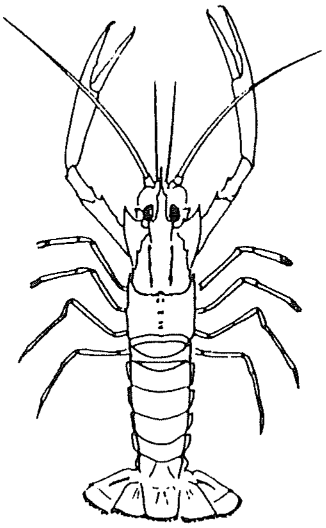
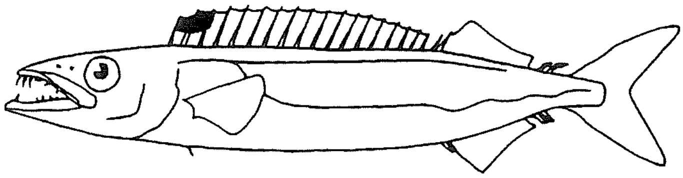
THE FISHERIES BIOLOGY OF DEEPWATER CRUSTACEA AND FINFISH ON THE CONTINENTAL SLOPE OF WESTERN AUSTRALIA

Final Report to the Fisheries Research and Development Corporation (FRDC Project 1988/74)





Editor: Sebastian F. Rainer
CSIRO Marine Laboratory
Marmion, W.A.

CSIRO
AUSTRALIA

December 1992

Division of Fisheries

Contents

Executive Summary

Contents

Project title

Fisheries biology of deepwater Crustacea and finfish on the continental slope of Western Australia.

Objectives

To investigate the population biology of the commercially important species, primarily crustaceans and finfish, caught in the North West Slope Trawl Fishery (NWSTF) and Western Deep Water Trawl Fishery (WDWTF).

This work aimed to measure standing stocks, growth rates, natural mortality rates, and reproductive periodicity, to enable estimation of potential yields from the fishery.

Specific objectives were to:

- obtain information on the size composition, growth, mortality, and reproductive biology of the principal commercial prawn species. Namely, the penaeid species *Aristaeomorpha foliacea, Haliporoides sibogae, Aristeus virilis, Plesiopenaeus edwardsianus, Penaeopsis eduardoi,* and the carid species *Heterocarpus woodmasoni* and *Heterocarpus sibogae*.
- identify potentially commercial stocks of fish within the NWST and WDWT fisheries with respect to latitude and depth.
- maintain a logbook program giving species emphasis to species-specific prawn catch and effort information, and by-catch of finfish and squid species.
- assess the species composition of the discarded portion of the catch.

Database

The logbook program and database, for the collection, storage and retrieval of information on catches by commercial vessels, was completed as planned.

The computer database on the NWSTF, WDWTF and Timor Sea deepwater trawl fishery during the life of the fisheries up to 31 March 1991. The database has been completed and verified against processed catch information up to 31 December 1991. Data from 1 January 1992 up to 30 June 1992 have been entered but not yet verified. All data have been transferred to the Australian Fisheries Service or the Australian Fisheries Management Authority for entry into the AZFIS database.

Observers

Observers on commercial cruises ensured accurate recording of the catch species and collected material for studies of reproduction and growth. The number of trips made by observers were:

1988	—	2 cruises
1989	—	5 cruises
1990	—	10 cruises
1991	—	8 cruises
1992	—	2 cruises

Detailed reports were made by the observers and are held on file (see Appendix III).

Research projects

CSIRO managed its research in this project through the following subprojects:

- **diet and feeding of crustaceans**
- **deepwater crustaceans**
- **finfish**
- **squid resources**

These subprojects are described in more detail below. The subproject on squid resources was partly funded, and subprojects on crustaceans were fully funded, by CSIRO.

Diet and feeding behaviour of crustaceans

A preliminary study was carried out on the diet and feeding behaviour of commercial deepwater penaeid and carid prawns from the continental slope of north-western Australia, to assess their availability to alternative methods of harvesting, by

- determining from their diet the extent to which (and when) they feed on the sea bottom or in the water column,
- assessing from their diet whether potting may be an efficient method of harvesting.

The diets of six species of prawn were determined. Three penaeid prawns ate mainly bottom-living species, while the red prawn and the two main carid species both ate significant quantities of midwater prey. The probable existence of commercial prawns in midwater suggests that knowledge is also needed about the sizes of the midwater components of their stocks, and about their susceptibility to midwater trawling. Proposals for midwater and trapping studies are being prepared.

Deepwater crustaceans

A. Scampi

Three species of scampi are caught commercially on the North West Slope. These are *Metanephrops velutinus* (previously called *M. andamanicus*), *M. australiensis* and *M. boschmai.* Each species is found within a different depth range: *M. boschmai* at 300–380 m, *M. velutinus* at 370–440 m, and *M. australiensis* at 430–500 m.

The scampi catch has varied considerably. It was 161 tonnes in 1985/86, fell to 92 tonnes in 1987/88, rose to a peak of 166 tonnes in 1988/89, and was only 55 tonnes in 1990/91.

The fluctuating catch of scampi can probably be attributed partly to a portion of the fleet targeting on prawns in water where scampi are naturally less abundant, and partly to a real decrease in abundance as a result of fishing pressure.

Detailed analysis of *M. australiensis* length-frequency data indicates that females mature at about 4+ years, fully enter the fishery at 5+ to 6+ years, at about 50 mm carapace length. Their maximum life span is about 10–12 years, at a maximum of about 75 mm carapace length. The exploited biomass on the NWS was about 110 tonnes in 1990/91 and 1991/92.

Long-term management strategy should include substantial closure periods, preferably on a rotational basis if sufficient grounds exist. Knowledge of the rate of recovery, of early growth rates and of the physical effects of trawling, is still required in order to set appropriate closure periods, which must be balanced against the value of penaeid and carid catches from a ground.

B. Deepwater Prawns

The main research objectives were to obtain information of the size composition growth, reproductive biology and mortality of each of the seven species of prawn and carid crustaceans that are caught in commercial quantities in the deepwater trawl fisheries. The long-term objective is to use this information to estimate the exploitable stocks and sustainable yield of the fishery.

The red prawn, *Aristaeomorpha foliacea*, is a widely distributed species up to 50–55 mm carapace length. It dominated prawn catches at the start of the fishery, with catches of 25–75 kg · hr^{-1} and a peak of 419 tonnes in 1987/88. It is fished mainly during the day. Its lifespan is at least four years, has a highly aggegated breeding population, and may be susceptible to overfishing. Other prawn species have similar life spans; their abundance in the catches has varied considerably with targeting practices at different times.

Long-term management will require information on stock-recruitment relationships for individual species, with more data needed particularly on the abundance-of small size classes. Depletion studies should be carried out. Live marketing of bugs, crabs and scampi may be possible.

Finfish

The three initial high-priority research objectives identified for this subproject were to:

- identify commercially exploitable species (stocks) and determine distribution by exploratory fishing
- improve recording in logbooks of fish from commercial vessels
- increase precision of recording of species composition from both retained and discarded components of catch

Exploratory fishing in the WDWTF indicated the potential for commercial multispecies trawling on the upper slope south of Geraldton. The main commercial fish in this area are mirror dory and big-spined boarfish. A large number of other deepwater species were also found, but none in commercial quantity..

Squid resources

The objectives of the project were to record the species composition of cephalopod molluscs (cuttlefish, squid and octopus) caught by commercial trawlers in the WDWTF and NWSTF. These records were used to:

- prepare a guide to shipboard identification of cephalopod molluscs by the scientific observers and skippers involved in the fishery, and
- redesign logbooks so the by-catch retained is accurately documented,
- identify commercially exploitable species of squid and assess their potential.

Cephalopods (mainly squid) were the main component of the by-catch of deepwater demersal crustacean trawling , mostly caught between 350 and 450 m. They were caught throughout the year, with a seasonal increase in October–November. The largest annual catch was 34 tonnes; the arrow squid *Nototodarus hawaiiensis* dominated the squid catches.

1 Introduction

Dr B. F. Phillips

Contents

Background

Promising catches of scampi and deepwater prawns at depths between 300 and 500 m were made on the north-western continental slope of Australia in 1982 by the CSIRO chartered research vessel, FRV *Soela.*

Following trial fishing by the KFV Fisheries Pty Ltd vessel FV *Courageous* in 1983 and the discovery of additional scampi grounds in 1984 by FRV *Soela,* the Commonwealth Department of Primary Industries and Energy released a development plan for the fishery and eight trawlers began operating in the specified development area in March 1985. This area subsequently became the North West Slope Trawl Fishery.

The number of boats in the fishery have been ranged from a high of 21 (fishing under 12 endorsements) in 1986/87 to five in 1990/91.

Most of the vessels in this fishery are prawn trawlers endorsed for the Gulf of Carpentaria. Initially, fishing was with standard prawn trawling equipment. However, modifications for deepwater trawling were rapidly developed, including large-capacity winches, stern-towed twin nets and catch handling equipment capable of rapidly processing large volumes of fragile product.

Fishing effort has been seasonal as participating vessels have fished the scampi grounds mainly during closures or periods of low catch rate in the northern prawn fishery. Recently two dedicated deepwater trawlers have entered the fishery and have been fishing the area continuously.

CSIRO began a research project in January 1985 (FIRTA 1985/82) to

- obtain information on the size, mortality, growth rates and reproduction of the three commercial scampi species,
- document the catch and fishing effort by type and quantity, and
- improve yield estimates for the fishery.

Answers to the questions were sought in two ways. First, the participating trawlers were required to complete and return a daily logbook record of their fishing activity and catches. Analysis of these records provides daily and seasonal information on the composition of the catch and rates of catch by species, area and depth.

Second, samples of the catch were measured on board commercial trawlers for growth and mortality estimation. Information on the fecundity and life cycles of these species was also collected.

In 1986/87, a second fishery, the Western Deep Water Trawl Fishery, began and was included in the area covered by the research.

At industry's request, the research was expanded in 1988 to include the deepwater prawns, bugs and squid that make up the bulk of the catch. This is the basis of the present project (FIRDC 1988/74).

Because of the cessation of FIRTA and the establishment of FIRDC, this grant started at the unusual date of 1 January 1989 and was originally intended to finish on 31 December 1991. It was later extended to 30 June 1992 to allow an orderly collection of essential data on the fisheries, and allow for a proper transfer of responsibilities to the appropriate authorities to be established by that date.

Daily logbooks of fishing activity and catches were used to obtain information on daily and seasonal variations in catch composition and rates by species, area and depth. In addition, scientific observers on board the commercial vessels collected data and samples for laboratory analysis of growth, number of eggs and life cycles of each species, from which sustainable harvest levels could be estimated. The discarded component of the catch was also monitored to provide assessments of total yield.

All of the data collected were used to develop advice on appropriate management measures to maintain the resources and profitability of the fishery.

This report details the results of the studies carried out under the project and also some other studies funded by CSIRO which have relevance to the results. The areas covered by this report are the North West Slope Trawl Fishery (NWSTF; Fig. 1.1) and the Western Deep Water Trawl Fishery (WDWTF; Fig. 1.2). The inner zones are designated exclusively for Australian endorsement holders. The outer zones are also available to other fishers (including overseas interests), on approval. All of the data collected in the study are from the inner zone except for finfish in the WDWTF. The report also includes data on the Timor Sea deepwater trawl fishery which takes catches of similar species and often using the same vessels.

Composition

The bulk of the catches have been made in the NWSTF (Fig. 1.3) rather than the WDWTF (Fig. 1.4). The main catch was of three groups: scampi, prawns and squid (Fig. 1.5).

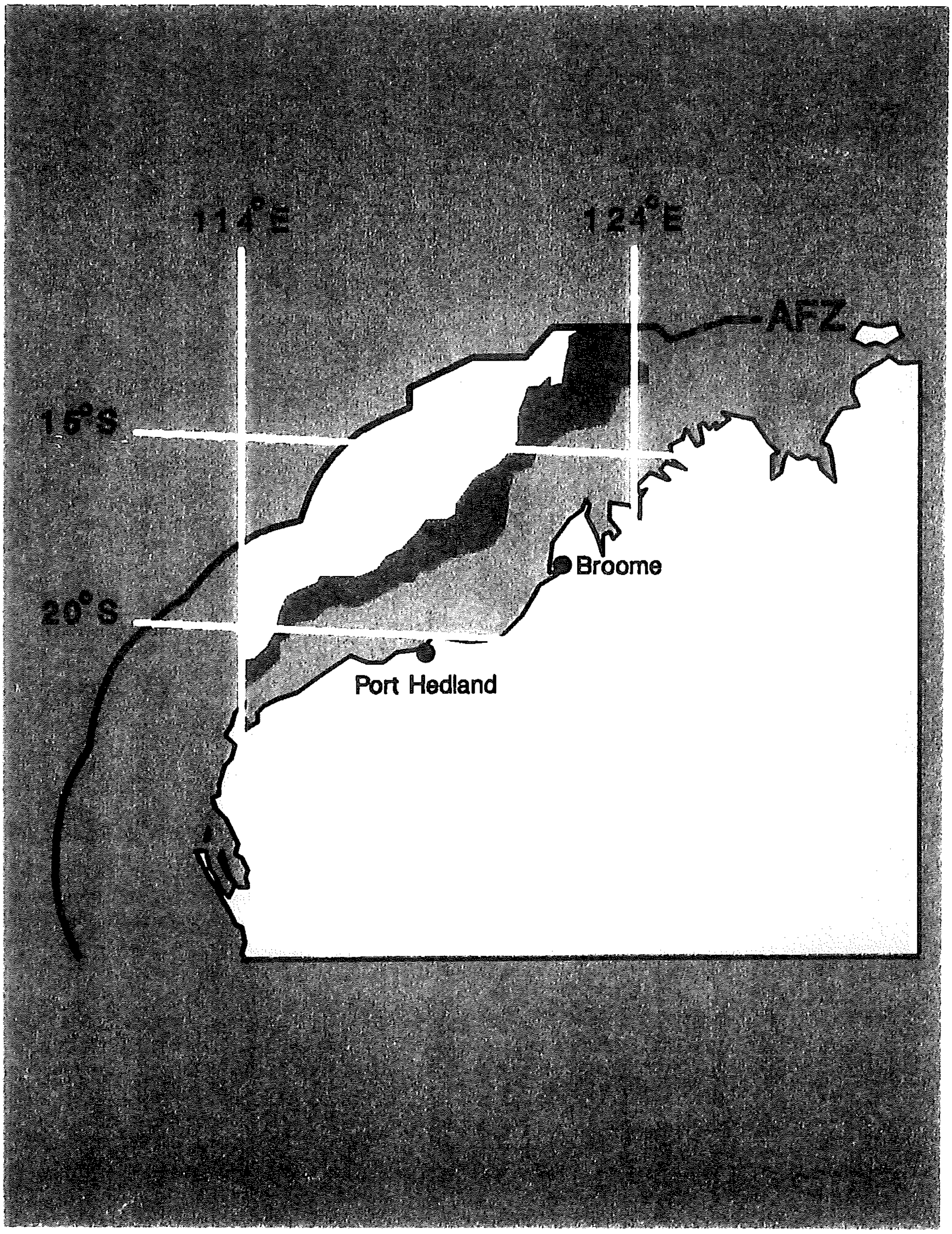


Fig. 1.1 Location of the North West Slope Deep Water Fishery.

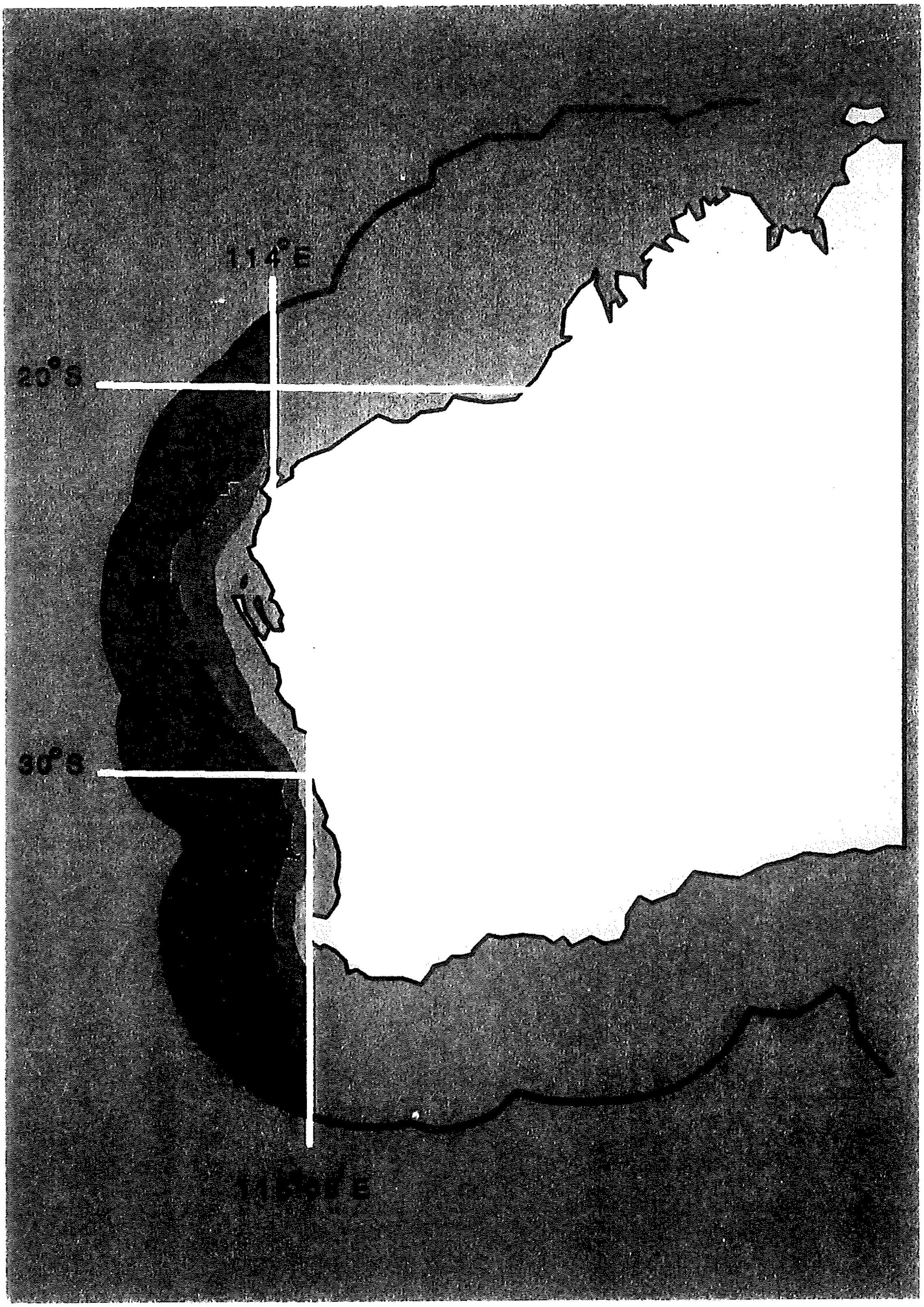


Fig. 1.2 Location of the Western Deep Water Trawl Fishery.

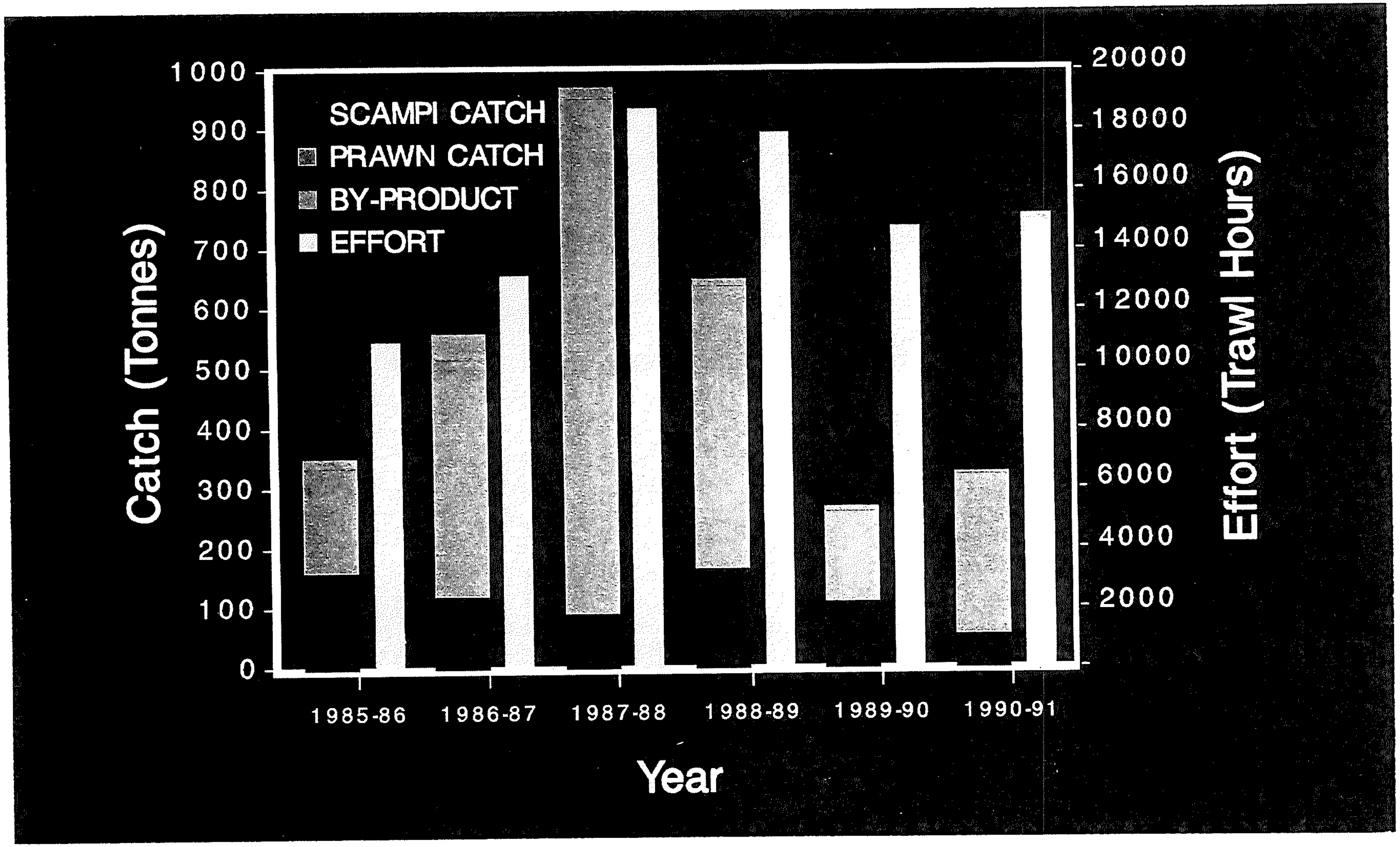


Fig. 1.3 Annual catch and effort for the North West Slope Deep Water Fishery

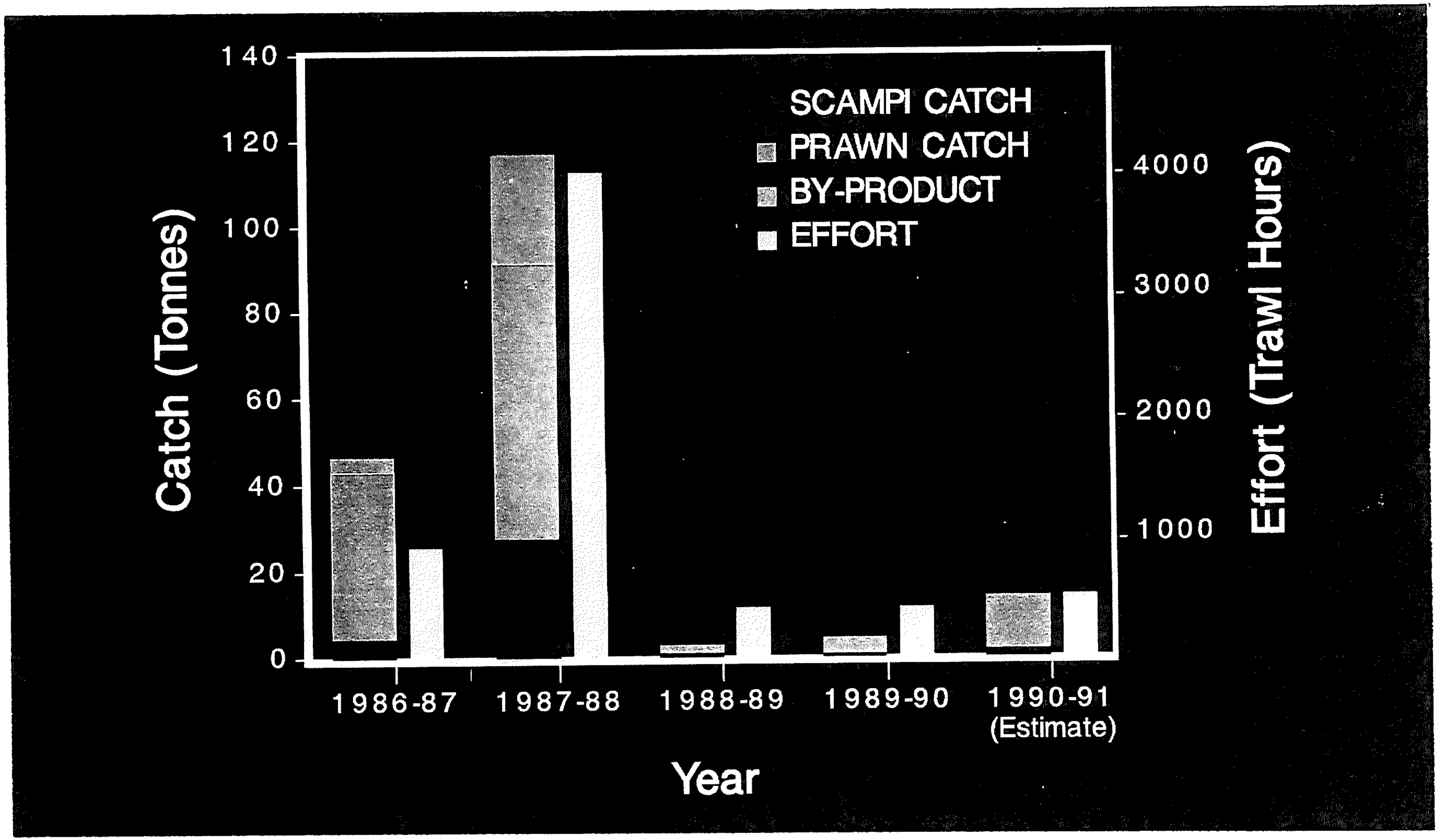


Fig. 1.4 Annual catch and effort for the Western Deep Water Trawl Fishery

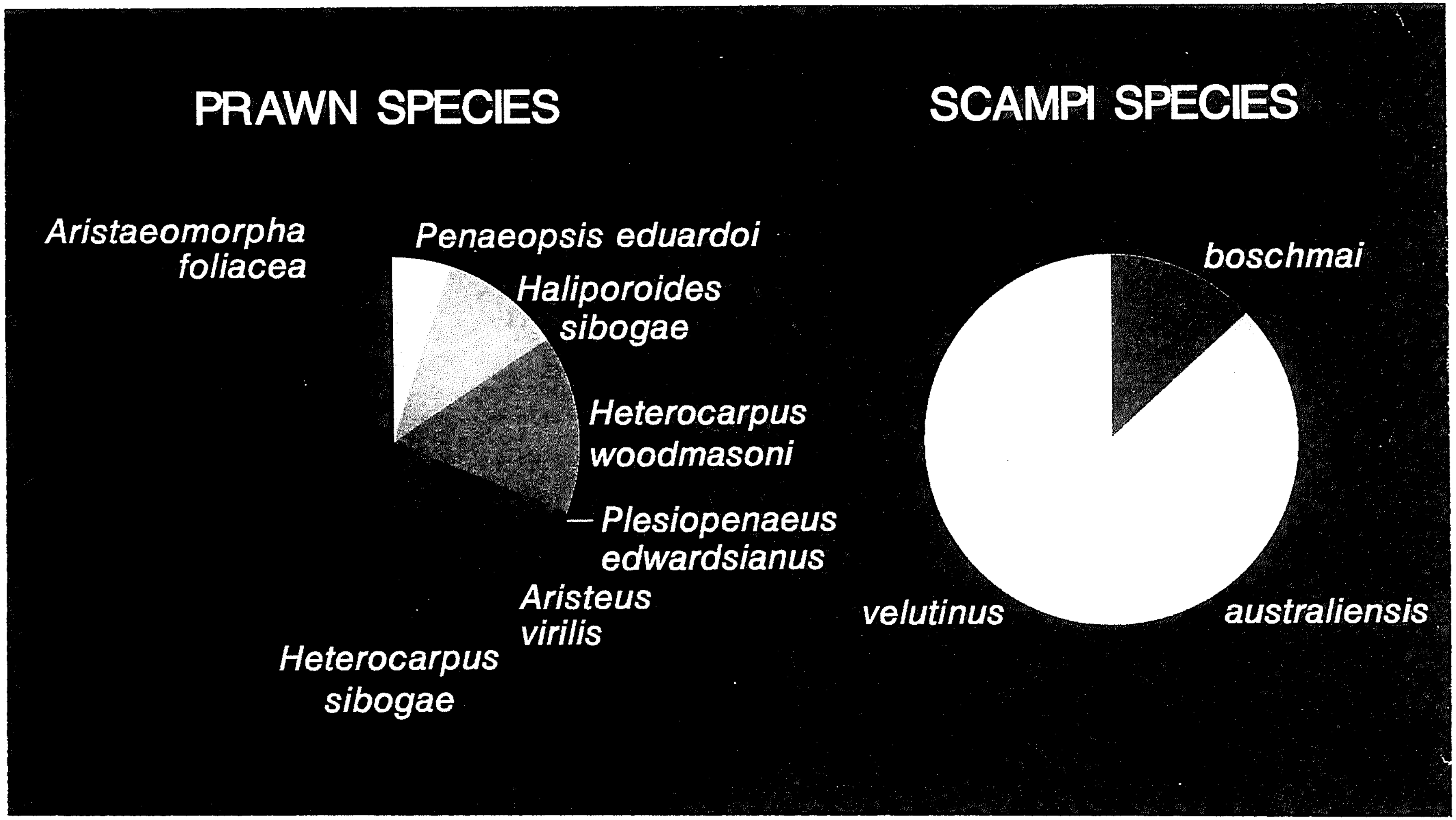


Fig. 1.5 Species composition of crustacean catches in the North West Slope Deep Water Trawl Fishery (1986–1989)

Scampi

Three species of scampi are caught commercially on the North West Slope. These are *Metanephrops velutinus* (previously called *M. andamanicus*), *M. australiensis* and *M. boschmai*. Each species is found at a different depth range: *M. boschmai* at 300–380 m, *M. velutinus* at 370–440 m, and *M. australiensis* at 430–500 m.

Prawns

The prawn component varies according to time of day. For example, prawns may make up more than 80 per cent of a daylight catch but less than 35 per cent at night. The prawn component also varies with targeting to suit particular overseas markets.

Six commercially important prawn species are caught in the fishery: four are penaeids (about 67 per cent of the catch), and two are carids. The penaeid species are: red prawn (*Aristaeomorpha foliacea*), pink prawn (called royal red prawn in New South Wales) (*Haliporoides sibogae*), pink striped prawn (*Aristeus virilis*), and giant scarlet or carabinero prawn (*Plesiopenaeus edwardsianus*). The red prawn is the most abundant and also the most important commercially, although catches of pink striped prawns increased markedly in 1989/90. The two carid species are: red carid prawn (*Heterocarpus woodmasoni*), and white carid prawn (*Heterocarpus sibogae*). The latter is the most abundant, but *H. woodmasoni* is the most commercially important.

By-catch

The most important by-catch in the fishery, in terms of both tonnage and value, is squid. The main squid species is *Nototodarus hawaiiensis*. Other by-catch may include deepsea bugs (more correctly, slipper lobsters), fish such as ling and silver dory, and precious shells.

Catch and effort trends

During the brief history of this multispecies fishery it has changed in character from a predominantly scampi fishery with a prawn by-catch to a prawn fishery with a scampi by-catch.

The fluctuating catch of scampi can be attributed partly to changes in the proportion of the fleet targeting on prawns, which are mostly in depths or areas where scampi are naturally less abundant, and partly to a real decrease in abundance as a result of fishing pressure.

The reason for fluctuations in the catch of prawns is even less clear. They may be because of seasonal variations in abundance but a small part is due to some fishermen discarding the less valuable carid prawn component of the catch. Market forces, such as the world-wide decrease in prawn prices over recent years, may be having an effect, but lower catches may also represent a real decrease in prawn stocks.

Management

This is a young and developing fishery and many factors influence the catch. Changes in fishing gear and in the particular species targeted, differences in the experience of skippers, variable levels and distribution of fishing effort, and fluctuating market trends, all affect the catch.

It is not yet possible to provide estimates of sustainable harvest levels with any confidence. However, there is enough information to make some observations on the future management of commercial fishing for scampi and also on the exploration of prawns.

These are contained in the detailed reports in the individual chapters in this report.

Priorities in the future

Plans are in hand for the NWSTF to become a managed fishery. Furthermore, management may eventually be based on individual transferable quotas. Therefore, it will be necessary to set total allowable catch limits for both scampi and deepwater prawns.

At present it is not possible to provide accurate yield estimates, for the reasons discussed previously. However, future research will be aimed at providing the information to make these estimates.

Such information would include more logbook data and selected biological studies of important species, including the deepwater prawn *Aristaeomorpha foliacea*.

If closure were accepted as a management option, the rate of recovery of the fishing grounds would need to be estimated. This would lead to a measure of the productivity of these grounds for scampi.

Current catch and effort data probably underestimate the number of deepwater prawns and some of the rarer species of scampi because their distribution may extend to below 800 m, which is deeper than is currently fished.

The results of a recent survey by the CSIRO Fisheries Research Vessel, FRV *Southern Surveyor*, support this possibility but further exploratory fishing will be needed to find these resources.

In the future, research will need to be directed toward finding alternative harvesting techniques for both scampi and deepwater prawns. This would probably include midwater trawling for deepwater prawns and would definitely include trapping for scampi and prawns.

2 The Western Deep Water Trawl and North West Slope Trawl Fisheries

Mr D. Evans

Contents

Introduction

Combined, the WDWTF and NWSTF cover most of the waters off the West Australian coast between the 200 metre isobath and the AFZ boundary. Extending over a wide range of latitudes, depths and sea temperatures, they encompass a variety of topographical features and substrate types. Not surprisingly, each fishery differs markedly from the other, and is also large enough to harbour distinct variables within itself.

Both fisheries are relatively new and are not yet under formal management plans. Instead, annual development plans for each are drawn up by the Australian Fisheries Management Authority — AFMA (formerly the Australian Fisheries Service — AFS) to provide flexible control over fishing effort in such a way as to induce commercial venture yet prevent premature over-exploitation of stocks. Formal management plans for the NWSTF are expected to be introduced by the end of 1992, but the WDWTF will remain developmental.

In September 1989, a development plan was initiated for a third fishery — the Western and North Western Deep Water Trawl Fishery — comprising the outer regions of the existing NWSTF and WDWTF. The plan was to limit foreign vessels, in particular, to the deeper water west of the 1000 metre isobath, but only one vessel operated in the area over a two year period, and the fishery was rejoined with the WDWTF and NWSTF in 1991.

Endorsements

Applications from industry for endorsements to fish in either fishery are invited annually by AFMA following the issue of developmental plans. Successful application is generally based upon — in the case of fishing companies reapplying — past performance (fishing for a stipulated minimum number of days), and for first-time applicants — on submission of operational plans and the availability of endorsements.

Fishing companies occasionally transfer endorsements to vessels not originally specified. This is accepted practice and allows them to continue fishing when originally endorsed vessels break down or are otherwise unavailable.

Table 2.1 shows show how numbers of vessels endorsed has changed and indicates how effort and industry interest have varied over the developmental years.

Table 2.1. Number of endorsed vessels, and number of vessels actually fishing, in the North West Slope Deep Water Fishery (NWSTF) and the Western Deep Water Trawl Fishery (WDWTF), between 1985 and 1992.

Development year		No. endorsed	No. fished
NWSTF			
1	15 Mar 85 — 17 Apr 86	8	11
2	18 Apr 86 — 30 Apr 87	12	21
3	1 May 87 — 30 Apr 88	12	20
4	1 May 88 — 30 Jun 89	12	9
5	1 Jul 89 — 30 Jun 90	12	9
6	1 Jul 90 — 30 Jun 91	12	5
7	1 Jul 91 — 30 Jun 92	12*	2 (to end Dec 91)

* Actual number of endorsements issued not known but believed to be the same as previous years.

Development year		No. endorsed	No. fished
WDWTF			
–	1 Apr 86 — 30 Mar 87	–	11
1	1 Jul 87 — 31 Jul 88	~100	20
2	1 Aug 88 — 31 Jul 89	19	4
3	1 Aug 89 — 31 Jul 90	9	6
4	1 Aug 90 — 31 Jul 91	10	6
5	1 Aug 91 — 31 Jul 92	15*	3 (to end Dec 91)

* Actual number of endorsements issued not known but development plan suggested this number would be endorsed.

The North West Slope Trawl Fishery

Background

The occurrence on the North West Slope of the scampi (nephropid lobster) *Metanephrops australiensis* was noted in 1978 during an exploratory cruise by the CSIRO chartered research vessel, FV *Courageous* (Sainsbury 1979). Findings from subsequent cruises by the CSIRO research vessel, FRV *Soela* in 1982 (Anon. 1983) and 1984 (Davis and Ward 1984), and an independent investigation by KFV Fisheries (Carter *et al.* 1983) indicated potential for the establishment of a crustacean trawl fishery. Development plans for the North West Slope Trawl Fishery began in 1985 and the fishery was born. Scampi formed the main component of catches in the early years but, as stocks of scampi have declined, prawns and carid shrimps have been increasingly targeted and now provide the majority of the catches by weight.

Location

The fishery lies off the coastal strip between North West Cape and Wyndham in the north-west of Australia. It is bounded in the North by longitude 124°E., and in the South by longitude 114°E. Inshore and offshore boundaries are the 200 m isobath and the 800 m isobath, respectively.

Fishery characteristics

Fishing is entirely by demersal trawl and targets three scampi, four penaeid prawn, and two carid shrimp species. Several other species are retained as by-catch. Targeting fluctuates considerably and is influenced mainly by market demand and seasonal variations in stock abundance.

Twelve vessels are endorsed to fish annually, but in recent years, rarely more than six have fished actively in each year. The annual catch and effort statistics on p.46 indicate how effort and targeting have fluctuated since 1986/87.

Cruise duration is limited by freezer space, fuel and freshwater reserves, but is typically four to five weeks. Weather rarely forces vessels back to port but fishing days are often lost sheltering at nearby islands or outrunning cyclones.

With the exception of two purpose-built deepwater trawlers, which work throughout the year, most vessels are Northern Prawn fishery trawlers and tend to fish the NWSTF only during seasonal closures of that fishery. Closures occur in July, and from December to April. Recently, two other purpose-built trawlers arrived from Queensland and have been fishing continuously in the NWSTF since May 1992.

Principal commercial species

Scampi	*Metanephrops australiensis, M. velutinus, M. boschmai*
Carid shrimps	*Heterocarpus sibogae, H. woodmasoni*

Penaeid Prawns	*Aristaeomorpha foliacea, Aristeus virilis, Haliporoides sibogae, Plesiopenaeus edwardsianus*

By-catch species

Squid	*Nototodarus hawaiiensis*
Scampi	*Metanephrops neptunus*
Blind Scampi	*Nephropsis stewarti, N. serrata*
Deepwater Bugs	*Ibacus ciliatus pubescens, I. alticrenatus*
Spear Lobsters	*Linuparus sordidus*
Whip Lobsters	*Puerulus angulatus, P. velutinus*

Common names for the above can be found in the main introduction to this report.

Fish species are rarely kept as by-catch as most are either unmarketable, unpalatable or too small. Large, edible species, such as ling and mirror dory, are occasionally caught but are usually kept for crew consumption only.

Deepwater shells were once a small part of the by-catch but prices declined rapidly as oversupply replaced rarity and few are kept any more.

Vessel characteristics

Demersal trawling for crustaceans in deep water is similar to that in shallow water. Vessels designed for the latter are readily available in WA and require only minor modification to enable them to fish in deep water. For this reason, most vessels currently endorsed are modified shallow water prawn trawlers, mainly from the Northern Prawn fishery. Many of the companies which own them are WA-based.

Modifications include the installation of large capacity winches, altering warp towing points and winch positions, and adapting existing processing regimes to accommodate the more fragile deepwater species. Vessels can generally be cheaply and quickly reconverted for NPF operations as the seasons dictate.

Most fishing effort in recent years, however, has been by two trawlers, built specifically for deepwater operations. These are based on traditional NPF design but the modifications mentioned were built in at construction. They are very similar in appearance and layout to NPF vessels but lack long, outrigged booms, characteristic of the latter. Although NWSTF trawlers come in several classes, the similarity in design between the NPF and purpose-built vessels allows the following general description:

- all-steel construction, 22–29 m LOA. with five to eight crew members — comprising skipper, mate, cook and deckhands — typically accommodated in 4 two-berth cabins

- powered by a single diesel main engine producing 275–530 kW. Electrical (240V), hydraulic and freezer systems powered by main engine, auxiliary diesel(s), or a combination of both.
- navigation and fish-finding equipment typically includes radar, autopilot, colour plotter, Global Positioning System (GPS), colour and paper sounders. Communication is via UHF and VHF transmitters and occasionally telex and fax machines.
- Winches — all hydraulic. Usually comprising two main trawl winches with 14–16 mm warp wire, two smaller winches for lazy-line retrieval and spilling trawl bags, and several small capstan winches for general purpose lifting.
- A-frames and boom design variable but all support and guide trawl warps and lifting lines. Warp tow points outboard but generally close to the vessel.

Typical vessel layout

Wheelhouse forward of amidships. Air-conditioned living quarters set forward below foredeck with four twin-berth cabins. Galley and cold store below wheelhouse. Dry store for food and packaging material in bilge void below living quarters. Main work deck aft of galley and housing spill tray, brine tanks, conveyors and processing area. Deck above work deck and aft of wheelhouse supports trawl winches (on main work deck in purpose-built trawlers). Freezer hold of about 35 tonne capacity set amidships below main work deck with shelved blast freezer section. Engine room aft of that and extending to transom.

Trawl gear

No restrictions on net headrope length or mesh size exist in either deepwater fishery and several different types of net have been tried. For prawns and scampi, polypropylene nets of the 'Florida flyer' type are fairly standard. These are based on NPF banana prawn nets with extended wing panels and slightly different seaming. Vessels tow nets in either double or triple arrays giving a total headrope length of between 47 and 75 m (26–40 fathoms), depending on vessel power. Wing mesh size is typically 60 mm (2·25") for prawns and 90 mm (3·5") for scampi. Cod-ends are of heavier gauge and generally 45 mm (1·75") mesh, regardless of target species. Footropes are wire-cored 'combination rope', preceded by a mud-chain. Chain links, or 'drops' connect the two, their length affecting the amount of 'bite' into the substrate. Tickler chains are strung between the trawl wing corners and lead the whole assembly.

Net spread is achieved with steel or steel/timber otter boards attached to the outer wings of a net array. All-steel 'Bison' boards, typically 'No. 5's, are preferred. Steel skids connect, support and guide the inner wings of arrayed nets. Skids and boards are connected to the main warp by long wire bridles. Chain sweeps run from the skids and boards to the net wings.

Fishing techniques

Most vessels are capable of fishing to 900 m but the best commercial aggregations of prawns and scampi occur in 350–600 m. Relatively flat substrates of mud or silt are preferred for demersal trawling since nets are easily snared on boulders and rocky outcrops. Uninterrupted stretches of 10 n.m. or more are considered ideal. Discrete grounds for the various species have been identified and are governed by geographical location, depth and substrate type.

Fishing techniques are similar for prawns and scampi though prawn nets do not dig into the sediment as much as scampi trawls and employ smaller meshes in the wings. Suitable bottom and depth are located and maintained by echo-sounder and trawl paths generally follow a fixed depth contour to within 5 m. Trawl speed is 2·5–3 knots, depending on depth, tide and substrate and warp length : depth ratio is about 2·8:1. Combined shoot-away and haul-up time is considerable, typically one hour at 500 m. Shot duration is 3–5 hours (actual bottom time), depending on species. Deepwater prawns are more fragile than scampi and prawn shots tend to be shorter to minimise product damage. Trawling is usually around the clock except when targeting the red prawn, *Aristaeomorpha foliacea*, which rises to midwater at night. Selected fishing areas are commonly wide enough to allow three or four consecutive trawls, but particularly fruitful runs will be retrawled, though rarely on exactly the same track. An exception is when targeting the pink-striped prawn, *Aristeus virilis*.

Recent improvements in the accuracy of GPS navigation systems interfaced with colour plotters has enabled a practice hitherto reserved for shallow water prawning. It is believed in the fishery that the repeated trawling of an area, with reasonable precision, creates a 'venturi' effect that attracts and concentrates prawns from outside areas into the 'trough' created —. possibly to feed in the disturbed sediment. Adoption of this method in the NWSTF appears to be responsible for a marked recent increase in catches of the pink-striped prawn although it seems not to work with other species. Troughs can be fished for up to several weeks before catches decline.

Processing

Full cod-ends are retrieved over vessels' quarters (or stern, in purpose-built trawlers). Full 'bags' are emptied onto an aluminium spill-tray and the catch passes through coarse strainer bars into a hopper bin below, filled with refrigerated sea water.

Plastic conveyor belting lifts the catch out of the hopper bin and onto a horizontal conveyor at each side of which crew members stand and pick off the desired species. Species are graded by eye and placed in bins containing refrigerated seawater with an antioxidant solution to prevent melanosis (blackening) of the product. Once sorted, the product is boxed, weighed and placed in a blast freezer for several hours before being repacked in the main freezer hold.

Large prawns and scampi are usually boxed whole in 3 kg cartons with top layers neatly arranged or 'finger-laid' to enhance presentation. Small and damaged specimens, and by-product species such as bugs, spear lobsters and whip lobsters are usually headed, and the tails are packed in 12 kg cartons.

The Western Deepwater Trawl Fishery

Background

Concerted fishing began in the WDWTF in 1986 even though development plans were not implemented until July 1987. 11 vessels, already endorsed for the NWSTF, fished the region between April 1986 and March 1987, targeting crustaceans. Very little exploratory fishing was done prior to 1986, with the exception of a cruise in 1979 by the Japanese vessel *Taiyo Maru,* which found commercial quantities of big-spined boarfish (*Pentaceros decacanthus*), and smaller quantities of other commercial finfish species (Heald and Walker 1982). However, throughout its history the WDWTF has experienced only low and sporadic fish trawling effort.

Initially, fishing was concentrated in the northern region of the fishery, particularly to the west of North West Cape and southwest of Shark Bay, exploiting pockets of scampi and prawns. By 1988 catches had declined considerably and fishing in those areas became sporadic, usually confined to a few days each year by vessels on route to destinations further north. At about this time deepwater bugs (*Ibacus alticrenatus*) were found off Lancelin and small quantities of the scampi (*Metanephrops velutinus*) were taken to the west of Bunbury. These areas were fished only in the summer NPF closure period and neither ground has been exploited since early 1990. Most of what little fishing effort currently remains in the WDWTF targets finfish.

Location

The fishery lies off the coast of WA between Cape Leeuwin and North West Cape and its northern boundary, longitude 114°E. is the southern boundary of the NWSTF. The southern limit is at longitude 115°08'E. and the inshore and offshore boundaries are the 200 m isobath and the AFZ line, respectively.

Fishery characteristics

Fishing effort varies considerably from year to year and is much less than in the NWSTF. Rarely more than half of endorsements annually issued are used and the fishery is not regarded by industry as being particularly productive. The total boat days fished per year is typically about 80, roughly a tenth of that in the NWSTF — see Annual catch and effort statistics (pp. 46, 47). The 1991/92 season has witnessed a slight increase, due to the relatively sustained efforts of one vessel, but yield and general interest have remained low.

As with the NWSTF, most vessels are principally dedicated to other fisheries, tending to fish only during seasonal closures of those fisheries. The diversity of such fisheries has led to many different types of vessel being used in the WDWTF including fish, scallop and prawn trawlers, but few were designed for deepwater and many are too small to cope effectively with the prevailing rough sea conditions.

In addition, few are suitably equipped for demersal operations on very rough bottom, a feature common to much of the fishery, or for midwater trawling. Cruise duration is therefore often curtailed by bad weather or gear damage, and is rarely more than two weeks.

Principal species targeted

Fishing is generally demersal and targets crustaceans and finfish, with emphasis on the latter in recent years. Catch patterns are not clearly defined as species diversity is considerable, few specific grounds have been identified, and targeting is characteristically opportunistic.

Recent interest has been shown in orange roughy (*Hoplostethus atlanticus*) following reasonable catches to the west of the southern boundary of the WDWTF, but several SEF vessels which trawled between Cape Leeuwin and Rottnest Island had little success. Relatively large catches (up to five tonnes) of big-spined boarfish were landed in that area, however.

Some industry members believe that potential still exists for finding large aggregations of orange roughy in the WDWTF but the expense of exploratory fishing and SEF commitments have so far precluded them from further attempts.

In the southern area of the fishery from Cape Leeuwin to Geraldton, several other commercial species are landed but not in large quantities. mirror dory (*Zenopsis nebulosus*), deepwater flathead (*Platycephalus conatus*), green-eyed dogsharks (Squalidae), alfonsino (*Beryx splendens*), and squid (*Nototodarus hawaiiensis* and *N. gouldi*) are amongst the most commonly caught. Ruby snapper (*Etelis carbunculus*), lenko snapper (*Dentex tumifrons*) are occasionally caught in the northern region between Geraldton and North West Cape.

Vessel characteristics

Trawlers have been of such diverse nature over the years that it is impossible to give a general description of vessel and trawl types or fishing methods. Vessels range from 18 m converted tuna boats to 85 m foreign factory ships, and include NPF, Shark Bay scallop and South East Fishery trawlers. A wide variety of nets, targeting techniques and processing methods have also been employed.

A lack of significant success over the years in the WDWTF points, perhaps, as much to the general unsuitability of available vessels as it does to the apparent lack of resources. Essentially, vessels have either been too small to cope effectively with the WDWTF sea conditions, too large to be economically sustained by the small catches, too suited to other forms of fishing to be economically modified for effective fish trawling, or hampered by poor market response when catches have been relatively good.

Fish trawls and methods

It is proposed not to detail the wide variety of trawl gear and methods employed; either demersal fish or crustacean trawls are used. Crustacean trawls have been described in the NWSTF section. Fish trawls are generally larger, with cod-end meshes typically of 75-100 mm and wing meshes varying from 200 mm to 1·6 m or more. Nets are towed singly and are commonly spread with 'super V' trawl doors. Long sweeps between the trawl doors and net wings extend the swept area of fish trawls by creating a herding effect. Footropes incorporate a variety of rubber disks, bobbins and rollers designed to enable the trawl to travel over rough terrain without digging into the substrate or hooking up on ledges and boulders.

Fish schools, if large and acoustically reflective, can be seen on echosounders as marks and are targeted directly. Some vessels also use sounders attached to the net headrope which indicate precisely when the trawl is on the bottom, what the net opening is, and whether fish are passing into the net. This option is very effective but expensive and most of the smaller vessels do not have it. Trawl speed is 3–3·5 knots and trawl duration is governed by the abundance of marks and the extent of trawlable ground.

Processing

As with other aspects of fish trawling, catch processing has not evolved into any fixed pattern. Methods include putting whole fish in refrigerated brine tanks, storing gutted and gilled fish on ice or in an ice slurry, and full processing to frozen fillets.

3 The Scientific Observer and Logbook Programs

Contents

3.1 The Observer Program

Mr D. Evans

Background

In early 1986, CSIRO began putting scientific observers on commercial vessels in the NWSTF and WDWTF. Their objectives were to gather biological data on commercial prawn and scampi species, and ensure logbooks were being correctly filled out. It has always been a requirement for endorsement that holders provide berths for scientific observers on their vessels, whenever requested to do so. Industry has been extremely cooperative in this regard.

Between February 1986 and February 1988, 13 observer cruises, mostly in the NWSTF, were undertaken totalling 144 days at sea at an average of 11 days per cruise. eleven different vessels belonging to four companies were covered.

Late 1988 saw increasing interest in deepwater fisheries, particularly in the WDWTF, and this current FIRDC-funded study was started, with greater emphasis on multispecies research than the previous study, particularly regarding finfish and squid. A need for better observer coverage was identified, particularly in the WDWTF. A formal observer program was set up within CSIRO, headed by a technical officer with considerable seagoing experience.

Aims

The principal objectives of the program were to ensure that biological and logbook data from the fisheries were accurately recorded, that operational aspects were fully understood, and that sampling was carried out correctly.

To achieve this, data needed to be collected, and observations made, at source. The program ensured that suitable people were recruited, and that they were adequately trained to perform these duties. An observer manual was produced to prepare observers for lengthy periods at sea, to guide them towards achieving their objectives, and to help them overcome the multitude of logistic problems characteristic of deepwater cruises.

Logistics

The program manager constantly liaised with industry to maintain up-to-date knowledge of vessel movements, species targeting, and availability of berths for observers. CSIRO scientific staff were thus able to choose vessels working in desired areas or catching species on which data was needed. The program manager subsequently arranged berths on suitable vessels and coordinated travel arrangements for observers to reach ports of departure. Such ports included Darwin, Broome, Port Hedland, Exmouth, Geraldton, Fremantle, Bunbury and Albany.

Working kits were prepared and issued to observers prior to every cruise. These included an observer manual, species identification booklets, lists of objectives and specific instructions on data collection, measuring, recording and photographic equipment, sample preservation gear, protective clothing, and first aid kits.

Cruises in the NWSTF tended to be of four to five weeks' duration since fishing grounds were well offshore and vessels stayed at sea until fuel reserves became low. Occasionally, observers managed to transfer earlier to port-bound vessels but this was dependent on circumstance and good weather. In the WDWTF, due to such factors as bad weather, greater incidence of damage to trawl gear, and lack of long-term product storage facilities, cruises tended to be shorter, ranging from three days to two weeks, rarely longer.

Observer objectives and methods

- To collect distributional and biological data on commercial and potentially commercial species of crustaceans, finfish and squid, by:

  direct observation, length frequency measurement of representative samples, recording of maturity stages, collecting samples for laboratory analysis

- To ensure the accurate and comprehensive completion of logbooks, and timely return for data entry of completed logsheets, by:

  checking logbook entries at source against positional, landed catch and processed product observation, providing skippers with on board instruction in logbook completion, personally collecting completed logsheets and encouraging skippers to return future logsheets quickly.

- To record the discarded component of catches with particular regard to species with fluctuating commercial status, by:

  obtaining total catch weights by visual estimation or calculating hopper bin volume and subtracting kept product weight, subsampling catch for composition determination by species and weight

- To obtain information on all aspects of the fishing process including targeting techniques, trawl gear design and operation, and catch handling and processing regimes, by:

  direct observation, discussion with crew members, photographic recording, active involvement in processing operations

- To collect and preserve specimens for laboratory-based photographic and taxonomic work, or as requested by allied institutions such as museums, by:

  selecting fresh specimens in good condition and ensuring specimens remain intact with colours preserved through correct freezing techniques

- To provide a written account of cruises documenting objectives achieved, observations made, vessel and crew details, suggestions for future observers, and general impressions, by:

  keeping cruise journals and submitting cruise reports within one month following cruises.

Cruise records

Cruise reports were required to be completed within one month by observers for every cruise undertaken (see Appendix III for details). Reports were submitted to the program manager along with biological data sheets. Because reports often contained confidential information about vessels and companies, all reports were stamped 'confidential', restricted in circulation, and kept under lock and key at all times.

Vessel coverage

Between late 1988 and March 1992 a total number of 421 days were spent at sea by observers on 13 different vessels owned by eight companies (see Appendix III for details):

WDWTF

- ten cruises conducted
- six vessels covered
- six participating companies
- average cruise duration — eight days

NWSTF

- sixteen cruises conducted
- seven vessels covered
- three participating companies
- average cruise duration — twenty-three days

An additional twelve-day cruise was conducted in the allied Timor Sea deepwater fishery to collect data on the scampi, *Metanephrops sibogae*. It is believed this species possibly also occurs at the northern limits of the NWSTF but no catches have yet been recorded.

3.2 The Deepwater Logbook and Database Program

Mr J. R. Garvey

Summary

A logbook program was used to record the commercial catch and fishing effort of vessels endorsed in the North West Slope and Western Deep Water Trawl Fisheries (NWSTF, WDWTF). The program has been in continuous operation since commercial exploitation started in 1985. Completion of logbooks was compulsory under the annual Commonwealth development plans for both fisheries. Logbook data were entered and stored on the deepwater logbook database system (DWLDS) at the CSIRO Division of Fisheries Laboratory, Marmion. Data were transferred to the Australian Fisheries Management Authority (AFMA, formerly AFS), in Canberra, for storage on the AFZIS national fisheries database. The logbook program was completed as planned, under contract to AFS, during the tenure of the FIRDC Grant 88/74.

Background

Initially, vessels used Northern Prawn Fishery logbooks, until a deepwater crustacean logbook designed for the NWSTF and WDWTF fisheries was introduced in 1985. This logbook was modified a number of times until a standard A3 format was developed in late 1986. The format was modified slightly in late 1989.

Up to 1989, most effort in both fisheries was directed at deepwater crustaceans. The small number of vessels trawling for fish used either a deepwater crustacean logbook or a Great Australian Bight (GAB) logbook. After 1989, interest in trawling for fish in the WDWTF increased, and a separate logbook for fish and squid was introduced for those vessels.

Description

Fishing activity was recorded in the logbooks by skippers of commercial vessels for each shot (trawl). Data include the weight of the retained catch of each species, together with the date, depth, start position, start and finish time of the shot. Type of trawling gear and mesh size were noted, with any comments on the fishing operation.

Catches of the commercially important crustaceans were recorded in number of cartons, which ranged from 3 kg to 15 kg. The type of product, either whole (heads-on) or headless was recorded and differentiated in the logbook database. Catches of whole scampi were recorded by grade, which were ≤ 50, 51-70, 71-90 and > 90 scampi per 5-kg box. Skippers were asked to identify the species mix of their scampi catch, however compliance was haphazard.

Prawn catches were often recorded by grade, but the variation in the prawn grading systems used by different companies made it impractical to differentiate prawn grades in the logbook database. Other crustaceans were recorded by species groups (i.e., lobsters and crabs). Cephalopod catches were pooled, however most would have been of *Nototodarus hawaiiensis*. In the crustacean logbook, catches of different species of fish were pooled. Fish and squid catches were recorded by species in the Fish / Squid logbook.

Skippers were encouraged to send in logsheets regularly. Freepost envelopes were supplied with the logbooks, and an agent was contracted in Port Hedland to collect and forward the logsheets. After return to CSIRO, logsheets were edited to extract the maximum amount of valid data, following the procedures outlined in Primary Operations Manual (Vol. 1). Information and experience gained from the scientific observer program were valuable in interpretation of the varying quality of the logsheets. The data were then entered into the (DWLDS) and subsequently checked for keyboard errors.

The DWLDS data were validated using processor returns sent in by the endorsement holders, following the procedures set out in the DWLDS Advanced Operations Manual (Vol. 2). Discrepancies were investigated by cross referencing with other landings by the same vessel or other vessels of the same company. Large discrepancies were resolved by inquiry to the fishing company or scientific observer. The discrepancies from this process were used as an estimate of error for the annual catch summaries. The annual percentage differences between the logged catches and processor returns for the commercially targeted crustaceans (Chapter 2, pp. 19 *et seqq.)* have ranged from 0·1 per cent to 9·7 per cent during 1989 and 1990 fishing years. Small amounts of fish were caught from the WDTF and the market was unstable, so validation from processor returns was not possible for Fish / Squid logbooks.

The DWLDS was maintained on a Cleveland 386 IBM-compatible computer using dBase IV (Borland). Backup onto tape cartridge ensured that in the unlikely event of system failure, loss of data would be restricted to one week. Tape backups were stored off-site.

Statistics were extracted from the database using the query-by-example module of dBase IV, and a suite of applications described in the Data Output Manual (Vol. 3). Presentation graphics of the data outputs where produced using Atlas Graphics (STSC) and Quattro Pro (Borland). These graphics included graphs of species catch and catch per unit effort (CPUE), and spatial mapping of uncorrected effort, catch and CPUE by 30' latitude and longitude.

Interaction with observer program

The DWLDS was used in the scientific observer program for cruise planning. Previous targeting by the available vessel, within its possible fishing area, was examined to identify those species most likely to be encountered on an observer cruise. All vessels fishing in the NWSTF and WDTF were included in the DWLDS due to the compulsory logbook system. This meant that observer cruises covered as broad a cross section of the vessels' fishing as possible.

The scientific observer program ensured that skippers had frequent contact with CSIRO officers, who were able to answer their questions about the logbooks, correct previous errors and report back the skippers' views of the program. Information from skippers was essential in interpretation of the commercial data, for example the improvement in position fixing with the introduction in 1989 of GPS navigation to the vessels. The scientific observer program was important in helping the skippers to identify species using the CSIRO Guides to deepwater crustaceans, fish and cephalopods, thus ensuring the accuracy of the catch data.

Utilisation

Outputs from the DWLDS included various types of catch and effort data. For example, average scampi catch in the NWSTF and the Timor Sea areas are displayed for the 1988/89 season in Fig. 3.2.1, and the annual average scampi catch in these areas during the 1985–91 period are displayed in Fig. 3.2.2. Summaries of catch and effort were compiled annually for presentation at Industry / Government Meetings on the NWSTF and WDWTF.

Strict confidentiality was enforced in the release of logbook data. Requests from endorsement holders about the logbook data were met only if the requested data had been previously released in summary form, or related to their own fishing activities. Many requests for access to the logbook data were made by Government and other agencies. These were met if Australian Bureau of Statistics guidelines for confidentiality were satisfied and written consent from AFS was provided.

The logbook database has been the primary source of data for the estimation of changes in relative abundance of the exploited species of the NWSTF and WDWTF. To estimate relative abundance, catch per unit effort (CPUE) has been calculated using the logbook data in a number of ways. The results have been reported at Industry / Government meetings on the NWS and WDW fisheries, and provided the basis of much of this report and its related publications.

Management considerations

The logbook program has had an important role in monitoring the development of the multispecies fisheries of the NWSTF and WDWTF. Management of many fisheries is constrained by the lack of reliable records of fishing patterns from the start of commercial exploitation. The NWSTF and WDWTF are unusual in that the DWLDS provides a verified, shot-by-shot record of the evolution of these multispecies fisheries. These data will be useful for the informed management of the fisheries as they progress from Development to Managed status. Under the present Commonwealth management provisions, the managed status will require output controls (total allowable catch) to be set for the fisheries. The DWLDS provides the basis for catch levels to be set by reference to catch history from the start of the fishery.

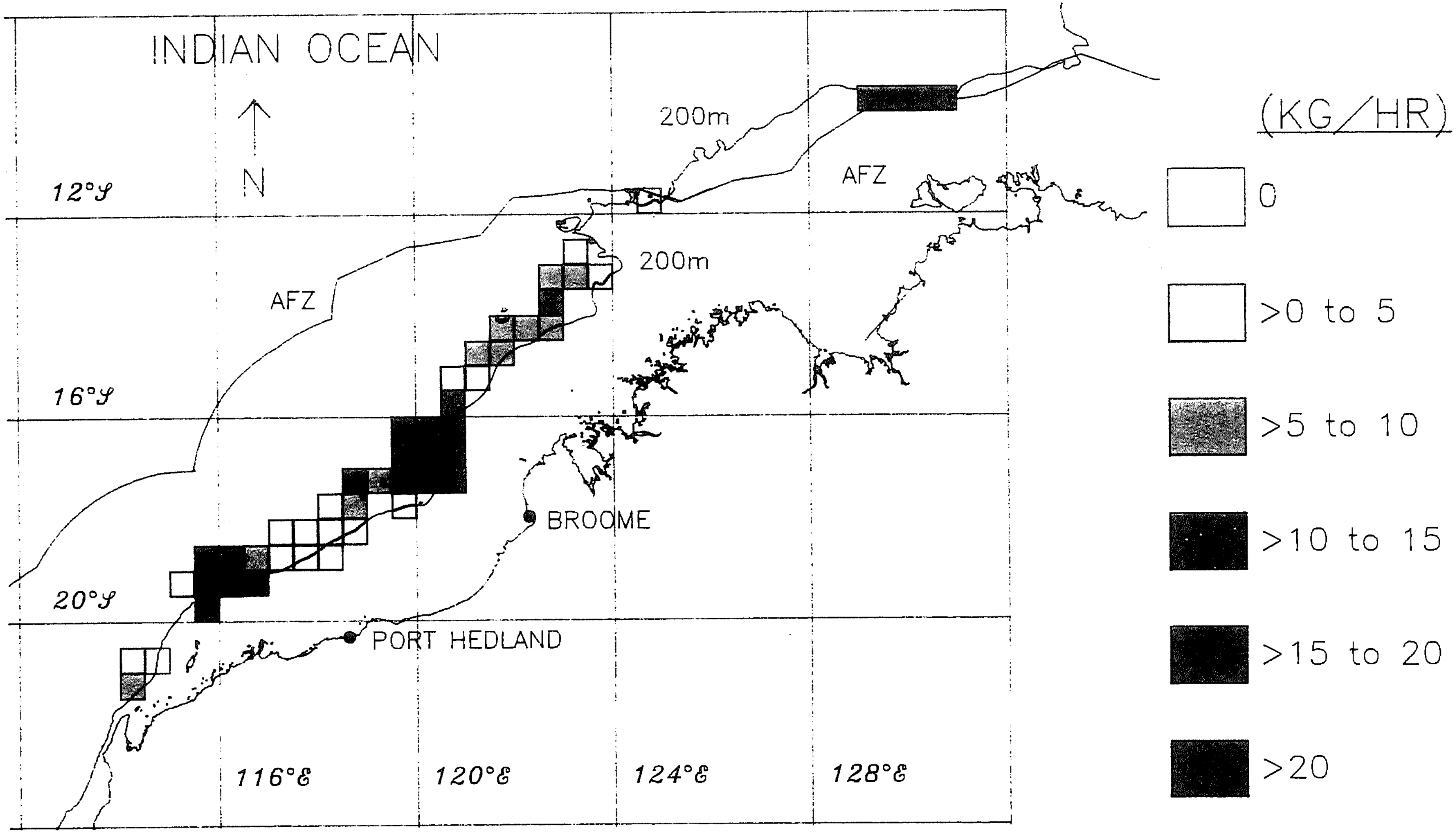


Fig. 3.2.1 Scampi catches in the NWSTF and Timor Sea areas: average catches in the 1988/89 season in each half-degree square of the fisheries, in six abundance categories.

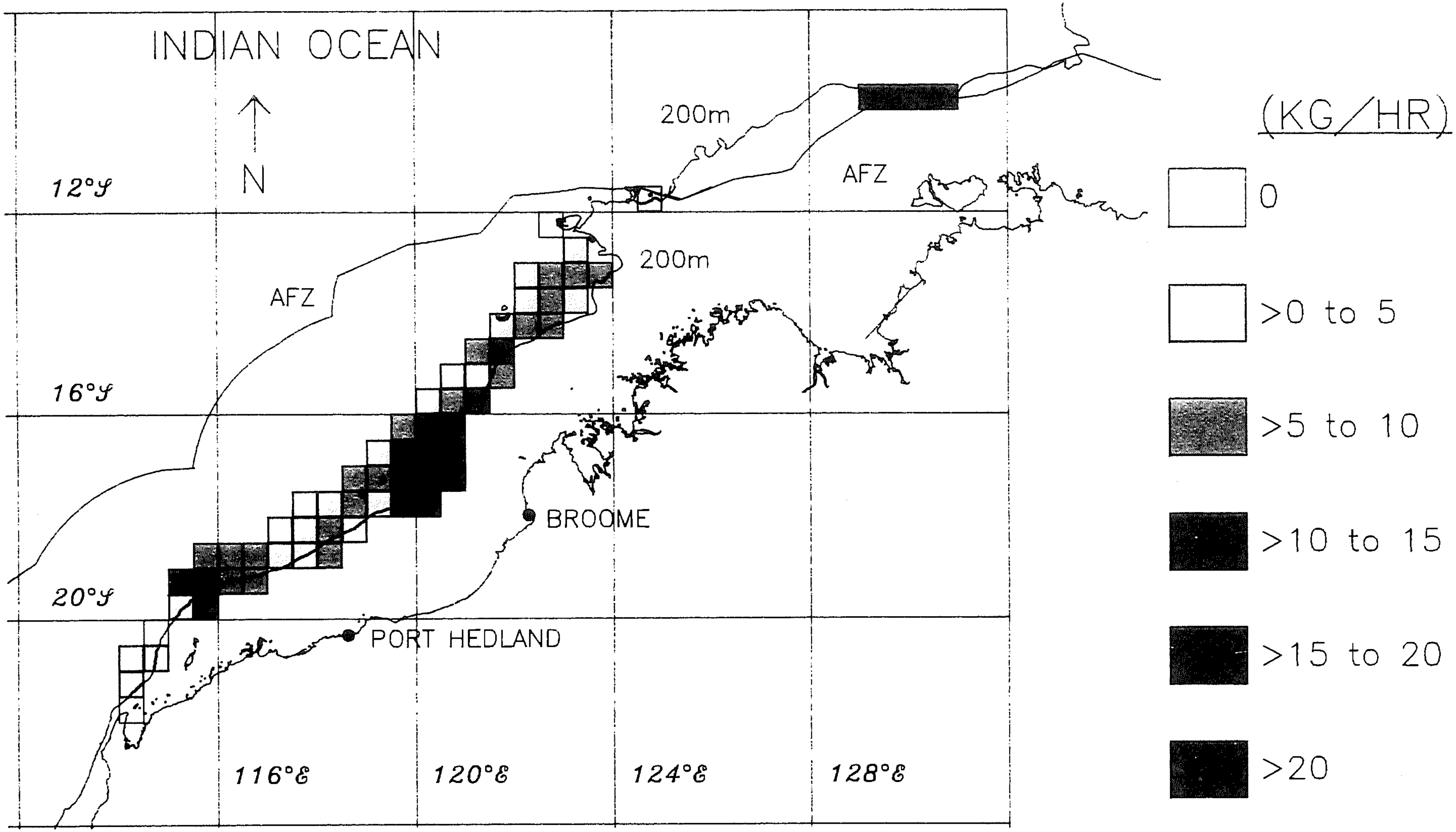


Fig. 3.2.2 Scampi catches in the NWSTF and Timor Sea areas: average annual catches between 1985/86 and 1990/91 in each half-degree square of the fisheries, in six abundance categories.

4 The fisheries biology of the crustaceans

Contents

4.1 Scampi

Dr B. F. Philips

Objectives:

- to obtain information on the size, fishing and natural mortality, growth, reproduction and migration of the three scampi species — *M. australiensis, M. velutinus* and *M. boschmai* — from the existing North West Slope fisheries.
- to document the catches and the fishing effort by type and quantity.
- to provide information to management which will allow for the rational exploitation of the scampi resources.

Three species of scampi are caught commercially on the North West Slope. These are *Metanephrops velutinus* (previously called *M. andamanicus*), *M. australiensis* and *M. boschmai*. Each species is found at a different depth range: *M. boschmai* at 300–380 m, *M. velutinus* at 370–440 m, and *M. australiensis* at 430–500 m.

The data from the NWSTF (Table 4.1.1) shows a picture of an irregular but continuing decline in the scampi catch over the six-year life of the fishery. The data on catch of scampi for the WDWTF (Table 4.1.2) are too variable for useful analysis.

The scampi catch has varied considerably. It was 161 tonnes in 1985/86, fell to 92 tonnes in 1987/88, rose to a peak of 166 tonnes in 1988/89, and was only 55 tonnes in 1990/91.

The fluctuating catch of scampi can be attributed partly to a portion of the fleet targeting on prawns in water where scampi are naturally less abundant, and partly to a real decrease in abundance as a result of fishing pressure.

Australian scampi are generally poor candidates for continuous harvesting by non-selective fishing methods such as trawling. There are several biological reasons for this:

- scampi species are long living and slow growing, taking possibly six to eight years to attain commercial size;
- females brood eggs for a large part of the year and probably spawn annually. During this protracted egg-bearing period the females (particularly *M. velutinus*) are more readily caught, possibly because they need to emerge from their burrows more often than males to aerate the eggs;
- scampi produce only 100 to 900 larvae per brood, which is considerably less than other types of lobster; and
- the larvae probably settle and adopt a benthic habit soon after hatching, so there would be little likelihood of wide dispersal to repopulate heavily fished areas. New fisheries are always expected to experience a fall in the catch per unit effort during

their development or 'fish down' phase, since they begin by fishing a virgin stock.

The apparent decline in the catch of scampi poses urgent questions for the managers of this fishery. In particular, can the scampi component of the fishery be successfully managed and what are the best options?

Would rotational closures, a form of long-term management be commercially viable? This approach requires a sufficient area of fishing grounds to employ the fishing fleet on a rotational basis, or to have the fleet fish other resources.

Also needed is knowledge of the rate of recovery of a fished ground so appropriate closure periods can be set.

The adoption of different fishing methods will also be considered. If substantial prawn stocks exist in an area closed to fishing for scampi, midwater trawling of the prawns during vertical migration may be an effective method of harvesting while at the same time avoiding the bottom-dwelling scampi.

Table 4.1.1 Annual catch and effort statistics for the North West Slope Trawl Fishery (CPUE — catch per unit effort; catch in metric tonnes)

Statistic	1985/86	1986/87	1987/88	1988/89	1989/90	1990/91
	(1 April — 31 March)					
Total catch	348·6	553·2	959·9	643·1	260·1	317·4
Scampi catch						
Total	161·9	121·0	92·0	166·2	110·2	55·2
% catch as tails	9·8	14·5	23·1	28·1	51·5	31·9
Prawn catch						
Total	174·2	394·3	853·7	469·3	146·1	261·8
Penaeids	90·7	287·0	575·5	304·3	86·4	240·5
Aristaeomorpha foliacea	49·7	199·5	418·7	219·6	24·4	89·6
Haliporoides sibogae	27·1	60·8	59·7	52·8	26·0	19·6
Aristeus virilis	12·6	24·1	92·8	30·7	35·5	127·0
Plesiopenaeus edwardsianus	1·7	2·6	4·4	1·2	0·6	4·3
Carids	50·9	95·2	220·9	162·2	58·6	21·3
Heterocarpus sibogae	22·5	55·3	135·5	46·5	10·8	14·2
Heterocarpus woodmasoni	28·4	40·0	85·4	115·7	47·8	7·1
By-catch						
Total	12·5	37·8	15·2	7·5	3·8	0·4
Squid	9·2	34·2	13·9	6·6	2·3	0·1
Fish	2·3	2·4	0·6	0·7	0·1	0·1
Spear lobster (*Linuparus* sp.)	1·1	0·2	0·2	0·2	1·2	0·2
Effort (1000s trawl hours)	10·8	13·0	18·5	17·7	14·4	14·7
Number of boat days fished	726	967	1459	1365	888	940
No. of boats	11	21	20	13	9	5
CPUE ($kg \cdot h^{-1}$); total product[1]	32·4	42·6	52·2	36·3	18·1	21·6

[1] average CPUE rate for fleet

Table 4.1.2 Annual catch and effort statistics for the Western Deep Water Trawl Fishery (CPUE — catch per unit effort; catch in metric tonnes)

Statistic	1986/87	1987/88	1988/89	1989/90	1990/91
		(1 April — 31 March)			
Total catch	46·1	116·3	2·6	4·1	17·6
Scampi catch					
Total	4·5	27·6	0·8	0·5	1·7
% catch as tails	8·6	8·7	8·7	20·3	0·0
Prawn catch					
Total	38·6	63·6	0·1	0·2	0
Penaeids	90·7	287·0	575·5	304·3	86·4
Haliporoides sibogae	25·6	53·0	0·1	0·2	0·0
Aristeus virilis	0	0	0	0	0
Carids	50·9	95·2	220·9	162·2	58·6
Heterocarpus sibogae	11·4	2·1	0	0	0
Heterocarpus woodmasoni	0	0·1	0	0	0
By-catch					
Total	3·0	25·1	1·6	3·3	5·9
Squid	1·1	10·8	0·1	0	0·3
Fish	0·6	2·1	0·7	2·1	13·5
Bugs (*Ibacus* sp.)	1·3	7·0	0·8	1·2	2·1
Crabs (*Chaceon* sp.)	0·7	5·3	0	0	0
Effort (1000s trawl hours)	0·9	4·0	0·4	0·4	0·5
Number of boat days fished	84	390	66	81	84
No. of boats	11	20	4	6	6
CPUE ($kg \cdot h^{-1}$); total product [1]	51·2	28·9	6·6	11·1	35·5

[1] — average CPUE rate for fleet

Table 4.1.3 Annual catch and effort statistics for the Timor Sea Deep Water Trawl Fishery (CPUE — catch per unit effort; catch in metric tonnes)

Statistic	1987/88	1988/89	1989/90	1990/91
Total catch	326·1	66	35·6	12·8
Scampi catch				
Total	218·4	39	26·2	10·5
% as tails	17·4	36	84·8	63·6
Prawn Catch				
Total	103·5	27	7·5	1·9
By-catch				
Total	4·2	0·4	1·8	0·3
Effort (1000s trawl hours)	9·2	3·5	2·6	1·1
Number of boats	12	9	6	6
Number of boat days fished	548	219	156	70
CPUE ($kg \cdot h^{-1}$); total product [1]	35·6	19·3	13·8	11·6

[1] — average CPUE rate for fleet

A paper dealing with the scampi data from 1985/86 to 1988/89 was presented at the Shellfish Life Histories and Shell Fishery Models meeting held by ICES in Canada in June 1990. This paper (included below, pp. 49 *et seqq.)* includes a discussion of future management options for scampi fisheries in Australia.

Management options recorded in the paper are:

Long-term management strategy should incorporate substantial closure periods because fishing grounds that were permitted prolonged periods of rest between pulses of fishing effort showed substantial recovery and greater yields than consistently fished areas. As the Australian fishery consists of areas of high scampi abundance interspersed with widespread areas which support only low densities, rotational closures appear to offer the most rational method for managing these resources. This approach requires that sufficient grounds exist, or are found, to employ the fishing fleet on a rotational basis.

Knowledge of the rate of recovery of a fished ground is also needed to set appropriate closure periods. If the ground is continuing to produce penaeid and carid prawn catches then the value of these products foregone during the closure should be less than the expected return from future scampi catches.

Development of a Trawl Fishery for Deepwater Metanephropid Lobsters off the North-Western Continental Slope of Australia. Designing a Management Strategy Compatible with Species Life History

Summary

A trawl fishery has developed on the north-western continental slope of Australia since 1983 for four species of metanephropid lobsters (*Metanephrops australiensis, M. velutinus, M. boschmai* and *M. sibogae*). Management options are constrained by consideration of aspects of the life history biology common to the genus *Metanephrops*. These include distribution, rate of growth, increased activity with age, fecundity and reproductive strategy. Abundance indices based on commercial catch and effort statistics collected since 1985, reveal trends for different patterns and levels of fishing effort on these stocks, enabling the possible consequences of various management measures to be predetermined.

Introduction

Clawed lobsters of the genus *Metanephrops* occur on the continental slopes of many countries, but prior to 1985, were commercially fished only off south-eastern Africa (Berry 1969) and fished experimentally in the western Atlantic Ocean and Caribbean Sea (Roe 1966).

Metanephropids, called scampi in Australia were first reported, on the North West Slope of Australia in 1894 (Alcock 1894). However, it was not until 1982 that promising commercial quantities were caught (Anon. 1983). Following successful fishing trials by a commercial trawler in 1983 (Carter *et al.* 1983), and discovery of additional fishing grounds in 1984 (Davis and Ward 1984), a commercial fishery based on three species of scampi (*M. velutinus, M. australiensis and M. boschmai*) began in 1985. In 1987, a fourth species, *M. sibogae*, was discovered to the north of Australia in waters bordering Indonesia. A fifth, rare species, *M. neptunus,* was also occasionally caught. Controlled development of these fisheries occurred through legislation that defined the fishery boundaries, limited entry and required completion of catch and effort logbooks to facilitate stock assessment research.

Although scampi occur over a wide geographic range, the largest catches have been taken within clearly defined areas of the north-western continental slope of Australia (Fig. 4.1.1). Twelve stern trawlers of 23–30 m length towing multiple 'Otter' trawls fished these areas. Due to the importance of penaeid and carid prawn by-catch (Wallner and Phillips 1988), mesh size is never larger than 75 mm. Fishing is conducted continuously during both day and night over soft, muddy bottom in depths of 250–500 m, although catch rates at dawn and dusk may be higher (Ward and Davis 1987). Seasonal patterns of

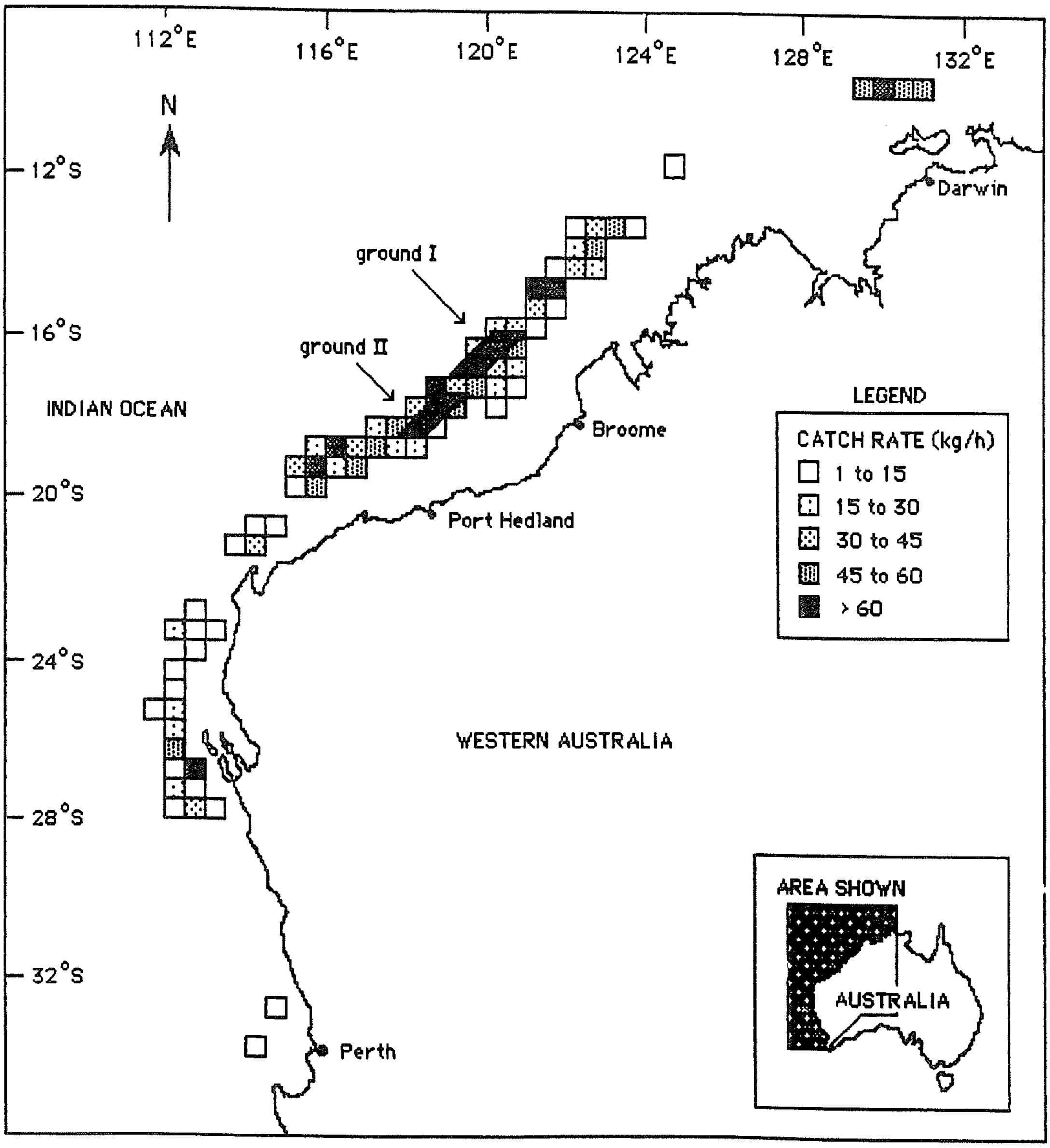


Fig. 4.1.1 Distribution and relative abundance of four combined species of *Metanephrops* spp. off the western Australian continental slope. Fishing grounds I and II mentioned in the text are also indicated.

fishing effort result from seasonal closures in other shallow-water penaeid fisheries in which these vessels also participate. Scampi, which have higher export value, are generally targeted preferentially to prawns. However, fluctuations in market conditions, or the presence of aggregated schools of the penaeid *Aristaeomorpha foliacea*, can affect target preference.

Methods

Commercial catches were sampled at approximately two-monthly intervals between February 1986 and December 1988. The most abundant species of scampi was sampled from the commercial catch aboard the vessel. The sample was counted and weighed, then the individuals sexed, assessed for spawning condition, recent moulting, presence of parasites, and measured using carapace length as defined by Berry 1969). These measurements were used to estimate growth rates and to obtain information about the population structure and life histories for these species.

Trawl logbook data provide a shot by shot breakdown of all fishing activity, giving position, time of day, trawl duration, depth, fishing gear used, and catch retained. Analysis of these records provided information on the composition of the catch and rates of catch by species, time, area and depth. Catch per unit of effort (CPUE) was standardised according to the total length of net towed, by scaling to a common 73·2 m total headline length. Comparisons of CPUE in the two fishing grounds in this study were made only using data obtained from vessels known to target scampi.

Results

Fishery production

During the initial three years or 'development phase', between 1985–88, the fishery displayed a rapid expansion in commercial catch and effort (Fig. 4.1.2). Total catch increased from 350 tonnes in 1985/86 to 1404 tonnes in 1987/88, an increase of 301 per cent. This was produced by a 194 per cent increase in effort from 10 800 trawl hours to 31 700 trawl hours. In 1985/86, scampi composed 47 per cent of the total catch and the greatest proportion of the fishery value; this declined progressively to 24 per cent in 1987/88. A redirection of target preference from scampi to penaeid and caridean prawns was partly responsible for this change (Wallner and Phillips 1988).

In 1988/89, total catch and effort declined to 655 tonnes and 19 700 trawl hours respectively. The scampi catch was 188 tonnes or 29 per cent of the total catch. No major new fishing grounds were discovered in the latter year and depressed world market prices, particularly for prawns, may have contributed to lower effort.

Simultaneously, the proportional prawn component of the catch increased from 54 per cent of the catch in 1985/86 (174 tonnes) to 73 per cent in 1987/88 (1021 tonnes). Of this catch, four deepwater penaeid species were of commercial importance and accounted for 67 per cent of the catch: *Aristaeomorpha foliacea*, *Haliporoides sibogae*, *Aristeus virilis* and *Plesiopenaeus edwardsianus*. Of these, *A. foliacea* was the single most important species, comprising 49 per cent of the prawn catch and 43 per cent of the total fishery catch. Two carid species, *Heterocarpus woodmasoni* and *H. sibogae*, made up the balance of the commercial prawn catch.

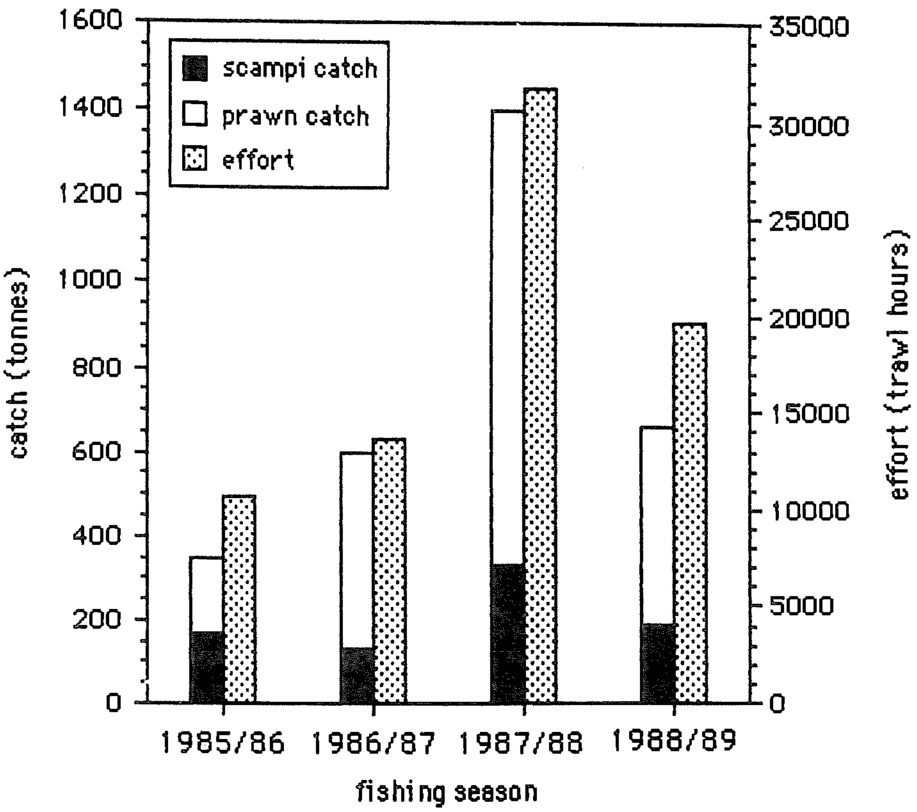


Fig. 4.1.2 Annual scampi catch, prawn catch and effort levels for four fishing seasons.

Distribution

Standardised commercial trawl CPUE as an index of relative scampi abundance is plotted on a map showing the spatial distribution of these species (Fig. 4.1.1). *Metanephrops* spp. are probably similar to *Nephrops norvegicus* in expending considerable energy in building burrows (Rice and Chapman 1971) and in displaying aggressive home-ranging behaviour (Farmer 1975). Consequently, scampi habitat is closely correlated with sediment type and grain size. McLoughlin *et al.* (1988) found that areas of calcareous muddy sands supported the highest concentrations of *Metanephrops* spp. around the Scott Reef–Rowley Shoals area. Carter *et al.* (1983) noted that *M. velutinus* and *M. boschmai* have reduced carapace spination and were more frequently caught with mud adhering to the exoskeleton than *M. australiensis.* They suggested that the latter species prefers comparatively firmer substrate, may not build extensive burrows and may be active outside burrows for considerable periods of time, while *M. velutinus* and *M. boschmai* make deeper burrows in softer sediment. In these areas of preferred substrate, commercial scampi trawling produced fairly constant catch rates, which may indicate that scampi tend toward an even distribution on the bottom.

Scampi occur from about 260 m to about 500 m on the continental slope but each species has a clearly defined depth distribution (Fig. 4.1.3). *Metanephrops boschmai* dominates from 260–360 m, with the 300–320 m interval the most preferred depth. *Metanephrops velutinus* occurs from 340–440 m with 380–400 m most preferred. *Metanephrops australiensis* is the dominant species in the deepest areas between 420 m and 500 m, with peak abundance occurring between 440 and 460 m depth. Although *M. sibogae* is geographically distinct, it prefers depths between 260 to 320 m, similar to those for *M. boschmai*.

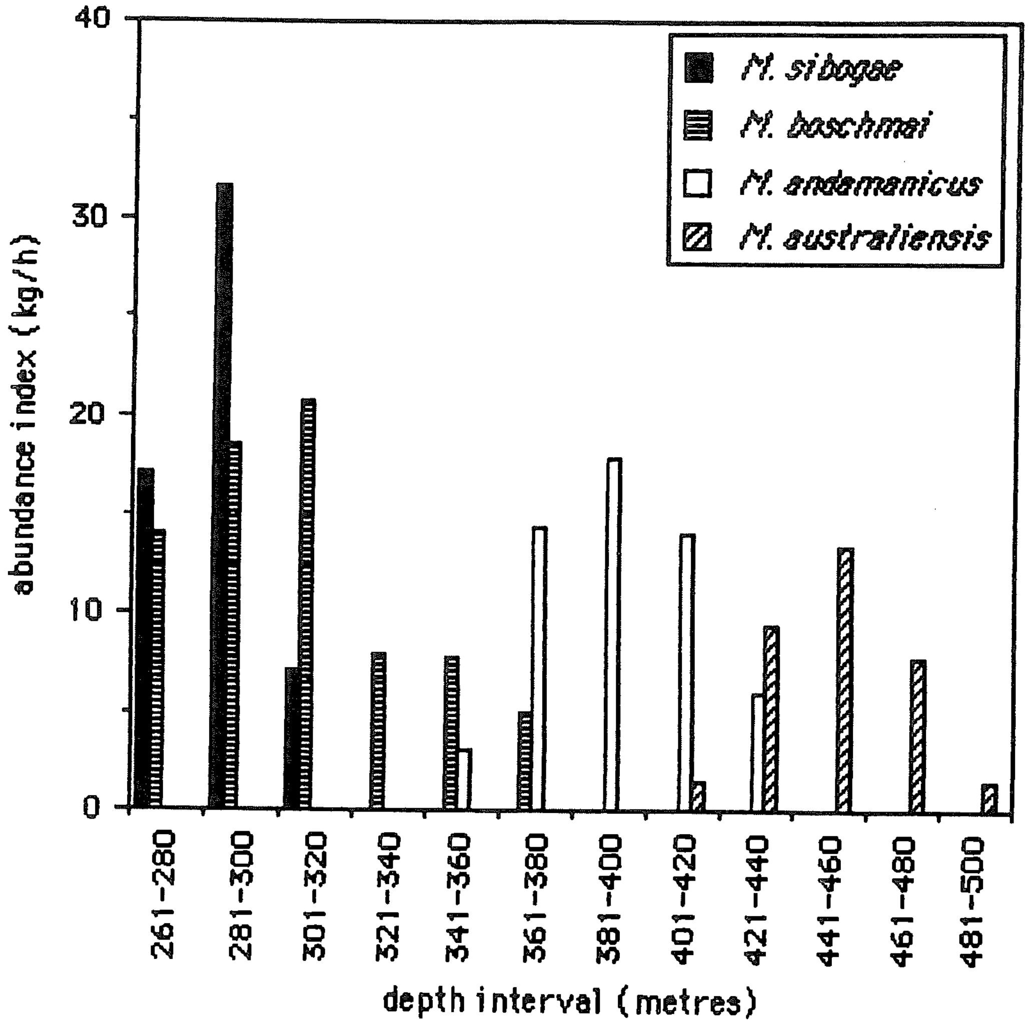


Fig. 4.1.3 Depth distributions for four species of metanephropid lobsters

Population structure and growth

Size frequency distributions of different scampi species were characteristically polymodal. An example, for *M. australiensis* is presented in Figure 4.1.4. It is assumed this polymodality was the result of annual recruitments forming age (size) cohorts. Analysis of length frequency data indicated that length frequency histograms for *M. australiensis, M. velutinus* and *M. boschmai* may be successfully separated into 6, 5 and 3 component cohorts respectively.

The figure also indicates the 50 per cent selection size for *Nephrops norvegicus* for a 70 mm cod-end trawl (Main and Sangster 1984). The trawl nets in this fishery use mesh of 51–90 mm in the wing panels and 45–51 mm cod-ends, thus the mesh selection size for Australian scampi species could be smaller than indicated. Juveniles less than about 25 mm carapace length are rarely retained by the nets. However, small size classes that are apparently above the mesh

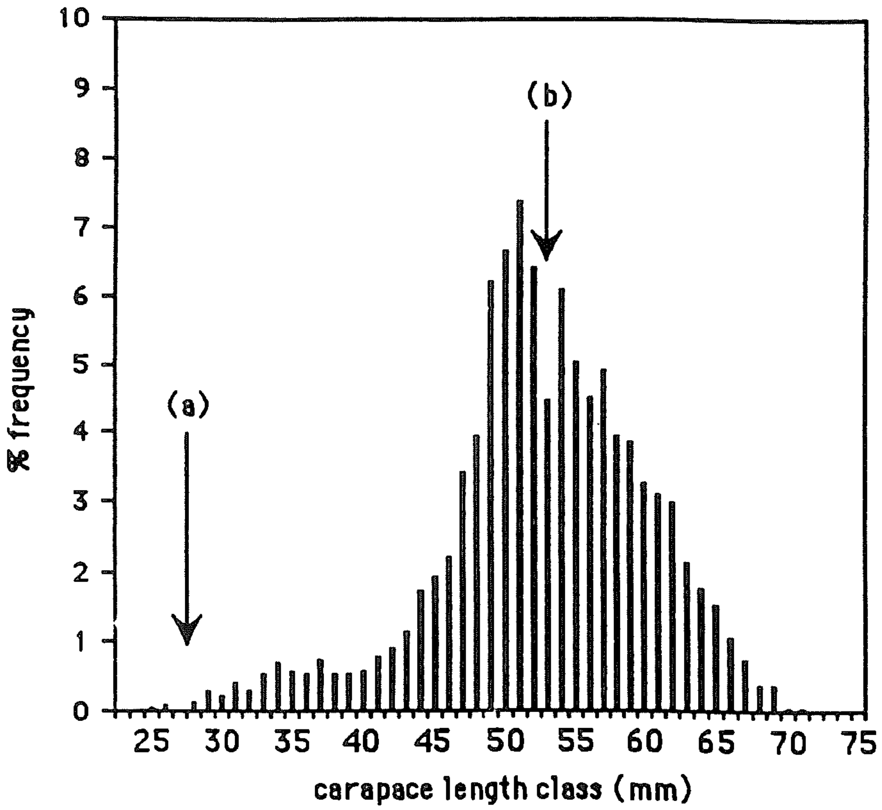


Fig. 4.1.4 Carapace length-frequency distribution for *Metanephrops australiensis*, both sexes combined; (a) indicates the 50% mesh selection size for *Nephrops norvegicus* using 70 mm cod-end trawl mesh; (b) indicates the size at which 50% of the females sampled were ovigerous.

selection size are also poorly represented in the samples. This is attributed to reduced catchability of young animals, possibly due to greater proportions of time spent in burrows. Therefore, although small scampi may occur on the fishing grounds they do not recruit fully to the fishery until about 3+ years (*M. boschmai*) or 4+ years (*M. velutinus* and *M. australiensis*) (Wallner *et al.* 1989).

Metanephrops australiensis and *M. boschmai* males and females were almost always equally represented in the catch. However, samples of *M. velutinus* frequently had significantly greater numbers of females than males. This usually occurred during periods when proportions of females carrying berry was high. It is hypothesised that berried female *M. velutinus*, a deeper-burrowing scampi, emerge from the burrow for longer periods to oxygenate the brood and therefore suffer a higher catchability. Berried females were sometimes up to 72 per cent of the total *M. velutinus* catch.

Reproduction

Mating and reproduction in *Metanephrops* spp. are probably similar to that described for *Nephrops norvegicus* (Farmer 1975) and *M. velutinus* (Berry 1969). Fertilised eggs are attached to the pleopods, where they are incubated for many months. The embryo is lecithotrophic, nourished from a large yolky egg. The larvae of *M. thomsoni* and *M. challengeri* hatch in an advanced stage of development and undergo only a few moults before adopting a benthic habit as a juvenile (Uchida and Dotsu 1973, Wear 1976). Reproductively mature metanephropids probably moult and spawn annually.

Australian scampi have lower fecundity than *Nephrops norvegicus*. Female *N. norvegicus* produce between 800 and 5000 eggs (Farmer 1975), while the number of newly spawned eggs for the most fecund Australian scampi species (*M. australiensis*) is between 400 and 1500. The effective fecundity is at least 50 per cent lower due to attrition during the long incubation period (Wallner *et al.* 1989), a feature similarly reported for *N. norvegicus* (Figueiredo *et al.* 1983). Fecundity (F) for all species conformed to a similar linear relationship varying with the carapace length (CL) of the animals ($F = -734{\cdot}2 + 27{\cdot}55\ CL$; $R^2 = 0{\cdot}58$).

Catch rates

Catch rate trends were examined for two small productive trawl grounds (Table 4.1.4, Fig. 4.1.1). The CPUE for fishing grounds I and II since initial commercial fishing until April 1989 is shown in Figure 4.1.5. These data are superimposed upon the monthly trawl effort. Fishing effort on both grounds, is periodic, with little fishing between April and June and intensive fishing during spring and summer months, particularly in January and February. At both grounds, initial CPUE declined very rapidly in response to relatively low levels of effort as surplus standing stocks were removed.

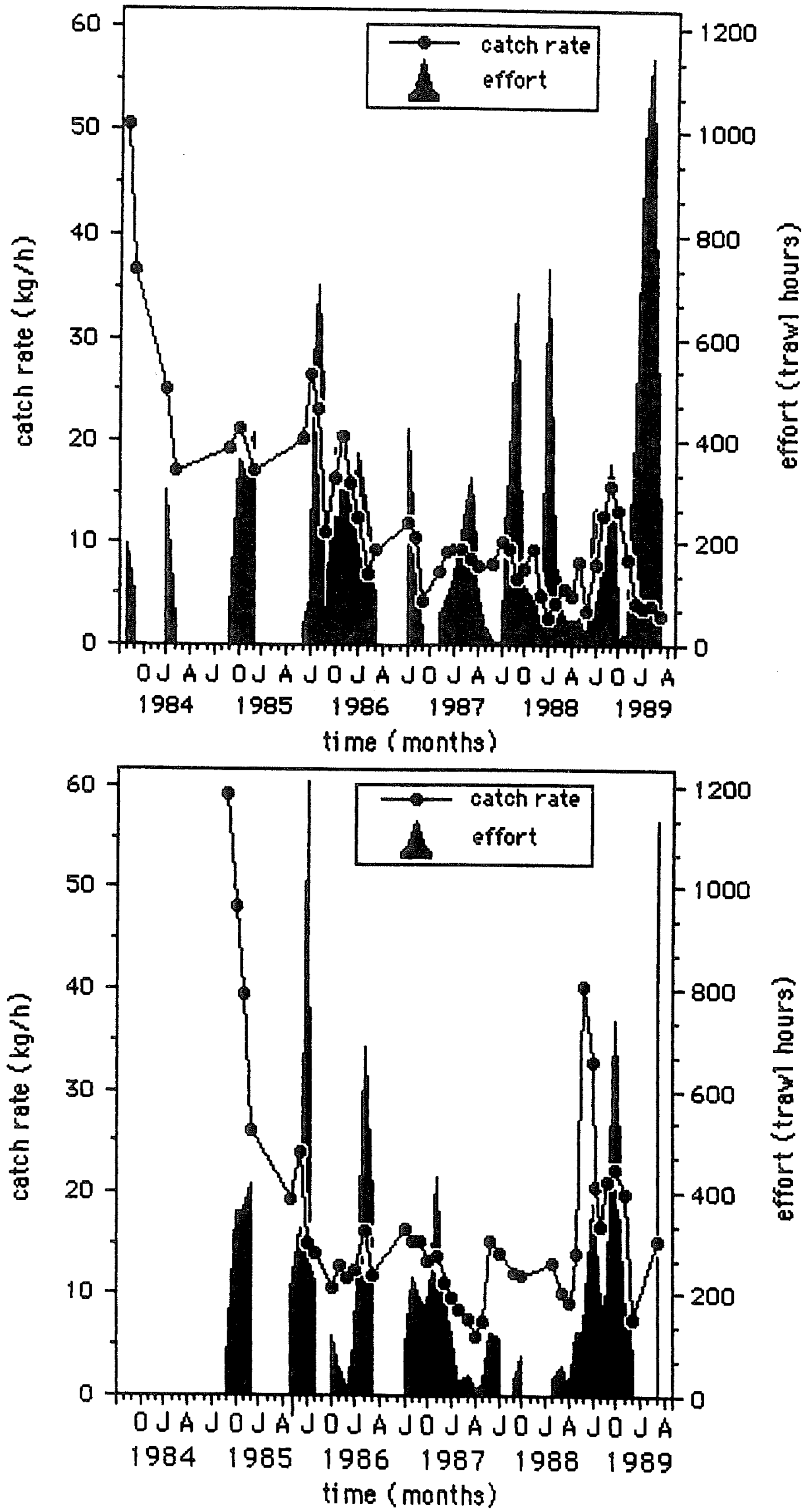


Fig. 4.1.5 Monthly fishing effort and corresponding catch per unit effort for: *A*, *Metanephrops velutinus* (from trawl ground I); *B*, *Metanephrops australiensis* (from trawl ground II)

After the rapid initial depletion, the CPUE for ground I (Fig. 4.1.5*A*) decreased further, although short-lived but significant rises in the catch rate were apparent following periods of little or low fishing activity. This phenomenon is presumably a result of increased catchability as scampi that are exposed to less trawl disturbance emerge from burrows for longer periods. The pattern for ground II (Fig. 4.1.5*B*) is similar except that effort levels between December 1986 and May 1988 were much lower than for ground I. This preceded a very large increase in the CPUE during June and July 1988 when the mean catch rate recovered to a level of 70 per cent of that obtained from fishing the virgin stock.

Table 4.1.4. Location, depth, area and dominant species for fishing grounds I and II.

	Ground I	Ground II
Location	17·40°S.–18·40°S.	16·10°S.–17·10°S.
Depth	360–420 m	420–480 m
Area	222 km^2	222 km^2
Dominant species	*M. velutinus*	*M. australiensis*

These two fishing grounds are of similar area but ground II produced 147 tonnes for 8547 hours of effort, 39 per cent more catch than ground I, for 13 per cent less effort. Although differing latitudes, depths and species confound any statistical comparison, it is hypothesised that differences in the distribution of effort through time contributed to the greater catch at ground II.

Discussion

Australian scampi species have similar life histories characterised by being long-lived, having a prolonged brood period, relatively low fecundity and direct larval development. The widespread distribution of metanephropids indicates that these attributes, conforming to the *K* life history strategy concept of Pianka (1970), have been successful for the group. However, the same features have negative consequences when populations of scampi are fished.

Despite their burrowing behaviour, scampi are vulnerable to capture by trawling and females of at least one species (*M. velutinus*) exhibit higher catch rates during the brooding period. Instantaneous fishing mortality rates estimated for parts of this fishery at between 0·04 month^{-1} (– 0·003) and 0·15 month^{-1} (– 0·012[BFP]) (Wallner *et al.* 1989) act for many months upon the spawning stock. The reproductive strategy of scampi involves a very brief pelagic larval phase and it is therefore probable that settled larvae and juveniles up to several years old co-inhabit the same grounds as adult stocks. Although these animals are not directly caught by trawling activities, it is possible that destruction of burrows, or removal of food species (Wassenberg and Hill 1989), may result in a significant mortality of pre-recruit age classes.

Long-term management strategy should incorporate substantial closure periods. Fishing grounds that were permitted prolonged periods of rest between pulses of fishing effort showed substantial recovery and greater yields than consistently fished areas. As the Australian fishery consists of areas of high scampi abundance interspersed with widespread areas that support relatively low densities, rotational closures appear to offer the most rational method for managing these resources. This approach requires that sufficient grounds exist, or are found, to employ the fishing fleet on a rotational basis. Knowledge of the rate of recovery of a fished ground is also needed to set appropriate closure periods. If the ground is continuing to produce penaeid and carid prawn catches then the value of these products foregone during the closure should be less than the expected return from future scampi catches.

Demersal trawling tends to reduce the topographic and structural complexity of the bottom and these effects may lower the productivity of this fishery. Observations made during this study indicate faunal changes, such as the virtual elimination of once-common large hexactinellid sponges from heavily trawled areas. The long-term effects of this type of change are not yet known. Trap fishing is used to take *Nephrops norvegicus* in Scottish waters, and this method is currently under investigation. Midwater trawling may also permit the harvesting of vertically migratory penaeid and carid stocks without disturbing the bottom or inflicting undesirable fishing mortality upon recovering scampi populations. This method has yet to be attempted, but it is intended to conduct preliminary sampling probably in 1992/93.

References

Alcock, A. (1894). Natural history notes from H.M. Indian Marine Survey Steamer 'Investigator' ser. II, no. I. On the results of deep sea dredging during the season 1890–91. *Annals and Magazine of Natural History* **13**(6), 225–245.

Anon. (1983). CSIRO finds scampi and carid prawns on the N.W. Shelf. *Australian Fisheries* March 1983, 13.

Berry, P.F. (1969). The biology of *Nephrops andamanicus* Wood-Mason (Decapoda, Reptantia). South African Association for Marine Biological Research, Oceanographic Research Institute, Investigational Report No. 22: 55 pp.

Carter, D., Maxwell, J.G.H. and Bowtell, C. (1983). 'Cautious optimism' over potential for scampi fishery on N.W. Shelf. *Australian Fisheries* November 1983, 2–12.

Davis, T.L.O. and Ward, T.J. (1984). CSIRO finds two new scampi grounds of the North West Shelf. *Australian Fisheries* August 1984, 41–47.

Farmer, A.S.D. (1975). Synopsis of biological data on the Norway lobster *Nephrops norvegicus* (Linnaeus, 1758). *FAO Fisheries Synopses* No. 112, 97 pp.

Figueiredo, M.J., Margo, O. and Franco, M.G. (1983). The fecundity of *Nephrops norvegicus* (L.) off the Portuguese west coast. *Bol. Inst. Nac. Invest. Pescas* **9**, 5–116.

Howard, F.G. (1982). The Norway lobster. Department of Agriculture and Fisheries for Scotland, Marine Laboratory, Scottish Fisheries Information Pamphlet No. 7, 15 pp.

Main, J. and Sangster, G.I. (1984). The behaviour of the Norway lobster, *Nephrops norvegicus* (L.) during trawling. Department of Agriculture and Fisheries for Scotland, Scottish Fisheries Research Report No. 34: 23 pp.

McLoughlin, R.J., Davis, T.L.O. and Ward, T.J. (1988). Sedimentary provinces and associated bedforms and benthos on the Scott Reef–Rowley Shoals platform off north-west Australia. *Australian Journal of Marine and Freshwater Research* **39**(2), 133–144.

Pianka, E.R. (1970). On r- and K- selection. *American Naturalist***104**, 592–597.

Rice, A.L. and Chapman, C.J. (1971). Observations on the burrows and burrowing behaviour of two mud-dwelling crustaceans, *Nephrops norvegicus* and *Goneplax rhomboides*. *Marine Biology* **10**, 330–342.

Roe, R.B. (1966). Potentially commercial nephropids from the western Atlantic. *Transactions of the American Fisheries Society* **95**(1), 92–98.

Uchida, T. and Dotsu, Y. (1973). On the larva hatching and larval development of the lobster, *Nephrops thomsoni*. *Bulletin of the Faculty of Fisheries, Nagasaki University*. **36**, 23–35.

Wallner, B. and Phillips, B. (1988). From scampi to deepwater prawns: developments in the North West Shelf deepwater trawl fishery. *Australian Fisheries* September 1988, 4 pp.

———, Phillips, B.F. and Hobbs, L.J. (1989). The fisheries biology of scampi (*Metanephrops* spp.). Fishing Industry Research and Development Council, final report to FIRTA, grant number 1985/82. 46 pp.

Ward, T.J. and Davis, T.L.O. (1987). Diel periodicity of *Metanephrops australiensis* and other deep-water crustaceans of northwest Australia. *Fisheries Research* **5**, 91–97.

Wassenberg, T.J. and Hill, B.J. (1989). Diets of four decapod crustaceans (*Linuparus trigonus, Metanephrops andamanicus, M. australiensis* and *M. boschmai*) from the continental shelf around Australia. *Marine Biology* **103**(2), 161–168.

Wear, R.J. (1976). Studies on the larval development of *Metanephrops challengeri* (Balss, 1914) (Decapoda, Nephropidae). *Crustaceana* **30**(2), 113–122.

4.2 Growth of the Australian Scampi, *Metanephrops australiensis*

S. F. Rainer

Introduction

After the initial discovery of commercial quantities of scampi on the North West Slope in 1982/83 (Anon 1983), length-frequency data were collected on the subsequent exploratory surveys in 1983, by FV *Courageous* (Carter *et al.* 1983) and by FRV *Soela* (Davis and Ward 1984*a*, *b*). The first estimate of the growth rate of the Australian scampi, *Metanephrops australiensis* from the North West Slope was for a life span of six or more years (Carter *et al.* 1983). Additional length frequency data on *M. australiensis* were collected subsequently as part of the fisheries biological studies of the commercial crustaceans of the North West Slope undertaken by the CSIRO Division of Fisheries between 1985 and 1992.

Scampi taken by commercial trawls typically include few animals smaller than 40 mm carapace length (CL). More small animals were found during initial exploration of the scampi resources, with small-mesh nets. These scampi had three or four distinct modes in length frequency, usually interpreted as annual cohorts (e.g., Carter *et al.* 1983). The largest mode usually includes a wide size range of large animals, and is therefore likely to include more than one cohort. The earlier estimates of longevity and growth of *M. australiensis* were based on limited data, and additional data are now available to provide more precise estimates of growth. A preliminary analysis of part of the present data (Wallner and Phillips in press) has suggested the presence of six cohorts in the commercial catch. A detailed analysis is presented here, using additional data both for cohort analysis and for the comparison of population structure in areas subject to differing levels of fishing effort.

Data

Length-frequency data were used from three sample sets, taken in August 1983, in November 1986 and in October–November 1991, respectively. All data were based on carapace length (CL), measured from the base of the suborbital spine to the mid-dorsal posterior margin of the carapace.

The 1983 CL data were from a fisheries resources survey by FV *Courageous*, using a twin-rigged 14-fathom banana net with 50-mm mesh cod-end (Carter *et al.* 1983). These data were from several areas of the North West Slope, but mainly from the South Rowley grounds (between 17°50'–18°10'S. and 118°10'–118°30'E.), in 400–440 m depth. The original CL data were no longer available, so the data used for modal analysis were obtained from Fig. 3 in Carter *et al.* (1983); these were for males and females combined.

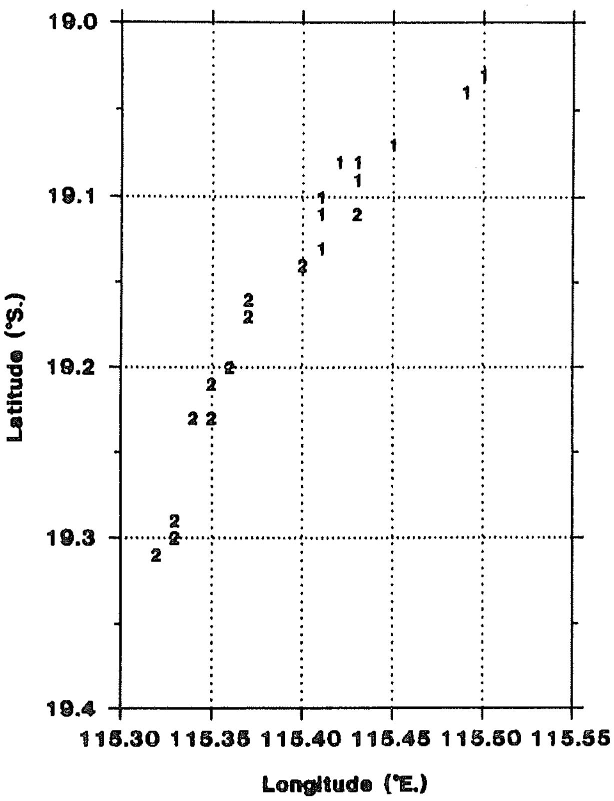


Fig. 4.2.1 Location of trawls in North Rankin areas 1 and 2 of the North West Slope Trawl Fishery. Trawls are numbered by area.

The 1986 and 1991 CL data were collected by trained scientific observers using on-board subsampling of the catches of commercial trawlers, together with data on sex, maturity and (where appropriate) egg stage. The commercial trawlers used two- or three-net configurations, with 75-mm cod-ends (see Chapter 2, pp. 19 *et seqq.* for further details). The 1986 and 1991 data were from the North Rankin ground (Fig. 4.2.1), between 18°55'–19°35'S. and 115°30'–115°55'E., where the fishery operates in depths of 400–460 m.

The 1986 data were from trawls between 19°00'–19°10'S. and 115°42'–115°54'E., in depths of 438–442 m, approximately in Area 1 of the 1991 samples (see below). The 1991 data came from two areas (Areas 1, 2) within the North Rankin ground, each with a different fishing history (Table 4.2.1). Area 1 comprised a 16 n.m. long region within depths of 415–435 m, to the north of the fishing ground, where fishing effort had been highest followed by a period of limited trial fishing only in 1989 and 1990. Catch rates were highest in 1988 (16·7 kg · h^{-1}), then decreased to 8·8 kg · h^{-1} in 1989 and 10·0 kg · h^{-1} in 1990. Area 2 was about 25 n.m. long, between depths of 405–425 m, in the southern half of the ground. It was fished heavily in 1987 and 1988, then less intensely in 1989 and 1990, but still at a considerably higher level than Area 1. The area yielded over 21 kg · h^{-1} in both 1987 and 1988, then decreased to 12·7 kg · h^{-1} in 1989 and 10·3 kg · h^{-1}. in 1990.

Table 4.2.1. Fishing history of Areas 1 and 2 of the North Rankin fishing ground: annual effort (total hours of trawl time on the bottom) and annual catch of *Metanephrops australiensis* (kg), between 1986 and 1990.

	Year				
	1986	1987	1988	1989	1990
Area 1					
Effort	199	211	99	14	36
Catch	2190	2197	1601	123	371
Area 2					
Effort	39	200	288	144	175
Catch	511	4527	6046	1857	1777

Method of analysis

CL-frequency data were analysed by computer-based dissection of overlapping frequency distributions, using algorithms provided by the MIX program (Macdonald and Green 1988), run on a 486 IBM-compatible computer. The component distributions were assumed to represent annual recruitment classes and to be normal, with equal standard deviations. Growth was assumed to approximate a von Bertalanffy model. For each data set, the significance of departure from the summed normal distributions was assessed by a χ^2 test, using an increasing number (4–10) of overlapping distributions.

Results

Preliminary analysis of the 1986 data (largest CL = 74 mm) indicated similar frequency distributions in male and female scampi, with the modes for individual frequency distributions within 0·5–1·5 mm of each other. Since clear modes were evident in the *Courageous* data, analysis of these were made on the basis that sex-based differences in growth rate were unlikely to result in the generation of spurious cohorts, at least among the smaller scampi.

The 1983 CL data (Fig. 4.2.2) showed three maxima at 30 mm, 42 mm and 51 mm CL. Acceptable ($P \geq 0{\cdot}10$) χ^2 values were obtained with these data, with 4, 5 or 8 cohorts (Table 4.2.2). With four or five cohorts, the first three modes were located on the obvious maxima; with eight cohorts, modes were located at intermediate CLs as well as on the maxima. Overall, cohort modes were located between 30·5 and 66·3 mm, and length at maximum age (L_∞) was between 71·2 and 81·0 mm (Table 4.2.2). These L_∞ values were somewhat greater than the largest CL of 65 mm in the scampi analysed, and similar to the largest CLs recorded in the present fisheries biology study (76 mm for female scampi and of 75 mm for male scampi).

Table 4.2.2. Number of year classes (N), estimated von Bertalanffy growth parameters (L_∞ , t_1, k), χ^2 deviation and probability of fit (P), for *M. australiensis* from the North West Slope in August 1983, collected with FV *Courageous* (number of scampi, n = 1212).

N	L_∞	t_1	k	χ^2 (P)
4	81·0	1·9	0·250	47·1 (0·15)
5	80·5	1·9	0·260	47·1 (0·12)
6	79·5	1·9	0·259	47·7 (0·092)
7	58·0	1·5	0·514	50·0 (0·038)
8	**71·2**	**3·1**	**0·181**	**41·4 (0·18)**
10	65·6	2·9	0·214	63·7 (< 0·001)

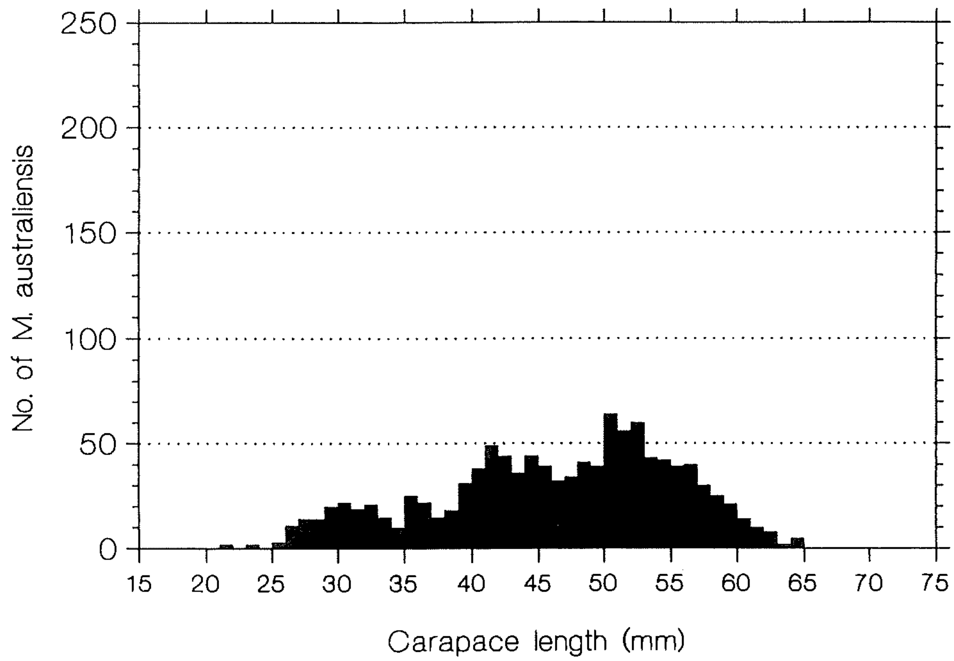


Fig. 4.2.2 Carapace lengths of *Metanephrops australiensis* trawled by FV *Courageous* from the South Rowley Shoals in August 1983

The 1986 CL data showed a broad peak at around 49–52 mm CL for males and 51–53 mm CL for females (Fig. 4.2.3); the peak was skewed, with most of the animals to the right of the mode. No clear modes were present among the smaller male scampi, but an additional peak was present at 34–35 mm CL in the females. Analysis of these data indicated that a minimum of five cohorts (Table 4.2.3) is needed to achieve a satisfactory fit for both male and female scampi. However, the modes of these cohorts are more closely spaced than for

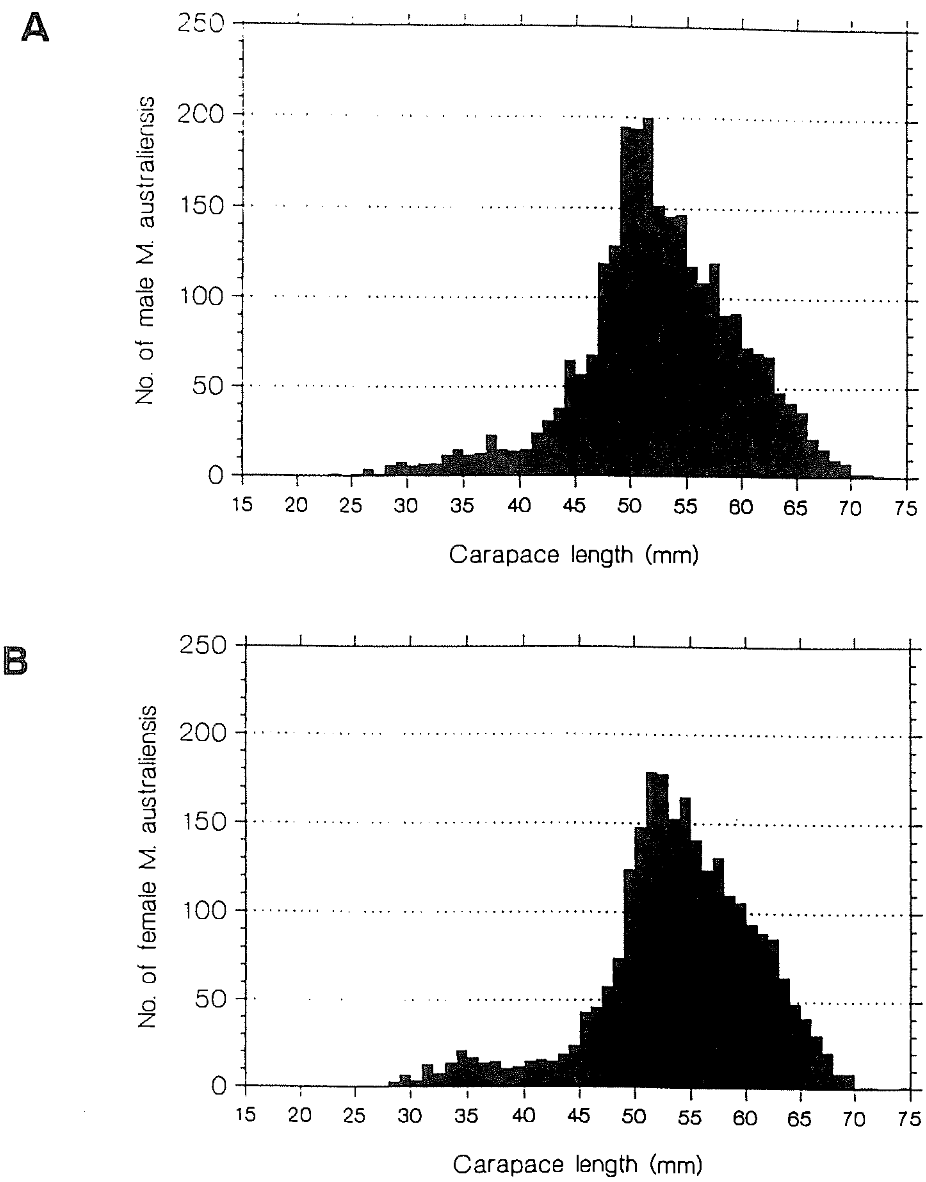


Fig. 4.2.3*A*, *B* Carapace lengths of male and female *Metanephrops australiensis* sampled from commercial trawlers on the North Rankin ground in November 1986; *A*, males; *B*, females

the four- and five-cohort year-class data from 1983, implying much slower growth. With the use of ten year classes, the smaller modes are located in similar positions to the eight modes of the 1983 data, and a similar growth curve is implied, with L_∞ = 77·4 mm for males and 76·2 mm for females.

The 1991 data indicated substantial differences in length frequency distributions between each area, and between males and females (Figs 4.2.4, 4.2.5). In Area 1, the data for both males and females had only one peak, at 50–51 mm CL in the males and at 51–52 mm CL in the females. The CL-distribution of males could be fitted well ($P \geq 0{\cdot}6$)

Table 4.2.3. Number of year classes (*N*), estimated von Bertalanffy growth parameters (L_∞ , t_1, *k*), χ^2 deviation and probability of fit (*P*), for *M. australiensis* from the North Rankin ground of the North West Slope in November 1986, collected from commercial vessels. *A.* Males (*n* = 2654); *B.* Females (*n* = 2354).

A. Males

N	L_∞	t_1	k	χ^2 (*P*)
4	74·7	1·3	0·499	58·9 (0·035)
5	94·9	2·6	0·165	52·5 (0·088)
6	98·4	2·7	0·155	53·3 (0·063)
7	71·7	2·2	0·297	54·9 (0·037)
8	113·8	3·2	0·094	37·7 (0·43)
9	86·8	2·8	0·150	40·5 (0·28)
10	**77·4**	**2·6**	**0·187**	**44·5 (0·13)**

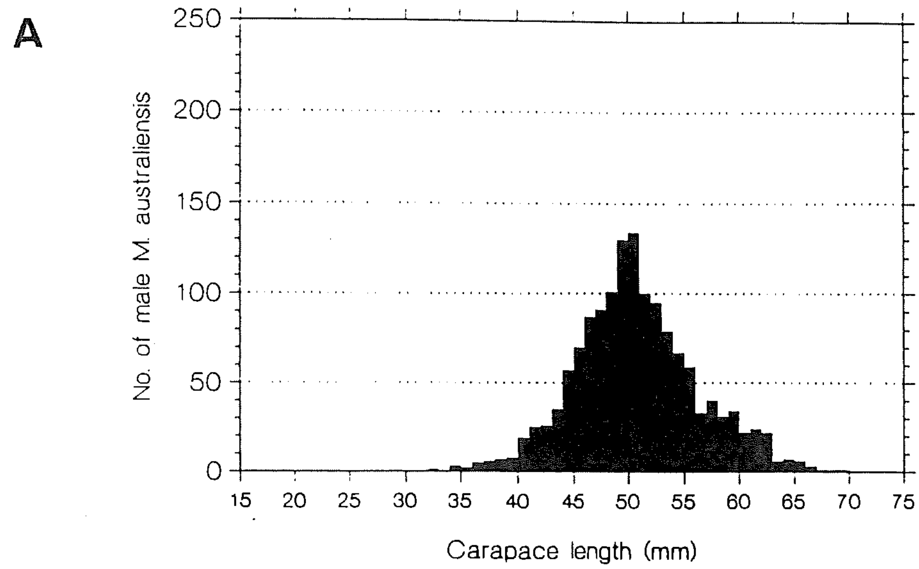
B. Females

N	L_∞	t_1	k	χ^2 (*P*)
4	69·5	1·1	0·660	43·0 (0·20)
5	83·4	2·5	0·220	26·0 (0·86)
6	81·1	2·4	0·234	26·4 (0·82)
7	71·3	2·1	0·318	27·7 (0·73)
8	100·1	3·9	0·105	23·9 (0·85)
9	**77·0**	**3·3**	**0·179**	**25·1 (0·76)**
10	76·2	3·2	0·183	26·0 (0·67)

with only four year classes, while the distribution for females needed at least six year classes (Table 4.2.4).

Consistent estimates for the von Bertalanffy growth curve parameters with those for the 1983 and 1986 data required the assumption of eight classes for females. In Area 2, the data for both sexes again had only one peak; the males showed a broad maximum at 44–51 mm CL, the females a narrower maximum between 47–53 mm. In the analysis of these data, the CL-distribution of males could not be fitted significantly ($P \geq 0{\cdot}05$) with fewer than nine year classes (Table 4.2.5), and ten year classes were needed to provide a consistent growth curve with the earlier data. A significant fit could not be achieved at all for females; however, a growth curve consistent with the earlier data was provided by assuming the presence of ten year classes in the data.

As shown from the 1991 data, growth curves that were consistent among the various analyses required the assumption of eight to ten year classes in the various sample data, corresponding to von Bertalanffy growth curves with $L_\infty \approx 80$ mm and $k \approx 0{\cdot}150$. On this basis, the modal CLs for each year class (Table 4.2.6) represent



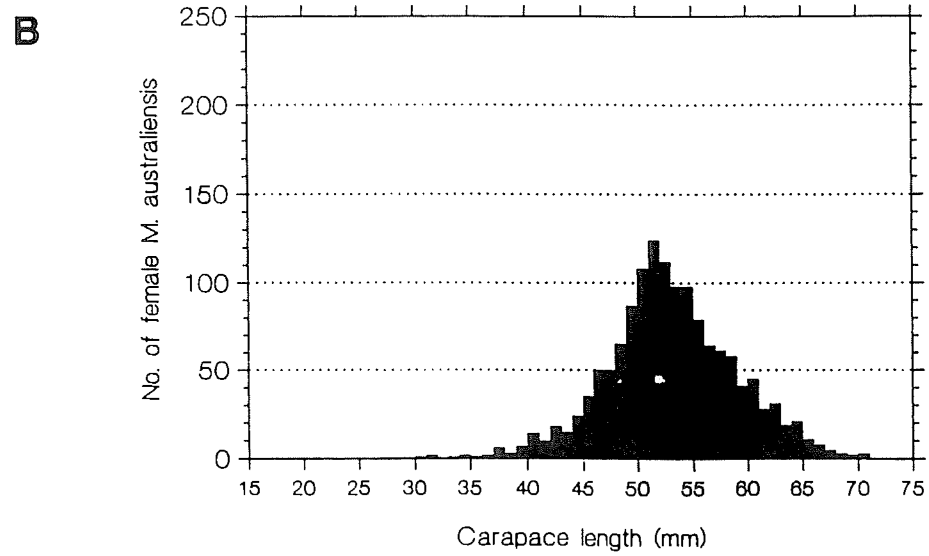


Fig. 4.2.4*A, B* Carapace lengths of male and female *Metanephrops australiensis* sampled from commercial trawlers in Area 1 of the North Rankin ground in October–November 1991; *A*, males; *B*, females.

maximum ages of 10+ to 12+ years old, at 59·7–64·6 mm CL for 10+ scampi and at 66·1–68·6 mm CL for 12+ scampi.

Discussion

A consistent feature of the trawl data is the paucity of small *M. australiensis*. A major cause of this is presumably mesh selectivity, although age-related differences in habitat or in catchability may also play a part. These factors may each place limitations on the analysis

Table 4.2.4. Number of year classes (N), estimated von Bertalanffy growth parameters (L_∞, t_1, k), χ^2 deviation and probability of fit (P), for *M. australiensis* from Area 1 of the North Rankin fishing ground on the North West Slope in October–November 1991, collected from commercial vessels. *A.* Males (n = 1430); B. Females (n = 1412).

A. Males

N	L_∞	t_1	k	χ^2 (P)
4	66·3	2·5	0·394	22·8 (0·78)
5	102·7	5·1	0·094	22·6 (0·75)
6	109·4	5·1	0·083	25·6 (0·65)
7	65·6	3·4	0·263	22·2 (0·68)
8	**74·4**	**3·9**	**0·187**	**22·5 (0·61)**
9	104·1	5·9	0·074	16·1 (0·88)
10	98·2	5·7	0·082	15·9 (0·86)

B. Females

N	L_∞	t_1	k	χ^2 (P)
4	60·3	1·5	0·744	47·1 (0·041)
5	*1	7·4	0	35·2 (0·28)
6	84·1	2·3	0·220	20·9 (0·89)
7	165·7	4·7	0·048	19·4 (0·91)
8	94·9	3·8	0·115	18·8 (0·90)
9	**85·2**	**3·5**	**0·142**	**17·7 (0·91)**
10	74·2	3·1	0·196	23·1 (0·63)

[1] Value outside range of calculation

of length-frequency data obtained by trawling. Mesh selectivity may be particularly important in the use of a mathematical technique to analyse overlapping distributions, since it may operate in a 'knife-edge' manner to bias the representation of animals within a cohort. No data exist to quantify the effect of these factors in trawl data on *Metanephrops* species. Independent means of validating the mathematical analyses of the CL data were therefore sought, from the changes in modal positions in the early data and from a comparison of population structure in Areas 1 and 2 of the North Rankin ground.

Length-frequency data collected early in the development of the fishery for *Metanephrops australiensis* indicated the presence of several distinct modes between 30 and 50–55 mm CL. These data were collected from the Rowley Shoals grounds, either to the south (Carter *et al.* 1983) or nearby, to the north (Davis and Ward 1984), using trawls with finer-mesh cod-ends (40 or 50 mm) than the 75 mm mesh nets now used in the fishery. The trawls on the South Rowley Shoals ground were made in August 1983, and those on the North

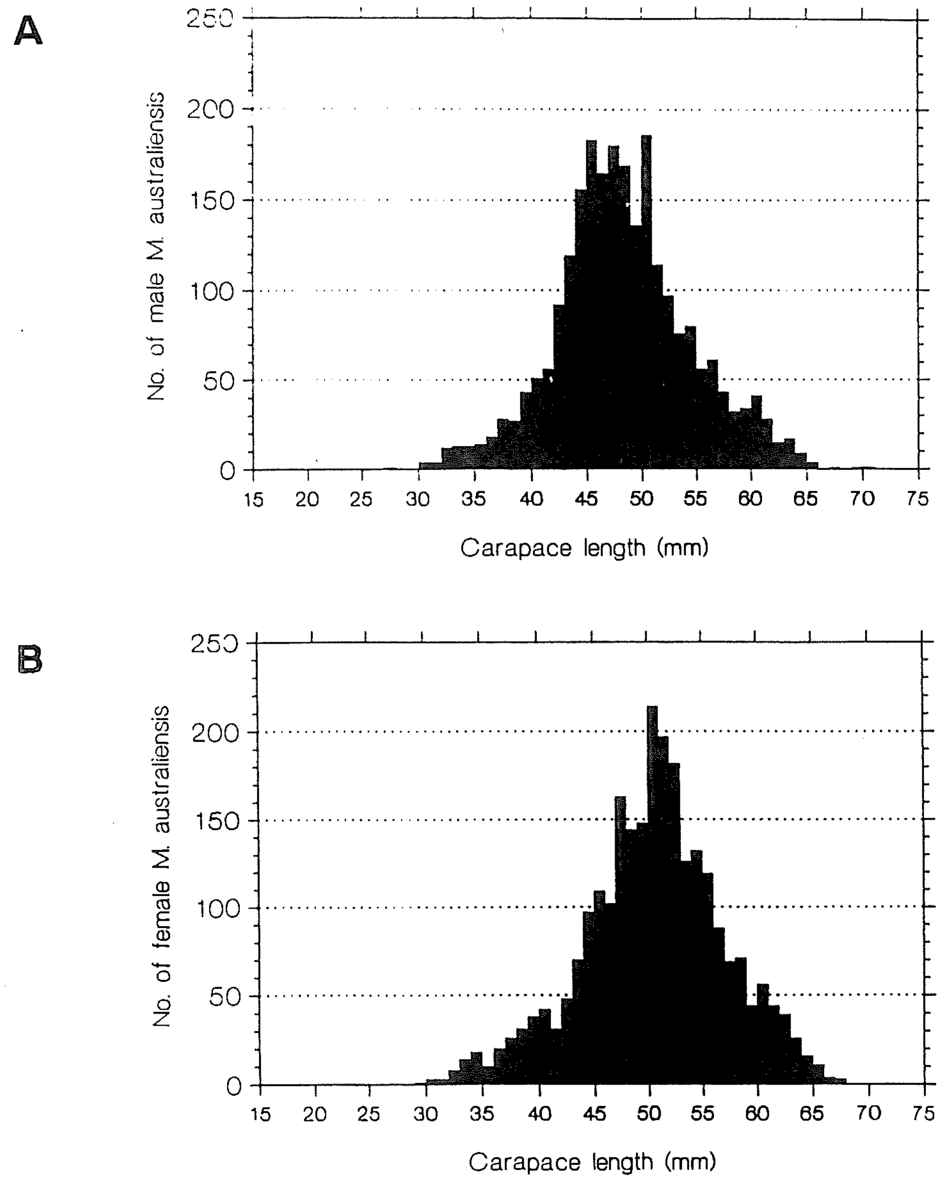


Fig. 4.2.5*A*, *B* Carapace lengths of male and female *Metanephrops australiensis* sampled from commercial trawlers in Area 2 of the North Rankin ground in October–November 1991; *A*, males; *B*, females

Rowley Shoals ground nearly six months later, in January–February 1984.

As shown by the MIX analysis of the August–September 1983 data, the main modes in CL can be interpreted as either successive annual cohorts, or as large cohorts each separated by a smaller cohort. On the assumption that the various maxima represent distinct cohorts, then the maxima at 29–30 and 41 mm CL in August–September 1983 probably correspond to the maxima at 32 and 45 mm CL in January–February 1984. This would represent an increase of 2–3 mm and 4 mm respectively in a little under six months. Since seasonal

Table 4.2.5. Number of year classes (N), estimated von Bertalanffy growth parameters (L_∞ , t_1, k), χ^2 deviation and probability of fit (P), for *M. australiensis* from Area 2 of the North Rankin fishing ground on the North West Slope in October–November 1991, collected from commercial vessels. *A*. Males (n = 2380). B. Females (n = 2567).

A. Males

N	L_∞	t_1	k	χ^2 (P)
4	*[1]	3·8	0	49·5 (0·025)
5	61·9	1·9	0·474	51·6 (0·011)
6	136·8	5·5	0·055	46·3 (0·029)
7	93·8	4·4	0·104	44·8 (0·031)
8	90·6	4·3	0·109	41·7 (0·046)
9	91·2	4·3	0·108	37·8 (0·081)
10	**77·0**	**3·8**	**0·152**	**40·1 (0·038)**

B. Females

N	L_∞	t_1	k	χ^2 (P)
4	61·4	1·6	0·674	75·0 (< 0·001)
5	66·7	2·5	0·337	70·3 (< 0·001)
6	63·2	2·3	0·400	50·3 (0·008)
7	91·6	4·6	0·105	64·0 (< 0·001)
8	91·5	4·2	0·112	42·5 (0·029)
9	97·3	4·4	0·100	50·4 (0·003)
10	**78·1**	**3·9**	**0·150**	**46·3 (0·006)**

[1] Value outside range of calculation

differences in water temperature are small at the depth of the scampi grounds, seasonal differences in growth are likely to be similarly small. The differences in CL are therefore equivalent to growth of about 5–8 mm on an annual basis. This suggests that the maxima considered above are of cohorts two years apart, an interpretation consistent with the MIX analyses of the commercial data collected in 1986 and 1991 from the North Rankin ground.

Comparison of the length-frequency distributions of scampi collected in 1991 from Area 1 of the North Rankin ground with those collected in November 1986 shows no difference in the modal size group (49–52 mm CL for males, 50–52 mm for females) but a decrease in the relative abundance of larger (> 55 mm CL) animals. In contrast, scampi from Area 2 have relatively more smaller animals, with the modal size of male scampi from Area 2 being only 44–51 mm CL. The MIX analyses of these samples also indicate that there has been a shift in population structure towards smaller animals of both sexes. The difference in population structure, at least among female scampi,

Table 4.2.6 Estimated carapace lengths and percentage distribution of animals among length cohorts of scampi sampled in 1983, 1986 and 1991, based on von Bertalanffy growth curves with $L_\infty \approx 80$ mm and $k \approx 0{\cdot}150$.

	Year Class										
	2+	3+	4+	5+	6+	7+	8+	9+	10+	11+	12+
Aug 1983: males + females											
CL	–	30·5	37·2	42·8	47·5	51·4	54·7	57·4	59·7	–	–
%	–	13·4	6·9	28·3	0	34·4	3·0	10·4	3·7	–	–
Nov 1986: males											
CL	29·6	37·8	44·6	50·2	54·8	58·7	61·9	64·5	66·7	68·6	–
%	1·7	4·3	8·7	39·4	20·3	12·7	7·7	3·4	1·9	0	–
Nov 1986: females											
CL	–	34·2	41·2	47·1	52·0	56·1	59·5	62·4	64·8	66·8	–
%	–	4·5	3·2	7·3	39·4	16·4	15·8	6·8	6·6	0	–
Oct–Nov 1991											
Area 1: males											
CL	–	38·3	44·4	49·5	53·8	57·3	60·2	62·6	64·6	–	–
%	–	2·0	14·7	51·0	17·4	5·4	8·4	0	1·1	–	–
Area 1: females											
CL	–	33·8	40·6	46·5	51·6	56·1	59·9	63·3	66·2	68·7	–
%	–	0·5	3·7	14·0	44·2	20·4	10·4	5·7	0·5	0·6	–
Area 2: males											
CL	–	34·1	40·1	45·3	49·8	53·6	56·9	59·7	62·2	64·3	66·1
%	–	2·9	8·7	35·5	30·0	10·1	6·2	3·8	2·6	0	0·1
Area 2: females											
CL	–	34·4	40·5	45·7	50·2	54·1	57·4	60·3	62·8	64·9	66·8
%	–	3·0	7·8	18·8	33·5	20·6	6·7	5·9	3·7	0	0·1

is consistent with the period of highest exploitation occurring in 1986 and 1987 in Area 1, but in 1987 and 1988 in Area 2.

Implications for the fishery

From the beginning of the scampi fishery in 1985, catches of scampi initially decreased from 169·9 tonnes in 1986/86 to 92·0 tonnes in 1987/88, then rose to 166·9 tonnes in 1988/89. Since then, catches have decreased to 55·2 tonnes in 1990/91 and to 57·9 tonnes in 1991/92. Over this period, the NWSTF has operated as a Development Fishery. With the proposal that it should be made a managed fishery using TACs, there is therefore an urgent need for reliable data to derive the TACs. The catchability of scampi by demersal trawl gear is unknown, and there are no reliable estimates of the size of the virgin stock of *M. australiensis* on the NWS. However, in fisheries where few data exist, but which appear to be operating at a sustainable level, then this level may be taken to approximate the Maximum Constant Yield (MCY; Annala 1989).

The proportion of the scampi catch comprised by *M. australiensis* has increased over the life of the fishery. In 1989/90, 15·3 of the 44·6 tonnes of identified scampi catch was *M. australiensis*. Assuming that half of the 13·7 tonnes of 'mixed *australiensis*' grades comprised *M. australiensis* brings the *M. australiensis* catch to 22·2 tonnes, about half of the identified scampi catch; applying this proportion to the total scampi catch of 55·2 tonnes suggests a total *M. australiensis* catch of 27–28 tonnes in 1989/90. The largest catch of *M. australiensis* taken in any one year is 28·1 tonnes, and an upper estimate of MCY is probably about 25 tonnes. In a developed fishery, MCY may be related to biomass B as MCY = $0{\cdot}5 \cdot F_{0{\cdot}1} \cdot B_{av}$, where $F_{0{\cdot}1}$ is a reference fishing mortality derived from yield per recruit, and B_{av} is the average recruited biomass (Annala 1989). $F_{0{\cdot}1}$ is usually close to natural mortality M, which can be estimated as $M = \ln(100) \cdot (\text{maximum age})^{-1}$ (Annala 1989). Taking maximum age for *M. australiensis* as 10 years, then $M \approx 0{\cdot}46$, and $B_{av} \approx 110$ tonnes. While there are many assumptions underlying this estimate of steady-state biomass, it provides the first estimate based on catch data in the commercial fishery. It is compatible with the previous estimate by Wallner *et al.* (1988), of 92 tonnes for the virgin biomass of *M. australiensis* in the heavily fished region between 16°10'S. and 17°10'S., but suggests that the early estimate by Davis and Ward (1984*a*), of 300 tonnes over the entire area of the fishery, was probably too high.

Metanephrops australiensis, like other species of scampi, are believed to live in burrows; they have relatively small numbers of eggs (generally < 1500 eggs per brood), an extended period of development while being carried on the female, and the females have an apparently high susceptibility to capture by trawling. The ability of the fishery for *M. australiensis* to maintain any particular yield will therefore be strongly affected both by possible effects of trawling on adult and juvenile animals in burrows, and by the capacity of populations to maintain adequate recruitment.

No data exist on the effects of trawling on survival of *Metanephrops* species. However, comparison of the proportion of small *M. australiensis* taken with comparable gear suggests that recruitment of juvenile animals (less than 40 mm CL; i.e., < 4 years old) may vary widely. In the 1986 samples from the North Rankin ground (Fig. 4.1.3), juvenile animals comprised 5·5 per cent of male and 5·6 per cent of female *M. australiensis*. In the 1991 samples from area 1 of the North Rankin ground (Fig. 4.1.4), juveniles comprised 2·2 per cent and 1·8 per cent of males and females respectively; in area 2 (Fig. 4.1.5), the equivalent values were 7·4 per cent and 6·7 per cent.

The choice of an optimal management regime to regulate the yield of a target species usually requires a good knowledge of its biology and population dynamics. For *Metanephrops australiensis*, however, this study shows that there is still considerable uncertainty about its growth rates. This gives similar uncertainty about the time required for *M. australiensis* to reach maturity, or to estimates of recruitment or mortality that could be used to model its population dynamics.

Further research is therefore essential, not only on the physical effects of trawling on *M. australiensis*, but also on growth rates as a basic parameter in its fisheries biology.

Conclusions

Growth of *Metanephrops australiensis* is to a similar size in both sexes (~ 75 mm CL). Using a von Bertalanffy growth model, with L_∞ = 71·2–81·0 mm CL and k = 0·142–0·187, this size is reached in an estimated 10–12 years after settlement, Females become mature at ~ 40 mm CL, at about 4+ years old. Use of a life span of ten years, in conjunction with annual catch rates in 1990/91 and 1991/92 of around 25 tonnes, suggest an exploited biomass of ~ 110 tonnes of *M. australiensis* on the NWS fishery grounds. Improved management will required additional data on early growth rates as well as recruitment, mortality and the effects of trawling.

References

Annala, J.H. (1989). Guide to biological reference points for the 1989 fisheries assessment meetings. Report from the fishery assessment plenary, May 1989: stock assessment and yield estimates. pp. 7–15. MAFFish, Wellington, New Zealand.

Anon. (1983). CSIRO finds scampi and carid prawns on NW Shelf. *Australian Fisheries*, March 1983 **42**(3), 13.

Carter, D., Maxwell, J.G.H. and Bowtell, C. (1983). 'Cautious optimism' over potential for scampi fishery on NW shelf. *Australian Fisheries*, November 1983 **42**(11), 2–12.

Davis, T.L.O. and Ward, T.J. (1984*a*). CSIRO finds two new scampi grounds off the North West Shelf. *Australian Fisheries*, August 1984 **43**(8), 41–45.

——— and Ward, T.J. (1984*b*). Biology of *Metanephrops* species. *Australian Fisheries*, August 1984 **43**(8), 46–47.

Macdonald, P.D.M. and Green, P.E.J. (1988). User's guide to program MIX: an interactive program for fitting mixtures of distributions. Release 2.3. Ichthus Data Systems; Hamilton, Ontario, Canada. 60 pp.

Wallner, B.G. and Phillips, B.F., in press. Development of a trawl fishery for deepwater metanephropid lobsters off the North West continental slope of Australia. Designing a management strategy compatible with species life history. *ICES Meeting*, June 1990, Canada.

———, Phillips, B.F. and Hobbs, L.J. (1988). Final report to the Fishing Industry Research and Development Council –FIRTA Grant No. 1985/88.

4.3 Distribution, growth and reproductive development of the Giant Red Prawn, *Aristaeomorpha foliacea* (Risso, 1827), in the North West Slope Trawl Fishery

Dr V. A. Wadley

Summary

Aristaeomorpha foliacea (Risso, 1827) is a deepwater penaeid prawn of importance to fisheries in many parts of the world. Since 1985, it has been trawled on the continental slope of north-western Australia. *A. foliacea* has been found from 116–125°E. in the NWSTF, usually in depths of 375–550 m. Grounds to the south of the Rowley Shoals produced the highest catches. The prawns are fished only during daylight; at night they are not caught in demersal trawls. Catches have varied greatly from year to year, with a peak of 419 tonnes in 1987/88. The fishery is open all year, with peak catches in January and February. Catch rates have declined since 1986.

Male *A. foliacea* showed signs of sexual maturity from 18 mm CL, and from 23 mm CL (corresponding to a 1+ year class), nearly all males had sperm in the terminal vas deferens. A few females had a spermatophore in the thelycum at 20 mm CL, and from 36 mm CL (corresponding to a 1+ year class), nearly all females had a spermatophore and were in either the intermediate or final stage of ovarian development. Both sexes were reproductively mature throughout the year, in all regions of the fishery.

A large proportion of males formed a mode at 38·8 mm CL, with small proportions in two other modes. Females had large proportions in modes at 43·3 and 51·8 mm CL, with a small proportion at 26·6 mm CL. From the population size-structure and following a cohort through time, three year classes were found in prawns from commercial catches. The lifespan is probably at least four to five years. The aggregation of reproductively mature prawns in a small area, possibly for breeding purposes, and the declining catch rates, cause concern for continued sustainable exploitation at the current levels of effort.

Introduction

The giant red prawn, *Aristaeomorpha foliacea* (Risso, 1827) is a penaeid crustacean of worldwide commercial importance. It is fished in depths of 250–1300 m by demersal trawlers, in New Zealand (under the common name royal red prawn), off eastern Africa, Japan, the temperate Atlantic and the Indo-West Pacific (Holthuis 1980). Once a lucrative fishery in the Mediterranean and off northern Africa, the species is rare there today. *A. foliacea* attracted commercial fisheries interest in Australia in 1985, when it appeared as a by-catch of scampi trawling (Wallner and Phillips 1988). High catch rates and export markets indicated a resource of potential importance (Wadley and Evans 1992). Little was known of the distribution or biology of the species in Australian waters.

Fishing for *A. foliacea* is permitted throughout the NWSTF but effort has been concentrated on the 'Crossroads' grounds, south of the Rowley Shoals (SRS). These are the closest prawn grounds to the major port, Port Hedland. The SRS has been the most exploited region of the fishery, accounting for more than 90 per cent of the red prawn catch in each fishery year (Wadley and Morris 1991).

In 1985, the NWSTF was declared a development fishery under Australian Commonwealth management. Before management based on output controls could be implemented, assessment of the stock sizes of the species of commercial interest was needed (Jernakoff 1988). This paper reports the results of the research on *A. foliacea* to determine the distribution and size of the stock and the basic biology of the species.

Methods

Data on *Aristaeomorpha foliacea* came from two sources: a compulsory logbook program, and the samples taken by shipboard scientific observers. In the logbooks, skippers recorded the catch by species and grade for each shot. The data were usually checked on board by a scientific observer and later verified by independent landings data. Analysis of the logbook data provided information on the spatial and temporal distribution of *A. foliacea*. The shipboard scientific observers measured and recorded the reproductive condition of prawns from commercial catches. Analysis of these data provided information on the size and age structure of the population.

The prawns were caught commercially by demersal trawlers of about 25 m length. The gear was targeted along bathymetric contours, usually in bottom depths of 375–550 m, although the species has been recorded in the NWSTF in depths of 300–600 m. Trawl positions were determined by Global Positioning System satellite navigation. Soft mud or muddy sand bottoms were preferred. Three 'Florida Flyer' nets of 57 mm (2·25") wing mesh and 45 mm (1·75") cod-end were spread between T5 Bison boards, usually with 63 m (30 fathom) headrope. Red prawns were caught only during daylight, with bottom time of about 2–3 h per trawl.

The catch of all three nets was emptied into a tank of refrigerated seawater and moved by conveyor belt to sorters. Samples of *A. foliacea* were taken from the conveyor at random with respect to size. For any sample, the carapace length (CL) of each prawn was measured to the nearest mm and its sex and reproductive development recorded. A parasitic bopyrid isopod beneath the carapace was noted when present. Usually, a sample of about 300 prawns was measured from a shot.

The prawns were dead on capture, so tagging and aquarium studies to determine growth rates were impossible. Monthly sampling from selected locations to determine growth rates was constrained by the fishing patterns of the commercial vessels (and by the movements of the prawns themselves). Usually, samples were collected from the same place about every second month. Physical measurements (water salinity, temperature etc. could not be made because of the logistics of the fishing operations.

The length-frequency data used for analysis of the size structure of the population were taken from an area bounded by 17°30'S. and 19°S. and 116°30'E. and 119°E. (known to fishers as 'Containers'). Data from more than one shot were pooled, where necessary, to provide sufficient individuals for analysis. Criteria for pooling were sequential shots within 50 m depth and 30' latitude or longitude, usually from sequential trawls.

Data for the description of the full range of length were taken from January 1992, when a large number of < 35 mm CL individuals were measured. The samples from December 1987 provided a large number of individuals from consecutive trawls over a similar area / depth and represent the size structure of the population. Data selected for analysis of monthly growth were from January, February and March 1991. These data provided consecutive monthly sampling from a similar area and depth, and represented the complete size spectrum (including < 30 mm CL) available from commercial samples. Data for analysis of annual growth were from five times periods: 2–15 December 1987, 18–26 February 1988, 1–26 August 1988, 7–12 December 1988, and 5–7 February 1989. This provided a period of 14 sequential months (a year with about a season of overlap).

Normal components of the length-frequency data were fitted using the program MIX (Macdonald and Green 1988). Age groups were estimated, where possible, from the size-frequency data (Macdonald and Pitcher 1979). Modes from MIX were used to estimate the growth rate and other population parameters.

B. de Boer and R. Litchfield (CSIRO Biometrics Unit) and I. James (University of Western Australia) are gratefully acknowledged for assistance in statistical analysis of length-frequency data. S. Morris collected shipboard data and assisted with the analysis. J. Garvey analysed the catch and effort data.

Results

Reproductive development

Female *Aristaeomorpha foliacea* were recognised by the shape of the rostrum (Fig. 4.3.1*A*) and the thelycum (open-type) between the bases of the fifth pereiopods. Males were recognised by the shape of the rostrum (Fig. 4.3.1*B*) and the petasma. Rostral shortening occurred in both sexes before maturity (as observed in *Aristeus antennatus* by Sardà and Demestre 1989), so rostral shape was not used to determine sex in prawns of < 30 mm CL. The presence of a spermatophore in the thelycum of a female usually marked the start of reproductive development. Developing gonad was noted beneath the carapace (Stage 1, Fig. 4.3.1*C*), extending to the first and second abdominal segments (Stage 2, Fig. 4.3.1*D*) and to the fourth and fifth abdominal segments (Stage 3, Fig. 4.3.1*E*). The gonad changed colour as it developed, from a pink / red (Stage 1), to a blood red (Stage 2), then a deep red / brown (Stage 3). Reproductive development in males was monitored by the presence of sperm (whitish opaque substance) in the terminal vas deferens (Fig. 4.3.1*F*) and the joined petasma (Fig. 4.3.1*G*). These macroscopic characters were rapid and reliable for differentiation of reproductive stages in the field, and were validated by reference to ovarian histological preparations of *A. foliacea* from the Sicilian Channel by Levi and Vacchi (1988).

Male *A. foliacea* from the NWSTF had a joined petasma at about 18 mm carapace length (CL) and developed sperm at about 20 mm CL; from 23 mm CL, nearly all males had sperm in the terminal vas deferens. In females, a spermatophore could be present in the thelycum from 20 mm CL; from 36 mm CL, nearly all females had a spermatophore. Most females of greater than 41 mm CL had fully-developed gonads, with the ovarian lobes extending to the fifth abdominal segment. Both sexes were reproductively mature throughout the year and females with spermatophores were present in all samples.

Reproductive condition in samples taken at all times of the year is being analysed and will be presented separately. The incidence of the bopyrid parasite was low (< 1 per cent) in the samples examined. It occurred on both males and females. A similar parasite was observed or *Aristeus antennatus* from Porto Fino (Gulf of Genoa, Italy) in March 1991 (Wadley and Orsi Relini, personal observation).

Spatial variation in catch

A. foliacea was found throughout the NWSTF and into the Arafura Sea (Fig. 4.3.2). Catch rates were low (5–10 kg $\cdot$ h^{-1}) in most parts of the fishery except the SRS region, where catches were usually between 25–75 kg $\cdot$ h^{-1} (Fig. 4.3.3). The pattern was sustained over six years, despite the distribution of considerable effort in other regions of the fishery (Fig. 4.3.4). In 1990, there were catches in the deeper water (400–500 m) west of SRS (Fig. 4.3.3). This was probably due to effort in deeper water targeted at *Aristeus virilis*, rather than a change in the distribution of *A. foliacea*.

Interannual variation in catch

The catch of *A. foliacea* has ranged from 24 tonnes (1989/90) to 419 tonnes (1987/88, Table 4.1.1). An understanding of the patterns of fishing effort (Chapter 4.6) is essential to interpretation of the large interannual variation in the prawn catch. In 1985, scampi was the predominant catch of the SRS region; the catch of *A. foliacea* was about 50 tonnes. In the 1985/86 fishing year, the catch of *A. foliacea* was about 200 tonnes; in 1986/87, 419 tonnes (Table 4.1.1). This increase, and the concentration of the catch in the SRS region, is shown in Fig. 4.3.3. The increase in the first year (1985/86–1986/87) was probably due to improved searching and targeting. The rate decreased steadily thereafter (Figs 4.6.9, 4.6.10), for reasons discussed in Chapter 4.6.

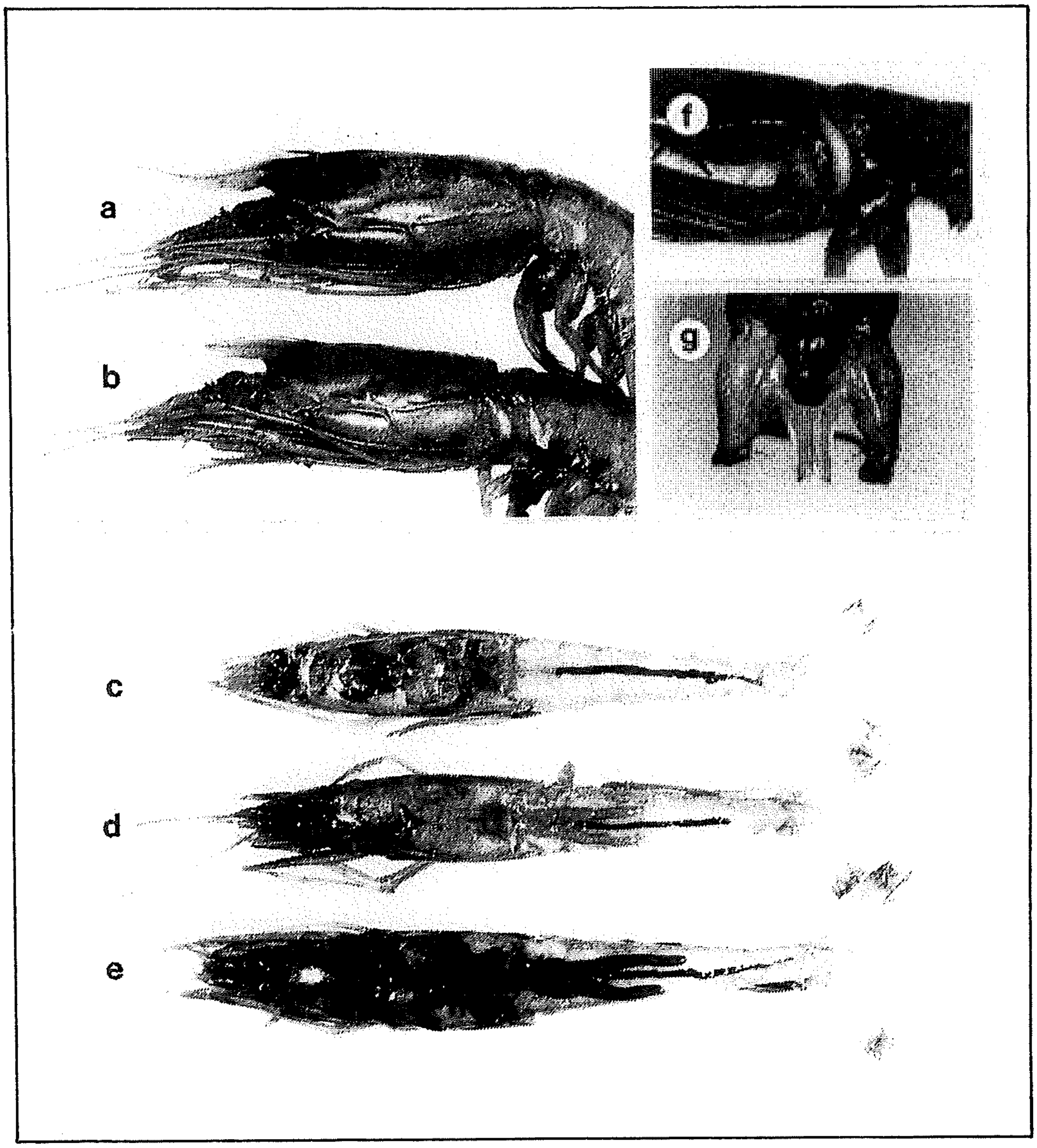


Fig. 4.3.1*A*–*G* *Aristaeomorpha foliacea* showing rostrum from lateral view in: *A*, adult female; *B*, adult male; reproductive development in females from dorsal view of longitudinal section of: *C*, stage 1 gonad; *D*, stage 2 gonad; *E*, stage 3 gonad (see text for description of stages); reproductive development in males with: *F*, sperm (white, centre) in the terminal vas deferens, lateral view; *G*, adult petasma (centre) located between first pereiopods, anterior view.

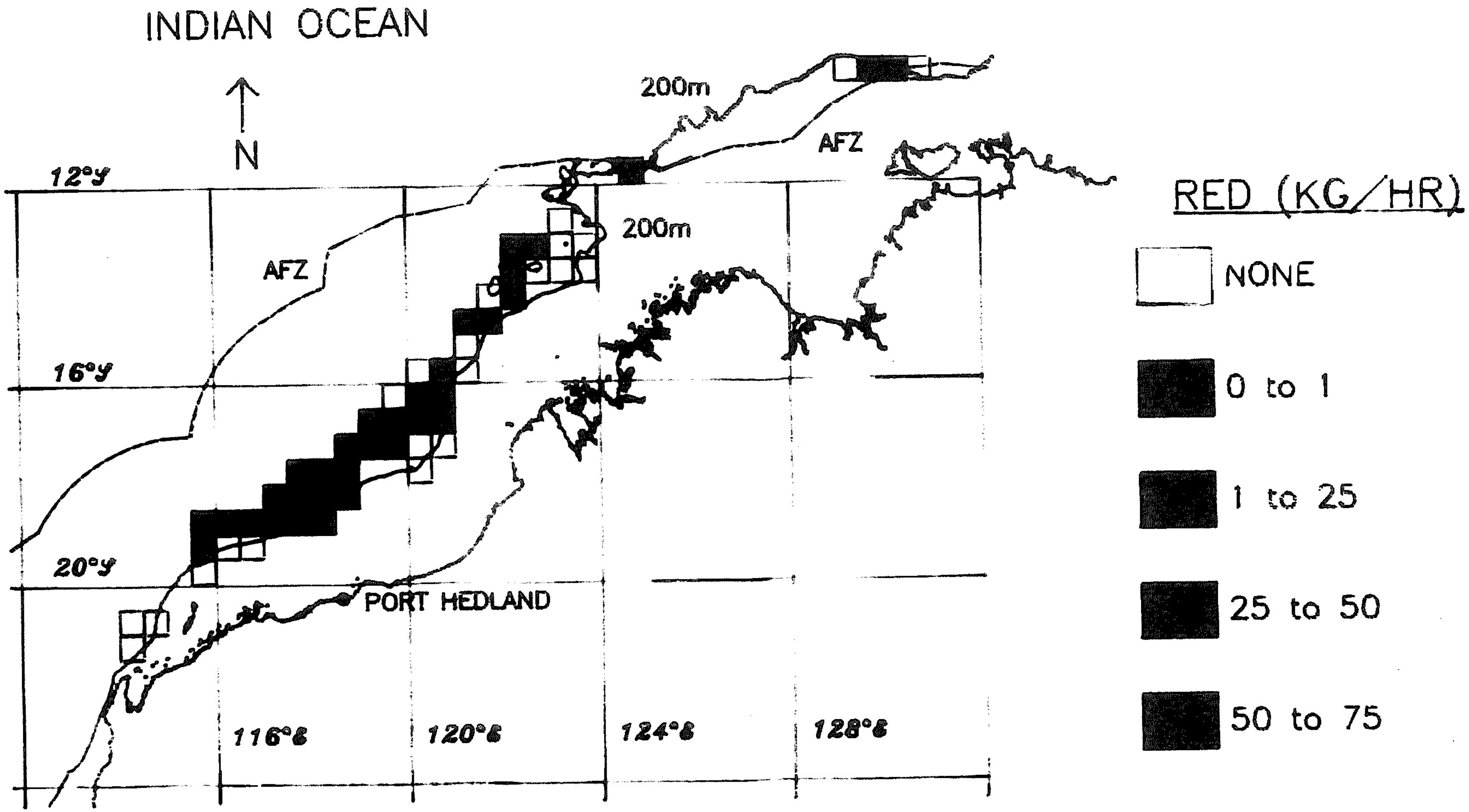


Fig. 4.3.2 The catch per unit effort (unstandardised, kg $\cdot$ h^{-1}) of *Aristaeomorpha foliacea* in the NWSTF area, by half-degree square in 1987/88.

Table 4.3.1. Annual growth series: mean values (mm CL) of the normal components (C1–C4) of length-frequency for *Aristaeomorpha foliacea*. The number of trawl shots (T) and individuals (*n*) is given for females and males (f, m) in each month, and the standard deviation (*s*, in parentheses) for each mean. The proportion of *n* in each component is given as a percentage.

Month	T	Sex	*n*	Means C1	C2	C3	C4
Dec 1987	21	f	2084	26·2 (3·7) 10%	43·3 (4·2) 61%	51·8 (2·5) 29%	
		m	2971	27·2 (4·2) 6%	38·8 (2·8) 92%	46·5 (3·1) 2%	
Feb 1988	10	f	803	32·4 (2·8) 6%	42·9 (2·6) 47%	49·4 (3·1) 47%	
		m	1333	32·0 (2·3) 4%	39·0 (2·2) 80%	41·1 (4·0) 16%	
Aug 1988	11	f	1613	31·8 (4·4) 13%	37·5 (1·7) 21%	45·1 (4·6) 34%	52·4 (2·5) 32%
		m	1906	35·1 (4·3) 29%	41·4 (1·9) 71%		
Dec 1988	10	f	1512	38·7 (5·4) 100%			
		m	1097	25·7 (2·4) 5%	35·1 (2·4) 95%		
Feb 1989	7	f	1535	26·4 (3·0) 7%	42·5 (3·4) 78%	49·8 (2·6) 150%	
		m	1235	37·1 (2·2) 100%			

Size structure of the population

The size distribution of female and male *A. foliacea* is shown in Fig. 4.3.5 and Table 4.3.1, using data from December 1987. In females, three components were found by MIX. The low proportion (10%, Table 4.3.1) in the first component was probably related to net escapement by small prawns and / or their scarcity in that time and place. The second and third components each had a high proportion of prawns. By inference, these components in females correspond to year classes of 1+ (26·2 mm CL), 2+ (43·4 mm CL) and 3+ (51·8 mm CL). In males, three components were found. Very low proportions in the

Table 4.3.2. Monthly growth series: mean values (mm CL) of the normal components (C1–C4) of length-frequency for *Aristaeomorpha foliacea*. The number of trawl shots (T) and individuals (*n*) is given for females and males (f, m) in each month, and the standard deviation (*s*, in parentheses) for each mean. The proportion of *n* in each component is given as a percentage.

Month	T	Sex	*n*	Means C1	C2	C3	C4
Jan 1991	14	f	2927	39·3	42·0	49·3	55·1
				(5·8)	(2·2)	(2·6)	(1·1)
				39%	38%	21%	2%
		m	2792	36·6	37·6		
				(0·7)	(3·5)		
				11%	89%		
Feb 1991	3	f	411	44·1	48·6	53·0	
				(2·0)	(1·8)	(1·9)	
				25%	54%	21%	
		m	461	40·4			
				(2·3)			
				100%			
Mar 1991	14	f	2084	29·3	46·4	50·6	
				(5·0)	(3·8)	(3·2)	
				5%	74%	21%	
		m	3529	38·8			
				(2·8)			
				100%			

first and third components resulted in an essentially unimodal distribution for biological purposes. Again by inference, these components in males correspond to year classes of 1+ (27·2 mm CL), 2+ (38·8 mm CL) and 3+ (46·5 mm CL). At least one year class (0+) of both females and males would exist at sizes smaller than the net could retain. Inference of age structure from size structure is nevertheless inconclusive, and requires validation by the progression of a cohort.

The size structure of the population based on female size data from January 1992 defined a component with a mode at 28·8 mm CL; this is interpreted as the 1+ age group. Assuming a monthly growth of 1·16 mm CL (see below), this modal size in January is commensurate with the 1+ modes at 26·2 mm CL in December and 32·4 mm CL in February (1987 data). Definition of the 1+ peak in samples with many juveniles indicates that there is a single peak, as far as can be determined with commercial nets.

Size structure: monthly and annual factors

The monthly growth rate for 2+ females for the three months January to March 1991 (Table 4.3.2) was 1·47 mm CL month^{-1}, from 42·0 mm CL in January 1991 to 46·4 mm CL in March 1991. The monthly rate for 3+ females was 0·43 mm CL month^{-1}, from 49·3 mm CL in January 1991 to 50·6 mm CL in March 1991. For males, the monthly growth rate for the 2+ group was 0·40 mm CL month^{-1}, from 37·6 mm CL in January 1991 to 38·8 mm CL in March 1991 (Fig. 4.3.6).

The annual growth rate for 1+ females for the 14 months December 1987 to February 1989 (Table 4.3.1, Fig. 4.3.7) was 1·16 mm CL month^{-1}, from 26·2 mm CL in December 1987 to 42·5 mm CL in February 1989. Within 14 months, the 1+ class had grown to the length of the 2+ year class of the previous year.. The annual rate for 2+ females was 0·46 mm CL month^{-1}, from 43·4 mm CI in December 1987 to 49·8 mm CL in February 1989. The rate for 3+ females could not be determined due to the absence of large animals in December 1988 and February 1989. For males, the annual growth rate for the 1+ group was 0·71 mm CL month^{-1}, from 27·2 mm CL in December 1987 to 37·1 mm CL by February 1989. For 2+ males, the rate of 0·33 mm CL month^{-1} was estimated on 8 months' growth, from 38·8 mm CL in December 1987 to 41·4 mm CL in August 1988. The rate for 3+ males could not be determined due to the absence of large animals except in December 1987.

Discussion

Catch rates of *Aristaeomorpha foliacea* on the SRS grounds were high (usually between 25–75 kg · h^{-1} (Wadley and Morris 1990) compared with other deepwater prawn fisheries in the world. Off north-western Sicily, 25 kg · h^{-1} was considered a good catch rate (Levi and Vacchi 1988). Rates of about 15 kg · h^{-1} were recorded by Dietrich (1987) off Mozambique. Catch rates for pandalids off Cochin and Quilon, in south-western India, averaged 74 kg · h^{-1} with a maximum in the range of 103–201 kg · h^{-1} at different depths (Suseelan 1974). Similarly to *A. foliacea* on the SRS, the pandalids were abundant (over 70% of the catch) in a small area (within three squares of 10 n.m. on a line perpendicular to the coast, in depths 300–375 m). Possible reasons for the aggregation of *A. foliacea* on the SRS include the soft mud of the bottom sediments (Mc Loughlin *et al.* 1988) or a breeding phenomenon.

Analysis of the catch and effort from commercial data indicates an overall decrease in the relative abundance of *A. foliacea* over the period 1985–90. The red prawn resource has been increasingly utilised as catches of the more valuable scampi resource have declined (Phillips and Jernakoff 1991).

Mature female *A. foliacea* were found throughout the year on the SRS, unlike the Mediterranean stocks where ovaries were mature mainly from May to October (Orsi Relini and Semeria 1983). Water temperature at 500 m (close to the depth of fishing) off Port Hedland is about 8–9°C, off Cochin about 10–11°C (Wyrtki 1971) and presumably similar in the Mediterranean; seasonal variation in temperature at this depth should be similar in the three areas. Further

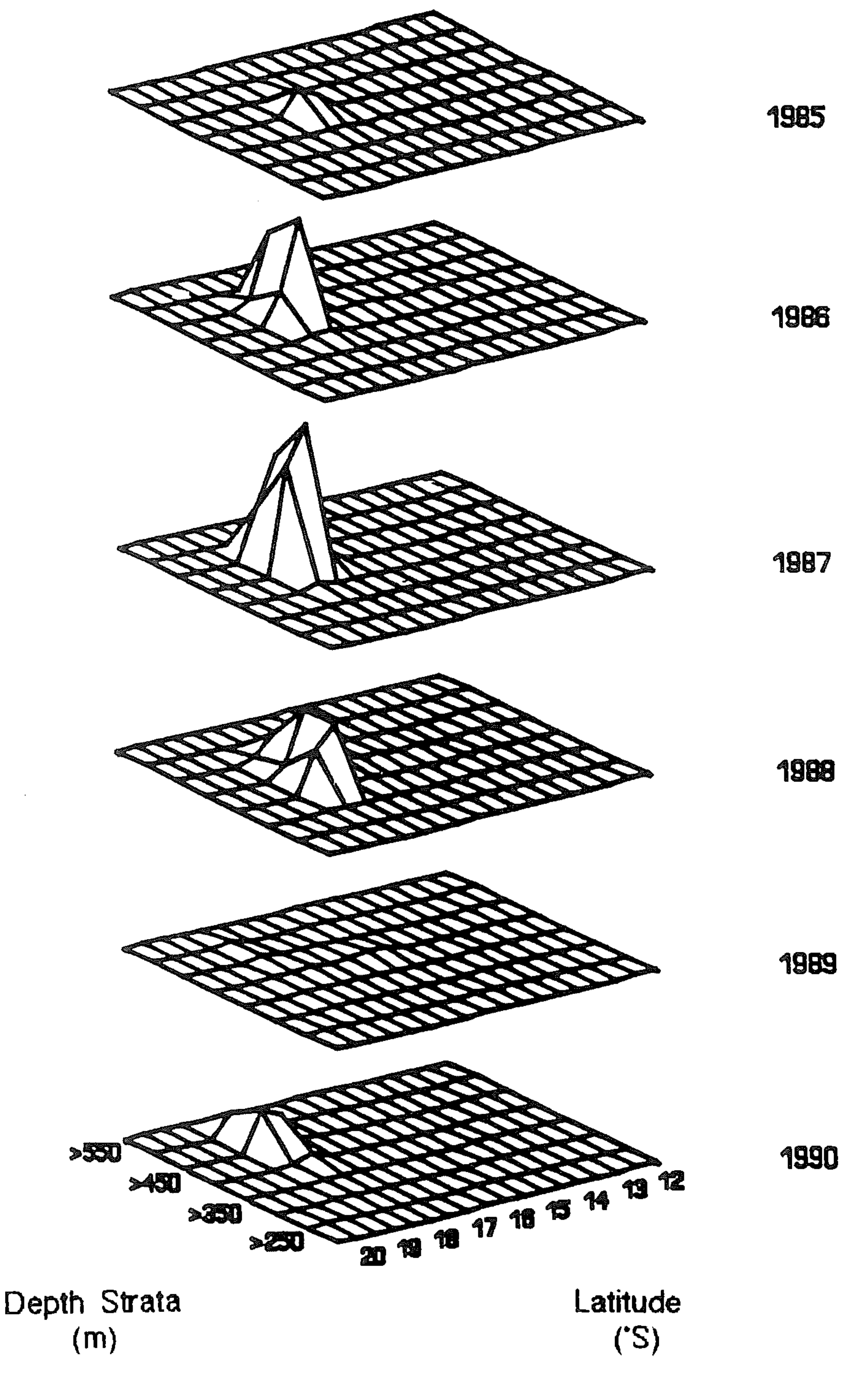


Fig. 4.3.3 The catch of *Aristaeomorpha foliacea* by depth and latitude in the North West Slope Trawl Fishery, by 50 m bathymetric contour, from 1985 to 1990 (catch unstandardised for effort but see Fig. 4.3.4); peak heights are relative to catch.

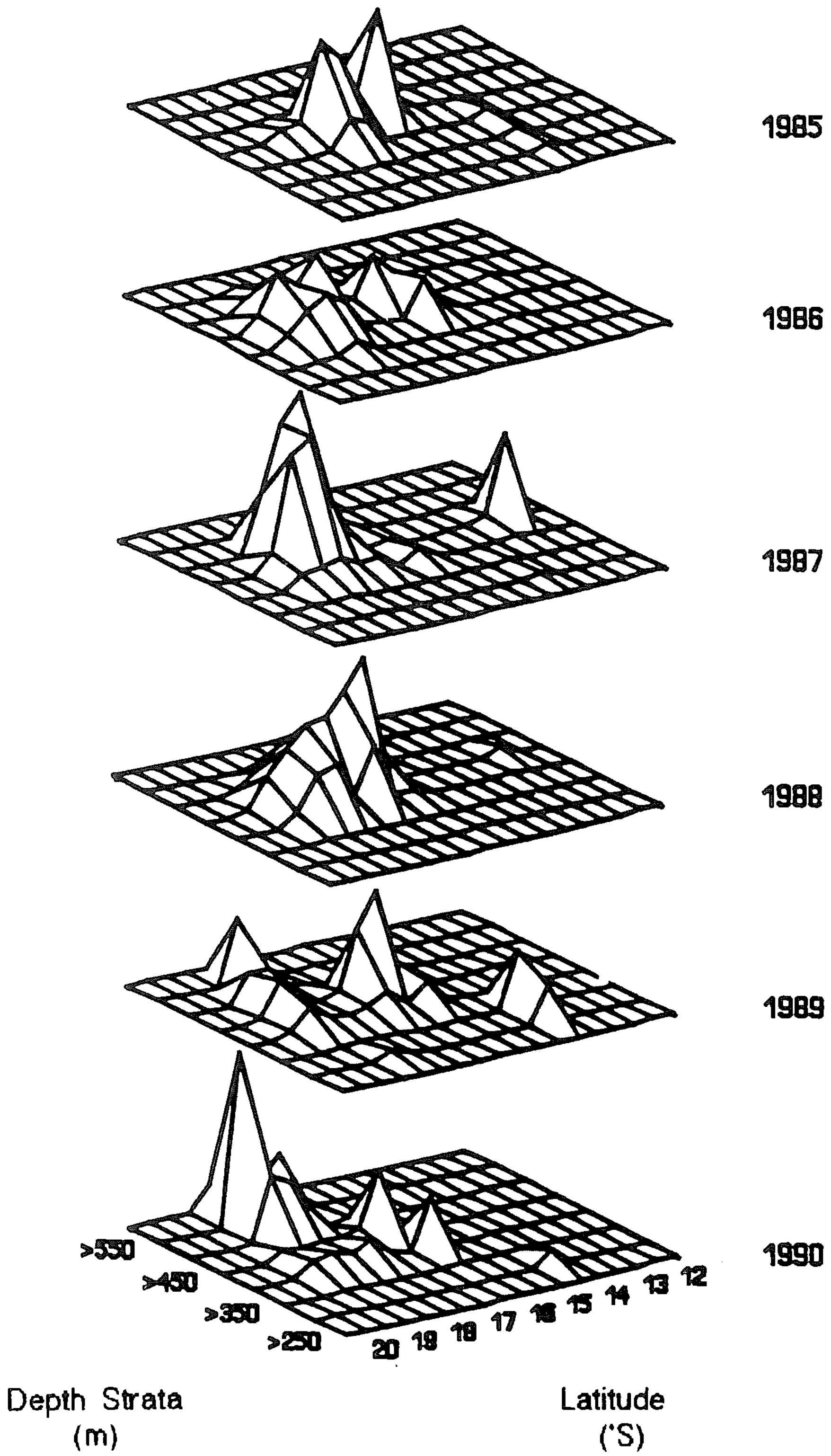


Fig. 4.3.4 Total effort for all species by depth and latitude in the North West Slope Trawl Fishery, by 50 m bathymetric contour, from 1985 to 1990; peak heights are relative to effort.

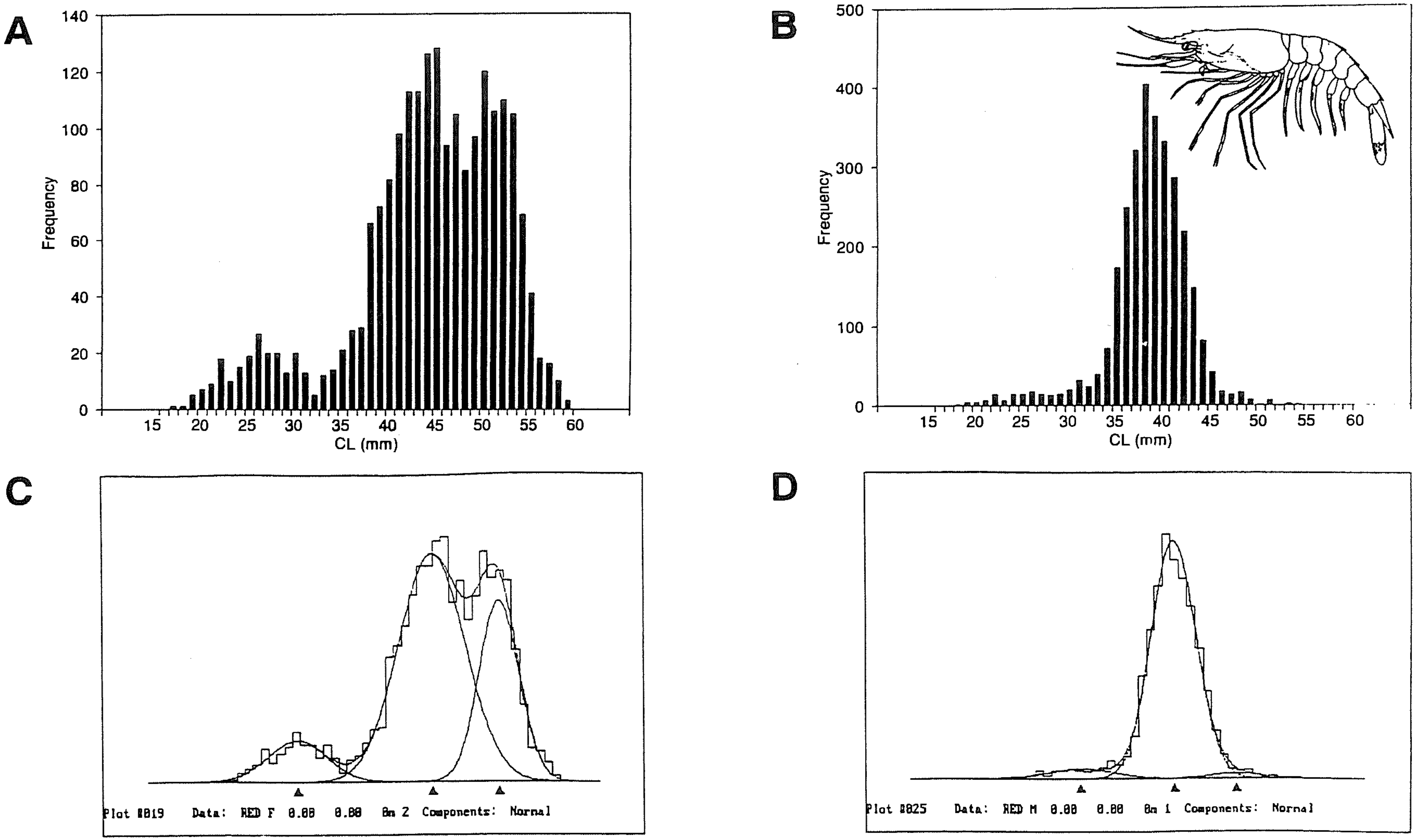


Fig. 4.3.5*A–D* *Aristaeomorpha foliacea*: length-frequency from December 1987 for *A*, females; *B*, males; analysis of normal components showing means (triangles) for *C*, females; *D*, males.

studies of the SRS stocks could focus on the apparent lack of reproductive periodicity.

In a highly aggregated species such as *A. foliacea*, effective exploitation may cause severe local depletion of the stock. Overfishing and recruitment failure are among the causes suggested for the decline of *Aristeus antennatus* and *A. foliacea* in the Mediterranean (Relini and Orsi Relini 1987). Small size-classes of *A. foliacea* have not been sampled in the NWSTF, so there would be no early warning of recruitment failure. Somers *et al.* (1987) showed that retention by a 44 mm cod-end mesh was 100% for > 30 mm CL prawns (>90% for > 20 mm CL prawns). The numbers of 15–30 mm CL (1+ year class) prawns found in January 1991 indicate that commercial nets can retain them, although the proportions are unreliable. The stock / recruitment relationship may be difficult to determine because the length of planktonic larval stages is unknown and the larvae are difficult to catch even on known fishing grounds (Heldt 1955).

Trophic studies recorded midwater species in the foregut of *A. foliacea* (Rainer 1992), suggesting that the prawns were feeding in midwater at night. This is a possible explanation of the presence of *A. foliacea* in daylight demersal trawls and its absence at night. Studies on the vertical distribution of pelagic crustacean communities (Wadley 1986) recorded the greatest biomass between 250–300 m at night. Foxton (1970) showed that pelagic penaeids migrate at least 400 m on a diel cycle and Pearcy *et al.* (1977) found a community of micronekton off Oregon migrated generally 200–400 m on a diel cycle. Assuming that *A. foliacea* migrate into the water column at night, acoustics could rapidly determine the position. The location of the stock at night could be exploited in the harvest of *A. foliacea*, by trawling in midwater. It has been suggested that trawling for prawns interferes with the more valuable scampi resource in the same habitat; midwater trawling for prawns would remove this interaction. The concomitants of less gear damage and no habitat destruction may attract fishers to midwater trawling.

Growth rates determined in this study provide a monthly rate that is commensurate with the annual rate, although the rates for 1+ females differed from 2+ females, and 1+ females grew slower than 1+ males. Males matured between 18–23 mm CL, corresponding to a 1+ year class. Females matured from 20 mm CL, corresponding also to a 1+ year class. Although the some females in the 1+ year class could be immature, all those in the 2+ year class were mature and most had ripe ovaries; in the 3+ year class, almost all were mature and had ripe ovaries. Three year-classes were identified, so allowing for at least a year of life as larvae / juveniles, the prawns live for at least four years. Comparisons with other deepwater penaeids cannot be drawn due to the lack of published growth data (Orsi Relini and Relini 1985). Somers *et al.* (1987) showed that all prawns >30 mm CL would be retained in the commercial nets, so some mature prawns in the size range 18–30 mm CL (males) and 20–30 mm CL (females) could escape. Nevertheless, most of the exploited prawns are

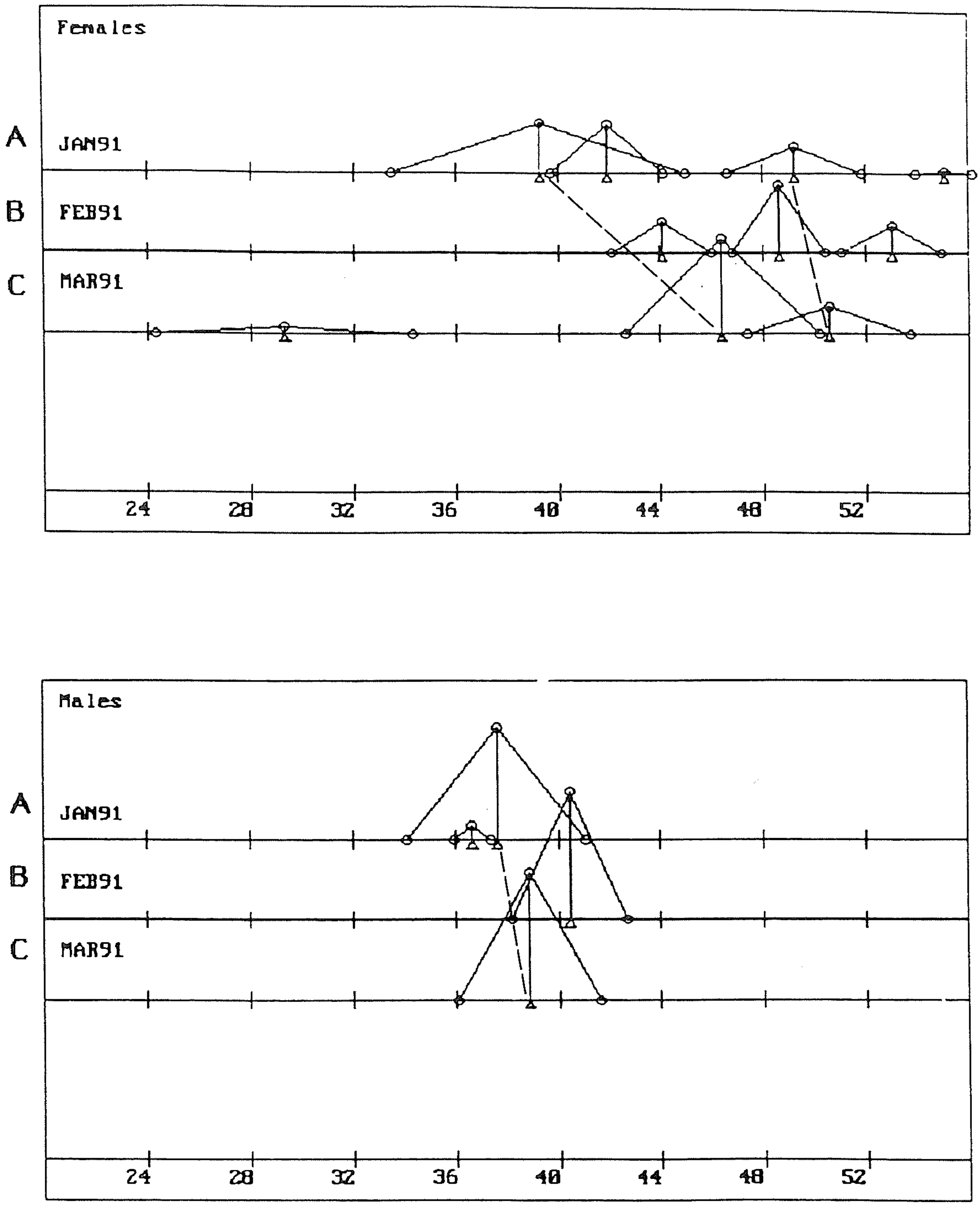


Fig. 4.3.6*A–C* Length-frequency of female (upper) and male (lower) *Aristaeomorpha foliacea* from: *A*, January 1991; *B*, February 1991; *C*, March 1991. Analysis of normal components is shown as mean (apex of triangle), standard deviation (width of triangle) and proportion (height of triangle); progression of a cohort is shown by the dashed line.

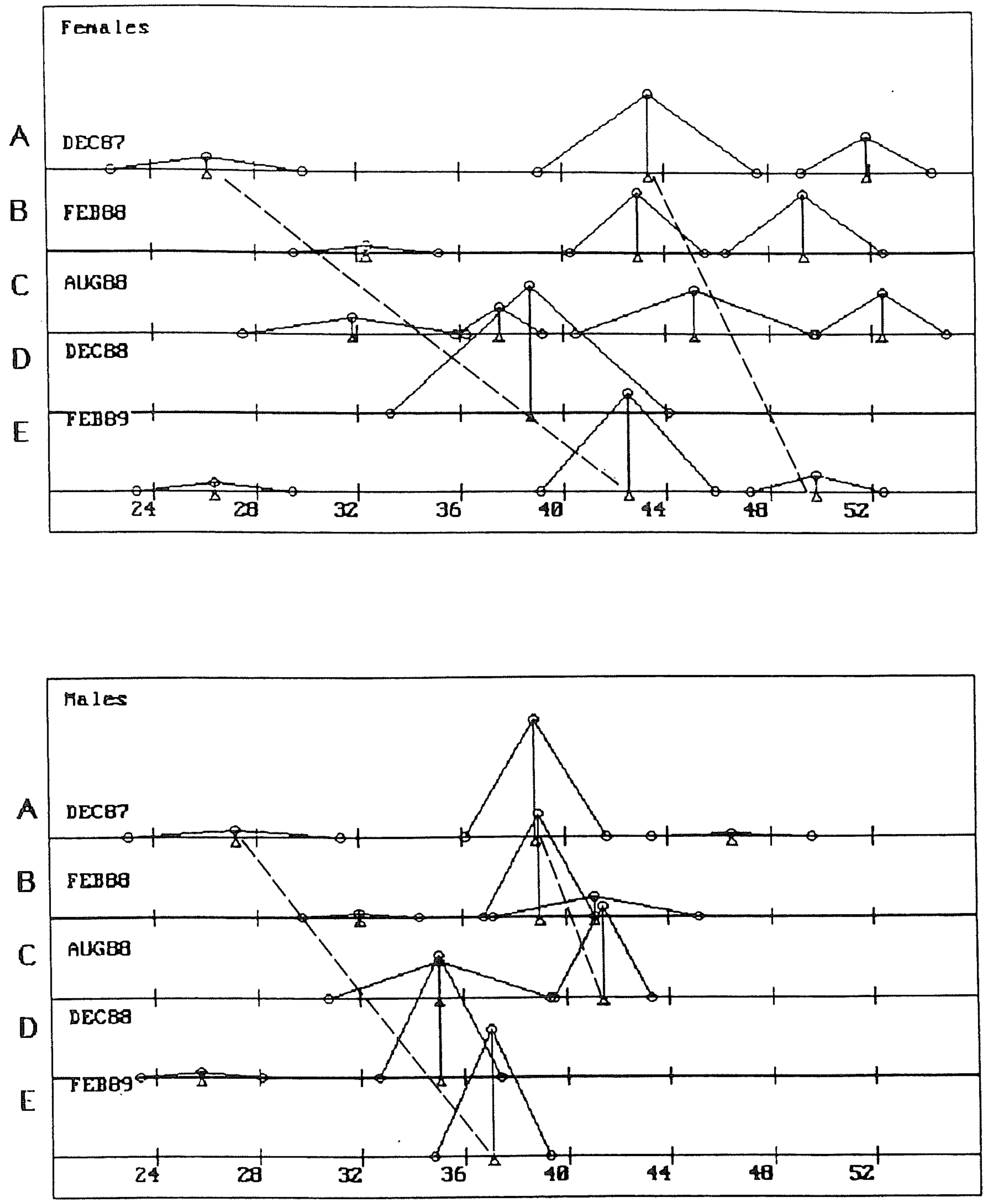


Fig. 4.3.7*A–E* Length-frequency of female (upper) and male (lower) *Aristaeomorpha foliacea* from: *A*, December 1987; *B*, February 1988; *C*, August 1988; *D*, December 1988; *E*, February 1989. Analysis of normal components is shown as mean (apex of triangle), standard deviation (width of triangle) and proportion (height of triangle); progression of a cohort is shown by the dashed line.

in breeding condition, and this could be the reason for their aggregation and susceptibility to trawling.

Given the amount of effort on the SRS stocks, the aggregation of reproductively mature prawns in a small area and the decline in catch rates, the potential is high for over-exploitation of *A. foliacea* in the NWSTF. Closure of an area of the SRS to record the time for stocks to recover, or a management plan to redirect effort to areas of the NWSTF other than the SRS, would merit attention in the interests of the future sustainability of the fishery.

References

Dietrich, B. (1987). Review of the deep-water shrimp stock and its exploitation in the waters off the People's Republic of Mozambique. *Fischerei-Forschung, Rostock* **25**(3), 67–75.

Foxton, P. (1970). The vertical distribution of pelagic decapods (Crustacea: Natantia) collected on the Sond cruise 1965. II. The Penaeidae and general discussion. *Journal of the Marine Biological Association of the United Kingdom* **50**, 961–1000.

Heldt, J. H. (1955). Contribution à l'étude de la biologie des crevettes pénéides *Aristaeomorpha foliacea* (Risso) et *Aristeus antennatus* (Risso) (formes larvaires). *Bulletin de la Société des Sciences Naturelles de Tunisie* **8**,9–31.

Holthuis, L. B. (1980). FAO species catalogue. Volume 1. Shrimps and prawns of the world. An annotated catalogue of species interest to fisheries. *FAO Fisheries Synopses* **125**, 1–1261.

Jernakoff, P. J. 1988. The Western and North West Shelf Deep-water Trawl Fisheries: Research Priorities. Bureau of Rural Resources Bulletin No. 1, 33 pp. (AGPS: Canberra.)

Levi, D. and Vacchi, M. (1988). Macroscopic scale for simple and rapid determination of sexual maturity in *Aristaeomorpha foliacea* (Risso, 1826) (Decapoda: Penaeidae). *Journal of Crustacean Biology* **8**(4), 532–538.

Macdonald P. D. M. and Green P. E. J. (1988). User's guide to program MIX: an interactive program for fitting mixtures of distributions. Release 2.3. 60 pp. (Ichthus Data Systems: Hamilton, Ontario, Canada.)

——— and Pitcher, T. J. (1979). Age-groups from size-frequency data: a versatile and efficient method of analysing distribution mixtures. *Journal of the Fisheries Research Board of Canada* **36**, 987–1001.

McLoughlin, R. G., Davis, T. L. O. and Ward, T. J. 1988. Sedimentary provinces, and associated bedforms and benthos on the Scott Reef–Rowley Shoals platform off North-West Australia. *Australian Journal of Marine and Freshwater Research* **39**(2), 133–144.

Orsi Relini, L. and Relini, G. (1985). An attempt to assign Bertalanffy growth parameters to *Aristeus antennatus* Risso 1816 (Crustacea

Decapoda) of the Ligurian Sea. *Rapports de la Commission international de la Mer Méditerranée* **29**(5), 301–304.

——— and Semeria, M. (1983). Oogenesis and fecundity in bathyal penaeid prawns, *Aristeus antennatus* and *Aristaeomorpha foliacea. Rapports de la Commission international de la Mer Méditerranée* **28**(3), 281–284.

Pearcy, W. G., Krygier, E. E., Mesecar, R. and Ramsey, F. (1977). Vertical distribution and migration of oceanic micronekton off Oregon. *Deep-Sea Research* **24**, 223–245.

Rainer, S.F. (1992). Diet of .prawns from the continental slope of north-western Australia. *Bulletin of Marine Science* **50**(2), 258–274.

Relini, G. and Orsi Relini, L. (1987). The decline of red shrimp stocks in the gulf of Genoa. *Investigaciones Pesqueras* **51** (Supl. 1), 245–260.

Sardà, F. and Demestre, M. (1989). Shortening of the rostrum and rostral variability in *Aristeus antennatus* (Risso, 1816) (Decapoda: Aristeidae). *Journal of Crustacean Biology* **9**(4), 570–577.

Somers, I. F., Crocos, P. J. and Hill, B. J. (1987). Distribution and abundance of the tiger prawns *Penaeus esculentus* and *P. semisulcatus* in the north-western Gulf of Carpentaria, Australia. *Australian Journal of Marine and Freshwater Research* **38**, 63–78.

Suseelan, C. (1974). Observations on the deep-sea prawn fishery off the south-west coast of India with special reference to pandalids. *Journal of the Marine Biological Association of India* **16**(2), 491–511.

Wadley, V. A. (1986). The community structure of micronekton from an oceanic eddy. Ph.D. Thesis, University of Sydney. 144 pp.

——— and Evans, D. (1992). Crustaceans from the Deepwater Trawl Fisheries of Western Australia. 44 pp. CSIRO Australia.

——— and Morris, S. M., (1991). Deepwater fishery for prawns and carids off Western Australia. *In* Proceedings of the International Crustacean Conference, 2–6 July 1990: Brisbane, Queensland. *Memoirs of the Queensland Museum* **31**, 400.

Wallner, B. and Phillips, B. 1988. From scampi to deepwater prawns: developments in the North West Shelf deepwater trawl fishery. *Australian Fisheries* **47**(9), 34–38.

Wyrtki, K. (1971). Oceanographic Atlas of the International Indian Ocean Expedition. 531 pp. (National Science Foundation: Washington, D.C.)

4.4 The Biology of Scampi, Prawns, Carids, Bugs and Crabs Exploited by Deepwater Trawling

Dr V. A. Wadley

Introduction

A wide variety of crustaceans was regularly recorded in the commercial catches from the WDWTF and NWSTF. Forty-one species of commercial crustaceans, including scampi, prawns, carids, bugs and crabs, were included in CSIRO's Deepwater Crustacean Guide (Wadley and Evans 1991). The additional non-commercial crustaceans in the catch included hundreds of species. A range of lifespan (one to tens of years), reproductive strategy and population parameters was encompassed in these deepwater crustaceans. Knowledge of the biology and diversity of the exploited crustaceans is important in managing the fishery.

The fisheries biology of the most abundant and commercially important crustaceans (scampi and deepwater red prawns) was covered in Chapters 4.1–4.3. Additional information is presented here to augment the other chapters, and should not be read as an exhaustive treatment of either scampi or red prawns. The crustaceans of lesser commercial importance, including some prawns and the carids, bugs and crabs, appear only in this chapter.

Methods

Data were collected from commercial logbooks and by scientific observers on commercial vessels, as detailed in Chapter 3 (pp. 29 *et seqq.)*. Biological information is given below for ten species or species groups, arranged in order of decreasing commercial importance. The information for each species is presented at the expense of some redundancy in, for example, reproduction in penaeids, carids and standard length measurements.

The information includes the characteristic features of the species, taken partly from the CSIRO Deepwater Crustacean Guide (Wadley and Evans 1991). The distribution in the NWSTF and WDWTF is given, with an indication of the worldwide distribution where available from the literature.

Background information on the fishery includes the range of depth, preferred habitat, catch and (unstandardised) catch rate for each species. Processing and grading are outlined as background to the data collected in commercial logbooks. The practices of many operators over all areas and times of the fishery have been summarised. Current practice for a particular species may be different from the summarised information provided.

The biology of the commercial species includes the distinguishing features for females and males and the characteristics of sexual maturity, egg colour and egg development. The measurement used for size is given. The length frequency of the species in samples from commercial catches is provided from scientific observer data. Samples from consecutive trawls over the same area were pooled to provide sufficient individuals for analysis (details held in 'Commercial-in Confidence' cruise reports, CSIRO Marmion laboratory). The size structure of each species was analysed using MIX (Macdonald and Green version 3.1, Ichthus Data). Based on the normal components of the length frequency from MIX, longevity was estimated for some species, as an initial step towards stock assessment.

Results

Metanephrops and *Nephropsis* species (scampi)

In the family Nephropidae, two genera were found in the WDWTF and NWSTF. These were *Metanephrops* (scampi) and *Nephropsis* (blind scampi). Characteristic features of the five species of *Metanephrops* (*M. australiensis*, *M. boschmai*, *M. neptunus*, *M. sibogae* and *M. velutinus*) were given in Wadley and Evans (1991). In commercial logbooks, Nephropidae were usually recorded as scampi, without differentiation to species. Scampi were packed whole in three grades (see Chapter 3.2); animals < 30 mm CL were tailed or discarded. The whole animals were usually packed in 3 kg cartons, with all layers finger-laid. Tails, including those of soft or broken animals, were packed in 12 kg cartons. *M. boschmai* were usually tailed because of their small size. *M. neptunus* do not occur in commercial quantities and the occasional animals were valued for the table. Tails of *Nephropsis* scampi (mainly two species, N. *serrata* and *N. stewarti* Macpherson, 1990) were mixed into the 12 kg cartons.

Female scampi have any or all of the following: eggs on the pleopods; gonopores on the coxae of the third pereiopods; unmodified first pleopods. In juvenile specimens, the gonopores are the most reliable character. Male scampi have gonopores on the coxae of the fifth pereiopods and modification of the first pleopods as copulatory stylets. In juveniles, the gonopores are again the most reliable character, as the copulatory stylets are not fully developed in small males.

Reproductive development in females was recognised by the blue colour of the ripening ovary (except in *M. neptunus* where the colour was not visible through the carapace). The size of eggs increases with development and the colour changes from blue to orange. The shade of colour and its change with egg development varies according to species. In each species, four stages of egg development were recognised routinely in the field. The fourth (last) stage eggs were always large and clear; large orange spots gave an overall orange colour (visible as eyespots under magnification). The number of eggs in a brood was estimated as 800–1500 from limited observations on *M. australiensis* and *M. velutinus*.

Red prawn, *Aristaeomorpha foliacea*

Aristaeomorpha foliacea, the most abundant species of the family Aristeidae in the NWSTF, is easily distinguished by its bright red colour. The carapace is smooth apart from an hepatic spine on the side. The rostrum is long and arched but as males mature their rostrum shortens, as though the anterior half were missing. In females there are 5–10 teeth on top of the rostrum, none beneath. In mature males, there are 5–7 teeth on top. Females grow considerably larger (to 62 mm CL) than males (to 53 mm CL), with disproportionate enlargement of the carapace relative to the remainder of the body. In New Zealand, the same species is fished commercially as the royal red prawn (Webber *et al.* 1990).

Catches of *A. foliacea* have ranged from 24·4 tonnes (1989/90) to 418·7 tonnes (1987/88; Table 4.1.1). The species was taken as by-catch of scampi until 1986/87, when substantial catches were taken, followed by record catches the next year. Catches beyond the capacity of the vessel processing equipment were taken in 1987/88; retained catches as recorded were substantially less than the total catch. The spatial distribution of the catch over six years (Fig. 4.3.3) shows that most (> 90%) of the catch is taken each year from the Southern Rowley Shoals grounds known to fishers as 'Crossroads'.

Red prawns are caught during daytime demersal trawls; they are believed to rise into midwater at night. Trawls are usually of 2–3 hours duration. The prawns are graded into 10/20 per pound (large) and 20/30 per pound (small); occasionally, those larger than 10/20 per pound may be graded separately. Whole prawns are packed in 3 kg cartons, usually with a finger-laid top layer. Soft and broken prawns are tailed and packed in 3 kg cartons. Animals smaller than 20/30 per pound are usually discarded. The prawns are delicate and prone to melanosis; careful handling and dipping in antioxidant solution are mandatory. During processing, the prawns have a characteristic odour. Contact with unprotected skin may cause problems. The 10/20 grade are mostly females. Although dark ovary may detract from the overall appearance, the large carapace of females is a delicacy in Spain, the major export market.

Female *A. foliacea* have any or all of the following: long rostrum; enlarged carapace; thelycum (may hold spermatophore) between fifth pereiopods; dark ovary beneath the carapace, possibly extending to the abdominal segments; gonopores on the coxae of the third pereiopods. The thelycum is cupped, relatively deep, and bounded by anteriorly-projected lobes at both the anterior and posterior margins. In juveniles, the thelycum and gonopores may not be obvious without magnification. The spermatophore is rounded, relatively small, pale yellow / cream in colour and firmly implanted in the thelycum. The spermatophore is lost (by inference, not observation) during each moult because of the open-type thelycum, although it is not as easily displaced during handling or freezing as in other species. Males have any or all of the following: abbreviated rostrum; gonopores on the coxae of the fifth pereiopods; petasma between the first pleopods; sperm duct (white) prominent laterally above the fifth pereiopods. In juveniles, the unjoined petasma is the initial means of differentiating males.

The onset of reproductive development in females appears to coincide with the presence of a spermatophore in the thelycum. Three stages of ovary development were routinely recorded in the field. The stages were differentiated by the amount and colour of ovary beneath the carapace, and the colour and posterior extension of the ovarian lobes beneath the abdominal segments. In males, reproductive development is marked by the joining of the petasma and the presence of sperm in the terminal vas deferens. In mature males, the spermatophore may exude from the gonopore.

The length was measured dorsally along the carapace, from the posterior margin of the orbit to the posterior margin of the carapace. The length frequency (Fig. 4.3.5) shows three well-defined modes in females (means of 26·2, 43·4 and 51·8 mm CL) corresponding to a lifespan of at least three years. In males, the distribution was apparently unimodal at a mean of 38·8 mm CL, although three normal components were resolved in the analysis.

Pink striped prawn, *Aristeus virilis*

The pink striped prawn is a penaeid prawn of the family Aristeidae. It is the dominant prawn in mid-slope depths, although it occurs also on the lower slope with *A. mabahissae* and others of the same genus. *A. virilis* is distinguished from its congeners by a mat surface on the carapace, pink bands on the tail segments, a long rostrum with three spines on top, and a stout, large body.

A. virilis is caught mainly in the south-western area of the NWSTF, between 18°30'S. and 19°S. and between 350 and 550 m depth. The distribution in 1987/88 (Fig. 4.4.1) shows the highest catch rates on the grounds south-west of Rowley Shoals. Catches at lower rates were widespread in the NWSTF, extending to the Arafura Sea. *A. virilis* is found throughout the Indo-West Pacific region, from eastern Africa to Japan, New Hebrides and New Caledonia. In the Mediterranean, its relative, *A. antennatus*, is fished commercially from Barcelona, Genoa and other ports. This has replaced the fishery for *Aristaeomorpha foliacea*, which is no longer found in the Mediterranean. Despite searching, *A. antennatus* was not found in the NWSTF.

Catches of *A. virilis* have ranged from 12·6 tonnes (1985/86) to 127·0 tonnes (1990/91; Table 4.1.1). In 1989/90, the species was successfully targeted in deeper water (> 450 m). The historical aspect of targeting, shown for 6 years in Fig. 4.4.2, is important in calculating long-term annual catches; a six-year average catch would be misleading as an indication of abundance.

Pink striped prawns are caught day and night in demersal trawls. The trawls are usually of 4 hours duration. The main grounds are over sand or mud bottom, in depths of 350–550 m. Catches may increase with repeated trawling over the same ground; any depletion experiments in future should be designed accordingly.

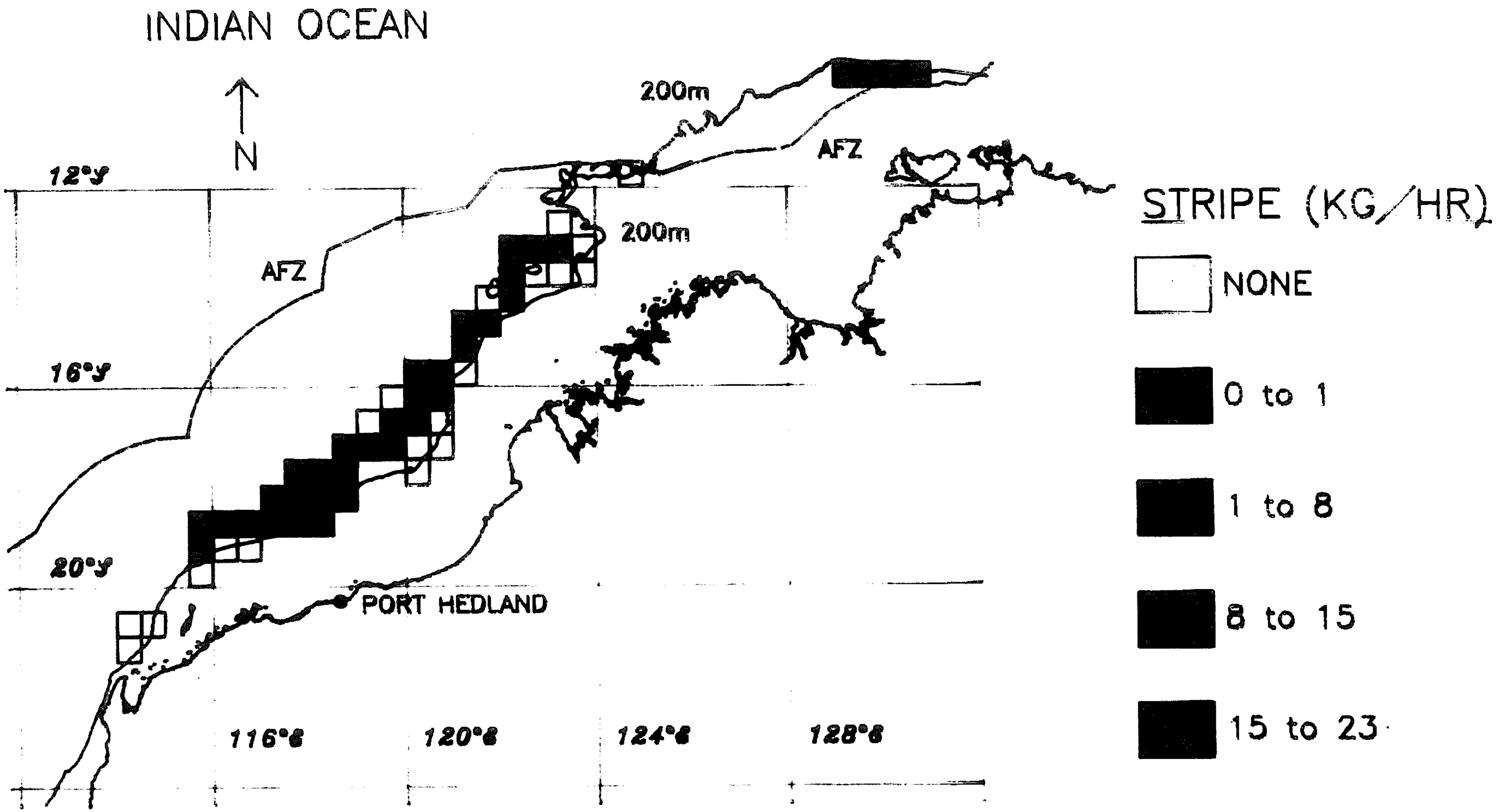


Fig. 4.4.1 The catch per unit effort (unstandardised, kg · h^{-1}) of *Aristeus virilis* in the NWSTF area, by half-degree square in 1987/88.

Table 4.4.1. Mean values of the normal components of length frequency of prawns. The number of individuals (*n*) is given for females and males (f, m) of each species, and the standard deviation (*s*, in parentheses) for each mean.

Species	Sex	*n*	Means 1	2	3	4	5
Aristaeomorpha foliacea	f	2084	26·2 (3·7)	43·4 (4·2)	51·8 (2·5)		
	m	2971	27·2 (4·2)	38·8 (2·8)	46·5 (3·1)		
Aristeus virilis	f	4660	43·7 (2·4)	44·4 (4·3)			
	m	2601	33·3 (1·3)	35·1 (2·9)			
Heterocarpus woodmasoni	f	841	27·7 (3·2)	31·3 (1·2)			
	m	946	27·6 (3·3)	31·1 (1·1)			
Heterocarpus sibogae	f	3532	25·1 (2·2)	30·3 (1·1)	34·2 (1·5)		
	m	779	24·9 (2·1)	32·7 (2·1)			
Haliporoides sibogae	f	1150	19·6 (0·9)	23·8 (1·0)	27·7 (1·3)	35·9 (3·5)	
	m	158	19·2 (0·9)	24·5 (1·5)	28·3 (1·4)		
Plesiopenaeus edwardsianus	f	275	43·8 (2·5)	51·0 (1·8)	60·4 (2·8)	67·1 (1·3)	73·0 (2·8)
	m	218	46·5 (4·9)	55·1 (3·1)			

The prawns are graded into 10/20 per pound (large) and 20/30 per pound (small). Whole prawns are packed into 3 kg cartons, with a finger-laid top layer. Soft or broken prawns are tailed and packed in 3 kg cartons. Animals smaller than 20/30 size are tailed or occasionally discarded. The prawns are robust to handling but somewhat subject to melanosis, so dipping in antioxidant solution is required.

Female *A. virilis* have a thelycum between the fifth pair of pereiopods and a longer rostrum than males of the same size. Males have any or all of the following: gonopores on the coxae of the fifth pereiopods; petasma between the first pleopods; sperm duct (white) prominent laterally above the fifth pereiopods.

Reproductive development in females is marked by a spermatophore in the thelycum. The spermatophore is large and cream in colour. It

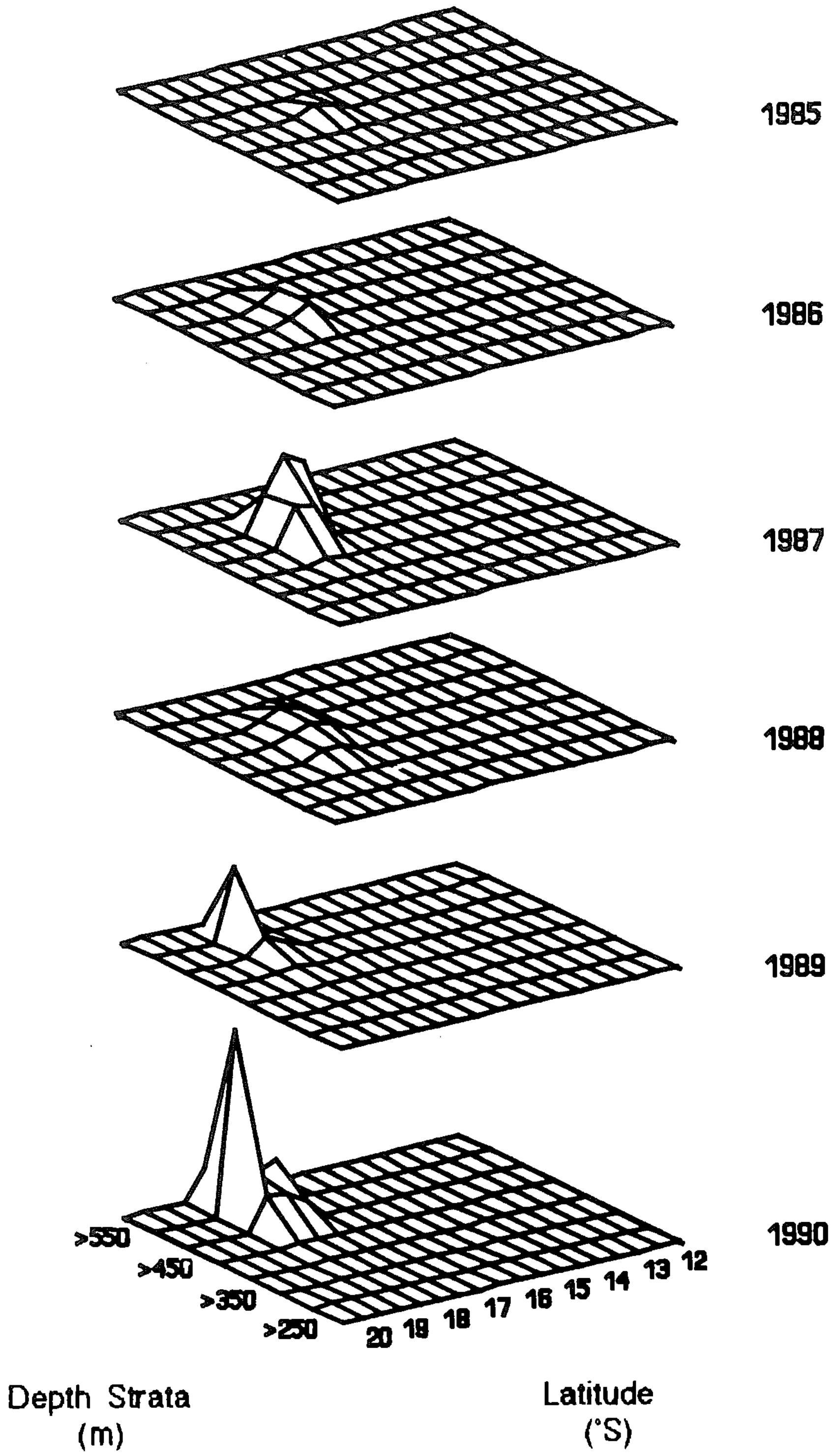


Fig. 4.4.2 The catch of *Aristeus virilis* by depth and latitude in the North West Slope Trawl Fishery, by 50 m bathymetric contour, from 1985 to 1990 (catch unstandardised for effort but see Fig. 4.3.4); peak heights are relative to catch.

is occasionally detached from the thelycum with processing or dislodged after freezing / defrosting. Developing ovary shows blue through the carapace and, with full maturity, through the first to third abdominal segments.

The length was measured dorsally along the carapace, from the posterior margin of the orbit to the posterior margin of the carapace. Males were up to 46 mm CL, females 61 mm CL (although occasional larger specimens have been reported by fishermen). *A. virilis* has a narrow range of length in both females and males (Fig. 4.4.3*A*, *B*). In females, a large proportion of lengths were in a mode with mean of 44·4 mm CL, although analysis defined a small proportion in a mode with mean at 43·7 mm CL. In males, a similar result was obtained, with a large proportion at 35·1 mm CL and a small proportion at 33·3 mm CL (Table 4.4.1, Fig. 4.4.3*C*, *D*). In both females and males, these distributions may be regarded as essentially unimodal for biological purposes. There is little evidence from the NWSTF data to support an hypothesis that *A. virilis* live for more than a year (or two, considering the juvenile period to grow to > 35 mm CL).

Red carid, *Heterocarpus woodmasoni*

The red carid belongs to the family Pandalidae. It occurs on the NWSTF with at least four other species of the genus *Heterocarpus*, from which it may be differentiated by its deep red colour. It has a long, upturned rostrum of the same shape in females and males. Two prominent ridges on the side of the carapace terminate in anterior spines. The dorsal posterior margin of the third abdominal segment bears a hooked spine.

H. woodmasoni is found throughout the NWSTF and on the slope of eastern Australia. The distribution extends to Indonesia, Taiwan and the tropical Indo-West Pacific. It also occurs in the Arabian Sea and eastern Africa.

Catches of *H. woodmasoni* have ranged from 7·1 tonnes (1990/91) to 115·7 tonnes (1988/89; Table 4.1.1). Distribution of red carids in the NWSTF (Fig. 4.4.4) has followed less closely than other species the distribution of effort (Fig. 4.3.4), particularly in 1988 and 1989. Red carids often occur in catches together with *Aristaeomorpha foliacea* and *Metanephrops boschmai*. In 1988/89, red carids were selectively targeted due to market demand in Japan but the lack of correspondence between effort and catch suggests that they are not yet effectively targeted. Catches have declined in recent years.

H. woodmasoni is common on sand or mud bottom, mainly in depths of 300–500 m, although it has been recorded in 290–655 m. Red carids are caught day and night in demersal trawls. The trawls are usually of 3–4 hours duration. The prawns are graded into 20/30 per pound (large), 30/40 per pound and 40/50 per pound (small). Whole prawns are packed into 3 kg cartons, usually without finger-laying. The prawns are robust to handling and not particularly subject to melanosis. Frozen whole product is exported to Japan, Europe and Canada.

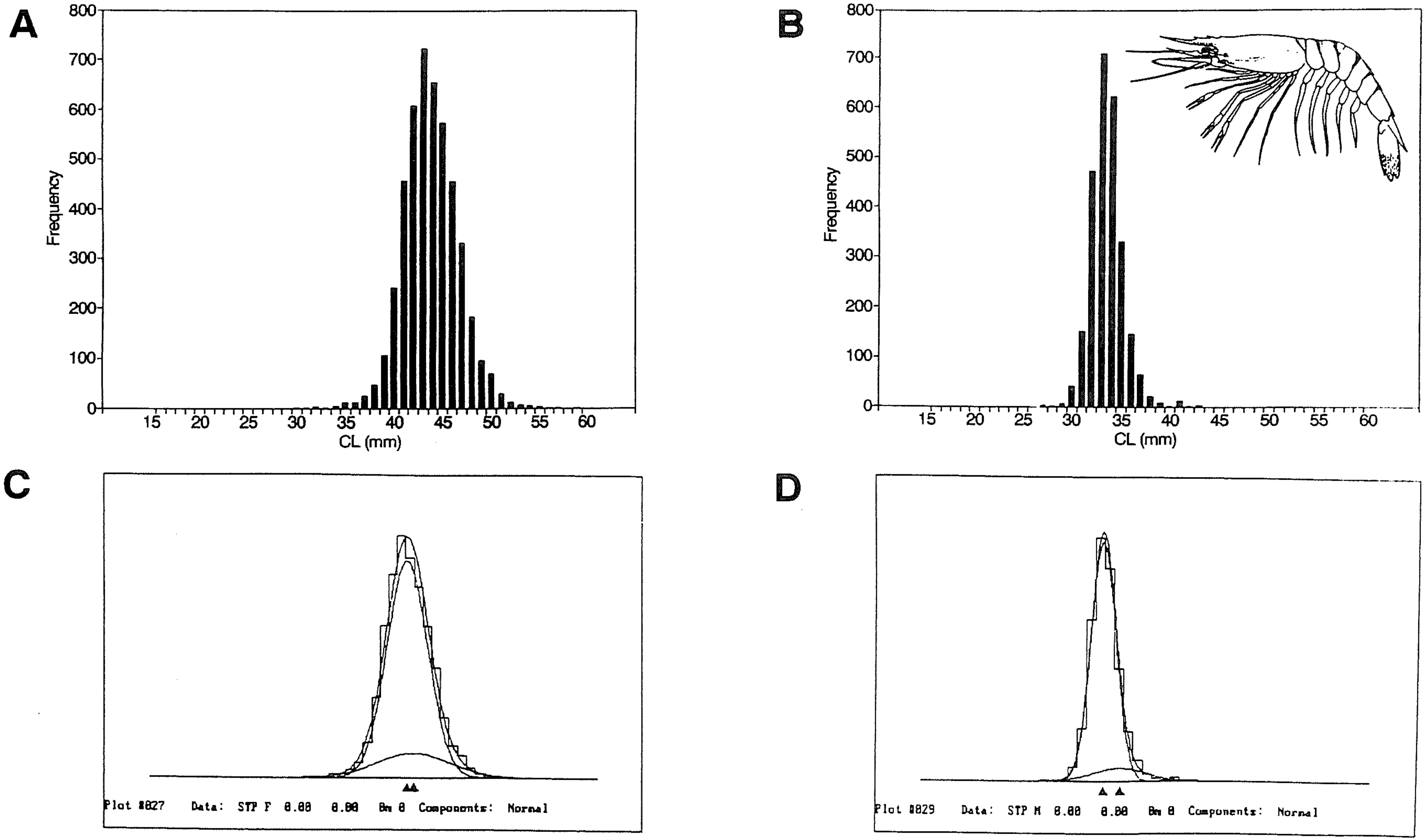


Fig. 4.4.3*A–D* *Aristeus virilis*: length-frequency from April 1990 for *A,* females; *B,* males; analysis of normal components showing means (triangles) for *C,* females; *D,* males.

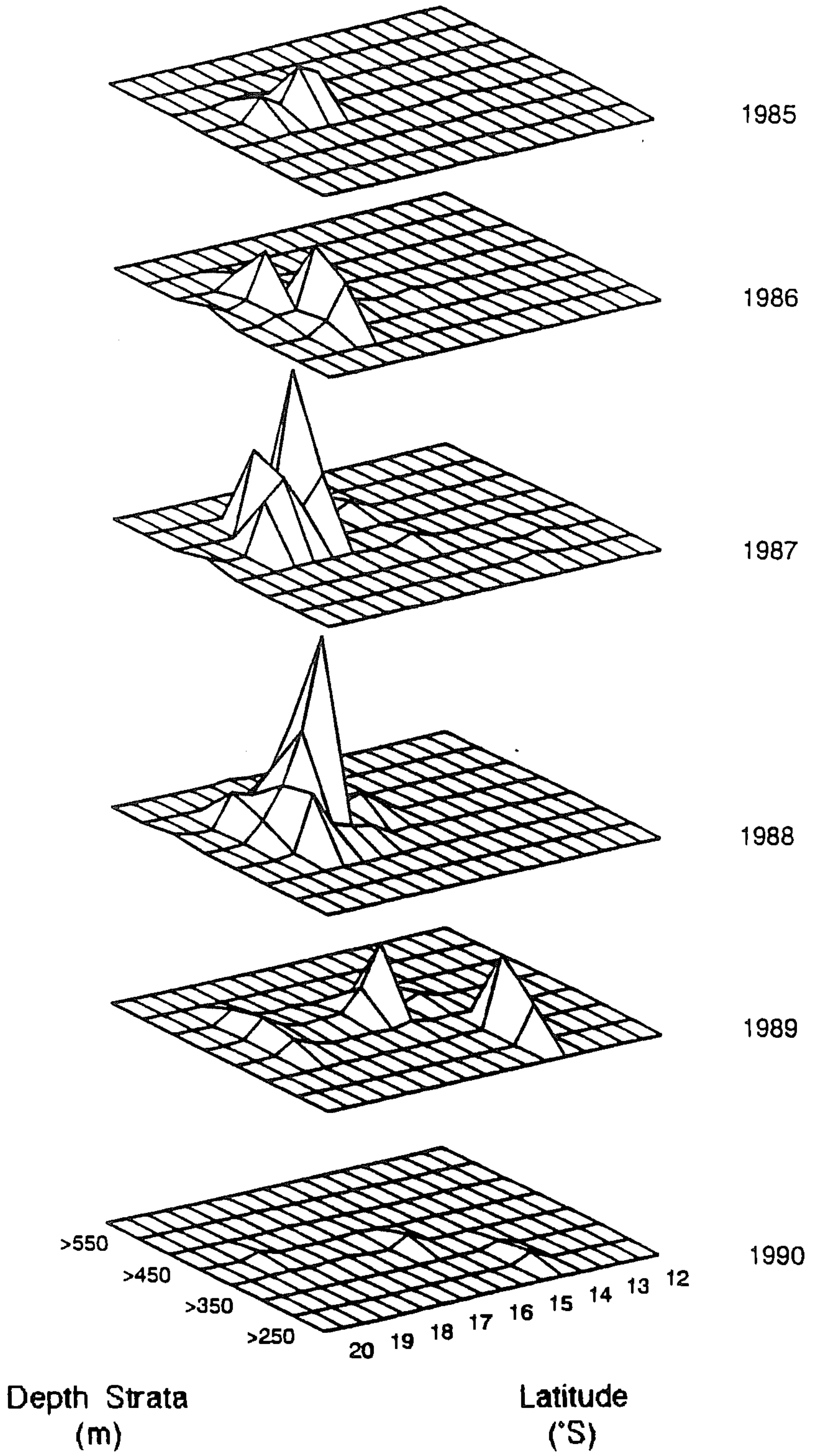


Fig. 4.4.4 The catch of *Heterocarpus woodmasoni* by depth and latitude in the North West Slope Trawl Fishery, by 50 m bathymetric contour, from 1985 to 1990 (catch unstandardised for effort but see Fig. 4.3.4); peak heights are relative to catch.

Female *H. woodmasoni* often have eggs attached to the pleopods. They have an unmodified endopod attached to the first pleopod and an appendix interna only on the second pleopod. Males have a modified, club-shaped endopod on the first pleopod and both an appendix interna and an appendix masculina on the second pleopod.

Reproductive development in females is marked by darkening of the ovary beneath the carapace. The development of eggs through three stages may be seen without magnification. Stage 1 eggs are small and dark brown / black. Stage 2 are larger and dark or light brown. Stage 3 are larger and light brown, greenish or clear. In stage 3, eye spots give a gritty appearance to the eggs.

The length was measured dorsally along the carapace, from the posterior margin of the orbit to the posterior margin of the carapace. The largest *Heterocarpus woodmasoni* were about 38 mm CL in both females and males (Fig. 4.4.5*A, B*) The smaller sizes may be under-represented due to escapement from the net. Analysis of the normal components should therefore be interpreted with caution, due to inadequate sampling of the population. There were two modes in both females (means 27·7 and 31·3 mm CL) and males (means 27·6 and 31·3 mm CL; Table 4.4.1, Fig. 4.4.5*C, D*), indicating that the lifespan may be two or more years. The practical difficulty in sorting this species into three grades is apparent from the bimodal distribution of length frequency.

White carid, *Heterocarpus sibogae*

The white carid, *Heterocarpus sibogae*, belongs to the family Pandalidae. It may be differentiated from the other species of the genus *Heterocarpus* in the NWSTF by its pale colour and equal-length of the spines on the third and fourth abdominal segments.

Fishermen do not distinguish the less abundant *H. hayashii* from *H. sibogae*. In *H. hayashii* the spine on the fourth abdominal segment is usually slightly shorter than the one on the third segment and a red spot may be seen on the posterior lateral carapace of fresh specimens. In fresh specimens of *H. sibogae*, a red spot may be visible laterally on the third abdominal segment.

H. sibogae is common throughout the NWSTF and into the WDWTF. It occurs in the eastern Atlantic, southern Africa, Indonesia, South China Sea, Philippines, Japan, Hawaii and the south-west Pacific.

Catches of *H. sibogae* have ranged from 19·6 tonnes (1990/91) to 60·8 tonnes (1986/87; Table 4.1.1). The species is often discarded; recorded catches are probably considerable underestimates of the size of the resource.

H. sibogae is very common on sand or mud bottom, mainly in depths of 320–520 m, although it has been recorded in 247–850 m in the NWSTF. White carids are caught day and night in demersal trawls, usually of 3–4 hours duration. The carids are not graded but packed whole into 12 kg cartons. They have particularly sweet flavour, are robust to handling and not particularly subject to

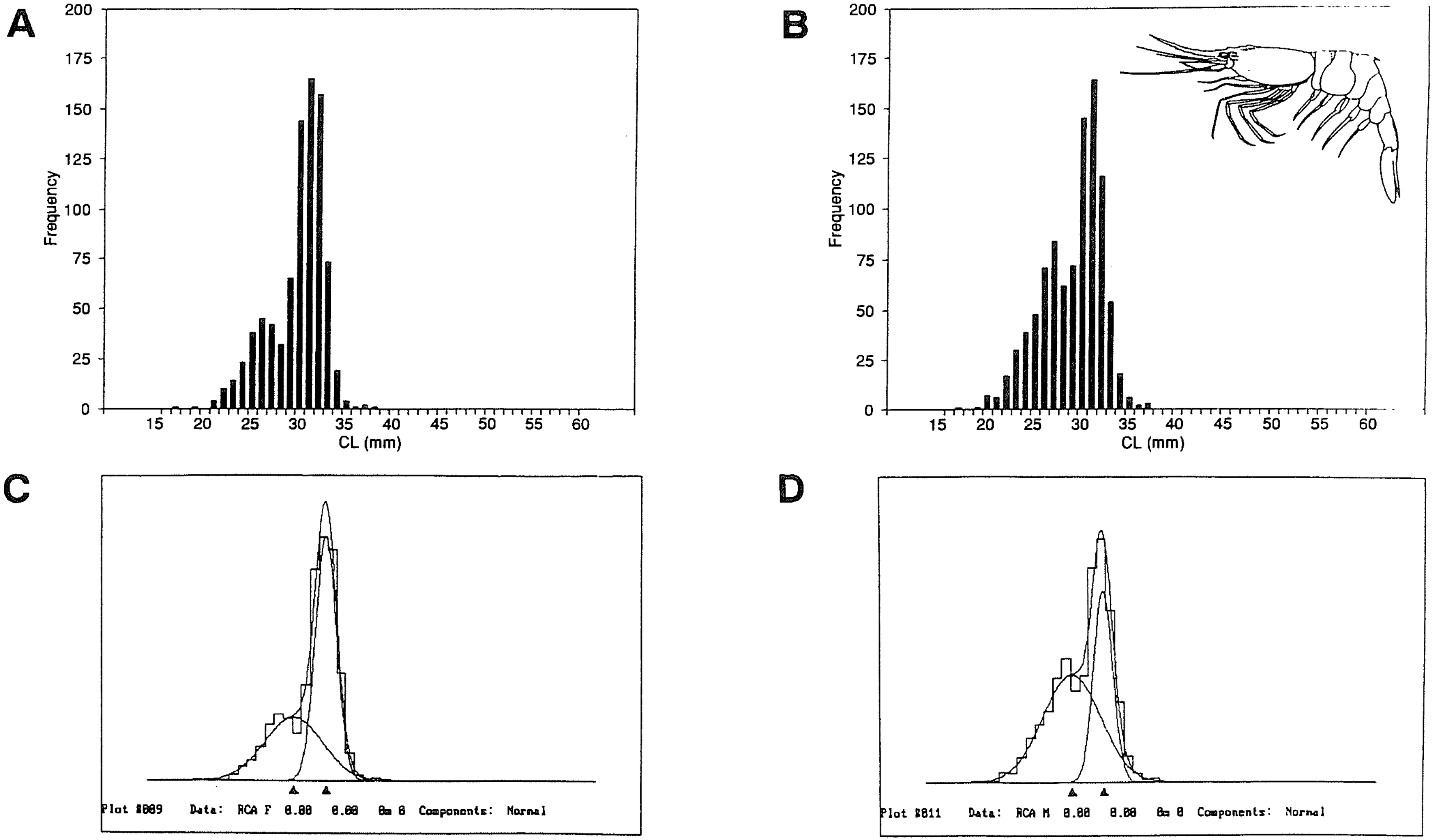


Fig. 4.4.5*A–D* *Heterocarpus woodmasoni*: length-frequency from June 1990 for *A*, females; *B*, males; analysis of normal components showing means (triangles) for *C*, females; *D*, males.

melanosis. However, low meat recovery, pale colour after cooking and very low price have brought little commercial interest to this species.Female *H. sibogae* often have eggs attached to the pleopods. They have an appendix interna only on the second pleopod and a gonopore on the coxa of the third pereiopod. Males have a pair of horn-shaped spikes ventrally between the first and second abdominal segments (in females, a small projection occurs in the same place). Males possess both an appendix interna and an appendix masculina on the second pleopod. The male gonopore is on the coxa of the fifth pereiopod.

Reproductive development in females was recognised by the blue ovary beneath the carapace. The development of eggs through 3 stages may be seen without magnification. Stage 1 eggs are small and blue. Stage 2 are larger and blue / green. Stage 3 are larger and light brown or clear. In stage 3, eye spots give a gritty appearance to the eggs.

The length was measured dorsally along the carapace, from the posterior margin of the orbit to the posterior margin of the carapace. The largest *H. sibogae* (Fig. 4.4.6*A*, *B*) were about 38 mm CL in both females and males, although females of 41 mm CL and males of 39 mm CL have been recorded in the NWSTF. As with other small crustaceans, the smaller sizes may be under-represented due to escapement from the net. Analysis of the normal components should again be interpreted with caution, due to inadequate sampling of the population. There were three modes in females (means 25·1, 30·3 and 34·2 mm CL) and two in males (means 24·9 and 32·7 mm CL; Table 4.4.1, Fig.4.4·6*C*, *D*), indicating that the lifespan may be at least three years.

Pink prawn, *Haliporoides sibogae*

The pink prawn, *Haliporoides sibogae*, is a penaeid of the family Solenoceridae; four other species (at least) of this family occur in the NWSTF but each belongs to a different genus. *H. sibogae* is fished commercially in Japan, New Zealand (as the jack-knife prawn, Webber *et al.* 1990) and New South Wales (as the royal red prawn, Baelde 1991, 1992). The taxonomic status of *H. sibogae* is unclear at present, but the eastern form was designated a subspecies, *H. sibogae australiensis*, by Kensley *et al.* (1987). *H. sibogae* was recognised by its pale pink colour, pubescent carapace, short, arched rostrum (same shape in both sexes), and three spines on the lateral carapace.

H. sibogae is caught over soft sand or mud, in depths of 100–1500 m (Grey *et al.* 1983). In the NWSTF, it is usually found in 350–600 m. It is distributed throughout the Indo-West Pacific, including Madagascar, Australia (north-west, north and east), New Zealand, Malay Archipelago, South China Sea and Japan.

Catches of *H. sibogae* have ranged from 19·6 tonnes (1990/91) to 60·8 tonnes (1986/87; Table 4.1.1). The species has always been a by-catch of other crustacean species on the NWSTF. The distribution in 1986/87 (Fig. 4.4.7) shows highest catch rates in HDS where effort (Fig. 4.3.4) was greatest, although lower catch rates ($< 8\ \mathrm{kg \cdot h^{-1}}$)

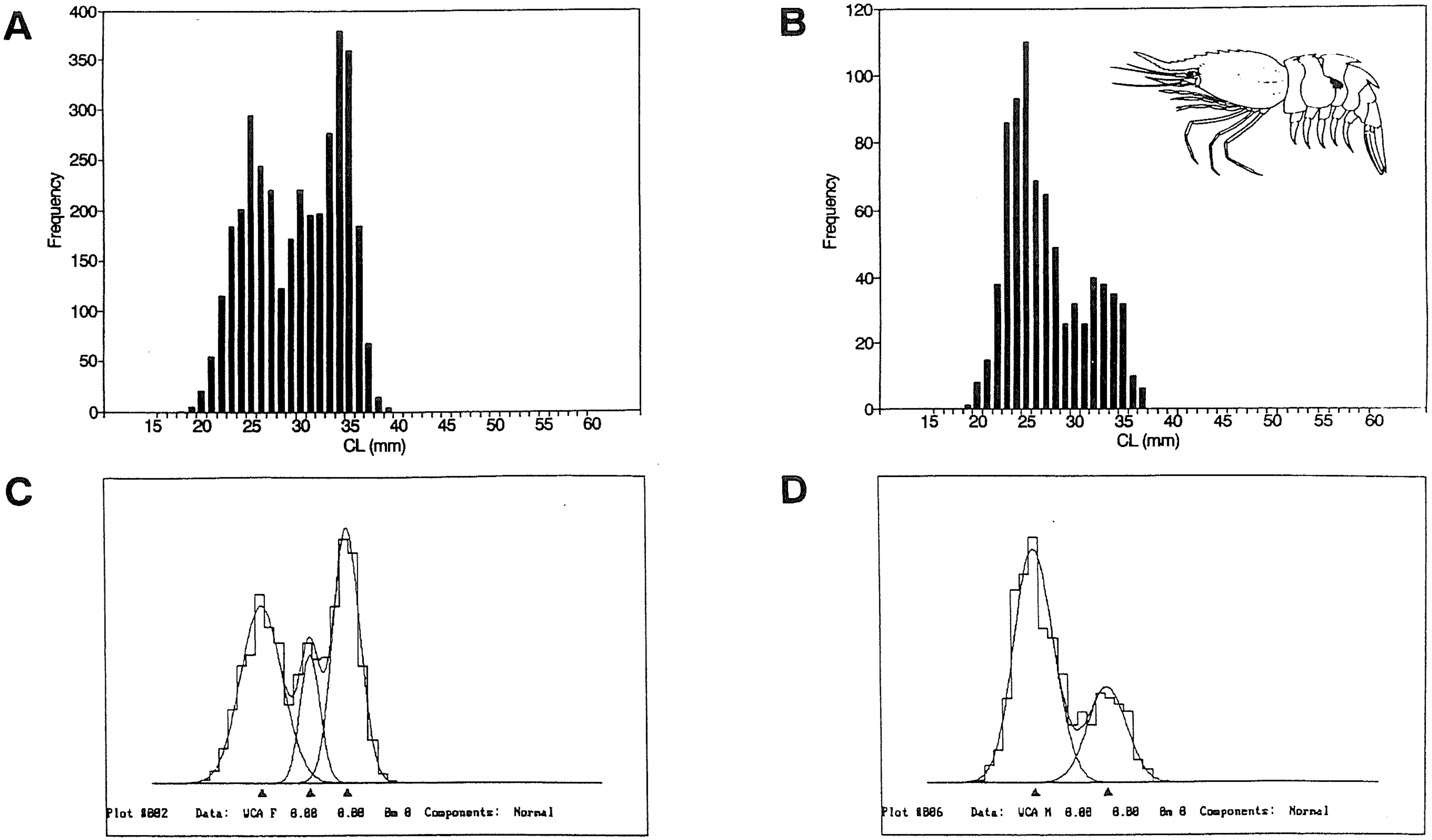


Fig. 4.4.6*A–D* *Heterocarpus sibogae*: length-frequency from June 1990 for *A,* females; *B,* males; analysis of normal components showing means (triangles) for *C,* females; *D,* males.

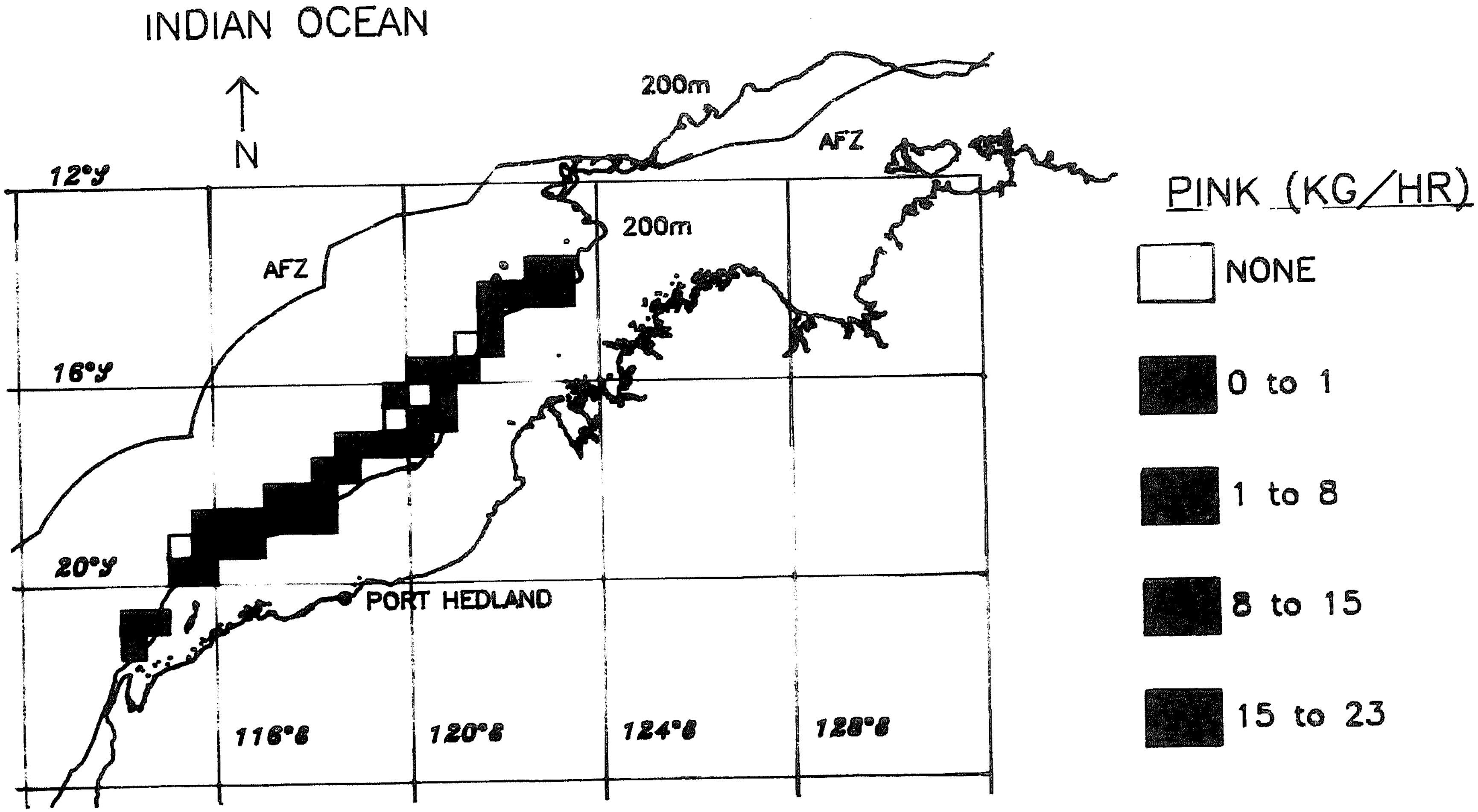


Fig. 4.4.7 The catch per unit effort (unstandardised, kg · h^{-1}) of *Haliporoides sibogae* in the NWSTF area, by half-degree square in 1986/87.

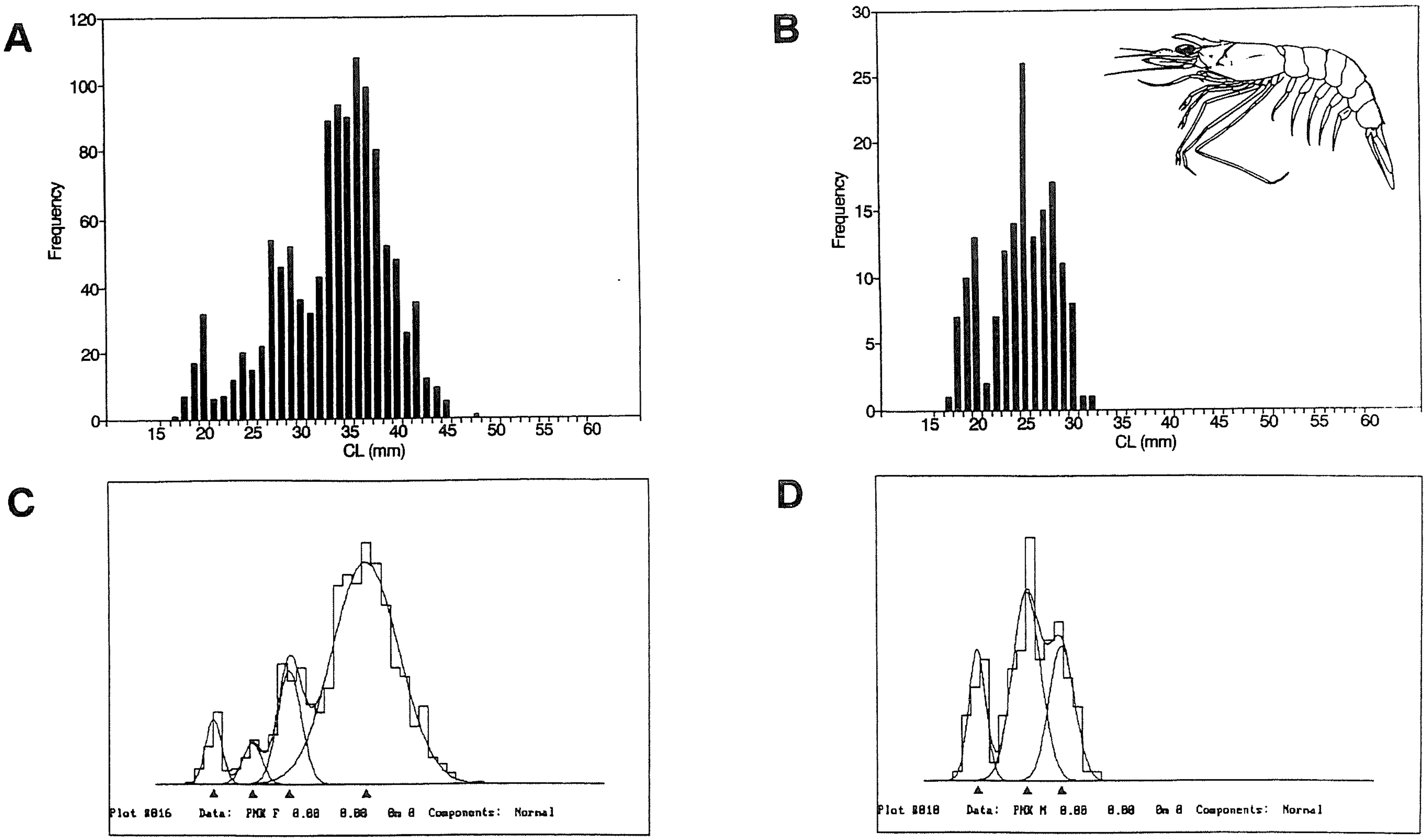


Fig. 4.4.8*A–D* *Haliporoides sibogae*: length-frequency from August 1990 for *A*, females; *B*, males; analysis of normal components showing means (triangles) for *C*, females; *D*, males.

were widespread. However, the practice of discarding this species means that recorded annual catch underestimates the true annual catch by a significant amount.

Pink prawns are caught by day and night, usually as by-catch of other species of crustaceans. The prawns are not graded but tailed, packed in 12 kg cartons and sold on the domestic market as prawn meat. They oxidise rapidly and dipping in chilled brine with antioxidant is essential to prevent discolouration.

Female *H. sibogae* may be quickly recognised in the field by the hard, white, moon-shaped plates on the posterior borders of the coxae of the third pereiopods. The thelycum is covered by a membrane; very rarely an amber-coloured spermatophore (may resemble a single or paired trail) is seen injected through the membrane. Females grow to a larger size than males. Males have a prominent petasma (which may be damaged or removed in processing) between the first pleopods, in addition to two rod-like projections on the coxae of the fifth pereiopods. The pale yellow sperm duct may be difficult to see against the white flesh but the swollen vas deferens in mature males is prominent.

The appearance of ovary beneath the carapace signals reproductive development in females. Three stages of reproductive development were recognised in the field. The dark blue ovary is a feature of mature females and may extend posteriorly from the carapace to the fifth abdominal segment.

The length was measured dorsally along the carapace, from the posterior margin of the orbit to the posterior margin of the carapace. The largest *H. sibogae* (Fig. 4.4.8*A, B*) were about 47 mm CL in females and 33 mm CL in males although males of 44 mm CL have been recorded in the NWSTF. As with the other small crustaceans, the smaller sizes are probably under-represented due to escapement from the net. Analysis of the normal components should again be interpreted with caution, due to inadequate sampling of the population. There were four modes in females (means 19·6, 23·8, 27·7 and 35·9 mm CL) and three in males (19·2, 24·5 and 28·3 mm CL; Table 4.4.1, Fig. 4.4·8*C, D*), indicating that the lifespan may be at least four years.

Scarlet prawn, *Plesiopenaeus edwardsianus*

The scarlet prawn, *Plesiopenaeus edwardsianus*, is a penaeid prawn of the family Aristeidae. Of the four species of Aristeidae found in the NWSTF, *P. edwardsianus* is by far the largest and would be commercially attractive if it could be found in larger quantities. It may be recognised by its smooth, shiny carapace and scarlet red colour. The rostrum has three teeth above, none below, and is longer in females than males.

Catches of *P. edwardsianus* ranged from 0·6 tonnes (1989/90) to 4·4 tonnes (1987/88; Table 4.1.1). Although never large, the size of the catch has been similar each year. The retained catch is probably a reliable estimate of relative abundance in this species.

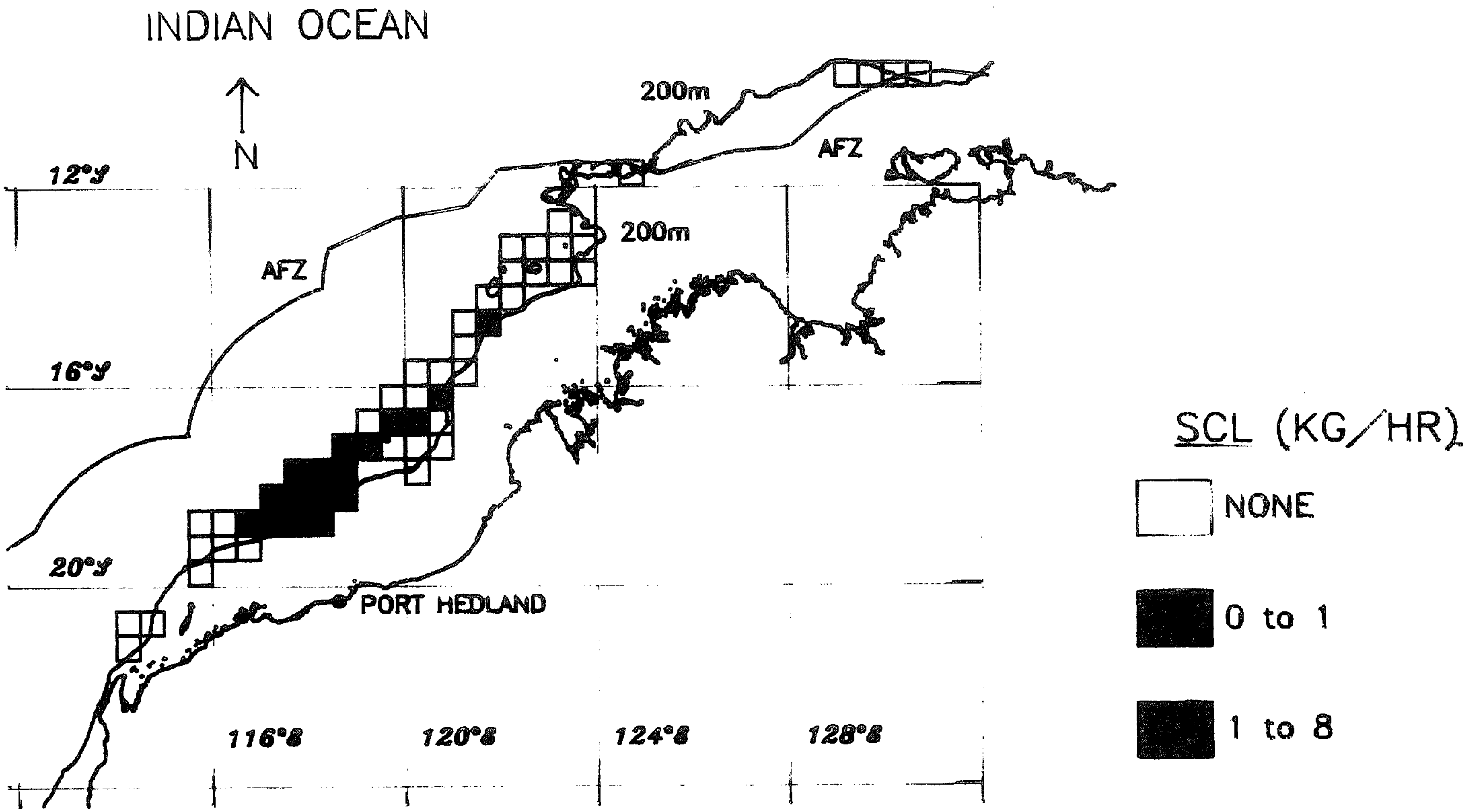


Fig. 4.4.9 The catch per unit effort (unstandardised, kg · h^{-1}) of *Plesiopenaeus edwardsianus* in the NWSTF area, by half-degree square in 1987/88.

P. edwardsianus is distributed from 15°30'S. to 20°S. in the NWSTF (1987/88; Fig. 4.4.9). Catch rates are low, usually < 8 kg · h^{-1}.

Scarlets are caught day and night in demersal trawls of about four hours duration. They are found over sand and mud bottom, mainly in 450–600 m depth. Worldwide, they have been recorded to 1800 m depth and further resources may be discovered when the deeper waters of the slope of NW Australia are explored. *P. edwardsianus* usually occurs as a small by-catch of trawling for other crustaceans in the NWSTF.

The prawns are graded into > 10 (very large) and 10/20 per pound and packed whole in 3 kg boxes.

Female *P. edwardsianus* have a deep, cup-shaped thelycum between the fifth pereiopods. The gonopore is on the coxa of the third pereiopod. Firmly lodged in the thelycum, the spermatophore is pale yellow and smaller than in other NWSTF species.

The developing ovary is difficult to see through the dark exoskeleton. The sperm duct is visible as a thin, pale yellow line along the posterior carapace to the fifth pereiopod.

The length was measured dorsally along the carapace, from the posterior margin of the orbit to the posterior margin of the carapace. *P. edwardsianus* has a wide range of length in both females and males (Fig. 4.4.10*A*, *B*). Small prawns (< 20/30) are rarely caught, suggesting spatial partitioning of juveniles, possibly in water deeper than that trawled to date. In females, there were five modes (means 43·8, 51·0, 60·4, 67·1 and 73·0 mm CL) and two in males (46·5 and 55·1 mm CL; Table 4.1.1, Fig. 4.4.10*C*, *D*), indicating that the lifespan may be at least five years.

Red-flecked prawn, *Penaeopsis eduardoi*

Three species of the family Penaeidae occurred in potentially commercial quantities in the WDWTF and NWSTF. In the genus *Penaeopsis*, *P. eduardoi* was a by-catch of other penaeids. The less abundant *P. rectacuta* was not differentiated by fishermen from *P. eduardoi*. *P. eduardoi* is characterised by pale pink colour with red flecks on the abdominal segments. The rostrum is long and straight, and an hepatic spine is present.

The red-flecked prawn is caught over sand or mud bottom. It occurs in depths of 250–570 m but mainly in 250–570 m in the NWSTF. It is distributed across north-western and northern Australia, Indonesia, the Bay of Bengal, Taiwan, Japan, Philippines, and Fiji.

Female *P. eduardoi* are occasionally found with a small, brown spermatophore firmly lodged in the thelycum. The spermatophore is particularly difficult to see at night in the coloured lights on the fishing boats. The developing ovary shows blue through the carpace and abdomen. The petasma is prominent on males but the sperm duct is obscure, and exuding spermatophores from the coxa of the fifth pereiopod may be used instead as an indication of sexual maturity.

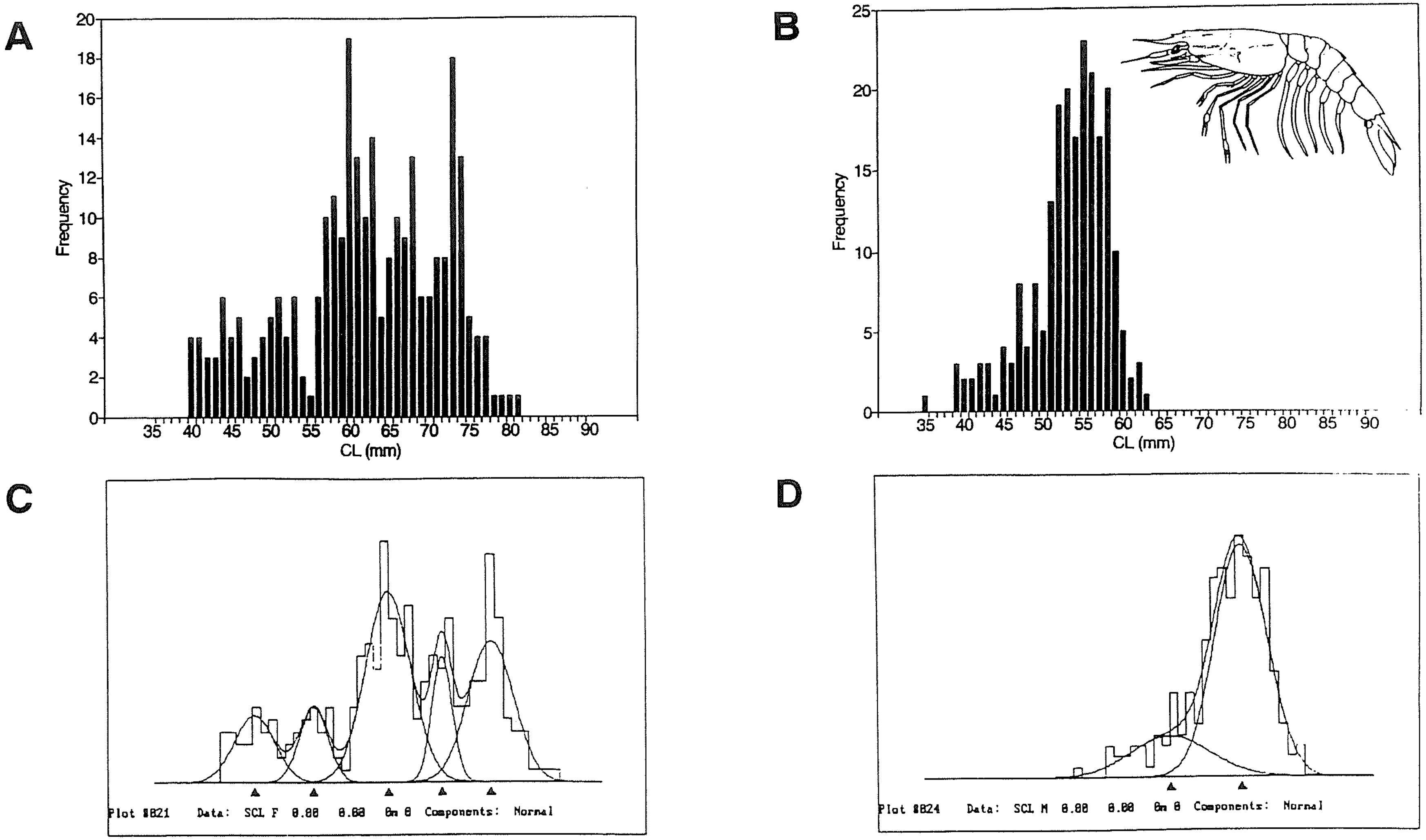


Fig. 4.4.10*A–D* *Plesiopenaeus edwardsianus*: length-frequency from April 1990 for *A*, females; *B*, males; analysis of normal components showing means (triangles) for *C*, females; *D*, males.

Penaeopsis are often caught but only occasionally retained. They are tailed and mixed with other prawns. Although they attracted some commercial interest in 1985/86, they are of little interest now compared with other more lucrative prawn species.

Bugs, *Ibacus* and *Thenus* species

Three species of *Ibacus* and one of *Thenus*, all from the family Scyllaridae, were found in the WDWTF and NWSTF; of these, only *Ibacus alticrenatus* was found in commercial quantities.

I. alticrenatus occurred in the WDWTF and to a lesser extent in the NWSTF. Its distribution continues around the southern and eastern slope to Queensland and also New Zealand. It may be recognised by its white tail fan and 7–9 teeth at the lateral margin of the carapace, lying posterior to the deep slot. The congeneric *I. ciliatus pubescens*, caught in northern waters, may be recognised by 11–14 lateral teeth.

Female bugs have gonopores on the coxae of the third pereiopods, males on the fifth pair. Females have no hair on the antennular plates, males usually have sparse hair. Length was measured dorsally along the midline of the carapace, from the posterior margin of the orbit to the posterior margin of the carapace. Sometimes bugs are measured from the anterior margin of the carapace to the posterior margin, a slightly greater distance than our measure. Female *I alticrenatus* grow larger (to 53 mm CL) than males (to 46 mm CL). Female *I. ciliatus pubescens* grow to 71 mm CL, males to 68 mm CL. The length frequency of *I. alticrenatus* has a wide range in both females and males. The large size of bugs relative to the net size (scampi gear of 90 mm mesh) should provide reliable sampling of the adults in the population, although the juveniles were not well represented. Small specimens of 16–30 mm CL were occasionally caught and could be sexed without a microscope. In both sexes, there were four modes, indicating that the lifespan may be at least four years.

Catches of bugs in the WDWTF have ranged from 0·8 tonnes (1988/89) to 7·0 tonnes (1987/88). *I. alticrenatus* would account for the whole catch in the WDWTF, based on reports by shipboard observers. Catches in the NWSTF ranged from 9 kg (1985/86) to 429 kg (1987/88). *I. alticrenatus* may account for some of the north-western catch but *I. ciliatus pubescens* is the most common species in the NWSTF. Actual catches of bugs may be greater than reported, due to discarding practices. When bugs are the target, catches at commercial rates are possible. Working the same ground repeatedly over several days may increase the catch rate of bugs and change the size-structure of the catch. Results of depletion experiments should therefore be interpreted with caution.

The bugs are tailed and frozen at sea. The tails are sold on the domestic market in 12 kg cartons. Bugs are often alive after capture, so tagging experiments, aquarium determination of growth rates and live marketing may be feasible.

Crabs, *Chaceon bicolor* and *Hypothalassia armata*

Crabs are caught occasionally by the trawlers and deserve mention for their potentially high market price, based on fisheries in other parts of the world.

Chaceon bicolor (family Geryonidae) is found over sand and mud bottom from 275 m to the lower slope. World distribution for this species includes the central Pacific (where it is fished commercially) to eastern Australia. The genus *Geryon* has recently been renamed *Chaceon* (Manning and Holthuis 1989). *C. bicolor* has been recorded to depths of 1600 m and may occur in the deeper, unsearched areas of the slope of western and north-western Australia. Elsewhere, it is fished in traps; the untargeted catches to date from trawls and lobster pots are an indication of a potential resource. *C. bicolor* may be recognised by the pale cream colour with darker patches on the dorsal carapace. Supply of product is intermittent but it has been well received on the domestic market in Darwin under the common name 'snow crab'.

Hypothalassia armata, from the family Xanthidae, is found over rock and mud bottom, generally from rock lobster pots rather than trawls. Depth of occurrence ranges between 30 and 540 m. Its distribution includes western, southern and eastern Australia, through the south Pacific to Japan and Guam. The smooth carapace and dark spines on the anterior carapace, legs and claws characterise the species. The claws, full of rich meat, are unequal in size and black-tipped. Female specimens have been absent from catches to date.

The size of crabs was measured as the distance between the widest portion of the carapace, including any spines. The data were recorded in scientific observer cruise reports but were insufficient for analysis.

Discussion and conclusions

The commercially-exploited crustaceans of the WDWTF and NWSTF have a wide range of size and lifespan. Targeting among at least forty species of crustaceans is a feature of the NWSTF. This diversity should be addressed in the management strategy for the resource. The fishery has changed from scampi to prawns to the current mixture of scampi and prawns; it may change again as resource exploration proceeds on the continental slope.

The price of crustaceans on the domestic and international markets, availability of product and exploratory fishing have contributed to the dynamics of targeting. On one level, the fishery is a scampi fishery with a prawn by-catch; on another level, it is a smorgasbord of products from which commercial operators develop a cost-effective 'portfolio'.

Directions for future research

An understanding of the stock-recruitment relationship is basic for management of the fisheries. Sampling to date from commercial vessels has not taken the smaller size-classes of many of the exploited species. Designed sampling with smaller-mesh nets is required to estimate the number and proportion of the smaller sizes of the populations for stock assessment.

In order to interpret the catch of crustaceans in the NWSTF (and to a lesser extent the WDWTF), effort expended over many species must be standardised based on targeting rules. The trends in CPUE may then be examined in relation to exploitation by the fishery. This analysis is an essential part of any stock assessment for the NWSTF.

Depletion experiments, trawling the same ground repeatedly to estimate the absolute abundance, are a standard method of stock assessment. Practical experience of fishing on the NWSTF indicated that catch rates may increase markedly over a period of some days' trawling on the same ground, before a typical depletion pattern is observed. Duration of depletion experiments may therefore be critical to a meaningful assessment of the stock. Depletion studies should be designed on the basis of pilot experiments for many of the deepwater crustaceans.

Trapping and midwater trawling are used in the harvest of deepwater crustaceans in other parts of the world. These methods have the advantage of causing little environmental disturbance, relative to trawling, and may be targeted effectively at one species. Exploratory fishing with these methods may be environmentally and even economically worthwhile, once the resource distribution and abundance is known.

The deepwater crustaceans have traditionally been regarded as poor subjects for experiments due to their moribund condition on capture. Recent success with retaining live scampi with eggs (including transport from Port Hedland to Perth) indicates that this should be reviewed. Some of the more robust crustaceans (scampi, *Heterocarpus sibogae*, the fish-louse *Bathynomus*, bugs and crabs) could be maintained for experimental work. The aspect of live marketing of the crustaceans may provide the applied impetus for this research.

References

Baelde, P. (1991). Assessment of the Australian deep-water royal red prawn stock using commercial catch and effort data. *Fisheries Research* **12**, 243–258.

———. (1992). Reproductive biology of commercially exploited deep-water royal red prawns (*Haliporoides sibogae*, Solenoceridae) in south-east Australia. *Marine Biology* **113**, 447–456.

Grey, D. L., Dall, W. and Baker, A. (1983). A Guide to the Australian Penaeid Prawns. Northern Territory Government Printing Office, Darwin. 140 pp.

Kensley, B., Tranter, H. A. and Griffin, D. J. G. (1987). Deepwater Decapoda Crustacea from Eastern Australia (Penaeidea and Caridea). *Records of the Australian Museum* **39**, 263–331.

Macpherson, E. (1990). Crustacea Decapoda: On a collection of Nephropidae from the Indian Ocean and Western Pacific. *In:* A. Crosnier (ed.) Résultats des campagnes MUSORSTOM **6**, *Memoirs du Muséum national de l'Histoire naturelle (A)* **145**, 289–328.

Manning, R. B. and Holthuis, L. B. (1989). Two new genera and nine new species of geryonid crabs (Crustacea, Decapoda, Geryonidae). *Proceedings of the Biological Society of Washington* **102**, 50–77.

Wadley, V. A. and Evans, D. (1991). Crustaceans from the West and North West Slope Deepwater Trawl Fisheries. CSIRO Australia. iv+44 pp.

Webber, W. M., Fenaughty, C. M. and Clark, M. R. (1990). A guide to some common offshore shrimp and prawn species of New Zealand. *New Zealand Fisheries Occasional Publications* **6**, 1–42.

4.5 The Diet of North West Slope Prawns

Dr S. F. Rainer

Background

Prawns are generally carnivorous, feeding on a wide range of animals. Since midwater and bottom habitats each have their characteristic species, the diet of deepwater prawns can indicate which habitats they feed in. Many midwater crustaceans migrate towards surface waters at night but it is not known whether crustaceans such as the NWS prawns, which are trawled by demersal gear, also migrate upwards at night. The present work suggests that some prawns not only migrate into midwater at night, but also feed there.

Four species of penaeid prawns and two species of carid prawns make up most of the prawn catch in the NWSTF. The main penaeids are the giant red prawn (*Aristaeomorpha foliacea*), the pink striped prawn (*Aristeus virilis*), and the carabinero prawn (*Plesiopenaeus edwardsianus*), all species in the family Aristeidae, and the pink or royal red prawn (*Haliporoides sibogae*), a species of the family Solenoceridae. The main carid species are the white carid (*Heterocarpus sibogae*) and the red carid (*H. woodmasoni*). Most of these species are widely distributed in the Indo-Pacific while giant reds and carabineros are also fished in the Atlantic Ocean and the Mediterranean Sea. Until now, there have been no studies on the diets of Australian deepwater prawns.

Methods

Stomach contents were examined from prawns taken in commercial trawls off the NWS, in depths of 315–485 m. Trawling gear was either a three-net trawl with two skids and twin otter boards or a twin-rig boom-trawl. Trawls had 5- or 5·6 cm mesh in the body and wings, with 4·2- or 5 cm mesh cod ends. The trawls were towed at 2–3 knots, with bottom times usually of three hours during the day and around five hours at night.

A sample of around 50 prawns was taken for each species (Table 4.5.1). Back in the laboratory, the prawns were measured and their sex and maturity were determined. The quantity and type of food in their stomachs were then identified, using a microscope, to the main prey groups. These included foraminiferans (a group of single-celled benthic and planktonic animals), sponges, coelenterates (stingers), molluscs (bivalves, snails, squid and octopus), bristleworms, crustaceans, echinoderms (starfish and urchins), and fish.

Within these groups, it was useful to consider several in more detail. Much of the coelenterate material contained batteries of nematocysts (stinging cells). The types of nematocysts found and their arrangement indicate that they came from siphonophores, a group of colonial midwater and surface-living jellyfish that includes the Portuguese Man-of-War. Sea-snail remains were mostly thick-shelled, indicating that they came from bottom-living species, or thin-walled, often with

Table 4.5.1 Mean size, gut weight and percentage fullness of prawns sampled from the North West Slope. Values are means ± 1 standard error; *n* — number of prawns sampled.

Species	Carapace Length (mm)	Body Weight (g)	Stomach Weight (g)	Stomach Fullness (%)	*n*
Penaeids					
Aristaeomorpha foliacea	30·8 ± 3·9	9·2 ± 3·1	0·33 ± 1·03	23·5 ± 22·1	94
Aristeus virilis	32·1 ± 5·6	16·8 ± 8·4	0·24 ± 0·13	50·3 ± 31·0	110
Haliporoides sibogae	28·3 ± 2·0	12·5 ± 1·9	0·24 ± 0·08	64·1 ± 27·6	49
Plesiopenaeus edwardsianus	59·5 ± 10·7	57·9 ± 24·6	3·06 ± 7·85	32·2 ± 27·7	43
Carids					
Heterocarpus sibogae	33·0 ± 3·7	16·1 ± 4·6	0·35 ± 0·34	30·4 ± 35·3	185
Heterocarpus woodmasoni	29·5 ± 2·1	12·1 ± 2·8	0·15 ± 0·07	12·5 ± 21·3	168

large numbers of shell fragments from heteropods and pteropods, midwater snails that include sea butterflies. The setae of bristleworms came only from bottom-living forms, as did the sea urchin fragments found. Arrow worms, which were found in small numbers, are fast-mo‵ ing small animals known only from midwater.

Catch rates were calculated from log book returns. NWSTF trawlers change location or depth according to the species being targeted. Catch rates therefore provide a sensitive indicator of the availability of different prawn species at different times of the day and night. Hourly catch rates were therefore calculated for catches taken with prawn nets (i.e., 5 or 5·6 cm mesh), from log book returns for four years (April 1985 — March 1989).

Composition of the diet

Crustaceans usually made up the bulk of the stomach contents. However, foraminiferans, coelenterates, sea-snails, bristleworms, echinoderms and fish were also important in one or more species.

Giant reds (Fig. 4.5.1*A*) contained a wide range of both benthic and midwater prey, including foraminiferans, coelenterates, cephalopods, crustaceans and fish. Cephalopod (mainly squid) remains were found in 16 per cent of the giant reds, and comprised 4·7 per cent of their food by volume. The coelenterate material appeared to be all from siphonophores. Small amounts of clearly benthic prey (small bivalves, bristleworms and echinoderms) were also found. Taken together, this suggests that giant reds feed both in midwater and on the sea bottom.

Pink stripes contained a similar range of prey to giant reds, but with fewer coelenterates and squid, and more bivalves, sea snails, bristleworms and echinoderms (Fig. 4.5.2*A*). Pink stripes from a night sample contained more foraminiferans, bristleworms and small sea-snails, while a daytime sample contained more crustaceans, fish and

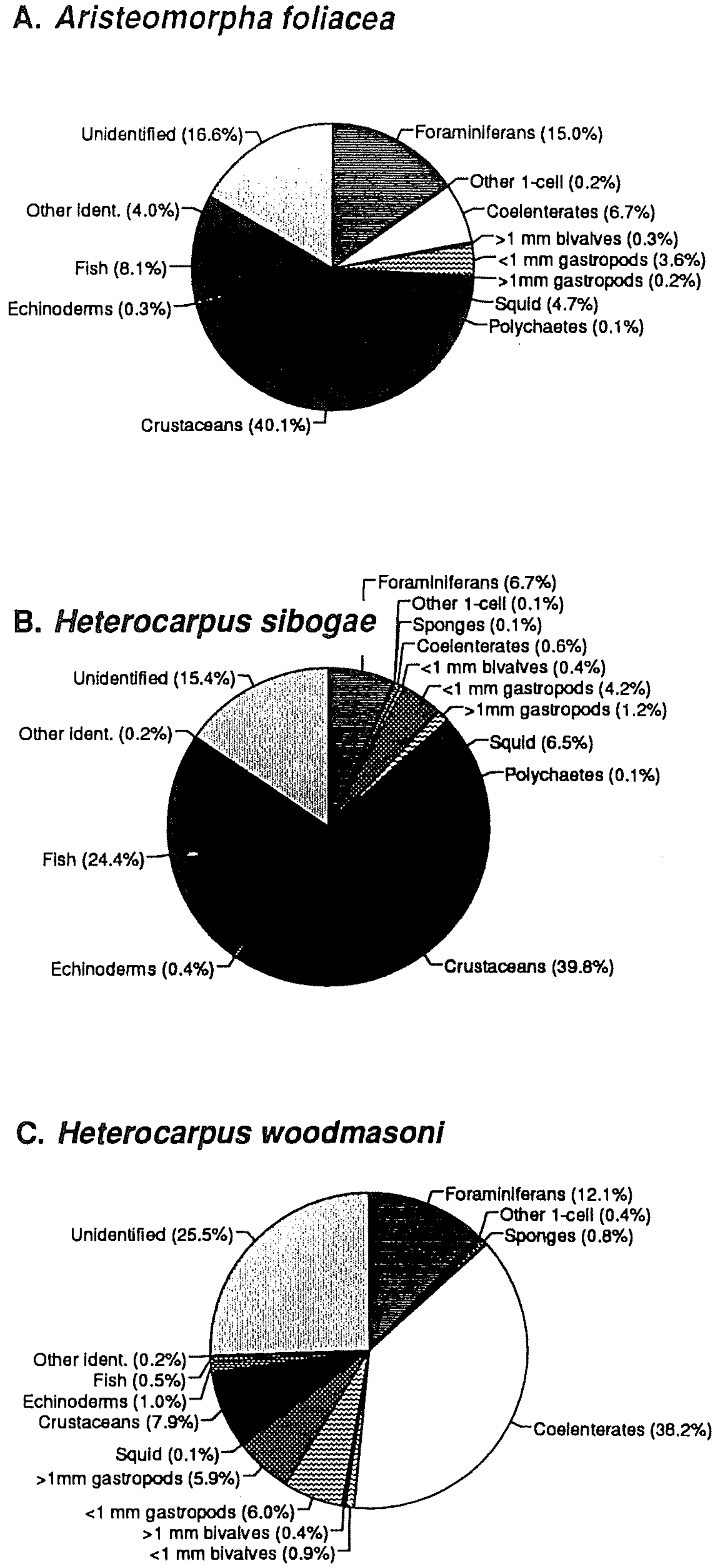


Fig. 4.5.1*A–C* Relative abundance of major prey types in midwater-feeding prawns: *A*, *Aristaeomorpha foliacea*; *B*, *Heterocarpus sibogae*; *C*, *Heterocarpus woodmasoni*.

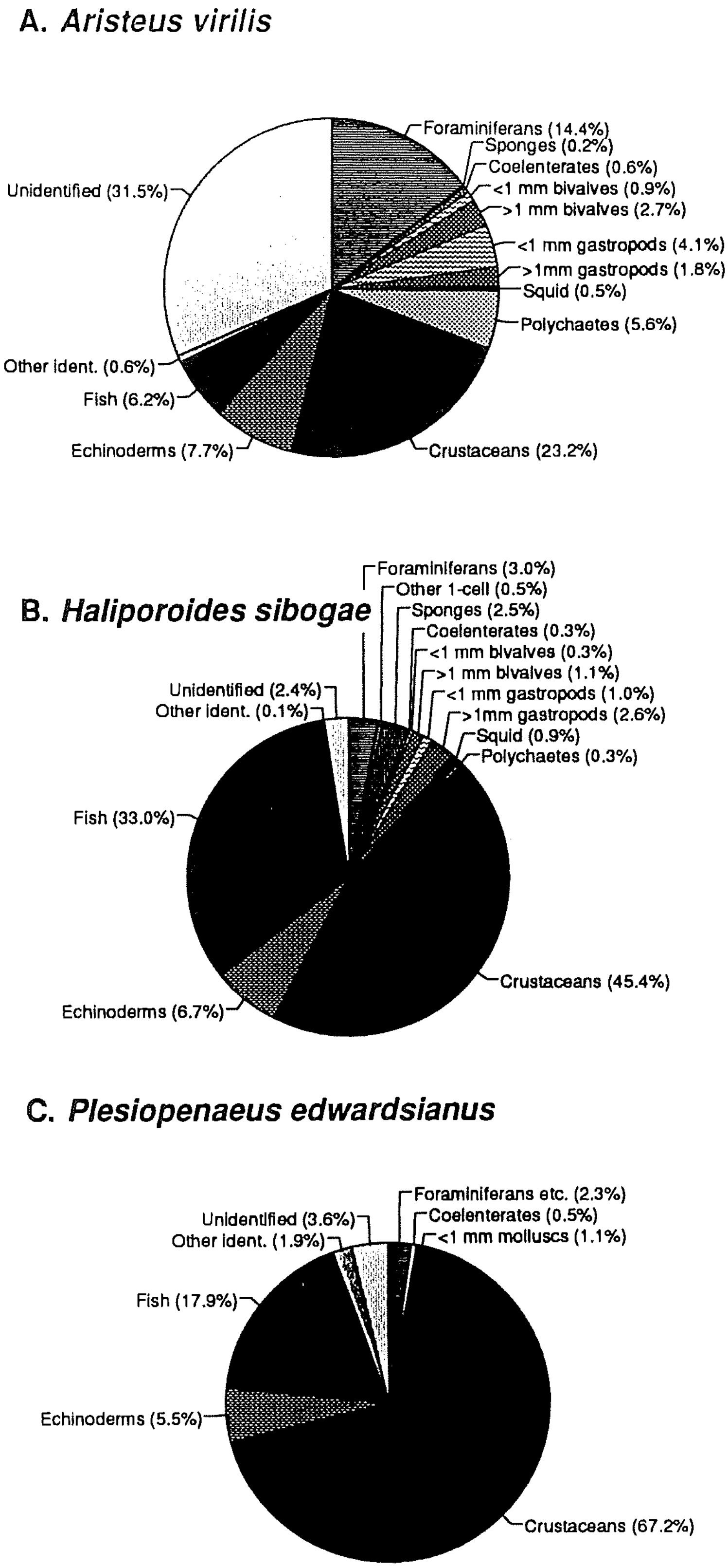


Fig. 4.5.2*A–C* Relative abundance of major prey categories in demersally feeding prawns: *A*, *Aristeus virilis*; *B*, *Haliporoides sibogae*; *C*, *Plesiopenaeus edwardsianus*.

echinoderms. All the bristleworms were bottom-living forms; crustaceans included cumaceans, ostracods, amphipods, isopods, prawns and crabs; echinoderms included parts of sea urchins, brittle stars and sea cucumbers. These prey indicate that pink stripes feed during the day and at night, searching actively for a wide range of bottom-living animals, including many burrowing species.

Pinks (Fig. 4.5.2*B*) contained mostly crustaceans, echinoderms and fish remnants. The crustaceans were mainly decapods and the echinoderms were sea urchins and sea cucumbers. These prey indicate that pinks feed almost entirely on the bottom.

Carabineros (Fig. 4.5.2*C*) contained mainly crustaceans and fish, usually as large, easily identifiable pieces. The crustaceans included isopods, amphipods and decapods (mostly prawns and crabs). Most of the prey were benthic, indicating that carabineros feed mainly on bottom-living prey, particularly crustaceans and fish.

White carids (Fig. 4.5.1*B*) contained mainly crustaceans, fish, foraminiferans and molluscs (both squid and small sea-snails). The crustaceans eaten were mainly prawns; the sea-snails included many examples of ocean-dwelling sea butterflies. White carids collected during the day had more crustaceans and fishes, while white carids collected at night had more foraminiferans, coelenterates, small bivalves and midwater sea-snails. The volume of food in the stomachs was similar in both the day and the night samples. White carids are therefore apparently able to feed actively on midwater prey at night and on benthic prey during the day.

Red carids (Fig. 4.5.1*C*) contained mainly siphonophores, foraminiferans, sea-snails and crustaceans. The crustaceans were mainly decapods, while the sea-snails were mainly sea butterflies. The only traces of benthic animals were from sponges and echinoderms. Red carids collected early in the day had more food in their stomachs than those taken in the early evening, and particularly more siphonophore material. Red carids taken later in the day had small quantities of foraminiferans, sea-snails and echinoderms, which were absent or present only in very small quantities earlier in the day. Fish remains in the early samples often included flesh, while later samples had only bones or scales. Red carids therefore probably feed almost entirely in midwater, probably at night, but they can supplement their diet with larger surface-living benthic animals during the day.

Catch rates

The catch rates of 11 833 trawls in the NWSTF were analysed. (Table 4.5.2). Average catches during the day (0600–1759 h) were greater than those at night (1800–0559 h), with daytime catches being between 16·5 times greater than night catches for giant red prawns and 1·4 times greater for pink prawns. The trawl times averaged 3·9 hours on the bottom at night, 3·0 hours during the day.

Table 4.5.2. Mean catch rates of six species of prawn caught in the North West Slope fishery during daytime (0800–1759 h) and night time (1800–0559 h), in kg · h^{-1}, ± 1 standard error.

Species	Day	Night
Penaeids		
Aristaeomorpha foliacea	30·6 ± 0·6	1·9 ± 0·1
Aristeus virilis	4·1 ± 0·1	2·0 ± 0·1
Haliporoides sibogae	4·8 ± 0·1	3·4 ± 0·1
Plesiopenaeus edwardsianus	0·24 ± 0·01	0·16 ± 0·01
Carids		
Heterocarpus sibogae	6·8 ± 0·1	2·7 ± 0·1
Heterocarpus woodmasoni	8·6 ± 0·3	2·1 ± 0·2

Interpretation of prey data

Using the stomach contents of prawns as a guide to their feeding behaviour is complicated by several factors. A important possibility to be considered is that the prawns may have been feeding on discarded by-catch from previous trawls, as is known for shallow-water crabs and the deepwater lobster, *Linuparus trigonus*, (e.g., Wassenberg and Hill 1989). However, most of the squid, crustacean and fish found were too small to be taken in prawn trawl nets, so that feeding on discards is unlikely to be a major source of food for the deepwater prawns of the NWS.

Vertical migration or burrowing?

Lower demersal catches would result if the prawns migrate into midwater at night. They could also result if the prawns burrowed into the sediment. Ward and Davis (1987) found lower night-time catches of white and red carids on the NWS, but could not determine the cause. King (1984) suggested that pink prawns make diel vertical migrations in Fijian waters, while Graham and Gorman (1985) thought that royal red prawns (= pink prawns) off New South Wales may bury at night.

Many species of midwater decapods migrate daily into near-surface waters (e.g., Roe 1984). Giant reds and the red prawn *Aristeus antennatus* may swim several hundred metres up from the bottom at night (Maurin 1962). The NWS prawns that ate midwater prey such as siphonophores, arrow worms and sea butterflies were giant reds, white carids and red carids. These three species have the greatest diel change in catch rates, strongly suggesting that these species migrate off the bottom at night, to feed in midwater.

Small amounts of midwater prey were found in pink stripes, pinks and carabineros. This could have come from feeding on midwater animals that have come down to the sea floor. However, the slightly lower catchability of these three species at night suggests rather that they may also make at least short-term trips above the sea floor

Other deepwater fisheries / species

The food and behaviour of several of the deepwater prawns from the NWS differ from what has been found in other areas. In the Bay of Biscay and off Morocco, giant reds apparently feed mainly during the day, eating benthic and pelagic crustaceans — the latter being midwater species that may have descended to the sea floor during the day (e.g., Lagardère 1977). On the NWS, giant reds probably feed mainly during both day and night.

Off south-western India, red carids feed mainly on pandalid prawns and foraminiferans, indicating that they feed on the sea floor (Suseelan 1974). On the NWS, red carids apparently feed mainly on midwater prey.

Two prey groups (siphonophores and squid) were unexpectedly abundant in the diet of the NWS prawns. Siphonophores may occur in large numbers in midwater (Barham 1963), and coelenterates have been found as a common food item in midwater crustaceans in both the northern Pacific and the north-eastern Atlantic (e.g., Roe 1984). Feeding on midwater coelenterates, and on siphonophores in particular, by the demersal decapods off Western Australia may be a more common mode of feeding than is usually understood.

Squid were mainly eaten by white carids (up to 15·2 per cent of the stomach contents by volume) and by giant reds (4·7 per cent of the stomach contents). Squid remains have also been found in scampi from the NWS (Wassenberg and Hill 1989). The main squid eaten by the prawns, *Abralia andamanica*, is a small species. Judging by the frequent occurrence of remnants of sexually modified arms, sperm capsules and egg capsules in the stomach contents, many of the squid were sexually mature. Squid often reproduce by mass spawning, followed by the death of the spawners (e.g., Roper *et al.* 1984). While crustaceans are more usually food for squid, these post-spawning squid would be easy targets for deepwater prawns to reverse this part of the food chain!

Implications of midwater populations of deepwater prawns

If the dominant demersal prawn species also occur in midwater, both the operation of the fishery and its management could be affected. The midwater prawns may themselves be commercially exploitable. Further, until we know the proportion of the populations that are in midwater at any time, we cannot estimate population sizes accurately. Both considerations suggest that midwater studies on the biology and fishery dynamics of these prawns may be necessary.

References

Barham, E. G. (1963). The deep scattering layer as observed from the bathyscaphe *Trieste*. *Proceedings of the 16th International Congress on Zoology* 1963,: 298–300.

Gooding, R. M., Polovina, J. J. and Dailey, M. D. (1988). Observations of deepwater shrimp, *Heterocarpus ensifer*, from a submersible off the island of Hawaii. *Marine Fisheries Review* **50**(1), 32–39.

Graham, K. J. and Gorman, T. B. (1985). New South Wales deepwater prawn fishery research and development. pp. 231–243 *in* P. C. Rothlisberg, B. J. Hill and D. J. Staples, eds. Second Australian national prawn seminar. NPS2, Cleveland, Australia.

King, M. G. (1984). The species and depth distribution of deepwater caridean shrimps (Decapoda, Caridea) near some southwest Pacific Islands. *Crustaceana* **47**, 174–191.

———. (1988). Topic Review: Deep-water shrimps. South Pacific Commission Workshop on Pacific Inshore Fishery Resources (Noumea, New Caledonia, 14–25 March 1988). *SPC/Inshore Fisheries Research./WP·13*, 25 pp.

Lagardère, J. P. (1977). Recherches sur le régime alimentaire et le comportement prédateur des decapodes benthiques de la pente continentale de l'Atlantique nord oriental (Golfe de Gascogne et Maroc). pp. 397–408 *in* B.F. Keegan, P. O'Ceidigh and P.J.S. Boaden, eds. Biology of benthic organisms. Pergamon Press, New York.

Maurin, C. (1962). Les crevettes profondes du littoral français de la Méditerranée. Répartition selon la profondeur. Notes biométriques. *Rapports et Procès-verbaux de la Réunion de la Commission internationale de la Mer Méditerranée* **15**(2), 147–154.

Roe, H. S. J. (1984). The diel migrations and distributions within a mesopelagic community in the north east Atlantic. 2. Vertical migrations and feeding of mysids and decapod Crustacea. *Progress in Oceanography* **13**, 269–318.

Roper, C. F. E., Sweeney, M. J. and Nauen, C. E. (1984). FAO species catalogue. Vol. 3. Cephalopods of the world. An annotated and illustrated catalogue of species of interest to fisheries. *FAO Fisheries Synopses* No. 125 3, 1–277.

Suseelan, C. (1974). Observations on the deep-sea prawn fishery off the south-west coast of India, with special reference to pandalids. *Journal of the Marine Biological Association of India* **16**(2), 491–511.

Wallner, B. and Phillips, B. F. (1988). From scampi to deepwater prawns: developments in the North West Shelf deepwater trawl fishery. *Australian Fisheries* **47**(9), 34–38.

Ward, T. J. and Davis, T. L. O. (1987). Diel periodicity of *Metanephrops australiensis* and other deep-water crustaceans of Northwest Australia. *Fisheries Research* **5**, 91–97.

Wassenberg, T. J. and Hill, B. J. (1989). Diets of four decapod crustaceans (*Linuparus trigonus*, *Metanephrops andamanicus*, *M. australiensis* and *M. boschmai*) from the continental shelf around Australia. *Marine Biology* **103**, 161–167.

4.6 Estimation of the Relative Abundance of Commercial Crustaceans from the North West Slope Trawl Fishery Using Commercial Catch and Effort Data

Mr J R. Garvey, Dr V. A. Wadley and Dr B. F. Phillips

Introduction

Prior to commercial exploitation of crustaceans from the continental slope of north-western Australia, initial research activity was concentrated on finding high-yielding areas of metanephropid lobsters (scampi), rather than estimating the abundance of the existing species (Anon. 1983, Carter *et al.* 1983). Absolute abundance and yield estimates were calculated for *Metanephrops australiensis, M. boschmai* and *M. velutinus* from a 31-day survey cruise by the CSIRO chartered research vessel *Soela* (Davis and Ward 1984). These estimates were calculated for three specific high-yielding scampi areas using catch rates of the *Soela* gear.

In order to estimate the relative abundances of some of the commercially exploited species, catch per unit effort (CPUE) have been calculated using the commercial catch and effort data from the compulsory logbook program. These CPUE have been reported at annual deepwater industry meetings and by Wallner and Phillips (1988, 1990). It was recognised that the variations in the annual catches of the main commercial species (especially scampi and the deep water penaeid *Aristaeomorpha foliacea*), were due to both changes in their abundances and changes in the targeting behaviour of the fleet (Phillips and Jernakoff 1991). Two methods of calculating CPUE were devised to take targeting into account.

This paper will critically review the two methods previously used to calculate CPUE. A third method is put forward which incorporates specific characteristics of the NWSTF.

Background

Exploited species

More than 40 species of commercial and potentially commercial crustaceans have been caught from the NWSTF (Wadley and Evans 1992), however only a small number of species are commercially exploited. These comprise three species of scampi and six species of prawn (Chapter 2, pp. 21 *et seqq.)*

Three scampi species (*Metanephrops australiensis, M. velutinus, M. boschmai*) and three species of prawn (*A. foliacea, A. virilis* and *H. woodmasoni*) are targeted by the vessels involved in the fishery. *Haliporoides sibogae* and *Heterocarpus sibogae* are relatively low in value, while *Plesiopenaeus edwardsianus* is a valuable species but has only been caught in low quantities. These three species are mainly caught incidentally when fishing for the other species.

Table 4.6.1. Percentage use of triple gear (%T) and average headline length (HL, in m) in the North West Slope Trawl Fishery between 1985 and 1990 fishing years

Fishing year	1985	1986	1987	1988	1989	1990
%T	79	29	45	39	68	100
HL	65	57	53	60	51	53

Vessels, gear and fishing year

Most of the boats that have worked in the fishery are Northern Prawn Fishery (NPF) vessels, fishing during NPF closures or periods of low catch (Wallner and Phillips 1988), although two boats have fished full time since 1986. All the vessels are similar in design and their tonnages range from around 150 to nearly 300 tonnes. Due to the involvement of the vessels from other fisheries, the fishing year for the NWSTF was from the 1st April to the 31st March in the next year.

The majority of fishing is carried out using multiple demersal prawn trawls (i.e., double and triple rigged gears), similar to those used in the NPF. General modifications for deepwater fishing have been the addition of extra weight to the boards and sleds, and larger capacity winches for the longer warps. A particular development during the first four years of the fishery was the use of stern towed twin gear (Wallner and Phillips 1988). In later years there was an increased use of triple gear (Table 4.6.1). Headline lengths were on average larger during the early years, especially for twin gear. Headline lengths used have varied from 32 m to 108 m, however 90 per cent of all shots have used gears with headline lengths between 45 m and 81 m.

The gear can be further classified into 'prawn gear' and 'scampi gear'. Prawn gear has a wing-end mesh size of 60 mm (2·5") or less. Scampi gear is prawn gear with the wing-end panels replaced with panels of 72 mm (3") or larger mesh size. Scampi gear was often used when targeting scampi as the larger wing-end meshes reduced prawn by-catch. A more detailed discussion of the gears used in this fishery can be found in Chapter 2.

Monitoring

Under the compulsory logbook program, the retained catch, trawl start and finish time, trawl position and depth data are recorded for every shot. While the catch of each prawn species is recorded, the catch data for the three major scampi species are pooled. Fishermen were asked to identify the species of their scampi product, however compliance was haphazard. The logged crustacean catches were verified from processor returns for each landed catch. The CSIRO scientific observer program was used to further validate the accuracy of the logbook data. Both the scientific observer program and logbook program are discussed in detail in Chapter 3.

Temporal trends in catch and effort

The annual catches of the targeted commercial species have been extremely variable over the six years of operation (Fig. 4.6.1). The dominant species over the six year period has been *A. foliacea*, however the decrease in the annual catch of that species has resulted in scampi and *Aristeus virilis* dominating the annual catch during the fishing years 1989 and 1990. There have been large changes in the number of boats in the fishery although nominal effort (expressed as trawl hours) has not varied to the same extent (Fig. 4.6.2). The difference between the two measures of effort is due to the introduction of two full-time boats to the fishery during the 1986 fishing year, and a general increase in the number of days that the other boats spent in the fishery from 1988/89 to 1990/91.

The nominal effort for each month over the six year period shows the seasonal nature of the fishery (Fig. 4.6.3). There are generally two effort peaks within a year, due to vessels moving into the NWSTF from the NPF. There are corresponding peaks in the monthly catches of scampi (Fig. 4.6.4*A*), *A. foliacea* (Fig. 4.6.4*B*), *A. virilis* (Fig. 4.6.4*C*) and *H. woodmasoni* (Fig. 4.6.4*D*). The differences in the monthly catches of the four species, between months, and between species for each month, are due to the target preferences of the vessels working in the fishery at that time, and the changes in the abundance of those species.

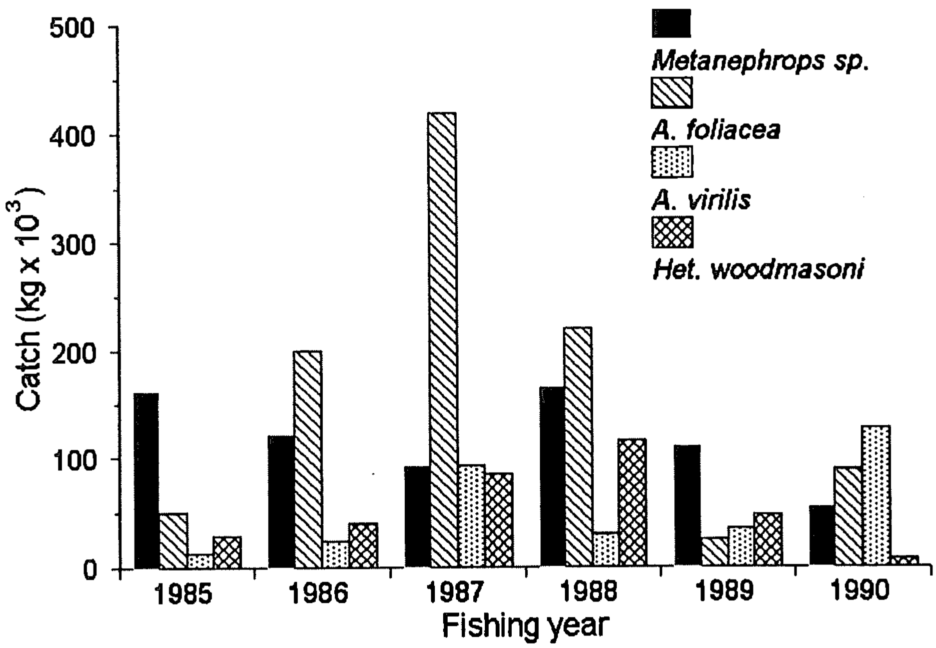


Fig. 4.6.1 Annual catches of targeted crustaceans for the fishing years 1985 to 1990.

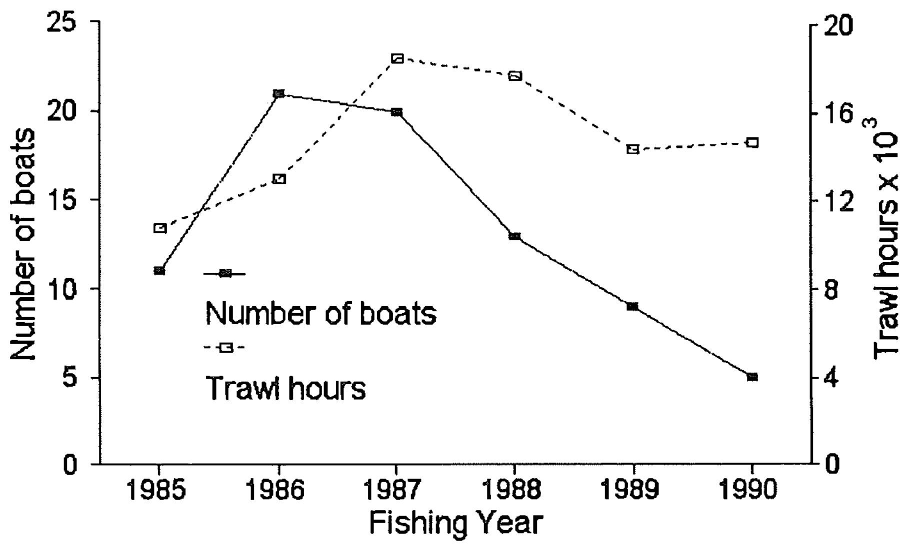


Fig. 4.6.2 Annual nominal effort in trawl hours and number of boats for fishing years 1985 to 1990.

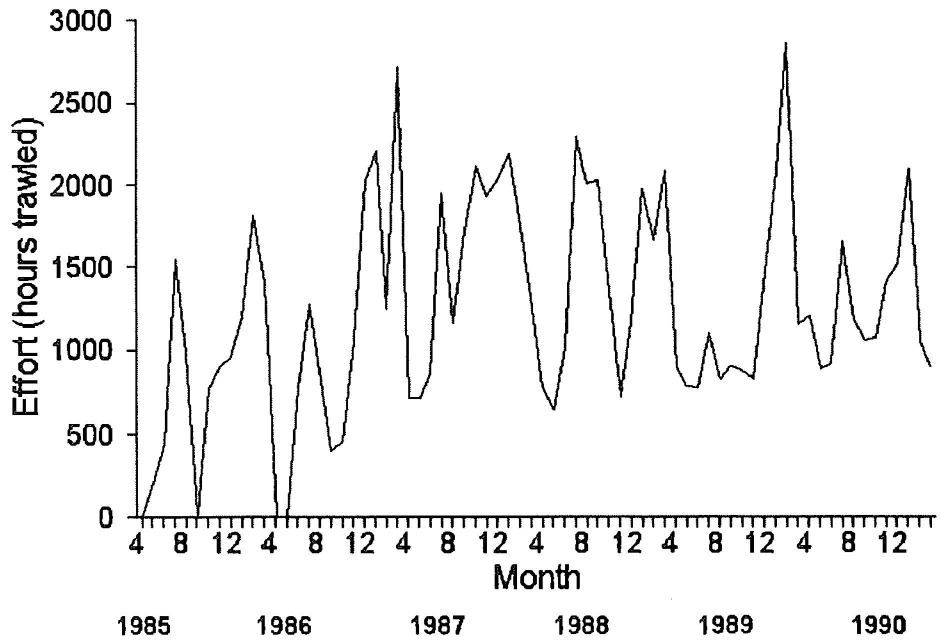


Fig. 4.6.3 Monthly nominal effort in trawl hours from April 1985 to March 1990.

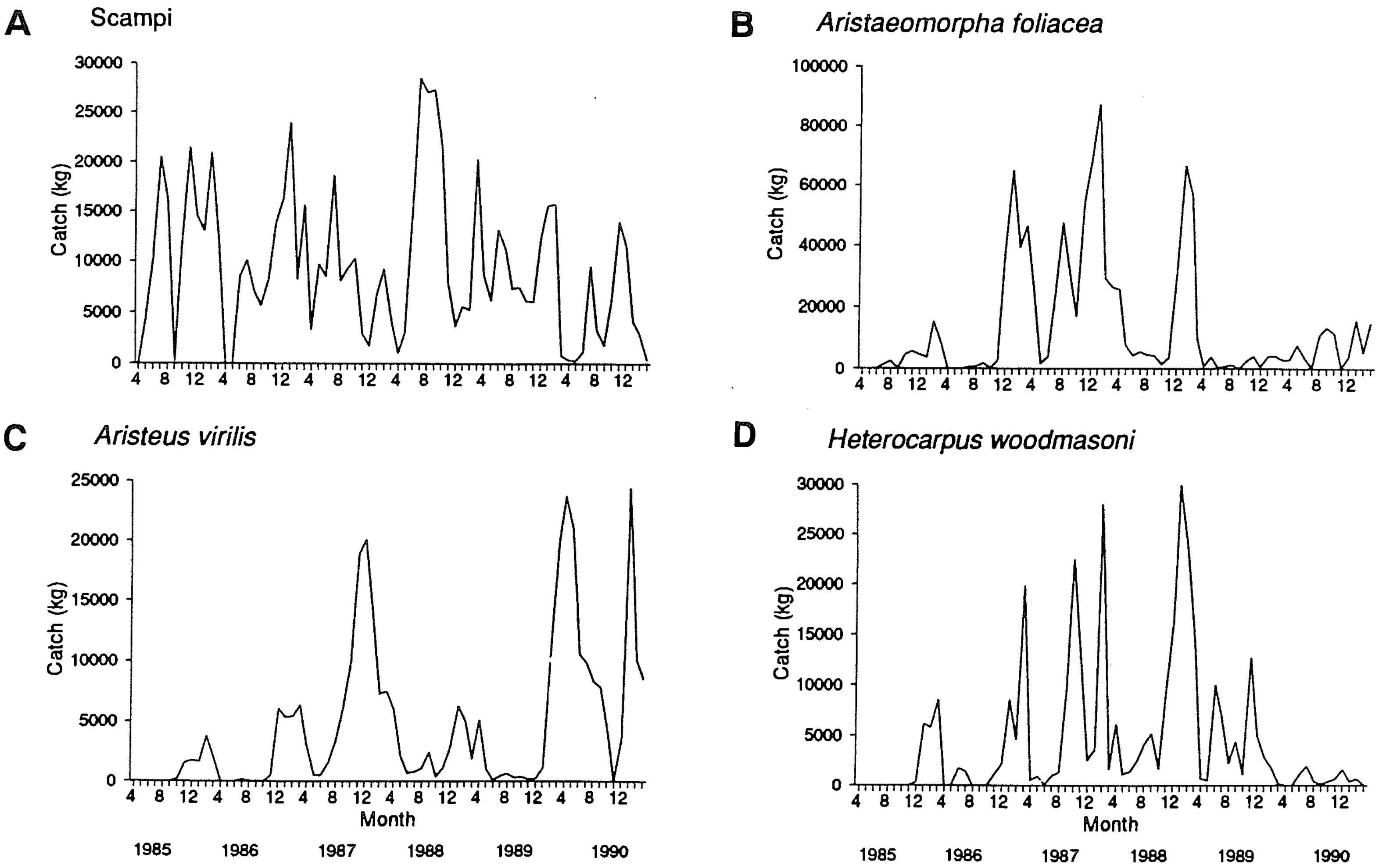


Fig. 4.6.4*A*-*D* Monthly catches of targeted crustaceans from April 1985 to March 1990: *A*, scampi; *B*, *Aristaeomorpha foliacea*; *C*, *Aristeus virilis*; *D*, *Heterocarpus woodmasoni*.

Estimating the abundance of crustaceans from the NWSTF

Proportional catch method

Method

Catch per unit effort (CPUE) for pooled scampi and pooled prawn species have been presented at industry meetings and in Wallner and Phillips (1988). The measure of fishing effort used by this method was uncorrected trawl hours. Annual CPUE figures were calculated using the following equation —

$$U_s = \Sigma(C_{sx}/g_{sx} \, . \, P_{sx}/\Sigma P_{sx}),$$

where: U_s = CPUE for species s (kg · h^{-1})
C_{sx} = Annual catch of species s for vessel x (kg)
C_{tx} = Annual catch of all species for vessel x (kg)
g_x = Annual uncorrected effort for vessel x (hours)
P_{sx} = Weighting factor of species s for vessel x
$= C_{sx}/C_{tx}$
n = number of vessels in fishery

Annual CPUE figures for *each vessel* were weighted by the proportion of annual scampi or prawn catch in the vessel's annual catch of all species. The weighted vessel figures were used to calculate an annual CPUE for the fishery. Vessels with higher proportions of a species group in their catches contributed proportionally more of their annual CPUE to the annual species group CPUE.

The main assumptions of this method are —

- All vessels are equal in their fishing power.
- Effort is randomly distributed across the fishery, both spatially and temporally.
- Targeted effort is proportional to the catch of the targeted species.

Results

The annual CPUE figures indicate a decrease in the relative abundances of both prawn and scampi (Fig. 4.6.5). Scampi CPUE decreased from 13·7 kg · h^{-1} in the 1985 fishing year to 4·4 kg · h^{-1} in 1990, with a pause in the declining trend in 1988. These results indicate a decrease in the relative abundance of scampi of around 67 per cent over the six-year period.

In the 1985 fishing year prawn CPUE was 25·2 kg · h^{-1} and increased to 41·4 kg · h^{-1} in 1986. Prawn CPUE then decreased to a low of 11·1 kg · h^{-1} in 1989 and increased a year later to 16·7 kg · h^{-1}. These results indicate a decrease in the realative abundance of prawns of around 62 per cent from 1986 to 1990 fishing years.

Representative-area method

Method

Monthly CPUE for *Metanephrops velutinus* and *M. australiensis* were calculated by defining species specific areas within the NWSTF

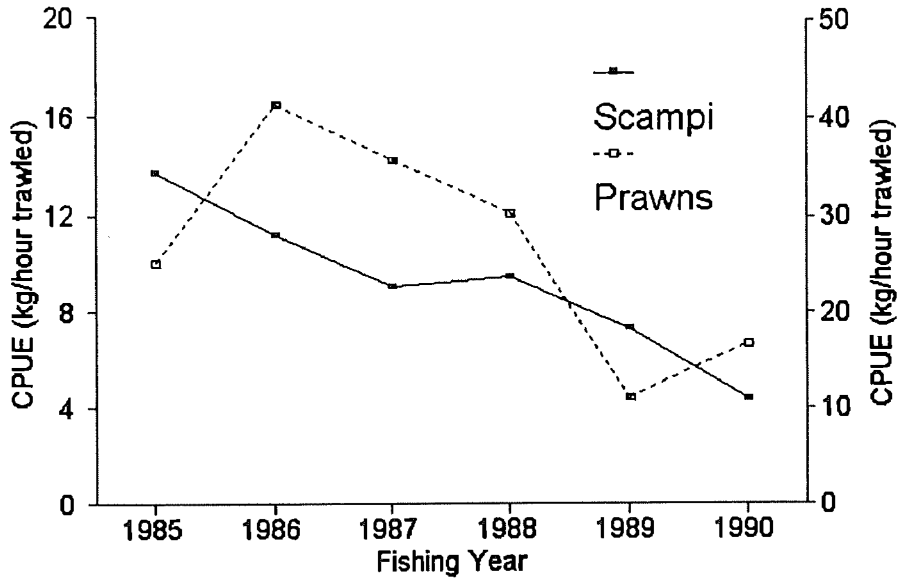


Fig. 4.6.5 Annual scampi and prawn CPUE (kg · h^{-1}) for 1985 to 1990 fishing years; calculated using the proportional catch method.

(Wallner and Phillips 1988, 1990). The location, depth, area and dominant species for fishing grounds I and II (Wallner and Phillips 1990) are given in Table 4.1.4 (p. 57).

CPUE was calculated from total scampi catch and effort for each ground for each month. A vessel's monthly catch and effort was included or excluded from the calculation of monthly CPUE based on the researchers' knowledge of the species targeted by the vessel when it was fishing those grounds. Effort was defined as trawl hours, corrected by gear to a total headline length of 73·2 m (40 fathoms).

Values of monthly CPUE for years prior to the start of the logbook program were obtained from fishing company surveys of the areas, and the monthly catch and effort from those surveys were treated in the same manner as the logbook data.

The main assumptions of this method are —

- Scampi caught in each ground are of a single species.
- Scampi are randomly distributed over each ground.
- Scampi abundance is constant within each month.
- Fishing is random over each ground for each month.
- The effort expended by the included vessels on each ground is targeted at scampi.
- The power of a vessel's fishing effort is proportional to the headline length of the gear used.

In order to estimate the relative abundance of each scampi species for the NWSTF, this method also assumes that the assigned areas are the major habitat for each species, or that they are representative areas and effort is unifomly distributed over the entire fishery.

Results

The CPUE of both species of scampi decreased from initial high values of greater than 50 $kg \cdot h^{-1}$ to around 20 $kg \cdot h^{-1}$ within the first year of each ground being fished (Fig. 4.6.6). The CPUE of both species decreased gradually from then on and by early 1987, both CPUE were less than 10 $kg \cdot h^{-1}$. In later months *M. australiensis* CPUE was generally greater than 10 $kg \cdot h^{-1}$, while *M. velutinus* CPUE was lower. The CPUE of both species increased from previous levels in middle to late 1988, however the values of CPUE had returned to previous levels by early 1989. These results indicate that by 1989, the relative abundances of *M. velutinus* and *M. australiensis* had decreased by around 95 per cent and 75 per cent respectively, from pre-exploitation levels.

Half-degree latitude method

Method

Annual CPUE for pooled scampi species and *Aristaeomorpha foliacea* were calculated for fishing years 1985 to 1990. There were slight differences in the method used for scampi and *A. foliacea* because of depth and latitudinal differences in their distribution.

The measure of fishing effort used by this method was trawl hours (i.e., the time that the trawl gear was working on the sea floor). Shots using fish gear, shots with a duration of less than 30 minutes and 'bad' shots (e.g., when the otter boards twisted or holes were torn out of the nets) were excluded from the analysis.

Monthly CPUE values were calculated for pooled scampi and *A. foliacea* for half-degree latitudes (HDL) and depth ranges specific for each species. For each month, the CPUE values were averaged, weighted for the area of each HDL, to calculate a monthly CPUE for the NWSTF (see below). Where a HDL had no effort, it was left out of the calculation.

$$U_j' = \Sigma A_i U_{ji} / \Sigma A_i,$$

where: U_j' = CPUE for NWSTF for month j ($kg \cdot h^{-1}$)
U_{ji} = CPUE of HDL i for month j ($kg \cdot h^{-1}$)
A_i = relative area of HDL i

The monthly CPUE values for the NWSTF (U') were then averaged to calculate the annual CPUE (see below). Where a month had no effort, it was left out of the calculation.

$$U = \Sigma U_j' / n,$$

where: U = annual CPUE for NWSTF
n = number of months with a value of U_j'

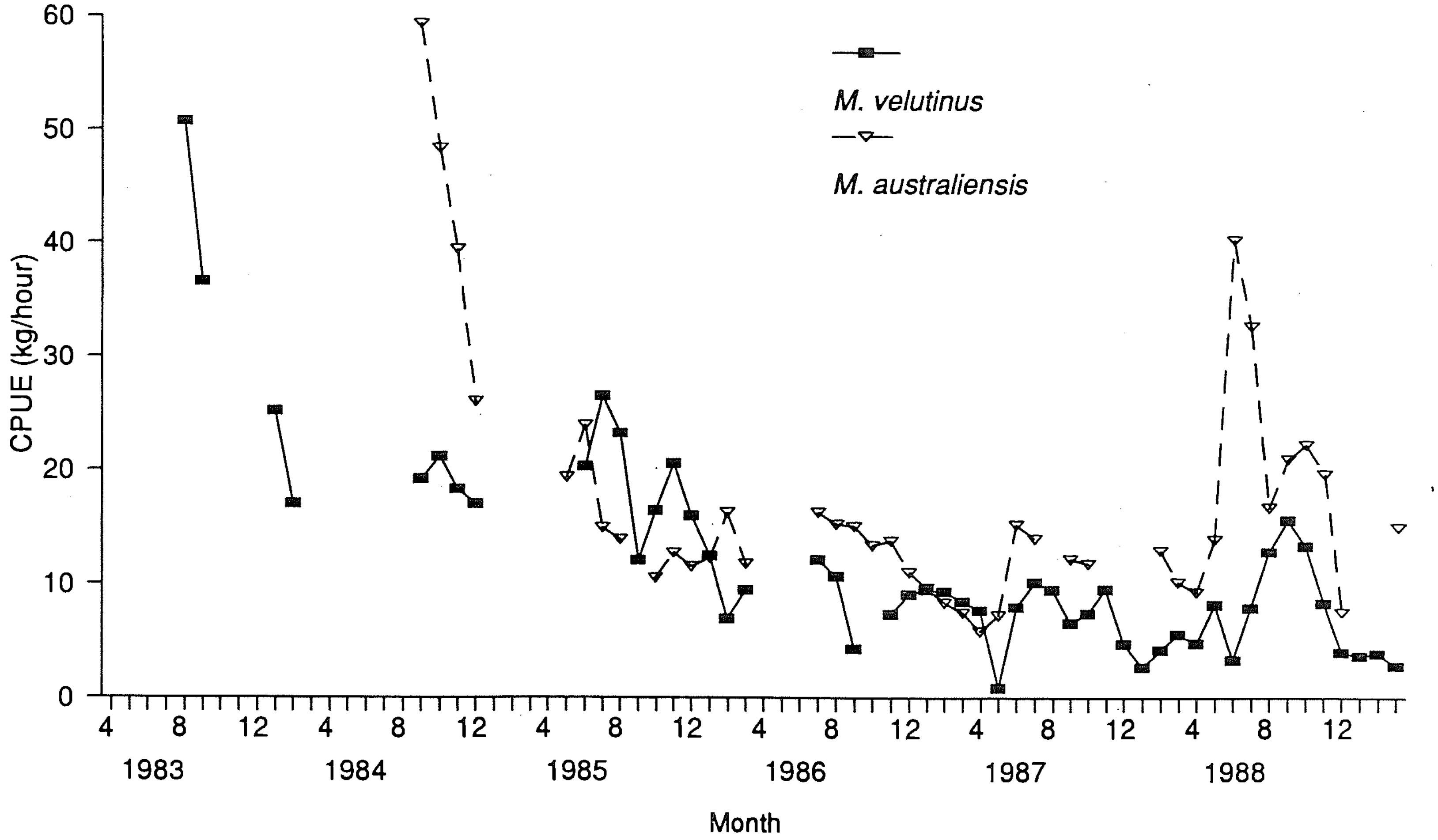


Fig. 4.6.6 Monthly CPUE ($kg \cdot h^{-1}$) for *Metanephrops australiensis* and *M. velutinus* from April 1983 to March 1988; calculated using the representative area method.

Before the monthly CPUE was calculated, specific species or species group differences were taken into account, for gear interactions, spatial distribution and catch composition.

a) Scampi

Effort from trawling using either scampi or prawn gear was included in the calculation of monthly CPUE, as an annual average of 53 per cent of total scampi catch was caught by vessels using prawn gear.

Monthly scampi CPUE was calculated for each HDL from 13°00'S. to 20°00'S., the area which has accounted for an annual average of 94 per cent of the total scampi catch. Within each HDL, only shots within ≥ 250 m to < 500 m were used, the depth range that has accounted for an annual average of 93 per cent of the total scampi catch.

b) *Aristaeomorpha foliacea*

Effort from trawling using scampi gear was excluded from the calculation of monthly CPUE, as an annual average of 85 per cent of the total prawn catch was caught by vessels using prawn gear.

A. foliacea catches are limited to a narrow band of latitude and depth. An annual average of 95 per cent of *A. foliacea* catch is from between 17°30'S. and 19°00'S. while an annual average of 96 per cent is from ≥ 350 m to < 500 m depth. Effort from other areas was excluded from the calculation of monthly *A. foliacea* CPUE.

Three rules for allocating monthly effort within a HDL were used —

- **All-effort rule** — The total catch of scampi or *A. foliacea* was divided by the total effort to calculate the monthly CPUE.
- **Species rule** — The effort from trawling when scampi or *A. foliacea* were caught was summed. The total scampi catch was divided by this effort to calculate the monthly CPUE.
- **Targeted rule** — The scampi or *A. foliacea* catch and effort was summed over days when a vessel's scampi or *A. foliacea* catch was 50 per cent or greater of its total catch of targetable species. The summed catch was divided by the summed effort to calculate the monthly CPUE.

The half-degree latitude method requires a number of assumptions. These are —

- All vessels are equal in fishing power.
- Fishing is random within each HDL.
- Species are randomly distributed within each HDL.
- Species abundance is constant within each month.
- Unfished HDL have a species abundance equal to the average HDL abundance.
- Unfished months have a species abundance equal to the annual abundance.

For the **species rule** —

- When a vessel is targeting a species, it will catch that species.

For the **targeted rule** —

- When a vessel is targeting a species, that species will make up the majority of the catch of **targetable** species.

For Scampi only —

- Scampi species have similar population parameters.

Results

Scampi

The CPUE calculated by each of the three rules indicates decreasing relative abundances over the six years of commercial exploitation (Fig. 4.6.7). Values for 1985 fishing year are similar for all rules, diverging for later years with the values of the all-effort rule being constantly lower than the species and targeted values. From around 15 $kg \cdot h^{-1}$ in 1985, the all-effort CPUE values decrease to 4·7 $kg \cdot h^{-1}$, the species CPUE values to 7·8 $kg \cdot h^{-1}$ and the targeted CPUE values to 8·8 $kg \cdot h^{-1}$ in 1990 fishing year, indicating a decrease in the relative abundance of scampi of around 66 per cent, 47 per cent and 42 per cent respectively over the six year period.

Each of the three rules indicates an increase in the relative abundance of scampi in the 1988 fishing year from 1987 levels. The raw-data values are the total annual scampi catch divided by the total annual nominal effort.

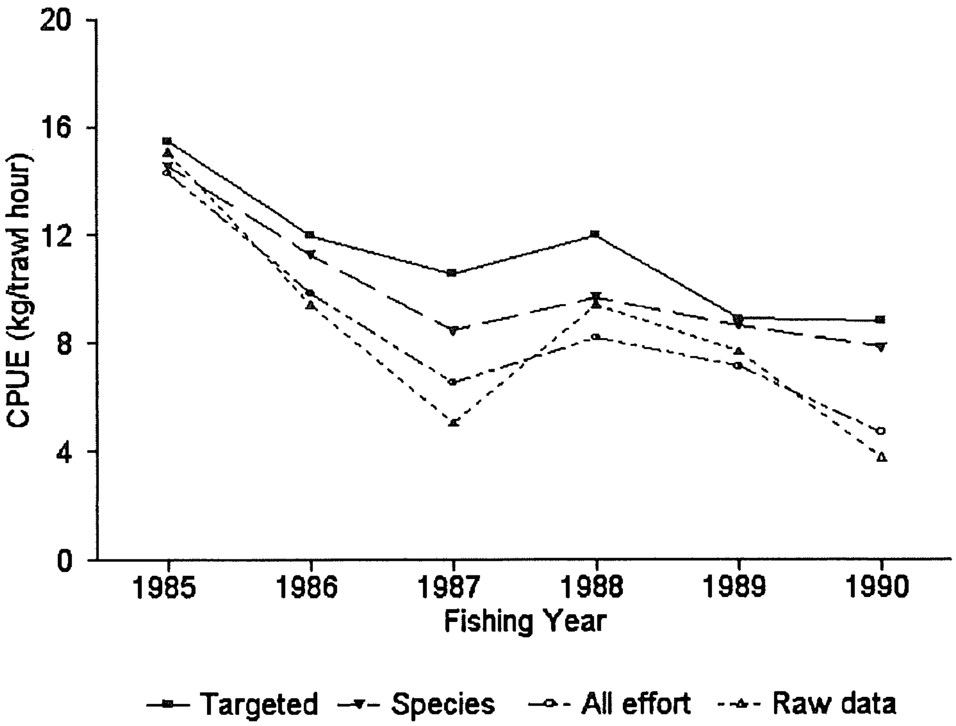


Fig. 4.6.7 Annual scampi CPUE ($kg \cdot h^{-1}$) for 1985 to 1990 fishing years: Raw-data values are calculated from the annual scampi catch and nominal effort; Other values are calculated using the half-degree latitude method applying the all-effort rule, species rule and the targeted rule.

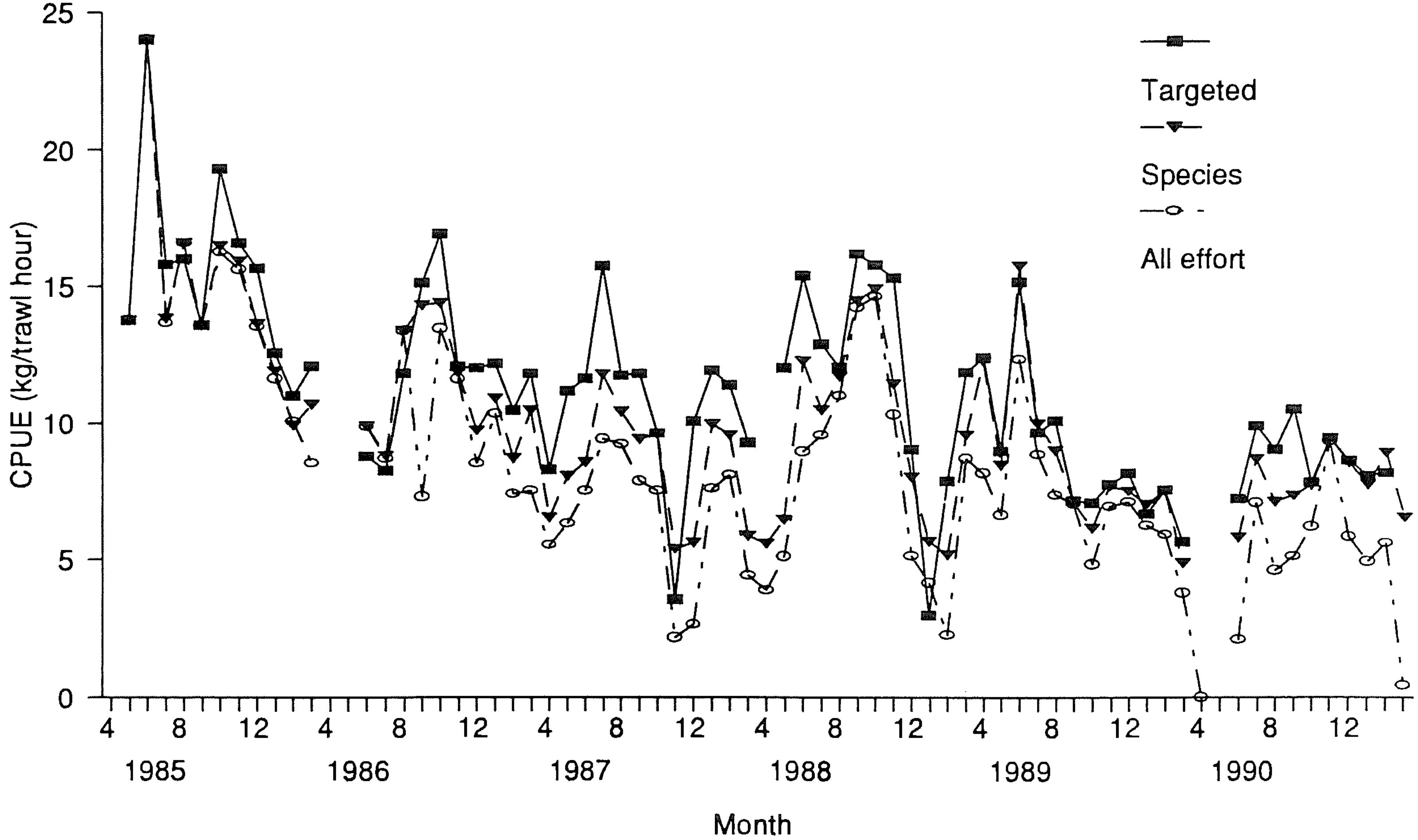


Fig. 4.6.8 Monthly scampi CPUE (kg · h – 1) from April 1985 to March 1990; calculated using the half degree latitude method applying the all effort rule, species rule and the targeted rule.

The monthly CPUE figures (Fig. 4.6.8) indicate a decrease in the abundance of scampi, however there are large intra-annual variations in the monthly CPUE figures for all rules. As with the annual CPUE figures, the all-effort CPUE values are generally lower than the species and targeted CPUE values after the first year.

Aristaeomorpha foliacea

The annual CPUE figures indicate a decrease in the relative abundance of *A. foliacea* (Fig. 4.6.9), however there are marked differences between the all-effort, species and targeted figures in the first three years. All rules indicate increases in the abundance of *A. foliacea* after 1985 fishing year, with the all-effort values rising from 9·9 $kg \cdot h^{-1}$ in 1985 to 26·5 $kg \cdot h^{-1}$ in 1987. The species and targeted rules indicate that abundance was highest in 1986, from 21·1 $kg \cdot h^{-1}$ to 49·5 $kg \cdot h^{-1}$ and 33·9 $kg \cdot h^{-1}$ to 66·9 $kg \cdot h^{-1}$ respectively. The values for all-effort CPUE decrease after 1987, while those from the species and targeted rules decrease after 1986 fishing year.

Each of the three rules indicates that the abundance of *A. foliacea* was lowest in 1989 fishing year, and that there was an increase in abundance in 1990. The CPUE values from the species and targeted rules indicate that from 1986 to 1990 fishing years, the abundance of *A. foliacea* has decreased by 60 per cent or 62 per cent respectively.

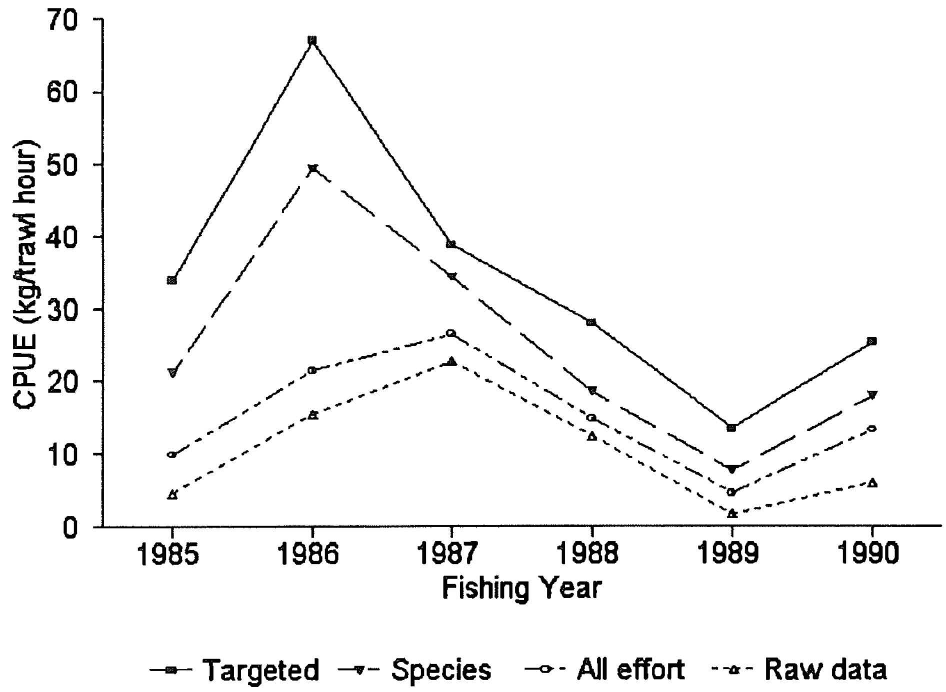


Fig. 4.6.9 Annual *Aristaeomorpha foliacea* CPUE ($kg \cdot h^{-1}$) for 1985 to 1990 fishing years: raw-data values are calculated from the annual *A. foliacea* catch and nominal effort; Other values are calculated using the half-degree latitude method applying the all-effort rule, species rule and the targeted rule.

The all-effort values indicate a decrease of 52 per cent from the peak value in 1987 to 1990. The raw-data values are the total annual *A. foliacea* catch divided by the total annual nominal effort.

The monthly CPUE figures indicate large intra-annual variations in the abundance of *A. foliacea* (Fig. 4.6.10). As with the annual CPUE figures, the differences between the all-effort CPUE values and the species and targeted CPUE values are greater during the earlier years, with the largest difference occurring in January 1987.

Discussion

In the absence of a regular (and usually expensive) fishing survey program, obtaining reliable commercial catch per unit effort data is one of the most important basic steps in stock assessment (Gulland 1983). The method chosen to calculate CPUE from the commercial catch and effort data should give the closest estimate of the relative abundance of the species being fished. The unit of effort chosen for the method should give the best estimate of fishing mortality for the exploited species (Gulland 1983). The method should also cope with the problem of effort aggregation, which is the tendency for vessels to concentrate their fishing activities to times of the year and areas of high catch rates.

The NWSTF fits Gulland and Garcia's (1984) definition of a *single-multi-target* fishery, i.e., a number of exploited species are targeted by a limited number of boats which change their targeted species from season-to-season, or even trip-to-trip. The problem with this type of multispecies fishery is determining the 'true' effort on one or another species (Gulland and Garcia 1984). Since mortality is not simultaneous for all species for a given effort, the method devised to calculate CPUE should allocate the appropriate effort to catches of a given species. Therefore the method should be based on an understanding of the distribution of catch and effort, effectiveness of different gear types, and other factors that influence the targeting behaviour of the fishery.

The recommended measure of fishing effort where little time is spent searching for high concentrations of the targeted species is trawl hours (Gulland 1956, Gulland 1964, Gulland 1983). Searching is carried out in the NWSTF by trawling, as the depth of water and exploited species (i.e., crustaceans) make searching methods such as try nets and acoustic technologies ineffective. Other measures such as number of shots or days fished will give the a value of effort equal to trawl hours reduced by a factor, if the number of hours trawled per shot, or per day remains relatively constant. This may not be the case in a developing fishery such as the NWSTF. For all three methods reviewed above, the unit of effort chosen was trawl hours.

The three methods reviewed differ in the ways that they deal with spatial and temporal effort aggregation, and how they allocate a vessel's effort to a targeted species. The three methods are discussed separately below —

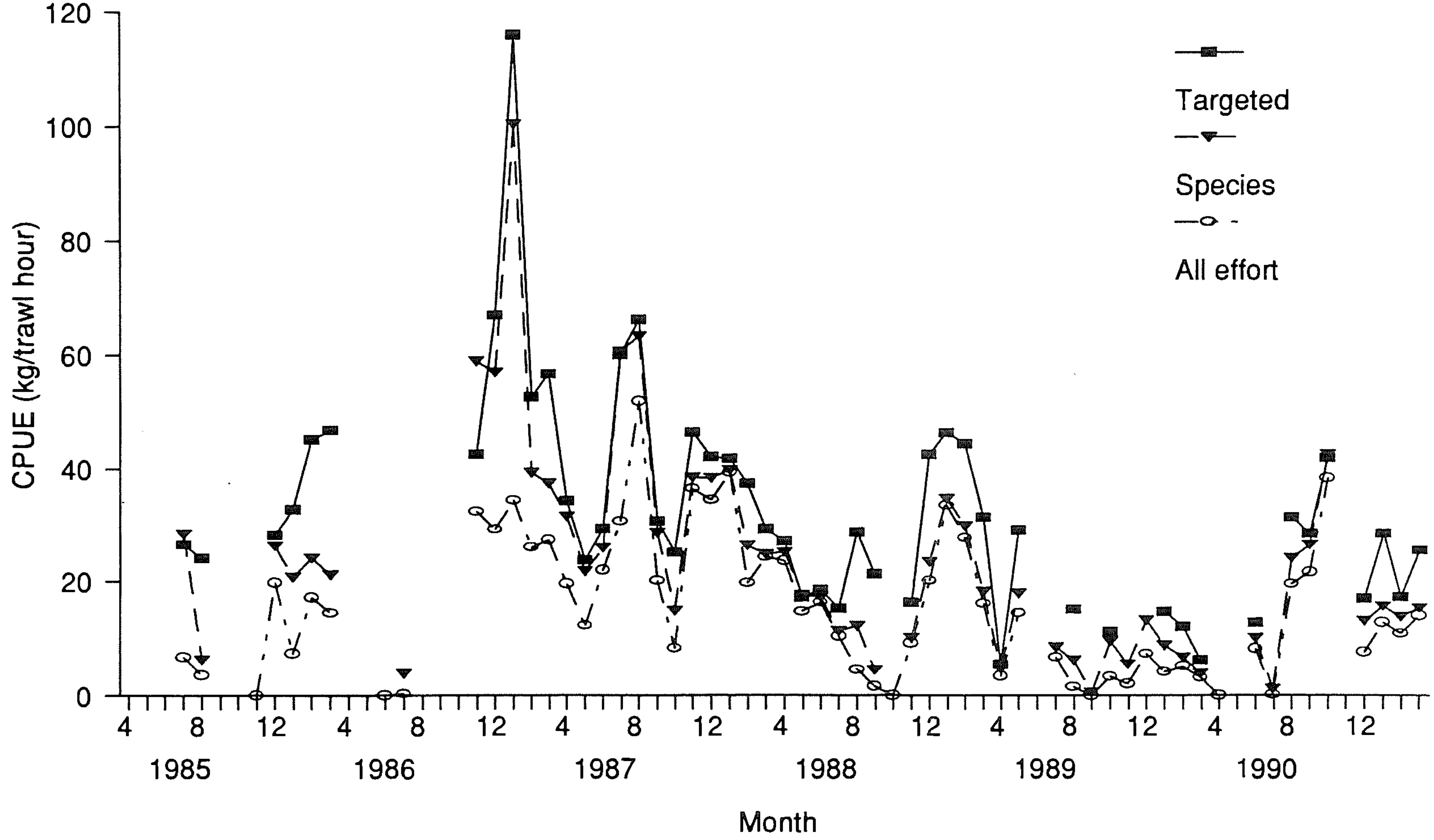


Fig. 4.6.10 Monthly *Aristaeomorpha foliacea* CPUE (kg · h - 1) from April 1985 to March 1990; calculated using the half degree latitude method applying the all effort rule, species rule and the targeted rule.

Proportional catch method

Effort aggregation is not addressed by this method as it uses vessels' total annual catch and effort to calculate annual CPUE. CPUE will therefore be weighted to areas and times where vessels were most active. Generally abundances are over-estimated in this case as these areas and times are usually where catch rates are high.

Targeting on different species is dealt with by weighting a vessel's CPUE by the proportion of a species group (i.e., scampi or prawns) in the vessel's total catch. The effect of this weighting procedure is illustrated by the two scenarios below —

Scenario A has two vessels active in the fishery. Vessel X fishes in one area and catches both prawns and scampi. Vessel Y fishes a different area and only catches prawns. The real CPUE of scampi (U_S) and prawns (U_p) is 0·5 kg · h^{-1}. The calculated CPUEs are —

Vessel	Effort (hours)	Scampi (kg)	Prawn (kg)	U_s	U_p
X	2	1	1	0·5	0·5
Y	2	0	1	–	0·5
Calculated CPUE				**0·5**	**0·5**

Scenario B is similar except that Vessel X changes its targeting practice and fishes in one area for scampi and in another for prawns, for one hour in each area. The real CPUE for scampi and prawns is 1 kg · h^{-1}. The calculated CPUE are —

Vessel	Effort	Scampi (hours)	Prawn (kg)	U_s (kg)	U_p
X	2	1	1	1	1
Y	2	0	2	–	1
Calculated CPUE				**0·5**	**0·84**

While the Proportional catch method accurately calculates the CPUE in *Scenario A*, it underestimates the CPUE in *Scenario B*, as this method does not allocate effort when a vessel changes its targeting strategy. Because the NWSTF is a multispecies fishery where not all the exploited species are caught in every shot, the results from this method will be incorrect.

The final problem with this method is that it deals with pooled scampi and pooled prawn species. Figure 4.6.1 shows that the prawn species mix is not constant. The CPUE values for pooled prawns using this method may be influenced more by the different catch rates of the different species than changes in the relative abundances of all the prawns in the fishery.

Representative-area method

This method deals with both spatial and temporal effort aggregation and targeting by spatially segregating the fishery into species specific scampi grounds, and by calculating monthly scampi CPUE. Monthly CPUE take into account any seasonal changes in the catchability of scampi, and control for changes in the intensity of fishing by vessels over the year (Gulland 1964, Gulland 1983). By spatially separating the areas, the expansion of a fisheries range can also be taken into account. This can be seen in 1984 (Fig. 4.6.6), when fishing had just started on the *Metanephrops australiensis* grounds, while the *M. velutinus* grounds had been exploited a year before.

The assumption that the grounds are specific for each scampi species can be tested. In the 1990 fishing year, 11 per cent (6·2 tonnes) and 28 per cent (15·2 tonnes) of the total annual scampi catch was caught on grounds I and II, respectively. Scampi species were identified from the logbook records for 88 per cent and 99 per cent of the catches from those grounds. From ground I, 49 per cent of the scampi catch was *M. velutinus* and 36 per cent *M. australiensis*. The rest were mixed catches of both species. From ground II, 52 per cent of the scampi catch was *M. australiensis* and 0·5 per cent was *M. velutinus*, however 47 per cent were mixed catches of both species. These data indicate that both areas have mixed populations of *M. velutinus* and *M. australiensis* and that the assumption that the calculated CPUE from each area represent changes in the abundance of specific scampi species must be questioned. Further more, as 61 per cent of the scampi catch in the 1990 fishing year came from outside these two areas, the assumption that the CPUE values are representative of the relative abundance of scampi in the NWSTF must also be questioned.

The fishing power of vessels is related to the type and swept area of the gear, i.e., the size of the gear and the speed of the boat (Gulland 1964, 1983). The chosen unit of effort (trawl hours) can be corrected by a power index calculated from a vessel's catch rates. The representative-area method attempts to correct effort by assuming that a vessel's fishing power is proportional to the total headline length of the gear it is trawling. This assumption may be invalid because of changes in the gear used.

The average total headline length has changed from 65 m in 1985 to 54 m in 1990 (Table 4.6.1), giving a potential reduction of the total swept area of 17 per cent. Over the same period there has been a change in the types of multiple prawn gear used. The fishery was dominated by double and twin gear from 1986 to 1988, but by 1990 only triple gear was used in the fishery.

Andrew *et al.* (1991) showed that there were no significant differences in the catches of crustaceans (prawns and slipper lobsters) between single and multiple prawn gears when controlled for swept area. This indicates that differences in fishing power of multiple prawn gears are due to differences in swept area, and are not intrinsic to the type of gear. Stirling (1991) showed that when increasing the spread ratios of different types of multiple prawn gear, swept area increases proportionally more for triple gear than double gear. This indicates that even though the total headline length has decreased, the change to triple gear has probably kept the swept area the same for each unit of effort.

In developing fisheries fishing power usually increases with time, as skippers learn more about where to fish, when to fish, and which gear is the most efficient at catching the targeted species (Garrod 1964). The power indices calculated by the representative-area method are larger for fishing in earlier years, as the average headline length has decreased during the life of the fishery, and would bias CPUE upwards for the later years of the fishery.

The vessels chosen for inclusion for this method were identified by the researchers from their intimate knowledge of the fishery, rather than by an external rule. This *ad hoc* basis for allocating effort on the defined scampi grounds means that the results cannot be extended to years later than 1988. Also, the values of scampi CPUE for years earlier than 1985 must be questioned. Because fishing was not as intensive before 1985, as was during later years, these values may be biased upwards by exceptional catches of scampi.

Half-degree latitude method

This method deals with the problem of effort aggregation by dividing the fishery into areas of 30' latitude and calculating monthly CPUE. However, for looking at long-term changes in the abundance of species, a single annual figure for the fishery is more appropriate (Gulland 1964). The method of Gulland (1983) was applied for the early parts of this method to deal with effort aggregation. Although this procedure smoothed out some of the biases in the data, especially for scampi (Fig. 4.6.7, raw-data vs all-effort), the problem of targeting was not addressed.

Hall and Penn (1979) allocated effective effort to two penaeid prawn species exploited in Shark Bay WA. They identified areas of preferred habitat for each species by correlating the proportion of the two prawns from trawl survey catches by sediment type. The proportion of species preferred habitat to total trawled area was used in the method of Gulland in two different ways to calculate CPUE for each species.

Because such habitat information was not available for this study, two other rules were used. For the species rule, effort was allocated by using the effort from shots that catch a particular species (Tilzey *et al.* 1990). This rule assumes that those units of effort directed towards a species will always catch that species. In heavily exploited fisheries this assumption may be invalid if catches of a species are rare, although sufficiently valuable to justify searching. In a developing fishery however, a species biomass would not normally be at such a low level. CPUE could be underestimated if a large proportion of effort was expended towards a second species in an area where the first species is generally less abundant. This could happen where one species habitat overlaps another.

The targeted rule is derived from ICNAF (1960) and Ketchen (1964). This rule allocates effort by selecting catches where the proportion of a species is above a chosen level. This rule deals with multispecies fisheries where only a few species are caught at any one time, and fishermen target them where they are most abundant. It also deals with the problem of underestimating relative abundance due to incidental catch, discussed in the previous paragraph. The species proportion level is chosen from frequency plots of the proportion of the species in the catch.

How effective these two techniques were in allocating the appropriate effort for scampi and *Aristaeomorpha foliacea* are discussed below.

Scampi

All rules indicate that there was a decrease in the relative abundance of scampi from 1985 to 1990 fishing years (Fig. 4.6.7), however they differ from each other regarding the magnitude of the decrease, depending on how each deals with the targeting problem.

The values calculated for the first year of the fishery are similar for all three rules, indicating that there was uniform targeting on scampi by all vessels. This situation changed rapidly, and by 1987 some vessels had switched to targeting prawns, resulting in *A. foliacea* dominating the total annual catch (Fig. 4.6.1). The difference between the all-effort and species values in 1987 is due to the amount of effort expended towards catching *A. foliacea*. While fishing for this species, some scampi is caught incidentally, which is the reason for the difference between the species and targeted values.

The annual CPUE figures are calculated from monthly CPUE which show high variations by all rules (Fig. 4.6.8). These variations could be due to seasonal changes in the catchability of scampi, however they are most likely due to vessels moving from areas of low scampi abundance to newly discovered areas of higher abundances, or areas that had been subjected to little effort during previous years. The distance of the fishery is greater than 750 n.m. from south-west to north-east, and with as few as five boats working the fishery in a year it is unlikely that all areas with scampi populations from 13°S. to 20°S. are fished.

The apparent increase in scampi abundance in 1988 can be explained in two ways. During 1986 and 1987, vessels switched their targeting to *A. foliacea* and concentrated their effort in the limited area where that species is caught. Scampi in the trawled area were caught as by-catch and their abundance was reduced. Because effort was concentrated on another species, little searching was done for scampi on other grounds with possibly higher abundances. The CPUE figures would therefore underestimate the real abundance of scampi for those years. Alternatively, it is possible that the increase is real. During 1986 and 1987 there was little fishing pressure on known scampi grounds due to targeting on *A. foliacea*. The lower fishing mortality on these grounds allowed growth of recruits and an increased biomass. In 1988 when targeting returned to scampi, these grounds were subjected to increased fishing intensities, and the higher CPUE values reflect the higher abundances.

The major problem with the pooled scampi CPUE figures is that they are averaging the abundances of three *Metanephrops* species. Unless their population characteristics are similar, the three scampi species cannot be considered a unit stock and the pooled scampi CPUE will not accurately reflect fishing mortality on each of the species biomass. Also, if species differ in their population densities, a switch from targeting one species to another species of higher density will cause the calculated CPUE to overestimate the relative abundance of the first species.

The spatial areas used to weight the monthly CPUE may be too large. Although the general method corrects for aggregation, it is possible that the scampi grounds are more restricted within each HDL. In this case the weighting factors could possibly be greater than they should be and bias the CPUE figures for HDL with large surface areas.

Aristaeomorpha foliacea

All rules indicate a decrease in the relative abundance of *A. foliacea* (Fig. 4.6.9). The differences between the raw-data values and the all-effort values illustrate the effect of filtering out data from outside the limited area where most *A. foliacea* are caught. In some fishing years (1985, 1989, 1990), this has increased CPUE by a factor of two, where significant amounts of effort were outside the *A. foliacea* area.

The difference between the all-effort and species values is due to the effort that did not catch *A. foliacea*. The difference is greater during the first three years of the fishery, especially 1986. This indicates that a large proportion of the effort within the *A. foliacea* area was not directed at that species. The apparent increase in abundance in 1986 is probably due to the developing nature of the fishery. Most targeting in the first year was directed at scampi (see above) and so most effort would not have been in areas of high *A. foliacea* abundance. It is also possible that amounts of *A. foliacea* were discarded during that first year as markets were generally being developed for scampi. Both these factors would cause the CPUE for that year to underestimate the relative abundance of *A. foliacea*.

The CPUE values from the species and targeted rules indicate that there has been an appreciable reduction in the annual average biomass of *A. foliacea*. The difference between the values from the two rules is due to the amount of effort where *A. foliacea* was **not** the dominant species of the catch. Both measures indicated similar decreases in abundance from 1986 to 1990 (60 per cent and 62 per cent respectively).

The monthly CPUE values for *A. foliacea* indicate dynamic variations in the abundance of that species within a year. The apparent twice yearly fluctuations in the abundance of *A. foliacea* may be indications of aggregation. The decreasing trend for the upper values of these fluctuations and the low values for monthly CPUE in mid- to late-1988 and 1989 are the reason for the declining trend in the annual CPUE figures.

Both the species or targeted rules allocate effort in each HDL, however the CPUE figures calculated by each rule indicate that they differ in their ability to allocate effort to the targeted species. The appropriateness of the targeted rule for scampi and *Aristaeomorpha foliacea* can be examined by plotting the cumulative annual catch of a species by a threshold level of the percentage component of that species in a vessels daily catch.

High proportions of scampi are caught at the 50 per cent level for most years (Fig. 4.6.11*A*). The targeted rule at the 50 per cent level is effective for estimating the relative abundance of scampi for most years, however it may overestimate the abundance of scampi in the 1987 fishing year. The difference in the shape of the curve from the 1987 fishing year is most likely because the fleet was targeting mainly *Aristaeomorpha foliacea* in that year.

The annual cumulative catch plots for *Aristaeomorpha foliacea* are not as tight than those for scampi (Fig. 4.6.11*B*). Using the 50 per cent targeted rule, the results would overestimate the abundance of *Aristaeomorpha foliacea* for at least three years (1989, 1985, 1990). These figures indicate that there were significant incidental catches of other species when fishing in the *Aristaeomorpha foliacea* grounds for most years. However, as both the species and the targeted rules indicate similar changes in abundance of *A. foliacea* over the fishing years 1986 to 1990, the simultaneous catches of other species with *A. foliacea* has not affected the relative abundance estimates over the five-year period.

There are problems associated with the half-degree latitude method that should be taken into account when using it to estimate the relative abundances of the exploited species from the NWSTF. The method uses uncorrected effort for calculating CPUE. It has been demonstrated that using headline length to correct for swept area is probably biasing CPUE in the wrong direction. Looking at power indices calculated using Gulland's (Gulland 1956, 1983, Robson 1966) or Kimura's (Kimura 1981, Beadle 1991) method would give correction factors for effort and indicate changes over the six-year period. By correcting effort in this manner, a closer estimate of the relative abundances of the exploited species can be achieved.

The assumption that HDL with no effort have an abundance equal to the fishery monthly average should be investigated. Expansion of the range of the fishery is a problem with some fisheries, where areas of high abundances are fished down and the fleet moves further out in search of new grounds. By not estimating the abundance on the 'fished-out' grounds, the calculated CPUE would be kept high and overestimate the true abundance of a species over its range (Gulland 1983). This does not seem to have happened in the NWSTF where the cental and lower areas (16°S.–19°S.) have been consistently fished over the six-year period.

This problem would have its greatest effect on the estimate of the relative abundance of scampi. Scampi CPUE is calculated using 14 HDLs while *Aristaeomorpha foliacea* is calculated using three HDLs. The localised scampi grounds in each HDL would have to be identified and the seasonal variations in their abundance examined, in

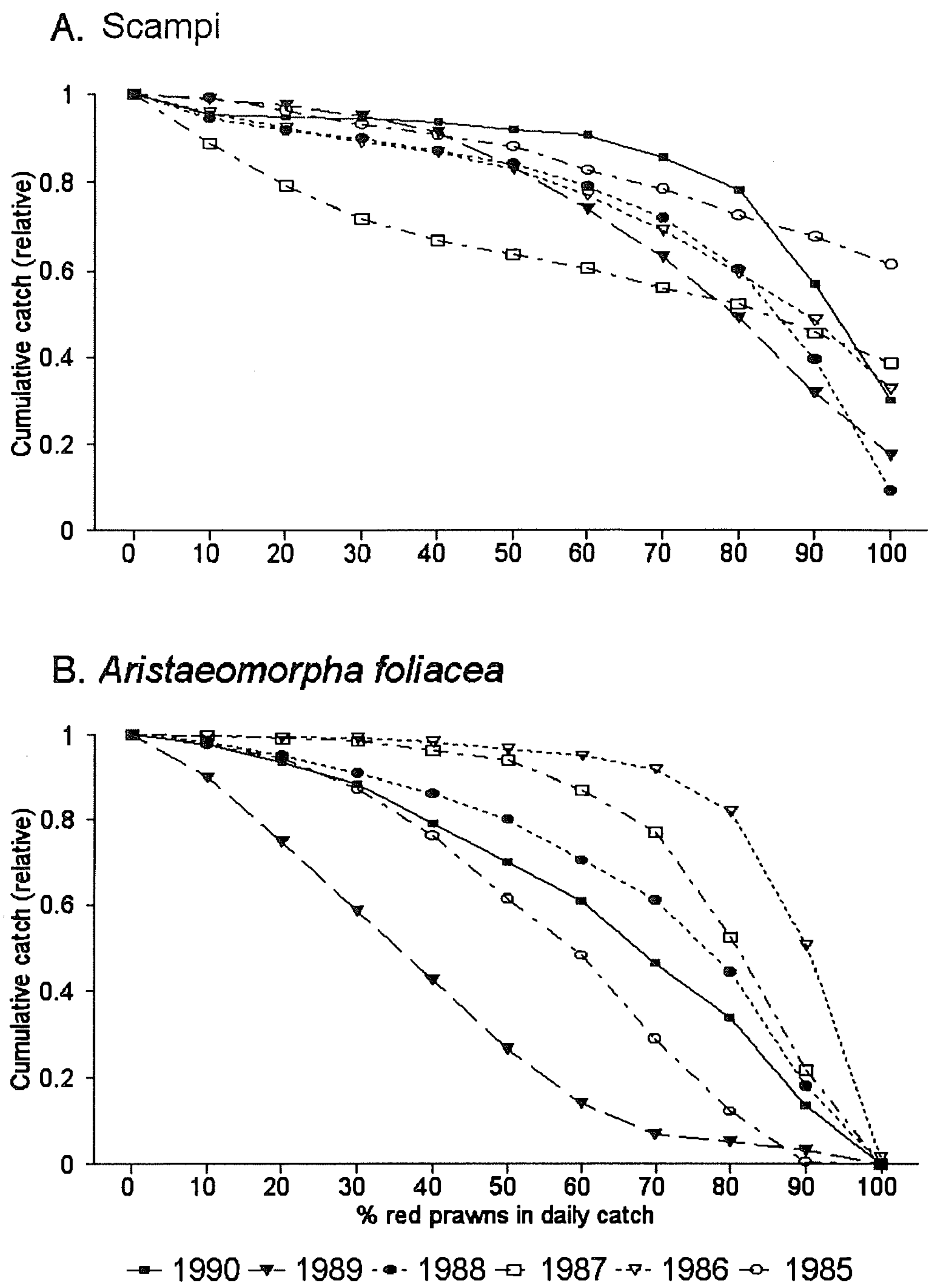


Fig. 4.6.11*A, B* Cumulative relative annual catch of: *A*, scampi; *B*, *Aristaeomorpha foliacea;* by threshold levels of the percentage component of that species in a vessels daily catch.

order to interpolate CPUE for areas that are less often fished. Similar work should be carried out for other exploited species in the fishery.

Conclusions

Three methods of calculating the relative abundances of exploited species from the NWSTF have been used since the start of the Deepwater Logbook Program. All show declining trends in the relative abundances of the exploited species (especially scampi and *Aristaeomorpha foliacea*). However, the changing nature of the fishery has made two of the methods unsuitable.

The proportional catch method was useful as a rough indication of changes in abundance during the very early stages of the fishery, when scampi was the primary target and the vessels fished together for a limited season. However, as vessels now change their targeted species within the fishing year, this method is inappropriate.

The representative-area method was more appropriate for the early stage of the fishery, where vessels were similarly rigged and fished limited areas. Changes in the fishery, both in gear and fishing grounds, make this method inappropriate for longer term analysis of the relative abundances of scampi species.

The half-degree latitude method is appropriate at this stage for looking at general trends in the fishery. It deals adequately with effort aggregation however there are specific problems depending on the species it is applied to —

Scampi

The targeted rule indicates that the abundance of pooled scampi species in the NWSTF has decreased to just less than half of the virgin biomass. Although this is to be expected after the initial fish-down period, the variation in the weighted monthly CPUE figures indicates that the scampi fishery is not homogenous. The scampi fishery is probably characterised by local populations of *Metanephrops* species of differing abundances being subjected annually to different levels of fishing intensity.

Aristaeomorpha foliacea

Using either the species or the targeted rule, the results indicate that there has been a appreciable decrease in the abundance of this species of around 60 per cent from 1986 to 1990, in the limited area that they are fished. The monthly CPUE figures indicate that there are dynamic intra-annual variations in the abundance of *A. foliacea* which indicate that other factors as well as fishing may be influencing changes in abundance.

Further research is needed to fine tune the half-degree latitude method and deal with some of the problems indicated by the variation in the monthly CPUE values, for both scampi and *Aristaeomorpha foliacea*. The avenues for future research that have been identified are —

- Gulland's (Gulland 1956, 1983, Robson 1966) and Kimura's (Kimura 1981, Beadle 1991) methods should be used to calculate power indices for the vessels fishing the NWSTF in order to standardise effort, and investigate the variables influencing variation in CPUE and vessel power indices (Kimura 1981, Beadle 1991)

- The stock/fleet dynamics of the NWSTF should be analysed in detail. The specific targeted fishing grounds should be identified within each half-degree latitude, and the relationship between the changes in abundance on those grounds and fleet targeting behaviour examined.
- After identifying targeted fishing grounds, seasonal CPUE variations should be examined for trends in abundance. Average annual CPUE should be calculated taking the seasonal trends, and using the area of targeted grounds for weighting factors.

The NWSTF is a developing fishery and the trends in both the catches and the relative abundances of some of the exploited species indicates that it has not reached an equilibrium state. A greater understanding of the dynamics of the fluctuations in catch and effort is necessary before a more fully informed management regime can be implemented.

References

Andrew, N. L., Graham, K. J., Kennelly, S. J. and Broadhurst, M. K. (1991). The effects of trawl configuration on the size and composition of catches using benthic prawn trawls off the coast of New South Wales, Australia. *ICES Journal of Marine Science* **48**, 201–209.

Anon. (1983). CSIRO finds scampi and carid prawns on NW shelf. *Australian Fisheries* **42** (3), 13.

Carter, D., Maxwell, J. G. H. and Bowtell, C. (1983). 'Cautious optimism' over potential for scampi fishery on NW shelf. *Australian Fisheries* **42** (11), 2–12.

Davis, T. L. O. and Ward, T. J. (1984). CSIRO finds two new scampi grounds off the North West Shelf. *Australian Fisheries* **43** (8), 41–45.

Garrod, D. J. (1964). Effective fishing effort and the catchability coefficient *q*. *Rapports et Procès-verbal de la Réunion, CIEM* **155**, 68–70.

Gulland, J. A. (1956). On the fishing effort in English demersal fisheries. *Fisheries Investigations Series 2, Ministry of Agriculture, Fisheries and Food* **20** (5), 1–41.

———. (1964). Catch per unit effort as an index of abundance. *Rapports et Procès-Verbal de la Réunion, CIEM* **155**, 8–13.

———. (1983). Fish Stock Assessment. A Manual of Basic Methods. (John Wiley and Sons: Chichester.)

——— and Garcia, S. (1984). Observed patterns in multispecies fisheries. *In*: May, R.M. (Ed.), Exploitation of marine communities, pp. 155–190, Dahlem Konferenzen. (Springer-Verlag: Berlin.)

Hall, N. G. and Penn, J. W. (1979). Preliminary assessment of effective effort in a two species trawl fishery for penaeid prawns in Shark Bay, Western Australia. *Rapports et Procès-verbal de la Réunion, CIEM* **175**, 147–154.

ICNAF (1960). Proceedings of the joint scientific meeting of ICNAF, ICES and FAO on fishing effort, the effect of fishing on resources and the selectivity of fishing gear. Volume 1. *Special Publications, ICNAF* **2**, 1–45.

Ketchen, K. S. (1964). Measures of abundance from fisheries for more than one species. *Rapports et Procès-verbal de la Réunion, CIEM* **155**, 113–116.

Kimura, D. K. (1981). Standardized measures of relative abundance based on modelling log (c.p.u.e.), and their application to Pacific ocean perch (*Sebastes alutus*). *Journal du Conseil international pour l'Exploration de la Mer* **39**, 211–218.

Phillips, B. and Jernakoff, P. (1991). The North West Slope trawl fishery: what future does it have? *Australian Fisheries* **50** (7), 18–20.

Robson, D. S. (1966). Estimation of the relative fishing power of individual ships. *ICNAF Research Bulletin* **3**, 5–14.

Stirling, D. (1991). Techcetera. Board talk. *Australian Fisheries* **50** (5), 24–25.

Tilzey, R. D. J., Zann-Schuster, M., Klaer, N. and Williams, M. J. (1990). The south east trawl fishery: Biological synopses and catch distributions for seven major commercial fish species. Bureau of Rural Resources Bulletin No. 6. (Australian Government Publishing Service: Canberra.)

Wadley, V. A. and Evans, D. R. (1992). Crustaceans from the West and North West Slope Deepwater Trawl Fisheries. Illustrated, 40 pp. (CSIRO: Australia.)

Wallner, B. and Phillips, B. (1988). From scampi to deepwater prawns: developments in the North West Shelf deepwater trawl fishery. *Australian Fisheries* **47** (9), 34–38.

———. (1990) Development of a trawl fishery for deepwater metanephropid lobsters off the North West continental slope of Australia. Designing a management strategy compatible with species life history. *Symposium on Shellfish Life Histories and Shellfishery Models*. Moncton, N.B., Canada.

5 The Fisheries Biology of the Finfish

Dr A. Williams

Contents

5.1 Summary

Research activities

- Ninety-five trawls were made during an exploratory fishing survey by FRV *Southern Surveyor* in the WDWTF during 30 days in January and February 1991. Sampling was carried out along 16 predetermined transects between 200 m and 1400 m, on bottom features of interest and on acoustic marks. Catches of potentially commercial fish species were generally small. Some encouraging catches were made of upper-slope species, especially mirror dory and big-spined boarfish, indicating that the upper-slope region south of Geraldton offers the best prospect for commercial multispecies trawling. No large catches were made on the mid-slope and the species of commercial interest were caught in only very small quantities. No features of bottom topography of the type that hold concentrations of orange roughy were found.
- A deepwater demersal fish logbook introduced into the WDWTF enabled the recording of commercial catch and effort data during 1990 and 1991. Summaries of these data appear in Chapter 5.4. Effort was concentrated on the upper slope in 200–500 m between 32°S.–34°S. and, in common with the findings of the scientific survey, big-spined boarfish and mirror dory were the dominant component of trawl catches. No fish trawling was undertaken in the NWSTF.
- The first museum collections of fishes from the west-coast continental slope were made and > 1700 photographic slides of fish specimens were taken and catalogued. A species list, together with distributional limits in the WDWTF (depth and latitude), museum collection registration numbers and photographic slide catalogue numbers is provided. Photographs were used to illustrate fish species in two different field identification guides. One covered commercial species and was distributed to the fishing industry and to AFZ observers to assist accurate species identification for logbook entries. The second covered most species caught during the study period and was essential for determining catch compositions accurately and consistently. The collection of fishes included many undescribed and rare species, and the catch composition data permitted a scientific analysis of slope fish assemblages to be made.

Fishery prospects

- There is potential for commercial multispecies demersal trawling on the southern region (south of ~ 28°S.) of the upper slope in the WDWTF. Trawling would be based on a suite of species dominated by big-spined boarfish and mirror dory. Insufficient data are currently available to assess the size of the resource or the productivity of the region. Promotion of deepwater species in the WA marketplace will be required to establish a successful fishery.

- Exploratory fishing (trawling and searching for fishing grounds) by experienced personnel on well-equipped domestic trawlers, two joint-venture factory trawlers and on FRV *Southern Surveyor* failed to find evidence of a mid-slope demersal fish resource in the WDWTF.

5.2 Introduction

The discovery and subsequent exploitation of demersal fish resources on the Australian continental slope in recent years has provided the impetus for exploration of previously unfished waters around southern Australia. In particular, the rapid expansion of the fishery for orange roughy (*Hoplostethus atlanticus*) has accelerated the exploration of the mid-slope region (~750–1200 m) in south-eastern Australia and in the eastern Great Australian Bight (GAB), e.g., Bulman *et al.* (in press), Newton and Klaer (1991), respectively.

Until recently, however, the continental shelf and slope waters of the extensive western coastline of Western Australia (WA) were largely unexplored by demersal trawlers. Prior to 1989, when the present study began, the only documented offshore exploration was a survey undertaken by a Japanese factory trawler in 1978 that had WA Fisheries Department observers aboard (Heald and Walker 1982). That survey concentrated primarily on the continental shelf and the information collected, pertained mainly to commercial shelf species in less than 200 m. Some catch composition data from the upper continental slope to a depth of 602 m were also collected, but the number of deep trawls was small. Data from Soviet trawl survey work conducted off WA prior to the declaration of Australia's Exclusive Economic Zone remain unavailable to this time. In essence, practically no data were available from the west coast of WA on the slope fish species that were of major commercial importance elsewhere in Australia and, from an ichthyological perspective, the west-coast outer shelf and slope remained virtually unsampled (Paxton *et al.* 1989).

The need for management of offshore resources in newly explored areas led to the introduction of developmental management plans for a number of regions including, in 1987, the Western Deep Water Trawl Fishery (WDWTF) off the west coast of WA (Fig. 1.2). Between 1990 and 1992, the first exploratory fishing on the slope region by suitably equipped commercial and research vessels took place. A study of the demersal fishes taken by these fishing operations was the basis of a research project undertaken by the CSIRO Division of Fisheries at the Marmion Laboratories between March 1989 and June 1992. The research on fishes was part of a larger project to examine deepwater resources including crustaceans; the stated objectives of the study applicable to demersal fishes were as follows:

- to identify potentially commercial stocks of fish within the WDWTF and NWSTF.
- to maintain a logbook program giving special emphasis to species-specific catch and effort information on prawns, finfish and squid.
- to assess the species composition of the discarded portion of the catch.

Data came from two primary sources: first, a logbook program (see Chapter 3.2; p. 35) was established in the first year of the project and subsequently supported with a seagoing scientific observer program (see Chapter 3.1; p. 31), and second, an exploratory fishing survey undertaken by FRV *Southern Surveyor* (see Chapter 5.3; below).

The results of this study are presented here (Chapter 5) and the following research areas are detailed: results of the CSIRO survey, summaries of the commercial catch and effort in the WDWTF in 1990 and 1991, summaries of information on a range of commercial species taken in the fishery, a description of the specimen collections and photographic records made and an account of the continental-slope fish assemblages.

5.3 CSIRO Exploratory Fishing Survey of the Western Deep Water Trawl Fishery

Introduction and survey objectives

The WDWTF is a developmental fishery off the west coast of WA, bounded in the north by the 114°E. meridian (North West Cape), in the south by the 115°08'E. meridian (Cape Leeuwin) and by the 200 m isobath and the AFZ boundary. Prior to 1989, when the present study began, knowledge of the west-coast offshore fishes was confined mainly to commercial species from the continental shelf (Heald and Walker 1982). Limited catch composition data had been collected from a small number of trawls made on the upper-continental slope to a depth of 602 m (Heald and Walker 1982), however, the greater part of the outer shelf and slope was unexplored. Accordingly, the survey objectives were aimed at documenting some of the more fundamental characteristics of the fishery. The primary objectives of the survey were:

- To identify the distributions of potentially commercial stocks of fish in the WDWTF by latitude and depth.
- To provide information on catch rates, abundance and catch composition of dominant fish species in relation to depth and locality.
- To provide information on distribution of fishing grounds and bottom features.
- To provide a scientific description of the WA slope fish community.
- To obtain taxonomic specimens and photographic records of fish species.
- To obtain taxonomic specimens and record distribution of squid and crustacean species by latitude and depth.

Survey design and data analysis

Survey design

An integrated sampling design combined predetermined trawl stations on transects to provide records of fish distribution by latitude and depth, and target stations on acoustic marks and topographic features to provide information on fish aggregations. This approach was best suited to sampling the great horizontal and vertical range of this fishery (1000 n.m. between the northern and southern boundaries, 200–1400 m depth range) considering first, the time available (30 days), and second, the expectation that many commercial species would be highly aggregated or concentrated on rough bottom. This design was also feasible given the limited historical data on the distribution of commercial stocks, the lack of reliable bathymetric information, and the lack of recognised trawl grounds.

The area between the northern and southern boundaries of the fishery was divided into eight 100' blocks of latitude within which 16 oblique transects zig-zagged across the continental slope between the 200 m and 1400 m isobaths (Fig. 5.3.1; Table 5.3.1). Within each block, 6 depth strata (200–400 m, 400–600 m, 600–800 m, 800–1000 m 1000–1200 m, and 1200–1400 m) were sampled at predetermined positions that were allocated in two groups (i.e., strata 1, 3, 5, and 2, 4, 6) on alternate transects. Trawls at these stations were of 30 min duration (bottom time).

Table 5.3.1 WDWTF exploratory fishing survey: details of transects

Transect no.	Start		Finish		Distance (n.m.)
	Latitude; Longitude	Depth (m)	Latitude; Longitude	Depth (m)	
1	21°40' S.; 114°00' E.	200	21°49' S.; 113°47' E.	~400	16
	21°49' S.; 113°47' E.	~400	22°10' S.; 113°10' E.	1400	40
2	22°10' S.; 113°10' E.	1400	23°20' S.; 113°15' E.	200	71
3	23°20' S.; 113°15' E.	200	24°10' S.; 111°35' E.	1400	105
4	24°10' S.; 111°35' E.	1400	25°00' S.; 112°15' E.	200	62
5	25°00' S.; 112°15' E.	200	25°50' S.; 111°23' E.	1400	69
6	25°50' S.; 111°23' E.	1400	26°40' S.; 112°40' E.	200	86
7	26°40' S.; 112°40' E.	200	26°57' S.; 112°24' E.	~500	28
	26°57' S.; 112°24' E.	~500	27°30' S.; 112°09' E.	1400	35
8	27°30' S.; 112°09' E.	1400	28°00' S.; 112°52' E.	~700	48
	28°00' S.; 112°52' E.	~700	28°23' S.; 112°52' E.	1100	22
	28°23' S.; 112°52' E.	1100	28°20' S.; 113°21' E.	200	25***
9	29°10' S.; 114°03' E.	200	29°26' S.; 113°40' E.	1400	25
10	29°26' S.; 113°40' E.	1400	30°00' S.; 114°30' E.	200	55
11	30°00' S.; 114°30' E.	200	30°50' S.; 114°29' E.	1400	50
12	30°50' S.; 114°29' E.	1400	31°40' S.; 115°07' E.	200	60
13	31°40' S.; 115°07' E.	200	32°30' S.; 114°24' E.	1400	63
14	32°30' S.; 114°24' E.	1400	32°37' S.; 114°29' E.	1000	8
	32°37' S.; 114°29' E.	1000	33°20' S.; 114°30' E.	200	43
15	33°20' S.; 114°30' E.	200	34°10' S.; 114°03' E.	1400	55
16	34°10' S.; 114°03' E.	1400	35°02' S.; 114°26' E.	1400	55
	35°02' S.; 114°26' E.	1400	35°02' S.; 115°08' E.	200	35

Total steaming distance on 16 transects estimated at .... 1056 n.m. @ 7 knots = 151 h
Time for fishing stations .... 96 stations @ 2·5 h = 240 h
Steaming from Port Hedland to WDWTF at 20°20'S.; 114°00' E.. 260 n.m. @10 knots = 26 h
Steaming to and from Geraldton .... 107 n.m. @ 10 knots = 11 h
Steaming from WDWTF at 35°02'S.; 115°08'E. to Albany .... 150 n.m. @ 10 knots = 15 h
Time for docking (Port Hedland, Geraldton, Albany) = 6 h
Time in Geraldton = 24 h
Time lost at ends of cruise in Port Hedland (12 h) and Albany (15 h) = 27 h
Time remaining for directed fishing or contingencies (~ 9 days) = 220 h
Total time (30 days) .... 720 h

***Steam to and from Geraldton, 107 n.m.

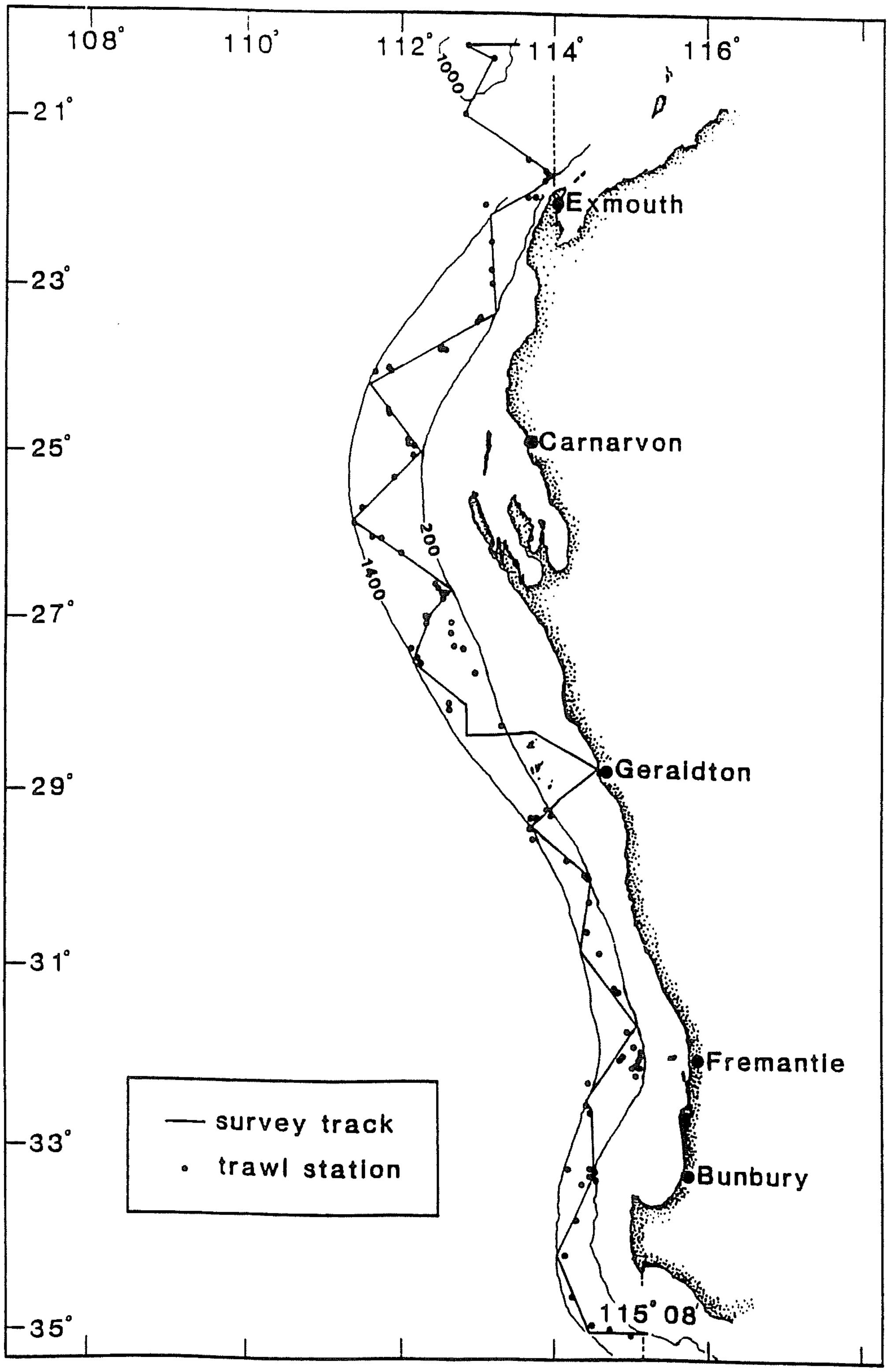


Fig. 5.3.1 WDWTF exploratory fishing survey: map of WA west coast showing survey track, trawl stations, fishing blocks and 200 m and 1400 m isobaths.

In addition to these stations, up to six trawls on acoustic marks per block could be made if suitable marks were found; seven days were allocated to investigate a list of target areas (Table 5.3.2) that included the Rottnest Canyons and the Exmouth Plateau. Transects were plotted to intersect these target areas. Any loss or gain of time during survey was balanced around these directed fishing operations.

The fishing gear used throughout the survey was a combination of 'Polyvalent' trawl doors and a 'High-rise' Engel trawl net fitted with heavy ground gear and a 40 mm cod-end liner. Scanmar transducers permitted the monitoring of net geometry and trawl-door spread for all trawls made in depths of less than 1200 m. In deeper water, a Furuno FNR 700 net recorder was used to monitor headline height and no trawl-door transducers were used. The echo sounders used during the survey were a Furuno FE881 (28 kHz), a Simrad EK500 (38 kHz) and Simrad EK400 (12 kHz). The water column was acoustically surveyed continuously while underway.

A Photosea 2000 stereo camera was used for underwater photographic surveying of aggregations and on topographic features where the ground was deemed to be untrawlable.

The composition of each trawl catch was recorded by weights and numbers for all species present, and taxonomic specimens were collected and photographed. Biological information was recorded for commercial species.

Data analysis

Data were analysed to provide summaries of the distribution of catch and effort, catch rates and estimates of biomass. For computation of mean catch rates, trawl catch data were transformed to a measure of kilograms caught per hour of fishing time (net on bottom) and averaged using all records from a particular latitude block or depth stratum. Data from predetermined stations were treated separately from target stations and data from aborted stations were not included. Replicate station data were removed from analyses by fishing block as these were concentrated in Block 2. All catch data are displayed for commercial and non-commercial species groups. Calculation of biomass expressed the total weight of fish (g) per swept area of tow (m^2). Swept area was calculated from tow speed (knots) · 1·852 (km · n.m.$^{-1}$) · tow duration (net time on the bottom, in hours) · 0·019 (estimated wing spread in km).

Data were analysed using a range of multivariate statistical techniques to describe community structure. Full details are given in Chapter 5.6.

Results

The survey was completed in two legs: the first (21 January–4 February) covered the area between the Exmouth Plateau and Geraldton and the second (5 February–19 February) from Geraldton to Cape Leeuwin. A total of 95 trawls were attempted in depths from 200–1460 m (Table 5.3.3).

Table 5.3.2 WDWTF exploratory fishing survey: details of fishing targets

Target	Area
A	**Exmouth Plateau** Approximately 48 hours are allocated to fishing this area commencing from the point of entry to the Western Deep Water Trawl Fishery at ~20°20'S.; 114°00'E. By virtue of the large area involved this was limited to two transects across the plateau: to the centre of its shallowest region (~20°20'S.; 112°51'E. in 700–800 m) and then from this point across the Monte Bello Trough to the 200 m station at the beginning of Transect 1 (21°40'S.; 114°00'E.). The path taken across the Monte Bello Trough crossed the hill feature at ~ 20°56'S.; 113°37'E.
B	**Plateau in 400 m at position 21°49'S.; 113°47'E.** This area is crossed by Transect 1.
C	**Hill and canyon in 1200–1400 m at end of Transect 1.** This area is crossed by Transect 1.
D	**Hill in 500 m at position 26°57'S.; 112°24'E.** This area is crossed by Transect 7.
E	**Hill and canyon in 900–1400 m at position 28°23'S.; 112°52'E.** This is a extensive and interesting area crossed by Transect 8.
F	**Plateau in 400 m at position 29°15'S.; 113°55' E.** This area is crossed by Transect 9.
G	**Plateau in 1400 m at position 30°43'S.; 114°29'E.** This area is crossed by Transect 11.
H	**Twin hill feature peaking at ~1700 m at position 31°13'S.; 114°42'S.** This feature appears to be in water deeper than the lower limit to be surveyed. However, it is an interesting feature.
I	**The Perth canyons** This is an extensive area of canyons with one large hill peaking at ~900 m and a second large hill peaking at ~1300 m. It is the single most interesting feature appearing on the draft deepwater bathymetric charts and as such deserved close examination. The close proximity of this area to Perth makes it well suited to further exploration and development if fish resources are discovered there.
J	**Hill feature at position 32°37'S.; 114°29'S.** This area is crossed by Transect 14.
K	**Mid-slope adjacent to Cape Leeuwin ~34°S.–35°S.** The time remaining for directed fishing during the last 3–4 days of the survey will concentrate on hill features on the mid-slope in this region.

Table 5.3.3 Details of stations and transects on FRV *Southern Surveyor* survey of the Western Deep Water Trawl Fishery. (– not applicable or data not available.)

Tran-sect no.	Stn no.	Stn type*	Date	Time Start–finish	Position Start lat.; long. (°S.) (°E.)	Finish lat.; long. (°S.) (°E.)	Course (°)	Depth Start–finish (m)	Stratum or depth range (m)	Catch rate (kg h^{-1})	Catch wt. (kg)	Trawl time (min)	Trawl speed (knots)	Head line (m)	Board spread (m)	Notes
–	1	–	23.1.91	–	–	–	–	–	–	–	–	–	–	–	–	Waypoint #1
–	2	E	23.1.91	0605–0635	20°16·5'; 113°13·5'	20°17·8'; 113°12·3'	210	913–914	913–914	6·51	3·04	28	2·8	4·2	66·0	–
–	3	E	23.1.91	1025–1055	20°07·8'; 112°55·1'	20°07·8'; 112°56·3'	120	868–854	854–868	61·40	30·7	30	3·2	4·6	67·0	–
–	4	E	23.1.91	2010–2100	20°55·4'; 112°51·5'	20°53·2'; 112°52·3'	40	1139–1128	1120–1180	18·12	15·1	50	2·8	–	–	–
–	5	E	24.1.91	0530–0605	21°28·2'; 113°38·6'	21°28·9'; 113°40·2'	140	1022–1023	1022–1023	18·51	10·8	35	2·8	3·2	77·2	–
–	6	T	24.1.91	0934–0937	21°37·5'; 113°55·8'	21°37·5'; 113°55·8'	210	328–328	328–328	0	1·08	0	2·8	–	–	Abort
–	7	T	24.1.91	1100–1130	21°39·3'; 113°58·2'	21°37·9'; 113°59·3'	30	209–215	209–215	133·60	66·8	30	2·8	4·0	–	–
1	8	P	24.1.91	1436–1452	21°44·7'; 113°52·3'	21°44·5'; 113°52·5'	30	320–290	200–400	0	38·6	0	3·2	4·3	–	Abort
1	9	P	24.1.91	1700–1720	21°44·4'; 113°52·2'	21°43·4'; 113°53·2'	40	274–273	200–400	0	0·07	0	3·0	6·4	–	Repeat, abort
1	10	P	24.1.91	2015–2100	21°50·6'; 113°46·7'	21°49·1'; 113°47·6'	30	685–650	600–800	7·12	3·56	30	3·0	–	–	–
1	11	P	24.1.91	0015–0045	21°54·1'; 113°40·7'	21°51·5'; 113°41·7'	30	1158–1100	1000–1200	12·40	6·2	30	3·0	–	–	–
1	12	P	25.1.91	0740–0810	22°00·5'; 113°08·4'	21°58·7'; 113°08·7'	15	1460–1700	1460–1700	0	7·69	0	2·8	–	–	Abort
2	13	P	25.1.91	1355–1440	22°28·6'; 113°12·4'	22°26·2'; 113°12·3'	0	1258–1305	1200–1400	27·44	20·58	45	3·0	–	–	–
2	14	P	25.1.91	1938–2010	22°47·4'; 113°13·2'	22°45·8'; 113°13·6'	15	880–910	800–1000	9·79	5·22	32	3·0	4·3	68·0	–
2	15	P	26.1.91	0110–0140	22°59·9'; 113°14·3'	22°57·6'; 113°14·4'	30	482–544	400–600	22·04	11·02	30	3·0	–	–	–
3	16	P	26.1.91	0630–0700	23°25·4'; 113°03·9'	23°23·7'; 113°05·5'	20	297–311	200–400	79·96	39·98	30	3·0	–	–	–
3	17	P	26.1.91	0825–0900	23°25·4'; 113°03·9'	23°23·6'; 113°05·1'	30	300–302	200–400	295·76	167·6	34	3·2	4·2	–	Replicate
3	18	T	26.1.91	1520–1550	23°46·4'; 112°36·5'	23°44·8'; 112°36·8'	15	576–587	576–587	0	0	0	3·2	4·0	–	Abort
3	19	P	26.1.91	2010–2040	23°44·6'; 112°35·5'	23°42·9'; 112°35·9'	350	612–620	600–800	25·12	12·56	30	3·0	–	–	–
3	20	P	26.1.91	2215–2245	23°44·8'; 112°35·3'	23°42·7'; 112°35·9'	10	612–623	600–800	0		0·05	0	–	–	Repl., abort
3	21	P	27.1.91	0550–0630	24°00·4'; 111°54·1'	23°58·7'; 111°54·4'	15	1060–1064	1000–1200	37·04	23·46	38	3·0	–	–	–
3	22	P	27.1.91	0855–0925	23°59·5'; 111°54·1'	23°57·6'; 111°54·3'	10	1061–1071	1000–1200	85·20	42·6	30	3·0	–	–	Replicate
4	23	P	27.1.91	1500–1545	24°09·6'; 111°39·5'	24°07·5'; 111°39·4'	20	1293–1320	1200–1400	65·08	32·54	30	3·0	–	–	–
4	24	P	28.1.91	0050–0130	24°30·2'; 111°50·9'	24°28·1'; 111°51·4'	20	892–905	800–1000	20·44	10·22	30	3·0	–	–	–
4	25	P	28.1.91	0245–0330	24°30·6'; 111°50·4'	24°32·2'; 111°48·5'	210	895–901	800–1000	26·68	13·34	30	2·5	–	–	Replicate
4	26	P	28.1.91	0840–0905	24°51·3'; 112°07·1'	24°49·9'; 112°07·1'	10	467–478	400–600	50·76	21·15	25	3·2	–	–	–

Transect no.	Stn no.	Stn type*	Date	Time Start–finish	Position Start lat.; long. (°S.) (°E.)	Finish lat.; long. (°S.) (°E.)	Course (°)	Depth Start–finish (m)	Stratum or depth range (m)	Catch rate (kg h^{-1})	Catch wt. (kg)	Trawl time (min)	Trawl speed (knots)	Head line (m)	Board spread (m)	Notes
4	27	T	28.1.91	1205–1235	24°52·9'; 112°07·8'	24°51·6'; 112°06·9'	350	444–468	444–468	45·10	22·55	30	3·2	4·1	–	–
4	28	T	28.1.91	1433–1525	24°55·7'; 112°11·4'	24°53·4'; 112°11·2'	5	318–344	318–344	1931·32	1706	53	3·3	3·9	–	–
5	29	P	28.1.91	1840–1910	25°07·2'; 112°09·4'	25°05·1'; 112°09·3'	20	306–319	200–400	0	0	0	3·0	–	–	Abort
5	30	P	28.1.91	2100–2135	25°07·5'; 112°09·3'	25°09·0'; 112°09·5'	170	312–312	200–400	105·70	61·66	35	3·2	–	–	Repeat 29
5	31	P	29.1.91	0140–0215	25°19·1'; 111°56·5'	25°17·2'; 111°56·3'	350	612–610	600–800	21·14	12·33	35	3·2	3·6	–	–
5	32	P	29.1.91	0710–0740	25°41·2'; 111°30·9'	25°42·4'; 111°30·3'	190	1115–1125	1000–1200	41·40	20·7	30	3·0	–	–	–
6	33	P	29.1.91	1225–1300	25°52·1'; 111°27·2'	25°49·5'; 111°26·5'	350	1254–1277	1200–1400	80·57	47	35	3·0	–	–	–
6	34	T	29.1.91	2025–2055	26°02·1'; 111°39·3'	26°01·3'; 111°37·9'	300	1000–1005	1000–1005	0	0	0	3·0	–	–	Abort
6	35	P	30.1.91	0020–0045	26°05·3'; 111°46·7'	26°04·4'; 111°47·1'	10	882–874	800–1000	50·71	21·13	25	3·2	–	–	–
6	36	P	30.1.91	0435–0510	26°14·5'; 112°03·2'	26°12·8'; 112°02·4'	350	690–691	600–800	26·93	15·71	35	3·0	4·0	77·0	–
6	37	P	30.1.91	1005–1035	26°35·7'; 112°29·0'	26°37·8'; 112°29·7'	160	508–500	400–600	0	721·8	0	–	43·0	74·0	Abort
6	38	P	30.1.91	1630–1710	26°40·4'; 112°32·7'	26°42·9'; 112°33·5'	170	478–456	400–600	88·22	58·81	40	3·0	3·6	76·0	Repeat 37
7	39	P	30.1.91	1910–1940	26°42·6'; 112°41·1'	26°40·8'; 112°40·5'	340	200–194	200–400	38·46	19·23	30	3·0	4·5	69·0	–
7	40	P	30.1.91	2135–2137	26°42·3'; 112°38·4'	26°42·1'; 112°38·5'	160	285–285	200–400	0	10·6	0	3·0	–	–	Abort
7	41	P	31.1.91	0312–0355	26°45·0'; 112°36·6'	26°47·3'; 112°35·9'	210	346–367	200–400	77·58	55·6	43	3·2	4·0	74·0	–
7	42	P	31.1.91	0628–0658	26°57·0'; 112°22·3'	26°58·2'; 112°21·4'	210	666–688	600–800	31·04	15·52	30	3·2	–	–	–
7	43	P	31.1.91	1005–1035	27°06·8'; 112°22·9'	27°05·0'; 112°22·3'	350	714–713	600–800	45·24	22·62	30	3·2	4·6	83·0	–
7	44	P	31.1.91	1500–1530	27°22·1'; 112°10·8'	27°20·6'; 112°10·4'	350	1009–996	1000–1200	53·22	26·61	30	3·0	–	–	–
8	45	P	31.1.91	1930–1930	27°28·5'; 112°13·4'	27°35·5'; 112°12·0'	130	750–900	1000–1200	0	0	0	–	–	–	Abort
8	46	P	31.1.91	2130–2140	27°32·8'; 112°15·1'	27°33·2'; 112°15·5'	130	1107–140	1000–1200	0		0	0	2·9	–	Repeat, abort
8	47	P	1.2.91	0015–0040	27°32·8'; 112°15·2'	27°33·4'; 112°16·0'	136	1104–110	1000–1200	19·44	8·1	25	3·0	3·5	82·0	Repeat
8	48	P	1.2.91	0950–1020	28°00·0'; 112°41·0'	27°58·0'; 112°42·1'	10	945–946	800–1000	42·96	20·05	28	3·0	–	–	–
8	49	P	1.2.91	1235–1315	28°04·1'; 112°42·6'	28°00·6'; 112°41·9'	347	854–853	800–1000	114·21	76·14	40	3·0	3·5	80·0	–
–	50	E	2.2.91	0615–0620	28°16·8'; 113°17·8'	28°16·8'; 113°17·8'	350	520–520	520–520	0	6·104	0	3·0	–	–	Abort
–	51	E	2.2.91	1610–1640	27°17·2'; 112°45·2'	27°15·8'; 112°44·5'	350	510–520	510–520	43·12	21·56	30	3·5	4·8	86·0	–
–	52	T	2.2.91	1930–2015	27°08·8'; 112°44·8'	27°06·4'; 112°44·1'	350	438–370	370–438	106·81	76·55	43	3·0	3·4	84·0	–
–	53	E	3.2.91	0110–0145	27°04·7'; 112°44·7'	27°03·4'; 112°43·2'	340	303–333	303–333	0	2·05	0	3·3	–	–	Abort
–	54	E	3.2.91	0615–0650	27°23·0'; 112°51·9'	27°20·8'; 112°51·8'	350	306–279	279–306	262·63	153·2	35	3·3	3·6	72·0	–
–	55	E	3.2.91	1230–1236	27°38·2'; 113°00·1'	27°38·7'; 113°00·6'	340	248–252	248–252	0	0	0	3·0	3·6	56·0	Abort
9	56	P	6.2.91	0955–1030	29°15·8'; 113°56·8'	–	350	320–325	200–400	426·86	249	35	3·0	3·7	83·0	–

Tran-sect no.	Stn no.	Stn type*	Date	Time Start–finish	Position Start lat.; long. (°S.) (°E.)	Finish lat.; long. (°S.) (°E.)	Course (°)	Depth Start–finish (m)	Stratum or depth range (m)	Catch rate (kg h^{-1})	Catch wt. (kg)	Trawl time (min)	Trawl speed (knots)	Head line (m)	Board spread (m)	Notes
9	57	P	6.2.91	1400–1445	29°20·5'; 113°58·3'	29°18·6'; 113°56·8'	330	490–505	400–600	104·36	52·18	30	3·0	4·3	76·0	–
9	58	P	6.2.91	1840–1910	29°21·8'; 113°46·6'	29°20·4'; 113°45·9'	330	942–970	800–1000	89·12	44·56	30	3·0	3·6	88·0	–
9	59	P	7.2.91	0705–0717	29°22·6'; 113°42·8'	29°22·0'; 113°43·9'	350	1160–1167	1000–1200	0	0	0	3·0	–	–	Abort
9	60	P	7.2.91	1114–1115	29°28·9'; 113°42·3'	29°28·9'; 113°42·3'	350	1160–1160	1000–1200	0	0	0	–	–	–	Abort
9	61	P	7.2.91	1535–1605	29°35·4'; 113°44·9'	29°34·0'; 113°44·7'	355	1132–1136	1000–1200	69·54	34·77	30	3·0	4·0	100·0	Repeat 60
10	62	P	7.2.91	2230–2300	29°51·9'; 114°11·6'	29°50·3'; 114°10·9'	350	770–760	600–800	13·74	6·87	30	3·0	3·2	90·0	–
11	63	P	8.2.91	0940–1010	30°01·2'; 114°29·2'	29°59·7'; 114°28·4'	335	255–265	200–400	33·34	16·67	30	3·0	3·8	70·0	–
11	64	T	8.2.91	1135–1210	30°00·1'; 114°27·8'	29°58·1'; 114°27·1'	355	380–380	360–380	764·91	446·2	35	3·0	3·9	79·0	–
11	65	P	8.2.91	1430–1500	30°00·0'; 114°27·1'	29°58·6'; 114°26·5'	340	480–490	400–600	145·66	72·83	30	3·0	3·6	86·0	–
11	66	P	8.2.91	2145–2215	30°16·7'; 114°30·2'	30°15·2'; 114°29·7'	350	684–684	600–800	22·34	11·17	30	3·2	3·5	88·0	–
11	67	P	9.2.91	0710–0735	30°39·1'; 114°27·7'	30°39·0'; 114°27·6'	350	1058–1080	1000–1200	14·50	6·04	25	3·0	–	–	–
12	68	P	9.2.91	1336–1407	30°51·9'; 114°37·3'	30°50·5'; 114°36·9'	350	893–887	800–1000	98·63	42·74	26	2·4	3·0	95·0	–
12	69	T	9.2.91	2019–2031	31°16·2'; 114°50·2'	31°16·8'; 114°50·3'	340	613–614	613–614	0	5·32	0	3·0	–	–	Abort
12	70	T	9.2.91	2240–2320	31°17·0'; 114°52·6'	31°14·9'; 114°52·3'	350	475–512	475–512	91·62	61·08	40	3·2	3·5	79·0	–
13	71	P	10.2.91	0823–0855	31°44·7'; 114°59·7'	31°43·0'; 114°58·7'	340	390–485	200–400	258·00	129	30	3·2	3·4	76·0	–
13	72	P	10.2.91	1240–1310	32°02·3'; 114°54·5'	32°00·8'; 114°55·0'	0	670–640	600–800	80·92	40·46	30	3·2	4·4	77·0	–
–	73	E	10.2.91	1943–2026	31°53·2'; 115°05·7'	31°54·1'; 115°04·6'	205	411–550	350–550	71·55	51·28	43	3·1	5·0	–	–
–	74	E	11.2.91	0915–1015	31°55·2'; 115°10·2'	31°57·4'; 115°08·5'	210	320–850	320–850	125·40	104·5	50	3·2	4·0	75·0	–
–	75	T	11.2.91	1700–1735	32°09·8'; 115°02·8'	32°07·9'; 115°03·8'	25	484–470	470–484	611·66	356·8	35	2·9	4·0	82·0	–
–	76	T	12.2.91	0715–0750	32°07·9'; 115°06·7'	32°06·1'; 115°08·1'	30	308–295	295–308	175·37	102·3	35	3·2	4·5	70·0	–
–	77	T	12.2.91	0955–1020	32°04·9'; 115°09·4'	32°03·4'; 115°10·2'	30	270–285	270–285	1350·48	562·7	25	3·2	4·3	79·0	–
–	78	E	12.2.91	1310–1340	32°02·3'; 115°08·9'	32°00·6'; 115°09·7'	30	510–510	490–510	104·42	52·21	30	3·2	4·3	79·0	–
–	79	E	12.2.91	1945–2108	32°02·5'; 114°52·6'	32°05·3'; 114°51·3'	189	7001–200	700–1200	0	0	0	2·8	4·2	85·0	Abort
–	80	T	13.2.91	0930–1010	32°14·4'; 115°06·4'	32°12·4'; 115°05·5'	20	286–287	286–287	198·60	132·4	40	3·0	4·3	70·0	–
–	81	T	13.2.91	1230–1308	32°10·2'; 115°08·2'	32°08·4'; 115°09·0'	25	225–230	225–230	313·26	198·4	38	3·0	4·4	65·0	–
13	82	P	13.2.91	1935–2005	32°19·8'; 114°28·6'	32°18·3'; 114°29·0'	20	1280–1310	1200–1400	19·12	9·56	30	3·0	–	–	–
14	83	P	14.2.91	0735–0805	32°34·6'; 114°27·2'	32°33·0'; 114°25·8'	330	1030–1140	1000–1200	78·42	39·21	30	3·0	4·2	87·0	–
14	84	P	14.2.91	1148–1230	32°40·4'; 114°28·2'	32°38·8'; 114°26·4'	320	880–960	800–1000	125·66	83–·/7	40	–	4·2	82·0	–
14	85	T	14.2.91	2245–2320	33°17·9'; 114°12·6'	33°15·8'; 114°11·1'	330	982–982	982–982	85·97	50·15	35	3·0	4·5	85·0	–
14	86	T	15.2.91	0920–0950	33°18·9'; 114°31·9'	33°18·0'; 114°30·6'	310	220–220	220–220	0	0	0	3·2	–	–	Abort

Tran-sect no.	Stn no.	Stn type*	Date	Time Start–finish	Position Start lat.; long. (°S.) (°E.)	Finish lat.; long. (°S.) (°E.)	Course (°)	Depth Start–finish (m)	Stratum or depth range (m)	Catch rate (kg h^{-1})	Catch wt. (kg)	Trawl time (min)	Trawl speed (knots)	Head line (m)	Board spread (m)	Notes
14	87	P	15.2.91	2300–2325	33°17·9'; 114°30·8'	33°19·1'; 114°30·6'	360	468–430	400–600	53·83	22·43	25	3·2	5·0	72·0	–
15	88	T	16.2.91	0820–0950	33°24·1'; 114°31·4'	33°22·5'; 114°31·8'	10	203–204	203–204	174·12	87·06	30	3·3	5·0	62·0	–
15	89	P	16.2.91	1055–1125	33°22·9'; 114°29·6'	33°21·4'; 114°30·6'	5	399–350	200–400	507·20	253·6	30	3·2	5·0	58·0	–
15	90	P	16.2.91	1355–1425	33°25·5'; 114°21·0'	33°24·6'; 114°22·5'	45	817–780	800–1000	69·68	34·84	30	3·2	4·9	90·0	–
15	91	T	16.2.91	2155–2200	33°49·7'; 114°17·5'	33°49·7'; 114°17·5'	45	1050–1050	1050–1050	0	5·265	0	3·0	4·5	82·0	Abort
16	92	P	17.2.91	1040–1045	34°12·8'; 114°07·7'	34°12·8'; 114°07·7'	45	1240–1225	1200–1400	0	5·94	0	2·9	–	–	Abort
16	93	P	17.2.91	2300–2300	34°39·4'; 114°15·5'	34°39·4'; 114°15·5'	45	890–890	800–1000	0	0	0	3·0	–	–	Abort
16	94	P	18.2.91	1050–1120	34°56·9'; 114°29·3'	34°57·3'; 114°29·0'	215	900–958	800–1000	52·55	21·02	24	3·1	4·6	85·0	–
16	95	P	18.2.91	1615–1640	34°59·2'; 114°43·6'	35°00·2'; 114°42·9'	200	738–750	600–800	83·11	31·86	23	3·2	4·2	85·0	–
16	96	T	18.2.91	2140–2205	35°04·9'; 114°59·7'	35°05·9'; 114°58·4'	220	870–920	870–920	101·07	37·06	22	3·2	4·4	85·0	–

* P = predetermined; T = target; E = exploratory

For ease of presentation and interpretation of the survey results, the cruise narrative, description of catches and their interpretation are described separately for each of the two legs. This chapter contains a series of charts that summarise the catch weights and catch rates of commercial and non-commercial species in each of the depth strata and latitude blocks fished during the survey. In addition, these charts display the data from predetermined and target trawls separately and combined. In common with shelf and inshore fishes, slope species exhibit a transition from a mainly tropical to a mainly temperate assemblage with increasing latitude (see Chapter 5.6). There is an extensive zone of overlap and no distinct discontinuity. However, the greatest detectable change is in the region of 26–28°S., just north of Geraldton. For this reason, catches of commercial species are presented in two groups, a 'northern region' suite from north of 27°S. and a 'southern region' suite from south of 27°S. Several species, such as mirror dory, deepsea snapper and oreo dory, occurred in both.

Cruise narrative, Exmouth to Geraldton

On leaving Port Hedland, there was a 28-hour steam to the first exploratory fishing area, the Exmouth Plateau, a large offshore platform between 20°S. and 21°S. latitude in 800–1000 m depth. As no fishing records and very little bathymetric data were available for the Plateau region it was decided to search the highest area of the Plateau first and then move in a south-easterly direction towards the coast and the start of the first transect. We were unable to locate a ridge and hill feature shown on navigational charts near the centre of the Plateau and found only an undulating, featureless bottom. No evidence of fish concentrations was detected by the sounders or in two trawls made in this central area between 854 m and 914 m. On 23 January we proceeded in a south-easterly direction and completed two further exploratory trawl shots in 1022–1123 m. We passed over several deep topographic features (including a canyon and ridge feature south of the Monte Bello Trough), but no significant acoustic fish marks were detected until we reached the upper slope (200–300 m) whilst approaching the beginning of the first survey transect station at 21°45'S. in 200 m.

The remaining 11 days of the first leg of the cruise were devoted to a systematic trawl survey along eight transects extending from North West Cape to Geraldton (21°45'S.–28°45'S.) at depths from 200–1400 m. There were six depth strata at 200 m intervals, all of which were fished once in each pair of transects (seaward and landward). An important aspect of the survey design was the allocation of a substantial proportion of the cruise time to searching for and fishing topographic features and acoustic marks. This allocation of time also provided a buffer against time lost due to bad weather and gear repairs. Generally the fishing operations ran smoothly (although net deployment and retrieval took longer than anticipated) and, despite moderate sea conditions (wind Force 4–6), no time was lost due to the weather.

In total, 54 trawls were completed during the first leg; 38 of these were predetermined transect stations (which included replicates and repeats), nine were exploratory shots (i.e., not on fish marks) and the remaining seven were target shots on fish marks. Sixteen shots were aborted, due mainly to gear fouling on rough bottom; in the process two nets were damaged irreparably. In addition, five SDL drops were completed.

Description of catches, Exmouth to Geraldton

The fish catches were highly diverse and contained up to 39 species per shot with most species represented by small numbers of individuals. Most of the standard 0·5 h trawl shots yielded very small quantities of fish (often less than 20 kg). No fish species of potential commercial interest were caught in anything approaching commercial quantities. To the contrary, the species identified as being of interest prior to the cruise and that were expected to be in catches during the first leg, i.e., alfonsino (*Beryx splendens*), Darwins roughy (*Gephyroberyx darwini*), deepsea snapper (*Dentex tumifrons*), gemfish (*Rexea solandri*), John dory (*Zeus faber*), mirror dory (*Zenopsis nebulosus*), yellow-eyed nannygai (*Centroberyx australis*), warty oreo dory (*Allocyttus verrucosus*), and ruby snapper (*Etelis carbunculus*), were caught only in small quantities. Several of these species were represented only by very small individuals. The greatest catch rate of any of the above-mentioned species was 42 $kg \cdot h^{-1}$ of mirror dory.

The EK400 and EK500 sounders ran continuously during the survey and provided permanent records (printed echograms) of the bottom and acoustic targets. No large acoustic fish marks were recorded during this period except in the shallower reaches of the upper slope (350 m). In this shallower zone, bottom and mid-water fish aggregations were evident as strong acoustic marks but these apparently consisted of predominantly small, pelagic, semi-pelagic and mesopelagic 'bait fishes'. The largest single catch of the first leg (1706 kg) was taken during a 53 min target shot in 318 m in one such aggregation, and this was almost entirely made up by a small (15 cm) 'sea-bass', *Malakichthys* sp.

A fish identification catalogue was updated with Polaroid photographs and diagnostic characters of each species on a shot by shot basis to ensure consistency in identification and recording of catch composition over the duration of the survey. Representatives of each species were photographed on 35 mm film and retained for museum collections; these included several new species and new records of fish species in Australian waters. The fish species represented a predominantly subtropical biological community and most were different from those known from the deepwater trawl fisheries of the Great Australian Bight and south-eastern Australia. There were, however, several exceptions amongst the mesopelagic and deepwater benthic and benthopelagic fishes that were represented in particular strata along the range of the survey. One example was the oreo dory, which is common in the GAB and SEF and which was caught in 1160 m at the low latitude of 22°S.

Crustaceans and cephalopods were also recorded by species, weight and number at all stations. In total, about 59 species of crustaceans and 30 species of cephalopods were identified. The crustaceans caught on the upper continental slope (200–800 m) included several commercial species, that are currently being fished in the North West Slope Trawl Fishery. These included two species of scampi (*Metanephrops boschmai* and *M. velutinus*), the pink striped prawn (*Aristeus virilis*) and pink prawn (*Haliporoides sibogae*). A variety of crustaceans, including potentially commercial species, were caught in mid-slope depths (800–1700 m). Two species of bugs, *Ibacus alticrenatus* and *I. ciliatus pubescens*, were trawled in moderate numbers at depths of less than 400 m. The most common cephalopod caught was the pelagic Goulds arrow squid (*Nototodarus gouldi*). The number of crustaceans captured was higher than expected given the characteristics of the fishing gear (large net meshes and heavy bobbin gear) and suggested that crustaceans may have been present in significant numbers in the mid- and upper-slope depths of the area surveyed.

In summary, whilst a great diversity of fishes, crustaceans and cephalopods were caught, there were no catches large enough to indicate the presence of significant resources. Other than some strong acoustic marks from apparently small fish species in the shelf-break region (200–300 m), nothing of note was detected by echo sounders during this leg. Of interest were the catches of crustaceans in the upper-slope depths towards the northern end of the fishery.

Cruise narrative, Geraldton to Cape Leeuwin

After a day in the port of Geraldton, during which refuelling and change of some crew took place, we steamed to our first station on transect 9 on 5 February. Weather conditions deteriorated during this time (winds increasing to Force 8 on a moderate swell) which caused fishing operations to be delayed until the following day.

Due to the departure of one of the two Fishing Masters in Geraldton for compassionate reasons, the fishing operations were limited to 16–18 hour periods between approximately 0700 h and 2400 h. A night-time rostered sounder watch was established for scientific staff during this leg, to utilise the non-fishing time to searching for marks of interest. This proved useful on occasions when marks found at night could be fished first thing in the morning. However, it was often not possible to retrace our course because the distances involved were prohibitive.

During the first five days, during which the weather was consistently rough, 17 trawls were made between 29°16'S. and 32°02'S. The bottom over this stretch of the fishery was rough for large distances, and considerable time was spent searching for fish marks and enough trawlable ground for 30 min tows. Particular difficulty was experienced in trawling the deepest depth strata (1000–1200 m, 1200–1400 m) in this area due to soft mud, in which the gear tended to 'bog down', and to limestone slabs on which the gear came fast. During this period, some strong acoustic marks were found in upper-slope waters (350–500 m) and some moderately successful catches were made.

On 10 February, we arrived at the Perth Canyons, an area of particular interest for exploration due to its topography, depth range and latitude. The main arm of the canyon and the surrounding slope area, in depths from around 200 m to in excess of 1500 m, were systematically surveyed on a transect grid over three days. In addition, the 850–1100 m depth range was searched over most of the canyon area as it was of interest to know if the distribution of orange roughy extended this far north. Nine trawls were completed in this time; five of these were targeted at marks in 225–510 m and four were exploratory trawls in 320–1200 m. The underwater camera was deployed in the main canyon during a break in the weather on the second night. By 13 February the weather conditions had deteriorated, making target shots on the steep canyon walls extremely difficult. Since the surveying had been completed, we departed this area and continued with the remaining transect stations.

The last part of the second leg was a disappointing end to the survey: weather conditions were generally difficult and increased to Force 6 on a 6–7 m swell, and an early return to port was necessitated due to the medical condition of one of the scientific staff. During approximately five days, fifteen trawls were made; five were targeted shots and ten were on predetermined stations. A further two camera drops were made successfully. A greater proportion of rough ground was found as we progressed south, and several trawls were aborted due to gear fouling. Almost an entire day was lost after one hook-up, with the gear taking several hours to get off the bottom and a further eight hours being needed to fit a new net and ground gear.

One of the main interests in the southern area was the extent of the orange roughy resource. Accordingly, nine of these trawls and the majority of the searching conducted during this time occurred in waters between 900 and 1100 m. Several bottom features of interest such as small hills and ridges, and what were thought to be coral lumps, were detected. However, these were not like the large or extensive features that hold concentrations of mid-slope species, and no encouraging fish marks were seen. The absence of fish marks on the sounders was reflected in trawl catches, with no fish species being caught in quantity.

In total, 41 trawls were completed during the second leg: 24 were on predetermined transect stations, 13 were target shots on marks and four were exploratory shots in the Perth Canyons. Eight shots were aborted due to gear becoming fouled or bogged and one net was damaged irreparably. Three camera drops were made and seven SDL stations completed.

Description of catches, Geraldton to Cape Leeuwin

Some larger catches were made during the second leg but in general terms the trawls and acoustic returns were disappointing. Many of the potentially commercial fish species caught had been identified prior to the survey from this part of the fishery. However, others, including blue grenadier (*Macruronus novaezelandiae*), ling (*Genypterus blacodes*) and smooth dory (*Pseudocyttus maculatus*) were not taken.

In general terms, the best catches were made in upper-slope depths from 275–500 m. In these catches, big-spined boarfish (*Pentaceros decacanthus*) and mirror dory, two potentially commercial species, were often the dominant components of the catch. Highest catch rates for the two species were 519 $kg \cdot h^{-1}$ and 536 $kg \cdot h^{-1}$ respectively. The rock cod (*Epinephelus septemfasciatus*) was also caught in appreciable quantity (559 $kg \cdot h^{-1}$) in one shot.

A range of other potentially commercial species was caught in the shallower strata of the survey, including alfonsino, black-spotted boarfish (*Zanclistius elevatus*), conway (*Oplegnathus woodwardi*), Darwins roughy, king dory (*Cyttus traversi*), deepwater flathead (*Platycephalus conatus*), gemfish, latchet (*Pterygotrigla polyommata*), morwong (*Nemadactylus macropterus*), yellow-eyed nannygai, oilfish (*Ruvettus pretiosus*), ocean perch (*Helicolenus* sp., deep-sea snapper and tusk (*Dannevigia tusca*), None was caught in large quantities.

On the mid-slope, in depths greater than 800 m, catches were particularly small. The species of commercial interest in these depths, orange roughy, warty oreo dory, spiky oreo dory (*Neocyttus rhomboidalis*), deepsea perch (*Trachyscorpia capensis*) and ribaldo (*Mora moro*) were caught in very small quantities. Only one orange roughy, the species of principal interest, was caught.

The poor catches in the deeper water might have been expected from the lack of marks or appropriate topography detected on the echo sounders. Areas with bottom features such as small hills, ridges and 'coral lumps' were found. However, these tended to be small and were unlike the bottom features off southern Tasmania that hold the concentrations of fish from which the vast majority of Australia's mid-slope catches are taken. Not until we reached the most southerly extreme of the fishery, just west of the border with the GAB fishery, were any diffuse fish marks found consistently on the bottom in the mid-slope depths. The Perth Canyon area, which was searched fairly extensively, showed no signs of containing concentrations of fish in depths greater than 800 m — although it should be noted that in the canyon area no successful trawls were made in depths greater than 850 m.

Fish communities changed markedly during this leg with an apparent rapid shift towards temperate species in the Geraldton region and the appearance of a typical southern Australian fauna south of Perth.

Crustaceans and squid were collected during this leg but identifications on many of these are awaiting verification. Bugs were caught in modest quantities in depths less than 400 m with the best catch rate being 50 $kg \cdot h^{-1}$.

In summary, with the exception of some encouraging catches on the upper slope, indications of fish in trawl catches and on echo sounders were disappointing. The 16 survey transects were completed but gear and operational problems, as well as bad weather, did not permit as many exploratory and target trawls to be made as was planned. In particular, there was limited coverage of the most southerly part of the fishery.

Distribution of trawl stations

To provide a coverage of the fishery, 48 predetermined trawl stations were allocated evenly across the eight blocks with one in each of the six depth strata in each block. However, the final distribution of stations was unequal (Fig. 5.3.2*A*). In some blocks (1, 5, 6, 8) not all

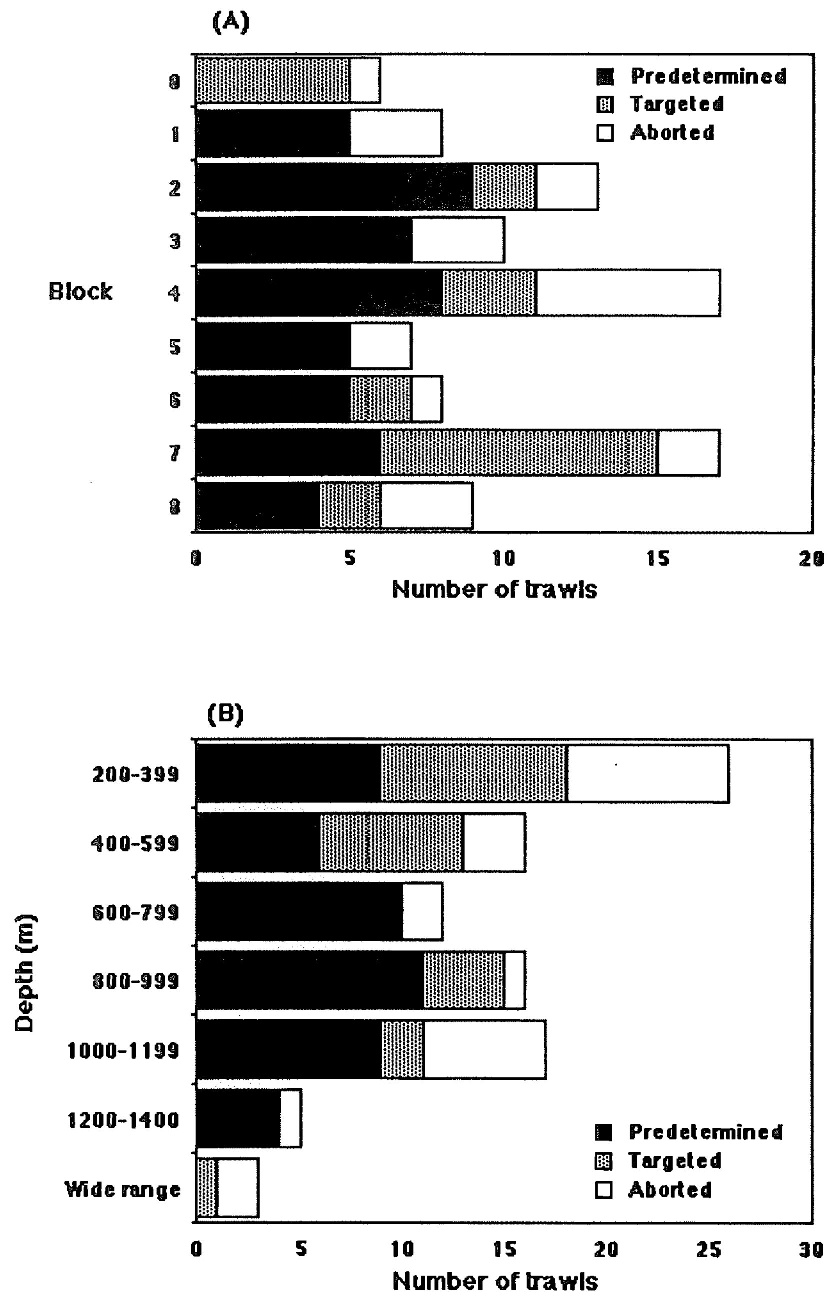


Fig. 5.3.2*A*–*B* WDWTF exploratory fishing survey: *A*, trawl types by fishing block; *B*, trawl types by depth stratum.

stations (or alternative locations) could be trawled and therefore the minimum number of six stations per block was not completed. In blocks 2, 3, and 4, replicate stations were completed. The minimum number of six stations per depth stratum was completed for all strata except the deepest (1200–1400 m) and duplicates were completed for some strata (Fig. 5.3.2*B*). The deepest stratum was the most difficult and time consuming to fish and no target or duplicate trawls were attempted.

The distribution of exploratory and target trawl stations (targeted trawls) was uneven, being concentrated in blocks 0, 4 and 7 and in the shallowest two strata. This concentration of targeted effort by block resulted from the investigation of the Exmouth Plateau (Block 0) and Rottnest Canyon (Block 7), and utilisation of the remaining time at the end of Leg 2 in an area just north of Geraldton (Block 4). The concentration of effort by depth was due to the relatively high number of fish marks targeted in the 200–400 m range. In deeper water, target effort occurred on the Exmouth Plateau and on the mid-slope (800–1200 m) south of Fremantle (Blocks 7 and 8). Three targeted shots exceeded a 200 m depth range and were termed 'wide range'.

Fish species: catches and interpretation

The distribution of catch rate by fishing block was examined for all trawls combined, and for predetermined and target trawls separately (Fig. 5.3.3*A–C*). There are a number of important points to note from these figures: first, the relatively large but uneven contribution made by the target trawls to the combined data; second, the relatively low proportions of commercial species in all except target trawls in Block 6. In addition, the high target trawl catch rate of non-commercial fish in Block 2 resulted from a single, very large catch of sea-bass, and the absence of any commercial species taken in the northern end of the fishery (Blocks 0 and 1). The relatively high target catch rates in Block 7 are due to target shots of big-spined boarfish, mirror dory and cod at the Rottnest Canyons.

The corresponding trawl summaries are also shown for each depth stratum (Fig. 5.3.4*A–C*). These show a general trend of decreasing catch rate with depth, for both commercial and non-commercial species. Catch rates of commercial species were negligible below 600 m, and no commercial species were caught in the deepest stratum (1200–1400 m).

Northern region (Exmouth to 27°S.)

No fish species were caught in commercial quantities in this region during the survey; the weights of the commercial species taken above 27°S., combined for all trawls, was extremely small (Fig. 5.3.5).

Deepsea (lenko) snapper, an almost miniature replica of pink snapper, were common in catches in 200–300 m but were never taken in quantity. Over 50 tonnes were taken by Japanese exploratory fishing in this area in the 1970s (Heald and Walker 1982), with largest catch rates from depths between 230 and 260 m. The small size of deepsea snapper, generally in the 13–21 cm range, probably

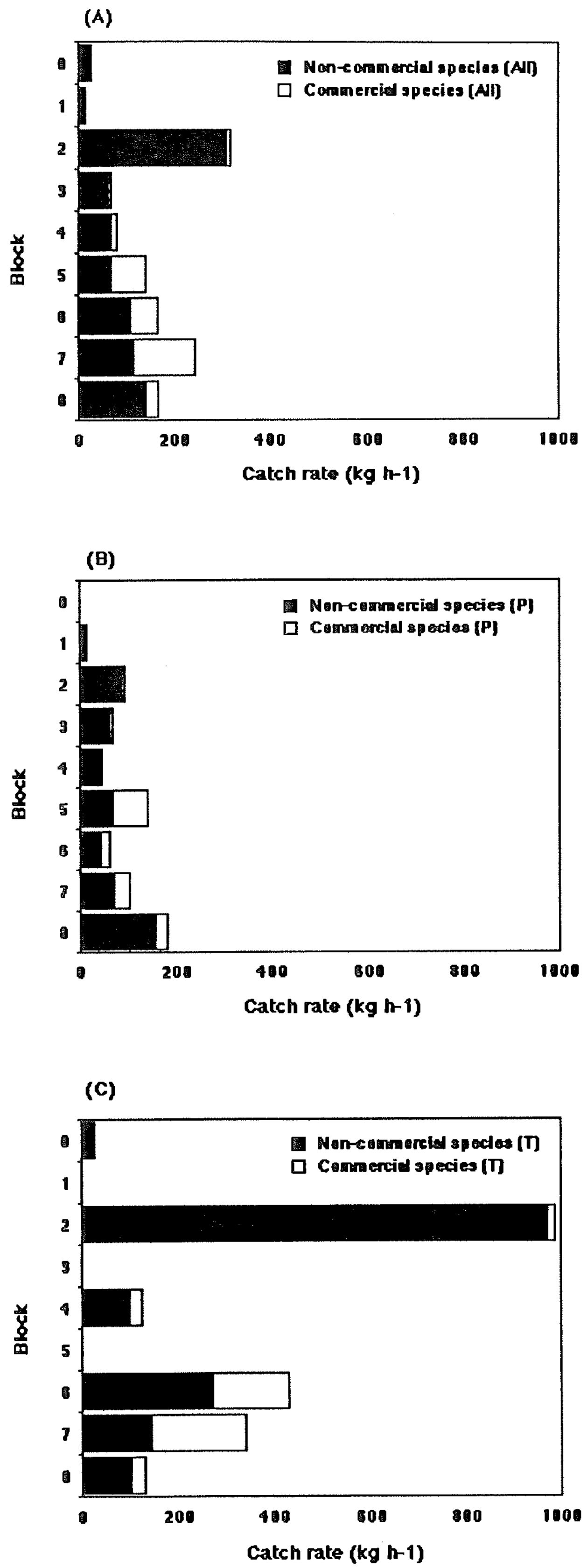


Fig. 5.3.3*A–C* WDWTF exploratory fishing survey: catch rates by block showing commercial and non-commercial species: *A*, all trawls; *B*, predetermined trawls only; *C*, target trawls only.

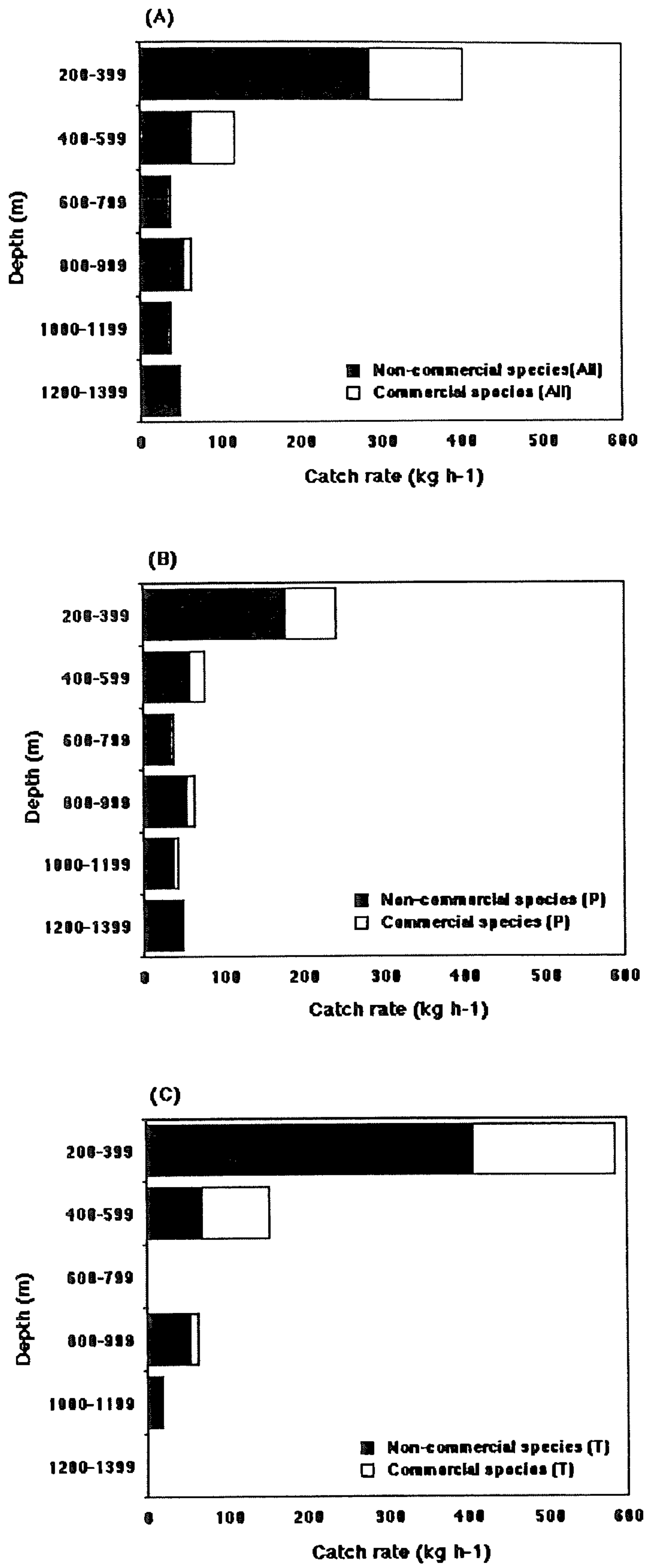


Fig. 5.3.4*A–C* WDWTF exploratory fishing survey: catch rates by depth stratum showing commercial and non-commercial species: *A*, all trawls; *B*, predetermined trawls only; *C*, target trawls only.

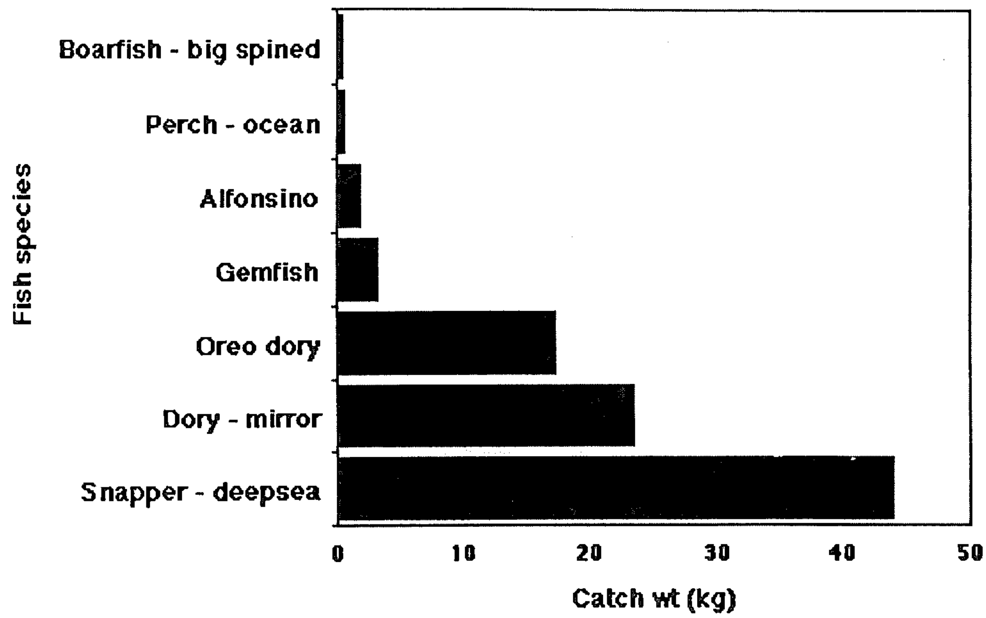


Fig. 5.3.5 WDWTF exploratory fishing survey: catch weights of commercial species from 'northern region' north of 27°S.

make them unattractive in the domestic marketplace. However, their potential as an export species to Japan may be worth investigation for several reasons: first, small sparid fishes (snappers) are highly prized in Japan; second, the records of Heald and Walker (1982) indicate the fish may be locally abundant; third, the fish are usually in good condition when landed and last, there is existing expertise in Carnarvon for shipping whole, chilled snapper to Japan.

Ruby snappers (jobfish or sharp-toothed snappers) were caught in only one shot, although it is known that they are present in appreciable quantities near the shelf break, i.e., in 200–250 m (Chapter 5.4). This is likely to be attributable to low vulnerability to our gear, which was heavy and towed relatively slowly, and to the fact that trawl duration was short (30 min) for fish that are fast moving and active swimmers.

Mirror dory were caught in quantity on the second leg, and it is assumed that they were vulnerable to the gear used. During the first leg, this species was present in several catches but the highest catch rate was only about 40 $kg \cdot h^{-1}$ and many of the fish taken were juveniles. Despite being distributed along practically the entire west and north-west coasts of WA, mirror dory appear to be relatively scarce north of Geraldton.

Oreo dory are one of a group of deepwater dories generally caught as by-catch to the orange roughy fishery. They occurred in many of the mid-slope catches along the entire coast but, in the northern region, always in small quantities that comprised only small fish. In other parts of southern Australia, it is widely distributed, often forming large schools over the mid-slope. However, in this region, oreo dory showed no potential for commercial exploitation.

A variety of prawns, scampi and bugs were caught in modest quantities on the upper slope, and several species of carid and penaeid prawns were caught on the mid-slope (see Chapter 4). These included a number of species taken commercially in the NWSTF. The relatively high numbers of some of these taken by an unsuitable gear (fish net and heavy ground gear) may indicate that significant numbers of crustaceans may have been present.

Southern region (27°S. to Cape Leeuwin), upper-slope region (200–700 m)

Several species were caught in encouraging quantities south of 27°S. although there were also poor catches of some other species of interest (Fig. 5.3.6). Ling and stargazer, previously recorded in low numbers from commercial catches in the WDWTF, were not caught during the survey.

Big-spined boarfish were caught in quantities of up to about 500 $kg \cdot h^{-1}$. They appeared to be fairly widespread in the 300–500 m depth range and to be locally abundant in this region. Despite having several 'unappealing' characteristics (it attains a size of less than 1 kg, is difficult to handle because of its large and sharp dorsal fin spines,

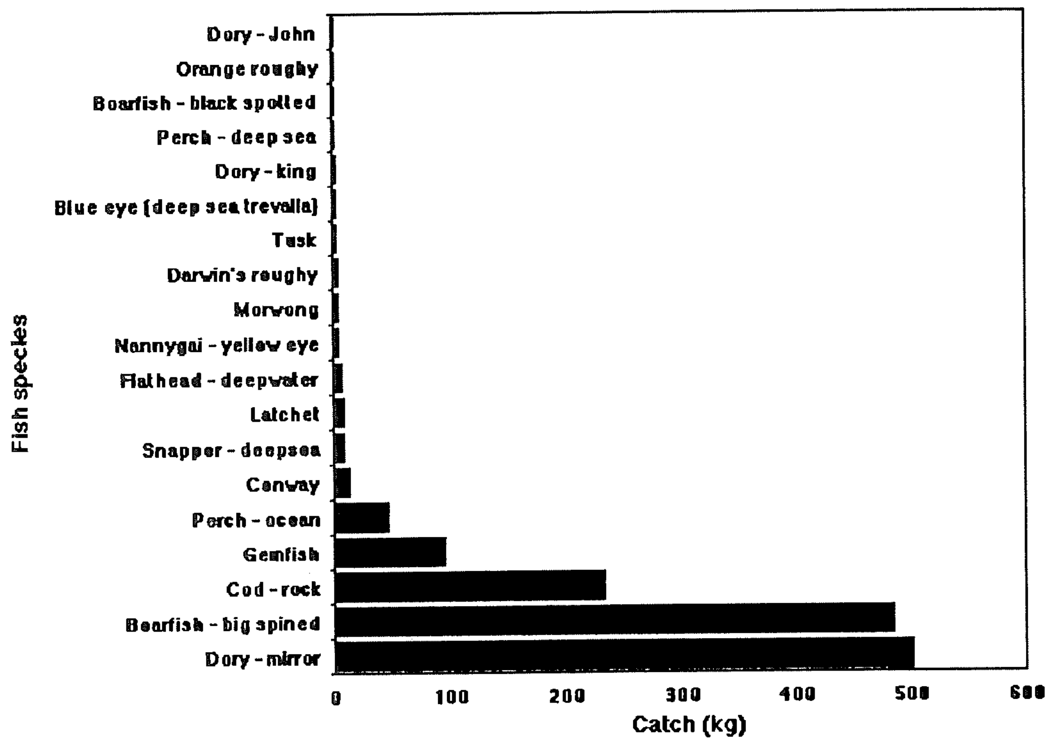


Fig. 5.3.6 WDWTF exploratory fishing survey: catch weights for commercial species from 'southern region' (south of 27°S.), upper-slope depths (200–700 m).

and has a tough skin), the flesh is both tasty and attractive in appearance. The species is a member of the boarfish family, which contains several shelf species, e.g., giant and long-snouted boarfishes, and would seem to have some potential in a multispecies-based upper-slope trawl operation. Whilst boarfishes are well regarded in parts of the domestic market, promotion and marketing will be needed to underpin a successful market entry of this previously unknown species, at least in WA.

Mirror dory were caught in quantities exceeding 500 $kg \cdot h^{-1}$ and are widespread along this section of the western Australian coast (as well as the north-western coast). The species is closely related to the cosmopolitan and highly prized John dory, and is well known in eastern -states domestic markets. The flesh is fine and the taste very good, but it will probably need promotion to be accepted on the WA market. It is likely to be a potentially important species in any multispecies trawl fishery based on the upper slope, and is often caught along with big-spined boarfish.

Gemfish appear to be widespread up the west coast and were caught in numerous trawls on the upper-slope region. However, catches were usually small and often only small fish were seen. Previous reports of running-ripe fish, and observation of one fish in spawning condition during this cruise may indicate the presence of a spawning stock off WA. Gemfish are a schooling species and are highly migratory. Commercial aggregations, if they exist, may therefore take a long time to track down (as was the case for the eastern Bass Strait stock).

Rock cod were caught in one shot only, but at a catch rate of over 550 $kg \cdot h^{-1}$, with all fish in the 10–20 kg range. In all probability, this species is not particularly vulnerable to trawl gear and may be best targeted by drop-lining. Interestingly, it was caught with hapuka (an important NZ commercial species) and a single deepsea trevalla, both of which are also likely to be more vulnerable to drop-line gear than trawls.

Shelf species: a number of commercially important shelf species were also taken in small quantities, e.g., morwong, flathead and knifejaw. Catch information from the GAB indicates that, in the GAB fishery, these species are more likely to occur in quantity in depths < 200 m.

Southern, mid-slope region (700–1400 m)

This region produced generally small catches (Fig. 5.3.7). and little of interest was seen on the sounders despite a disproportionately high allocation of time to searching the 850–1100 m depth range for orange roughy ground. The number of successful trawls made in this depth range during Leg 2 was fewer than was planned, for the reasons outlined in the cruise narrative. Blue grenadier and smooth dory, previously recorded from this fishery by CSIRO, were not caught during the survey.

Orange roughy was the species of principal interest in this area but only one fish was caught. No ground with the apparent potential to hold aggregations of orange roughy was found. The highly seasonal nature of the fisheries for roughy in some areas (particularly when

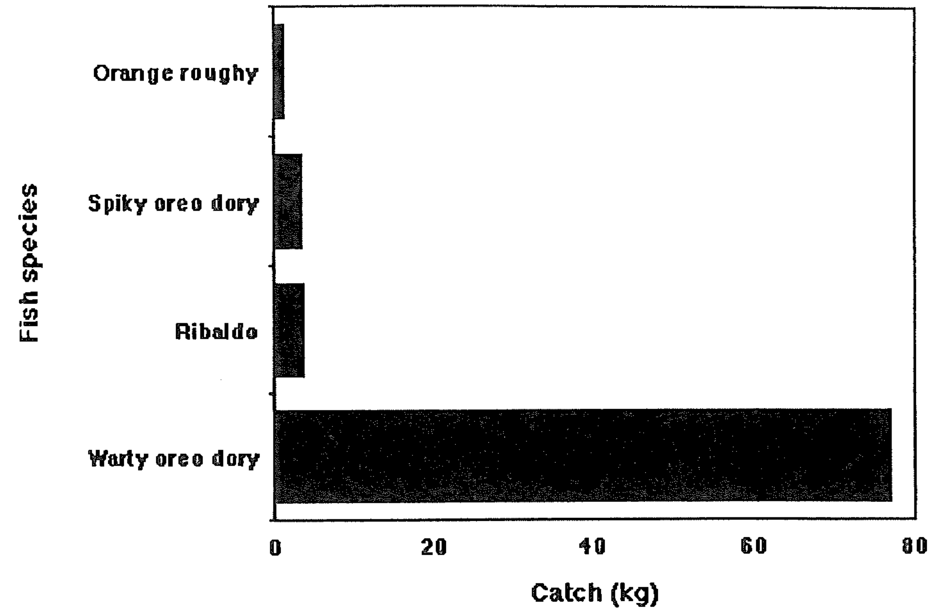


Fig. 5.3.7 WDWTF exploratory fishing survey: catch weights for commercial species for 'southern region' (south of 27°S.), mid-slope depths (700–1400 m).

based upon spawning aggregations), and the high degree of aggregation of the species, indicate that commercial concentrations could easily be missed during a survey of short duration. Thus far, however, all commercial exploratory fishing has failed to find concentrations of roughy in this area.

Oreo or deepwater dories are represented by five species in temperate Australian waters. Four species (warty, spiky, smooth and black dory) attain a large size and the latter two are commercially important species in the South Eastern Fishery (SEF). Only oreo dory and spiky dory were caught during the survey although no large catches or large individual fish were taken. Smooth dory have been recorded in small quantities from the fishery previously (Chapter 5.4) but black dory are thus far unrecorded west of Tasmania. Experience from south-eastern Australia indicates that oreos are found on similar bottom to orange roughy and therefore the comments on the lack of suitable trawl ground apply equally to these species.

Fishing grounds: bottom types and features

No clearly defined fishing grounds or topographic features (hills or canyons) holding concentrations of fish were identified during the survey. Large areas of the upper- and mid-slope were found to be flat and easy to bottom trawl, and known features such as the Perth Canyons could be target trawled. Examples of the ground types found in the fishery are shown by a series of echograms (Appendix V) printed from the Simrad EK500 (38 kHz) scientific depth sounder. These are copies of colour originals and show positions printed on the top margin of the echogram and the approximate depth range of the bottom annotated by hand. The original colour copy, which is a continuous printout of the entire survey, is held in CSIRO archival storage at the Marine Laboratories in Hobart.

Several transects were made on the Exmouth Plateau (total distance > 200 n.m.) searching for features of interest. The bottom was uniformly flat or gently undulating (Appendix V.1), soft and easy to trawl; the ridge and hill features shown on navigational charts near the centre of the Plateau were not found. Poor soundings were made in the adjacent Monte Bello Trough due to bad weather.

The ground in the northern mid-slope region was variable in character, ranging from moderate gradients between areas of flat or undulating bottom, where trawls were made (Appendix V.2), to areas of very rough bottom where trawling was not attempted (Appendix V.3). No substantial fish marks were seen on any of this ground and much of the rough bottom, in common with rough ground throughout the survey area, showed conspicuous side-lobing. On the upper-slope, large expanses of flat or undulating ground were sounded; diffuse marks were seen over some (Appendix V.4) and more intense marks on or near the bottom were found on others (Appendix V.5). Trawls through marks down hard on the bottom in this area produced mixed catches of mainly small fish including mirror dory and gemfish (Appendix V.6). Interesting bottom features often had good fish marks associated with them and these were investigated for target trawling or camera drops (Appendix V.7).

Difficulty was experienced with mid-slope trawling between Geraldton and Perth which, on the basis of what was recovered in the net, was due to soft mud, in which the trawl doors 'bogged', and to limestone slabs on which the gear came fast. This type of ground appeared flat or undulating and easily trawlable (Appendix V.8); much of the bottom was clearly rough and was not sampled (Appendix V.9). Large areas of flat bottom on the upper-slope between Geraldton and Perth were characterised by reasonable fish marks (Appendices V.10, V.11) but only small mixed catches were taken.

The Perth Canyons were generally very steep-sided (Appendix V.12) with extensive areas of pinnacles (Appendix V.13). One of the northern arms of the Canyon was less steep and the upper-slope edge fairly flat (adjoining Appendices V.14, V.15) and some areas of the Canyon walls were trawlable with target shots (Appendix V.16). The floor of the Canyon was photographed at the base of a steep wall (Appendix V.17) and found to be very soft sediment (stirred up by the drifting camera apparatus) dotted with angular limestone slabs. The surrounding shallow edges of the Canyon had flat and cliff areas with some conspicuous fish marks (Appendix V.18 shows station 77 from which mirror dory and rock cod were each taken with catch rates of > 500 kg hr^{-1}).

Much of the upper-slope south of the Perth Canyons was flat or undulating for large distances and could be trawled without obstruction (Appendix V.19). Several minor bottom features were found and one was investigated by a photographic transect (Appendix

V.20, showing school of yellow-eyed nannygai. On the mid-slope considerable time was devoted to searching for topographic features of the type that hold concentrations of orange roughy and deep-water dories. Minor features such as ridges (Appendix V.21), small hills (Appendix V.22) and 'coral lumps' (Appendix V.23) were found but all were small relative to similar features in fishing grounds in the SEF, and no evidence of fish concentrations was identified.

Miscellaneous

Extensive collections of fish, crustaceans and squid were made for Museum collections. Fishes have been registered in the collections of the CSIRO Division of Fisheries, in Hobart, the Australian Museum in Sydney (AM), the Museum of Victoria in Melbourne (MV) and the Western Australian Museum in Perth (WAM). Collections of South East Fishery ITQ species and some other commercial species from the South East and Great Australian Bight fisheries were made for the stock discrimination projects being undertaken by the CSIRO Division of Fisheries and by Dr J. Paxton of the AM.

Summary of trawl survey

Ninety-five trawls were made in the largely unexplored WDWTF during 30 days in January and February 1991. Sampling was carried out along 16 predetermined transects between 200 m and 1400 m, on bottom features of interest and on acoustic marks. All transect stations were attempted but, due to a combination of adverse factors, the number of successful exploratory and target shots completed in the most southerly reaches of the fishery (south of 33°S.) was less than planned.

Catches of potentially commercial fish species were generally small. Some encouraging catches were made of upper-slope species (especially mirror dory, big-spined boarfish and rock-cod) were made, indicating that the upper-slope region south of Geraldton offers the best prospects for a commercial multispecies trawling operation. Catches on the mid-slope were, without exception, small. The fish assemblage on the mid-slope region north of Shark Bay, which included the Exmouth Plateau, was characterised by high diversity but particularly low fish abundance. The acoustic returns from echo sounders did not indicate concentrations of fish that may have been missed by trawls. No features of bottom topography were found on the mid-slope that may hold concentrations of orange roughy or oreo dories.

Scampi and deepwater prawns were caught on the upper- and mid-slope in the most northerly reaches of the fishery. This was of particular interest because the quantities taken using a large-mesh fish net and heavy ground gear indicated that some species may have been present in significant numbers.

Extensive collections of fish, crustaceans and squid, including many undescribed and rare species, were made for CSIRO and museum collections (AM, MV, WAM). The composition of each catch was recorded by species for each station, which will enable an analysis of community structure to be made.

5.4 The Commercial Fishing and Logbook Program

Introduction

A major objective of this project was to organise the recording of catch and effort data from commercial fish trawling, as it was anticipated that an increase in fish trawling on the west-coast continental slope would follow the declaration of this region as a Developmental Fishery. Increased fishing effort was expected because a minimum performance criterion (20 days fishing annually) was a condition of access to the fishery and because of an expansion of exploratory fishing for orange roughy across southern Australia at that time. The deepwater crustacean logbook and inshore fish logbook in use in WA at this point were unsuitable for recording catch data for slope fish. Accordingly, a catch and effort logbook dedicated to slope fishes was designed and introduced to the WDWTF. The logbook, which was designed following consultation with industry and other fisheries agencies (AFS, BRR, WAMRL), recorded coded gear details and catch and effort on a daily log sheet (Appendices IV·2, IV·3). A translation of the logbook in Russian, made as part of the project, was used in joint-venture fishing in the WDWTF, off south-eastern Australia and in the GAB. Details of the logbook database are given in Chapter 2.

During this phase of the project, knowledge of continental-slope fishes by the fishing industry and seagoing scientific observers in WA was so limited that even commercial species were not known. It was vital to the success of the logbook program that accurate fish identifications were made on board commercial fishing vessels. A field identification guide to potentially commercial fishes was therefore produced and distributed to industry and scientific observers. This 'Deepwater Fish Guide' utilised colour photographs, line drawings and a system of key features to aid species recognition, and was written in non-scientific style for ease of use (see example pages of Appendix IV.1). The format of the guide included geographic distribution and general biological information for each species, and promoted the 'recommended marketing names' established by the Department of Primary Industries and Energy (DPIE). To facilitate the collection of accurate data aboard foreign vessels, the Australian Species Code (ASC) system of code numbers was used in both the identification guide and logbook. A copy of the guide was given to each WDWTF endorsement holder and to each NWSTF endorsement holder who had previously logged a fish catch, and 30 copies were sent to AFS for distribution to the AFZ observers. An additional copy was supplied to each endorsement holder upon request. The feedback from local industry on the usefulness of the guide was positive and, in addition, several requests for copies were received from interstate and overseas companies and restaurants for use in marketing and promotion roles.

Every effort was made to place scientific observers aboard commercial vessels undertaking fish trawling and, with the willing cooperation of the companies and skippers involved, all early trips were covered. Details of these trips are given in Chapter 3. Data collected by the author from the joint venture operations of the Japanese factory trawler FV *Akebono Maru No. 3* are discussed but not incorporated into the database. The joint venture fishing operation of the Russian factory trawler FV *Star of Crimea* (WDWTF, May–June 1992), which occurred after the CSIRO observer program had finished, was documented by AFZ observers. Only limited information from that work was available at the time of writing but data on species distributions are incorporated into this report.

Catch and effort in the WDWTF

During the period of this study, no fish trawling was carried out in the NWSTF and therefore all data relate to the WDWTF. The catch and effort data collected from all domestic fish-trawling operations undertaken in the WDWTF between April 1988 and January 1992 are summarised in this report. Total annual catch and effort summaries for the fishery are given for *each fishing year* (April through to March of the following year). Other summaries represent the *calendar years* 1990 and 1991 during which the fish trawling logbook program was operational.

Fish landings and nominal effort for each fishing year between April 1988 and January 1992 are shown in Fig. 5.4.1. (Note that the data for the fishing year 1991/92 are not available through to March 1992). The data indicated a steady increase in fish trawling effort and fish

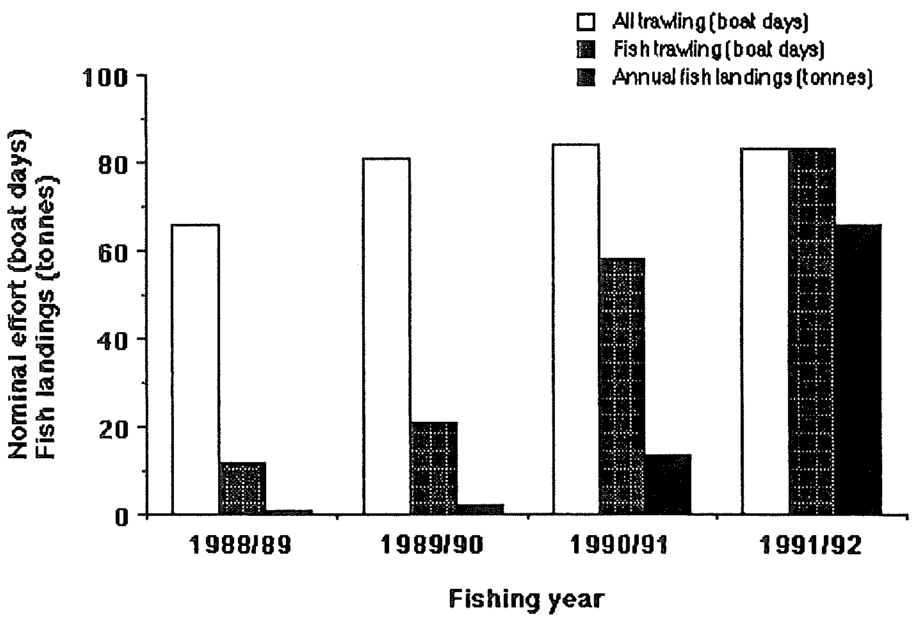
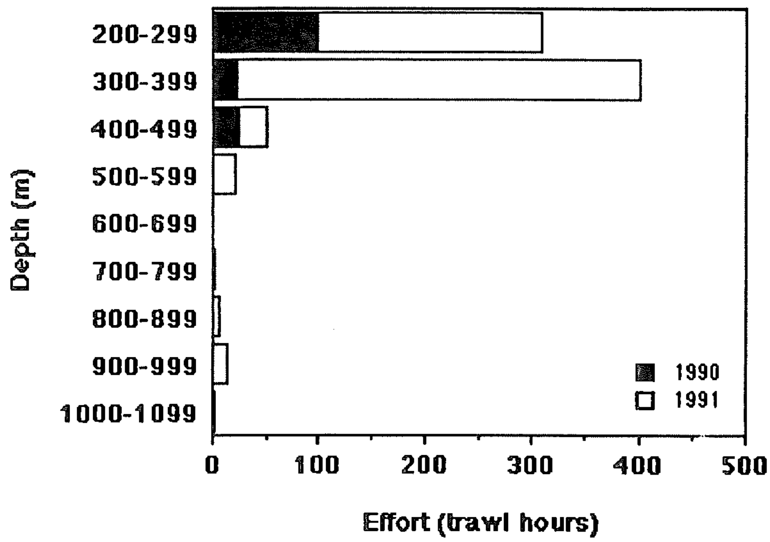


Fig. 5.4.1 WDWTF: annual landed fish catch, total nominal effort and fish trawling effort (boat days) for fishing years (March/April) 1988/89–1991/92.

catch over this period, with the probable greatest effort and the largest total annual landed catch of 65·9 tonnes occurring in 1991/92. The ratio of fish trawling to crustacean trawling increased each year over this period and accounted for all the effort in the 1991/92 year.

The distribution of fishing effort by depth and latitude over the last two fishing years (Fig. 5.4.2*A*, *B*, respectively) showed that effort was concentrated on the upper slope in 200-500 m in both years but at different latitudes, being at 22°S.–24°S. in 1990 and at 32°S.–34°S. in 1991. These summary data reflect the operations of two individual



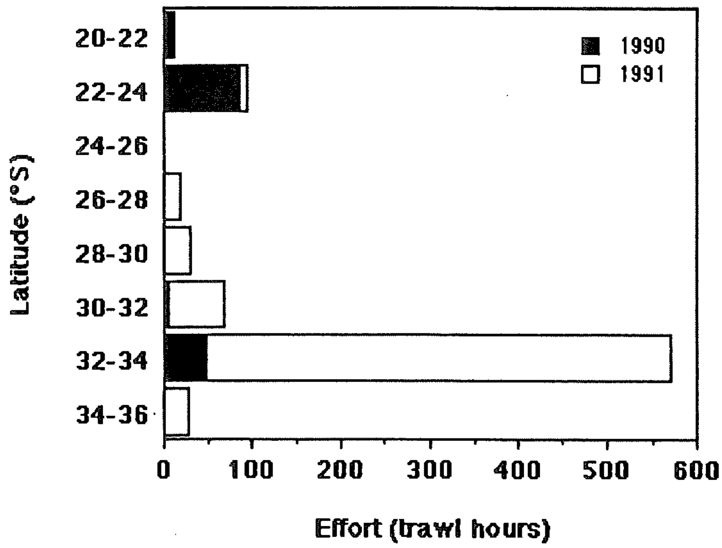


Fig. 5.4.2*A*, *B* WDWTF: distribution of fish trawling effort in 1990 and 1991: *A*, by depth; *B*, by latitude.

operators, who generously gave their permission for release of the information. There was a greater spread of effort in 1991, resulting from some exploratory fishing in mid-slope depths for orange roughy around the area of Cape Leeuwin (34°S.–36°S.), and from some upper-slope work undertaken from the port of Geraldton over the range 26°S.–30°S.

Due to the extensive depth and latitudinal range of the fishery, a great diversity of potentially commercial species were caught and recorded in logbooks. For ease of presentation and because the west-coast slope fish fauna can be recognised as forming a number of discrete assemblages (Chapter 5.6), treatment of the fishery and fish species has been divided into subgroups. A convenient division of the fishery is achieved by dividing it into a northern and a southern region at 27°S. This latitudinal break is convenient in terms of the distribution of effort and the distributions of some of the fish species of interest; it does not represent a clearly defined boundary separating tropical and temperate assemblages. Within each area, the fish species characteristic of the upper and mid-slope regions (~ 200–700 m and ~700 m and deeper, respectively) are discussed separately.

Northern, upper-slope region (Fig. 5.4.3)

The majority of the fishing effort in this region was concentrated in the shallowest range of the upper slope (~ 200–300 m) adjacent to the Ningaloo Reef area (at ~ 22°S.). Trawl catches typically contained a wide range of fishes, most of which are common on the deeper continental shelf of north-western Australia (Sainsbury *et al.* 1984) and which are characteristically tropical Indo-West Pacific species. Among these were several commercial species, the most abundant of which were ruby snapper, yellow perch (*Lutjanus carponotatus*), deepsea snapper, Darwins roughy and northern pearl perch (*Glaucosoma bergeri*). A number of minor species were retained for sale but were not recorded by species name in logbooks. These included other lutjanids (emperors), at least two species of serranids (cods), several carangids (trevallys), priacanthids (big eyes) and a variety of sharks. Several 'southern' species were also taken, including the wide-ranging commercially important pink snapper (*Pagrus auratus*).

Total recorded landings during 1990 and 1991 for the six major species (Fig. 5.4.3) show that overall catches of all species were small, although dominated by ruby snapper. The 1991 catch was a small fraction of the 1990 catch, reflecting a greatly reduced level of effort in this region (Fig. 5.4.2*B*).

Records by observers indicate that trawl by-catch from this region was relatively low in volume and consisted almost entirely of small quantities of a wide range of fish species. Individual sponges were taken occasionally but no coral was seen in the nets.

Summary information on the species caught in greatest numbers from this region, ruby snapper and deepsea snapper, as well as on some minor species, is provided in Chapter 5.5.

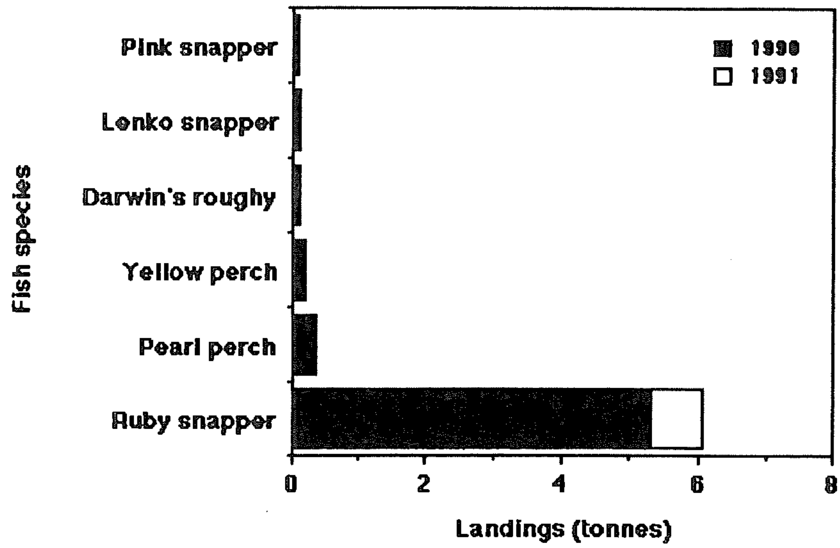


Fig. 5.4.3 **WDWTF: catch composition of major species from northern, upper-slope region (north of 27°S., 200–700 m).**

Northern, mid-slope region

No commercial fishing was undertaken on the mid-slope region in the northern end of the fishery. The only information from this part of the fishery comes from the CSIRO survey (Chapter 5.3).

Southern, upper-slope region (Figs 5.4.4, 5.4.5)

Fish trawling effort was highest in this region of the fishery. A large number of shelf-break and upper-slope species, many of them common across southern Australia, were taken and recorded in log books. Annual landings increased greatly from 1990 to 1991, however, only seven species were caught in quantities > 0·5 tonnes (Fig. 5.4.4). Two species, big-spined boarfish and mirror dory, made up about 95 per cent of the landed catch and were the only fishes landed in an appreciable quantity from the fishery during the course of this study. The five other species in this group were commonly seen in catches but were never taken in quantity. Large numbers of gemfish were taken occasionally but discarded due to small size (see discussion of discards below).

Of the 12 species recorded in logbooks but totalling < 0·5 tonne (Fig. 5.4.5), only cod and ocean perch (*Helicolenus percoides*) were true slope species with centres of distribution below 200 m. The remaining species are all characteristic of the southern Australian shelf fauna and taken in depths < 200 m. The alfonsino and possibly the yellow-eyed nannygai are semi-pelagic species and are usually taken as by-catch in demersal trawls. Three other commercial species recorded in low numbers from this region by CSIRO observers, Bight redfish (*Centroberyx gerrardi*), blue-eye trevalla (*Hyperoglyphe antarctica*)

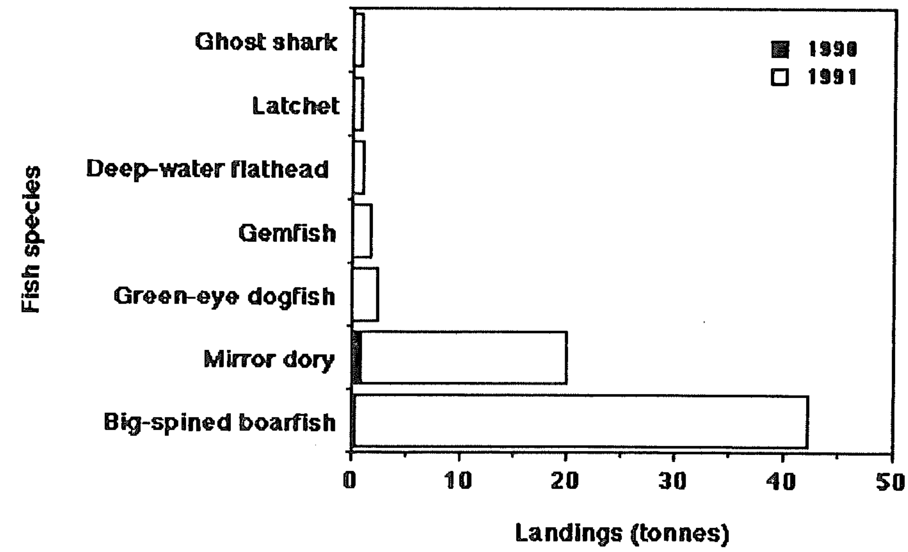


Fig. 5.4.4 WDWTF: catch composition of major species (annual catch > 0·5 tonnes) from southern, upper-slope region (south of 27°S., 200–700 m).

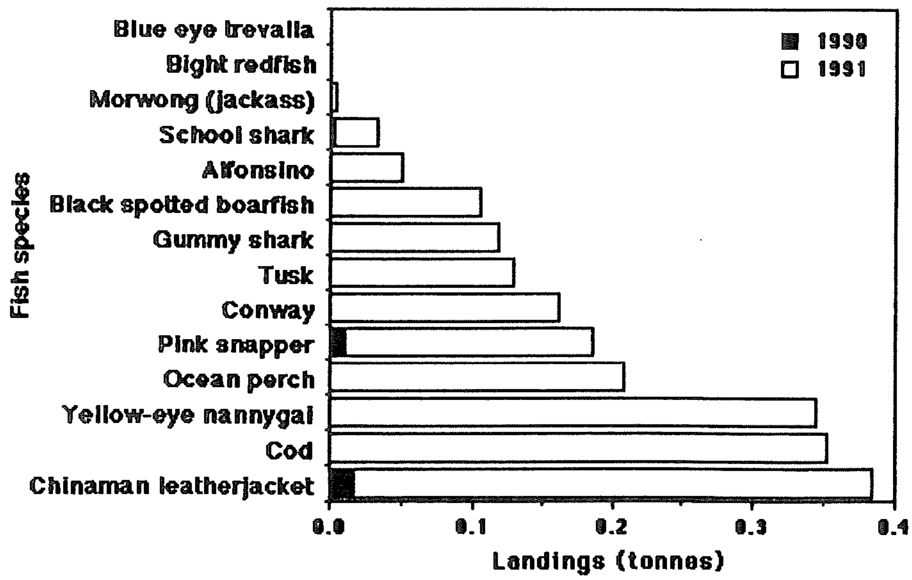


Fig. 5.4.5 WDWTF: catch composition of minor species (annual catch < 0·5 tonnes) from southern, upper-slope region (south of 27°S., 200–700 m).

and purple stargazer (*Pleuroscopus pseudodorsalis*) were not recorded in commercial logbooks.

Summary information on the species of greatest interest from this region, big-spined boarfish, mirror dory and gemfish, together with several minor species, is provided in Chapter 5.5.

Southern, mid-slope region (Fig. 5.4.6)

Although many of the commercially important southern Australian mid-slope species were recorded from the WDWTF, catches were small and no commercial quantities were taken. Orange roughy was the species of primary interest from mid-slope depths of ~ 800 m and deeper. Despite being recorded in several trawls from the southernmost reach of the fishery, it was represented only by small numbers of fish in individual trawls. Much the same was true for the other important mid-slope species, primarily the oreo dory group, with warty oreo dory and spiky oreo dory being recorded in most trawls deeper than ~ 800 m, but only in small quantities. The smooth dory was caught during joint venture fishing in the WDWTF but the species was not recorded from the catches of domestic trawlers. There were no records of the black oreo dory (*Allocyttus niger*) from the WDWTF. Blue grenadier, ling and ribaldo, all species of commercial interest generally found in the shallower range of the mid-slope and the deeper upper-slope, were recorded in small numbers by observers but not recorded in logbooks. King dory was recorded in small quantities.

Summary information on orange roughy and several minor species is provided in Chapter 5.5.

Unidentified landings (Fig. 5.4.7)

Unidentified 'mixed fishes' comprised a wide range of tropical and temperate species from the shelf-break and upper-slope region. Similarly, 'mixed sharks' included a range of species from the shallow range of the northern and southern regions of the fishery. Relative to the total quantities of identified landings, the unidentified portion of

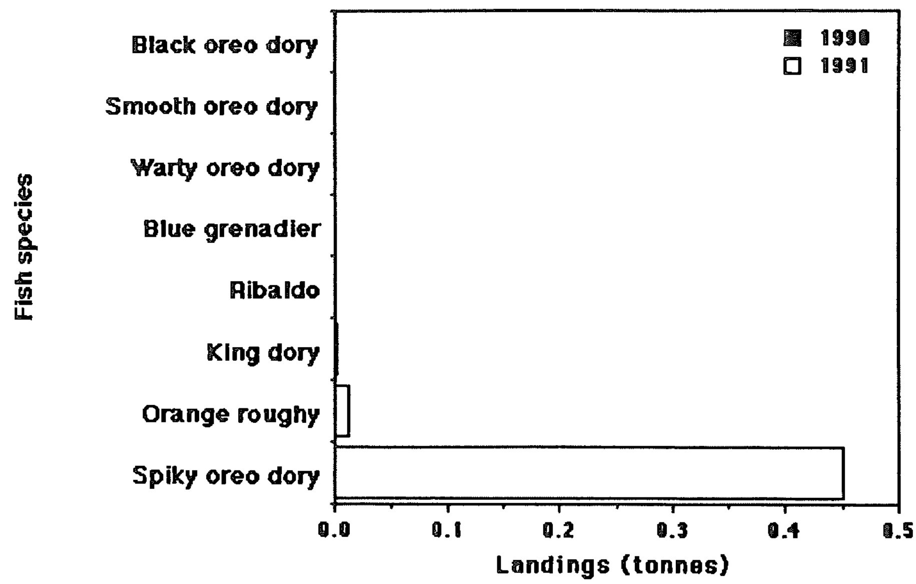


Fig. 5.4.6 WDWTF: catch composition of commercial species from southern, mid-slope region (south of 27°S., 700–1500 m).

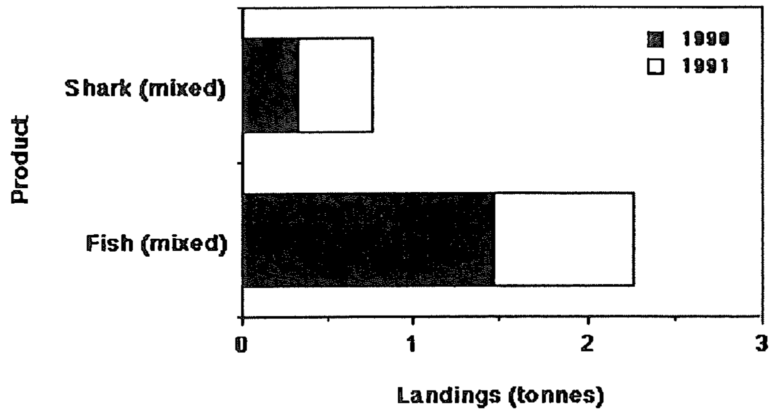


Fig. 5.4.7 WDWTF: unidentified landings, all regions.

the retained catch was small, reflecting the concerted effort that skippers put into completion of the logbooks.

Discards (Fig. 5.4.8)

In addition to providing the largest landings of any single species, big-spined boarfish also dominated the reported discards (Fig. 5.4.8). The fact that a larger quantity was discarded than was retained was due to a number of factors, most importantly the small size of many fish and the difficulty in selling this species (discussed in more detail in Chapter 5.5). Discarded 'mixed fish' comprised primarily non-commercial species but did include small individuals of commercial species such as mirror dory and deepsea snapper. Large numbers of small gemfish were taken regularly on the upper slope at around 32°S. and accounted for the discarding of this species. Appreciable quantities of small gemfish were also caught on the research survey at several places on the coast including positions further north. 'Mixed fish' discards also included warty and spiky oreo dory, for which there is no current market in WA.

Interpretation

Fishing effort in the WDWTF was low in the 1988/89–1991/92 fishing years and, despite a trend of increasing fish trawling effort, there were no signs that the overall effort will change substantially in the near future. The level of effort was not greatly influenced by the fishery-access performance criterion, because many operators completed none or only part of the required 20 days fishing. During the period of this study, the majority of fishing effort was made by just a few endorsement holders and by two joint-venture fishing operations. The low number of days fished was due to several factors, including the high cost of exploratory fishing in deep water, the lack of any proven fish resource or fishing grounds, and the lack of established markets for unfamiliar fish species. It was also clear, however, that the lack of experience in fish trawling and the unsuitability of many of the licensed vessels to trawl in deep water

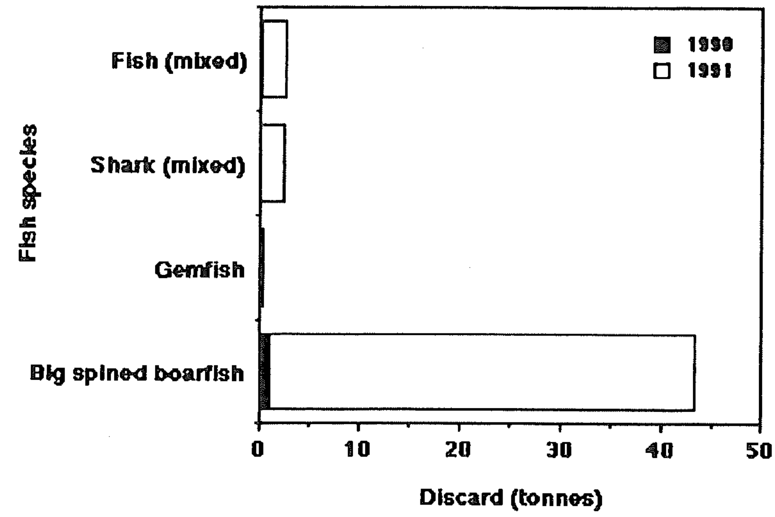


Fig. 5.4.8 WDWTF: discarded catch, all regions.

contributed to the general reluctance of many endorsement holders to fish.

An increased and more widely distributed effort in 1991 was mainly indicative of exploratory fishing by experienced deepwater vessels that gained endorsements for the first time in 1991. In particular, the fishing on the upper-slope at 32°S.–34°S. represented the only real sustained effort in one region during the period of the study. In fact, the true level of effort in 1991 was underestimated by logbook records because the fishing in mid-slope depths was targeted and did not take account of the considerable time searching for fish marks or suitable ground.

The potential of the northern region of the fishery is likely to be small because commercial catches comprised predominantly tropical shelf-break and shallow upper-slope species. These have a limited distribution southwards in the WDWTF along a section of coastline where the slope is extremely narrow. No commercial fishing was undertaken in deeper water in the northern reaches of the fishery.

Catches of upper-slope species south of Geraldton, dominated by big-spined boarfish and mirror dory, were the only indication of potential for a trawl fishery in the WDWTF. Although the low level of fishing made it difficult to assess the abundance of these species, some appreciable catches were taken. The distributions of the dominant species extend considerable distances and more exploratory fishing is required to establish the probable size of the resource. The large variety of commercial species on the southern upper slope in 200–400 m was due to the presence of many shelf species at their deeper limits of distribution. A considerable increase in the prospectivity of this region would result if the inshore boundary of the fishery was at 100 m depth, to permit trawling of these species where their abundances are higher. In any event, energetic promotion of slope fishes will be required to establish a fishery, because the dominant species are poorly known in WA.

Searching on the southern mid-slope failed to find any of the type of bottom topography (hills and ridges) that hold commercial concentrations of mid-slope species such as orange roughy and deepwater oreo dories, and catches from this region were characteristically low. Whilst the distribution of most of the commercial south-eastern Australian mid-slope species extended into the WDWTF, the low fish abundances and limited extension of distributional ranges northwards (except for a few scattered individuals) indicated that the southern WDWTF (~32°S.) is the north-western limit of many mid-slope species around southern Australia.

Our current understanding of the WDWTF represents a significant advance when compared to the extremely limited knowledge of the fishery in 1989 and much of this is due to the introduction of the logbook and fish guide. The continued management of the trawl fish database, as currently carried out by the CSIRO Division of Fisheries, will permit monitoring of future developments in the fishery.

5.5 Commercial Fish Summaries

5.5.1 Orange roughy (*Hoplostethus atlanticus*)

Background

The discovery of large, commercial concentrations of orange roughy off Tasmania in 1989 generated considerable interest in the distribution of this species in southern Australian waters. Since then, exploratory fishing has identified commercial aggregations at various localities between the north-eastern SEF and the western sector of the GAB at the latitude of Albany (~ 118°E.). In comparison to the SEF and GAB, relatively little mid-slope fishing has been undertaken in the WDWTF. The mid-slope trawl effort by domestic vessels in 1990 and 1991 was low (Fig. 5.4.2*A*), however, additional deepwater exploratory fishing was undertaken by joint-venture and scientific trawlers. In total, 38 valid demersal trawls were made in the southern range of the WDWTF (32°S.–35°S.) in 800–1200 m, together with an appreciable time spent searching for fish marks and for ground suitable for target trawling. Orange roughy occurred in 66 per cent of trawls, indicating that the species had a dispersed distribution in this region. However, catches could be quantified in terms of numbers of individuals rather than weight, indicating that the abundance of orange roughy was low. In contrast, survey data from non-targeted trawls in the SEF showed that orange roughy was the dominant mid-slope species being present in > 97 per cent of samples and constituting 23 per cent of the demersal fish biomass (Koslow *et al.* 1993). It is significant that the type of ground from which the majority of orange roughy catches are taken in the SEF (steep-sided, conical 'hills' rising to ~ 800–1100 m from bottom depths of ~ 1100–1500 m) has not been found in the WDWTF.

As a consequence of the negligible catch taken during the course of this study, little biological information on orange roughy was collected.

Limits of distribution in WDWTF

33°03'S., 114°37'E. — 35°05'S., 115°06'E.

Depth range in WDWTF

817–1175 m

Annual recorded catches

Negligible

Catch rates ($kg \cdot h^{-1}$)

Recent data unavailable (see below) but believed to be negligible.

Biology

A sample of 20 fish taken in January 1991 off Cape Leeuwin were 20–42 cm SL; they were 55 per cent females and had gonads in resting and maturing stages of development. A larger body of data collected by AFZ observers aboard the FV *Star of Crimea* joint-venture fishing in the WDWTF was unavailable at the time of writing.

Stock structure

A collection of whole specimens has been made for ongoing CSIRO research into stock structure.

Commercial potential

The exploratory fishing undertaken to date has provided no evidence for the existence of a commercial resource of orange roughy in the WDWTF.

5.5.2 Big-spined boarfish (*Pentaceros decacanthus*)

Background

This fish belongs to the boarfish family, which contains several temperate Australian shelf species that are well known and highly regarded in the market place. The comparatively poorly known big-spined boarfish had the second-highest total catch (480 kg) and catch rate (519 kg · h^{-1}) during the CSIRO fishery survey (Chapter 5.3), and the 42 tonnes landed in 1991 represented 58 per cent of the fish catch from the WDWTF that year. In 1991, it accounted for 89 per cent of the recorded fish discards from the fishery. The species is locally abundant and common in upper-slope trawl catches over a wide latitudinal range. In the WDWTF, it appears to be considerably more abundant and attains a greater size than elsewhere in Australian waters.

Limits of distribution in WDWTF

25°08'S., 112°09'E. — 34°59'S., 114°53'E., locally abundant between Geraldton and Bunbury.

Depth range in WDWTF

306–712 m, most abundant in ~300–500 m.

Annual recorded catches

1990: 0·3 tonnes

1991: 42·0 tonnes

Catch rates (kg · h^{-1})

1990: highest 275; mean 99

1991: highest 2738; mean 227

Biology

Regular sampling of commercial catches was not possible, and the data presented are pooled from several samples taken during 1991. Length-frequency data (Fig. 5.5.1*A–C*) show survey, pooled commercial and combined data respectively. Fish from the WDWTF

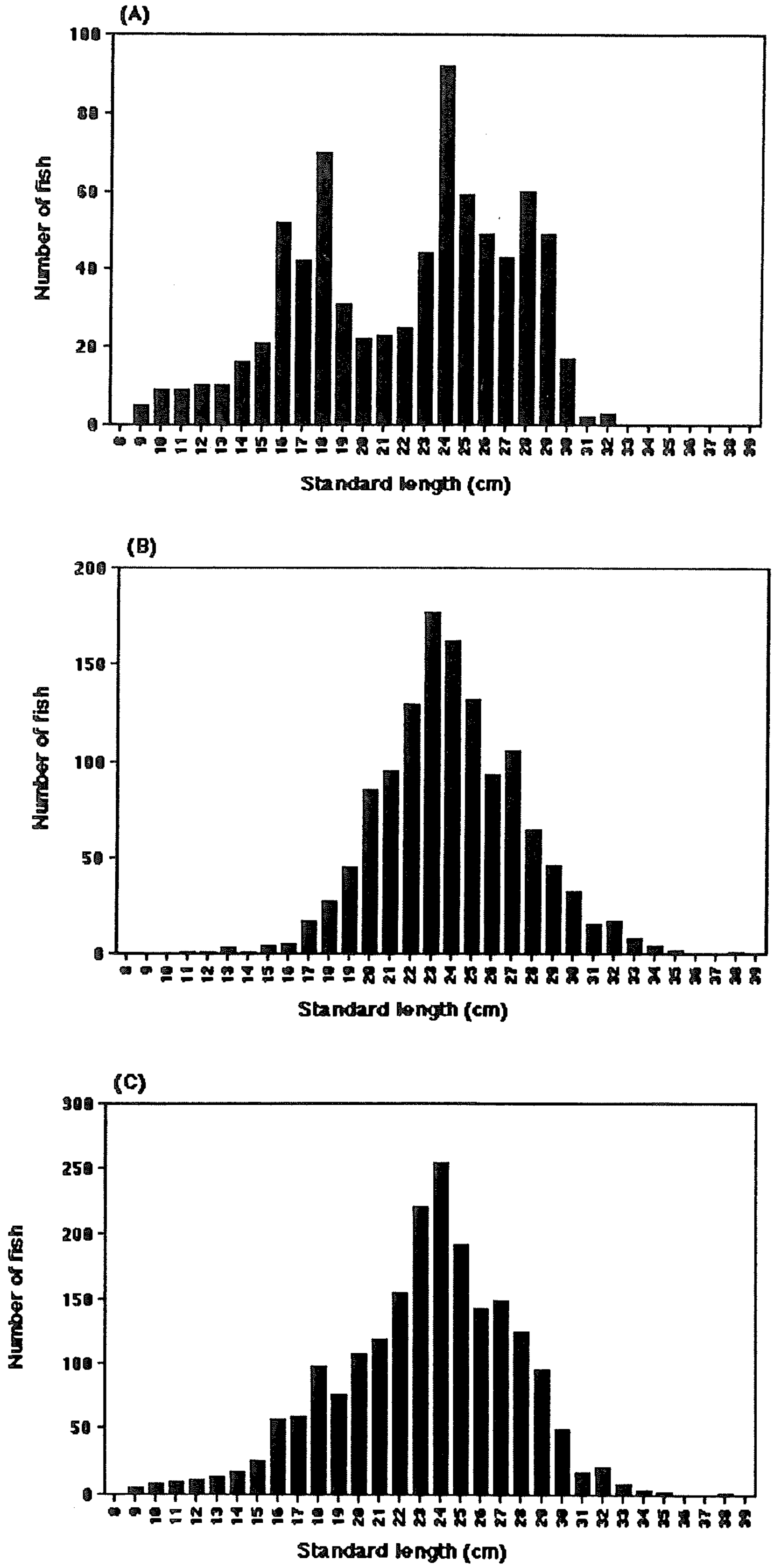


Fig. 5.5.1*A–C* Big-spined boarfish (*Pentaceros decacanthus*) length-frequency (standard length): *A*, pooled survey data ($n = 763$); *B*, pooled commercial catch data ($n = 1271$); *C*, combined data ($n = 2043$).

attain a considerably larger size than elsewhere in Australian waters (24 cm; May and Maxwell 1986). No ageing was attempted but otoliths were collected for archival storage in the Central Fish Ageing Facility. Resting stage gonads in 73 fish examined in early February, and mature or spent gonads in 52 fish examined in late July indicate that spawning was a winter event.

Stock structure

No work in progress or planned.

Commercial potential

Big-spined boarfish were common in upper-slope trawls and were taken in commercial quantities in mixed catches with mirror dory and gemfish. Boarfish were caught in appreciable quantities in several months of the year, indicating that they are likely to have year-round availability in this area. Despite these encouraging indications and the nature of the flesh of the fish, which is tasty and visually appealing, big-spined boarfish have several unappealing characteristics from a processing and marketing perspective. In particular, they attain only a relatively small size (≤ 1 kg), are difficult to handle because of their large and sharp dorsal and anal fin spines and they have a tough skin. In addition, the common name of this species proved to be a major barrier to selling early catches, as it was perceived by processors prepared to handle the product to be unacceptable in the market place. This was the major reason for rejection of some early catches and the discarding of large quantities of fish (Fig. 5.4.8). Since no acceptable alternative common name was available and no 'recommended marketing name' existed, the name 'diamond fish' was proposed by the CSIRO and the WA Fisheries Department for adoption by the Recommended Fish Marketing Names Committee to assist the promotion of this fish.

In summary, whilst other boarfish species are generally well regarded in the domestic market, promotion and marketing will be needed to achieve acceptance of this previously unknown species in WA. The species has potential in a multispecies upper-slope trawl operation.

5.5.3 Gemfish (*Rexea solandri*)

Background

Gemfish formed a common but relatively minor component of mixed trawl catches taken on the southern and mid-coast upper slope. A small quantity (~ 100 kg) of predominantly small fish (< 40 cm) was taken during the CSIRO survey. Small numbers of large fish (70–102 cm SL) were taken in commercial catches towards the end of the study period.

Limits of distribution in WDWTF

23°25'S., 113°04'E. — 33°20S., 114°30'E.

Depth range in WDWTF

216–596 m

Annual recorded catches

1990: 0·08 tonnes

1991: 1·7 tonnes

Catch rates (kg · h^{-1})

1990: highest 24; mean 9

1991: highest 110; mean 8

Biology

The identification of specimens taken for biological sampling was carefully checked using the key of Parin and Paxton (1990), because three species of *Rexea* were collected in the WDWTF. Regular sampling of gemfish was not possible, but biological data were obtained on four separate occasions at sea (January 1989, January, October and November 1991). Pooled length data from the CSIRO survey and commercial catch sampling, in which all gemfish in catches were measured, are shown in Fig. 5.5.2*A–C*).

Juvenile gemfish (< 20 cm SL) were common and sometimes abundant in WDWTF upper-slope trawls; the majority of fish were < 50 cm SL. A length of about 50 cm corresponds to the minimum length of fish taken in the east-coast spawning run and indicates that the majority of WA fish taken were likely to have been immature. In addition, however, a relatively small number of large individuals were caught at a size comparable to the largest size attained by east-coast fish (~ 110 cm LCF). The collection of maturing gonads in 42 fish in early October 1991 (mean GSI of five female fish = 22·6 per cent), and of mature and running ripe gonads in fish in late November 1991 (mean GSI of 20 female fish = 12·9 per cent; range 2·7–31·3 per cent) and in January 1989 and 1991, indicated that fish were in spawning condition for an extended spring and summer period.

Stock structure

Gemfish are widely distributed around southern Australia and extend north to at least 23°25'S. on the Western Australian coast. It is thought that there may be two stocks in Australian waters, one to the east of Bass Strait and another to the west. Although only limited biological sampling of WDWTF fish was possible, the presence of running-ripe fish in November (spring) and January (summer) supports the evidence for separate stocks, since 'eastern stock' gemfish spawn in winter. There is no direct evidence that spawning occurs off the west coast, however, the presence of large numbers of juvenile fish (8–20 cm) supports this possibility. Collections of whole fish and tissue samples were made for the ongoing stock discrimination work of Dr John Paxton (AM), and otoliths from a wide length range of fish were collected for archival storage at the Central Fish Ageing Facility.

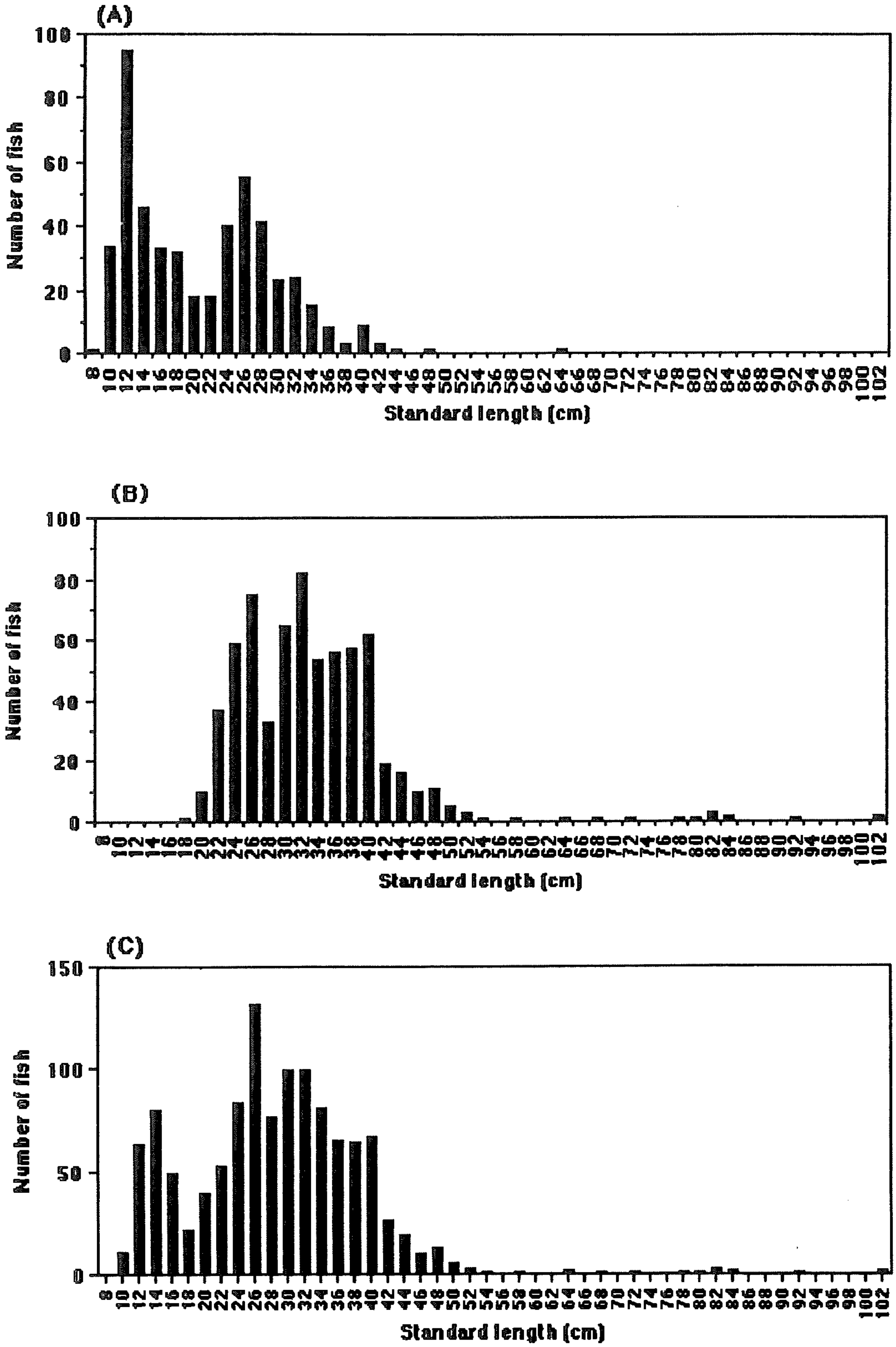


Fig. 5.5.2*A–C* Gemfish (*Rexea solandri*) length-frequency (standard length): *A*, pooled survey data (n = 501); *B*, pooled commercial catch data (n = 670); *C*, combined data (n = 1171).

Commercial potential

The presence of large fish in spawning condition in the WDWTF was an encouraging indication of the potential availability of this species on the west coast. Gemfish are known to be a highly migratory fish, moving a considerable distance north to spawn in eastern-Australian waters. Although there is no direct evidence for a spawning migration off the west coast, future exploratory fishing or research might seek to establish whether a northwards seasonal migration of fish from the GAB does occur. The species will be of some significance in upper-slope mixed-trawl catches and is readily sold on local markets. However, the number of fish taken thus far is small and concentrations of large fish have yet to be found.

5.5.4 Mirror dory (*Zenopsis nebulosus*)

Background

Mirror dory is a widespread and locally abundant upper-slope species that was taken in commercial quantities in the southern region of the WDWTF (around 32°S.). It is most frequently taken in mixed catches with big-spined boarfish.

Limits of distribution in WDWTF

21°39'S., 113°58'E. — 34°59'S., 114°53'E. It occurs between the southern and northern limits of the fishery but is locally abundant between Geraldton and Bunbury.

Depth range in WDWTF

209–712 m, most abundant in ~300–500 m.

Annual recorded catches

1990: 0·8 tonnes

1991: 19·2 tonnes

Catch rates (kg · h^{-1})

1990: highest 127; mean 71

1991: highest 505; mean 49

Biology

Careful identification of specimens taken for biological sampling was necessary in the northern region of the fishery because of the overlapping distribution of *Z. nebulosus* with an apparently tropical and undescribed species of *Zenopsis*. Regular sampling of commercial catches was not possible, and the data presented are from the CSIRO survey and pooled from the same commercial catches sampled for gemfish and big-spined boarfish during 1991. Length-frequency data (Fig. 5.5.3*A–C*) show survey, pooled commercial and combined data, respectively. Juvenile fish (9–21 cm SL) were taken in large numbers during the CSIRO survey but were not caught

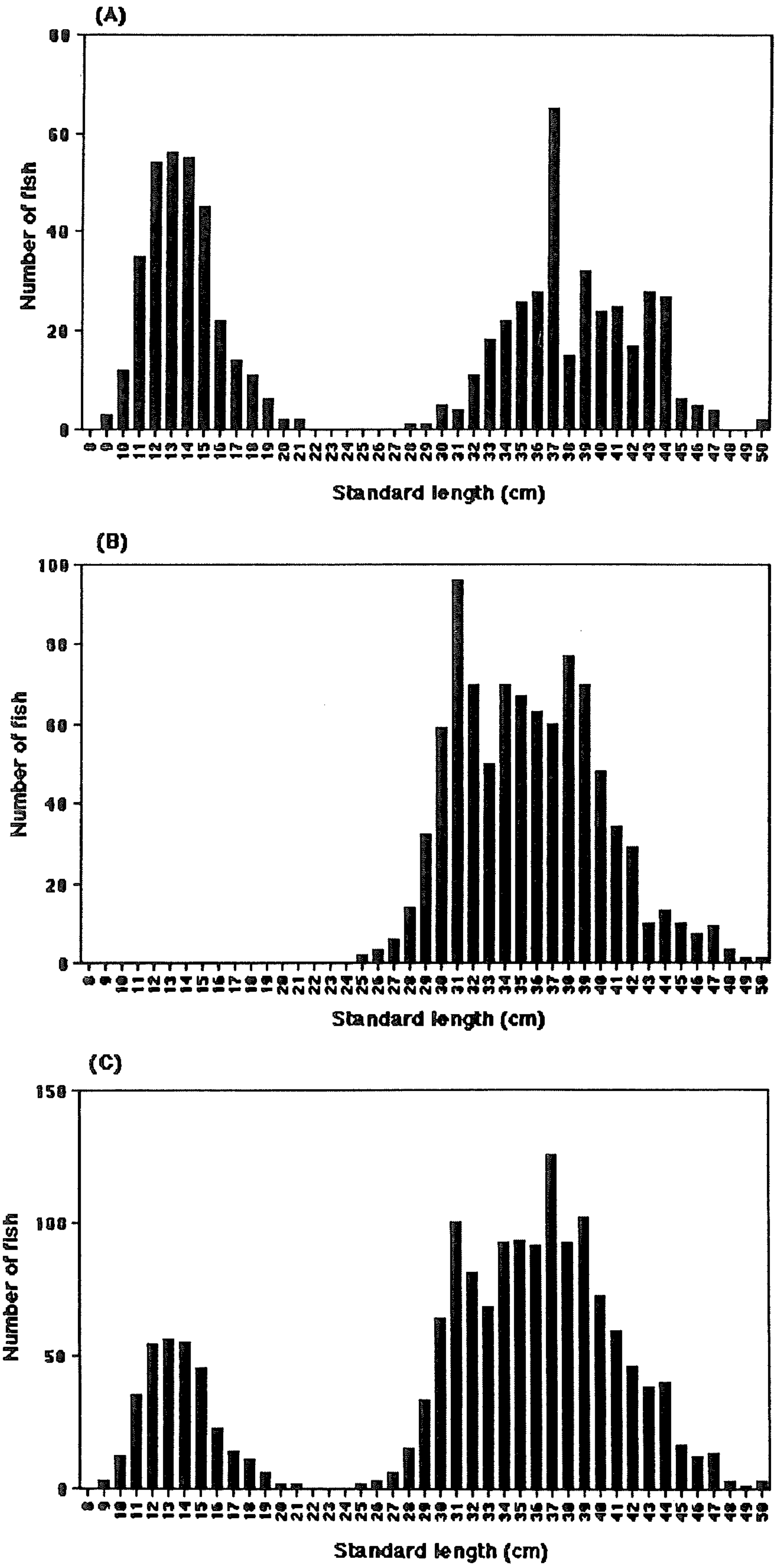


Fig. 5.5.3*A*–*C* Mirror dory (*Zenopsis nebulosus*) length-frequency (standard length): *A*, pooled survey data (n = 683); *B*, pooled commercial catch data (n = 904); *C*, data combined (n = 1587).

during commercial trawling. Comparison of length data for mirror dory from NSW waters (K. Rowling, unpublished data from the Sydney Fish Market) showed that their size range was similar to those taken by commercial fishing in the WDWTF. The observation of resting stage gonads in 139 fish examined in January and early February 1991, and reports from fishermen of fish in spawning condition in July 1991, indicated that, as in eastern Australia, mirror dory spawn in winter in the WDWTF.

Stock structure

Although mirror dory have a continuous distribution around southern Australia, the observation of fish in spawning condition and of large numbers of juvenile fish in the WDWTF supports the possibility of the existence of a western stock. Although no stock discrimination work is in progress, whole fish specimens were collected for the future genetic work by the CSIRO Division of Fisheries. In addition, otoliths were collected for archival storage at the Central Fish Ageing Facility. Correct identification of this fish is important because of the existence of an undescribed and morphologically similar second species (Bray 1983).

Commercial potential

Mirror dory were taken in commercial quantities in mixed catches with big-spined boarfish, gemfish and a range of market species. The fish were caught in appreciable quantities in several months of the year, indicating that they are likely to be available year-round in this area. Although mirror dory were an unfamiliar fish in WA when first landed, they were readily accepted by local markets and represented the potentially most valuable component of upper-slope mixed catches.

5.5.5 Ruby snapper (*Etelis carbunculus*)

Background

Ruby snapper have a tropical Indo-Pacific distribution and are found on the North West Shelf to depths > 200 m. They were caught in appreciable quantities by demersal trawling in the northern-most reach of the WDWTF in 1990 (Fig. 5.4.3).

Limits of distribution in WDWTF

21°15'S., 113°43'E. — 26°24'S., 112°38'E.; a tropical species with a limited distribution in the WDWTF.

Depth range in WDWTF

200–285 m, limited to the shelf break and extreme upper slope.

Annual recorded catches

1990: 5·3 tonnes

1991: 0·7 tonnes

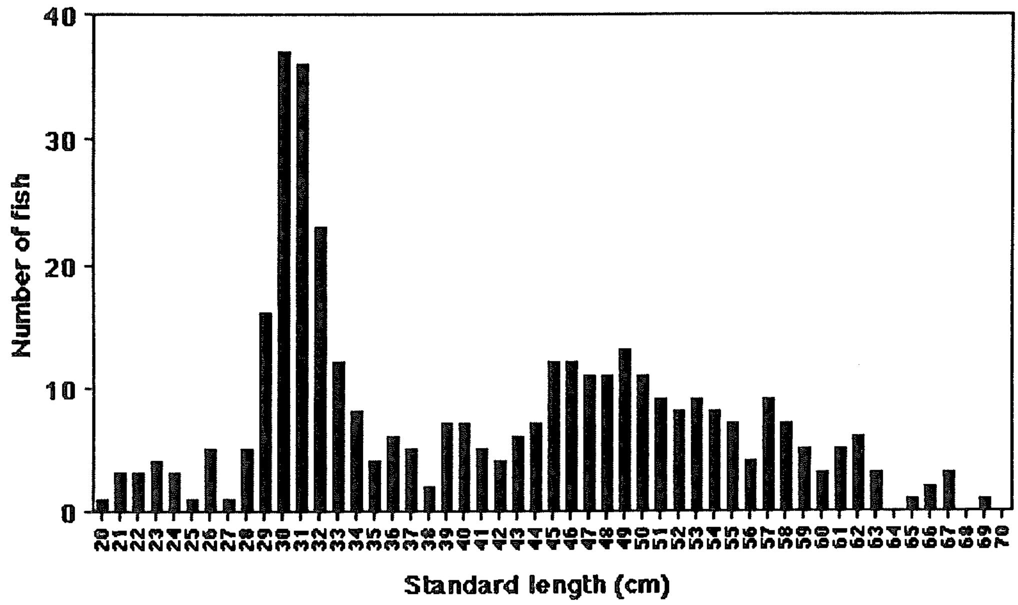


Fig. 5.5.4 Ruby snapper (*Etelis carbunculus*) length-frequency (standard length, n = 371).

Catch rates (kg · h^{-1})

1990: highest 600; mean 90

1991: highest 125; mean 90

Biology

Pooled length-frequency data from commer ial catches are shown in Fig. 5.5.4.

Stock structure

No information available.

Commercial potential

One of the 'sharp-toothed snapper' group of fishes that are important in north-western WA wet-line and trap fishing. This species is apparently vulnerable to demersal trawl gear and can be taken at high catch rates. However, it has a extremely limited distribution in the WDWTF and its commercial potential is therefore likely to be limited.

5.5.6 Deepsea snapper (*Dentex tumifrons*)

Background

Over 50 tonnes of deepsea snapper were taken by Japanese exploratory fishing off the west coast of WA in 1978 (Heald and Walker 1982), with highest catch rates being made in 230–260 m. The species was common in catches in 200–300 m but was never taken in quantity during the course of this study.

Limits of distribution in WDWTF

21°39'S., 113°58'E. — 32°10S., 115°08'E.

Depth range in WDWTF

Annual recorded catches

1990: 120 kg

1991: none

Catch rates (kg · h^{-1})

Not available

Biology

Pooled length-frequency data from commercial catches are shown in Fig. 5.5.5.

Stock structure

No information available.

Commercial potential

The small size of deepsea snapper, generally in the 13–21 cm range, will almost certainly make them unattractive in the domestic marketplace. However, their potential as an export species to Japan may be worth investigating for several reasons: first, small sparid fishes (snappers) are highly prized in Japan; second, the records of Heald and Walker (1982) indicate the fish was locally abundant; third, the fish are usually in good condition when landed and last, there is existing expertise in Carnarvon for shipping whole, chilled snapper to Japan.

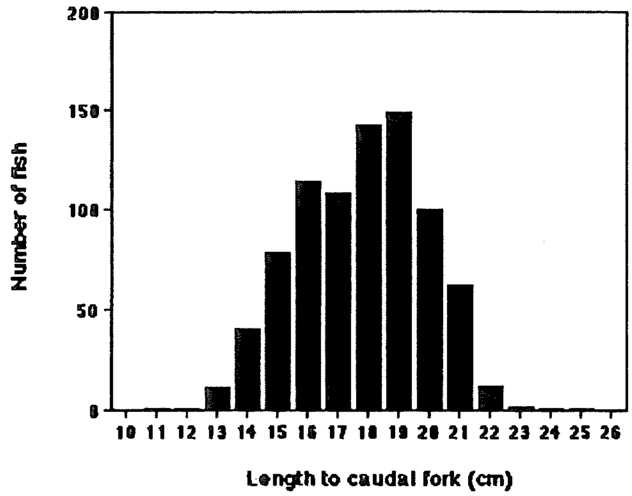


Fig. 5.5.5 Deep-sea snapper (*Dentex tumifrons*) length-frequency (length to caudal fork, n = 821).

5.5.7 Minor species

Alfonsino (*Beryx splendens*)

Limits of distribution: 21°38'S., 113°56'E. — 32°02'S., 114°54'E.; 209–670 m.

Taken in small quantities in upper-slope demersal trawls; although some large fish (> 1 kg) were caught, most were small individuals (< 150 g). One large mid-water catch was reported in 1991 by a vessel doing pelagic gear trials but no details were made available. Two different forms identified during the CSIRO survey indicated that the taxonomy of *Beryx* species in Australian waters is in need of review.

Blue-eye trevalla (*Hyperoglyphe antarctica*)

Limits of distribution: 30°00'S., 114°28'E.; 380 m.

Recorded only once from a trawl catch. Occasional reports of this species taken by dropline in the WDWTF are unverified but considered reliable. No details of its distribution or abundance are currently available.

Blue grenadier (*Macruronus novaezelandiae*)

Limits of distribution: 33°06'S., 114°30'E. — 34°59'S., 114°58'E.; 596–825 m.

A few individuals were recorded from two trawls at the southern end of the fishery. Although there is no known targeted exploratory fishing for this species, the rarity of incidental catches indicates that the presence of a commercial resource in the WDWTF is unlikely.

Cod (*Epinephelus septemfasciatus*)

Limits of distribution: 31°09'S., 114°52'E. — 32°09'S., 115°10'E.; 200–331 m.

One catch of ten large fish (total weight of 222 kg) was taken during the CSIRO survey but only 353 kg were recorded in commercial catches in 1991. This fish is likely to be an occasional by-catch species in shallow upper-slope trawl catches and to be more vulnerable to drop-lining than to trawling.

Darwins roughy (*Gephyroberyx darwini*)

Limits of distribution: 21°44'S., 113°52'E. — 33°13'S., 114°31'E.; 274–490 m.

Despite anecdotal reports of occasional large catches taken by crustacean trawlers in the NWSTF, none were witnessed by observers. Its distribution is continuous from the GAB to the North West Slope and the species was caught frequently in small numbers on the upper slope. Occasional large fish (~ 1 kg) were seen but most were small (< 200 g); there was no indication of a commercial resource of this species in the WDWTF.

King dory (*Cyttus traversi*)

Limits of distribution: 28°13'S., 113°07'E. — 35°08'S., 115°01'E.; 490–1103 m.

King dory were taken occasionally in deep upper-slope and shallow mid-slope mixed catches in small numbers. No substantial catches or large individuals were observed or reported.

Ling (*Genypterus blacodes*)

Limits of distribution: 33°06'S., 114°30'E. — 35°05'S., 114°53'E.; 596–989 m.

This species was recorded only rarely from the southernmost reaches of the WDWTF. Small quantities of an unidentified species of ling, a common by-catch species from deepwater crustacean trawling in the NWSTF, is sold under the name of pink ling, the other common name used for *G. blacodes*.

Morwong (*Nemadactylus macropterus*)

Limits of distribution: 31°55'S., 115°10'E. — 33°24'S., 114°31'E.; 203–357 m.

This shelf species was caught occasionally in small numbers in shallow reaches of the upper slope. However, the greatest abundance of morwong is likely to be in depths < 200 m. Whole specimens and otoliths were collected for stock discrimination studies by CSIRO.

Ocean perch (*Helicolenus* species)

Limits of distribution: 26°36'S., 112°29'E. — 33°18'S., 114°31'E.; 339–770 m.

The taxonomy of *Helicolenus* species in Australia is currently under review by Dr John Paxton of the AM and it is likely that the common commercial product marketed in south-eastern Australia as ocean or coral perch comprises at least two species. Small individuals of what may be more than one species were caught commonly in small numbers on the WDWTF upper slope. Large fish (> 30 cm) were not seen. Specimens were collected for studies of genetic stock discrimination.

Purple stargazer (*Pleuroscopus pseudodorsalis*)

Limits of distribution: 33°20'S., 114°30'E.; 435 m.

Only two individuals of this fish were observed in a single trawl catch; it seems likely that this is a relatively rare species in the WDWTF.

Smooth dory (*Pseudocyttus maculatus*)

Limits of distribution: 34°57'S., 114°22'E. — 35°08'S., 114°51'E.; 785–1150 m.

This species was caught in a number of trawls at the extreme southern end of the WDWTF but only as small fish and in small quantities. Specimens were collected for CSIRO stock discrimination studies.

Warty oreo dory (*Allocyttus verrucosus*)

Limits of distribution: 20°08'S., 112°55'E. — 35°05'S., 114°60'E.; 613–1293 m.

Warty oreo dory were recorded commonly in mid-slope trawls in quantities to about 1 tonne. Small individuals were caught during the CSIRO survey on the Exmouth Plateau in the northernmost reach of WDWTF and specimens were retained for CSIRO stock discrimination studies.

5.6 The Western Australian Continental-Slope Fish Community

Introduction

In recent years, exploitation of demersal fish resources on the Australian continental slope has provided much information on the previously little-known fishes of this region (Koslow *et al.* 1989). In particular, the rapid expansion of the fishery for orange roughy (*Hoplostethus atlanticus*) has accelerated the exploration of the mid-slope region (~ 750–1200 m) in south-eastern Australia and in the Great Australian Bight (GAB) (Bulman *et al.* in press, Newton and Klaer 1991, respectively). Despite these developments, the extensive western coastline of WA remained largely unexplored.

When the present study began in 1989, knowledge of the offshore fishes from the WA west coast was mainly on commercial species from the continental shelf (Heald and Walker 1982). Some catch composition data were available from a small number of trawls made on the upper continental slope to a depth of 602 m (Heald and Walker 1982) but, from an ichthyological perspective, the west-coast outer shelf and slope was virtually unsampled (Paxton *et al.* 1989). Prior to the declaration of Australia's Economic Exclusion Zone, several Soviet trawl surveys were conducted in the eastern Indian Ocean and on the Western Australian continental margin. However, data from those studies are unavailable at this time. Since 1989, exploration of the slope between North West Cape and Cape Leeuwin (Fig. 5.3.1), stimulated by the interest in discovering new fish resources, has been carried out by Australian commercial fishing vessels and by a research survey.

This paper describes the fish assemblages on the upper- and mid-slope regions off the west coast of WA. Abundance and diversity of the most numerous fish families and species is discussed in relation to depth down the slope and is compared with data from other slope regions. Slope fish biomass and patterns in horizontal and vertical distributions are examined in relation to the major water masses intersecting the west-coast slope region and the relevance of these observations to the concepts of zonation and community structure as applied to deepwater fish assemblages are discussed.

Materials and methods

Data collection

Refer to Chapter 5.3.

Taxonomic identifications

The preliminary nature of much of the taxonomy of Australian fishes noted by Paxton *et al.* (1989) is especially true of fishes from the continental slope region. Many of the species caught in this study were poorly known — many species were recorded from Australian waters for the first time and several species remain undescribed. To ensure continuity in taxonomic determinations and to permit cross-referencing during and following this study, a field identification guide was constructed and a collection of voucher specimens was established. The identification guide comprised primary morphometric and meristic data and a colour photograph of each fish considered to represent a species level entity. A list of species, including the location and registration numbers of voucher specimens and photographic slide catalogue numbers, is given in Appendix VI.

The primary source of reference used for classification and general distributions of fishes was Paxton *et al.* (1989). However, their data were viewed conservatively in light of the provisional status of much of the information available for Australian slope species. Recent changes in the family classification of fishes presented several options for some groups of interest to this study.

Data standardisation and reduction

Quantitative abundance data for entire catches, i.e., commercial and non-commercial species, were available only from the research cruise. Excluding aborted and targeted trawls, data from 66 trawl stations between 200–1400 m were used in analyses. At each station, the numbers and weights of all species were recorded. Distribution data from 50 commercial trawls between 200–1100 m, in which species identifications were verified, supplemented the survey data for some analyses.

Prior to analysis, samples from the survey data were standardised with respect to trawl speed and trawl duration; no allowance was made for variability in net geometry (wing spread and headline height) as these data were neither available for all trawl samples nor showed a clear relationship between net geometry and fishing depth. The species / samples data set was also reduced by eliminating pelagic species and taxa whose taxonomy remains problematic. Rare species which would not contribute to analysable patterns of distribution were eliminated before such analyses.

The species defined as pelagic included those whose association was unequivocally with the epi-, meso- or bathypelagic realms, or whose depth distributions were demersal and pelagic. A small number of exceptions to this general rule included those species for which an ontogenetic vertical distribution relationship was established, e.g., *Polymetme corythaeola* and *Photichthys argenteus* (Photichthyidae) which have a mesopelagic distribution only as juveniles. Taxa whose apparent distribution was benthic or benthopelagic, despite records to the contrary, were also retained, e.g., *Nansenia* cf. *ardesciaca* (Argentinidae) considered as mesopelagic by Smith *et al.* (1986). From the 451 nominal species collected overall, 131 pelagic species from the following taxa were excluded: Serrivomidae, Nemichthyidae, Eurypharyngidae, Bathylagidae, Opisthoproctidae, Gonostomatidae, Sternoptychidae, Astronesthidae, Melanostomiidae, Malacosteidae, Chauliodontidae, Stomiidae, Idiacanthidae, Myctophidae, Notosudidae, Paralepididae, Omosudidae, Alepisauridae, Evermannellidae, Scopelarchidae, Rondeletiidae, Barbourisiidae, Ogcocephalidae (*Coelophrys* sp.), Ceratoidae, Macrouridae

(*Mesobius* species, *Squalogadus modificus*), Melamphaidae, Diretmidae, Anoplogastridae, Carangidae, Chiasmodontidae, Gempylidae (*Lepidocybium flavobrunneum*, *Ruvettus pretiosus*, *Thyrsitoides marleyi*), Trichiuridae, Stromateidae (*Psenopsis obscura*) and Nomeidae.

Some data were eliminated prior to analysis in cases where field identifications of some species were found subsequently to be incorrect or discontinuous, and in other cases because the identifications remain unresolved. Taxa eliminated for these reasons were the *Squalus mitsukurii* and *S. megalops* species complexes (Squalidae), two forms of the *Helicolenus* species complex (Scorpaenidae), *Lepidotrigla* species (Triglidae), *Beryx* species (Berycidae), *Leptoderma* species (Alepocephalidae) and *Chaunax* species (Chaunacidae).

The large number of species entities retained from the survey data set included many rare species that were unlikely to contribute to analysable patterns of distribution but that would add considerably to computing demands during analysis. Consequently, rare species were removed prior to multivariate analyses of abundance data, using the method proposed by Field *et al.* (1982) in which only species having greater than an arbitrary percentage dominance at any station were retained. Selection by this criterion, as opposed to one based solely on numerical dominance, avoids bias towards species occurring at high abundance / low diversity stations. A selection level of greater than 5% dominance retained 94 species for analyses of similarities between stations. This total was reduced to a manageable size of 55 species for classification and ordination of species groups using a cutoff point at 15% dominance. A result of using this method of data reduction was that some otherwise rare species were dominant at a small number of stations and therefore failed to cluster. Accordingly, three 'dominant' species that occurred only once each, *Bajacalifornia* sp. W5 (Alepocephalidae), *Bathygadus* sp. W3 (Macrouridae) and *Lepidoperca* sp. W2 (Percichthyidae), were also removed.

For computation of biomass refer to Chapter 5.3.

Analysis of distribution patterns

The methods of analysis of multispecies distribution patterns followed the strategy outlined by Field *et al.* (1982) in which complementary classification and ordination methods were used to examine the relationships between samples (normal or Q-mode analysis) and between species (inverse or R-mode analysis). These analyses used matrices of similarity / dissimilarity coefficients calculated among samples or species using the Bray-Curtis 'percent difference' measure for numerical abundance data (Legendre and Legendre 1983). The Bray-Curtis measure is suitable for marine data sets because it is not affected by joint absences and gives more weight to abundant species than rare ones (Field *et al.* 1982). Q-mode and R-mode classification used hierarchical agglomerative clustering and two alternative methods for cluster formation. Complete linkage clustering joins an object to a cluster only when it is linked to all the objects that are already members of the cluster (Legendre and Legendre 1983): the large number of clusters formed in this way highlight discontinuities between clusters. Unweighted arithmetic average clustering uses the arithmetic average of similarity or distance between objects and agglomeration proceeds as the similarity or distance criterion is relaxed (Legendre and Legendre 1983): it was more useful for examining the relative positions of the clusters within the dendrograms produced.

Nonmetric multidimensional scaling (NMDS) was used for ordination of the data. Field *et al.* (1982) outlined its advantages over ordination techniques such as detrended correspondence analysis for use with species-samples matrices. MDS plots the best reconciliation of interstation or interspecies distances (derived from some function of the corresponding dissimilarity measures) as physical distances on maps of specified dimensionality (in these analyses, two- and three-dimensional (2D and 3D). The 'goodness of fit' of the distances to the dissimilarities in each case is measured by Kruskal's stress criterion, which, when low, indicates a good representation of the relationships between stations or between species in the specified dimensionality. The increase in stress as one moves to a solution in a lower dimension is an indication of the adequacy of the compressed representation.

All abundance data were transformed by logarithmic transformation prior to analysis. In addition, data for R-mode analysis were relativised by transforming the numerical abundance score for each species into a percentage of the total score of that species over all stations. The analyses were carried out on a Macintosh computer using the Proximities, Cluster and Alscal procedures in the SPSSX statistics program (Norusis 1990).

Results

Diversity, species numbers and numerical dominance

In total, about 360 nominal demersal species representing 91 families were collected: 319 species from 82 families were recorded during the survey and additional records of 41 species from 9 families were made from commercial trawls. In addition, approximately 138 pelagic species were taken during the descent and ascent of the demersal fishing gear. The majority (~ 90%) of the demersal species were taken in survey catches and few were caught in markedly larger proportions during commercial fishing. The notable exception was attributable to a targeted fishing operation for the lutjanid, *Etelis carbunculus*, a subtropical commercial shelf-break species, which, together the associated by-catch, was poorly sampled by survey trawls. The majority of 41 species not taken during scientific trawling were uncommon fishes taken in small numbers. Accordingly, the survey catches were considered to have representatively sampled the WA slope fish assemblages and to have generated a meaningful data set for numerical analysis.

The largest number of species in a family was 54, in the Macrouridae (Table 5.6.1), which outnumbered by 2·5 times the number of species in any other family and accounted for over one seventh of all species caught. The Squalidae, ranked second, contained 21 species. Over one third of the families collected were represented by a single species and only five included more than 10 species. The families with the most species were not necessarily the most numerically dominant. However, several of the families with large numbers of species had dominant representatives. The Macrouridae were remarkably dominant in terms of numbers of individuals. Two families, the Macrurocyttidae and Bathyclupeidae, were represented by single species but were amongst the most numerically abundant (Table 5.6.1).

With increasing depth down the slope, there was a continuous decrease in fish diversity as measured by the numbers of families and species present (Table 5.6.2). Sample sizes were unequal and may have resulted in a relative elevation of the species count between 800–1000 m and depressed the number of species in the deepest stratum (1200–1400 m). However, values from these strata are consistent with the overall trend. A similar trend with increasing depth was also observed in the number of individuals taken per trawl and in fish biomass (Tables 5.6.2, 5.6.3).

The high representation by the Macrouridae was the most striking feature of the patterns observed in the distribution of abundant groups (families and species) on the WA slope. Largely as a consequence of this, the number of numerically dominant families (ranked by percentage of the total number of individuals per stratum) decreased as depth increased (Table 5.6.2) with macrourids numerically dominant in all depths > 600 m. On the upper slope there was an almost complete turnover of the families ranked second to fourth between strata, in contrast to the mid-slope strata where the Alepocephalidae, Oreosomatidae and Synaphobranchidae were consistently found in relatively large numbers. In all strata except between 400–600 m the dominant family accounted for 40–50% of individuals. Excluding rare species (those accounting for < 1% of the total number of fish per stratum), the Acropomatidae and Chlorophthalmidae were represented by four and three species respectively, whereas in the deepest four strata the total numbers of macrourid species were 10, 15, 8 and 10, respectively. Generally the numerically dominant families had representatives in a wide range of depths extending over either the upper slope or the mid-slope, and sometimes both.

In the shallow upper-slope depth range, the dominant acropomatids were *Malakichthys elegans* and *Acropoma japonicum* (~ 36% and 9% of individuals, respectively), whilst over the deeper upper slope *Apogonops anomolus* was most abundant (~ 13%). Over the shallow mid-slope this family was represented by *Synagrops japonicus*, which was relatively scarce. The Trachichthyidae were well represented on the upper slope by *Gephyroberyx darwini* and a suite of small *Hoplostethus* species dominated by *H.* cf. *meditteraneus*. In contrast to south-eastern Australia, where *H. atlanticus* is the single most dominant mid-slope species, that species was relatively rare and no other trachichthyids were caught below 800 m. The Macrurocyttidae were represented by a single, small, undescribed species, *Zenion* sp. W1, and of the five gempylid species caught only two were present in appreciable numbers: *Rexea solandri* on the

Table 5.6.1. Numbers of demersal fish families and species

Family	Species	Family	Species
Macrouridae	54	Photichthyidae	2
Squalidae	21	Neoscopelidae	2
Alepocephalidae	20	Polymixidae	2
Triglidae	13	Grammicolepididae	2
Ophidiidae	13	Caproidae	2
Scorpaenidae	10	Cheilodactylidae	2
Rajidae	9	Mugiloididae	2
Moridae	9	Champsodontidae	2
Scyliorhinidae	8	Pleuronectidae	2
Serranidae	8	Ostriciidae	2
Acropomatidae	7	Tetraodontidae	2
Congridae	6	Rhinochimaeridae	2
Zeiidae	6	Sparidae	2
Halosauridae	6	Hexanchidae	1
Trachichthyidae	6	Orectolobidae	1
Chlorophthalmidae	5	Myliobatidae	1
Gempylidae	5	Pristiophoridae	1
Psychrolutidae	5	Muraenidae	1
Chimaeridae	4	Notocanthidae	1
Synaphobranchidae	4	Alopiidae	1
Triacanthodidae	4	Bathysauridae	1
Triakidae	4	Notosudidae	1
Harpadontidae	4	Ateleopodidae	1
Berycidae	4	Bregmacerotidae	1
Oreosomatidae	4	Merlucciidae	1
Platycephalidae	4	Holocentidae	1
Priacanthidae	4	Parazenidae	1
Uranoscopidae	4	Macrurocyttidae	1
Pentacerotidae	4	Veliferidae	1
Monocanthidae	4	Icelidae	1
Chaunacidae	3	Cyclopteridae	1
Squatiniade	3	Dactylopteridae	1
Urolophidae	3	Glaucosomatidae	1
Nettastomatidae	3	Banjosidae	1
Ipnopidae	3	Branchiostegidae	1
Lophiidae	3	Emmelichthyidae	1
Ogcocephalidae	3	Nemipteridae	1
Carapidae	3	Mullidae	1
Macrorhamphosidae	3	Bathyclupeidae	1
Hoplichthyidae	3	Mullidae	1
Macrorhamphosidae	3	Bathyclupeidae	1
Hoplichthyidae	3	Oplegnathidae	1
Apogonidae	3	Cepolidae	1
Bothidae	3	Sphyraenidae	1
Torpedinidae	2	Percophidae	1
Anacanthobatidae	2	Callionymidae	1
Argentinidae	2	Citharidae	1

Totals	Families =	90	Species =	359

Table 5.6.2 Numerically dominant four families in each stratum (shown as percentage of total number of individuals per stratum), mean numbers of fish and numbers of families, species and samples per stratum (survey data only)

Depth stratum (m)	200 –400	400 –600	600 –800	800 –1000	1000 –1200	1200 –1400
Acropomatidae (sea bass)	50	17				
Trachichthyidae (sawbellies)	24					
Macrurocyttidae (dwarf dories)	5					
Gempylidae (snake mackerels)	3					
Chlorophthalmidae (greeneyes)		20				
Scorpaenidae (scorpion fishes)		10				
Bathyclupeidae (bathyclupeids)			19			
Chaunacidae (coffin fishes)			8			
Neoscopelidae (new lanternfishes			6	10		
Ipnopidae (tripod fishes)						7
Synaphobranchidae (basketwork eels)					10	7
Oreosomatidae (oreo dories)				10	12	
Alepocephalidae (slickheads)				14	12	7
Macrouridae (whiptails)		8	42	41	50	49
Mean number of fish per standard trawl	3217	507	234	209	155	157
Number of families caught	61	41	35	29	25	16
Number of species caught	137	90	79	98	67	44
Number of samples	12	12	10	15	11	5

shallow upper slope and *Scombrolabrax heterolepis* over the mid-slope.

The Chlorophthalmidae were the dominant family in the 400–600 m stratum but represented only 20% of individuals, less than half the proportion accounted for by the single most dominant families in the other strata. Of the five species identified, *Chlorophthalmus nigripinnis* and *Chlorophthalmus* sp. W6 were the most numerous (13% and 6%, respectively). In common with the other chlorophthalmids, they were restricted to the shallow and mid-depths of the upper slope. The Scorpaenidae were among the most speciose families taken on the WA slope and included shallow species characteristic of the shelf and shelf-break (e.g., *Neosebastes nigropunctatus*, *N. pandus* and *N. thetidis*) and deep species restricted to the mid-depths on the mid-slope (e.g., *Trachyscorpia* spp.). The most abundant group was the *Helicolenus* species complex, which occupied a wide range of depths on the upper slope and accounted for about 7% of individuals in this stratum. The abundant macrourids in this depth range were mostly *Coelorinchus* species, of which the *C. fasciatus* species complex and *C. mirus* were most numerous.

The Macrouridae were the most numerous fishes in the deep upper slope / shallow mid-slope stratum (600–800 m). Here, the *C. fasciatus* complex was still present as the most numerous group, with

Table 5.6.3 Demersal fish biomass ($g \cdot m^{-2}$) by fishing block and depth stratum

Fishing block	Depth stratum (m) 200 –400	400 –600	600 –800	800 –1000	1000 –1200	Mean (200 –1200)	Mean (400 –1400)
1	1·28	0·19	0·07	0·25	0·14	0·39	0·16
2	3·14	0·46	0·23	0·16	0·40	0·88	0·31
3	1·02	0·83	0·22	0·31	0·36	0·55	0·43
4	1·19	0·42	0·31	0·68	0·31	0·58	0·43
5	4·03	0·99	0·13	0·75	0·65	1·31	0·63
6	0·32	0·66	0·21	0·73	0·14	0·41	0·44
7	2·37	0·44	0·77	0·94	0·74	1·05	0·72
8	3·21	–	0·87	0·62	–	1·57	0·75
Mean	2·07	0·57	0·35	0·56	0·39		

Malacocephalus laevis, *Nezumia* sp. W11, *Ventrifossa* sp. W8, *Coelorinchus* sp. W1 and *Lepidorhynchus denticulatus* also abundant. The single species of bathyclupeid collected during this study, *Bathyclupea* sp. W1, was the most numerous fish in this depth range, accounting for about 19% of all individuals caught. The Chaunacidae, with two problematic groups (*Chaunax endeavouri* and *C. fibriatus* species complexes), accounted for about 8% of the fishes taken in this stratum whilst the Neoscopelidae, represented by *Neoscopelus* sp. nov. (see Appendix 1) and *N. macrolepidotus*, ranked fourth with about 6% of individuals. *Neoscopelus macrolepidotus* was more abundant in the 800–1000 m stratum where it accounted for 10% of total numbers and, as such, was the equally most abundant species.

In depths greater than 800 m, the Macrouridae were the most speciose family and accounted for between 41% and 50% of the individuals in each of the three mid-slope strata (Table 5.6.2). *Cetonurus globiceps*, *Gadomus* cf. *multifilis*, three as yet unidentified species of *Trachonurus* and *Bathygadus cottoides* were the most numerous species, but also present in appreciable numbers were several species of the genera *Coelorinchus, Coryphaenoides, Nezumia and Ventrifossa*. Several species of Alepocephalidae were present in relatively high numbers and were widespread in mid-slope depths. In the 800–1000 m stratum *Xenodermichthys copei* and *Rouleina squamilatera* were most numerous (10% and 3% respectively), whilst in the two deeper strata a larger number of relatively uncommon species, mostly of the genera *Alepocephalus*, ranked the Alepocephalidae second or third most numerous in each. Oreosomatids are widespread and abundant on the southern Australian mid-slope and off south-eastern Australia are commercially important. On the west coast, they were represented by four species. Only

Allocyttus verrucosus was caught in appreciable numbers, making up 10% and 12% of numbers in the 800–1000 m and 1000–1200 m strata, respectively. The Synaphobranchidae, comprising four species, ranked fourth in each of the two deepest strata (1000–1200 m and 1200–1500 m). *Diastobranchus capensis* and *Synaphobranchus brevidorsalis* were most numerous, with a combined proportion of about 7% of numbers in each stratum; *S. affinis* and *S. kaupi* were contributed about 3% of numbers between 1000–1200 m. *Bathypterois ventralis*, one of three members of the Ipnopidae collected, accounted for 7% of numbers in the 1200–1400 m stratum.

Several other groups that were prominent on the WA slope in terms of biomass were less numerous. The Squalidae, with 21 species, ranked second in terms of numbers of species and in the six strata sampled ranked eleventh, sixth, ninth seventh eighth and eleventh, respectively, for numerical dominance. The *Squalus megalops* and *S. mitsukurii* species complexes were the dominant squalids on the upper slope (1–3% and ~ 1%, respectively), with *Deania calcea* relatively numerous (~ 1%) on the shallow mid-slope, and *Zameus squamulosus* widespread and relatively numerous (~ 1%) in the 800–1500 m strata. The Triglidae were represented by about 13 species, mainly members of the taxonomically problematic genera *Lepidotrigla* and *Satyrichthys*. This family was restricted mostly to the shallow and mid-range of the upper slope, with only *S. amiscus* extending below 500 m. Representatives of the Ophidiidae ranged from the upper slope to the deep mid-slope. The upper-slope species, *Dannevigia tusca* and *Genypterus blacodes*, were relatively large but rare off the west coast of WA, whereas several of the deep species were more numerous and contributed to the ranking of this family at fifth and seventh in the two deepest strata. The dominant species, *Monomitopus* sp. W1 and *Bassozetus* sp. W1, accounted for ~ 1–3% and ~ 1% of numbers, respectively.

Biomass

The biomass of demersal fishes for each of 38 block by depth strata was calculated from the results of the scientific survey data (Table 5.6.3) but, since many of the values are represented by single trawls only, the overall range of values is used for comparative purposes. Direct comparison of biomass estimates between studies can be difficult for many reasons, notably because of the biases inherent in trawl sampling, the unknown catchability of the species concerned and the unquantified seasonal and diel variability (May and Blaber 1989, Merrett *et al.* 1991). However, a broad comparison of the range of biomass values off WA with estimates from a range of geographical localities showed clearly that slope fish biomass was considerably lower than at all other sites (Table 5.6.4). Only the upper slope of the Porcupine Sea Bight, in the eastern North Atlantic (Merrett *et al.* 1991), fell within the range of values from WA ($< 1\ g \cdot m^{-2}$).

The data from south-eastern Australia provided an opportunity for a direct comparison of estimates because the distribution of many elements in the southern Australian slope fish assemblage is continuous between the east and west coasts (Koslow *et al.* 1993), and

Table 5.6.4 Continental slope demersal fish biomass estimates ($g \cdot m^{-2}$) from various geographic localities.

Author	Depth (m)	Site	Sampling method*	Catchability (q)	Biomass ($g \cdot m^{-2}$)
Koslow *et al.* (1993)	800–1200	SE Australia	35 m trawl	1	4·82
May & Blaber (1989)	500	SE Australia	35 m trawl	Variable	5·27
Wankowski & Moulton (1986)+	300–600	S. Australia	26 m trawl	0·5	3·4#
Merrett *et al.* (1991)	400–600	NE Atlantic	range of trawls	?	0·2
Merrett *et al.* (1991)	600–1200	NE Atlantic	range of trawls	?	1·6–2·8
Ohta (1983)+	~ 500–800	Japan	photographic transects	–	4·56
Haedrich & 2·45–2·72 Rowe (1977)	~ 500–1000		N Atlantic transects	photographic	–
This study	400–1200	W. Australia	35 m trawl	1	0·07–0·99¤

* length in metres refers to net headline length
\+ data from May and Blaber (1989)
\# commercial species only (excluded many species)
¤ range of values only; see also Table 5.6.3

because the trawl gear used in the studies of May and Blaber and Koslow *et al.* was the same as was used in the current study. Thus, estimates from the south-eastern Australian upper and mid-slope, 5·27 $g \cdot m^{-2}$ (May and Blaber), 4·82 $g \cdot m^{-2}$ (Koslow *et al.*) respectively, were of the order of five times greater than the highest single value (0·99 $g \cdot m^{-2}$) recorded off WA. These differences may actually be even greater considering the relatively conservative nature of the other estimates: May and Blaber used catchability coefficient $q < 1$, and Koslow *et al.*, in the light of subsequent commercial catches from the mid-slope, underestimated the contribution of the most abundant species, ***Hoplostethus atlanticus***. The biomass estimate of 3·4 $g \cdot m^{-2}$ from southern Australia (Wankowski and Moulton 1986) is also much larger than the WA values but is highly conservative as only commercial species were included in the estimate and catchability, q, was assumed to be 0.5.

The largest fish biomasses were trawled in the shallowest depth stratum and biomass was appreciably lower in all deeper strata (Table 5.6.3). (The figure for 200–400 m, Block 6 came from a single small catch). No clear relationship between biomass and latitude was apparent using data from all depth strata. However, with the relatively large and variable shallow stratum (200–400 m) excluded, a trend of increasing biomass with increasing latitude was noted (Table 5.6.3).

Multispecies distribution patterns (analysis of stations)

Classification of stations consistently showed a clustering of trawl stations along depth and latitudinal gradients (Fig. 5.6.1). At the 20% level of similarity, seven clusters were formed in two major groups: the first group contained upper-slope stations (clusters 1–4), and the second contained mid-slope stations (clusters 5–7) separated by depth at about 700 m. Cluster 1 combined six shallow stations from the low latitude region of the fishery (200–312 m; 21°37'–27°20'S.), while clusters 2 and 3 combined the mid-depth stations of the upper slope (346–510 m) at low latitude (24°40'–27°17'S.) and high latitude (26°45'–33°22'S.) respectively. Cluster 4 combined eight deeper upper-slope stations (482–714 m) from a broad latitudinal range (23°00'–32°02'S.). Clusters 5 and 6 comprised the shallower mid-slope stations (685–942 m), with the former showing coherence of the four southern-most stations (33°25'–35°05'S.), and the latter, the northern stations in two subclusters of latitudinal gradient (28°00'–32°40'S. and 20°08'–26°05'S.). Cluster 7 combined the mid-depth mid-slope stations (913–1460 m) in two subclusters combined on a latitudinal gradient (20°16'–22°29'S. and 23°59'–32°20'S.). Six stations (56, 89, 8, 63, 2 and 88) failed to cluster.

The seven station groups delineated in the dendrogram (Fig. 5.6.1) are shown in two- and three-dimensional NMDS plots (Figs 5.6.2, 5.6.3*A*–*C*) using the same cluster numbering as the dendrogram (Fig. 5.6.1). The stress criterion and correlation coefficient in the three-dimensional solution (0·147, 0·87, respectively) were a small improvement on the two-dimensional solution, indicating that the interstation relationships are more adequately shown in three dimensions. Nevertheless, both solutions show a reasonable fit to the data and a clear ordination of stations with depth (depth increases clockwise from cluster 1 in Figs 5.6.2 and 5.6.3*A*). Both solutions display the discontinuities between the shallow, mid-depth and deep reaches of the upper-slope clusters and those between the shallow and mid-depth ranges of the mid-slope. A clearer separation of latitudinal subclusters is achieved in the third dimension.

Multispecies distribution patterns (analysis of species)

R-mode classification discriminated four major groups of fishes in seven clusters (Fig. 5.6.4). Clusters 1–4 were formed by fishes with centres of abundance on the upper slope (Table 5.6.5) and comprised a shallow upper-slope group (cluster 4), two shallow / mid-depth upper-slope (clusters 1 and 3) and one deep upper-slope group (cluster 2). Cluster 5 comprised three species with range of distribution restricted to the upper depths of the mid-slope (~ 750–1000 m). Clusters 6 and 7 represented fishes with broader mid-slope distributions, but separated fishes with greatest abundances on the shallow (< 1000 m) and mid-depth (> 1000 m) mid-slope respectively (Table 5.6.5). Three species, *Argentina* sp. (Argentinidae), *Gephyroberyx darwini* (Trachichthyidae) and *Alepocephalus* cf. *longiceps* (Alepocephalidae) failed to cluster well with any group.

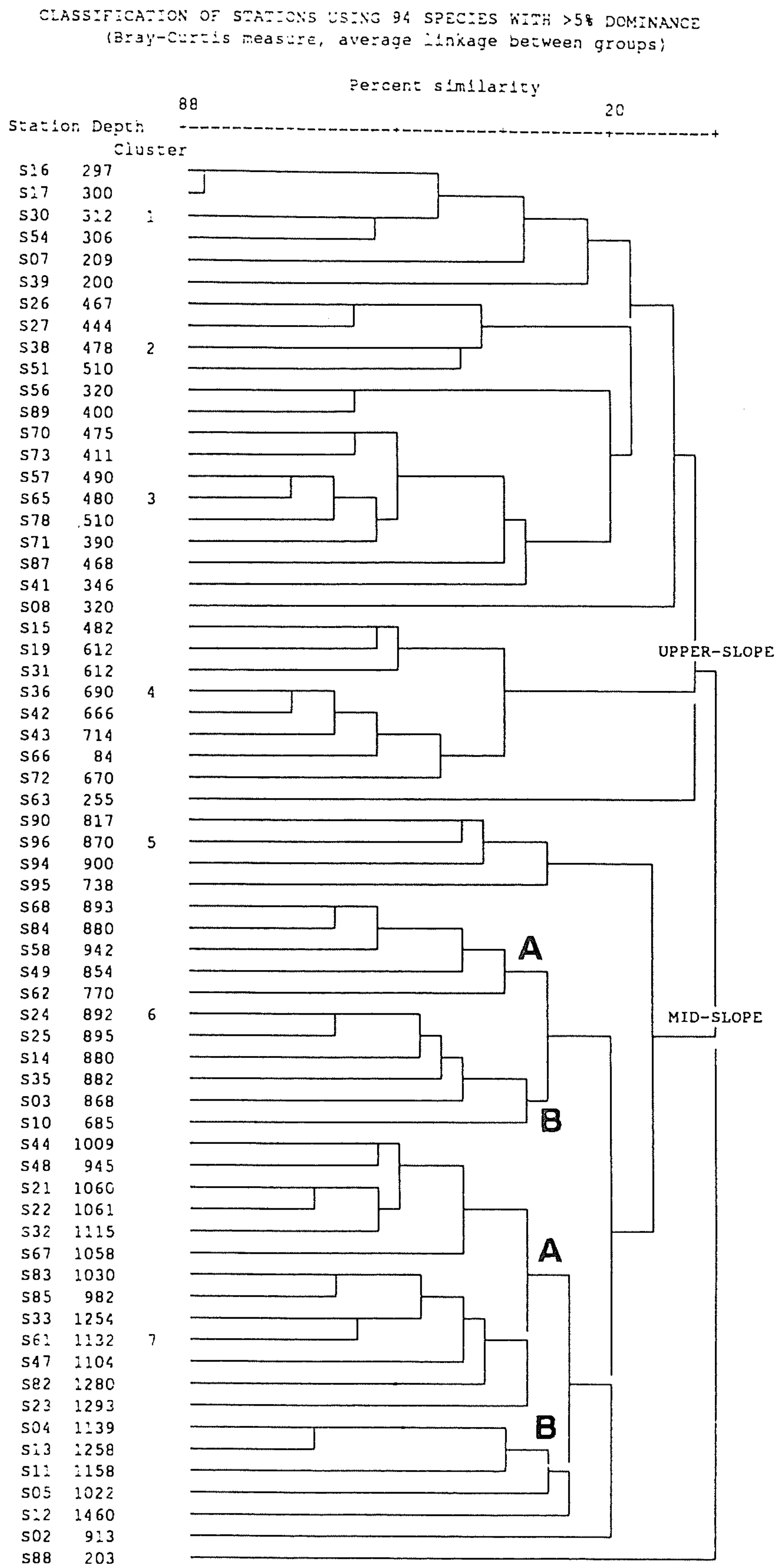


Fig. 5.6.1 Classification of Western Deep Water Trawl Fishery survey stations

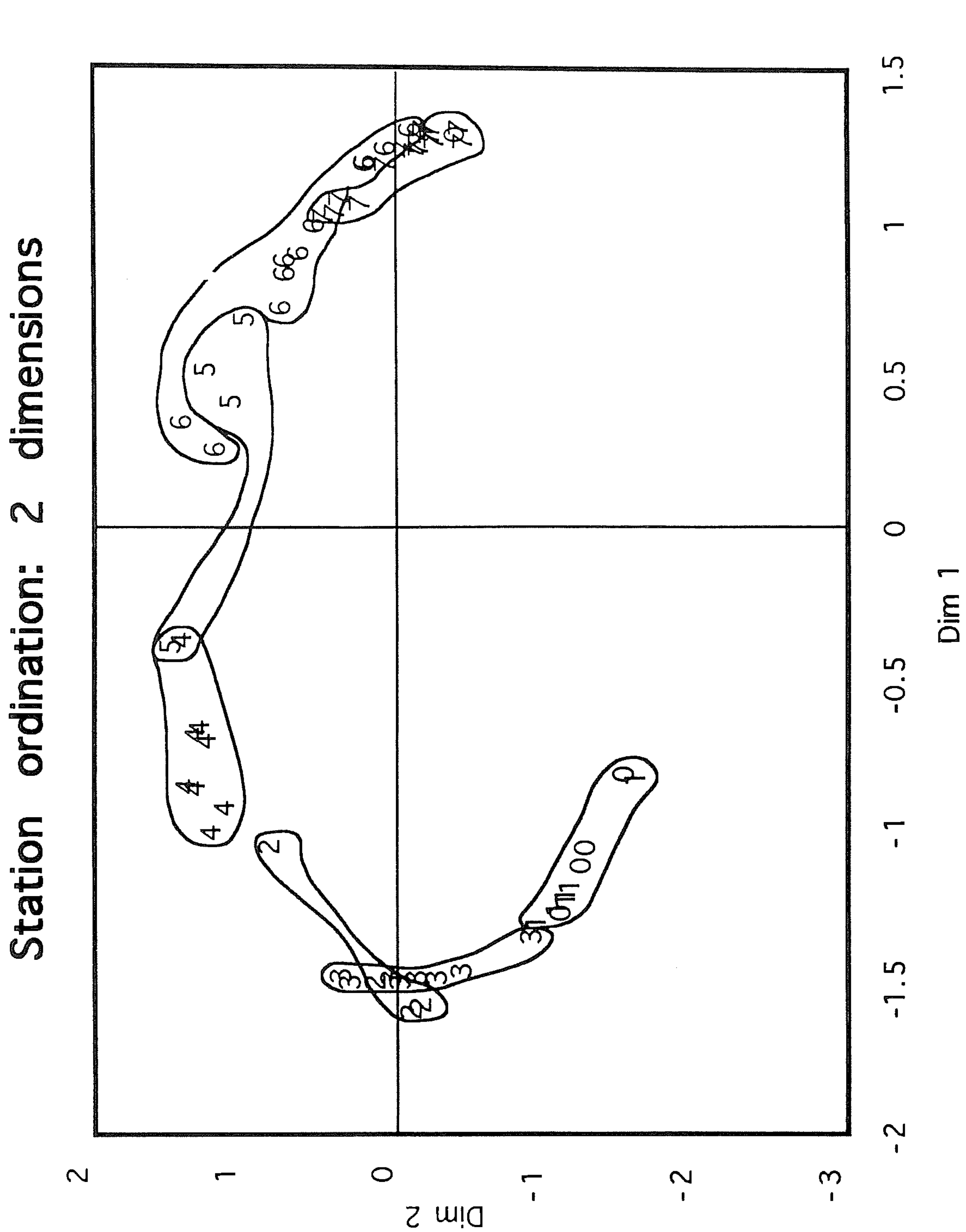


Fig. 5.6.2 Ordination of Western Deep Water Trawl Fishery survey stations (two dimensions)

Station ordination: 3 dimensions

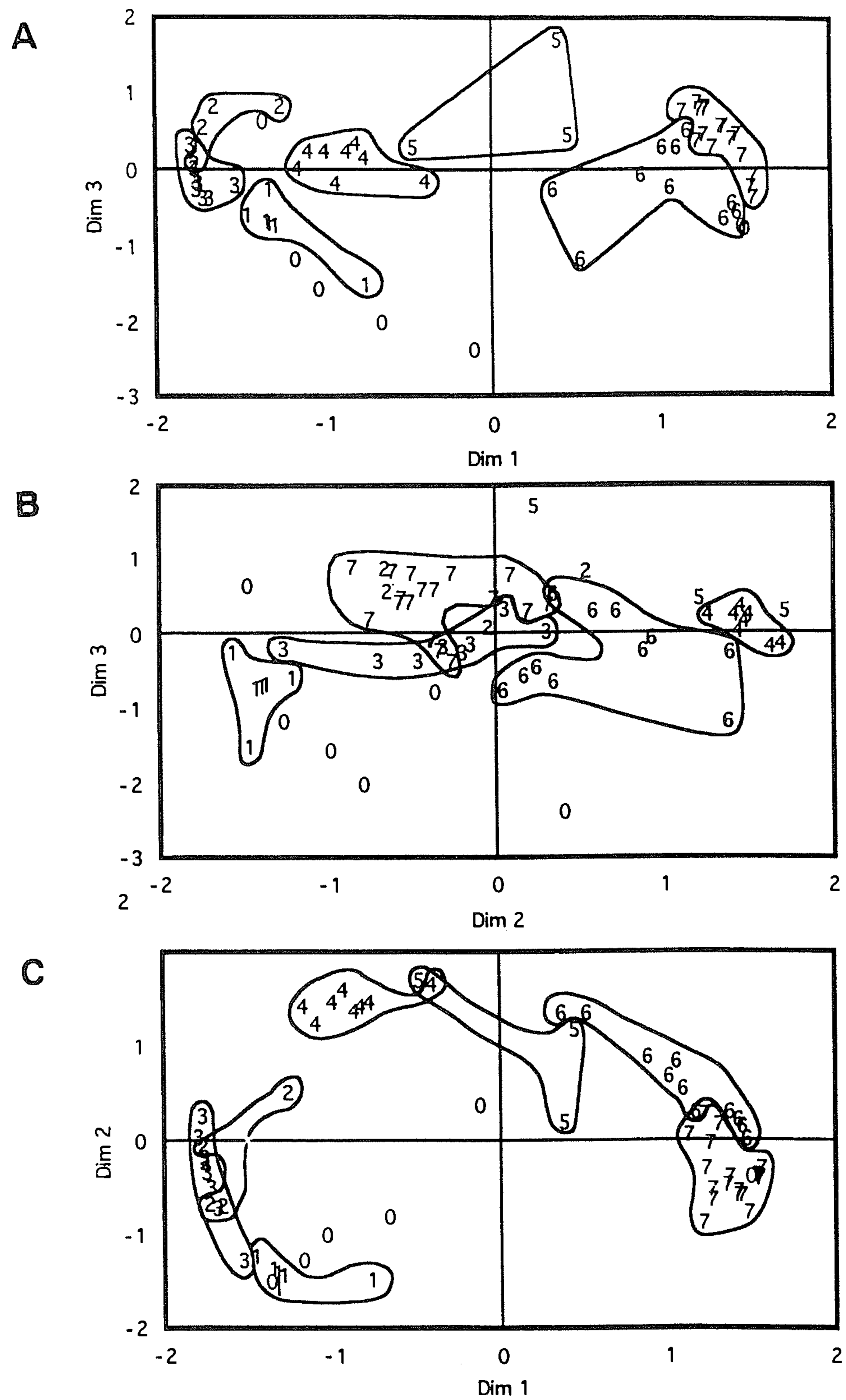


Fig. 5.6.3*A–C* Ordination of Western Deep Water Trawl Fishery survey stations (three dimensions)

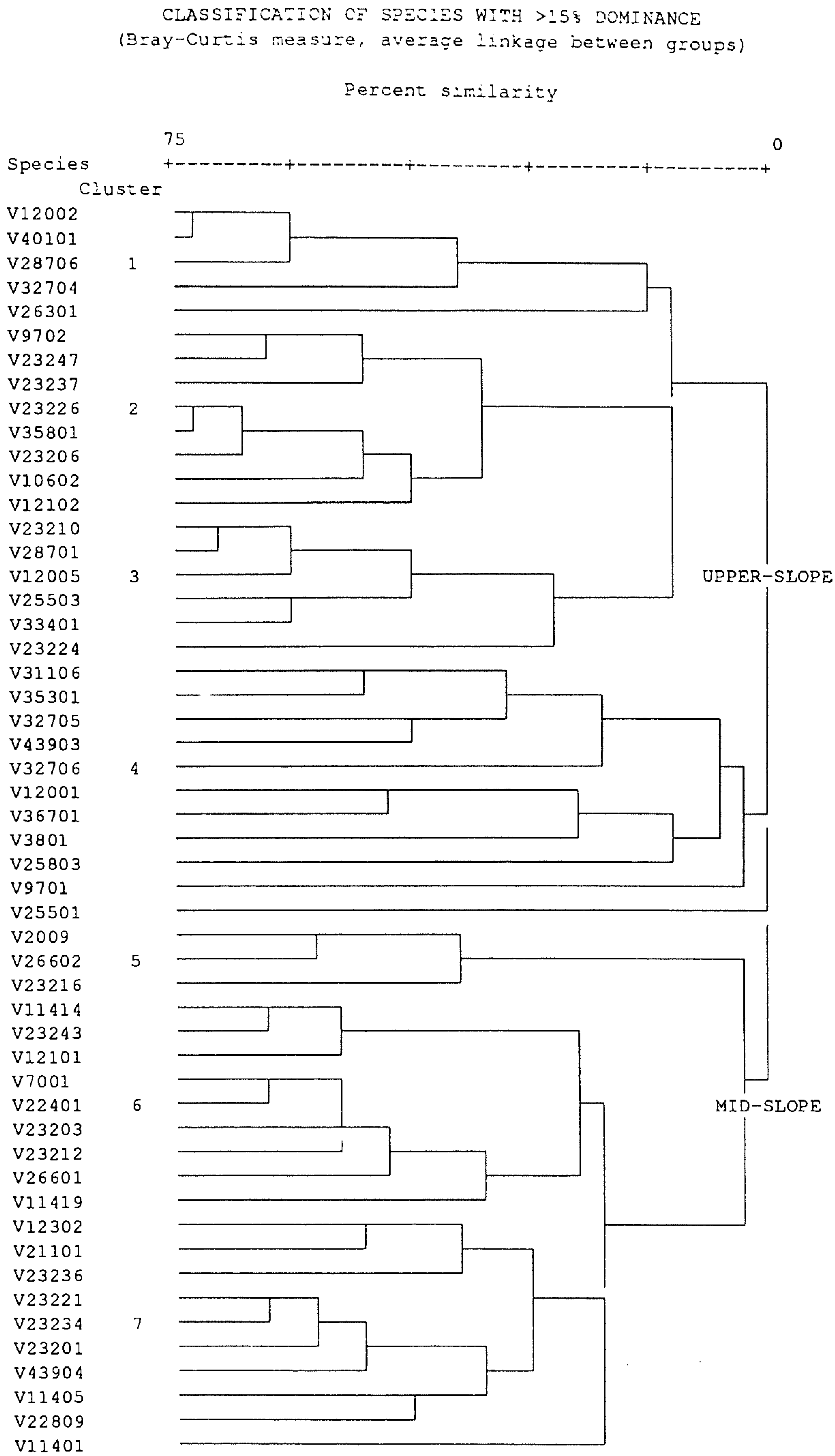


Fig. 5.6.4 Classification of species from Western Deep Water Trawl Fishery trawl survey

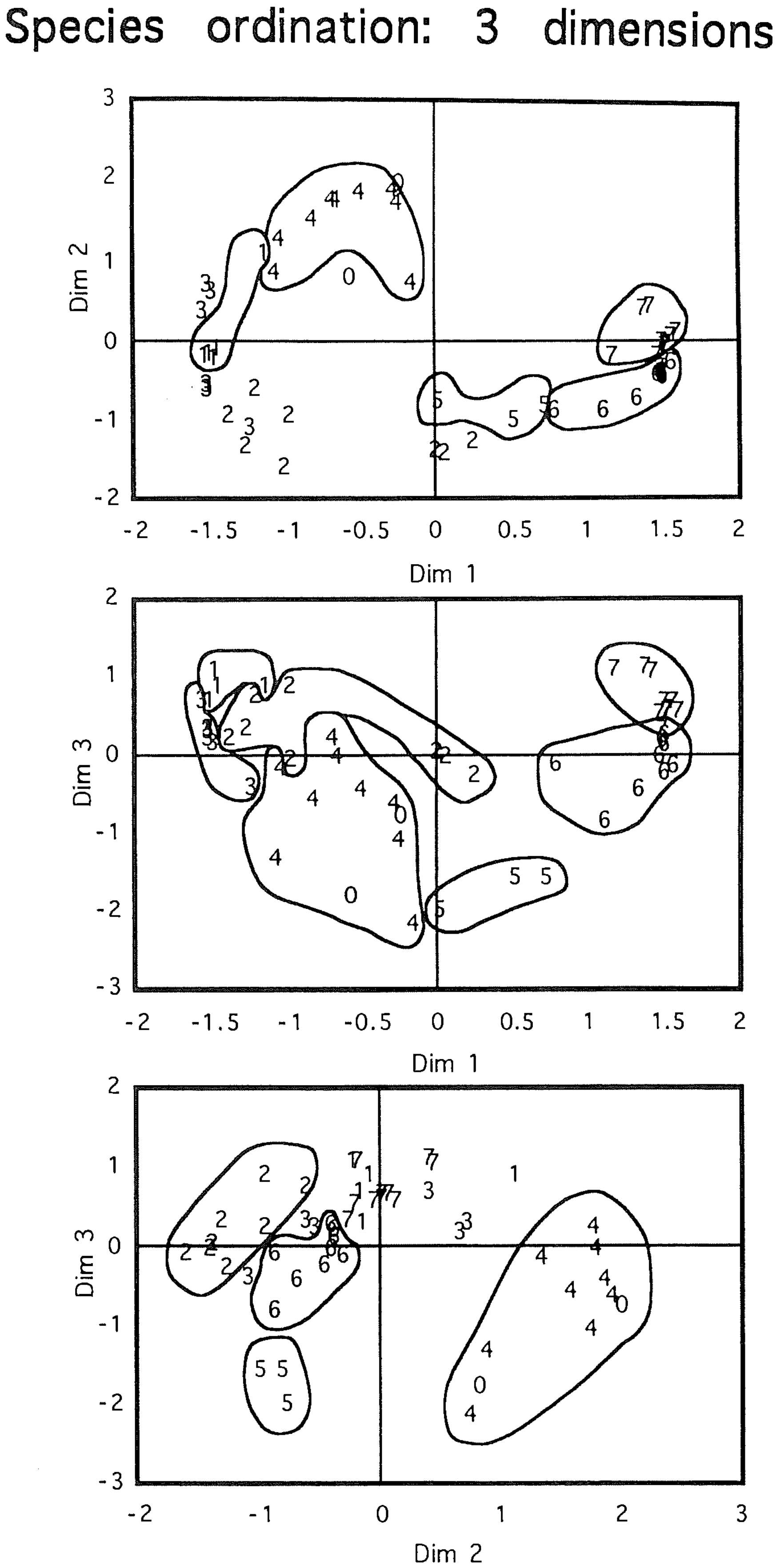


Fig. 5.6.5 Ordination of species from Western Deep Water Trawl Fishery trawl survey (three dimensions)

Table 5.6.5. Depth distributions (percentage of species total) from clusters.

Cluster number	Species code	Species	200 –300	300 –400	400 –500	500 –600	600 –700	700 –800	800 –900	900 –1000	1000 –1100	1100 –1200	1200 –1500	Min. depth	Max. depth
	12002	*Chlorophthalmus* sp. W1	0	0	46	54	0	0	0	0	0	0	0	328	510
	40101	*Champsodon* sp. W1	1	1	41	53	4	0	0	0	0	0	0	297	612
1	28706	*Setarches guentheri*	0	11	54	34	2	0	0	0	0	0	0	318	649
	32704	*Synagrops japonicus*	0	27	14	23	21	15	0	0	0	0	0	306	714
	26301	*Zenion* sp.	0	96	4	0	0	0	0	0	0	0	0	306	735
	9702	*Nansenia* cf. *ardesacia*	0	0	0	0	20	27	48	5	1	0	0	556	1009
	23247	*Ventrifossa* sp. W8	0	0	4	0	21	56	13	6	0	0	0	320	942
	23237	*Nezumia sp.* W11 (blue)	0	0	0	0	30	57	10	0	3	0	0	320	1009
2	23226	*Malacocephalus laevis*	0	0	13	5	55	27	0	0	0	0	0	411	870
	35801	*Bathyclupea* sp. W1	0	0	14	0	41	41	0	0	0	4	0	478	1104
	10602	*Polymetme corythaeola*	0	0	44	7	47	0	0	0	0	1	0	411	1115
	12102	*Neoscopelus* sp. nov.	0	0	0	0	100	0	0	0	0	0	0	612	690
	23210	*Coelorinchus* sp. W14 (D)	0	1	18	37	38	6	0	0	0	0	0	320	714
	28701	*Helicolenus* cf. *percoides*	0	6	52	31	7	5	0	0	0	0	0	320	770
3	12005	*Chlorophthalmus* sp. W6	0	31	30	35	4	0	0	0	0	0	0	200	670
	25503	*Hoplostethus mediterraneus*	0	18	75	7	0	0	0	0	0	0	0	320	510
	33401	*Apogonops anomalus*	5	35	12	48	0	0	0	0	0	0	0	200	510
	23224	*Lepidorhynchus denticulatus*	0	0	14	42	37	5	1	0	0	0	0	320	817

Cluster number	Species code	Species	200 –300	300 –400	400 –500	500 –600	600 –700	700 –800	800 –900	900 –1000	1000 –1100	1100 –1200	1200 –1500	Min. depth	Max. depth
	31106	*Malakichthys* cf. *elegans*	49	50	1	0	0	0	0	0	0	0	0	297	482
	35301	*Dentex tumifrons*	51	49	0	0	0	0	0	0	0	0	0	200	346
	32705	*Synagrops philippinensis*	0	100	0	0	0	0	0	0	0	0	0	306	478
	43903	*Rexea solandri*	0	97	2	1	0	0	0	0	0	0	0	216	596
4	32706	*Acropoma japonicum*	98	2	0	0	0	0	0	0	0	0	0	209	320
	12001	*Chlorophthalmus nigripinnis*	1	98	0	1	0	0	0	0	0	0	0	220	727
	36701	*Pentaceros decacanthus*	0	99	1	0	0	0	0	0	0	0	0	306	712
	3801	*Urolophus expansus*	5	95	0	0	0	0	0	0	0	0	0	203	400
	25803	*Centroberyx australis*	99	1	0	0	0	0	0	0	0	0	0	203	380
?	9701	*Argentia* sp. W1	99	1	0	0	0	0	0	0	0	0	0	255	438
?	25501	*Gephyrobryx darwini*	0	100	0	0	0	0	0	0	0	0	0	274	490
	2009	*Deania calcea*	0	0	0	0	0	41	35	24	0	0	0	738	900
5	26602	*Neocyttus rhomboidalis*	0	0	0	0	0	90	10	0	0	0	0	596	1240
	23216	*Coryphaenoides serrulatus*	0	0	0	0	0	0	94	6	0	0	0	740	982
	11414	*Rouleina* sp. W3 *sqamilatera*	0	0	0	0	5	0	65	17	14	0	0	685	1061
	23243	*Trachonurus* sp. W2 (big scale)	0	0	0	0	0	9	39	25	18	9	0	770	1132
	12101	*Neoscopelus macrolepidotus*	0	0	0	0	1	28	56	5	10	0	0	435	1022
	7001	*Diastobranchus capensis*	0	0	0	0	0	0	5	21	19	39	17	825	1280
6	22401	*Antimora rostrata*	0	0	0	0	0	0	13	22	11	11	43	825	1460
	23203	*Centonurus* cf. *globiceps*	0	0	0	0	0	0	36	19	21	3	21	740	1460
	23212	*Coelorinchus* sp. W16	0	0	0	53	0	2	12	21	7	5	0	510	1132
	26601	*Allocyttus verrucosus*	0	0	0	0	0	0	24	26	33	11	7	613	1293
	11419	*Xenodermichthys copei*	0	0	0	0	1	2	91	3	3	0	0	320	1030

Cluster number	Species code	Species	200 –300	300 –400	400 –500	500 –600	600 –700	700 –800	800 –900	900 –1000	1000 –1100	1100 –1200	1200 –1500	Min. depth	Max. depth
	12302	*Bathypterois ventralis*	0	0	0	0	1	0	14	4	3	17	60	690	1460
	21101	*Bathychaunax* cf. *melanostoma*	0	0	0	0	0	0	2	0	0	6	93	893	1460
	23236	*Nezumia* sp. W10	0	0	0	0	0	0	5	2	8	28	56	882	1460
	23221	*Gadomus multifilis*	0	0	0	0	0	0	5	10	47	15	22	817	1460
7	23234	*Nezumia* sp. W6	0	0	0	0	0	0	11	17	25	21	26	854	1258
	23201	*Bathygadus cottoides*	0	0	0	0	0	0	0	7	41	7	45	913	1280
	43904	*Scombrolabrax heterolepis*	0	0	0	0	0	0	14	48	15	3	19	854	1293
	11405	*Alepocephalus* sp. W4	0	0	0	0	0	0	0	5	4	71	21	945	1258
	2809	*Monomitopus* sp. W1	0	0	0	0	0	0	4	7	18	23	48	868	1258
	11401	*Alepocephalus* cf. *longiceps*	0	0	0	0	0	0	0	0	84	16	0	1022	1132

The shallow upper-slope group (cluster 4) combined temperate, tropical and wide-ranging species found in 200–400 m but rarely deeper. Commercial catch data (Heald and Walker 1982, Williams unpublished data) added more information to the distributions of three of these species and showed that the tropical sparid *Dentex tumifrons* ranged from 120–350 m, with highest catch rates in ~ 230–260 m. the pentacerotid *Pentaceros decacanthus* was most abundant between 300–400 m. Although documented as having a southern Australian distribution (May and Maxwell, 1986), it extended northwards to 23°20'S. Finally, the gempylid, *Rexea solandri* had highest catch rates between 300–400 m and a distinct temperate distribution that involves an extensive northwards spawning migration. The three shelf / upper-slope acropomatid fishes, *Acropoma japonica*, *Malakichthys* cf. *elegans* and *Synagrops philippinensis*, are tropical Indo-West Pacific in distribution, with these records representing range extensions for each; the berycid *Centroberyx australis* was known to be distributed along the coast from ~ 21°S.–35°S. in shelf-break and upper-slope depths (Shimizu and Hutchins 1987). The depth distribution of the two remaining species is not well represented by these data, due to their presence in one exceptionally large catch taken at 400 m. Thus, the distributions of the urolophid *Urolophus expansus* and the chloroph'thalmid *Chlorophthalmus nigripinnis* are temperate, with each species extending from the shelf to well down the upper slope (145–420 m and 80–600 m, respectively).

The two mid-depth clusters (1 and 3) broadly separated a low-latitude group (cluster 1) and a high-latitude group (cluster 3). Cluster 1 contained taxa that were characteristically tropical in distribution but with latitudinal ranges extending south to at least 27°S. Two species, *Setarches guentheri* and *Synagrops japonicus*, with circumglobal and widespread distributions respectively (Paxton *et al.* 1989), extended south of 30°S.

In contrast, the species in cluster 3, whilst all ranging at least as far north as 26°S., are essentially temperate in distribution. These records represent north-westerly range extensions for the temperate macrourid *Coelorinchus* sp. W14 (D) (*C. fasciatus* species complex), known from southern Australian waters, and the widely distributed temperate, south-west Pacific species *Lepidorhynchus denticulatus*. The trachichthyid *Hoplostethus* cf. *mediterraneus*, previously confused with the temperate, circumglobal species, *H. mediterraneus*, is recorded only from southern Australia. The scorpaenid *Helicolenus* cf. *percoides* is a potentially problematic entity, being part of a species complex currently under review. Two or three forms, possibly depth-stratified, were tentatively recognised during this work; the one form included in analyses was abundant in mid-coast samples but was not caught north of 26°36'S. Despite a similarity with the commercial temperate shelf species currently recognised as *H. percoides*, this form is likely to be different. The acropomatid, *A. anomolus*, is well known around southern Australia (Paxton *et al.* 1989) and this record represents a north-westerly extension of its range.

Over the deeper region of the upper slope, the abundant fishes characteristically ranged more widely, overlapping the mid-depth upper-slope assemblage and being found occasionally on the mid-slope at depths in excess of 1000 m. The centres of distribution of most were in the 600–800 m range but *Nansenia* cf. *ardesciaca* was most abundant below 800 m. Incorporation of this species into this group by multivariate analyses appeared to be because of the upper-slope extension of its distribution, which was not characteristic of the species abundant on the shallow mid-slope. The latitudinal distributions of the deep upper-slope species were generally wide and *N*. cf. *ardesacia*, a tropical species, was found as far south as 35°S.

The distributions of mid-slope assemblages, whilst generally well separated from those on the upper slope, were more difficult to characterise. The three groups established by classification and ordination comprised mostly species with wide vertical and latitudinal ranges, and groups were not separated from each other by clear discontinuities in depth distribution. In addition, the data contained too few samples to adequately detect discontinuities such as those in the south-eastern Australian mid-slope assemblages recognised by Koslow *et al.* (1993).

Cluster 5 comprised three species, *Deania calcea, Neocyttus rhomboidalis* and *Coryphaenoides serrulatus*, centred in the shallower region of the mid-slope (700–1000 m). Additional records indicate these are typically shallow mid-slope species, even though the distribution limits are much wider. For example, the squalid, *D. calcea*, widespread in the eastern Atlantic and eastern and western Pacific (including temperate southern Australia), is usually found between 400–900 m but has been recorded between 70–1450 m (Last and Stevens 1993). Similarly, around southern Australia, the other two species are most common on the shallow mid-slope but *C. serrulatus* has been recorded between 540–1100 m (Imamoto and Shcherbachev 1991) and *N. rhomboidalis* between 596–1240 m.

Although clusters 6 and 7 separated fishes with greatest abundances on the shallow (< 1000 m) and mid-depth (> 1000 m) mid-slope, respectively, no clear discontinuity was apparent (Table 5.6.5). Cluster 6 contained three species, *Diastobranchus capensis*, *Antimora rostrata* and *Cetonurus globiceps*, that were also relatively abundant below 1200, and cluster 7 contained three species, *Gadomus* cf. *multifilis*, *Nezumia sp. 6* and *Scombrolabrax heterolepis*, which were also abundant across the shallower mid-slope.

Discussion

The fish fauna of Australian waters is recognised as being diverse in world terms (Paxton *et al.* 1989), but only with recent collecting, following the commercial exploitation of upper- and mid-slope fishes, has the high number of species and great diversity of the offshore fish assemblages been fully recognised. One of the striking features of the continental slope fish assemblages off the west coast of WA was the large number of species present in the relatively few samples taken. The data do not lend themselves to a direct quantitative comparison with other areas because a meaningful index of diversity cannot be provided from the low number of samples spread over a wide

Table 5.6.6 Comparison of species numbers in slope fish assemblages

Locality	North Atlantic Basin	SE Australia (mid-slope)#	West. Australia (W coast, mid-slope)¤	West. Australia (W coast, upper & mid-slope)¤
Depth range (m)	204–5345	800–1200	800–1200	200–1500
Area sampled	***	~ 38–44°S. ~ 142–150°S.	~ 20–35°S. ~ 112–115°S.	~ 20–35°S. ~ 112–115°S.
Number of scientific cruises	63	30	1	1
Number of trawl catches examined	692	376	26 (36)	72 (122)
Number of species	325	118	123 (137)	319 (360)
Number of families	***	37	33 (35)	82 (91)

* data from Haedrich and Merrett (1990)
# data from Koslow *et al.* (1993)
¤ figures in parentheses include data from 50 commercial trawls

geographical range. The problem of comparison is compounded generally by selectivity problems inherent when using trawl gears of different types and sizes (Merrett *et al.* 1991). However, a broad comparison with two other areas where continental slopes have been well sampled using similar (large) trawl gear indicated that diversity, as measured by numbers of species present, is high off the WA coast. Thus, off south-eastern Australia and in the North Atlantic basin, fewer species were recorded from a far greater numbers of trawl samples in each case (Table 5.6.6).

The comparison must be made with qualifications and, whilst sample size was relatively low in the present study, the latitudinal range covered was much greater than that in south-eastern Australia. However, the summary of North Atlantic data by Haedrich and Merrett (1990) covered a large latitudinal and spatial range and is a better indication of the relative richness of the Western Australian fauna. The importance of sample size in such comparisons was demonstrated by Koslow *et al.* who showed that, whilst a high proportion (~ 50%) of fish species in a mid-slope assemblage may be caught in the first 20 or so trawls, the numbers of species caught increased steadily for approximately 140 trawls. Computation of the expected number of species based on a comparable number of trawls off WA was not attempted because of the small number of widely spread samples. However, based on the relationship with sample size, species numbers can be expected to rise appreciably with further trawling. It follows that sampling over a broad latitudinal range will elevate the number of trawls required to sample all species beyond the

140 estimated by Koslow *et al.* for a restricted region of the mid-slope.

In addition, the numbers of small species and those living in close association with the bottom were probably underestimated in the WA samples because of the selectivity of the large mesh net fitted with heavy bobbin gear that was used throughout the survey. This assumption is consistent with observations of fish by-catch taken by crustacean trawlers in the adjacent NW Australian crustacean fishery. Thus, in catches taken with relatively small-meshed nets fished 'hard' on the bottom, small benthic groups, e.g., ophidiids (lings) and congrids (conger eels), were most numerous. There was also an indication that fast-swimming, 'near-bottom' fishes may not have been vulnerable to our relatively slow trawls (~ 2·5 knots) of short duration (~ 30 min). For example, species such as the mobile lutjanid *Etelis carbunculus* were rare in survey catches but are taken in commercial quantities with light ground-contact fish trawls towed at higher speed for longer duration.

Wilson and Allen (1987) described several factors that have contributed to the development of the rich Australian coastal marine fauna. Most conspicuous are the geographic position of the continent (encompassing tropical and temperate seas), the long and physically diverse coast, and the long period of geological isolation of Australia's southern region that gave rise to a high degree of endemism in the southern temperate fauna. The contribution of each of these factors is vividly demonstrated on the long west coast of WA, where a diverse coastal fish fauna comprises a mix of tropical and temperate species, a variety of habitats (including coral reef), and a mix of widely distributed and endemic species.

Examination of the offshore fish assemblages showed that the same factors were important in the composition and diversity of the slope fauna. Thus, the predominantly tropical fauna evident at low latitudes gives way to a predominantly temperate fauna at high latitudes, with a mixture of tropical and temperate elements and warm-temperate species with limited distributions occupying the mid-coastal region. The nature of demersal habitats was observed only on rare occasions, either when substrate and epifauna were retained in trawls, or from photographs taken using a suspended deepwater camera. However, the extreme topography of the continental margin (apparent from soundings) undoubtedly afforded a great diversity of habitat types through partitioning and availability of resources, e.g., substrate types and food, respectively (Carney *et al.* 1982), and steep gradients in physiological parameters related to depth. The mix of widely and narrowly distributed species was different in the offshore assemblages, with a relatively large proportion of species being cosmopolitan or southern circumglobal in range, and relatively few narrowly distributed and endemic species.

The magnitude of the size and diversity of this deepwater fauna is put into perspective when compared to the total present-day Australian fish fauna of about 3600 species from 303 families (Paxton *et al.* 1989). The array of 360 species from 91 families in the first ichthyological collection from this region accounts for an appreciable proportion of the entire known fauna and comprises representatives from nearly one third of the recorded families. Whilst many of these are monotypic or rare, the Macrouridae are large and diverse, being represented by about 54 species in at least 17 genera. With the inclusion of the other species known from tropical, cool-temperate and mesopelagic waters, this family would rank amongst the ten most speciose in the Australian fish fauna.

Despite this, the Macrouridae are poorly known, with only 32 of the 57 species recorded by Paxton *et al.* (1989) currently identified. Off WA, most whiptail species were benthopelagic on the deep upper slope and mid-slope. However, several species of *Coelorinchus* were taken in the shallow reaches of the upper-slope and shelf-break region. The shallowest representative was *C. argenteus*, a widely distributed Indo-West Pacific species and a common component of the by-catch of trawlers fishing for crustaceans off northern Australia. A suite of widely distributed temperate Australian species, the *C. fasciatus* species complex (species C and D) and *C. mirus*, was most numerous over the middle and deep range of the upper slope; in 600–800 m *Coelorinchus* sp. D accounted for 10% of total numbers. Among the large number of species present on the mid-slope, *Gadomus* cf. *multifilis* and *Cetonurus globiceps* were the two most numerous species, accounting for up to 25% (1000–1200 m) and 10% (800–1000 m) of total numbers respectively. Elsewhere in Australian waters, both genera are poorly known: *Gadomus* from two unidentified species in north-western and eastern waters, and *Cetonurus* from recent records of *C. crassiceps* from a number of localities across southern Australia.

The acropomatids, or sea basses, represented by *Malakichthys elegans* and *Acropoma japonicum* on the shallow upper slope and by *Apogonops anomolus* on the deeper upper slope, were extremely abundant and dominated the fish assemblages in these regions. Target trawls through two large fish schools detected by echo sounder were found to contain predominantly *M. elegans*, where catch rates of this species alone exceeded 1890 $kg \cdot h^{-2}$.

Due to its large-scale commercial exploitation on the mid-slope, *Hoplostethus atlanticus*, the orange roughy, is the best known species among the numerous trachichthyids in Australian waters. Off WA, *H. atlanticus* was present in only small numbers, whereas a suite of small *Hoplostethus* species and *Gephyroberyx darwini* were relatively common and widespread on the upper slope.

The scorpion fish family (Scorpaenidae) is ranked the eighth most speciose in Australian waters, where 80 species inhabit mainly inshore reef areas and continental shelf waters. With about 10 species, the group was among the most speciose in WA slope waters, although several of these, *Neosebastes* species, *Neomerinthe* cf. *nielseni* and *Setarches longimanus* occurred only over the shallow upper slope and were probably near the lower limits of their vertical distributions. The genus *Helicolenus*, which is commercially important on the eastern-Australian upper slope, was caught between about 200–750 m but comprised at least two species whose distributional ranges probably overlap in the shallow range of the upper slope. Despite their common occurrence, no commercial quantities have been taken off WA. Similarly, the Triglidae are well represented in Australian waters. However, the family is relatively poorly known, with only 21 of the 33 recorded taxa identified to species. Considerable confusion surrounds the taxonomy of *Lepidotrigla*, the most speciose and numerous genus taken off WA, and apparently new species were taken of this and several other genera.

Biomass

The range of estimates of demersal fish biomass on the WA continental slope was low compared to all other geographical sites for which data are available, and several times lower than relatively conservative estimates from south-eastern Australia that are more directly comparable. The mechanisms of energy flow into the upper- and mid-slope demersal environment are not fully understood and the relative importance of down-slope and lateral fluxes have not yet been measured (Koslow *et al.* 1993). However, many studies of trophic relations of upper- and mid-slope fishes, including those in Australian waters (Bulman and Koslow 1992, Blaber and Bulman, 1987), have demonstrated the importance of the links between demersal assemblages and surface productivity via mesopelagic food chains. An explanation for the low biomass of the continental slope fish off WA may therefore be found by considering the productivity characteristics of the water masses off the Western Australian west coast.

In common with the southern African and South American continents, the western coastline of WA runs north-south and has its northern and southern extremes extending respectively into tropical and warm temperate regions. However, in contrast to the eastern boundary current systems of southern Africa and southern South America, which flow towards the equator, driving upwelling and fuelling biological productivity in surface waters, the coastal waters of the WA west coast are strongly influenced by the poleward flowing Leeuwin Current (Smith *et al.* 1991). This current is relatively low in nutrients (Rochford 1980, 1988) and exerts a marked influence on the productivity of inshore west-coast commercial fisheries (Lenanton *et al.* 1991). The current flows within about 100 km of the shelf-edge and penetrates to depths of about 250 m, with seasonally stronger flows reaching to at least 320 m (Smith *et al.* 1991). Both the neritic and oceanic zones off WA are characterised by similar assemblages of prominent epipelagic and nyctoepipelagic (nocturnal, vertically migrating) fishes to the Benguela system off southern Africa and Humboldt system off South America (Lenanton *et al.* 1991, Williams unpublished data). However, in the absence of upwelling or nutrient input from terrestrial runoff, the combined commercial catches of finfish off WA are three orders of magnitude lower than in the other major southern-hemisphere eastern boundary currents (Lenanton *et al.* 1991). A similarly low density of pelagic fishes is therefore probable in oceanic assemblages over the narrow WA continental slope which, in turn, will have a direct effect on the demersal fishes maintained by pelagic food chains. This hypothesis is consistent with the observed relationship between biomass and latitude off WA, which, with the relatively large and variable data from the shallow upper slope

(200–400 m) excluded, showed a trend of increasing biomass with increasing latitude (Table 5.6.3). With the assumption of a strong influence by surface productivity on demersal fish biomass, the observed pattern with latitude is interpreted as a waning influence of polewards-flowing, nutrient-poor tropical water.

The possible significance of lateral advection of food resources on to the mid-slope by deep-flowing currents, as postulated by Koslow *et al.* (1993) for waters off south-eastern Australia, and the possible input of energy from a down-slope flux of biological material from the shelf zone, are both unknown for the slope off WA. The existence of a deep current flowing towards the equator below 300 m was reported by Godfrey and Ridgeway (1985) off the WA west coast but its influence, if any, on slope bioenergetics is not known. An important down-slope flux in this region is unlikely since low nutrient availability in surface waters profoundly affects shelf productivity too. In contrast to south-eastern Australian waters, where fish biomass is very high on the mid-slope region relative to shallower water, fish biomass off WA is higher in the shallowest depth stratum than in all deeper strata, (Table 5.6.3). There is no consistent relationship between biomass and depth (i.e., with distance from surface productivity) over the slope. Thus, whilst decreasing biomass with depth has been observed in some other areas, e.g., the north-eastern Pacific (Pearcy *et al.* 1982), data from the eastern North Atlantic (Merrett *et al.* 1991) indicate that biomass increased with depth down the upper and mid-slope to a peak in the 1200–1400 m depth range before declining in deeper water.

Multispecies distribution patterns

The assignment of trawl stations and species into groups based on the analysis of multispecies similarities showed good agreement and identified fish assemblages that characterised shallow, mid-depth and deep regions on the upper slope and similar, but less distinct, ranges on the mid-slope. In addition, species groups with characteristically high- or low-latitude distributions were separated on both the upper and mid-slope. However, despite the consistency of these patterns and the marked influence of both depth and latitudinal gradients on species composition, the boundaries between 'adjacent' assemblages were weakly defined and no major depth or latitudinal discontinuities were observed.

Interpretation of these patterns was clarified by examining the distribution ranges of individual species and their relative densities along the depth gradient (Table 5.6.5). Thus, many stenobathic species occurred in the shallow upper-slope region but the proportion of eurybathic species increased with depth, making eurybathic species predominant overall. However, over much of the range of eurybathic species, individuals occurred occasionally or in low numbers and high population densities were found in only a relatively narrow part of the distribution. Furthermore, the modes or centres of abundance of each species within a group or assemblage, whilst occupying similar bathymetric intervals, were not coincident. Thus, whilst regions of the slope could be characterised by species assemblages, a degree of bathymetric overlap was usually present and the replacement of species occurring in high densities along the bathymetric gradient was continuous.

Steep gradients and rapid changes are observed in many physical and physiological parameters and, as depth increases, it is reasonable to expect a concomitant change in species composition with depth. However, whether the patterns in the vertical distribution of deepwater fishes may be interpreted as zones with identifiable boundaries (Carney *et al.* 1983) that extend horizontally to form structured, co-evolved communities, or whether these patterns are merely localised, fortuitous assemblages (Haedrich and Merrett 1990), is currently a matter of debate (Koslow 1993). Several recent studies in a number of geographical localities have interpreted the distribution patterns of slope fishes as zonation (Menzies *et al.* 1973, Haedrich *et al.* 1975, 1980, Day and Pearcy 1968, Pearcy *et al.* 1982), whilst others report continuous faunal replacement (Snelgrove and Haedrich 1985, Merrett and Marshall 1981).

Several sources of bias in the methods commonly used for analysis of multispecies distribution patterns will produce an oversimplification in the form of apparently well-defined zones. The use of clustering coefficients that emphasise the contribution of dominant species or analysis of collections made with small nets that generally undersample species present in small numbers can both lead to an oversimplified model of faunal zonation (Sulak 1982). Similarly, the distribution of samples along a gradient with undersampling in particular depth ranges or where the turnover of species is highest will lead to the detection of apparent boundaries or zones (Carney *et al.* 1983). The current data suggest that whilst 'zonation' may be used to describe the broad compartmentalisation of the physical gradient, in this case the bathymetry of the slope, it was inappropriate for the fish assemblages that were not sharply delineated.

The nearshore Leeuwin Current system off the western coastline of WA profoundly affects the distribution patterns evident in the shelf and inshore coastal marine faunas (Wilson and Allen 1987), with two distinct latitudinal elements separated by an extensive zone of intermixing. Similar distributions and wide overlap were evident in shallow upper-slope assemblages and may have been directly attributable to the Leeuwin Current since it is known to penetrate to 300 m (Smith *et al.* 1991). However, the data showed that, in all depths, high-latitude samples contained some tropical and subtropical species and that small proportions of temperate species were present in low latitude samples. In common with the patterns observed along the depth gradient, many species were widespread but abundant over only a relatively narrow range and the pattern of species replacement was one of gradual transition not abrupt change.

The temperate mid-slope assemblage reported by Koslow *et al.* as having horizontal continuity between the west coast of New Zealand and the GAB extended to the WA west coast. However, on the western coastline, the range extension of the dominant temperate elements was highly variable with some species not found beyond the southern extreme of the coastline but the distribution of others extending into the most northern reaches. The limited northwards penetration of major commercial species such as orange roughy, smooth oreo dory, blue grenadier and ling, indicated that the commercial prospectivity of the west-coast fishery was low.

The range extension of many temperate species into subtropical waters and the broad zone of overlap of tropical and temperate species beyond upper-slope depths may be evidence of an influence by major water masses, including the Leeuwin Current, on slope fish distributions off WA. However, no direct evidence exists and the processes remain unclear. A comparison with species ranges off eastern Australia and a knowledge of the early life history of some of the widely distributed species may provide an insight into mechanisms influencing slope fish distribution and the possible significance of the current systems off WA.

This report represents the first study of the fish assemblages of the WA slope, which extends over a wide range of latitude and depth. It provides the first account of slope fish assemblages from warm temperate and tropical Australian waters and permits comparison with the fish fauna off south-eastern Australia. An improved knowledge of the diversity, productivity and distribution of slope fishes is important to enable the long-term effects of intensive commercial fishing on the ecology of the slope region to be assessed.

5.7 Fish Collections, Fish Identification Guides and Photographic Slide Collection

To enable identification of the portion of the catch normally not retained during commercial fishing, collections of fishes were made at sea and examined ashore. It was evident early in the study that the slope fish fauna off WA was both highly diverse and that many of the species caught were poorly known. Thus, to permit continuity in identifications, and because the off-shore waters of the WA west coast had not previously been sampled for ichthyological collections, a considerable effort was put into curating the fish collections and making photographic records of fresh specimens. There are now extensive specimen collections held by the CSIRO and Australian Museum and lesser collections at the Victorian Museum, Western Australian Museum and Northern Territory Museum. The registration of these collections makes them available to the international scientific community.

Over 1700 photographic slides of WA slope fishes were catalogued during the course of the study and will assist future taxonomic studies of these collections. The slides have so far been used to provide photographs in two identification guides: first, the guide to commercial fishes distributed to industry and sea-going scientific observers in support of the WA logbook program (see Chapter 5.4) and second, a seven volume loose-leaf field guide for use at sea. It is anticipated that the latter guide will be expanded and used during subsequent continental slope fishing in southern Australian waters.

A provisional species list giving details of distributional limits by latitude and depth, fish collection registration numbers and photographic slide catalogue numbers in given in Appendix V. Identifications are being updated as part of ongoing work carried out in conjunction with an examination of continental slope fishes from Tasmania and north-eastern Australia. This comparative appraisal will permit publication of the work on the WA collections.

5.8 References

Blaber, S. J. M. and Bulman C. M. (1987). Diets of fishes of the upper continental slope of eastern Tasmania: content, calorific values, dietary overlap and trophic relationships. *Marine Biology* **95**, 345–356.

Bray, D. J. (1983). Revision of the fish family Zeidae. Unpublished Masters Thesis, School of Biological Sciences, Macquarie University, March 1983.

Bulman, C. M. and Koslow, J. A. (1992). Diet and food consumption of a deep-sea fish, orange roughy *Hoplostethus atlanticus* (Pisces: Trachichthyidae), off south-eastern Australia. *Marine Ecology Progress Series* **82**, 115–129.

———, Wayte, S. E. and Elliott, N. C. (in press). Orange roughy surveys, 1988 & 1989: Abundance indices. CSIRO Marine Laboratories Report No. 215. (CSIRO Division of Fisheries Research: Hobart, Australia.)

Carney, R. S., Haedrich, R. L. and Rowe, G. T. (1983). Zonation of fauna in the deep sea. *In:* The Sea, Vol. 8, ed. G. T. Rowe, pp. 371–398. (Wiley-Interscience: New York.)

Day, D. S. and Pearcy W. G. (1968). Species associations of benthic fishes on the continental shelf and slope off Oregon. *Journal of the Fisheries Research Board of Canada* **25**, 2665–2675.

Field, J. G., Clarke, K. R. and Warwick, R. M. (1982). A practical strategy for analysing multispecies distribution patterns. *Marine Ecology Progress Series* **8**, 37–52.

Godfrey, J. S. and Ridgeway, K. R. (1985). The large-scale environment of the poleward-flowing Leeuwin Current, Western Australia: longshore steric height gradients, wind stresses and geostrophic flow. *Journal of Physical Oceanography* **15**, 481–495.

Haedrich, R. L. and Merrett, N. R. (1990). Little evidence for faunal zonation or communities in deep sea demersal fish faunas. *Progress in Oceanography* **24**, 239–250.

———, Rowe, G. T. and Polloni, P. T. (1975). Zonation and faunal composition of epibenthic populations on the continental slope south of New England. *Journal of Marine Research* **33**, 191–212.

———, Rowe, G. T. and Polloni, P. T. (1980). The megabenthic fauna in the deep sea south of New England, USA. *Marine Biology* **57**, 165–179.

Heald, D. I. and Walker, M. H. (1982). 'Taiyo Maru 71' Demersal trawling cruise in Western Australian coastal waters south of 21°, July–September, 1979. Report No. 51, Department of Fisheries and Wildlife, Western Australia.

Imamoto, T. and Shcherbachev. (1991). Macrourid fishes of the subgenus *Chalinura*, genus *Coryphaenoides*, from the Indian

Ocean. *Proceedings of the California Academy of Sciences* **47**, 207–233.

Koslow, J. A. (1993). Community structure in North Atlantic deep sea fishes. *Progress in Oceanography.*

———, Bulman, C. M. and Lyle, J. M. (1993). The mid-slope demersal fish community off south-eastern Australia. *Deep-Sea Research.*

Last, P. R. L. and Stevens, J. (1993). Sharks and Rays of Australia.

Lenanton, R. C., Joll, L., Penn, J. and Jones, K. (1991). The influence of the Leeuwin Current on coastal fisheries in Western Australia. *Journal of the Royal Society of Western Australia* 74, 101–115.

May, J. L. and Blaber, S. J. M. (1989). Benthic and pelagic fish biomass of the upper continental slope off eastern Tasmania. *Marine Biology* **101**, 11–25.

May, J. L. and Maxwell, J. G. H. (1986). Field guide to Trawl Fish from Temperate Waters of Australia. 492 pp. (CSIRO Division of Fisheries Research: Hobart, Australia.)

Menzies, R. J., George, R. Y. and Rowe, G. T. (1973). Abyssal environment and ecology of the world oceans. (Wiley-Interscience: New York.)

Merrett, N. R., Gordon, J. D. M., Stemann, M. and Haedrich, R. L. (1991). Deep demersal fish assemblage structure in the Porcupine seabight (eastern North Atlantic): slope sampling by three different trawls compared. *Journal of the Marine Biological Association of the U.K.* **71**, 329–358.

——— and Marshall, N. B. (1981). Observations on the ecology of deep-sea bottom living fishes collected off northwest Africa (08°N–27°N). *Progress in Oceanography* **9**, 185–244.

Newton, G. and Klaer, N. (1991). Deep-sea demersal fisheries resources of the Great Australian Bight: a multivesssel trawl survey. Bureau of Rural Resources Bulletin No. 10. (Australian Government Publishing Service: Canberra.)

Norusis, M. J. (1990). SPSS Base System User's Guide. 520 pp. (SPSS Inc.: Chicago.)

Ohta, S. (1983). Photographic census of large-sized benthic organisms in the bathyal zone of Suruga Bay, central Japan. *Bulletin of the Oceanographic Research Institute, University of Tokyo* **15**, 1–224.

Parin, N. and Paxton, J. R. (1990). Australia's east coast gemfish. *Australian Fisheries*, May, 1990 supplement, 5 pp.

Paxton, J. R., Hoese, D. F., Allen, G. R. and Hanley, J. E. (1989). Zoological Catalogue of Australia: Volume 7, PISCES, Petromyzontidae to Carangidae. 665 pp. (Australian Government Publishing Service: Canberra.)

Pearcy, W. G., Stein, D. L. and Carney, R. S. (1982). The deep-sea benthic fish fauna of the northeastern Pacific Ocean on Cascadia and Tufts abyssal plains and adjoining continental slopes. *Biological Oceanography* **1**, 375–428.

Rochford D. J. (1980). Nutrient status of the oceans around Australia. CSIRO Fisheries and Oceanography 1977–1979 Annual Report

———. (1988). Seasonal influx of nitrates to the slope and shelf waters off north-west Australia. CSIRO Marine Laboratories Report 191, (CSIRO Division of Oceanography: Hobart, Australia.)

Sainsbury, K. J., Kailola, P. J. and Leyland, G. G. (1984). Continental Shelf Fishes of Northern and North-western Australia. 375 pp. (CSIRO Division of Fisheries Research: Hobart, Tasmania.)

Shimizu, T. and Hutchins, J. B. (1987). New Australian fishes. Part 21. A new species of *Centroberyx* (Berycidae). *Memoirs of the Museum of Victoria* **48**, 89–90.

Smith, M. M. and Heemstra, P. C. (1986). Smiths' Sea Fishes. (Springer-Verlag.)

Smith, R. L., Huyer, A., Godfrey, J. S. and Church, J. A. (1991). The Leeuwin Current off Western Australia, 1986–1987. *Journal of Physical Oceanography* **21**, 323–345.

Snelgrove, P. V. R. and Haedrich, R. L. (1985). Structure of the deep demersal fish fauna off Newfoundland. *Marine Ecology Progress Series* **27**, 99–107.

Sulak, K. J. (1982). A comparative taxonomic and ecological analysis of temperate and tropical demersal deep-sea fish faunas in the western North Atlantic. Unpublished Ph.D. dissertation. University of Miami, Florida.

Wankowski, J. W. J. and Moulton, P. L. (1986). Distribution, abundance and biomass estimates of commercially important demersal fish species in eastern Bass Strait, Australia. Department of Conservation and Lands, Fisheries and Wildlife Service Technical Report No. 62.

Wilson, B. R. and Allen, G. R. (1987). Major components and distribution of marine fauna. *In:* The Fauna of Australia. Vol. 1A. General Articles (eds G. R. Dyne and D. W. Walton) (Bureau of Flora and Fauna, Australian Government Publishing Service: Canberra.)

6 Cephalopods from Demersal Trawling on the North West Slope

Dr V. A. Wadley

Contents

Summary

Cephalopods were the main component of the by-catch of demersal trawling for scampi and prawns on the North West Slope. Cephalopods were caught throughout the North West Slope Trawl Fishery (NWSTF), mainly in the Rankin Bank area (about 115°30'E., 19°30'S.). A total of 20 species of cephalopods in 11 families was recorded since commercial deepwater trawling began in 1985. The dominant cephalopod was the ommastrephid squid, *Nototodarus hawaiiensis*. Other species of commercial interest included *Todaropsis eblanae, Loligo edulis* and *Moroteuthis loennbergi*. During the development of the fishery, research was focused on the distribution of species and biomass of cephalopods. Preliminary trophic studies recorded cephalopod remains in the foregut of prawns, namely *Aristaeomorpha foliacea*, *Heterocarpus sibogae* and *Plesiopenaeus edwardsianus*, among other deepwater species.

The largest cephalopod annual catch was 34 tonnes (in the 1986/87 logbook year); during the same period, the crustacean catch was 553 tonnes. Cephalopods were caught throughout the year, with a seasonal increase in October–November. Fishing effort was distributed between 200 and 800 m. Although the distribution of the species differs with depth, over 80 per cent of the cephalopod catch is trawled between 350 and 450 m.

Introduction

Following the discovery of commercial quantities of scampi *(Metanephrops* spp.) on the North West Slope in 1983 (Phillips and Wallner 1990), commercial quantities of prawns were found in the same area in 1986. Squid and finfish were taken as a by-catch of the crustacean fishery. In 1986/87, commercial quantities of squid were caught for the first time. Squid were often discarded, due to the greater economic return on crustaceans.

Little was known about the species or stock sizes of the slope resources of crustaceans, squid or finfish. Many of the deepwater species had not previously been recorded, much less exploited, in the Australian Fishing Zone (AFZ). Research was started in 1986 to assess the resources (including cephalopods) in the fishery (Jernakoff 1988), recognising that the early stage of exploitation of a fishery provides a unique opportunity to record the impact of harvesting on the stocks. The Commonwealth licence requires fishermen to carry scientific observers as required and record all retained catch. Data on the cephalopod resource were collected from commercial catches and logbooks. The NWSTF is subject to a development plan, currently in its seventh year. A management plan for the multispecies fishery, based on output controls, is being developed under Australian Commonwealth management.

Methods

The NWSTF extends from 114–124°E., including the waters from the 200 m isobath to the AFZ boundary at about 2000 m depth (Fig. 1.1). The depth of commercial fishing was generally between 350 and 500 m; depths greater than 800 m were rarely fished.

Squid specimens for the study were collected by CSIRO scientific observers on commercial vessels in the NWSTF. The collections from four observer trips in the NWSTF have been included here. The trips were in August 1988 (FV *Surefire*), December 1988 (FV *Admiralty Pearl*), February 1989 (FV *Courageous*) and April 1989 (FV *Striker*). The depth of these collections was in the range 370–455 m.

Logbook data from commercial fishing vessels from 1985 to 1990 were analysed. The logbook records were verified by comparison with landed catch. Some of the catch was recorded at the species level but cephalopods were usually not separated to species. Since *Nototodarus hawaiiensis* is the cephalopod of prime commercial interest, it is likely that most logbook records related to this species.

The commercial fishing operation was demersal trawling by vessels of 25–30 tonnes, for four to five weeks on each trip. Duration of each trawl was about four hours bottom time, with continuous trawling during day and night. Two types of gear were used: 90 mm (3·5") mesh nets for scampi, and 57 mm (2·25") mesh nets for prawns.

The freshly dead squid were photographed and measured (mantle length (ML) to the nearest mm) on the trawlers. Length-frequency data were grouped into 5-mm size classes. The squid were frozen at sea, and fixed and preserved after transport to the laboratory.

An illustrated guide was prepared to assist fishermen to identify the main species of cephalopods caught in the NWSTF (Wadley 1990). Features such as the leathery skin and three rows of papillae on the hectocotylus of *N. hawaiiensis* were described for identification. Identification characters of proven usefulness were selected from the literature, including Chun (1975 translation), Lu and Dunning (1982), Nesis (1987), Okutani (1980), Okutani *et al.* (1987), Roper *et al.* (1984) and Voss (1969). Accurate catch records from commercial vessels were obtained using the guide, with backup from seagoing scientific observers.

Foreguts of prawns from the NWSTF were examined in a study of their diet (Rainer 1992). Cephalopod remains (including beaks and hooks) were recorded as a percentage of foregut volume for seven species of prawns. The contents were scaled in six categories ranging from 0 per cent to 100 per cent.

Analysis of data

The fishing year for the NWSTF starts in April and ends in March. For analysis of logbook data, the area of the fishery was divided into half-degree squares (HDSs) numbered 1 (south) to 78 (north) (Fig. 6.1). The catches were summed for each square on a monthly and annual basis. Effort expended for these catches was recorded as hours of bottom time. The squid catches were incidental to the effort targeted at crustaceans. The logbook catch per effort (expressed as kg h^{-1}) should therefore not be used as an indication of the relative abundance of squid.

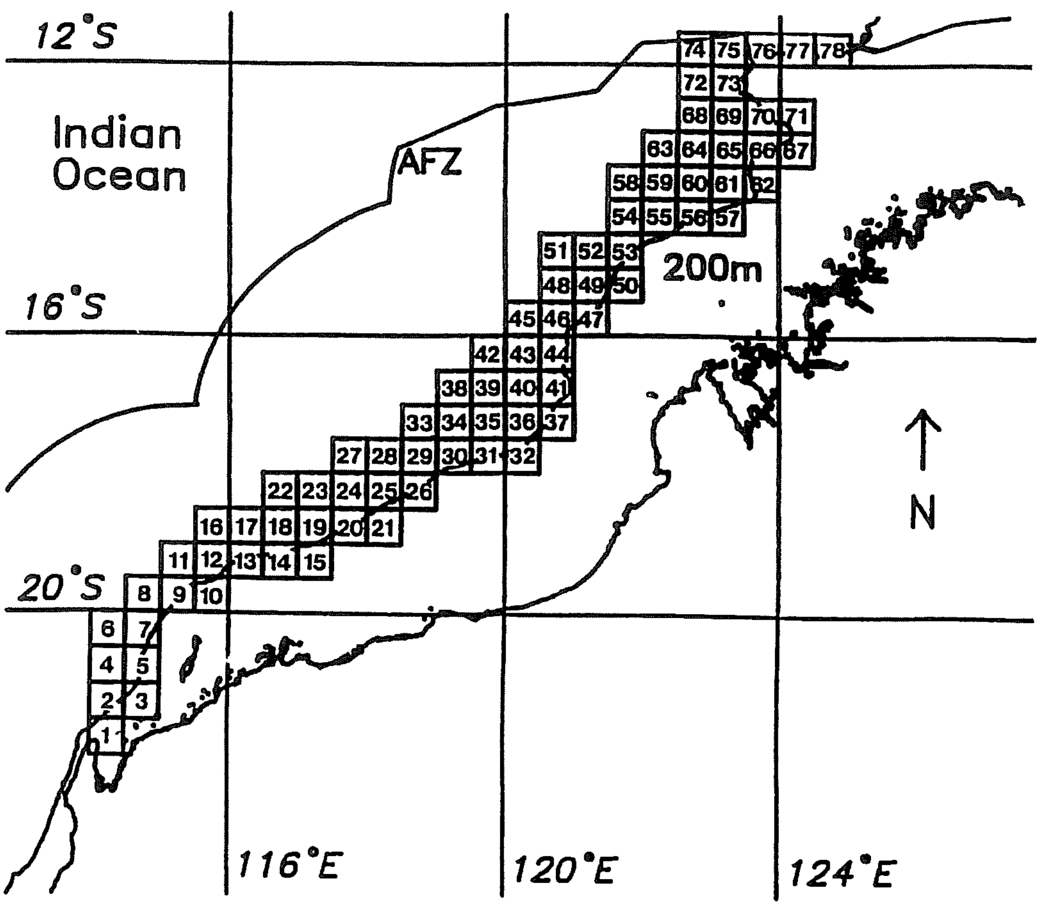


Fig. 6.1 Location of HDS 1 to 78 used for analysis of catch statistics in the North West Shelf Trawl Fishery. The boundary of the AFZ and the 200 m isobath are marked.

The HDSs were then aggregated for analysis into five areas based on the distribution of crustacean species. In two of these areas, cephalopods were collected from commercial vessels. One area was the prawn ground called Southern Rowley Shoals (SRS), between longitudes 116°E. and 119°E. (HDSs 13–15, 17–29, 33). The other area was the scampi ground called Northern Rowley Shoals (NRS), between longitudes 119°E. and 121°E. (HDSs 30–32, 34–47).

The distribution of catch with depth was investigated by summing the catch in 50 m depth zones from 200–750 m over the entire area of the fishery. The zone > 750 m referred predominantly to depths of 750–800 m, due to the lack of fishing in depths > 800 m.

Results

A total of 20 species of cephalopods in 11 families were collected from the NWSTF since commercial deepwater trawling began in 1985 (Table 6.1). The dominant cephalopod was the ommastrephid squid, *Nototodarus hawaiiensi*. This was established by examination of samples taken from commercial vessels (Wadley, personal observation). Scientific observers collected 197 (46 per cent) *N. hawaiiensis* in a total of 425 squid (Table 6.1). Other species of commercial interest included *Todaropsis eblanae, Loligo edulis* and *Moroteuthis loennberg*. Commercial potential was assessed on the quantity of the species in trawls, edibility, and the existence of a fishery for the species in other parts of the world.

The trawlers targeted scampi (five species of *Metanephrops*) and prawns (*Aristaeomorpha foliacea, Aristeus virilis, Plesiopenaeus edwardsianus, Penaeopsis eduardoi, Haliporoides sibogae, Heterocarpus sibogae, H. woodmasoni* and others). Squid (mainly *N. hawaiiensis*) and finfish were a by-catch. Both scampi and prawn nets caught large squid such as *N. hawaiiensis* but prawn nets, having a relatively smaller mesh, also caught small squid including *Abralia andamanica*.

The largest annual cephalopod catch was 34·2 tonnes (in the 1986/87 logbook year); during the same period, the crustacean catch was 553·2 tonnes (Table 6.2). Small discrepancies in the total annual catch of squid for the first four years (Tables 6.2, 6.3) were due to the inclusion of landed catches only in Table 6.2. The smallest annual catch of squid was 2·3 tonnes in 1989/90. Squid catches declined each year from 1986/87 to 1989/90.

Logbook data indicated that cephalopods were caught throughout the NWSTF, to a northern limit of 13°S. The largest annual catches (category 1–7 tonnes; Fig. 6.2) were from the Rankin Bank area (HDS 12, about 115°30'E., 19°30'S.; Figs 6.1, 6.2). In 1986/87, the largest squid catch (6967 kg; Table 6.3) was taken from this HDS. Areas south of Rowley Shoals (HDSs 24, 25, 29) and off Broome (HDSs 41, 44, 45, 47) have also delivered relatively large squid catches. The same HDSs produced large catches consistently from year to year; small or no squid catches were also consistent for a particular square (Table 6.3). The catch statistics are unstandardised for effort, which is anyway directed at crustaceans.

Table 6.1. Preliminary list of cephalopod species from the NWSTF.

ORDER SEPIOIDEA
- SEPIIDAE
  - *Sepia* species 1
- SEPIOLIDAE
  - *Rossia* species 1
  - *Heteroteuthis* species 1
  - *Iridoteuthis* species 1
  - *Sepiolina nipponensis* (Berry, 1911)

ORDER TEUTHOIDEA

SUBORDER MYOPSIDA
- LOLIGINIDAE
  - *Loligo edulis* Hoyle 1885

SUBORDER OEGOPSIDA
- ENOPLOTEUTHIDAE
  - *Abralia andamanica* Goodrich, 1898
- ONYCHOTEUTHIDAE
  - *Moroteuthis loennbergi* Ishikawa and Wakiya, 1914
- HISTIOTEUTHIDAE
  - *Histioteuthis celetaria pacifica* (G. Voss, 1962)
  - *Histioteuthis miranda* (Berry, 1918)
- OMMASTREPHIDAE
  - *Nototodarus hawaiiensis* (Berry, 1912)
  - *Ornithoteuthis volatilis* (Sasaki, 1915)
  - *Sthenoteuthis oualaniensis* (Lesson, 1830)
  - *Todaropsis eblanae* (Ball, 1841)
- THYSANOTEUTHIDAE
  - *Thysanoteuthis rhombus* Troschel, 1857
- CHIROTEUTHIDAE
  - *Chiroteuthis imperator* Chun, 1908
- CRANCHIIDAE
  - *Liocranchia reinhardti* (Steenstrup, 1856)

ORDER OCTOPODA

SUBORDER INCIRRATA
- OCTOPODIDAE
  - **Octopus* species 1
  - **Octopus* species 2
  - **Octopus* species 3

In addition, five species (probably representing three families) have not yet been identified.

* Species currently being examined, possibly undescribed; the *Octopus* fauna of the area is not well known.

The depth range of the NWSTF is 200–800 m. Squid catches recorded in logbooks (i.e., *N. hawaiiensis*, the only regularly commercial species) were primarily from 350–500 m depth. Of the total catch of squid, about 80 per cent were from the depth range 350–450 m (Fig. 6.3). The 19 species collected by scientific observers (Table 6.4) were, however, distributed throughout the range of depths that were sampled

Table 6.2. Annual catch and effort statistics, for squid and total catch, for the NWSTF. Catch figures here include landing data that were not incorporated in totals for 1985 to 1988, resulting in discrepancies between annual totals for Tables 6.2 and 6.3.

Statistic	Fishing year (1 April — 31 March) 1985/86	1986/87	1987/88	1988/89	1989/90	Total
Squid catch (t)	9·2	34·2	13·9	6·6	2·3	66·2
Total catch (t)	348·6	553·2	959·9	643·1	265·2	2770·0
Effort ($h \cdot 10^{-3}$)	10·8	13·0	18·5	17·7	14·5	74·5

on the slope (370–455 m). *Loligo edulis* was confined to the shelf, with a few individuals in the shallowest depths of the slope.

Squid were caught throughout the year when the fishery was operating, with a seasonal increase in catch in spring and summer (particularly October, December and January; Fig. 6.4). The highest catch rate recorded was 90 $kg \cdot h^{-1}$ in late spring (B. Wallner, personal communication).

Cephalopod species that were abundant in the collections obtained by scientific observers (*N. hawaiiensis*, *H. celetaria pacifica*, *Abralia andamanica*; Table 6.4) were distributed throughout the NRS and SRS areas of the fishery. Specimens of *H. celetaria pacifica* and *A. andamanica* were mainly juveniles.

N. hawaiiensis was caught in sufficient numbers for length-frequency analysis. Data from two areas (SRS and NRS), two gears (prawn and scampi) and four times (August and December 1988, February and April 1989) were combined for the histogram (Fig. 6.5). Male *N. hawaiiensis* were nearly twice as abundant as females. The size range for females (57–225 mm ML) was greater than for males (61–154 mm ML). The mean length of *N. hawaiiensis* was 97·7 mm ML (males) and 99·5 mm ML (females) (Table 6.4), corresponding to sexually mature specimens of about 500 g wet weight (Wadley, personal observation). Hectocotylisation of the ventral arm in males was apparent from 61 mm ML, although the sex of some animals up to 90 mm ML could not be differentiated. Distinct cohorts were not apparent from the length-frequency data but two modes (centred on 78 mm and 109 mm ML) were present in males and a small mode at 84 mm ML was present in females. The selection of slightly smaller scampi (from 57 mm ML) by prawn gear compared with larger scampi (from 66 mm ML) by scampi gear was apparent, but there were too few data for statistical analysis of bias due to net size.

Preliminary trophic studies recorded cephalopod remains in the prawns *Aristaeomorpha foliacea*, *Heterocarpus sibogae* and

Table 6.3

Squid catch (kg) by region and year for the North West Slope Trawl Fishery. Regions from south to north (half-degree squares 1 to 78), are identified on Fig. 6.1. Half-degree squares with no squid catch are not listed.

HDS	Fishing year (1 April — 31 March)					
	1985/86	1986/87	1987/88	1988/89	1989/90	Total
2	0	103	0	0	0	103
4	0	30	22	0	0	52
5	0	15	99	0	0	114
9	0	5	0	0	0	5
10	0	358	0	0	10	368
11	0	27	0	0	0	27
12	372	6 967	1 238	330	315	9 222
13	0	136	60	6	28	230
14	0	126	0	0	0	126
16	36	406	87	32	5	566
17	120	2 738	524	80	37	3 499
18	52	1 237	194	9	55	1 547
19	73	633	754	370	92	1 922
20	36	493	402	64	0	995
21	0	39	5	0	0	44
23	0	55	144	0	0	199
24	457	2 669	1 741	690	10	5 567
25	98	1 215	630	444	100	2 487
26	0	0	20	0	0	20
27	0	0	16	0	0	16
28	253	753	2 832	468	0	4 306
29	992	1 578	2 040	542	385	5 537
33	86	318	277	156	62	899
34	119	497	116	6	53	791
35	51	120	24	719	102	1 016
36	17	318	12	366	122	835
37	0	0	0	0	5	5
39	88	152	90	556	23	909
40	240	1 611	30	738	302	2 921
41	238	312	0	23	9	582
43	172	1 558	181	489	72	2 472
44	36	4 312	429	104	322	5 203
45	0	0	432	0	0	432
46	87	2 765	208	36	147	3 243
47	0	0	5	0	0	5
48	44	12	0	0	0	56
49	24	56	12	0	0	92
50	8	0	0	0	0	8
52	36	0	0	0	0	36
53	100	196	0	0	27	323
54	0	22	0	0	0	22
59	0	0	29	0	0	29
60	0	18	105	37	0	160
61	0	0	5	0	0	5
63	0	0	10	0	0	10
64	0	0	128	0	0	128
65	0	0	149	0	0	149
Total	3 835	31 850	13 050	6 265	2 283	57 283

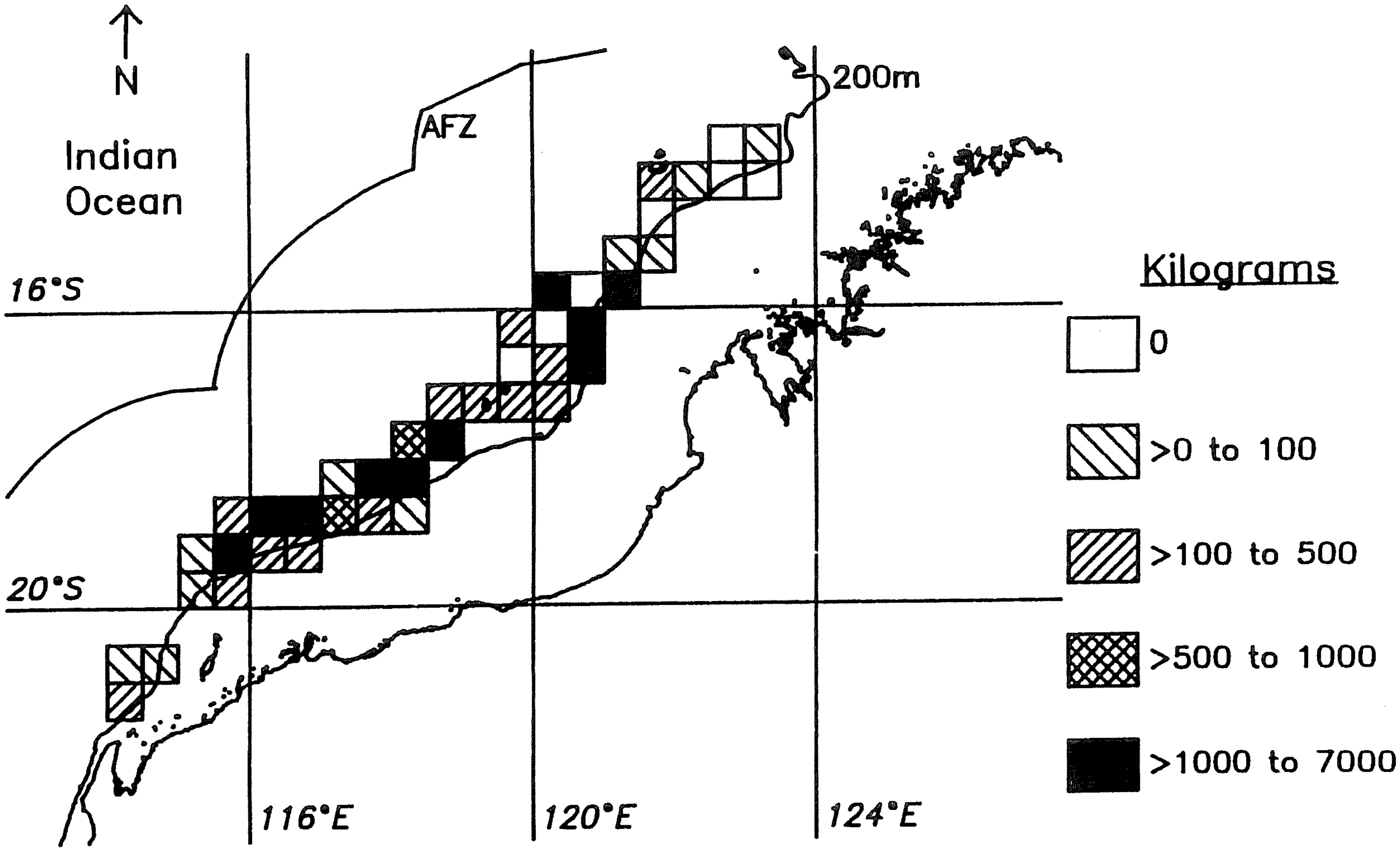


Fig. 6.2 Spatial distribution of squid catches from the North West Shelf Trawl Fishery during the 1986/87 logbook year. Unhatched HDS had no squid; absent HDS were not fished during that year.

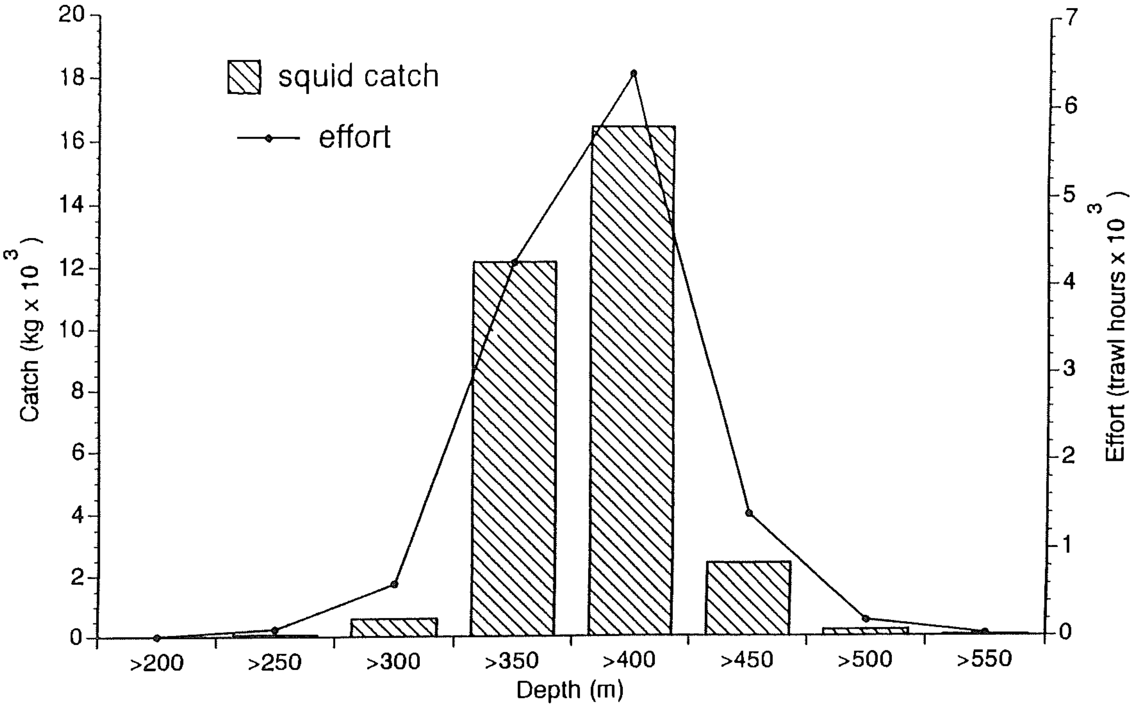


Fig. 6.3 Depth distribution of squid catches, by 50 m depth interval, from the North West Shelf Trawl Fishery during the 1986/87 logbook year.

Plesiopenaeus edwardsianus among other deepwater species (Table 6.5). *Heterocarpus sibogae* contained the most cephalopod remains, with 3 per cent of specimens (12 animals) containing more than 50 per cent cephalopod in the foregut. Similar quantities were found in *Plesiopenaeus edwardsianus* and *Aristaeomorpha foliacea* but these species also had relatively more specimens with small quantities of cephalopod material in the foregut. The percentage fullness attributable to cephalopods indicates that cephalopods were a small but widespread component of the prawn diet.

Discussion

Records of squid from commercial trawling on the north-western slope of Australia related predominantly to one species, *Nototodarus hawaiiensis* (Berry 1912), commonly known as the Hawaiian flying squid. This species has been reported from the Hawaiian and Midway Islands and the South China Sea, in addition to the waters off north western, northern and north-eastern Australia (Dunning 1988). It has been exploited in Australian waters only in the last six years, and was therefore not included in the commercial species of Dunning and Brandt (1985).

Table 6.4 Size distribution (*n* — number of individuals, SD — standard deviation) of squid species in order of decreasing abundance from the North West Shelf Trawl Fishery collections. Presence (indicated #) on prawn grounds (SRS) and scampi grounds (NRS) and the range of trawl depth of collection are shown. (n.d. — data not determined or unavailable).

Species	Sex	*n*	Mantle length (mm) Range	Mean	SD	Area SRS	NRS	Trawl depth (m)
N. hawaiiensis	M	107	61–154	97·7	21·8	#	#	375–460
	F	61	57–225	99·5	25·7	#	#	375–460
	J	29	50–90	73·7	10	#	#	375–425
H. c. pacifica	M	4	38–70	51·2	12·3	#	#	410–413
	F	14	35–122	90·9	40·5	#	#	396–420
	J/n.d.	110	20–115	45·4	18·9	#	#	370–460
A. andamanica	F	6	48–62	56·2	6	#	#	380–460
	J/n.d.	36	28–57	44	6·7	#	#	380–460
C. imperator	M	1	258	258			#	380
	F	4	113–43	82·2	52·2	#	#	380–405
	J	8	68–254	181·5	67·4	#	#	375–455
L. reinhardti	J	12	48–75	59·5	8·3		#	380
Octopus sp. 3	n.d.	11				#	#	393–460
Rossia sp. 1	F	2	52–58	55	3	#		380
	J	7	38–50	45·3	4·6	#	#	425–455
Octopus sp. 1	n.d.	9				#	#	375–413
Octopus sp. 2	n.d.	4				#		380–430
Sepia sp. 1	n.d.	4				#	#	375–413
T. eblanae	M	1	110	110			#	405
	F	1	99	99		#		375
Heteroteuthis sp. 1	J	1	21	21			#	396
Iridoteuthis sp. 1	J	1	22	22		#		380
Loligo sp. 1	J	1	28	28		#		380
M. loennbergi	J	1	272	272		#		410
O. volatilis	F	1	254	254		#		425
S. nipponensis	F	1	30	30		#		380
S. oualaniensis	F	1	215	215		#		n.d.
T. rhombus	F	1	205	205		#		n.d.

Little is known of the basic biology of *N. hawaiiensis*, although its habitat is demersal (Roper *et al.* 1984). During the present study, it was abundant in demersal trawls with high catch rates (up to 90 $kg \cdot h^{-1}$; Wallner, personal communication) indicating that the squid are effectively trawled from the sea floor. Although some squid may be caught during the setting and retrieval of a trawl, this is a relatively small (< 25 per cent) part of the operation and was reflected in the small numbers of pelagic cephalopods collected. The distribution with depth of *N. hawaiiensis*, with a peak catch at 350–450 m (Fig. 6.3), was within the range (275–650 m) reported by Roper *et al.* (1984).

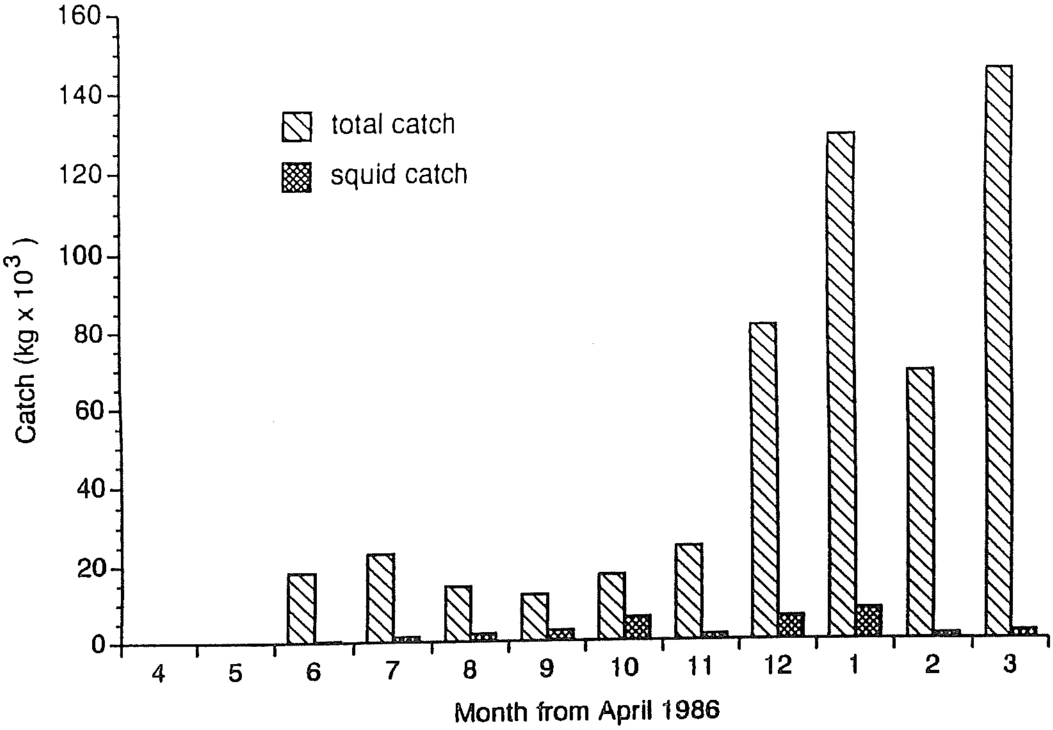


Fig. 6.4 Temporal distribution of squid catches by month for the North West Shelf Trawl Fishery fishing year from April 1986 (labelled 4) to March 1987 (labelled 3). The total catch is given for comparison.

Fishers are required to record only the retained portion of their catch. The logbook records therefore represent only a small percentage of the squid catch, much of which is discarded at sea because of its low commercial value relative to crustaceans. Even if it is discarded and unrecorded, the squid by-catch is part of the mortality due to fishing because the animals are dead when hauled to the surface. The decrease in recorded squid catches after 1986/87 probably reflected the increasing efficiency of targeting on crustaceans, rather than a variation intrinsic to the abundance of squid. Interannual variation is nevertheless high in the catch of all species from the NWSTF, including the target crustaceans (Phillips and Jernakoff 1991).

Cephalopods were recorded in abundance on the Rankin Bank, where crustaceans were scarce (relative to other areas of the fishery). The dominant cephalopod, *N. hawaiiensis*, was demersal, sharing a similar habitat with most of the crustacean species. Availability of food, distribution of predators, or physical factors may determine the areas where large catches of cephalopods and crustaceans were taken. The distribution of sediments in the area (McLoughlin *et al.* 1988) is likely to be a factor in the preferred habitats of demersal species. Alternatively, large catches of cephalopods in the Rankin Bank area may be attributed to local aggregation that enhances catchability. The

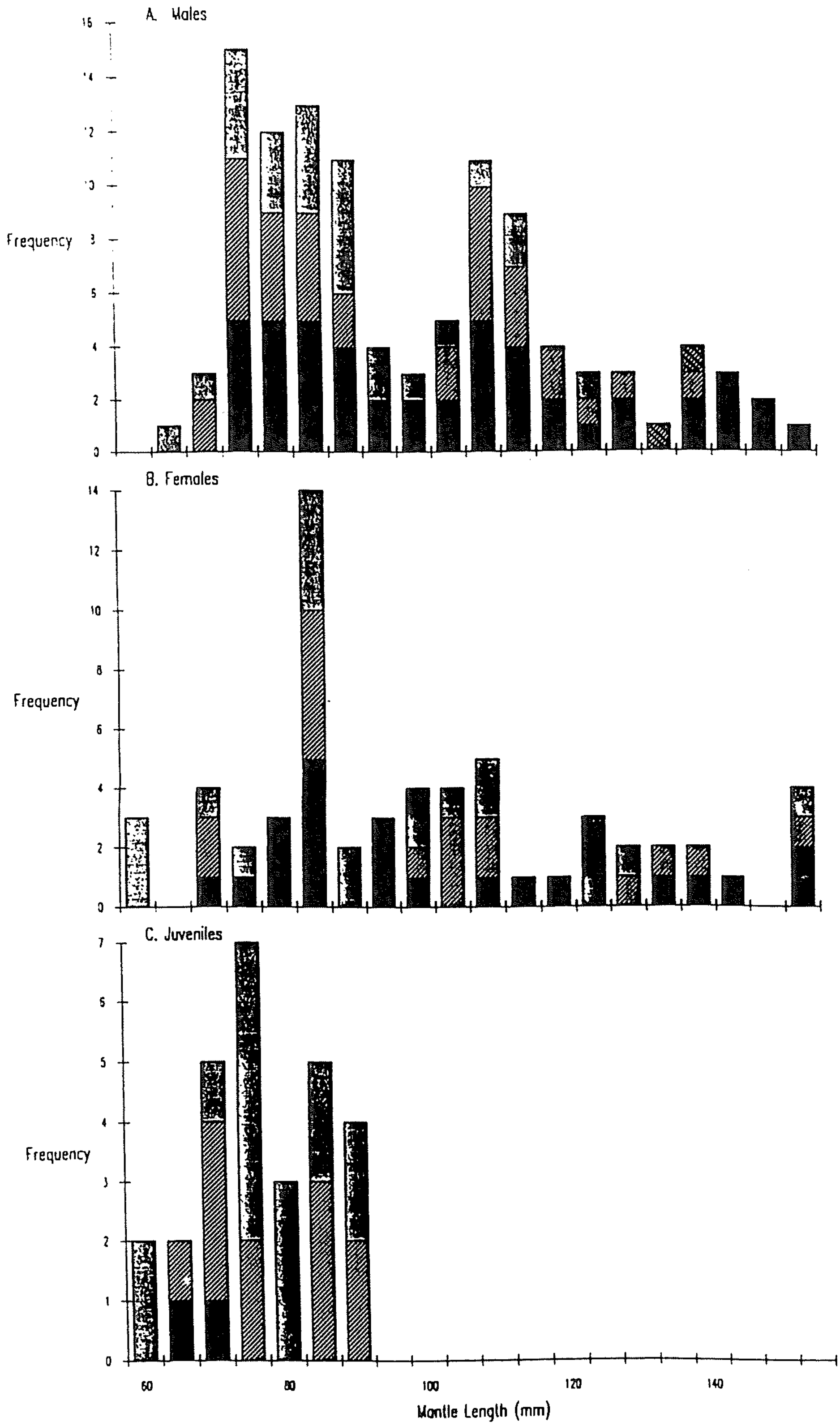


Fig. 6.5

Size distribution of *Nototodarus hawaiiensis* from the North West Shelf Trawl Fishery. The distribution of (a) males (b) females and (c) juvenile individuals are shown. One female of 225 mm ML was not included. The dates and methods of collection are differentiated by shading (dots = August 1988, region SRS, prawn gear; cross-hatched = December 1988, region SRS, scampi gear; oblique left up to right = February 1989, region SRS, prawn gear; filled = April 1989, region NRS, scampi gear).

Table 6.5 Deepwater crustaceans examined for the presence of cephalopods in the foreguts. The species of crustaceans and number of individuals (*n*) examined are given, in order of decreasing cephalopod content. Cephalopod volume in the crustacean foregut contents is shown for six relative percentage categories (0% cephalopods of total foregut contents, etc.).

Crustacean Species	*n*	Cephalopod volume in foregut 0%	< 1%	1–9%	10–49%	50–99%	100%
Heterocarpus sibogae	387	94	1	1	1	2	1
Plesiopenaeus edwardsianus	318	79	8	4	5	3	–
Aristaeomorpha foliacea	291	84	7	6	2	3	–
Acanthephyra armata	109	91	4	1	3	2	–
Aristeus virilis	307	92	2	3	2	1	–
Haliporoides sibogae	49	92	4	4	–	–	–
Heterocarpus woodmasoni	457	99	–	–	–	–	–

seasonal increase (late spring/early summer) points to a breeding aggregation as a possible factor in the catches, although no evidence of reproductive periodicity was found in this preliminary study.

About equal numbers of male and female *N. hawaiiensis* were reported from the North West Shelf of Australia during February 1983 ($n = 128$) and January 1984 ($n = 615$) by Dunning (1988). The sex ratio of about 2:1 in favour of males in the present study ($n = 197$) from the North West Slope during August and December 1988 and in February and April 1989 is at variance with Dunning's result. Further sampling would be required to determine whether this result is an artefact of small sample sizes or a difference in sex ratio with depth of water or time of year.

Other aspects of reproductive biology also differ between the two studies. In the study by Dunning (1988), the smallest mature female was 154 mm ML; the smallest mature male, 152 mm ML. From the NWSTF specimens, the smallest male with hectocotylised arm IV was 61 mm ML. This is an indication of the onset of maturity at a relatively small size, however the presence of viable spermatophores in Needham's sac was not recorded. Therefore, comparison of male size at sexual maturity cannot be made. The mean size of females was slightly larger than males in the present study (Table 6.4). In agreement with Dunning (1988), mature males and females were found at all times of the year. There was a slight seasonal increase in catch during late spring, in the small number of specimens examined to date. However, there was no indication of reproductive periodicity in gonadal development, or any increase in the number of females with eggs.

Cephalopods were an unexpected component of the diet of deepwater crustaceans. A literature search found the only previous reference to the matter in a study by Burukovskii (1980). He found cephalopods in 13·5 per cent of stomachs of the deepwater carabinero prawn

Plesiopenaeus edwardsianus from the south-eastern Atlantic. Many of the crustaceans appear to be opportunistic demersal feeders (Rainer 1992) which probably accounts for their ingestion of cephalopods (presumably dead). Apart from natural mortality of cephalopods, feeding in the trawl net or cephalopod discards from previous trawls are possible sources of dead or moribund cephalopods.

Further research on deepwater cephalopods is required to determine the stock size and distribution of the resource on the north-western slope of Australia. To effectively harvest the great variety of species of the NWSTF (Wallner and Phillips 1988), information is needed on the distribution and abundance of the component stocks. Localised seasonal increases of particular resources such as squid could then be effectively harvested in the overall targeting strategy.

References

Burukovskii, R. N. (1980). Some biological aspects of the shrimp *Plesiopenaeus edwardsianus* in the SE Atlantic. *Soviet Journal of Marine Biology* **6**(6), 315–320.

Chun, C. (1975). Scientific results of the German deepsea expedition Valdivia 1898–1899, Vol. 18, The Cephalopoda. Part I: Oegopsida. Part II: Myopsida, Octopoda. 436 pp. Israel Program for Scientific Translations. (Keter: Jerusalem.)

Dunning, M. C. (1988). First records of *Nototodarus hawaiiensis* (Berry, 1912) (Cephalopoda: Ommastrephidae) from northern Australia with a reconsideration of the identity of *N. sloani philippinensis* Voss, 1962. *Memoirs of the Museum of Victoria* **49**(1), 159–168.

——— and Brandt, S. B. (1985). Distribution and life history of deepwater squid of commercial interest from Australia. *Australian Journal of Marine and Freshwater Research* **36**, 343–359.

Jernakoff, P. J. (1988). The Western and North West Shelf Deep-water Trawl Fisheries: Research Priorities. Bureau of Rural Resources Bulletin No. 1, 1–33. Australian Government Publishing Service.

Lu, C. C. and Dunning, M. C. (1982). Identification guide to Australian arrow squid (family Ommastrephidae). *Victorian Institute of Marine Science Technical Report* **2**, 1–30.

McLoughlin, R. G., Davis, T. L. O. and Ward, T. J. (1988). Sedimentary provinces, and associated bedforms and benthos on the Scott Reef–Rowley Shoals platform off North-West Australia. *Australian Journal of Marine and Freshwater Research* **39**(2), 133–144.

Nesis, K. N. 1987. Cephalopods of the World. 351 pp. (T. F. H. Publications: Neptune City, N.J.)

Okutani, T. (1980). Useful and latent cuttlefish and squids of the world. National Cooperative Association of Squid Processors, Tokyo, 66 pp.

———, Tagawa, M. and Horikawa, H. (1987). Cephalopods from Continental Shelf and Slope around Japan. 194 pp. (Japan Fisheries Resource Conservation Association: Tokyo).

Phillips, B. F. and Jernakoff, P. J. (1991). The North West Slope Trawl Fishery. *Australian Fisheries* **50**(7), 18–20.

——— and Wallner, B. G. (1990). Development of a trawl fishery for deepwater metanephropid lobsters off the North West continental slope of Australia. Designing a management strategy compatible with species life history. *Symposium on Shellfish Life Histories and Shellfishery Models*. Moncton, N.B., Canada.

Rainer, S. F. (1992). Diet of prawns from the continental slope of north-western Australia. *Bulletin of Marine Science* 50(2): 258–274.

Roper, C. F. E., Sweeney, M. J. and Nauen, C. E. (1984). FAO species catalogue. Vol. 3. Cephalopods of the world. An annotated and illustrated catalogue of species of interest to fisheries. *FAO Fisheries Synopses* **125**(3), 1–277.

Voss, N. A. (1969). A monograph of the Cephalopoda of the north Atlantic. The family Histioteuthidae. *Bulletin of Marine Science* **19**(4), 713–867.

Wadley, V. A. 1990. Squid from the West and North West Slope Trawl Fishery. CSIRO Australia, 12 pp.

Wallner, B. and Phillips, B. (1988). From scampi to deepwater prawns: developments in the North West Shelf deepwater trawl fishery. *Australian Fisheries* **47**(9), 34–38.

Appendix I — Publications

Garvey, J. R. (1992). Changes in catch rates of prawns and scampi in the North West Slope Trawl Fishery. Abstract *In* Australian Marine Sciences Association Annual Conference, 5–8 July 1992: Mandurah, Western Australia. 33.

Phillips, B. F. and Jernakoff, P. (1991). The North West Slope Trawl Fishery: what future does it have? *Australian Fisheries* **50**(7), 18–20.

Rainer, S. F. (1991). Food and diurnal behaviour of deepwater prawns. Abstract *In* Proceedings of the International Crustacean Conference, 2–6 July 1990: Brisbane, Queensland. *Memoirs of the Queensland Museum* **31**, 400.

———. (1992). Crustaceans of the northwestern continental slope of Australia. Abstract *In* Australian Marine Sciences Association Annual Conference, 5–8 July 1992: Mandurah, Western Australia. 60.

———. (1992). Diet of prawns from the continental slope of north-western Australia. *Bulletin of Marine Science* **50**(2), 258–274.

Wadley, V. A. (1990). First Australian Workshop Pelagic Molluscs: Summary and Recommendations. *Australian Marine Science Bulletin* **109**, 16

———. (1990). Squid from the West and North West Slope Deepwater Trawl Fisheries. CSIRO Australia, 12 pp.

———. (1992). Biology of the deepwater red prawn, *Aristaeomorpha foliacea* (Decapoda: Aristeidae), on the north-west slope of Australia. Abstract *In* Australian Marine Sciences Association Annual Conference, 5–8 July 1992: Mandurah, Western Australia. 67.

———. (in press). Cephalopods from demersal trawling on Australia's North West Slope. In: *Recent Advances in Cephalopod Fishery Biology*. (T. Okutani, Ed.) *Memoirs of the Tokai University of Fisheries*.

——— and Evans, D. (1991). Crustaceans from the Deepwater Trawl Fisheries of Western Australia, CSIRO Australia, 44 pp.

——— and Morris, S. M. (1991). Deepwater fishery for prawns and carids off Western Australia. Abstract *In* Proceedings of the International Crustacean Conference, 2–6 July 1990: Brisbane, Queensland. *Memoirs of the Queensland Museum* **31**, 456.

Wallner, B. G. and Phillips, B. F. (1988). From scampi to deepwater prawns: developments in the North West Shelf deepwater trawl fishery. *Australian Fisheries* **47**(9), 34–38.

——— and Phillips, B. F. (1990) Development of a trawl fishery for deepwater metanephropid lobsters off the north-west continental slope of Australia. Designing a management strategy compatible with species life history. Symposium on Shellfish Life Histories and Shellfishery Models. Moncton, N.B., Canada.

Williams, A. (1990) Commercial Trawl Fish from the Western and North West Slope Deepwater Trawl Fisheries. 46 pp. CSIRO Australia,

———. (1992). Continental slope fishes from western and north western Australia. Abstract *In* Australian Marine Sciences Association Annual Conference, 5–8 July 1992: Mandurah, Western Australia. 69.

Appendix II — Transfer of Results to Industry

In each year of the grant a public seminar on the NWST and WDWT fisheries, jointly sponsored by AFS and CSIRO Marine Laboratories was held at the CSIRO Marine Laboratories at Marmion in Western Austrlalia. It was attended by approximately 60 participants, including fishers, representatives of all the fishing companies involved in the fisheries and other interested people in the industry, the Chief Executive of CSIRO, Dr John Stocker, the Director of the Fisheries Department in Western Australia, Mr Bernard Bowen and several Members of Parliament.

Summaries of each catch and effort data were provided to participating companies and the AFS through two articles published in *Australian Fisheries* (Wallner and Phillips 1988, Phillips and Jernakoff 1991).

Reports were made to the Scientific Advisory Committee and to the Western Fisheries Research Committee at its biannual meetings.

Scientific reports of results from the study have been published on the food and feeding of deepwater prawns (in *Bulletin of Marine Science*) and on the cephalopods from the demersal trawling (in *Memoirs of the Tokai University of Fisheries*). One paper has been submitted on designing the management strategy appropriate to the life history of scampi. Further papers for scientific publication are in preparation on the biology of the red prawn (*Aristaeomorpha foliacea*), on the growth and longevity of scampi, on the demersal fish communities of the Western Australian continental slope. It is further likely that the Deepwater Trawl Fisheries Guides to crustaceans, cephalopods and fish will be brought together as a single publication for commercial sale to a non-scientific readership.

In the month following the fisheries survey by FRV *Southern Surveyor* in 1991, a detailed cruise report containing preliminary results was circulated to Industry and the Scientific Advisory Committee (SAC) for the NWSF and WDWTF. Subsequently the results have been presented at the Western Fisheries Research Committee Meeting, at a public (Industry) Meeting and to the SAC.

Appendix III — Scientific observer coverage during 1988–1992

III.1 Fishing companies and vessels participating in CSIRO observer cruises, 1988-92

Company	Fishing Vessels
NWSTF	
Tiger Fisheries P/L	Surefire, Striker, Tarni, Inspiration, Incentive, Invincible, Titan
Newfishing Aust P/L	Angela Wright, Heron, Courageous, Kingfisher
A. Raptis & Sons P/L	Admiralty Pearl, Noble Pearl, Eylandt Pearl, Territory Pearl
Capricorn Fisheries	Capricorn Albatross
Woods Fisheries P/L (a late entry 1992 under Raptis endorsement)	Valkyrie Voyager, Valkyrie Venturer
WDWTF	
WA Seafood Exporters P/L	Ocean Producer, Ocean Exporter
A. Raptis & Sons P/L	Adelaide Pearl
Sophisticated Pursuit P/L	Daniel
Latitude Fisheries P/L	South Passage
McBoats Seafoods	Lady Pamela
Aries Fishing Co.	Kiama II
M.G Kailis P/L	Maria Louise
Newfishing Aust. P/L	Orion
Tiger Fisheries P/L	Striker
Foreign vessels under joint venture	Akebono Maru, Star of Crimea

III.2 Cruise reports on file at CSIRO Division of Fisheries

Year / Fishery	Observer	Vessel	Period of coverage From	To	No. of Days
1988					
NWSTF	D. Evans	*Surefire*	19 Aug	14 Sep	27
NWSTF	S. Morris	*Admiralty Pearl*	5 Dec	14 Dec	10
1989					
WDWTF	D. Wright	*South Passage*	23 Jan	12 Feb	12
NWSTF	D. Evans	*Courageous*	4 Feb	13 Feb	10
NWSTF	S. Morris	*Striker*	31 Mar	22 Apr	23
NWSTF	D. Evans	*Surefire*	1 Aug	8 Aug	8
WDWTF	A. Williams	*Akebono Maru*	21 Dec	31 Dec	11
1990					
WDWTF	V. Wadley	*South Passage*	13 Jan	20 Feb	8
NWSTF	D. Evans	*Courageous*	20 Jan	11 Feb	23
WDWTF	D. Wright	*Ocean Producer*	11 Mar	19 Mar	9
NWSTF	R. Jackson	*Surefire*	9 Apr	5 May	27
NWSTF	R. Jackson	*Surefire*	9 June	7 Jul	30
NWSTF	J. Garvey	*Surefire*	11 Aug	7 Sep	28
WDWTF	A. Williams	*Kiama*	28 Sep	30 Sep	3
NWSTF	R. Jackson	*Inspiration*	21 Nov	13 Dec	23
WDWTF	S. Rainer	*Kiama*	24 Nov	28 Nov	5
Timor	D. Evans	*Invincible*	5 Dec	16 Dec	12
1991					
WDWTF	N. Clear	*Ocean Producer*	12 Jan	21 Jan	10
NWSTF	R. Jackson	*Striker*	17 Jan	7 Feb	21
NWSTF	R. Jackson	*Titan*	7 Feb	10 Feb	4*
WDWTF	J. Garvey	*Adelaide Pearl*	20 Jan	31 Jan	12
NWSTF	R. Jackson	*Striker*	15 Feb	15 Mar	28
WDWTF	A. Williams	*Daniel*	6 Oct	9 Oct	4
NWSTF	M. Hannon	*Surefire*	10 Oct	12 Nov	34
WDWTF	A. Williams	*Daniel*	11 Nov	13 Nov	3
1992					
NWSTF	V. Wadley	*Surefire*	17 Jan	19 Feb	34
NWSTF	D. Evans	*Surefire*	19 Feb	21 Mar	32

*Note: transferred at sea from previous vessel

Appendix IV — Commercial guide and log book proformas

IV.1 Guides to commercial species — sample layout (Fish Guide)

Explanation of Format

Recommended Marketing Name: adopted as standard in Australian markets (listed alphabetically)

Scientific Name

Key features: to distinguish fish from similar species

Other Common Names: in use but not recommended.

Size: largest known to date

Habitat/Depth: where fish usually occur

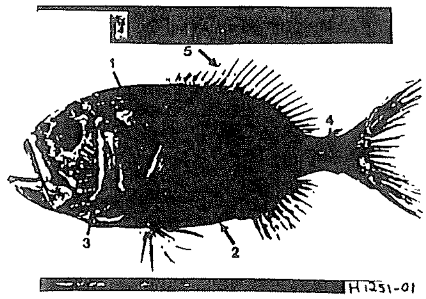
Distribution: as known at present

Existing Fisheries: at present

Markets/Products: general background information.

Remarks: information on catches, catch depths etc. from other fisheries and non-confidential data from W and NWSDWTF.

Orange roughy *Hoplostethus atlanticus*



Key Features: 1. Head, body and all fins bright orange 2. Bony scales along belly (scutes) weakly developed 3. Spines on gill cover weakly developed. 4. Lateral line scales large 5. Last dorsal fin spine longest

Other Common Names: sea perch (NSW, Qld, SA, Vic, WA)

Size: to 69 cm, at least 4 kg

Habitat: demersal **Depth:** in Australia 700-1300 m, mainly 900-1200 m

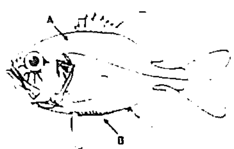
Distribution: Atlantic Ocean, Indian Ocean, NZ, southern Australia

Existing Fisheries: Atlantic Ocean, NZ, southern Australia

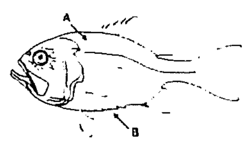
Markets/Products: domestic; fillet, whole fish

Remarks: Large catches taken in SET and GAB fisheries in recent years include an estimated 14000 t from a single spawning aggregation off Tasmania in 1989. Recorded by CSIRO from WDWTF as far north as 34°S in 825–1003 m.

Similar Species



Darwin's roughy A. Head, body colour silvery orange; fins pale orange B. 10–12 strong, bony belly scutes



Giant sawbelly (*Hoplostethus latus*) A. Body, fin colour pink B. 8–9 strong, bony belly scutes

DPIE Code 4024

Australian Species Code 255009

31

Similar Species: confusingly similar deep water fishes many of which are "commercial"; if not included in this guide they are marked "also commercial".

DPIE and scientific code numbers

IV.2 Collection of vessel data — sample gear form

GEAR DETAILS

Log number [ ] Date [/ /] Skipper's name [ ]

Vessel name, number & call sign [/ /]

Vessel details

Registered length (metres) [ ] Beam (metres) [ ]

Hull design [ ] Displacement [ ]

Endurance (days) [ ] Power 24V [ ] 240V [ ] Other [ ]

Main engine (HP/kW) [ ] Auxillary engine (HP/kW) [ ]

Refridgeration and capacity (e.g. freezer, brine, ice, snap) [ ]

On board processing facilities (e.g. filleting machines, meal plants, packaging machines) [ ]

Electronics

Navigation (e.g. radar, sat. nav., GPS) [ ]

Echo sounders – make and model [ ]

Net/board monitoring devices [ ]

Nets	Net code 1	Net code 2	Net code 3	Net code 4	Net code 5
Net type/design					
Midwater/bottom trawl (M/B)					
Headline length (m)					
Groundrope length (m)					
Cod end mesh (mm)					
Headline opening (m)					
Wingspread (m)					

Accessories					
Sweep length (m)					
Bridle length (m)					
Board type/design					
Warp length (m)					

IV.3 Collection of fishery data — sample daily log sheet for fish and squid catches

Deepwater Trawl Daily Log Sheet – Fish and Squid

Log no./Page no.	Date	Vessel name, number & call sign	Skipper's name	Invoice Fuel
/	/ /	/ /		

TRAWL DETAILS

		Shot number 1	2	3	4	5	6
Position	Latitude						
	Longitude						
Time (24 hr clock)	Start fishing (net on bottom)						
	Haul up (net off bottom)						
Depth (Specify M or F)	Start/Finish	/	/	/	/	/	/
Bottom temperature (°C)							
Net code (from gear details)							
Average trawl speed (knots)							
Problems with shot (Y/N)							

CATCH Estimated weight (whole fish) in kg. T = target species

Species / code		T	1	T	2	T	3	T	4	T	5	T	6
Alfonsino	258002												
Boarfish – big-spined	367004												
Darwin's roughy	255004												
Dogfish – green-eye	020007												
Dory – king	264001												
Dory – mirror	264003												
Flathead – deep water	296002												
Gemfish	439002												
Grenadier – blue	227001												
Ling	228002												
Mackerel – jack	337002												
Morwong	377003												
Orange roughy	255009												
Oreo dory	266004												
Oreo dory – spiky	266001												
Perch – ocean	287001												
Ribaldo	224002												
Shark – school	017008												
Arrow squid – Gould's	636006												
Arrow squid – Hawaiian	636005												
Others:													
Discards:													

Vessel notes:

IV.4 Collection of fishery data — sample daily log sheet for crustacean catches

Deep Water Trawl Daily Log Sheet

Log No. ______ Page No. ______ Date / / ______ Vessel Name ______ Skipper ______

Shot No.	Position (Degrees, Minutes)		Time (24 hour clock)		Depth (Average)	Catch: Whole Scampi (boxes)				Scampi Tails		Scampi Species	Prawns and Other Catch (boxes)	Shot Tally	Note: All nets fishing O.K.? (✓)	
	Lat	Long	Shoot away	Winch up	Metres	Lrg	Med	Sml	XSml	Lrg	Sml	(enter main species first)			Yes	No
1																
2																
3																
4																
5																
6																
7																
8																
9																
10																
Total for day																
Previous Totals																
Total on board																
Average box weight												Scampi Totals		Prawn & other totals	Totals all catch	

Gear

Is this the first day of the current trip? Yes ☐ No ☐

Have you changed gear since last day fished? Yes ☐ No ☐

If Yes to either of the previous questions please complete Gear Details below

No. of nets towed	No of boards towed	Total length of headrope (fathoms)	Mesh size (inches) Wings	Mesh size (inches) Cod end	Tickler chains (Y/N)

Before which Shot Number was gear changed? ☐

Vessel Notes

Remarks

Scampi with berry? Many ☐ Some ☐ Few ☐ None ☐

Soft-shelled scampi? Many ☐ Some ☐ Few ☐ None ☐

Weather? ☐

Sea conditions? ☐

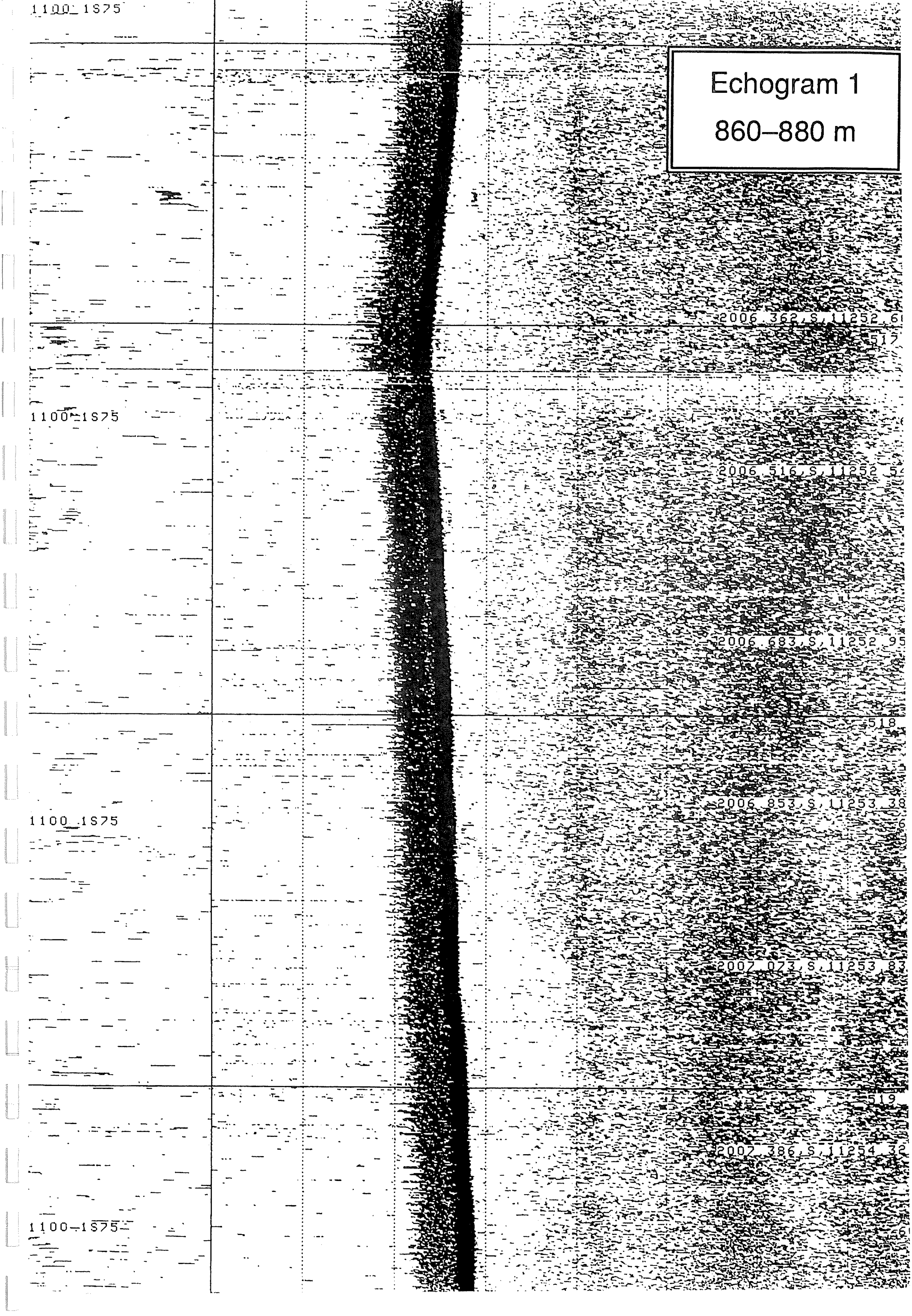
Tides? ☐

Other information? ☐

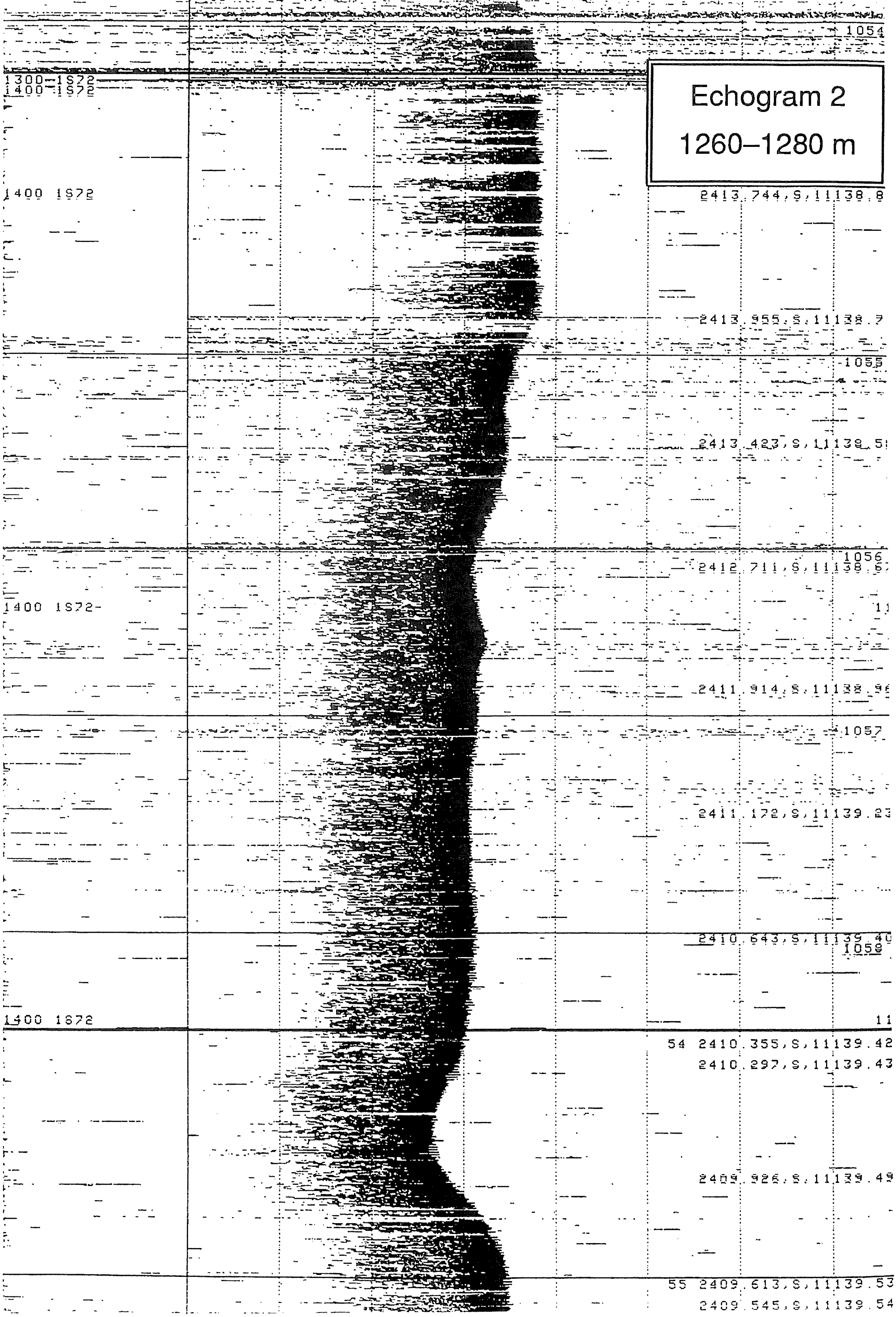
Appendix V — Fishing grounds: bottom types and features

Echograms typical of different areas and bottom types within the WDWTF are included, for the following positions and depths:

Echogram No.	Latitude (°S.)	Longitude (°E.)	Depth (m)
Exmouth Plateau			
1	20°06'	112°53'	860–1280
Northern region			
2	24°12'	111°39'	1260–1280
3	27°29'	112°10'	1200–1330
4	24°52'	112°07'	470–480
5	24°54'	112°11'	320–340
6	30°01'	114°28'	360–420
7	29°45'	114°20'	260–520
Geraldton — Perth			
8	30°52'	114°37'	870–880
9	30°42'	114°26'	1140–1280
10	31°17'	114°52'	450–490
11	31°44'	114°59'	380–470
Perth Canyons			
12	31°57'	115°09'	640–1050
13	32°00'	115°04'	750–1280
14	31°53'	115°02'	460–480
15	31°56'	115°03'	580–1300
16	32°04'	114°52'	780–1100
17	32°02'	115°01'	620–1000
18	32°03'	115°10'	270–370
Southern region			
19	33°22'	114°30'	300–370
20	33°16'	114°32'	340–540
21	34°41'	114°14'	840–1000
22	34°50'	114°24'	800–1040
23	33°46'	114°19'	900–960

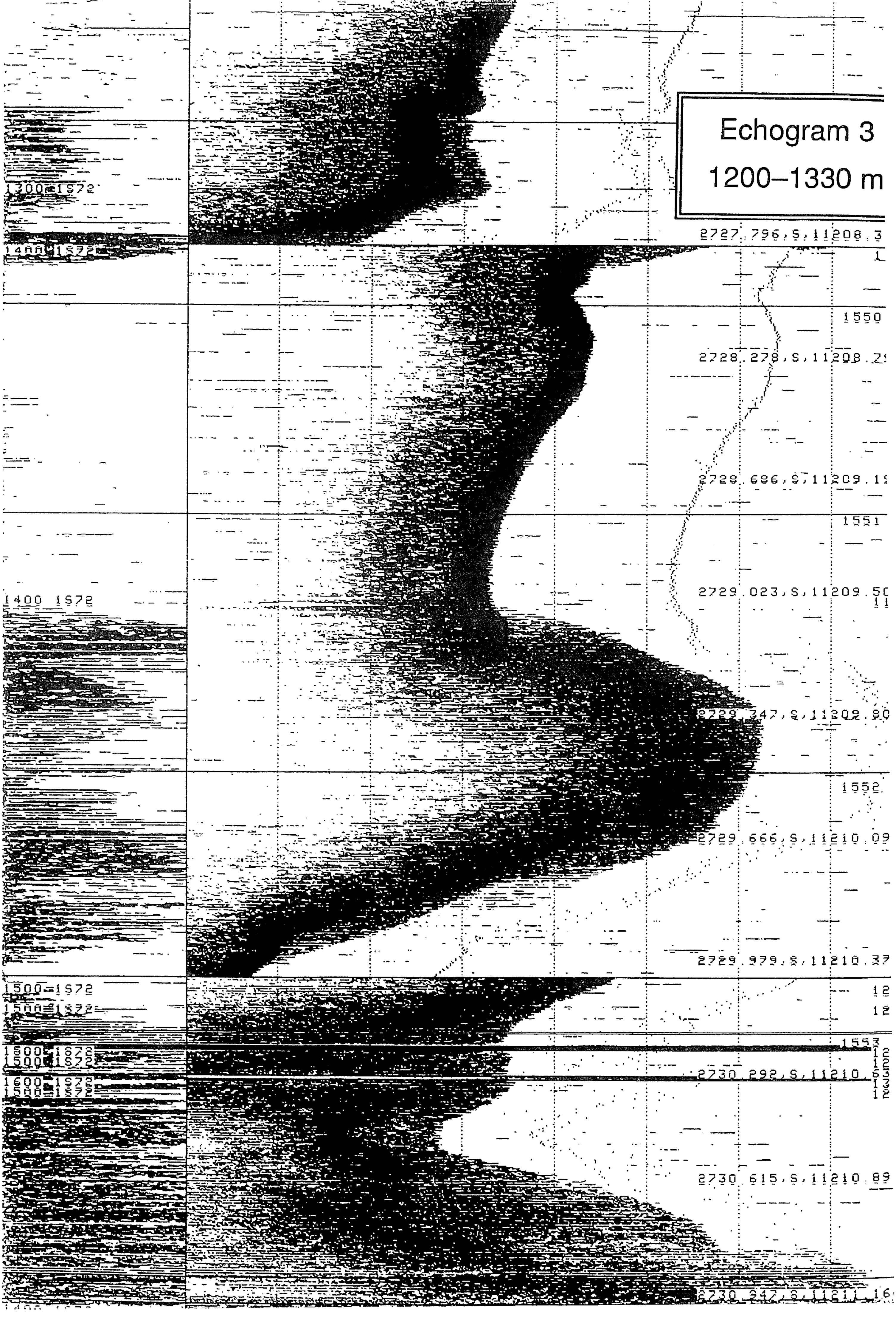


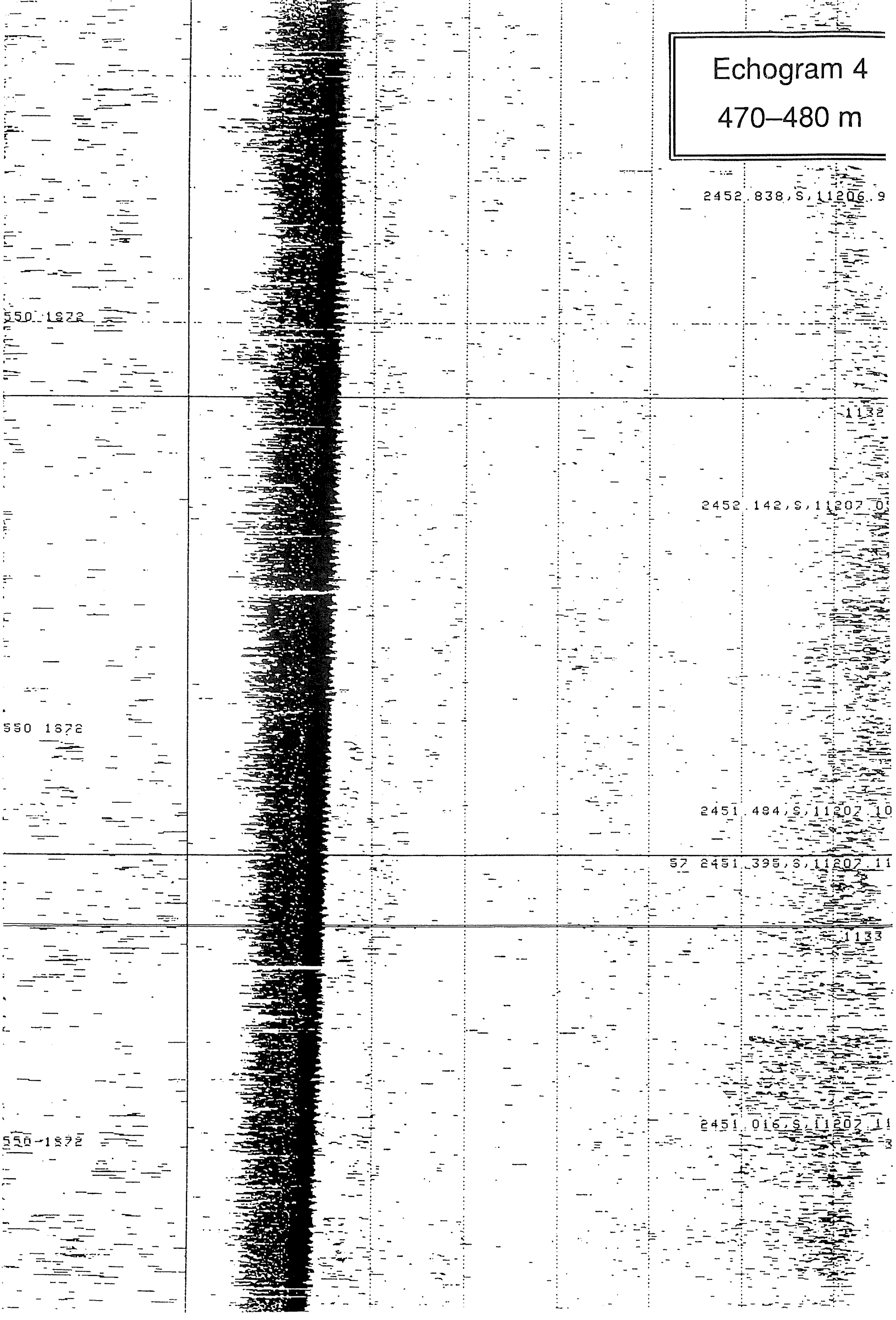
Echogram 1
860–880 m

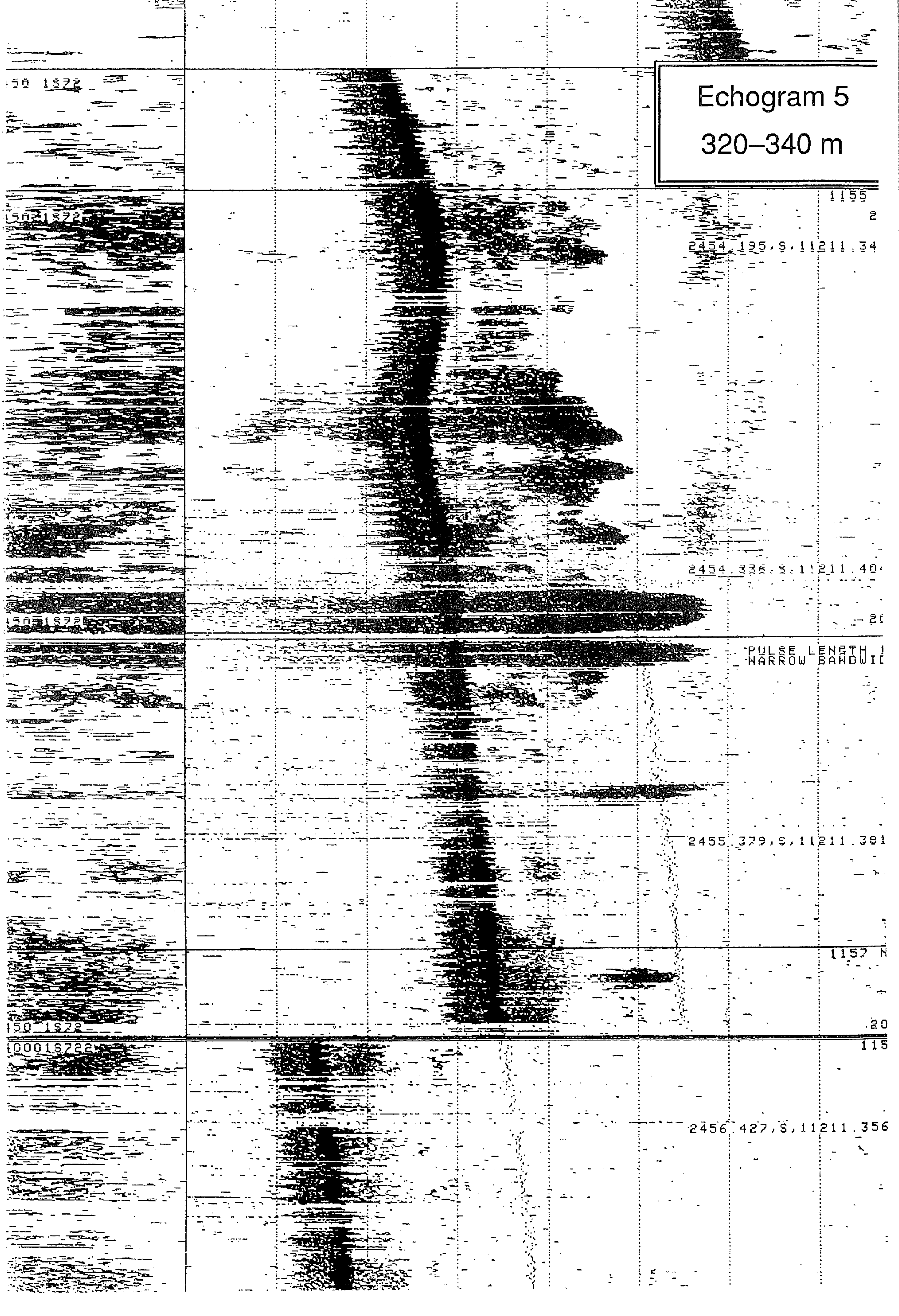


Echogram 2
1260–1280 m

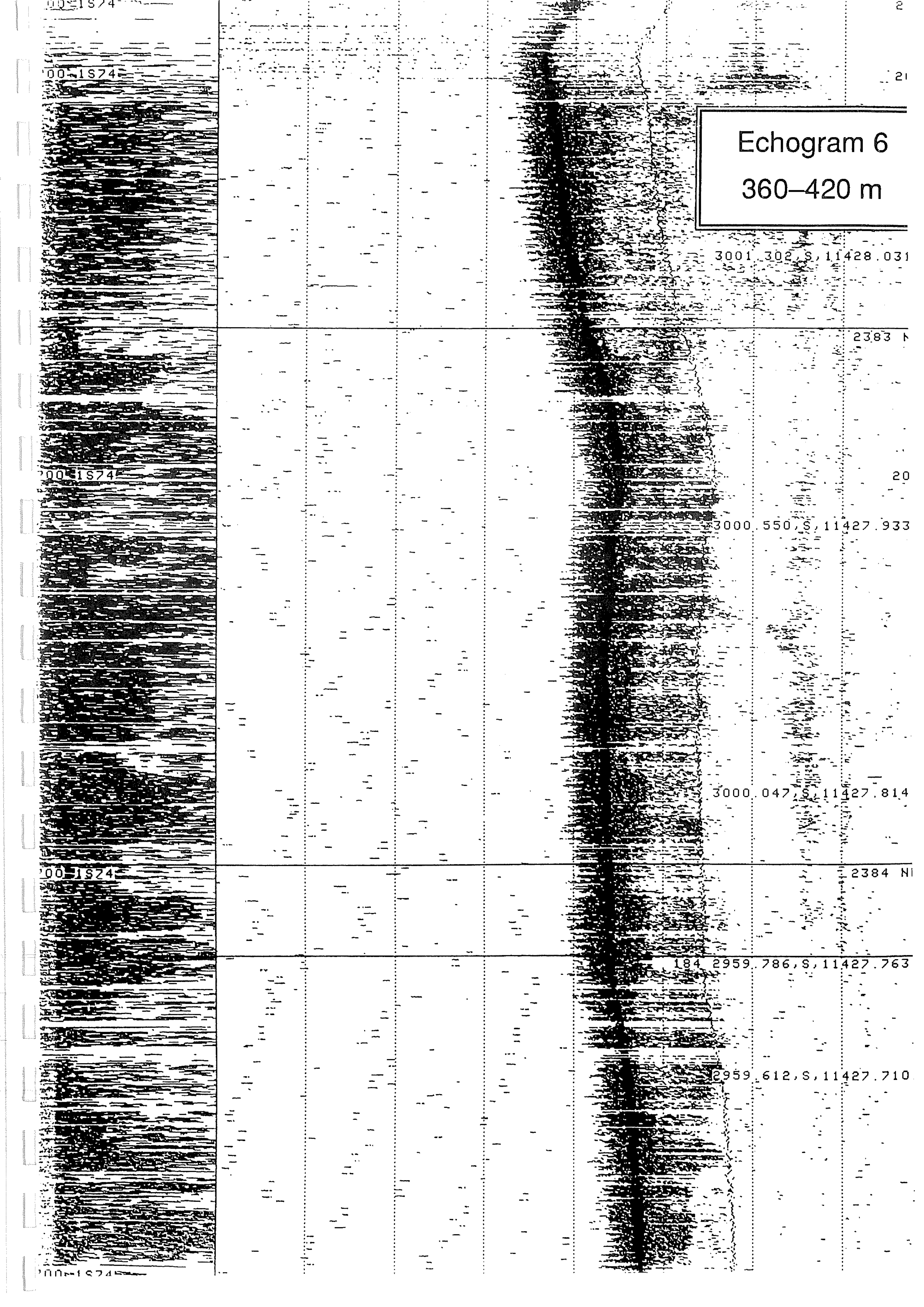
Echogram 3
1200–1330 m

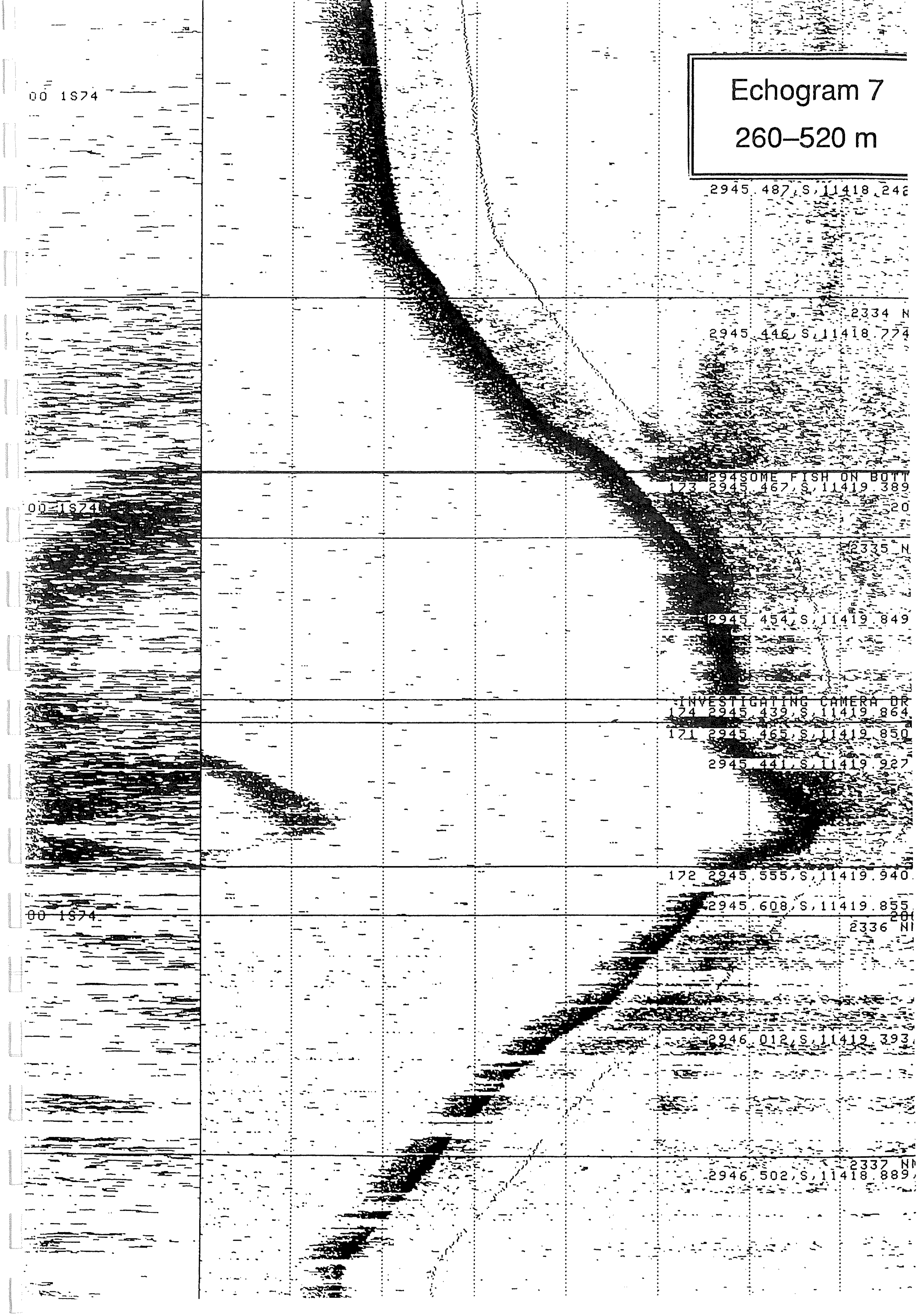



Echogram 4
470–480 m
2452.838,S,11206.9
550 1872
1132
2452.142,S,11207.0
550 1872
2451.484,S,11207.10
57 2451.395,S,11207.11
1133
2451.016,S,11207.11
550-1872

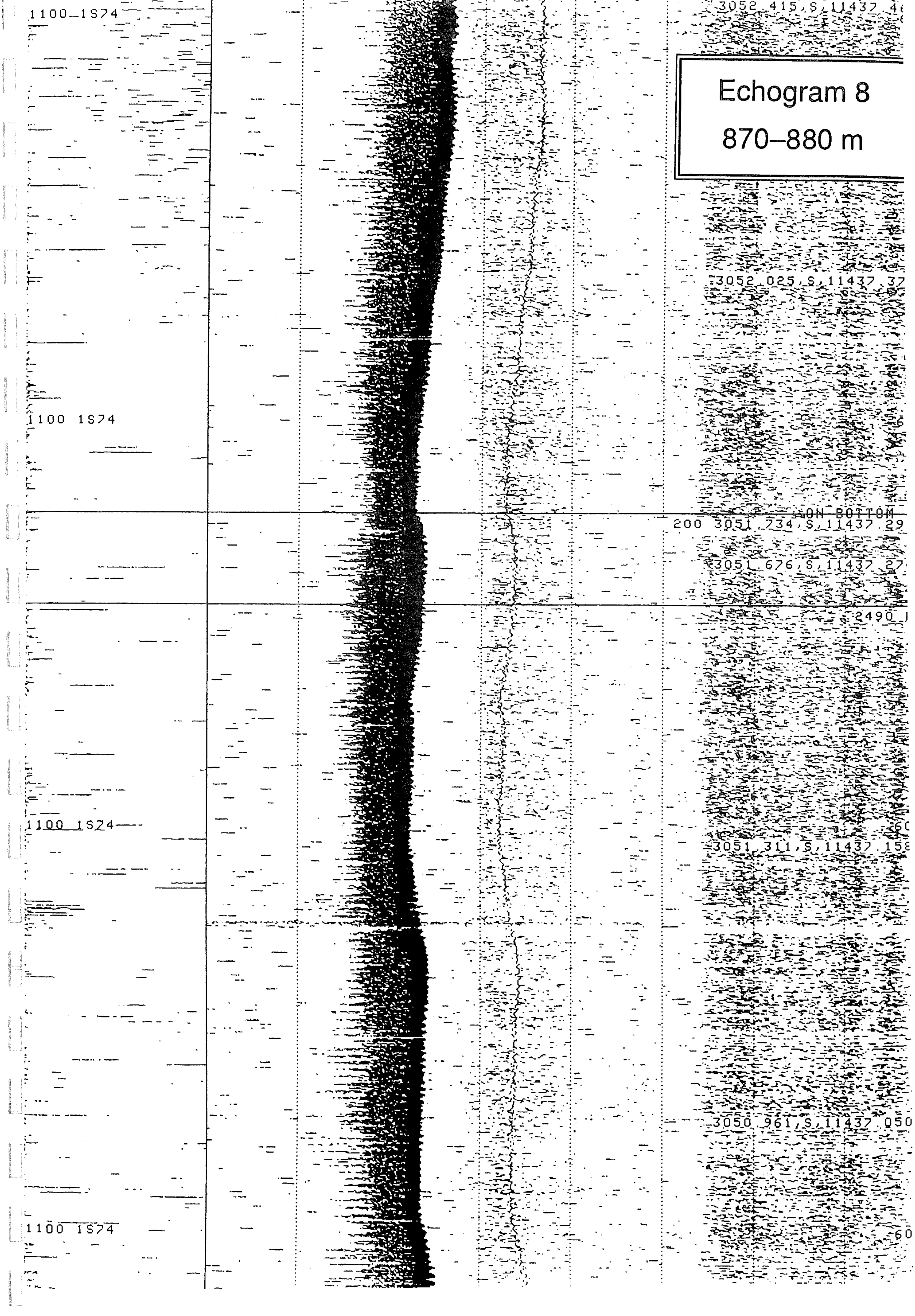


Echogram 5
320–340 m

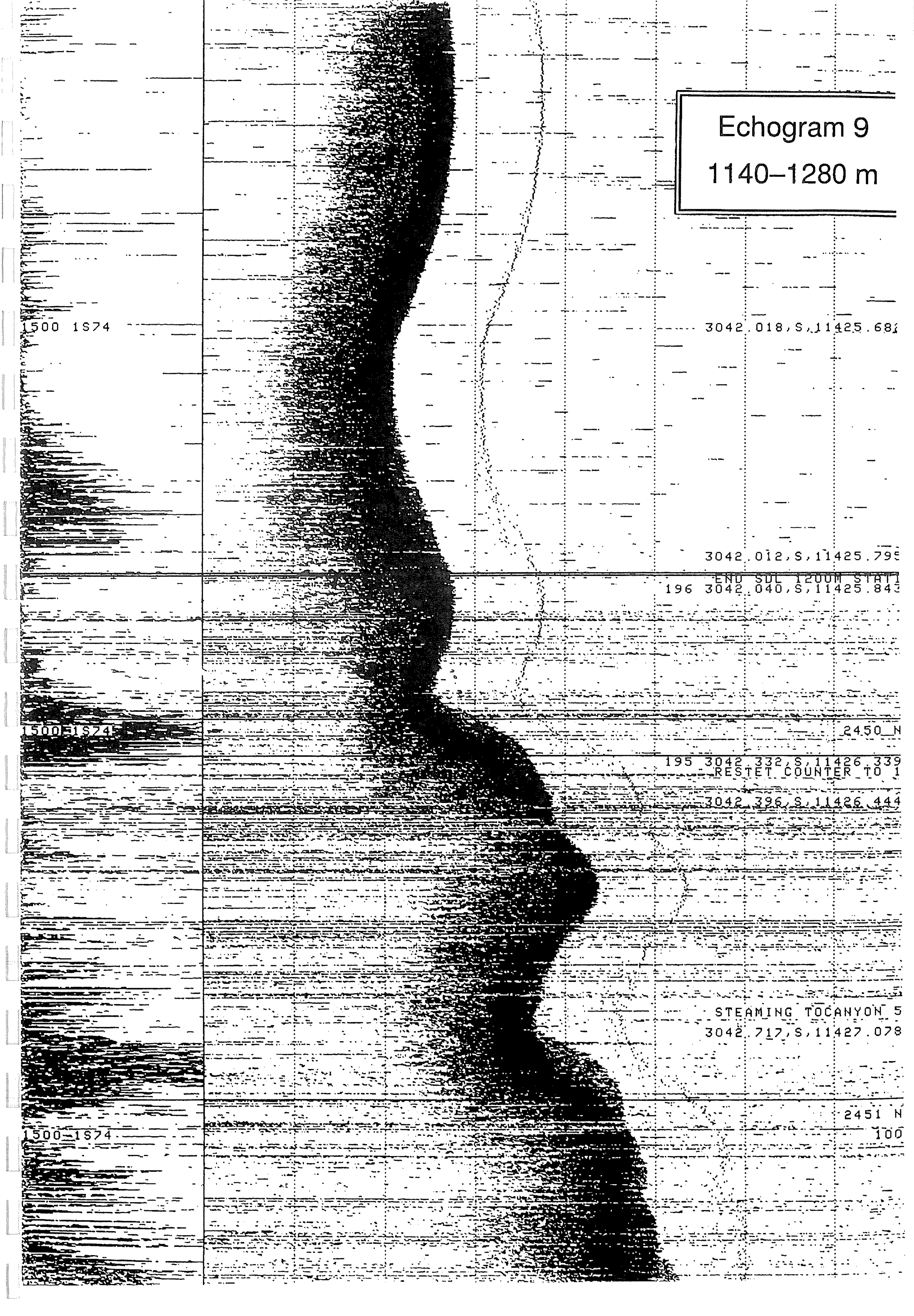

Echogram 6
360–420 m
3001.302,S,11428.031
2383
3000.550,S,11427.933
3000.047,S,11427.814
2384
184 2959.786,S,11427.763
2959.612,S,11427.710



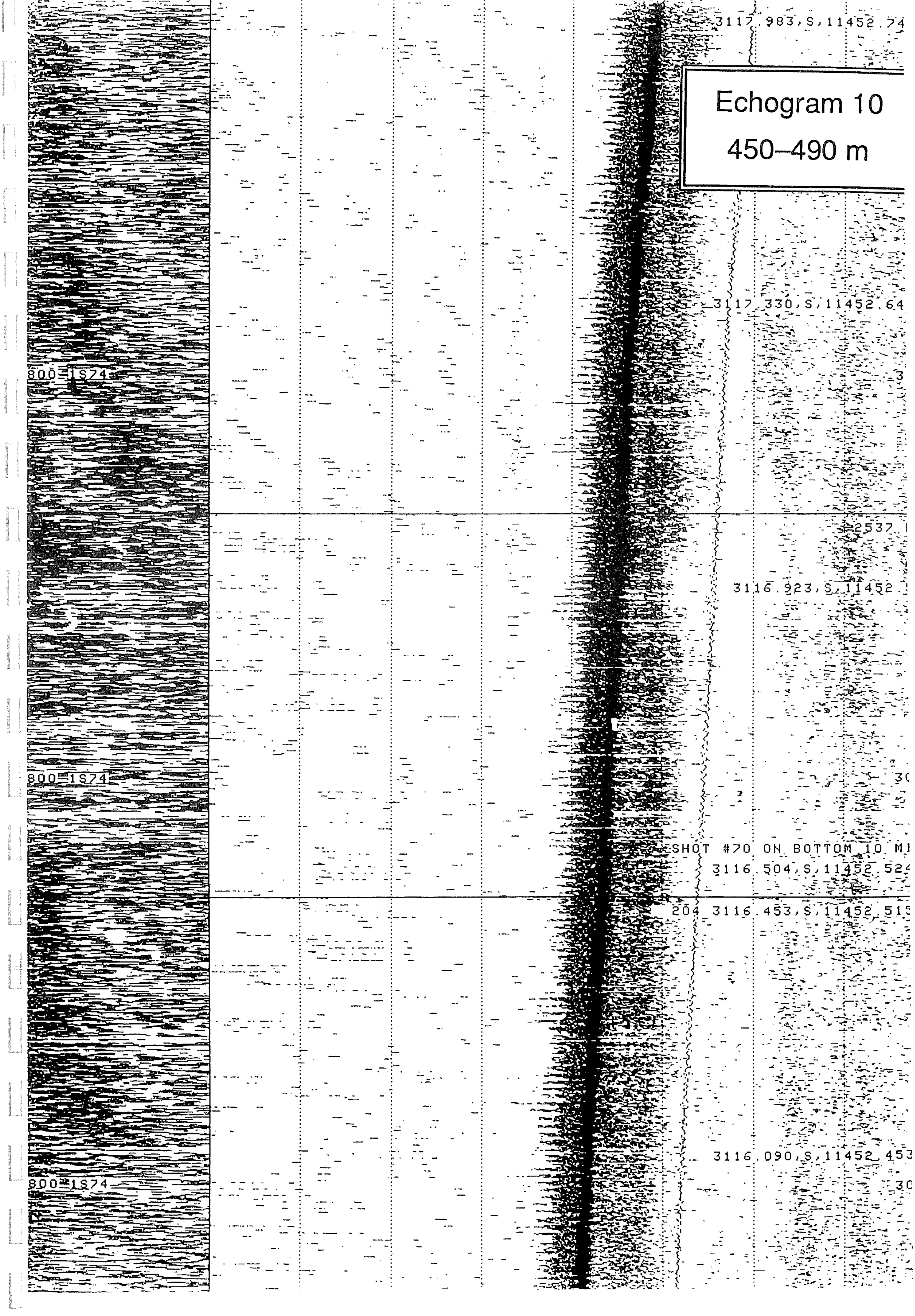
Echogram 7
260–520 m

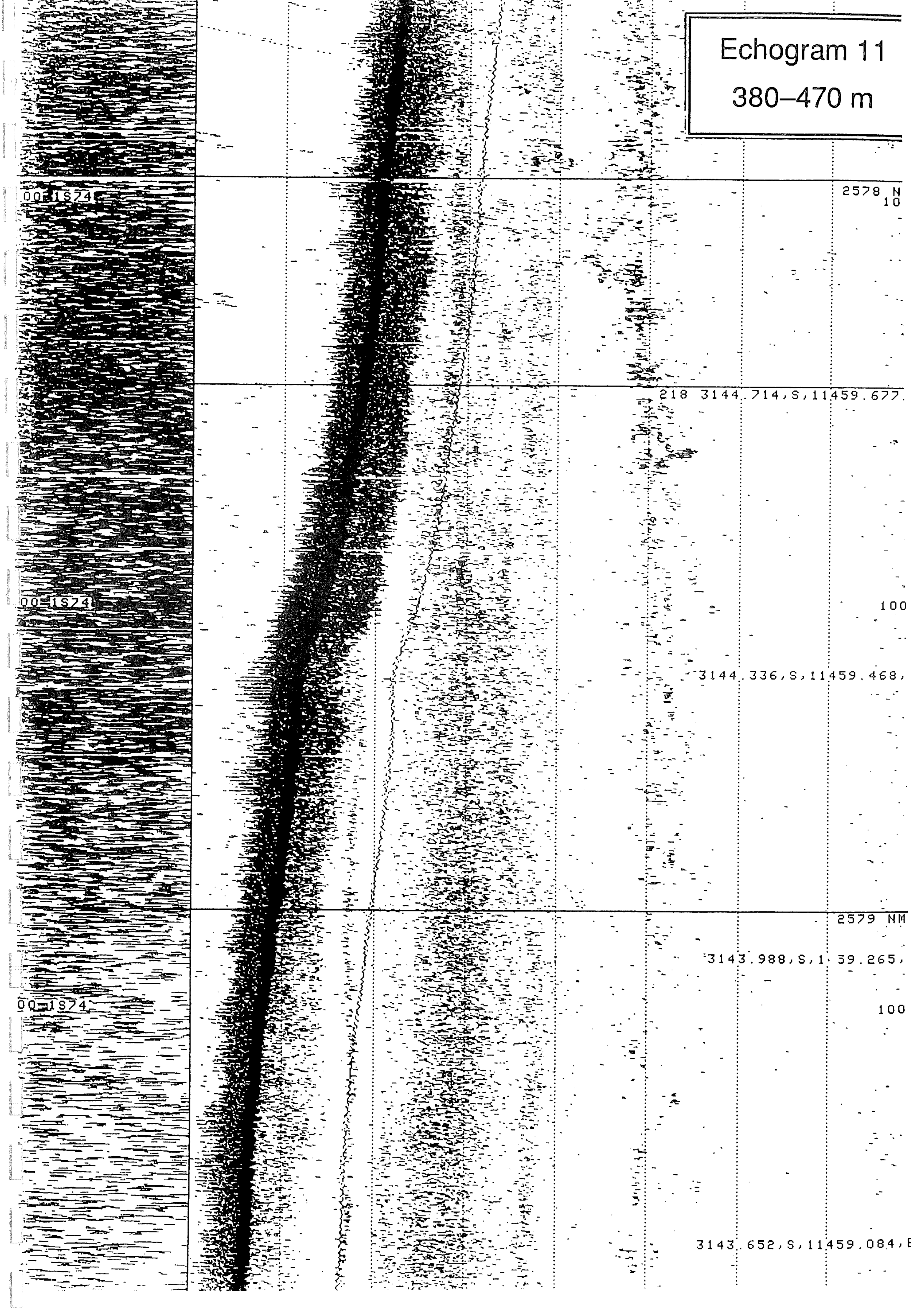


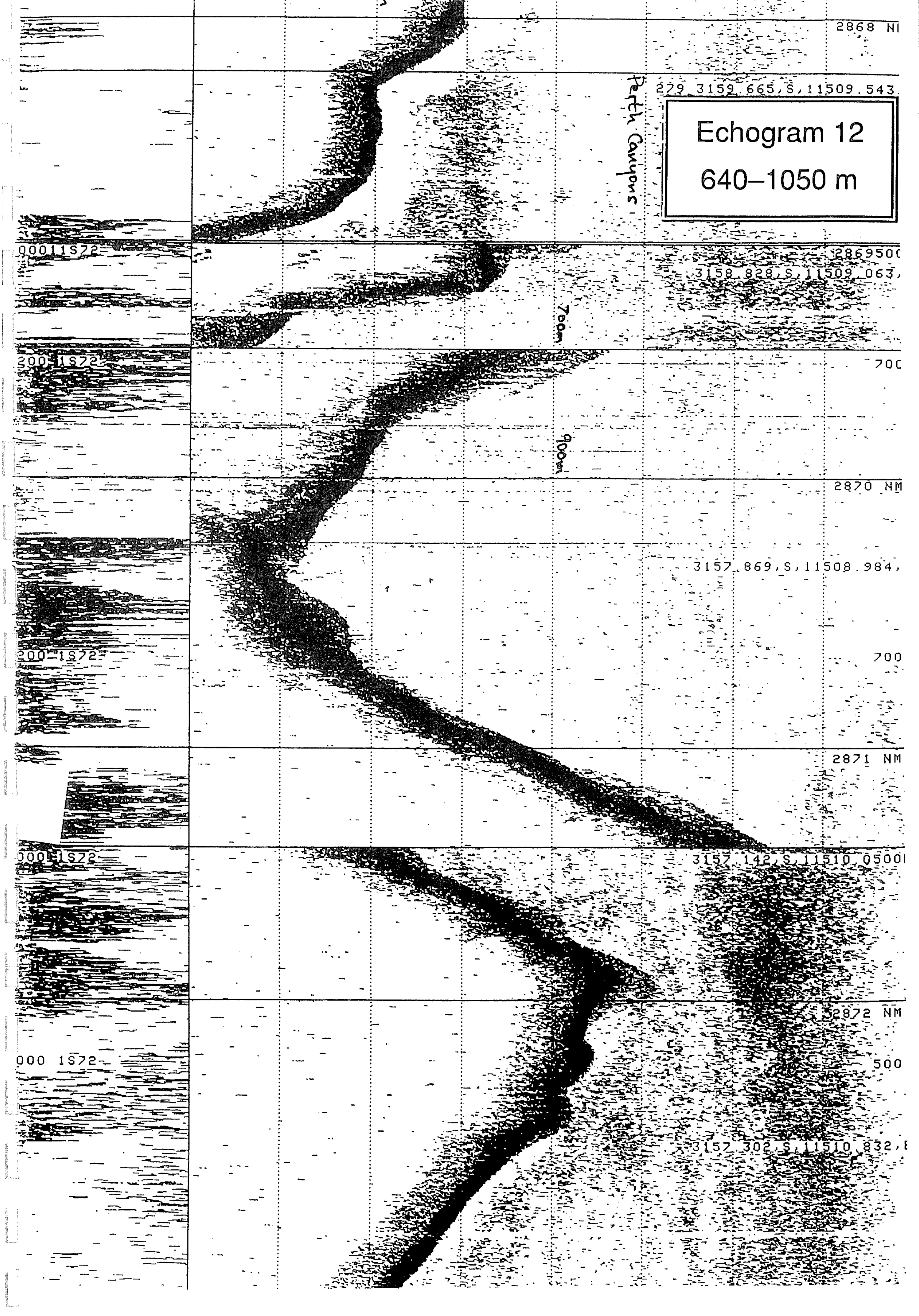
Echogram 8
870–880 m

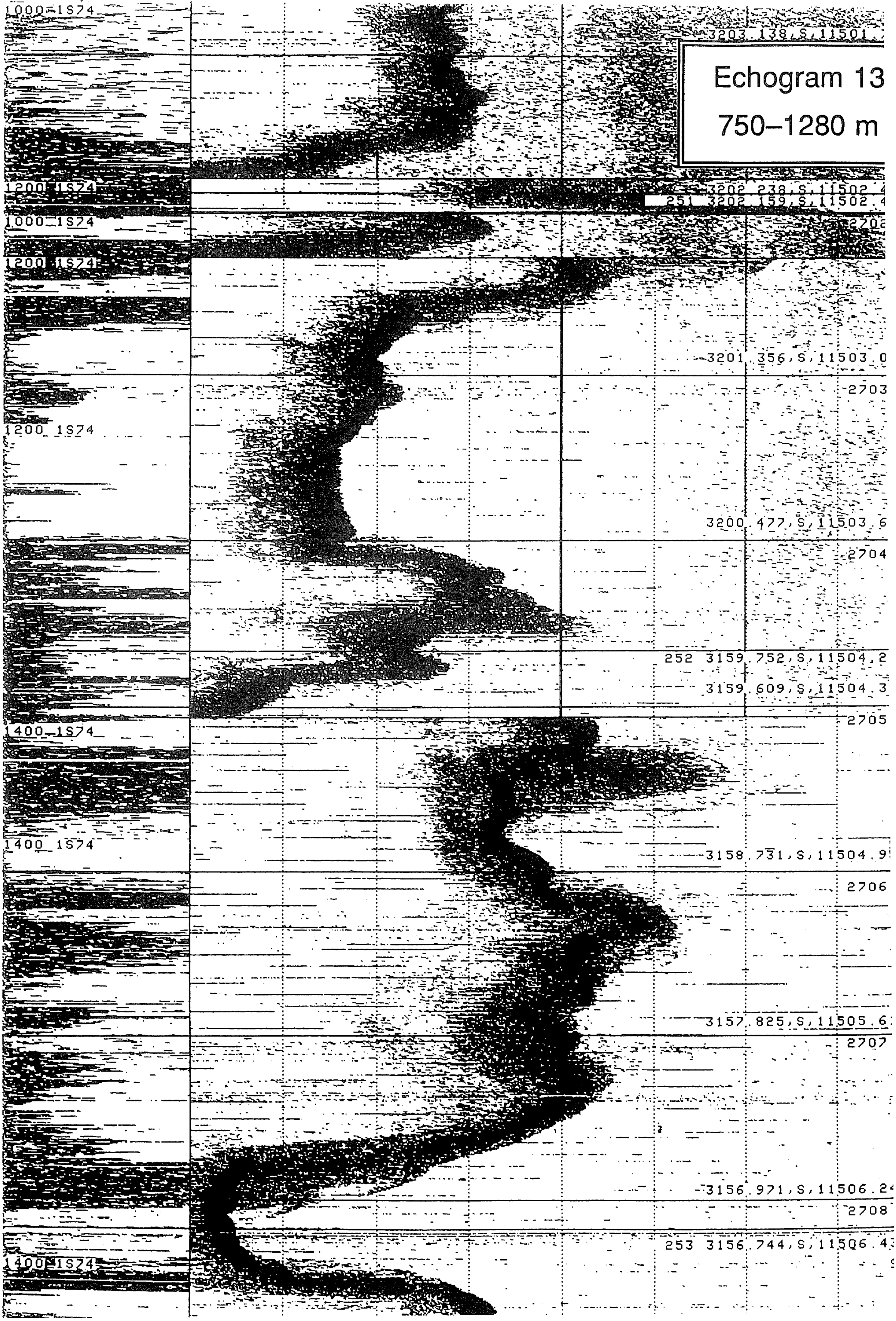


Echogram 9
1140–1280 m

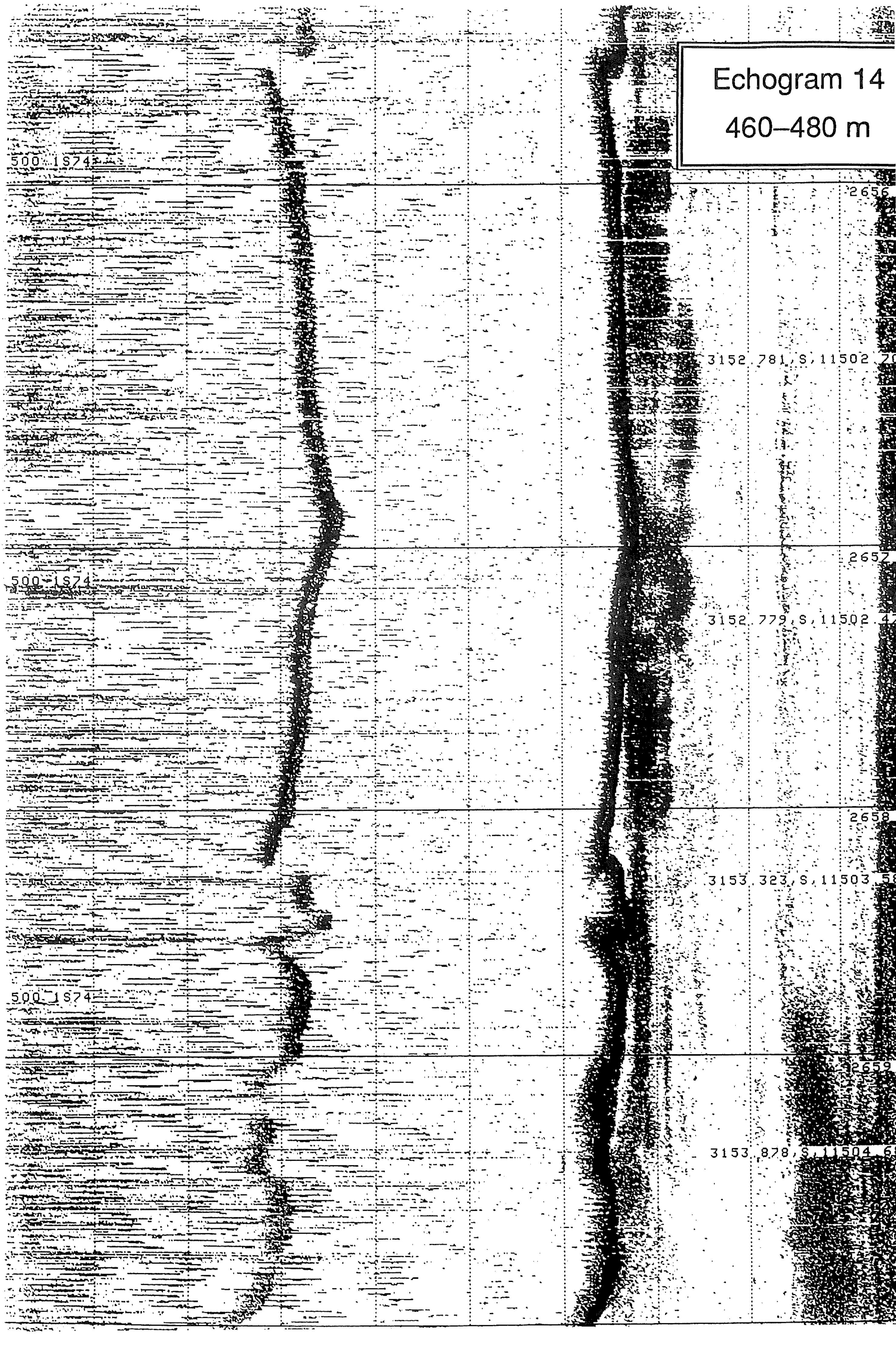

Echogram 10
450–490 m
3117.983,S,11452.74
3117.330,S,11452.64
800 1S74
2537
3116.923,S,11452.
800 1S74
SHOT #70 ON BOTTOM 10 MI
3116.504,S,11452.524
204 3116.453,S,11452.515
3116.090,S,11452.453
800 1S74


Echogram 11
380–470 m
00-1S74
2578 N
10
218 3144.714,S,11459.677.
00-1S74
100
3144.336,S,11459.468,
2579 NM
3143.988,S,1 59.265,
00-1S74
100
3143.652,S,11459.084,

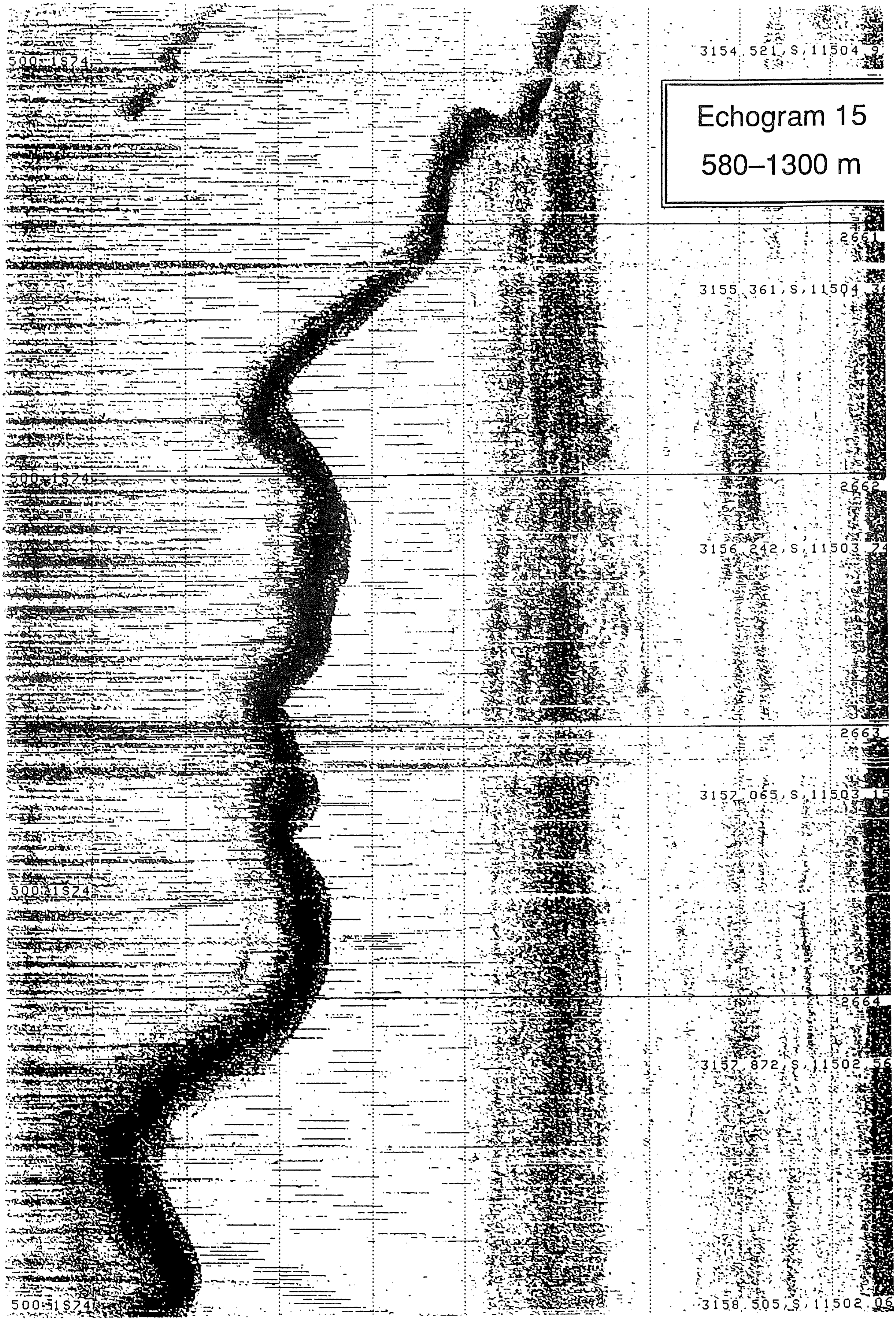

Echogram 12
640–1050 m
Perth Canyons
700m
900m
2868 NM
279 3159.665,S,11509.543
2869500
3158.828,S,11509.063,
2870 NM
3157.869,S,11508.984,
2871 NM
3157.142,S,11510.0500
2872 NM
3157.302,S,11510.832,
000 1S72
700
500

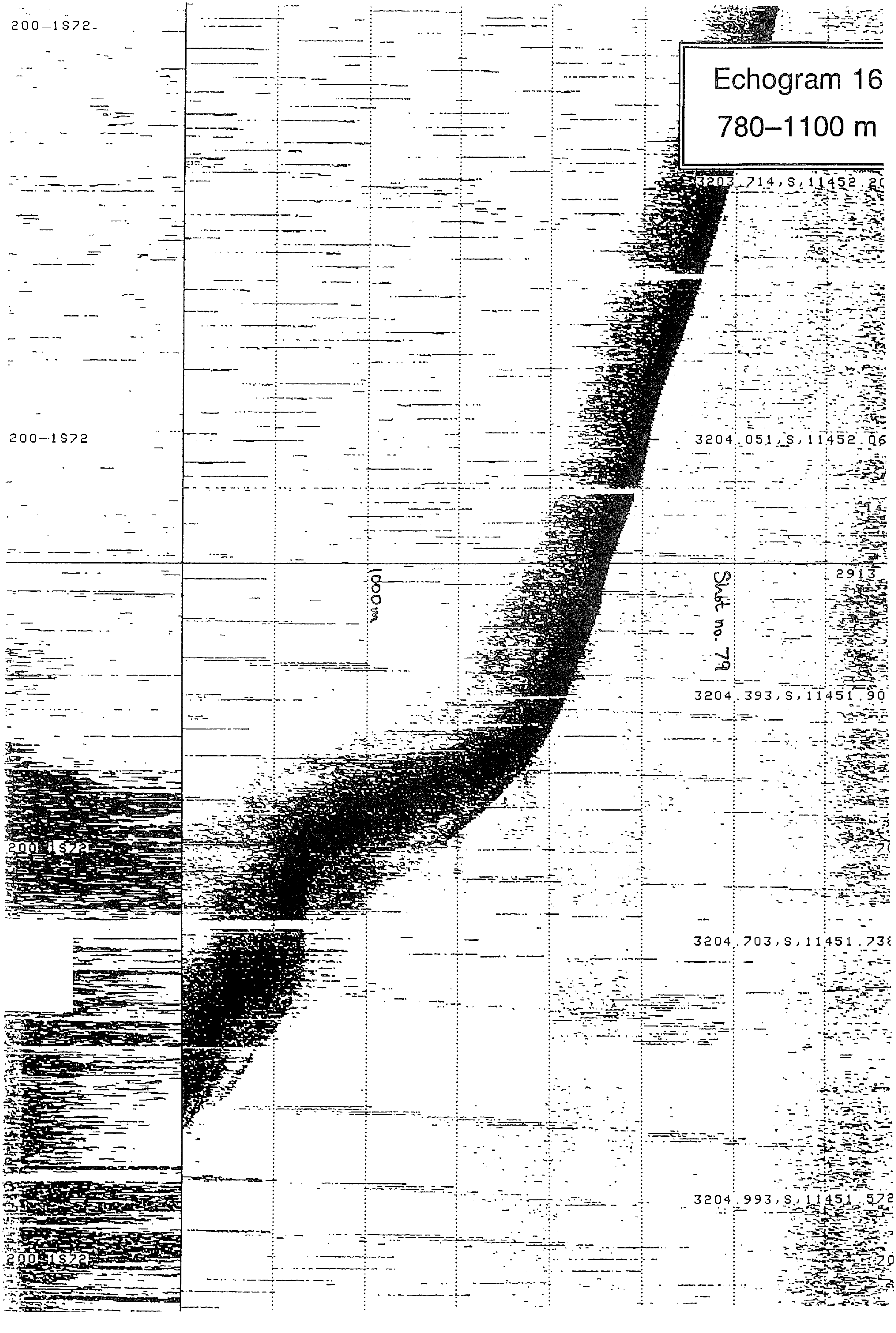


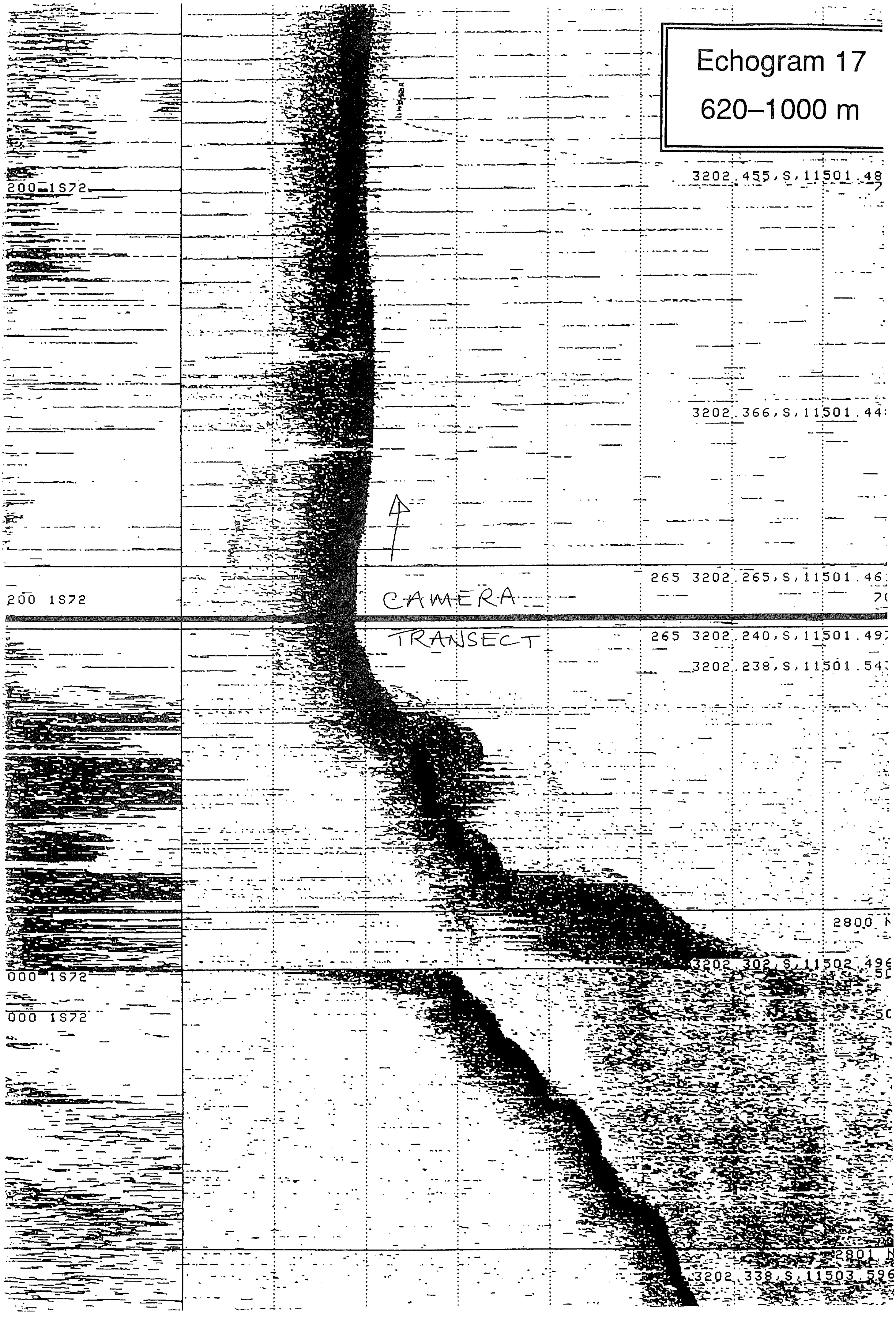
Echogram 13
750–1280 m



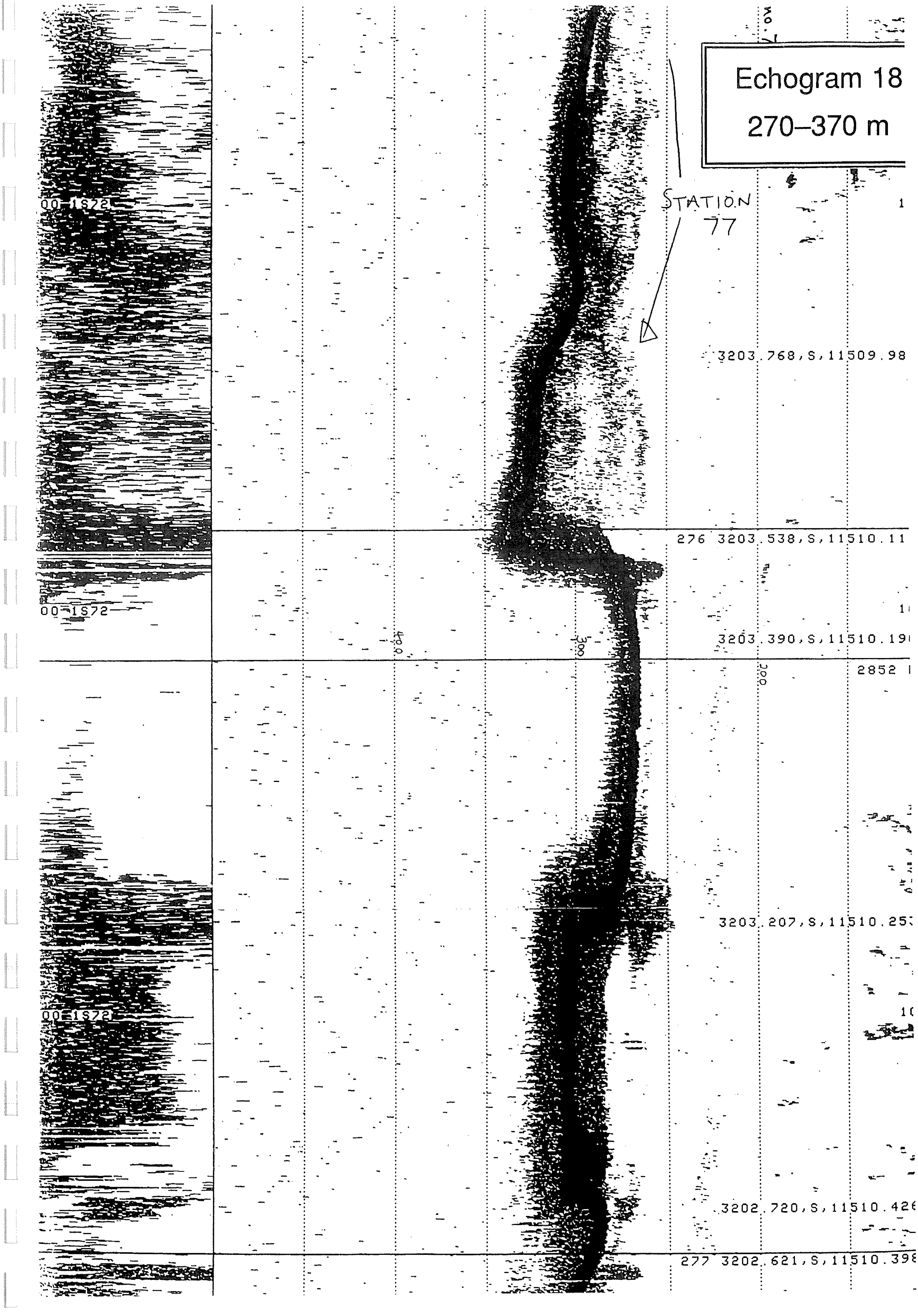
Echogram 14
460–480 m

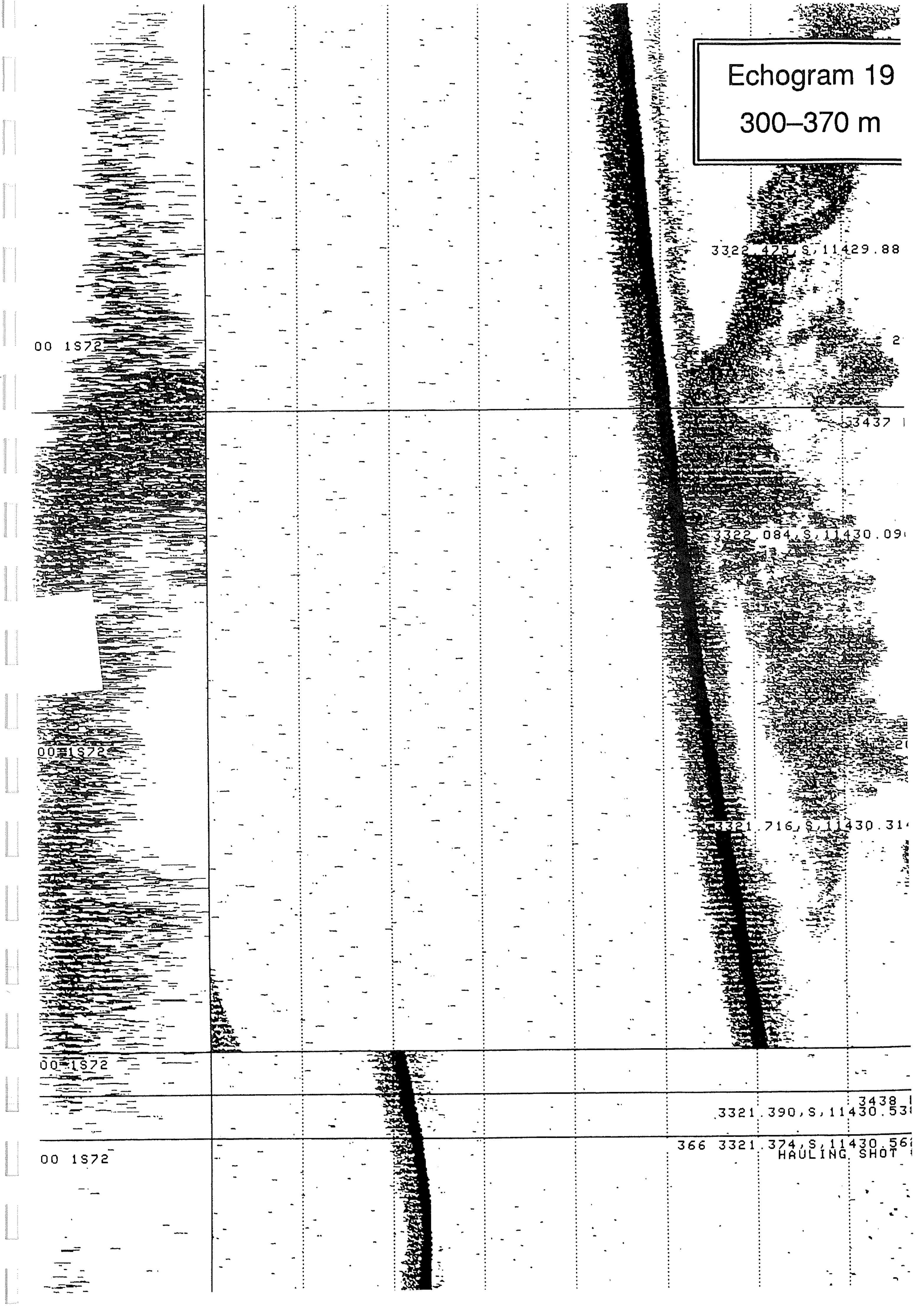

Echogram 15
580–1300 m
500 1S74
3154 521,S,11504
2661
3155 361,S,11504
500 1S74
2662
3156 242,S,11503
2663
3157 065,S,11503
500 1S74
2664
3157 872,S,11502
500 1S74
3158 505,S,11502


Echogram 16
780–1100 m
200-1S72
3203.714,S,11452.2
200-1S72
3204.051,S,11452.06
2913
1000m
Shot no. 79
3204.393,S,11451.90
200-1S72
3204.703,S,11451.73
3204.993,S,11451.572
200-1S72

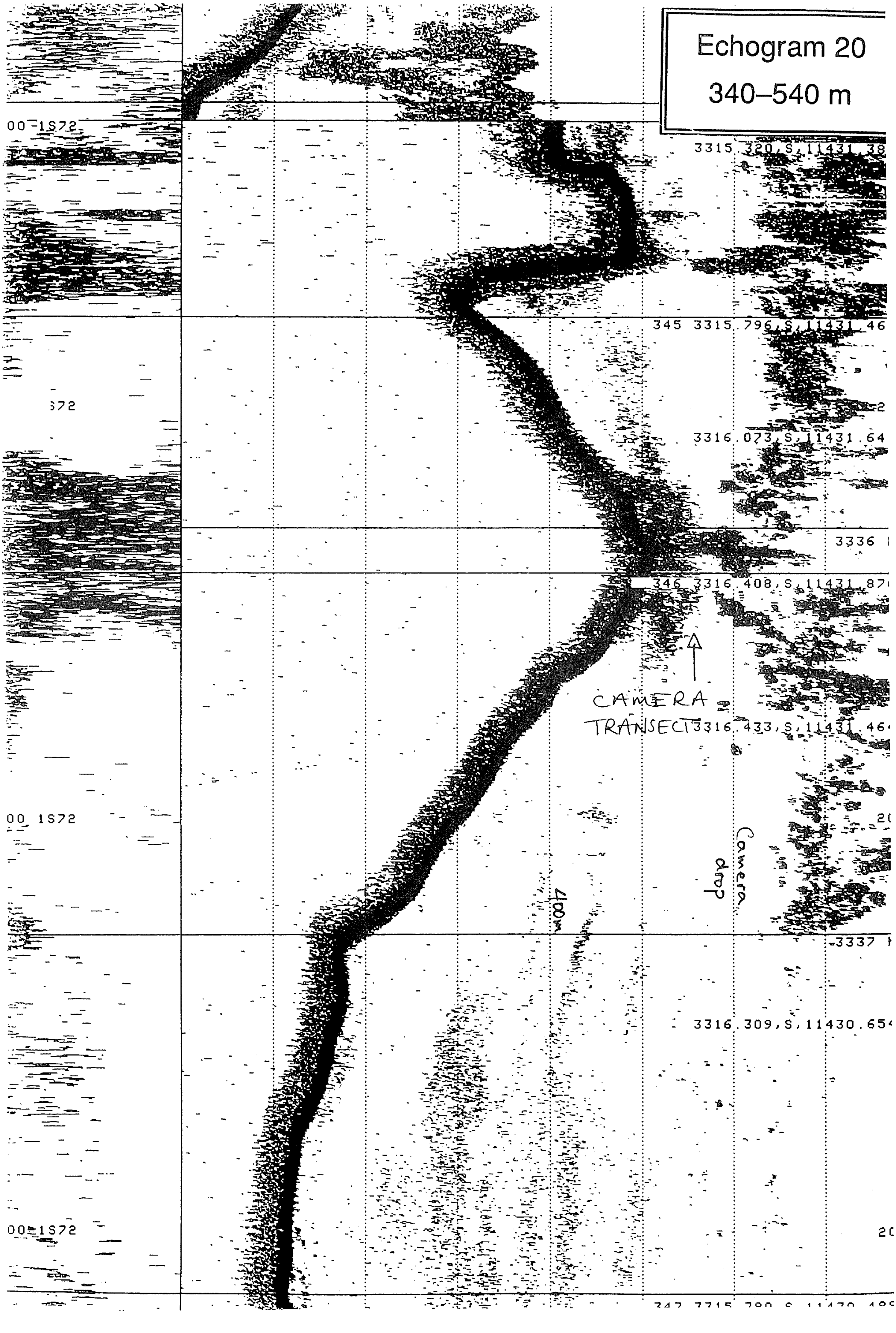


Echogram 17
620–1000 m
200 1S72
3202.455,S,11501.48
3202.366,S,11501.44
265 3202.265,S,11501.46
200 1S72
CAMERA
TRANSECT
265 3202.240,S,11501.49
3202.238,S,11501.54
2800
3202.302,S,11502.496
000 1S72
000 1S72
2801
3202.338,S,11503.596

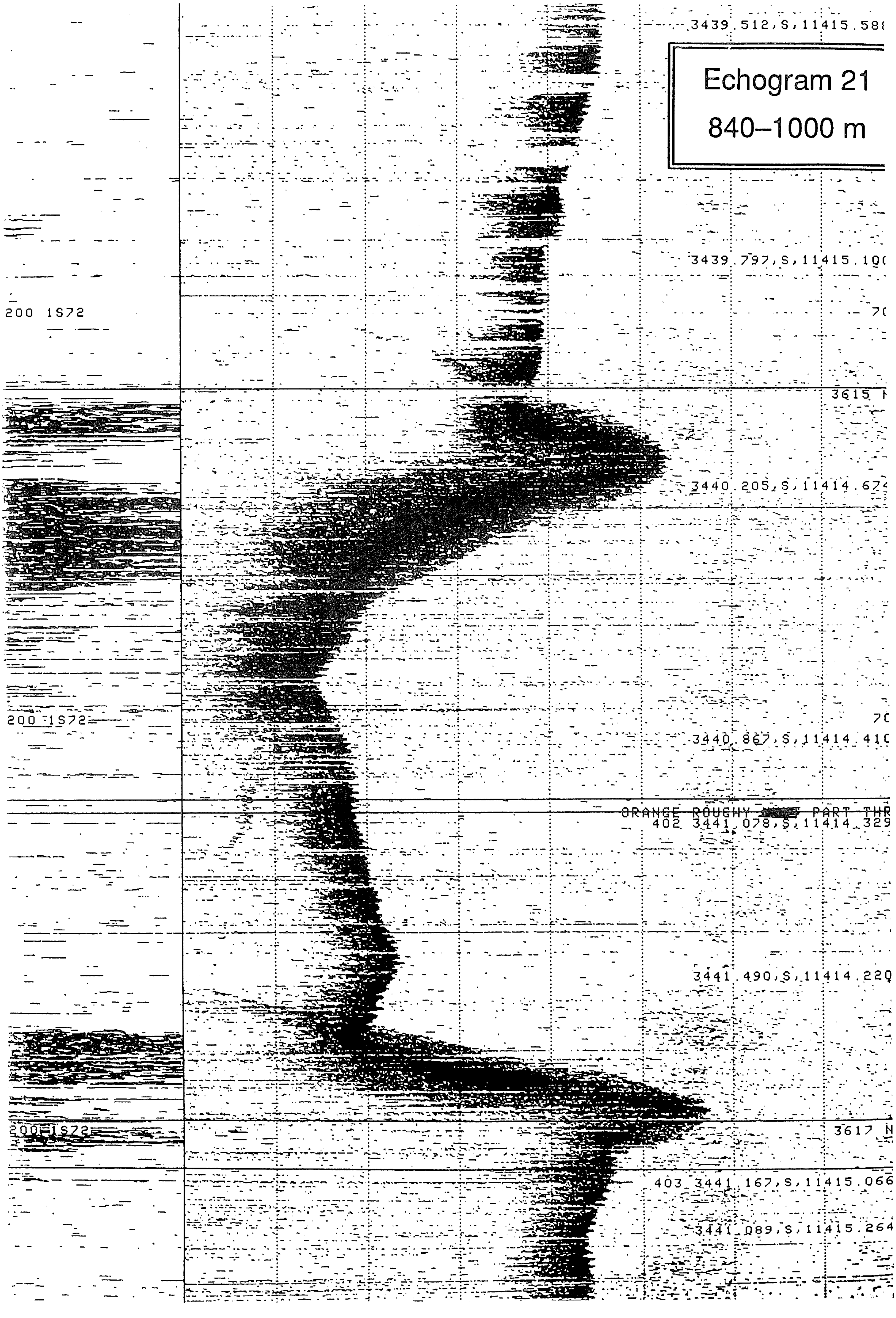

Echogram 18
270–370 m
STATION 77
3203.768,S,11509.98
276 3203.538,S,11510.11
3203.390,S,11510.19
2852
3203.207,S,11510.25
3202.720,S,11510.42
277 3202.621,S,11510.39
400
300
200
00 1S72



Echogram 19
300–370 m
3322.475,S,11429.88
00 1S72
3437
3322.084,S,11430.09
00 1S72
3321.716,S,11430.31
00 1S72
3438
3321.390,S,11430.53
366 3321.374,S,11430.56
HAULING SHOT
00 1S72

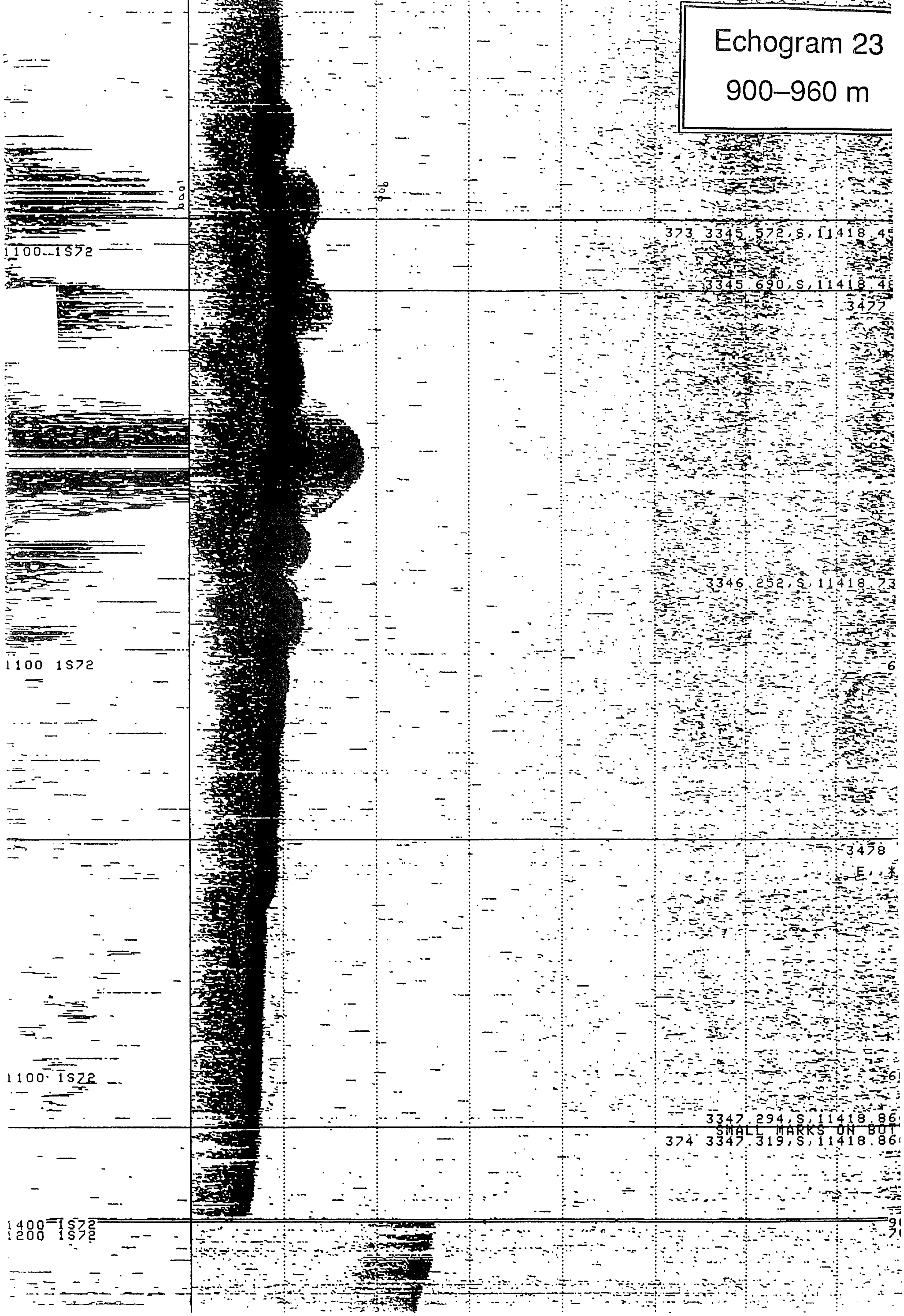


Echogram 20
340–540 m
00 1S72
3315.320,S,11431.38
345 3315.796,S,11431.46
3316.073,S,11431.64
3336
346 3316.408,S,11431.87
CAMERA
TRANSECT
3316.433,S,11431.46
00 1S72
Camera
drop
400m
3337
3316.309,S,11430.65
00 1S72



Echogram 21
840–1000 m


Echogram 22
800–1040 m
3450.402,S,11422.72
200-1S72
3450.100,S,11423.31
3636
410 3450.003,S,11423.48
3450.372,S,11423.83
3637
200-1S72
3451.192,S,11424.25
3638
3452.042,S,11424.71
200-1S72



Echogram 23
900–960 m

Appendix VI — Fish collections from the Western Deep Water Trawl Fishery

A provisional list of species, known distribution range, and registration numbers and photographic slide numbers of fish or slides in the CSIRO fish collection

Fam no.	Species	Depth (m) (min.–max.)	Latitude (°S.) (min.–max.)	Longitude (°E.) (min.–max.)	Regn nos	Photo. slide nos
5	*Heptranchias perlo*	318–484	24°53'–32°10'	112°08'–115°03'	H2013–02	248–251
13	*Parasycllium* sp. WA (rusty)	245–245	32°08'–32°08'	115°08'–115°08'	H2360–01	834–838
15	*Apristurus longicephalus*	685–685	21°51'–21°51'	113°47'–113°47'	H2549–08	1609
	Apristurus platyrhinchus	328*–1060	21°38'–34°57'	113°56'–114°29'		
	Apristurus sp. A4	942–942	29°22'–29°22'	113°47'–113°47'		
	Apristurus sp. (long snout)	684–942	26°15'–30°17'	112°03'–114°30'		
	Apristurus sp. F (fat head)	1030–1050	32°35'–33°50'	114°17'–114°27'	H2615–01	1298
	Apristurus sp. D	1240–1240	34°13'–34°13'	114°07'–114°08'		
	Asymbolus sp. F (= sp. 3)	225–400	32°10'–33°23'	114°30'–115°08'	H2613–01	1318
	Cephaloscyllium fasciatum	320–320	29°16'–29°16'	113°57'–113°57'	H2560–07	1523
	Galeus boardmani	213–510	24°53'–33°23'	111°54'–112°08'	H2013–03	252–259
17	*Iago sp. nov.* (sp. WA)	467–467	24°51'–24°51'	112°07'–112°07'	H2033–01	866
	Galeorhinus galeus	213–213	31°34'–31°34'	114°59'–114°59'		
	Galeus gracillus (sp. nov.)	467–467	24°51'–24°51'	112°07'–112°07'		
	Mustelus antarcticus	225–225	32°10'–32°10'	115°08'–115°08'		
	Mustelus sp. nov. (= sp. 2)	297–346	23°25'–27°23'	112°52'–113°04'	H2356–02	
20	*Centrophorus granulosus*	868–868	20°08'–20°08'	112°55'–112°55'	H2543–05	1646
	Centrophorus harrissoni	203–854	27°07'–34°59'	112°23'–114°44'	H2606–01	1308
	Centrophorus moluccensis	320–510	31°53'–32°10'	115°03'–115°06'	H2607–03	1309
	Centrophorus squamosus	882–882	26°05'–26°05'	111°47'–111°47'	H2572–01	1352
	Centrophorus uyato	200–738	24°51'–34°59'	112°07'–114°44'	H2574–05	1563
	Centroscyllium kamoharai	942–1254	23°60'–33°18'	111°54'–114°31'	H2560–02	1476
	Centroscymnus crepidater	870–880	32°40'–35°05'	114°28'–114°60'	H1815–02	1088
	Centroscymnus owstoni	868–1254	20°08'–35°05'	112°55'–114°60'	H2570–10	1648
	Dalatias licha	373–508	26°36'–32°55'	112°29'–114°39'		1124
	Deania calcea	738–900	30°52'–35°05'	114°37'–114°60'	H4686	1125
	Deania quadrispinosa	738–854	28°04'–34°59'	112°43'–114°44'	H2357–04	813–815
	Etmopterus brachyurus	475–612	25°19'–31°17'	111°56'–114°53'	H2604–01	1554
	Etmopterus lucifer	738–817	33°26'–34°59'	114°21'–114°44'		847–848
	Etmopterus pusillus	320*–882	26°05'–33°26'	111°47'–114°21'	H2608–01	1313
	Etmopterus unicolor	870–880	32°40'–35°05'	114°28'–114°60'		804–807
	Etmopterus sp. A (false *pusillus*)		no record			
	Euprotomicrus bispinatus	913–913	20°16'–20°16'	113°13'–113°13'	H2541–01	1633
	Squalus megalops	203–510	24°53'–33°24'	112°08'–114°31'	H2566–01	793–796
	Squalus megalops (fat spine)	209–478	21°39'–27°23'	112°52'–113°58'	H2567–10	
	(*Squalus megalops* (NW))**	300–300	23°25'–23°25'	113°04'–113°04'	H2566–01	1496
	(*Squalus megalops* (high fin))**	203–510	30°00'–33°24'	114°27'–114°31'		
	(*Squalus megalops* (bar tail))**	444–444	24°53'–24°53'	112°08'–112°08'	H2565–02	
	Squalus mitsukurii	220–670	24°51'–33°19'	112°07'–114°32'	H2564–01	1522
	Squalus mitsukurii (long snout)	312–508	25°08'–31°55'	112°09'–115°10'	H2574–04	1358
	(*Squalus mitsukurii* (NW))**	297–300	23°25'–23°25'	113°04'–113°04'	H2608–15	
	(*Squalus mitsukurii* (Perth))**	380–480	30°00'–31°45'	114°28'–114°60'		
	Zameus squamulosus	854–1254	20°08'–32°35'	112°55'–114°27'	H2560–03	1336
23	*Pristiophorus cirratus*	203–400	30°00'–33°24'	114°28'–114°31'	H2598–03	1524
24	*Squatina tergocellata*	203–400	29°16'–33°24'	113°57'–114°31'	H2590–02	1560
	Squatina sp. nov.	312–312	25°08'–25°08'	112°09'–112°09'	H2567–01	1470
28	*Narcine sp. nov.*	209–346	21°39'–32°05'	113°58'–115°09'	H3054–03	

Fam no.	Species	Depth (m) (min.–max.)	Latitude (°S.) (min.–max.)	Longitude (°E.) (min.–max.)	Regn nos	Photo. slide nos
	Torpedo macneilli	490–490	29°21'–29°21'	113°58'–113°58'	H1820–03	1099
31	*Pavoraja alleni*	200–475	24°51'–31°55'	112°07'–115°10'	H1818–01	1093–1094
	Pavoraja sp. 2 (NW blue)	520–1460	21°54'–31°16'	113°41'–114°50'	H2550–03	1350
	Pavoraja sp. 3 (pale)	508–690	26°15'–26°36'	112°03'–112°29'	H1816–02	1091–1092
	Raja gudgeri	468–490	29°21'–33°18'	113°58'–114°31'		
	Raja sp. E. (ocellated)	203–362	32°10'–33°24'	114°31'–115°08'	H2619–01	1287
	Raja sp. 12 (thin tail)	203–490	27°09'–33°24'	112°45'–114°31'	H1821–02	1102–1103
	Raja sp. 20	444–444	24°53'–24°53'	112°08'–112°08'	H1824–01	1105–1106
	Raja cf. *leylandi*	200–510	26°43'–32°02'	112°41'–115°09'	H2272–01	1116–1117
	Raja sp.	1254–1254	25°52'–25°52'	111°27'–111°27'	H2611–02	1316
33	*Anacanthobatis* sp. WA	482–1115	22°60'–25°41'	113°14'–111°31'	H1514–23	741–742
	Anacanthobatis sp. W2 (*sp. nov.*)	1115–1158	21°54'–25°41'	111°31'–113°41'	H2567–02	1466
38	*Urolophus expansus*	203–400	31°55'–33°24'	114°31'–115°10'	H2619–03	1284
	Urolophus flavomosaicus	200–306	26°43'–27°23'	112°41'–112°52'		
	Urolophus cf. *viridis* (WA)	200–380	26°43'–30°00'	112°41'–114°28'	H2590–04	1561
	Plesiobatis davesi	508–508	26°36'–26°36'	112°29'–112°29'		
39	*Myliobatis* cf. *hamlyni*	346–346	26°45'–26°45'	112°37'–112°37'	H2578–01	1570
41	*Hexatrygon* sp.	868–1115	20°08'–25°41'	111°31'–112°55'	H2543–07	1513
42	*Chimaera* sp. (black long spine)	685–1293	21°51'–24°10'	111°39'–113°47'	H2549–07	1368
	Chimaera sp. A	670–854	28°04'–32°02'	112°43'–114°54'		
	(*Chimaera* cf. sp. A (blue))**	738–982	29°22'–35°05'	113°47'–114°60'		
	Chimaera sp. E	438–520	27°09'–28°17'	112°45'–113°18'	H2585–01	1575
	Hydrolagus NW *lemures*	286–510	23°25'–33°23'	113°04'–114°30'		790–792
44	*Harriotta raleighana*	1030–1030	34°10'–34°10'	114°16'–114°16'–*		778–782
	Rhinochimaera pacifica	760–1293	22°29'–34°10'	113°12'–114°16'	H2552–02	1475
60	*Gymnothorax woodwardi*	244–244	32°06'–32°06'	115°10'–115°10'		
65	*Nettastoma melanura*	612–612	23°45'–23°45'	112°35'–112°35'	H2557–02	
	Nettastomatidae *gen. sp. nov.*	312–312	25°08'–25°08'	112°09'–112°09'	H2567–02	1467
	Venifica cf. *multiporosa*	1254–1254	25°52'–25°52'	111°27'–111°27'	H2570–03	1647
67	*Bassanago bulbiceps*	870–870	35°02'–35°02'	114°60'–114°60'		
	Bassango sp. W1	690–690	26°15'–26°15'	112°03'–112°03'	I31170–007	1366
	Bathyuroconger vicinus	1139–1139	20°55'–20°55'	112°51'–112°51'	H2544–19	1610
	Bathyuroconger sp.	854–854	28°04'–28°04'	112°43'–112°43'	H2584–05	
	Blachea xenobranchialis	300–312	23°25'–25°08'	112°09'–113°04'	H2567–03	1494
	Coloconger cf. *raniceps*	760–892	24°30'–26°36'	111°51'–112°36'	H3041–10	958–960
70	*Diastobranchus capensis*	825–1280	25°52'–35°05'	111°27'–114°60'	H3010–01	1018–1020
	Synaphobranchus affinis	854–1061	23°60'–32°40'	111°54'–114°28'	I31157–003	
	Synaphobranchus brevidorsalis	880–1460	20°55'–34°57'	112°51'–114°29'	H2544–20	1608
	Synaphobranchus kaupi	1030–1030	32°35'–32°35'	114°27'–114°27'	H2616–05	
75	*Serrivomer* sp. W1	913–1460	20°16'–28°00'	112°41'–113°13'	H2541–12	
76	Nemichthyidae gen. sp. W1	475–893	30°52'–31°17'	114°37'–114°53'	H2602–03	1322
79	*Eurypharynx pelecanoides*	1139–1139	20°55'–20°55'	112°51'–112°51'		
81	*Aldrovandia affinis*	868–1460	20°08'–32°40'	112°55'–114°28'	H2544–04	1587
	Aldrovandia phalacra	1022–1460	20°55'–32°35'	112°51'–114°27'	H2544–11	1500
	Aldrovandia rostrata	854–1460	22°01'–28°04'	112°43'–113°08'	H3040–08	1000–1002
81	**Halosauropsis macrochir*	842–842	35°25'–35°25'	117°21'–117°21'	H3008–03	946–948
	Halosaurus ovenii	690–690	26°15'–26°15'	112°03'–112°03'	H2573–20	1365
	Halosaurus sp.	913–913	20°16'–20°16'	113°13'–113°13'		
83	*Notacanthus sexspinnus*	870–982	33°18'–35°05'	114°13'–114°60'		
97	*Argentina* sp. W1	255–438	25°08'–32°14'	112°09'–115°06'	H2597–01	1547
	Nansenia cf. *ardesciaca*	556–1009	23°45'–35°05'	112°35'–114°60'	H2572–03	1354
98	*Melanolagus bericoides*	893–1254	25°52'–30°52'	111°27'–114°37'	H2570–12	1634
	Bathylagus sp.	1132–1132	29°35'–29°35'	113°45'–113°45'	H2595–01	
99	*Opistoproctus soleatus*	1460–1460	22°01'–22°01'	113°08'–113°08'		
106	*Diplophos taenia*	893–893	30°52'–30°52'	114°37'–114°37'	H2602–01	1321

Fam no.	Species	Depth (m) (min.–max.)	Latitude (°S.) (min.–max.)	Longitude (°E.) (min.–max.)	Regn nos	Photo. slide nos
	Gonostoma elongatum	1060–1060	24°00'–24°00'	111°54'–111°54'	H2559–09	
	Gonostoma sp.	1258–1460	22°01'–22°29'	113°08'–113°12'	H2551–11	1510
	Photichthys argenteus	482–1460	22°01'–35°05'	113°08'–114°60'		
	Polymetme corythaeola	411–1115	22°60'–32°52'	112°13'–114°35'	H3035–01	1059–1061
107	*Argyripnus iridescens*	312–510	25°08'–32°10'	112°09'–115°03'	H2604–03	1552
	Argyropelecus aculeatus	1061–1115	23°60'–25°41'	111°31'–111°54'	H2560–05	
	Argyropelecus gigas	714–1158	21°54'–34°15'	113°41'–114°20'	H3016–03	931–933
	Argyropelecus sladeni	880–880	22°47'–22°47'	113°13'–113°13'	H2553–10	
	Argyropelecus sp. (blacktail)				H2541–02	1589
	Argyropelecus sp.	1139–1139	20°55'–20°55'	112°51'–112°51'		
	Polyipnus spinifer	450–450	28°11'–28°11'	113°15'–113°15'	H2127–01	111–114
	Polyipnus tridentifer	480–690	23°45'–31°16'	112°35'–114°50'	H2573–07	1501
	Polyipnus triphanos	274–320	21°44'–21°45'	113°52'–113°52'	I31148–001	
	Polyipnus cf. *tridentifer*	482–482	22°60'–22°60'	113°14'–113°14'	H2573–07	
	Polyipnus sp.	328–1258	21°38'–22°29'	113°12'–113°56'	H2552–03	
	Sternoptyx diaphana	868–868	20°08'–20°08'	112°55'–112°55'	H2542–28	
	Sternoptyx obscura	913–1280	20°16'–32°20'	113°13'–114°29'	H2541–03	1505
	Sternoptyx pseudodiaphana	1030–1030	32°35'–32°35'	114°27'–114°27'		
	Sternoptyx sp.	320–320	21°45'–21°45'	113°52'–113°52'		
108	*Astronesthes* cf. *similis*	714–714	27°07'–27°07'	112°23'–112°23'	I31176–003	
	Astronesthes sp. W1 (*indicus* gp.)	482–482	22°60'–22°60'	113°14'–113°14'	I31154–009	
	Astronesthes sp. nov. (*Chrysophekidion* gp)	482–482	22°60'–22°60'	113°14'–113°14'	I31154–006	
	Borostomias eluscens	1460–1460	22°01'–22°01'	113°08'–113°08'	H2551–04	1591
	Heterophotus ophistoma	868–1022	20°08'–21°28'	112°55'–113°39'	H2542–19	1595
109	*Bathophilus* sp.		no data		I31178–002	1537
	Echiostoma barbatum	1254–1254	25°52'–25°52'	111°27'–111°27'	H2570–02	1478
	Eustomias sp.	913–913	20°16'–20°16'	113°13'–113°13'	I31142–006	
	Leptostomias sp.	854–1254	24°31'–28°04'	111°50'–112°43'	I31161–001	1594
	Melanostomias sp.	685–1460	21°51'–22°01'	113°08'–113°47'	H2549–01	1512
	Photonectes cf. *braueri*	900–900	34°57'–34°57'	114°29'–114°29'	H2624–02	1278
	**Photonectes* sp.W1 cf. *albipennis*	760–760	26°36'–26°36'	112°09'–112°09'	H3041–04	961–963
110	*Malacosteus niger*	895–895	24°31'–24°31'	111°50'–111°50'		
	Photostomias guernei	913–913	20°16'–20°16'	113°13'–113°13'	I31142–005	
111	*Chauliodus sloani*	482–1258	20°16'–34°13'	113°13'–114°08'	H2579–01	1464
112	*Stomias affinis*	1061–1061	23°60'–23°60'	111°54'–111°54'	I31158–006	1367
113	*Idiacanthus fasciola*	1061–1061	23°60'–23°60'	111°54'–111°54'	I31158–004	
114	*Alepocephalus* cf. *longiceps*	1022–1132	21°28'–29°35'	113°39'–113°45'	H2541–11	
	Alepocephalus sp. W1 (round scale)	880–960	22°47'–28°30'	112°55'–113°13'	H3061–01	260–263
	Alepocephalus sp. W2 (large scale)	982–1030	33°18'–34°10'	114°13'–114°16'	H3017–02	1691–1692
	Alepocephalus sp. W3 (white scale pocket)	1030–1280	20°55'–32°35'	112°51'–114°27'	H2544–18	1597
	Alepocephalus sp. W4 (scallop scale)	945–1258	20°55'–29°35'	112°51'–113°45'		
	Bajacalifornia cf. *megalops*	1280–1460	20°01'–32°20'	113°08'–114°29'	H2614–02	1303
	Bajacalifornia sp. W1	1022–1061	21°28'–24°00'	111°54'–113°39'		
	Bajacalifornia sp. W4 (small head)	880–880	22°47'–22°47'	113°13'–113°13'	H2553–02	1335
	Bajacalifornia sp. W5 (tan)	913–1139	20°16'–20°55'	112°51'–113°13'	H2544–03	1649
	Ericara sp. W1	1258–1258	22°29'–22°29'	113°12'–113°12'	H2552–07	1334
	Leptoderma sp. W1**	1280–1280	32°20'–32°20'		H2614–01	1297
	Leptoderma sp.**	913–913	20°16'–20°16'	113°13'	H2541–20	
	Leptoderma sp.**	1258–1258	22°29'–22°29'		H2552–01	
	Leptoderma sp.**	1139–1139	20°55'–20°55'		H2544–05	

Fam no.	Species	Depth (m) (min.–max.)	Latitude (°S.) (min.–max.)	Longitude (°E.) (min.–max.)	Regn nos	Photo. slide nos
	Narcetes sp. W1 cf. *lloydii*	913–1258	20°16'–32°35'	113°13'–114°27'	H2552–05	1330
	Rouleina cf. *attrita*	1139–1254	20°55'–25°52'	111°27'–112°51'	H2570–05	1514
	Rouleina sp. W3 prob. *sqamilatera*	685–1061	20°08'–30°52'	112°55'–114°37'	H2542–11	1636
	Rouleina sp. W4	1258–1258	22°29'–22°29'	113°12'–113°12'	H2552–06	1333
	Talismania cf. *antillarum*	685–1009	20°08'–28°00'	112°41'–112°55'	H2543–04	1644
	Talismania cf. *filamentosa*	913–913	20°16'–20°16'	113°13'–113°13'	H3008–04	949–951
	Talismania cf. *mekistonema*	1115–1254	25°41'–25°52'	111°27'–111°31'	H2569–08	1509
	Xenodermichthys copei	320–1030	21°51'–34°57'	114°29'–113°47'	H2549–02	1614
114A	*Leptochilichthys* cf. *pinguis*	1139–1158	20°55'–21°54'	112°51'–113°41'	H2544–23	1641
117	*Aulopus purpurissatus*	210–210	33°45'–33°45'	114°28'–114°28'	H2054–01	061–063
118	*Saurida longimanus*	297–297	23°25'–23°25'	113°04'–113°04'		
	Saurida micropectoralis	200–320	21°39'–26°43'	112°41'–113°58'	H2547–18	
	Saurida sp. W1	209–209	21°39'–21°39'	113°58'–113°58'		
	Saurida undosquamis	244–244	32°06'–32°06'	115°10'–115°10'		
118A	*Bathysaurus ferox*	982–1104	27°33'–35°07'	112°15'–115°01'	H3006–01	919–921
120	*Chlorophthalmus nigripinnis*	220–727	28°48'–35°02'	113°37'–115°02'	H2590–01	1559
	Chlorophthalmus sp. W1 (cf. sp·1 of Masuda)	328–510	21°38'–27°17'	112°45'–113°56'	H2100–01	327–330
	Chlorophthalmus sp. W2 (cf. *nigromarginatus*)	320–467	21°38'–24°51'	112°07'–113°58'	H2103–01	391–394
	Chlorophthalmus sp. W3 (triple spot)	200–346	21°39'–26°45'	112°37'–113°58'	H2566–02	1495
	Chlorophthalmus sp. W6 (large eye)	200–670	26°36'–32°10'	112°29'–115°03'	H2574–02	1361
121	*Neoscopelus macrolepidotus*	435–1022	20°08'–35°05'	112°55'–114°60'	H2563–01	1521
	Neoscopelus sp. nov.	612–690	21°51'–30°17'	113°47'–114°30'	H3089–01	1679–1681
122	*Benthosema fibulatum*	274–685	21°44'–25°08'	112°09'–113°52'	I31149–002	
	Bolinichthys nikolayi?	685–685	21°51'–21°51'	113°47'–113°47'	I31149–001	
	Diaphus chrysorhynchus	320–320	21°45'–21°45'	113°52'–113°52'		
	Diaphus holti	913–913	20°16'–20°16'	113°13'–113°13'	I31141–003	
	Diaphus knappi	1139–1139	20°55'–20°55'	112°51'–112°51'	H2544–10	
	Diaphus parri	1022–1460	20°55'–22°01'	112°51'–113°08'	H2544–09	
	Diaphus watesei	274–880	21°38'–33°18'	113°56'–114°31'	H2546–05	383–386
	Diaphus sp.	346–1460	20°08'–33°26'	112°55'–114°21'		
	Diaphus spp.	320–770	21°45'–29°52'	113°52'–114°12'		
	Electrona risso	1254–1254	25°52'–25°52'	111°27'–111°27'	I31168–004	
	Lampadena luminosa	868–868	20°08'–20°08'	112°55'–112°55'	H3085–01	1378
	Lampadena sp.	880–1280	25°52'–32°40'	111°27'–114°28'	H2602–04	1516
	Lampanyctus nobilis	868–1139	20°08'–22°47'	112°55'–113°13'	H2542–18	
	Lampanyctus sp.	482–1293	20°08'–32°20'	112°55'–114°29'		
	Myctophum asperum	1158–1158	21°54'–21°54'	113°41'–113°41'	I31150–004	
	Myctophum bracygnathum	685–685	21°51'–21°51'	113°47'–113°47'	I31149–003	
	Myctophum nitidulum	1139–1139	20°55'–20°55'	112°51'–112°51'		
	Notoscopelus caudispinosus	868–868	20°08'–20°08'	112°55'–112°55'	H2542–12	1630
	Scopelosis multipunctatus	913–913	20°16'–20°16'	113°13'–113°13'		
	Symbolophorus evermanni	1139–1139	20°55'–20°55'	112°51'–112°51'	H2626–01	1279
123	*Bathypterois guentheri*	868–1460	20°08'–24°30'	111°51'–112°55'	H2542–13	1472
	Bathypterois ventralis	690–1460	20°16'–27°33'	112°15'–113°13'	H2544–13	
	Bathypterois sp. W3 cf. *grallator*	1460–1460	22°01'–22°01'	113°08'–113°08'	I31151–002	1473
125	*Scopelosaurus smithi*?	913–913	20°16'–20°16'	113°13'–113°13'	I31141–010	
126	*Lestidium atlanticum*	666–666	26°57'–26°57'	112°22'–112°22'	I31175–002	1592
	Lestrolepis cf. *japonica*	945–945	28°00'–28°00'	112°41'–112°41'	H2583–02	1538
	Lestrolepis sp.	868–868	20°08'–20°08'	112°55'–112°55'	H2543–11	1638
127	*Omosudis lowei*	1158–1158	21°54'–21°54'	113°41'–113°41'	H2550–02	1323
128	*Alepisaurus brevirostris*	1139–1280	20°55'–32°20'	112°51'–114°29'	I31143–005	1601

Fam no.	Species	Depth (m) (min.–max.)	Latitude (°S.) (min.–max.)	Longitude (°E.) (min.–max.)	Regn nos	Photo. slide nos
128	*Alepisaurus ferox*					172–175
130	*Coccorella* sp. W1	945–945	28°00'–28°00'	112°41'–112°41'	I31178–005	1580
131	*Scopelarchus* cf. *analis*	1061–1061	23°60'–23°60'	111°54'–111°54'	I31158–008	
133	*Rondeletia loricata*	1139–1139	20°55'–20°55'	112°51'–112°51'	I31143–002	
134	*Barbourisia rufa*	1139–1460	20°55'–24°10'	111°39'–112°51'	H2551–02	1463
136	*Ateleopus sp.* W1 cf. *japonicus*	457–684	26°40'–30°17'	112°33'–114°30'	H2019–01	331–334
208	*Lophioides* sp. W3	300–300	23°52'–23°25'	113°04'–113°04'		
	Lophiomus setigerus	250–612	21°45'–32°14'	113°52'–115°06'		
	Sladenia sp. W1**	1139–1139	20°55'–20°55'	112°51'	H2544–02	1499
	Sladenia sp.**	1158–1158	21°54'–21°54'			
211	*Bathychaunax* cf. *melanostoma*	893–1460	20°55'–30°52'	112°51'–114°37'	H2551–03	1326
	Chaunax cf. *fimbriatus*	320–1060	21°38'–33°23'	113°56'–114°30'	H2565–13	1482–1484
	Chaunax sp. W3 (yellow spotted)	380–510	30°00'–32°02'	114°28'–115°09'	H2611–01	1304
	Chaunax sp. W3A (*pictus* group)	444–444	24°53'–24°53'	112°08'–112°08'	H2565–14	1489–1491
212	*Coelophrys* sp. W1	1009–1139	20°55'–27°22'	112°11'–112°51'	H2544–07	1503
	Dibranchus sp. W1	297–297	23°25'–23°25'	113°04'–113°04'	H2110–01	1204
	Halieutea sp. W3 cf. *stellata*	435–1115	24°53'–27°17'	112°45'–113°13'	H3040–10	1190–1193
	Halieutopsis sp. W1	942–942	29°22'–29°22'	113°47'–113°47'	H2592–05	
	Halieutopsis cf. *micropa*				H2593–01	1536
213	*Melanocetus* cf. *murrayi*	1293–1293	24°10'–24°10'	111°39'–111°39'		
214	*Diceratias bispinosus*	1009–1022	21°28'–27°22'	112°11'–113°39'	I31144–004	1504
216	Oneirodidae gen. sp. W1	1061–1061	23°60'–23°60'	111°54'–111°54'	I31158–003	1511
	Oneirodidae gen. sp. W2	1050–1050	33°50'–33°50'	114°17'–114°17'	H2622–02	1275
224	*Antimora rostrata*	825–1460	22°01'–34°57'	113°08'–114°29'	I31159–003	
	Halagyreus johnstoni					
	Laemonaema sp. W1	982–982	33°18'–33°18'	114°13'–114°13'	H2617–01	1290
	Lepidion microcephalus	843–843	35°26'–35°26'	117°25'–117°25'	H3007–06	907–909
	Mora moro	673–989	33°26'–35°05'	114°21'–115°00'	H484	749
	Physiculus sp. A	320–320	21°45'–21°45'	113°52'–113°52'	H2548–06	1606
	Physiculus sp. B	320–320	21°45'–21°45'	113°52'–113°52'	H2548–07	1617
	Physiculus sp. W4	320–508	26°36'–31°55'	115°10'–112°29'	H2574–08	1356
	Tripterophycis gilchristi	571–770	26°15'–35°02'	112°03'–115°02'	H2596–02	1526
225	*Bregmaceros* sp. W1	413–413	29°50'–29°50'	114°21'–114°21'	*	*
224A	*Euclichthys polynemus*	306–571	24°51'–33°18'	112°07'–114°31'	H2107–01	1206
	Melanonus zugmayeri	880–913	20°16'–20°16'	113°13'–113°13'		
227	*Macrouronus novaezelandiae*	596–825	33°06'–34°15'	114°20'–114°30'	H3025–07	1196–1198
228	*Bassozetus* sp. W1	1460–1460	22°01'–22°01'	113°08'–113°08'	H2551–01	1325
	Barathrodesmus sp. W1	714–892	24°30'–27°07'	111°51'–112°23'	H2562–02	1337
	Dannevigia tusca	203–390	28°53'–33°24'	113°41'–114°31'	H3052–01	985–987
	Dicrolene sp. W1 (pale)	435–945	25°59'–30°52'	112°38'–114°37'	H2583–11	1558
	Dicrolene sp. W2 (dark)	1158–1158	21°54'–21°54'	113°41'–113°41'	H2550–06	1351
	Diplacanthapoma sp. W1	868–868	20°08'–20°08'	112°55'–112°55'	H2542–22	1632
	Genypterus blacodes	596–989	33°06'–35°05'	114°30'–114°53'		1694
	Glyptophidium sp. W1	437–478	26°40'–27°49'	112°33'–113°01'	H3036–02	1068–1070
	Hoplobrotula armata	320–438	21°45'–27°09'	112°45'–113°52'	H2578–04	1527
	Monomitopus sp. W1	868–1258	20°08'–32°35'	112°55'–114°27'	H2543–03	1645
	Monomitopus sp. W2	1254–1254	25°52'–25°52'	111°27'–111°27'	H2570–11	
	Penopus cf. *microphthalmus*	1104–1104	27°33'–27°33'	112°15'–112°15'	H2582–01	1582
	Xyelacyba sp. W1	1158–1158	21°54'–21°54'	113°41'–113°41'	H2550–07	1324
229	*?Onuxodon* sp.	346–346	26°45'–26°45'	112°37'–112°37'	I31174–008	
	Pyramodon sp. W1	346–510	26°40'–33°18'	112°33'–114°31'	H2575–01	1564
	Carapidae gen. sp. W1	913–913	20°16'–20°16'	113°13'–113°13'	H2541–08	
232	*Bathygadus cottoides*	913–1280	20°16'–34°10'	113°13'–114°16'	H2571–02	1517
	Bathygadus sp. W2	1030–1030	34°10'–34°10'	114°16'–114°16'	H3017–08	1169–1171
	Bathygadus sp. W3	868–868	20°08'–20°08'	112°55'–112°55'	H2542–01	1631

Fam no.	Species	Depth (m) (min.–max.)	Latitude (°S.) (min.–max.)	Longitude (°E.) (min.–max.)	Regn nos	Photo. slide nos
	Cetonurus cf. *globiceps*	740–1460	22°01'–34°13'	113°08'–114°08'	H2551–15	1346
	Coelorinchus argentatus	320–320	21°45'–21°45'	113°13'–113°52'	H2305–02	279–280
	Coelorinchus matamua	870–870	35°05'–35°05'	114°60'–114°60'	H3008–09	1151–1153
	Coelorinchus sp. W1	478–1104	22°60'–30°17'	113°14'–114°30'	H2024–01	441–444
	Coelorinchus sp. W3	482–612	22°60'–23°45'	112°35'–113°14'	H1514–19	760
	Coelorinchus sp. W10	685–685	21°51'–21°51'	113°47'–113°47'	H2549–04	1518
	Coelorinchus sp. W13 (*mirus*)	306–510	24°53'–32°54'	112°08'–114°39'	H3028–03	1139–1141
	Coelorinchus sp. W14 (sp. D) cf. *fasciatus*	320–714	26°15'–35°02'	112°03'–115°02'	H2604–10	1312
	Coelorinchus sp. W15 (*innotabilis*)	770–1030	29°52'–35°05'	114°12'–114°60'	H3007–10	1130–1132
	Coelorinchus sp. W16	510–1132	27°17'–35°05'	112°45'–114°60'	H3008–08	1133–1135
	Coelorinchus sp. W22 (sharp scale)	685–1022	21°28'–24°31'	111°50'–111°39'	H2553–03	1331
	Coelorinchus sp. W25	1030–1030	32°35'–32°35'	114°27'–114°27'	H2615–02	1286
	Coelorinchus sp. C	390–475	31°17'–33°18'	114°31'–114°53'	H2604–02	1553
	Coryphaenoides serrulatus (W1)	740–982	32°40'–35°05'	114°28'–114°60'	H2616–02	1288
	Coryphaenoides cf. *rudis*	982–982	33°18'–33°18'	114°13'–114°13'	H2617–02	1292
	Coryphaenoides sp. W2 (muzzle)	945–1030	32°35'–35°07'	114°27'–115°01'	H3010–09	1160–1162
	Coryphaenoides sp. W3 (b&s)	982–1030	33°18'–34°10'	114°13'–114°16'	H3017–06	1166–1168
	Coryphaenoides sp. W4	1254–1460	22°01'–25°52'	111°27'–113°08'	H2561–03	1502
	Gadomus multifilis	817–1460	20°08'–34°15'	112°55'–114°20'	H3001–01	1006–1008
	Gadomus sp. W2	320–1158	21°51'–31°55'	113°47'–115°10'	H2596–03	1544
	Hymenocephalus sp. W1	684–880	22°47'–30°17'	113°13'–114°30'	H2553–11	
	Hymenocephalus sp. W4	666–945	26°15'–32°40'	112°03'–114°28'	H2573–24	
	Hymenocephalus sp. W5	714–945	27°07'–29°52'	112°23'–114°12'	H2584–15	
	Hymenocephalus spp.	320–1280	31°55'–32°20'	114°29'–115°10'		
	Hymenogadus sp. W1	430–690	17°45'–26°15'	112°03'–118°32'	H2573–14	1357
	Idiolophorynchus andriashevi	1240–1240	34°13'–34°13'	114°08'–114°08'	H2623–01	1280
	Lepidorhynchus denticulatus	320–817	22°60'–35°02'	113°14'–115°02'	H2023–01	433–436
	Macrosmia phalacra	1460–1460	22°01'–22°01'	113°08'–113°08'	H2551–19	1340
	Malacocephalus laevis	411–870	22°60'–34°59'	113°14'–114°44'	H2023–05	229–231
	Mataeocephalus sp. W1	685–945	20°08'–29°22'	112°55'–113°47'	H2542–30	1650
	Mataeocephalus sp. W2	690–895	24°30'–28°04'	111°51'–112°43'	H2580–07	1541
	Mesobius cf. *antipodum*	740–945	33°44'–35°07'	114°22'–115°01'	H3010–03	1023–1025
	Mesobius cf. *berryi*	1240–1240	34°13'–34°13'	114°08'–114°08'	H2623–02	1276
	Nezumia sp. W1	612–612	23°45'–23°45'	112°35'–112°35'	H1492–01	762
	Nezumia sp. W3	842–842	35°25'–35°25'	117°21'–117°21'	H3008–10	1154–1156
	Nezumia sp. W3A	714–945	27°07'–28°04'	112°23'–112°43'	H2580–04	1579
	Nezumia sp. W4	1293–1460	22°01'–24°10'	111°39'–113°08'	H2551–17	1345
	Nezumia sp. W5	685–895	21°51'–32°40'	113°47'–114°28'	H3041–12	1184–1186
	Nezumia sp. W6	854–1258	20°55'–33°18'	112°51'–114°13'	H2544–12	1507
	Nezumia sp. W7	842–842	35°25'–35°25'	117°21'–117°21'	H3008–11	
	Nezumia sp. W8	685–1258	20°08'–29°22'	112°55'–113°47'	H2549–10	1344
	Nezumia sp. W10	882–1460	22°01'–33°18'	113°08'–114°13'	H2617–03	1291
	Nezumia sp. W11 (blue)	320–1009	26°15'–32°02'	112°03'–114°54'	H2573–12	1363
	Nezumia sp. W13	612–913	20°16'–25°19'	111°56'–113°13'	H2549–17	
	Nezumia sp. W14	854–945	28°00'–30°52'	112°41'–114°37'	H2584–21	1515
	Nezumia sp. W15	685–685	21°51'–21°51'	113°47'–113°47'	H2549–13	
	Squalogadus cf. *modificatus*	1009–1280	20°55'–32°20'	112°51'–114°29'	H2614–03	1296
	Trachonurus sp. W1 (black)	892–1030	24°30'–34°10'	111°51'–114°16'	H3002–05	1148–1150
	Trachonurus sp. W2 (big scale)	770–1132	20°08'–32°40'	112°55'–114°28'	H2596–04	1545
	Trachonurus sp. W3 (small scale)	770–1293	20°16'–34°13'	113°13'–114°08'	H2596–01	1543
	Ventrifossa sp. W5	649–760	26°36'–28°06'	112°09'–113°27'	H3034–03	1181–1183
	Ventrifossa sp. W6	482–714	21°51'–28°06'	113°27'–113°47'	H2580–03	1539

Fam no.	Species	Depth (m) (min.–max.)	Latitude (°S.) (min.–max.)	Longitude (°E.) (min.–max.)	Regn nos	Photo. slide nos
	Ventrifossa sp. W7	684–882	20°08'–30°17'	112°55'–114°30'	H2573–21	1355
	Ventrifossa sp. W8	320–942	21°51'–33°26'	113°47'–114°21'	H2549–09	1274
	Ventifossa sp. W11 cf. *nigromaculata*	666–738	26°57'–34°59'	112°22'–114°44'	H2579–02	1508
	Macrouridae gen. sp. W1	1258–1258	22°29'–22°29'	113°12'–113°12'	H2551–13	1347
	Macrouridae gen. sp. W2	760–760	26°36'–26°36'	112°09'–112°09'	H3041–14	1396–1400
	Macrouridae gen. sp.	1258–1258	22°29'–22°29'	113°12'–113°12'	H2552–04	1329
251	*Poromitra crassiceps*	1139–1139	20°55'–20°55'	112°51'–112°51'	H2544–06	1588
	Scolepogadus sp.	1139–1139	20°55'–20°55'	112°51'–112°51'		
	Melamphaes sp.	1158–1158	21°54'–21°54'	113°41'–113°41'	H2550–08	
	Melamphaidae gen. sp. W1	913–913	20°16'–20°16'	113°13'–113°13'	I31178–008	
253	*Polymixia* cf. *berndti*	300–510	22°60'–30°00'	113°14'–114°28'	H2554–03	217–220
	Polymixia sp. W2 (long barbel)	444–467	24°51'–24°53'	112°07'–112°08'	H2565–09	
254	*Diretmichthys parini*	740–1293	20°55'–35°02'	112°51'–115°01'	H3009–01	901–903
	Diretmus argenteus	685–1139	20°08'–21°51'	112°55'–113°47'	H2542–07	
255	*Gephyroberyx darwinii*	274–490	21°44'–33°13'	113°52'–114°31'	H2044–01	1211
	Hoplostethus atlanticus	812–870	33°58'–35°05'	114°22'–114°60'	H1251–01	1269
	Hoplostethus intermedius	673–673	35°02'–35°02'	115°02'–115°02'	H3011–03	1032–1034
	Hoplostethus mediterraneus	320–510	24°53'–33°18'	112°08'–114°31'	H3023–06	1056–1058
	Hoplostethus cf. *melanopus*	435–760	20°37'–26°59'	112°38'–114°42'	H3041–01	1083–1085
	Hoplostethus cf. *shubnokovi*	447–760	18°14'–27°07'	112°23'–117°54'	H1514–22	1270–1271
257	*Anoplogaster cornuta*	1258–1258	22°29'–22°29'	113°12'–113°12'	I31152–003	
258	*Beryx splendens*	209–670	21°38'–32°02'	113°56'–114°54'	H2599–02	1557
	Beryx sp. W2 (big eye)	390–556	29°14'–31°45'	113°52'–115°00'	H2599–03	1556
	Centroberyx australis	203–380	26°42'–33°24'	112°38'–114°31'	H2577–01	1519
	Centroberyx gerrardi	210–210	33°45'–33°45'	114°28'–114°28'	H2008–01	055–056
261	*Ostichthys japonicus*	200–225	21°39'–26°43'	112°41'–113°58'	H2576–04	1569
262	*Parazen pacificus*	297–478	21°45'–27°23'	112°52'–113°52'	H3045–03	883–885
263	**Zenion* sp. cf. *japonicum*	306–735	21°45'–27°23'	112°52'–113°52'	H3040–01	1074–1076
264	*Cyttopsis cypho*	297–510	21°45'–32°02'	113°52'–115°09'	H2556–08	
	Cyttopsis roseus	209–616	21°39'–29°50'	113°58'–114°21'	H2591–04	1533
	Cyttus traversi	490–1003	28°13'–35°08'	113°07'–115°01'	H3009–02	916–918
	Zenopsis nebulosus	209–712	21°39'–34°59'	113°58'–114°53'	H2040–01	1693
	Zenopsis sp. nov.	209–392	16°54'–21°45'	113°52'–120°25'	H2046–01	1267
	Zeus faber	200–230	26°43'–32°00'	112°41'–115°13'		609–612
265	*Grammicolepis brachyusculus*	565–612	25°19'–26°25'	111°56'–112°20'	H3046–04	877–879
	Xenolepidichthys dalgleishi	405–612	17°00'–31°31'	114°43'–120°11'	H2079–01	103–104
266	*Allocyttus verrucosus*	613–1293	20°08'–35°05'	112°55'–114°60'	H2036–01	1214
	Neocyttus rhomboidalis	596–1240	26°36'–35°05'	112°09'–114°60'	H2034–01	1213
	Oreosoma atlanticum	670–825	32°02'–34°15'	114°20'–114°54'	H3016–01	940–942
	Pseudocyttus maculatus	900–1003	35°03'–35°08'	114°51'–115°01'	H3008–01	943–945
267	*Antigonia rhomboidea*	297–435	22°30'–25°36'	112°10'–113°35'	H3045–04	886–888
	Antigonia rubicunda	312–312	25°08'–25°08'	112°09'–112°09'	H2567–17	1481
268	*Lampris guttatus*				WAM	1695–1698
269	*Velifer multiradiatus*	210–210	28°09'–28°09'	113°17'–113°17'	H2020–01	133–136
279	*Centriscops obliquus* (= *humerosus*)	306–673	27°23'–35°02'	112°52'–115°02'	H3071–01	243–247
	Macroramphosus scolopax	225–308	27°23'–32°14'	112°52'–115°06'	I31185–009	
	**Macroramphosus* cf. *scolopax*	300–300	23°25'–23°25'			
	Notopogon cf. *fernandezianus*	270–712	24°51'–34°59'	112°07'–114°53'	H2567–04	1497
287	**Helicolenus* cf. *percoides*	320–770	26°36'–33°18'	112°29'–114°31'	H2574–01	1362
	**Helicolenus* sp. W3	203–225	32°10'–33°24'	114°31'–115°08'	H2613–03	1294
	Neomerinthe cf. *neilseni*	320–438	27°09'–31°55'	112°45'–115°10'	H2587–01	1528
	Neosebastes nigropunctatus	203–225	32°10'–33°24'	114°31'–115°08'	H2613–07	1293
	Neosebastes pandus	201–201	34°57'–34°57'	114°56'–114°56'	H3063–01	689–692

Fam no.	Species	Depth (m) (min.–max.)	Latitude (°S.) (min.–max.)	Longitude (°E.) (min.–max.)	Regn nos	Photo. slide nos
	Neosebastes thetidis	203–225	32°10'–33°24'	114°31'–115°08'	H2613–08	1302
	Setarches guentheri	318–649	17°50'–30°57'	114°48'–118°33'	H2006–02	238–242
	Setarches longimanus	297–297	23°25'–23°25'	113°04'–113°04'		324–326
	Tracyscorpia capensis	738–870	34°59'–35°05'	114°44'–114°60'	H2625–02	1277
	Tracyscorpia sp. W2	880–880	32°40'–32°40'	114°28'–114°28'	H2616–01	1289
288	*Lepidotrigla grandis*	209–346	21°39'–29°16'	113°57'–113°58'	H2547–07	1619–1620
	Lepidotrigla modesta	270–308	32°05'–32°14'	115°06'–115°09'	H2609–01	1305
	Lepidotrigla spiloptera	209–320	21°39'–25°08'	112°09'–113°58'	H2574–08	1621–1622
	Parapterygotrigla sp. W2	297–300	23°25'–23°25'	113°04'–113°04'	H2555–05	
	Peristedion liorhynchus	297–467	23°25'–24°56'	112°11'–113°04'	H2564–10	1485
	Peristedion sp. W2	444–444	24°53'–24°53'	112°08'–112°08'	H2564–11	1486
	Pterygotrigla hemisticta	300–320	21°45'–23°25'	113°04'–113°52'	H2548–11	1615–1616
	Pterygotrigla polyommata	203–400	30°01'–33°24'	114°29'–114°31'	H2597–04	1548–1551
	Pterygotrigla (spade nosed) = *gen. nov.* 2	300–300	23°25'–23°25'	113°04'–113°04'	H2556–10	
	Satyrichthys amiscus	320–714	26°15'–31°55'	112°03'–115°10'	H2608–03	1306
	Satyrichthys welchi	209–346	21°39'–32°05'	113°58'–115°09'	H2547–05	1626
	Satyrichthys cf. *adeni*	444–444	24°53'–24°53'	112°08'–112°08'	H2115–01	1233
	Satyrichthys sp. W4 (?*Heminodus*)	297–508	22°60'–27°09'	112°45'–113°14'	H2564–13	1487–1488
	Satyrichthys cf. *murrayi* (sp. W6)	297–300	23°25'–23°25'	113°04'–113°04'	H2555–07	
296	*Bembras* sp. W1	209–297	21°39'–23°25'	113°04'–113°58'	H2547–04	1625
	Elates ransonnetii	221–221	22°22'–22°22'	113°39'–113°39'		
	Platycephalus conatus	201–413	28°53'–33°24'	113°41'–114°31'		521–524
	Ratabulus diveridens	209–209	21°39'–21°39'	113°58'–113°58'	H2547–15	
297	*Hoplichthys citrinus*	300–612	23°25'–27°09'	112°45'–113°04'		367–370
	Hoplichthys haswelli	373–712	29°21'–34°59'	113°58'–114°53'		481–484
	Hoplichthys sp. 3 (pink)	510–1058	30°39'–34°59'	114°28'–114°53'	H2601–01	1319
299	*Ereunias* cf. *grallator*	565–760	26°25'–28°13'	112°20'–113°07'	I31175–001	1572–1573
305	*Ebinania* sp. W1	982–982	33°18'–33°18'	114°13'–114°13'		
	**Psychrolutes* sp.	684–690	26°15'–30°17'	112°03'–114°30'	H2573–03	
	**Psychrolutes* sp. W2	945–945	28°00'–28°00'	112°41'–112°41'	H2583–05	
	**Psychrolutes* cf. *marcidus*	571–571	32°52'–32°52'	114°35'–114°35'	H3026–01	934–936
	**Psychrolutes* sp. (large)	565–565	26°25'–26°25'	112°20'–112°20'	H3046–05	880–882
307	*Paraliparis* sp.	1030–1030	32°35'–32°35'	114°27'–114°27'	H2615–10	
308	*Dactyloptena peterseni*	250–250	27°29'–27°29'	112°50'–112°50'		
311	Anthiinae gen. sp. W1	209–312	21°39'–25°08'	112°09'–112°58'	H2567–05	1493
	Anthiinae gen. sp. W2		no record		H2589–01	1578
	Callanthias sp. W1	203–270	32°05'–33°24'	114°31'–115°09'	H2610–01/02	1315–1317
	Caprodon sp. W1 cf. *schegeli*	212–373	22°22'–32°54'	113°39'–114°39'	H2307–01	1244
	Doderleinia cf. *berycoides*	320–400	21°45'–17°00'	113°52'–120°14'	H2548–03	1596
	Epinephelus radiatus	218–250	21°19'–22°30'	113°35'–113°42'		
	Epinephelus septemfasciatus	200–331	31°09'–32°09'	114°52'–115°10'	H2130–01	142–147
	Lepidoperca sp. W1	203–225	32°10'–33°24'	114°31'–115°08'	H2613–05/06	1299–1300
	Lepidoperca sp. W2	203–225	32°10'–33°24'	114°31'–115°08'	H2613–04	1301
	Malakichthys cf. *elegans* (sp. W1)	297–482	22°60'–27°23'	112°52'–113°14'	H2554–15	
	Malakichthys sp. W2 (smooth chin)	320–320	21°45'–21°45'	113°52'–113°52'	H2548–01	1607
	Plectranthias japonicus	320–320	21°45'–21°45'	113°52'–113°52'	H2548–02	1628
	Polyprion americanus	270–270	32°05'–32°05'	115°09'–115°09'		
	Polyprion oxygeneios	350–350	32°18'–32°18'	114°58'–114°58'		937–939
320	*Glaucosoma bergeri*	220–250	22°25'–22°29'	113°36'–113°37'		
322	*Banjos banjos*	216–216	28°34'–28°34'	113°29'–113°29'	Reg	589–592
326	*Cookeolus boops* (= *japonicus*?)	200–300	23°25'–27°53'	113°04'–113°08'	H2575–03	1568

Fam no.	Species	Depth (m) (min.–max.)	Latitude (°S.) (min.–max.)	Longitude (°E.) (min.–max.)	Regn nos	Photo. slide nos
	Priacanthus macracanthus	209–320	21°39'–21°39'	113°58'–113°58'	H2085–01	1248
	Priacanthus sp. 2	297–297	23°25'–23°25'	113°04'–113°04'		
	Pristigenys niphonia	220–250	22°25'–22°29'	113°36'–113°37'		
327	*Epigonus macrops*	612–895	24°30'–25°19'	111°51'–111°56'	H2562–01	
	Epigonus occidentalis	612–613	23°45'–31°16'	112°35'–114°50'	H2603–01	1320
	Epigonus robustus	976–982	33°17'–33°18'	114°13'–114°13'	H2617–10	
	Synagrops japonicus	306–714	22°60'–32°10'	113°14'–115°03'	H2047–01	1249
	Synagrops philippinensis	306–478	21°45'–30°00'	113°52'–114°28'		
328	*Acropoma japonica*	209–320	21°39'–27°23'	112°52'–113°58'	H2547–12	
331	**Branchiostegus australis*	209–225	20°40'–21°39'	113°43'–113°58'	H2547–03	1612
334	*Apogonops anomolus*	200–510	21°45'–33°18'	113°52'–114°31'		
337	*Carangoides equula*	209–320	21°39'–21°45'	113°52'–113°58'		137–141
	Decapterus russelli	200–200	26°43'–26°43'	112°41'–112°41'	H2575–02	1567
	Naucrates ducta	467–467	24°51'–24°51'	112°07'–112°07'	H2564–05	1468
	Trachurus cf. *delagoa*	218–218	27°33'–27°33'	112°58'–112°58'		413–416
	Trachurus sp.	200–200	26°43'–26°43'	112°41'–112°41'	H2576–02	1567
342	*Brama ausini*	482–482	22°60'–22°60'	113°14'–113°14'		
	Brama sp. nov.	371–1009	27°22'–32°22'	112°11'–114°59'	H2580–02	1540
345	*Erythrocles* sp. W1	203–203	33°24'–33°24'	114°31'–114°31'	H2619–04	1285
	Plagiogenion macrolepis	230–230	32°00'–32°00'	115°13'–115°13'		
346	*Etelis carbunculus*	200–285	21°15'–26°24'	112°38'–113°43'	H2577–03	1359
	Etelis coruscans	285–285	26°42'–26°42'	113°43'–113°43'	H2577–02	1571
347	*Nemipterus bathybius*	209–225	20°40'–21°39'	113°43'–113°58'		
353	*Dentex tumifrons*	200–346	21°39'–32°10'	113°58'–115°08'	H3067–02	541–544
	Pagrus auratus	200–296	21°15'–32°24'	113°43'–115°01'		009–010
355	*Parupeneus chrysopleuron*	200–200	26°43'–26°43'	112°41'–112°41'	I31173–001	
358	*Bathyclupea* sp. W1	482–870	22°60'–33°58'	113°14'–114°22'	H3040–03	1080–1082
367	*Paristiopterus gallipavo*	204–213	28°03'–31°36'	113°15'–114°59'	H3068–01	513–515
	Pentaceros decacanthus	*306–712	*25°08'–34°59'	112°09'–114°53'	H3069–04	577–580
	Pseudopentaceros richardsoni	376–596	28°48'–33°13'	113°37'–114°31'	H3025–01	928–930
	Zanclistius elevatus	200–360	31°55'–33°24'	114°31'–115°11'	H2002–02	473–476
369	*Oplegnathus woodwardi*	203–380	29°57'–33°24'	114°27'–114°31'	H2608–05	1310
377	*Nemadactylus macropterus*	203–357	31°55'–33°24'	114°31'–115°10'	H2608–14	1311
	Nemadactylus valenciennes	203–203	33°24'–33°24'	114°31'–114°31'	H2619–05	1282
380	*Cepola* sp. W1	300–300	23°25'–23°25'	113°04'–113°04'	H2556–01	
382	*Sphyraena* sp. W1	209–300	21°39'–23°25'	113°04'–113°58'	H2547–14	
390	*Parapercis* cf. *macrophthalma*	225–390	31°55'–32°14'	115°06'–115°10'	H2608–02	1307
	Parapercis sp. W1	220–318	23°25'–33°19'	113°04'–114°32'	I31185–006	
	Parapercis sp. W2	220–297	23°25'–33°19'	113°04'–114°32'	H2556–09	
393	*Bembrops* cf. *curvatura*	320–320	21°45'–21°45'	113°52'–113°52'		
400	*Gnathagnus elongatus* (= *australiensis*?)	320–320	21°45'–21°45'	113°52'–113°52'	H2062–01	1252
	Kathetostoma nigrofasciatum	201–320	30°01'–34°57'	114°29'–114°56'	H2597–05	1549–1550
	Pleuroscopus pseudodorsalis	435–435	33°20'–33°20'	114°30'–114°30'	H3023–04	1050–1055
	Uranoscopus sp. 3	209–320	21°39'–21°45'	113°52'–113°58'	H2547–13	
401	*Champsodon* sp. W1	297–612	22°60'–27°17'	112°45'–113°14'	H3046–01	871–873
	Champsodon sp. W2	306–478	24°51'–27°23'	112°07'–112°52'	H2575–03	1565
402	*Kalimacrura*	1139–1139	20°55'–20°55'	112°51'–112°51'	I31143–012	
427	Callionymidae gen. sp. W2	390–490	27°09'–31°49'	112°45'–115°01'	H2587–03	1576
439	*Lepidocybium flavobrunneum*	1061–1061	23°60'–23°60'	111°54'–111°54'	I31158–001	
	Neoepinnula orientalis	435–510	24°51'–27°17'	112°07'–112°45'		717–720
	Rexea antefurcata	225–225	22°22'–22°22'	113°39'–113°39'	H3058–01	1372–1374
	Rexea prometheoides	297–320	21°45'–23°25'	113°04'–113°52'	I31147–001	1604
	Rexea solandri	216–596	23°25'–33°20'	113°04'–114°30'		429–432
	Ruvettus pretiosus	475–475	31°17'–31°17'	114°53'–114°53'		525–528

Fam no.	Species	Depth (m) (min.–max.)	Latitude (°S.) (min.–max.)	Longitude (°E.) (min.–max.)	Regn nos	Photo. slide nos
	Scombrolabrax heterolepis	854–1293	20°08'–35°07'	112°55'–115°01'	H3010–05	1026–1028
	Thyrsitoides marleyi	318–1254	24°56'–28°04'	112°11'–112°43'		501–504
440	*Aphanopus* sp. W1	854–1254	25°52'–30°52'	111°27'–114°37'	H2570–03	1593
	Benthodesmus sp.	685–868	20°08'–27°07'	112°23'–112°55'	H2542–32	1586
	Trichiurus lepturus	209–297	21°39'–23°25'	113°04'–113°58'		
445	*Hyperoglyphe antarctica*	380–380	30°00'–30°00'	114°28'–114°28'	H2598–02	1525
	Psenopsis obscura	868–868	20°08'–20°08'	112°55'–112°55'	H2543–02	1642
446	*Cubiceps baxteri*	1060–1060	24°00'–24°00'	111°54'–111°54'	H2559–01	
	Cubiceps pauciradiatus	868–868	20°08'–20°08'	112°55'–112°55'	H2543–01	1639
	Cubiceps squamiceps	467–467	24°51'–24°51'	112°07'–112°07'	H2564–23	
447	*Ariomma lurida*	297–318	23°25'–24°56'	112°11'–113°04'		
458	*Citharoides macrolepidotus*	297–435	23°25'–31°55'	113°04'–115°10'	H3045–05	889–891
460	*Chascanopsetta lugubris*	444–467	24°51'–24°53'	112°07'–112°08'	H2074–01	359–362
	Pseudorhombus megalops	297–300	23°25'–23°25'	113°04'–113°04'		
	Taeniopsetta ocellata	300–300	23°25'–23°25'	113°04'–113°04'	H2556–02	
461	*Poecilopsetta*?	312–320	21°45'–25°08'	112°09'–113°52'		
	Pleuronectidae gen. sp. W1	320–320	21°45'–21°45'	113°52'–113°52'	H2567–15	1469
464	*Halimochirurgus alcocki*	438–438	27°09'–27°09'	112°45'–112°45'	I31184–002	1584
	Halimochirurgus centriscoides	297–297	23°25'–23°25'	113°04'–113°04'	I31155–003	
	Paratriacanthodes retrospinus	467–482	22°60'–24°51'	112°07'–113°14'	I31154–001	
	Tydemania navigatorisi	482–482	22°60'–22°60'	113°14'–113°14'	I31154–002	
465	*Eubalichthys bucephalus*	204–213	31°13'–34°56'	114°56'–114°59'		673–676
	Eubalichthys quadrispinsi	213–270	31°13'–32°10'	114°56'–115°08'	H2610–04	1273
	Nelusetta ayraudi	200–360	29°20'–32°28'	114°02'–114°59'		69–70
	Parika scaber	203–203	33°24'–33°24'	114°31'–114°31'	H2619–07	
466	*Anaplocapros lenticularis*	203–324	31°12'–33°24'	114°31'–114°56'	H2613–09	1295
	Capropygia unistriata	203–203	33°24'–33°24'	114°31'–114°31'		191–194
467	*Lagocephalus* sp.	685–685	21°51'–21°51'	113°47'–113°47'	H2549–12	
	Omegophora armilla	255–255	30°01'–30°01'	114°29'–114°29'	I31186–002	469–472
	Sphoeroides pachygaster	318–318	24°56'–24°56'	112°11'–112°11'	H2566–03	1474

**under review

Appendix VII — Crustacean and related species collected from FRV *Southern Surveyor* cruise SS1/91

Caridea

Family Oplophoridae
Acanthephyra armata
Acanthephyra eximia
Acanthephyra smithi
Acanthephyra quadrispinosa
Notostomus gibbosus
Oplophorus novaezelandiae
Oplophorus spinosus
Oplophorus typhus

Family Nematocarcinidae
Nematocarcinus gracilis
Nematocarcinus productus
Nematocarcinus tenuirostris
Nematocarcinus undulatipes

Family Stylodactylidae
Stylodactylus licinus

Family Pasiphaeidae
Glyphus marsupialis
Eupasiphae gilesi
Eupasiphae latirostris
Pasiphaea barnardi
Pasiphaea longitaenia
Pasiphaea tarda
Pasiphaea sp. nov.

Family Pandalidae
Heterocarpus dorsalis
Heterocarpus sibogae
Heterocarpus tricarinatus
Heterocarpus cf. *hayashii*
Plesionika grandis
Plesionika quasigrandis
Plesionika martia
Plesionika martia orientalis
Plesionika semilaevis

Family Crangonidae
Pontophilus gracilis junceus

Family Glyphocrangonidae
Glyphocrangon aff. *hastacauda*
Glyphocrangon aff. *longirostris*
Glyphocrangon sp. 2

Glyphocrangon sp. 3
Glyphocrangon sp. 4

Penaeidea

Family Aristeidae
Hepomadus tener
Parahepomadus vaubani
Hemipenaeus carpenteri
Pseudaristeus sibogae
Aristeus aff. *mabahissae – not ID'd*
Aristeus virilis
Aristeus sp.
Plesiopenaeus edwardsianus
Plesiopenaeus coruscans
Plesiopenaeus nitidus

Family Benthesicymidae
Benthesicymus investigatoris

Family Solenoceridae
Haliporoides sibogae
Hymenopenaeus halli
Gordonella villosa
Solenocera melantho
Solenocera faxoni

Family Penaeidae
Penaeopsis rectacuta
Metapenaeopsis liui
Metapenaeopsis cf. *liui*
Metapenaeopsis andamanensis

Family Sergestidae
Sergestes arcticus? (ident. pending)
Sergia aff. *extenuatus (*ident. pending)
Sergia splendens? (ident. pending)

Macrura

Family Nephropidae
Metanephrops boschmai
Metanephrops velutinus
Nephropsis acanthacura
Nephropsis serrata
Nephropsis suhmi

Family Scyllaridae
Ibacus ciliatus pubescens
Ibacus alticrenatus

Family Polychelidae
Stereomastis aff. *nana*
Polycheles sp. 1
Polycheles sp. 2

Brachyura
Majidae spp.
Ovalipes sp.

Stomatopoda

Family Squillidae
Altosquilla sp.

Other Groups

Anomura

Family Galatheidae
Munida sp. 1
Munida sp. 2

Mysidacea

Family Lophogastridae
Gnathophausia ingens

Isopoda

Family Cymothoidae
Bathynomus sp.

Pycnogonida

Family Collosendeidae
Collosendeis sp.