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CASE STUDY 1: THE NORTHERN PRAWN FISHERY

Introduction by Neil Loneragan, CSIRO Division of Fisheries.

Geography of the Fishery

The Northern Prawn Fishery extends from the Kimberleys in W.A. to the Gulf of Carpentaria in Queensland, over about 6000 km of coastline between 10 S and 17 S (Fig. 1). The region is remote, with very little coastal development or conflicting resource use at present. The boundaries to the fishery are primarily political/jurisdictional rather than physical or ecological. This introduction to the fishery will concentrate on the Gulf of Carpentaria where most of the effort and catch is located. For example, in 1990, 78.3 % of the total effort, 86.5% of the tiger prawn catch and 46.3% of the banana prawn catch in the Northern Prawn Fishery came from the Gulf.

The Gulf of Carpentaria is a large shallow area of continental shelf, with water depths less than 70 m. Most of the fishing effort is located in depths shallower than 40 m. There are two quite different coastal sectors in the Gulf, corresponding to different catchment and drainage systems. The SE region is dominated by inflow from long rivers with large catchments and extensive flood plains. In the NW, an escarpment close to the coast means that there is much less runoff into the Gulf. The NE and SW regions of the Gulf have catchment characteristics which are intermediate between those of the SE and NW.

The area has a strongly seasonal, monsoonal climate, with pronounced wet and dry seasons. Approximately 90% of the rainfall occurs between December and April. This produces a strong seasonal cycle in salinity and vertical stratification in temperature and density in Gulf waters. The strong temperature stratification in October to February breaks down from March to July and then reforms in the following spring. The temperature ranges seasonally from 22 to 32 C. The seasonal cycle in chlorophyll a in the water column is correlated with rainfall, and is weaker offshore, where overall chlorophyll a levels are lower. Rainfall and runoff are greatest in the SE, followed by the NE (Weipa area) and then the NW.

Currents in the Gulf are dominated by tidal effects. Tidal residuals set up a net clockwise circulation in the Gulf, with limited exchange with seas to the north.

Prawn Biology

There are 9 common species of prawn in the region of the Northern Prawn Fishery, but commercial catches are dominated by the banana prawn *Penaeus merguiensis* and the tiger prawns *P. esculentus* and *P. semisulcatus*. To some extent, banana and tiger prawns are managed as separate fisheries. The life cycle of all three species is characterized by a juvenile inshore/estuarine stage and offshore adult and planktonic larval stages. Adults shed their eggs offshore, and larvae spend 2 to 4 weeks in the plankton, being advected to inshore nursery areas by the interplay of changes in vertical migration patterns in late larval stages and tidal currents. Larval diet also changes from yolk to phytoplankton to mixed phytoplankton and zooplankton as larvae develop. Juveniles spend 1 to 4 months inshore before leaving nursery areas to reproduce offshore, where they are subject to fishing. Individuals may reproduce at 6, 12 and 18 months of age.

The banana prawn (*P. merguiensis*) is widespread throughout the Indo-West Pacific region, and provides the largest yield of wild prawns in the world. In general, the adults are active and are fished during the day. Within the Gulf of Carpentaria, banana prawns are fished predominantly in the SE and the E, and the juvenile habitat consists of mangrove-lined creeks and estuaries. Over a ten year period, the mean annual catch of banana prawns was spatially correlated with the extent of inshore nursery habitat, with higher catches being taken from areas with longer, mangrove-lined creeks and rivers. There is strong interannual variation in the density of juveniles within their nursey habitats, and in the success of emigration from estuaries offshore. The latter appears to be strongly linked to rainfall. After moving offshore at about 4 months age, the juveniles form dense schools. Vessels target on schools, and spend much of their time searching for schools.

One species of tiger prawn, *P. esculentus*, is endemic to Northern Australia, while *P. semisulcatus* is widespread throughout Africa, India, Asia and the east and west coasts of Australia. The juvenile habitat of tiger prawns consists of seagrass beds, and the adults are fished in waters offshore from the seagrass nursey areas. Seagrass beds are restricted to a coastal strip less than 4 m in depth, primarily in the W, SW and NW of the Gulf. There is one isolated area of seagrass in the NE Gulf. Commercial effort and catches are also closely associated with seagrass beds. The spatial distribution of adults and sub-adults has been linked to depth and bottom type. High concentrations of sub-adults are found in shallow muddy waters, while adults are found in deeper waters. There is some separation of the two species according to adult habitat preference, with *P. semisulcatus* preferring deeper, more muddy habitat than *P. esculentus*. The adults do not form dense schools, and are active and are fished at night.

Predators of all 3 species have been identified and there are some suggestions that predation rates by fish are very high. Information has also been collected on the size, composition and bycatch of the fishery, and the impacts of the fishery on benthic fish and invertebrate communities and sea turtle populations.

The Fisheries

The banana and tiger prawn fisheries are quite distinct, because of the different behaviour patterns and recruitment dynamics of the target species. In 1982, the fishing effort on banana prawns occurred between February and July, with almost all of the effort concentrated in March and April (Fig. 2). The average banana prawn catch over the last decade has been about 4000 tonnes p.a., but has varied widely between years (Fig. 3). Increases in effective effort have meant that the time required to catch 90% of the total banana prawn catch has dropped from 200 to just 15 days. Very high catch rates are possible because of the schooling behaviour.

There has been a strong correlation between annual catch and rainfall over the relatively short history of the fishery, particularly in the SE Gulf. This correlation is emphasized by recent trends in catches from the SE sector landed in Karumba, where catches dropped for several years in succession coinciding with a decline in rainfall to a low of 30 tonnes in 1990, and recovered to 2000 tonnes in 1991, which was a high rainfall year. In some areas, a significant amount of variation in banana prawn catch is thus explained by the variation in an environmental variable. The banana prawn fishery is considered to be fully exploited, with the timing of fishing optimized to produce maximum dollar return per recruit on export markets.

In contrast to the banana prawn fishery, fishing effort on tiger prawns is distributed throughout the year (Fig. 2). The area fished for tiger prawns expanded from 1970 to 1982, when the last big expansion occurred. A considerable increase in tiger prawn catch associated with this exploitation of new fishing grounds occurred between 1976 and 1982. However, since 1982, few new grounds have been exploited, and there has been a marked decline in tiger prawn catches (Fig. 4). There is concern that a stock recruitment relationship may be important in the tiger prawn fishery, and that recruitment overfishing may have occurred. Unlike the banana prawn fishery, there is no evidence of strong interannual variation in catches of tiger prawns associated with environmental variables, except for the destruction of seagrass beds by cyclones.

An increase in production of prawns from mariculture in SE Asia (cultured prawns now constitute 30% of global markets) has led to declining prices for tiger prawns.

Management History

The objectives of management have been relatively simple, because of the remoteness of the area and few perceived resource conflicts. The banana prawn fishery has been managed to maximise the value of the catch, and more recently to increase net economic yield and profitability. Management strategies for banana prawns may not be as critical because of the apparent absence of a stock recruitment relationship over the observed population sizes. The tiger prawn fishery has been managed on the assumption that there is a stock recruitment relationship.

In 1977, attempts were made to limit access to the fishery, and 292 licences were issued. However, this led to an immediate increase in effective effort, because small vessels were replaced by larger vessels. By the mid-1980s, there had been a general decline in both catch (particularly of tiger prawns) and profitability, and a buy-back scheme was instituted to reduce effort. Because of concern over further declines in tiger prawn catches, further limitations were imposed in 1986, with reductions in season length, gear restrictions and increases in buy-back levies. Since 1986, catches of tiger prawns have stabilized. The original buy-back scheme has been replaced with a scheme which will guarantee a significant reduction in vessel numbers to approximately 120 by April 1, 1993.

Workshop Discussion.

It was agreed that the discussion would be generally restricted to the Gulf of Carpentaria fishery, as this was the location where we had most information, and that a reasonable time scale for thinking about management policy in relation to climate change was the next 100 years.

Management Objectives.

Attempts to agree on what should be the appropriate management objectives produced considerable debate, primarily over the breadth of the objectives appropriate to fisheries management. It was agreed that the historical objectives which had been to maximize the dollar value of the catch, and more recently to increase profitability, should be usefully expanded to include maintenance of the ecosystem which forms the basis of the fishery. It was noted that managers would then need to consider the possibility of resource conflicts, either in the short-term or the long-term. These included effects of coastal development, mining and tourism, and possible conflicts with traditional fisheries and newly developing fisheries (e.g. finfish).

There was also considerable discussion about the potential impacts of fishing on the marine environment, including harvesting of non-target species, disturbance to habitat, and indirect effects of harvesting via species interactions. It is not clear at present who has responsibility to monitor and manage impacts of the prawn fishery on the marine environment, where these do not affect the yield of the fishery.

Impacts of Climate Change on Habitat

The prawn fishery is supported by a number of key habitats, especially the inshore nursery habitats consisting of mangroves, estuaries and seagrasses. These habitats are strongly forced by a variety of climate-related parameters, including rainfall and runoff, and resulting patterns of salinity and stratification, water and air temperature, wind speed and direction as it affects circulation, and of course sea level. Larger scale climate patterns such as monsoons and ENSO may drive the local climate, while extreme events such as cyclones may be far more important than mean temperatures. For all of these parameters, it is likely that changes in the frequency and intensity of extreme events will be more important than changes in means. However, detecting changes in patterns of variation, especially variation at long time scales, will require effective long-term monitoring.

Impacts of Climate Change on Banana Prawns

In order to assess impacts in more detail, it was decided to use the prawn life cycle to identify key processes and components.

INSHORE JUVENILE PHASE.

The inshore juvenile phase is concentrated along a narrow strip at the mangrove-mud interface in tidal creeks and estuaries. Within these locations, the mangrove distribution is determined by the frequency of inundation by salt water. A characteristic time scale for colonisation and growth or recovery of mangrove forest in response to perturbation is probably about 10 to 20 years. Because of the local topography of the coastal plain in the SE Gulf, an increase in rainfall and sea-level associated with climate change is likely to increase the area of habitat for juvenile banana prawns. Severe cyclones can damage or destroy mangrove forests and an increase in cyclone frequency or intensity could adversely affect prawns.

Laboratory studies suggest that, on particularly hot days, temperatures of pools of water in tidal creeks and estuaries can exceed the upper tolerance limits for juvenile prawns. It is not known whether this is currently a significant source of mortality, as behavioural responses may allow prawns to avoid being trapped at high temperatures. However, the frequency of days on which this occurs is likely to rise significantly if mean temperatures increase by 3 C or more.

Current predictions about changes in the pattern and extent of rainfall do not suggest any deleterious effects on banana prawns. However, the timing of monsoon rainfall is critical for successful emigration of juveniles offshore for reproduction, and for recruitment to the fishery. The timing and strength of the monsoon already varies strongly from year to year, and shows marked correlation with the ENSO signal. If rainfall does increase, the increased runoff and turbidity could lead to greater emigration, and higher survival through decreased predation in turbid water.

OFFSHORE PHASES

Larval survival and inshore recruitment can be expected to depend on the effects of food and temperature on growth and mortality, levels of predation, and patterns of advection. Primary production in offshore areas is hypothesized to depend on nutrient input via runoff. Larvae may be dependent on phytoplankton blooms at critical feeding stages. There are very strong seasonal differences in survival of eggs through to recruitment as juveniles, which may be environmentally determined. Temperatures are likely to affect maximum growth rates of larvae, but we do not know enough to predict the interactive effects of changes in food and temperature. It is not clear whether changes in wind regime could affect the likelihood of advection to inshore areas. It is currently thought that interactions of vertical migration with tidal currents dominate transport.

The schooling behaviour of adults may be triggered by environmental cues but these are not well known. It has been postulated that dense schools stir up sediments and generate turbidity clouds which protect adults from predation. Changes in turbidity due to runoff or cyclones could change schooling behaviour or survival.

Impacts of Climate Change on Tiger Prawns

INSHORE JUVENILE PHASE.

Seagrass beds are critical to the survival of juvenile tiger prawns. Seagrass distribution and quality is affected by rainfall and salinity, sea level, turbidity, water temperature, and cyclone frequency. Seagrass beds are generally restricted to areas inshore of the 4 m depth contour, and this is thought to be due to light limitation in deeper water, and salinity effects. Seagrass species have a variety of reproductive modes, but generally have relatively poor dispersal capabilities. Monitoring of beds disturbed by cyclones six years ago suggests that recovery times can be much greater than six years, so that the distribution of seagrass at any one time may be a dynamic balance between infrequent gross disturbance and slow recovery. Studies of growth and dispersal of seagrass species in the Gulf suggest that seagrasses have a very limited capability for expansion and colonization into new areas. However, a variety of factors including increased cyclone frequency, increased turbidity and increased temperature could severely reduce their areal extent. Seagrass beds can probably adapt or respond to the relatively slow and limited changes in sea level predicted for the next 100 years, but their total area is unlikely to increase.

As tiger prawn habitats, seagrass beds can be classified according to their density and structural complexity. Both density and structural complexity are reduced by cyclone damage, and there may be a successional process involved in regaining complexity.

Direct effects of climate change on juvenile tiger prawns are rather less clear. Changes in temperature may affect prawn survival, although they may be able to avoid warm shallow water more easily on an open coastline. Increased turbidity could lead to decreased predation on prawns, but increased rainfall and decreased salinity could increase prawn mortality. Emigration of juvenile tiger prawns offshore appears to be size-dependent, but it is not clear whether they also respond to environmental cues such as salinity and temperature. There is still debate over whether there are one or two generations of tiger prawns per year. There appears to be a bimodal distribution of larval production, but one of these modes has very poor survival. An extensive data set covering six years from the NW Gulf is being analyzed to shed further light on the debate over the number of generations of tiger prawns per year.

OFFSHORE STAGES

The processes and questions involved in examining the possible effects of climate change on larval tiger prawns are similar to those outlined for banana prawns. One of the two annual egg production modes of tiger prawns has very low survival, but any environmental cause is not known. Tiger prawn larvae occur at higher temperatures and salinities than banana prawn larvae. It is not known whether this represents different tolerances and growth optima or is simply a reflection of the time and place of spawning. The mechanism for advection of tiger prawn larvae to their nursery habitat is likely to be the same as that for banana prawns, but more detailed knowledge of the time and place of adult spawning is required.

Adult tiger prawns do not school and are nocturnal. The nocturnal behaviour may serve to avoid predation, which is thought to be important for almost all stages. Adults have been shown to have strong depth-sediment preferences, and changes in climate and runoff could produce significant changes in the distribution of sediment types.

Summary of Ecological Analysis

Banana prawn stocks are characterized by extreme interannual variability, apparently driven by environmental variability. Impacts of climate change are likely to be seen as changes in the statistical pattern of high and low catches, possibly about a slowly changing mean. These will be very difficult to measure, and to attribute unambiguously to climate change. Tiger prawns show low interannual variability, and a possible stock recruitment relationship. If the stock recruitment relationship exists, it will be difficult to distinguish effects of fishing from environmental effects on stock dynamics.

For both banana and tiger prawns, climate change seems likely to exert its effect through changes in critical coastal habitats. In order to unambiguously detect climate change, let alone predict its effects, we need far better monitoring of coastal habitat, and a better understanding of the processes limiting habitat extent and quality. If we are to separate the direct effects of fishing from environmental effects, we will also need much better monitoring of the fishery and the stocks themselves.

Management Strategies.

The current management strategy includes regulation of the number of boats at a level designed to ensure profitability, and the optimisation of economic yield per recruit for banana prawns by controlling the opening date of the season. An additional seasonal closure is used to decrease effort during the tiger prawn spawning season. These measures are intended to permit a flexible response to changes in stock size and fleet behaviour.

At present, tiger prawns in the Gulf are managed as a single stock. A zonally-based management regime for tiger prawns might help to identify a stock-recruitment relationship, and to address some of the broader management issues (biodiversity, bycatch, species interactions, etc) referred to earlier. However, the stock structure of tiger prawns is unknown and enforcement of zonal closures in the Gulf could be difficult. These problems would need to be considered in determining the viability and value of a zonal management regime.

While conflicting resource uses are not obvious in this fishery, there have been concerns raised about bycatch and interactions with other potential fisheries. The development of a fin-fish fishery in the northern Gulf, although not planned to overlap spatially with the prawn fishery, could still raise questions about fish migration, life histories and ecological interactions. Managers and researchers need to find ways to address these issues. It is clear that most of the research effort has been focussed on inshore habitat which is probably most critical to prawn dynamics. Very little is known about changes in benthic habitat and associated ecosystems in offshore areas where prawn trawling takes place. Finally, the isolation of the Gulf means that multiple use of coastal zone resources has not been a major issue. Demographic shifts over periods as long as 50 to 100 years could change this, and create a need for coordinated coastal zone management policies.

Conclusions.

Long-term management of the prawn fishery, and the Gulf of Carpentaria coastal and marine resources, requires:

i) long-term baseline monitoring of key climate indicators and comparable oceanographic physical and chemical parameters;

ii) on-going long-term collection of fishery statistics, including by-catch, with adequate spatial resolution;

iii) monitoring of, and improved understanding of, the processes controlling critical habitat extent and quality;

iv) adequate protection of critical habitat, and an integrated plan for coastal zone management;

v) a better understanding of the temporal and spatial distribution of spawning in tiger prawns, to identify spawning periods and populations which effectively contribute to recruitment to the fishery.

Environmental monitoring will probably need to be carried out by a number of institutions and agencies, but this will only be effective if there is adequate coordination.

Figure Captions

Figure 1. Map showing the geographical limits of the Northern Prawn Fishery

Figure 2. Monthly effort (total days) for banana and tiger prawns in the Gulf of Carpentaria in 1982.

Figure 3. Total annual catches (tonnes) of banana prawns in the Northern Prawn Fishery between 1968 and 1990.

Figure 4. Total annual catch (tonnes) of tiger prawns in the Northern Prawn Fishery between 1968 and 1990.

Figure 1

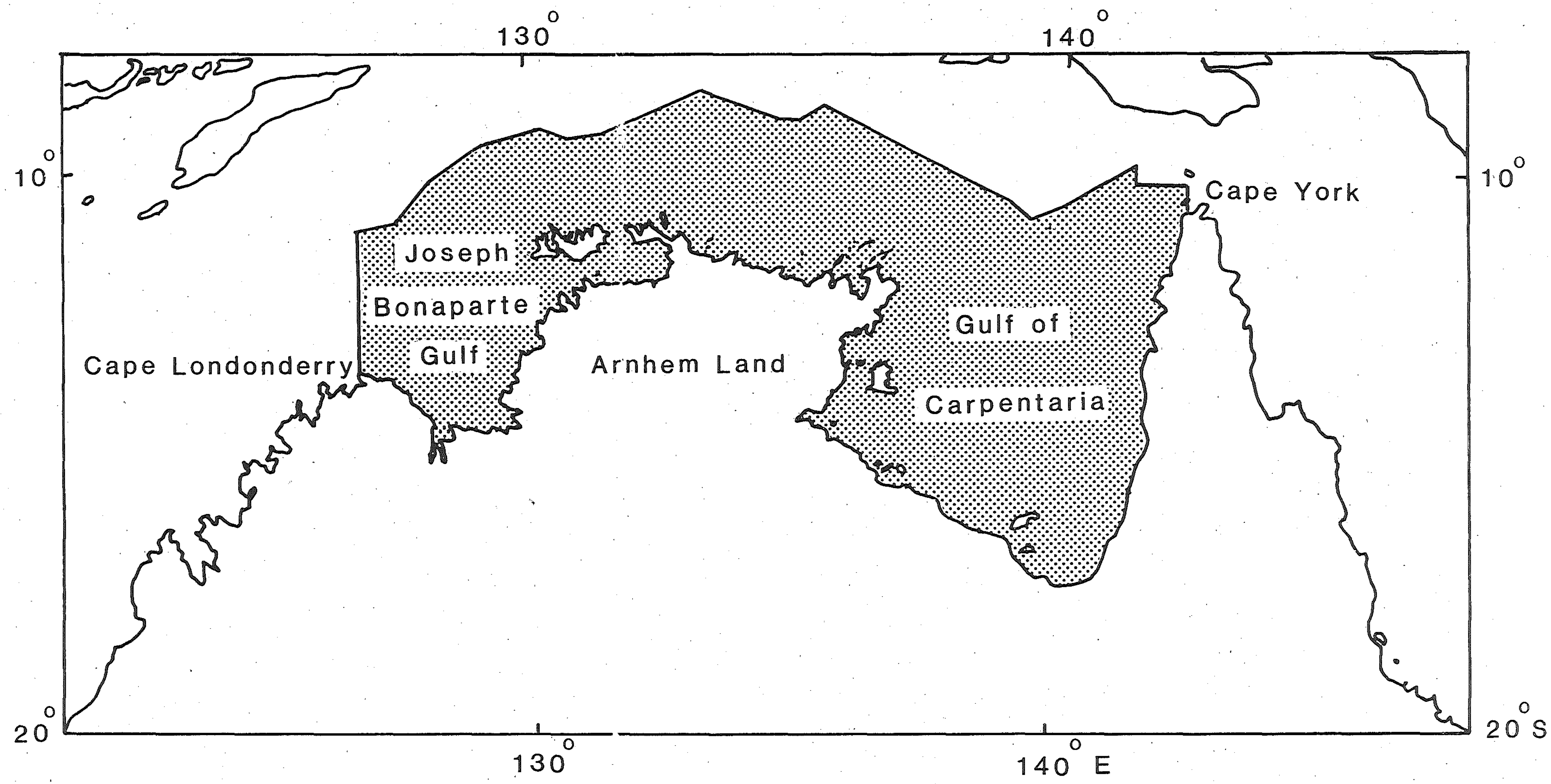
130°
140°
10°
10°
Cape York
Joseph
Bonaparte
Gulf
Cape Londonderry
Arnhem Land
Gulf of
Carpentaria
20°
20°S
130°
140° E

Figure 2

Monthly effort - Gulf of Carpentaria

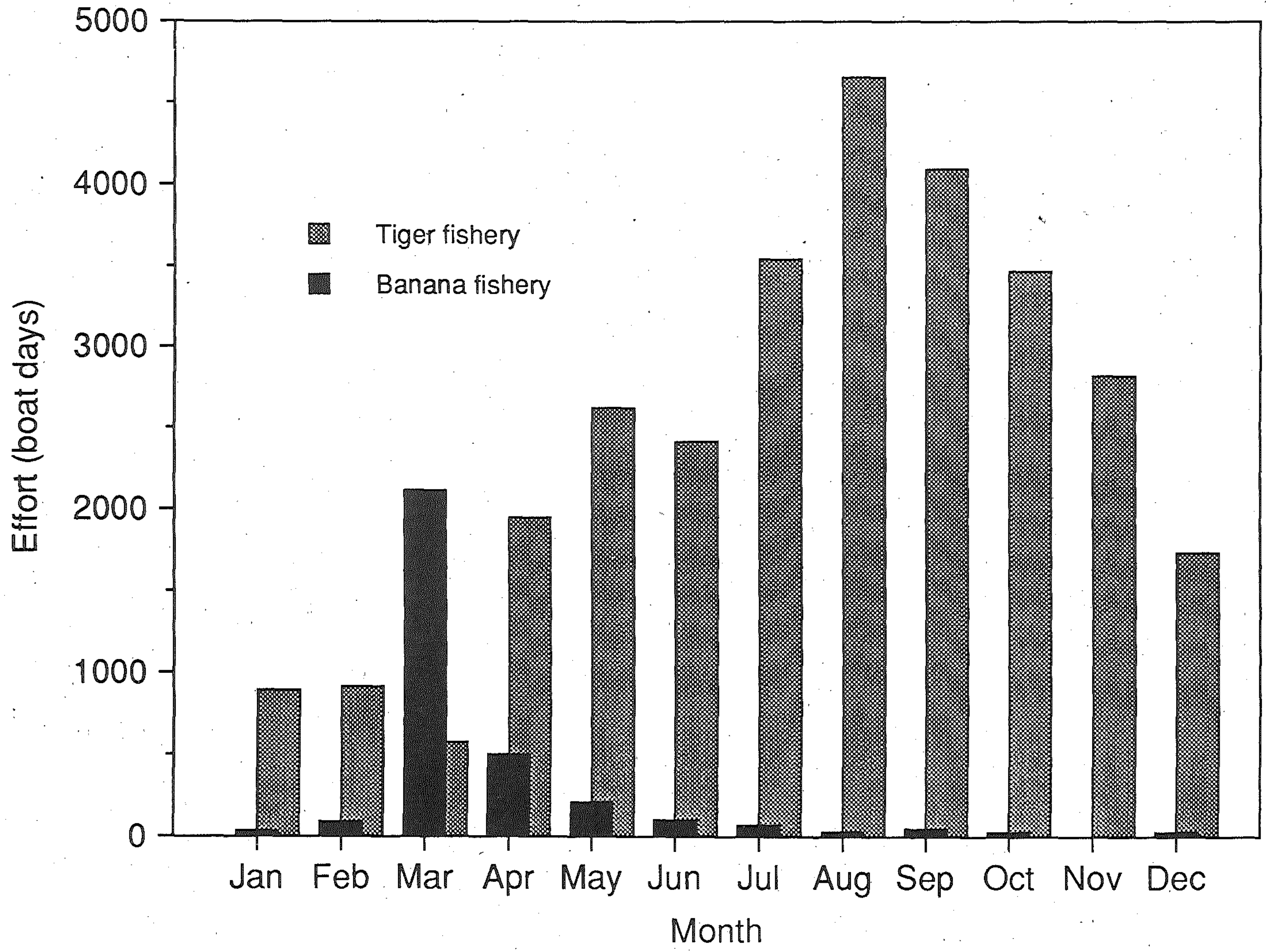

Figure 3

Annual Banana Prawn Catch - Northern Prawn Fishery

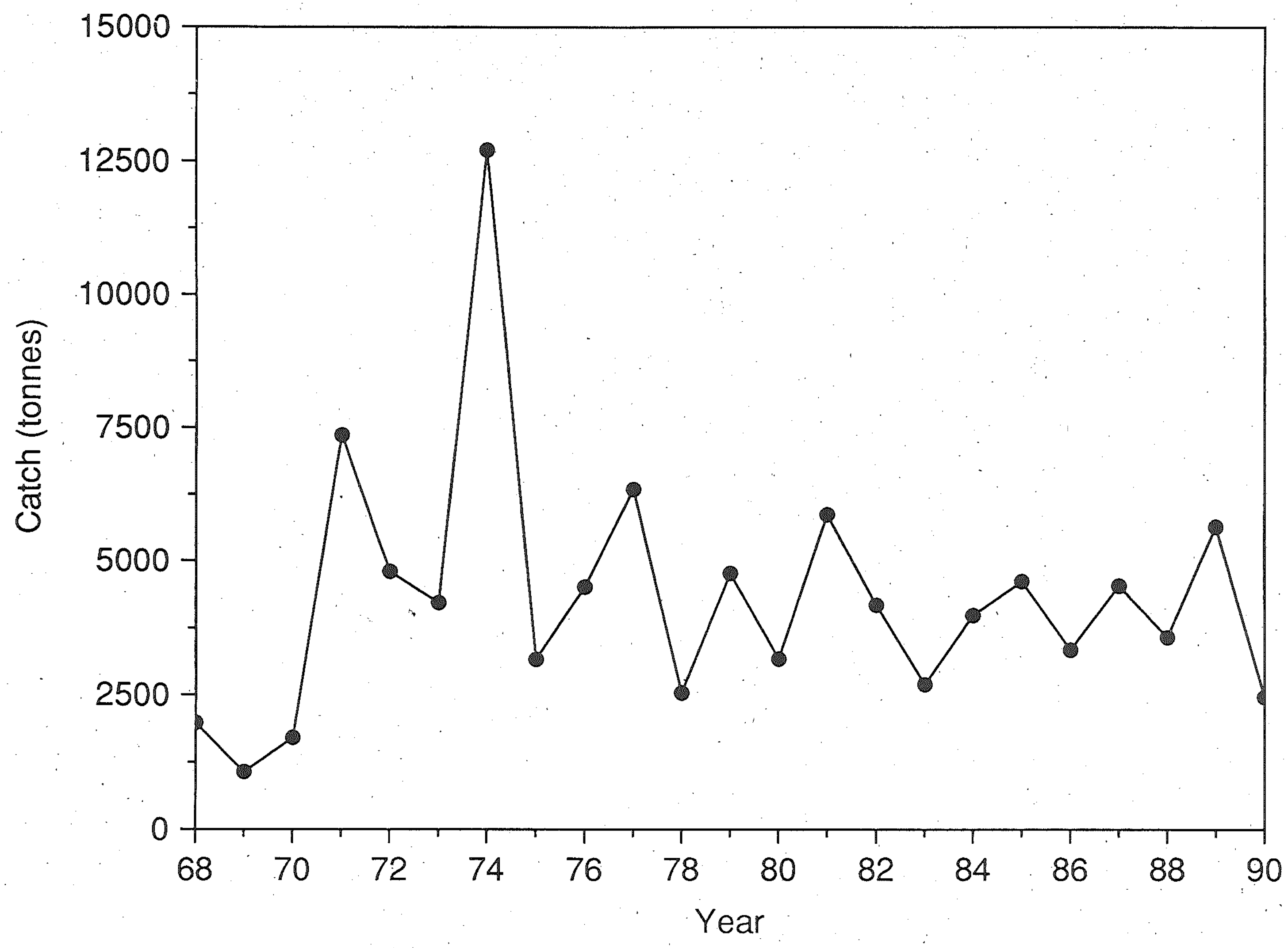

Figure 4

Annual Tiger Prawn catch - Northern Prawn Fishery