Assessment of Groundfish Stocks in Northern Australian Waters between 127-137°E

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Assessment of Groundfish Stocks in Northern Australian Waters between 127-137°E

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Objective

Assess the size of groundfish stocks in the Australian sectors of the Timor and Arafura Seas, including the northern trawl fish management zones, between longitudes 127-137°E.

Non-technical Summary

The project provided data for assessing the size of groundfish stocks in the Australian sectors of the Timor and Arafura Seas, between longitudes 127-137°E and latitudes 8-15°S. This was the first integrated approach to the scientific management of the groundfish stocks in this region. Bottom trawl surveys were conducted in depths of 20-200 m in the Timor and Arafura Seas during October-December 1990 (57 days), and in the Arafura Sea during September-October 1992 (48 days) aboard the chartered 25 m stern trawler FV *Clipper Bird.* Two hundred and seventy six randomly allocated stations were sampled using a standard Frank and Bryce trawl. A further 211 tows were made during trawl gear calibration experiments in 1992 to evaluate the effect of herding and the level of escapement of target species such as saddle-tailed snapper (*Lutjanus malabaricus*). Snappers and other species were collected during both surveys to provide information on age, growth, mortality and reproduction.

A novel and simple model for fish herding was developed relating trawl catches to trawl net width and door spread, allowing definition of the effective trawl pathwidth and substantially improving the swept area method. This method is commonly used around the world for estimating fish density and biomass from trawl survey data.

The project provided new information on the relative abundance and biomass of major species of fish in the Timor and Arafura Seas between 127-137°E. Together with the new information on herding and escapement, the project allowed fishery scientists and managers to review estimates of yield and resource management strategies for saddle-tailed snapper and gold-band snapper (*Pristipomoides multidens*) in northern Australia. Prior estimates of yield, based on logbook and observer data, are now considered less reliable than those derived from survey data. The results of analyses based on project data are published in scientific papers, fishery status reports and workshop proceedings.

Keywords

Lutjanus malabaricus, snapper, groundfish, herding, trawl survey, Timor Sea, Arafura Sea

Background

The Northern Territory Fisheries Division has researched groundfish stocks in the Timor and Arafura Seas since the declaration of the Australian Fishing Zone in 1979. This research is conducted within the Division's Aquatic Resource Management Program and focuses on tropical snappers including saddle-tailed snapper (*Lutjanus malabaricus*) and gold-band snapper (*Pristipomoides multidens*). The principal objectives of that program are to:

- estimate the size of tropical snapper stocks in the Timor and Arafura Seas;
- examine spatial and temporal variations in the distribution and abundance, and biology of major fish stocks in northern waters;
- identify stocks which are shared between Australia and Indonesia; and,
- refine fishery models and review stock assessments.

A new proposal, describing a fishery-independent assessment of groundfish stocks in northern Australian waters between longitudes 127-137°E, was submitted to the former Fishing Industry Research and Development Council (FIRDC) for funding during 1990-93. The FIRDC Board advised that it would not fund the charter vessel component for the proposal; however FIRDC would fund requested salaries and operational expenses if an alternative source of funding could be secured for the charter component. Alternative sources of funding for the charter vessel components were found for surveys in 1990 and 1992, and the revised project began in 1990 (Table 1). The project's salary and operational funds were provided by the Northern Territory Government (approx $413000 during 1990-94), FIRDC ($230000 during 1990-92) and the Fishing Research and Development Corporation (FRDC $162000 in 1992-94). The charter vessel component of the project was funded by the Fisheries Development Trust Account held by the former Australian Fisheries Service (AFS $150000 in 1990-91), and the Australian Fisheries Management Authority (AFMA $154000 in 1992-93).

Table 1. Summary of grants received for the project. External funding was provided by the Australian Fisheries Management Authority (AFMA), former Australian Fisheries Service (AFS), Fisheries Research and Development Corporation (FRDC) and former Fishing Industry Research and Development Council (FIRDC).

Year	Agency	Operational and Salaries ($)	Charter Component ($)
1990-91	FIRDC	115000	-
	AFS	-	150000
1991-92	FIRDC	115000	-
1992-93	FRDC	112000	-
	AFMA	-	154000
1993-94	FRDC	50000	-
Total Grants		392000	304000

Need

Under the Offshore Constitutional Settlement agreement between the Commonwealth and the Northern Territory, the groundfish trawl and longline fisheries off northern Australia remained "status quo" and were managed by the former AFS, and later AFMA, from 1979 until 1995; under this "status quo" agreement, the Northern Territory managed demersal trap, dropline and gillnet fisheries in waters adjacent to the Northern Territory. Staff from the CSIRO Division of Fisheries (notably Keith Sainsbury) and the NT Fisheries Division (notably Rex Edwards) were involved with the initial determination of Total Allowable Catches (TACs) for the northern trawl fishery. These analyses were based on logbook data collected by Taiwanese and Australian authorities since 1974 and 1979, respectively, and exploratory surveys conducted on the Northwest Shelf, and in the Kimberley-Timor Region, Arafura Sea and Gulf of Carpentaria during 1978-80. After that time, research by CSIRO on the Northwest Shelf provided further input to regular revisions of TACs for this region. In contrast, there were no adequate data for management based on scientific assessments of the multi-species, multi-fleet trawl fisheries in the Kimberley-Timor Region, and the Arafura Sea. This project addressed this lack of data within Australian sectors of the Timor and Arafura Seas, between longitudes 127-137°E.

Objective

Assess the size of groundfish stocks in the Australian sectors of the Timor and Arafura Seas, including the northern trawl fishery management zones, between longitudes 127-137°E (Fig. 1), and specifically:

- acquire data on the status of groundfish stocks;
- obtain fishery-independent indices of abundance for groundfish in the study area;
- determine important population parameters for abundant taxa; and,
- assess groundfish stocks between 127-137°E.

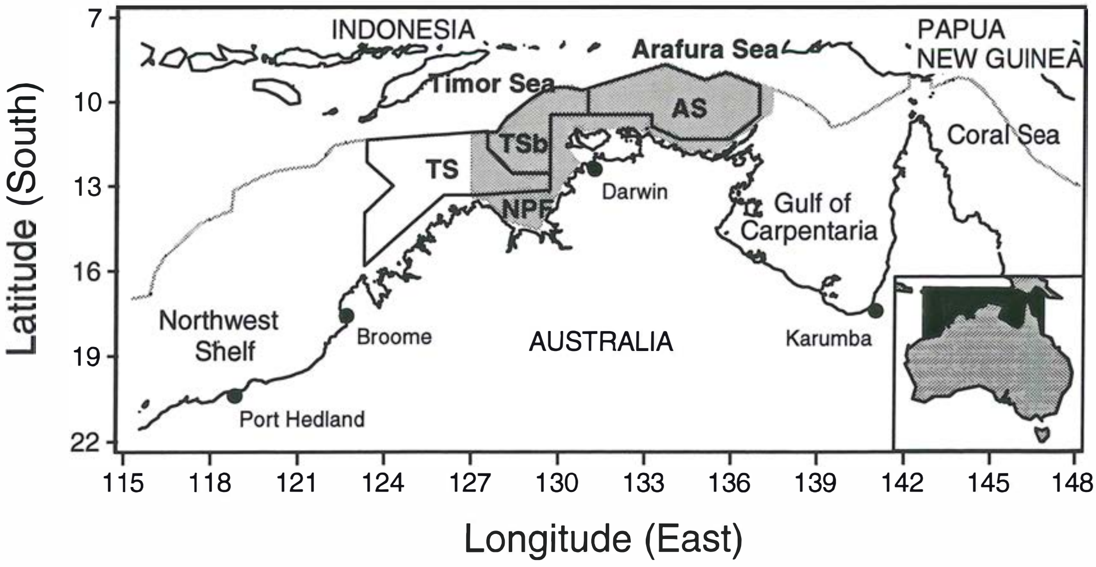

Figure 1. Australian sectors of the Timor and Arafura Seas, between longitudes 127-137°E, surveyed during the project (shaded). Relevant fishery management zones are indicated: Arafura Sea Trawl Fishery Management Zone (AS); Northern Prawn Fishery Seasonal Closure Zone (NPF); Timor Sea Trawl Fishery Management Zone (TS); and, Timor Box (TSb). The seaward boundary of the Australian Fishing Zone is indicated (—).

Methods

Bottom trawl surveys were conducted in depths of 20-200 m in the Timor and Arafura Seas during October-December 1990 (57 days), and in the Arafura Sea during September-October 1992 (48 days) aboard the chartered 25 m stern trawler FV *Clipper Bird* (owned by Raptis and Sons). A total of 276 randomly allocated stations were sampled using a standard Frank and Bryce trawl net with a headline length of 26 m and stretched mesh sizes of 38-230 mm (Fig. 2); the net was configured with 30 m bridles and 30 m sweeps. A further 211 tows were made during trawl gear calibration experiments in 1992 to evaluate the effect of herding and the level of escapement of target species, including saddle-tailed snapper. Specimens of selected species were collected during both surveys to provide information on age, growth, mortality and reproduction (Table 2).

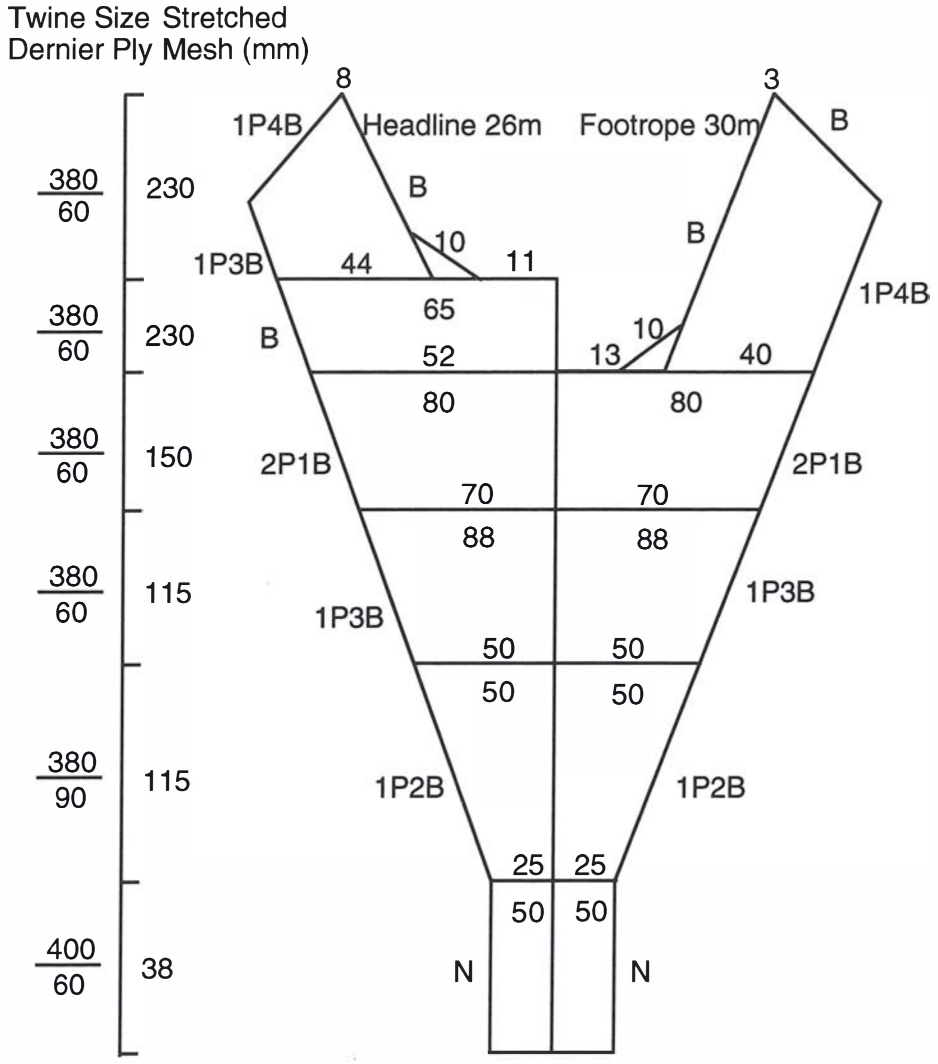

Figure 2. Net plan for the standard Frank and Bryce net used during the bottom trawl surveys of 1990 and 1992.

1990 Trawl Survey

The initial design of the survey (FIRDC application 1990-91) was expanded, at the request of the then AFS, to include the inshore Northern Prawn Fishery Seasonal Closure Zone (Fig. 1). Two hundred and forty stations were allocated in depths of 20-200 m, and in proportion to the surface area of the four management zones within the study region:

- 53 stations in the Timor Box (68100 km^2);
- 93 stations in the Arafura Sea Trawl Fishery Management Zone (TFMZ) (118600 km^2);
- 27 stations in the Timor Sea TFMZ (34900 km^2); and,
- 67 stations in the Northern Prawn Fishery Seasonal Closure Zone (85000 km^2).

Field work was conducted in 4 legs during 20 October - 16 December 1990, and gear trials were conducted south of Flat Top Bank (129°15'E, 12°15'S) in the Timor Sea during 17-19 October. Stations were sampled during daylight using a standard Frank and Bryce net, and samples were sorted to the species level. Personnel from the NT Museum of Arts and Sciences, NT University, former AFS, CSIRO Fisheries Division, International Food Institute of Queensland and James Cook University collaborated during the survey. Total shiptime was 57 days.

Of the 240 stations scheduled for sampling:

- 199 stations were successfully sampled (Fig. 3);
- 7 stations were abandoned following extensive net damage;
- 34 stations were either not sampled due to rough ground, or not visited because of lost time due to rough sea conditions.

In addition, 7 replicate tows were made at one station, and 25 tows were made during gear trials, exploratory fishing and gear comparisons.

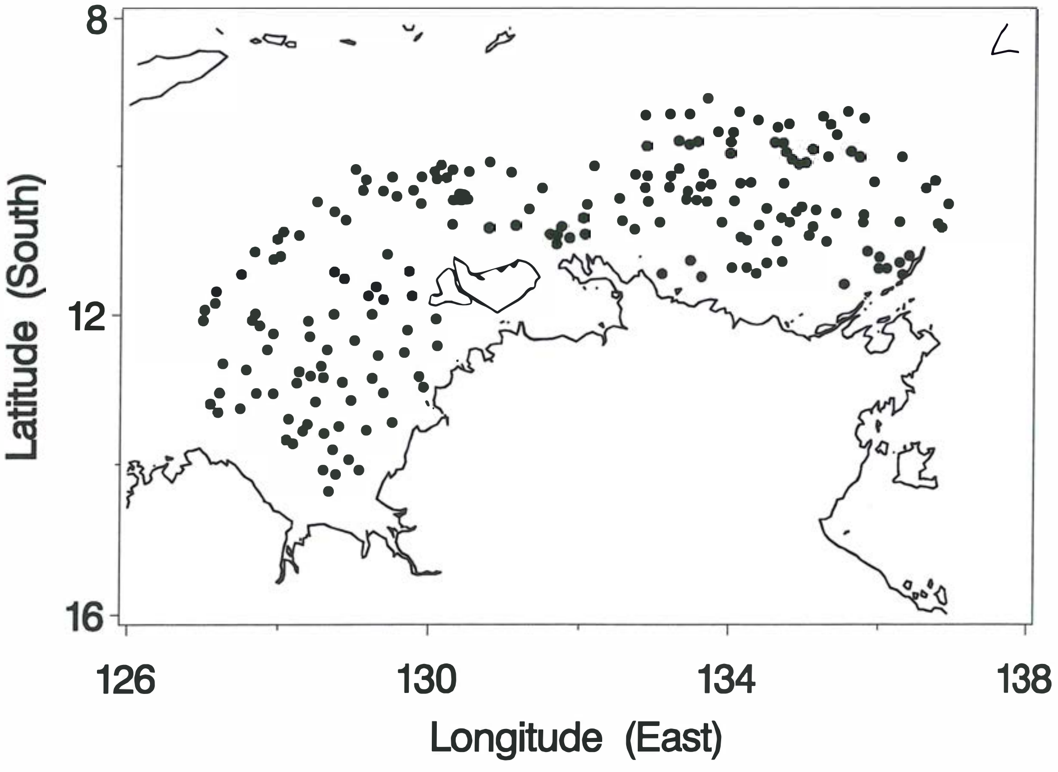

Figure 3. Random stations (•) occupied during the 1990 trawl survey of the Australian sectors of the Timor and Arafura Seas, between longitudes 127-137°E.

1992 Trawl Survey

The 1992 survey was designed to calibrate the survey gear by investigating the effect of herding and the level of escapement for saddle-tailed snapper, and about 30 other selected species. The survey was conducted in 3 legs during 4 September - 22 October 1992 on board the FV *Clipper Bird*; gear trials were conducted in Darwin Harbour on 2 September. Personnel from the NT Fishing Industry Training Committee, NT Museum of Arts and Sciences, Australian Maritime College, CSIRO Fisheries Division and James Cook University collaborated during the survey. Total shiptime was 48 days.

The field work was conducted in 2 parts within the Arafura Sea TFMZ: (1) search for a region of high catch rates (CPUEs) for target species, and low variance; and, (2) gear calibration. The remainder of the Arafura Sea TFMZ was surveyed in transit to the main study site, and only selected species were sorted from the samples and measured due to limited shiptime. In all, 70 stations were sampled randomly within the Arafura Sea TFMZ using the standard trawl configuration, and 211 tows were made during gear calibration in a region bounded by 10°20'-10°40'S and 134°00'-134°40'E (Fig. 4). Data for gear calibration were acquired using the standard Frank and Bryce trawl net with sweeps of 0, 30 and 90 m in length, a Frank and Bryce net modified into a box trawl, and a Frank and Bryce net with a maximum stretched mesh of 115 mm. In all cases, bridle length was 30 m. Each net was towed within 1 nautical mile wide longitudinal trawl lanes during periods of 1-2 days at a time. Net type, and trawl lanes were allocated randomly. Gear geometry was determined using a Scanmar net monitor on loan from the Australian Maritime College during 4-10 September 1992.

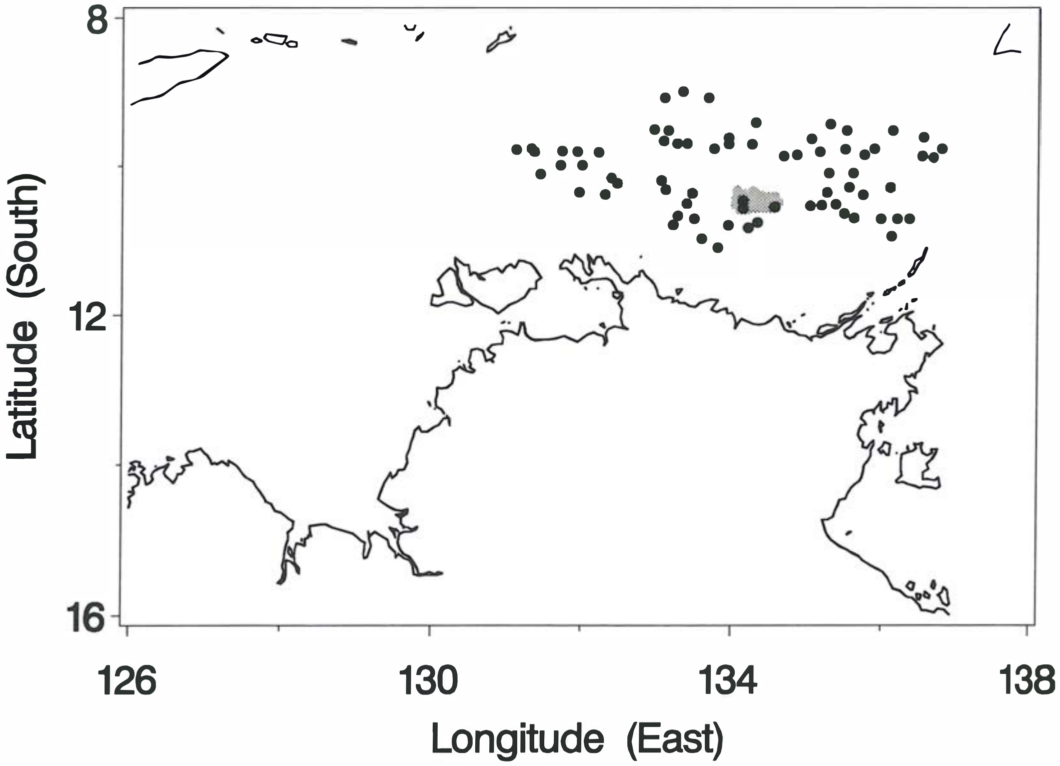

Figure 4. Random stations (•) occupied during the 1992 trawl survey of the Australian sector of the Arafura Sea, and main study site for gear calibration (⊛).

Table 2. Types of data collected during the surveys: weight; length frequencies; and, biological data (age, sex and gonad condition). During the 1990 survey, samples were sorted to the species level, and weights of all species were recorded. During the 1992 survey, only selected species were sorted from the samples and measured due to limited shiptime.

Scientific Name	Common Name	Types of Data		
		weight	length	biological
Abalistes stellaris	starry triggerfish	✓	✓	
Diagramma pictum	painted sweetlip	✓	✓	✓
Epinephelus (all species)	cods	✓	✓	
Lethrinus choerorynchus	lesser spangled emperor	✓	✓	
Lethrinus fraenatus	blue-lined emperor	✓	✓	✓
Lethrinus lentjan	red-spot emperor	✓	✓	✓
Lutjanus erythropterus	scarlet snapper	✓	✓	✓
Lutjanus malabaricus	saddle-tailed snapper	✓	✓	✓
Lutjanus sebae	red emperor	✓	✓	✓
Lutjanus timorensis	Timor snapper	✓	✓	✓
Lutjanus vittus	one-band snapper	✓	✓	
Lutjanidae (all species)	snappers	✓	✓	
Nemipterus furcosus	rosy threadfin-bream	✓	✓	✓
Nemipterus hexodon	ornate threadfin-bream	✓	✓	✓
Parupeneus pleurospilus	spotted golden goatfish	✓	✓	
Pristipomoides multidens	gold-band snapper	✓	✓	✓
Pristipomoides typus	sharp-tooth snapper	✓	✓	✓
Psenopsis humerosa	black-spot butterfish	✓	✓	✓
Saurida micropectoralis	short-finned lizardfish	✓	✓	✓
other species		✓		

Detailed Results

The project provided new data for use in stock assessment of groundfish in the Timor and Arafura Seas, and the first fishery-independent estimate of sustainable yield for saddle-tailed and gold-band snappers in northern Australia. Data have been analysed by scientists and managers from the Fisheries Division, AFMA, Bureau of Resource Sciences, CSIRO and Indonesian fishery agencies at workshops and working groups held since 1990. Findings have been reported at numerous meetings and seminars, and published in scientific papers, fishery status reports and workshop proceedings.

Herding of groundfish

Ramm and Xiao (1995; attachment 1) developed a simple model relating trawl catch to net width and door spread which allowed estimation of effective herding distance (H), catch due to net alone, catch due to net alone, catch due to herding and effective trawl pathwidth (W_{eff}). This model significantly improved the commonly used swept area method for estimation fish density and biomass. Herding occurred in at least 14 of the 36 selected species observed during the experiment. For saddle-tailed snapper, the target species in the Arafura Sea fishery, H=74 m (standard error 18 m) and W_{eff}=36 m (6 m) for the standard trawl configuration.

Stock assessment

Data from the 1990 and 1992 surveys, and surveys conducted by CSIRO in the Gulf of Carpentaria during 1990-92, were examined by the Northern Fisheries Research Committee's

Trawl Fisheries Assessment Working Group during meetings held in Canberra (29 July-2 August 1991) and Darwin (9-13 November 1992, 25-26 October 1994). Estimates of stock abundance were derived for saddle-tailed snapper and the commercial category "large *Lutjanus*" (generally *L. erythropterus, L. malabaricus, L. sebae, L. timorensis*) in the TFMZs of the Timor Sea, Arafura Sea and Gulf of Carpentaria. Estimates of stock abundance were also derived for gold-band snapper in the Timor Box region of the Timor Sea (Ramm, 1995; attachment 2).

Results from the Northern Fisheries Research Committee's Trawl Fisheries Assessment Working Group are reported in unpublished reports, copies of which are held in the Fisheries Division Library (GPO Box 990, Darwin, NT 0801, phone 08-89244165):

Blaber, S., Staples, D., McLoughlin, K., Newton, G., Campbell, R., Brewer, D., Stevens, J., Ramm, D., Buckworth, R., Slack-Smith, R., Hall, N., Johnson, G., Adisukresno, S., Naamin, N., Badrudin, M., and Muchsin, I. (1992). Stock Assessment Working Group Report, Australia-Indonesia Workshop on Arafura Sea Fisheries, Darwin, 1992.

McLoughlin, K., and Ramm, D.C. (Eds) (1994). Stock Assessment Working Group Report, Australia-Indonesia Workshop on Arafura Sea Fisheries, October 1994, Darwin

Sainsbury, K., Campbell, R., Brewer, D., Harris, A., McLoughlin, K., Ramm, D., Staples, D., Xiao, Y., and Knuckey, I. (1991). Trawl Fisheries Assessment Working Group Report, Northern Fisheries Research Committee, Canberra.

Stock assessments and management recommendations based on survey data and gear calibration experiments are also summarised in:

McLoughlin, K., Staples, D., and Ramm, D. (1994). Northern Fish Trawl, pp. 25-30. In 'Fishery Status Reports 1993 - Resource Assessments of Australian Commonwealth Fisheries' (Eds McLoughlin, K., Staples, D., and Maliel, M.). Bureau of Resource Sciences, Canberra.

Ramm, D., and McLoughlin, K. (1995). Northern Trawl Fishery, pp. 25-29. In 'Fishery Status Reports 1994 - Resource Assessments of Australian Commonwealth Fisheries' (Eds McLoughlin, K., Wallner, B., Staples, D.). Bureau of Resource Sciences, Canberra.

Staples, D. (ED.) (1992). Northern Fish Trawl. Fishery Status Report, Bureau of Rural Resources, Canberra.

Other project findings are published in:

Ramm, D.C. (1995). Collaborative research and management - the key to the sustainable management of groundfish resources in the Timor and Arafura Seas. Proceedings of the conference on "Neighbours at Sea - The Shared Interests of Australia and Indonesia in the Timor and Arafura Seas", Darwin, November 1995, and Australian Centre for Maritime Studies, *Maritime Studies*, **85**, 4-12. (Attachment 4)

Ramm, D.C. (1995). Dynamics of the deepwater snapper (*Pristipomoides*) resource in the Timor Sea. South Pacific Commission and Forum Fisheries Agency Workshop on the Management of South Pacific Inshore Fisheries. Manuscript collection of country statements and background papers - Volume II. South Pacific Commission. *Integrated Coastal Fisheries Management Project Technical Document,* **12**, 23-38. (Attachment 2)

Ramm, D.C., and Xiao, Y. (1995). Herding of groundfish and effective pathwidth of trawls. *Fisheries Research*, **24**, 243-259. (Attachment 1)

Xiao, Y., and Ramm, D.C. (1994). A simple generalized model of allometry, with examples of length and weight relationships for 14 species of groundfish. *US Fisheries Bulletin*, **92**, 664-70. (Attachment 3)

Project findings and related research were also communicated at Industry workshops, local seminars and national and international scientific meetings:

- 1990 Fisheries Assessment Working Group (Canberra);
- 1991 Fisheries Assessment Working Group (Canberra);
- 1991 Northern Prawn Fishery pre-season workshop (Cairns);
- 1991 Conference Australian Marine Science Association (Brisbane);
- 1991 Conference Australian Fish Biology Society (Hobart);
- 1992 Australian-Indonesian Stock Assessment Workshop on the Arafura Sea (Darwin);
- 1992 NT Industry Workshops (Darwin, January and December);
- 1992 Northern Prawn Fishery pre-season workshop (Cairns);
- 1992 Asian Fisheries Forum (Singapore);
- 1993 Indo-Pacific Fish Conference Workshop (Maumere);
- 1993 Workshop of Tropical Snappers and Groupers (Campeche);
- 1993 CalCOFI Conference (Los Angeles);
- 1993 Regional Conference Australian Marine Science Association (Darwin);
- 1994 Australia-Indonesia Workshop on Arafura Sea Fisheries (Darwin);
- 1994 Fisheries Seminar Series, University of British Columbia (Vancouver);
- 1995 Stock Assessment Workshop (Darwin);
- 1995 South Pacific Commission Workshop on Coastal Fisheries Resource Management (Noumea); and,
- 1996 Review of Northern Territory Fisheries (Darwin).

Species distributions

At least 482 species were recorded during the 1990 survey (Table 3). Of these, approximately 20 species were new records for northern Australian waters, including a rare specimen of eagle ray *Aetomylaeus vespertilio*, the first recorded capture of this species since it was described by Bleeker in 1852 based on a specimen caught off Indonesia. In addition, 2-3 other species are being identified by NT Museum staff, and may represent new species. Voucher specimens were lodged with the Museum and Art Gallery of the Northern Territory.

The most abundant species of fish, by weight, recorded during the 1990 survey was saddle-tailed snapper, which occurred in 71% of the samples and accounted for 7.3% of the total weight of fish. The most frequently caught fish was the long-nosed tripod fish (88% of the samples), followed by the grey lizardfish. The top-10 species of fish accounted for about 35% of the total weight of fish recorded during that survey, and the top-40 species accounted for 74% of the total catch (Table 4).

Distribution maps, based on survey data collected in 1990 and 1992, are given for:

- saddle-tail snapper (Fig. 5);
- scarlet snapper (Fig. 6);
- red emperor (Fig. 7);
- gold-band snapper (Fig. 8);
- sharp-tooth snapper (Fig. 9);
- one-band snapper (Fig. 10);
- rosy threadfin-bream (Fig. 11);
- ornate threadfin-bream (Fig. 12);
- painted sweetlip (Fig. 13);
- red-spot emperor (Fig. 14);
- sunrise goatfish (Fig. 15);

Species mean and maximum CPUE values recorded during the 1990 survey, together with some statistics for interpreting the distribution plots, are summarised in Table 5.

Table 3. Checklist, weight (kg) and occurrence of fish collected during the 1990 survey of the Australian sectors of the Timor and Arafura Seas, between longitudes 127-137°E. The 8-digit species code is the Code for Australian Aquatic Biota.

Scientific Name	Common Name	Species Code	Weight (kg)	Occurrence (n=206)
bullhead sharks				
Heterodontus zebra	Japanese bullhead shark	37007002	1.43	1
catsharks				
Atelomycterus sp	long-lipped spotted catshark	37015005	0.14	2
Chiloscyllium punctatum	brown-spotted catshark	37013008	1.50	1
Halaelurus sp 1	short-lipped spotted catshark	37015004	3.90	10
Stegostoma varium	leopard catshark	37013006	175.00	6
gummy sharks				
Mustelus mananzo	black tip gummy shark	37017004	1.03	1
Mustelus sp	grey gummy shark	37017005	5.30	3
Triakidae	gummy sharks	37017000	0.51	1
sharks				
Carcharhinus amboinensis	Java shark	37018026	22.00	1
Carcharhinus dussumieri	wide-mouthed blackspot shark	37018009	764.02	96
Carcharhinus macloti	shark	37018025	4.22	2
Carcharhinus plumbeus	sandbar shark	37018007	10.50	1
Carcharhinus sorrah	Sorrah shark	37018013	1.50	1
Carcharhinus tilstoni	blacktip shark	37018014	92.00	11
Hemigaleus microstoma	weasel shark	37018020	71.07	39
Hemipristis elongatus	fossil shark	37018011	142.70	8
Negaprion acutidens	lemon shark	37018029	100.00	1
Rhizoprionodon acutus	milk shark	37018006	129.23	27
Rhizoprionodon acutus	milk shark	37018066	2.67	2
Rhizoprionodon taylori	shark	37018024	9.27	4
hammerhead sharks				
Sphyrna blochii	slender hammerhead shark	37019003	1.20	1
Sphyrna lewini	scalloped hammerhead shark	37019001	6.23	8
Sphyrna mokarran	great hammerhead shark	37019002	100.00	1
dogfishes				
Squalus megalops	piked dogfish	37020006	1.46	3
sawfishes				
Pristis cuspidatus	narrow sawfish	37025002	331.50	5
shovelnose-rays				
Aptychotrema sp 1	shovelnose-ray	37027004	100.00	1
Rhina ancylostoma	shark ray	37026002	93.50	2
Rhinobatos sp 2	plain shovelnose-ray	37027005	1.15	2
Rhynchobatus djiddensis	white-spotted shovelnose-ray	37026001	1139.78	51
numbfishes				
Torpedinidae	numbfish	37028000	0.76	6
Narcine westraliensis	ornate numbfish	37028005	0.04	1
skates				
Irolita waitii	round skate	37031012	1.61	1
Raja sp 1	eyed skate	37031011	0.13	1
stingrays				
Amphotistius kuhlii	blue-spotted stingray	37035004	38.58	19
Amphotistius sp 1	brown stingray	37035012	25.36	3
Amphotistius sp 2	brown-reticulated stingray	37035013	0.88	6
Amphotistius sp 3	black-spotted stingray	37035014	55.22	59
Dasyatididae	stingrays	37035000	664.65	22

Dasyatis sephen	cowtail stingray	37035011	755.00	7
Dasyatis thetidis	black stingray	37035015	1410.00	11
Himantura toshi	coachwhip stingray	37035005	2056.78	75
Hymantura sp A	leopard-spotted "toshi"	37035902	100.00	1
Taeniura melanospila	stingray	37035017	150.00	1
rat-tailed rays				
Gymnura australis	rat-tailed ray	37037001	48.09	29
stingarees				
Urolophidae	stingarees	37038000	0.14	1
Urolophus sp 1	brown stingaree	37038009	2.09	3
eagle rays				
Aetobatus narinari	spotted eagle ray	37039003	60.00	1
Aetomylaeus nichofii	barbless duckbill ray	37039002	15.53	9
Myliobatididae	eagle rays	37039000	50.00	1
oxeye herrings				
Megalops cyprinoides	oxeye herring	37054001	5.90	2
eels				
Anguillidae	eels	37056000	0.01	1
Congridae	conger-eels	37067000	0.01	1
Gymnothorax sp 1	brown moray-eel	37060004	0.10	1
Gymnothorax sp 2	mottled moray-eel	37060005	0.52	2
Lumiconger arafura	black conger-eel	37067005	1.37	5
Muraenesox bagio	pike-eel	37063003	10.96	4
Muraenesox cinereus	dark-finned pike-eel	37063002	1.74	4
Muraenidae	moray-eels	37060000	0.11	3
sardines and herrings				
Amblygaster sirm	spotted sardine	37085006	0.21	1
Anodontostoma chacunda	bony-bream	37085015	15.97	5
Dussumieria elopsoides	slender rainbow sardine	37085010	29.74	27
Herklotsichthys koningsbergeri	large-spotted herring	37085007	0.08	1
Herklotsichthys lippa	small-spotted herring	37085008	33.37	24
Pellona ditchela	ditchelee	37085009	1349.65	82
Sardinella albella	perforated scale sardine	37085014	16.63	10
Sardinella gibbosa	gold-stripe sardine	37085013	13.69	13
anchovies				
Engraulididae	anchovies	37086000	0.54	7
Setipinna tenuifilis	Long-fin anchovy	37086008	90.08	6
Stolopherus indicus	Indian anchovy	37086006	13.47	28
Thryssa hamiltonii	hamilton's thryssa	37086005	2.22	4
Thryssa setirostris	longjaw thryssa	37086004	7.08	9
wolf-herrings				
Chirocentrus dorab	wolf-herring	37087001	57.99	58
herring smelts				
Argentinidae	herring smelts	37097000	0.03	2
Glossanodon sp	Glossanodon		0.31	4
lizardfishes				
Saurida longimanus	long-finned lizardfish	37118014	78.51	65
Saurida micropectoralis	short-finned lizardfish	37118005	427.84	124
Saurida sp 1	white-spotted lizardfish	37118006	143.26	59
Saurida sp 2	grey lizardfish	37118016	343.65	161
Saurida undosquamis	checkered lizardfish	37118001	186.99	50
Synodus hoshininis	black-shouldered lizardfish	37118010	2.18	42
Synodus indicus	Indian lizardfish	37118009	17.00	1
Synodus macrops	enigmatic lizardfish	37118012	0.37	3
Synodus sageneus	banded lizardfish	37118004	1.56	12
Synodus variegatus	variegated lizardfish	37118003	0.02	1

Trachynocephalus myops	painted saury	37118002	2.99	10
bombay-ducks				
Harpadon translucens	bombay-duck	37119001	98.93	6
cucumber fishes				
Chlorophthalmus nigromarginatu	cucumber fish	37120004	1.18	8
Chlorophthalmus sp	cucumber fish		0.45	2
lantern fishes				
Myctophidae	lantern fishes	37122000	6.60	7
barracudinas				
Lestidium atlanticum	barracudina	37126506	0.10	3
Lestrolepis japonica	barracudina	37126505	0.01	1
catfishes				
Ariidae	catfishes	37188000	0.35	2
Arius thalassinus	giant salmon catfish	37188001	433.39	108
Plotosidae	eel-tail catfishes	37192000	0.14	1
frogfishes				
Batrachomeus occidentalis	western frogfish	37205001	0.04	1
Batrachomeus trispinosus	frogfish	37205003	0.32	3
goosefishes				
Lophiomus setigerus	goosefish	37208001	2.45	10
anglerfishes				
Antennariidae	anglerfishes	37210000	0.02	2
Tathicarpus butleri	black-spot anglerfish	37210003	0.03	3
Tetrabrachium ocellatum	anglerfish	37210010	0.01	1
handfishes				
Dibranchus sp	ovate handfish	37212003	0.01	1
Halieutaea stellata	starry handfish	37212002	9.97	24
Malthopsis lutea	handfish	37212101	0.01	1
Ogcocephalidae	handfishes	37212000	0.01	1
unicorn cods				
Bregmacerotidae	unicorn cods	37225000	0.02	2
cusk-eels				
Hoplobrotula armata	cusk-eel		0.60	1
Ophidiidae	cusk-eels	37228000	1.75	7
Ophidion muraenolepis	black-edged cusk-eel	37228006	0.05	1
Sirembo imberbis	golden cusk-eel	37228005	0.15	3
Spottobrotula amaculata	cusk-eel	37228010	0.16	1
rattails				
Macrouridae	rattails	37232000	5.97	8
pineapple-fishes				
Monocentrus japonicus	Japanese pineapple-fish	37259002	32.58	17
squirrelfishes				
Ostichthys japonicus	Japanese squirrelfish	37261003	11.39	8
Sargocentron rubrum	red squirrelfish	37261001	77.94	45
dories				
Zenopsis nebulosus	mirror dory	37264003	1.02	1
Zeus faber	john dory	37264004	5.91	3
boarfishes				
Antigonia rhomboidea	pink boarfish	37267001	0.70	7
Antigonia rubescens	rosy boarfish		0.02	1
veilfins				
Velifer hypselopterus	high-finned veilfin	37269002	28.01	58
flutemouths				
Fistularia petimba	rough flutemouth	37278002	25.83	93
razor-fishes				
Centriscus scutatus	grooved razor-fish	37280001	3.91	20

seahorses				
Hippocampus histrix	seahorse	37282005	0.01	1
Syngnathidae	seahorses	37282000	0.12	1
scorpionfishes and stonefishes				
Apistus carinatus	long-finned waspfish	37287011	1.14	10
Brachypteruis serrulatus	butterfly-cod		0.04	1
Cottapistus cottoides	marbled stingfish	37287014	1.19	9
Dendrochirus zebra	many-spotted butterfly-cod	37287026	0.80	2
Erisphex potti	stingfish	37287033	0.51	3
Inimicus sinensis	spotted stonefish	37287020	1.67	12
Liocranium praepositum	blackspot scorpionfish	37287015	0.43	7
Minous coccineus	spotted stingfish	37287029	0.05	2
Minous trachycephalus	striped stingfish	37287024	0.01	1
Minous versicolor	plumb-striped stingfish	37287021	0.03	1
Neocentropogon sp	pale stingfish	37287035	0.14	4
Neocentropogon sp	butterfly-cod	37287100	0.02	1
Neomerinthe amplisquamiceps	orange scorpionfish	37287039	11.52	13
Pterois russelli	spotless butterfly-cod	37287012	1.23	13
Pterois volitans	ornate butterfly-cod	37287040	0.07	1
Scorpaenidae	scorpionfishes and stonefishes	37287000	0.07	4
Scorpaenodes smithi	little scorpionfish	37287032	0.04	1
Scorpaenopsis cirrhosa	weedy stingfish	37287038	0.26	6
Scorpaenopsis sp	yellow-finned scorpionfish	37287037	0.27	5
gurnards				
Gargariscus prionocephalus	shield head armoured gurnard	37288013	0.23	1
Lepidotrigla argus	long-finned gurnard	37288010	0.92	5
Lepidotrigla grandis	supreme gurnard	37288020	0.30	3
Lepidotrigla sp 1	blue-finned gurnard	37288016	120.52	86
Lepidotrigla sp 2	thin-finned gurnard	37288015	3.59	28
Lepidotrigla spiloptera	red-fringed gurnard	37288017	0.64	3
Pterygotrigla hemisticta	half-spotted gurnard	37288009	0.01	1
Pterygotrigla leptacanthus	dark fin gurnard	37288014	1.16	2
Satyrichthys rieffeti	spotted armoured-gurnard	37288021	10.22	11
Satyrichthys welchi	robust armoured-gurnard	37288019	0.05	1
Triglidae	gurnards	37288000	0.68	3
velvetfishes				
Erisphex aniarus	marbled wasp fish	37290002	0.03	1
flatheads				
Bembras japonicus	green-spotted flathead	37296026	0.21	1
Cymbacephalus nematophthalmus	fringe-eye flathead	37296023	0.85	1
Elates ransonneti	dwarf flathead	37296013	8.50	60
Onigocia macrolepis	notched flathead	37296025	0.02	1
Onigocia spinosa	spiny flathead	37296022	0.47	7
Platycephalidae	flatheads	37296000	0.10	4
Platycephalus arenarius	sand flathead	37296021	0.49	1
Platycephalus indicus	flathead	37296033	1.10	2
Ratabulus diversidens	oranged-freckled flathead	37296011	4.22	10
Rogadius asper	olive-tailed flathead	37296024	0.39	5
Sorsogona tuberculata	heart-headed flathead	37296030	0.08	2
Suggrundus bosschei	small-eyed flathead	37296031	0.13	1
Suggrundus harrisii	Harris's flathead	37296010	4.04	3
Suggrundus japonicus	Japanese flathead	37296029	12.69	25
Suggrundus macracanthus	large-spined flathead	37296012	9.88	47
Suggrundus rodricensis	white-finned flathead	37296019	4.25	43
Suggrundus sp 1	flathead	37296018	62.72	73

spiny flatheads				
Hoplichthyidae	spiny flatheads	37297000	0.44	6
flying-gurnards				
Dactyloptena papilio	large-spotted flying-gurnard	37308001	6.39	22
Dactyloptera peterseni	one-spined flying-gurnard	37308002	12.11	12
sea-moths				
Pegasus volitans	sea-moth	37309002	0.10	1
rock-cods and coral-trout				
Anthias sp	rock-cod	37311050	0.01	1
Callanthics sp	rock-cod	37311100	0.02	1
Cepholopholis boenack	brown-banded rock-cod	37311101	0.09	2
Chelidoperca sp 1	blue-spotted sea-bass	37311023	0.08	5
Doderleinia berycoides	cod	37311025	7.69	3
Epinephelus areolatus	yellow-spotted rock-cod	37311009	62.69	64
Epinephelus episticus	black-dotted rock-cod	37311046	0.21	1
Epinephelus heniochus	three-lined rock-cod	37311019	18.35	33
Epinephelus latifasciatus	spotty-finned rock-cod	37311043	3.81	4
Epinephelus maculatus	brown-spotted rock-cod	37311011	1.62	2
Epinephelus quoyanus	bar-breasted rock-cod	37311040	0.15	1
Epinephelus radiatus	rock-cod	37311042	0.45	2
Epinephelus rankini	Rankin's rock-cod	37311010	6.00	1
Epinephelus sexfasciatus	six-banded rock-cod	37311017	89.12	98
Epinephelus sp	rock-cod	37311018	3.00	2
Epinephelus suillus	Malabar rock-cod	37311007	119.24	30
Plectropomus maculatus	coral-trout	37311012	27.78	17
Serranidae	rock-cods and coral-trout	37311000	0.64	10
Synagrops philippinensis	sharp-toothed sea-bass	37311028	116.17	57
soapfishes				
Diploprion bifasciatum	two-banded soapfish	37312002	0.38	1
dottybacks				
Pseudochromis furescus ?	dottyback		0.02	1
Pseudochromis quinquedentatus	spiny dottyback	37313001	0.26	16
pearl-perches				
Glaucosoma magnificum	threadfin pearl-fish	37320002	3.68	4
grunters				
Pelates quadrilineatus	four-lined grunter-fish	37321001	8.44	6
Terapon jarbua	crescent grunter-perch	37321002	17.11	58
Terapon theraps	large-scaled grunter-perch	37321003	1152.43	62
banjosids				
Banjos banjos	banjosid	37322001	0.24	1
big-eyes				
Priacanthidae	big-eyes	37326000	0.12	1
Priacanthus hamrur	black-spot big-eye	37326005	13.07	11
Priacanthus macracanthus	large-spined big-eye	37326001	45.82	41
Priacanthus sp1	robust big-eye	37326009	4.39	9
Priacanthus tayenus	threadfin big-eye	37326003	452.23	128
Pristigenys niphonia	big-eye	37326006	1.67	3
cardinal-fishes				
Apogon albimaculosus	cream-spotted cardinal-fish	37327014	0.09	4
Apogon brevicaudatus	many-banded cardinal-fish	37327005	0.27	1
Apogon carinatus	ocellated cardinal-fish	37327027	0.10	4
Apogon ellioti	flag-fin cardinal-fish	37327013	0.77	26
Apogon melanopus	monster cardinal-fish	37327016	4.47	7
Apogon nigripinnis	yellow ring cardinal-fish	37327009	0.66	14
Apogon poecilopterus	pearly-finned cardinal-fish	37327026	4.56	62

Apogon quadrifasciatus	broad-banded cardinal-fish	37327008	33.64	41
Apogon semilineatus	black-tipped cardinal-fish	37327004	0.03	1
Apogon septemstriatus	seven-banded cardinal-fish	37327012	24.88	104
Apogon sp 1	cardinal-fish	37327025	0.02	1
Apogon sp 2	faint-banded cardinal-fish	37327029	0.03	2
Apogonidae	cardinal-fishes	37327000	0.01	1
Rhabdamia gracilis	slender cardinal-fish	37327022	0.27	8
bass				
Acropoma japonicum	Japanese bass	37328001	220.35	50
whitings				
Sillago sp	whiting	37330000	12.60	17
tile-fishes				
Branchiostegus sawakinensis	tile-fish	37331001	3.99	13
false trevallies				
Lactarius lactarius	false trevally	37333001	8.43	4
black kingfishes				
Rachycentron canadus	black kingfish	37335001	87.16	32
suckerfishes				
Echeneis naucrates	slender suckerfish	37336001	13.29	30
trevallies, scads and queenfishes				
Absalom radiatus	fringe-finned trevally	37337047	6.02	2
Alectis ciliaris	round-headed pennantfish	37337018	4.01	8
Alectis indicus	high-brow pennantfish	37337038	658.88	11
Alepes sp *(melanoptera)*	small-mouth scad	37337051	190.42	83
Alute mate	yellow-tail scad	37337024	55.40	36
Apolectus niger	black pomfret	37339001	102.38	47
Carangidae	trevallies, scads and queenfish	37337000	0.09	6
Carangoides chrysophrys	long-nosed trevally	37337011	112.89	72
Carangoides equula	whitefin trevally	37337013	13.18	24
Carangoides fulvoguttatus	yellow-spotted trevally	37337037	1.72	2
Carangoides gymnostethus	bludger trevally	37337022	2.43	6
Carangoides hedlandensis	bump-nosed trevally	37337042	20.36	26
Carangoides humerosus	epaulet trevally	37337031	166.86	64
Carangoides malabaricus	Malabar trevally	37337005	432.55	84
Carangoides talamparoides	white-tongued trevally	37337043	15.05	7
Carangoides uii	onion trevally	37337021	571.74	93
Caranx bucculentus	blue-spotted trevally	37337016	894.35	56
Caranx ignobilis	giant trevally	37337027	23.98	7
Caranx para	banded scad	37337036	4.23	4
Caranx tille	Tille trevally	37337049	33.68	6
Decapterus kurroides	mackerel scad	37337056	2.76	2
Decapterus macarellus	mackerel scad	37337055	2.93	6
Decapterus macrosoma	slender scad	37337017	0.59	5
Decapterus russellii	Indian scad	37337023	909.35	82
Gnathanodon speciosus	golden trevally	37337012	30.31	7
Megalaspis cordyla	finny scad	37337028	18.93	18
Scomberoides commersonianus	Talang queenfish	37337032	12.07	4
Scomberoides tol	needle-scaled queenfish	37337044	26.16	34
Selar boops	ox-eye scad	37337008	520.97	78
Selar crumenophthalmus	big-eye scad	37337009	74.02	36
Selaroides leptolepis	yellow-striped trevally	37337015	881.12	72
Seriolina nigrofasciata	black-banded kingfish	37337014	69.78	77
Ulua aurochs	mirror-mouthed trevally	37337041	141.16	55
Uraspis uraspis	white-tongued jack	37337020	29.31	42
moon-fishes				
Mene maculata	moon-fish	37340001	76.10	31

ponyfishes				
Gazza minuta	toothed ponyfish	37341007	149.63	40
Leiagnathus aureus	false toothed ponyfish	37341018	21.30	50
Leiognathus bindus	orange-tipped ponyfish	37341002	999.91	138
Leiognathus blochii	ponyfish	37341013	2.58	7
Leiognathus decorus	ornate ponyfish	37341016	175.67	6
Leiognathus elongatus	elongate ponyfish	37341011	2.97	7
Leiognathus equulus	narrow-banded ponyfish	37341014	208.72	17
Leiognathus fasciatus	broad-banded ponyfish	37341009	57.60	21
Leiognathus leucuscus	whipfin ponyfish	37341005	210.92	17
Leiognathus moretoniensis	ponyfish	37341012	148.42	90
leiognathus smithursti	Smithurst's ponyfish	37341004	0.18	1
Leiognathus sp	vermiculated ponyfish	37341003	175.56	22
Leiognathus splendens	black-tipped ponyfish	37341010	153.53	4
Secutor insidiator	pugnose ponyfish	37341006	210.96	42
Secutor ruconius	deep pugnose ponyfish	37341015	4.17	3
fusiliers				
Caesio cuning	yellow tail fusilier	37346018	10.84	3
Dipterygonotus balteatus	mottled fusilier	37346013	0.04	3
Pterocaesio digramma	twin yellow-striped fusilier	37346009	24.60	15
sea perches and snappers				
Lipocheilus carnolabrum	snapper	37346031	2.04	1
Lutjanidae	tropical snappers	37346000	1.49	1
Lutjanus argentimaculatus	mangrove-jack	37346015	21.57	5
Lutjanus bitaeniatus	snapper	37346025	11.81	4
Lutjanus carponotatus	stripey	37346011	14.59	6
Lutjanus erythropterus	scarlet snapper	37346005	438.10	24
Lutjanus johni	golden snapper	37346030	28.41	5
Lutjanus lemniscatus	maroon sea-perch	37346010	0.80	1
Lutjanus lutjanus	big-eye sea-perch	37346008	88.84	26
Lutjanus malabaricus	saddle-tailed snapper	37346007	3483.63	142
Lutjanus quinquelineatus	five-lined snapper	37346006	2.31	2
Lutjanus russelli	Russell's snapper	37346012	161.52	81
Lutjanus sebae	red emperor	37346004	270.39	61
Lutjanus timorensis	Timor snapper		95.90	7
Lutjanus vittus	one-band snapper	37346003	826.18	114
Pristipomoides multidens	gold-band snapper	37346002	420.75	82
Pristipomoides typus	sharp-tooth snapper	37346019	86.20	14
Symphorus nematophorus	chinaman snapper	37346017	16.50	2
threadfins, monocle-breams				
Nemipteridae	threadfin/monocle-breams	37347000	0.35	3
Nemipterus balinensis	threadfin-bream		2.73	2
Nemipterus bathybius	threadfin-bream	37347001	119.76	40
Nemipterus celebicus	five-lined threadfin-bream	37347004	124.86	46
Nemipterus furcosus	rosy threadfin-bream	37347005	598.81	76
Nemipterus hexodon	ornate threadfin-bream	37347014	1013.33	144
Nemipterus isacanthus	twin-lined threadfin-bream	37347019	68.01	27
Nemipterus marginatus	red filament threadfin-bream	37347016	1.19	5
Nemipterus metopias	yellow-cheeked threadfin-bream	37347013	1.86	7
Nemipterus nematopus	yellow-tipped threadfin-bream	37347002	566.94	96
Nemipterus peronii	notched threadfin-bream	37347003	146.84	69
Nemipterus virgatus	yellow-lipped threadfin-bream	37347009	41.02	27
Parascolopsis eriomma	monocle-bream	37347015	25.00	2
Parascolopsis sp 2	yellow-bellied dwarft monocle-bream	37347010	6.37	26
Pentapodus porosus	north-west whiptail	37347007	56.64	29
Scolopsis monogramma	threadfin monocle-bream	37347006	31.77	17

Scolopsis taeniopterus	red-spot monocle-bream	37347008	271.71	83
Scolopsis vosmeri	white-cheeked monocle-bream	37347018	0.43	5
silver-biddies				
Gerres filamentosus	whipfin silver-biddy	37349003	191.95	43
Gerres subfasciatus	banded silver-biddy	37349005	43.91	17
Pentaprion longimanus	long-finned silver-biddy	37349002	1605.23	148
sweetlips, javelin-fishes				
Diagramma pictum	painted sweetlip	37350003	903.33	86
Hapalogenys kishinouyei	lined javelin-fish	37350001	20.02	21
Plectorhinchus polytaenia	ribboned sweetlip	37350005	2.09	1
Pomadasys argenteus	white-finned javelin-fish	37350009	0.34	1
Pomadasys kaakan	yellow-finned javelin-fish	37350004	52.94	12
Pomadasys maculatum	blotched javelin-fish	37350002	1737.09	21
Pomadasys trifasciatus	javelin-fish		116.78	5
emperors, sea-breams				
Gymnocranius elongatus	swallow-tail sea-bream	37351010	23.53	8
Gymnocranius robinsoni	blue-lined sea-bream	37351005	13.65	7
Lethrinus choerorynchus	lesser spangled emperor	37351001	0.96	2
Lethrinus fraenatus	blue-lined emperor	37351006	85.57	28
Lethrinus lentjan	red-spot emperor	37351007	399.97	59
Lethrinus nematacanthus	threadfin emperor	37351002	72.63	19
Lethrinus variegatus	variegated emperor	37351014	6.14	5
snappers				
Argyrops spinifer	long-spined sea-bream	37353006	35.64	26
Dentex tumifrons	deepsea snapper	37353002	13.20	2
croakers				
Argyrosomus sp	orange croaker	37354012	15.61	3
Johnius amblycephalus	green-backed croaker	37354009	0.69	1
Johnius vogleri	sharp-toothed hammer croaker	37354007	29.71	16
Protonibea diacanthus	black jewfish	37354003	24.71	3
Sciaenidae	croakers	37354000	299.95	17
goatfishes				
Mullidae	goatfishes	37355000	0.21	3
Parupeneus chrysopleuron	yellow-banded goatfish	37355016	2.23	7
Parupeneus pleurospilus	spotted golden goatfish	37355004	99.19	44
Upeneus asymmetricus	gold-band orange-barred goatfi	37355010	73.39	27
Upeneus bensasi	bar-tailed goatfish	37355002	53.26	60
Upeneus luzonius	dark-barred goatfish	37355009	14.16	16
Upeneus moluccensis	gold-band goatfish	37355003	467.06	64
Upeneus sp	orange-barred goatfish	37355008	117.78	86
Upeneus sp 2	goatfish	37355222	85.27	6
Upeneus sulphureus	sunrise goatfish	37355007	1005.45	99
Upeneus sundaicus	ochre-banded goatfish	37355013	49.11	17
Upeneus tragula	spotted goatfish	37355014	1.32	3
batfishes				
Drepane punctata	spotted batfish	37362005	2.64	4
Ephippididae	batfishes	37362000	0.74	1
Platax batavianus	hump-headed batfish	37362002	120.90	45
Platax teira	round-face batfish	37362004	0.01	1
Zabidius novemaculatus	nine-spined batfish	37362003	57.13	38
threadfin scats				
Rhinoprenes pentanemus	threadfin scat	37364001	35.89	5
butterflyfishes, coralfishes				
Chaetodon aureofasciatus	golden-striped butterflyfish	37365013	0.04	1
Chaetodon modestus	butterflyfish	37365006	3.46	13
Chelmon marginalis	margined coralfish	37365007	0.67	3

Chelmon mulleri	Muller's coralfish	37365015	2.11	11
Coradion altivelis	highfin coralfish	37365018	0.80	5
Coradion chrysozonus	orange-banded coralfish	37365004	4.77	28
Heniochus diphreutes	schooling bannerfish	37365005	0.65	2
Parachaetodon ocellatus	ocellate coralfish	37365003	3.83	24
angelfishes				
Chaetodontoplus duboulayi	scribbled angelfish	37365009	40.57	26
Chaetodontoplus personifer	yellow-tail angelfish	37365008	13.79	14
Pomacanthus sexstriatus	six-banded angelfish	37365010	1.46	1
deep sea boarfishes				
Histiopterus typus	deep sea boarfish	37367008	3.51	3
damselfishes				
Pomacentridae	damselfishes	37372000	0.01	1
pullers				
Pristotis jerdoni	green puller	37372001	10.80	21
sea-pikes				
Sphyraena forsteri	blotched sea-pike	37382005	157.36	73
Sphyraena obtusata	long-finned sea-pike	37382001	84.53	58
Sphyraena putnamiae	military sea-pike	37382006	506.92	71
Sphyraenidae	sea-pikes	37382000	0.01	1
threadfins				
Polydactylus multiradiatus	Gunther's threadfin	37383002	28.51	8
Polydactylus nigripinnis	black-finned threadfin	37383001	161.60	11
Polynemidae	threadfins	37383000	8.24	3
wrasses, tuskfishes				
Anampses lennardi	blue and yellow wrasse	37384016	0.41	1
Choerodon cephalotes	purple tuskfish	37384004	18.07	11
Choerodon monostigma	dark-spot tuskfish	37384008	118.59	91
Choerodon schoenleinii	blue tuskfish	37384010	14.16	4
Choerodon sp 2	wedge-tailed wrasse	37384009	15.68	22
Choerodon vitta	red-spot tuskfish	37384006	0.76	3
Labridae	wrasses and tuskfishes	37384000	0.11	1
Xiphocheilus typus	blue-toothed tuskfish	37384014	0.40	10
Xyrichtys jacksonensis	purple-spotted wrasse	37384012	0.59	2
parrotfishes				
Scarus ghobban	blue-barred orange parrotfish	37386001	5.83	8
jawfishes				
Opisthognathus latitabundus	blotched jawfish	37388001	0.14	1
grubfishes				
Mugiloididae	grubfishes	37390000	0.01	1
Parapercis alboguttata	blue-nosed grubfish	37390006	1.32	7
Parapercis nebulosa	red-barred grubfish	37390003	1.06	4
Percophids				
Percophidae	Percophid	37393000	0.01	1
Bembrops curratura	Bembrops		0.47	9
stargazers				
Uranoscopus cognatus	two-spined yellow-tailed stargazer	37400008	9.46	47
Uranoscopus sp 1	white-spotted stargazer	37400009	0.66	4
Uranoscopus sp 2	one-spined yellow-tail stargazer	37400016	21.62	21
saber gills				
Champsodon longispinnis	saber gill	37401002	0.23	5
Champsodontidae	saber gills	37401000	20.74	62
blennies				
Xiphasia setifer	blenny	37408001	0.01	1

eel-blennies				
Congrogadoides amplimaculatus	eel-blenny	37411001	0.25	12
Congrogadoides spinifer	eel-blenny	37411002	0.01	1
sandlances				
Bleekeria viridianguilla	sandlance	37425002	0.06	2
dragonets				
Callionymidae	dragonets	37427000	0.16	5
Callionymus moretonensis	ocellated dragonet	37427003	1.38	28
Dactylopus dactylopus	fingered dragonet	37427005	0.01	1
gobies				
Gobiidae	gobies	37428000	0.12	9
surgeon fishes				
Acanthuridae	surgeon fish	37437000	0.50	2
Acanthurus grammoptilus	ring-tailed surgeon fish	37437002	0.27	1
spinefeet				
Siganus fuscescens	pin-spotted spinefoot	37438001	43.78	48
snake mackerels				
Gempylidae	snake mackerels	37439000	0.70	2
Rexia prometheoides	snake mackerel		5.97	9
hairtails				
Trichiurus lepturus	large-headed hairtail	37440004	1140.90	120
Tentoriceps cristatus	crested hairtail	37440006	5.82	14
mackerels, tunas				
Rastrelliger kanagurta	Indian mackerel	37441012	1732.09	115
Sarda orientalis	mackerel	37441006	2.42	2
Scomberomorus commerson	narrow-banded Spanish-mackerel	37441007	7.77	3
Scomberomorus munroi	Munro's Spanish-mackerel	37441015	62.39	29
Scomberomorus queenslandicus	school Spanish-mackerel	37441014	149.62	51
Scombridae	mackerels	37441000	0.01	1
Thunnus albacares	yellowfin tuna	37441002	0.01	1
butterfishes				
Psenopsis humerosa	black-spot butterfish	37445007	353.57	70
cube heads				
Nomeidae	cube heads	37446000	0.06	1
eye-brow fishes				
Ariomma indica	Indian eyebrow-fish	37447007	337.92	51
Ariomma brevimanus	eye-brow fish		0.89	1
halibuts				
Psettodes erumei	tropical halibut	37457001	101.57	96
citharids				
Brachypleura novaezeelandiae	yellow citharid	37458001	2.87	49
Citharidae	citharids	37458000	0.10	2
lefteye flounders				
Arnoglossus waitei	Waite's flounder	37460026	0.49	22
Bothidae	lefteye flounder	37460000	0.24	12
Engyprosopon grandisquama	mottled wide-eyed flounder	37460012	0.45	8
Grammatobothus polyophthalmus	three-spot flounder	37460010	3.63	53
Psettina gigantea	rough-scaled flounder	37460033	0.16	5
Pseudorhombus argus	peacock flounder	37460038	0.58	5
Pseudorhombus arsius	large-toothed flounder	37460009	3.59	10
Pseudorhombus diplospilus	four twin-spot flounder	37460015	8.01	44
Pseudorhombus dupliciocellatus	three twin-spot flounder	37460004	7.32	20
Pseudorhombus elevatus	deep-bodied flounder	37460008	5.23	50
Pseudorhombus spinosus	spiny flounder	37460011	4.00	22

righteye flounders				
Samaris cristatus	cockatoo righteye flounder	37461006	2.24	5
soles				
Dexillichthys muelleri	tufted sole	37462007	0.49	2
Soleidae	soles	37462000	0.03	1
Zebrias craticula	wicker-work sole	37462003	0.07	2
Zebrias quagga	zebra sole	37462004	0.04	1
tongue-soles				
Cynoglossidae	tongue-soles	37463000	12.24	21
Cynoglossus macrophthalmus	big-eyed tongue-sole	37463008	0.35	2
Trixiphichthys weberi	long-nosed tripodfish	37464001	719.59	175
tripodfishes				
Triacanthodes ethiops	tripodfish	37464003	0.03	2
triggerfishes, leatherjackets				
Abalistes stellaris	starry triggerfish	37465011	211.80	94
Alutera monoceros	unicorn leatherjacket	37465022	14.82	17
Anacanthus barbatus	beardie	37465010	0.14	6
Balistidae/Monacanthidae	triggerfishes, leatherjackets	37465000	0.24	1
Chaetoderma penicilligera	tasselled leatherjacket	37465013	0.82	5
Monacanthus chinensis	fan-bellied leatherjacket	37465009	0.71	2
Paramonacanthus filicauda	threadfin leatherjacket	37465024	22.58	43
Paramonacanthus japonicus	Japanese leatherjacket	37465017	1.19	15
Pseudomonacanthus elongatus	four-banded leatherjacket	37465029	1.33	3
Pseudomonacanthus peroni	pot-bellied leatherjacket	37465020	6.66	14
Thamnaconus hypargyreus	lesser-spotted leatherjacket	37465012	0.36	5
Thamnaconus striatus	leatherjacket	37465101	0.19	1
Thamnaconus tessellatus	highly spotted leatherjacket	37465026	0.43	1
boxfishes, turretfishes				
Rhynchostracion nasus	small-nosed boxfish	37466005	67.31	85
Rhynchostracion rhinorhynchus	horn-nosed boxfish	37466009	1.87	4
Tetrosomus gibbosus	black-blotched turretfish	37466006	4.96	14
toadfishes, pufferfishes				
Amblyrhynchotes spinosissimus	chinese puffer fish	37467022	3.39	6
Anchisomus multistriatus	many-striped pufferfish	37467010	0.19	5
Arothron reticularis	reticulated pufferfish	37467021	0.15	1
Arothron stellatus	starry pufferfish	37467014	6.71	12
Canthigaster rivulata	brown-lined toadfish	37467018	0.02	1
Chelonodon patoca	mottled pufferfish	37467015	1.60	5
Lagocephalus inermis	smooth golden pufferfish	37467008	3.49	12
Lagocephalus lunaris	rough golden pufferfish	37467012	84.23	26
Lagocephalus sceleratus	silver-stripe pufferfish	37467007	4.93	37
Lagocephalus spadiceus	half-smooth golden pufferfish	37467017	194.86	88
Tetraodontidae	toadfishes, pufferfishes	37467000	0.26	4
Torquigener pallimaculatus	orange-spotted toadfish	37467009	2.02	14
porcupine-fishes				
Cyclichthys hardenbergi	plain porcupine-fish	37469008	26.94	19
Cyclichthys jaculiferus	long-spined porcupine-fish	37469004	96.49	45
Cyclichthys orbicularis	short-spined porcupine-fish	37469007	0.21	3
Total Fish			47620	

Table 4. Top-40 species of fish, ranked by weight, recorded during the 1990 survey of the Australian sectors of the Timor and Arafura Seas, between longitudes 127-137°E (n=206).

Rank	Scientific Name	Common Name	Weight		Occurrence
			(% total)	(% cumul)	(%)
1	*Lutjanus malabaricus*	saddle-tailed snapper	7.3	7.3	71
2	*Himantura toshi*	coachwhip stingray	4.3	11.6	38
3	*Pomadasys maculatum*	blotched javelin-fish	3.6	15.3	11
4	*Rastrelliger kanagurta*	Indian mackerel	3.6	18.9	58
5	*Pentaprion longimanus*	long-finned silver-biddy	3.4	22.3	74
6	*Dasyatis thetidis*	black stingray	3.0	25.3	6
7	*Pellona ditchela*	ditchelee	2.8	28.1	41
8	*Terapon theraps*	large-scaled grunter-perch	2.4	30.5	31
9	*Trichiurus lepturus*	large-headed hairtail	2.4	32.9	60
10	*Rhynchobatus djiddensis*	white-spotted shovelnose-ray	2.4	35.3	26
11	*Nemipterus hexodon*	ornate threadfin-bream	2.1	37.4	73
12	*Upeneus sulphureus*	sunrise goatfish	2.1	39.5	50
13	*Leiognathus bindus*	orange-tipped ponyfish	2.1	41.6	69
14	*Decapterus russellii*	Indian scad	1.9	43.5	41
15	*Diagramma pictum*	painted sweetlip	1.9	45.4	43
16	*Caranx bucculentus*	blue-spotted trevally	1.9	47.3	28
17	*Selaroides leptolepis*	yellow-striped trevally	1.9	49.2	36
18	*Lutjanus vittus*	one-band snapper	1.7	50.9	57
19	*Carcharhinus dussumieri*	wide-mouthed blackspot shark	1.6	52.5	48
20	*Dasyatis sephen*	cowtail stingray	1.6	54.1	4
21	*Trixiphichthys weberi*	long-nosed tripodfish	1.5	55.6	88
22	*Dasyatididae*	stingrays	1.4	57.0	11
23	*Alectis indicus*	high-brow pennantfish	1.4	58.4	6
24	*Nemipterus furcosus*	rosy threadfin-bream	1.3	59.6	38
25	*Carangoides uii*	onion trevally	1.2	60.8	47
26	*Nemipterus nematopus*	yellow-tipped threadfin-bream	1.2	62.0	48
27	*Selar boops*	ox-eye scad	1.1	63.1	39
28	*Sphyraena putnamiae*	military sea-pike	1.1	64.2	36
29	*Upeneus moluccensis*	gold-band goatfish	1.0	65.2	32
30	*Priacanthus tayenus*	threadfin big-eye	0.9	66.1	64
31	*Lutjanus erythropterus*	scarlet snapper	0.9	67.0	12
32	*Arius thalassinus*	giant salmon catfish	0.9	68.0	54
33	*Carangoides malabaricus*	Malabar trevally	0.9	68.9	42
34	*Saurida micropectoralis*	short-finned lizardfish	0.9	69.8	62
35	*Pristipomoides multidens*	gold-band snapper	0.9	70.6	41
36	*Lethrinus lentjan*	red-spot emperor	0.8	71.5	30
37	*Psenopsis humerosa*	black-spot butterfish	0.7	72.2	35
38	*Saurida* sp 2	grey lizardfish	0.7	72.9	81
39	*Ariomma indica*	Indian eyebrow-fish	0.7	73.7	26
40	*Pristis cuspidatus*	narrow sawfish	0.7	74.4	3
		other fish (442 taxa)	25.7	100.0	

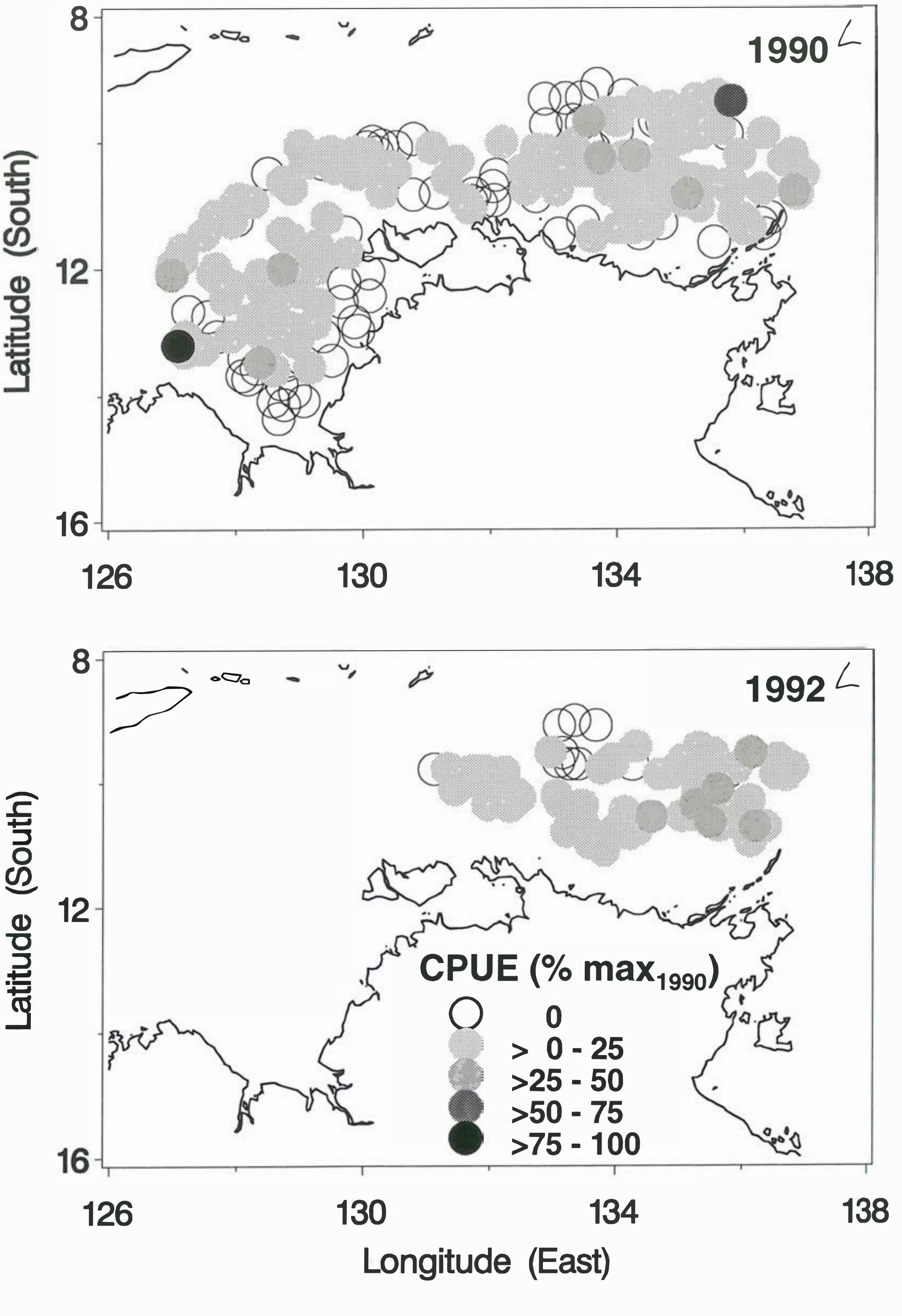

Figure 5. Distribution of saddle-tail snapper (*Lutjanus malabaricus*) based on catch data from the 1990 and 1992 trawl surveys. The maximum CPUE during the 1990 survey was 498 kg/h.

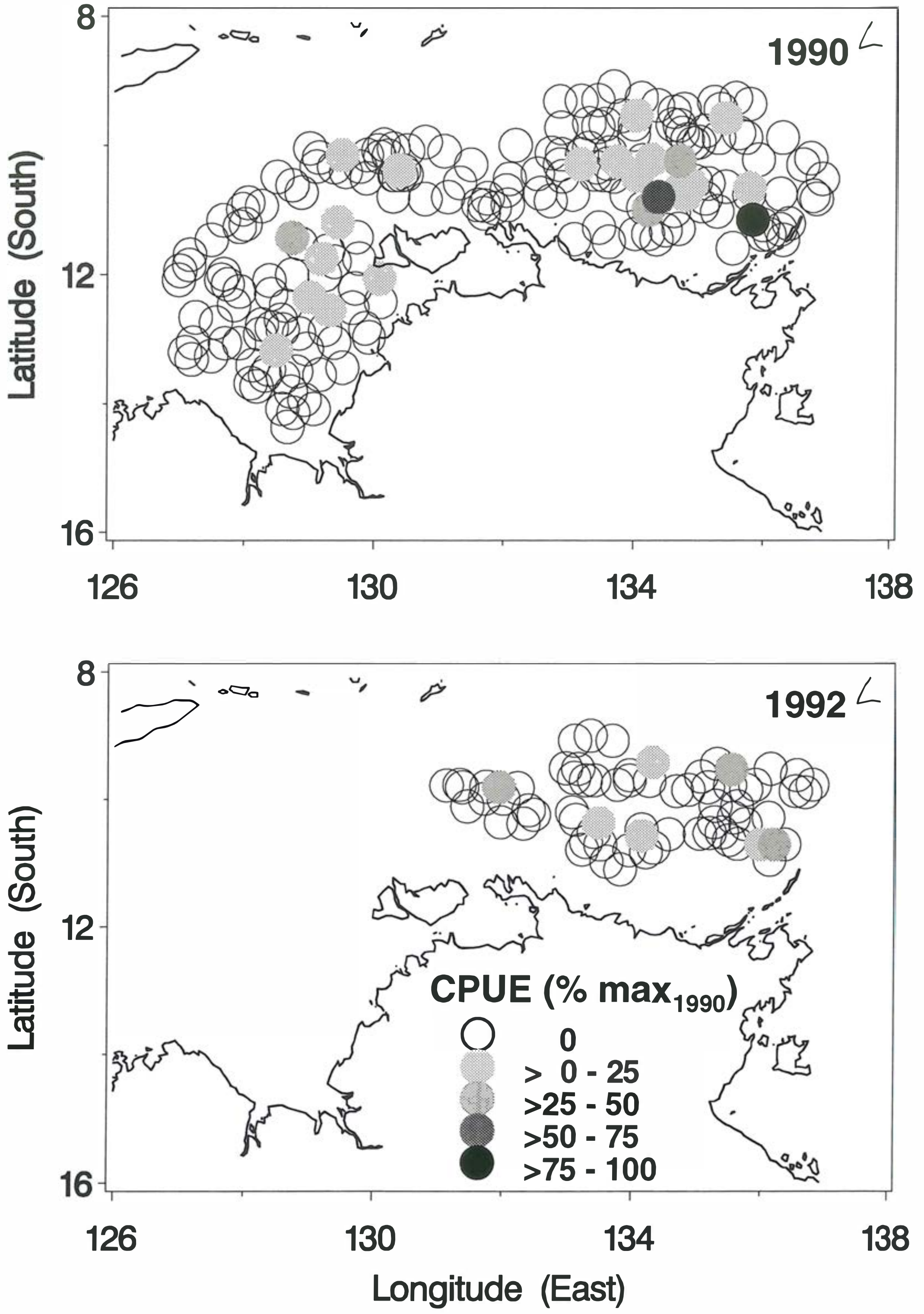

Figure 6. Distribution of scarlet snapper (*Lutjanus erythropterus*) based on catch data from the 1990 and 1992 trawl surveys. The maximum CPUE during the 1990 survey was 254 kg/h.

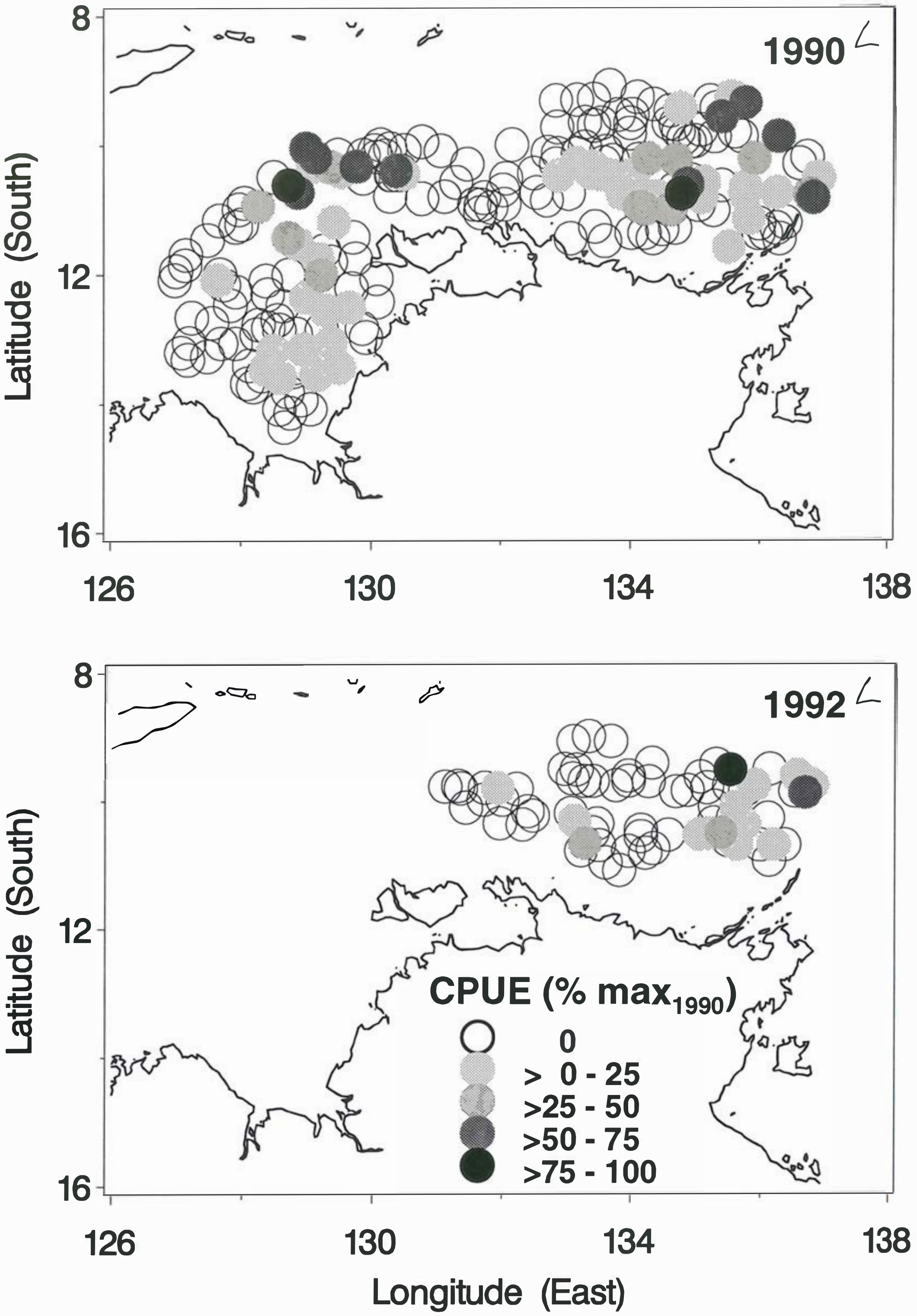

Figure 7. Distribution of red emperor (*Lutjanus sebae*) based on catch data from the 1990 and 1992 trawl surveys. The maximum CPUE during the 1990 survey was 32 kg/h.

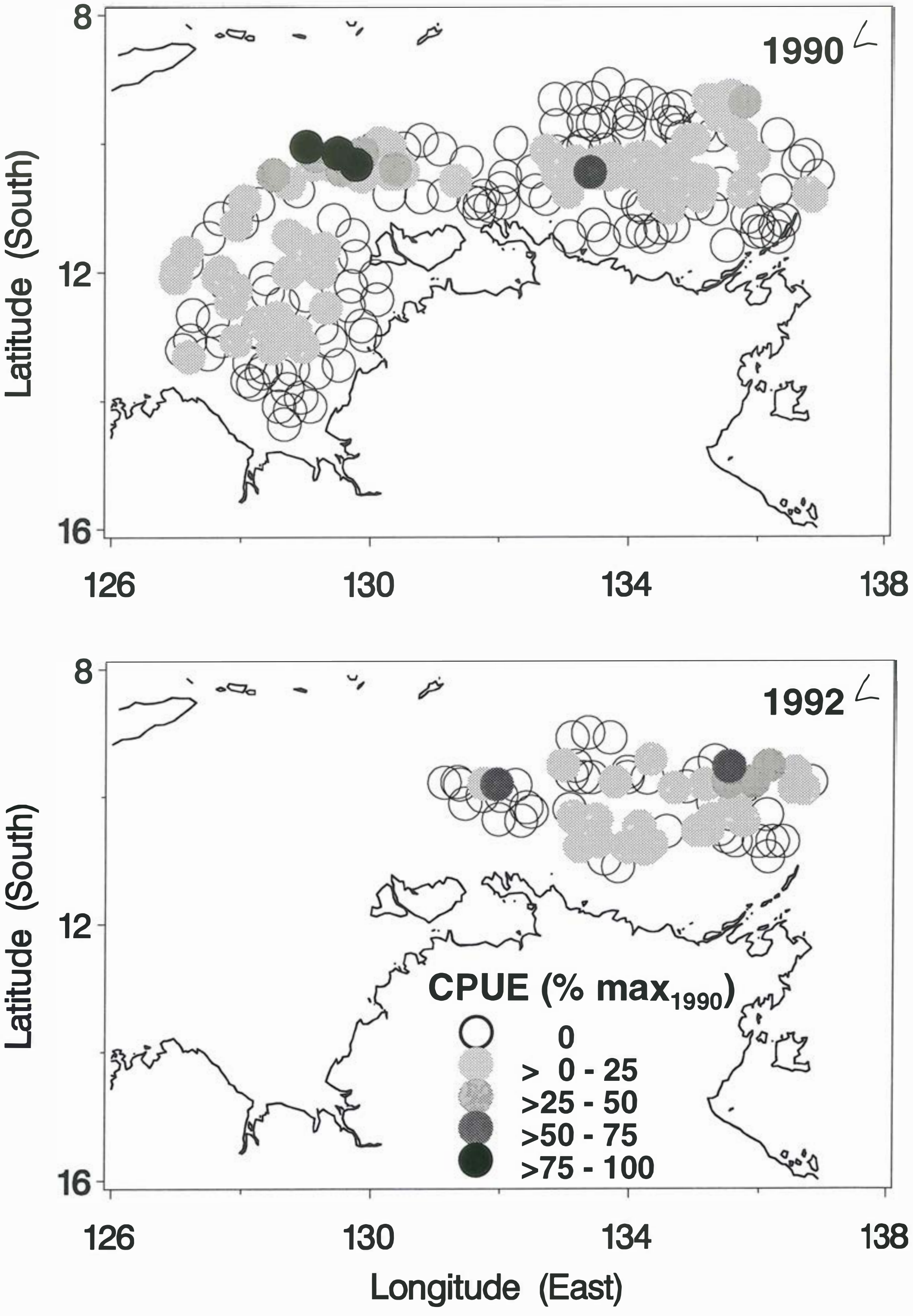

Figure 8. Distribution of gold-band snapper (*Pristipomoides multidens*) based on catch data from the 1990 and 1992 trawl surveys. The maximum CPUE during the 1990 survey was 79 kg/h.

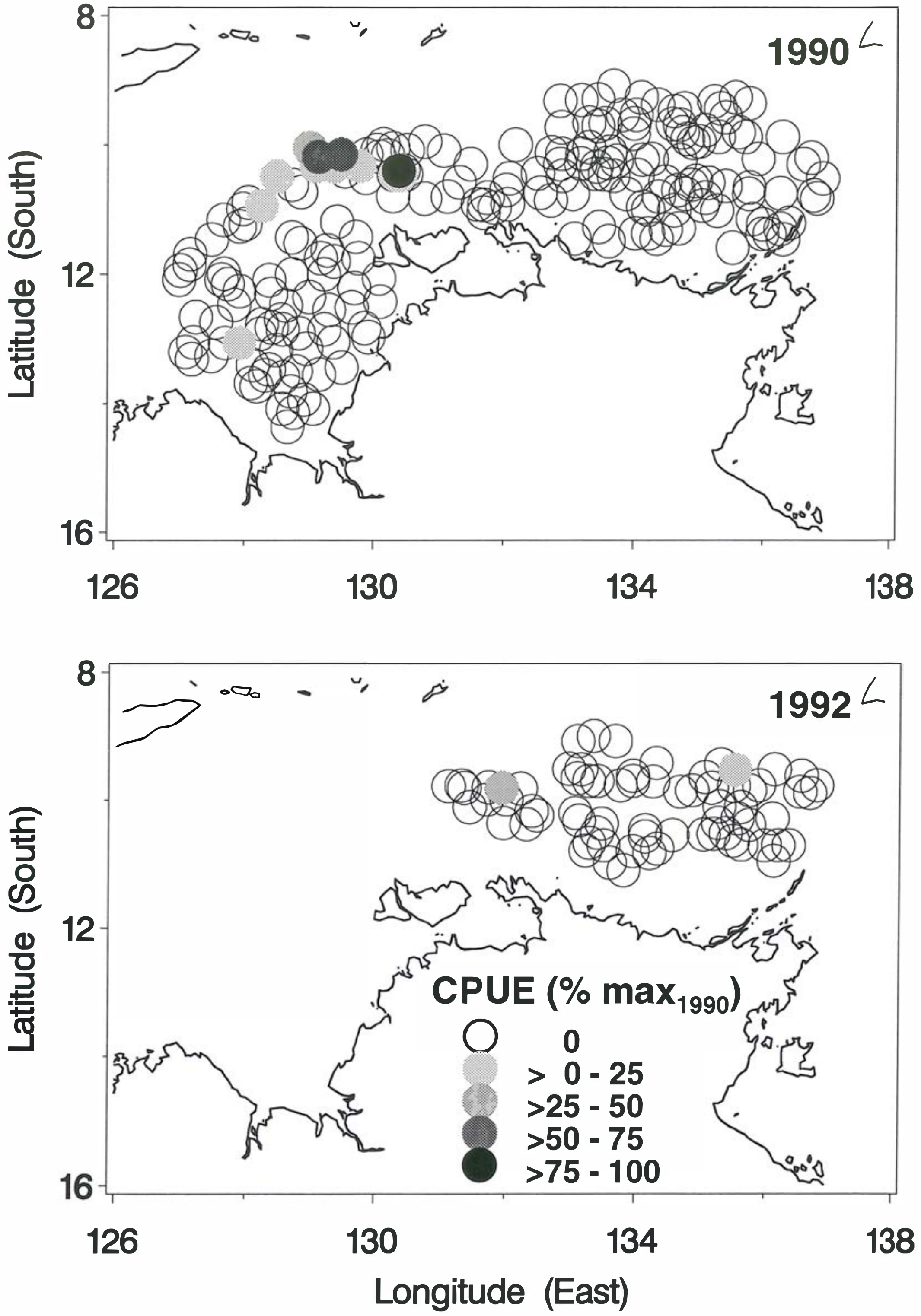

Figure 9. Distribution of sharp-tooth snapper (*Pristipomoides typus*) based on catch data from the 1990 and 1992 trawl surveys. The maximum CPUE during the 1990 survey was 48 kg/h.

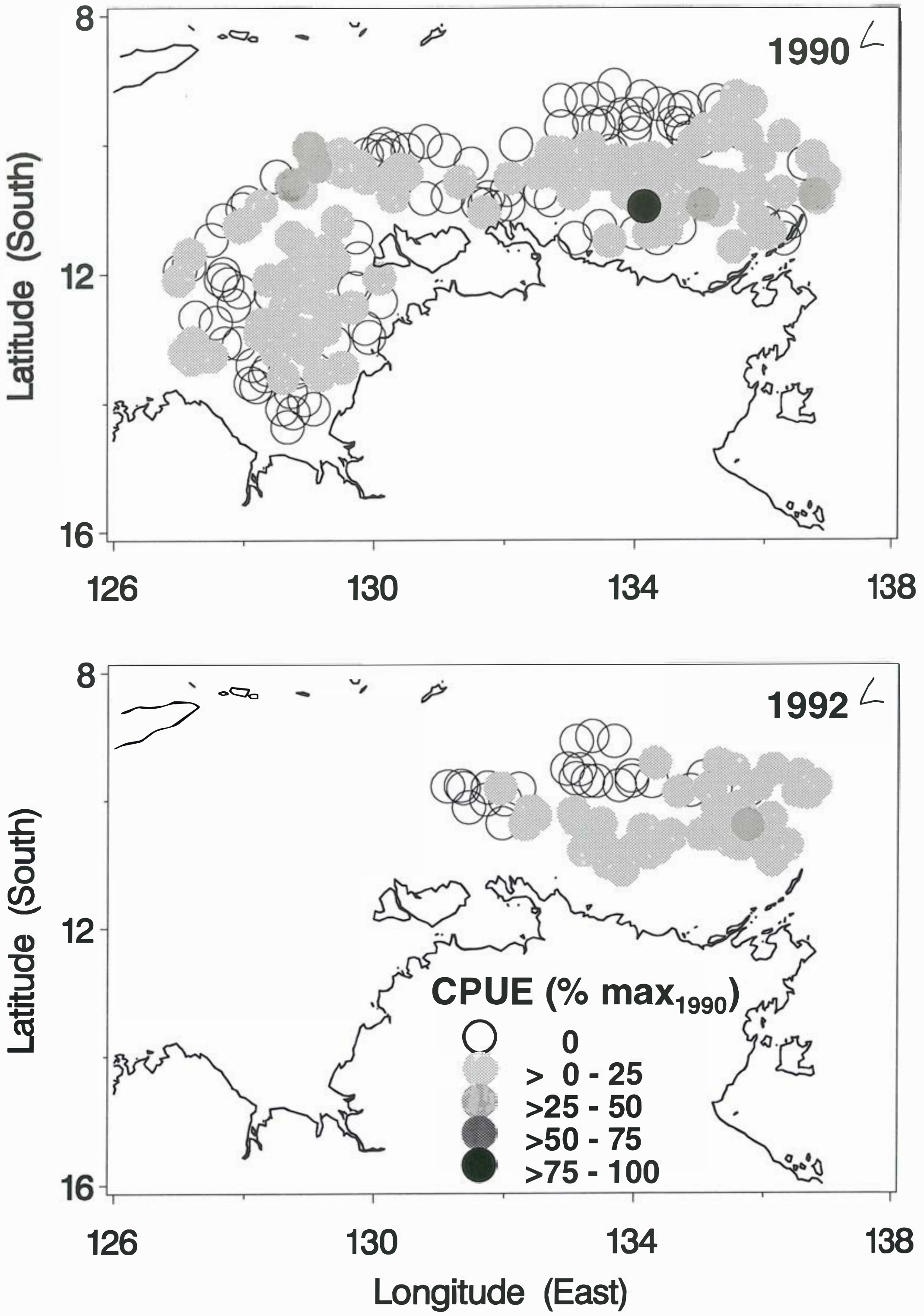

Figure 10. Distribution of one-band snapper (*Lutjanus vittus*) based on catch data from the 1990 and 1992 trawl surveys. The maximum CPUE during the 1990 survey was 256 kg/h.

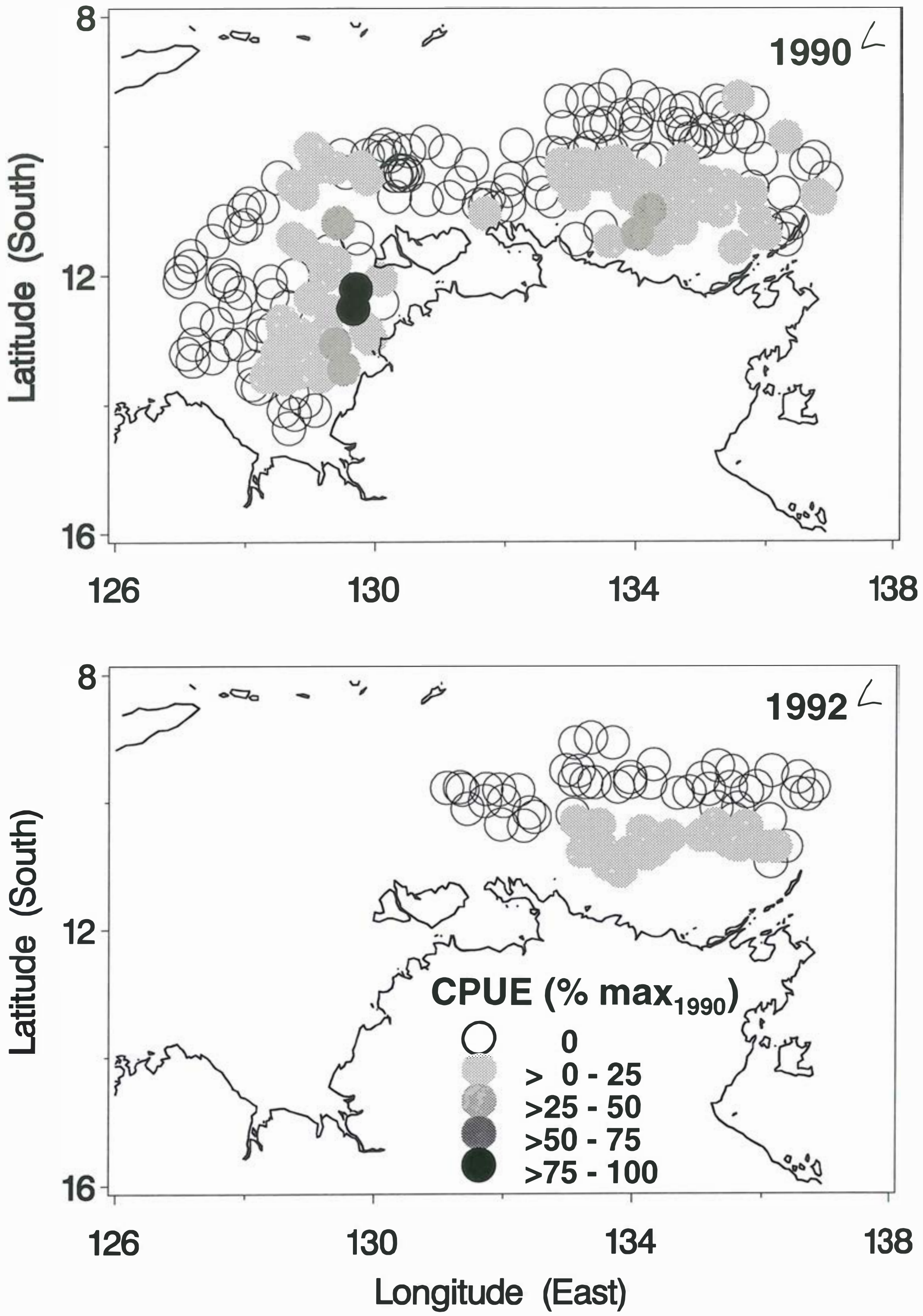

Figure 11. Distribution of rosy threadfin-bream (*Nemipterus furcosus*) based on catch data from the 1990 and 1992 trawl surveys. The maximum CPUE during the 1990 survey was 170 kg/h.

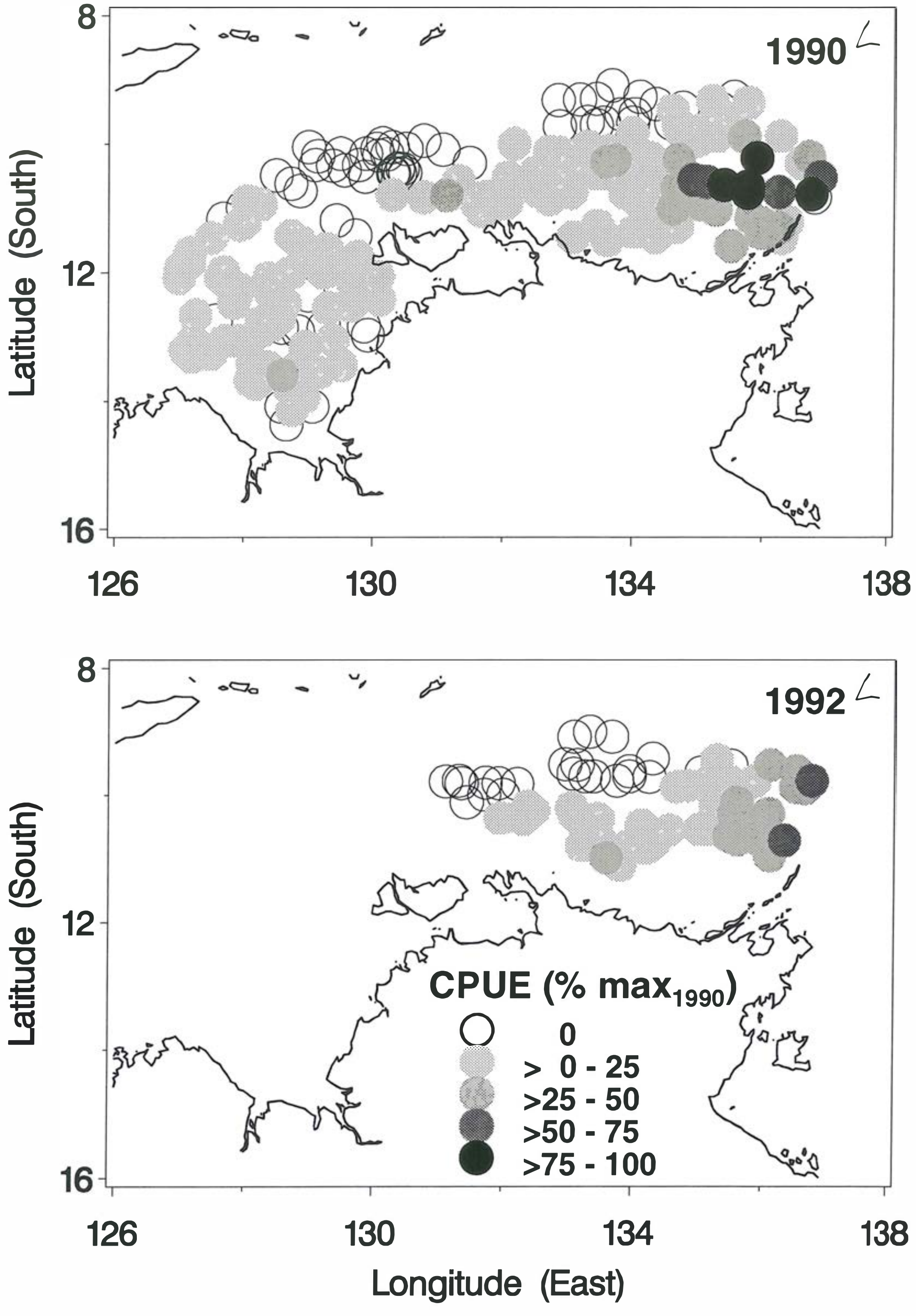

Figure 12. Distribution of ornate threadfin-bream (*Nemipterus hexodon*) based on catch data from the 1990 and 1992 trawl surveys. The maximum CPUE during the 1990 survey was 95 kg/h.

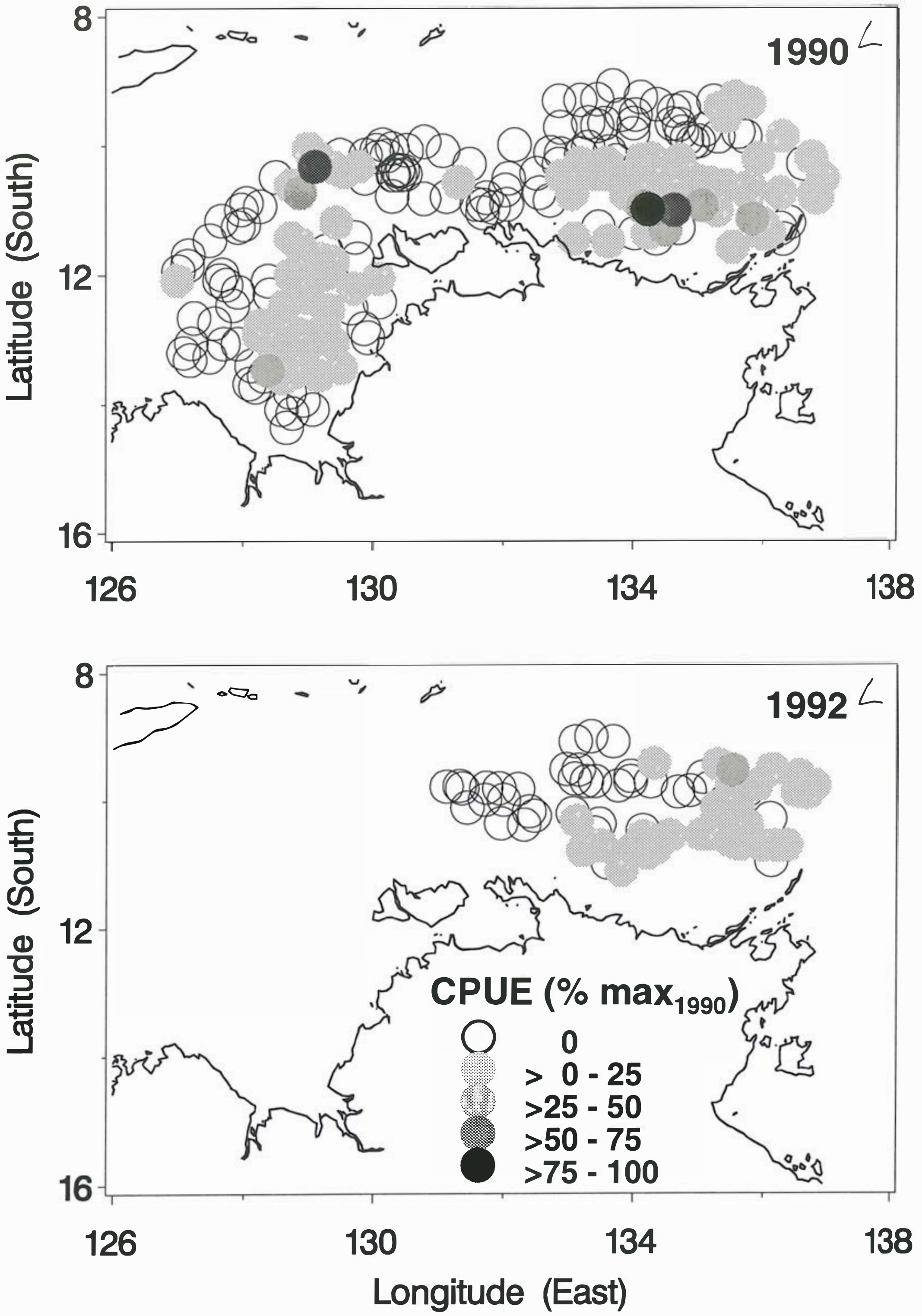

Figure 13. Distribution of painted sweetlip (*Diagramma pictum*) based on catch data from the 1990 and 1992 trawl surveys. The maximum CPUE during the 1990 survey was 200 kg/h.

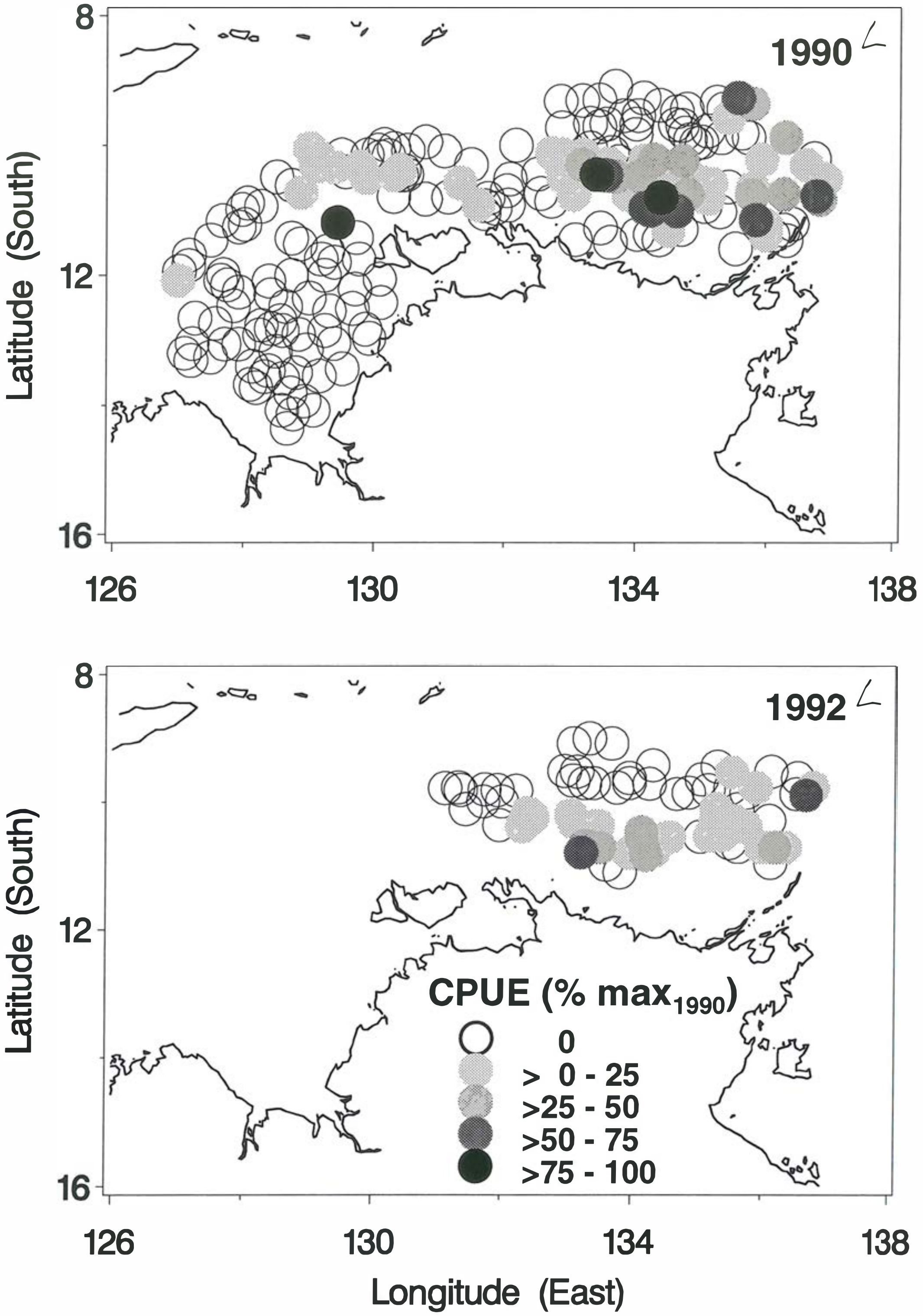

Figure 14. Distribution of red-spot emperor (*Lethrinus lentjan*) based on catch data from the 1990 and 1992 trawl surveys. The maximum CPUE during the 1990 survey was 54 kg/h.

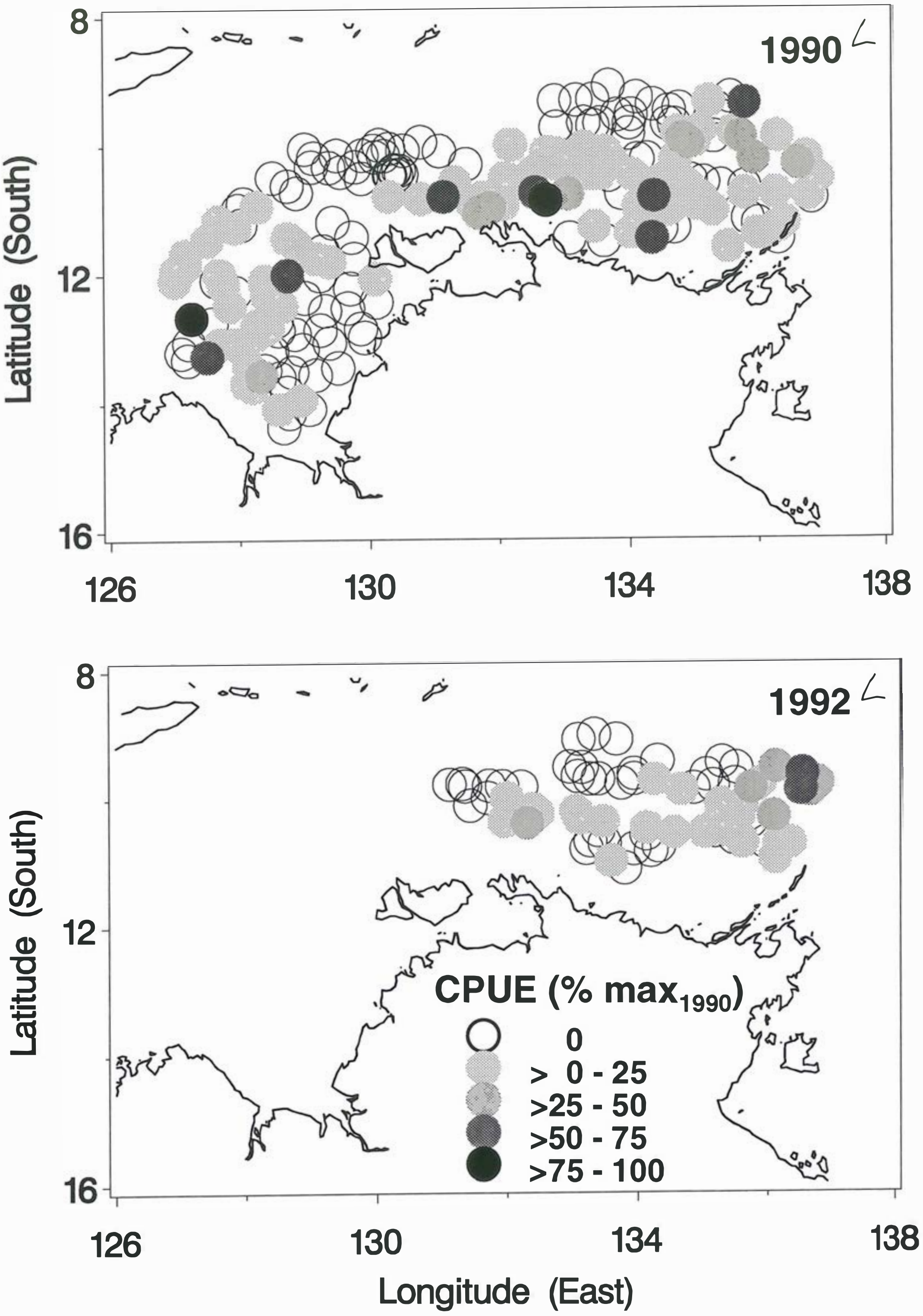

Figure 15. Distribution of sunrise goatfish (*Upeneus sulphureus*) based on catch data from the 1990 and 1992 trawl surveys. The maximum CPUE during the 1990 survey was 152 kg/h.

Table 5. Maximum and mean CPUEs recorded during the 1990 survey, together with percentages of the maximum CPUE, standard error (SE) and coefficient of variation (CV) for species with distribution plots in Figures 5-15 (n=206).

Figure	Common Name	CPUE recorded in 1990						
		percent of maximum (kg/h)				mean	SE	CV
		25%	50%	75%	100%	(kg/h)	(kg/h)	(%)
5	saddle-tailed snapper	125	249	374	498	33.8	3.81	162
6	scarlet snapper	64	127	191	254	4.3	1.56	526
7	red emperor	8	16	24	32	2.7	0.41	219
8	gold-band snapper	20	40	59	79	4.2	0.73	251
9	sharp-tooth snapper	12	24	36	48	0.9	0.34	566
10	one-band snapper	64	128	192	256	8.1	1.61	285
11	rosy threadfin-bream	43	85	128	170	5.9	1.33	327
12	ornate threadfin-bream	24	48	71	95	9.7	1.19	175
13	painted sweetlip	50	100	150	200	9.0	1.53	245
14	red-spot emperor	14	27	41	54	3.9	0.65	242
15	sunrise goatfish	38	76	114	152	9.8	1.65	243

Length-weight relationships

Length-weight relationships were determined for 14 species of groundfish, including saddle-tailed snapper and gold-band snapper, using a simple generalised model of allometry (Xiao and Ramm, 1994; Attachment 3).

Postgraduate Project

In 1991, a PhD student began a related project at the NT University, with a postgraduate scholarship was funded by the FRDC component of the project. Due to difficulties, and uncertainties, in obtaining funds for the charter component of the trawl surveys, the PhD thesis was necessarily focussed on coastal regions near Darwin and Port Essington on the Coburg Peninsula. These regions were relatively inexpensive to access, and not dependent on charter funding. The PhD project, entitled "Utilisation of inshore habitats by juvenile fish" was to examine the role of inshore habitats in the life history of lutjanid snappers and other commercial species in waters between 127-137°E. Studies elsewhere have indicated that inshore habitats are important nursery areas for fish, and the project aimed to provide additional information for the sound management of lutjanid stocks in northern waters. Unfortunately, the student deferred their candidature in August 1992, and later withdrew from the project. They had completed all the preliminary work required to conduct the project, including literature review, gear development and sampling designs, and obtained approval to sample in aboriginal areas. The original PhD project was subsequently revised and modified to a suitable MSc project focussing on the distribution and abundance of juvenile fish in Darwin Harbour and Port Essington. The revised MSc project began briefly in 1993, but was terminated following the departure of the MSc student; no further attempts were made to complete this project.

Benefits

The project has provided new information on the spatial distributions, relative abundances and community structure of groundfish in the Timor and Arafura Seas between 127-137°E. Together with new information on herding and escapement, the project lead to analyses which provided fishery managers with the first fishery-independent estimates of sustainable yield for saddle-tailed and gold-band snappers in northern Australia. Project results were supported by Industry and adopted by fishery managers. Overall, the project has contributed significantly to the ecologically sustainable use of the snapper and other groundfish resources in northern Australia through improved knowledge on fishery biology and population dynamics (Attachment 4).

Earlier analysis of fishery logbook data conducted by the Northern Fisheries Assessment Working Group (1990) indicated that snapper stocks in the Arafura Sea may have been overfished by trawlers during 1988-90. Fishery managers acted on the Working Group's advice and reduced fishing pressure in the area by discontinuing foreign vessel access arrangements. Fishery-independent information derived from the 1990 and 1992 surveys were used to constrain population dynamic models for saddle-tailed snapper in the Arafura Sea, and gold-band snapper in the Timor Sea. The new results confirmed that exploitation levels in the Arafura Sea during 1988-90 approached, or possibly exceeded, long-term sustainable levels. Logbook and observer data are now considered less reliable than those derived from survey data (eg Northern Fisheries Assessment Working Group Report 1992). Further, fishery models developed during the project formed the basis for management decisions into the Timor Box snapper fishery and development of Demersal Fishery Management Plan. The models have also been used to guide future research and focus human and financial resources on defining critical model parameters.

Intellectual Property and Valuable Information

Intellectual property and valuable information gathered during this project have been published and are freely available to the industry and public.

Further Development

Present uncertainties in yield estimation for snappers may be further reduced by research on stock structure, species mixing rates between Australian and Indonesian waters, ontogenetic changes in habitat preferences, and exploitation rates by Australian and Indonesian fisheries.

Staff

The project research team consisted of David Ramm (principal investigator), Yongshun Xiao (contract scientist funded by FRDC); Anne Coleman (scientist); Julie Lloyd (scientist) and Niall Connolly (PhD student funded by FRDC). Dr Yongshun Xiao, contract scientist, was recruited in January 1991 for a 3-year period ending January 1994; this period was extended following approval from FRDC until April 1994. Mr Niall Connolly was awarded the postgraduate scholarship in April 1991 to conduct a PhD thesis on "Utilisation of inshore habitats by juvenile fish". However, Mr Connolly deferred his candidature in August 1992 and later withdrew from his PhD project. Permission was granted by FRDC (Marko Zagar 19 November 1992) to revise the postgraduate project, and proceed with a 2-year MSc study. A MSc student was subsequently appointed in 1993, but later withdrew.

Field staff exchanges with CSIRO Fisheries Division colleagues were negotiated with Dr Keith Sainsbury (then program leader, Northwest Shelf trawl surveys, CSIRO). Similar arrangement were also extended to technicians, scientists and students from NT Fishing Industry Training Committee, former NT Museum of Arts and Sciences, NT University, Australian Maritime College (Launceston), former Australian Fisheries Services, International Food Institute of Queensland (Brisbane) and James Cook University (Townsville) (Table 6).

Table 6. Collaborators, affiliation and number of survey legs participated during 1990, 1992.

Collaborator	Affiliation	1990	1992
Sandy Teagle	NT Fishing Industry Training Committee		1
Helen Larson	NT Museum of Arts and Sciences	1	
Daniel Lo Choy	NT Museum of Arts and Sciences	1	
Rex Williams	NT Museum of Arts and Sciences	1	2
Cathy Sanderson	NT University (undergraduate student)	1	
Marcus Strauss	Australian Maritime College		2
Arthur Hinson	former Australian Fisheries Service	1	
Karl Staisch	former Australian Fisheries Service	1	
Keith Sainsbury	CSIRO Fisheries Division	1	
Ted Wassenberg	CSIRO Fisheries Division		1
Wade Whitelaw	CSIRO Fisheries Division	1	
Tracy Hay	International Food Institute of Queensland	1	
Sue Poole	International Food Institute of Queensland	1	
Kath Kelly	James Cook University (undergraduate student)		1
Tim Ward	James Cook University (postgraduate student)	1	

Final Cost

The final cost of the project was $1119000, of which $392000 was contributed by FIRDC/FRDC, and $ 304000 was contributed by AFS/AFMA (Table 1).

Acknowledgments

I sincerely thank Yongshun Xiao for his collaboration, and Keith Sainsbury for advice, help and guidance during the project. I am most grateful to Sandy Teagle of the NT Industry Training Committee, Helen Larson, Daniel Lo Choy, and Rex Williams of the NT Museum of Arts and Sciences, Cathy Sanderson of the NT University, Marcus Strauss of the Australian Maritime College, Arthur Hinson and Karl Staisch of the former Australian Fisheries Service, Ted Wassenberg and Wade Whitelaw of CSIRO, Tracy Hay and Sue Poole of the International Food Institute of Queensland, and Kath Kelly and Tim Ward of James Cook University for assistance in the field. Thank you also to the crew of the FV *Clipper Bird*, particularly skipper Jon Abbey and Paul Baetsen, Jacki Abbey, Leonie Diggle and Carol McKay, and the staff of the Fisheries Division, including Anne Coleman, Julie Lloyd, Charles Bryce, John MacCartie and Peter McKenna for their assistance.

Attachment 1

Herding of groundfish and effective pathwidth of trawls

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Herding in groundfish and effective pathwidth of trawls

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Abstract

The swept area method requires quantitative information on the effective pathwidth W_{eff} of a trawl to estimate absolute densities of groundfish. Herding of some groundfish by the bridles, sweeps and doors of a trawl will extend W_{eff} beyond that of the net proper and limits applicability of that method. Generally, the two most commonly used values for W_{eff} (net width and door spread) will result in biased density estimates. We developed a model relating fish catch to net width and door spread that allows estimation of effective herding distance H, catch due to the net proper C_W, catch due to herding C_H, and W_{eff}, thereby significantly improving the swept area method. We analysed trawl catch data using a special case of this model and found that herding occurred in at least 14 of 36 abundant northern Australian groundfish. For *Lutjanus malabaricus*, the target species in the Arafura Sea trawl fishery, $H=73.90$ (asymptotic standard error (ASE) 18.11) m. Thus $C_W=26.44$ (ASE 6.06) kg h^{-1}, $C_H=43.48$ (ASE 13.57) kg h^{-1} and $W_{\mathrm{eff}}=35.64$ (ASE 5.97) m for a trawl with a door spread of 60 m and a net width of 15 m. Other species had $H>80$ m or were not herded. Our findings stress the need to examine herding and review previous applications of the swept area method for estimating fish biomass.

Keywords: Fish; Herding; Effective trawl pathwidth; *Lutjanus malabaricus*

1. Introduction

The swept area method has been commonly used in trawl surveys to estimate absolute densities of groundfish. However, this method is limited by difficulties in defining and estimating the effective trawl pathwidth of the gear which depends on fish behaviour and fish–gear interactions, trawl configuration and rigging, and physical conditions on the fishing

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ground. It is generally accepted that the groundrope, bridles, sweeps and doors of a trawl towed along the seabed stimulate fish, either directly and/or through interaction with the substrate including disturbance of sediments and production of sediment plumes (e.g. Main and Sangster, 1981). Fish present in areas impacted by the advancing gear may react to such stimuli by swimming into the path of the net, thereby being herded, or away from the net, thereby escaping capture. Herding may extend the effective trawl pathwidth beyond that of the net proper, and has been inferred in many commercial species of fish (Bridger, 1969; Hemmings, 1969a,b; Foster, 1969; Foster et al., 1981; Mhalathkar et al., 1982; Mathai et al., 1984; Strange, 1984; Engås and Godø, 1989; Andrew et al., 1991), although other taxa including prawns and shovelnose lobsters (Andrew et al., 1991), and some zooplankters (Boltovskoy et al., 1985; Boltovskoy and Mazzoni, 1988) may not be herded.

The effects of herding on fish catch can be modelled variously depending on the type and availability of data and underlying assumptions. Foster (1969) and Foster et al. (1981) developed an individual-based model with seven physical quantities and eight probabilities. Although two physical quantities were approximated as constants, estimation of the remaining 13 parameters required data that were described by the authors as scarce or non-existent, limiting the application of their model. A similar model relating probability of fish catch to door spread was developed by Fuwa et al. (1988) and Fuwa (1989) and could be fitted into experimental data. Both models provided considerable insights into herding processes, but both assumed that fish had spatially homogeneous distributions and individuals of all species had the same constant swimming speed. Since fish generally have heterogeneous spatial distributions and their swimming behaviour is variable, the validity of both assumptions needs examination and may explain partly the lack of applications of those models. Also, the effects of herding on the effective trawl pathwidth and subsequent estimation of fish density and biomass were not quantified.

Lutjanus malabaricus occurs throughout the Indo-Pacific (Allen and Talbot, 1985) and is a major commercial species in the Arafura Sea groundfish trawl fishery off northern Australia. Biomass and sustainable yield estimates for this species in the Arafura Sea were derived from fishery-independent trawl surveys using the swept area method but differed by an order of magnitude over a hypothesized range of herding effects and trawl retention coefficients (D.C. Ramm, unpublished data, 1991). Consequently, a project was undertaken to refine density and biomass estimates by examining evidence for, and quantifying the extent of, herding in major commercial and/or abundant groundfish in northern Australia. In this paper, we present new evidence for herding in groundfish and develop a simple analytical model relating catch to net width, door spread, effective herding distance and effective trawl pathwidth. Unlike Foster (1969) and Foster et al. (1981), and Fuwa et al. (1988) and Fuwa (1989), we make no essential assumptions about homogeneous spatial distributions and constant fish swimming speeds in our model. More importantly, we define and estimate effective herding distance, effective trawl pathwidth and other herding parameters, and hence substantially improve the performance of the swept area method. We analyse our trawl catch data using a special case and discuss useful extensions of the model.

2. Methods

2.1. Data collection

Fish were sampled from the Australian sector of the Arafura Sea in depths of 55–64 m during daylight hours (06:00–19:00 h) between 6 September and 15 October 1992. The study site (10°20′–10°40′S; 134°00′–134°40′E) was located on a major trawl ground and had relatively constant catch rates for *L. malabaricus* and uniform depth and substrate, as indicated by our previous 1990 survey of the Timor and Arafura Seas (9–14°S, 127–137°E) and commercial catch and effort data (D.C. Ramm, unpublished data, 1990). A Frank and Bryce trawl net, with a headrope of 26 m and stretched mesh of 230 mm in the wing and 38 mm in the codend, was used during sampling and was towed at a survey speed of approximately 2.3 m s^{-1} from a chartered 25 m stern trawler, FV ‘Clipper Bird’; the ratio of warp length to water depth was 3.5:1. This particular type of net is used widely in groundfish surveys in Australia and is smaller than those typically employed in the Arafura Sea trawl fishery. We chose to vary door spread by varying sweep length, and deployed three trawl configurations: net with 30 m bridles and no sweeps (FB30), net with 30 m bridles and 30 m sweeps (FB60, standard configuration used in our surveys), and net with 30 m bridles and 90 m sweeps (FB120). The experimental range of door spread covered the hypothesized herding distances of species under study. Trawl configurations were randomly sequenced for periods of 1 or 2 days and towed along randomly allocated east–west lanes spaced 1800 m apart. The number of tows in each direction was balanced with respect to prevailing tidal currents to ensure data comparability. Fifty-four tows of 0.5 h duration were made for each configuration. Headrope height and either door spread or net width were measured at 1 min intervals using a netsonde (Scanmar C4004 with height and distance sensors) during 4–10 September 1992 only, and mean values were used in later analysis where measurements were not available. Positions and overground trawl speeds were measured by a global positioning system (Trimble Navigation Transpak GPS), and depths by echo sounder (Koden Fish Finder CVS 886). Thirty-six commercial and/or abundant species of fish were sorted from the catches and weighed on board to within an accuracy of ±5%. Because of time constraints, individuals of 20 species were counted and their length to caudal fork or total length was measured to the nearest 1 cm for 70 of 162 tows, except for *L. malabaricus* for which these data were collected for 151 tows. Analyses were based on catch data in kg h^{-1} unless otherwise specified.

2.2. *Model development*

Although herding processes are poorly understood, studies indicate that trawl catch may increase with increasing door spread (Foster, 1969; Foster et al., 1981; Mhalathkar et al., 1982; Strange, 1984; Mathai et al., 1984; Engås and Godø, 1989; Andrew et al., 1991). Our herding model is framed on door spread and catch data and is readily interpreted in these terms. In describing this model, we refer to the positions of the left door (D_1), left wing-tip (W_1), trawl centreline, right wing-tip (W_2) and right door (D_2) located on the transverse axis of the trawl (Fig. 1(a)). We assume that fish catch, C, for a given species in a trawl, is a function of door spread of the form

$$C=\int_{D_1}^{D_2}\dot{C}(x)\mathrm{d}x \tag{1}$$

with $D=D_2-D_1\geqslant 0$ as door spread and $\dot{C}(x)$ as catch per unit of door spread at point x along the transverse axis (Fig. 1(b)). It follows that catch attributed to the net proper, with $W=W_2-W_1\geqslant 0$ as net width, is:

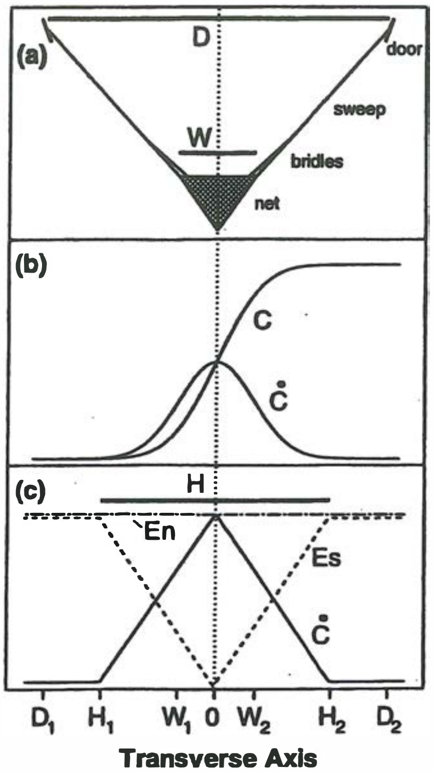

Fig. 1. Herding in groundfish. (a) Schematic trawl with its centreline at $x=0$, door spread $D=D_2-D_1$ and net width $W=W_2-W_1$. (b) General functional relationships for fish catch C and catch per unit of door spread $\dot{C}(x)$. (c) The special case of our general model with constant rate of fish encounter En and a rate of fish escapement Es increasing linearly away from the centreline over the effective herding distance $H=H_2-H_1$. Not to scale.

$$C_W=\int_{W_1}^{W_2}\dot{C}(x)\mathrm{d}x \tag{2}$$

and catch attributed to herding is:

$$C_H=\int_{D_1}^{W_1}\dot{C}(x)\mathrm{d}x+\int_{W_2}^{D_2}\dot{C}(x)\mathrm{d}x \tag{3}$$

Both catch components (Eqs. (2) and (3)) can generally be evaluated once an appropriate functional form of $\dot{C}(x)$ is specified.

In theorizing its functional form, it may be helpful to decompose $\dot{C}(x)$ into a rate of fish encounter by the advancing trawl $En(x)$ (i.e. a measure of absolute fish density) and a rate of fish escapement $Es(x)$ such that:

$$\dot{C}(x)=En(x)-Es(x) \tag{4}$$

Note that $Es(x)$ includes fish escaping from in front of the advancing trawl and from within the net proper. Assuming that $Es(x)$ increases with distance away from the trawl centreline, we define the effective herding distance H of a given species as $H=H_2-H_1\geqslant 0$ with H_1 and H_2 located on either side of the centreline where $Es(x)=En(x)$. Thus $\dot{C}(x)$ would increase from zero at $x=H_1$ to a maximum, $\max(\dot{C}(x))$, at the centreline, and then decrease to zero at $x=H_2$ (Fig. 1(b)). Beyond this range, when $x<H_1$ or $x>H_2$, $Es(x)=En(x)$ with no nett contribution to overall fish catch even though some herding may still occur. For a given trawl, $\dot{C}(x)$ is given by:

$$\dot{C}(x)=\begin{cases} f(x) & D_1\leqslant H_1\leqslant x\leqslant H_2\leqslant D_2 \quad \text{or} \quad H_1\leqslant D_1\leqslant x\leqslant D_2\leqslant H_2 \\ 0 & \text{otherwise}\end{cases} \tag{5}$$

Note that the effective herding distance H is both species specific and gear specific and can only be estimated by varying door spread over the range $D<H$ to $D>H$. Therefore, H may exceed D when D is small.

The effective trawl pathwidth, W_{eff}, has often been defined as net width ($Weff=W$) or door spread ($W_{\text{eff}}=\text{D}$). Such definitions are usually biased because they do not account for variations in $En(x)$, $Es(x)$ and $\dot{C}(x)$ along the transverse axis. Generally, densities of fish herded by a trawl (with sweeps) will be underestimated if $W_{\text{eff}}=D$, and overestimated if $W_{\text{eff}}=W$. Use of most other measures lying between W and D as W_{eff} will lead to either underestimation or overestimation depending on the extent of herding. During development of our model we initially set

$$W_{\text{eff}}=W\left(1+\frac{C_{\text{H}}}{C_{\text{W}}}\right)$$

but this somewhat intuitive measure assumes that each unit of net width, W, along the transverse axis contributed equally to fish catch, and hence overestimates W_{eff}. Here, we define W_{eff} in terms of fish catch C and the rate of fish encounter $En(x)$, such that:

$$W_{\text{eff}}=\frac{C}{En(x)}=\frac{C}{\dot{C}(x)+Es(x)} \tag{6}$$

based on Eq. (4).

While Eq. (6) removes some of the ambiguities and inadequacies of previous definitions, information on $En(x)$ and $Es(x)$ is usually unavailable. However, if $Es(x)$ is negligible, i.e. $\text{Es}(x)\approx 0$, at the centreline of the trawl where $\dot{C}(x)=\max(\dot{C}(x))$, then:

$$W_{\text{eff}}=\frac{C}{\max(\dot{C}(x))} \tag{7}$$

and independent of the rate of fish escapement $Es(x)$. Eqs. (1)–(7) represent our general herding model. Effects of various other factors, such as latitude, longitude, depth and time of day on fish catch can be included in this model by modifying herding parameters or introducing separate terms.

2.3. Special case

For a species with an effective herding distance of H in a (symmetrical) trawl with net width W and door spread D, we assume that the rate of fish encounter is constant, i.e. $En(x) = En$, and the rate of fish escapement increases linearly away from the trawl centreline over the range H (Fig. 1(c)). In this case:

$$Es(x) = \begin{cases} Es(0) + \frac{2a}{H}|x| & |x| \leqslant \frac{H}{2} \\ En & |x| > \frac{H}{2} \end{cases}$$

with $Es(0)$ as the rate of fish escapement at the centreline and $a = En - Es(0)$. If $Es(0) \approx 0$, then $a = En = \max(\dot{C}(x))$.

In our special case, the catch per unit of door spread at point x along the transverse trawl axis is:

$$C(x) = \begin{cases} a\left(1 + \frac{2}{H}|x|\right) & |x| \leqslant \frac{H}{2} \\ 0 & |x| > \frac{H}{2} \end{cases} \tag{8}$$

and Eqs. (1), (2), (3) and (7) become, respectively:

$$C = \begin{cases} \frac{1}{2}aH & H \leqslant D \\ aD\left(1 - \frac{D}{2H}\right) & D < H \end{cases} \tag{9}$$

$$C_W = aW\left(1 - \frac{W}{2H}\right) \tag{10}$$

$$C_H = \begin{cases} a\left[\frac{H}{2} - W\left(1 - \frac{W}{2H}\right)\right] & H \leqslant D \\ a\left[D\left(1 - \frac{D}{2H}\right) - W\left(1 - \frac{W}{2H}\right)\right] & D < H \end{cases} \tag{11}$$

$$W_{\text{eff}} = \begin{cases} \frac{H}{2} & H \leqslant D \\ D\left(1 - \frac{D}{2H}\right) & D < H \end{cases} \tag{12}$$

We use this special case (Eqs. (8)–(12)) to analyse our trawl catch data, with separate terms introduced to correct, where appropriate, for effects of habitat type through latitude, longitude, and depth, and time of day on fish behaviour and catch (e.g. Engås and Ona, 1990). Parameters were estimated using the least squares method, and errors in derived parameters such as W_{eff} were obtained by applying Gauss's law of propagation of errors.

It should be noted that, in some cases, H may be undefined for some forms of $\dot{C}(x)$, but W_{eff} can still be defined and generally estimated. For example, if $\dot{C}(x)$ decreases exponentially and symmetrically from the trawl centreline, i.e. $\dot{C}(x) = ae^{-rx}$ for one branch of the curve, with $a = \max(\dot{C}(x))$ and r as a constant rate of decrease, then:

$$C = \int_0^{D/2} 2\dot{C}(x)\mathrm{d}x = \int_0^{D/2} 2ae^{-rx}\mathrm{d}x = \frac{2a}{r}\left(1 - e^{-\frac{1}{2}rD}\right)$$

$$C_W = \frac{2a}{r}\left(1 - e^{-\frac{1}{2}rW}\right)$$

$$C_H = \frac{2a}{r}\left(e^{-\frac{1}{2}rW} - e^{-\frac{1}{2}rD}\right)$$

$$W_{\mathrm{eff}} \leqslant \frac{C}{a}$$

3. Results

Door spread varied significantly among the three trawl configurations, with means of 42.3, 60.1 and 80.6 m for FB30, FB60 and FB120, respectively ($F_{2,313} = 4261.28$, $P < 0.0001$, $n = 316$). Headrope height was similar among all configurations, with a grand mean of 2.9 m ($F_{2,650} = 0.15$, $P = 0.8633$, $n = 653$). Logistic limitations resulted in small (< 15%) but significant differences in net width, measured at the wing-tips, with means of 15.6, 14.4 and 13.7 m ($F_{2,323} = 194.50$, $P = 0.0001$, $n = 326$), bridle angles of 26°, 22° and 16°, and small (< 5%) but significant differences in trawl speed with means of 2.0, 2.1 and 2.1 m s^{-1} ($F_{2,158} = 5.70$, $P = 0.0041$, $n = 161$) for trawl configurations FB30, FB60 and FB120, respectively. Overall, these configurations allowed for large differences in door spread, with only small changes in net width and trawl speed, and no variation in headrope height. Fishing depths were similar throughout the study, with a grand mean of 59.5 m ($F_{2,159} = 1.35$, $P = 0.2618$, $n = 162$).

Stepwise regression analysis of fish catch against door spread, latitude, longitude, depth and time of day using maximum r^2 improvement technique indicated that trawl configuration was a major determinant of catch variation in nine out of the 36 species of fish measured, although catches for some of these also varied with time of day, latitude, longitude and/or depth (Tables 1 and 2). Thus catches of *Abalistes stellaris*, *Diagramma pictum*, *Epinephelus sexfasciatus*, *Nemipterus furcosus*, *Nemipterus hexodon*, *Nemipterus nematopus*, *Nemipterus peronii*, *Parupeneus pleurospilus* and *Saurida micropectoralis* increased with door spread. Catches of *Carangoides chrysophrys*, *Lethrinus lentjan*, *Lutjanus erythropterus*,

Table 1

Mean catch (kg h^{-1}), standard deviation (kg h^{-1}) and coefficient of variation (CV) for 36 species of fish in each of three trawl configurations (FB30, $n=54$; FB60, $n=54$; FB120, $n=54$) from northern Australian waters from September 6 to October 15, 1992

Species	Common name	FB30			FB60			FB120		
		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
Abalistes stellaris	Starry triggerfish	4.5948	2.6726	58.1658	6.2579	2.8327	45.2660	10.7850	4.6978	43.5586
Carangoides chrysophrys	Long-nosed trevally	2.3119	2.6507	114.6546	2.2063	2.8586	129.5653	7.5224	14.1698	188.3681
Caranx bucculentus	Blue-spotted trevally	0.0219	0.0928	423.7443				0.1015	0.3011	296.6502
Diagramma pictum	Painted sweetlip	10.7137	8.0823	75.4389	14.5276	10.0973	69.5043	17.6412	14.5430	82.4377
Epinephelus areolatus	Yellow-spotted rock-cod	0.5807	0.6869	118.2883	0.6181	0.7252	117.3273	0.7724	1.0649	137.8690
Epinephelus heniochus	Three-lined rock-cod	0.0741	0.2722	367.3414	0.0978	0.3438	351.5337	0.1410	0.3455	245.0355
Epinephelus maculatus	Brown-spotted rock-cod				0.0233	0.1715	736.0515			
Epinephelus sexfasciatus	Six-banded rock-cod	0.8033	0.7550	93.9873	0.9648	0.7222	74.8549	2.1341	1.5276	71.5805
Epinephelus coiodes	Malabar rock-cod	2.0048	4.9931	249.0573	3.5919	6.7018	186.5809	3.1511	6.4332	204.1573
Lethrinus choerorynchus	Lesser spangled emperor	0.0274	0.1610	587.5912						
Lethrinus fraenatus	Blue-lined emperor	0.9359	1.8745	200.2885	1.0263	2.0794	202.6113	0.9478	2.3557	248.5440
Lethrinus lentjan	Red-spot emperor	19.2496	19.1717	99.5953	21.7748	19.5695	89.8722	29.7211	20.4431	68.7831
Lethrinus nematacanthus	Threadfin emperor				0.0100	0.0735	735.0000	0.0293	0.1521	519.1126
Lutjanus argentimaculatus	Mangrove-jack	0.7093	3.4475	486.0426	1.2741	5.0310	394.8670	0.6651	2.1334	320.7638
Lutjanus erythropterus	Scarlet snapper	24.0737	42.2731	175.5987	21.8424	50.9199	233.1241	27.1143	49.4477	182.3676
Lutjanus johni	Golden snapper	0.2037	1.4969	734.8552	1.4815	10.8866	734.8363	7.9444	58.3795	734.8510
Lutjanus lemniscatus	Maroon sea-perch	0.0970	0.5208	536.9072	0.0204	0.1497	733.8235			

Lutjanus lutjanus	Big-eye sea-perch	0.8778	2.9850	340.0547	0.4344	1.1864	273.1123	1.1281	3.0625	271.4742
Lutjanus malabaricus	Saddle-tailed snapper	56.8537	60.0144	105.5594	73.8740	47.9115	64.8557	70.6906	53.0315	75.0192
Lutjanus quinquelineatus	Five-lined snapper	0.0193	0.1191	617.0984	0.0078	0.0572	733.3333			
Lutjanus russelli	Russell's snapper	2.0681	2.7472	132.8369	3.1290	3.9461	126.1138	3.8886	4.1733	107.3214
Lutjanus sebae	Red emperor	4.2044	6.0301	143.4236	4.5993	5.7228	124.4276	3.7588	5.8189	154.8074
Lutjanus vittus	One-band snapper	15.2130	27.5919	181.3705	17.5334	22.8476	130.3090	19.0955	18.9007	98.9799
Nemlpterus celebicus	Five-lined threadfin-bream	0.0111	0.0451	406.3063	0.0211	0.0768	363.9810	0.0887	0.4700	529.8760
Nemipterus furcosus	Rosy threadfin-bream	4.9196	3.8302	77.8559	9.2197	6.5334	70.8635	18.9467	9.3089	49.1320
Nemipterus hexodon	Ornate threadfin-bream	5.6781	3.5040	61.7108	7.2216	3.1543	43.6787	14.1169	6.7142	47.5614
Nemipterus isacanthus	Twin-lined threadfin-bream	0.0307	0.1294	421.4984	0.0459	0.2895	630.7190	0.0281	0.1500	533.8078
Nemipterus nematopus	Yellow-tipped threadfin-bream	9.8789	3.8711	39.1855	12.4718	5.5705	44.6648	17.6775	7.7943	44.0916
Nemipterus peronii	Notched threadfin-bream	0.1667	0.2497	149.7900	0.2459	0.3857	156.8524	0.5862	0.4929	84.0839
Parupeneus chrysopleuron	Yellow-banded goatfish	0.0067	0.0490	731.3433	0.0237	0.1306	551.0549	0.0130	0.0667	513.0769
Parupeneus pleurospilus	Spotted golden goatfish	1.4548	1.4106	96.9618	2.6054	2.2444	86.1442	3.7223	2.4001	64.4790
Plectropomus maculatus	Coral trout	0.2411	1.0558	437.9096	0.5222	1.8967	363.2133	0.3833	1.4160	369.4234
Pristipomoides multidens	Gold-band snapper	4.2607	5.5640	130.5889	5.3618	5.2645	98.1853	5.8066	5.5681	95.8926
Saurida micropectoralis	Short-finned lizardfish	4.4926	2.5668	57.1340	7.0660	4.2394	59.9972	13.9711	5.7851	41.4076
Upeneus moluccensis	Gold-band goatfish	0.0119	0.0462	388.2353	0.0456	0.2006	439.9123	0.7323	3.3934	463.3893
Upeneus sulphureus	Sunrise goatfish	4.3263	18.5377	428.4885	12.8267	40.6200	316.6832	14.0578	20.9469	149.0055

Table 2

Results of fitting a stepwise regression model of the form, catch $= a + b \cdot \text{door} + c \cdot \text{latitude} + d \cdot \text{longitude} + e \cdot \text{depth} + f \cdot x_1 + g \cdot x_2$, for 36 species of fish collected from northern Australian waters from 6 September to 15 October 1992 ($n = 162$) using maximum r^2 improvement technique with three independent variables retained in the final regression equation

Species	*a*	SE	*T*	*P*> |*T*|	var1	PE	SE	*T*	*P*> |*T*|	var2
*Abalistes stellaris**	307.42	144.18	2.132	0.0345	door	0.1227	0.0259	4.734	0.0001	depth
Carangoides chrysophrys	632.63	347.23	1.822	0.0704	door	0.0564	0.0624	0.903	0.3678	depth
Caranx bucculentus	19.30	5.97	3.235	0.0015	lat	−0.4158	0.3345	−1.243	0.2157	depth
*Diagramma pictum**	−3004.56	814.55	−3.689	0.0003	door	0.1815	0.0531	3.414	0.0008	lat
Epinephelus areolatus	−75.35	61.61	−1.223	0.2231	lon	0.5633	0.4587	1.228	0.2213	x_1
Epinephelus heniochus	9.61	6.34	1.515	0.1317	door	0.0016	0.0016	0.986	0.3256	lat
Epinephelus maculatus	−5.06	3.31	−1.531	0.1278	lat	0.2212	0.1862	1.188	0.2368	depth
*Epinephelus sexfasciatus**	112.37	43.53	2.581	0.0107	door	0.0206	0.0078	2.634	0.0093	depth
Epinephelus coiodes	−392.71	274.91	−1.429	0.1551	door	0.0640	0.0448	1.430	0.1547	lat
Lethrinus choerorynchus	−2.47	1.81	−1.367	0.1737	door	−0.0006	0.0005	−1.392	0.1659	lat
Lethrinus fraenatus	−425.88	170.18	−2.503	0.0133	lon	3.0245	1.1583	2.611	0.0099	depth
Lethrinus lentjan	−2336.06	1441.39	−1.621	0.1071	door	0.2605	0.0977	2.667	0.0085	lon
Lethrinus nematacanthus	−9.06	7.20	−1.258	0.2103	door	0.0007	0.0005	1.468	0.1440	lon
Lutjanus argentimaculatus	138.28	73.02	1.894	0.0601	lat	−13.0165	6.9493	−1.873	0.0629	x_1
Lutjanus erythropterus	3534.80	3642.37	0.970	0.3333	lat	−87.7794	88.2997	−0.994	0.3217	lon
Lutjanus johni	−5082.75	2613.43	−1.945	0.0536	door	0.2029	0.1705	1.190	0.2359	lat
Lutjanus lemniscatus	7.99	12.77	0.626	0.5322	door	−0.0036	0.0023	−1.569	0.1186	depth
Lutjanus lutjanus	−17.34	212.30	−0.082	0.9350	lat	−9.6888	4.7177	−2.054	0.0417	lon
Lutjanus malabaricus	−10293.00	4101.86	−2.509	0.0131	door	0.3312	0.2676	1.238	0.2177	lat
Lutjanus quinquelineatus	0.03	0.03	1.055	0.2930	door	−0.0005	0.0004	−1.307	0.1930	x_1
Lutjanus russelli	−172.31	319.20	−0.540	0.5901	door	0.0540	0.0271	1.989	0.0484	lon
Lutjanus sebae	−903.46	447.77	−2.018	0.0453	lat	12.8076	10.7595	1.190	0.2357	lon
Lutjanus vittus	−1221.09	1776.13	−0.688	0.4928	lat	−87.9213	42.6784	−2.060	0.0410	lon
Nemipterus celebicus	15.58	9.17	1.699	0.0912	lat	−0.4476	0.5140	−0.871	0.3852	depth
*Nemipterus furcosus**	−1853.29	460.15	−4.028	0.0001	door	0.3667	0.0312	11.759	0.0001	lon
*Nemipterus hexodon**	−1620.42	325.80	−4.974	0.0001	door	0.2191	0.0221	9.923	0.0001	lon
Nemipterus isacanthus	56.73	14.79	3.836	0.0002	lat	−1.2027	0.3585	−3.355	0.0010	lon
*Nemipterus nematopus**	1441.39	507.35	2.841	0.0051	door	0.1696	0.0431	3.935	0.0001	lon
*Nemipterus peronii**	−42.79	33.18	−1.290	0.1991	door	0.0073	0.0028	2.584	0.0107	lon
Parupeneus chrysopleuron	−7.20	6.86	−1.050	0.2954	lat	−0.1947	0.1649	−1.181	0.2395	lon
*Parupeneus pleurospilus**	562.92	141.67	3.973	0.0001	door	0.0577	0.0092	6.237	0.0001	lat
Plectropomus maculatus	−49.95	61.01	−0.819	0.4142	door	0.0105	0.0110	0.953	0.3419	depth
Pristipomoides multidens	313.62	408.13	0.768	0.4434	door	0.0422	0.0274	1.538	0.1260	lon
*Saurida micropectoralis**	−520.85	371.85	−1.401	0.1633	door	0.1889	0.0316	5.978	0.0001	lon
Upeneus moluccensis	387.55	159.29	2.433	0.0161	lon	−2.0120	1.0843	−1.856	0.0654	depth
Upeneus sulphureus	1360.75	554.03	2.456	0.0151	door	0.2404	0.1404	1.711	0.0890	lat

PE, parameter estimate; SE, standard error; *, species showing signs of herding; door, door spread; lat, latitude; lon, longitude; depth, water depth; x_1 and x_2 are related to time of day, t, by $x_1 = \sin(2\pi t/24)$ and $x_2 = \cos(2\pi t/24)$.

Lutjanus johni, *Lutjanus lutjanus*, *Lutjanus sebae*, *Lutjanus vittus*, *Upeneus moluccensis* and *Upeneus sulphureus* showed no significant correlation with door spread. Trends in the remaining 18 species were unclear from stepwise regression analysis. Regression analysis of number of fish caught (individuals h^{-1}) yielded similar results. Means and variances of length frequency distributions for all measured species varied little among trawl configurations (Table 3).

PE	SE	T	$P>\|T\|$	var3	PE	SE	T	$P>\|T\|$	$F_{3,158}$	P	r^2
−5.1702	2.4029	−2.152	0.0329	x_1	−0.4195	0.3821	−1.098	0.2740	30.207	0.0001	0.3524
−10.6207	5.7870	−1.835	0.0683	x_1	−1.0110	0.9203	−1.099	0.2736	5.027	0.0024	0.0698
−0.2510	0.0836	−3.003	0.0031	x_2	−0.0838	0.0434	−1.929	0.0555	4.961	0.0026	0.0687
76.6474	19.6987	3.891	0.0001	lon	16.3951	5.7999	2.827	0.0053	11.263	0.0001	0.1605
−0.1950	0.0922	−2.116	0.0359	x_2	−0.5441	0.2040	−2.667	0.0085	3.740	0.0124	0.0486
−0.9134	0.6029	−1.515	0.1318	x_1	0.0315	0.0351	0.897	0.3710	1.596	0.1926	0.0110
0.0461	0.0460	1.002	0.3177	x_1	0.0140	0.0108	1.290	0.1989	1.226	0.3022	0.0042
−1.8831	0.7255	−2.596	0.0103	x_2	0.4131	0.2575	1.604	0.1107	17.651	0.0001	0.2368
13.2829	11.3386	1.171	0.2432	depth	4.2361	4.1496	1.021	0.3089	1.111	0.3466	0.0021
0.2420	0.1721	1.406	0.1617	x_2	0.0329	0.0224	1.471	0.1432	2.163	0.0946	0.0212
0.3456	0.9693	0.357	0.7219	x_1	−0.1097	0.2286	−0.480	0.6322	2.281	0.0814	0.0233
17.4093	10.7355	1.622	0.1069	x_2	−8.6474	4.7361	−1.826	0.0698	4.924	0.0027	0.0681
0.0671	0.0536	1.251	0.2127	x_2	−0.0210	0.0237	−0.889	0.3752	1.715	0.1662	0.0131
−0.3392	0.4139	−0.820	0.4137	x_2	1.0462	0.9130	1.146	0.2536	1.846	0.1411	0.0155
−19.2732	26.0839	−0.739	0.4611	x_1	−12.0646	5.2179	−2.312	0.0221	2.346	0.0749	0.0245
108.3565	63.2021	1.714	0.0884	lon	29.2934	18.6086	1.574	0.1174	2.214	0.0887	0.0221
−0.1310	0.2128	−0.616	0.5389	x_2	−0.1067	0.0755	−1.413	0.1596	1.635	0.1835	0.0117
1.4854	1.3920	1.067	0.2875	depth	−1.3365	1.1820	−1.131	0.2599	2.429	0.0674	0.0259
132.2811	99.1978	1.334	0.1843	lon	66.6263	29.2068	2.281	0.0239	2.818	0.0409	0.0328
−0.0078	0.0085	−0.920	0.3591	x_2	−0.0183	0.0189	−0.969	0.3341	1.063	0.3667	0.0012
.8795	2.0265	0.434	0.6649	depth	0.9055	2.5188	0.359	0.7197	2.279	0.0816	0.0233
5.7477	3.1892	1.802	0.0734	x_2	−1.6343	1.4075	−1.161	0.2473	2.120	0.0998	0.0204
16.0629	12.6500	1.270	0.2060	x_2	−7.7806	5.5829	−1.394	0.1654	2.880	0.0378	0.0338
−0.1828	0.1284	−1.423	0.1567	x_2	−0.0687	0.0668	−1.030	0.3048	1.343	0.2624	0.0064
13.7523	3.4272	4.013	0.0001	x_2	8.8670	1.5120	5.865	0.0001	61.908	0.0001	0.5316
12.0512	2.4266	4.966	0.0001	x_2	4.5341	1.0705	4.236	0.0001	46.781	0.0001	0.4604
−0.3280	0.1059	−3.097	0.0023	x_1	0.0291	0.0212	1.374	0.1715	7.444	0.0001	0.1072
−8.4801	3.2209	−2.633	0.0093	depth	−5.0288	4.0035	−1.256	0.2109	18.862	0.0001	0.2497
0.5143	0.2107	2.441	0.0157	depth	−0.4437	0.2618	−1.694	0.0922	14.170	0.0001	0.1971
0.0689	0.0489	1.409	0.1608	x_2	−0.0217	0.0216	−1.005	0.3165	1.661	0.1775	0.0122
−21.1174	3.4262	−6.163	0.0001	lon	−2.5455	1.0088	−2.523	0.0126	28.065	0.0001	0.3352
0.8346	1.0168	0.821	0.4130	x_1	−0.2510	0.1617	−1.553	0.1225	1.124	0.3412	0.0023
−2.3160	3.0390	−0.762	0.4471	x_1	−0.6307	0.6007	−1.050	0.2953	1.384	0.2496	0.0071
7.0317	2.3607	2.979	0.0034	depth	−7.1693	2.9343	−2.443	0.0157	49.884	0.0001	0.4767
−1.9657	0.9073	−2.166	0.0318	x_1	0.3125	0.2140	1.460	0.1462	3.032	0.0310	0.0365
−129.9267	52.6787	−2.466	0.0147	x_1	−5.2277	3.0660	−1.705	0.0901	3.693	0.0132	0.0478

Analysis of changes in catch with door spread using Eq. (9), with separate terms introduced to correct for the effects of latitude, longitude, depth and time of day, was made for all 36 species, but, because of limited data and other considerations discussed later, reliable estimates of herding parameters could be obtained only for *L. malabaricus*, with $a = 1.9617$ (asymptotic standard error (ASE) 0.3594) kg h^{-1} m^{-1} and $H = 73.90$ (ASE 18.11) m for the experimental door spread range ($F_{2,160} = 127.5170$, $P \ll 0.0001$, $r^2 = 0.6145$, $n = 162$). For the standard survey configuration (FB60), with door spread $D = 60$ m and net width $W = 15$ m, substitution of estimated values of a and H into Eqs. (9)–(11) gives $C_W = 26.44$

Table 3

Summary of length (cm) measurements calculated from pooled samples for 20 species of fish in each of three trawl configurations (FB30, $n=54$; FB60, $n=54$; FB120, $n=54$) from northern Australian waters from 6 September to 15 October 1992, with means and standard deviations being estimated from two parameter gamma distributions

Species	FB30					FB60					FB120				
	n	Mean	SD	Min	Max	*n*	Mean	SD	Min	Max	*n*	Mean	SD	Min	Max
Abalistes stellaris	120	29.1392	4.56786	16	34	164	27.8286	4.58045	14	35	250	27.3191	4.40252	15	35
Carangoides chrysophrys	135	20.1492	3.28152	16	49	111	19.8885	3.24277	13	55	286	18.9279	2.07114	15	54
Diagramma pictum	135	19.5873	1.65075	19	63	136	24.0959	1.67210	23	62	166	12.5079	1.59296	12	61
Epinephelus sexfasciatus	66	26.4000	2.00000	9	28	63	26.4000	2.00000	16	27	136	26.4000	2.00000	15	27
Epinephelus coiodes	4	65.0893	4.61628	58	74	11	50.7554	3.64747	47	82	9	58.1607	4.13968	51	76
Lethrinus lentjan	634	27.6396	4.15874	20	39	549	27.4313	4.10549	19	40	919	27.2852	4.12428	20	40
Lutjanus erythropterus	268	21.6952	1.50550	22	52	229	20.1760	3.68314	21	52	178	24.6374	3.29980	24	54
Lutjanus johni	120	52.3127	3.63016	41	56										
Lutjanus lutjanus	432	13.6342	1.45270	11	19	141	13.6877	2.12438	10	19	230	15.1302	1.86037	12	20
Lutjanus malabaricus	783	49.3088	9.62564	10	70	983	52.1387	8.25828	9	71	1064	52.2349	8.09744	10	68
Lutjanus russelli	57	24.4098	1.69388	23	45	81	24.3420	4.48688	21	40	84	27.8968	6.48138	21	43
Lutjanus sebae	38	26.4000	2.00000	25	54	42	13.9179	1.06114	12	52	37	14.6212	1.01461	14	53
Lutjanus vittus	994	21.0697	3.02153	10	29	1858	20.3674	2.83639	9	36	1578	20.2519	3.10127	8	31
Nemipterus furcosus	316	20.8110	2.91804	16	26	548	20.9146	2.86206	15	26	1076	20.8111	2.77618	14	26
Nemipterus hexodon	611	17.5142	2.45470	7	26	664	18.1222	2.53431	10	26	1203	17.5132	2.49146	9	26
Parupeneus pleurospilus	73	21.0554	3.20310	17	27	140	21.1789	3.19745	16	27	176	21.2795	2.75675	11	27
Pristipomoides multidens	42	13.4299	1.37185	13	52	56	22.7677	1.57993	20	56	46	15.5805	1.33323	15	56
Saurida micropectoralis	225	28.5341	3.71172	21	41	288	27.8704	2.64945	21	41	585	27.6266	2.72757	22	40
Upeneus moluccensis	6	10.3704	1.12485	10	12	6	11.2836	0.78300	10	16	346	15.0385	1.04357	9	17
Upeneus sulphureus	1691	14.6056	1.01353	11	16	1920	14.3429	0.99530	11	16	2674	14.7794	1.02559	11	15

n, number of individuals.

Table 4
Results of successfully fitting Eq. (8) with correction, *B*, for the effects of latitude (lat), longitude (lon), water depth (depth) and time of day (time) for five species of fish collected from northern Australian waters from 6 September to 15 October 1992 ($n = 162$)

Species	*A*	ASE	*H*	ASE	*B*	ASE	*F*	d.f.	*P*	r^2
Epinephelus coiodes	0.3420	0.9170	64.2406	37.1775	−0.7256,lat	2.2719	12.8964	3,159	0.01452	0.1957
Epinephelus heniochus	0.0024	0.0020	120.9053	266.3896			9.0271	2,160	0.12667	0.1014
Lutjanus malabaricus	1.9617	0.3594	73.8970	18.1114			127.5170	2,160	0.00003	0.6145
Lutjanus russelli	0.0747	0.0000	99.5607	0.6451			116.2478	1,161	0.50370	0.4193
Pristipomoides multidens	0.1725	0.3082	80.2701	49.5347	−0.0084,lon	0.0671	48.5487	3,159	0.00001	0.4781

(ASE 6.06) kg h^{-1}, $C_H = 43.48$ (ASE 13.57) kg h^{-1} and $W_{eff} = 35.64$ (ASE 5.97) m for this species. This analysis also provides evidence for herding in four other species, i.e. *Epinephelus coiodes*, *Epinephelus heniochus*, *Lutjanus russelli* and *Pristipomoides multidens* (Table 4).

4. Discussion

Our herding model relates fish catch to door spread, allowing estimation of species specific effective herding distance and effective trawl pathwidth and other derived parameters for a given trawl. This model significantly improves the swept area method, and contrasts with individual-based probabilistic models of Foster (1969) and Foster et al. (1981), and Fuwa et al. (1988) and Fuwa (1989), by making no essential assumptions about constant swimming speeds and homogeneous spatial distributions of fish. Use of a special case of this model in analysis of data collected in this study indicates applicability of our general model.

Our model and findings have many applications. In the case of *L. malabaricus*, the target species in the Arafura Sea trawl fishery, our results can be used directly to improve estimates of stock biomass and sustainable yield through use of appropriate W_{eff} in the swept area method. Such application is significant since present estimates of biomass and yield based on catch and effort data are generally unreliable because of poorly documented discard practices (e.g. Jernakoff and Sainsbury, 1990). The findings also provide knowledge of relationships between relative and absolute densities, furthering understanding of reliability and usefulness of stock assessments based on relative indices of abundance. Also, information on fish herding can be used to improve the selectivity of trawls to target species and reduce by-catch.

There are limitations to our herding model, and indeed all previous herding models as well, in that data must be collected for each species to determine various parameters of interest. Also, we assumed $Es(x) \approx 0$ at the trawl centreline in calculating W_{eff}. This assumption may be a good approximation, in our case, because the Frank and Bryce net had small mesh sizes (38–150 mm stretched mesh along the centreline) and fished close to the substrate, and the commercial species studied, particularly *L. malabaricus*, are of large sizes (e.g. 30–70 cm in length) and generally found 0.5–5 m above the bottom. Preliminary results from testing two Frank and Bryce nets of different headrope height as an unreported part of the same study indicated no significant differences in catch of species studied for a change of headrope height from 2.9 to 4.5 m (D.C. Ramm, unpublished data, 1992). Therefore, fish escapement over the headrope height of 2.9 m used here was minimal. Also, we did not consider escapement of some fish swimming within the mouth of the advancing net upon net retrieval which may lead to underestimation of W_{eff}. This bias may decrease with increasing tow duration for a given towing speed, but was not investigated here because our experiments were designed around a survey tow duration of 0.5 h. Finally, variations in door spread can only be achieved by varying sweep length or sweep angle and we chose the former. However, during our experiment, sweep angle was found to change but the problem was not rectified because of logistic constraints including limited access to the netsonde. Although these limitations may bias estimates of herding parameters using our special case, they do not affect our general herding model.

The unclear trends of herding in some species studied (Table 2) have various alternative interpretations. Herding signals in those species may have been too weak or fish density too low to result in an observable increase in catch with increased door spread. Also, there would have been no apparent increase in catch with increased door spread, and hence herding, if a species had had $H < 40$ m, the minimum door spread used, or if the door spread range studied had been too narrow to detect increases in catch. Trawl catches are also determined by factors other than herding; differences in catch due to gear configuration for some species may well have been masked by large variations in spatiotemporal distributions.

The degree of herding is also species specific because of differences in species size, behaviour, and associated density and swimming speed (Peters, 1983; Calder, 1984). In reality, many factors may mask the relations between size and density, and herding behaviour. Our data indicated that herding was not directly related, at least interspecifically, to fish lengths, as evidenced by a wide overall range of sizes in the herded species and those for which herding was not inferred (Tables 2–4). This size independence was also intraspecific because there were no significant differences in size-frequency distributions among the three net configurations for all nine species for which herding was inferred. By contrast, Engås and Godø (1989) concluded that size compositions of cod and haddock, constructed from annual catch data divided into two size groups, were affected by sweep length. Although their conclusion might have resulted from inappropriate data grouping, their hypotheses regarding mechanisms by which size composition varies with sweep length as a result of differential fish swimming speeds and the intensity of ground gear stimulus are very interesting and should be tested using fish of different sizes under strictly controlled conditions. Andrew et al. (1991) also claimed size-related herding effects for whiting. It should be noted that, even if herding is size dependent, the effects of fish swimming speed may be overridden by factors such as abundance, particularly considering the confounding nature of fish aggregating behaviour, sampling bias and measurement error.

The model developed here provides a framework for more detailed analysis of the effects of herding on fish catches. Like door spread, other variables such as substrate, depth and warp length can be incorporated, if required, into our model, either through model parameters or as independent terms, and related to fish catches (e.g. Table 2). Another useful model extension is to incorporate fish size frequency distributions. If these distributions are known or assumed, the model may be extended as:

$$C(D) = \int_{-\infty}^{\infty} aL^b n(L) f(L; D; \alpha)\,\mathrm{d}L$$

where L is a length measurement, $n(L)$ is the number of animals for measurement L, f is the probability density function of L, door spread D and net width W, a and b are allometric parameters, and α is a parameter vector. However, this version of the model is data intensive, requiring large numbers of length measurements over a wide size range and from many tows; length data collected during this study were insufficient for performing such analysis. In the absence of additional information, the model presented here incorporates the major effects of fish herding and would be adequate for most usages.

Varying degrees of herding were inferred in 14 species of fish, although effective herding distance and other parameters could be estimated reliably from the present data only for

L. malabaricus (Table 4). Approximately linear increases in catch with increasing door spread, as observed in *A. stellaris*, *D. pictum*, *E. sexfasciatus*, *N. furcosus*, *N. hexodon*, *N. nematopus*, *N. peronii*, *P. pleurospilus* and *S. micropectoralis* (Table 2), indicate that these species have effective herding distance $H > 80$ m and beyond the experimental door spread range. Herding parameters for these species may have been obtained if a maximum door spread of 120–140 m had been used. The existence of herding implies that estimates of density using the swept area method, and derived estimates of biomass and sustainable yields, were overestimated for instance, for *L. malabaricus* when net width was used as effective trawl pathwidth $W_{eff} = W$ (e.g. Liu et al., 1978) and would have led, in the worse case, to a collapse of the fishery. Our findings identify an urgent need to review previous applications of the swept area method, especially in fisheries where this is the primary method for estimating biomass and sustainable yield by determining herding effects and revising density and biomass estimates for target species.

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Attachment 2

Dynamics of the deepwater snapper (*Pristipomoides*) resource in the Timor Sea

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Dynamics of the deepwater snapper (*Pristipomoides*) resource in tropical Australia

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Abstract

Deepwater snappers ***Pristipomoides multidens*** and ***Pristipomoides typus*** are harvested commercially in the Timor Sea off northern Australia by a small hightec Australian fishery which began in 1987. Catches have increased to 260-330 t/year of deepwater snappers, mostly *P. multidens*. A fishery targeting deepwater snappers on adjoining Indonesian fishing grounds is also developing, and concerns are growing about the extent of the *Pristipomoides* resource in the Timor Sea and the effectiveness of present management strategies in maintaining sustainable levels of fishing. The present Australian management plan is based on a limited entry fishery with 22 vessels initially licensed, and a 2 for 1 licence transfer scheme to reduce effort in the short term. Under this scheme, each new operator must acquire two existing licences to gain access to the fishery. However, even under this strict regime, new technology and high market values for deepwater snappers could drive catches in this fishery to 1200-1500 t/year. Further, the developing Indonesian fishery may be exerting additional pressure on what is likely to be a shared fishery resource.

Threats to the sustainability of the *Pristipomoides* resource led to a revision of previous stock assessments using all available data. A biomass dynamics model was developed using monthly catch and effort data and trawl survey data for the Australian sector of the Timor Sea; fishery data from the Indonesian grounds are scarce. At the 90% confidence level, unexploited biomass and sustainable yield for *Pristipomoides* on the adjoining Australian and Indonesian grounds ranged from 2988-9516 t and 71-215 t/month (852-2580 t/year), respectively; minimum values were considered conservative and maximum values were considered optimistic. The best fit of the model lead to an unexploited biomass of 6341 t and a sustainable yield of 107 t/month (1284 t/year). This analysis identified future research needs and a potential failure in the present management strategies for *Pristipomoides* in the Timor Sea. The Australian strategy, with a 2 for 1 licence transfer scheme, is unlikely to cap effort and maintain catches at the conservative or best fit sustainable yield levels, and alternative management strategies such as individually transferable effort quotas must be considered urgently. Steps must also be taken to develop and implement a suitable management strategy for *Pristipomoides* in the Indonesian sector, and reach agreement on an overall joint management plan for shared Australian-Indonesian groundfish resources in the Timor Sea.

Introduction

Deepwater snappers *Pristipomoides multidens* and *Pristipomoides typus* are harvested commercially in the Timor Sea off northern Australia (Fig. 1) by a small hightec fishery which began in 1987 following exploratory fishing during 1975-82 (Stehouwer, 1981; Clark, 1984). Catches have increased to 260-330 t/year of deepwater snappers and the target species is *P. multidens* which accounts for about 76% of the catches (Lloyd, 1994). Concerns are growing about the extent of the *Pristipomoides* resource in the Timor Sea, the degree to which this resource is shared by Australia and Indonesia, the development of the Indonesian *Pristipomoides* fishery, and the effectiveness of present management strategies in maintaining sustainable levels of fishing.

Australian vessels are based in Darwin and operate in the Australian sector of the Timor Sea in an area of patch reefs between 127-131°E and 9-12°S. Skippers actively search for fish marks using colour sounders, GPS, plotters, detailed bathymetric charts and local knowledge. In particular, they search for 'Christmas tree' shaped fish marks, said to be characteristic of *Pristipomoides* aggregations, located in depths of 80-160 m along reef faces and on sand flats between pinnacles. Skippers then either anchor or maintain the vessel in position above these aggregations and crews fish until schools break up, presumably due to the fishing operation. Water currents in the area may reach 0.5-1.0 m/s and considerable skill is required to maintain the vessel on site and position the fishing gear within schools of snapper. Three to six 3-6 droplines are generally used at any one time, each with 15-30 tuna circle hooks (size 13/0) baited with squid. Heavy monofilament line (breaking strain 100-200 kg) is often used as the mainline and hooks are connected by 10-15 cm snoods and three-way swivels. Lines are set within 30 m of the seabed and soak times are in the order of 3-15 minutes; longer soak times may result in loss of gear and fish through shark predation. The preferred mode of operation is to use fixed lines operated from hydraulic reels. Alternatively, lines may be buoyed and set free of the vessel, and later retrieved with a hydraulic pot hauler. Fish traps are used occasionally to target other species, notably red snappers *Lutjanus erythropterus*, *Lutjanus malabaricus*, and *Lutjanus sebae*. Snappers are usually spiked, bled and held in ice slurries on deck, then gilled and gutted, and soldier packed on ice in large insulated boxes. Fishing trips are usually of 5-7 days duration, with vessels returning to Darwin where the product is airfreighted to major cities in southern Australia. Markets prices during 1994 averaged 5.40-7.52 AU$/kg (max=AU$11.4/kg; Christine Julius, pers comm, Department of Primary Industry and Fisheries, Darwin, June 1995).

Sustainable yields for the deepwater snapper resource were initially estimated using two methods (Ramm, 1993): (1) trawl survey data, collected from the Timor Sea in 1990, were used as the basis of a yield per recruit model; and, (2) annual catch and effort data were fitted to a biomass dynamics model. Annual sustainable yields for *Pristipomoides* in the Australian sector of the Timor Sea were estimated at 400-1000 t. Subsequently, management arrangements for the fishery were reviewed and the fishery was declared closed in 1994 with 22 licensed vessels. About 60 licence holders, who had previously held rights to fish but had not done so in recent years and did not have the required capacity to fish on the remote *Pristipomoides* grounds (eg vessel with appropriate marine survey certificate) were transferred to the inshore snapper fishery.

The current fishery management plan incorporates a 2 for 1 licence transfer scheme to reduce effort in the short term. Under this scheme, each new operator must acquire two existing licences to gain access to the fishery. However, even under this strict regime, new technology and high market values for deepwater snappers could drive catches in this fishery to 1200-1500 t/year, thereby exceeding the recent estimates of sustainable yield. Further, fishery developments targeting deepwater snappers on adjoining Indonesian fishing grounds may be exerting additional pressure on what is likely to be a shared fishery resource. These threats to the sustainability of the *Pristipomoides* resource led to a revision of the stock assessment, using all available data; findings are reported here.

Methods

Monthly catches of *Pristipomoides* and fishing effort (boatday) for the deepwater snapper fishery in the Australian sector of the Timor Sea were obtained from data on fishing methods, areas, days fished and catch by commercial categories which were reported through a compulsory monthly logbook scheme for fisheries under Australian (Northern Territory) jurisdiction. Data for vessels operating droplines and targeting deepwater snapper within the Australian sector of the Timor Sea between June 1987, the start of the domestic fishery, and December 1994 (91 months) were selected and used in the analysis.

The combined biomass of *P. multidens* and *P. typus* in the Australian sector of the Timor Sea in November 1990 was estimated from trawl survey data (Ramm, unpublished data). The mean catch rate for *Pristipomoides* was 15.24 kg/h (se=3.44 kg/h, n=49), and the survey biomass, estimated by swept area method, was 3100 t (se=900 t) (using effective trawl pathwidth=30-50 m, trawl retention=0.9-1.0, Timor Sea survey area=68100 km^2; Ramm and Xiao, in press; Ramm, unpublished data).

The data were fitted to a biomass dynamics model using the difference equation

$$B_t = B_{t-1} + r\, B_{t-1} - d\, B_{t-1}^2 - C_{t-1}$$

with B_t as predicted biomass at month t, B_{t-1} as biomass at month t-1, r as the intrinsic (monthly) rate of population growth, d as a density dependent factor and C_{t-1} as catch during month t-1; the unexploited biomass was $B_0 = r/d$. The model was developed on a Microsoft Excel spreadsheet using concepts of Norm Hall (pers comm, Western Australia Fisheries Department, Perth, July 1994). Parameters r and d were estimated from the model. Catchability q was the slope of the regression

$$obsCPUE_t = q * B_t$$

with $obsCPUE_t$ as observed catch rate for month t. Thus

$$q = \sum(obsCPUE_t * B_t) / \sum(B_t^2)$$

and the predicted catch rate for month t was

$$pCPUE_t = q * B_t.$$

Deviations ($obsCPUE_t$ - $pCPUE_t$) and (survey biomass - $B_{November\ 1990}$) were squared and used to calculate the log likelihood for each pair of observations assuming a Gaussian probability distribution. Accumulated log likelihood values for a range of estimates of parameters r and d were maximised for the 91 monthly observations and the survey biomass estimate using the Excel Solver function. Bayesian estimates of posterior probability, calculated using the Excel Table function, were used to identify confidence regions. Three basic assumptions were made in fitting the model: (1) the *Pristipomoides* resource under investigation is a single stock within a single area with its biomass equally distributed between Australian and Indonesian sectors of the Timor Sea; (2) the intrinsic monthly rate of population growth (r) for *Pristipomoides* lies between 0 and 0.1 (equivalent to an annual r of 0 - 1.9); and, (3) biological parameters for *P. multidens* and *P. typus* are similar.

Sustainable yields were determined using a fixed rule harvest strategy

$$H_t = a + b * B_{t-1}$$

with H_t as the harvest during month t, a as escapement and b as fixed rate of harvest. The sustainable yield (optimum harvest strategy), within ranges of a from -250 to 0 t and b from 0 to 0.1, was determined over a 25 year time horizon (to December 2020) using the Excel Table function.

Results

Monthly effort in the dropline fishery in the Australian sector of the Timor Sea ranged from 3-187 boatdays with a mean of 60.0 boatdays (se=4.25 boatdays, n=91), and catches of *Pristipomoides* ranged from 0-61 t with a mean of 18.1 t (se=1.36 t, n=91). Annual catch and effort rose from 24 t of *Pristipomoides* and 145 boatdays in 1987, to a maximum catch of 329 t in 1993 and a maximum effort of 1156 boatdays in 1992 (Table 1). The annual number of boats catching > 20 t/year of *Pristipomoides* ranged from 1-5 (mean=3).

The best fit of the data to the biomass dynamics model occurred at r=0.068 and d=1.07E-5 with log(likelihood)=-581.86. However, the likelihood surface was ill-defined and wedge shaped within the range of parameters r and d considered (Fig. 2). Posterior Bayesian probabilities were used to identify the 10, 30, 50, 70 and 90% confidence regions for parameter estimates, and derived unexploited biomass ranges and corresponding sustainable yield estimates for *Pristipomoides* for the Timor Sea are summarised in Table 2. At the 90% confidence level, unexploited biomass and sustainable yield for *Pristipomoides* ranged from 2988-9516 t and 71-215 t/month, respectively. Taking the minimum values of these estimates (conservative scenario: r=0.096, d=3.2E-5), the long-term (25 years to December 2020) fished down biomass was 1627 t. At the opposite end of the range (optimistic scenario: r=0.090, d=9.5E-6), the long-term fished down biomass was 4808 t. At the best fit of the model (best fit scenario), the unexploited biomass estimate was 6341t, sustainable yield was 107t/month and the long-term fished down biomass was 3557 t.

Discussion

Sustainable yield estimates for *Pristipomoides* in the Timor Sea ranged from a conservative scenario of 71 t/month (852 t/year), to a best fit scenario of 107 t/month (1284 t/year), and an optimistic scenario of 215 t/month (2580 t/year). If the *Pristipomoides* biomass is evenly distributed between Australian and Indonesian sectors of the Timor Sea, and the yield is equally shared between these two zones, then the sustainable yield for *Pristipomoides* in the Australian sector ranges from a conservative 35t/month (426 t/year), to a best fit 53 t/month (642 t/year), and an optimistic 107 t/month (1290 t/year). These findings are similar to previous estimates for this fishery based on annual catch and effort data from the period 1987-93, and 1990 survey data alone (400-1000 t; Ramm, 1993). Present *Pristipomoides* catches in the Australian sector of the Timor Sea are around 300-315 t/year, and within approximately 100 t/year of the conservative sustainable yield estimate.

Munro (this workshop) stressed the importance of obtaining comparative information on fishery species for baseline information and reference in stock assessment. However, comparisons with other assessments of *Pristipomoides* resources are difficult because deepwater snapper resources elsewhere in the tropics, including those within the Indonesian archipelago, generally occur along narrow shelf breaks rather than extensive patch reef systems on broad continental shelves as in the Timor Sea. Consequently, biomasses and yields are usually reported in relation to the length of reef face (in nautical miles: nm) at the 100 fathom (184 m) bathymetric contour. Further, findings have generally been reported for groups of species rather than individual species. For example, the sustainable yield for deepslope fishery resources, including *Pristipomoides*, of the Mariana Archipelago has a 95% confidence interval of 0.165-0.280 t/nm/year (Polovina, 1987). Similar methodology was applied to deepslope multi-species fishery resources for the whole of the South Pacific resulting in biomass and sustainable yield estimates of 22165 t and 2323-6720 t/year, respectively (Dalzell and Preston, 1992). Because the geographic extent of the *Pristipomoides* resource in the Timor Sea is poorly documented, estimates of density and sustainable yield per square nautical mile can only be approximated at this stage. If the surface area (vertical projection) of the *Pristipomoides* grounds is between 18000-36000 nm^2 (61740-123480 km^2) and if the likely unexploited biomass of the *Pristipomoides* resource is 2988-9516 t (90% confidence interval), then unexploited density and sustainable yield estimates for this resource would range from 0.083-0.529 t/nm^2 (0.024-0.154 t/km^2) and 0.024-0.143 t/nm^2/year (0.007-0.042 t/km^2/year), respectively.

Fishery managers should be conservative in their approach to managing the *Pristipomoides* resource in the Timor Sea because of large uncertainties associated with the three basic assumptions made in the model. The assumption that *Pristipomoides* is a single stock with its biomass equally distributed between Australian and Indonesian sectors is a useful first extrapolation of the survey biomass estimate from the Australian sector to the total region considered. However, this assumption clearly requires quantification and variations in the biomass ratio between the two sectors will result in changes in biomass estimates. For example, the best fit estimate with biomass ratios of 1:2 and 2:1 (Australian sector: Indonesian sector) lead to unexploited biomasses of 9418 t and 4802 t, respectively. Also, there is no information on long-term variations in biomass which may occur through fluctuations in recruitment, migration and/or large scale changes in the carrying capacity of the environment. Finally, little is known about catches of *Pristipomoides* and fishing effort in the Indonesian sector. Under the single shared stock assumption, overfishing in one sector of the Timor Sea would lead to depleted catches in both sectors.

Under the present management plan for *Pristipomoides* in the Australian sector of the Timor Sea, the fishery has a limited entry with 22 vessels initially licensed and new operators may enter the fishery under a 2 for 1 licence transfer scheme. While this type of scheme will reduce the number of fishing vessels in the fishery, it is doubtful that the reduction will be sufficient to maintain catches at, or below, the sustainable yield. On the contrary, this scheme may lead to a rapid increase in catch and effort as inactive licence holders are replaced by a few highly motivated operators who have each outlaid large capital for the purchase of a suitable vessel (AU$0.5-1.0M) and two licences (about AU$70000 each). Top boats in the fishery are capable of catching 100 t/year of *Pristipomoides*, thus a single 2 for 1 licence transfer introducing another hightec vessel into the fishery could increase the total annual catch of *Pristipomoides* to the conservative sustainable yield for the Australian sector; three new vessels could take total catches to the best fit yield. In the worse case, catches from the existing top-5 vessels and eight new vessels, entering the fishery through eight 2 for 1 transfers, could exceed the optimistic sustainable yield if they each caught ≥100 t/year (ie total annual catch ≥1300 t). Total catches of *Pristipomoides* may also increase through improved technology and greater fishing power of the existing fleet.

If the 2 for 1 licence transfer scheme is not a sustainable management strategy, what other options exist? Firstly, the number of licences required for a transfer may be increased. For example, the transfer scheme may be increased to 3 for 1, or even 4 for 1. However, these types of schemes are unlikely to work because of high costs and complicated business deals required to acquire 3 or 4 licences. Alternatively, managers may consider individually transferable quotas (ITQs). ITQs have been used with varying degrees of success in temperate fisheries and may reduce effort and introduce economic stability (Kearney, this workshop). However, ITQs are generally not suitable for managing tropical multi-species fisheries, such as the *Pristipomoides* dropline fishery, where fishing may continue for some species while other valuable species, which have reached quota, are discarded or high-graded; ITQs can also result in under reporting, thereby jeopardising the research value of logbooks, and remove small operators (Kearney, this workshop). Another option is individually transferable effort quotas (ITEs) which were successfully introduced in the Torres Strait prawn fishery to cap effort (Bishop *et al*, 1992; Bishop, this workshop; O'Brien, this workshop). Under ITEs, vessel owners are allocated fishing days based on the maximum number of days fished per year over a 3-5 year period leading up to the introduction of the scheme. Each operator is also given an additional allocation for non-fishing and/or breakdown periods. Like ITQs, ITEs may be sold to other operators in unit quota parcels. However, unlike ITQs, fisheries managed under ITEs are less likely to be overfished during poor years because limits are set on effort rather than catch. Thus poor years will result in lower catches for a given amount of effort.

The analysis has identified needs for further research to reduce some of the uncertainties associated with estimation of sustainable yield for *Pristipomoides* in the Timor Sea. In particular, new research should aim to quantify the three basic assumptions made during modelling. The extent of the *Pristipomoides* stock, and the degree to which it is shared by Australia and Indonesia could be determined through resource surveys and genetic studies.

Estimates of intrinsic rate of population growth for *Pristipomoides* could be refined through theoretical consideration (eg Pauly, 1982) and experimentation (Ramm, unpublished data). Studies on biological parameters for *Pristipomoides*, such as growth and age at recruitment, are necessary to validate the third assumption and/or allow the use of alternative fishery models (eg age-structured models). Also, the biomass dynamics model used here may be improved through standardisation of fishing effort (Chris Mees, pers comm, Marine Resource Assessment Group Ltd, this workshop), quantification of fishing learning behaviour, and documentation of catch and effort in the Indonesian sector of the Timor Sea.

The analysis has also identified a potential failure in the present management strategy for *Pristipomoides* in the Australian sector of the Timor Sea. The 2 for 1 licence transfer scheme is unlikely to cap effort and maintain catches at, or below, the conservative or best fit sustainable yield levels, and alternative management strategies such as ITEs must be considered urgently. Steps must also be taken to develop and implement a suitable management strategy for *Pristipomoides* in the Indonesian sector, and reach agreement on an overall joint management plan for shared Australian-Indonesian groundfish resources in the Timor Sea.

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Tables

Table 1. Annual catch of *Pristipomoides* and effort in the dropline fishery in the Australian sector of the Timor Sea during 1987-94.

Year	Catch (t)	Effort (boatday)
1987	23.6	119
1988	58.8	145
1989	77.5	207
1990	259.1	824
1991	326.1	1033
1992	261.1	1156
1993	329.1	1126
1994	315.7	847

Table 2. Estimated ranges of unexploited biomass and sustainable yield for *Pristipomoides* in the Timor Sea for selected confidence levels between 10-100%.

Confidence Level (%)	Unexploited Biomass (t)		Sustainable Yield (t/month)	
	min	max	min	max
10	5984	6779	109	112
30	5343	7326	100	128
50	4780	7874	114	147
70	4043	8421	76	168
90	2988	9516	71	215
100	45	201600	.02	5080

Figure Captions

Figure 1. *Pristipomoides* fishing grounds (shaded area) in the Timor Sea which are covered by this study.

Figure 2. Likelihood surface for intrinsic rate of population growth (r) and density dependence (d) estimated from the biomass dynamics model for *Pristipomoides* in the Timor Sea.

Figure 3. Sustainable yields (shaded area) for *Pristipomoides* in the Timor Sea fishery for confidence levels between 10-90%.

Figure 4. Total catch and biomass of *Pristipomoides* in the Timor Sea under (a) the conservative scenario with $r=0.096$, $d=3.2E-5$, $B_o=2988$ t, sustainable yield=71 t/month and long-term fished down biomass=1627 t, and (b) the best fit scenario with $r=0.068$, $d=1.07E-5$, $B_o=6341$ t, sustainable yield=107 t/month and long-term fished down biomass=3557 t.

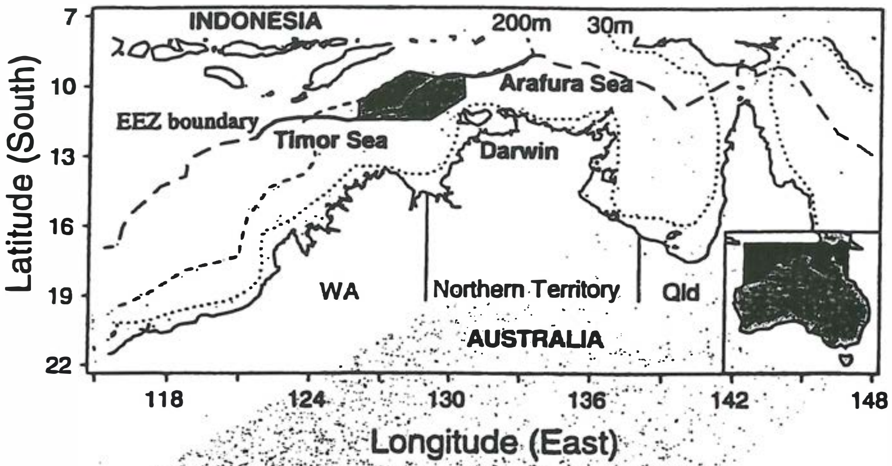
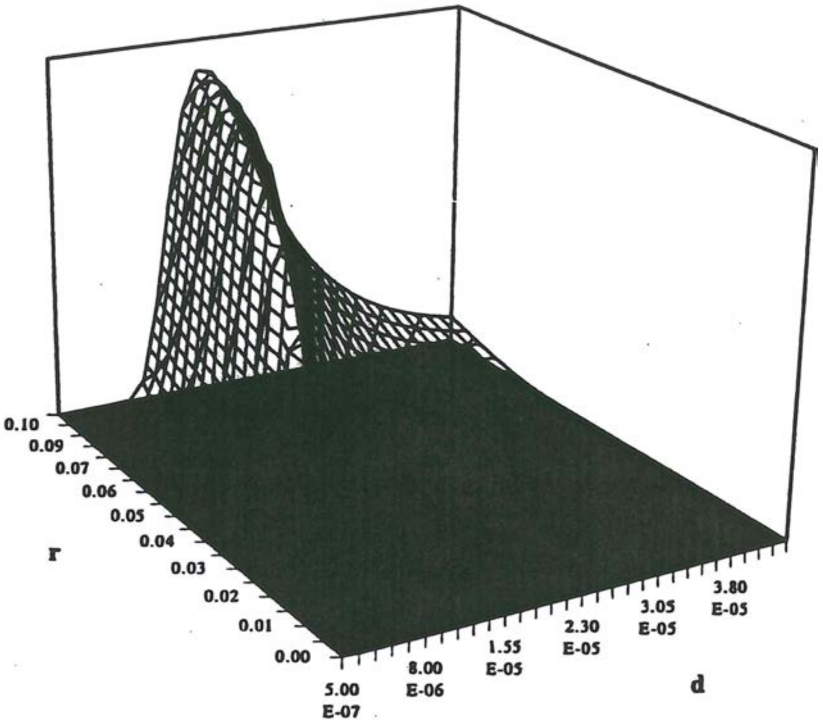

INDONESIA
200m
30m
Arafura Sea
EEZ boundary
Timor Sea
Darwin
WA
Northern Territory
Qld
AUSTRALIA
Latitude (South)
7
10
13
16
19
22
118
124
130
136
142
148
Longitude (East)

Figure 1

8


0.10
0.09
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
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3.80 E-05
d

Figure 2

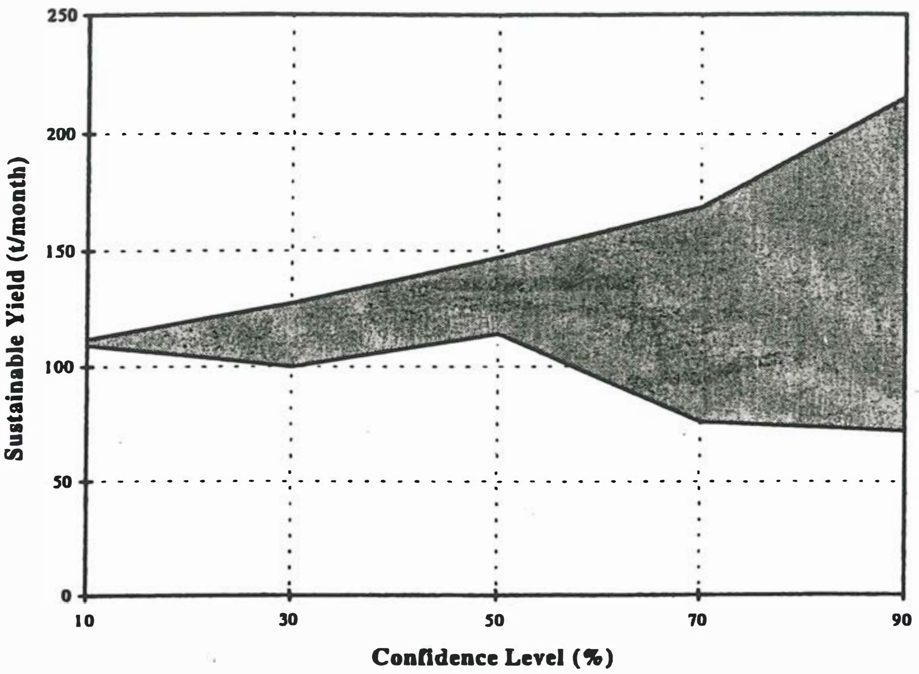

Figure 3

10

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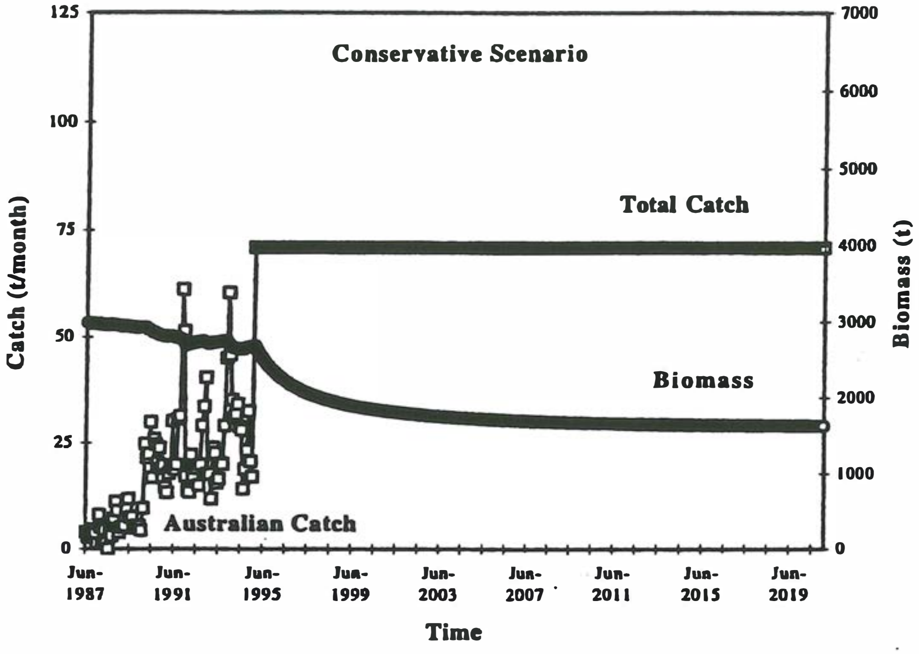

Figure 4a

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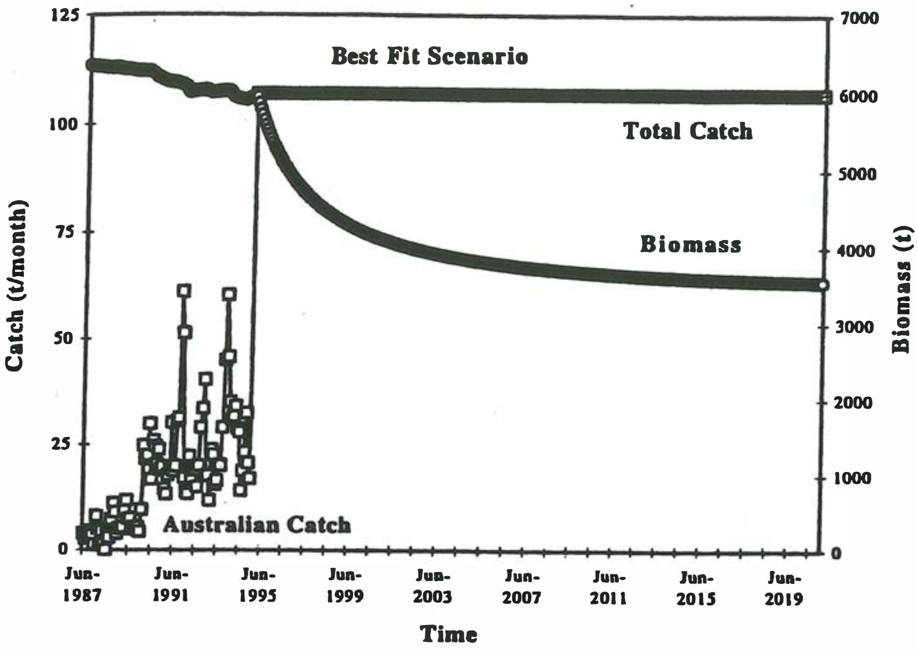

Figure 4b

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Attachment 3

A simple generalized model of allometry, with examples of length and weight relationships for 14 species of groundfish

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A simple generalized model of allometry, with examples of length and weight relationships for 14 species of groundfish

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Allometry is a set of relations between an animal's characteristics and its body size, and is applied in many branches of biological sciences including ecology, physiology, and morphology (Peters, 1983; Calder, 1984; Schmidt-Nielsen, 1984; Bookstein et al., 1985; Reiss, 1989). Allometry is represented by the power function, $W = AL^{X_2}$, where W is a characteristic of an animal (e.g. body weight), L is its body size, and A and X_2 are its allometric parameters. To determine an allometric relationship for a particular characteristic, the power function is usually, albeit at times inappropriately, double log-transformed into a simple linear equation,

$$Y = X_1 + X_2X_3, \qquad (1)$$

with $Y = \log(W)$, $X_1 = \log(A)$, and $X_3 = \log(L)$, and is then fit to data from different individuals.

Use of allometry in this way assumes constancy of X_1 and X_2 in Equation 1. While both allometric parameters may be treated approximately as constants in certain applications, the assumption may be violated for a wide variety of biological phenomena because of genetic, phenotypic, and/or behavioral variability among individual animals. In fact, Mosimann and James (1979) have concluded that X_2 varies spatially in the Florida red-winged blackbird, *Agelaius phoeniceus*. Variability in X_2 is also implied in Reiss' (1989) hypothesis that X_2 contains phylogenetic information and is less variable intraspecifically than interspecifically. Peters (1983) convincingly demonstrated interspecific variation in X_2 and computed its mean and standard deviation for metabolic rates scaled to body sizes across many animal taxa. Variability in X_1 has not been examined but is certainly implied in the comprehensive appendices of Peters' (1983) book on the ecological implications of body size and in Reiss' (1989) monograph on the allometry of organismic growth and reproduction. X_1 may be strongly negatively correlated with X_2 for length-weight relationships in fish (e.g. Caillouet, 1993).

Variability in X_1 and X_2 may have major implications in the widely used allometric equation because it represents a fundamental concept in biology (Peters, 1983). In this paper, we generalize Equation 1 by explicitly incorporating variability in and correlation between, X_1 and X_2, and study the consequences of such variability and correlation in allometric predictions. The generalized model is demonstrated by using length and weight relationships for 14 species of groundfish of the families Centrolophidae, Haemulidae, Lethrinidae, Lutjanidae, Nemipteridae, and Synodontidae from northern Australian waters.

Model

Suppose that a joint probability distribution of X_1 and X_2 conditional on X_3 could be formed for a group of animals, with each individual having its own pair of allometric parameters which it retains throughout its life, and that values of pairs of allometric parameters are serially independent. The value of Y for the ith individual with allometric parameter pair (X_{1i}, X_{2i}) at X_3 is

$$Y_i = X_{1i} + X_{2i}X_3.$$

For a group of animals selected randomly from the population, the expected value of Y at X_3 is

$$E[Y \mid X_3] = E[X_1 + X_2X_3] \qquad (2)$$

with variance

$$\begin{aligned} V[Y \mid X_3] &= V[X_1 + X_2X_3] \qquad (3) \\ &= E[Y^2 \mid X_3] - E[Y \mid X_3]^2 \\ &= E[(X_1 + X_2X_3)^2] - E[X_1 + X_2X_3]^2. \end{aligned}$$

Given information on how X_1 and X_2 vary, one can develop Equations 2 and 3. X_2 may closely follow a normal distribution for metabolic rate of animals scaled to body size (Peters, 1983), being strongly negatively correlated with X_1 for length-weight relationships in fish (e.g. Caillouet, 1993). We will assume below that X_1 and X_2 follow a joint normal distribution, i.e. $(X_1, X_2) \sim N(\mu_1, \mu_2; \sigma_1^2, \sigma_2^2; \rho)$ with mean μ_i, and variance σ_i^2 of X_i, and correlation coefficient ρ. Under general conditions, the sum (or average) of a number of random variables is approximately normally distributed, and such approximation can be quite good even if that number is relatively small. The above assump-

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tion would be at least approximately valid because both X_1 and X_2 can be regarded as the sum (or average) of numerous (e.g. genetic, phenotypic, and behavioral) random components. Analogous models may be developed for other probability distributions. Under that assumption, Equations 2 and 3 become, respectively,

$$\begin{aligned} E[Y \mid X_3] &= E[X_1 + X_2 X_3] \\ &= \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \frac{1}{2\pi\sigma_1\sigma_2\sqrt{1-\rho^2}} (x_1 + x_2 X_3) e^{-\frac{1}{2(1-\rho^2)}\left[\frac{(x_1-\mu_1)^2}{\sigma_1^2} - 2\rho\frac{(x_1-\mu_1)(x_2-\mu_2)}{\sigma_1\sigma_2} + \frac{(x_2-\mu_2)^2}{\sigma_2^2}\right]} dx_1 dx_2 \\ &= \mu_1 + \mu_2 X_3, \end{aligned} \tag{4}$$

and

$$\begin{aligned} V[Y \mid X_3] &= V[X_1 + X_2 X_3] \\ &= E[Y^2 \mid X_3] - E[Y \mid X_3]^2 \\ &= E[(X_1 + X_2 X_3)^2] - E[X_1 + X_2 X_3]^2 \\ &= \sigma_1^2 + 2\sigma_1\sigma_2\rho X_3 + \sigma_2^2 X_3^2. \end{aligned} \tag{5}$$

Thus variability in, and correlation between, X_1 and X_2 only affect $V[Y \mid X_3]$. $V[Y \mid X_3]$ increases linearly with ρ from $(\sigma_1 - \sigma_2 X_3)^2$ at $\rho = -1$ through $\sigma_1^2 + \sigma_2^2 X_3^2$ at $\rho = 0$ to $(\sigma_1 + \sigma_2 X_3)^2$ at $\rho = 1$. It quadratically decreases with σ_1, σ_2, and X_3 to a minimum of $\sigma_2^2 X_3^2(1-\rho^2) \geq 0$ at $\sigma_1 = -\sigma_2\rho X_3$, $\sigma_1^2(1-\rho^2)$ at $\sigma_2 = -\sigma_1\rho / X_3$ and $\sigma_1^2(1-\rho^2)$ at $X_3 = -\sigma_{1\rho}/\sigma_2$, respectively, and finally increases unboundedly, under the constraint that σ_1, σ_2, and $X_3 \geq 0$. However, if X_1 and X_2 are both deterministic $(\sigma_i^2 = 0, \rho = 0)$, $V[Y \mid X_3] = 0$.

If X_1 is random $(\sigma_1^2 > 0)$ and X_2 is deterministic $(\sigma_2^2 = 0, \rho = 0)$, $V[Y \mid X_3] = \sigma_1^2$. If X_2 is random $(\sigma_2^2 > 0)$ and X_1 is deterministic $(\sigma_1^2 = 0, \rho = 0)$, $V[Y \mid X_3] = \sigma_2^2 X_3^2$. Finally, if X_1 and X_2 are random but independent $(\sigma_1^2 > 0, \sigma_2^2 > 0$ and $\rho = 0)$, $V[Y \mid X_3] = \sigma_1^2 + \sigma_2^2 X_3^2$.

Data and parameter estimation

Data on fish weight at length were collected from Australia's continental shelf in the Timor and Arafura Seas (9–14°S, 127–137°E) from 20 October to 16 December 1990 as part of the Northern Territory Department of Primary Industry and Fisheries' program assessing commercial fish stocks. Of 240 stations allocated randomly within a depth range of 20–200 m, 199 were successfully sampled with a Frank and Bryce trawl net (headline height, 2.9 m; wing spread, 14.4 m; door spread, 60.1 m) at a speed of 1.54–2.06 m·s^{-1}. Nearly 48 tonnes of fish representing about 483 species in 119 families were caught during sampling. A representative subsample of individuals of 14 species, mostly of commercial fish, of the families Centrolophidae, Haemulidae, Lethrinidae, Lutjanidae, Nemipteridae, and Synodontidae were frozen immediately on board, returned to the laboratory, thawed, sexed, measured (fork length) to the nearest 1 mm, and weighed (wet weight) to the nearest 1 g with an electronic balance (Mettler, PC4000). For each of the 14 species, data on individual wet weight at length were pooled across all stations and fit to all cases of Equations 4 and 5 for females, males, and mixed sexes. Parameter estimates indicated by hats (^) were obtained by linear regression for Equation 1 by using SAS regression procedure (SAS Institute Inc., 1985) and by maximizing the general likelihood function,

$$L = \prod_{i=1}^{n}\left[2\pi V[Y \mid X_3] + \sigma_e^2\right]_i^{-\frac{1}{2}} e^{-\frac{[Y_i - E[Y \mid X_3]_i]^2}{2[V[Y \mid X_3]_i + \sigma_e^2]}},$$

for all other models by using the simplex algorithm of SYSTAT nonlinear regression procedure (Wilkinson, 1989). We included a model error term, σ_e^2, in the likelihood function to show that, in this case, it is compounded with σ_1^2 and is hence equivalent to σ_1^2 and $\sigma_1^2 + \sigma_e^2$ for estimation purposes. For this reason, we treated both error components collectively as 'σ_1^2' during model fitting and result presentation, unless otherwise stated.

Results

Some statistics of fish length and weight data used in this analysis are given in Table 1. We attempted to fit data for mixed sexes (both sexable and unsexable individuals included) and males and females (with unsexable juveniles excluded) of each of 14 species of groundfish to all cases of Equations 4 and 5. However, parameters could be estimated for models with σ_1^2 or σ_2^2 only; those in models simultaneously with σ_1^2 and σ_2^2, or simultaneously with σ_1^2, σ_2^2 and ρ could not be estimated because of overparameterization. Estimates of parameters, derived from linear regression of Equation 1 by using least squares method—equivalent to maximizing the likelihood function

$$L = \prod_{i=1}^{n} \left[2\pi\sigma_1^2\right]^{-\frac{1}{2}} e^{-\frac{[Y_i - E[Y|X_3]_i]^2}{2\sigma_1^2}}$$

and from maximizing the likelihood function

$$L = \prod_{i=1}^{n} \left[2\pi\sigma_2^2 X_3^2\right]^{-\frac{1}{2}} e^{-\frac{[Y_i - E[Y|X_3]_i]^2}{2\sigma_2^2 X_3^2}},$$

are given in Tables 2 and 3 respectively. Estimates in both tables are very similar between sexes for each species and between species, roughly with a species-wide $\hat{\mu}_1 = -10.89$, $\hat{\mu}_2 = 2.99$, $\sigma_1 = -0.006638$ and $\hat{\sigma}_2 = 0.014932$. Thus, while $V[Y|X_3]$ can be treated approximately as a constant, as is usually assumed in previous applications, it does change quadratically with X_3.

Discussion

Peters (1983) observed a large amount of variability in most allometric relationships and recognized a need to identify independent variables of general biological interest other than size. The general model presented in this study takes into account both body size and parameter variability among individual animals in allometric predictions. A major problem in allometry is that allometricians are more apt at providing a statistical description of a new data set than at using their data for hypothesis testing (Peters, 1983). This tendency has led to a plethora of only slightly different allometric equations, none of which can be rejected objectively. Our general model or any of its special cases would form a basis for intrataxal or intertaxal generalizations by treating some of those estimates of allometric parameters as intrataxal or intertaxal variations, hence providing a means for a general "house cleaning" in allometry.

Incorporating more independent variables in allometric modelling may explain more variability in the dependent variable, but it may result in a loss of a basis for comparison between, and manipulation of, allometric equations, such as allometric cancellation (Calder, 1984). The model presented above conforms exactly with conventional allometry and maintains commensuration by its estimated parameter means.

Specification of error structures in allometric models is an essential part of allometric modelling. Errors for Equation 1 are often assumed to be normally distributed with a constant variance, say σ_e^2. Several other interpretations arise from $V[Y|X_3]$ in that, for estimation purposes, σ_e^2 can be interpreted by any combinations of terms on the right-hand side of Equation 5. These and other alternative interpretations may pose problems for some applications. Thus, error structures of an allometric model must be specified cautiously.

There was no gain in precision or accuracy in estimates of allometric parameters in length and weight relationships of some fishes from considering individual variability of allometric parameters. Both Equation 1 and Equations 4 and 5 with σ_1^2 or σ_2^2, alone give an equally adequate description of weight at length data from all 14 species of groundfish concerned. Overparameterization occurred in cases of Equations 4 and 5 simultaneously with σ_1^2 and σ_2^2, or simultaneously with σ_1^2, σ_2^2, and ρ, and, as a result, not all parameters could be estimated from our data. The overparameterization lent further support to this conclusion. Also, although σ_1^2 and σ_2^2 can be estimated separately for each species, they are either equivalent to model error or take such small values (Tables 2 and 3) that $V[Y|X_2]$ can be treated effectively as constant. Finally, when interpreting regression results from various cases of the general model, it should be noted that all other variability will be confounded with, and added to, that of allometric parameters. Our data sets are of moderate sizes (Table 1) and many others of similar size could be expected to behave similarly. Individual variability of allometric parameters probably has a negligible effect on allometric predictions in length and weight relationships of certain fishes. Thus, our work supports the common use of Equation 1 to model intraspecific length and weight relationships in those fishes. However, all parameters in Equations 4 and 5 may be estimable simultaneously for length and weight relationships, as well as for other allometric relationships, if larger data sets or higher taxonomic levels, or both, are used.

A key assumption in our model is that the independent characteristic, L, (e.g. length) has little measurement error relative to the dependent characteristic, W (e.g. weight). Theoretically, this may not be the case. However, we believe that our model will provide good approximations for many allometrically scaled phenomena, such as length and weight relationships in certain fishes. For other allometric phenomena, alternative formulations, such as those of Pienaar and Ricker (1968), Saenger (1989), Seim and Saether (1983), and Shoesmith (1990) may be useful.

$V[Y|X_3]$ is a function of the independent variable whenever there is individual variability in X_2 or in X_1 and X_2. If this is not taken into account in regres-

Table 1

Some statistics of length and weight data for mixed sexes (both sexable and unsexable individuals included), males and females (with unsexable juveniles excluded) of each of 14 species of groundfish caught in northern Australian waters during 20 October to 16 December 1990.

			Fork length (mm)				Body weight (g)			
Sex	Species	*n*	Mean	SD	Min	Max	Mean	SD	Min	Max
Mixed										
Diagramma pictum	painted sweetlip	413	374.753	135.174	127	610	1,044.94	906.31	27	3,415
Lethrinus fraenatus	blue-lined emperor	48	344.562	63.134	201	450	907.77	469.80	165	1,837
Lethrinus lentjan	red-spot emperor	334	278.521	43.792	190	430	457.04	234.31	143	1,567
Lutjanus erythropterus	scarlet snapper	172	431.105	54.429	255	536	1,269.63	417.65	255	2,373
Lutjanus malabaricus	saddle-tailed snapper	590	377.398	151.595	86	765	1,170.71	1074.90	13	7,251
Lutjanus sebae	red emperor	182	342.346	125.237	94	596	1,144.50	974.22	18	4,736
Lutjanus timorensis	Timor snapper	43	415.256	38.608	211	453	1,339.72	271.27	178	1,663
Lutjanus vittus	one-band snapper	450	188.364	30.864	98	300	114.65	59.41	15	461
Nemipterus furcosus	rosy threadfin-bream	479	164.382	34.187	38	250	95.61	55.97	3	300
Nemipterus hexodon	ornate threadfin-bream	479	149.714	28.517	93	230	73.35	44.00	15	252
Pristipomoides multidens	gold-band snapper	293	314.055	117.079	131	585	818.53	882.70	50	3,800
Pristipomoides typus	sharp-tooth snapper	131	207.130	106.140	87	550	302.01	540.41	12	2,705
Psenopsis humerosa	black-spot butterfish	254	158.106	14.633	105	195	106.74	32.23	25	202
Saurida micropectoralis	short-finned lizardfish	444	261.218	34.039	110	410	194.26	90.32	12	850
Female										
Diagramma pictum	painted sweetlip	185	405.827	118.834	185	610	1,192.71	847.30	88	3,377
Lethrinus fraenatus	blue-lined emperor	32	318.031	48.035	201	445	690.22	313.06	165	1,757
Lethrinus lentjan	red-spot emperor	255	265.435	35.665	194	422	389.43	185.90	146	1,567
Lutjanus erythropterus	scarlet snapper	78	430.731	43.480	345	536	1,285.32	402.82	627	2,373
Lutjanus malabaricus	saddle-tailed snapper	193	472.637	90.217	175	716	1,702.28	811.06	89	5,196
Lutjanus sebae	red emperor	88	386.159	86.001	197	535	1,357.81	791.64	155	3,176
Lutjanus timorensis	Timor snapper	25	414.520	22.417	378	451	1,320.64	207.65	978	1,663
Lutjanus vittus	one-band snapper	212	181.835	24.025	120	262	100.01	41.03	29	289
Nemipterus furcosus	rosy threadfin-bream	240	161.429	25.781	38	230	85.36	40.47	7	239
Nemipterus hexodon	ornate threadfin-bream	270	146.463	23.825	97	208	67.34	33.01	18	176
Pristipomoides multidens	gold-band snapper	98	356.735	117.750	180	585	1,103.23	1,001.25	108	3,800
Pristipomoides typus	sharp-tooth snapper	29	287.034	111.650	135	550	593.48	720.46	42	2,705
Psenopsis humerosa	black-spot butterfish	101	167.050	12.046	138	195	126.50	30.13	61	202
Saurida micropectoralis	short-finned lizardfish	164	284.860	36.753	197	410	256.20	111.99	71	850
Male										
Diagramma pictum	painted sweetlip	119	448.303	111.902	177	594	1,528.94	917.86	77	3415
Lethrinus fraenatus	blue-lined emperor	16	397.625	56.707	216	450	1,342.88	431.39	191	1837
Lethrinus lentjan	red-spot emperor	74	325.743	35.281	220	430	698.30	229.21	202	1469
Lutjanus erythropterus	scarlet snapper	93	433.312	59.850	258	535	1,267.23	421.10	255	2233
Lutjanus malabaricus	saddle-tailed snapper	200	449.215	122.859	183	765	1,622.40	1,121.62	105	7251
Lutjanus sebae	red emperor	45	423.822	94.510	187	596	1,772.42	1,048.84	124	4736
Lutjanus timorensis	Timor snapper	17	428.353	19.193	388	453	1,436.12	183.58	1,021	1613
Lutjanus vittus	one-band snapper	225	197.858	31.901	128	300	132.84	67.83	32	461
Nemipterus furcosus	rosy threadfin-bream	205	178.800	30.351	115	250	120.09	61.04	28	300
Nemipterus hexodon	ornate threadfin-bream	125	165.832	32.361	107	230	99.21	58.00	20	252
Pristipomoides multidens	gold-band snapper	127	333.276	108.795	141	580	897.81	840.95	60	3,475
Pristipomoides typus	sharp-tooth snapper	35	267.314	99.371	114	530	477.31	581.00	27	2,617
Psenopsis humerosa	black-spot butterfish	117	153.821	13.416	105	191	97.19	26.08	25	198
Saurida micropectoralis	short-finned lizardfish	263	249.433	19.805	186	295	161.19	41.16	63	289

sion analysis, too much weight would be given to observations of the dependent variable in the region with high variances, and the analysis will be overly sensitive to chance events or bias affecting observations in this region of the independent variable.

Length and weight relationships in fishes are often required for stock assessment and for intra- and inter-specific comparisons. Although many data are available on weight at length relationships of fishes from New Guinea (Showers, 1993) and New Cale-

Table 2

Estimates of mean and standard error of allometric parameters obtained for mixed sexes, males, and females of each of 14 species of groundfish, caught in northern Australian waters during 20 October to 16 December 1990 by linear regression of Equation 1 by using least squares method. $P \leq 0.0001$ applies to all species for separate sexes.

Mixed

Species[1]	$\hat{X}_1$ (SE)	$\hat{X}_2$ (SE)	$n-2$	$F_{1,n-2}$	P	R^2
Diagramma pictum	–11.4249 (0.0650)	3.0427 (0.0111)	411	75,363.608	0.0000	0.9946
Lethrinus fraenatus	–11.1084 (0.2933)	3.0501 (0.0503)	46	3,673.450	0.0001	0.9874
Lethrinus lentjan	–10.8678 (0.1287)	3.0049 (0.0229)	332	17,226.485	0.0001	0.9810
Lutjanus erythropterus	–10.2265 (0.2323)	2.8569 (0.0383)	170	5,550.516	0.0001	0.9701
Lutjanus malabaricus	–10.4713 (0.0478)	2.8926 (0.0082)	588	125,849.921	0.0000	0.9953
Lutjanus sebae	–10.7588 (0.0752)	2.9931 (0.0130)	180	52,732.028	0.0001	0.9966
Lutjanus timorensis	–10.2548 (0.5172)	2.8916 (0.0858)	41	1,134.654	0.0001	0.9643
Lutjanus vittus	–10.5972 (0.0985)	2.9136 (0.0188)	448	23,905.566	0.0000	0.9816
Nemipterus furcosus	–10.6433 (0.1163)	2.9552 (0.0229)	477	16,672.088	0.0000	0.9721
Nemipterus hexodon	–10.8475 (0.1277)	3.0010 (0.0256)	477	13,778.375	0.0000	0.9665
Pristipomoides multidens	–10.4284 (0.0629)	2.9192 (0.0110)	291	69,881.156	0.0000	0.9958
Pristipomoides typus	–10.6474 (0.0672)	2.9462 (0.0128)	129	52,895.132	0.0001	0.9975
Psenopsis humerosa	–11.8119 (0.2644)	3.2487 (0.0523)	252	3,863.670	0.0001	0.9385
Saurida micropectoralis	–12.3581 (0.1948)	3.1560 (0.0351)	442	8,106.551	0.0001	0.9482

Female

Species[1]	$\hat{X}_1$ (SE)	$\hat{X}_2$ (SE)	$n-2$	$F_{1,n-2}$	R^2
Diagramma pictum	–11.4854 (0.1323)	3.0526 (0.0222)	183	18,940.693	0.9904
Lethrinus fraenatus	–10.9359 (0.4586)	3.0204 (0.0797)	30	1,435.635	0.9788
Lethrinus lentjan	–11.0141 (0.1823)	3.0314 (0.0327)	253	8,591.353	0.9713
Lutjanus erythropterus	–11.1443 (0.3965)	3.0123 (0.0654)	76	2,120.223	0.9649
Lutjanus malabaricus	–10.6937 (0.1855)	2.9290 (0.0302)	191	9,397.044	0.9800
Lutjanus sebae	–10.9484 (0.2014)	3.0256 (0.0339)	86	7,943.456	0.9892
Lutjanus timorensis	–8.5750 (1.6316)	2.6136 (0.2708)	23	93.182	0.7934
Lutjanus vittus	–10.4418 (0.1823)	2.8824 (0.0351)	210	6,752.525	0.9697
Nemipterus furcosus	–9.0380 (0.2490)	2.6379 (0.0491)	238	2,888.362	0.9236
Nemipterus hexodon	–10.5120 (0.1626)	2.9366 (0.0327)	268	8,081.145	0.9678
Pristipomoides multidens	–10.4544 (0.1318)	2.9235 (0.0226)	96	16,739.747	0.9942
Pristipomoides typus	–10.3553 (0.1890)	2.8933 (0.0337)	27	7,358.630	0.9962
Psenopsis humerosa	–12.0558 (0.5391)	3.2969 (0.1054)	99	978.916	0.9072
Saurida micropectoralis	–12.4764 (0.3404)	3.1777 (0.0603)	162	2,777.965	0.9446

Male

Species[1]	$\hat{X}_1$ (SE)	$\hat{X}_2$ (SE)	$n-2$	$F_{1,n-2}$	R^2
Diagramma pictum	–11.8373 (0.1399)	3.1102 (0.0230)	117	18,239.181	0.9936
Lethrinus fraenatus	–11.5601 (0.5382)	3.1252 (0.0901)	14	1,204.055	0.9877
Lethrinus lentjan	–11.1870 (0.3227)	3.0589 (0.0558)	72	3,002.105	0.9763
Lutjanus erythropterus	–9.9051 (0.2875)	2.8006 (0.0474)	91	3,487.397	0.9743
Lutjanus malabaricus	–10.6166 (0.1268)	2.9171 (0.0209)	198	19,525.208	0.9899
Lutjanus sebae	–11.5487 (0.2166)	3.1216 (0.0359)	43	7,544.416	0.9942
Lutjanus timorensis	–9.4597 (1.8694)	2.7597 (0.3085)	15	80.011	0.8316
Lutjanus vittus	–10.5218 (0.1447)	2.9007 (0.0274)	223	11,186.525	0.9804
Nemipterus furcosus	–10.9360 (0.1538)	3.0150 (0.0297)	203	10,282.691	0.9805
Nemipterus hexodon	–10.9499 (0.2803)	3.0188 (0.0550)	123	3,011.431	0.9604
Pristipomoides multidens	–10.3481 (0.1032)	2.9054 (0.0179)	125	26,357.314	0.9952
Pristipomoides typus	–10.3289 (0.1707)	2.8902 (0.0308)	33	8,794.451	0.9961
Psenopsis humerosa	–10.6433 (0.3927)	3.0174 (0.0780)	115	1,495.187	0.9280
Saurida micropectoralis	–11.6679 (0.4003)	3.0307 (0.0726)	261	1,744.792	0.8694

[1] See Table 1 for common names.

Table 3

Estimates of mean and asymptotic standard error (ASE) of allometric parameters obtained for mixed sexes, males, and females of each of 14 species of groundfish, caught in northern Australian waters during 20 October to 16 December 1990 by fitting Equations 4 and 5 with $V[Y|X_3] = \sigma_2^2 X_3^2$ excluding the model error term (σ_e^2).

	Mixed		
Species[1]	**$\hat{\mu}_1$ (ASE)**	**$\hat{\mu}_2$ (ASE)**	**$\hat{\sigma}_2$ (ASE)**
Diagramma pictum	−11.4010 (0.0624)	3.0386 (0.0107)	0.015684 (0.000536)
Lethrinus fraenatus	−11.0788 (0.2791)	3.0450 (0.0480)	0.011364 (0.001120)
Lethrinus lentjan	−10.8528 (0.1295)	3.0022 (0.0231)	0.011431 (0.000427)
Lutjanus erythropterus	−10.2207 (0.2246)	2.8559 (0.0371)	0.011478 (0.000598)
Lutjanus malabaricus	−10.4315 (0.0455)	2.8858 (0.0079)	0.015562 (0.000445)
Lutjanus sebae	−10.7324 (0.0705)	2.9885 (0.0124)	0.013522 (0.000691)
Lutjanus timorensis	−10.3142 (0.4613)	2.9015 (0.0766)	0.010599 (0.001097)
Lutjanus vittus	−10.5948 (0.0968)	2.9132 (0.0186)	0.012502 (0.000405)
Nemipterus furcosus	−10.3566 (0.1275)	2.8986 (0.0252)	0.028576 (0.000918)
Nemipterus hexodon	−10.8451 (0.1281)	3.0006 (0.0257)	0.021340 (0.000683)
Pristipomoides multidens	−10.4311 (0.0626)	2.9196 (0.0111)	0.012057 (0.000483)
Pristipomoides typus	−10.6917 (0.0692)	2.9547 (0.0134)	0.012299 (0.000737)
Psenopsis humerosa	−11.8293 (0.2619)	3.2521 (0.0518)	0.015465 (0.000673)
Saurida micropectoralis	−12.3549 (0.1919)	3.1555 (0.0346)	0.017171 (0.000567)

	Female		
Species[1]	**$\hat{\mu}_1$ (ASE)**	**$\hat{\mu}_2$ (ASE)**	**$\hat{\sigma}_2$ (ASE)**
Diagramma pictum	−11.4694 (0.1271)	3.0499 (0.0214)	0.016512 (0.000844)
Lethrinus fraenatus	−10.8822 (0.4288)	3.0111 (0.0747)	0.011972 (0.001450)
Lethrinus lentjan	−10.9932 (0.1843)	3.0276 (0.0331)	0.011992 (0.000515)
Lutjanus erythropterus	−11.1343 (0.3913)	3.0106 (0.0646)	0.009438 (0.000718)
Lutjanus malabaricus	−10.6957 (0.1742)	2.9293 (0.0284)	0.015106 (0.000754)
Lutjanus sebae	−10.9216 (0.1938)	3.0211 (0.0328)	0.013024 (0.000956)
Lutjanus timorensis	−8.5443 (1.5702)	2.6085 (0.2606)	0.011468 (0.001567)
Lutjanus vittus	−10.4305 (0.1808)	2.8802 (0.0348)	0.012749 (0.000602)
Nemipterus furcosus	−8.0532 (0.2559)	2.4435 (0.0506)	0.030733 (0.001396)
Nemipterus hexodon	−10.4947 (0.1627)	2.9332 (0.0328)	0.017758 (0.000753)
Pristipomoides multidens	−10.4486 (0.1296)	2.9225 (0.0224)	0.012449 (0.000864)
Pristipomoides typus	−10.3916 (0.1853)	2.8998 (0.0333)	0.011512 (0.001461)
Psenopsis humerosa	−12.0680 (0.5276)	3.2992 (0.1032)	0.015033 (0.001037)
Saurida micropectoralis	−12.4710 (0.3370)	3.1768 (0.0598)	0.017557 (0.000955)

	Male		
Species[1]	**$\hat{\mu}_1$ (ASE)**	**$\hat{\mu}_2$ (ASE)**	**$\hat{\sigma}_2$ (ASE)**
Diagramma pictum	−11.7895 (0.1296)	3.1023 (0.0214)	0.012092 (0.000760)
Lethrinus fraenatus	−11.5461 (0.4630)	3.1229 (0.0776)	0.009625 (0.001619)
Lethrinus lentjan	−11.1988 (0.3127)	3.0609 (0.0541)	0.009055 (0.000704)
Lutjanus erythropterus	−9.9036 (0.2774)	2.8003 (0.0458)	0.011754 (0.000834)
Lutjanus malabaricus	−10.5854 (0.1203)	2.9120 (0.0199)	0.014870 (0.000728)
Lutjanus sebae	−11.5462 (0.2006)	3.1212 (0.0334)	0.009834 (0.000989)
Lutjanus timorensis	−9.4896 (1.7559)	2.7646 (0.2898)	0.008735 (0.001411)
Lutjanus vittus	−10.5171 (0.1433)	2.8998 (0.0272)	0.012371 (0.000566)
Nemipterus furcosus	−10.9048 (0.1524)	3.0089 (0.0295)	0.014279 (0.000690)
Nemipterus hexodon	−10.9325 (0.2732)	3.0153 (0.0538)	0.023605 (0.001481)
Pristipomoides multidens	−10.3460 (0.1004)	2.9051 (0.0175)	0.011230 (0.000680)
Pristipomoides typus	−10.3560 (0.1709)	2.8951 (0.0311)	0.010902 (0.001254)
Psenopsis humerosa	−10.6920 (0.3878)	3.0271 (0.0771)	0.014853 (0.000951)
Saurida micropectoralis	−11.6947 (0.3976)	3.0356 (0.0721)	0.016898 (0.000725)

[1] See Table 1 for common names.

donia (Kulbicki et al., 1993), systematic data are lacking from northern Australian waters. Because our data covered relatively large size ranges of each of the 14 species of fish concerned, our estimates of allometric parameters and associated relationships will improve stock assessments of major groundfish in northern Australian waters.

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Attachment 4

Collaborative research and management - the key to the sustainable management of groundfish resources in the Timor and Arafura Seas

Proceedings of the conference on
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Collaborative Research and Management – The Key to the Sustainable Management of Groundfish Resources in the Timor and Arafura Seas

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*The waters between Australia and Indonesia support major groundfish resources, including deepwater snappers (*Pristipomoides*) on the Sahul Banks in the Timor Sea and red snappers (*Lutjanus*) in the Arafura Sea; some of these resources are thought to be shared by Australia and Indonesia. Recent research indicates that deepwater and red snappers may become over-exploited if fishing effort is not adequately controlled within both Australian and Indonesian waters, leading to the collapse of fisheries in both sectors and a reduction in the income and livelihood of Australian and Indonesian resource user-groups. The key to the ecologically sustainable management of groundfish resources in the Timor and Arafura Seas, and the long-term economic viability of Australian and Indonesian fishing industries, is through collaborative research and management. Such collaboration should aim to identify sustainable resource management strategies which will enhance community benefits and provide new opportunities to fishing communities. The challenge facing scientists and managers is to develop strategies which meet national and international requirements, and the very different needs of Australian and Indonesian fishing industries.*

Introduction

The Timor and Arafura Seas, between Australia and Indonesia (Fig. 1), support major fishery resources, including groundfishes, pearl oysters, squids, shrimps and sharks (e.g. Ramm and Xiao, 1994). Groundfishes, the focus of this paper, consist of fish living in close association with the seabed, such as snappers, emperors, cods and trevallies. The groundfish assemblage off northern Australia has a high species diversity, with over 450 species of fish recorded (e.g. Russell and Houston, 1989), and supports multi-species fisheries. About 100 species from 19 families are of commercial importance (Fig. 2), although the species composition of retained catches follows market demand and varies between fishing fleets (Edwards, 1983; Ramm, 1989). Australian fleets currently target deepwater snappers (*Pristipomoides multidens* and *Pristipomoides typus*) on the Sahul Banks in the Timor Sea, and red snappers (mainly *Lutjanus malabaricus* and *Lutjanus erythropterus*) in the Arafura Sea. These resources are thought to be shared by Australia and Indonesia.

Recent research indicates that catches of deepwater snappers in the Timor Sea along the Sahul Banks, and red snappers in the Arafura Sea, are approaching, or have exceeded, estimates of sustainable yields (e.g. Naamin *et al*, 1994; Ramm, in press). Immediate steps are

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required to develop and implement ecologically sustainable management strategies for snapper resources in these waters, and reach agreement on joint management strategies for groundfish resources shared by Australia and Indonesia. This paper summarises the utilisation of groundfish resources in the Timor and Arafura Seas, and current research to determine their size and extent. Future directions are outlined, including the needs for collaborative Australian-Indonesian research and management to ensure the long-term sustainability of groundfish resources shared by both countries.

Groundfish Fisheries in the Timor and Arafura Seas

Groundfish resources of the Timor and Arafura Seas, and further west on the Northwest Shelf, were explored by Japanese stern trawlers during 1959-1963 (Sainsbury, 1987), and extensively fished by Taiwanese pair trawlers during 1971-1990 (Liu, 1976; Liu *et al.*, 1978; Edwards, 1983; Sainsbury, 1987, 1988). In addition, Thai stern trawlers fished in the Arafura Sea during 1985-1990, while pair trawlers from Zhejiang Province (China) fished in the Timor Sea in 1989, and Australian stern trawlers have operated off northern Australia since the late 1980s (Ramm and Xiao, in press). The Taiwanese fleet retained a large variety of groundfish species including snappers (family: Lutjanidae), threadfin breams (Nemipteridae), trevallies (Carangidae), and lizardfishes (Synodontidae). The fishery developed rapidly during the 1970s and the total annual retained catch peaked around 49200 t in 1974. Early estimates of annual maximum sustainable yield (MSY) for all commercial species of groundfish were 336000 t, 250000 t and 447000 t for the Northwest Shelf, Timor Sea and Arafura Sea (Australian and Indonesian sectors), respectively (Liu, 1976; Liu et al. 1978). Subsequently, the annual all-species MSYs were revised downwards, based on new information and a longer time series of catch and effort data, to 87000 t for the Northwest Shelf (Sainsbury, 1982), then 36000 t, 20000 t and 30000 t for the Northwest Shelf, Timor Sea and Arafura Sea (Australian sector only), respectively (Edwards, 1983). However, inadequate data on groundfishes in the Timor and Arafura Seas lead to large uncertainties in estimates of MSY and resource size (Jernakoff and Sainsbury, 1990).

Following ratification of Australia's Fishing Zone in 1979, offshore fisheries in northern Australian waters were managed by the Commonwealth Department of Primary Industries and Energy (Canberra). Groundfish trawling was confined to management zones on the Northwest Shelf, and in the Timor and Arafura Seas, so as to minimise user conflicts with the developing shrimp trawl fishery in inshore waters. Taiwanese, Thai and Zhejiang trawlers fished under various licence arrangements, and effort shifted from the Northwest Shelf to the Arafura Sea to target red snappers, mainly *L. malabaricus*. Later, in 1990, licence arrangements for these fleets were discontinued following increased activity by Australian groundfish trawlers in the Arafura Sea. New management legislation was introduced in February 1995, and the groundfish trawl fishery in the Australian sectors of the Arafura and Timor Seas within Northern Territory waters (approximately 128-140°E) is now managed under a joint Northern Territory-Commonwealth authority under Northern Territory law. Similarly, groundfish trawling within Western Australian waters (west of about 128°E) and Queensland waters (Gulf of Carpentaria east of about 140°E) is managed under respective state laws.

Deepwater snappers (mainly *P. multidens*) are targeted by a small, technologically advanced, dropline and trap fleet operating within the Australian sector of the Timor Sea. This fishery, which began in 1987 following feasibility fishing by Japanese vessels during 1975-82 (Stehouwer, 1981; Clark, 1984), operates on the Sahul Banks in an area of patch reefs between 128-131°E and 9-12°S known locally as the 'Timor Box' (Lloyd, 1994). Annual catches have increased to around 260-330 t of deepwater snappers. A fishery for deepwater snappers is also developing within Western Australian waters, west of approximately 128°E, and vessels operating in that fishery are based along the Kimberley coast of Western Australia.

As for the groundfish trawl fishery, dropline and trap fisheries within the Australian sector of the Sahul Banks are managed under Northern Territory and Western Australian law within their respective territorial waters. Although each management agency has separate management strategies, there is on-going dialogue and overall agreement on a common approach to ecologically sustainable management of groundfish resources. In addition, groundfish trawling is not allowed in the Timor Box, and the Darwin-based deepwater snapper fishery is a closed entry fishery with a 2 for 1 licence transfer scheme to reduce effort in the short term; at the time of writing this paper, there were 21 licences to harvest snappers in the Timor Box.

Groundfish fisheries also operate in the Indonesian sectors of the Timor and Arafura Seas. However, catch and effort data for these fisheries are generally difficult to extract from fishery reports because fishing operations are diverse, and landings are summarised by province (e.g. Direktorat Jenderal Perikanan, 1994). A large number of trawlers, based in Kandari (Sulawesi), Ambon (Maluku), Sorong and Merauke (Irian Jaya), and smaller eastern ports, operate in the Arafura Sea where they take shrimps and groundfishes. Recent reports on fishing on the Sahul Banks indicate that an increasing number of Indonesian vessels, generally from Karimun (Sumatra), are targeting deepwater snappers (Mick Munn, Northern Territory Department of Primary Industry and Fisheries, pers comm, October 1995).

Current Fisheries R&D

Over the past five years, research on groundfishes in the region has focussed on the resources of the Arafura Sea, and in particular, population modelling and stock assessment of red snappers. The Northern Territory Department of Primary Industry and Fisheries (NTDPIF) conducted random trawl surveys in the Australian sectors of the Timor and Arafura Seas between 127-137°E in 1990, and between 131-137°E in 1992, and CSIRO conducted similar surveys in the Gulf of Carpentaria during 1990-94. The NTDPIF project provided biological information on abundant species, and the first fishery-independent assessment of the extent of snapper stocks in the Timor and Arafura Seas. Biomass estimates were based on a new and simple model for fish herding which substantially improved the swept area method commonly used for estimating fish density and biomass from trawl survey data (Ramm and Xiao, 1995).

Red snapper data were examined jointly by Australian and Indonesian scientists during stock assessment workshops held in Darwin in 1992 and 1994 (Blaber *et al*., 1992; Naamin *et al*., 1994). Participants included fisheries scientists and managers from the Directorate General of Fisheries (Jakarta), Research Institute for Marine Fisheries (Jakarta), NTDPIF (Darwin), Western Australia Fisheries Department (Perth), Queensland Department of Primary Industries (Brisbane), Bureau of Resource Sciences (Canberra), Australian Fisheries Management Authority (Canberra), CSIRO Fisheries Division (Brisbane), and industry representatives. National workshops were also held in Canberra in 1990 and 1991. All of these workshops were based largely on research data from Ramm (NTDPIF), and Sainsbury and Blaber (CSIRO), and fishery logbook data, including those acquired by McLoughlin (Bureau of Resource Sciences) and Naamin (Research Institute for Marine Fisheries).

During the 1992 Australia-Indonesia Workshop, data were analysed using two distinct models:

(1) catch and effort data from trawl fisheries were fitted to a biomass dynamics model; and

(2) trawl survey data from the Australian sector of the Arafura Sea, and Gulf of Carpentaria, were fitted to a yield-per-recruit model ($F_{0.1}$ strategy model).

The biomass dynamics model performed poorly because of large uncertainties in model parameters due to insufficient contrast in the catch and effort data set. Consequently, participants placed greater emphasis on the results from the $F_{0.1}$ strategy model which were based on newly acquired survey data. Annual sustainable yields for the whole of the Arafura Sea were estimated at 9000-23000 t for red snappers, and 45000-115000 t for all fish, including shark.

Overall, the analyses were limited by a paucity of logbook data on catch and effort within the Indonesian sector of the Arafura Sea and uncertainties about the distribution of groundfishes, particularly snappers, in that sector. Participants recommended that collaborative Australian-Indonesian fisheries research projects be initiated to address these gaps in knowledge. Two years later, a collaborative study between the Research Institute for Marine Fisheries, NTDPIF and the Bureau of Resource Sciences was initiated to collate available fishery data from the Indonesian sector of the Arafura Sea. Preliminary results indicated that the annual catch of red snappers in that sector is presently around 6000-9000 t (McLoughlin, Nurzali and Ramm, unpub data). These early findings should be interpreted cautiously because of the large number of vessels in the area, and the diversity of fishing operations.

During the 1994 workshop, participants extended the biomass dynamics model of red snappers in the Arafura Sea to combine, for the first time, catch and effort data from Australian and Indonesian sectors and auxiliary trawl survey data; the model was developed by Hall (Western Australia Fisheries Department). Sustainable yield estimates derived from this model indicated that total annual harvests of 6000 t of red snappers in the Arafura Sea would probably lead to the collapse of the fishery (Fig. 3). However, as in 1992, higher estimates of annual sustainable yields were derived using an alternative $F_{0.1}$ strategy model based on survey data alone. Also, the application of the biomass dynamics model was limited by a paucity of information on trawling activities in the Indonesian sector and the distribution and abundance of groundfishes in that area. Participants recommended that research and management needs be addressed through:

- further collation and interpretation of fishery data for trawl fisheries in the Arafura Sea;
- conducting research surveys throughout the Arafura Sea; and
- exploring management strategies for groundfish resources shared by Australia and Indonesia.

NTDPIF has also conducted research on deepwater snappers on the Sahul Banks in the Timor Sea. Catch and effort data from the Darwin-based fishery and data from the 1990 trawl survey were fitted to a biomass dynamics model similar to that used for red snappers; basic assumptions were made about deepwater snapper distribution in Indonesian waters because no data were available for that region. The model predicted a combined unexploited deepwater snapper biomass for both sectors of the Sahul Banks of about 2990-9520 t, and an annual sustainable yield of 850-2580 t (Fig. 4; Ramm, in press). As for red snappers, there were large uncertainties in model parameters because of scant information on Indonesian fishing activities in the region, and the degree of movement of snappers between Australian and Indonesian waters. In addition, the catch and effort time series for this fishery is shorter than that for the trawl fishery. However, the analysis identified research priorities and the potential failure of current management strategies for deepwater snappers in the Timor Sea. Other research is investigating techniques for obtaining repeatable indices of relative abundance and age structure for deepwater snappers, and other groundfishes, in the Timor Sea (Lloyd, unpub. data). Methods developed during that study may be used to establish regular and long-term surveys of the Sahul Banks.

NTDPIF is also researching responsible (environmentally friendly) fishing gear technology, and the effects of trawling on non-targeted species and the marine environment. These issues threaten the viability and profitability of many fisheries and are subject to growing worldwide concern. This research is of particular relevance to trawl fisheries in Australia where issues of long-term ecological sustainability, maintenance of biodiversity and community structure and protection of critical fisheries habitats are being incorporated into fisheries management plans. These issues are being addressed, in part, through collaborative research on by-catch reduction devices applicable to groundfish trawls (Ramm *et al.*, 1993) and shrimp trawls (Mounsey *et al.*, 1995; Robins-Troeger *et al.* 1995).

Future Directions

Recent research indicates that some fishery resources in the Timor Sea, particularly along the Sahul Banks, and in the Arafura Sea, may become over-exploited if fishing effort is not adequately controlled within both Australian and Indonesian waters. In the case of shared resources, overfishing in one sector would lead to the collapse of fisheries in both sectors and reduce the income and livelihood of Australian and Indonesian resource users. Urgent steps must be taken to:

- quantify the extent to which groundfish resources are shared between Australia and Indonesia;
- determine basic population parameters (eg. age, growth, mortality) for all major commercial species;
- develop and implement sustainable management strategies for snapper resources in the Timor and Arafura Seas; and
- reach agreement on joint management arrangements for groundfish resources shared by Australia and Indonesia.

Throughout this paper, I have assumed that groundfish resources on the Sahul Banks in the Timor Sea, and in the Arafura Sea are shared between Australia and Indonesia. This assumption is based on limited regional knowledge of water currents, larval dispersal, and ontogenetic migration of fishes, from shallow nursery grounds to deeper adult habitats, and the fact that fishes do not recognise international maritime boundaries! There are, however, major physical differences between the Timor and Arafura Seas which may effect the degree to which some groundfish resources are shared within these regions. The Sahul Banks are located on the edge of the Australian continental shelf – to the south, the seabed rises gradually, while to the north, it dives to over 3000 m in the Timor Trench which extends eastwards to the Banda Sea. This trench is likely to be an effective barrier to larval dispersal and migration of groundfish species inhabiting shelf waters. As a result, groundfish populations on the Sahul Banks, and shelf waters to the south, are likely to form discrete stocks which are genetically distinct from those found in the Timor Sea north of the trench and adjacent to Timor. In contrast, the Arafura Sea is generally shallow (<80 m) and on the continental shelf connecting Australia and Indonesia (Irian Jaya), and Papua New Guinea to the east. In this sea, groundfishes are mostly harvested in the central zone which is bisected by the maritime boundary. It is likely that these groundfish stocks are shared. Note that other fishery resources, such as barramundi and some species of shrimp, inhabit the coastal zone and may form distinct stocks within Australian and Indonesian sectors of the Arafura Sea.

The key to ecologically sustainable management of groundfish resources in the Timor and Arafura Seas, and the long-term economic viability of Australian and Indonesian fishing industries, is through collaborative research and management. Such collaboration should be directed at:

(1) identifying sustainable management strategies for snapper and groundfish resources in the Timor and Arafura Seas, including joint-management options for those resources shared by Australia and Indonesia; and

(2) enhancing community benefits, including income and livelihood of fishing communities, through the sustainable use of fishery resources and improved opportunities and training for local fishing industry men and women.

Collaborative research and management should include: assessment of snapper and other groundfish resources in the Timor and Arafura Seas; development of procedures for collaborative management of shared fishery resources; introduction of sustainable fishing methods for the Timor and Arafura Seas; introduction and/or maintenance of monitoring systems for groundfish fisheries; and implementation of post-harvest technology for key species of groundfish.

Collaboration in fisheries may be undertaken through existing arrangements between Australia and Indonesia. For example, collaboration dealing with matters of strategic and commercial importance to Indonesia Bagian Timur (Eastern Part of Indonesia) and the Northern Territory of Australia may be conducted under the Memorandum of Understanding (MOU) signed by the Governments of the Republic of Indonesia and the Northern Territory in January 1992. This MOU outlines a broad range of activities to develop various sectors. Those relevant to the fishing industry include fishing industry development, trade and trading infrastructure, and professional educational services. Collaboration addressing the joint management of fishery resources shared by Australia and Indonesia may be addressed in consultation with the Commonwealth Government under the 1992 Agreement between the Government of Australia and the Government of the Republic of Indonesia relating to co-operation in fisheries.

The challenge facing scientists and managers is to develop and implement sustainable resource management strategies which follow national guidelines on ecologically sustainable development and international agreements on shared resources, and incorporate the very different needs of Australian and Indonesian fishing industries. On the one hand, Australian groundfish fisheries in the Timor and Arafura Seas have adapted to low population densities in northern Australia, isolation and a domestic market where consumers generally pay more for fish, per unit weight, than for beef, other red meats and poultry. Within this socio-economic climate, selective fishing methods have been developed to reduce by-catch and harvest snappers and other large-sized fish, and post-harvest technology has been developed to turn small quantities of fish into high quality product for sales in southern Australia. In turn, resource management strategies aim explicitly to sustain snapper resources through small limited-entry fisheries and selective fishing methods. On the other hand, the Indonesian trawl fishery harvests a wide variety of groundfish species, from small-sized goatfish to large-sized snappers, which are usually frozen whole and shipped to markets in south-east Asian. These fisheries take large and diverse quantities of fish which, today, in Australia, would be considered of low quality and value. So then, how do we sustain the shared groundfish resources in the Timor and Arafura Seas and meet the needs of small Australian fleets servicing specialised, low volume, markets and large Indonesian fleets servicing diverse, high volume, markets?

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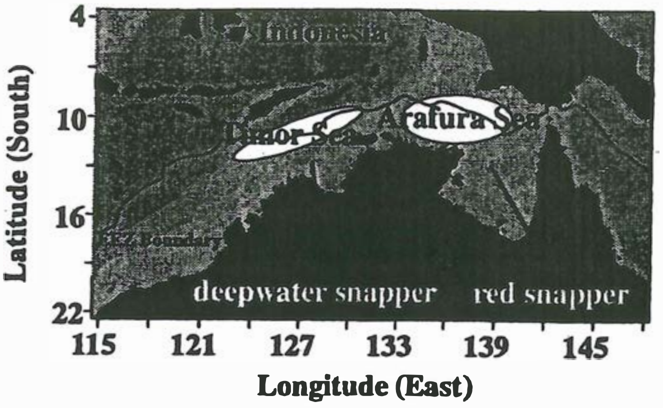

Figure 1. Major fishing grounds for snappers in the Timor and Arafura Seas.

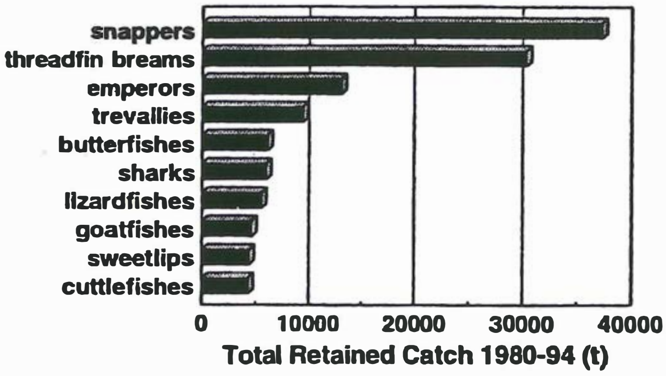

Figure 2. Total retained catches for top-10 groundfish groups in the Australian sectors of the Timor and Arafura Seas, and Northwest Shelf, during 1980-94.

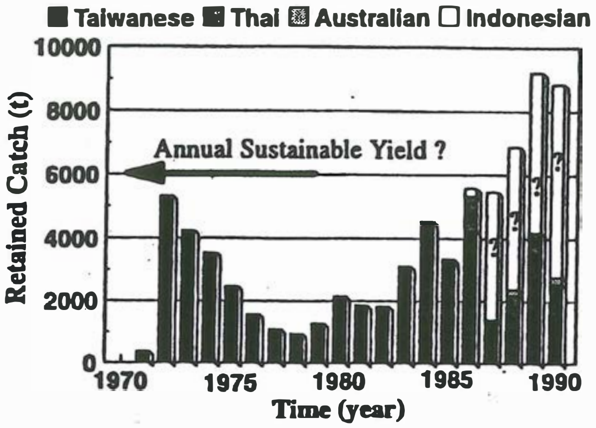

Figure 3. Annual retained catch (t) of red snappers in the Arafura Sea, and estimated annual sustainable yield. Data for 1971-79 based on Edwards (1983) and Sainsbury (unpub. data).

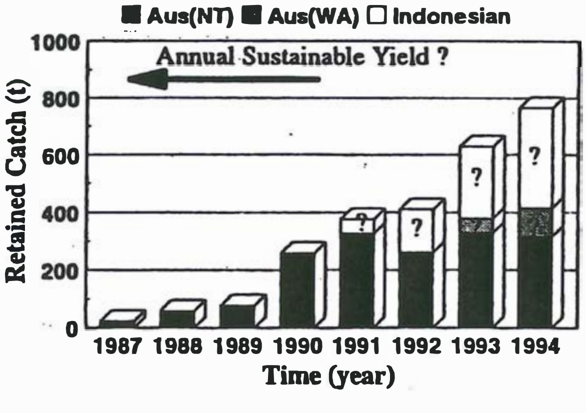

Figure 4. Annual retained catch (t) of deepwater snappers in the Timor Sea, and estimated annual sustainable yield.