EFFECTS OF TRAWLING ON THE MARINE HABITAT ON THE NORTH WEST SHELF OF AUSTRALIA AND IMPLICATIONS FOR SUSTAINABLE FISHERIES MANAGEMENT

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Introduction

Fish resources may be used in a variety of ways. The policy challenge for management is to allocate these resources between competing uses when members of the community with rights of access wish to use them in incompatible ways. Making a management decision will involve compromise between optimising the community benefits from various users of these resources and minimising the detrimental effects resulting from each type of use, so as to maximise the chances of long-term sustainable use of the resources. For most fish resources, however, there is considerable uncertainty about both the dynamics of the resource and the effects on it of exploitation, both direct or indirect. Furthermore, there is the need to identify the linkages between the fish resources and the habitats which support and nourish them.

Threats to fish resources in the past have focused on the problems of overfishing, with management responses leading to constraints being placed on fishing operations, most notably through strategies to limit harvest rates. More recently however, there has been concern about the destruction of the habitats which are required to support many of our fish resources. Generally, this concern has focused on the effects of fishing itself on the marine habitat. An early reference to this problem appeared in 'Guide to the Fishmarket', written by Dr. Bellamy, a Cornishman, as long ago as 1842.

> "Fishing, taken generally, interferes in the slightest way with the habits of the creatures in question; but the employment of a trawl, during a long series of years, must assuredly act with the greatest prejudice towards them. Dragged along with force over considerable areas of marine bottom, it tears away, promiscuously, hosts of inferior beings there resident, besides bringing destruction on the multitudes of smaller fishes, the whole of which, be it observed, are the appointed diet of those edible species sought as human food. It also disturbs and drags forth the masses of deposited ova of various species. An interference with the economical arrangement of creation, of such magnitude and of such duration, will hereafter bring its fruits in a perceptible diminution of these articles of consumption for which we have so great necessity. The trawl is fast bringing ruin on numbers of poorer orders requiring the most considerable attention."

Today, sustainable utilisation of our marine resources has become a high priority. While the concerns about sustainability may not be new, the need to deal with them effectively has perhaps never been greater because of increasing demands placed on marine resources. Although management decisions are made in the knowledge of the 'best available scientific advice', individual decisions are often still demonstrated to be incorrect by the excessive depletion of some fish resources.

In this paper some of the issues concerning sustainable use of the marine fish resources through sustaining their habitat are illustrated. The paper is in three parts. The first identifies some of the problems facing managers of Australia's tropical marine fish resources, the second reviews the North West Shelf fishery and describes some of the changes to the ecological communities in this region, and the third describes both the research and the management approach taken in this region. While much of this has been described elsewhere (see Sainsbury 1987; 1988; 1991), the focus here will be on both the effects of trawling on the marine habitat and the relationship between this habitat and the fish species composition found on the North West Shelf.

Tropical multispecies fisheries

1. The management problem

It is widely recognized that fishing activities modify the structure and dynamics of ecological communities. For example, changes in the relative abundance of species in exploited communities are common (Hempel 1978; Cushing 1980). Furthermore, the decrease of a few species may be critical if these are the only ones catchable or marketable. On the other hand, widespread changes in community composition may be irrelevant if most species are catchable or have similar market value. Unfortunately the changes that happen to communities which include exploited species are not reliably predictable, and consequently the economic and social effects of such changes are also not reliably predictable. In most situations the dynamics of marine communities are poorly understood and reasons for the observed changes in an exploited community are hard to determine. Typically, ecological theory can be used to derive a number of different hypotheses about the mechanisms and dynamics of change that are all consistent with the observations of an exploited community. However, there is considerable uncertainty about the mechanisms which should be emphasized in a community model and there are also limitations imposed by the information available. Consequently, prediction of a marine community's response to changes in fishing activities resulting from management decisions can remain highly uncertain.

While much attention in the past has focused on the fisheries in temperate Australia, within the last decade the tropical fisheries of northern Australia have been receiving more attention. Unlike the fisheries in temperate waters, Australian tropical fisheries are normally characterised by a large number of species (generally several hundreds) in which commercial interest is usually shown in only a small portion. In addition to the monitoring difficulties caused by this high species diversity, the biology of most species is largely unknown and there are numerous interactions between the species themselves. While predator-prey relationships and competition for food resources will be important in determining the response of the community to exploitation, the actual role these interactions play in the dynamics of the community can, at most, only be guessed at. Finally, the fishing mortality is usually not equal for all species in the community and can be highly influenced by the targeting behaviour of the fishers. For example, some species are specific to a particular depth range and if this depth range is highly targeted by the fishing effort, the fishing mortality on these species can be high while it remains low on the more widespread species (Sainsbury 1982).

These features of tropical multispecies fisheries combine to increase the uncertainties in scientific advice to managers. A common approach to management under uncertainty is the 'certainty equivalent' approach in which a 'best model' of the resource is selected as the most likely of the available possible models and used to derive management actions that are then applied to the resource as a whole. Alternatively, consideration can be given to a number of alternative ecological interpretations of the available data, and the consequences of the possible management options can be evaluated across all these alternative models. With the 'certainty equivalent' approach the resource is managed as if the most likely available model is true; it ignores the uncertainties in understanding about resource dynamics and usually results in the whole resource being treated under the same management regime. This can increase the risk to the resource if an error is made, and future observations of the resource usually have little power to discriminate between different hypotheses about resource dynamics because possible control variables are confounded. Another approach is based on the methodology developed by Walters and Hilborn (1976; 1978) and Walters (1986) for management of resources with poorly known dynamics. This approach, often termed 'actively adaptive management', attempts to develop a 'reasoned empiricism' by managing the resource in a way which permits accelerated identification of the response of the resource to exploitation and provides guidance to the selection of long-term management options. In the following we discuss the application of this actively adaptive management approach to a tropical fish community off north-western Australia.

2. The North West Shelf—A case study

The character of Australia's tropical multispecies fisheries and the related management problems are well illustrated by the fishery located on Australia's North West Shelf region (Figure 1). The area supports a diverse and productive demersal fish community and has been fished mostly by foreign distant-water fleets (Sainsbury 1987).

Major commercial fishing first took place on the North West Shelf between 1959 and 1963 when Japanese stern trawlers targeted the large fish stocks of the genus *Lethrinus*. During the next three years, over seven thousand tonnes of this genus were caught with a catch rate around 500 kg/hour. Species of this single genus comprised about half of the catch. In 1972 Taiwanese pair trawlers began operations in the area. The fishing was initially very intensive with annual catches of between 20,000 and 30,000 tonnes for the first five years. The retained catch mostly comprised the genera *Nemipterus*, *Saurida*, *Lutjanus* and *Lethrinus*. In 1979 the area came within the Australian Fishing Zone and consequently under Australian management. While the Taiwanese continued to trawl under a licence arrangement with the Australian Government, a small domestic trap fishery began operation in the western part of the shelf in the early 1980's mainly in areas subjected to little trawling (Moran *et al.* 1988).

The Taiwanese continued to fish the North West Shelf until 1989, by which time a small domestic trawl operation had also become established. However, in this time several changes to the biotic community on the Shelf had taken place. First, a major change within the species composition of the fish catch was observed, although the total catch rate of the trawl fishery remained relatively constant. During the initial years the larger species groups, dominated by the genera *Lutjanus* and *Lethrinus*, accounted for 40% to 60% of the catch, while two other genera, *Nemipterus* and *Saurida*, together comprised around 10%. By the mid-1980's, however, this situation had reversed with *Lutjanus* and *Lethrinus* species comprising about 10% of the catch, and *Nemipterus* and *Saurida* around 25%. Secondly, the demersal habitat of the Shelf was also known to have altered during this period. The quantity of epibenthic fauna (mostly sponges, alcyonarians, and gorgonians) caught in trawls was observed to be considerably less than that recorded prior to and during the early development of the pair trawl fishery. Based on research data, the average catch rate of sponges fell from around 500 kg/hour to only a few kilograms/hour (Sainsbury 1987).

Changes in the relative species composition of catches on the North West Shelf was of little consequence to the Taiwanese pair trawl fishery, as all retained species had a similar commercial value (Liu and Lai 1980). However, the domestic Australian fishing operations have no market for *Nemipterus* and *Saurida*, and rely heavily on *Lethrinus* and *Lutjanus* species for commercial viability. With the introduction of Australian management after 1979, options for maximising the involvement of the domestic industry were considered, including trap fishing. Expansion of the trap fishery, however, seemed possible only if there was a return to something like the historical fish community composition. Furthermore, the poor state of knowledge about the resource dynamics made prediction of the resource's response to major alterations in the historical management regime highly uncertain. It was not clear whether or not the fish community could recover its earlier composition or what management actions would be best in attempting a recovery.

3a. CSIRO Study—1982–1983

A central management issue arising from the fish community changes observed on the North West Shelf (NWS) was the fact that while the species composition had initially been attractive commercially, the present day composition was not. Given this situation, three questions arose in response to the needs of management:

1) What caused these changes in species composition?
2) Is it worth trying to reverse the change?
3) If recovery is attempted, what management strategy should be followed?

Little was known about the fish communities on the NWS at this time and so the CSIRO Division of Fisheries undertook an intensive two year study during 1982 and 1983. As a result of this research a series of alternative hypotheses were developed to explain the observed change in community composition. These were:

i) environmentally-induced changes in the fish community, independent of the fishery;
ii) multiple, independent responses by the fish species to exploitation;
iii) alteration of biological interactions, such as predation and competition, due to fishing;
iv) indirect effects of fishing such as habitat alteration.

While the NWS is influenced by the oceanographic phenomenon known as the El Niño-Southern Oscillation, the precise nature of changes in the community dynamics on the Shelf in response to these events remains unknown and quantitative models based on hypothesis (i) could not be developed. Changes of type (ii) are possible and involve highly density-dependent population parameters (Sainsbury 1987) for which simple models could be developed. Ecological theory offers numerous possible mechanisms which could be used to generate simple models to test hypothesis (iii).

Less was known, however, about the relationship between the fish stocks and their habitat, notably the habitat provided by demersal epibenthic organisms. To examine habitat usage by the major fish types a 35 mm camera system with two illuminating strobes was fitted to the head rope of the trawl gear, and a colour photograph was taken every 24 seconds for the duration of each 30 minute trawl. From these photographs the major habitat types were identified, based on the presence or absence of large epibenthic organisms (> 25 cm along the major axis), and the association between fish and habitat was calculated. The results showed that, in general, *Lutjanus* and *Lethrinus* species occurred predominantly within those habitats which contained large epibenthic organisms, while *Nempiterus* and *Saurida* species favored the open sandy habitats. If these results are indicative of a dependence of certain fish species on certain habitat types, then alteration of the relative amount of each habitat in an area by trawling would alter the fish community composition in that area.

Either separately or together, hypotheses (ii), (iii) or (iv) are able to explain the changes in fish species composition observed on the NWS. However, each of these possible causes of change can have different management implications. If the management objective is to maximise the catch of *Lutjanus* and *Lethrinus* species, and the main cause of the current decline in these species is the loss of large epibenthic habitat (hypothesis iv) and/or trawl-induced changes in competitive/predation interactions (hypothesis iii), then there would be scope for expansion of the trap fishery to replace trawling with an expectation of recovery of the associated habitat and/or a return to the high carrying capacities of these species. On the other hand, if the historical decline in catches of *Lethrinus* and *Lutjanus* species is because these stocks have intrinsically low productivity (hypothesis ii), then the scope for expansion of domestic fisheries of any kind is limited.

3b. Experimental management scheme—1986–1991

To clarify the possible dynamics underlying the multispecies trawl fishery on the NWS, an experimental management scheme was introduced between 1986 and 1991. This scheme consisted of applying three different management regimes on three large areas of the NWS (Figure 1). This management approach is 'actively adaptive' because it includes taking management actions that intentionally try to increase the contrast between control variables. This approach improves identification of the key processes in the dynamics of the managed system. (A more complete description of the application of this approach to the NWS is given in Sainsbury 1991).

CSIRO Division of Fisheries monitored:

1) how the various fish species responded to the changed fishing regimes;
2) the recovery rate of habitats after trawling ceased; and
3) the effect of trawling on habitats.

The monitoring was based on a stratified sampling strategy with 105 randomly located thirty minute trawls undertaken during the same season each year. A photographic transect was conducted for each trawl to monitor the habitat (as discussed earlier). A video camera was used during some trawls to determine the effects of the trawl gear on epibenthic organisms.

Data from the western zone, which was closed to commercial trawling for the duration of the experiment (from Oct. 1985-Figure 1) shows that there was an increase in both the combined populations of *Lutjanus* and *Lethrinus* species (Figure 2a) and the abundance of both large and small epibenthic organisms (Figure 2b). Recovery of the small epibenthic organisms has been fairly rapid, but recovery of larger epibenthic organisms is much slower. This indicates that there will be a considerable time lag after trawling ceases before recovery of large epibenthic organisms is substantial. Within the zone in which commercial trawling continued throughout the experimental period (Figure 1), the opposite trends are observed. Except for the year 1990 (where the catch data are influenced by two very large catches within this zone), there was a steady decrease in the catch rates of *Lutjanus* and *Lethrinus* species (Figure 3a) and an associated decrease in the two sizes of epibenthic organisms (Figure 3b).

These results show a good correlation between the catch rate of the large commercial fish species and the abundance of epibenthic organisms. However, this does not necessarily imply an ecological association, as both the fish and epibenthic populations may be responding separately to the effects of trawling. To test for this possibility, the likelihoods of observing the experimental results described above under alternative models of the resource dynamics were calculated. Three of these models included a response by the fish populations based on changes in interspecific and intraspecific processes alone while a fourth alternative assumes that the carrying capacity of all groups of fish species is determined by the amount of suitable habitat, and habitat abundance is altered by the effects of trawling (for a full description of the models and necessary steps in calculating the likelihoods refer to Sainsbury 1991). Combining the historical catch and effort information with the research data collected on the NWS since 1982, the most likely model of the resource dynamics is that in which the abundance of the major fish groups is limited by the amount of suitable habitat available.

While the effects of trawling on epibenthic habitats may be inferred from the continued decline in such habitats in the areas trawled (and the recovery in the areas closed to trawling), direct video observations were made of the passage of the trawl gear over the sea bed. A video 8 camera was placed in an underwater housing and attached to the headline of the trawl gear. The camera was positioned so that it looked down and back towards the footrope. The field of view encompassed the ground gear and an area of around 3 to 4 metres both in front and behind.

The results of those video observations are given in Table 1 (a complete description and analysis of the observations will be published elsewhere). The fate of epibenthic organisms after impact with the trawl gear remained unknown in over half (52%) of the 393 observations. Where the fate on impact was known (188) epibenthic organisms remained intact in only 10% of the cases, with damage (detachment from the sea-bed) occurring in the other 90% of observations. Bounds on the probability of damage on impact with trawl gear can be calculated by making extreme assumptions about the observations when the fate was unknown. If all observations where the fate is unknown are included in the undamaged category then the probability of damage due to the passage of the trawl is 0.43, whereas if all unknown outcomes are considered to have resulted in damage then the probability of damage is 0.95. Of particular interest in assessing the effect of trawls on the epibenthos is the proportion of damaged items which are caught in the net compared to those that rolled under the net and so would not be caught and seen by ship-board observers. From the video observations only 10% of the damaged organisms were seen to be thrown up and into the net. Hence it would appear that the amount of benthos recovered in a trawl net is only a small component of the benthos that is damaged by the trawl ground gear. Absence of benthos in the recovered net does not necessarily imply that none was damaged

Discussion

The analysis carried out on the North West Shelf has proved very useful in guiding management actions despite the initial levels of uncertainty. Results to date indicate that the composition of the multispecies fish community on the NWS (and possibly other tropical areas of Northern Australia) is at least partially habitat dependent and that historical changes in relative abundance and species composition in this region are at least in part a result of the damage inflicted on the epibenthic habitat by the demersal trawling gear. Furthermore, continued alteration of the demersal habitat due to trawling will probably continue to alter the species composition with increasingly adverse effects on catches of *Lutjanus* and *Lethrinus* species. Recovery of the large epibenthic organisms in the areas which have been closed to trawling appears to be slow.

There appears to be considerable scope for using the 'adaptive' management approach in fisheries research to provide active feed-back between management action and empirical learning. New management measures can and should be introduced in ways that provide information which will guide the choice of long-term management actions. Such approaches can be expected to enhance management for sustainable resource use.

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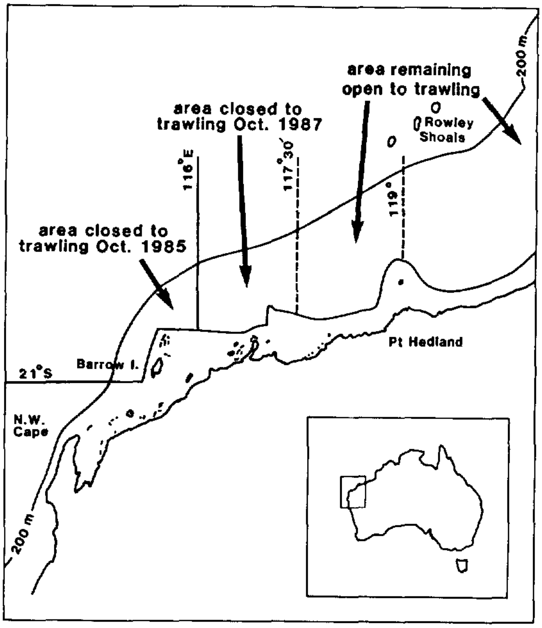

Figure 1. The area on the North West Shelf in which the CSIRO research was conducted. The zoning used during the experimental management between 1986 and 1991 is also shown.

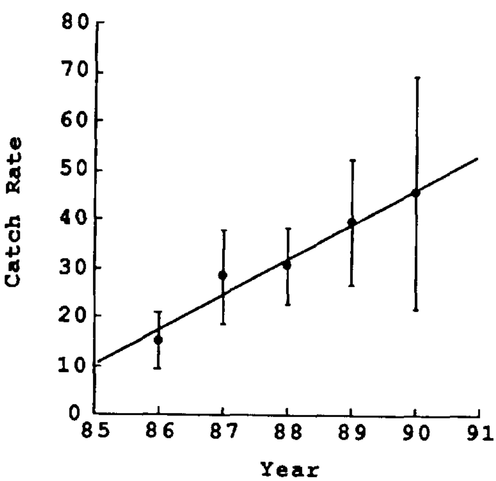

Figure 2a. Total catch rate of *Lethrinus* and *Lutjanus* (kg/30 min) in the zone closed to trawling in October 1985 based on the annual research data. Standard errors and line of best fit are also shown.

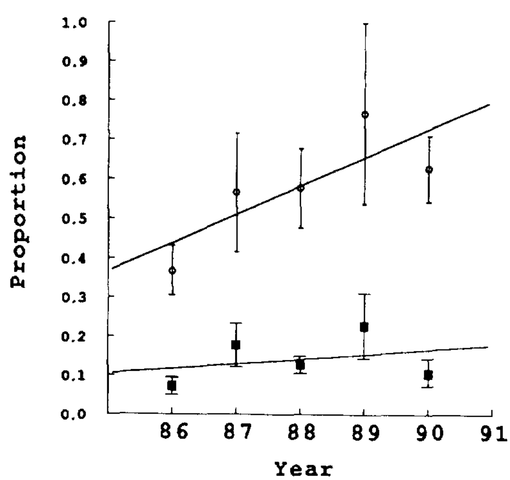

Figure 2b. Proportion of sea-bed with large (closed square) and small (open circle) benthos in the zone closed to trawling in October 1985 based on the annual research data. Standard errors and line of best fit are also shown.

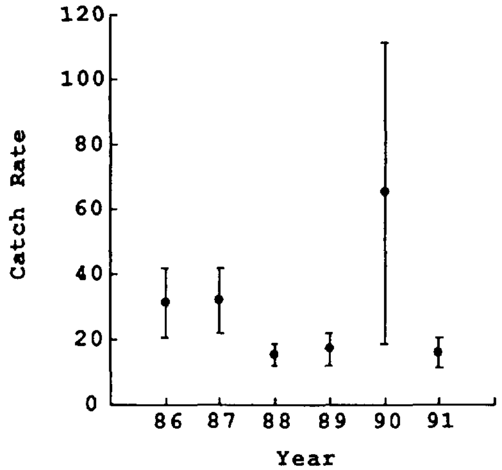

Figure 3a. Total catch rate of *Lethrinus* and *Lutjanus* (kg/30 min) in the zone left open to trawling based on the annual research data. Standard errors and lines of best fit are also shown.

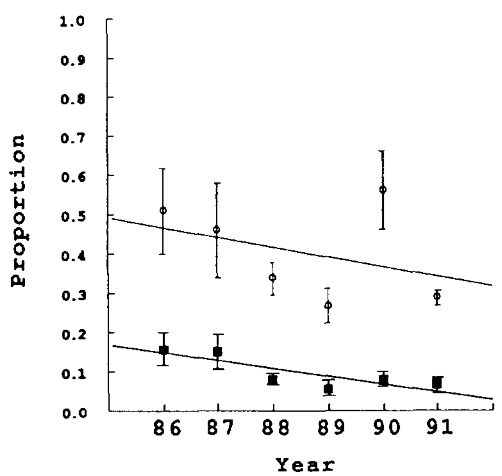

Figure 3b. Proportion of sea-bed with large (closed square) and small (open circle) benthos in the zone left open to trawling based on the annual research data. Standard errors and lines of best fit are also shown.

Table 1. Effects of demersal trawling on marine epibenthos

Observed effects due to the passage of the trawl ground gear on epibenthic items larger than the width of the ground gear itself (about 15 cm). These data are based on video observations taken of seven 30 minute demersal trawls.

Type of observation	*Number*	*Percent*
No observed effect	19	5
Broken and rolled under net	154	39
Broken and caught in net	15	4
Unknown	205	52
Total observations	393	100