ASSESSMENT OF THE IMPACT OF ENVIRONMENTAL FACTORS AND NEW TECHNOLOGY ON THE NORTHERN PRAWN FISHERY

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OBJECTIVES

(i) To identify and quantify possible environmental factors that might explain the inter-annual variation in catches of the two species of tiger prawn in the NPF.

(ii) To estimate the impact that GPS and plotter units has had on the effectiveness of fishing effort in the NPF.

PREDICTED COMMENCEMENT AND COMPLETION DATE

Commencement date:	1 July 1994
Completion date:	30 June 1996

FRDC PROGRAM

Natural Fisheries Resources

Sub-Program: Management of Fisheries

SUMMARY

- No environmental factors were identified that explain the inter-annual variation in catches of the two species of tiger prawn throughout the Northern Prawn Fishery (NPF). There were, however, significant correlations between recruitment indices and environmental factors in some regions of the NPF for both species of tiger prawns.
- The GPS and plotter system increased the effectiveness of fishing effort in the NPF by 12% after three years of use.

RECOMMENDATIONS

- That a review of the fishing power of NPF vessels be conducted on a regular basis.
- That nominal effort continue to be adjusted by the rate of annual change in fishing power in all future stock assessments.
- That the assumed rate of increase in fishing power remain at 5% per annum.
- That further research is conducted on the environmental effects on tiger prawn recruitment by combining the effects of fishing effort in the analysis.

BACKGROUND

There has been a great deal of speculation in recent times about whether the tiger prawn stocks in the NPF were, and continue to be, overfished (Somers 1994). There are two problems in assessing if this is the case: (i) environmental factors may be affecting the productivity and availability of stocks; and (ii) the effort used in stock assessments may not be a correct measure of the effective effort expended in the fishery.

Extensive research has been conducted around the world focusing on the influence of environmental factors on fish stocks (Mendelssohn and Cury 1987; Walters and Collie 1988). There have been cases cited whereby environmental fluctuations have affected the availability and abundance of fish stocks, and consequently the catch (Loucks and Sutcliffe 1978; Morgan 1989). There is also evidence that the environment affects the stock-recruitment relationships of some Australian penaeid prawn stocks (Penn and Caputi 1985, 1996; Vance et al 1985).

One commonly used environmental variable in fisheries studies is sea surface temperature (Chen and Shelton 1996). There are two principal reasons for this: (i) temperature has been shown to have direct physiological effects on animals; and (ii) temperature is often a signal indicating ocean processes (Bakun and Parrish 1980). In this study I have used air temperature as an index of sea surface temperature. Data on the former are readily available, while data on the latter have not been routinely collected. Other commonly used environmental variables are rainfall and runoff. As with temperature, both rainfall and runoff show a strong correlation with the abundance of prawn stocks in some fisheries (Penn and Caputi 1985; Vance et al 1985).

The second problem, the correct measurement of effective effort, has also been extensively studied worldwide (Gulland 1956, 1969; Robson 1966; Taylor and Prochaska 1985; Baelde 1991; Brown et al. 1995). It remains a difficult problem to solve due to incomplete data sets, confounding factors and difficult models. In the NPF, Buckworth (1987) estimated that between 1979 and 1986 there was a 5% annual increase in fishing power due to increases in swept area brought about by increases in headrope length and engine power.

One of the most influential recent technological advances used by the NPF fleet, and subsequently one of the main causes of increases in effective fishing effort in the NPF, has been the introduction and use of Global Positioning Systems (GPS) and plotter systems. These electronic aids have changed the way NPF fishers search for and catch prawns.

This study attempts to discover relationships between environmental variables and tiger prawn recruitment in the Northern Prawn Fishery, and examine the effect of GPS and plotter systems on relative fishing power of the NPF fleet on tiger prawns. The information obtained here will be used in future stock assessments and will help achieve the objectives of the management plan for the NPF.

METHODS

(I) ENVIRONMENTAL FACTORS

Correlation analysis was used to determine possible relationships between tiger prawn recruitment indices and environmental factors. The NPF was divided into eight tiger prawn fishery regions: Weipa, Karumba, Mornington, Vanderlins, Groote, Gove, Arnhem and Melville (Fig.1). The years used in the analysis were 1970 to 1995. All years between 1970 and 1995 were used in the initial analysis. Subsequently, the data were divided into pre-1986 (1970 to 1985) and post-1986 (1986 to 1995) sets to account for changes considered to be due to the development of the fishery (the NPF was a developing fishery before the mid-1980s) and more precise logbook practices in the later years. When there were relatively few data points in a set of data the analysis was not conducted for that set. Recruitment indices for each year were matched with environmental factors for that and the previous year (example: 1985 catches with combinations of July 1984 to June 1985 environmental factors)

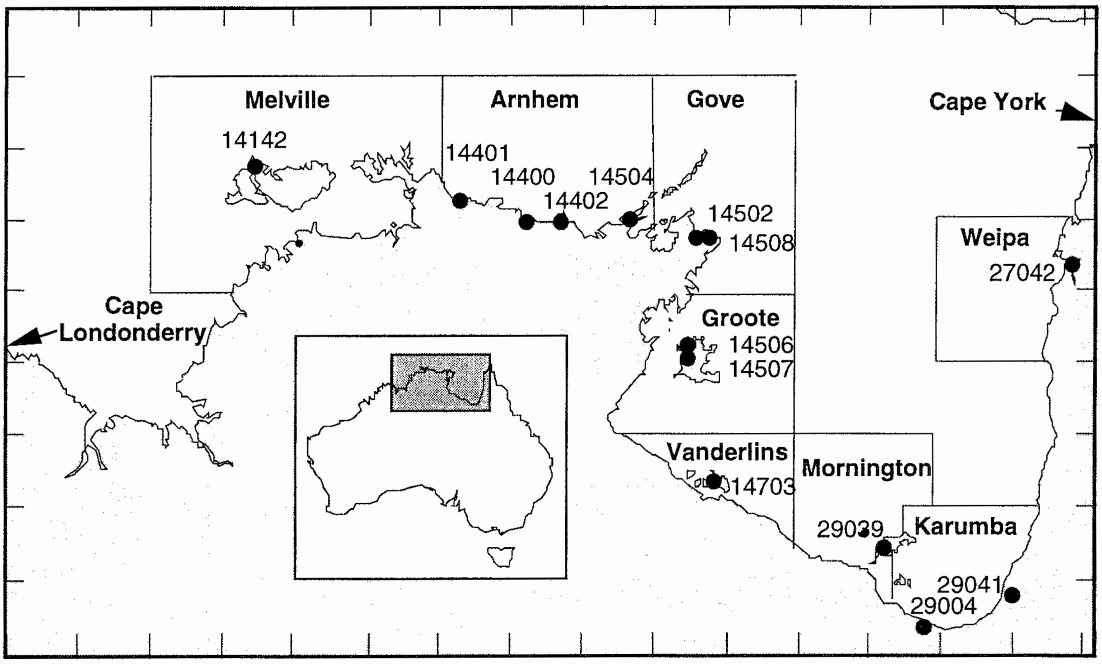

Figure 1 Map of the Northern Prawn Fishery with fishing regions and station numbers.

The recruitment indices were estimated from commercial fishery data collected from trawler logbooks and landings returns. The logbooks included each trawler's catch organised into species groups (banana prawn, tiger prawn, endeavour prawn and king prawn). The position (latitude and longitude) was also recorded for each day spent fishing. Landing returns collected from trawler owners and prawn processors were used to adjust the logbook entries to find the correct yearly landings for each trawler.

Logbook catch data for each species group was divided into the catch of each species. This is done using the proportions of species in each grid calculated from various CSIRO research projects and a joint industry/CSIRO project. Banana prawns included white banana prawns (*Penaeus merguiensis* - Pm) and red-legged banana prawns (*P. indicus* - Pi). Tiger prawns included brown tiger prawns (*P. esculentus* - Pe) and grooved tiger prawns (*P. semisulcatus* - Ps). Endeavour prawns included blue endeavour prawns (*Metapenaeus endeavouri* - Me) and red endeavour prawns (*M. ensis* - Mes). King prawns included blue-legged king prawns (*P. latisulcatus* - Pl) and red-spot king prawns (*P. longistylus* - Plo).

Recruitment indices chosen for each region were:

- 'cat-Ps' - catch of Ps (kg),
- 'cat-Pe' - catch of Pe (kg),
- 'tot-Ps' - catch of all species while targeting Ps (kg),
- 'tot-Pe' - catch of all species while targeting Pe (kg),
- 'nom-CPUE-Ps' - nominal catch per unit effort of Ps (kg/day),
- 'nom-CPUE-Pe' - nominal catch per unit effort of Pe (kg/day),
- 'eff-CPUE-Ps' - effective catch per unit effort of Ps (kg/day),
- 'eff-CPUE-Pe' - effective catch per unit effort of Pe (kg/day).

The recruitment index 'nom-CPUE-Ps' was calculated from the total catch of all species of prawns caught when the boat was fishing for grooved tiger prawns ('tot-Ps') divided by the nominal number of days spent targeting that species. A boat was defined as targeting Ps if:

(1) over half the total catch of prawns for that day were tiger, endeavour or king prawns, and

(2) more tiger prawns were landed than either endeavour or king prawns, and

(3) over half the tiger prawns caught were Ps.

The recruitment index 'eff-CPUE-Ps' used the catch described above. The effort term, however, was calculated using a 5% adjustment in nominal effort each year with 1993 taken as the standard year.

Similarly, for 'nom-CPUE-Pe' and 'eff-CPUE-Pe'.

Environmental factors were calculated from data collected by the Bureau of Meteorology, Melbourne. These were from land-based recording stations in northern Australia from which data is collected at different intervals: monthly, daily or every three hours. Each region used in this analysis has at least one daily weather recording station. Occasionally the recording station failed to collect the data and there are therefore several missing values in the data set used in the analysis. Positions and numbers of recording stations are presented on Fig. 1.

The environmental factor chosen for each region was:

- 'max-temp' - maximum temperature (°C).

The environmental factors chosen for each station were:

- 'tot-rain' - total rainfall (mm),
- 'NovDec-rain' - rainfall for November and December (mm),
- 'JanFeb-rain' - rainfall for January and February (mm),
- 'MarApr-rain' - rainfall for March and April (mm),
- 'NovJan-rain' - rainfall from November to January (mm),
- 'NovFeb-rain' - rainfall from November to February (mm),
- 'NovMar-rain' - rainfall from November to March (mm),
- 'NovApr-rain' - rainfall from November to April (mm).

(II) TECHNOLOGICAL CHANGE

This analysis is also based primarily on commercial fishery data collected from trawler logbooks and landings returns. The regions used in the environmental component of the study, mentioned above, are also used in this section.

Data from 1988 to 1992 were used as these years span the introduction and general adaptation of the GPS and plotter systems. During this period, the fishing seasons lasted from either April 1 or 15 to November 30, but the main tiger prawn season was from August 1 to November 30. Only the latter period was used in this analysis.

All trawlers in the NPF catch both banana and tiger prawns. The data set used, however, was the monthly catch per boat in the tiger prawn fishery for each region. This is the catch of all species of prawns when the boat is targeting tiger prawns. A boat was classified as fishing for tiger prawns if over half of the catch for that day were tiger, endeavour or king prawns. The data were not separated into species groups.

The analysis included vessel characteristics — boat length, headrope length of trawl gear and the presence or absence of GPS and plotter units — as well as the number of years a skipper had worked with plotters. The vessel characteristics were recorded when the trawlers first entered the NPF and updated when necessary. Gear records were collected every year. The years that GPS and plotters were first installed in each trawler were obtained from Vessel Inspection Reports collected by Fisheries Patrol officers at the start of each season; a ships chandlery (Taylor Marine in Cairns); and during interviews with trawler owners and skippers.

Interviews were held with 32 paid skippers, 6 owner-skippers and 14 owners or company personnel. They provided background information on the use of the GPS and plotter systems and described how they used the system. Fishers were also asked to estimate how much its installation increased their efficiency of fishing.

The number of years the boat's skipper had worked with a plotter (skipper experience) was derived from skipper lists linked with GPS-plotter lists. From these data, each boat that fished each year was placed into one of the GPS categories:

1. no GPS and no plotter and therefore no skipper experience,
2. GPS but no plotter and therefore no skipper experience,
3. GPS and plotter on-board and the first year the skipper has used a plotter,
4. GPS and plotter on-board and the second year the skipper has used a plotter,
5. GPS and plotter on-board and the skipper has three or more years experience with a plotter.

The statistical model used for this analysis was derived in Robins, Die and Wang (submitted - Appendix 2). The statistical model used was:

$$\log(c_{ijkt}) = \alpha + \alpha_1 \log(g_{i.k.}) + \alpha_2 \log(l_i) + \beta(X_{i.k.}) + \delta \log(E_{ijkt}) + \log(h(N_{.jkt})) + \varepsilon_{ijkt}$$

where c_{ijkt} denotes the catch of the ith boat, in area j, during year k and month t; α is the intercept; α_1 is the gear effect and $g_{i.k.}$ is the total headrope length of gear being used; α_2 is the boat length effect and l_i is the length of the boat; $\beta(X_{i.k.})$is the effect of the GPS category and $X_{i.k.}$ is the GPS category for that boat; E_{ijkt} is fishing effort and δ generalises the fishing mortality function; $h(N)$ is an unknown abundance function expressed by year, area and month and their interactions; and ε_{ijkt} is the error term.

This model compares catches of boats of differing characteristics (headrope length, boat length, GPS category) fishing in the same area during the same year and month. It was assumed that any factor which had an impact on fishing power is covered by these boat characteristics. The GPS category used in this model includes whether a boat has a GPS and/or a plotter and also the length of time a skipper has been using a plotter.

It was fitted by PROC GLM in SAS. The resulting parameter estimates were used in the calculation of the increase in fishing power due to GPS and plotter units in the whole NPF fleet each year:

$$I_k = \sum_{s=0}^{5} \beta_s g_{sk}$$

where I_k is the average increase in fishing power due to the introduction of GPS and plotter units in the NPF; β_s is the effect of GPS category s; and g_{sk} is the proportion of boats in each category during year k.

RESULTS

(I) ENVIRONMENTAL FACTORS

The northern parts of Australia experience distinct wet and dry seasons, in summer (October to March) and winter (April to September), respectively. During the wet season the salinity of the ocean is reduced, air temperature is high and air pressure is low. Conversely, during the dry season ocean salinity increases, air temperature drops and air pressure rises (Fig. 2). Generally, winds are from a north-easterly direction during the wet season, and are south-westerly during the dry.

Each tiger prawn fishing region follows the general trends outlined above. Catches of both tiger and banana prawns varied between regions each year and also within regions between years.

Significant correlations (5% significance) between recruitment indices and environmental factors for each region and each station within regions are in Appendix 1. Environmental factors and recruitment indices, their correlation coefficients, associated probabilities, and the number of observations are given.

WEIPA

The Weipa region has a weather recording station at Weipa airport (27042). As in the rest of the Gulf, the regional climate is dominated by the wet season in summer and the dry in winter. The rainfall recorded at this station ranged from 1422 mm to 2582 mm with an average of 1919 mm since 1970. There have been no dramatic climatic changes during the last 10 years, average rainfall has remained similar to the 26 year average. The air temperature has reached an average maximum of 33.03°C.

Weipa and the surrounding region contain both banana and tiger prawn fishing grounds. The area has produced white banana prawns with an average of about 860 t/year since 1970 and 730 t/year since 1986. The region has always produced significant quantities of grooved tiger prawns (155 t/year on average since 1970 and 130 t/year on average since 1986) and some red endeavour prawns. Smaller numbers of brown tiger prawns, blue endeavour prawns and blue-legged king prawns have also been caught. Landings further south (to Cape Keerweer) have been dominated by white banana prawns.

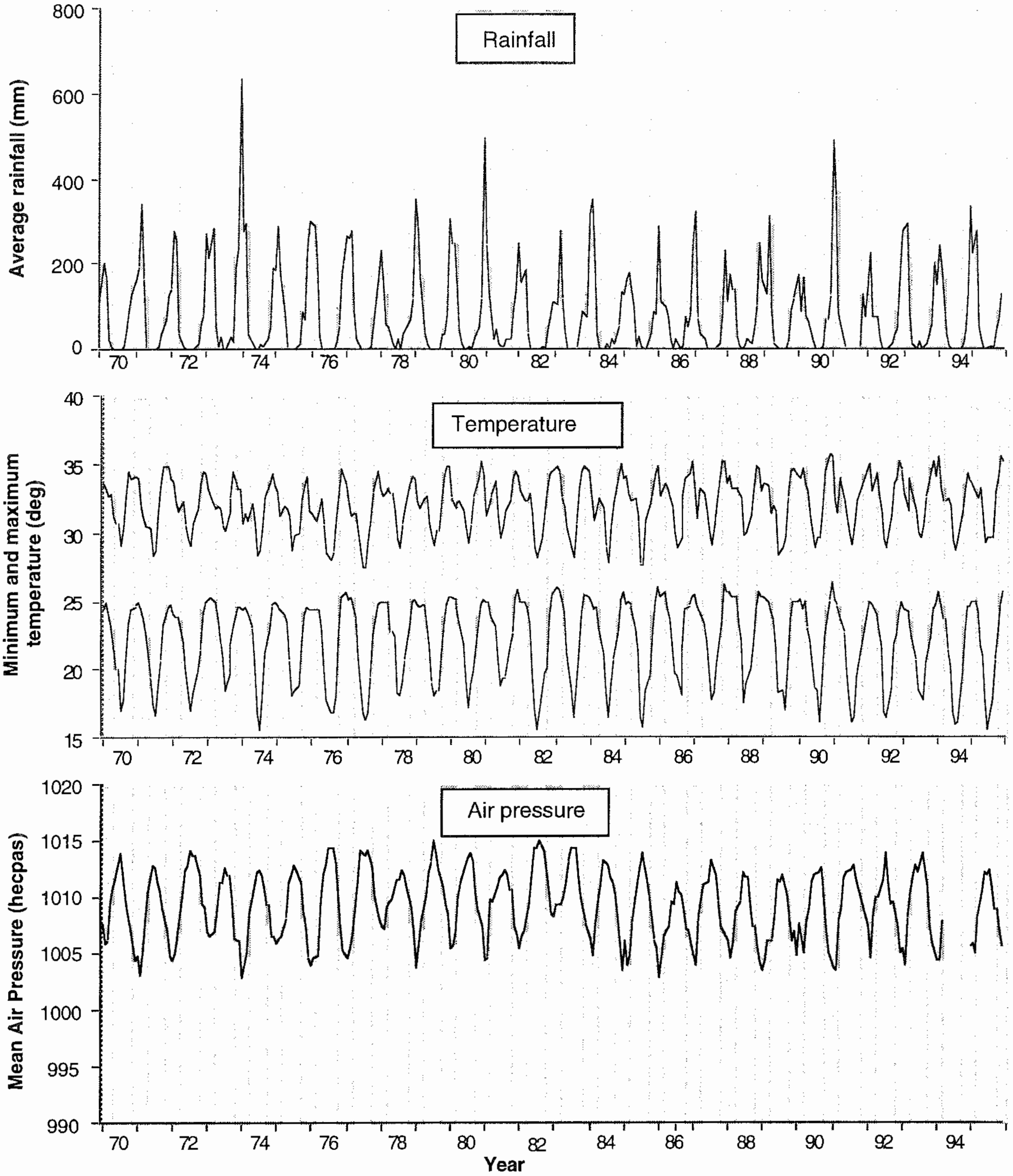

Figure 2 Average rainfall, minimum and maximum temperature and mean air pressure from all stations considered in the NPF from 1970 to 1995. Shaded areas represent the dry season.

Grooved tiger prawn fishery catch over the last 10 years (1986 to 1995) has ranged from 10 t to 540 t, with an average of 210 t/year. CPUE has tended to remain relatively steady around 200 kg/day with an increase in 1995 to 500 kg/day. Catches of brown tiger prawns in this region have been low.

There were significant correlations in the grooved tiger prawn fishery between 'nom-CPUE-Ps' and 'eff-CPUE-Ps' with 'max-temp' using post-1986 data. Correlations were also significant between these two recruitment indices and 'NovJan-rain' when all years and pre-1986 years were analysed. All other combinations of indices and factors were not significant. Post-1986 years had a significant correlation between 'tot-Ps' and 'MarApr-rain'. Brown tiger prawn indices were not tested due to the low effort expended targeting this species and subsequently low numbers being caught (App. 1 (A)).

KARUMBA

The Karumba region has two recording stations (Normanton Post Office - 29041 and Burketown Post Office - 29004). The rainfall recorded at 29041 ranged from 493 mm in 1983 and 1988 to 2141 mm in 1974. The average yearly rainfall has been 885 mm since 1970. The other station (29004) recorded an average of 805 mm per year and ranged from 412 mm in 1988 to 1852 mm in 1974. There are no total rainfall figures between 1976 and 1981. The air temperature reached an average of 37.09°C.

Karumba contains both banana and tiger prawn fishing grounds, but generally has produced more of the former. The average white banana prawn catch per year was about 900 t with a maximum catch of 3854 t in 1974. The region has been producing significant quantities of brown tiger prawns since the late-70s (935 t/year on average since 1986) and small quantities of blue endeavour prawns.

Brown tiger prawn fishery catch over the last 10 years ranged from 288 t in 1987 to 1169 t in 1995 with an average of 490 t/year. CPUE fluctuated between 48 and 707 kg/day in the very early years (1970s), then gradually fell from 262 kg/day in 1980 to 189 kg/day in 1989, in the early-90s it has tended to remain relatively steady around 300 kg/day, but rose dramatically to 457 kg/day in 1995. There were small catches of grooved tiger prawns in this region.

No significant correlations were found for any of the three groups of data in the brown tiger prawn fishery for station 29041. Data from station 29004 using post-86 data, however, exhibited strong significant correlations between the CPUE recruitment indices and five different combinations of the monthly rainfall totals. Grooved tiger prawn indices were not tested (App. 1 (B)).

The Groote region has been an important producer of tiger prawns, with smaller numbers of banana and endeavour prawns being landed. In recent years the main species caught has been grooved tiger prawns (average of 644 t/year from 1986 to 1995). The average catch of brown tiger prawns during the last 10 years was 294 t/year.

Very high grooved tiger prawn fishery catches were recorded in the early 1980s, but have since decreased to an average of about 800 t/year since 1986. CPUE has fluctuated around 200 kg/day, but has been as low as 137 kg/day in 1986 and as high as 324 kg/day in 1995. Brown tiger prawn fishery catches have dropped markedly. The average catch before 1986 was 672 t/year and after 1986 was only 333 t/year. In recent years (1986-1995) average CPUE was 180 kg/day with a range of 131 to 272 kg/day.

Data for all years at station 14506 showed relatively strong correlations between CPUE indices for both species and rainfall factors. Most of these relations also apply with the pre-1986 data set. This was due to 16 out of the 19 observations used in the former data set also belonging in the latter. The post-1986 data was not tested due to the small amount of data available. The station at Alyangula Police Station (14507) had significant correlations between brown tiger prawn CPUE recruitment indices and some rainfall combinations. There was a significant correlation between 'eff-CPUE-Ps' and 'JanFeb-rain'. Pre-86 data had numerous significant correlations with rainfall factors, however, there were few observations in the data set (App. 1 (E)).

GOVE

The Gove region has weather recording stations at Yirrkala Mission (14502) and Gove airport (14508). However, rainfall and temperature data are missing for many years from both stations. Yirrkala mission has data from 1971 to 1975, while Gove Airport has data from 1971 to 1973 and 1987 to 1994. The first station was therefore excluded from the analysis. Yearly rainfall for the latter station ranged from 939 to 1862 mm with an average of 1350 mm from 1987 to 1994. Temperatures reached an average maximum of 33.6°C for those years.

While banana, tiger and endeavour prawns have been landed in the Gove region, grooved tiger prawns have been the main component of the catch. This area was not commonly fished until

1977. The average catch of grooved tiger prawns since then was 220 t/year and since 1986 was 195 t/year.

Grooved tiger prawn fishery catch ranged between 163 t and 392 t with an average catch of 250 t/year since 1986. Average CPUE was 177 kg/day over these years. Brown tiger prawn fishery catch was much lower with a ten year average of 8 t/year.

There were significant correlations between the grooved tiger prawn fishery recruitment indices and temperature when all the data were tested. Two of these were negative correlations. Station 14505 had a significant correlation between 'eff-CPUE-Ps' and 'MarApr-rain' when all years were used. The brown tiger prawn fishery was not tested due to low catches (App. 1 (F)).

ARNHEM

The Arnhem region has weather recording stations at Echo Island (14504), Milingimbi Aws (14402), Maningimbi (14400) and Warruwi (14401). Echo Island had an average yearly rainfall of 1506 mm, and ranged between 994 and 1932 mm. Milingimbi had an average yearly rainfall of 1216 mm, and ranged between 924 and 1714 mm. Rainfall data, however, was only recorded here until 1984. Maningimbi had an average yearly rainfall of 1206 mm, and ranged between 321 and 1910 mm. Warruwi had an average yearly rainfall of 1174 mm, and ranged between 640 and 1890 mm. The average maximum temperature from this region was 33.70°C.

The Arnhem region has been successfully fished for banana prawns since 1974 and tiger prawns since 1980. The banana prawn catch has ranged from nothing in 1977 and 1978 to 1312 t in 1974. Since 1986, an average of 112 t have been landed each year, with tiger prawns of both species being caught. Over the last 10 years an average of 60 t/year of grooved tiger prawns and 30 t/year of brown tiger prawns have been landed. A small number of blue endeavour prawns were also caught.

Since 1986 the grooved tiger prawn fishery average catch has been 87 t/year and CPUE has been around 177 kg/day. The brown tiger prawn fishery catch has ranged between less than 1 t to 42 t with a 10 year average of 15 t/year. CPUE has been around 158 kg/day since 1986.

There were no significant correlations from station 14400 and 14401 when all data was included. But there is one between 'nom-CPUE-Ps' and 'NovJan-rain' for the pre-1986 years and between 'nom-CPUE-Ps' and 'MarApr-rain' for the post-1986 data from station 14400. There was not enough data to test station 14402. There were significant correlations between 'tot-Ps' and 'NovMar-rain' and between 'eff-CPUE-Ps' and 'JanFeb-rain' when post-1986 was included from station 14504. All of these correlations have data sets with few observations (App. 1 (G)).

MELVILLE

The Melville region has a weather recording station at Garden Point Police Station on Melville Island (14142). The average yearly rainfall recorded at this station was 1964 mm with a range of 1441 to 2563 mm. The average maximum temperature for this region was 35.69°C.

There were reasonable quantities of banana, tiger and endeavour prawns caught in the Melville region. The average catch of white banana prawns has been 596 t/year over the last 10 years, while an average of 156 t/year of red-legged banana prawns were caught. Most of the tiger prawns caught were grooved tigers with an average of 113 t/year since 1986. There were minor quantities of brown tiger prawns landed (an average of 11 t/year since 1986). More red endeavour prawns were landed than blue endeavour prawns. The average yearly catches since 1986 have been 70 and 36 t respectively.

The total yearly catch from the grooved tiger prawn fishery during the last 10 years has ranged from 42 to 414 t, with an average of 216 t/year. CPUE had a 10 year average of 295 kg/day and ranges from 175 to 516 kg/day. The brown tiger prawn fishery catch average from 1986 to 1995 was 4 t/year. Average CPUE was 131 t/day for 1986 to 1995.

There was a significant correlation between 'eff-CPUE-Ps' and 'max-temp' in the Melville region. There are also significant correlations between the grooved tiger prawn CPUE recruitment indices and 'NovMar-rain' when data from 1970 to 1995 was included. These relationships also hold for the pre-1986 data and the nominal CPUE index relationship holds for the post-1986 data. There were significant positive correlations between the recruitment indices 'tot-Ps' and 'cat-Ps' and the environmental factor 'JanFeb-rain'. when data from 1970 to 1985 and when pre-1986 data are used (App. 1 (H)).

(II) TECHNOLOGICAL CHANGE

In 1988 and 1989 the GPS operated only sporadically, because few satellites were in orbit. It was not until 1990 that the system was useable most of the time, and not until 1991 that the system was fully operational. During the first year (1988) 8% of boats had a GPS on board and 7% of these also had a plotter; in 1989, these numbers rose to 31% and 20%, respectively; and by 1992, 99% of trawlers had a GPS and 98% had a GPS and plotter (Fig. 3).

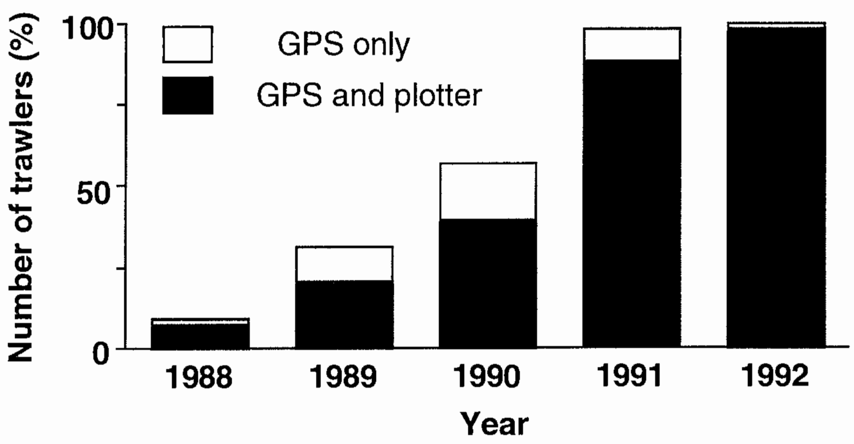

Figure 3 Percentages of trawlers with a GPS and/or a plotter unit in the NPF from 1988 to 1992.

The installation of a GPS without a plotter led to an increase in relative fishing power of 4% over boats without a GPS. During the fisher's first year of using a plotter, fishing power increased by 7% over trawlers without a GPS or plotter. An additional year of experience with a plotter increased fishing power to 9% higher than boats without a GPS. A third year of experience resulted in a 12% increase in fishing power (Fig. 4).

The annual increases in efficiency due to the use of GPS and plotters in the NPF are therefore indicated by a gradual climb from 0.5% in 1988 to 9.6% in 1992 (Fig. 5). By extension when all skippers have at least three years experience with a plotter, the increase is likely to be about 12%.

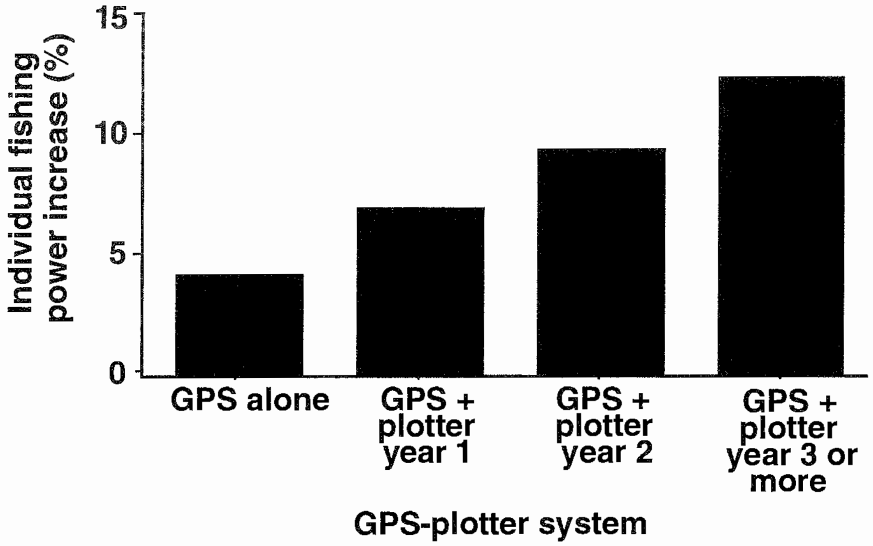

Figure 4 **Effect of GPS and plotter units on the fishing power of individual trawlers in the NPF.**

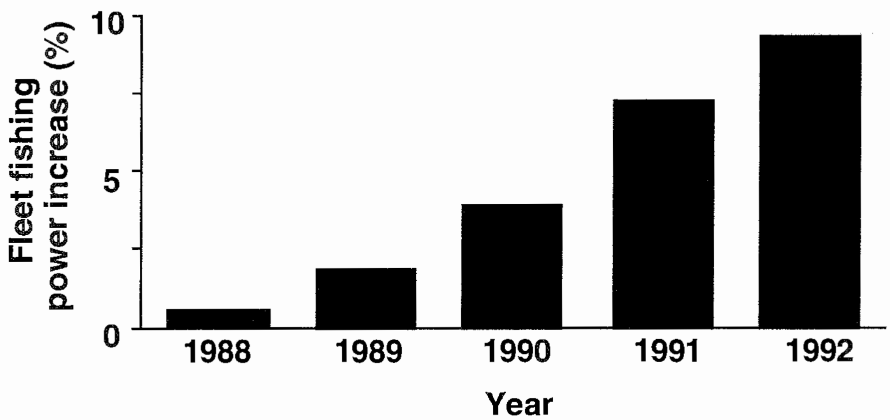

Figure 5 **Effect of the GPS and plotter system on the fleet fishing power of the NPF (1988 - 1992).**

DISCUSSION

Management strategies for the NPF can be more effectively evaluated when environmental factors that impact on the fishery and increases in fishing power are understood.

(I) ENVIRONMENTAL FACTORS

There have been no general NPF-wide relationships found between recruitment indices and environmental factors.

In both grooved tiger prawn and brown tiger prawn fisheries positive correlations were seen between maximum temperature and various recruitment indices for Weipa, Mornington, Vanderlins and Gove.

Rainfall and recruitment indices had some positive (high rainfall linked with high catch) and some negative (low rainfall linked with high catch) correlations in different regions, again for both tiger prawn fisheries. Fisheries in the Mornington region showed relatively strong negative correlations between various rainfall month combinations and brown tiger prawn recruitment indices. This is from the Mornington Island station and not the mainland station. These relationships were observed only when all years from 1970 to 1995 were considered.

The Groote region showed strong positive correlations for grooved tiger prawn and brown tiger prawn fishery recruitment indices when all years and pre-1986 years were analysed. Most data used in the "all year" analysis, however, were also pre-1986 data. Weipa, Arnhem and Melville regions had a positive correlation between a rainfall factor and a recruitment index for data from 1970 to 1995. The same relationship existed with pre-1986 data for Weipa and Melville.

Some of these relationships may have occurred by chance given the large number of recruitment indices and environmental factors tested. Many significant correlations, mainly from post-1986 data sets, are possibly the result of the small number of observations (Weipa, Karumba, Arnhem and Melville regions).

Significant correlations exist in various regions but further research in this area is needed to determine whether incorporating the effects of fishing effort will help identify the relationship between environmental variables and recruitment.

(II) TECHNOLOGICAL CHANGE

The GPS and plotter system is one of the most influential technological changes seen in the NPF. Not only has it revolutionised how the fishers catch prawns, but it has also opened new grounds to trawling.

Information from trawler owners, fishers and fleet masters suggests that one of the main advantages of the GPS and plotter systems has been that the fisher can target prawns more accurately. Once a productive area is detected using the try-net, fishing is concentrated in that area until the catch drops significantly. The GPS and plotter system enable the fisher to keep the boat in the preferred area and even trawl over the same spot several times. Another advantage of the system is that information, such as untrawlable fishing grounds, can be recorded onto the charts. Areas that were previously ignored because of inaccuracies in the charted position of 'foul ground' and of the boat, can now be trawled to a greater extent. The skipper can fish between and along reefs and around foul ground. Successful grounds from previous seasons are also recorded and fishers can find these grounds again. The trawlers and their gear sustain less damage as there are fewer 'hook-ups', and less time is wasted searching for fishing grounds, so more time is spent trawling each night.

The fishing charts (= plotter records) are continually improving. Many fishers believe that the GPS and plotter system has made fishing easier, and a skipper's experience is no longer such a large factor affecting boat profitability.

Fishers estimated that the GPS-plotter system had improved the fishing power of their trawlers by between 5 and 75%, with most estimates falling between 10 and 40%. Our estimate is about 12% after three years experience with plotters (Fig. 2). The result is probably an underestimate, because boats without a GPS on board could follow boats with a GPS and plotter system, and our analysis was not able to accommodate this feature.

The GPS-plotter units are not the only cause of increases in fishing power. Every change made to the trawlers either increases fishing power or improves the life-style of the fishers. In the last decade of fishing in the NPF, navigational and fish-finding aids have been introduced into the fishery, and gear and boats improved. Net makers are continually redesigning and modifying the gear, including the nets and the boards, chains and set-ups. Boat builders and engineers are also making improvements. Skippers and crew are improving their fishing skills and techniques. It is impossible to calculate the increases resulting from these changes.

A 'skipper effect' was apparent in the analysis. We did not estimate the variance accounted for by the fisher, but our analysis showed that fishing power increased by 2 or 3% each year from the first to the third year that a skipper has been working with a plotter unit. This can be attributed not only to fishers becoming more proficient with the system, but also to an improvement in their fishing charts. The fisher builds up his own charts through experience and collects other fishers' charts to supplement his own. The rate at which the skipper's experience influences fishing power beyond three years is not known.

The increase in fishing effort in the NPF from 1970 to 1986 was about 10-fold (Buckworth 1987). Over those years nominal effort increased 430%, therefore, relative fishing power increased by 5% per year. However, Buckworth only took into account the rise in nominal days fished, and continual improvements to existing technology, namely, increases in swept area due to 87lengthening headropes and increasing engine power. He notes that if other technological improvements or innovations had been included in the analysis, the increase would be even greater. The GPS and plotter system is one of these innovations. Although he only considered data from 1970 to 1986, his suggested 5% per year rate of increase in fishing power has been used in all recent NPF tiger prawn stock assessments (Somers 1994, Wang and Die 1995). As the GPS-plotter effect is only one component in the fishing power of a boat, the estimate obtained here will not change this accepted rate of increase, but helps build a clearer picture of what constitutes the real effective effort increases in the NPF.

The 12% increase in fishing power estimated due to the introduction of GPS and plotter systems equates to the addition of 15 boats into the current fleet of 126. If the estimate is conservative, it equates to an even greater number of boats. Increases in fishing power such as these show that management may have to consider further effort controls in the NPF.

EXTENSION OF RESULTS

A preliminary paper of the GPS component of this study was presented at the 1995 NPF Mid-season Fremantle Forum. The final paper was presented at the 1996 World Fisheries Congress in a poster format. 'Evaluation of fishing efficiency in the Northern Prawn Fishery' was presented at Biometrics 95 (International Biometric Society Australasian Region) in September 1995. This covered the mathematical component of the study.

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APPENDIX 1

Significant correlations between recruitment indices and environmental factors by region and station, with the number of observations (n), correlation coefficient (r) and associated probability (p).

(A)

Weipa

Region

Years	Recruitment indices	Environmental factor	n	r	p
post-86	nom-CPUE-Ps	max-temp	9	-0.93	<0.001
	eff-CPUE-Ps	max-temp	9	-0.89	0.002

Station 27042

Years	Recruitment indices	Environmental factor	n	r	p
all	nom-CPUE-Ps	NovJan-rain	24	0.45	0.027
	eff-CPUE-Ps	NovJan-rain	24	0.46	0.023
pre-86	nom-CPUE-Ps	NovJan-rain	16	0.55	0.026
	eff-CPUE-Ps	NovJan-rain	16	0.55	0.027
post-86	tot-Ps	MarApr-rain	8	0.79	0.021

(B)

Karumba

Station 29004

Years	**Recruitment indices**	**Environmental factor**	**n**	**r**	**p**
post-86	nom-CPUE-Pe	NovFeb-rain	7	0.90	0.005
	nom-CPUE-Pe	NovMar-rain	7	0.76	0.049
	nom-CPUE-Pe	JanFeb-rain	7	0.89	0.007
	eff-CPUE-Pe	NovFeb-rain	7	0.84	0.019
	eff-CPUE-Pe	JanFeb-rain	7	0.83	0.022

(C)

Mornington

Region

Years	Recruitment indices	Environmental factor	n	r	p
all	tot-Pe	max-temp	20	0.53	0.016
	cat-Pe	max-temp	20	0.53	0.017

Station 29039

Years	Recruitment indices	Environmental factor	n	r	p
all	tot-Pe	tot-rain	22	-0.55	0.008
	tot-Pe	NovFeb-rain	22	-0.50	0.018
	tot-Pe	NovMar-rain	22	-0.50	0.019
	tot-Pe	NovApr-rain	22	-0.54	0.010
	tot-Pe	JanFeb-rain	22	-0.44	0.041
	cat-Pe	tot-rain	22	-0.55	0.009
	cat-Pe	NovFeb-rain	22	-0.49	0.022
	cat-Pe	NovMar-rain	22	-0.49	0.020
	cat-Pe	NovApr-rain	22	-0.53	0.011
	cat-Pe	JanFeb-rain	22	-0.43	0.045
	eff-CPUE-Pe	NovApr-rain	22	0.44	0.039

Station 29004

Years	Recruitment indices	Environmental factor	n	r	p
all	tot-Pe	NovDec-rain	21	-0.44	0.046

(D)

Vanderlins

Region

Years	Recruitment indices	Environmental factor	n	r	p
all	tot-Ps	max-temp	17	0.48	0.049
	cat-Ps	max-temp	17	0.66	0.002
	eff-CPUE-Ps	max-temp	17	-0.51	0.035
post-86	nom-CPUE-Ps	max-temp	8	0.90	0.002
	eff-CPUE-Pe	max-temp	8	0.84	0.010

(E)

Groote

Region

Years	Recruitment indices	Environment factor	n	r	p
pre-86	tot-Pe	max-temp	16	-0.53	0.035
	cat-Pe	max-temp	16	-0.51	0.043

Station 14507

Years	Recruitment indices	Environment factor	n	r	p
all	nom-CPUE-Pe	NovDec-rain	16	0.54	0.033
	eff-CPUE-Pe	NovJan-rain	14	0.61	0.020
	eff-CPUE-pe	NovMar-rain	14	0.55	0.043
pre-86	nom-CPUE-Pe	NovDec-rain	7	0.91	0.005
	nom-CPUE-Pe	NovJan-rain	6	0.93	0.008
	nom-CPUE-Pe	NovFeb-rain	6	0.83	0.042
	nom-CPUE-Pe	NovMar-rain	6	0.88	0.021
	nom-CPUE-Ps	NovFeb-rain	6	0.88	0.019
	nom-CPUE-Ps	NovMar-rain	6	0.86	0.028
	eff-CPUE-Pe	NovDec-rain	6	0.89	0.007
	eff-CPUE-Pe	NovJan-rain	6	0.94	0.005
	eff-CPUE-Pe	NovFeb-rain	6	0.85	0.034
	eff-CPUE-Pe	NovMar-rain	6	0.88	0.019
	eff-CPUE-Ps	NovJan-rain	6	0.87	0.024
	eff-CPUE-Ps	NovFeb-rain	6	0.95	0.003
	eff-CPUE-Ps	NovMar-rain	6	0.93	0.008
post-86	eff-CPUE-Ps	JanFeb-rain	8	0.83	0.012

Station 14506

Years	Recruitment indices	Environmental factor	n	r	p
all	nom-CPUE-Pe	tot-rain	19	0.66	0.002
	nom-CPUE-Pe	NovDec-rain	19	0.49	0.035
	nom-CPUE-Pe	NovMar-rain	19	0.66	0.002
	nom-CPUE-Pe	NovApr-rain	19	0.67	0.002
	nom-CPUE-Pe	MarApr-rain	19	0.56	0.013
	nom-CPUE-Ps	tot-rain	19	0.62	0.005
	nom-CPUE-Ps	NovDec-rain	19	0.47	0.044
	nom-CPUE-Ps	NovMar-rain	19	0.65	0.003
	nom-CPUE-Ps	Nov-Apr-rain	19	0.64	0.003
	nom-CPUE-Ps	MarApr-rain	19	0.51	0.026
	eff-CPUE-Pe	tot-rain	19	0.58	0.010
	eff-CPUE-Pe	NovMar-rain	19	0.57	0.012
	eff-CPUE-Pe	NovApr-rain	19	0.59	0.007
	eff-CPUE-Pe	MarApr-rain	19	0.54	0.016
	eff-CPUE-Ps	tot-rain	19	0.56	0.012
	eff-CPUE-Ps	NovMar-rain	19	0.56	0.013
	eff-CPUE-Ps	NovApr-rain	19	0.58	0.009
	eff-CPUE-Ps	MarApr-rain	19	0.52	0.022
pre-86	nom-CPUE-Pe	tot-rain	16	0.65	0.006
	nom-CPUE-Pe	NovMar-rain	16	0.63	0.009
	nom-CPUE-Pe	NovApr-rain	16	0.63	0.008
	nom-CPUE-Pe	MarApr-rain	16	0.51	0.044
	nom-CPUE-Ps	tot-rain	16	0.61	0.012
	nom-CPUE-Ps	NovMar-rain	16	0.62	0.011
	nom-CPUE-Ps	NovApr-rain	16	0.61	0.012
	eff-CPUE-Pe	tot-rain	16	0.56	0.024
	eff-CPUE-Pe	NovMar-rain	16	0.52	0.040
	eff-CPUE-Pe	NovApr-rain	16	0.55	0.027
	eff-CPUE-Ps	tot-rain	16	0.54	0.031
	eff-CPUE-Ps	NovMar-rain	16	0.51	0.045
	eff-CPUE-Ps	NovApr-rain	16	0.54	0.029

(F)

Gove

Region

Years	**Recruitment indices**	**Environment factor**	**n**	**r**	**p**
all	tot-Ps	max-temp	14	0.58	0.030
	cat-Ps	max-temp	14	0.60	0.025
	nom-CPUE-Ps	max-temp	14	-0.67	0.009
	eff-CPUE-Ps	max-temp	14	-0.69	0.006

Station 14508

Years	**Recruitment indices**	**Environment factor**	**n**	**r**	**p**
all	eff-CPUE-Ps	MarApr-rain	12	0.58	0.049

(G)

Arnhem

Station 14400

Years	**Recruitment indices**	**Environment factor**	**n**	**r**	**p**
pre-86	nom-CPUE-Ps	NovJan-rain	6	-0.86	0.028
post-86	nom-CPUE-Ps	MarApr-rain	8	-0.74	0.035

Station 14504

Years	**Recruitment indices**	**Environment factor**	**n**	**r**	**p**
post-86	tot-Ps	NovMar-rain	6	-0.83	0.039
	eff-CPUE-Ps	JanFeb-rain	6	0.82	0.048

(H)

Melville

Region

Years	Recruitment indices	Environment factor	n	r	p
all	eff-CPUE-Ps	max-temp	24	0.46	0.024

Station 14142

Years	Recruitment indices	Environment factor	n	r	p
all	tot-Ps	JanFeb-rain	22	0.46	0.030
	cat-Ps	JanFeb-rain	22	0.45	0.037
	nom-CPUE-Ps	NovMar-rain	22	0.56	0.007
	eff-CPUE-Ps	NovMar-rain	22	0.49	0.020
pre-86	tot-Ps	JanFeb-rain	13	0.72	0.005
	cat-Ps	JanFeb-rain	13	0.65	0.016
	nom-CPUE-Ps	NovMar-rain	13	0.67	0.012
	eff-CPUE-Ps	NovMar-rain	13	0.63	0.022
post-86	nom-CPUE-Ps	NovMar-rain	9	0.71	0.031
	nom-CPUE-Ps	NovApr-rain	9	0.69	0.038

APPENDIX 2

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The impact of Global Positioning Systems and plotters on fishing power in the Northern Prawn Fishery, Australia

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Abstract

The impact of Global Positioning Systems (GPS) and plotter systems on the relative fishing power of the Northern Prawn Fishery (NPF) fleet on tiger prawns was investigated from commercial catch data. A generalised linear model was used to account for differences in fishing power between boats and changes in prawn abundance. It was found that boats that used a GPS alone had 4% greater fishing power than boats without a GPS. The addition of a plotter raised the power by 7% over boats without the equipment. For each year between the first to third that a fisher has been working with plotters, there is an additional 2 or 3% increase. It appears that when all boats have a GPS and plotter for at least 3 years the fishing power of the fleet will increase by 12%. Management controls have reduced the efficiency of each boat and lowered the nominal effort, but this may not have been sufficient to counteract the increases. Further limits on effort will be needed to maintain the desired levels of effort.

Introduction

One of the main objectives in most fishery management plans around the world is to ensure the long-term viability of the fishery. To achieve this the level of fishing effort that affects fish resources must be known. There are two types of estimates of fishing effort: nominal fishing effort (the amount of resources devoted to fishing) and effective fishing effort (actual fishing mortality) (Cunningham and Whitmarsh 1980). Decisions based on nominal effort alone, or on inaccurate estimates of effective fishing effort may result in management not meeting its biological objectives. Except where noted, we shall refer to 'effective fishing effort' as 'effort'.

One of the causes of inaccurate estimates of effort is not taking into account increases in the effectiveness of each unit of nominal effort (Gulland 1956, 1969; Robson 1966; Taylor and Prochaska 1985). Such increases may occur quite rapidly when a new technological device or change in fishing method is found to help catch more fish or reduce the cost of fishing and is adopted by the whole fleet. Rothschild (1972), Griffin et al. (1977), Shepherd (1977) and Wang and Die (1996) discuss accurate estimates of fishing effort and why it is vital for a successful management plan .

The relative fishing power — a measure of a boats' effectiveness in catching fish compared to the average boat in the fleet — can be analysed to determine what effect increases in effectiveness have had on nominal effort (Gulland 1956, 1969; Robson 1966; Beverton and Holt 1957; Sanders and Morgan 1976; Taylor and Prochaska 1985; Baelde 1991).

A collection of different fishing power models have been applied to many fisheries around the world. These techniques were used in the preliminary stock assessment of the New South Wales Royal Red Prawn Fishery and in planning an effective effort-limiting management strategy for the Gulf of Mexico Reef Fish

Fishery (Taylor and Prochaska 1985; Baelde 1991). Brunenmeister (1984) also used a similar method in looking at the standardisation of nominal effort for brown, white and pink shrimp stocks from the Gulf of Mexico. Similarly, changes in nominal effort was estimated using fishing power analysis in the Western Rock Lobster Fishery, Australia (Brown et al. 1995).

The Northern Prawn Fishery (NPF), like all fisheries around the world, has experienced increases in effective effort. The NPF extends from Cape Londonderry, Western Australia, to Cape York, Queensland, along several thousand kilometres of coastline (Fig. 1). The average landing of export quality prawns was around 8 000 tonnes per year from 1986 to 1995 which makes it one of Australia's most valuable fisheries (Dan et al. 1994). The total catch of 10 294 t landed by 125 trawlers in 1995 was made up of eight species of prawns. Three species constituted around 80% of this catch: the white banana prawn (*Penaeus merguiensis,* 38%), brown tiger prawn (*P. esculentus*, 25%) and grooved tiger prawn (*P. semisulcatus,* 15%) (Robins and Somers 1994; Sachse and Robins 1995).

The NPF is divided into a day-time banana prawn fishery and a night-time tiger prawn fishery, which have different fishing operations and different management strategies. The highly variable annual catch of banana prawns appears to be closely associated with rainfall; the fishery does not appear to be over-exploited (Somers 1994). In contrast, the catch in the tiger prawn fishery, has declined since fishing effort increased in the early 1980s (Somers 1994). This was not attributed to any one cause but nevertheless management acted quickly in an effort to reverse the downward trend. In 1986, management regulations were introduced to control fishing effort and thereby reduce overfishing of recruits and rebuild the stocks (Somers 1994). These regulations included a restructure which reduced the fleet by around 50%; seasonal, area and daylight closures; and net restrictions. However, there have been increases in the effectiveness of each unit of nominal effort since the employment of this extensive management package, one of the most significant changes being the use of Global Positioning Systems (GPS) and plotter systems.

The GPS and plotter units were introduced to the NPF fleet in 1988. This technology was quickly adopted across the whole fleet with most boats having a GPS and plotter by 1992. These devices changed how fishers catch prawns and opened new ground to trawling. As these navigational aids provided continuous positioning with more accuracy than previously, fishing grounds could be trawled more effectively. The GPS uses satellites to establish the position of the boat, while the plotter enables the fisher to record information about the fishing operations on top of coastline charts. Prawn catches, untrawlable ground, 'hot spots' (areas which have produced high catches) and any other navigational information are plotted on the chart.

We examined the effect that GPS and plotter systems have had on the relative fishing power of the boats in the tiger prawn fishery (which is the fishery most vulnerable to overfishing). Our approach, is similar to Brunenmeister (1984), Taylor and Prochaska (1985), Baelde (1991) and Hilborn and Walters (1992) but allows for factors specific to this fishery: continuous recruitment and spatial and temporal differences in abundance due not only to different recruitment patterns but also to changes in fishing and natural mortality.

In the NPF, trawlers are not always skippered by the same person, so we have related fishing power to not only the boat but also the fisher. For this study we included the length of time a fisher has been using a plotter unit (referred to here as 'fisher's experience'). Fisher experience, gear size and boat length have been included in this study as possible determinants of the fishing power.

The information obtained here will be used in all future stock assessments on the NPF. It will also be useful to help in reaching the objectives of the NPF management plan.

Materials and Methods

Data sources

The analysis described in detail below is based primarily on commercial fishery data collected from trawler logbooks and landings returns. The logbooks include each trawler's catch by species group (banana prawn, tiger prawn, endeavour prawn and king prawn) and its position on each day spent fishing. Landing returns collected from trawler owners and prawn processors were used to adjust the logbook entries to find the correct yearly landings for each trawler.

Data from 1988 to 1992, were used, as these years span the introduction and general adaptation of the GPS and plotter system. The fishing seasons lasted from around 1 April to 30 November, but the main tiger prawn season was from 1 August to 30 November. Only the later period was used in this analysis.

The NPF was divided into 10 regions: Weipa, Mitchell, Karumba, Mornington, Vanderlins, Groote, Gove, Arnhem, Melville and Bonaparte (Fig. 1). As Mitchell and Bonaparte are predominantly banana prawn fishery grounds, they were omitted from the analysis.

All trawlers catch both banana and tiger prawns. The data set used, however, was the monthly catch per boat for each region when trawlers target tiger prawns.

The analysis also includes vessel characteristics — boat length, headrope length of trawl gear and the presence or absence of GPS and plotter units — as well as the number of years a fisher has worked with plotters. The vessel characteristics were recorded when the trawlers first entered the NPF and updated when necessary. Gear records are collected every year. The years that GPS and plotters were first installed in each trawler, and fisher lists for each year, were obtained from Vessel Inspection Reports collected by Fisheries Patrol officers at the start of each season; a ships chandlery— Taylor Marine in Cairns— and during interviews with trawler owners and fishers.

Interviews were held with 32 paid fishers, 6 owner-fishers and 14 owners or company personnel. They provided background information on the use of the GPS and plotter systems and described how they used the system. Fishers were also asked to estimate how much its installation increased their efficiency of fishing.

The number of years the boat's fisher had worked with a plotter (fisher experience) was derived from fisher lists linked with GPS-plotter lists. From these data, each boat that fished each year was placed into one of 5 GPS categories:

1. no GPS and no plotter and therefore no fisher experience,
2. GPS but no plotter and therefore no fisher experience,
3. GPS and plotter on-board and the first year the fisher has used a plotter,
4. GPS and plotter on-board and the second year the fisher has used a plotter,
5. GPS and plotter on-board and the fisher has three or more years experience with a plotter.

Statistical Model

In general, using traditional methods as defined by Beverton and Holt (1957), in a fishery with a closed population (no emigration or immigration) the catch of each vessel is given by:

$$
\begin{aligned}
c_{ijkt} &= N_{jkt}(1-e^{-Z_{.jkt}})F_{ijkt} / Z_{.jkt} \\
&= F_{ijkt}\overline{N}_{.jkt}
\end{aligned}
\qquad (1)
$$

where c_{ijkt} denotes the catch of the ith boat, in area j, during year k and month t; $N_{.jkt}$ is the biomass at the start of month t; total mortality is denoted by $Z_{.jkt}$, and F_{ijkt} is fishing mortality. The average abundance during period t, $\overline{N}_{.jkt}$, replaces $N_{jkt}(1-e^{-Z_{.jkt}}) / Z_{.jkt}$.

Fishing mortality is assumed to be:

(2) $$F_{ijkt} = q_{ijkt}E_{ijkt}$$

where q_{ijkt} is the catchability coefficient and E_{ijkt} is fishing effort .

To account for generalisations that apply to a prawn fishery — including continuous recruitment, spatial heterogeneity and temporal differences — we made the following assumptions in our model:

(a) the relationship between catch and abundance is:

(3) $$c_{ijkt} = F_{ijkt}h(N_{.jkt})$$

where $h(N_{.jkt})$ is an unknown abundance function. This is a generalisation of eq. (1) to account for continuous recruitment, spatial differences and temporal differences.

(b) fishing mortality is:

(4) $$F_{ijkt} = q_{ijkt}(E_{ijkt})^{\delta}$$

where δ is an unknown parameter that generalises eq. (2). This allows density-dependence of catch and the possibility of CPUE-dependence on effort (Taylor and Prochaska 1985, Richards and Schnute 1992);

(c) the catchability for each boat i during year k is assumed to be:

(5) $$\log(q_{i.k.}) = \alpha + \alpha_1 \log(g_{i.k.}) + \alpha_2 \log(l_i) + \beta(X_{i.k.})$$

where α is the intercept; α_1 is the gear effect; $g_{i.k.}$ is the total headrope length of gear being used; α_2 is the length effect; l_i is the length of the boat; $\beta(X_{i.k.})$is the effect of the GPS category and $X_{i.k.}$ is the GPS category for that boat.

The statistical model used for this analysis is obtained by combining eqs. (3), (4) and (5):

(6) $$\begin{aligned}\log(c_{ijkt}) &= \alpha + \alpha_1 \log(g_{i.k.}) + \alpha_2 \log(l_i) + \beta(X_{i.k.}) \\ &+ \delta \log(E_{ijkt}) + \log(h(N_{.jkt})) + \varepsilon_{ijkt}\end{aligned}$$

where ε_{ijkt} is the error term. The abundance term, $h(N_{.jkt})$, is expressed by year, area and month and their interactions.

While logarithmic transformation linearises the model, it does not guarantee stabilisation of the variance of the error components. To account for the heterogeneous variance components, a weighted regression was used. The weighting of nominal fishing effort was found to be appropriate in terms of stabilising the residuals.

The reasoning for this is that

$$Var\{\log(c)\} \propto Var(c) / c^2,$$

and if $Var(c) \propto E$ and $c \propto E$,

we would have $Var\{\log(c)\} \propto 1/E.$

This model was fitted by PROC GLM in SAS and the parameter estimates were used in the calculation of increase in fishing power due to the introduction of GPS and plotter units in the NPF for year k:

(7)

$$I_k = \sum_{s=0}^{5} \beta_s g_{sk}$$

where I_k is the average increase in fishing power due to the introduction of GPS and plotter units in the NPF and g_{sk} is the proportion of boats in category s during year k.

Results

Data Summary

In 1988 and 1989 the GPS operated only sporadically, as few satellites were in orbit. It was not until 1990 that the system was useable most of the time, and not until 1991 that the system was fully operational. During the first year (1988) 8% of boats had a GPS on board and 7% had a GPS as well as a plotter; in 1989, these numbers rose to 31% and 20%, respectively; in 1990, they rose to 57% and 40%; in 1991, they rose to 97% and 87%; in 1992, 99% of trawlers had a GPS and 98% had a GPS and plotter (Fig. 2).

The average headrope length of trawl gear used by NPF trawlers during the tiger prawn season did not change dramatically from 1988 to 1992. The total length of trawl gear for the whole fleet, however, decreased when boat numbers began dropping after the fleet was restructed between 1985 and April 1993. The average length of trawlers in the fleet remained relatively constant from 1988 to 1992 (Table I).

Results of the statistical analysis

Estimates of model parameters, including the effect of the GPS and plotter systems on the power of boats, and the relative fishing power and fishing mortality estimates were obtained using eq. (6)(Table II). The installation of a GPS without a plotter led to an increase of 4% in relative fishing power (over boats without a GPS). During the fisher's first year of using a plotter, fishing power increased by 7% over trawlers without a GPS or plotter; an additional year of experience with a plotter increased it to 9%; a third year increased it to 12%. The coefficient for gear is 0.566, which means if the headrope length of the trawl gear increased from 16 to 25 metres, the catch would increase by 22%. Similarly the coefficient for length of vessel was 0.4, or if the vessel length increased from 20 to 25 m, the catch would increase by 9%.

In our model, following Taylor and Prochaska (1985), catch is the observed variable and nominal effort one of the explanatory variables. In our case nominal effort resulted in a good index of catch, with the estimate of δ being close to 1 (Table 2). Therefore, it would also have been viable to use CPUE as the independent variable. This may not be the case, however, for other fisheries. The generalised model that we used considers annual, monthly and spatial differences in the interaction term. Baelde (1991) includes interactions of the abundance term (depth, latitude and time) in his model. Brunenmeister (1984) includes month and area terms, but excludes all interactions, as he thought they would confound the estimates of area and month effects. Taylor and Prochaska (1985) omit the population variable and incorporate any changes in stock size in the error term. The model defined in Hilborn and Walters (1992) is very similar to ours. It contains an abundance term that takes account of annual differences, and the authors note that the model can be changed to include interaction terms, such as vessel size and area interactions.

The annual increases in efficiency due to the use of GPS and plotters in the NPF as calculated using eq. (7) are indicated by a gradual climb from 0.5% in 1988 to 9.6% in 1992 (Fig. 3). By extension when all fishers have at least three years' experience with a plotter, the increase is likely to be about 12%.

Discussion

The measurement of effort has always been a fundamental part of fisheries science. And it becomes even more important when fisheries are managed using effort limiting controls (input controls) (Rothschild 1972; Taylor and Prochaska 1985). The increase in efficiency of boats and fishers, and subsequently fleets has occurred in fisheries around the world. This is due to better boat and gear design, improved fishing techniques, an increase in fisher experience, and an advancement in electronic technology. Every increase in efficiency results in nominal effort and effective effort diverging making the correct estimation of effective effort critical (Cunningham and Whitmarsh 1980).

The management objectives for the NPF are to ensure the long-term viability of the biological resource and the maximum economic efficiency of the fishery. The style of management is to regulate the level and pattern of fishing effort rather than the level or composition of landings (Taylor 1994). This fishery is no different from many others in that efficiency has increased dramatically since its discovery in the 1960s. In 1987, management aimed at lowering effort in the NPF by 40%. Has this been achieved? Nominal fishing effort has decreased considerably since the mid-to-late eighties when more than 250 boats worked in the tiger fishery. There are now only 124 boats fishing. We know that today's fleet is more effective than in the earlier days, but not by how much.

Management strategies for the fishery cannot be evaluated unless the rate of increase in fishing power is known and the reasons for this increase understood. Tiger prawn predictions of equilibrium yield for the NPF are very sensitive to the rate of increase in fishing power that is assumed in the model. By varying the rate of increase in fishing power between 2 and 10% the model predicts that, *Penaeus* *esculentus* could be slightly under-fished to severely over-fished, while *Penaeus semisulcatus* could be slightly under-fished to fully fished (Wang and Die 1996).

The increase in fishing effort in the NPF from 1970 to 1986 was about 10-fold (Buckworth 1987). Over those years nominal effort increased 430%, therefore, relative fishing power increased by 5% per year. However, Buckworth only took into account the rise in nominal days fished, and increases in swept area due to increases in headrope length and engine power. He notes that if other technological improvements had been included in the analysis, the increase would be even greater. The GPS and plotter system is one of these improvements. Not only has it revolutionised how the fishers catch prawns, but it has also opened new grounds to trawling.

The GPS-plotter units are not the only cause of increases in fishing power. Every change made to the trawlers either increases fishing power or improves the life-style of the fishers. In the last decade of fishing in the NPF, navigational and fish-finding aids have been introduced into the fishery, and gear and boats improved. Net makers are continually redesigning and modifying the gear, including the nets and the boards, chains and set-ups. Boat builders and engineers are also making improvements. Fishers and crew are improving their fishing skills and techniques. It is impossible to calculate the increase resulting from these changes.

Information from trawler owners, fishers and fleet masters suggests that one of the main advantages of the GPS and plotter systems has been that the fisher can target more accurately. Once a productive area is detected, fishing is concentrated on that area until the catch drops significantly. The GPS and plotter system enable the fisher to keep the boat in the preferred area and even trawl over the same spot several times. Another advantage of the system is that information — such as untrawlable fishing grounds — can be recorded onto the charts. Areas that were previously ignored because of inaccuracies in the charted position of 'foul ground' and of the boat, can now be trawled to a greater extent. The fisher can trawl between and along reefs and around foul ground. Successful grounds from previous seasons are also recorded and fishers can find these grounds again. The trawlers and their gear sustain less damage as there are fewer 'hook-ups', and less time is wasted searching for fishing grounds, so more time is spent trawling each night.

The fishing charts (= plotter records) are continually improving. Many fishers believe that the GPS and plotter system has made fishing easier, and a fisher's experience is no longer such a large factor affecting boat profitability. Inexperienced fishers are now competing on a more equal footing with the more skilled. Similar behaviour was suggested by Hilborn (1985), although he did not focus on the use of GPS and plotters, but states that, in general it would be expected that many less skilled fishermen will imitate or follow the fishing pattern and techniques of the more skilled. This applies to a greater extent when they obtain copies of the plotter records of successful fishers. Consequently, there are no longer many 'secret grounds', according to trawler fishers and owners.

Fishers estimated that the GPS-plotter system had improved the fishing power of their trawlers by between 5 and 75%, with the most estimates falling between 10 and 40%. Our estimate is around 12% after three years (Fig. 4). In the Western Australian Rock Lobster Trap Fishery, the use of GPS systems also increased fishing power by 12% (Brown et al. 1995). Our result is probably an underestimate, because boats without a GPS on board could follow boats with a GPS and plotter system.

Factors other than GPS and plotters also determine the fishing power of a boat; fisher skill for example (Gulland 1956; Cunningham and Whitmarsh 1980; Rothschild 1972; Brunenmeister 1984; Hilborn and Ledbetter 1985; Hilborn and Walters 1992). In fact, Gulland (1956) said that many trawler-owners believe the fisher's efficiency is the most important factor in the fishing power of the boat, and the set of instruments used is the second most important factor. Such physical characteristics of a trawler as gear size, boat length, vessel tonnage, vessel age and horsepower can also affect the fishing power of fleets (Beverton and Holt 1957; Rothschild 1972; Griffin et al. 1977; Hilborn and Walters 1992).

The 'fisher effect' in the Icelandic cod fishery was found by Palsson and Durrenberger (1982) to be a myth. They concluded that the real reasons for a fisher's success or failure were the size of the boats and the frequency of trips.

In contrast, a 'fisher effect' was apparent in the NPF. We have not estimated the variance accounted for by the fisher, but our analysis showed that fishing power increased by 2 or 3% each year from the first to the third year that a fisher has been working with a plotter unit. This can be attributed not only to fishers becoming more proficient with the system, but also to an improvement in their fishing charts. The fisher builds up his own charts through experience and collects other fishers' charts to supplement his own. The rate at which the fisher's experience continues to increase beyond 3 years is not known.

Although Buckworth (1987) only considered data from 1970 to 1986, his suggested 5% rate of increase in fishing power has been used in all recent NPF tiger prawn stock assessments (Somers 1994; Wang and Die 1996). As the GPS-plotter effect is only one component in the fishing power of a boat, the estimate obtained here will not change this accepted rate of increase, but helps build a clearer picture of the sources for real effective effort increases in the NPF.

Nominal effort did drop 39% from 1988 to 1993, as proposed by the management regime. However, the addition of GPS and plotter systems has increased the efficiency of trawlers by at least 12%, and other factors have increased it further. This increase equates to the addition of 15 boats into the current fleet of 126. If the estimate is conservative it equates to even more additional boats. Management controls such as gear restrictions have reduced efficiency, but probably not sufficiently to counteract the increase. Clearly a reduction in 'nominal effort' does not necessarily mean a corresponding reduction in 'effective effort'. It is obvious that in order to successfully manage a fishery such as the NPF all changes to the fleet that make the boats more efficient need to be documented and included in effort estimates. Increases in fishing power, such as that attributed to the GPS and plotter units, show that management may have to consider further effort controls in the NPF.

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Figure captions

Fig. 1 Map of the Northern Prawn Fishery, showing fishing regions used in our study.

Fig. 2 Percentages of trawlers with a GPS and/or a plotter in the Northern Prawn Fishery.

Fig. 3 Effect of the GPS and plotter system on the fishing power of the Northern Prawn Fishery fleet from 1988 to 1992.

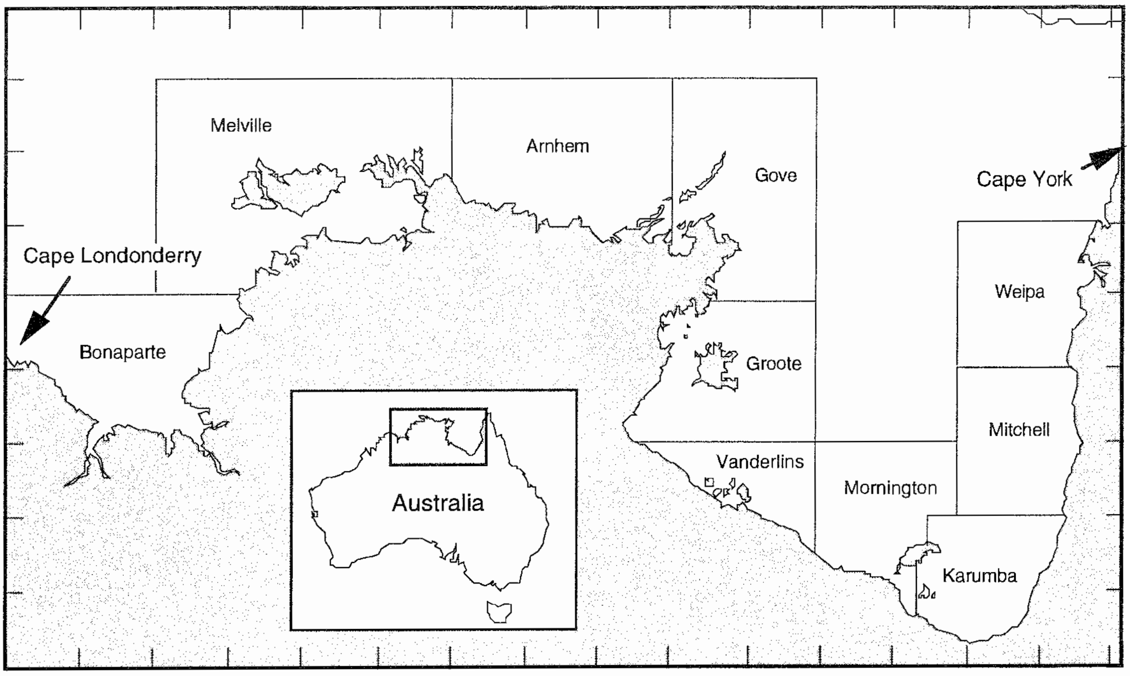
Table 1 Average headrope length, total headrope length, number of boats and average boat length in the Northern Prawn Fishery from 1988 to 1992.

Year	Average headrope length (fathoms)	Total headrope length (fathoms)	Number of boats	Average boat length (metres)
1988	23.24	2070	222	21.80
1989	23.94	5195	223	21.92
1990	23.66	4678	200	21.60
1991	23.97	3955	172	21.83
1992	23.43	3899	170	21.48

Table 2 Parameter estimates and their standard errors for the generalised linear model of relative fishing power in the Northern Prawn Fishery.

Variable	Parameter	Estimate	Std. Error
effort	δ	1.067	0.005
average headrope length	α_1	0.566	0.022
average boat length	α_2	0.399	0.030
GPS but no plotter	β_{100}	0.037	0.010
GPS and plotter during fishers 1st year of experience	β_{111}	0.068	0.008
GPS and plotter during fishers 2nd year of experience	β_{112}	0.091	0.009
GPS and plotter during fishers 3rd or more years of experience	β_{113}	0.123	0.011

R^2=0.923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Mitchell
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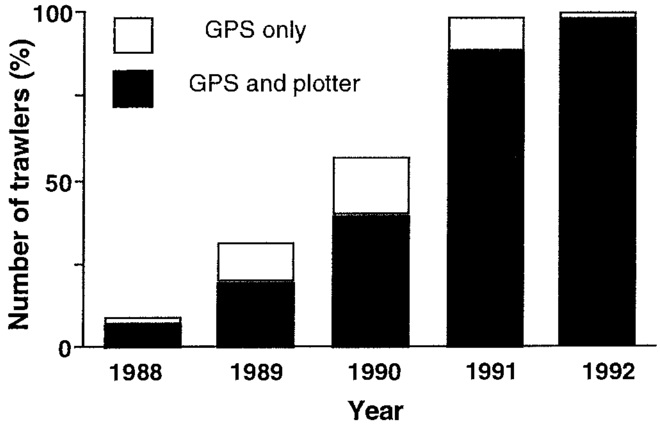
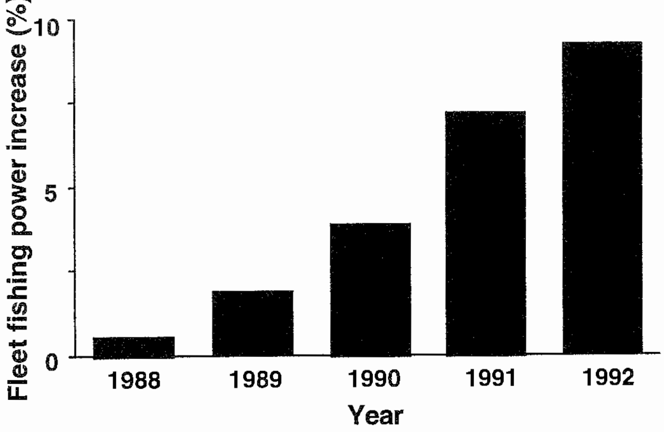

100
50
0
Number of trawlers (%)
GPS only
GPS and plotter
1988
1989
1990
1991
1992
Year


Fleet fishing power increase (%)
10
5
0
1988
1989
1990
1991
1992
Year