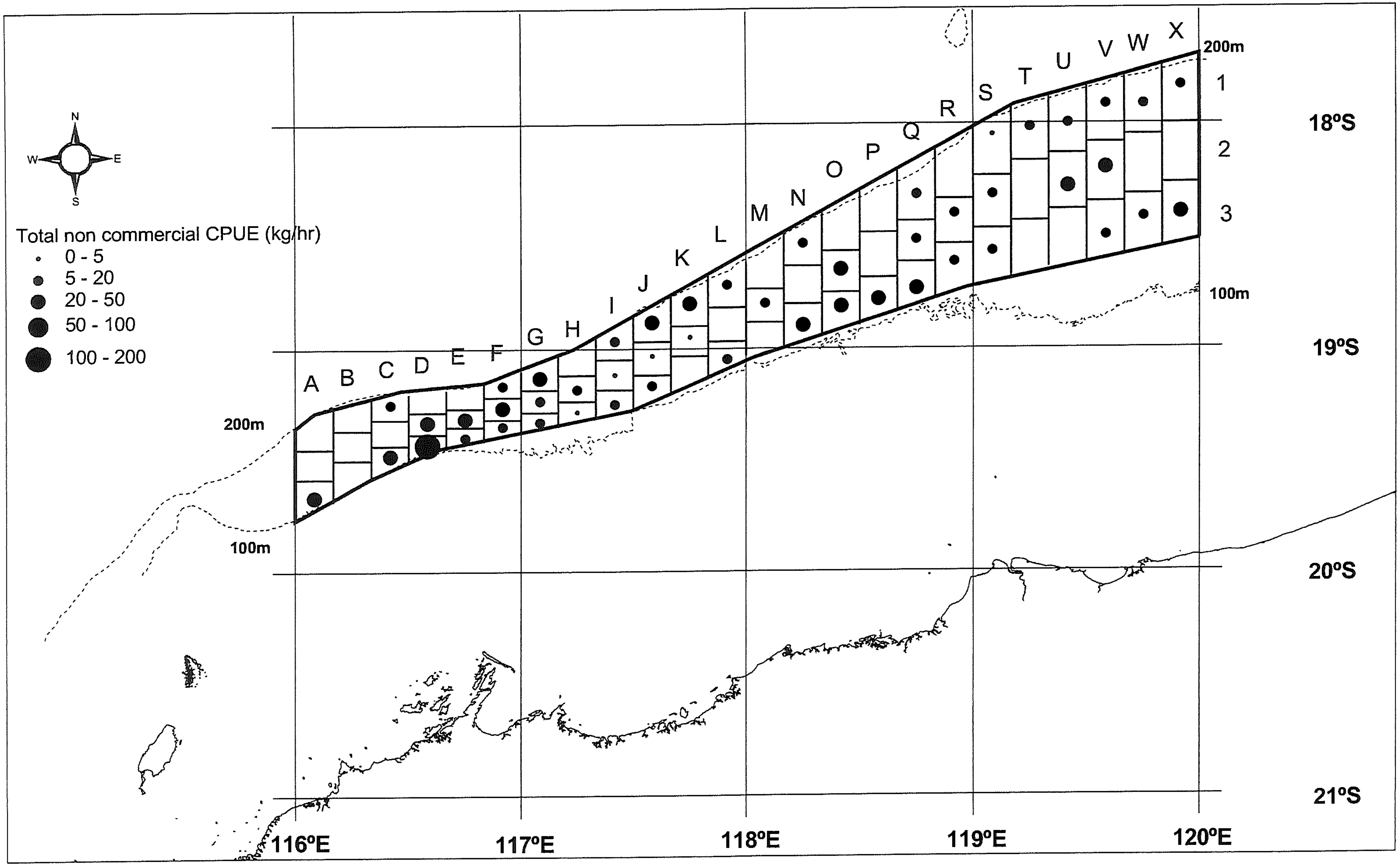

N
W
E
S
Total non commercial CPUE (kg/hr)
0 - 5
5 - 20
20 - 50
50 - 100
100 - 200
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
1
2
3
200m
100m
200m
100m
18ºS
19ºS
20ºS
21ºS
116ºE
117ºE
118ºE
119ºE
120ºE

Figure 11: Spatial distribution of the total catch (kg) of all the recorded benthos retained in the trawl net per block in the fish trawl survey area off the Pilbara coast.

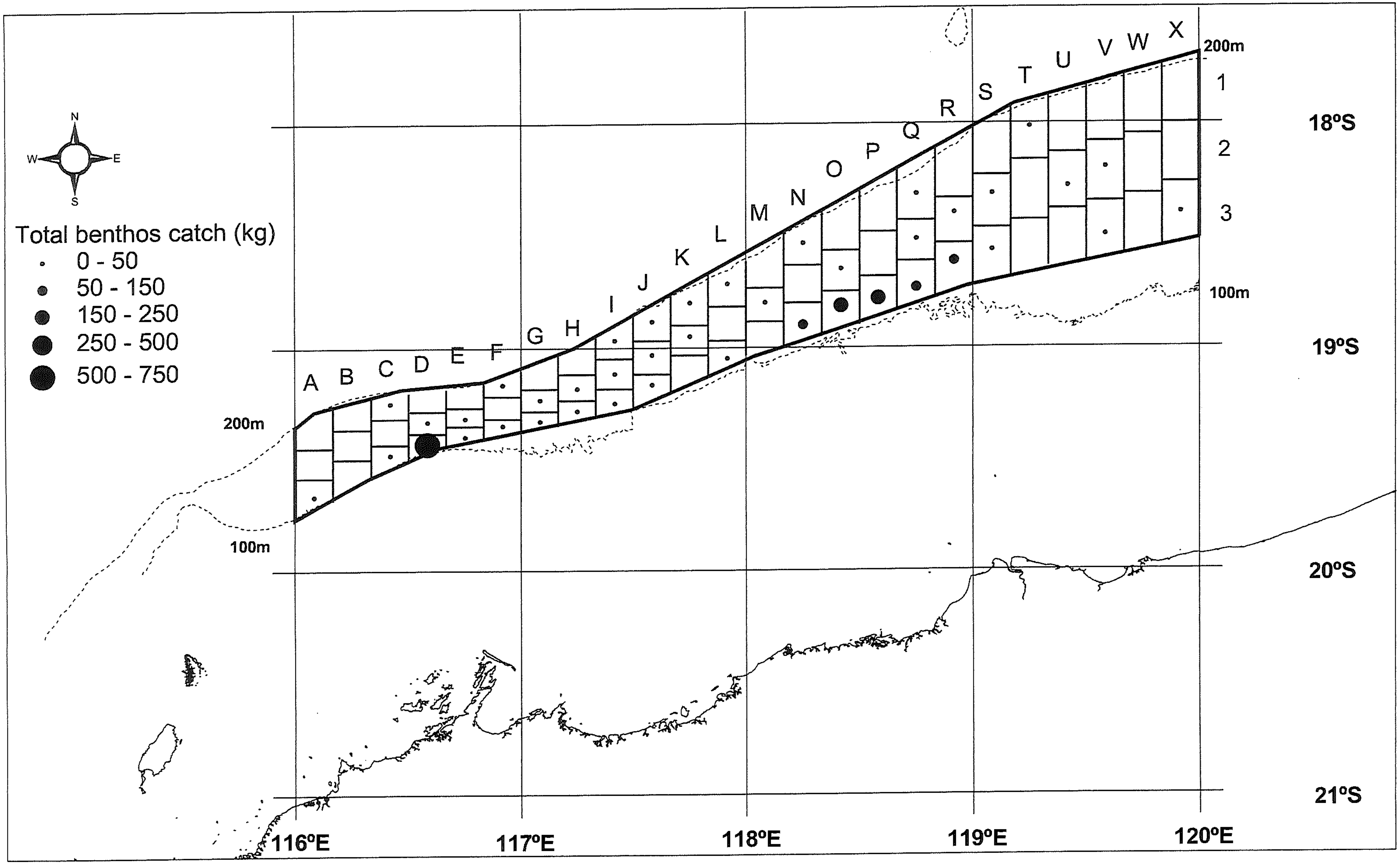

N
W
E
S
Total benthos catch (kg)
0 - 50
50 - 150
150 - 250
250 - 500
500 - 750
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
1
2
3
200m
100m
200m
100m
18ºS
19ºS
20ºS
21ºS
116ºE
117ºE
118ºE
119ºE
120ºE

Figure 12: Spatial distribution of the CPUE (kg trawl hour^{-1}) of all the recorded benthos retained in the trawl net per block in the fish trawl survey area off the Pilbara coast.

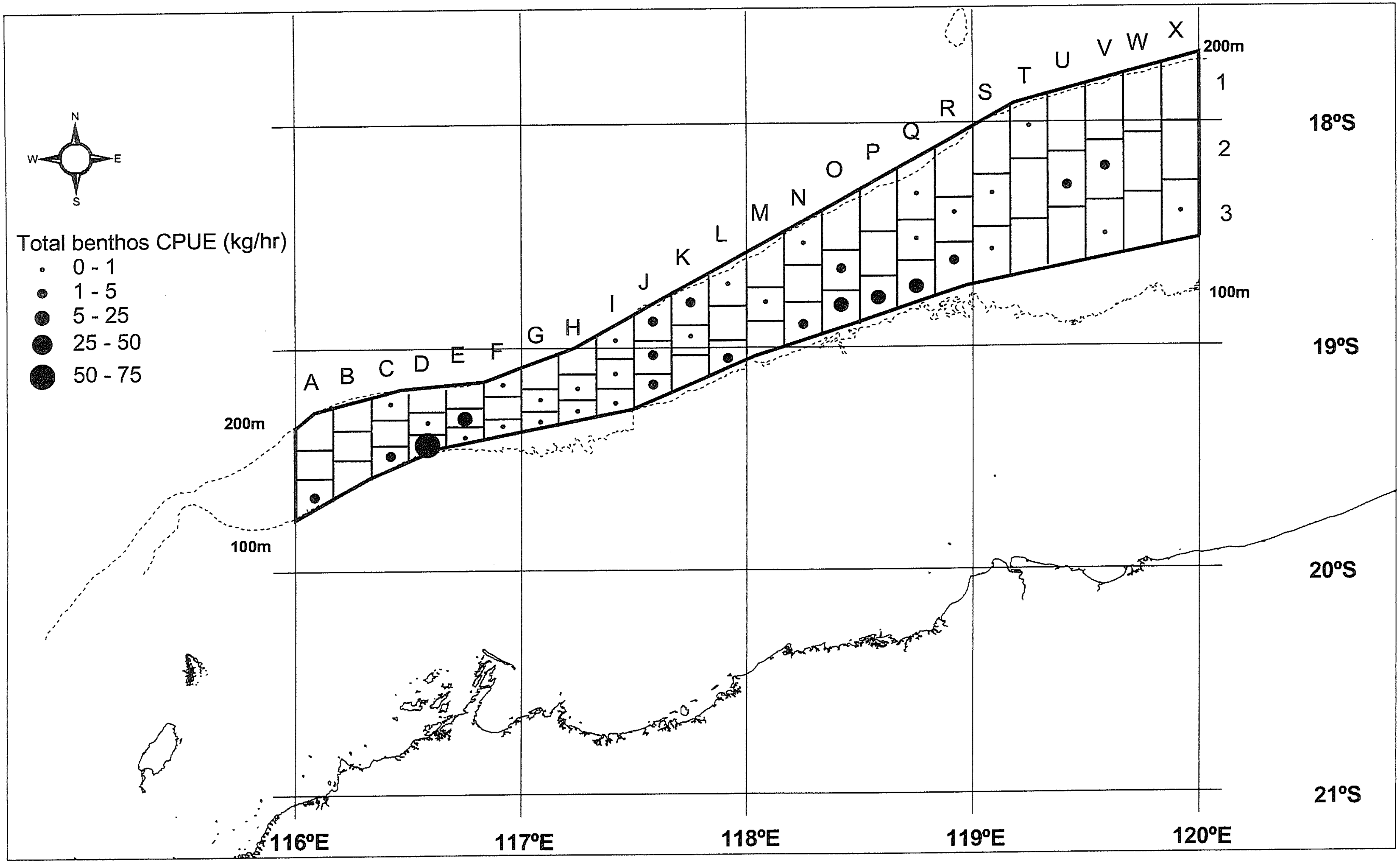

N
W
E
S
Total benthos CPUE (kg/hr)
0 - 1
1 - 5
5 - 25
25 - 50
50 - 75
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
200m
1
2
3
100m
200m
100m
18ºS
19ºS
20ºS
21ºS
116ºE
117ºE
118ºE
119ºE
120ºE

Figure 13: Spatial distribution of the total catch (kg) of Porifera (sponges) retained in the trawl net per block in the fish trawl survey area off the Pilbara coast.

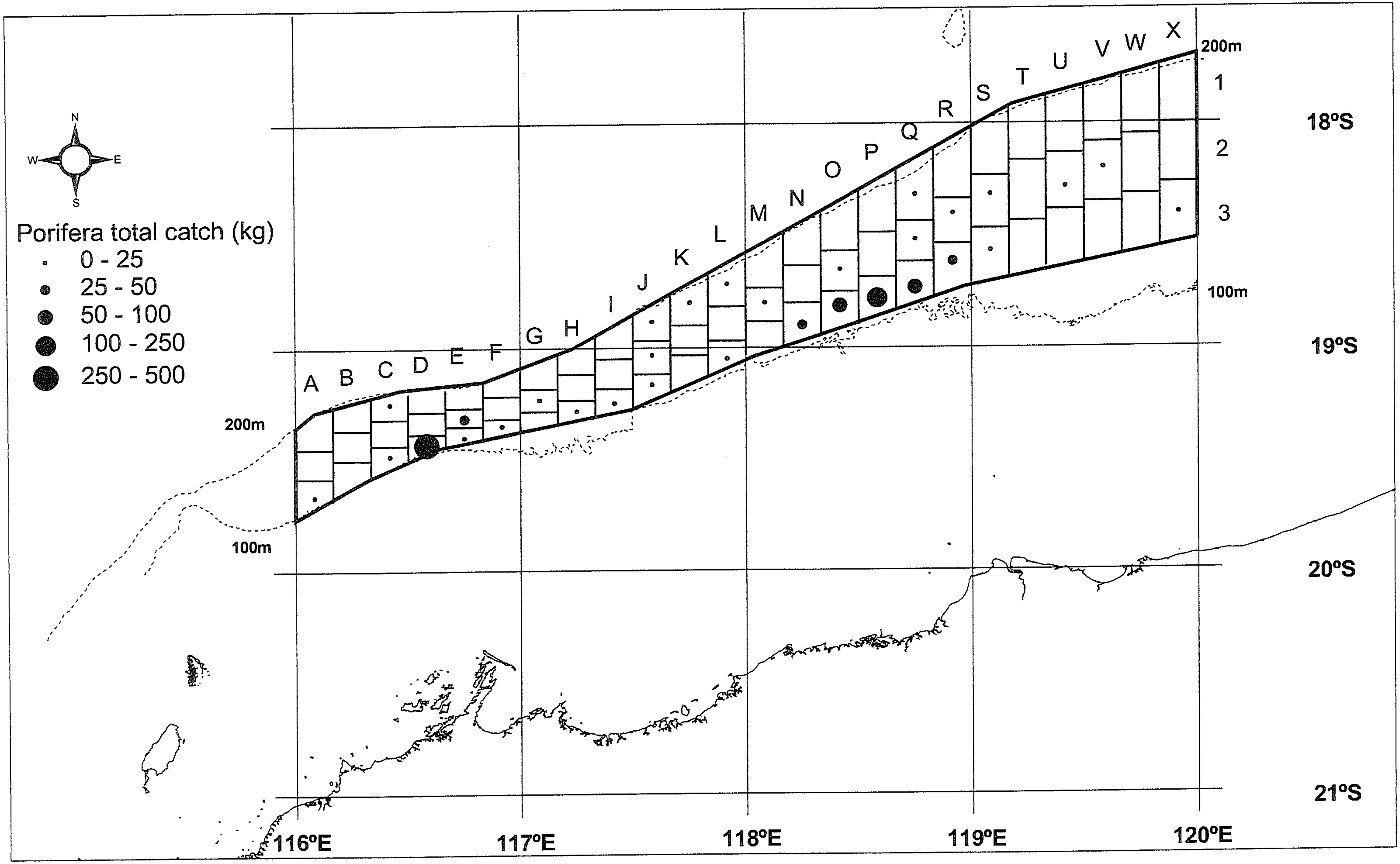

N
W
E
S
Porifera total catch (kg)
0 - 25
25 - 50
50 - 100
100 - 250
250 - 500
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
200m
1
2
3
18ºS
19ºS
20ºS
21ºS
200m
100m
100m
116ºE
117ºE
118ºE
119ºE
120ºE

Figure 14: Spatial distribution of the CPUE (kg trawl hour^{-1}) of Porifera (sponges) retained in the trawl net per block in the fish trawl survey area off the Pilbara coast.

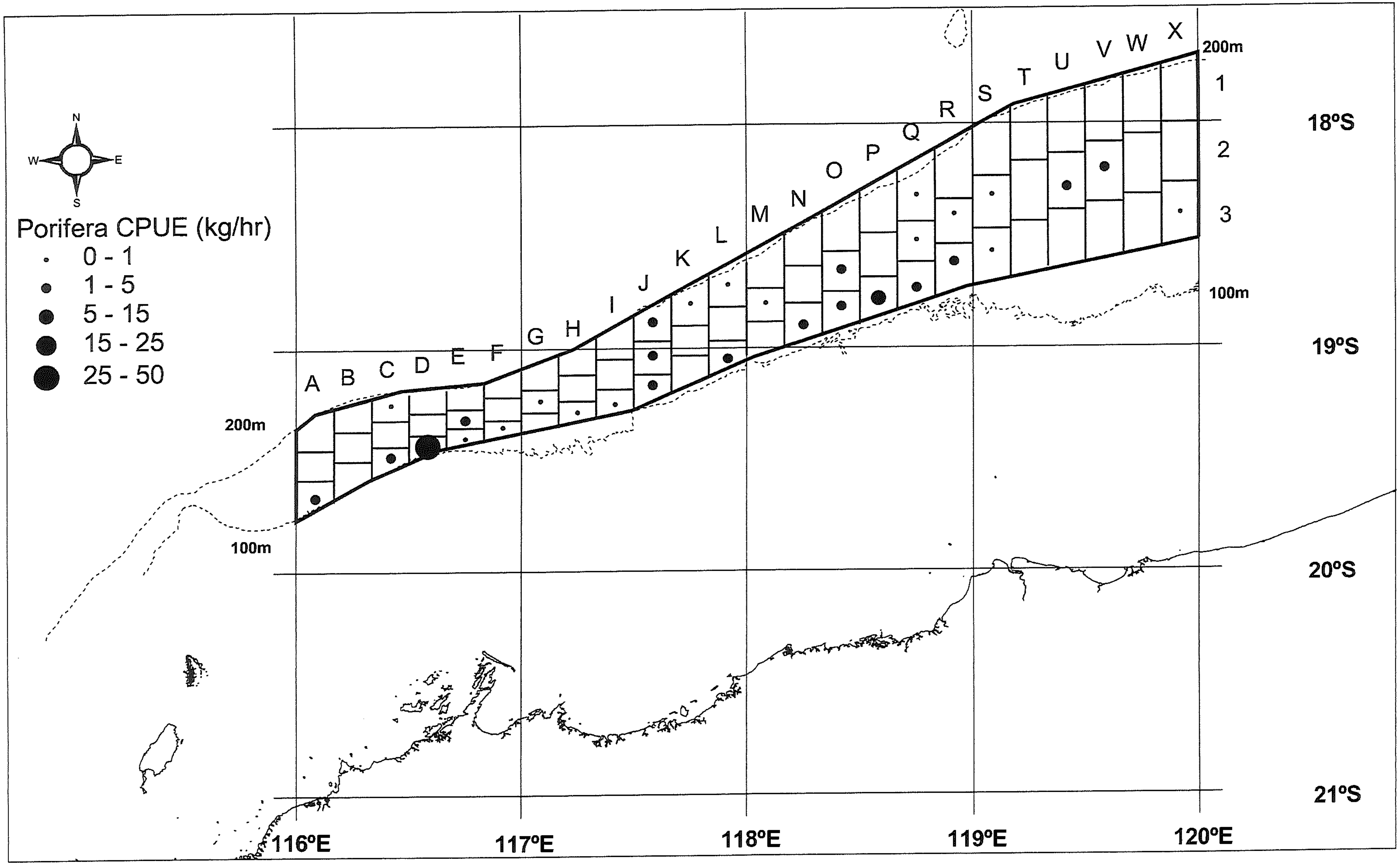

N
W
E
S
Porifera CPUE (kg/hr)
0 - 1
1 - 5
5 - 15
15 - 25
25 - 50
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
1
2
3
200m
100m
200m
100m
18ºS
19ºS
20ºS
21ºS
116ºE
117ºE
118ºE
119ºE
120ºE

Figure 15: Spatial distribution of the total catch (kg) of *Glaucosoma buergeri* (pearl perch) per block in the fish trawl survey area off the Pilbara coast.

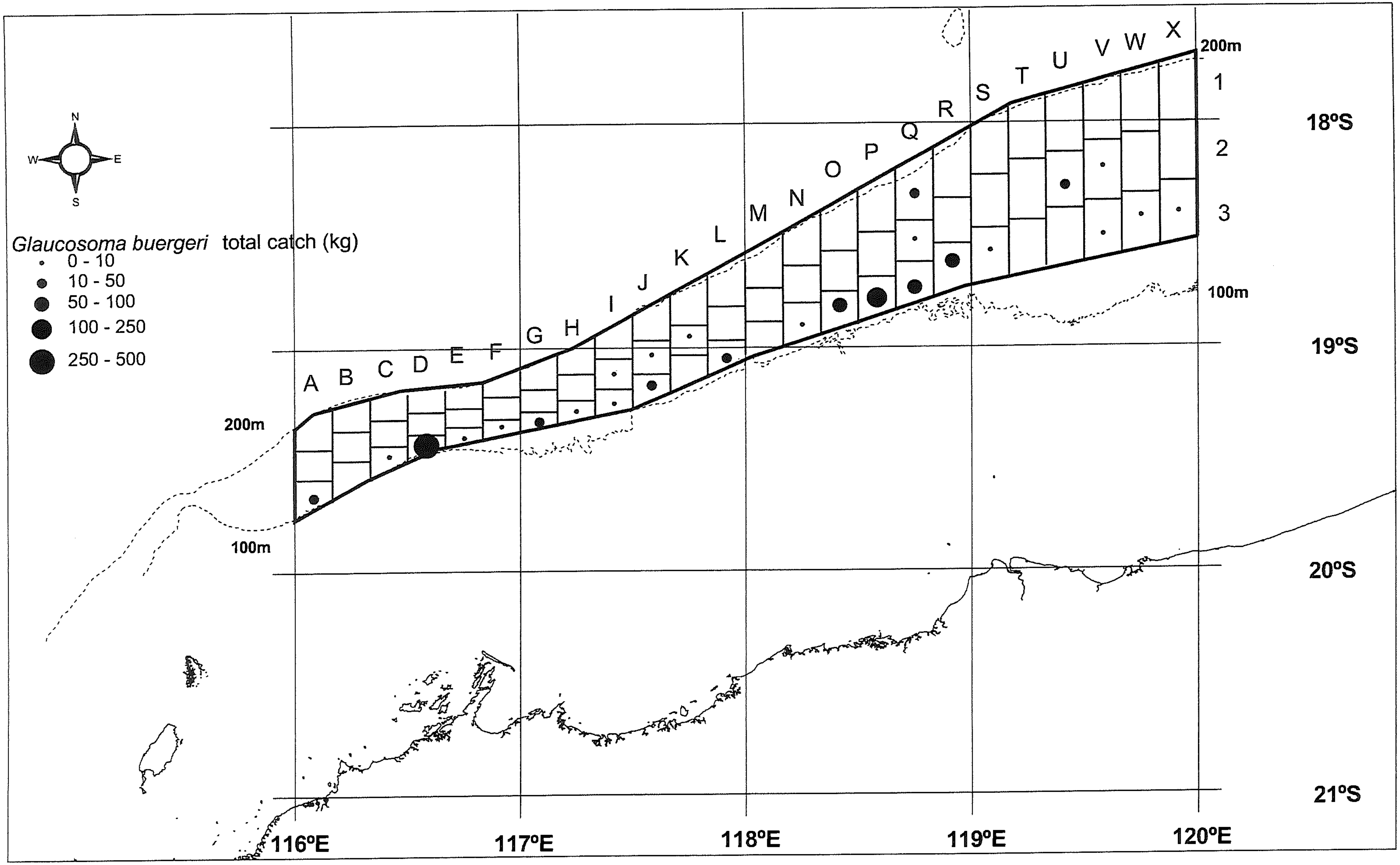

N
W
E
S
Glaucosoma buergeri total catch (kg)
0 - 10
10 - 50
50 - 100
100 - 250
250 - 500
A B C D E F G H I J K L M N O P Q R S T U V W X
1
2
3
200m
100m
200m
100m
18ºS
19ºS
20ºS
21ºS
116ºE
117ºE
118ºE
119ºE
120ºE

Figure 16: Spatial distribution of the CPUE (kg trawl hour^{-1}) of *Glaucosoma buergeri* (pearl perch) per block in the fish trawl survey area off the Pilbara coast.

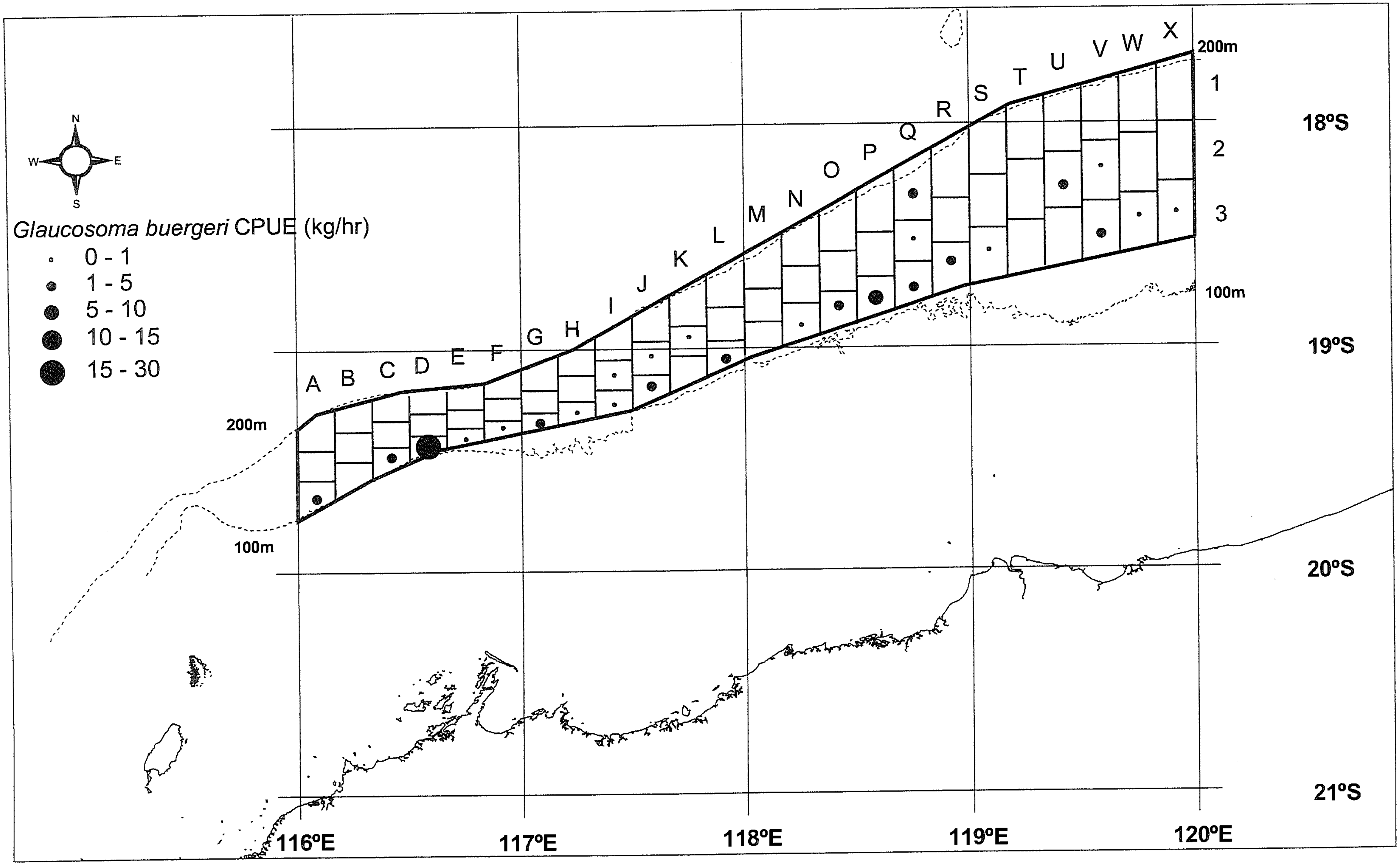

N
W
E
S
Glaucosoma buergeri CPUE (kg/hr)
0 - 1
1 - 5
5 - 10
10 - 15
15 - 30
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
1
2
3
200m
100m
200m
100m
18ºS
19ºS
20ºS
21ºS
116ºE
117ºE
118ºE
119ºE
120ºE

Figure 17: Spatial distribution of the total catch (kg) of *Lutjanus malabaricus* (scarlet seaperch) per block in the fish trawl survey area off the Pilbara coast.

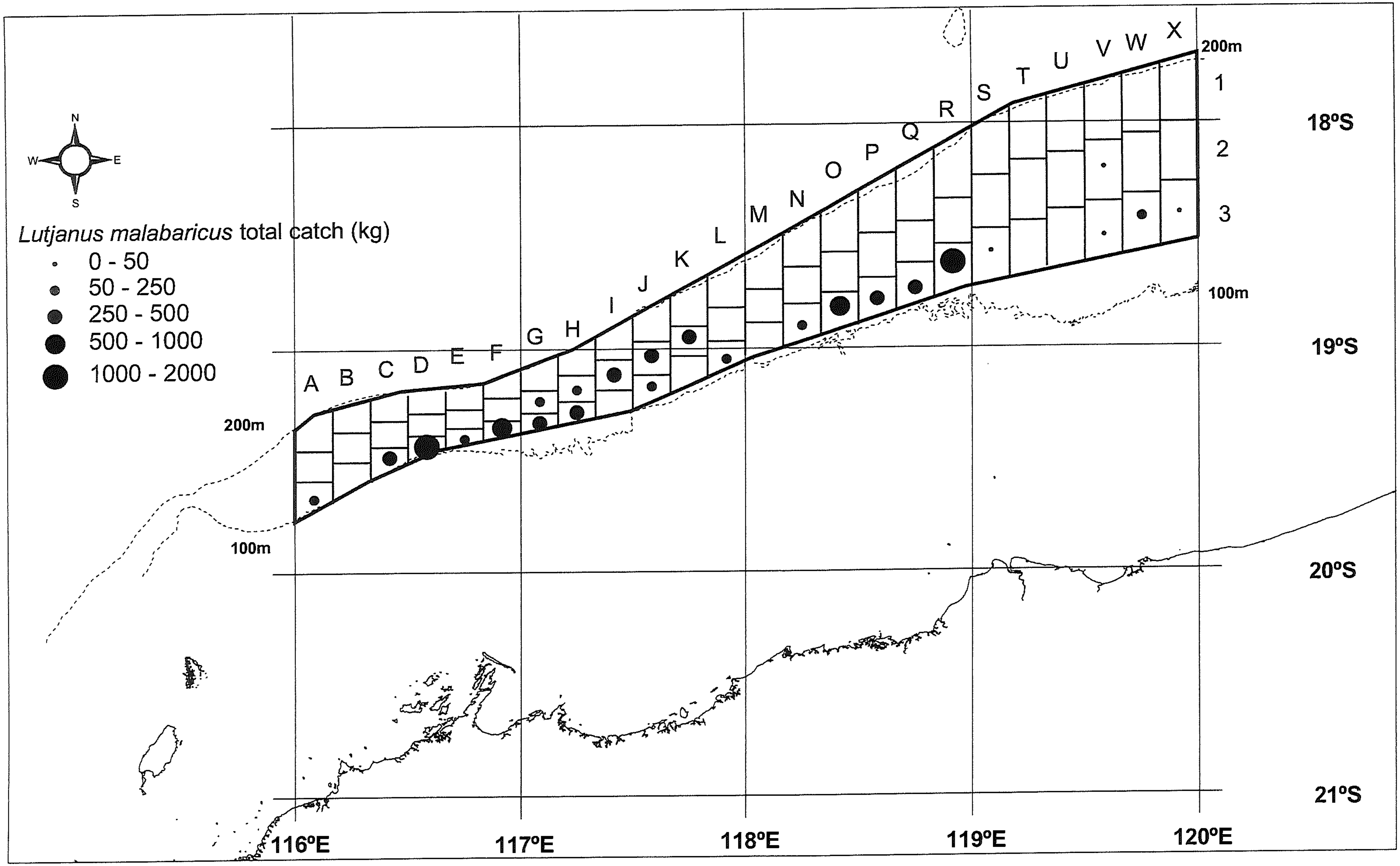
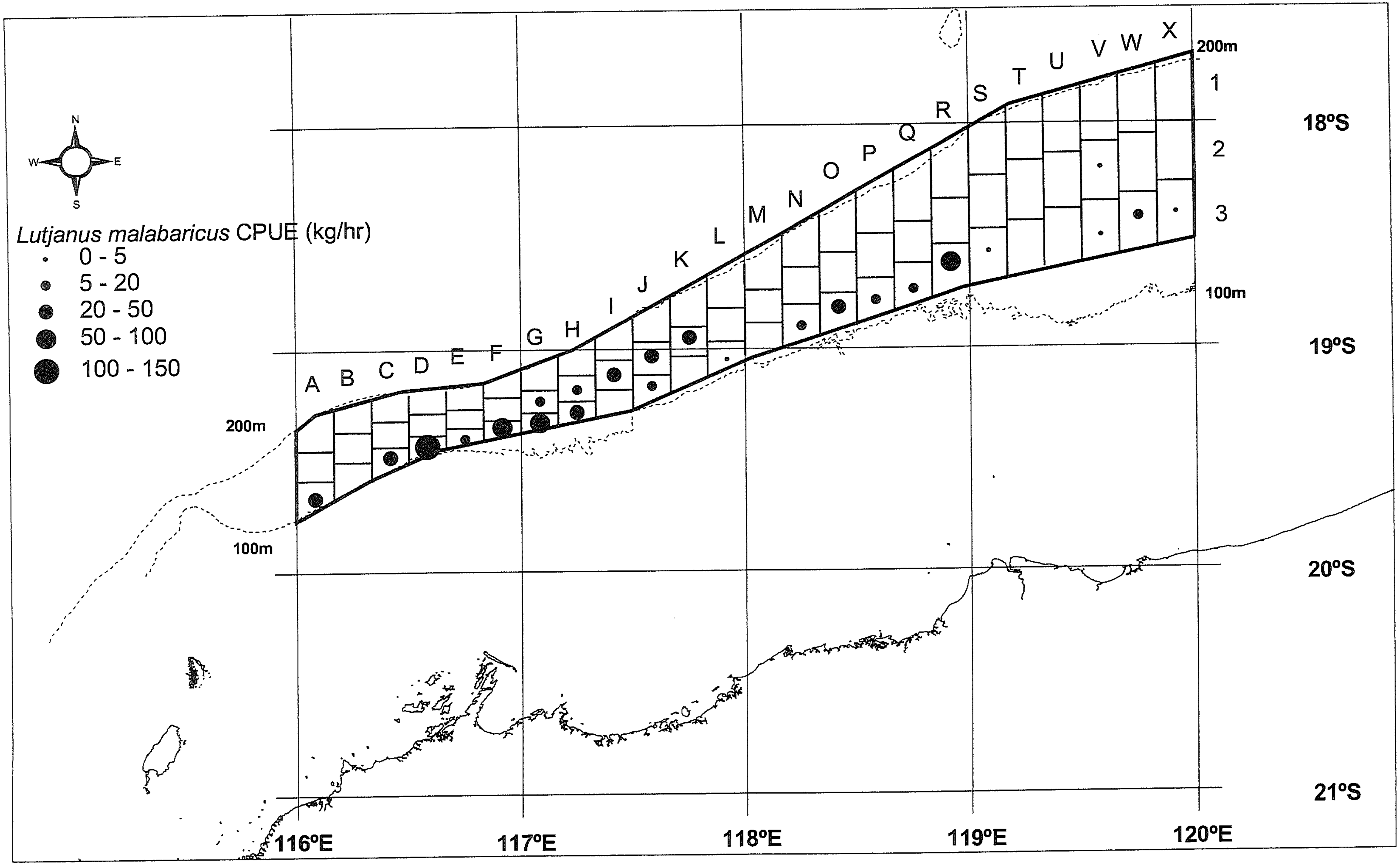

N
S
W
E
Lutjanus malabaricus total catch (kg)
0 - 50
50 - 250
250 - 500
500 - 1000
1000 - 2000
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
1
2
3
200m
100m
200m
100m
18ºS
19ºS
20ºS
21ºS
116ºE
117ºE
118ºE
119ºE
120ºE

Figure 18: Spatial distribution of the CPUE (kg trawl hour^{-1}) of *Lutjanus malabaricus* (scarlet seaperch) per block in the fish trawl survey area off the Pilbara coast.



N
W
E
S
Lutjanus malabaricus CPUE (kg/hr)
0 - 5
5 - 20
20 - 50
50 - 100
100 - 150
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
1
2
3
200m
100m
200m
100m
18ºS
19ºS
20ºS
21ºS
116ºE
117ºE
118ºE
119ºE
120ºE

Figure 19: Spatial distribution of the total catch (kg) of *Lutjanus russelli* (Moses perch) per block in the fish trawl survey area off the Pilbara coast.

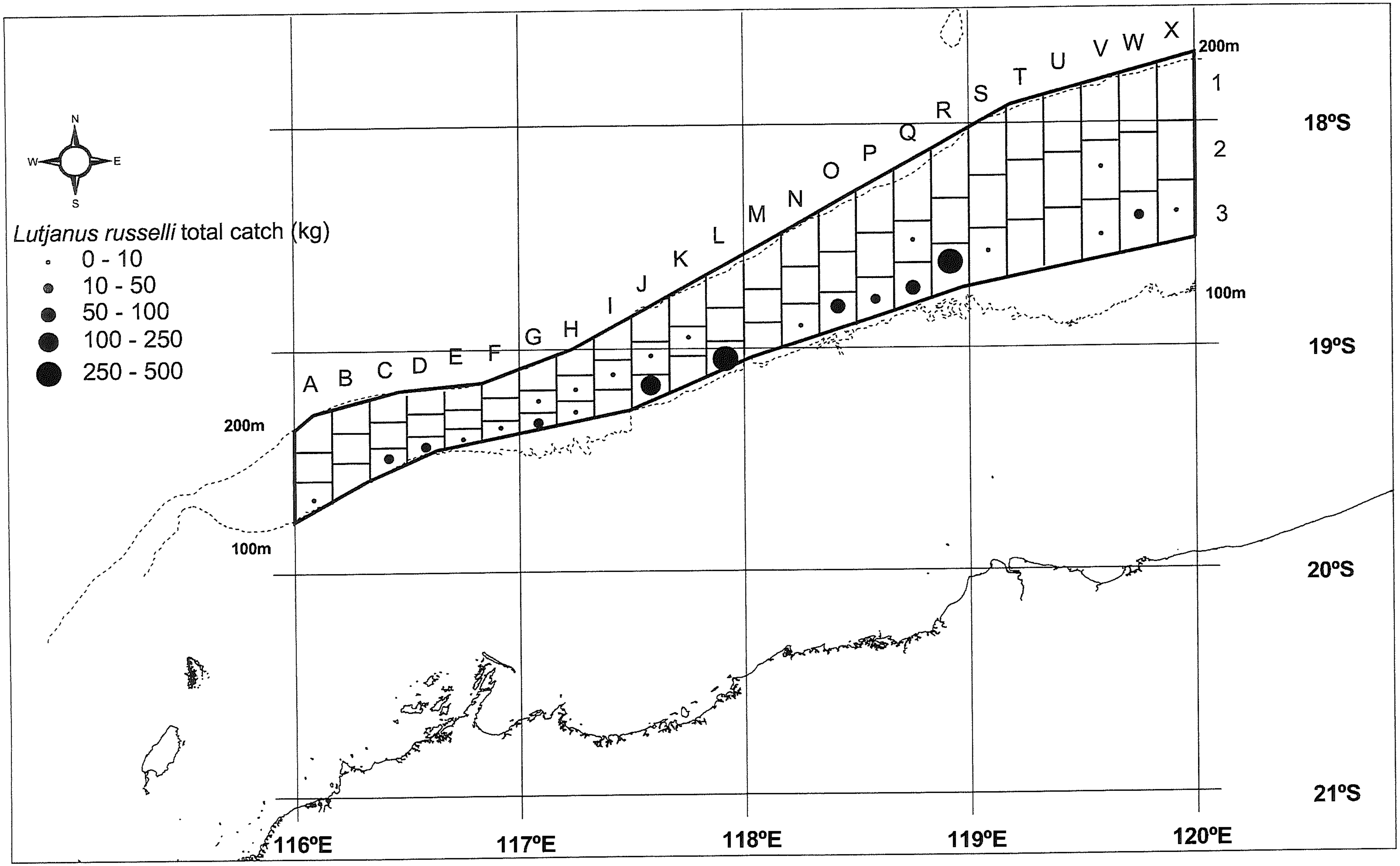
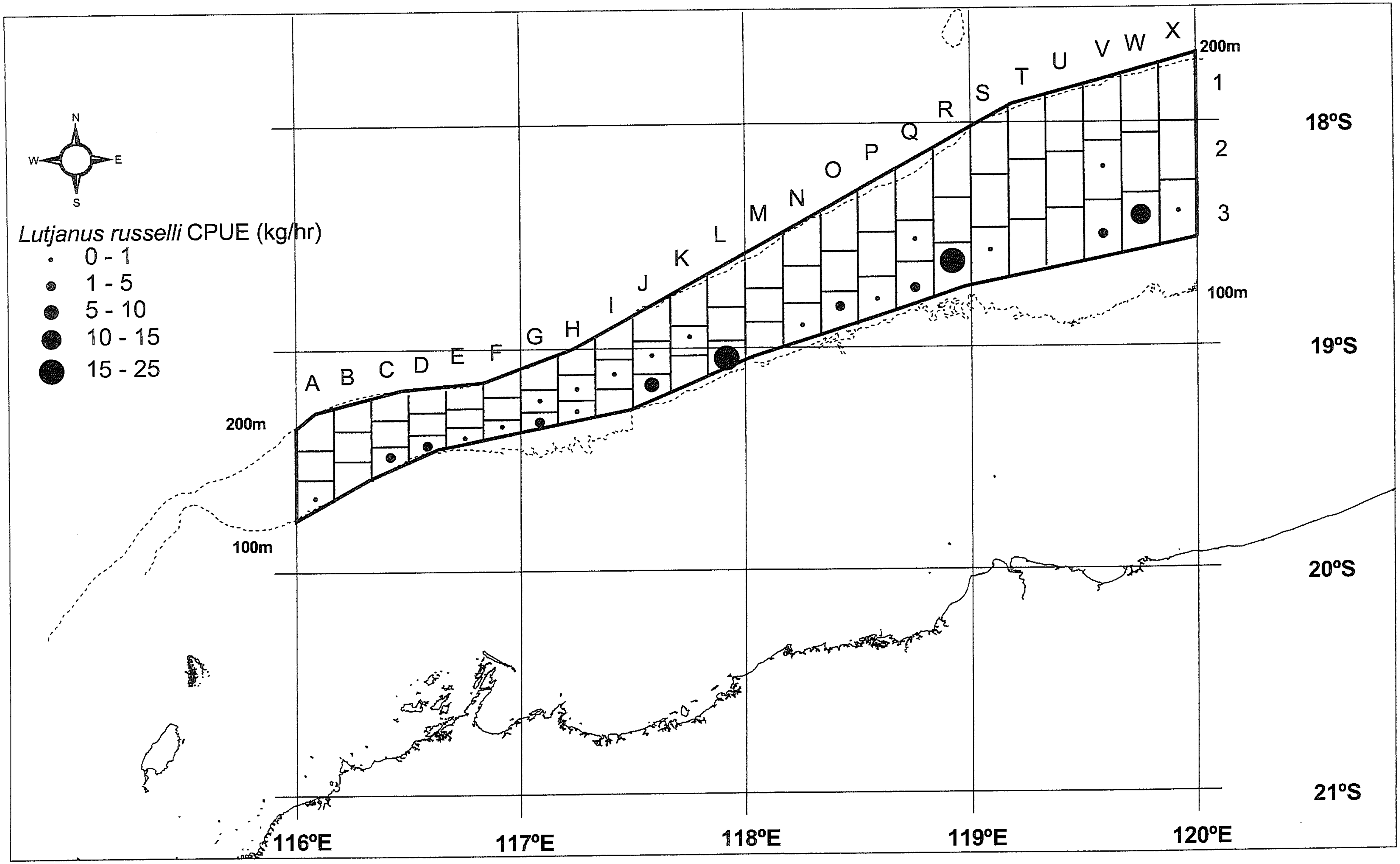

N
W
E
S
Lutjanus russelli total catch (kg)
0 - 10
10 - 50
50 - 100
100 - 250
250 - 500
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
200m
1
2
3
100m
200m
100m
18ºS
19ºS
20ºS
21ºS
116ºE
117ºE
118ºE
119ºE
120ºE

Figure 20: Spatial distribution of the CPUE (kg trawl hour^{-1}) of *Lutjanus russelli* (Moses perch) per block in the fish trawl survey area off the Pilbara coast.



N
W
E
S
Lutjanus russelli CPUE (kg/hr)
0 - 1
1 - 5
5 - 10
10 - 15
15 - 25
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
1
2
3
200m
100m
200m
100m
18ºS
19ºS
20ºS
21ºS
116ºE
117ºE
118ºE
119ºE
120ºE

Figure 21: Spatial distribution of the total catch (kg) of *Pristipomoides multidens* (goldband snapper) per block in the fish trawl survey area off the Pilbara coast.

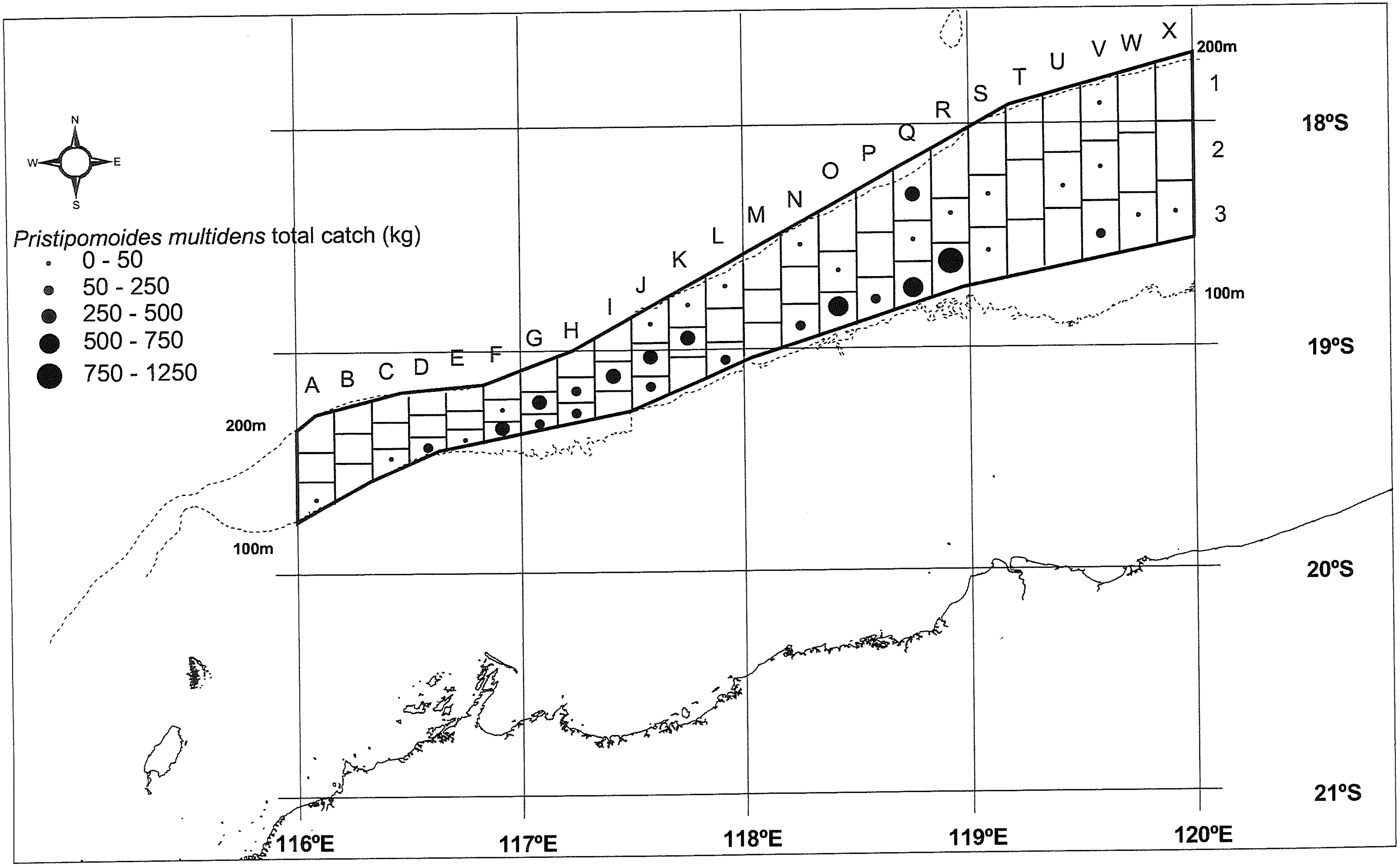

N
W
E
S
Pristipomoides multidens total catch (kg)
0 - 50
50 - 250
250 - 500
500 - 750
750 - 1250
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
1
2
3
200m
100m
200m
100m
18ºS
19ºS
20ºS
21ºS
116ºE
117ºE
118ºE
119ºE
120ºE

Figure 22: Spatial distribution of the CPUE (kg trawl hour^{-1}) of *Pristipomoides multidens* (goldband snapper) per block in the fish trawl survey area off the Pilbara coast.

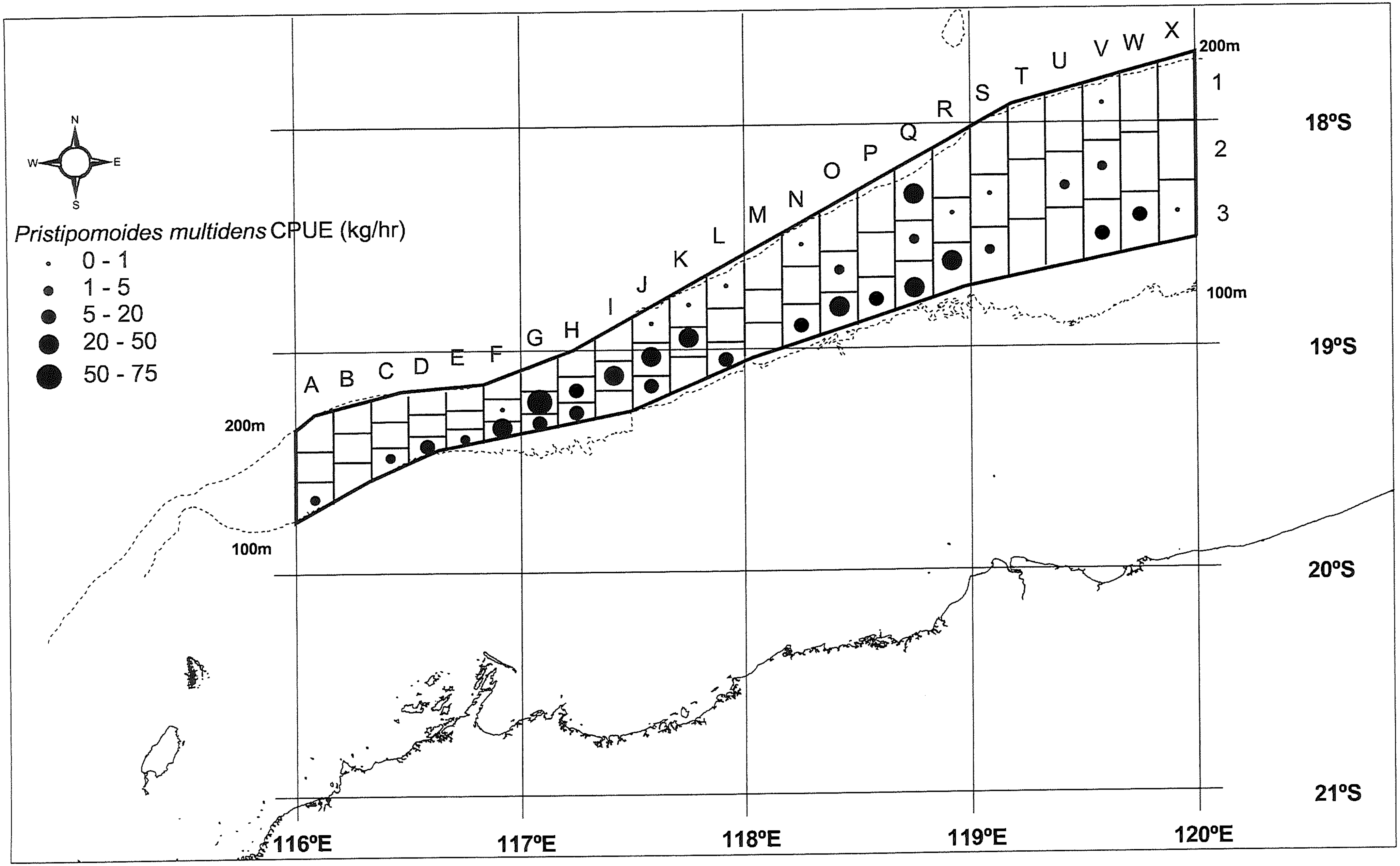

N
S
E
W
Pristipomoides multidens CPUE (kg/hr)
0 - 1
1 - 5
5 - 20
20 - 50
50 - 75
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
1
2
3
200m
100m
200m
100m
18°S
19°S
20°S
21°S
116°E
117°E
118°E
119°E
120°E

Figure 23: Spatial distribution of the total catch (kg) of *Pristipomoides typus* (sharptooth snapper) per block in the fish trawl survey area off the Pilbara coast.

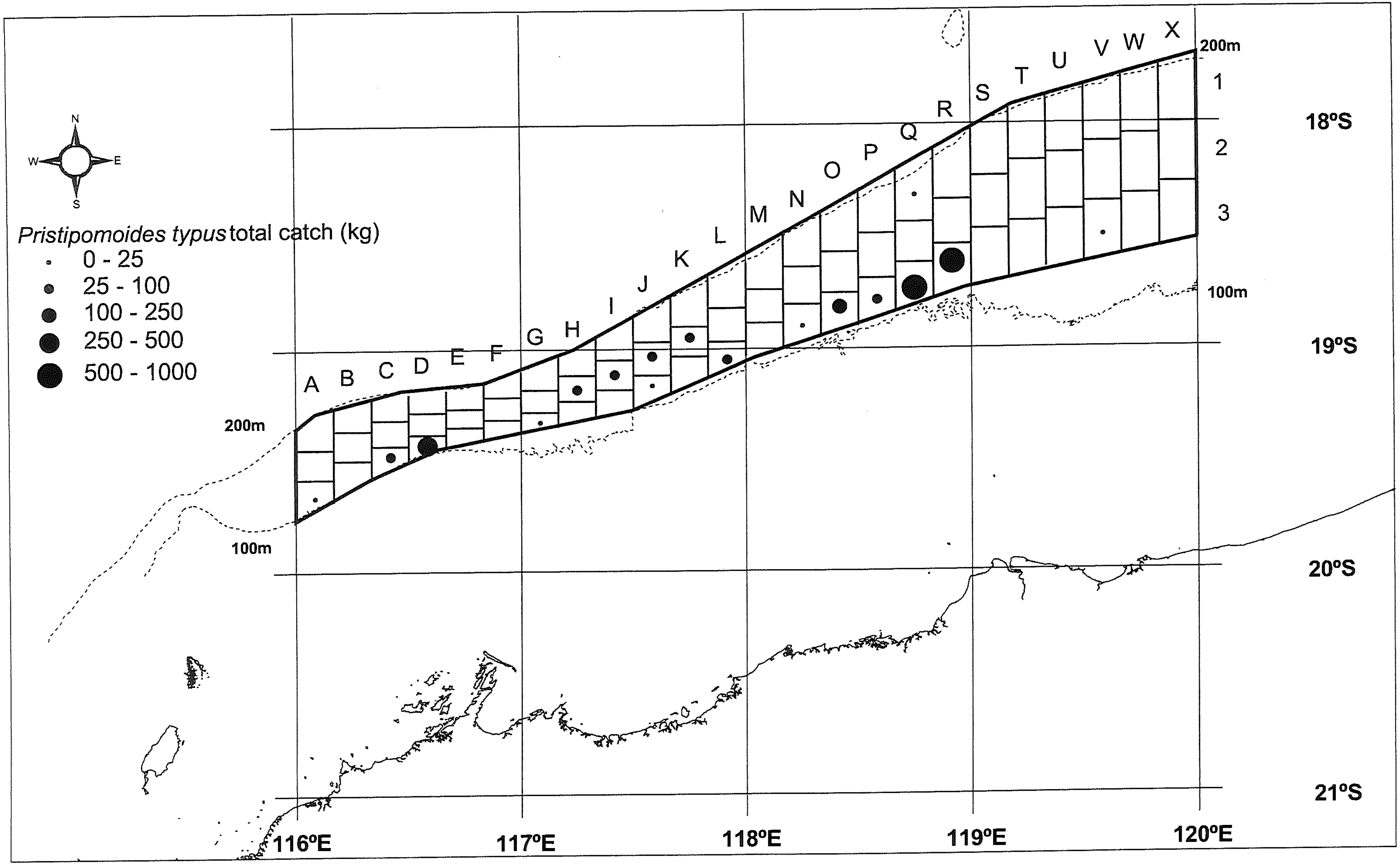
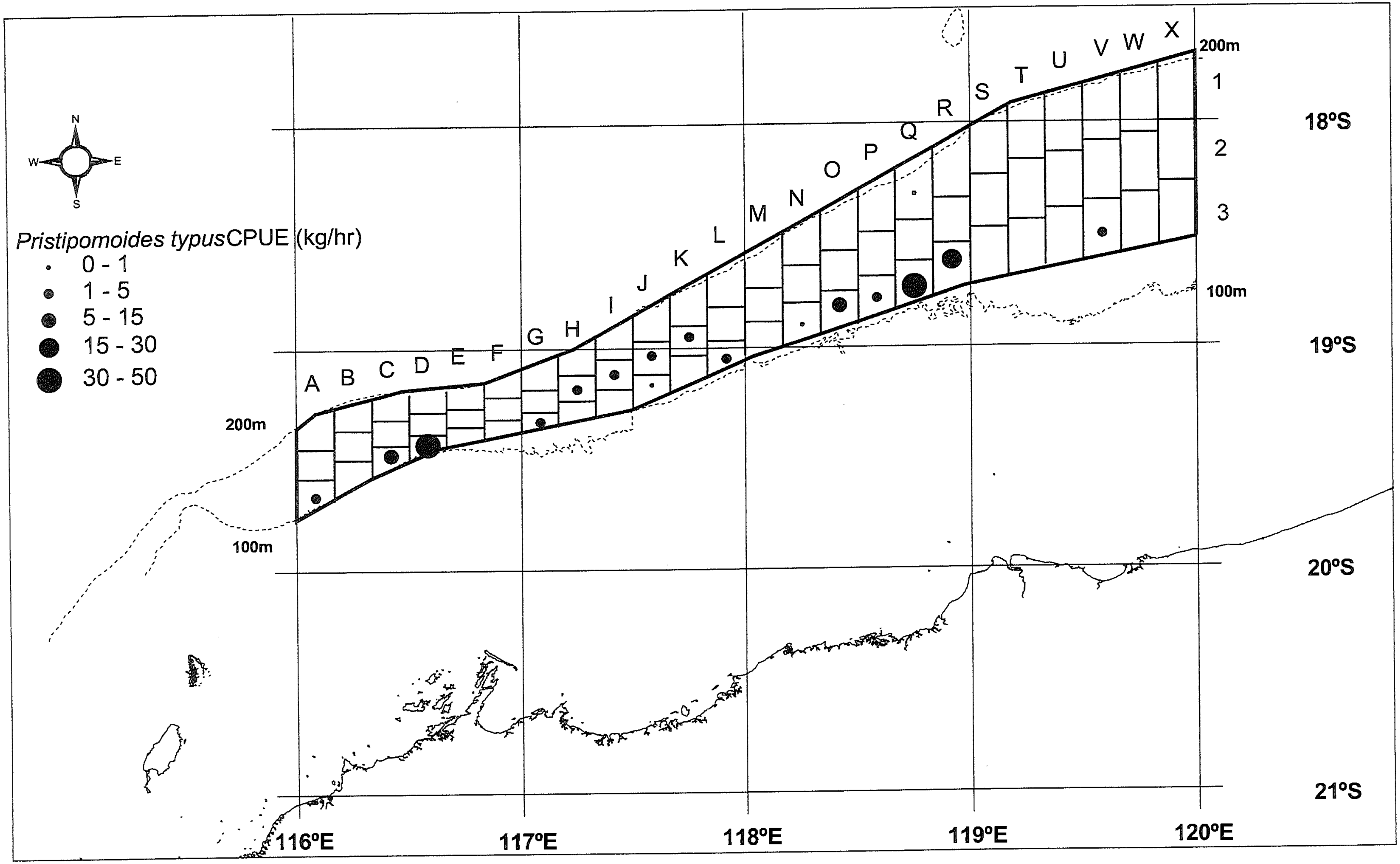

N
W
E
S
Pristipomoides typus total catch (kg)
0 - 25
25 - 100
100 - 250
250 - 500
500 - 1000
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
1
2
3
200m
100m
200m
100m
18ºS
19ºS
20ºS
21ºS
116ºE
117ºE
118ºE
119ºE
120ºE

Figure 24: Spatial distribution of the CPUE (kg trawl hour^{-1}) of *Pristipomoides typus* (sharptooth snapper) per block in the fish trawl survey area off the Pilbara coast.



Pristipomoides typus CPUE (kg/hr)
0 - 1
1 - 5
5 - 15
15 - 30
30 - 50
N
S
E
W
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
1
2
3
200m
100m
200m
100m
18ºS
19ºS
20ºS
21ºS
116ºE
117ºE
118ºE
119ºE
120ºE

Figure 25: Spatial distribution of the total catch (kg) of all Chondrichthyes (sharks and rays) per block in the fish trawl survey area off the Pilbara coast.

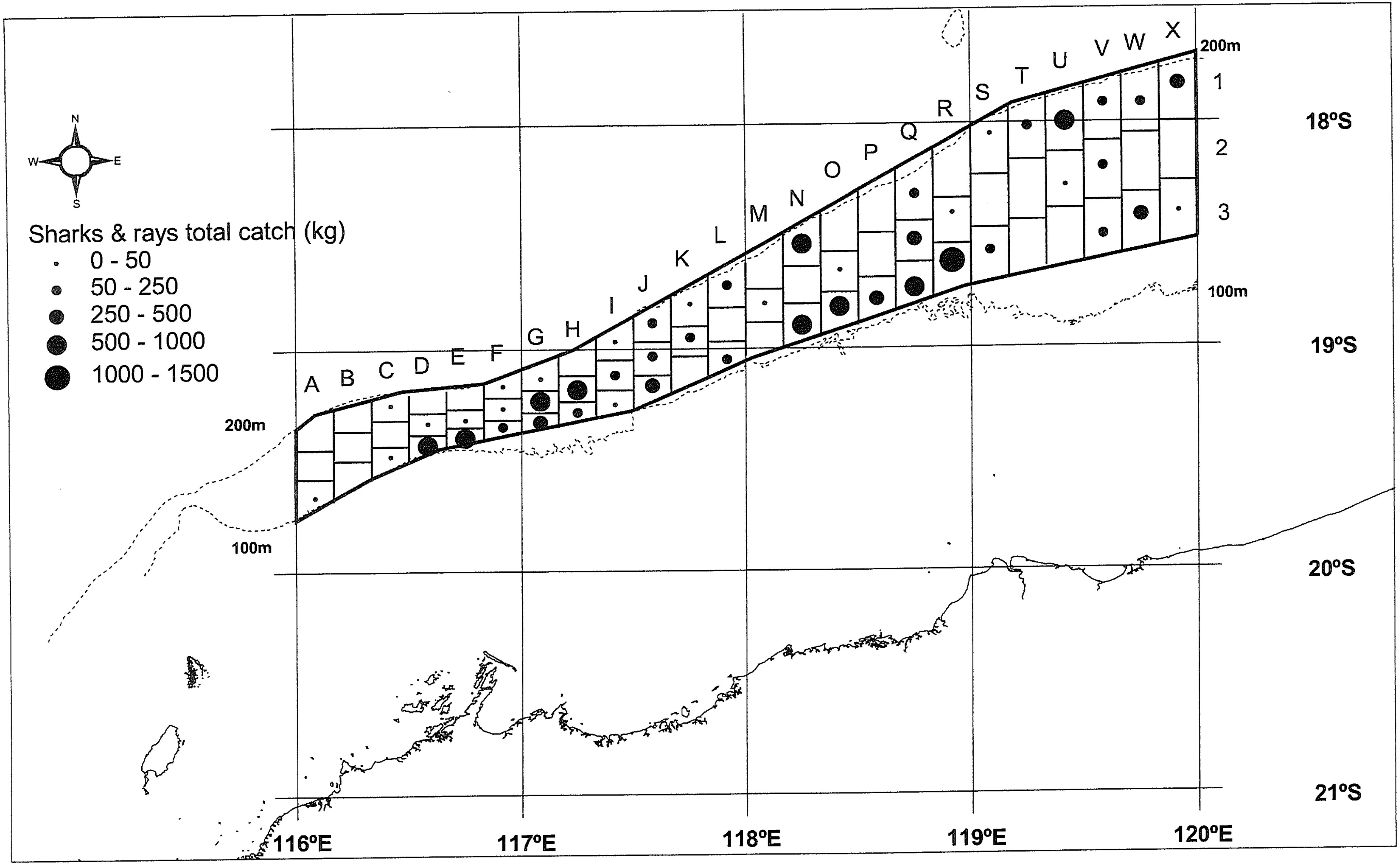

N
W
E
S
Sharks & rays total catch (kg)
0 - 50
50 - 250
250 - 500
500 - 1000
1000 - 1500
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
1
2
3
200m
100m
200m
100m
18ºS
19ºS
20ºS
21ºS
116ºE
117ºE
118ºE
119ºE
120ºE

Figure 26: Spatial distribution of the CPUE (kg trawl hour^{-1}) of all Chondrichthyes (sharks and rays) per block in the fish trawl survey area off the Pilbara coast.

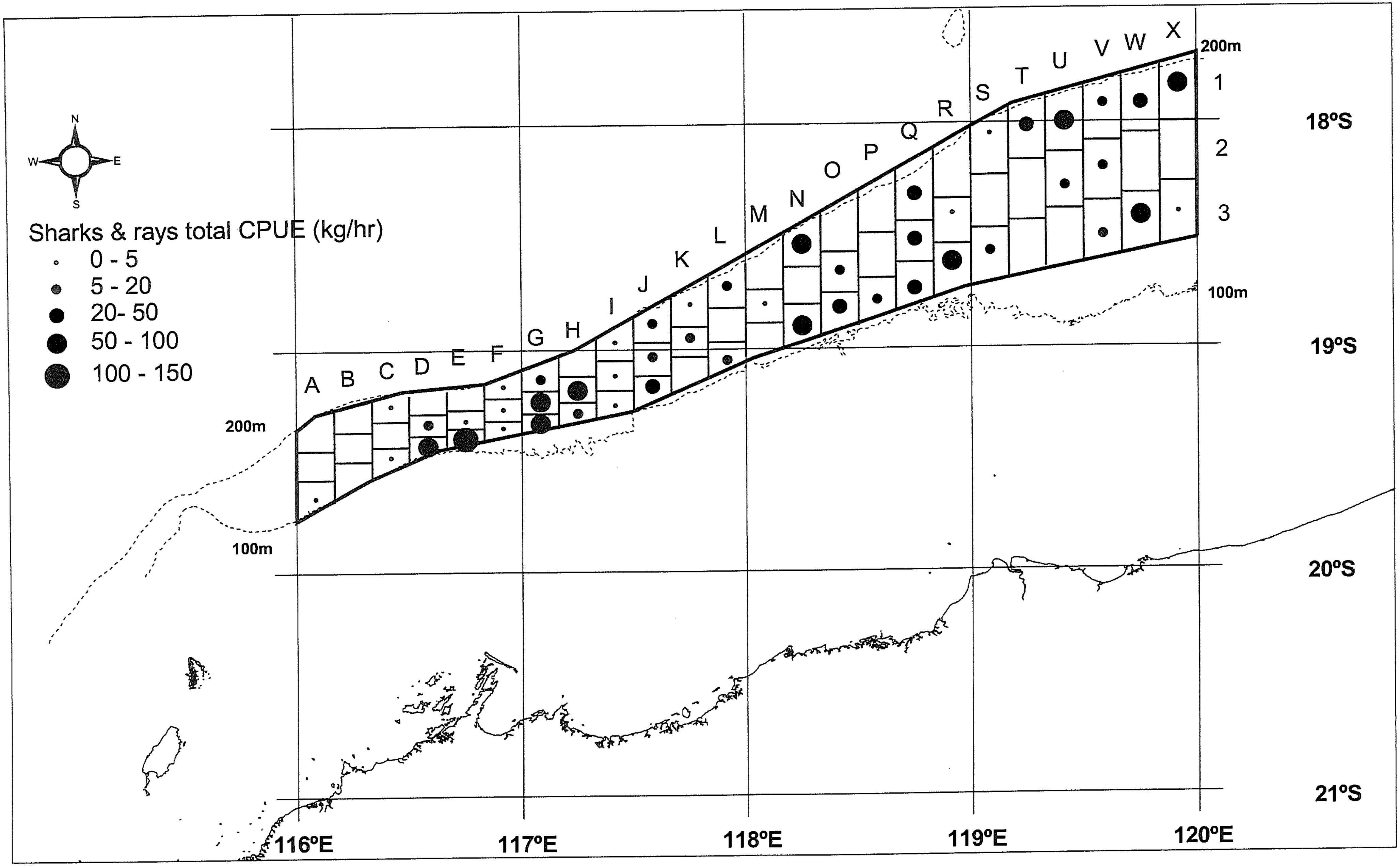

N
W
E
S
Sharks & rays total CPUE (kg/hr)
0 - 5
5 - 20
20- 50
50 - 100
100 - 150
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
1
2
3
200m
100m
200m
100m
18ºS
19ºS
20ºS
21ºS
116ºE
117ºE
118ºE
119ºE
120ºE

Figure 27: Spatial distribution of the total catch (kg) of Chondrichthyes (sharks and rays) of commercial importance per block in the fish trawl survey area off the Pilbara coast.

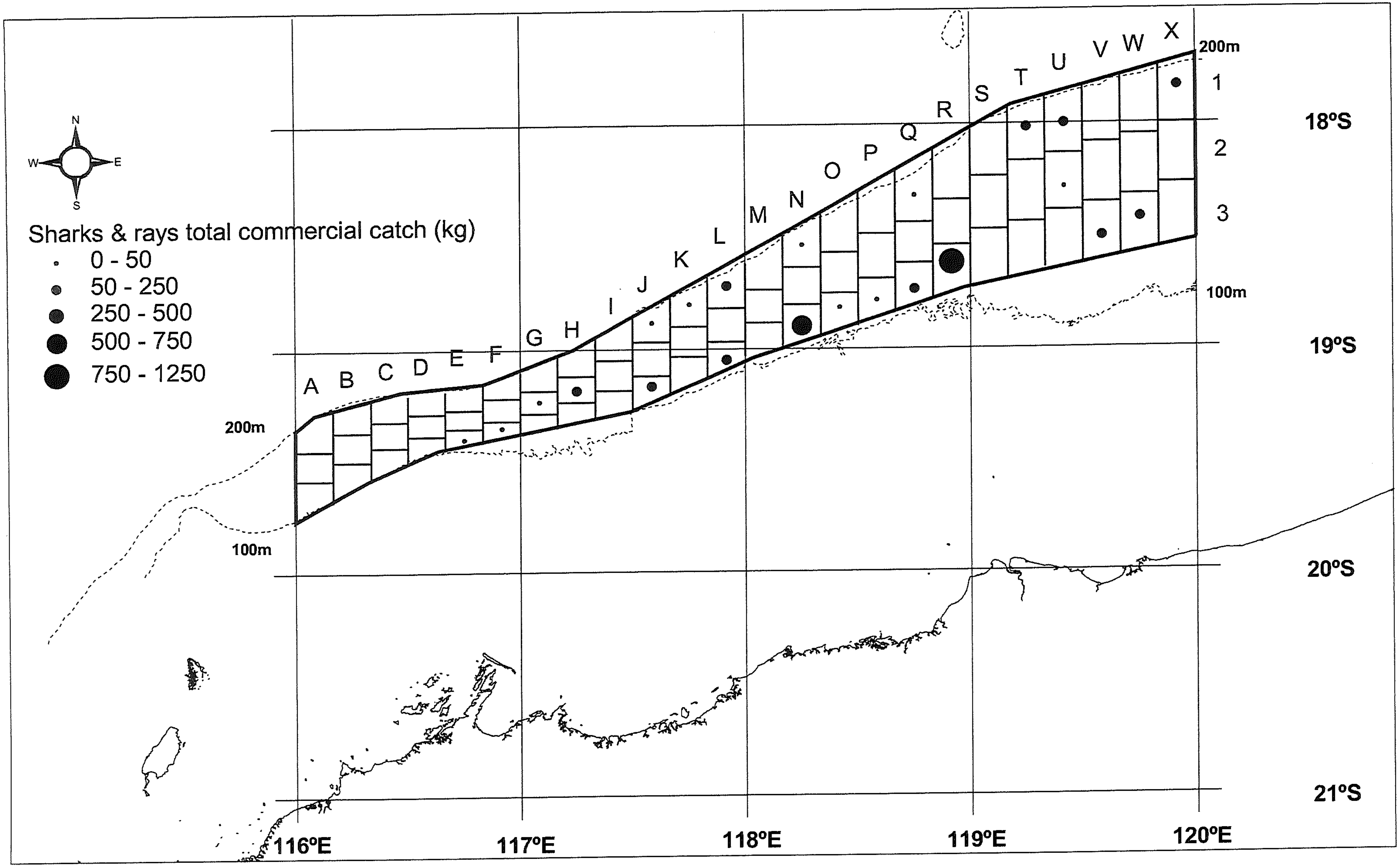

N
W
E
S
Sharks & rays total commercial catch (kg)
0 - 50
50 - 250
250 - 500
500 - 750
750 - 1250
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
1
2
3
200m
100m
200m
100m
18ºS
19ºS
20ºS
21ºS
116ºE
117ºE
118ºE
119ºE
120ºE

Figure 28: Spatial distribution of the CPUE (kg trawl hour^{-1}) of Chondrichthyes (sharks and rays) of commercial importance per block in the fish trawl survey area off the Pilbara coast.

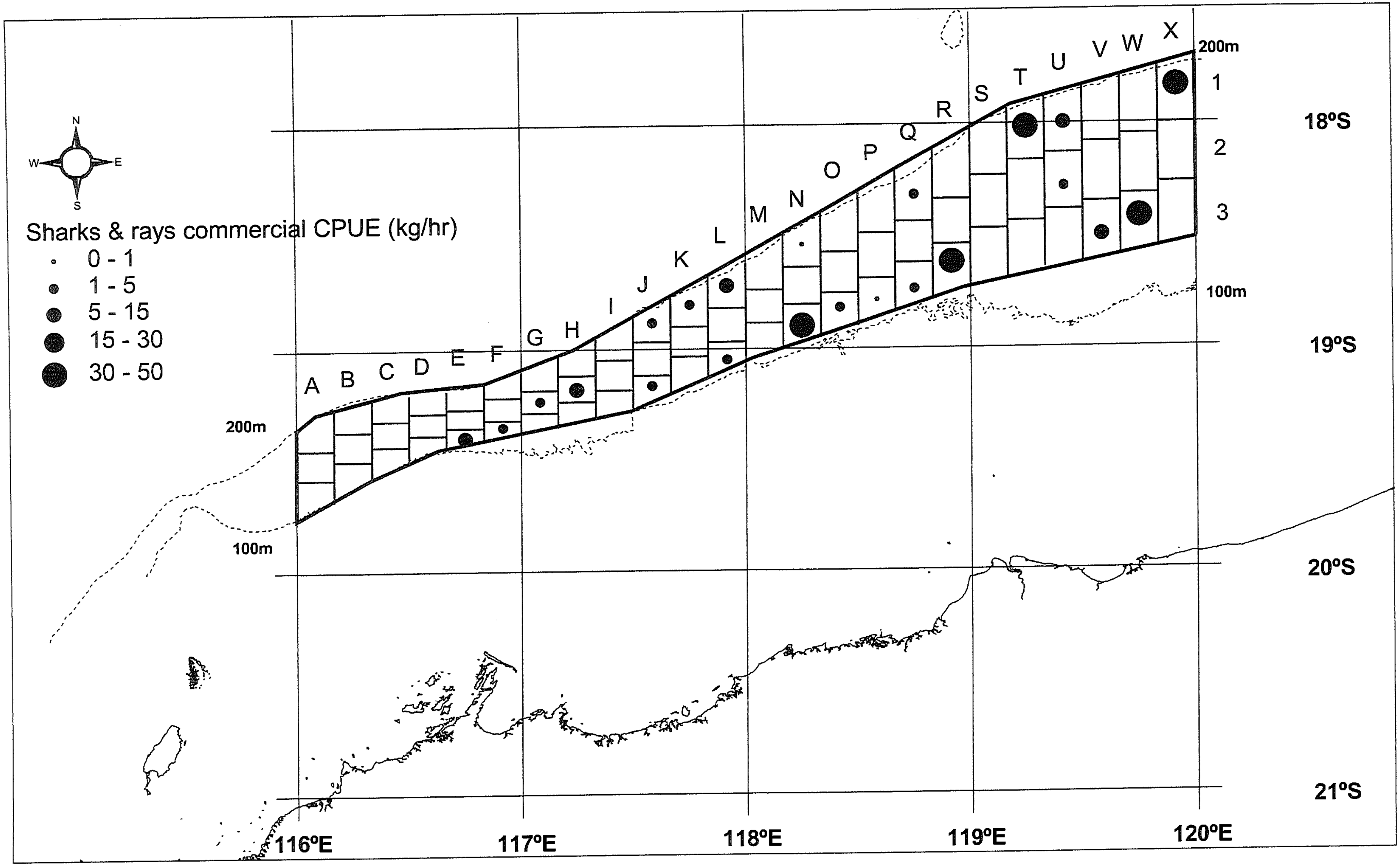

N
W
E
S
Sharks & rays commercial CPUE (kg/hr)
0 - 1
1 - 5
5 - 15
15 - 30
30 - 50
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
1
2
3
200m
100m
200m
100m
18ºS
19ºS
20ºS
21ºS
116ºE
117ºE
118ºE
119ºE
120ºE

Figure 29: Spatial distribution of the total catch (kg) of non-commercial Chondrichthyes (sharks and rays) per block in the fish trawl survey area off the Pilbara coast.

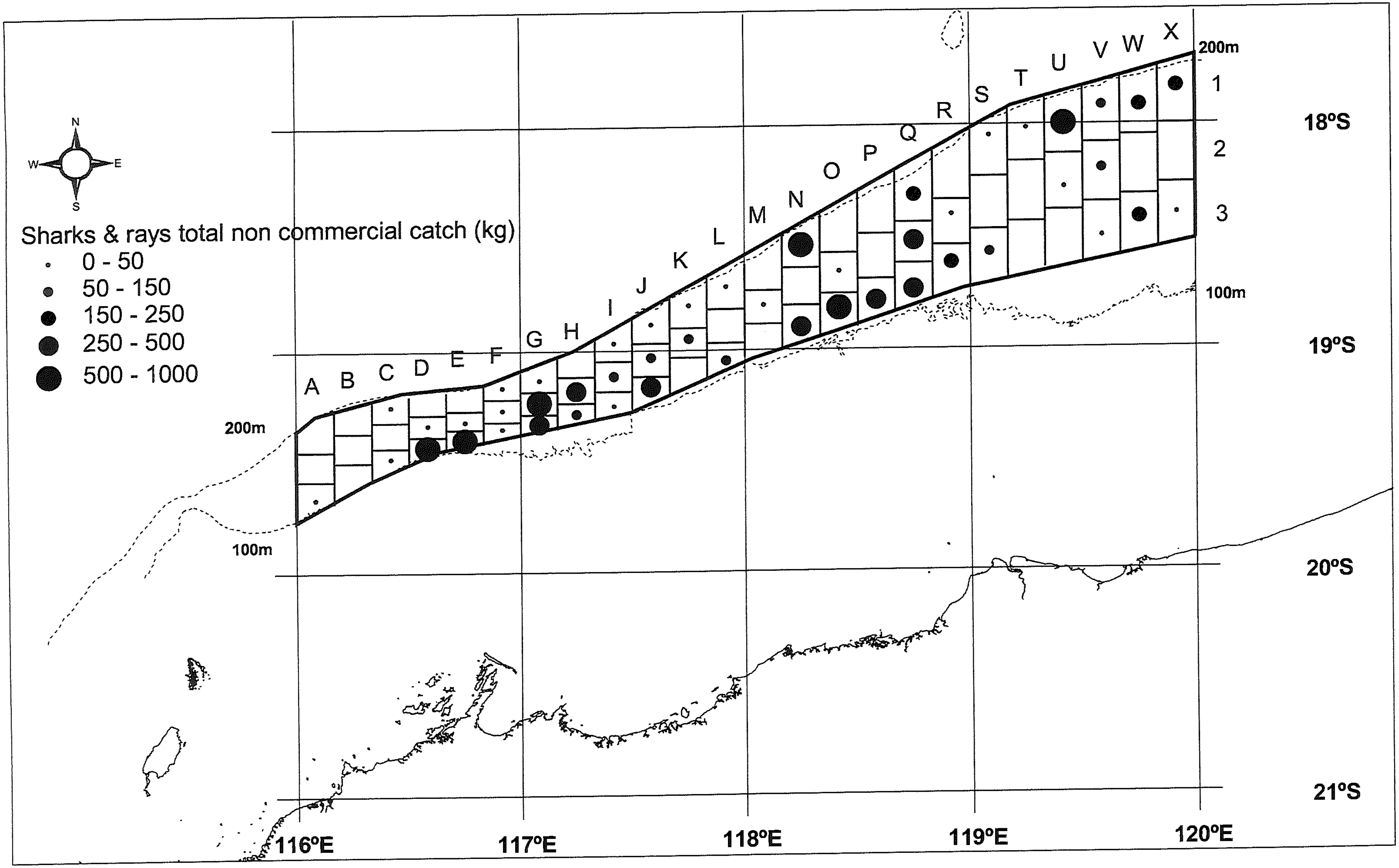
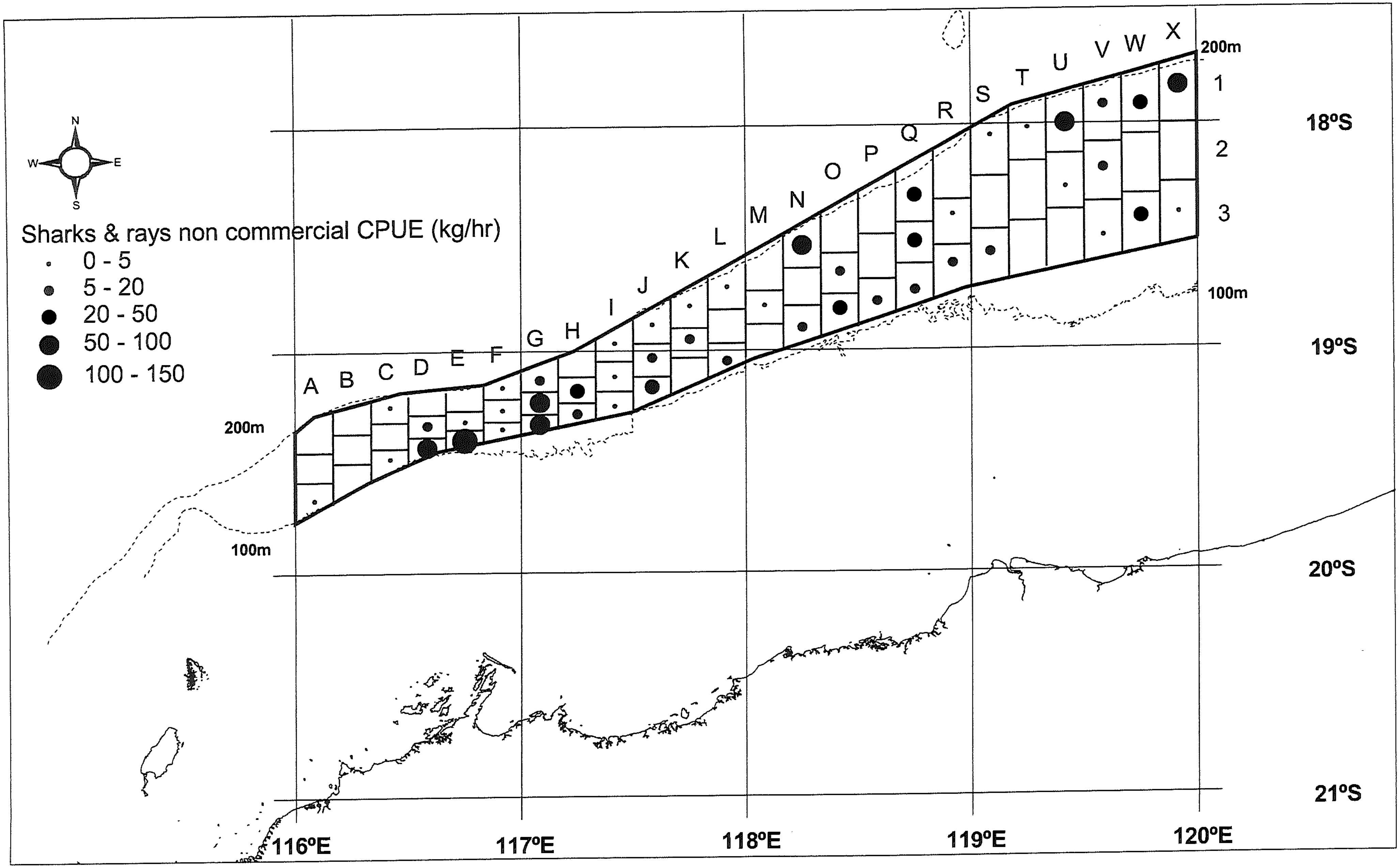

N
W
E
S
Sharks & rays total non commercial catch (kg)
0 - 50
50 - 150
150 - 250
250 - 500
500 - 1000
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
1
2
3
200m
100m
200m
100m
18ºS
19ºS
20ºS
21ºS
116ºE
117ºE
118ºE
119ºE
120ºE

Figure 30: Spatial distribution of the CPUE (kg trawl hour^{-1}) of non-commercial Chondrichthyes (sharks and rays) per block in the fish trawl survey area off the Pilbara coast.


N
W
E
S
Sharks & rays non commercial CPUE (kg/hr)
0 - 5
5 - 20
20 - 50
50 - 100
100 - 150
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
1
2
3
200m
100m
200m
100m
18ºS
19ºS
20ºS
21ºS
116ºE
117ºE
118ºE
119ºE
120ºE

Appendix 5: Provisional species list of the fish fauna from the 100-200 m depth zone off the Pilbara coast of Western Australia (includes common names, Australian Aquatic Biota Codes [CAAB] - Yearsley et al., 1997; Rees et al., 1999 and preferred common names if different).

Scientific Name (* denotes commercial species)	**Authority**	**Common Name (local)**	**CAAB Code**	**CAAB Common Name (if different)**
Chondrichthyes				
Heterodontidae: Horn Sharks				
Heterodontidae spp.	Undifferentiated	Horn Sharks	37 007000	
Heterodontus zebra	(Gray, 1831)	Zebra Horn Shark	37 007002	
Odontaspididae: Grey Nurse Sharks				
Carcharias taurus	Rafinesque, 1810	Grey Nurse Shark	37 008001	
Alopiidae: Thresher Sharks				
Alopias spp.	Undifferentiated	Thresher Sharks	37 012000	
Stegostomatidae: Zebra Sharks				
Stegostoma fasciatum	(Hermann, 1783)	Leopard Shark	37 013006	Zebra Shark
Scyliorhinidae: Cat Sharks				
Scyliorhinidae spp.	Undifferentiated	Cat Sharks	37 015000	
Halaelurus boesemani	Springer & D'Aubrey, 1972	Speckled Cat Shark	37 015004	Banded Cat Shark
Triakidae: Hound Sharks				
* Triakidae spp.	Undifferentiated	Hound Sharks	37 017000	
Carcharhinidae: Whaler Sharks				
* Carcharhinidae spp.	Undifferentiated	Whaler Sharks	37 018000	
Negaprion acutidens	(Rüppell, 1837)	Lemon Shark	37 018029	
Sphyrnidae: Hammerhead Sharks				
* Sphyrnidae spp.	Undifferentiated	Hammerhead Sharks	37 019000	
Squalidae: Dogfishes				
* Squalidae spp.	Undifferentiated	Dogfishes	37 020000	
Squalus spp.	Undifferentiated	Greeneye Dogfishes	37 020901	
Squatinidae: Angel Sharks				
Squatina sp. B	[in Last & Stevens, 1994]	Western Angel Shark	37 024005	

Appendix 5: cont.

Scientific Name (* denotes commercial species)	Authority	Common Name (local)	CAAB Code	CAAB Common Name (if different)
Pristidae: Sawfishes				
* *Pristis* spp.	Undifferentiated	Sawfishes	37 025000	
Rhynchobatidae: Sharkfin Guitarfishes				
* Rhynchobatidae spp.	Undifferentiated	Sharkfin Guitarfishes	37 026000	
* *Rhynchobatus djiddensis*	(Forsskål, 1775)	White-spotted Guitarfish	37 026001	Giant shovelnose Ray
Rhina ancylostoma	Bloch & Schneider, 1801	Shark Ray	37 026002	
Rhinobatidae: Shovelnose Rays				
* Rhinobatidae spp.	Undifferentiated	Shovelnose Rays	37 027000	
Rajidae: Skates				
Rajidae spp.	Undifferentiated	Skates	37 031000	
Raja sp. D	[in Last & Stevens, 1994]	False Argus Skate	37 031030	Blotched Skate
Dasyatididae: Stingrays				
Dasyatididae spp.	Undifferentiated	Stingrays	37 035000	
Dasyatis annotata	Last, 1987	Plain Maskray	37 035012	
Dasyatis leylandi	Last, 1987	Painted Maskray	37 035013	
Dasyatis thetidis	Ogilby, 1899	Black Stingray	37 035002	
Himantura toshi	(Gray, 1831)	Black-spotted Whipray	37 035020	
Gymnuridae: Butterfly Rays				
Gymnura australis	(Ramsay & Ogilby, 1886)	Australian Butterfly Ray	37 037001	
Urolophidae: Stingarees				
Urolophidae spp.	Undifferentiated	Stingarees	37 038000	
Urolophus flavomosaicus	Last & Gomon, 1987	Patchwork Stingaree	37 038010	
Urolophus westraliensis	Last & Gomon, 1987	Brown Stingaree	37 038009	
Myliobatididae: Eagle Rays				
Myliobatididae spp.	Undifferentiated	Eagle Rays	37 039000	

Appendix 5: cont.

Scientific Name (* denotes commercial species)	Authority	Common Name (local)	CAAB Code	CAAB Common Name (if different)
Rays: All species grouped (Dasyatididae, Gymnuridae, Hexatrygonidae, Myliobatididae and Urolophidae)				
Rays, all spp.	Undifferentiated	Rays, all spp.	37 990001	
Chimaeridae: Shortnose Chimaeras				
* *Hydrolagus lemures*	(Whitley, 1939)	Blackfin Ghost Shark	37 042003	

Actinopterygii

Scientific Name	Authority	Common Name (local)	CAAB Code	CAAB Common Name (if different)
Muraenesocidae: Pike Eels				
* *Muraenesox cinereus*	(Forsskål, 1775)	Dark-finned Pike Eel	37 063002	
Oxyconger leptognathus	(Bleeker, 1858)	Large-eyed Pike Eel	37 063001	
Nettastematidae: Duckbill Eels				
Nettastomatidae spp.	Undifferentiated	Duckbill Eels	37 065000	
Clupeidae: Herrings, Sardines and Pilchards				
Dussumieria elopsoides	Bleeker, 1849	Slender Rainbow Sardine	37 085010	Sharp-nosed Sprat
Engraulididae: Anchovies				
Stolephorus indicus	(van Hasselt, 1823)	Indian Anchovy	37 086006	
Synodontidae: Lizardfishes				
Saurida filamentosa	Ogilby, 1910	White-spotted Lizardfish	37 118006	
Saurida micropectoralis	Shindo & Yamada, 1972	Lizardfish, Short-finned	37 118005	
Saurida spp.	Undifferentiated	Deepsea Lizardfishes	37 118901	
Saurida tumbil	(Bloch, 1795)	Common Grinner	37 118028	Lizardfish sp.
Saurida undosquamis	(Richardson, 1848)	Checkered Lizardfish	37 118001	Brushtooth Lizardfish
Synodus macrops	Tanaka, 1917	Enigmatic Lizardfish	37 118012	
Trachinocephalus myops	(Forster, 1801)	Painted Saury	37 118002	
Chlorophthalmidae: Greeneyes				
Chlorophthalmidae spp.	Undifferentiated	Greeneyes or Cucumberfishes	37 120000	

Appendix 5: cont.

Scientific Name (* denotes commercial species)	**Authority**	**Common Name (local)**	**CAAB Code**	**CAAB Common Name (if different)**
Ateleopodidae: Jellynosefishes				
Atelopus spp.	Undifferentiated	Jellynosefishes	37 136000	
Ariidae: Catfishes				
* *Netuma thalassinus*	(Ruppell, 1837)	Giant Salmon Catfish	37 188001	Common Forktailed Catfish
Batrachoididae: Frogfishes				
Batrachomoeus occidentalis	Hutchins, 1976	Western Frogfish	37 205001	
Lophiidae: Bottom-dwelling Monkfishes				
Lophiomus setigerus	(Vahl, 1797)	Goosefish	37 208001	Handfish sp.
Ogcocephalidae: Batfishes and Handfishes				
Ogcocephalidae spp.	Undifferentiated	Batfishes, Handfishes	37 212000	
Halieutaea stellata	(Vahl, 1797)	Starry Handfish	37 212002	
Moridae: Morid Cods				
Mora moro	(Risso, 1810)	Ribaldo	37 224002	
Ophidiidae: Lings				
* Ophidiidae spp.	Undifferentiated	Lings	37 228000	
Brotula multibarbata	Temminck & Schlegel, 1847	Bearded Cusk Eel	37 228012	none
Ophidion muraenolepis	(Gunther, 1880)	Black-edged Cusk Eel	37 228006	none
Sirembo imberbis	(Temminck & Schlegel, 1847)	Golden Cusk Eel	37 228005	Ass-Fish
* *Spottobrotula amaculata*	Cohen & Nielsen, 1982	Ling sp.	37 228010	
Macrouridae: Whiptails				
Macrouridae spp.	Undifferentiated	Whiptails	37 232000	
Polymixiidae: Beardfishes				
Polymixia berndti	Gilbert, 1905	Pacific Beardfish	37 253001	
Monocentrididae: Pineapplefishes				
Monocentris japonica	(Houttuyn, 1782)	Japanese Pineapplefish	37 259002	

Appendix 5: cont.

Scientific Name (* denotes commercial species)	Authority	Common Name (local)	CAAB Code	CAAB Common Name (if different)
Holocentridae; Squirrelfishes and Soldierfishes				
Holocentridae spp.	Undifferentiated	Squirrelfishes, Soldierfishes	37 261000	
Myripristis botche	Cuvier, 1829	Pale Soldierfish	37 261004	none
Ostichthys japonicus	(Cuvier, 1829)	Japanese Squirrelfish	37 261003	Northwest Red Fish
* *Ostichthys kaianus*	(Gunther, 1880)	Kai Islands Squirrelfish	37 261005	none
Sargocentron lepros	(Allen & Cross, 1983)	Sandpaper Squirrelfish	37 261025	none
Sargocentron rubrum	(Forsskål, 1775)	Red Squirrelfish	37 261001	
Zeidae: Dories				
* *Zenopsis nebulosus*	(Temminck & Schlegel, 1845)	Mirror Dory	37 264003	
Zeus faber	Linnaeus, 1758	John Dory	37 264004	
Caproidae: Boarfishes				
Antigonia rhomboidea	McCulloch, 1915	Pink Boarfish	37 267001	Rhomboidal Boarfish
Veliferidae: Veilfins				
Velifer hypselopterus	Bleeker, 1879	High-finned Veilfin	37 269002	Sail Veilfin
Fistulariidae: Flutemouths				
Fistularia commersonii	Ruppell, 1838	Smooth Flutemouth	37 278001	
Fistularia petimba	Lacepede, 1803	Rough Flutemouth	37 278002	
Syngnathidae: Pipefishes and Seahorses				
Solegnathus hardwickii	(Gray, 1830)	Pallid Pipefish	37 282099	none
Scorpaenidae: Scorpionfishes				
* Scorpaenidae spp.	Undifferentiated	Scorpionfishes	37 287000	
Neocentropogon aeglefinis	(Weber, 1913)	Scorpionfish sp.	37 287034	
Neomerinthe amplisquamiceps	(Fowler, 1938)	Orange Scorpionfish	37 287039	none
Neosebastes entaxis	Jordan & Starks, 1904	Orange-banded Scorpionfish	37 287009	Orange Scorpionfish
Pterois russelli	Bennett, 1831	Spotless Firefish	37 287012	none

Appendix 5: cont.

Scientific Name (* denotes commercial species)	Authority	Common Name (local)	CAAB Code	CAAB Common Name (if different)
Pterois volitans	(Linnaeus, 1758)	Red Firefish	37 287040	
Scorpaenodes smithi	Eschmeyer & Rama-Rao, 1972	Little Scorpionfish	37 287032	Blackspot Scorpionfish
Setarches longimanus	(Alcock, 1894)	Red Scorpionfish	37 287013	none
Tetraroge sp.	Unidentified	Scorpionfish sp. (id. code PDW68)		
Triglidae: Gurnards				
Triglidae spp.	Undifferentiated	Gurnards	37 288000	
Lepidotrigla argus	Ogilby, 1910	Long-finned Gurnard	37 288032	none
Lepidotrigla cf. *bispinosa*	[Gomon, pers. comm.]	Red-fringed Gurnard	37 288017	
Lepidotrigla grandis	Ogilby, 1910	Supreme Gurnard	37 288033	none
Lepidotrigla russelli	del Cerro & Lloris, 1995	Blue-fringed Gurnard	37 288016	
Lepidotrigla sp. 2	[in Sainsbury et al, 1985]	Thin-finned Gurnard	37 288015	Mottled Red Spot Gurnard
Lepidotrigla spp.	Undifferentiated	Butterfly Gurnards	37 288901	
Pterygotrigla hemisticta	(Temminck & Schlegel, 1844)	Half-spotted Gurnard	37 288009	Northwest Latchet
Pterygotrigla leptacanthus	(Gunther, 1880)	Black-finned Gurnard	37 288014	Dark Fin Gurnard
Satyrichthys rieffeli	(Kaup, 1859)	Spotted Armoured Gurnard	37 288023	none
Satyrichthys spp.	Undifferentiated	Armoured Gurnards (id. code PDW18)	unassigned	
Satyrichthys welchi	(Herre, 1925)	Robust Armoured Gurnard	37 288019	none
Aploactinidae: Velvetfishes				
Erisphex aniarus	(Thomson, 1967)	Dark-finned Velvetfish	37 290002	Marbled Wasp Fish
Platycephalidae: Flatheads				
Bembras longipinnis	Imamura & Knapp, 199	Green-spotted Flathead	37 296026	
Elates ransonnetii	(Steindachner, 1877)	Dwarf Flathead	37 296013	
Inegocia japonica	(Tilesius, 1812)	Rusty Flathead	37 296029	
Ratabulus diversidens	(McCulloch, 1914)	Orange-freckled Flathead	37 296011	

Appendix 5: cont.

Scientific Name (* denotes commercial species)	Authority	Common Name (local)	CAAB Code	CAAB Common Name (if different)
Dactylopteridae: Flying Gurnards				
Dactyloptena macracanthus	(Bleeker, 1854)	Mottled Flying Gurnard	37 308003	
Dactyloptena orientalis	(Cuvier, 1829)	Oriental Sea-robin	37 308004	none
Dactyloptena papilio	Ogilby, 1910	Large-spotted Flying Gurnard	37 308001	
Dactyloptena peterseni	(Nystrom, 1887)	One-spined Flying Gurnard	37 308002	
Dactyloptena spp.	Undifferentiated	Flying Gurnards	37 308000	
Serranidae: Rock Cods (Groupers)				
* *Cephalopholis sonnerati*	(Valenciennes, 1828)	Tomato Cod	37 311045	Tomato Grouper
* *Cromileptes altivelis*	(Valenciennes, 1828)	Barramundi Cod	37 311044	Humpback Grouper
* *Epinephelus amblycephalus*	(Bleeker, 1857)	Yellow-lipped or Blunt-headed Cod	37 311015	Bighead Grouper
* *Epinephelus areolatus*	(Forsskål, 1775)	Yellow-spotted Rock Cod	37 311009	Areolate Grouper
* *Epinephelus bilobatus*	Randall & Allen, 1987	Frostback Cod	37 311062	Twinspot Grouper
* *Epinephelus bleekeri*	(Vaillant, 1877)	Duskytail Groper	37 311041	Bleeker's Grouper
* *Epinephelus coioides*	(Hamilton, 1822)	Estuary Cod	37 311007	Orange-spotted Grouper
* *Epinephelus epistictus*	(Temminck & Schlegel, 1843)	Black-dotted Rock Cod	37 311046	Spottedback Grouper
* *Epinephelus heniochus*	Fowler, 1904	Three-lined Rock Cod	37 311019	Bridled Grouper
* *Epinephelus latifasciatus*	(Temminck & Schlegel, 1843)	Spotty-finned Rock Cod	37 311043	Banded Grouper
* *Epinephelus malabaricus*	(Bloch & Schneider, 1801)	Greasy or Slimy Cod	37 311150	Malabar Groper
* *Epinephelus morrhua*	(Valenciennes, 1833)	Comet Groper	37 311151	Comet Grouper
* *Epinephelus multinotatus*	(Peters, 1877)	Rankin Cod	37 311010	White-blotched Grouper
* *Epinephelus radiatus*	(Day, 1868)	Radiant Cod	37 311042	Oblique-banded Grouper
* *Epinephelus sexfasciatus*	(Kuhl & van Hasselt, 1828)	Six-banded Rock Cod	37 311017	Sixbar Grouper
Acropomatidae: Lanternbellies and Temperate Ocean-basses				
Acropoma japonicum	Gunther, 1859	Japanese Bass	37 311167	
Doederleinia berycoides	(Hilgendorf, 1879)	Rosy Sea Bass	37 311025	Rosy Bass

Appendix 5: cont.

Scientific Name (* denotes commercial species)	**Authority**	**Common Name (local)**	**CAAB Code**	**CAAB Common Name (if different)**
Glaucosomatidae: Pearl Perches				
* *Glaucosoma buergeri*	Richardson, 1845	Pearl Perch	37 320001	Northern Jewfish
* *Glaucosoma magnificum*	(Ogilby, 1915)	Threadfin Pearl Perch	37 320002	
Teraponidae: Grunters				
Terapon jarbua	(Forsskål, 1775)	Crescent Grunter Perch	37 321002	Concave Striped Grunter
Banjosidae: Banjosids				
* *Banjos banjos*	(Richardson, 1846)	Banjofish	37 322001	
Priacanthidae: Bigeyes				
Cookeolus japonicus	(Cuvier, 1829)	Long-finned Bigeye	37 326002	Long-finned Bullseye
* *Priacanthus hamrur*	(Forsskål, 1775)	Lunar-tailed Bigeye	37 326005	Black Spot Bigeye
* *Priacanthus macracanthus*	Cuvier, 1829	Red Bigeye	37 326001	
* *Priacanthus* spp.	Undifferentiated	Bigeyes	37 326901	
* *Priacanthus tayenus*	Richardson, 1846	Threadfin Bigeye	37 326003	
Pristigenys niphonia	(Cuvier, 1829)	White-striped Bigeye	37 326006	
Apogonidae: Cardinalfishes				
Apogonidae spp.	Undifferentiated	Cardinalfishes	37 327000	
Apogon carinatus	Cuvier, 1828	Ocellated Cardinalfish	37 327027	
Apogon fasciatus	(Shaw, 1790)	Broad-banded Cardinalfish	37 327008	Twin-striped Cardinalfish
Apogon poecilopterus	Cuvier, 1828	Pearly-finned Cardinalfish	37 327026	
Apogon semilineatus	Schlegel, 1843	Black-tipped Cardinalfish	37 327004	
Malacanthidae: Tilefishes				
* *Branchiostegus sawakinensis*	Amirthalingam, 1969	Blunt-headed Tilefish	37 331001	
Rachycentridae: Black Kingfishes				
* *Rachycentron canadum*	(Linnaeus, 1766)	Cobia	37 335001	Black Kingfish
Echeneidae: Suckerfishes				
Echeneis naucrates	Linnaeus, 1758	Slender Suckerfish	37 336001	

Appendix 5: cont.

Scientific Name (* denotes commercial species)		Authority	Common Name (local)	CAAB Code	CAAB Common Name (if different)
Carangidae: Trevallies and Jacks					
*	Carangidae spp.	Undifferentiated	Trevallies, Jacks	37 337000	
	Alectis ciliaris	(Bloch, 1787)	Round-headed Pennantfish	37 337018	African Pompano
*	*Carangoides chrysophrys*	(Cuvier, 1833)	Longnose Trevally	37 337011	
*	*Carangoides equula*	(Schlegel, 1844)	Whitefin Trevally	37 337013	
	Carangoides hedlandensis	(Whitley, 1934)	Bumpnose Trevally	37 337042	
	Carangoides malabaricus	(Bloch & Schneider, 1801)	Malabar Trevally	37 337005	
*	*Carangoides talamparoides*	Bleeker, 1852	White-tongued Trevally	37 337043	Imposter Trevally
*	*Caranx sexfasciatus*	Quoy & Gaimard, 1825	Bigeye Trevally	37 337039	
	Caranx tille	Cuvier, 1833	Tille Trevally	37 337049	
	Decapterus kurroides	Bleeker, 1855	Redtail Scad	37 337056	none
	Decapterus macarellus	(Cuvier, 1833)	Mackerel Scad	37 337055	none
	Decapterus macrosoma	Bleeker, 1851	Slender Scad	37 337017	
	Decapterus russellii	(Ruppell, 1830)	Indian Scad	37 337023	Red-tailed Round Scad
	Decapterus spp.	Undifferentiated	Scads	37 337901	
*	*Parastromateus niger*	(Bloch, 1795)	Black Pomfret	37 337072	
*	*Scomberoides* spp.	Undifferentiated	Queenfish	37 337905	
	Selar crumenophthalmus	(Bloch, 1793)	Bigeye Scad	37 337009	
*	*Seriola dumerili*	(Risso, 1810)	Amberjack	37 337025	Eye Streak Kingfish
*	*Seriola lalandi*	Valenciennes, 1833	Yellowtail Kingfish	37 337006	
*	*Seriola rivoliana*	Valenciennes, 1833	Yellow Kingfish	37 337052	none
*	*Seriolina nigrofasciata*	(Ruppell, 1829)	Black-banded Kingfish	37 337014	
Leiognathidae: Ponyfishes					
	Leiognathus bindus	(Valenciennes, 1835)	Orange-tipped Ponyfish	37 341002	
	Leiognathus ruconius	(Hamilton-Buchanan, 1822)	Deep Pug-nosed Ponyfish	37 341015	

Appendix 5: cont.

Scientific Name (* denotes commercial species)	**Authority**	**Common Name (local)**	**CAAB Code**	**CAAB Common Name (if different)**
Lutjanidae: Sea Perches and Snappers				
* *Lipocheilus carnolabrum*	(Chan, 1970)	Tang's Snapper or Golden Sea Perch	37 346031	none
* *Lutjanus argentimaculatus*	(Forsskål, 1775)	Mangrove Jack	37 346015	
* *Lutjanus bitaeniatus*	(Valenciennes, 1830)	White-tipped or Indonesian Sea Perch	37 346025	
* *Lutjanus erythropterus*	Bloch, 1790	Red Snapper	37 346005	Crimson Sea Perch
* *Lutjanus malabaricus*	(Schneider, 1801)	Scarlet Sea Perch	37 346007	
* *Lutjanus quinquelineatus*	(Bloch, 1790)	Five-lined Sea Perch	37 346006	Blue-lined Sea Perch
* *Lutjanus russelli*	(Bleeker, 1849)	Moses Perch	37 346012	Russell's Snapper
* *Lutjanus sebae*	(Cuvier, 1828)	Red Emperor	37 346004	
* *Lutjanus vitta*	(Quoy & Gaimard, 1824)	Flagfish	37 346003	One Band Sea Perch
* *Pristipomoides multidens*	(Day, 1870)	Goldband Snapper	37 346002	
* *Pristipomoides sieboldii*	(Bleeker, 1854-57)	Lavender Jobfish	37 346064	none
* *Pristipomoides typus*	Bleeker, 1852	Sharptooth Jobfish	37 346019	Threadfin Snapper
* *Symphorus nematophorus*	(Bleeker, 1860)	Chinaman Fish	37 346017	Chinaman
Caesionidae: Fusiliers				
Pterocaesio chrysozona	(Cuvier, 1830)	Goldband Fusilier	37 346009	none
Nemipteridae: Threadfin Breams and Monocle Breams				
* Nemipteridae (*Parascolopsis* spp.)	Undifferentiated	Monocle Breams	37 347000	
* *Nemipterus bathybius*	Snyder, 1911	Yellowbelly Threadfin Bream	37 347001	
* *Nemipterus nematopus*	(Bleeker, 1851)	Yellow-tipped Threadfin Bream	37 347002	
* *Nemipterus peronii*	(Valenciennes, 1830)	Notched Threadfin Bream	37 347003	
* *Nemipterus celebicus*	(Bleeker, 1854)	Five-lined Threadfin Bream	37 347004	Striped Threadfin Bream
* *Nemipterus furcosus*	(Valenciennes, 1830)	Rosy Threadfin Bream	37 347005	
* *Nemipterus virgatus*	(Houttuyn, 1782)	Yellowlip Threadfin Bream	37 347009	
* *Parascolopsis tanyactis*	Russell, 1986	Yellow-bellied Dwarf Monocle Bream	37 347010	Yellow-bellied Sea Bream
* *Nemipterus zysron*	(Bleeker, 1856)	Slender Threadfin Bream	37 347013	

Appendix 5: cont.

Scientific Name (* denotes commercial species)	Authority	Common Name (local)	CAAB Code	CAAB Common Name (if different)
* *Parascolopsis eriomma*	(Jordan & Richardson, 1909)	Rosy Dwarf Monocle Bream	37 347015	Rosy Sea Perch
* *Nemipterus mesoprion*	(Bleeker, 1853)	Slender Yellow-tipped Threadfin Bream	37 347026	Mauvelip Threadfin Bream
Gerreidae: Silver Biddies				
Pentaprion longimanus	(Cantor, 1850)	Longfin Silver-Biddy	37 349002	
Haemulidae: Grunter Breams				
* *Hapalogenys kishinouyei*	Smith & Pope, 1906	Lined Javelinfish	37 350001	Striped Javelinfish
Pomadasys argenteus	(Forsskål, 1775)	White-finned Javelinfish	37 350009	Spotted Grunter
Lethrinidae: Emperors and Sea Breams				
* *Gymnocranius griseus*	(Schlegel, 1844)	Naked-headed Sea Bream	37 351003	
* *Lethrinus olivaceus*	Valenciennes, 1830	Longnose Emperor	37 351004	
* *Gymnocranius grandoculis*	(Valenciennes, 1830)	Robinson's Sea Bream	37 351005	Blue-Lined Large Eye Bream
* *Lethrinus lentjan*	(Lacepede, 1802)	Redspot Emperor	37 351007	
* *Lethrinus nebulosus*	(Forsskål, 1775)	Spangled Emperor	37 351008	none
* *Gymnocranius elongatus*	Senta, 1973	Swallowtail Sea Bream	37 351010	
* *Lethrinus xanthochilus*	Klunzinger, 1870	Yellowlip Emperor	37 351020	
Sparidae: Breams				
* *Pagrus auratus*	(Bloch & Schneider, 1801)	Pink Snapper	37 353001	Snapper
* *Dentex tumifrons*	(Temminck & Schlegel, 1843)	Lenko Snapper	37 353002	Sea Bream
* *Argyrops spinifer*	(Forsskål, 1775)	Frypan Snapper	37 353006	Frypan Bream
Sciaenidae: Jewfishes				
* *Protonibea diacanthus*	(Lacepede, 1802)	Black Jewfish or Northern Mulloway	37 354003	
Johnius laevis	Sasaki & Kailola, 1991	Round-nosed Croaker	37 354004	
Mullidae: Goatfishes				
Mullidae *(Upeneus* spp.)	Undifferentiated	Goatfishes	37 355000	
Upeneus bensasi	(Temminck & Schlegel, 1843)	Bar-tailed Goatfish	37 355002	
Upeneus moluccensis	(Bleeker, 1855)	Goldband Goatfish	37 355003	

Appendix 5: cont.

	Scientific Name (* denotes commercial species)	Authority	Common Name (local)	CAAB Code	CAAB Common Name (if different)
*	*Parupeneus heptacanthus*	(Lacepede, 1801)	Spotted Golden Goatfish	37 355004	Red Spot Goatfish
	Upeneus luzonius	(Jordan & Seale, 1907)	Dark-barred Goatfish	37 355009	Saddle Goatfish
*	*Parupeneus chrysopleuron*	(Temminck & Schlegel, 1843)	Yellow-striped Goatfish	37 355016	
*	*Parupeneus ciliatus*	(Lacepede, 1801)	Black-saddled Goatfish	37 355024	Cardinal Goatfish
	Parupeneus spp.	Undifferentiated	Goatfishes	37 355900	
Ephippidae: Batfishes					
	Ephippidae spp.		Batfishes	37 362000	
	Zabidius novemaculeatus	(McCulloch, 1916)	Short-finned Batfish	37 362003	Nine-spined Batfish
Chaetodontidae: Butterflyfishes and Angelfishes					
	Heniochus diphreutes	Jordan, 1903	Schooling Bannerfish	37 365005	
	Chaetodon modestus	Schlegel, 1842	Triple-banded Angelfish	37 365006	
	Chaetodontoplus personifer	(McCulloch, 1914)	Yellowtail Angelfish	37 365008	
	Chaetodon assarius	Waite, 1905	Western Butterflyfish	37 365012	
	Pomacanthus imperator	(Bloch, 1787)	Emperor Angelfish	37 365014	
	Coradion altivelis	McCulloch, 1916	Highfin Coralfish	37 365018	
Pentacerotidae: Boarfishes					
*	*Histiopterus typus*	(Temminck & Schlegel, 1843)	Three-barred Boarfish	37 367008	Deep Sea Boarfish
Sphyraenidae: Pikes					
*	*Sphyraena obtusata*	Cuvier, 1829	Long-finned Sea Pike	37 382001	Striped Sea Pike
*	*Sphyraena jello*	Cuvier, 1829	Giant Seapike	37 382004	Pickhandle Barracuda
*	*Sphyraena putnamiae*	Jordan & Seale, 1905	Military Sea Pike	37 382006	Chevron Barracuda
*	*Sphyraena* spp.	Undifferentiated	Striped Sea Pikes	37 382901	
Labridae: Wrasses					
*	*Bodianus perditio*	(Quoy & Gaimard, 1834)	Goldspot Pigfish	37 384007	Orange Threadfin Pigfish
*	*Choerodon monostigma*	Ogilby, 1910	Darkspot Tuskfish	37 384008	
*	*Choerodon sugillatum*	Gomon, 1987	Wedge-tailed Wrasse	37 384009	

Appendix 5: cont.

Scientific Name (* denotes commercial species)	**Authority**	**Common Name (local)**	**CAAB Code**	**CAAB Common Name (if different)**
* *Choerodon schoenleinii*	(Valenciennes, 1839)	Blue Tuskfish	37 384010	Blue Bone Grouper
Choerodon zamboangae	(Seale & Bean, 1907)	Purpleeyebrow Tuskfish	37 384011	
* *Xyrichtys jacksonensis*	(Ramsay, 1881)	Purplespot Tuskfish	37 384012	
Scaridae: Parrotfishes				
* Scaridae spp.	Undifferentiated	Parrotfishes	37 386000	
* *Scarus ghobban*	Forsskål, 1775	Orange Blue-barred Parrotfish	37 386001	Blue-barred Parrotfish
Uranoscopidae: Stargazers				
Uranoscopidae spp	Undifferentiated	Stargazers	37 400000	
Uranoscopus sp. 1	[in Sainsbury et al, 1985]	White-spotted Stargazer	37 400009	
Uranoscopus sp. 2	[in Sainsbury et al, 1985}	One-spined Yellowtail Stargazer	37 400016	
Champsodontidae: Gapers				
Champsodon longipinnis	Matsubara *et al*, 1964	False Lizard Fish	37 401002	
Callionymidae: Stinkfishes				
Callionymidae spp.	Undifferentiated	Stinkfishes	37 427000	
Gempylidae: Snake Mackerels and Gemfishes				
* Gempylidae spp.	Undifferentiated	Snake Mackerels, Gemfishes	37 439000	
Rexea prometheoides	(Bleeker, 1856)	Royal Escolar	37 439006	
Trichiuridae: Hairtails				
* *Trichiurus lepturus*	Linnaeus, 1758	Large-headed Hairtail	37 440004	
Scombridae: Mackerels and Tunas				
Scombridae spp.	Undifferentiated	Mackerels,Tunas	37 441000	
* *Auxis thazard*	(Lacepede, 1800)	Frigate Mackerel	37 441009	
* *Euthynnus affinis*	(Cantor, 1850)	Mackerel Tuna	37 441010	
* *Sarda orientalis*	(Temminck & Schlegel, 1844)	Oriental Bonito	37 441006	
* *Scomberomorus munroi*	Collette & Russo, 1980	Spotted Mackerel	37 441015	
Thunnus alalunga	(Bonnaterre, 1788)	Albacore Tuna	37 441005	

Appendix 5: cont.

Scientific Name (* denotes commercial species)	**Authority**	**Common Name (local)**	**CAAB Code**	**CAAB Common Name (if different)**
Xiphiidae: Broadbill Swordfishes				
Xiphias gladius	Linnaeus, 1758	Broad-billed Swordfish	37 442001	
Centrolophidae: Trevallas				
* *Psenopsis humerosa*	Munro, 1958	Blackspot Butterfish	37 445007	none
Ariommatidae: Eyebrow Fishes				
* *Ariomma indica*	(Day, 1870)	Indian Eyebrow Fish	37 447007	
Ariomma sp.	[in Sainsbury et al, 1985]	Elongate Eyebrow Fish	37 447003	
Psenes cf. *arafurensis*	[Gunther, 1889]	Black Butterfish (id. code PDW67)	37 (446011)	
Psettodidae: Halibuts				
* *Psettodes erumei*	(Bloch & Schneider, 1801)	Tropical Halibut	37 457001	Australian Halibut
Citharidae: Citharids				
Brachypleura novaezeelandiae	Gunther, 1862	Yellow Citharid	37 458001	
Bothidae: Lefteye Flounders				
Arnoglossus waitei	Norman, 1926	Waite's Flounder	37 460045	none
Grammatobothus polyophthalmus	(Bleeker, 1866)	Three-eyed Flounder	37 460010	
Psettina gigantea	Amaoka, 1963	Rough-scaled Flounder	37 460033	
* *Pseudorhombus dupliciocellatus*	Regan, 1905	Three Twin-spot Flounder	37 460004	Ocellated Flounder
Pseudorhombus elevatus	Ogilby, 1912	Deep-bodied Flounder	37 460008	
Pseudorhombus jenynsii	(Bleeker, 1855)	Small-toothed Flounder	37 460002	
Pseudorhombus quinquocellatus	Weber & de Beaufort, 1929	Five-eyed Flounder	37 460025	
Triacanthidae: Tripodfishes				
Trixiphichthys weberi	(Chaudhuri, 1910)	Long-nosed Tripodfish	37 464001	Long-nosed Triple Spine Fish
Balistidae: Triggerfishes				
Abalistes stellaris	(Bloch & Schneider, 1801)	Starry Triggerfish	37 465011	
Sufflamen fraenatus	(Latreille, 1804)	Golden Triggerfish	37 465014	
Xanthichthys lineopunctatus	(Hollard, 1854)	Lined Triggerfish	37 465016	Speckled Triggerfish

Appendix 5: cont.

Scientific Name (* denotes commercial species)	Authority	Common Name (local)	CAAB Code	CAAB Common Name (if different)
Monacanthidae: Leatherjackets				
* Monacanthidae spp.	Undifferentiated	Leatherjackets	37 465901	
* *Aluterus monoceros*	(Linnaeus, 1758)	Unicorn Leatherjacket	37 465022	Grey Leatherjacket
* *Eubalichthys caeruleoguttatus*	Hutchins, 1977	Blue-spotted Leatherjacket	37 465018	Blue-finned Leatherjacket
Paramonacanthus filicauda	(Gunther, 1880)	Threadfin Leatherjacket	37 465024	
Paramonacanthus japonicus	(Tilesius, 1810)	Japanese Leatherjacket	37 465017	
Thamnaconus hypargyreus	(Cope, 1871)	Lesser-spotted Leatherjacket	37 465012	Yellow-spotted Leatherjacket
Thamnaconus striatus	(Kotthaus, 1979)	Many-lined Leatherjacket	37 465019	
Ostraciidae: Boxfishes				
Ostraciidae spp.	Undifferentiated	Boxfishes	37 466000	
Lactoria cornuta	(Linnaeus, 1758)	Cowfish	37 466004	
Lactoria diaphana	(Bloch & Schneider, 1801)	Transparent Boxfish	37 466007	
Lactoria gibbosus	(Linnaeus, 1758)	Black-blotched Turretfish	37 466006	
Ostracion nasus	Bloch, 1785	Small-nosed Boxfish	37 466005	
Ostracion cubicus	Linnaeus, 1758	Yellow Boxfish	37 466013	
Tetraodontidae: Toadfishes				
Tetraodontidae spp.	Undifferentiated	Toadfishes	37 467000	
Canthigaster rivulata	(Temminck & Schlegel, 1850)	Brownline Toby	37 467018	
Lagocephalus inermis	(Temminck & Schlegel, 1850)	Golden Pufferfish	37 467008	
Lagocephalus lunaris	(Bloch & Schneider, 1801)	Rough Golden Pufferfish	37 467012	
Lagocephalus sceleratus	(Gmelin, 1789)	Silver-stripe Pufferfish	37 467007	Giant Toadfish
Lagocephalus spadiceus	(Richardson, 1844)	Half-smooth Golden Pufferfish	37 467017	
Torquigener hicksi	Hardy, 1983	Hicks' Toadfish	37 467026	none
Torquigener parcuspinus	Hardy, 1983	Yellow-eyed Toadfish	37 467029	none
Tylerius spinosissimus	(Regan, 1908)	Fine-spined Pufferfish	37 467022	Chinese PuffefFish

Appendix 5: cont.

Scientific Name (* denotes commercial species)	Authority	Common Name (local)	CAAB Code	CAAB Common Name (if different)
Triodontidae: Pufferfishes				
Triodon macropterus	Lesson, 1830	Blackspot Keeled Pufferfish	37 468001	
Diodontidae: Porcupinefishes				
Cyclichthys orbicularis	(Bloch, 1785)	Short-spined Porcupinefish	37 469007	Many-spined Porcupinefish
Cyclichthys spilostylus	(Leis & Randall, 1982)	Spot-base Burrfish	37 469003	Yellow & Black Spot Porcupinefish
Diodon holocanthus	Linnaeus, 1758	Freckled Porcupinefish	37 469005	Long Spine Porcupinefish
Lophodiodon calori	(Bianconi, 1855)	Violet Porcupinefish	37 469010	

Cephalopoda

Sepiidae: Cuttlefish				
* *Sepia* spp.	Undifferentiated	Cuttlefish	23 607901	
Teuthoidea (ORDER): Squid				
* Squid spp.	Undifferentiated	Squid	23 615901	
Octopodidae: Octopuses				
* *Octopus* spp.	Undifferentiated	Octopuses	23 659901	

Crustacea

Penaeidea, Caridea (INFRAORDERS): Prawns and Carid Shrimps				
Penaeidea, Caridea	Undifferentiated	Prawns, Carid shrimps	28 710901	
Penaeidae: Penaeid Prawns				
Melicertus marginatus	(Randall, 1840)	Prawn sp. L1 (id. code PDW07)	unassigned	
* *Penaeus monodon*	Fabricius, 1798	Leader Prawn	28 711051	Black Tiger Prawn
Solenoceridae: Solenocerid Prawns				
Cryptopenaeus clevai	Crosnier, 1985	Red Coral Prawn	28 714001	

Appendix 5: cont.

Palinuridae: Spiny Lobsters					
*	*Linuparus trigonus*	(Von Siebold, 1824)	Red Spear Lobster	28 820004	Painted Lobster
	Panulirus ornatus	(Fabricius, 1798)	Painted Rock Lobster	28 820006	Ornate Rock Lobster
Scyllaridae: Balmain Bugs, Shovel-nosed Lobsters, Slipper Lobsters					
	Scyllaridae spp.	Undifferentiated	Balmain Bugs etc.	28 821000	
*	*Ibacus* spp.	Undifferentiated	Balmain Bugs	28 821901	
*	*Ibacus pubescens*	Holthuis, 1960	Velvet Bug	28 821002	none
*	*Ibacus novemdentatus*	Gibbes, 1850	Nine-toothed Bug	28 821003	
Brachyura (INFRAORDER): Crabs					
	Brachyura spp.	Undifferentiated	Crabs	28 850901	
Portunidae: Swimming Crabs					
	Portunidae spp.	Undifferentiated	Swimming Crabs	28 911000	
	Portunus sanguinolentus	(Herbst, 1899)	Redspot Swimmer Crab	28 911006	
	Scylla spp.	Undifferentiated	Mud Crabs	28 911902	
	Charybdis miles	(De Haan, 1835)	Crab sp. L1 (id. code PDW09)	unassigned	
	Charybdis bimaculata	(Miers, 1886)	Brown-lined Crab (id. code PDW15)	unassigned	
Squillidae: Mantis shrimps					
	Squillidae spp.	Undifferentiated	Mantis Shrimps	28 051000	

Other Marine Organisms

Porifera (PHYLUM): Sponges				
	Porifera spp.	Undifferentiated	Sponges (id. code PDW08)	unassigned
Scyphozoa (CLASS): Jellyfish				
	Scyphozoa spp.	Undifferentiated	Jellyfish	11 001901
Alcyonacea (ORDER): Gorgonians, Soft Corals, Sea Whips etc.				
	Alcyonaceans	Undifferentiated	Gorgonians, etc. (id. code PDW16)	unassigned
Antipatharia (ORDER): Black Corals				
	Antipatharians	Undifferentiated	Black Corals (id. code PDW33)	unassigned

Appendix 5: cont.

Scientific Name (* denotes commercial species)	Authority	Common Name (local)	CAAB Code	CAAB Common Name (if different)
Thaliacea (CLASS): Salps				
Thaliaceans	Undifferentiated	Salps (id. code PDW10)	unassigned	
Holothurioidea (CLASS): Sea Cucumbers				
Holothurioidae spp.	Undifferentiated	Sea Cucumbers (id. code PDW36)	unassigned	
Echinodermata (PHYLUM): Sea Urchins, Feather Stars, Starfish etc.				
Echinoderms	Undifferentiated	Sea Urchins, etc. (id. code PDW14)	unassigned	
Hydrophiidae: Sea Snakes				
Hydrophiidae spp.	Undifferentiated	Sea Snakes	39 125000	
Unidentified Bycatch spp.				
Unidentified Bycatch spp.	Undifferentiated	Uid. Bycatch spp. (id. code UID99)	unassigned	

Appendix 6: Occurrence of species or taxonomic group by depth strata (in alphabetical order).

	Depth range (m)					
Species (* denotes commercial)	**93-120**	**121-140**	**141-160**	**161-180**	**181-200**	**Total**
Abalistes stellaris	38	2				**40**
Acropoma japonicum	13	34	19	8	6	**80**
Alcyonaceans, undifferentiated	36	17	6	3	1	**63**
Alectis ciliaris		1				**1**
Alopias spp., undifferentiated	1					**1**
* *Aluterus monoceros*	3					**3**
Antigonia rhomboidea			1	6	5	**12**
Antipatharians, undifferentiated	8	9	2		2	**21**
Apogon carinatus	2		1	1		**4**
Apogon fasciatus		2				**2**
Apogon poecilopterus		1				**1**
Apogon semilineatus	1					**1**
Apogonidae spp., undifferentiated		1				**1**
* *Argyrops spinifer*	77	46	5			**128**
* *Ariomma indica*	24	35	14	9	1	**83**
Ariomma sp. [in Sainsbury et al, 1985]			1	3		**4**
Arnoglossus waitei		1				**1**
Atelopus spp., undifferentiated				1		**1**
* *Auxis thazard*	5	4	2			**11**
* *Banjos banjos*	5	3	5	2		**15**
Batrachomoeus occidentalis	2	3	1			**6**
Bembras longipinnis		1	1	6	3	**11**
* *Bodianus perditio*	2	1				**3**
Brachypleura novaezeelandiae	1					**1**
Brachyura spp., undifferentiated	10	15	2	2	1	**30**
* *Branchiostegus sawakinensis*	10	21	2	2		**35**
Brotula multibarbata		1				**1**
Callionymidae spp., undifferentiated	1	6	1	2		**10**
Canthigaster rivulata	2	1				**3**
* Carangidae spp., undifferentiated	72	42	7	2		**123**
* *Carangoides chrysophrys*	1					**1**
* *Carangoides equula*	25	29	17	12	6	**89**
Carangoides hedlandensis	1					**1**
Carangoides malabaricus	1					**1**
* *Carangoides talamparoides*	5	4				**9**
* *Caranx sexfasciatus*	1					**1**
Caranx tille		1				**1**
* Carcharhinidae spp., undifferentiated	36	23	15	4	4	**82**
Carcharias taurus	2	1	1	1		**5**
* *Cephalopholis sonnerati*	1					**1**
Chaetodon assarius	1					**1**
Chaetodon modestus	1	15	9	5	4	**34**

Appendix 6: cont.

Species (* denotes commercial)	**Depth range (m)**					
	93-120	**121-140**	**141-160**	**161-180**	**181-200**	**Total**
Chaetodontoplus personifer	25	3	1			**29**
Champsodon longipinnis	5	21	3	8		**37**
Charybdis bimaculata	1	1	3	1		**6**
Charybdis miles	1	8	7	1		**17**
Chlorophthalmidae spp., undifferentiated		1	1			**2**
* *Choerodon monostigma*	1					**1**
* *Choerodon schoenleinii*	1					**1**
* *Choerodon sugillatum*	1					**1**
Choerodon zamboangae	2					**2**
Cookeolus japonicus		2	1	1		**4**
Coradion altivelis	25	4	1	1		**31**
* *Cromileptes altivelis*	1					**1**
Cryptopenaeus clevai	1	2	3			**6**
Cyclichthys orbicularis	5	2	1			**8**
Cyclichthys spilostylus	13	7	1			**21**
Dactyloptena macracanthus	7			2	1	**10**
Dactyloptena orientalis			1			**1**
Dactyloptena papilio			1			**1**
Dactyloptena peterseni	24	17	1	2		**44**
Dactyloptena spp., undifferentiated	9	2	1	1		**13**
Dasyatididae spp., undifferentiated	6	10	9	1	1	**27**
Dasyatis annotata	1	1	2	1		**5**
Dasyatis leylandi	1	1				**2**
Dasyatis thetidis	2	1				**3**
Decapterus kurroides		3	3	2	1	**9**
Decapterus macarellus	2	1	1			**4**
Decapterus macrosoma	6		1	2		**9**
Decapterus russellii	2					**2**
Decapterus spp., undifferentiated	8	4				**12**
* *Dentex tumifrons*	1	1	1	11	8	**22**
Diodon holocanthus	1					**1**
Doederleinia berycoides			1			**1**
Dussumieria elopsoides				1		**1**
Echeneis naucrates	2	1	1	1		**5**
Echinoderms, undifferentiated	34	36	6	6	2	**84**
Elates ransonnetii		1		2	1	**4**
Ephippidae spp., undifferentiated	1					**1**
* *Epinephelus amblycephalus*	7	2				**9**
* *Epinephelus areolatus*	41	6	1			**48**
* *Epinephelus bilobatus*	2	1				**3**
* *Epinephelus bleekeri*	1					**1**
* *Epinephelus coioides*	7	2				**9**
* *Epinephelus epistictus*		2				**2**

Appendix 6: cont.

Species (* denotes commercial)	**Depth range (m)**					
	93-120	**121-140**	**141-160**	**161-180**	**181-200**	**Total**
* *Epinephelus heniochus*	1	2				**3**
* *Epinephelus latifasciatus*	1	4				**5**
* *Epinephelus malabaricus*	1					**1**
* *Epinephelus morrhua*	3					**3**
* *Epinephelus multinotatus*	11					**11**
* *Epinephelus radiatus*			1	1		**2**
* *Epinephelus sexfasciatus*	1					**1**
Erisphex aniarus		9	1			**10**
* *Eubalichthys caeruleoguttatus*	18					**18**
* *Euthynnus affinis*		2		1		**3**
Fistularia commersonii	4	3				**7**
Fistularia petimba	54	25	4	1	1	**85**
* Gempylidae spp., undifferentiated		1	1	4	3	**9**
* *Glaucosoma buergeri*	62	21	2			**85**
* *Glaucosoma magnificum*	2					**2**
Grammatobothus polyophthalmus	1					**1**
* *Gymnocranius elongatus*	1					**1**
* *Gymnocranius grandoculis*	48	7				**55**
* *Gymnocranius griseus*	3		1			**4**
Gymnura australis	26	33	9			**68**
Halaelurus boesemani	4	3	1			**8**
Halieutaea stellata	9	11	4	2		**26**
* *Hapalogenys kishinouyei*	43	69	15	5	1	**133**
Heniochus diphreutes	12	1				**13**
Heterodontus spp., undifferentiated	1					**1**
Heterodontus zebra		2	1	1		**4**
Himantura toshi	1	6				**7**
* *Histiopterus typus*	1	4	10	6	4	**25**
Holocentridae spp., undifferentiated		1				**1**
Holothurioidae spp., undifferentiated			1			**1**
* *Hydrolagus lemures*				1	2	**3**
Hydrophiidae spp., undifferentiated	2					**2**
* *Ibacus novemdentatus*	1	3	4	8	3	**19**
* *Ibacus pubescens*				1	2	**3**
* *Ibacus* spp., undifferentiated				2		**2**
Inegocia japonica			1			**1**
Johnius laevis	1					**1**
Lactoria cornuta	10	2	1			**13**
Lactoria diaphana	11	1				**12**
Lactoria gibbosus	1					**1**
Lagocephalus inermis	3	2				**5**
Lagocephalus lunaris	35	26	2			**63**
Lagocephalus sceleratus	11	6	2	3		**22**

Appendix 6: cont.

Species (* denotes commercial)	93-120	121-140	141-160	161-180	181-200	Total
	Depth range (m)					
Lagocephalus spadiceus	38	38	10	4	1	**91**
Leiognathus bindus	28	21	3			**52**
Leiognathus ruconius		1				**1**
Lepidotrigla argus		2	1			**3**
Lepidotrigla cf. *bispinosa*	2	5	3	2	1	**13**
Lepidotrigla grandis	4	5	5	3	3	**20**
Lepidotrigla russelli	8	4	2			**14**
Lepidotrigla sp. 2	3	20	1	4		**28**
Lepidotrigla spp., undifferentiated	1	9	4	4	2	**20**
* *Lethrinus lentjan*	12					**12**
* *Lethrinus nebulosus*	5					**5**
* *Lethrinus olivaceus*	2					**2**
* *Lethrinus xanthochilus*	1					**1**
* *Linuparus trigonus*		2		7	3	**12**
* *Lipocheilus carnolabrum*		1		1	1	**3**
Lophiomus setigerus	7	19	8	6	4	**44**
Lophodiodon calori	11	1	2	1		**15**
* *Lutjanus argentimaculatus*	19	3				**22**
* *Lutjanus bitaeniatus*	1					**1**
* *Lutjanus erythropterus*	32	3				**35**
* *Lutjanus malabaricus*	77	46				**123**
* *Lutjanus quinquelineatus*	14	3				**17**
* *Lutjanus russelli*	68	19				**87**
* *Lutjanus sebae*	47	6				**53**
* *Lutjanus vitta*	61	4				**65**
Macrouridae spp., undifferentiated		1	2			**3**
Melicertus marginatus		3			1	**4**
* Monacanthidae spp., undifferentiated	3					**3**
Monocentris japonica	6	17	17	8	6	**54**
Mora moro				1		**1**
* *Muraenesox cinereus*	3	1	1		1	**6**
Myliobatididae spp.			1		1	**2**
Myripristis botche	7			1		**8**
Negaprion acutidens	2					**2**
* *Nemipterus bathybius*	25	76	28	15	8	**152**
* *Nemipterus celebicus*	44	15				**59**
* *Nemipterus furcosus*	1					**1**
* *Nemipterus mesoprion*	1					**1**
* *Nemipterus nematopus*	7	1				**8**
* *Nemipterus peronii*	1					**1**
* *Nemipterus virgatus*	60	70	19	3		**152**
* *Nemipterus zysron*	2	1				**3**
Neocentropogon aeglefinis	1	4				**5**

Appendix 6: cont.

Species (* denotes commercial)	**Depth range (m)**					
	93-120	**121-140**	**141-160**	**161-180**	**181-200**	**Total**
Neomerinthe amplisquamiceps		2	3			**5**
Neosebastes entaxis			2	2	1	**5**
Nettastomatidae spp., undifferentiated		2	3			**5**
* *Netuma thalassinus*	36	23	3			**62**
* *Octopus* spp., undifferentiated	2	2	1	4	1	**10**
Ogcocephalidae spp., undifferentiated	4	6	4	1	3	**18**
* Ophidiidae spp., undifferentiated		1		1	1	**3**
Ophidion muraenolepis	1		3			**4**
Ostichthys japonicus		8	1	1	1	**11**
* *Ostichthys kaianus*	1	6	1	3	3	**14**
Ostraciidae spp., undifferentiated	1					**1**
Ostracion cubicus	1					**1**
Ostracion nasus	1					**1**
Oxyconger leptognathus		1	1			**2**
* *Pagrus auratus*	1					**1**
Panulirus ornatus	3	7	1	1		**12**
Paramonacanthus filicauda	5					**5**
Paramonacanthus japonicus	1					**1**
* *Parascolopsis eriomma*	8	7	2			**17**
* *Parascolopsis* spp., undifferentiated	7		1			**8**
* *Parascolopsis tanyactis*	13	11	4		1	**29**
* *Parastromateus niger*	2	3				**5**
* *Parupeneus chrysopleuron*	23	1	3	1		**28**
* *Parupeneus ciliatus*	1					**1**
* *Parupeneus heptacanthus*	57	7				**64**
Parupeneus spp., undifferentiated	1	1	1		1	**4**
Penaeidea, Caridea, undifferentiated	7	19	5	1		**32**
* *Penaeus monodon*		1	2			**3**
Pentaprion longimanus	54	27	5			**86**
Polymixia berndti					1	**1**
Pomacanthus imperator	1					**1**
Pomadasys argenteus	2	1				**3**
Porifera spp., undifferentiated	49	28	6	3	1	**87**
Portunidae spp., undifferentiated		2	4	1		**7**
Portunus sanguinolentus		1				**1**
* *Priacanthus hamrur*	51	38	6	3	1	**99**
* *Priacanthus macracanthus*	33	38	19	10	3	**103**
* *Priacanthus* spp., undifferentiated	22	12	5	1	3	**43**
* *Priacanthus tayenus*	23	8				**31**
Pristigenys niphonia		1	1	1		**3**
* *Pristipomoides multidens*	96	55	12	1		**164**
* *Pristipomoides sieboldii*		1				**1**
* *Pristipomoides typus*	48	24				72

Appendix 6: cont.

Species (* denotes commercial)	Depth range (m)					
	93-120	**121-140**	**141-160**	**161-180**	**181-200**	**Total**
* *Pristis* spp., undifferentiated	2	1	2			**5**
* *Protonibea diacanthus*	3	1				**4**
Psenes cf. *arafurensis*		1				**1**
* *Psenopsis humerosa*	37	38	14	7	4	**100**
Psettina gigantea		2				**2**
* *Psettodes erumei*	21	9				**30**
* *Pseudorhombus dupliciocellatus*	22	5	1			**28**
Pseudorhombus elevatus		1	1			**2**
Pseudorhombus jenynsii		1				**1**
Pseudorhombus quinquocellatus	3	1				**4**
Pterocaesio chrysozona	2					**2**
Pterois russelli	11	2	1			**14**
Pterois volitans	1					**1**
Pterygotrigla hemisticta		4	2		2	**8**
Pterygotrigla leptacanthus					1	**1**
* *Rachycentron canadum*	6	6	2	1		**15**
Raja sp. D				1		**1**
Rajidae spp., undifferentiated			1			**1**
Ratabulus diversidens	2	7	6	3	4	**22**
Rays - all spp., undifferentiated	4	11	2	3	2	**22**
Rexea prometheoides		1				**1**
Rhina ancylostoma		1				**1**
* Rhinobatidae spp., undifferentiated	26	27	9	4	1	**67**
* Rhynchobatidae spp., undifferentiated	12	5	2	1		**20**
* *Rhynchobatus djiddensis*	10	10	2	1		**23**
* *Sarda orientalis*	2		1		1	**4**
Sargocentron lepros		1				**1**
Sargocentron rubrum	38	3				**41**
Satyrichthys rieffeli	6	13	14	10	5	**48**
Satyrichthys spp., undifferentiated	1	3	5	2	1	**12**
Satyrichthys welchi		1	1			**2**
Saurida filamentosa	45	45	17	6	5	**118**
Saurida micropectoralis			1			**1**
Saurida spp., undifferentiated	9	10	7	3		**29**
Saurida tumbil				1		**1**
Saurida undosquamis	42	27	6	5	1	**81**
* Scaridae spp., undifferentiated	1					**1**
* *Scarus ghobban*	4	1				**5**
* *Scomberoides* spp., undifferentiated	1	1				**2**
* *Scomberomorus munroi*	1	1				**2**
Scombridae spp., undifferentiated			1			**1**
* Scorpaenidae spp., undifferentiated	1	8	1	1	1	**12**
Scorpaenodes smithi				1		**1**

Appendix 6: cont.

Species (* denotes commercial)	**Depth range (m)** **93-120**	**121-140**	**141-160**	**161-180**	**181-200**	**Total**
Scyliorhinidae spp., undifferentiated	1	6	1	1	1	**10**
Scylla spp., undifferentiated	1					**1**
Scyllaridae spp., undifferentiated		4	2	1		**7**
Scyphozoa spp., undifferentiated	8	3	3	1	1	**16**
Selar crumenophthalmus	1					**1**
* *Sepia* spp., undifferentiated	34	39	12	2		**87**
* *Seriola dumerili*	1	2	1			**4**
* *Seriola lalandi*	1	1				**2**
* *Seriola rivoliana*	3					**3**
* *Seriolina nigrofasciata*	6	7				**13**
Setarches longimanus		1	3		2	**6**
Sirembo imberbis		4	2		1	**7**
Solegnathus hardwickii	4	1	1			**6**
* *Sphyraena jello*	9	2				**11**
* *Sphyraena obtusata*	3	5				**8**
* *Sphyraena putnamiae*	15	8	1			**24**
* *Sphyraena* spp., undifferentiated	4	3				**7**
* Sphyrnidae spp., undifferentiated	27	12	1			**40**
* *Spottobrotula amaculata*				2		**2**
* Squalidae spp., undifferentiated		1		2	3	**6**
Squalus spp., undifferentiated		4	1	3		**8**
Squatina sp. B	4	9	5	3	1	**22**
* Squid spp., undifferentiated	29	30	16	7	2	**84**
Squillidae spp., undifferentiated	2	7	3		2	**14**
Stegastoma fasciatum	2	1		1		**4**
Stolephorus indicus		1		1		**2**
Sufflamen fraenatus	2					**2**
* *Symphorus nematophorus*	1					**1**
Synodus macrops			1			**1**
Terapon jarbua	1	1				**2**
Tetraodontidae spp., undifferentiated	1	3	1	3	1	**9**
Tetraroge sp.					1	**1**
Thaliaceans, undifferentiated	1	5	1	1		**8**
Thamnaconus hypargyreus	6	11	7	7	2	**33**
Thamnaconus striatus	1	1				**2**
Thunnus alalunga		1				**1**
Torquigener hicksi			1	1	1	**3**
Torquigener parcuspinus				1		**1**
Trachinocephalus myops	2		1			**3**
* Triakidae spp., undifferentiated	8	8	7	4	2	**29**
* *Trichiurus lepturus*	46	30	17	2		**95**
Triglidae spp., undifferentiated	2		3	3	1	**9**
Triodon macropterus				1		**1**

Appendix 6: cont.

	Depth range (m)					
Species (* denotes commercial)	**93-120**	**121-140**	**141-160**	**161-180**	**181-200**	**Total**
Trixiphichthys weberi	64	52	9	3		128
Tylerius spinosissimus		1	3	2	2	8
Unidentified Bycatch spp.	1			1		2
Upeneus bensasi	2	3	6	1		12
Upeneus luzonius		1				1
Upeneus moluccensis	51	46	20	1		118
Upeneus spp., undifferentiated	1	8	2	2		13
Uranoscopidae spp., undifferentiated		5				5
Uranoscopus sp. 1	11	27	11	7	1	57
Uranoscopus sp. 2	1					1
Urolophidae spp., undifferentiated	1	1	4	3	4	13
Urolophus flavomosaicus	3					3
Urolophus westraliensis	1	1		2	1	5
Velifer hypselopterus	22	17	6	1		46
Xanthichthys lineopunctatus	4	1		1		6
Xiphias gladius		1				1
* *Xyrichtys jacksonensis*	1					1
Zabidius novemaculeatus	2					2
* *Zenopsis nebulosus*	7	21	15	11	6	60
Zeus faber	5	2			1	8