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 fleet on tiger prawns (*Penaeus esculentus* Haswell, 1879, and *P. semisulcatus* de Haan, 1850) was investigated from commercial catch data. A generalized 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 number of days available to fish, but this may not have been sufficient to counteract the increases. Further limits will be needed to maintain the desired levels of mortality.

Résumé : À l'aide de données sur les captures commerciales, on a étudié les effets du système de positionnement global (GPS) et des systèmes de traceur sur la capacité de capture relative de la flottille crevettière du nord de l'Australie visant les crevettes tigrées (*Penaeus esculentus* Haswell, 1879, et *P. semisulcatus* de Haan, 1850). Un modèle linéaire généralisé a été utilisé pour prendre en compte les différences de capacité de pêche des bateaux et les variations d'abondance des crevettes. Les chercheurs ont constaté que, dans le cas des bateaux qui utilisent le système GPS seul, la capacité de pêche était supérieure de 4 % à celle des bateaux qui ne l'utilisaient pas. L'addition d'un traceur a augmenté la capacité de 7 % par rapport aux bateaux ne disposant pas de cet équipement. Pour chaque année entre la première et la troisième année pendant laquelle un pêcheur a travaillé avec des traceurs, on note une augmentation supplémentaire de 2 à 3 %. Il apparaît que, lorsque tous les bateaux seront munis d'un GPS et d'un traceur pendant au moins 3 ans, il y aura une augmentation de 12 % de la capacité de pêche de la flottille. Les mesures de gestion ont réduit l'efficacité de chaque bateau et le nombre de jours de pêche, mais il semble que cela n'ait pas été suffisant pour contrebalancer les augmentations. De nouvelles limites seront nécessaires si l'on veut maintenir le taux de mortalité visé.

[Traduit par la Rédaction]

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 mortality or fishing effort that adversely 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." In our example, nominal fishing effort is measured in fishing days. Nominal fishing effort may refer to any measure of resources devoted to fishing (e.g., fishing days, trawl hours, number of hooks, or number of trawl shots).

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 with the standard 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 (*Haliporoides sibogae* de Man, 1907)(Baelde 1991). This study used several loglinear models to find the best combination of classification variables (effects of depth, latitude, and time period) and covariates (logarithms

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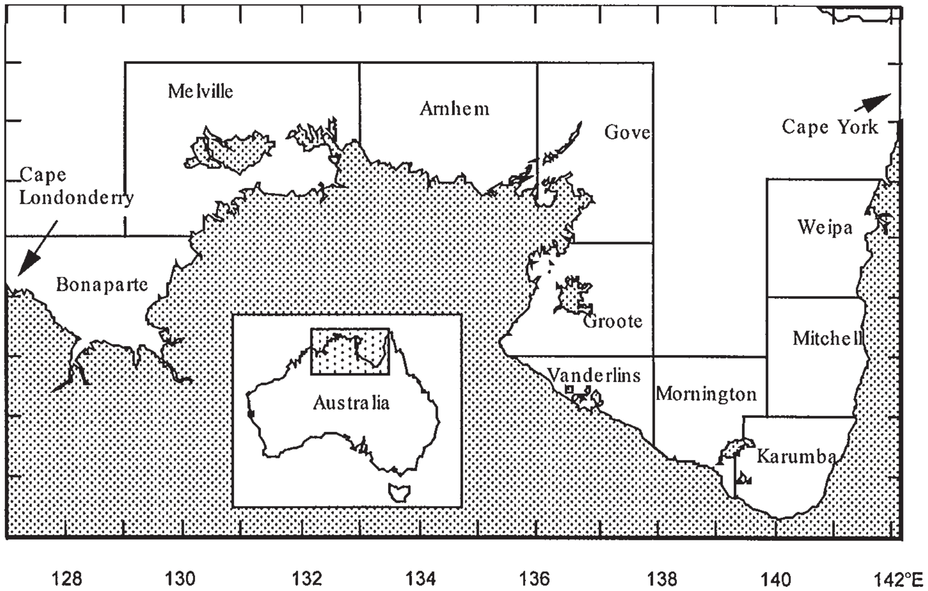
Fig. 1. Map of the northern prawn fishery, showing fishing regions used in our study.



of engine power, length, gross tonnage, headrope length, and codend mesh size of each vessel) that described the variability of catch per unit effort (CPUE). This information was used to estimate the CPUE of a standard vessel, which was then multiplied by observed effort to give a standardized effort and eventually a standardized CPUE. A fishing power study by Taylor and Prochaska (1985) examined the models behind planning an effective effort-limiting management strategy for the Gulf of Mexico reef fish fishery. This study used catch, vessel numbers, crew size, and vessel size in their loglinear model. The differences between the fishing power of adjoining states were determined, and the implications with respect to management were discussed. Brunenmeister (1984) also used a similar method in looking at the standardization of nominal effort for brown (*P. aztecus* Ives), white (*P. setiferus* (L.)), and pink (*P. duorarum* Burkenroad) shrimp stocks from the Gulf of Mexico. Similarly, changes in nominal effort was estimated using fishing power analysis in the western rock lobster (*Panulirus cygnus*) fishery, Australia (Brown et al. 1995). This study examined various factors influencing fishing power (radar, colour echo sounder, global positioning system, pot type) using a two-stage ANOVA regression technique. The nominal fishing effort was then standardized to determine changes in fishing power over time.

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 8000 t/year from 1986 to 1994, 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* de Man, 1888; 38%), brown tiger prawn (*P. esculentus* Haswell, 1879; 25%), and grooved tiger prawn (*P. semisulcatus* de Haan, 1850; 15%) (Robins and Somers 1994; Sachse and Robins 1995).

The NPF is divided into a daytime banana prawn fishery and a nighttime tiger prawn fishery, which have different fishing operations and different management strategies (Somers and Wang 1997). The highly variable annual catch of banana prawns appears to be closely associated with rainfall; the fishery does not appear to be overexploited (Somers 1994). In contrast, the catch in the tiger prawn fishery has declined since fishing effort increased in the early 1980s. 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 and area closures; daylight trawling bans; and net restrictions. However, there have been increases in the effectiveness of each fishing day since the establishment 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 achieved, 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 that have produced high catches), and any other navigational information are plotted on the chart. NPF skippers have expressed the opinion that GPS and plotter system have had a major impact on their fishing efficiency, particularly for the less experienced fishers.

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 based on traditional fishing power models 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. This model permits catch to be a nonlinear function of effort and catchability to be a function of boat characteristics.

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 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 daily logbooks include each trawler's catch in kilograms by species group (banana prawn (*P. merguinesis* de Man, 1888, and *P. indicus* Milne Edwards, 1837), tiger prawn, endeavour prawn (*Metapenaeus endeavouri* Schmitt, 1926, and *M. ensis* de Hann, 1850), and king prawn (*P. latisculcatus* Kishinouye, 1896, and *P. longistylus* Kubo, 1943) and the position in latitude and longitude where the greatest number of prawns were caught during that day. Processor returns collected from trawler owners and prawn processors were used to check and adjust if necessary the total logbook catch of each trawler. If the total logbook catch didn't equal the total processed catch then the correct landings for that boat was determined following consultation with the fisher and boat owner. An adjustment factor was used to scale up or down the total logbook catches to equal the total landings catch for the whole fleet.

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, because most boats only target tiger prawns as these are the only abundant species during this period.

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 (kilograms) and effort (days) per boat for each region when trawlers target tiger prawns. A boat was defined as targeting tiger prawns if over half the catch for that day was tiger, endeavour, or king 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.

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

(*i*) no GPS and no plotter and therefore no fisher experience,
(*ii*) GPS but no plotter and therefore no fisher experience,
(*iii*) GPS and plotter onboard and the first year the fisher has used a plotter,
(*iv*) GPS and plotter onboard and the second year the fisher has used a plotter, and
(*v*) GPS and plotter onboard 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

$$(1)\qquad \begin{aligned} C_{baym} &= N_{.aym}(1 - \mathrm{e}^{-Z_{.aym}})F_{baym}/Z_{.aym} \\ &= F_{baym}\overline{N}_{.aym} \end{aligned}$$

where C_{baym} denotes the catch of the bth boat in area a during year y and month m; $N_{.aym}$ is the biomass at the start of month m; total mortality is denoted by $Z_{.aym}$, and F_{baym} is fishing mortality. The average abundance during period m, $\overline{N}_{.aym}$, replaces $N_{.aym}(1 - \mathrm{e}^{-Z_{.aym}})/Z_{.aym}$.

Fishing mortality is assumed to be

$$(2)\qquad F_{baym} = q_{baym}E_{baym}$$

where q_{baym} is the catchability coefficient and E_{baym} is nominal fishing effort (in this case fishing days).

To account for generalizations 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

$$(3)\qquad C_{baym} = F_{baym}h(N_{.aym})$$

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

(B) Fishing mortality is

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

where δ is an unknown parameter that generalizes eq. 2. This allows the possibility of CPUE dependence on nominal fishing effort (Taylor and Prochaska 1985; Richards and Schnute 1992). In general, the fishing mortality is assumed to be proportional to the nominal fishing effort. There are factors, however, that may violate this linear relationship: aggregation of stocks and targeting behavior of fishers. Our model allows a more general (nonlinear) relationship between catch and nominal effort.

(C) The catchability for each boat during year is assumed to be

$$(5)\qquad \log(q_{b.y.}) = \alpha + \alpha_1\log(g_{b.y.}) + \alpha_2\log(l_b) + \beta_X$$

where α is the intercept, α_1 is the gear effect, $g_{b.y.}$ is the total headrope length of gear being used, α_2 is the length effect, l_b is the length of the boat, and β_X is the effect of the GPS category, where X is $X_{b.y.}$, the GPS category (000, 100, 111, 112, and 113) for that boat. Note that the GPS category 000 will be used as the baseline, and hence the parameter β_{000} is assumed to be 0 in the analysis. The other four GPS parameters reflecting the effects of GPS (relatively to category 000) will be estimated from the data.

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

$$(6)\qquad \begin{aligned} \log(C_{baym}) = {} & \alpha + \alpha_1\log(g_{b.y.}) + \alpha_2\log(l_b) + \beta_X \\ & + \delta\log(E_{baym}) + \log(h(N_{.aym})) + \varepsilon_{baym} \end{aligned}$$

where ε_{baym} is the error term. The abundance term, $\log(h(N_{.aym}))$, is expressed by area, year, and month, and all of their interactions to account for all possible changes in abundance.

Table 1. Average headrope length, total headrope length, number of boats, and average boat length in the northern prawn fishery from 1988 to 1992.

		Headrope length (fathoms)		Boat length (m)	
Year	No. of boats	Mean	SD	Mean	SD
1988	222	23.24	4.58	21.80	3.12
1989	223	23.94	4.44	21.92	3.02
1990	200	23.66	4.52	21.60	3.09
1991	172	23.97	4.47	21.83	3.01
1992	170	23.43	4.55	21.48	3.05

While logarithmic transformation linearizes the model, it does not guarantee stabilization 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 stabilizing the residuals. The reasoning for this is that $\mathrm{var}(\log(C)) \propto \mathrm{var}(C)/C^2$, and if $\mathrm{var}(C) \propto E$ and $C \propto E$, we would have $\mathrm{var}(\log(C)) \propto 1/E$.

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:

$$(7) \qquad I_y = \beta_{100}\, d_{100,y} + \sum_{s=1}^{3} \beta_{11s}\, d_{11s,y}$$

where I_y is the average increase in fishing power resulting from the introduction of GPS and plotter units in the NPF, and $d_{x,y}$ are the corresponding proportions of boats in different GPS categories during year y.

The residual analysis confirms the theoretical result: the variance of $\log(C)$ is inversely proportional to the effort. We have also applied a Poisson loglinear model with overdispersion; the estimates are almost the same as the model used here. The overdispersion factor based on Pearson chi-square is 79, which is very high and indicates the importance of allowing overdispersion in the analysis. The corresponding confidence intervals taking account of overdispersion are also similar to those obtained here.

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%; and in 1992, 99% of trawlers had a GPS and 98% had a GPS and plotter. This demonstrates how quickly technological innovations can spread in a fleet of vessels competing for a common resource.

The average headrope lengths of trawl gear used by NPF trawlers during the tiger prawn season did not change dramatically from 1988 to 1992. The average length of trawlers in the fleet also remained relatively constant from 1988 to 1992. The range of headrope length (12 to 28 fathoms; 1 fathom is 1.829 m) and boat lengths (12.8 to 30 m) did not change over the period of the study (Table 1).

Table 2. ANOVA results for the generalized linear model of relative fishing power in the northern prawn fishery.

Source	df	SS	MS	$P > F$
Year*	4	132	33	0.0001
Area*	7	84	12	0.0001
Year × area*	28	119	4	0.0001
Month*	3	194	64	0.0001
Year × month*	12	49	4	0.0001
Area × month*	21	109	5	0.0001
Year × area × month*	75	167	2	0.0001
log effort*	1	21 523	21 523	0.0001
log gear*	1	307	307	0.0001
log length*	1	81	81	0.0001
GPS*	4	67	16	0.0001
Model	157	32 055	204	0.0001
Error	5946	2 692	0.45	
Corrected total	6103	34 748		

*Type III sums of squares were calculated for these terms.

Table 3. Parameter estimates and their standard errors for the generalized linear model of relative fishing power in the northern prawn fishery.

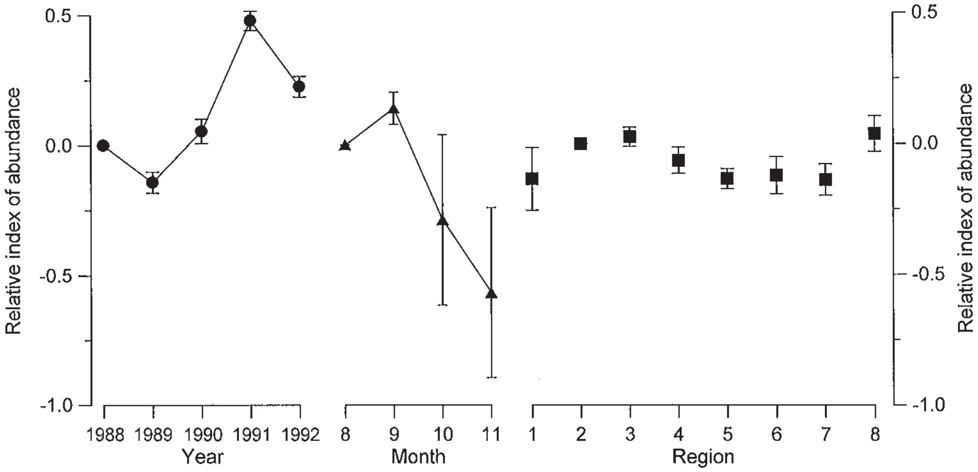
Variable	Parameter	Estimate	SE
Effort (days)	δ	1.067	0.005
Average headrope length (fathoms)	α_1	0.566	0.022
Average boat length (m)	α_2	0.399	0.030
GPS but no plotter	β_{100}	0.037	0.010
GPS and plotter (first year of experience)	β_{111}	0.068	0.008
GPS and plottor (second year)	β_{112}	0.091	0.009
GPS and plotter (third or more year)	β_{113}	0.123	0.011

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 (Tables 2 and 3). 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%; and a third year increased it to 12%. The coefficient for gear is 0.566, which means that, if the headrope length of the trawl gear increased from 16 to 25 m, 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 being close to 1 (Table 3). Therefore, it may be viable to use tiger prawn CPUE as an abundance estimate independent of effort. This may not be the case, however, for other fisheries. The generalized model that we used considers annual, monthly, and spatial differences in the interaction term. The differences in abundance between years, months, and regions (Fig. 2) are not considered here, as these are nuisance parameters for the purpose of our analyses.

Fig. 2. Relative index of abundance for main effects, year (circles), month (triangles), and region (squares: 1, Weipa; 2, Karumba; 3, Mornington; 4, Vanderlins; 5, Groote; 6, Gove; 7, Arnhem; and 8, Melville). Note that all indices are relative to the standard year (1988), month (8), and region (2).



Baelde (1991), for example, 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, pp. 125 to 132) 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. Further work should investigate the usefulness of abundance estimates obtained from these types of analyses.

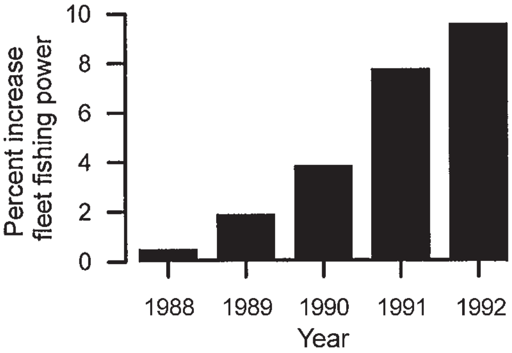
The annual increases in efficiency due to the use of GPS and plotters in the NPF as calculated using eq. 7 are indicated by a gradual climb from 0.5% in 1988 to 9.6% in 1992 (Fig. 3). By extension when all fishers have at least 3 years experience with a plotter, the increase is likely to be about 12%.

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 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 middle to late 1980s when more than 250 boats worked in the tiger prawn 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.

Fig. 3. Effect of the GPS and plotter system on the fishing power of the northern prawn fishery fleet from 1988 to 1992.



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 *P. esculentus* could be slightly underfished to severely overfished, while *P. semisulcatus* could be slightly underfished 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 resulting from 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 revolutionized how the fishers catch prawns, but it has also opened new grounds to trawling.

The GPS and plotter units are not the only cause of increases in fishing power. Every change made to the trawlers increases fishing power, improves the lifestyle of the fishers, or increases the boat's profitability. In the last decade of fishing in the NPF, navigational and fish-finding aids have been introduced into the fishery, and gear and boats have been improved. Net makers are continually redesigning and modifying the gear, including the nets and the boards, chains, and setups. 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.

Interviews were held with 32 paid fishers, 6 fishers who own the boat, and 14 owners or company personnel to provide background information on the use of the GPS and plotter systems and describe how they used the system. Fishers were also asked to estimate how much its installation increased their efficiency of fishing. It was suggested 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 behavior 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. Many fishers freely share plotter records with friends, but most tend to work in loose groups often changing fishing partners. Eventually most plotter records are passed around the whole fleet. Consequently, there are no longer many "secret grounds," according to trawler fishers and owners.

Fishers from the previously mentioned interviews estimated that the GPS and 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 3 years. 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, e.g., fisher skill (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). There may have been technological changes other than GPS and plotters that occurred in the NPF fleet over the study period. There is no data available for these; therefore, their effect will be confounded with the abundance effects.

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 but would be expected to plateau out after a length of time.

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 and 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 effort increases in the NPF.

Nominal effort did drop 39% from 1988 to 1993 through a fleet size reduction as proposed by the management regime consisting of a voluntary and accelerated buy-back scheme and a compulsory surrender (Taylor 1994). 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, 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.

This analysis has confirmed that technological change does impact fishing power. Technological improvements will continue to occur in most fisheries and consequently will lead to further fishing power increases. It is therefore essential that input-control fisheries, like the NPF, monitor technological change in their fleets.

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