The Impact of Technology on Fishing Power in the Western Rock Lobster (Panulirus cygnus) Fishery

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Abstract The impact of technology and other factors on the relative fishing power of the Western Rock Lobster fleet in Western Australia was investigated using commercial catch and vessel technology data for the years 1971 to 1996. This investigation identified the changes in the use of various components of fishing power during these years. General linear models were then used to assess the effects that these changes had on catch rates of legal-size, under-size and spawning lobsters. Year, month, migratory phase, region, soak-time, depth, and their interactions, were included in the models, as well as the fishing power factors such as type of trap, radar, echo sounders and global positioning systems (GPS). The modelling approach, the changes in usage of fishing power factors and the fishing efficiency increases are presented. Preliminary results estimate the fishing efficiency increase owing to colour echo sounders and GPS to be 15% to 20% each on the catch of deeper water stocks during the non-migratory period. These fishing power changes can be used to adjust catch rates, indices of abundance and nominal fishing effort to produce a time series of standardised effort for use in modelling the effect of exploitation on the breeding stock.

1. INTRODUCTION

The western rock lobster (WRL), Panulirus cygnus, fishery is situated along the west coast of Western Australia from Fremantle in the south, to just north of Kalbarri (see Figure 1). As Australia's largest single-species fishery, it represents a significant commercial asset to Western Australia (WA), valued at about $300m annually. Therefore, it is necessary that appropriate management strategies be developed and maintained for it. There are essentially two reasons for this: (i) Economic - there is a need to maintain sustainable catch rates to ensure commercial yields; (ii) Biological - there is a possibility of over-exploitation of the species, which would be both biologically and economically undesirable. There has been a decline in the level of the spawning stock of the WRL in the early 1990's, and the fishery is considered to be fully exploited with an exploitation rate exceeding 85% from recruitment to fishery and an annual exploitation rate exceeding 60% (Phillips & Brown, 1989; Bowen & Hancock, 1989). The present state of the economic and environmental balance of the fishery necessitates that all analyses and modelling of the fishery be based upon the most accurate and reliable data available.

Catch and effort data collected from the commercial fishery are used to assess the stock. If the estimates of fishing effort are inaccurate then the estimates of stock abundance could be inaccurate, potentially leading to poor management decisions. The effective fishing effort is influenced by changes in the fishing power of the fleet. These changes have been substantial in recent years, mainly owing to advances in technology, and have lead to increases in fishing power. Changes in fishing technology which result in changes in fishing efficiency can confound the interpretation of catch rates. Thus, the incorporation of fishing power into the catch and effort statistics will help to ensure that the models are more accurate and reliable.

A preliminary assessment of the effects of increases in fishing power on fishing effort and stock assessment in the WRL fishery has been undertaken by Brown et al. [1995]. It focussed on the effects of an onboard GPS and colour echo sounder on the catch rates of legal-size lobsters in deeper waters (37 metres or more) during the "reds" non-migratory period (February to June) for each season. It showed that the increases in catch rates owing to the new technology ranged from 13% to 17%, that overall stock abundance was declining, and that further research was needed to refine the standardisation of effort to incorporate the effects of fishing power. This paper presents the methodology and major findings of the subsequent research. It expands on the preliminary study by including other fishing power factors such as radar, various time periods, and more depth categories for legal-size, under-size and spawning lobsters for each season and combined seasons.

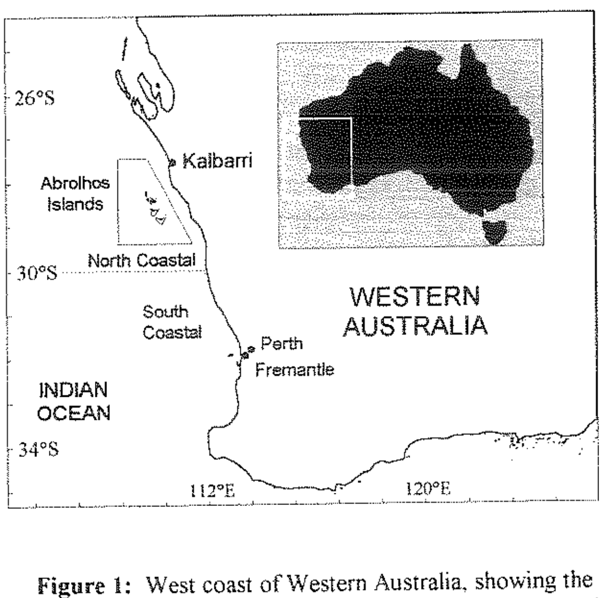

Figure 1: West coast of Western Australia, showing the three WRL fishing zones: Abrolhos Islands, North Coastal and South Coastal.

The motivation for standardising catch and effort data in stock assessments has mainly been to account for differences between vessels pertaining to fishing efficiency. Gulland [1956] and Beverton and Holt [1957] introduced frameworks and techniques for standardisation. Gulland's paper, which was significant for using a process of standardisation that compared vessel characteristics to a "standard vessel", used analysis of variance and least squares regression methods for modelling log catch per unit effort (CPUE). These methods were further developed by Robson [1966]. The relationship between vessel characteristics and the measurement of fishing power was also outlined by Parrish and Keir [1959]. Pope [1975] gives several examples of using linear regression to estimate fishing power factors that are continuous in nature, such as vessel length. Parsons et al. [1976] used a simple model for standardised effort in their stock assessment model. Gavaris [1980] used Robson's work to develop a multiplicative model to estimate catch rate and effort from commercial data. A standardised relative abundance model based on the assumption that CPUE is proportional to abundance was developed by Kimura [1981] in which fishing effort was standardised. This model was expanded by Stocker and Fournier [1984] in which forecast catch levels were improved by adjusting for vessel characteristics. Indices of abundance were also estimated by Allen and Punsly [1984] by standardising catch and effort. Large [1992] used a multiplicative abundance model that was adjusted for fishing power effects. Caputi [in press] considered that vessel characteristics, gear and equipment, and other factors that may affect catch rates should be examined when analysing catch and effort data. The impact of GPS and associated plotter systems on the relative fishing power of the Northern Prawn Fishery fleet in the tiger prawn fishery in Australia was estimated to be about 12% with three years of experience with the equipment [Robins et al. 1996]. This study highlighted the continuing gain in efficiency as a result of storing GPS information on computer.

In the WRL fishery the spatial and temporal dynamics were modelled by Walters et al. [1993], in which the seasonal nature of moulting, recruitment, migration, fishing seasons and fishing effort were taken into account. Caputi et al. [1995a] indicated that the effects of increases in fishing power need to be assessed in the prediction of catches based on indices of puerulus and juvenile abundance. Nominal fishing effort (number of traps lifted) was adjusted for increases in fishing power to analyse the relationship between spawning stock, environment, recruitment and fishing effort in the WRL fishery [Caputi et al. 1995b].

2. METHODS

2.1 Databases Used

Voluntary research log books. These have been completed by 20% to 30% of the fleet since 1964/65 and contain daily catch and fishing effort data, such as the number of traps lifted and soak-time (number of days the trap has been in the water), for legal-size, under-size and spawning lobsters, by 10' latitude transects and 5 depth zones.

Vessel, gear and equipment interviews. Interviews were held with fifty fishers throughout the fishery to obtain detailed information on changes that had occurred with their vessels, gear and technology between 1971/72 and 1989/90. Since these fishers had also been completing voluntary research log books, there are time series of catch and effort data that are synchronous with these changes.

Gear and equipment returns. Since 1989/90 fishers have been required to submit an annual form that shows any gear and technology changes made to their vessels. These give an indication of the presence or absence of various pieces of gear and equipment onboard each vessel. This database provided a larger sample of vessels than did the interviews database. Because this database was incomplete, information was interpolated when possible. If the forms indicated that a vessel had a piece of equipment, such as a GPS, in one season and again in a subsequent season, then it was assumed that the vessel had the equipment for all of the intervening seasons.

2.2 Fishing Power Assessment

The calculations of fishing power changes have been based on the general linear modelling (GLM) methodology given in the preliminary study by Brown et al. [1995]. The models used can be represented in the following simplified example:

$$Y = a + b_i(AREA_i) + c_j(MONTH_j) + \ldots + d(GPS) \quad (1)$$

Where a, b_i, c_j and d are parameter estimates, Y is the log-transformed catch rate, and GPS represents one fishing power factor. The model compares the catch rates of the vessels with the fishing power factor present to those with the fishing power factor absent. This is done by assigning a value of 1 to GPS for those with the factor, and 0 to those without it. A measure of the proportional difference in the catch rates between vessels with and without GPS, and therefore an indication of its fishing power, is then given by exp(d). Fishing power factors that were binary in nature (e.g., GPS, radar) were modelled with this presence/absence approach. Other fishing power factors of interest needed to be modelled as continuous variables.

Brown et al. [1995] used a two-stage analysis of variance (ANOVA) and regression approach to calculate fishing power. The initial ANOVA was undertaken on the logarithmically transformed catch rates to account for the variation due to some of the main factors that affect catch rates, such as month, depth, soak-time, and pot-type, which all are assumed to be fixed effects in the model. The residuals from the ANOVA were then used in a regression model to test the effects of various fishing power factors.

This study, however, has focused on a one-stage GLM approach to calculate fishing power. It was thought that this approach would provide a more complete structure for modelling catch rates as it provides the ability to account for interactions between fishing power factors and other factors because they are all included simultaneously in the model. The logarithmic transformation of the catch rates was used as the link function for each general linear model because the distribution of catch rates was skewed. Since there were some zero catches in the data, a constant was added to each catch rate to allow for the logarithmic transformation.

The main fishing power factors analysed were colour echo sounder, GPS, radar, and pot-type. Analyses could be done for pieces of equipment (modelled as binary variables) only where there were sufficient records of vessels with and without the equipment. The first task, therefore, was to examine the time series of data and select the appropriate seasons for analysis for each fishing power factor. The criterion used to select the seasons was that approximately 15% to 85% of the vessels must have had the equipment onboard. This gave sufficient numbers of records to allow for the statistical analysis. Records from different seasons were analysed together and a variable representing the season was included as a factor in the model. Interactions between this and other variables were explored.

Analyses were performed to assess the effects of the fishing power factors on catch rates of legal-size, under-size and spawning lobsters within the framework of the following considerations:

Time period: By the two distinct phases of the fishery: migratory "whites" – from November to January, when newly-moulted, immature, coastal lobsters leave the shallow onshore reefs and move seaward to deeper waters [Phillips, et al., 1980]; and "reds" – February to June, when more non-migratory lobsters are caught;

Spatial area: By regions within the coastal fishery;

Depth: By shallow (0-20 fm) and deep (20+ fm) waters;

Soak-time: One, two or three days;

Interactions: Between the above factors (e.g., month and region);
Between the above factors and the fishing power factors. (E.g., depth and GPS, which examines whether the effect of GPS is consistent over the various depth categories.)

3. RESULTS

3.1 Changes in Vessel Characteristics, Gear and Equipment.

Figure 2 shows the time series of the percentages of vessels with various pieces of equipment in the fishery. It shows the introduction of radar in the 1970's, colour echo sounders in the mid 1980's, and the rapid increase in the use of GPS in the early 1990's. Colour echo sounders replaced black and white echo sounders as underwater scanners, and GPS replaced radar as a navigational tool. Although almost all vessels now have a colour echo sounder and a GPS onboard, many vessels have also retained black and white echo sounders and radar; they would generally not, however, employ the superceded equipment for regular use. For analysing the effect on catch rates of using colour echo sounders, the appropriate seasons were 1983/84 to 1989/90; for GPS, the appropriate seasons were 1989/90 to 1991/92. Radar was suitable for analysis in all seasons from the mid 1970's but was examined over the same period as colour echo sounder. Pot-type was included in all analyses. Figure 3 shows a trend in the usage of pot-types away from beehive pots and towards the newer batten pots.

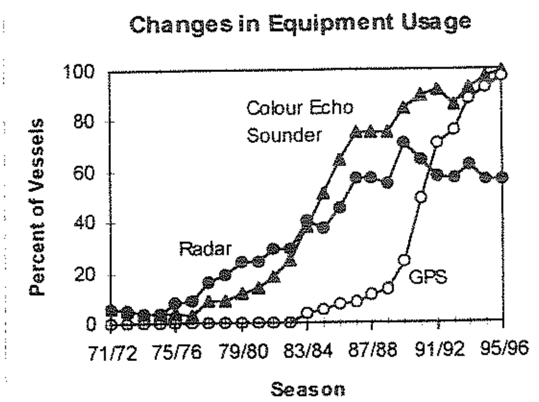

Figure 2: The changes between 1971/72 and 1995/96 in the percentages of vessels equipped with the fishing power factors radar, colour echo sounder and GPS.

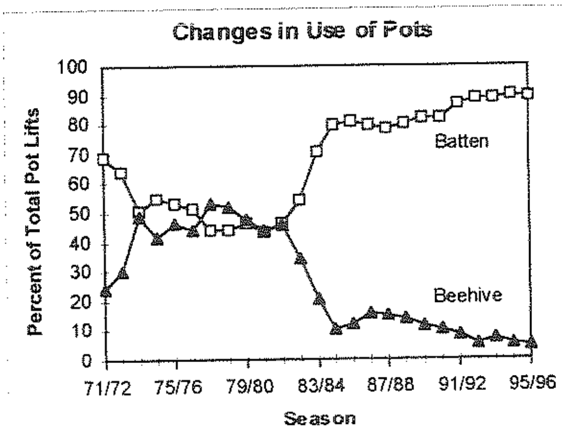

Figure 3: The percentages of batten pot lifts and beehive pot lifts from 1971/72 to 1995/96.

3.2 Fishing Power

Table 1 shows an ANOVA table resulting from a GLM procedure using SAS statistical software. The analysis was performed on the transformed catch rates within coastal regions during the reds period in depths of at least twenty fathoms for 1988/89 to 1991/92. It shows the mean square error for each variable in the model. The associated probability for each parameter is based on testing its significance as if it were the last variable to enter the model. It can be seen GPS was significant even when the model has already accounted for all other variables.

Factor	df	Mean Square	Prob. > F
Region	6	1065	0.0001
Month	4	3772	0.0001
Year	2	2893	0.0001
Soak-time	2	1095	0.0001
Pot-type	1	145	0.0282
Depth	2	1002	0.0001
Region*Month	24	482	0.0001
GPS	1	1305	0.0001
Residual	7071	30	0.0001

Table 1: ANOVA table showing the significance of GPS.

Results for some of the analyses of catch rates of legal-size, under-size and spawners are presented in Tables 2 - 4. Each table shows analyses by whites and/or reds periods of the fishery in shallow water (0-20 fm) and/or deep water (20+ fm) for the two combinations of seasons, 1983/84 to 1988/89 and 1989/90 to 1991/92. Each analysis shows the parameter estimate for the fishing power factor, its standard error, and the estimated percentage increase in catch rate. Table 2, for example, shows that, for the 1983/84 to 1988/89 combined seasons analysis, for deep water during the reds period, a vessel with a colour echo sounder had a catch rate which is approximately 28% greater than the catch rate of a vessel without a colour echo sounder. Table 3 shows that batten pots were catching 88% more under-size lobsters than beehive pots during the whites, in shallow waters, for the latter seasons.

The increases in catch rates varied considerably by depth and period. Generally, for legal-size lobsters, the effect of colour echo sounder, radar, and GPS was greater in deeper water and during the reds period. Colour echo sounder had a very large effect on the catch rates of under-size lobsters during both whites and reds (67% and 106%, respectively), while radar (13%) and GPS (7%) showed moderate effects during the whites and no effect during the reds. For spawners, colour echo sounder and GPS increased catch rates by 15% and 16%, respectively, while radar showed no effect. The pot-type showed some consistent results. For legal-size, batten pots were generally catching 14% to 20% more than beehive pots, but beehive pots were catching more in deep water during the reds. Catch rates of under-size lobsters were very much greater with batten pots than with beehive pots, ranging from 88% to 354%. For spawning lobsters, beehive pots were catching more in the earlier seasons (16% difference), while batten pots were catching more in the latter (8% difference).

1983/84 – 1988/89		Whites			Reds		
Depth	Factor	Parameter	SE	% Increase in catch rate	Parameter	SE	% Increase in catch rate
0-20 fm	Colour E.S.	0.014	0.016	2	0.045	0.010	5
	Radar	-0.048	0.014	-5	-0.049	0.009	-5
	Pot-type	0.178 BAT	0.021	19	0.186 BAT	0.014	20
20+ fm	Colour E.S.	0.104	0.025	11	0.249	0.028	28
	Radar	-0.062	0.021	-6	0.136	0.028	15
	Pot-type	0.181 BAT	0.027	20	0.127 BEE	0.033	14
1989/90 – 1991/92		Whites			Reds		
Depth	Factor	Parameter	SE	% Increase in catch rate	Parameter	SE	% Increase in catch rate
0-20 fm	GPS	0.007	0.011	1	-0.016	0.007	-2
	Pot-type	0.208 BAT	0.019	23	0.129 BAT	0.013	14
20+ fm	GPS	0.079	0.017	8	0.144	0.022	15
	Pot-type	0.034 BAT	0.022	3	0.056 BEE	0.026	6

Table 2: Summary of results for legal-size lobsters.

1983/84 – 1988/89	Whites			Reds		
Factor	Parameter	SE	% Increase in catch rate	Parameter	SE	% Increase in catch rate
Colour E.S.	0.514	0.046	67	0.725	0.031	106
Radar	0.126	0.045	13	-0.105	0.034	-10
Pot-type	0.816 BAT	0.047	126	1.512 BAT	0.038	354
1989/90 – 1991/92	Whites			Reds		
Factor	Parameter	SE	% Increase in catch rate	Parameter	SE	% Increase in catch rate
GPS	0.063	0.023	7	-0.012	0.015	-1
Pot-type	0.629 BAT	0.037	88	0.746 BAT	0.028	111

Table 3: Summary of results for under-size lobsters (0-20 fm only).

1983/84 – 1988/89			
Factor	Parameter	SE	% Increase in catch rate
Colour E.S.	0.141	0.029	15
Radar	-0.054	0.025	-5
Pot-type	0.152 BEE	0.029	16
1989/90 – 1991/92			
Factor	Parameter	SE	% Increase in catch rate
GPS	0.151	0.023	16
Pot-type	0.076 BAT	0.028	8

Table 4: Summary of results for spawning lobsters (20+ fm, whites only).

4 DISCUSSION

The impact of technology on the catch rate of legal-size lobsters was more noticeable in deep waters. When vessels fish further offshore, in deeper waters, GPS and radar become more effective as navigational tools, and a colour echo sounder becomes more effective as an underwater scanner and depth monitor. The results indicate that these pieces of equipment do not have as much an impact on catch rates in shallow waters. The impact of colour echo sounders was more consistent than that of radar and GPS, across both whites/reds periods and shallow/deep water. Both radar and GPS resulted in increased catch rates of legal-size lobsters in deep water during the reds period, and increased catch rates of under-size lobsters in deep water during the whites period. The catch rates of under-size lobsters were affected significantly by the use of a colour echo souder and batten pots. The catch rates of spawning lobsters has been increased significantly by GPS and colour echo sounder, but not by radar.

The type of pot used had a significant impact on catch rates of legal-size, under-size and spawning lobsters. Generally, catch rates of legal-size lobsters in shallow waters with batten pots were greater than those with beehive pots. This supports the findings of the preliminary study by Brown et al. [1995]. Beehive pots were catching more in deep waters during the reds period.

The analyses of whites and reds periods generally showed that, for legal-size lobsters, the impact of fishing power factors was greater during the reds than the whites, and, for under-size, the impact was greater during the whites.

The combined effect of radar and GPS, which have similar functions onboard a vessel, is not clear. The effect of GPS in the latter seasons resulted in a 15% better catch rate for vessels equipped with a GPS, compared to vessels which had either radar and no GPS, or neither radar nor GPS (for legal-size lobsters in deeper water during the reds period). The corresponding effect of radar in the earlier seasons was assessed to be 15%. This indicates that the proportional difference in catch rates between vessels which have GPS and vessels which have neither GPS nor radar may be up to 30%.

Parameter estimates that were negative do not indicate that the use of the fishing power factor decreases the catch rate. Statistically, the significance of the parameter is based on a one-tailed test. That is, the fishing power factor is being tested to determine if it is increasing the catch rate, and not to determine if it is increasing or decreasing the catch rate. Intuitively, the presence of, for example, a GPS onboard a vessel could, if anything, only increase its fishing power, and so a negative parameter estimate for GPS could be thought of as implying that it has no effect on the catch rate.

The assessment of fishing power factors during seasons other than those presented here has been done. Results indicate similar effects on catch rates for the fishing power factors. For example, for the seasons 1971/72 to 1982/83, colour echo sounder increased catch rates of legal-size lobsters by about 15%, in deep water, reds.

The use of general linear modelling was useful for analysing the interview, returns and log book datasets, considering their statistically unbalanced nature. The results, however, are not based on a properly designed random experiment, but on data that is produced from choices made by fishers (e.g., targeting specific regions at certain times). The assumption of independence between observations was not wholly satisfied because the datasets included daily records from the same vessels. The analysis is also affected by the fact that better fishers may tend to use better equipment first. Given this, the resulting standard error and significance for the parameter estimates should be considered only as a guide

Fishing power increases in the WRL fishery fleet have occurred between 1971 and 1996 as a result of the adoption of better fishing gear and more technologically advanced equipment. The estimates of fishing power increases can be applied to the nominal effort in order to standardise the overall fishing effort to account for these fishing power increases

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