Small fry or big fish on the North-West Shelf?

Most of the continental shelf around Australia is narrow and already largely exploited by Australian fishermen. But off our north-western coast, the shelf is wide, the water is productive, and few Australians apart from prawn fishermen have attempted to establish a fishery there.

The net in the background entrains a school of small mid water fish.

At the moment a fleet of Taiwanese vessels is exploiting the area. Taiwanese gill netters catch mid-water species such as shark, tuna, and Spanish mackerel, while the larger pair trawlers, mostly in the 350-tonnage class with a length of 30–40m, trawl for fish at or near the sea-bed. The fishery yielded an average of 53 500 tonnes annually for Taiwan between the years 1972 and 1978, the year preceding the declaration of the Australian Fishing Zone. This nearly matched the average fin fish catch — 59 500 tonnes — from all other Australian fisheries.

For the Taiwanese, access to the northern Australian fishing grounds is negotiated on an annual basis under a bilateral arrangement. This involves providing commercial access for them, and so far has not included Australian participation in the fishing and marketing operations. In the period 1984–85, Australia negotiated with Taiwan to set a quota of 27 500 tonnes per year for the whole northern demersal (bottom-dwelling) fishery. This will generate for Australia just over $1 million in licence and access fees. The Department of Primary Industry estimates this catch to have a gross value to the Taiwanese of $10–15 million.

Joint venture arrangements would involve a partnership between Australian and foreign organizations, generally using foreign boats and crew. Such agreements present a greater opportunity for phasing-in Australian operations in the catching, processing, marketing, and servicing sectors.

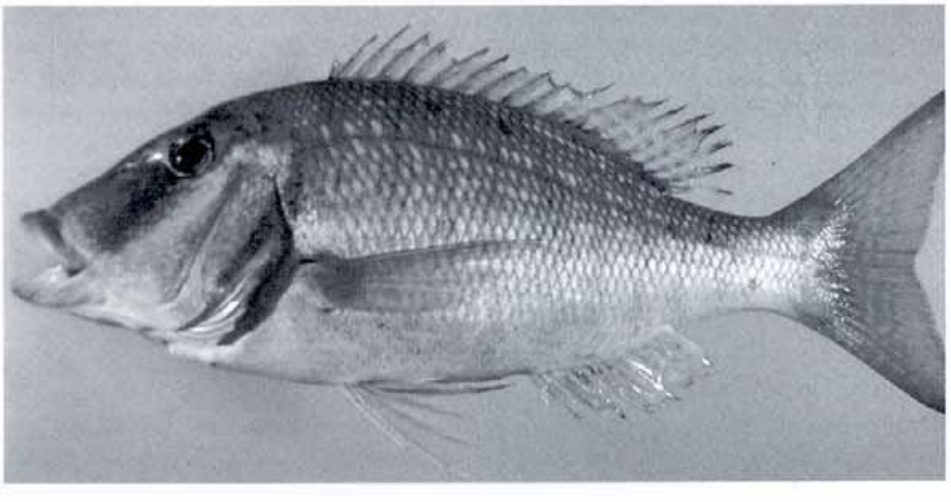
Australian involvement in the fishery as it stands would probably be export-oriented, since the fish currently harvested are mostly small and unfamiliar to Australians. But the North-West Shelf part of the fishery is a promising area for development, aiming at the Australian market since it supports a higher proportion of the larger, more highly valued fish species than most of the other continental shelf areas of northern Australia. Calculations suggest that at least 4000 tonnes of large fish could be taken annually from the North-West Shelf, but the extent to which careful management can alter the populations of species available to fishing is not known. Perhaps fishermen could catch even higher yields of large fish.

To investigate this potential and to obtain advice on optimum catch quotas and the best way of catching fish to maintain good yields, the CSIRO Division of Fisheries Research is examining the fishery resources and current industry on the North-West Shelf.

The *Soela* study

The Division began an intensive sampling study of the region in 1982. A series of 10 one-month-long cruises by the chartered CSIRO research vessel *Soela* collected data on water characteristics, the sediment and bottom environment, fish biology, and other information relevant to the fishery.

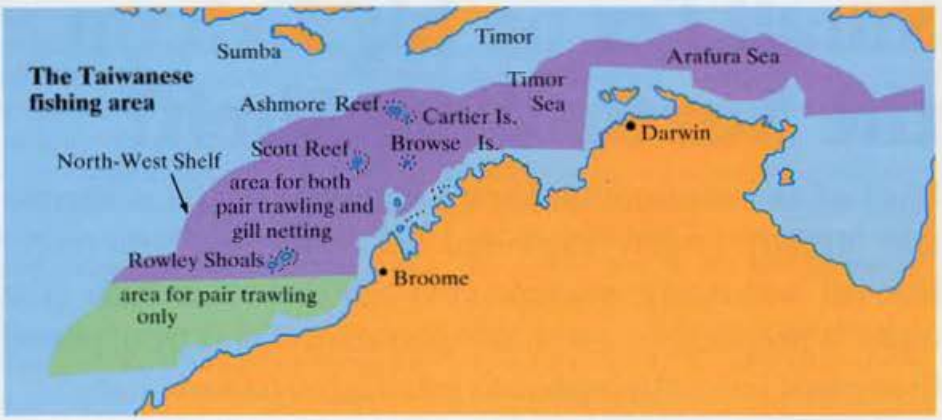
A scientific research team co-ordinated by Dr Peter Young examined chemical and physical properties of the water, plankton (the food of the young fish larvae), waterborne organic particles (another possible food source for young fish), the plants and small animals living in the bottom sediments, and the life cycles and diets of selected fishes.



One of the Shelf's hermaphroditic fish — the lesser-spangled emperor.

The bow of the *Soela* plunging through rough waters.

Information came not only from the research cruises, but also from commercial catch data and collaborative studies with other organizations such as the CSIRO Division of Oceanography and the Western Australian Department of Fisheries and Wildlife. The second phase of the program, which begins after a thorough analysis of the information already collected, will focus more fully on the fishery.



Foreign fishermen are permitted to operate in these areas off northern Australia.

As with all tropical ecosystems, a rich assemblage of species, including coral reef fauna, resides on the North-West Shelf. The CSIRO team made more than 400 trawl hauls following a random pattern to sample the 1000 or so species identified in the area. But of these, only a few hundred species are sought by fishermen and fewer still have a high commercial value.

The demersal fish that the CSIRO group studied in detail were thread-fin breams, emperors, snappers, trevallies, lizard fishes, goat fishes, sharks, and the single species known as the starry trigger fish. The scientists studied reproductive cycles and seasonal distribution of young fish of various species from each category.

One important finding was that many young fish live on the Shelf fishing grounds rather than in coastal nursery areas such as mangroves, and this pattern exposes them to trawling. Also significant was the observation that a number of species of fish undergo sex changes during their lives. This phenomenon, known as hermaphroditism (see the box), can have important implications for fishery management if an imbalance of the sexes results from selec-

Gender-bending in the ocean

To work out the growth rate of a population, scientists need to have data on the species' reproductive capacity. Often they assume that the species has a sex ratio of one to one. But on the North-West Shelf, as in other waters, particularly tropical ones, fish population statistics are sometimes confounded by sex inversion — a single individual spending part of its life as either male or female and later reversing its sex.

Sex inversion appears among a number of commercial fish species, including barramundi, coral trout, thread-fin bream, wrasse, parrot fish, tarwhine, snapper, yellow-fin bream, monocle bream, sweetlip, and emperor. It has a range of manifestations from simultaneous maleness and femaleness to protogynous hermaphroditism (female first, then male) and protandrous hermaphroditism (maleness followed by femaleness). The most frequently encountered form of sex inversion is a change from female to male.

In the past, size-related differences in sex ratio among fishes have been ascribed to different growth rates between the sexes. Dr Young and Mr Richard Martin, also of the Division, studied the seasonal cycle of reproduction in a number of hermaphroditic emperor and thread-fin bream species on the Shelf to determine how reproduction is related to the onset of sex inversion and size-related sex ratios.

Thread-fin bream are an important food fish of the North-West Shelf. The CSIRO researchers examined 13 species of this fish and found the size-related differences in sex ratio in two species were caused by protogynous sex inversion and not by male fish growing faster than females.

Among emperor species, the females also predominate at smaller sizes and males at larger sizes. Individual fish may change sex over a wide range of sizes, resulting in considerable overlap in the size distributions of male and female sections of a population.

An examination of specimens showed that the testes of males were typical secondary sex organs — they had a similar cross-sectional structure to the ovaries and contained brown bodies, which are remnants of specialized ovarian cells. Dr Young and Mr Martin also observed individuals with intersex gonads.

What triggers off the sex change in these fish? Studies on sex-inverting fish kept in laboratory tanks have revealed that the transformation can be socially controlled. When a male was removed from a tank, one or more of the remaining females changed sex, but only when the females were in spawning condition. This suggested that sex inversion may be controlled by a shortage of males when the population of females is in this condition.

But Dr Young has pointed out that in a natural environment the disappearance of a few males would go unrecognized by schooling non-territorial female fish, particularly during non-spawning periods.

Sex inversion poses a problem for fisheries management. Fishing operations take the larger fish and, when these are mainly of one sex, the ratio of the population can be thrown severely out of kilter; obviously this has implications for the population's reproductive potential. If sex reversal is socially controlled in the population, sufficient females may respond to the shortage of males by changing to keep the sexes in balance. If, however, sex reversal is a function of age — as has been described for species of snapper — the removal of males will not affect females and problems may arise.

Evidence for protogynous hermaphroditism in some lethrinid fishes. P.C. Young and R.B. Martin. *Journal of Fish Biology*, 1982, **21**, 475–84.

A sweetlip among coral.

A tagged coral trout.

tion for larger individuals, which are mostly of the same sex.

The North-West Shelf lies in a region transitional between tropical and subtropical influences. Although significant upwelling, which brings nutrient-rich water up to the surface, doesn't occur here, CSIRO data revealed the existence of seasonally repeated patterns of water movement, affecting nutrient availability.

Mr David Rochford and Mr Nick Bulleid, oceanographers with the Division of Fisheries Research and the Division of Oceanography respectively, identified intrusions of cold relatively nutrient-rich water that wash onto the Shelf each summer. These intrusions coincide with a seasonal increase in the abundance of larval fish in the plankton. Dr David Tranter studied the vertical differences in chlorophyll concentration and particle-size distribution in North-West Shelf waters and showed that the distribution of phytoplankton reflects the water movements.

The CSIRO also incorporated training courses for Australian Fishing Zone observers into the Shelf program. Since Australia's declaration of the Zone in 1979, the country has assumed responsibility for all foreign and local fisheries within 200 nautical miles of the coast. Under the present management program for the North-West Shelf, these observers board fishing vessels to check log books and sample and identify the catch.

Change in fish stocks

The North-West Shelf program is the first comprehensive examination of a tropical marine ecosystem, and its results are helping scientists understand how such ecosystems work.

Previous *Soela* studies in northern Australia have shown that the shallow coastal waters — less than 50 m deep — carry small species of scad, trevally, grunts, goat fish, silver biddies, sardines, anchovies, and leather jackets. These can occur in large quantities; catches of up to 2 tonnes per half hour were recorded.

In deeper waters over the muddy sands of the Arafura Sea, the main fish were hairtail, butterfish, thread-fin bream, lizard fish, goat fish, and species of snapper. Deeper bottom fish of the Timor Sea, which has large areas of hard bottom, included reef fish such as emperors, snappers, and sweetlip.

The most significant observations made by the CSIRO scientists concerned the adult fish stocks of the Shelf. Data collected by the *Soela* in 1982 show a dramatic decline in these stocks since 1966, the year the Japanese research vessel *Nagu Naru* collected samples in the same area. Both vessels had similar equipment — the difference in catch showed as a marked decline in the proportion by weight of the larger fish, notably emperors and snappers. The relative weights of other species such as lizard fish, thread-fin bream, starry trigger fish, and goat fishes have either remained constant or increased.

Dr Young and Dr Keith Sainsbury, also of the Division of Fisheries Research, are investigating whether the changes are largely caused by the fishery or by some other influence. The fishery could be altering populations directly through the removal of particular species. Alternatively, the effect could be an indirect one. For example, trawling equipment could be adversely affecting the habitat of bottom-dwelling fish. On the other hand, changed biological interactions (competition or predation) between species following trawling could be a major influence.

The Shelf has been trawled since 1935 when the Japanese began an experimental program in the area. They fished the area commercially between 1958 and 1963, and fishing stopped mainly because of marketing problems in Japan rather than stock depletion.

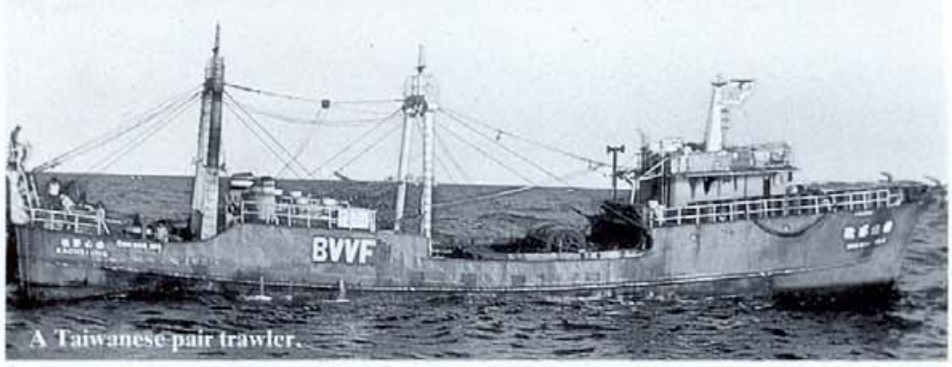
Sponges provide a good index of the amount of disturbance caused by trawling. These organisms live on the sea floor and get dredged up with the fish catch, becoming less numerous as an area is subjected to more intensive trawling. Japanese scientists on research cruises between 1962 and 1966 reported high fish catch rates on the North-West Shelf fishing ground, and noted that these occurred with large quantities of sponges — up to 2 tonnes per haul. The mid-Shelf region between Dampier and Port Hedland was particularly rich. However, the *Soela* found less than one-tenth of a tonne of sponges per haul there.

The CSIRO team is particularly interested in fish–habitat associations and, in the case of the sponge habitat, the final data would have to show a definite association between the two components before any conclusions could be drawn about the reasons for changes in fish numbers in this environment.

The Taiwanese fishery

The Taiwanese began trawling in tropical north-western Australian waters in 1971 with a fleet of 150- to 500-tonne pair trawlers. Their catch reached a peak in 1974, when more than 100 pair trawlers landed

A diver checks a mid-water trawl net.



A Taiwanese pair trawler.

about 84 000 tonnes of fish, half of which came from the North-West Shelf. In that year the total Australian fish catch was about 58 000 tonnes of fish.

Two years later the Taiwanese catch had dropped to 55 000 tonnes, to which the North-West Shelf contributed only 10 000 tonnes and the catch per unit fishing effort was about half the 1971–72 level.

Dr Rex Edwards of the Department of Primary Production in Darwin has evaluated the extent of the Taiwanese pair trawler fishery in northern Australian waters during the 1970s. He summarized information from statistics provided by the Institute of Oceanography at the National Taiwan University for the period and from log books given to the Department of Primary Industry in Canberra after the declaration of the Australian Fishing Zone.

For smaller trawlers, fishing trips from Taiwan take up to 120 days, with about 28 days spent travelling to and from the fishing grounds. The largest trawlers (of more than 500 tonnes) may spend up to 5 months in the fishing areas. The vessels trawl in daylight in most areas, but on the North-West Shelf some night trawling occurs. Each tow takes 3 hours, and during this time sweeps an area of 80 ha.

The trawlers work in pairs, with each vessel towing its own net. While one takes a turn at setting its net, the other vessel sorts its last catch.

The pair trawlers aim for relatively small fish from a range of breams, tropical snappers, trevallies, scads, butterfish, and others, weighing from 300 to 400 g. Butterfish and squid are especially preferred by the Taiwanese. Between November and April, vessels concentrate in the Arafura Sea, where these two species are more numerous than elsewhere. From May to October, the Taiwanese switch their efforts to the North-West Shelf, where stocks of the preferred fish are relatively high.

In all, the demersal trawl catch along the North-West Shelf consists of several hundred commercially valuable species and about a thousand others, which are caught incidentally to the main catch and usually discarded. The catch is graded into 30- to 40-kg cases and frozen without processing. In the Arafura Sea, up to 33% of the catch

Battered, fried, and judged

The *Soela* cruises gave researchers from a number of CSIRO Divisions their chance to 'test the waters' of the North-West Shelf. For example, officers from Division of Food Research laboratories in Sydney and Hobart have been studying two very important aspects of the area's catch — the spoilage characteristics and nutritional value of the fish.

Dr June Olley, Mr Allan Bremner, Ms Jo Statham, and Mr Stephen Sykes, of the Division's Tasmanian laboratories, looked at four Shelf fish — the thread-fin bream, the long-spined sea bream, the painted sweetlip, and a snapper-like fish — to assess their keeping qualities.

The fish, either frozen or packed in ice on board the boat, were sent by air freight to Hobart. There, after they had been steamed or deep-fried in batter, a panel scored them for odour and flavour characteristics.

The panel sampled cooked offerings prepared from fish that had been frozen or stored on ice for varying lengths of time. Characteristics noted included: off-odour and off-flavour (odour acceptability and flavour acceptability); wetness, firmness, and springiness when the cooked fish were first tasted; and, after several chews, the sample's toughness, succulence, and fibrousness.

Accompanied by salt, vinegar, tomato sauce, and, of course, fried chips, the taste sessions began with a course of crumbed and fried fillets. With true gustatory thoroughness, the panellists sniffed and chewed their way through the following few weeks and came up with a detailed record of the smell, taste, and texture of progressively older fish samples.

The panel declared that all four species were acceptable in flavour at first taste. The long-spined sea bream and the snapper-like fish gained the highest scores for acceptability and the painted sweetlip the lowest. But all the scores were relatively high and compared favourably with results obtained from similar panels for high-priced species such as scallops and trevally.

All the fish samples frozen on board gained higher scores than those that had been stored on ice. During iced storage for up to 23 days, obvious changes occurred in all four species, as indicated by the panel's sniffing of the raw whole fish and 'taste profiles' of the cooked fish. However, these changes only marginally decreased the acceptability ratings when fillets were presented deep-fried — batter and hot oil compensated well. Very little detectable change occurred in any of the species in their first 10 days in ice after catching.

At the Division's Sydney laboratories, Dr Tony Evans, Mr Alan Fogerty, and their colleagues are carrying out a very different assessment of fish flesh. They are looking at the fatty acid composition of the oils of some of the catch, particularly the so-called long-chain unsaturated fatty acids.

The acids being studied occur only in seafood. Marine phytoplankton synthesize them and then they pass along the food chain to fish.

Two of these fatty acids — one 20 carbon atoms long with 5 double bonds (that is, 20 : 5) and the other 22 carbon atoms long with 6 double bonds (22 : 6) — have attracted the attention of biochemists. In animals, they strongly influence the conversion of another fatty acid, arachidonic acid, to a group of powerful but poorly understood hormone-like substances — the prostaglandins, thromboxanes, prostacyclins, and leukotrienes.

These substances affect a number of functions — such as bleeding time, platelet aggregation, blood viscosity, and vascular spasm — that are all associated with coronary disorders.

One study involving Eskimos, who rely on fish products as their main source of nutrition, showed virtually no evidence of heart disease. Perhaps there may be more to a good dose of cod-liver oil than we thought.

Tropical species from the North-West Shelf of Australia: sensory assessment and acceptability of fish stored on ice. H.A. Bremner, J.A. Statham, and S.J. Sykes. *Proceedings of the Indo-Pacific Fisheries Council Workshop on Fish Technology and Marketing, Melbourne, October 1984.*

may be discarded. The discarded or 'trash' component of the catch has caused a number of problems in calculating the total catch per haul, since fishermen don't weigh what they throw away. Further, the species trashed differ between areas, seasons, and vessels, and even between pair vessels of a trawl pair.

Dr Edwards calculated the catch per unit effort of the Taiwanese fishery for the period 1972–79 by dividing the total catch by the number of declared hauls, with a correction factor for the variable rate of recovery of log books. The figures showed a decline, which might have been due to underestimation of the trash component or to heavy fishing in localized areas.

The information available on catches made by the Taiwanese before the implementation of the Australian Fishing Zone is very limited. Dr Edwards concluded that the quality of the catch statistics published in Taiwan for the North-West Shelf was difficult to assess. He noted many errors in catch composition and trawling effort data.

Species diversity

In the past, catch quotas for the northern trawl fishery have been set without consideration of the species making up the catch. Researchers have used a number of models based on single-species fisheries in the analysis of North-West Shelf fish stocks. Using one of the methods, Dr Sainsbury estimated the 'virgin state' biomass of the Shelf in 1973 to be about 232 000 tonnes, giving an annual yield of 58 000 tonnes. Applying another model he found an annual yield of only 23 000 tonnes.

As tropical fish live in small schools rather than the large aggregates of one or two species found in temperate areas, trawlers catch many species in a single trawl — despite attempts at 'targetting'. Unfortunately, operators can't identify all the species in a haul for their log books, so statistics are 'lumped' and represent groups of species. This creates problems for scientists attempting to apply models that relate intensity of fishing to changes in the size of fish stocks. These models have been designed for single-species fisheries and, as indicated, have dubious predictive value when applied to tropical fish stocks.

Classical fisheries theory was developed for simple temperate ecosystems such as the North Sea fishery where the industry seeks just a few, or even one, species. This approach ignores biological interactions between species — in complex communities, competition between species and predation are important controls of fish numbers.

A delicacy from the Shelf

Known variously as scampi, the Norway lobster, or langoustine, deep-water species of the crustacean family Nephrodiae are relished in Europe as a high-priced delicacy. In the early 1900s, the research vessel *Endeavour* first reported catches of scampi off Australia, but only recently has this shellfish been looked at as a potential industry for the country.

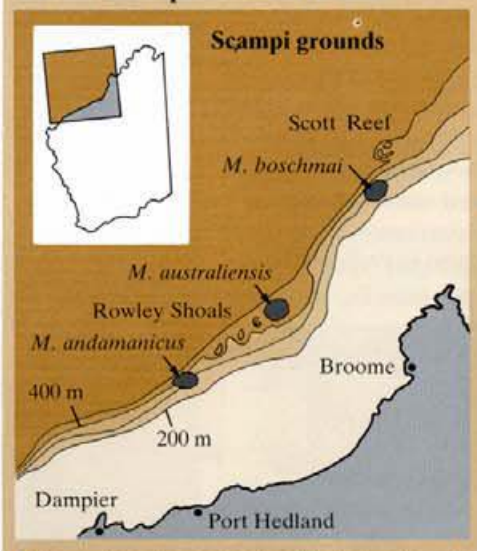
Research that CSIRO has conducted on the North-West Shelf gave the first indications that scampi resources existed there. After investigations by CSIRO's chartered research vessel, the *Soela*, the company KFV Fisheries (Qld) Pty Ltd decided to investigate the extent of the resource.

Using a 26-metre trawler, the *Courageous*, the KFV project team headed by Dr Garrey Maxwell, a fisheries consultant, carried out a direct fishing assessment of the commercial potential of scampi.

The results indicated that catch rates of up to 50 kg per hour can be achieved off north-western Australia. The survey concluded that an isolated fishery on the North-West Shelf for scampi species would be uneconomic unless the associated catch of prawns and other crustaceans could also be marketed.

Such an incidental fishery already exists off the eastern coast of South Africa. That country directs its langoustine catch to the high-value luxury end of the food market, exporting mainly to Switzerland and Canada.

Location of the three main scampi grounds, and the main species found in each.



Meanwhile, CSIRO has continued its research into the fishery and completed a survey of the whole north-western area as part of the *Soela* study. Dr Tim Davis and Dr Trevor Ward supervised the study, which was carried out in waters ranging from 300 to 500 metres depth. Their underwater photographs revealed that scampi live in a cold low-light environment of sandy mud, with a rippled surface often disturbed by animal holes, burrows, and tracks.

The CSIRO scientists found that the 2 hours either side of dusk and dawn appeared to be the best times for catching scampi and prawns. They also identified two new scampi grounds north of a spot called . Rowley Shoals, offshore from Broome. These two new grounds contain scampi at high densities, doubling the size of the potential fishery.

Any Australian scampi fishery will need to be managed carefully. The three main species on the North-West Shelf have a low reproductive capacity and live for about 5–6 years. Dr Davis has used theoretical mortality rates to predict a safe minimum annual catch level of 184 tonnes for the areas identified by his study. He emphasizes that this estimate is extremely conservative and that other scampi grounds probably exist on the Shelf.

CSIRO finds two new scampi grounds off the North-West Shelf. T.L.O. Davis and T.J. Ward. *Australian Fisheries*, 1984, **43**(8), 41–5.

'Cautious optimism' over potential for scampi fishery on NW Shelf. *Australian Fisheries*, 1983, **42**(11), 2–12.

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

Scampi from the North-West Shelf.

The dark world of the Shelf bed revealed by CSIRO's underwater TV camera.

Exploitation can alter the balance of interactions between species. Trawling itself modifies the habitat of demersal fish by disturbing the sea-bed. A more subtle influence is the selectiveness of the method — the equipment used in any one kind of trawling simultaneously harvests many species, but puts more pressure on some than others. Different fish groups have maximum sustainable yields at different intensities of fishing effort, and a fishing strategy that gets the best yield from one group may over- or under-fish other groups. Prediction of species mix is the weakest aspect of available fisheries management models.

For example, squid have become more abundant in the Arafura Sea and the Gulf of Thailand since fisheries began in each of these areas. This change may reflect changes in the composition of stocks, including a reduction of populations of squid predators as a direct result of fishing.

As part of his assessment of North-West Shelf stocks, Dr Sainsbury examined the responses to exploitation by each of the major fish groups. Thread-fin bream, trevallies, squid, and cuttlefish — groups targeted by the Taiwanese — all showed no signs of overfishing. From the commercial data, lizard fish appeared to be disappearing, but research data showed that the species was actually increasing. Dr Sainsbury suggested that commercial operators were discarding the species and not recording it in the catch.

Larger fish, particularly snappers and emperors, have not fared well with the development of the fishery — emperors have become progressively less abundant in the commercially fished areas. According to the earlier Japanese data, emperors originally constituted up to half of the total commercial catch on the Shelf. Now they make up only 10% of it.

But CSIRO's research data show that emperors are still abundant in the shallower, less-fished part of the Shelf. Such areas may be providing a refuge for the species.

Dr Sainsbury predicts that larger species will continue to decline under existing harvesting practices, which are designed to produce a high yield from the fish community as a whole. He believes that an indiscriminate multi-species trawl fishery will generally result in an increase of small species and a decrease in larger ones.

Future research

The main goal of the North-West Shelf study is to find what fishery management directions need to be followed to give Australia maximum benefit.

Phase one, described in this article, is the study of the ecology — including predation, competition, reproduction, and the habitat requirements — of fish species. This phase is leading to the development of a mathematical model of the Shelf's populations that will allow scientists to predict the likely outcome of different fishery management strategies.

The aim of the second phase is to determine the range of fisheries that are likely to be economically viable. Researchers will link the mathematical model to economic information on the costs and returns from different types of fishery; in particular they will examine the possibility of Australian involvement in catching and processing. The viability of each fishery option depends critically on the density and species mix available for exploitation.

Phase two will address the following questions.

- ▷ Using the ecological data, can scientists determine whether fisheries management will significantly alter the species mix and fish density?
- ▷ If so, what potential fisheries appear economically viable? Fishery options range from the present bilateral arrangement, through various forms of joint venture fishery, to a fully Australian fishery.
- ▷ Of the economically viable fisheries, which provide the greatest benefit to Australia?

Large-scale fishery experiments seem the best way for researchers to answer management questions that can't be reliably dealt with by existing ecological models.

Ideally, any new fishery should be evaluated through an experimental management plan, in which only a part (rather than the whole) of the resource is tested. Such a plan would enable fisheries scientists to properly assess the new fishery without placing the whole resource at risk. It would also minimize any disruption of the existing fishery, which may, after all, turn out to be the only viable one. But in any case, the testing of alternative fishery practices that include more Australian industry involvement requires a period of resource recovery — perhaps involving closing some areas to further exploitation.

Mary Lou Considine

A trawl-net releases 3½ tonnes of mixed North-West Shelf fish species.

More about the topic

Taiwanese fisheries in the north — monitoring and benefits for Australia. J.R. Branford. *Australian Fisheries*, 1984, **43**(2), 14–19.

The Taiwanese pair trawler fishery in tropical Australian waters. R.R.C. Edwards. *Fisheries Research*, 1983, **2**, 47–60.

The biological management of Australia's multi-species tropical demersal fisheries: a review of problems and some approaches. K. Sainsbury. *CSIRO Marine Laboratories Report* No. 147, 1982.

CSIRO defining fish stocks on NW Shelf. K.J. Sainsbury. *Australian Fisheries*, 1979, **38**(3), 4–12.

Optimal mesh size for tropical multi-species trawl fisheries. K.J. Sainsbury. *Journal du Coneil International pour l'Exploration de la Mer*, 1984, **41**, 129–39.