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Abstract

Catch data from a Taiwanese pelagic gill-net fishery that operated off northern Australia between 1974 and 1986 were analysed. The fishery's annual catch in the Australian Fishing Zone averaged about 7000 tonnes processed weight, with shark, tuna and mackerel being the main species. Fishing effort nearly doubled between 1982 and 1983, while catch per unit effort (CPUE) declined from about 16 kg/km h in 1977 to about 7 kg/km h in 1986. After 1983, the Taiwanese put proportionately more fishing effort into an area north and east of the Wessel Islands, where they targeted tuna. Both the CPUE and body length of shark (principally *Carcharhinus tilstoni*) and mackerel (principally *Scomberomorus commerson*) declined over the history of the fishery, which suggests over-exploitation. However, tuna (*Thunnus tonggol*) appeared to be less affected by fishing pressure. No seasonal pattern in CPUE was evident for shark, while the CPUE for tuna and mackerel was generally highest between June and September. The catch rates were highly variable, partly because *C. tilstoni* tend to form groups of predominantly one sex or size range.

Dedication

This work is dedicated to Durant Hembree, a good friend and colleague, who died suddenly in May 1987. Durant spent many long months on fishing boats, both Australian and foreign, collecting data in his own field of whales and dolphins and for others like ourselves. Much of the work in this study would not have been possible without Durant's contributions.

Durant was an extraordinary man. His dedication, enthusiasm and hard work earned him the high regard and love of those who were fortunate enough to know him.

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Contents

Introduction

The Taiwanese operated a pelagic gill-net fishery in the offshore waters of northern Australia from the early 1970s until mid-1986. They fished from the North West Shelf to north of the Gulf of Carpentaria, but effort was concentrated north of the Wessel Islands. Shark, longtail tuna (*Thunnus tonggol*), and mackerel (*Scomberomorus* spp.) were the target species, with shark comprising about 80% of the catch by weight. Of the sharks, two species, *Carcharhinus tilstoni* (Whitley) and *C. sorrah* (Valenciennes in Müller & Henle), accounted for about 60% of the total catch by weight. The product was marketed in Taiwan, chiefly for domestic consumption, although some was exported.

Before management measures were introduced, the annual catch of the Taiwanese fishery in the area between northern Australia and Papua New Guinea averaged about 25,000 t live weight. When the Australian Fishing Zone (AFZ) was declared in 1979, the fishing area and vessel numbers were restricted, and a catch quota of 7,000 t (equivalent to 10,000 t live weight) was imposed.

In 1986, the Australian Government limited the length of gill-nets to 2.5 km to reduce the by-catch of dolphins. As the Taiwanese were using nets that averaged 16 km in length, their fishing operations became uneconomic and they were effectively excluded from the AFZ.

In the early 1980s a small Australian gill-net fishery for shark developed in inshore waters of the Northern Territory, and was subsequently extended to northern Western Australia and northern Queensland. Annual landings from 1984–88 fluctuated from about 100 to 450 t (liveweight). The species composition of this catch is similar to that taken offshore by the Taiwanese. Most of the catch is sold through the Victorian market for domestic consumption, with annual catch fluctuations reflecting marketing problems rather than shark abundance. More recently, after bans in Victoria on many species of northern shark because of high mercury levels, attempts have been made to establish export markets.

Because of the importance of the Taiwanese and Australian fisheries, considerable research effort was directed at developing and managing the pelagic stocks. The population structure, reproductive biology, diet, age and growth of *C. tilstoni* and *C. sorrah* were described by Stevens and Wiley (1986) and Davenport and Stevens (1988); and their stock structure was described by Lavery and Shaklee (1989). The biology of some other sharks taken by the fishery was documented by Stevens and Lyle (1989). Aspects of fishery development and marketing were examined by Lyle (1984), Lyle and Timms (1984), Lyle et al. (1984) and Welsford et al. (1984).

After the Taiwanese gill-netting off northern Australia ended, the stocks of shark, mackerel and tuna were lightly exploited in the AFZ until late 1989, when Taiwanese longliners started fishing in the zone. Observers estimate that in the first year of operation, up to 3,500 t of shark and other fish would have been taken. However, gill-netting is continuing outside the AFZ, presumably on the same stocks; the impact of this fishing on the stocks in the AFZ is unknown.

Analysis of the commercial and research data on the Taiwanese gill-net fishery that operated in the AFZ from 1974 to 1986 gives us invaluable information on the response of the stocks to fishing pressure, patterns in the distribution and abundance (temporal and spatial) of the stocks, and an insight into the dynamics of the Taiwanese fishing strategy. Such information provides a basis for future management should this become necessary. This report provides an analysis of the catch, effort and catch-composition data from the Taiwanese fishery.

Materials and Methods

Catch-and-effort statistics

Characteristics of the Taiwanese fishery

Vessels

The Taiwanese gill-netters were steel vessels of 160 to 380 t, 30 to 45 m long. They included converted Taiwanese longliners and stern trawlers as well as purpose-built gill-netters. Millington and Walter (1981) give a general description of their layout.

Fishing gear and operations

The gill-nets were of multifilament nylon with a diagonal stretched mesh between 14.5 and 19.0 cm. The net lengths increased from about 8 km in 1979 to about 16 km in late 1985, with some nets longer than 20 km. The nets fished at about 15 m depth (range 8–18 m) in 1980 to about 20 m in 1986 (Table 1). For every kilometre of headline about 50 polystyrene buoys (30 cm diameter) were attached. The buoy lines were usually 1–2 m long, but could be varied to fish the net from surface to subsurface. Between late 1983 and early 1985, there was a transition to smaller torpedo floats attached directly to the headline, effectively bringing the net to the surface. The net was hauled by a power block, the efficiency of which was upgraded when longer nets were used. The nets were set just before dusk, setting taking 1–2 h. They were allowed to drift until hauling began around midnight, which generally took 6–9 h but could take as long as 16, depending on the size of the catch. Details of the fishing operation are provided by Millington and Walter (1981).

Table 1
Dimensions of the gill-nets of the Taiwanese fishery (from measurements taken by Commonwealth Observers aboard the vessels in the AFZ).

Year	Net-length (km)		Net depth (m)	Surface area (m^2)
	Mean	Range	Average	
1979	7.5	3.5 –10.8	15	112,500
1980	7.5	3.6 –10.8	15	112,500
1981	8.6	6.8 –10.4	15	129,000
1982	10.2	6.0 –18.5	16	163,200
1983	12.6	8.8 –18.5	17	214,000
1984	12.8	7.4 –18.5	18	230,400
1985	14.6	10.6 –18.5	19	277,400
1986	15.8	7.1 –18.5	20	316,000

Processing of the catch

Tuna and mackerel were stacked whole in the freezer; on some vessels the caudal fins were trimmed first. Sharks were trunked, gutted and had their fins removed before freezing. Fins from large sharks were retained and dried in the sun.

Areas fished

Before 1978, the Taiwanese fished throughout northern Australian waters, to within 12 nautical miles (22 km) of the coast, from the North West Shelf to Cape York. In August 1978, the Gulf of Carpentaria was closed to foreign fishing. With the introduction of the AFZ in November 1979, the permitted fishing area included waters from the Monte Bello Islands to the western end of Torres Strait and at least 12 nm (22 km) from the Australian coast (Fig. 1a). The gill-netters were excluded from an area around Melville Island and from within 25 nm (46 km) off Eighty Mile Beach (Western Australia) (Fig. 1a). In November 1980, the area of exclusion off Arnhem Land and the Wessel Islands was increased to between 30 and 40 nm (56 and 74 km) from the coast, and Joseph Bonaparte Gulf was closed to Taiwanese gill-netters. In August 1983, all vessels were restricted to grounds north of 18 °S.

Based on the distribution of Taiwanese effort between 1979 and 1986, we defined three main fishing areas for the purpose of our analyses: a western area (10.5° to 17°S, 121° to 130°E), Arafura area (9° to 12°S, 133° to 136.5°E) and a Wessels area (9° to 11°S, 136.5° to 139°E) (Fig. 1b).

Pre-AFZ catch-and-effort data

Catch, and some effort, data from 1974–79 are given by Walter (1981); the 1977 and 1978 figures are from Liu (1985). No effort data were given for 1974–76, although it was recorded that 67 vessels fished in 1976. The effort for 1976 (Fig. 2) was estimated by assuming that each vessel made 152 sets each year (based on post-AFZ logbook records). It was assumed that effort in 1975 was the same as in 1976. All these data include catches taken from outside the AFZ and require adjustment to make them comparable with post-AFZ information.

The proportion of catch and effort falling within the 200 nm (371 km) AFZ for 1977 and 1978 was calculated from data reported by 5° map grid squares off northern Australia by Liu (n.d.). The proportion of available fishing area (taking the land into account) that lies within the Australian 200 nm limit was estimated subjectively. It was assumed that effort and catches were spread evenly over each 5° square. Calculations indicated that, in 1977, 52% of the catch and 54% of the effort was within the 200 nm limit. For 1978, these values were 27% and 25%, respectively. Walter's (1981) figures were then adjusted by these percentages, assuming the proportion of catch and effort in the AFZ from 1974–76 was the same as in 1977 and the proportions in 1979 were the same as in 1978 (Table 1). The effort from 1975 to 1979 was adjusted to km h assuming a net length of 7.5 km, net depth of 15 m and a fishing time of 15 h (Table 2).

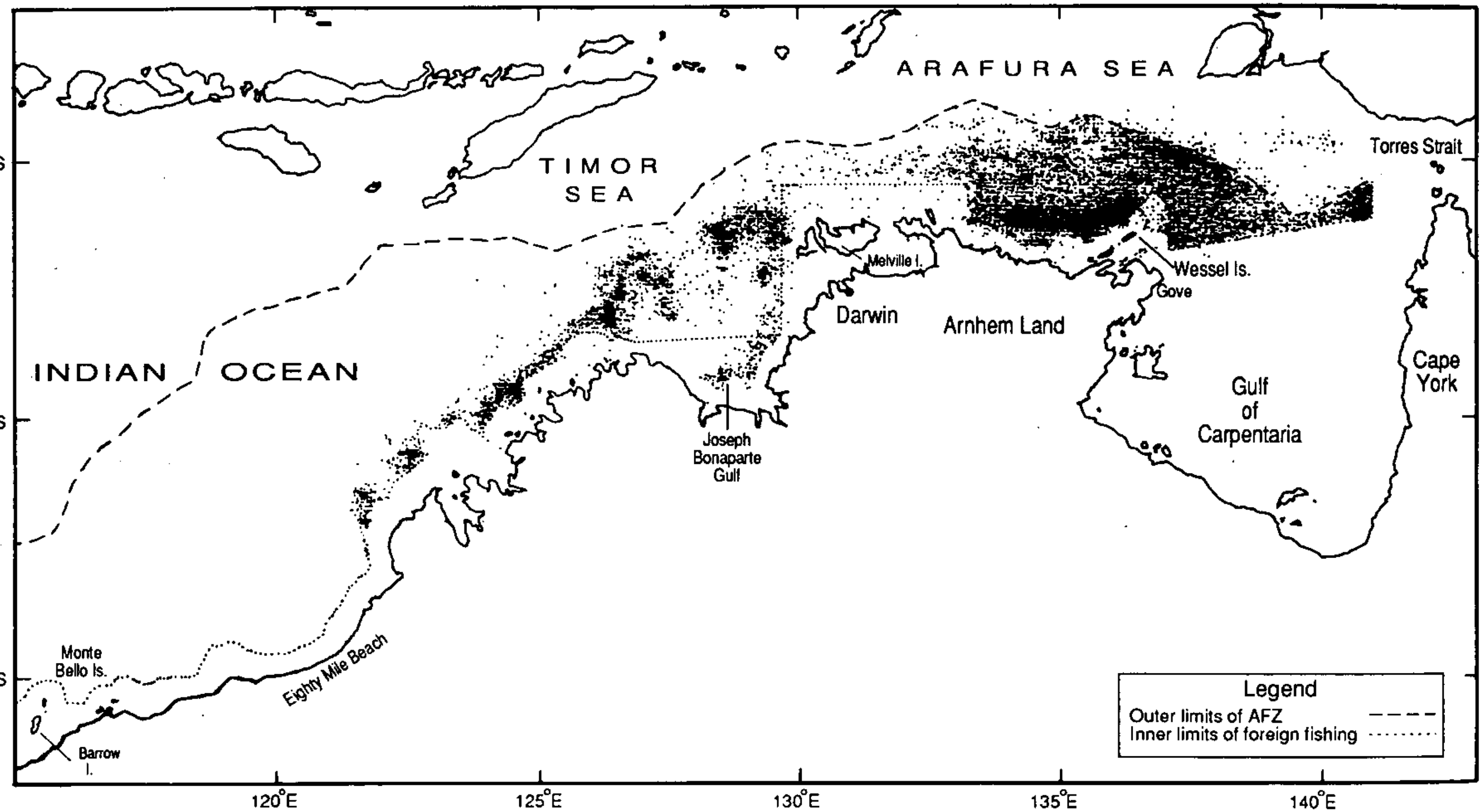

Fig 1a
Area of Taiwanese gill-netting in northern Australian waters. Each dot represents a single gill-net set. These data come from logbook records 1979–1986.

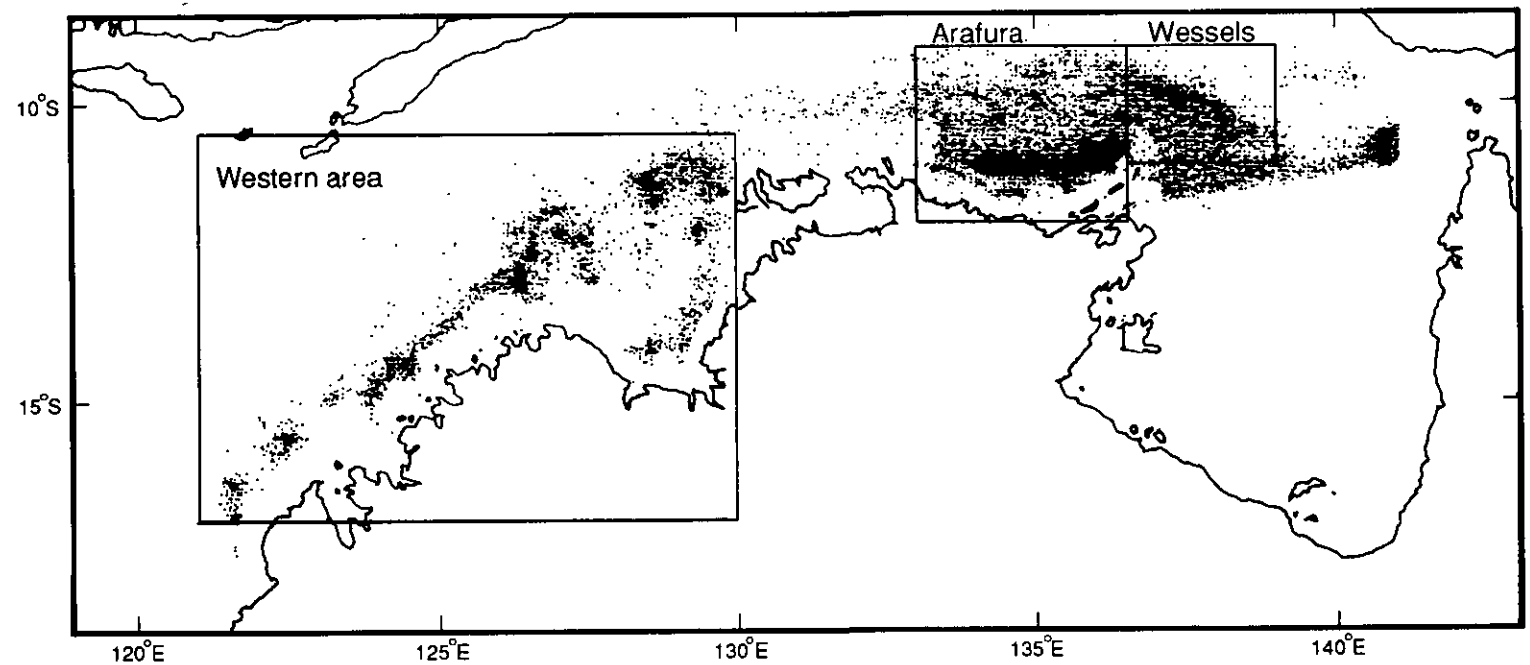

Fig 1b
Map shows the three areas referred to in our analyses of catch statistics: a Western area, Arafura and Wessels.

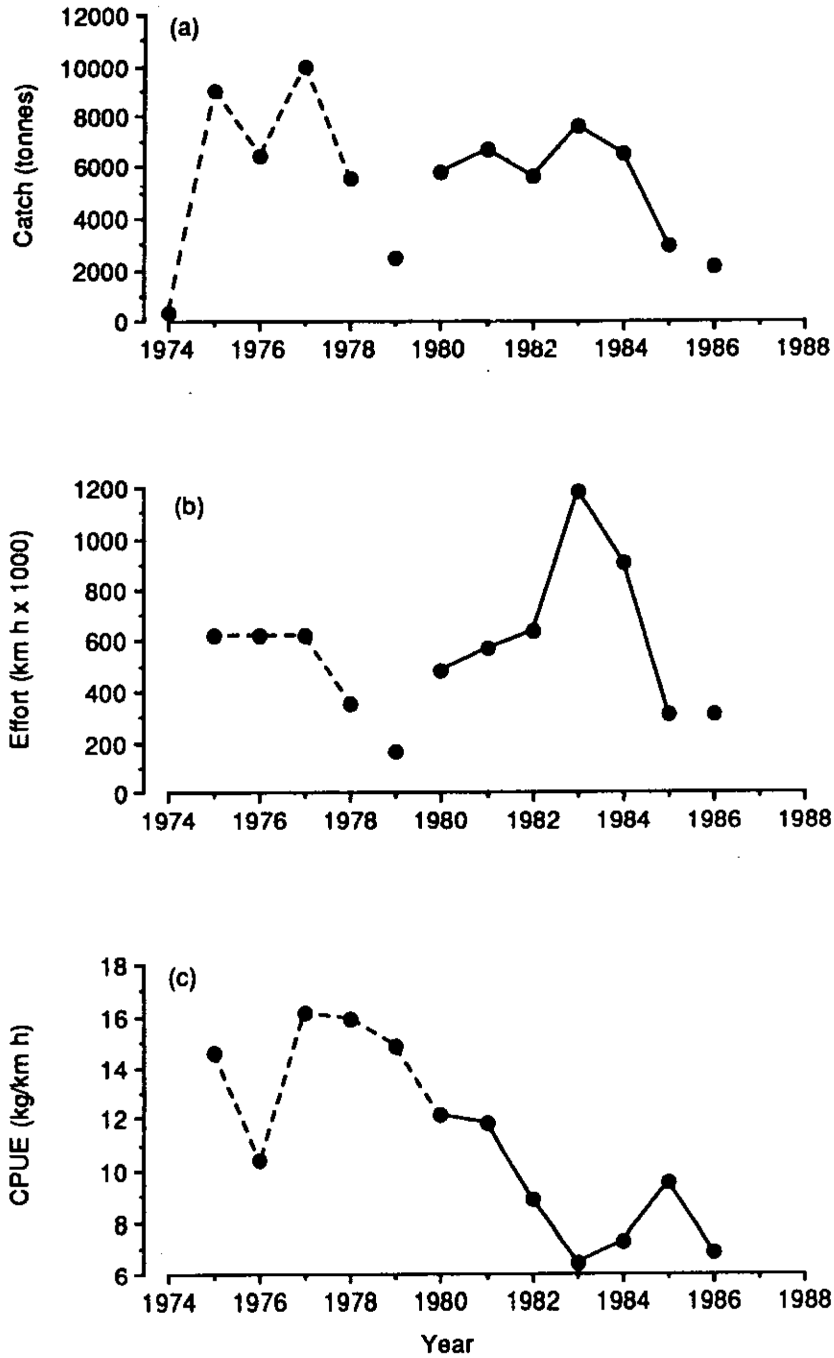

Fig 2
(a) Annual total catch (tonnes), (b) effort (km h) and (c) CPUE (kg/km h) of the Taiwanese gill-net fleet in northern Australian waters between 1974 and 1986. N.B. Figures for 1979 and 1986 are for part of the year only, so are not linked to other catch and effort data.

Table 2
Catch-and-effort data for the Taiwanese gill-net fishery in Australian waters. (Pre-AFZ figures adjusted from Walter (1981). Logbook figures based on all records but with effort corrected to km h. See Methods section for adjustments and corrections applied.)

	Pre-AFZ		AFZ logbook	
Year	**Catch (t)**	**Effort (km h)**	**Catch (t)**	**Effort (km h)**
1974	321.4	–	–	–
1975	8,997.6	618,637.5	–	–
1976	6,455.3	618,637.5	–	–
1977	9,970.7	618,075.0	–	–
1978	5,528.2	347,400.0	–	–
1979[1]	2,468.6	166,837.5	813.5	63,166.4
1980	–	–	5,831.1	482,052.2
1981	–	–	6,694.7	568,819.8
1982	–	–	5,624.1	636,323.8
1983	–	–	7,589.9[2]	1,179,812.0
1984	–	–	6,544.2	908,567.6
1985	–	–	2,929.5	309,106.8
1986	–	–	2,111.1	309,364.0

1 The 1979 pre-AFZ data are for January to June and the logbook data for November and December.
2 The 1983 catch figure exceeds the 7000 t quota, largely because the figures in this table are based on a calendar year, whereas the quota period was not.

Post-AFZ catch-and-effort data

Catch quotas and vessel numbers

A quota of 7,000 t a year was allocated for 30 gill-netters from November 1979 to October 1982, under a bilateral agreement. This level of quota was determined in early 1979 by a Northern Fisheries Committee Working Group. Estimates of biomass in the area fished were based on the 1975 and 1976 Taiwanese catch, at rates of exploitation of 0.5 to 0.75. Gulland's (1971) equation 0.5MBo was used to estimate a maximum sustainable yield (MSY) of 5,345 t. Because the calculations of MSY were biased conservatively in a number of areas, the quota was initially set at 7,000 t. It was set at 5,250 t for a nine-month period from November 1982, and reduced to 5,000 t for the 12 months from August 1983 to allow for pending joint-venture proposals. Eight joint-venture vessels were allocated a 2,000 t quota from October 1983 to August 1984.

As a result of pressure from conservation groups over the dolphin catch, the number of bilateral vessels was reduced to 15 longliners (of which 11 were also licensed as gill-netters) from August 1985 to July 1986. These 15 bilateral vessels were allocated 2,700 t of quota. Six joint-venture vessels received a 1,500 t quota.

Data sources

The three main sources of catch-and-effort data for the Taiwanese fishery from 1979 are AFZ logbooks, radio reports and annual reports produced by the National Taiwan University.

(i) AFZ logbooks

In 1980, a logbook system was implemented by the Australian Department of Primary Industry to recover data by individual set. The information recorded included logtype, boat code, date, net specifications, fishing times, water depth, total catch and catch components of the major commercial groups (shark, tuna and mackerel).

Three logtypes were used: GN01, GN02 and GN04 (GN03 was not used). GN01 recorded effort as hours (x 100) from the start of the set to the start of the haul. GN02 recorded effort as hours (x 100) from the start of the set to the end of the haul. GN04 recorded effort as the number of sets, each record representing one set. The Taiwanese reported shark as processed weight. The department had intended that live weight be recorded; the mistake was not discovered until the logbook system had been in operation for some time. Figures for the total catch and for the components of the catch were recorded as weights on the GN01 and GN04 logtypes. On the GN02 logs, while the total catch estimate was recorded as a weight, the catch components could be recorded as either weight or number. The logbook data were stored on the Australian Fisheries Zone Information System (AFZIS).

(ii) Radio reports

The Taiwanese were also required to provide a radio report every six days giving their position and catch for the previous six days. Logtype (RR01), boat code, date, time (at which report was sent), position (at the time of reporting), effort (as the number of sets), total catch (kg) and the catch breakdown (shark, tuna and mackerel) were reported. The catch information in the radio reports was expected to correspond with that in the logbooks. The radio report data were also stored on the AFZIS database.

(iii) Taiwanese Annual Reports

Data from the logbooks kept independently by the Taiwanese are summarised in reports of the National Taiwan University (1980–1985). Catch and effort statistics are presented by half-degree squares for 3 monthly periods between 1980 and 1985. Effort is expressed as 100 pcs (panels) x 10 h from 1980 to 1983 and as 1000 pcs x h from 1984 to 1985. We were not able to ascertain whether the unit of time (hours) included setting or hauling of the net.

(iv) AFZ Observers

In addition to these main sources of catch and effort data, the Australian Fisheries Service placed observers onboard Taiwanese vessels to collect information on net specifications, catch composition and catch weight. Not all these data were collected from every boarding. Of the observer boardings, 40% were in the Arafura Sea; the remainder were from around the Wessels Islands and in the Timor Sea and North West Shelf. About 2% of the total gill-net sets were covered by the AFZ observers.

Data treatment

Catch data

To verify the catch-and-effort information and to determine which data set would be most suitable for analysis, we compared the different sets of catch data. Catch data from the AFZ logbooks and radio reports, and from the Taiwanese annual reports were examined by three-monthly intervals and by year (Table 3 and Figure 3). Figure 3 shows reasonable agreement between the data sets. The reasons for disparities include mis-reporting of catch, confusion between the different versions of the AFZ logbook, errors in estimating and recording catch weight, and errors in transcribing the written logs to computer file.

Table 3
Annual catch data from the Taiwanese gill-net fishery in Australian waters.

	Catch in tonnes		
Year	Radio Report Database	Logbook Database	Taiwanese Annual Report *
1979	706.82	813.50	
1980	5,660.01	5,655.59	3,980.29
1981	7,058.08	6,694.74	5,486.63
1982	6,894.71	5,624.11	7,936.72
1983	7,876.20	7,589.93	8,586.77
1984	6,182.83	6,544.21	6,291.12
1985	3,150.97	2,929.46	3,005.77
1986	2,134.71	2,111.11	

* These figures are extracted from the Taiwanese Annual Reports, which present data by half-degree squares. Catch figures include all half-degree squares within the AFZ and through which the AFZ boundary passes.

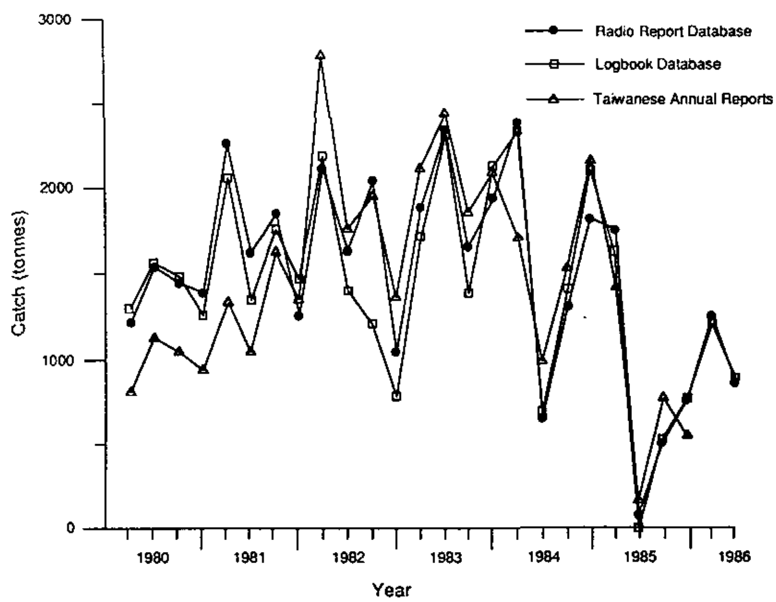

Fig 3
Catch data from radio report database, logbook database and Taiwanese annual reports by three-monthly period, Jan 1980-June 1986.

It was hoped to use observer estimates of catch as an independent check on the logbook data. We compared observer records and Taiwanese catch records (AFZ logbook entries) for 39 sets in 1985/86. Although anecdotal information suggested that when observers were onboard, the Taiwanese often entered the observer's catch figures in the AFZ logbooks, we found good, rather than exact, agreement between Taiwanese and observer catch estimates ($R = 0.86$, $p < 0.001$). In only two instances did the estimates coincide.

As the radio report data were derived from the AFZ logbooks, and since the logbook data were on a finer time and position scale than those in the Taiwanese annual reports, it was decided to use the AFZ logbook data for all analyses.

The logbook data were corrected for obvious errors such as repetition of records, typographical and transcription errors and unrealistic catch figures. On the GN02 logtypes, catch components could be recorded as either a weight or as numbers. Where the shark, tuna and mackerel catches were recorded as the number of individuals, these had to be converted to weights to make the data compatible. Average weights for shark (4.4 kg), tuna (2.9 kg) and mackerel (4.4 kg) were derived by comparing radio report records, where all catch components were recorded as weight, with the corresponding logbook records where catch components were in numbers. These average weights were checked against independently derived observer data.

Logbook records were examined for consistency between the reported figures for total catch and the reported figures for the shark, tuna and mackerel components, using a table showing the distribution of the ratio of the sum of the weights of the catch components to the total catch weight. For those entries where the total catch and its components had been recorded as weights, we retained all records with a ratio of 0.9–1.0, which allowed for a trash component (catch other than retained shark, tuna or mackerel) of up to 10%. Observers noted that the trash component of Taiwanese gill-net catches rarely exceeded 10%. If the weight of the catch components exceeded the total catch — that is if the ratio was greater than 1.0 — then that record was discarded. This retained 27% of the records where catch components were recorded as weights.

For many of the GN02 entries, it was apparent from the clustering of records around certain ratios that columns had been transposed (weights recorded as numbers or vice versa) when the data were transferred from logbook to computer. One cluster of records, where the catch components were recorded as weights, occurred around the ratio 0.25. Since the average weight of captured fish is about 4 kg, this suggested that the value for the sum of the catch components was about four times lighter than it should have been and that numbers had been placed in the weight column.

To rectify this situation, we assumed that records where weights had been recorded and where the ratio fell below 0.9, should have been numbers, transposed the columns accordingly, and converted the numbers to weights using our conversion factors. These records were then accepted if the new ratios were within the range 0.9–1.0.

The other cluster of records appeared where the catch components were recorded as numbers, around the ratio of 4.0. In this case, we assumed that the numbers should have been weights and corrected them accordingly, again accepting the new ratios in the range of 0.9–1.0. With the GN01 and GN04 logtypes, we retained 77% of the records by imposing these constraints. The GN02 logtypes where catch components were recorded as weights were treated in the same way.

The GN02 logtypes where catch components were recorded as number of individuals were first converted to weights. The resulting ratios of the sum of the catch components to total catch were normally distributed about the mode (ratio 1.0). To allow for a trash component and for a weight conversion error we accepted records to 0.25 either side of the mode (ratios 0.75–1.25). This resulted in retention of 69% of the GN02 records where catch components had been recorded as number of individuals.

Overall, we retained 71% of all records (17,234 out of 24,203 in the database). Because 29% of the records were removed, the analyses of catch, effort and CPUE presented in this report reflect trends rather than absolute values.

Net data

Although the logbooks contained information on net length and depth, few of these data had been entered on AFZIS and so were not available to us in this study. Independent information on net specifications collected during observer boardings showed considerable increases in net length and depth over the history of the fishery. Average net lengths increased by more than 100% between 1979 and 1986 (Table 2). Observers estimated the net lengths by either counting the number of net floats and multiplying by the inter-float distance, or by calculating the distance from the vessel's speed and the time it took to steam along the net. Average net depths increased from 15 m in 1979 to 20 m in 1986. However, observers recorded considerable variation in net depths between gill-netters, and sometimes even within a single vessel in one year.

Effort data

Effort figures on AFZIS were recorded in different units (number of sets or fishing time) in the different logbook types. As GN01 logtypes did not record hauling times they were adjusted by multiplying by a correction factor of 1.93. This correction factor is the average ratio of GN02 effort to GN01 effort during the period in which these logtypes overlapped. GN04 records were adjusted by allowing 15 h for each set; this is the average fishing time derived from GN02 records. While net length increased over the history of the fishery, this was accompanied by a parallel increase in power block efficiency and observers considered that hauling time did not alter significantly. Effort figures were standardised to kilometre hours (km h) according to the formula:

$$\text{effort (km h)} = \text{fishing time (h)} \times \text{net length (km)} \times \text{net depth (m)} / 15\ \text{m}$$

where fishing time is from the start of the set to the end of the haul and net lengths and depths are the annual values from Table 2. The divisor (15) used to standardise for net depth was the average net depth in 1979. Our effort figures are approximate only, as they use an average value for net length for the calendar year (Table 2) and are not weighted according to the number of sets made with nets of different lengths. This information was not available to us.

Catch composition

Species composition

Species composition data were collected routinely by observers, who were trained in identifying pelagic sharks and teleosts and were accompanied initially by scientific personnel. Length-frequency data were collected routinely for the main commercial species, and usually for all other retained species. The numbers of each species were counted, with counts for sharks being separated by sex. Fish and sharks were measured to the nearest centimetre as fork lengths (FL), or in some cases for sharks, as total lengths (TL). Fork lengths were converted to total lengths using length/weight relationships derived previously (Rohan et al. 1981; Stevens and Wiley 1986; Stevens and Lyle 1989) or in some cases, in this study or by the observers. For small catches, all fish were counted and measured, while large catches were subsampled.

Only certain species or categories were analysed, partly because they were the most important commercially and partly to avoid mis-identification of the less common or less distinctive species. Because of the high turnover in observers it was difficult to maintain a high level of taxonomic expertise. The main commercial species or species groups were: *C. tilstoni*, *C. sorrah*, the hammerhead sharks (*Eusphyra blochii*, *Sphyrna lewini and S. mokarran*), *T. tonggol* and the Spanish mackerel group (*S. commerson*, *S. munroi* and *S. fasciatum*). Species composition was calculated as the proportion, by number, of the total catch.

Size composition

To describe changes in the proportion of mature sharks over time, we attempted to take account of the effects of both year and month. Regression models were fitted to the proportions of mature sharks in each of the 41 months for which data were available (between April 1981 and April 1986). A requirement of regression is that all observations have equal variance, so the data were transformed (using arcsine [$\sqrt{}$proportion], a standard transformation) to stabilise the variance of the proportions (Snedecor and Cochran 1980). As the unequal sample sizes in different months also affect the variances of the observed proportions, the regressions were weighted according to the sample size. The fitted models allowed for monthly effects within years, and for changing levels in the proportions of mature sharks over the years. Data for both sexes were analysed together, with a factor included for sex. Because fewer than 12 months were represented in each year, interactions between the factors could not be fully tested. However, two-factor interactions were tested within the limits of the available data.

Catch variability of sharks

Aggregations

Two sets of research data were used to investigate the catch variability of sharks, which is attributable in part to their forming aggregations. The term *aggregation* is used rather than school, as schooling implies an orientation of the fish. Both sets recorded the length and sex of the captured sharks.

(i) A series of gill-net modification trials designed to investigate methods of decreasing the dolphin catch in gill-nets, was carried out on board the commercial Taiwanese gill-netter *Chyun Fure No. 7* (Hembree and Harwood 1987).

One experiment, in 1985, assessed the effect of metallic bead chain woven into panels of the net. The multifilament, 14–15 cm stretched-mesh net consisted of 14 panels, each panel almost 1 km in length. Alternate panels were modified with bead chain. Half the net was set off the stern of the vessel, the other half off the bow.

A second experiment, in 1986, examined the effects of submerging the net. During each fishing operation, two nets of equal length, depth (15 m) and mesh size (14–15 cm) were fished, one with the headline set on the surface, the other with the headline set 4.5 m below the surface. Each net consisted of five panels, each 975 m long; one net was set off the stern, the other off the bow.

(ii) Gill-nets used for research fishing in the Northern Pelagic Program (Stevens and Church 1984) were of 15 cm stretched-mesh monofilament, 500–1000 m long and 10 m deep, and were set within 3 m of the surface. The net, which was set and hauled from a hydraulically powered drum onboard the FV *Rachel* (Lyle et al. 1984), was usually set for less than 30 min before hauling.

Environmental effects

Data collected during the 1985 and 1986 gill-net modification trials were used to determine the possible effects of various environmental variables and fishing strategies on the number of sharks and fish caught. The variables recorded were: wind direction, wind speed, set direction, light (light availability on a scale of 0 for no light, to 4 for maximum light), moon phase (on a scale of 0 for no moon, to 8 for full moon), time at start of set, time at start of haul, sea swell, sea depth, and surface temperature. The data were analysed using multiple regressions with the shark (or fish) catch as the dependent variable. Log-transformations were used to normalise the catch data.

Logbook data were examined for possible effects of depth on the catches of shark, tuna and mackerel. Because the catch data were strongly skewed and dominated by the large catches, a linear regression was performed on log-transformed data. About one third of the tuna and mackerel data were zero catches, so for these species groups, the non-zero data only were analysed.

Results

Catch-and-effort statistics

1974–1986 northern AFZ

The annual total catch (tonnes), effort (km h) and CPUE (kg/km h) for the Taiwanese gill-net fleet from 1974 to closure of the fishery in 1986 are shown in Figure 2. The pre-AFZ component (1974–78) is based on the adjustments to Walter's (1981) figures (see methods), and the post-AFZ component is based on all the logbook records on the database. In our analyses we refer to calendar rather than quota years, because of the nature of the data available to us, and the variability in quota periods.

The total catch was very small during the first year of operation (Fig. 2a). It rose to between 6,500 and 10,000 t between 1975 and 1977, when there were few area constraints. After closure of the Gulf of Carpentaria in August 1978, the catch dropped to 5,500 t. With declaration of the AFZ in November 1979 and introduction of a 7,000 t quota, the catch fluctuated between about 5,500 and 8,000 t from 1980 to 1984, before dropping to around 3,000 t in 1985.

Annual effort was as high as 620,000 km h in the pre-AFZ period when up to 67 vessels were fishing (Fig. 2b). With vessel numbers limited to 30 after declaration of the AFZ, effort rose from about 500,000 km h in 1980 to 1,200,000 km h in 1983. Subsequently, effort declined as the number of vessels fishing declined towards the end of the fishery.

The CPUE declined from 16 kg/km h in 1977 to 6.5 kg/km h in 1983, before showing a slight rise in the last years of the fishery (Fig. 2c).

1979–1986 northern AFZ

The remaining analyses of catch, effort and CPUE were carried out on the proportion of the data (71% of available records) that satisfied the criteria outlined in the Materials and Methods section (Data Treatment). Annual total catch, effort and CPUE from 1979 to 1986 (Fig. 4) show the same trends as the total data. Between 1982 and 1983 effort nearly doubled; this was due to a 31% increase in the surface area of the nets and an increase in the number of sets.

When total catch is partitioned into shark, tuna and mackerel, Fig. 5a shows that the shark catch changed little from 1980 to 1983, then declined. The tuna catch peaked in 1983–84, before declining sharply (Fig. 5b). Mackerel catches fluctuated widely (Fig. 5c), although they were much smaller than shark or tuna catches. CPUE for shark and mackerel (Fig. 5d & f) was highest early in the fishery and then declined, although shark recovered somewhat after 1984, while tuna CPUE increased progressively until 1984 (Fig. 5e) and then declined.

Analyses by area

Different trends in total catch were apparent in the three areas. In the western area total catch was highest in 1980, before showing a general decline until 1985 (Fig. 6a). In the Arafura, the catch increased until 1983, and then declined (Fig. 6b), while in the Wessels it rose until 1984, and then declined (Fig. 6c). The pattern of effort was similar in the western area and Arafura, generally increasing until 1983, and then declining. In the Wessels, effort peaked one year later in 1984 and there was a proportionately larger increase in effort between 1980 and 1984 than there was between 1980 and 1983 in the other two regions (Fig. 6d, e & f). CPUE showed a relatively rapid decline in all areas from 1979 to 1983, after which it either levelled off or showed a slight rise (Fig. 6g, h & i).

Catch and CPUE were examined by area and catch category (Fig. 7). The shark catch generally declined from 1980 until the end of the fishery in the western area, while in the Arafura it remained relatively constant between 1980 and 1983 and then declined. The relatively smaller catches in the Wessels fluctuated considerably, increasing after 1982 (Fig. 7a, b & c). Shark CPUE was similar in all three regions: a decline followed high initial values, and then a slight rise (more pronounced in the western area) towards the end of the fishery (Fig. 7e, f & g). Tuna CPUE in the western area rose rapidly between 1979 and 1980, remained high in 1981 and then declined until 1983, after which it rose slightly. In the Arafura, tuna CPUE rose

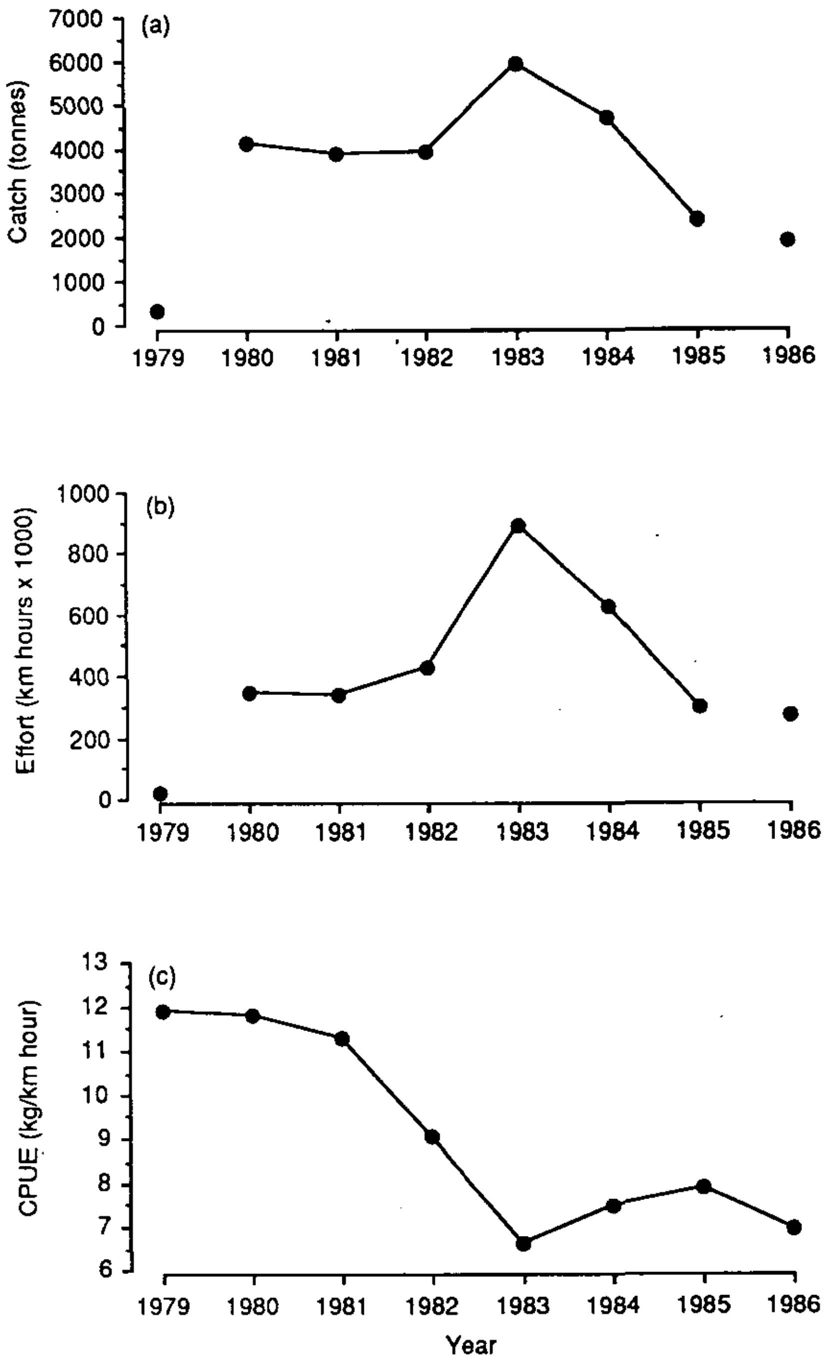

Fig 4
Edited logbook figures for (a) annual catch (tonnes), (b) effort (km h) and (c) CPUE (kg/km h) of the Taiwanese gill-net fleet in northern Australian waters between 1979 and 1986. N.B. Figures for 1979 and 1986 are for part of the year only, so are not linked to other catch and effort data.

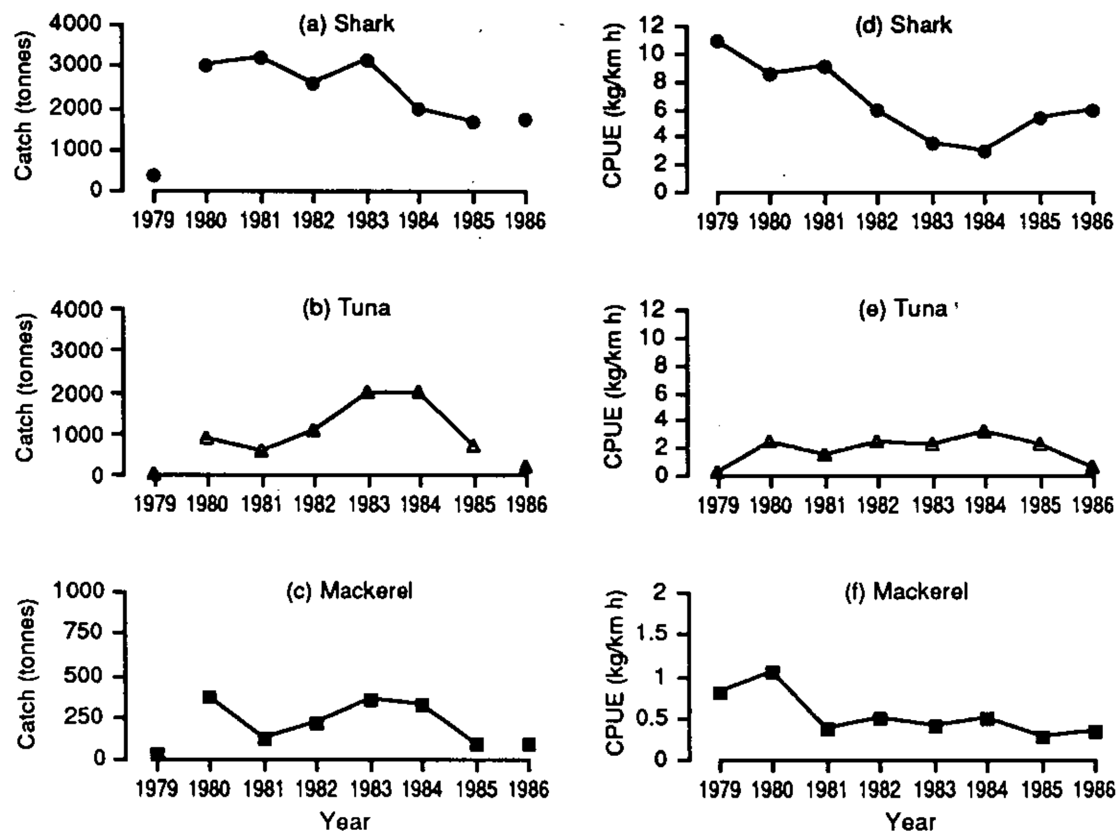

Fig 5
Catch and CPUE by species group in the AFZ: (a) shark catch; (b) tuna catch; (c) mackerel catch; (d) shark CPUE; (e) tuna CPUE; (f) mackerel CPUE. Figures for 1979 and 1986 are for part of the year only. The vertical scale for mackerel differs from those for shark and tuna.

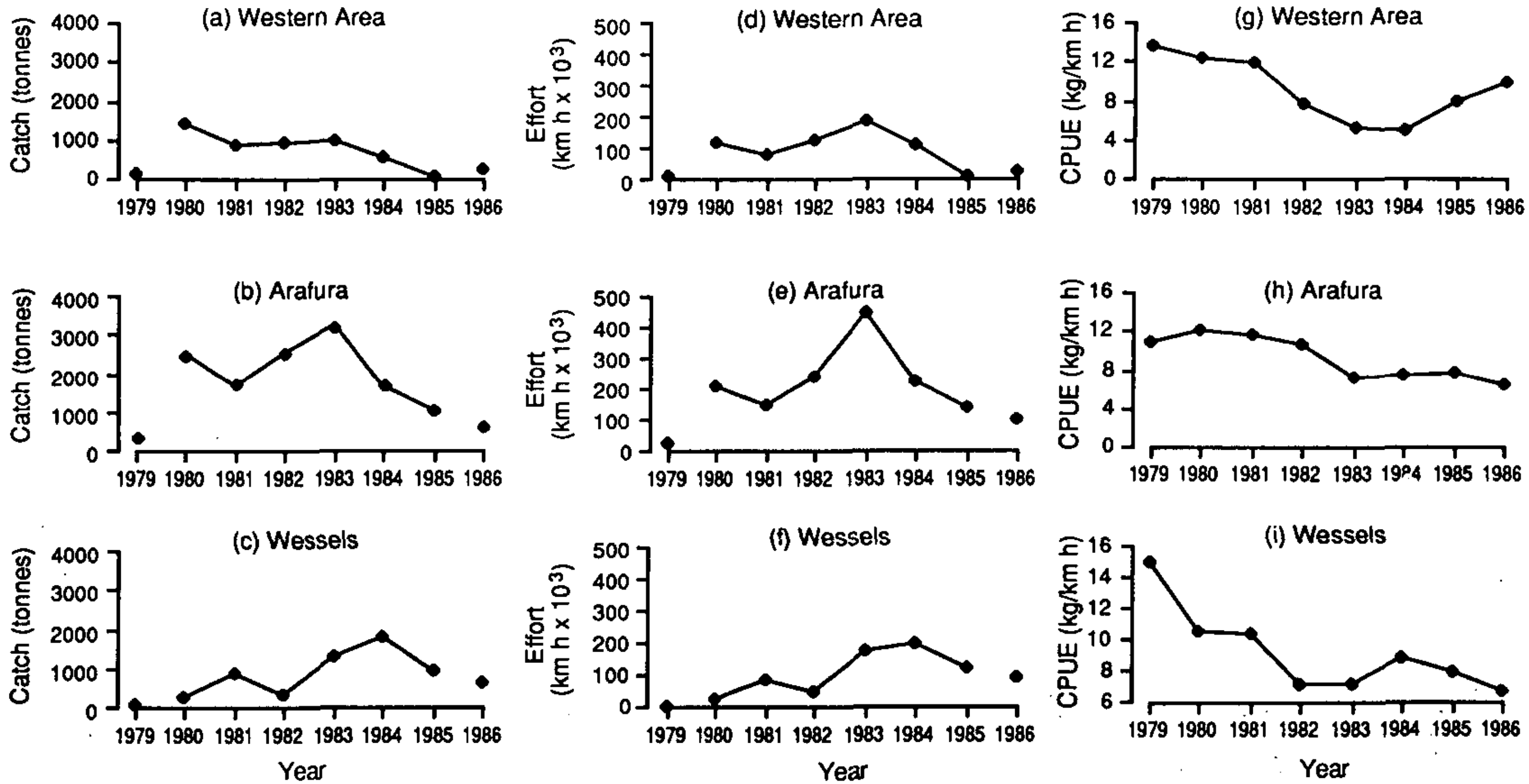

Fig 6
Catch (a-c) (in tonnes); effort (d-f) (km h); and CPUE (g-i) (kg/km h) in: the Western Area, Arafura, and Wessels. Figures for 1979 and 1986 are for part of the year only.

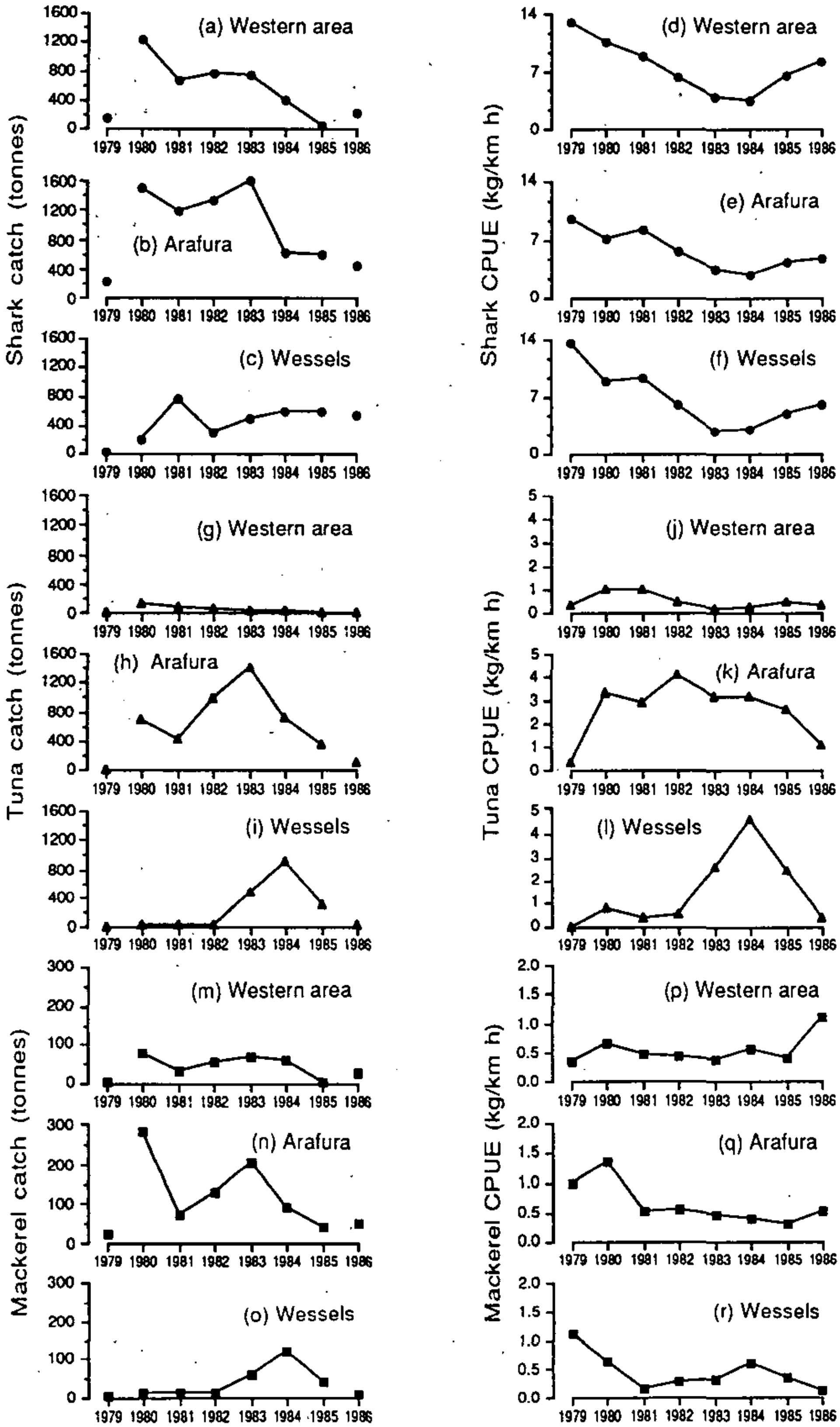

Fig 7

Shark (a-f), tuna (g-l) and mackerel (m-r) catch and CPUE by year in the Western Area, Arafura and Wessels. Vertical scales are not the same for the different species groups.

rapidly between 1979 and 1980 and remained high until 1984, before declining. In the Wessels area, CPUE rose sharply between 1982 and 1984, after which it dropped sharply (Fig. 7j, k & l). The mackerel catch in the western area and Arafura declined overall, while in the Wessels, the catches were low until 1982 and then increased sharply until 1984 (Fig. 7m, n & o). Mackerel CPUE generally declined from high initial values in the Arafura and Wessels, but in the western area a higher CPUE value was recorded near the end of the fishery (Fig. 7p, q & r).

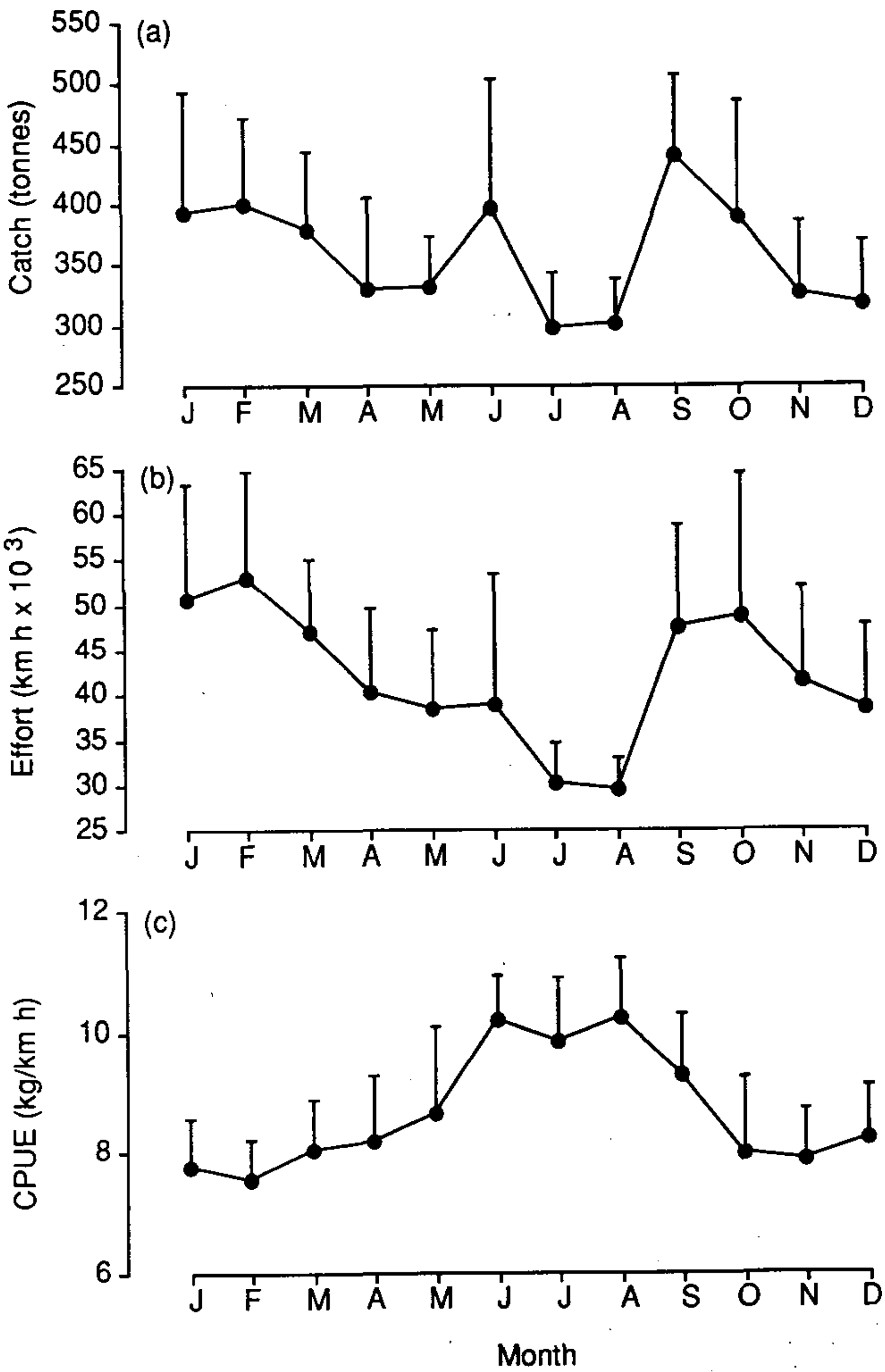

Fig 8
(a) Catch (tonnes), (b) effort (km h), and (c) CPUE (kg/km h) in the AFZ by month. Error bars show (half) one standard error.

Analysis by month

Trends in total catch, effort and CPUE by month are shown in Figs 8a, b and c. However, the variance about the means was very high, with the 95% confidence limits overlapping between all months. Any pattern would be likely to reflect factors associated with the quota year. The access period started in either August or November and finished in July or October. Vessel effort tended to be high at the beginning of the quota year from September to October and again in January to March, and lower during the rest of the year as the vessels filled their quota.

Analyses by month were carried out on the total catch, effort and CPUE by area, on the shark, mackerel and tuna catch and CPUE within the AFZ, and on the shark, tuna and mackerel catch within the three areas. However, the variances about the means were so high that significant trends were not apparent.

When the shark, tuna and mackerel CPUE were examined by month within the three areas, the variances were somewhat lower. To test for a seasonal difference in these data, an analysis of variance table was constructed using regression analysis. Effort values were weighted to obtain the appropriate CPUE figures. The analysis assumes there is no interaction between year and month, i.e. that the response over month is the same for each year. The validity of this assumption was examined by plotting the monthly CPUE data for each year.

The CPUE from the three areas was significantly different for shark over years, but not over months (Table 4; Fig. 9a, b & c). It was significantly different for tuna between years and months in the Wessels and Arafura, and between years in the western area (Table 4; Fig. 9d, e & f). Tuna CPUE was highest between June and September in both the Arafura and Wessels (Fig. 9e & f). The CPUE for mackerel was significantly different between years in the Arafura and Wessels, and between months in the Wessels and western area (Table 4; Fig. 9g, h & i). CPUE in the Wessels was highest between June and September (Fig. 9i).

Table 4
ANOVA tests for annual and seasonal differences in CPUE by catch component and area (df is degrees of freedom; * $p < 0.05$, ** $p < 0.01$).

Species Group	Year			Month		
Area	F	df	p	F	df	p
Sharks						
western	11.54	7,47	**	0.54	11,47	ns
Arafura	29.93	7,59	**	1.92	11,59	ns
Wessels	19.10	7,54	**	1.45	11,54	ns
Tuna						
western	3.20	7,47	**	1.81	11,47	ns
Arafura	2.79	7,59	*	2.61	11,59	**
Wessels	12.63	7,54	**	5.53	7,54	**
Mackerel						
western	1.49	7,47	ns	2.35	11,47	*
Arafura	4.52	7,59	**	1.58	11,59	ns
Wessels	7.54	7,54	**	4.67	11,54	**

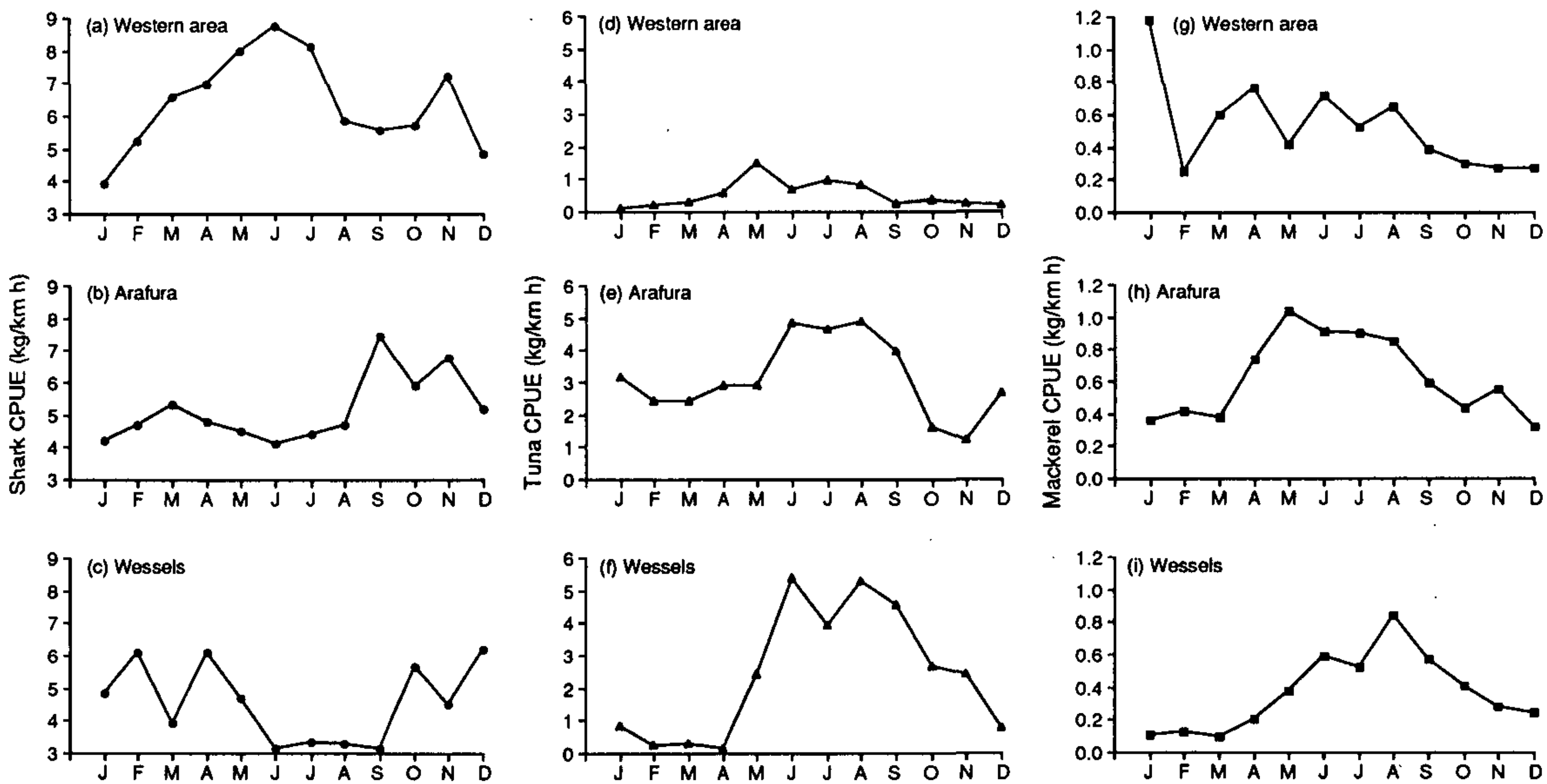

Fig 9
Shark CPUE (a-c), tuna CPUE (d-f), and mackerel CPUE (g-i) by month in the Western Area, Arafura and Wessels.

Catch composition

Species composition

Northern AFZ

Two sharks (*C. tilstoni* and *C. sorrah*), and one fish (*T. tonggol*), comprised about 70% by number of the Taiwanese gill-net catch in the AFZ. Mackerel, which together with sharks and tuna were a target group, represented about 5% of the catch by number (Table 5). *C. tilstoni* accounted for a considerably higher proportion (54%) and *C. sorrah* a considerably lower proportion (10%) of the catch in the Wessels area, while the proportion of *T. tonggol* was highest in the Arafura (21%) (Table 5). The edited logbook data indicate that sharks, tuna and mackerel comprised about 63%, 26% and 6% respectively of the catch by weight in the AFZ.

Table 5
Species composition of the Taiwanese gill-net catch (% by number: based on observer data between 1981 and 1986).

Species Group	AFZ (n = 118154)		western (n = 12701)		Arafura (n = 55199)		Wessels (n = 32367)	
	%	SE	%	SE	%	SE	%	SE
C. tilstoni	39.4	1.4	35.7	2.8	30.1	1.7	53.7	3.3
C. sorrah	16.3	0.8	16.6	1.9	20.2	1.3	10.2	1.2
Hammerheads	7.0	0.4	5.9	0.7	7.9	0.7	6.5	0.7
T. tonggol	15.1	1.2	7.8	1.8	21.2	2.1	12.6	2.4
S. commerson	3.0	0.3	2.3	0.7	3.4	0.4	2.9	0.6
Scomberomorus spp.	4.9	0.5	4.0	1.0	5.8	0.7	4.7	0.9

By year

When the species composition data for the AFZ were examined by year, the proportion of *C. tilstoni* in the total catch was lower in 1982–84 than in 1981, 1985 and 1986 (Fig. 10a). The differences between years 1982, 1983 and 1984 were small. The 1986 data may be biased, since there were far fewer sets monitored by observers (Appendix 1) than in other years. The proportions of *C. sorrah* (Fig. 10b) and of the hammerhead shark group in the catch did not vary greatly over the period monitored (13.6–17.5% and 3.4–8.4%, respectively). The proportion of *T. tonggol* in the catch was higher in 1982 and 1983 (22.2% and 20.9% of the catch respectively), while years 1981, 1984 and 1985 were lower (7.5–11.9% [Fig. 10c]). The proportion of mackerel in the catch was highest in 1985 (5.9%) and lowest in 1981 (2.8%), excluding the poorly sampled 1986 year (Fig. 10d).

By area

The annual species composition data, separated by area, are shown in Fig. 11. With a few exceptions, the proportions of the major species groups in the catch varied little over the years in each area, and in most cases the standard errors associated with the observations were large and overlapped between years. In the Arafura, and particularly the Wessels area in 1984, the proportion of *C. tilstoni* in the catch appeared to be lower, and the proportion of mackerel higher (Fig. 11e, h, i & l). In the Wessels, *T. tonggol* also comprised a higher proportion of the catch in 1984 and *C. sorrah* comprised a smaller proportion of the catch between 1983 and 1985 (Fig. 11j & k). Data for the western area are limited to a small number of sets

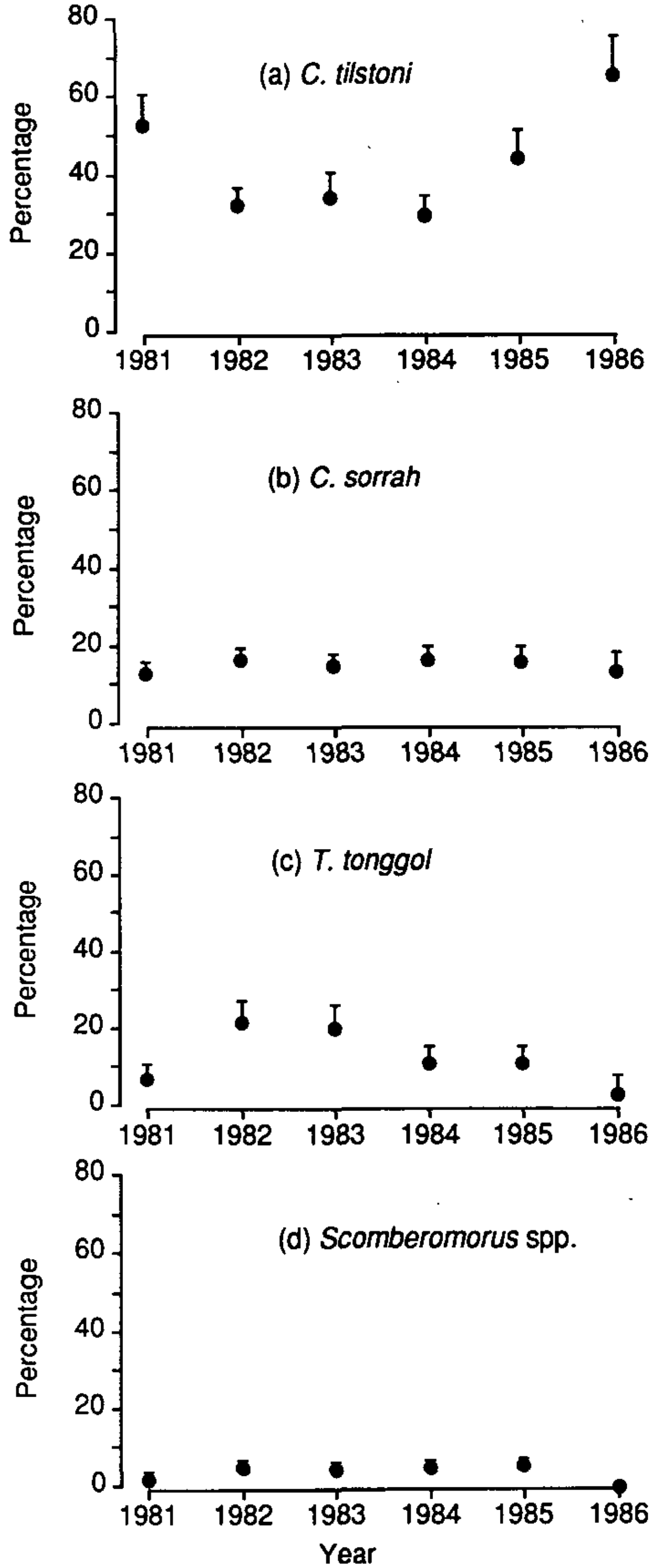

Fig 10
Percentage by number of the major components of the Taiwanese gill-net catch by year in the AFZ: (a) *C. tilstoni*, (b) *C. sorrah*, (c) *T. tonggol*, (d) *Scomberomorus* spp., from data collected by observers. Error bars indicate (half) 2 standard errors.

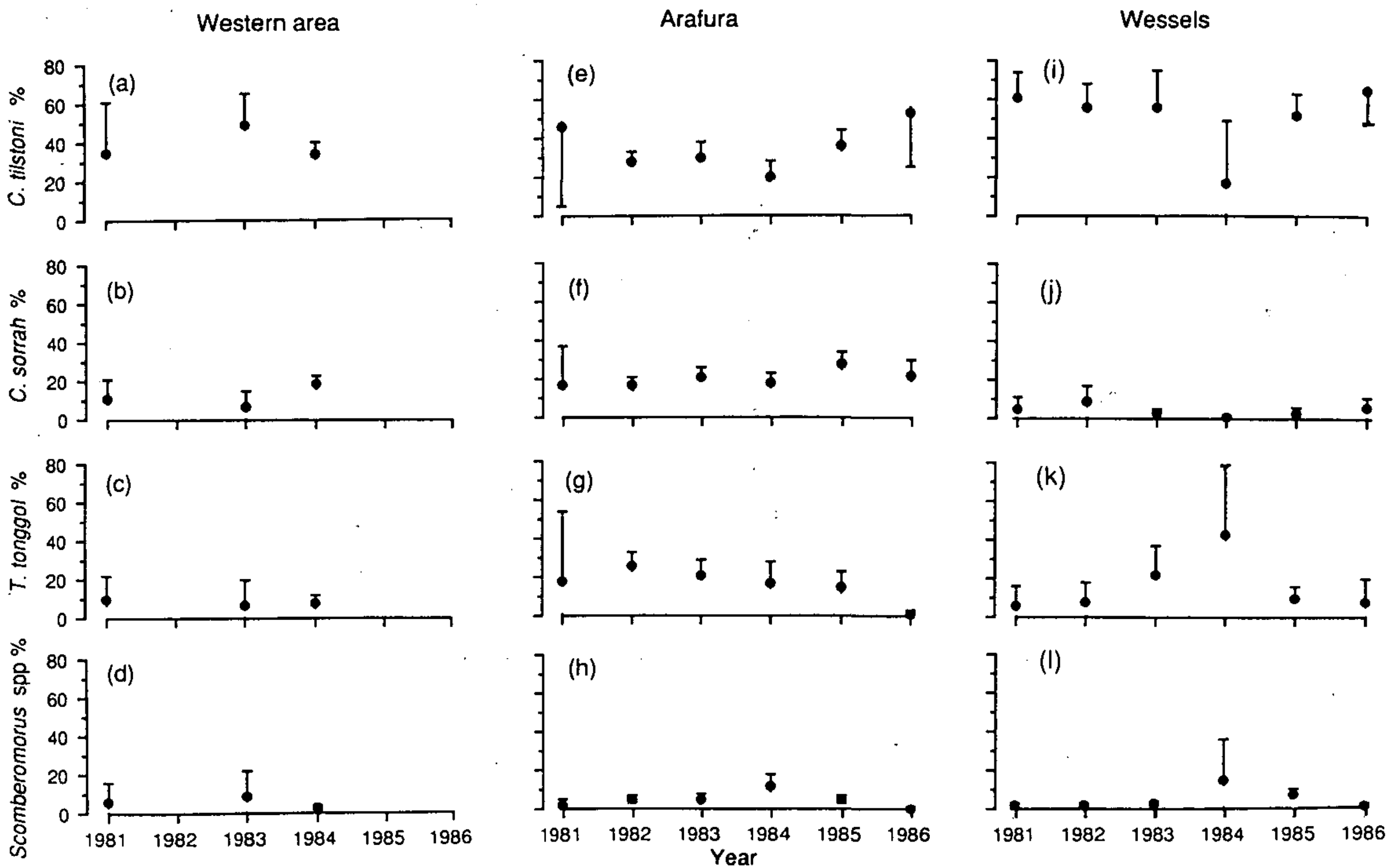

Fig 11
Percentage by number of the major components (*C. tilstoni, C. sorrah, T. tonggol, Scomberomorus* spp.) of the Taiwanese gill-net catch by year in the Western area (a-d), Arafura (e-h), and Wessels (i-l) from data collected by observers. Error bars indicate (half) 2 standard errors.

monitored over three years; no differences in catch category proportions are apparent between years because of the large standard errors associated with the data (Fig. 11a, b, c and d).

By month

Examination of the species composition data for the AFZ by month suggests that for 10 months of the year there was little change in the proportion of *C. tilstoni* in the catch (Fig. 12a). May and July are the outstanding months. The high value for May (75%) is probably a sampling artifact: there was only one year (1981) in which data were collected in May, and then only 5 sets were monitored, all in the Wessels area. Data for July (21 sets over three years, mostly in the Arafura, and to a lesser extent, the western area) suggest that *C. tilstoni* was less well represented at this time of year, making up 15.8% of the catch compared with 28.9–47.1% in other months (excluding May). Over the year, there was little change in the proportion of *C. sorrah* in the catch, with the standard errors overlapping in all months apart from August (8.3%), February (22.1%) and March (21.4%) (Fig. 12b). There was very little change in the monthly proportions of hammerheads in the catch. The proportion of *T. tonggol* in the catch ranged from a low in April (7.6%) to a high value in July (33.3%), with small differences between the other months (Fig. 12c). There are not sufficient data for May to suggest any trend. The monthly proportions of mackerel in the catch ranged from 0–17.6% and were highest in July and August (Fig. 12d). There were not enough data for May to be able to observe any trend.

By month and area

The monthly species composition data, separated by area, are shown in Fig. 13. Data for the western area were few; but there is some indication from Fig. 13 (a, b, c and d) that the lowest proportions of *C. tilstoni* were in July and of *C. sorrah* in August, while the highest proportions of *T. tonggol* were in July and of mackerel in August. In the Arafura, the proportion of *C. tilstoni* and *C. sorrah* in the catch was low in July, while *T. tonggol* and mackerel comprised a higher proportion of the catch at this time (Fig.13e, f, g and h). The proportion of hammerheads in the catch was similar throughout the year. In the Wessels area, the proportion of *C. tilstoni* in the catch was generally highest from February to June and lowest from August to January, while the reverse was apparent for *T. tonggol* and mackerel (Fig. 13i, k & l). No monthly trend in catch proportions was apparent for *C. sorrah* (Fig. 13j) or hammerhead sharks.

Sex composition

The sex composition of the shark catch only was examined (as sharks can be sexed externally). Data were only sufficient for examination of *C. tilstoni* and *C. sorrah*, and 1983 was the only year where we had information for every month of the year.

Chi-square analysis showed a significant difference in the sex ratio of *C. tilstoni* caught in all years except 1982 (Table 6a). There were proportionately more males in 1981 and from 1983 to 1985, with more females in 1986. No trend in sex ratio with year was apparent. Significantly more *C. sorrah* males were caught in 1982, 1983 and 1985 and significantly more females in 1981 and 1984. In 1986, the sex ratio was not significantly different from 1:1. No trend in sex ratio with year was evident (Table 6a).

When data from all years were pooled, *C. tilstoni* did not show any trend in sex ratio with month, while in 5 of the 12 months there was no significant difference from a 1:1 ratio (Table 6b). *C. sorrah* showed a general tendency towards increasing numbers of females from March through to December

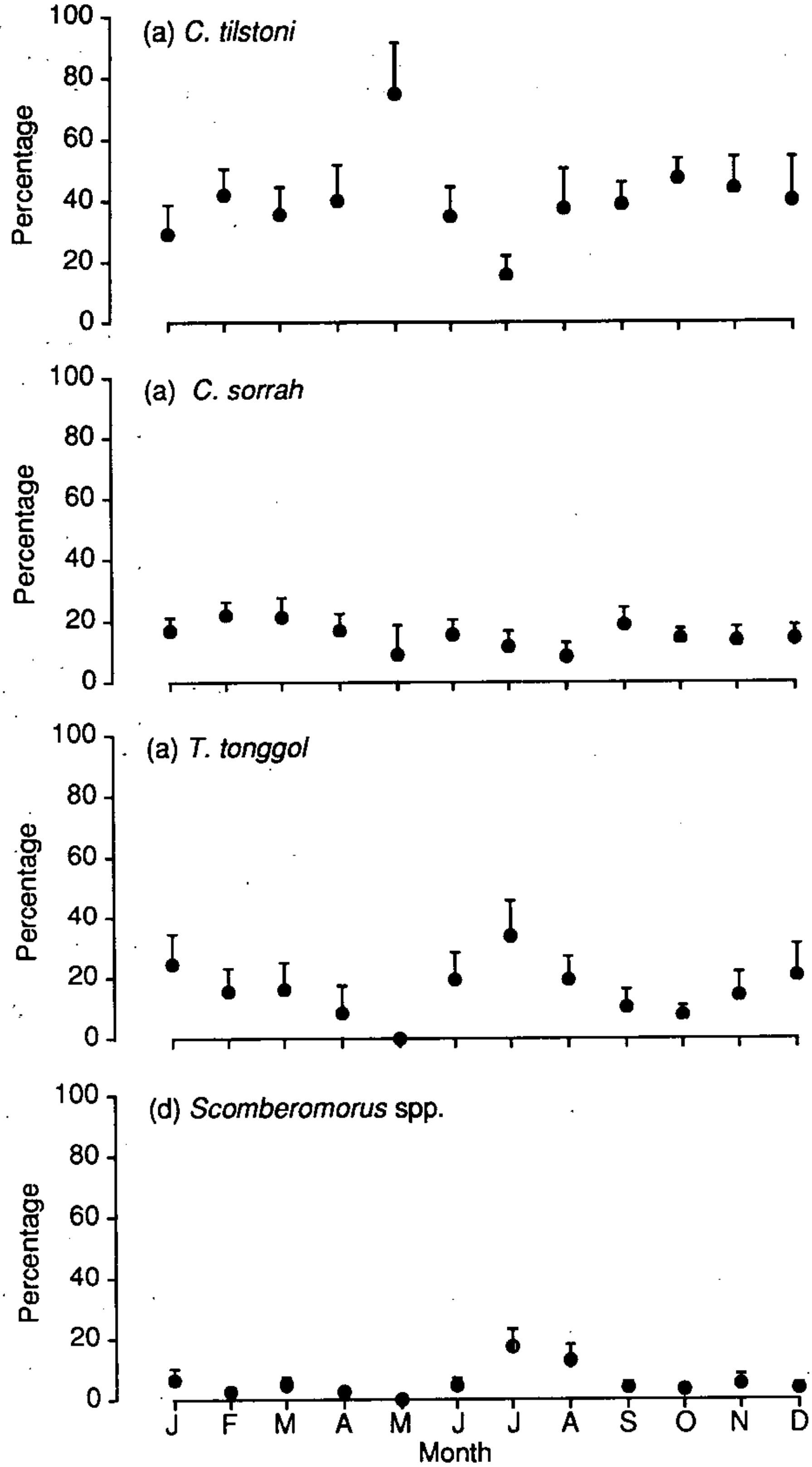

Fig 12
Percentage by number of the major components of the Taiwanese gill-net catch by month in the AFZ: (a) *C. tilstoni*, (b) *C. sorrah*, (c) *T. tonggol*, (d) *Scomberomorus* spp. from data collected by observers. Error bars indicate (half) 2 standard errors.

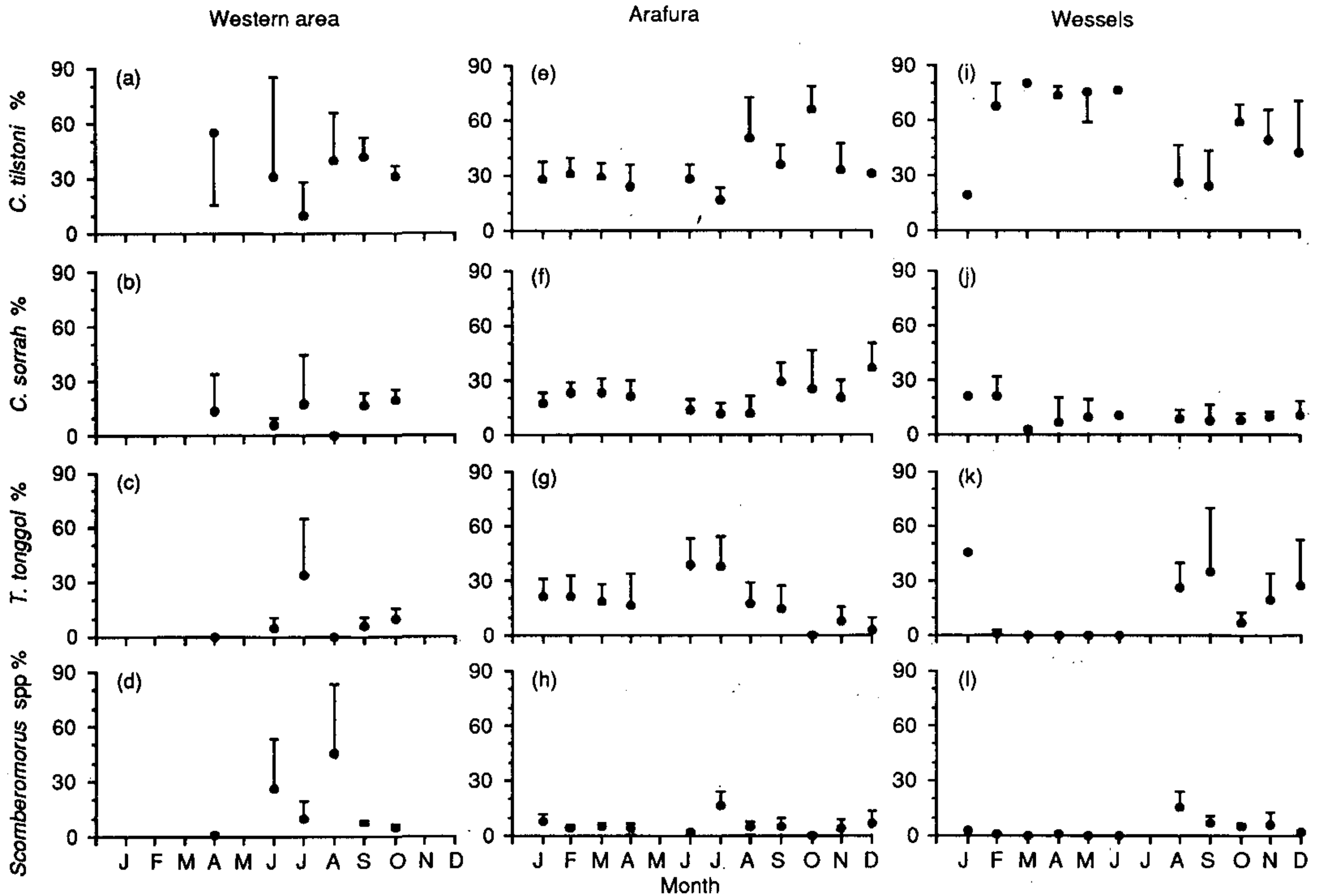

Fig 13
Percentage by number of the major components (*C. tilstoni, C. sorrah, T. tonggol, Scomberomorus* spp.) of the Taiwanese gill-net catch by month in the Western area (a-d), Arafura (e-h), and Wessels (i-l) from data collected by observers. Error bars indicate (half) 2 standard errors.

(Table 6b). However, this pattern was mainly a reflection of the 1983 data and there was too little information from other years to confirm the trend shown by the pooled data.

Table 6
Proportions of the sexes in catches of *C. tilstoni* and *C. sorrah* (* p < 0.05, ** p < 0.01, *** p < 0.001) by (a) year and (b) month.

(a)

Year	*C. tilstoni* Sample Size	Percent Male	χ^2	*C. sorrah* Sample Size	Percent Male	χ^2
1981	4,678	59.5	***	1,190	45.4	**
1982	6,802	50.4	ns	3,625	52.7	**
1983	7,785	59.2	***	3,487	55.2	***
1984	5,573	55.1	***	3,024	43.8	***
1985	16,959	56.8	***	4,624	55.4	***
1986	6,046	46.7	***	762	53.4	ns
TOTAL	**47,843**	**55.1**	***	**16,712**	**51.9**	***

(b)

Month	*C. tilstoni* Sample Size	Percent Male	χ^2	*C. sorrah* Sample Size	Percent Male	χ^2
Jan	2,044	46.5	**	1,406	57.5	***
Feb	9,533	50.0	ns	3,453	52.0	*
Mar	3,074	60.9	***	1,592	77.8	***
Apr	1,922	49.3	ns	887	54.7	**
May	156	60.9	**	53	52.8	ns
Jun	2,443	48.9	ns	1,173	43.6	***
Jul	1,151	48.0	ns	613	49.6	ns
Aug	2,778	51.5	ns	628	58.1	***
Sep	5,661	53.2	***	2,910	43.3	***
Oct	12,905	61.0	***	2,134	53.2	**
Nov	3,455	57.9	***	993	45.2	**
Dec	2,721	61.0	***	870	33.3	***

Size composition

C. tilstoni and *C. sorrah*

Length-frequency distributions for *C. tilstoni,* by sex, taken from the northern AFZ from 1981 to 1986 are shown in Figures 14a and b. An apparent decrease in the proportion of mature females (115 cm TL or greater) from 1981 to 1986 and of mature males (110 cm TL or greater) (Stevens and Wiley 1986) cannot be confirmed statistically (females R = 0.57, p = 0.24, 5df; males R = 0.75, p = 0.09, 5df). None of the annual size distributions are not composed of 12 months' data, nor are the same months always represented in the annual samples (Appendix 2).

Proportionally fewer mature *C. tilstoni* males were present in the catches in February, April, June, July and August (Fig. 15a). When these months were excluded from the analysis the regression (a decreasing trend in the proportion of mature sharks over the years of data collection) became significant (R = 0.89, p < 0.05, 5df). Proportionally fewer mature females were present in the March, June and July catches than at other times of the year. When these months were excluded from the analysis the decline in the proportion of mature fish was stronger but still not significant (R = 0.66, p = 0.16, 5df).

Length-frequency distributions for *C. sorrah*, by sex, from the AFZ for the same period are shown in Fig. 14c & d. The proportion of mature females (95 cm TL and greater) (Stevens and Wiley 1986) declined significantly with time ($R = 0.94$, $p < 0.01$, 5df), while no such trend was apparent for mature males (90 cm TL and greater). Monthly variations in the proportions of mature *C. sorrah* are not as marked as they are for *C. tilstoni* (Figs. 15c & d, 16c & d).

To determine whether the patterns of declining proportions of mature fish observed in the six years' pooled data are reflected in each of the years, we examined data for the months where four or more years were represented. Five years' data were available for February and four years' for January, March, September, October, November and December. In February, both sexes of *C. tilstoni* and *C. sorrah* show an apparent decline in the proportion of mature fish with time, but the regressions are not statistically significant. In January, March, September, October, November and December the proportion of mature male *C. tilstoni* declined each year, while the proportion of mature females declined each year for five out of seven months. However, with the exception of females in January ($R = 0.1$, $p < 0.001$, 3df), the regressions are not significant. In three of the six months, the regressions for *C. sorrah* have a negative slope, and in September the proportion of mature male *C. sorrah* increased significantly over time ($R = 0.97$, $p < 0.05$, 3 df).

Monthly length-frequency distributions for *C. tilstoni* from the AFZ are shown in Figures 16a and b. *C. tilstoni* are born at about 60 cm TL and January is the main parturition period (Stevens and Wiley 1986). New-born fish first appear in small numbers in the fishery length data in that month (Fig. 16a & b). *C. tilstoni* attain about 80 cm TL after 12 months (Davenport and Stevens 1988). The proportions of first-year fish (< 80 cm TL) increase slowly from January to May then rise to a sharp peak in July before declining (Fig. 15a & b). This is reflected in the large proportion of 70–80 cm fish in the July length-frequency samples (Fig. 16a & b). The proportions of mature fish show a corresponding decline in June and July (Fig. 15a & b).

Similar monthly size data for *C. sorrah* are shown in Figures 16c and d. *C. sorrah* are born at about 50 cm TL, mainly in January, and attain some 75 cm TL after 12 months (Stevens and Wiley 1986; Davenport and Stevens 1988). The proportions of first-year fish (< 75 cm TL) gradually increase from January to July (ignoring the May value, which is based on a very small sample of 10 females and 13 males) before declining again. The proportions of mature males show a corresponding drop in July, but this is not clearly evident for females (Fig. 15c & d).

Figure 15 is derived from monthly data pooled over six years, where the same months were not necessarily sampled in each year. There was an apparent seasonal decline in proportions of mature *C. tilstoni* observed early in the year; this was followed by an increase in the second quarter and a further decline to a minimum in July and then a steady rise (Fig. 15). We examined each year's data separately to see if this apparent seasonal pattern was consistent. While the poor seasonal coverage for most of the years made examination difficult, the available information did not generally contradict the pattern observed in the pooled data. When the *C. sorrah* data were treated in the same way, no clear seasonal pattern in the proportion of mature fish was evident.

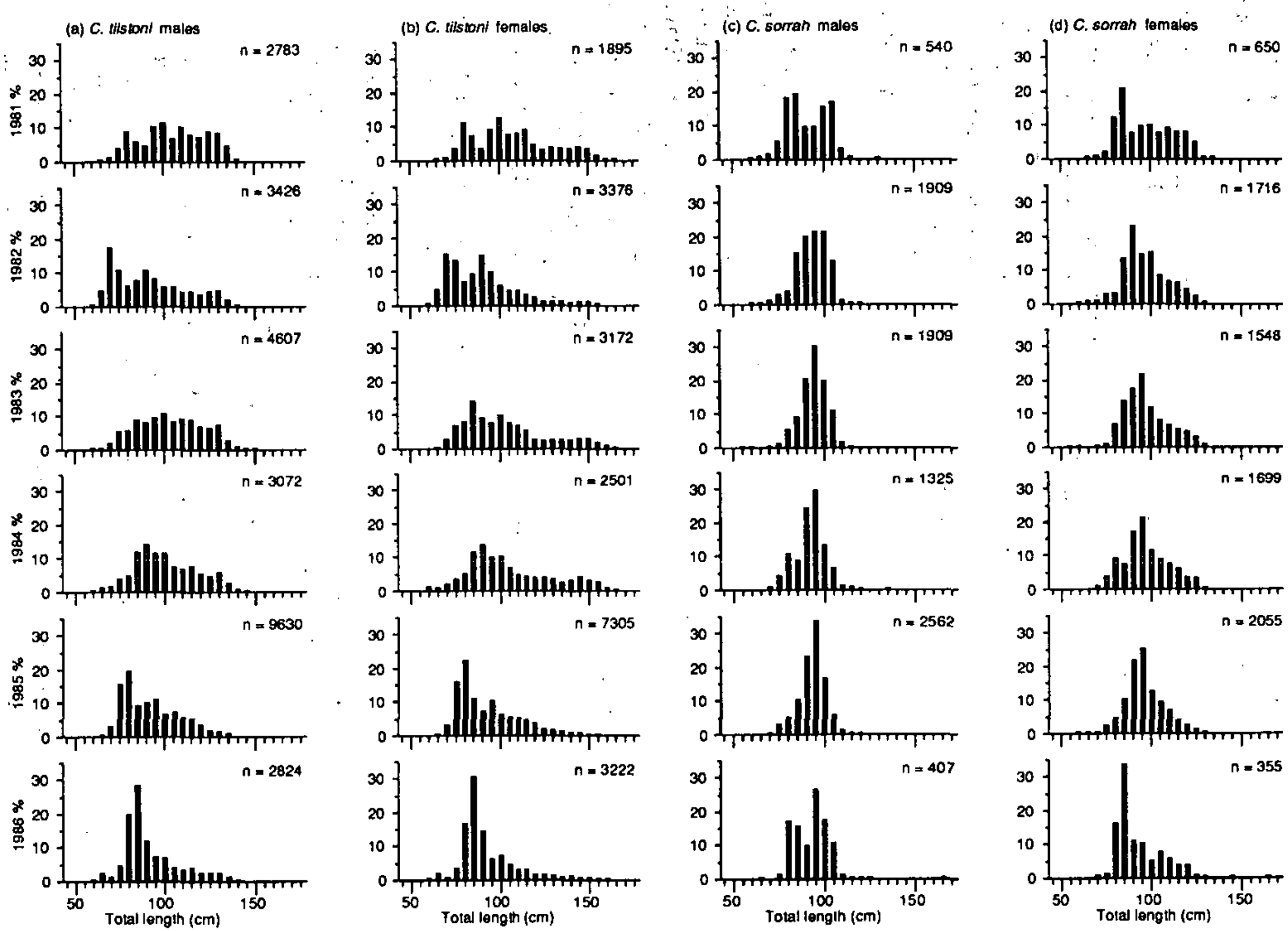

Fig 14
Length-frequency distributions (percentages) by year for (a) *C. tilstoni* males, (b) *C. tilstoni* females, (c) *C. sorrah* males, and (d) *C. sorrah* females in the AFZ.

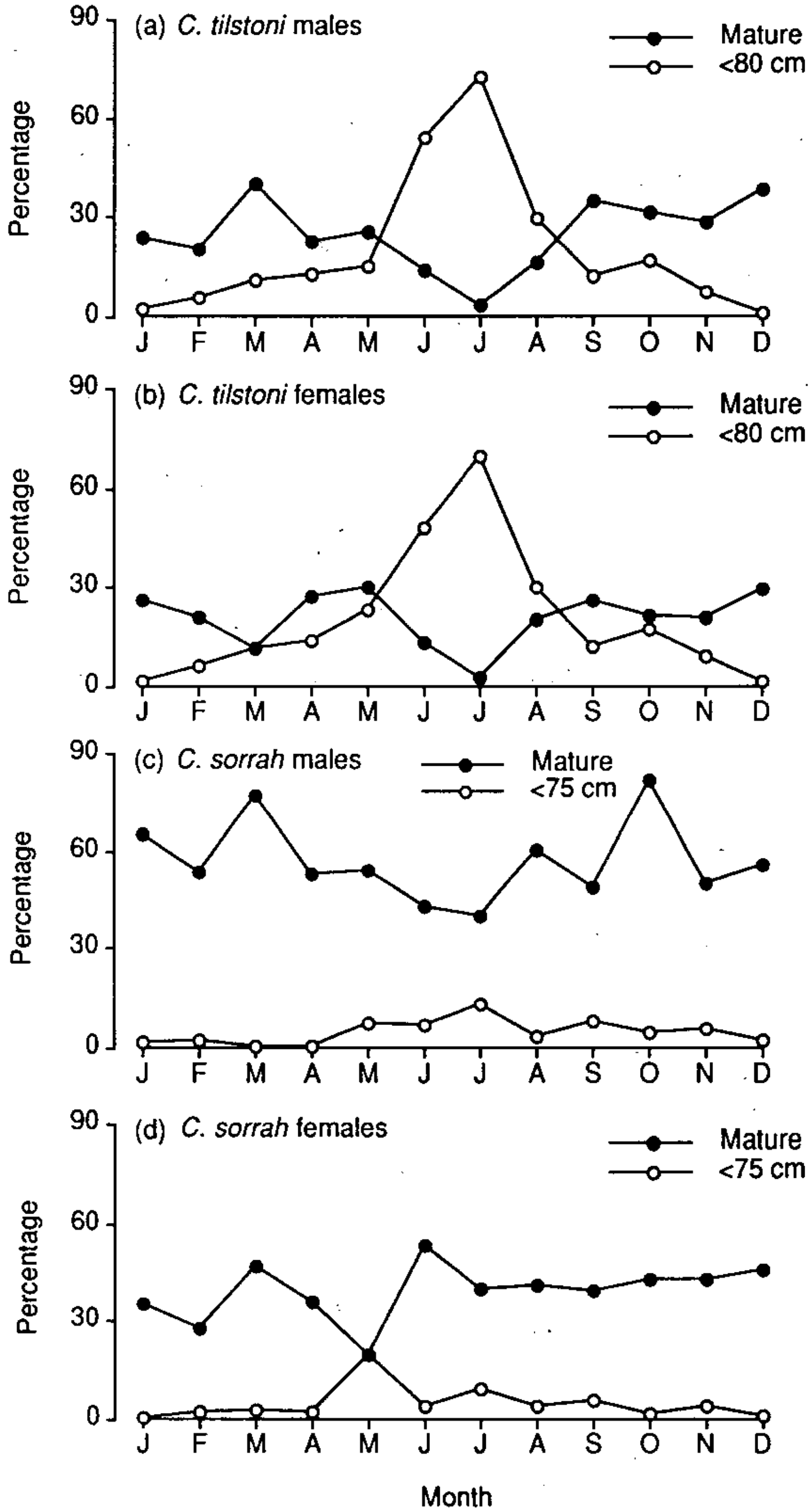

Fig 15
Proportion (by month) of mature and first year sharks in the catch: (a) *C. tilstoni* males, (b) *C. tilstoni* females, (c) *C. sorrah* males, and (d) *C. sorrah* females. For *C. tilstoni*, sample sizes > 500 except May (94 males, 56 females); for *C. sorrah*, sample sizes > 250 except May (13 males, 10 females).

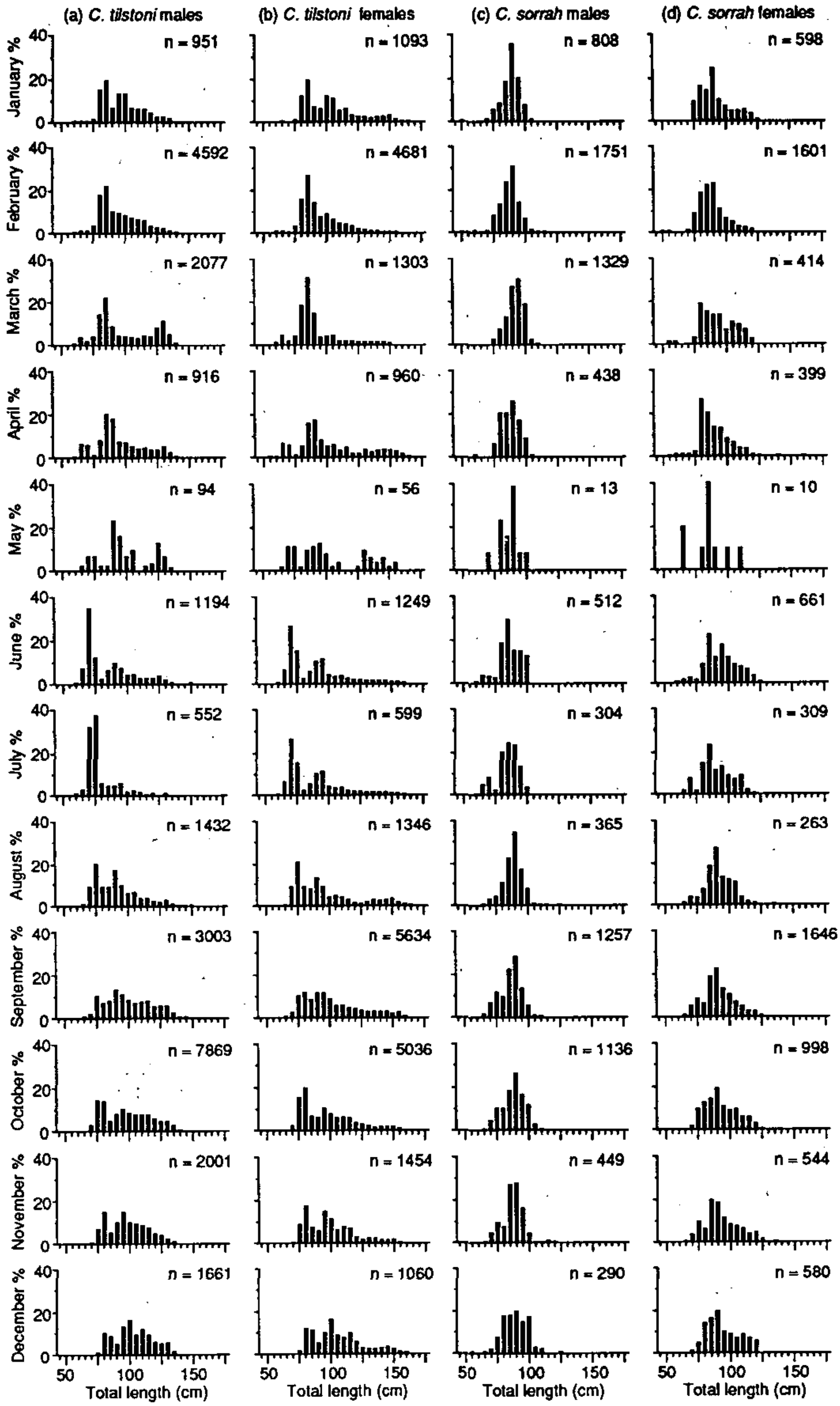

Fig 16
Length-frequency distributions (percentages) by month for (a) *C. tilstoni* males, (b) *C. tilstoni* females, (c) *C. sorrah* males, and (d) *C. sorrah* females, in the AFZ.

Regression models showed little or no interaction between month and sex, or between year and sex, so in subsequent analyses, year and month effects were assumed to be the same for both sexes. There was, however, an interaction between month and year, which implies that the seasonal pattern in each year was not the same for all years. So we examined changes over the whole timespan (April 1981–April 1986) rather than attributing any change to month and year effects only.

For *C. tilstoni*, when we ignored the year–month interaction, year, month and sex were all highly significant ($F = 15.53$, df = 5, 64, $p < 0.001$; $F = 3.09$, df = 11, 64, $p = 0.002$; $F = 9.77$, df = 1,64, $p = 0.003$ respectively). Over the period of the study, there was a significant change in the proportion of mature *C. tilstoni* ($F = 9.59$, df = 40,40, $p < 0.001$). There was an overall decrease in the proportion of mature sharks from April 1981 to April 1986 with a marked dip in 1982 followed by a rise and then a continued decline. The apparent dip in 1982 was mainly due to the June and July figures, which made up a large portion of the 1982 data. The analyses suggest that a lower proportion of mature sharks were caught in June and July than in other months. The proportion of mature males was significantly higher than the proportion of mature females ($F = 20.52$, df = 1,40, $p < 0.001$).

C. sorrah showed a significant variation in the proportion of mature sharks over the 41 months of the study period, allowing for different seasonal patterns within the years ($F = 2.41$, df = 40,40, $p = 0.003$), but there is no pattern that can be ascribed to year or month. There is no apparent decline in the proportion of mature sharks over the years, nor any consistent pattern within years. The proportion of mature males was consistently higher than mature females ($F = 48.85$, df = 1,40, $p < 0.001$).

T. tonggol

Length-frequency distributions of *T. tonggol* taken from the AFZ between 1981 and 1986, and of *S. commerson* between 1982 and 1986 are shown in Figure 17. The monthly length-frequency distributions of these species are shown in Figure 18. When the mean length of *T. tonggol* was plotted sequentially by month from 1981 to 1986, no obvious seasonal trend (over months within years) was apparent; if anything, there was a gradual increase in mean length over years. Fitting a regression model that included terms for month within year and for year (allowing polynomials up to order 4 for month and 2 for year) did not show any regular seasonal or yearly pattern. A regression containing the linear term for year only gave a significant coefficient of 0.544 cm (SE = 0.053), indicating an average increase of about 0.5 cm per year in mean length over the period of observations. However, many higher-order terms were significant, indicating that no simple pattern is apparent.

S. commerson

When the mean length of *S. commerson* was plotted sequentially by month from 1982 to 1986, there was evidence of both a seasonal effect (with a peak in mean length around September) and a general decrease in average length over years. Fitting similar regression models to those used for *T. tonggol* showed a significant linear decrease in mean monthly length over the years of about 2 cm per year (coefficient -2.04, SE = 0.203). Including the quadratic term for years ($p < 0.001$) indicated that there was little or no decrease initially, but the decrease became greater over the years: about 2 cm from 1983–4 and 4 cm from 1984–5. The decrease in mean length was about 6 cm from 1985–6, but there are too few data for 1986 for this estimate to be reliable.

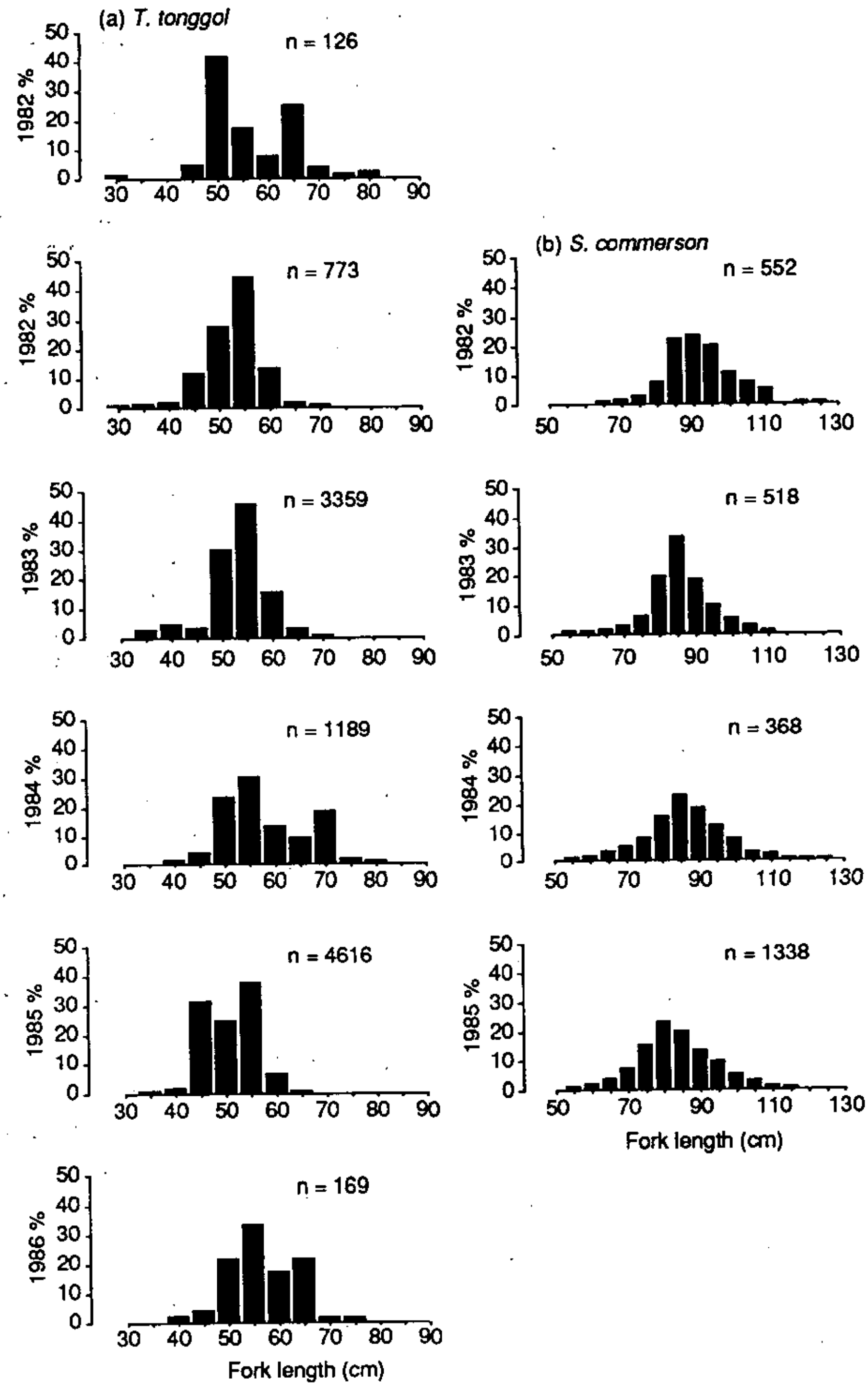

Fig 17
Length-frequency distributions (percentages) by year for (a) *T. tonggol,* and (b) *S. commerson.*

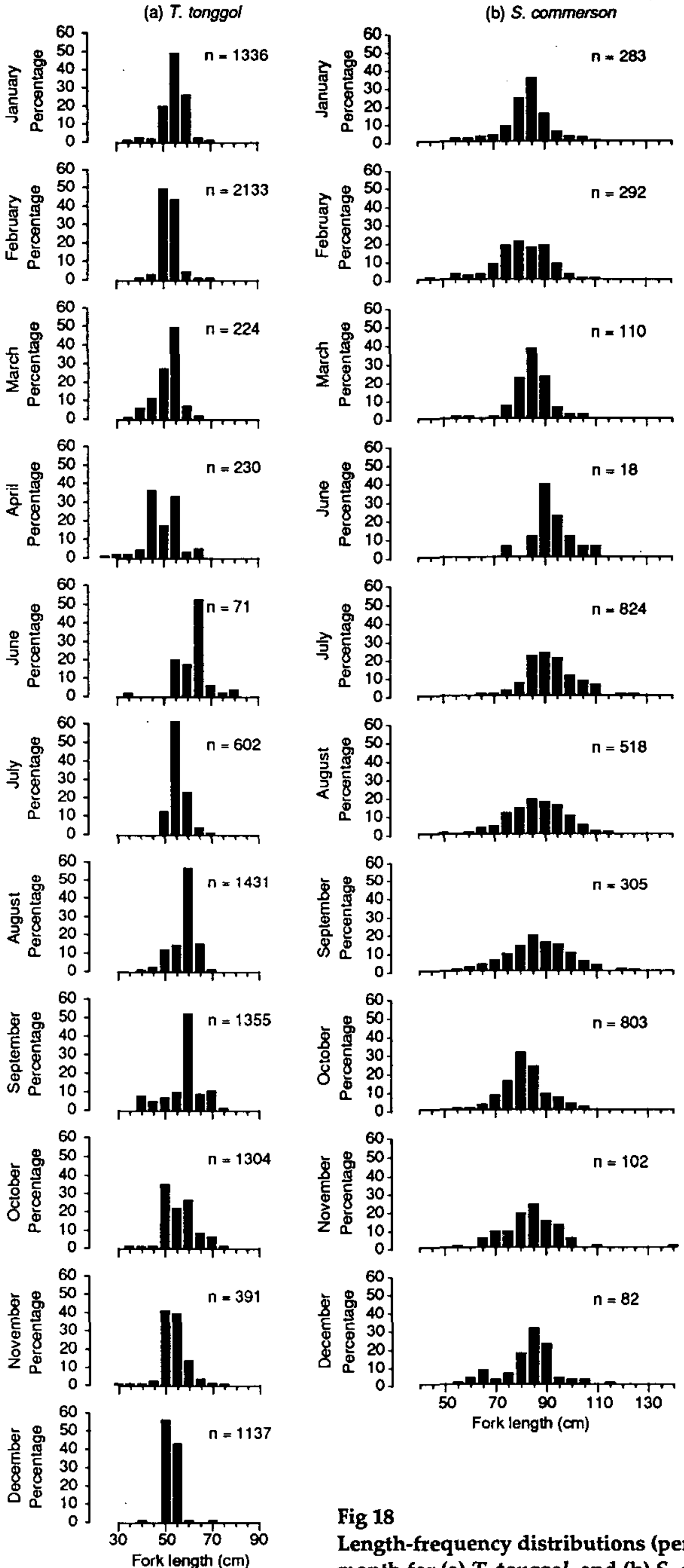

Fig 18
Length-frequency distributions (percentages) by month for (a) *T. tonggol*, and (b) *S. commerson*.

Catch variability and aggregations

Anecdotal catch information suggested that *C. tilstoni* and *C. sorrah* tend to aggregate by sex and size. This was investigated with two sets of research data (see Materials and Methods section).

In the 1985 and 1986 gill-net modification trials, the shark catch was recorded by 1 km panel along the gill-net. We examined four sets that had caught over 1200 individuals. As only *C. tilstoni* was caught in large enough numbers, analysis was restricted to this species. If *C. tilstoni* aggregates by size and/or sex, and the net samples one or more aggregations, it might be expected that groups of panels would contain sharks of the same size range and sex ratio. Three-way contingency tables were used to analyse for differences in length between panels and sex. Length was divided into four size classes (< 65, 65–69, 70–74, ≥ 75 cm FL) to meet the requirement of the analysis that there should be more than five sharks in at least 80% of the cells. Sex ratio differences were tested by chi-square analysis against an expected 1:1 ratio.

The median lengths of sharks from each of the four sets are shown in Table 7. Of the 14 panels fished in Set 1, 12 were analysed, two contained too few sharks. There was no interaction of panel and sex in relation to length distribution ($c^2 = 35.64$, df = 33, $p > 0.20$). Females were significantly larger in the length distribution of the sexes ($c^2 = 18.82$, df = 3, $p < 0.001$), but not between panels ($c^2 = 24.8$, df = 33, $p > 0.20$). Males predominated in all panels. In eight panels, the sex ratio was significantly different from 50:50 ($p < 0.001$ in panels 2 and 7; $p < 0.01$ in panel 14; $p < 0.05$ in panels 5, 6, 8, 12 and 13).

Table 7
Median lengths (cm FL) of *C. tilstoni* from four sets with large shark catches, from the 1985 and 1986 gill-net modification trials.

Set	Panels	Median length (cm FL)	
		Males	Females
1	2–14	64.0–67.0	64.0–68.5
2	1–5, 7–11	66.0–68.0	66.0–70.0
3	1–5, 7–11	65.0–69.0	66.0–69.0
4	1–5,	65.0–68.0	67.0–68.0
	7–11	67.0–69.5	69.0–71.0

Ten panels were fished in Set 2 (Fig. 19). There was no effect of interaction between sex and panel ($c^2 = 27.98$, df = 27, $p > 0.20$) on the length distribution. Males predominated in all 10 panels. In three panels (1, 3 and 9), the sex ratios were significantly different from 50:50 ($p < 0.001$, $p < 0.01$ and $p < 0.05$ respectively). There were differences in length distribution between sexes ($c^2 = 11.61$, df = 3, $p < 0.01$) and between panels ($c^2 = 128.22$, df = 27, $p < 0.001$). For males, comparing the four length groups in adjacent panels indicated that panels 1–9 were similar (median lengths 66–68 cm), panel 10 had slightly larger sharks (median length 67 cm); panel 11 had larger sharks (median length 68 cm) but also many smaller ones (Fig. 19). For females, the same comparison of adjacent panels indicated that there were three groups of broadly similar panels: panels 1 and 2 (which had few small sharks), panel 11 (larger sharks and, as with the males in panel 11, many small sharks). There was no significant difference between panels 3–10 (median lengths 66–69), but they were different from panels 1, 2 and 11 (median lengths 67, 69 and 70 cm, respectively).

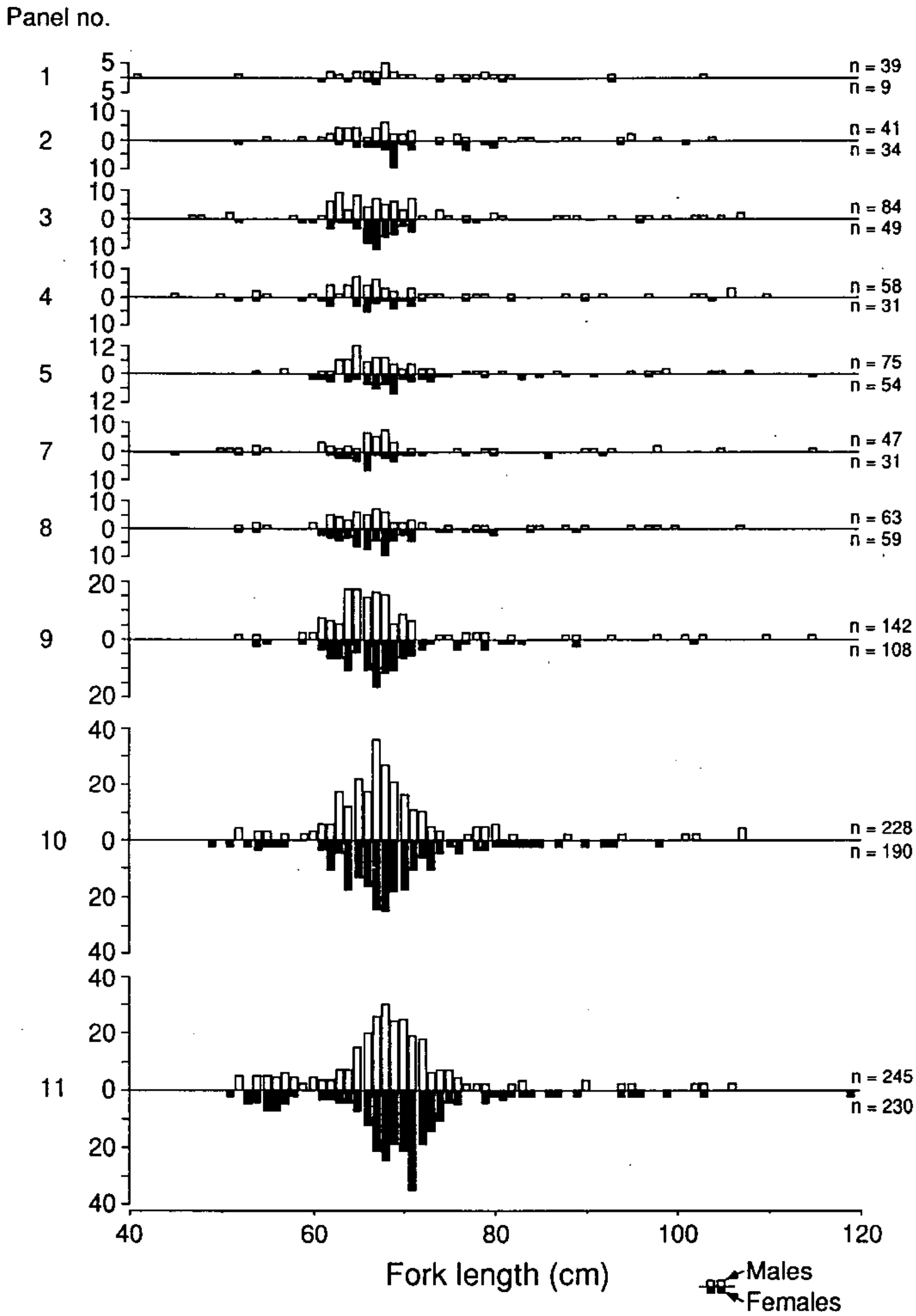

Fig 19
Length-frequency distributions (as numbers) for *C. tilstoni* in the gill-net panels of Set 2 in the 1986 gill-net modification trials.

Over the 10 panels fished in Set 3, there was no interaction between panel and sex affecting the length distribution ($c^2 = 36.04$, df = 27, $p > 0.10$), but there was a significant difference in the length distribution of sharks between sexes ($c^2 = 25.81$, df = 3, $p < 0.001$) and between panels ($c^2 = 130.66$, df = 27, $p < 0.001$). In all 10 panels the sex ratio was not significantly different from 50:50. Since there was no interaction between panel and sex alone, the data for all panels were combined to look for the differences in length distribution related to sex. Females were slightly more numerous in the two middle length-classes (65–69 and 70–74 cm). The males were somewhat smaller and the size-distribution was skewed to the right. When each panel was tested against adjacent panels, there appeared to be three groups of panels. In each group there were panels of statistically similar length distributions, while the panels of one group were significantly different from the panels of another group. In group 1 (panels 1–4) the median-length for both sexes was 67 cm, in group 2 (panels 5, 7 and 8) it was 65 cm for males and 66 cm for females, and in group 3 (panels 9–11) it was 68 cm for both sexes.

Ten panels were fished in Set 4. There was no panel by sex interaction ($c^2 = 30.32$, df = 27, $p > 0.20$) but there was a difference due to sex ($c^2 = 47.8$, df = 3, $p < 0.001$) and panel ($c^2 = 101.78$, df = 27, $p < 0.001$). The sex difference appears because females are larger than males. The panel difference is due to two groups of panels: panels 1–5 and panels 7–11. This coincides with surface and subsurface panels, respectively. The surface panels (1–5) caught smaller sharks than the subsurface panels (7–11). Panel 7, in which females predominated, was the only panel where the sex ratio was significantly different from 50:50 ($p < 0.01$).

While statistically significant differences in length distributions between groups of panels were apparent in Sets 2, 3 and 4, the differences between the median length values are so small that they are probably meaningless from a biological viewpoint. When panels were combined and Sets 1, 2, 3 and 4 tested for differences in size distribution, there was a highly significant difference for both sexes in length distribution between the sets ($p < 0.001$, df = 12).

If *C. tilstoni* aggregates by size and/or sex, it might be expected that catches that are not related in space or time would have different sex ratios and size compositions. On the other hand, repeated catches in a small area and short timeframe might sample the same aggregation (depending on its size) so that catches would have a similar size or sex composition.

We examined the nine largest FV *Rachel* catches that came from different locations at different times. *C. tilstoni* comprised the largest part of the shark catch in eight of these sets, with 45–460 individuals in each set. We also examined all FV *Rachel* sets where the positions at the start of set were within 5 nm (9.3 km) and within 5 h of each other. There were 129 groups of sets that satisfied these criteria. The number of sets in a group varied between two and four. Size composition and sex ratio between sets within groups were compared by three-way contingency tables. As this analysis requires at least 15 sharks of each sex in each set, only six groups could be analysed. Shark length was divided into five size classes (< 65, 65–69, 70–74, 75–79 and ≥ 80 cm FL) and the analysis was run separately on males and females. For the nine largest FV *Rachel* sets, sex ratio differences were tested by chi-square analysis against an expected 1:1 ratio.

Of the nine largest sets, four had sex ratios that were not significantly different from 1:1. In one set the difference was just significant ($p < 0.05$) and females predominated; in the four remaining sets, the sex ratio varied significantly from 1:1 ($p < 0.01$) and males predominated. In comparisons of size distributions between sets, contingency table analysis indicated a highly significant difference between the sets ($p < 0.001$, df = 32) for both sexes (median lengths of fish from these sets ranged between 57 and 88.5 cm for males and 57 and 93 cm for females).

For the six groups of FV *Rachel* sets made within 5 nm and 5 h of each other, the sex ratios between sets within groups were significantly different in only one group ($p < 0.05$, df = 1), while the length distributions were significantly different in two groups (maximum difference in median length between sets within a group was 14.5 cm). In one group, *C. tilstoni* males showed a significant difference in length distribution between two sets ($p < 0.05$, df = 3) (the median lengths of males were 77 and 89 cm, and of females 95 and 83 cm). In another group, female *C. tilstoni* showed a significant difference ($p < 0.01$, df = 4) between the length distributions in adjacent sets. The median lengths of all fish from these two sets were 89.5 and 75.0 cm for males, and 90.0 and 73.0 cm for females.

Sets within groups were combined and the data examined for differences between groups. For both sexes there was a highly significant difference in the length distributions between groups ($p < 0.001$, df = 20).

If sexual segregation is associated with reproduction (Strasburg 1958), it might be expected that unequal sex ratios in an aggregation would imply that the sex ratios of mature fish in the population are unequal. Using all the data from the panel experiments and the FV *Rachel* sets, we separated each catch into immature and mature fish and examined the sex ratios of these components separately, but could find no pattern. Similarly, when the nine largest FV *Rachel* sets were examined by log-linear analysis with three-way contingency tables, a complicated interaction of set, sex and maturity was found. Furthermore, when the sets were examined separately, the analysis indicated a different pattern in each set. Any relationships between sex ratio and maturity in *C. tilstoni* aggregations were not, therefore, apparent from these data.

Catch variability and environmental effects

In the 1985 gill-net modification experiment, four of the 43 sets were excluded from the analysis because only half the net was set. There were missing variables in the data set and different variables were missing for different sets. Regression models were fitted to the data, each regression excluding all sets where any one of the variables had a missing value. There was a significant relationship ($p = 0.001$) between shark catch and wind direction and/or set direction (these were positively correlated; $R = 0.701$). More sharks were caught when the wind was from the east (wind directions during this experiment varied mostly between 025° and 150°). Moon phase and/or light availability (these were highly correlated; $R = 0.892$) were significantly associated with shark catch ($p = 0.042$), with more sharks being caught close to new moon or when there was less light. Wind speed and swell were highly correlated ($R = 0.891$) but there was no significant relationship with shark catch. Depth was just insignificant ($0.05 < p < 0.10$), with more sharks being caught where depth was greater. There were too many missing values to examine the effects of temperature. Times at start of set and start of haul had no significant bearing on the catch.

The only variables tested that had a significant effect on the fish catch were depth, wind speed and light. More fish were caught in shallower depths ($p = 0.013$), with higher wind speeds ($p = 0.015$) and with less available light ($p = 0.077$).

In the 1986 gill-net modification experiment, 4 of the 41 sets were excluded from the analysis because only half the net was set. Various models were fitted to the data. Models that included temperature suggested that this parameter was not a useful predictor of shark catch. Thus, rather than excluding the nine sets where temperature was not recorded, we used models that ignored temperature. A generalised linear regression model was used, with light as a factor and other variables as continuous covariates. As light was not recorded for three sets, a similar model that omitted light was also used so the data from all 37 complete sets could be included.

More sharks were caught when there was less light ($p = 0.004$) and when hauling started later ($p < 0.001$). It is not clear whether later times for start of set increased shark catches. Time at start of set significantly increased shark numbers in some analyses ($p = 0.026$), but when two atypical sets (very late start-of-set times) were removed from the analysis, this variable was no longer significant ($p = 0.240$). Wind direction was significant in some analyses ($p = 0.012$), which suggests larger shark numbers with winds west of north (contrasting with the 1985 experiment, where higher shark catches were associated with winds east of north), but in analyses using all 37 sets and excluding 'light availability', wind direction was not significant ($p = 0.280$). For a given level of light availability, it appeared that more sharks were caught with a fuller moon. Wind speed, swell and sea depth were not significant. Possibly their effects were obscured by other concurrent conditions: for example, greater sea depth tended to coincide with later start of haul times, and depths tended to be greater later in the study period, when wind direction also tended to be more easterly.

The only significant variables affecting fish catch were swell and moon phase. More fish were caught with a larger swell ($p < 0.001$) and when the moon phase was close to new moon ($p < 0.001$).

Set direction was usually about 45° greater than wind direction. Nets were set from the port side of the vessel, so setting in a direction a little off the wind to starboard prevented the vessel's being blown onto the net.

Most Taiwanese gill-net sets were made between depths of 30 and 70 m. The depths of 15,229 shark catches, 9,999 non-zero tuna catches and 10,343 non-zero mackerel catches are recorded in the logbooks. The proportion of non-zero tuna and mackerel catches steadily declined with increasing depth. There was a statistical relationship between catch and depth when a linear regression was performed for each of the shark, tuna and mackerel catches. These relationships were:

shark: $\log(\text{catch}) = 6.2 + 0.0075\ \text{depth}$ ($p < 0.01$; $R^2 = 0.012$),

indicating a slight increase in catch with increasing depth;

tuna: $\log(\text{catch}) = 7.25 - 0.038\ \text{depth}$ ($p < 0.01$; $R^2 = 0.064$)

mackerel: $\log(\text{catch}) = 5.17 - 0.023\ \text{depth}$ ($p < 0.01$; $R^2 = 0.043$), indicating a slight decrease in catch with increasing depth for both species groups. While these relationships are statistically significant, this is more likely a result of large sample sizes than any real effect of depth on catch.

Discussion

Catch-and-effort statistics

The quality of the catch and effort data was a problem. Simple punching, typographical and transcription errors (which suggests that the logbook database was not adequately validated) could be corrected easily. Other problems were more difficult and involved making various assumptions, and in some cases discarding data. These problems included lack of pre-AFZ statistics, different logtypes recording different catch and effort units, failure to account for net dimensions increasing with time, and discrepancies between either weights or numbers of the catch components and total catch. However, overall there was reasonable agreement between the three sources of catch data and between independent observer estimates of catch and the corresponding Taiwanese logbook entries.

Based on all available data, annual catches averaged about 7,700 t between 1975–78. After the AFZ was declared in 1979, catches were restrained by a 7,000 t quota. Anecdotal information suggests that pre-AFZ Taiwanese effort was concentrated in inshore areas, including the Gulf of Carpentaria. Catch rates (at least since 1984) are higher inshore, with gill-net CPUE from inshore Arnhem Land and the Gulf of Carpentaria (from CSIRO's Northern Pelagic Program) being 6–18 times higher than in the adjacent Taiwanese zone (Lyle 1987).

Taiwanese catches during the pre-AFZ period were made with maximum net-lengths of 8 km. To maintain catch rates between 1979 and 1983, the Taiwanese increased their fishing effort dramatically. Between 1982 and 1983, effort nearly doubled; this was due to a 31% increase in the surface area of the net and a large increase in the number of sets during the period. Catch-per-unit-effort dropped from 1977–83, after which it increased slightly in the last years of the fishery. This slight reversal of the CPUE trend resulted from a reduction in vessel numbers as the Taiwanese began to divert their vessels outside the AFZ after the Australian government announced its intention to limit net length. The small number of vessels may have been able to maintain better catch rates by fishing in the best areas.

Different measures of fishing time have been used in gill-net CPUE calculations: Lyle and Timms (1984) used the time between completion of the set and start of the haul (soak time), while Lyle (1987) used time between completion of the set and completion of the haul. In this study we used time from start of the set to completion of the haul, which will give the most conservative estimates of CPUE. Perhaps a more realistic fishing time would be set time/2 + soak time + haul time/2. Such a model would increase our estimates of CPUE by about 30%. Analysis of catch, effort and CPUE trends by area and catch category suggest that the western area was less productive, particularly for tuna, and that after 1983 the Taiwanese put proportionately more effort into the Wessels, where they targeted tuna.

Shark and mackerel CPUE generally declined with time in all three areas (ignoring the mackerel CPUE for the western area in 1986, which is based on few data), as did tuna CPUE in the western area. However, tuna CPUE in the Arafura remained relatively constant between 1980–85 while it increased considerably in the Wessels between 1979–84. Shark and mackerel resources in the northern AFZ appear to have been considerably over-exploited by the Taiwanese gill-net fishery. Shark CPUE declined from about 11 kg/km h in 1979 to about 3 kg/km h in 1984, while mackerel CPUE declined from about 1 kg/km h in 1980 to 0.3 kg/km h in 1985–86.

The effect of Taiwanese fishing on the tuna stocks is less clear. CPUE increased from about 0.3 kg/km h in 1979 to 3 kg/km h in 1984, before dropping rapidly in the last two years of the fishery to 0.6 kg/km h in 1986. Analysis of seasonal trends in the catch, effort and CPUE was largely precluded by the high variances in the data. Shark CPUE showed no significant seasonal pattern in any of the areas, while tuna CPUE in the Wessels and Arafura, and mackerel CPUE in the Wessels, was highest between June and September. The apparent seasonal increase in the abundance of tuna and mackerel in this region may be due to increased productivity resulting from an enrichment of nutrients in an area northeast of the Wessel Islands (Rochford 1962, 1966). Based on radio report data (essentially the same as the logbook data), Lyle and Read (1985) also found that the major Taiwanese tuna fishing area lay in the vicinity of the Wessel Islands. These authors reported a tendency for catch rates to be higher from May to September and, to a lesser extent, December to March.

Catch composition

The Taiwanese catch was dominated by *C. tilstoni*, *C. sorrah* and *T. tonggol* (Table 5). In the inshore gill-net catch of CSIRO's Northern Pelagic Program, by contrast, *C. tilstoni* and *C. sorrah* accounted for 72% by number, *C. macloti* comprised 14%, and *Scomberomorus* spp. 2%. Hammerhead sharks and *T. tonggol* accounted for less than 1% (Lyle 1987). In an inshore gill-netting survey in the Northern Territory, teleosts only accounted for 13% of the catch by number, and *T. tonggol* was caught infrequently (Lyle and Timms 1984). The reason for the higher proportion of *T. tonggol* in the Taiwanese catch than in the research catches may be that the Taiwanese were targeting them (Lyle and Read 1985) or that they were more abundant in that region. An aerial survey of tuna off the Northern Territory recorded most schools within 50 nm of the coast; few schools were observed in the Wessels area but coverage of this region was poor (Lyle and Read 1985).

The lower proportion of *C. tilstoni* and *C. sorrah* and higher proportion of *T. tonggol* in the Taiwanese catches of 1983–1984, particularly from the Wessels (and to a lesser extent the Arafura), are mainly a reflection of low CPUE for shark and high CPUE for tuna in the Wessels during this period. An increase in the relative contribution of tuna to the total Taiwanese catch between 1980–84 was noted by Lyle and Read (1985), who reported that changes in target fishing were mainly a response to market pressure. The comparative prices of shark, tuna and mackerel in Taiwan determined the preferred species.

Major seasonal trends in species composition also correlate with the CPUE data. *C. tilstoni* and *C. sorrah* generally comprise a low proportion of the catch around July in most areas, while the proportion of *T. tonggol* and mackerel is high at this time. This would appear to be due to high CPUE for tuna and mackerel between June and September in the Arafura and Wessels.

Analysis of the size composition data for the major species was complicated by the unequal seasonal sampling coverage in each year. This confounded detection of any annual or seasonal changes in length. The results suggest that the proportion of mature *C. tilstoni* declined over the period of the fishery. One seasonal effect was detected in June–July, when the proportions of mature fish were low and of one-year-old fish were high. As January is the main parturition period (Stevens and Wiley 1986), it might be expected that the proportion of neo-natals would increase in the next few months. Gear selectivity does not account for the large increase in July: neo-natal *C. tilstoni* would be about 70 cm TL in July, whereas peak selectivity for 15 cm mesh-size gill-nets is at 99 cm TL (unpublished data). No significant annual or seasonal changes in the proportion of mature *C. sorrah* were detected.

T. tonggol and *S. commerson* length-frequencies were analysed for changes in mean length, by year, and by month within year. *T. tonggol* showed no obvious seasonal trend in length distribution and there appeared to be an increase of about 0.5 cm FL per year in mean length over the period of observations. However, no simple pattern adequately described this length increase and it may have no biological significance. The mean lengths of *S. commerson* decreased by about 2 cm FL per year between 1982–86, with this decrease becoming greater in the last few years. A seasonal effect was also evident, with a peak in mean lengths around September. This seasonal peak may be associated with the annual northward migrations of larger fish along the east coast of Queensland during September (McPherson 1981). Anecdotal information suggests that there is a similar annual 'run' of mackerel northwards along the coast of Western Australia. Over the period of the fishery, decreases in the mean length and proportion of mature *C. tilstoni* and *S. commerson* may be a result of over-exploitation. This is supported by the decline in CPUE in the Taiwanese fishery.

C. tilstoni and *C. sorrah* have similar life-histories (Stevens and Wiley 1986; Davenport and Stevens 1988), so their apparent difference in response to fishing pressure is interesting. Lyle and Griffin (1987) noted differences in the proportions of these two sharks caught by gill-net and longline. Lyle (1987) reported that during the Northern Pelagic Program *C. tilstoni* and *C. sorrah* comprised 57% and 20% of the gill-net catch, and 19% and 47% of the longline catch respectively. If *C. sorrah* is less susceptible to gill-netting, it may have been less affected by Taiwanese fishing pressure.

T. tonggol appears to have withstood Taiwanese fishing pressure better than *S. commerson*, although it was taken in larger quantities. Little is known about the stock size or structure of *T. tonggol* in the Australian region (Wilson 1981). Electrophoretic studies suggest there are two major stocks of *S. commerson* in Australia: one in eastern Australia and a second, wide-ranging, stock in southern Papua New Guinea, the Torres Strait, and across northern Australia (CSIRO Division of Fisheries Research [1984]).

The catches and catch rates of shark in the northern Australian fishery are highly variable between sets (Lyle and Timms 1984; Lyle 1987). Stevens and Wiley (1986) noted that both *C. tilstoni* and *C. sorrah* were found in groups of predominantly one sex or size range, sometimes with small spatial distributions.

As the research data used to investigate sex and size segregation in the present study were not collected for that purpose, interpretation is difficult. However, they suggest that the sex ratios and size composition of *C. tilstoni* catches by panel within a net, or between sets of a net that are made close together in space and time are usually consistent. However, there are significant differences in sex ratio and size composition between sets made in different areas or at different times. These data suggest that *C. tilstoni* occur in aggregations that may have an about equal sex ratio or may be composed predominantly of one sex, and that the fish within an aggregation are of similar size. Based on the size of the nets where the catch was recorded by 1 km panels, these aggregations of sharks may be at least 5–10 km across.

Sex and size segregation in *C. tilstoni* are not as marked as in some shark species. The proportions of the sexes ranged from about 50–80%, but 100% unisexual aggregations were not found in the present study or in Stevens and Wiley's (1986). While comparatively large differences in median lengths were evident between aggregations, there was rarely a complete absence of a major part of the size range from an aggregation. By contrast, some schools of mature *Squalus acanthias*, are composed almost entirely of one sex (Ketchen 1986). Some sharks show marked size segregation with areas occupied almost exclusively by one size group (Olsen 1954; Stevens 1976).

Sex and size segregation are common among elasmobranchs. They are thought to be associated with reduction of inter- and intra-species competition, or with reproduction or migration (Backus et al. 1956; Springer 1960, 1967; Strasburg 1958). It is difficult to relate the relatively weak sex and size segregation of *C. tilstoni* to any of these factors. All size ranges, including neo-natal,s occupy the same geographic range, so reduction of intra-species competition is unlikely. *C. tilstoni* does not appear to make regular seasonal migrations (unpublished data). Unequal sex ratios in a group are not necessarily found among the mature fish, and the data in the present study did not show any relationship between sex ratio and maturity of fish in a group. While the benefits of sex and size segregation in *C. tilstoni* groups may not be clear, the formation of groups may confer predatory advantages.

Examination of the effects of various environmental parameters and fishing strategies on catch variability confirmed the strong influence of light on catches, but was inconclusive in determining the effects of most of the other parameters recorded. The 1985 and 1986 gill-net modification experiments are not directly comparable, since they tested the effects upon catch of different gear configurations. Some apparent differences in the effects of environmental factors could in fact be seasonal: the 1985 experiment ran from September to November, the 1986 experiment in February and March. There could be a seasonal difference in the abundance of sharks both between experiments and within one experiment.

In both experiments many variables were correlated: for example, wind speed and sea swell, light availability and moon phase, wind direction and set direction. However, there are many missing values, and they are not consistent across sets or variables. The experiments were not designed to test the effects on the shark or fish catch of environmental variables, and it is quite possible that unrecorded factors influence the size of the catch.

It is nonetheless evident from both experiments that light is a significant factor in the size of shark and fish catches — more light means smaller catches. Presumably the net is more visible when there is more light. The other significant variable, wind direction, is interesting. In the 1985 experiment, the more easterly winds gave higher shark numbers, while in the 1986 experiment, more sharks were caught when winds were westerly. Since wind direction tends to be a 'grouped' factor (that is, there are clumps of similar wind directions in the data sets), it is possible that a seasonal relationship or another, unrecorded, variable related to wind direction or time had a bearing on the numbers of sharks caught.

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Appendix 1

Appendix 1 (a)
Number of Taiwanese gill-net sets monitored by observers in the AFZ.

	Year						
Month	1981	1982	1983	1984	1985	1986	n
Jan			15	7	4	4	30
Feb		12	8	5	16	6	47
Mar		18	12	2		2	34
Apr	4	10				6	20
May	5						5
Jun	8	15	5				28
Jul	2	16	3				21
Aug			6		13		19
Sep	4		6	23	14		47
Oct	16		9	38	19		82
Nov		21	5	5	3		34
Dec	12		6	3	1		22
Total	51	92	75	83	70	18	389

Appendix 1

Appendix 1 (b)
Number of Taiwanese gill-net sets monitored by observers in the western area.

	Year						
Month	1981	1982	1983	1984	1985	1986	n
Jan							0
Feb							0
Mar							0
Apr	3						3
May							0
Jun	3						3
Jul	2						2
Aug			3				3
Sep			6	23			29
Oct				38			38
Nov							0
Dec							0
Total	8	0	9	61	0	0	78

Appendix 1

Appendix 1 (c)
Number of Taiwanese gill-net sets monitored by observers in the Arafura area.

	Year						
Month	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**n**
Jan			12	7	3	3	25
Feb		7	4	5	11		27
Mar		18	12				30
Apr		10					10
May							
Jun		12					12
Jul		13	2				15
Aug			2		5		7
Sep	1				11		12
Oct	2						2
Nov		7	3	1	1		12
Dec				2			2
Total	**3**	**67**	**35**	**15**	**31**	**3**	**154**

Appendix 1

Appendix 1 (b)
Number of Taiwanese gill-net sets monitored by observers in the Wessels area.

	Year						
Month	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**n**
Jan						1	1
Feb		4			3	4	11
Mar				1			1
Apr						2	2
May	5						5
Jun	1						1
Jul							0
Aug					8		8
Sep	1				3		4
Oct	7		8		19		34
Nov		8	2	4	2		16
Dec	2		4		1		7
Total	**16**	**12**	**14**	**5**	**36**	**7**	**90**

Appendix 2

Appendix 2 (a)
Number of male *C. tilstoni* measured in each month and year from Taiwanese gill-net sets catches in the AFZ.

	Year						
Month	1981	1982	1983	1984	1985	1986	n
Jan		557	535	99	236	223	1,093
Feb		295	357	273	1,779	1,715	4,681
Mar		264	261	48		699	1,303
Apr	111					585	960
May	56						56
Jun	73	1,009	167				1,249
Jul.	7	467	125				599
Aug			559		787		1,346
Sep	92		279	1,201	1,075		2,647
Oct	962		467	717	2,890		5,036
Nov		784	195	16	459		1,454
Dec	594		227	147	92		1,060
Total	1,895	3,376	3,172	2,501	7,318	3,222	21,484

Appendix 2

Appendix 2 (b)
Number of *C. tilstoni* females.

	Year						
Month	1981	1982	1983	1984	1985	1986	n
Jan			283	58	309	301	951
Feb		458	175	363	2,434	1,162	4,592
Mar		427	780	97		773	2,077
Apr	18	310				588	916
May	94						94
Jun	159	898	137				1,194
Jul	22	394	136				552
Aug			605		827		1,432
Sep	156		435	1,562	861		3,014
Oct	1,440		1,125	897	4,407		7,869
Nov		939	434	26	602		2,001
Dec	894		497	69	201		1,661
Total	2,783	3426	4,607	3,072	9,641	2,824	26,353

Appendix 2

Appendix 2 (c)
Number of *C. sorrah* males.

			Year				
Month	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**n**
Jan			372	62	111	54	599
Feb		149	527	128	669	128	1,601
Mar		260	145	3		6	414
Apr	7	224				168	399
May	10						10
Jun	44	525	92				661
Jul	29	220	60				309
Aug			1		262		263
Sep	44		77	813	612		1,546
Oct	316		54	457	171		998
Nov		338	65	18	123		544
Dec	200		155	218	7		580
Total	**650**	**1,716**	**1548**	**1,699**	**1,955**	**356**	**7,924**

Appendix 2

Appendix 2 (d)
Number of *C. sorrah* females.

			Year				
Month	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**n**
Jan			296	95	240	177	808
Feb		282	418	296	629	125	1,750
Mar		440	867	9		13	1,329
Apr	2	344				92	438
May	13						13
Jun	30	447	35				512
Jul	47	206	51				304
Aug			3		362		365
Sep	75		29	406	747		1,257
Oct	251		74	447	364		1,136
Nov		189	33	21	206		449
Dec	122		103	51	14		290
Total	**540**	**1908**	**1909**	**1325**	**2,562**	**407**	**8,651**

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