Australian Vessel Performance in the East Coast Tuna Longline Fishery

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Introduction

The Australian east coast tuna longline fishery is currently exploited by domestic vessels and by Japanese vessels under an access agreement. The Japanese fleet access to eastern Australian waters is shown in Figure 1. About 100 Japanese vessels were involved in 1989, although numbers have since fallen to around half that level. Their fleet consists of three groups of vessels: large (200–500 Gross Registered Ton, GRT) longliners which fish in the southern part of the Japanese fishery (south of lat. 25°S) when the southern bluefin tuna, *Thunnus thynnus,* fishery is not underway; smaller (150–200 GRT) longliners which fish in Australia's northern tropical and subtropical waters and in the adjacent Exclusive Economic Zones (EEZs); and a small group of Japanese vessels which follow the stocks in both the northern and southern zones of the fishery. The Japanese vessels target the full range of tuna and billfish species available in the Australian EEZ, the total catch being 6,068 metric tons (t) on average in the years 1987–89. The average catch composition by weight was: 2,589 t yellowfin tuna, *Thunnus albacares* (about 43% of the total by weight), 557 t bigeye tuna, *Thunnus obesus* (9%), 1,453 t albacore, *Thunnus alalunga* (24%), 699 t swordfish, *Xiphias gladius* (11.5 %), and 770 t marlin (12.5%) (148 t black marlin, *Makaira indica*, 281 t blue marlin, *Makaira mazara,* and 341 t striped marlin, *Tetrapturus audax*) (McIlgorm, 1995).

The Australian vessels operate from various ports along the coast. They are typically smaller (<15 m) than the Japanese vessels, operate with lighter monofilament gear than the Kuralon[1] used by the Japanese, and target stocks which are closer to the surface. Of the approximately 100 Australian boats engaged in the fishery, 50% reported catching only yellowfin tuna. The catch composition by weight of the Australian fleet during 1987–89 averaged 295 t yellowfin tuna (85%), 9 t bigeye tuna (3%), 31 t albacore (9%), 5 t swordfish (1%), and 7 t striped marlin (2%) (McIlgorm, 1995). The overwhelming concentration of yellowfin tuna in the Australian vessels' catch, as compared with the Japanese vessels, is explained by the tendency of Australian vessels to fish surface schools within 50 n.mi. from shore (Fig. 2). For this reason, the Australian fishery, unlike the Japanese fishery, can be modeled as a single-species fishery, with catches of other species regarded as by-catch. An analysis of the performance of the multispecies Japanese vessels is contained in McIlgorm (1995).

This paper describes the results of an analysis of the catching performance of the Australian vessels in the fishery. A sample of 3,860 daily observations on domestic vessels engaged in the fishery in the period 1987–90 was used to relate tuna catch to vessel characteristics and operations. The effect on the catch of factors such as vessel type, fishing conditions (moon phase, sea surface temperature), fishing practices (soak time, patrolling the longline), location in terms of distance from the coast, and seasonal and annual fluctuations in stocks is estimated.

Tuna Production Model

The basis of the analysis is the Cobb-Douglas production function which is a simple economic model of production which describes the harvesting of tuna by an individual vessel:

$$h = AE^{\alpha}x^{\beta},$$

where h is daily harvest in metric tons, E is the daily amount of effort measured in thousands of hooks fished, x is the stock of tuna susceptible to the vessel's fishing gear during the day, A is the catchability coefficient, and α and β are constants. A special form of this model, in which $\alpha = \beta = 1$, was adopted by Schaefer (1967) in a time-series study

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ABSTRACT—A sample of daily observations on the activities of Australian vessels longlining for yellowfin tuna, Thunnus albacares, *during 1987–90 was analyzed, using a production function approach, to determine the effects of vessel characteristics and operational practices and conditions. Significant differences were found between the tuna fisheries in the northern and southern regions of the inshore yellowfin tuna fishery in the east Australian Exclusive Economic Zone. The type of vessel used, and fishing practices such as soaktime, patrolling the longline, and choice of surface water temperature were found to have significant effects on yellowfin tuna catch rates.*

[1] Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

of the eastern Pacific yellowfin tuna fishery, and it has been extensively used in bioeconomic studies to relate total harvest to fishing effort and fish stock. The model has also been used in cross-sectional studies to estimate the relationship between the catch and effort of individual vessels. Examples are the Strand et al. (1981) study of the Atlantic surf clam fishery, and the Bjorndal (1989) study of the North sea herring fishery. Other cross-sectional studies, such as those of Morey (1986) and Squires (1987), estimate cost functions derived from general forms of production functions which include the Cobb-Douglas as a special case.

The Cobb-Douglas production function cannot be directly estimated because of the absence of observations on the stock of fish encountered by each vessel. For this reason it will not be possible to estimate the catchability coefficient, A, or the coefficient of stock, β. However, indirect measures of the factors influencing catchability, and of stock levels, can be generated by means of a series of dummy variables. Using these measures, together with the observations on catch and effort, the constant, α, on fishing effort in the production function can be estimated. The factors affecting the tuna stock encountered by each vessel, and the vessel's catchability coefficient can be divided into the categories of vessel characteristics, fishing practices, and stock levels.

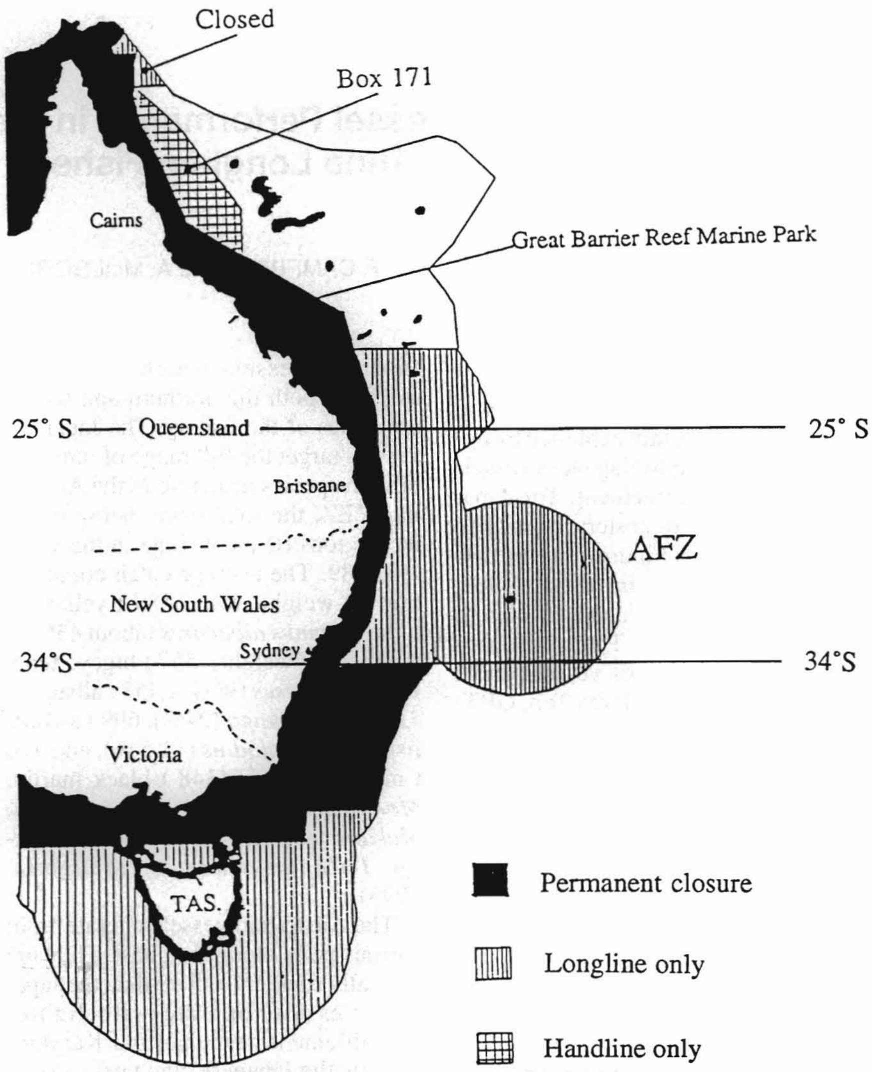

Figure 1. — Japanese vessel access to the east Australia Fishing Zone (AFZ) in 1989. The areas south of lat. 34°S, adjacent to the Great Barrier Reef Marine Park and Box "171" have been closed to fishing since 1984.

Vessel Characteristics

Four types of vessels are used in the domestic longline fishery. Planing longliners are high-speed, high-horse power, low-displacement hull vessels of up to 15 m length and are commonly used in Australian rock lobster fisheries. Multipurpose vessels are displacement-hull vessels under 15 m that undertake alternative fisheries such as trapping, droplining, or potting, as well as tuna longlining. Many trawlers convert to longline gear when the tuna stocks are available, whereas purpose-built longliners are displacement-hull vessels that can be up to 18 m in length and have been designed specifically for longlining and droplining of fish for fresh markets. It is possible that the vessels which are specifically designed for the fishery will have an advantage in terms of catchability, and that the speed of the planing longliner and the length of purpose-built vessels will provide an additional advantage.

Fishing Practices

Several choices which are made by vessels may affect catchability and/or the level of stock open to exploitation. Catchability may be affected by the length of soak time, by intermittent patrolling of the longline during the day to retrieve fish and rebait hooks, or by moon phase. Catchability is thought to rise in the darker phases of the moon (DPIE[2]), and tidal patterns are also associated with moon phase. The choice of where to fish in terms of distance from the coast (0–12, 12–50, 50–100, or >100 n.mi.), or in terms of sea surface temperature may affect the stock level in the locality.

[2] DPIE. 1990. New South Wales logbook co-ordinators report. Aust. Fish. Serv., Dep. Primary Ind. Energy, Canberra, Aust. Unpubl. doc.

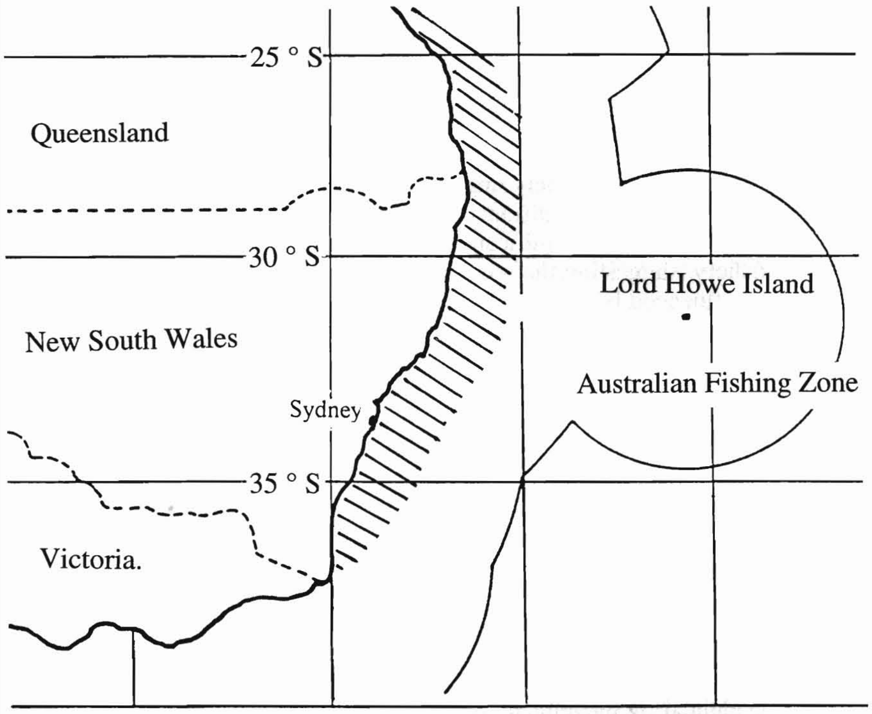

Figure 2. — The area of the domestic fishing effort along the New South Wales and Southern Queensland coasts. The hatched area represents the inshore fishing grounds favored by the domestic vessels.

Stock Levels

Harvest will be determined by the level of fish stocks susceptible to the vessel's fishing gear during the day, the latter being influenced by the general stock conditions in the EEZ. Tuna and billfish are migratory, and stocks are known to fluctuate on a seasonal and annual basis.

All these factors are accounted for in the production analysis. In addition the analysis allows for the possibility of significant differences between the northern and southern zones of the domestic fishery. The northern zone is defined as the area north of Sydney, from lat. 34° to 25°S; the southern zone is the area south of Sydney, from lat. 34° to 38°S (Fig 2).

Estimation

It is convenient to estimate the production model in logarithmic form. The equation estimated is:

$$\ln(h) = A + aPt + b_1Z_1 + b_2Z_2 + b_3Z_3 + c_1C_1 + c_2C_2 + c_3C_3 + m_1M_1 + m_2M_2 + m_3M_3 + q_1Q_1 + q_2Q_2 + q_3Q_3 + y_1Y_1 + y_2Y_2 + y_3Y_3 + \alpha\ln(E) + \gamma T + \delta\ln(St) + U,$$

where: $\ln(h)$ is the natural logarithm of daily yellowfin tuna harvest, A is a constant, a, b_1, b_2, b_3, c_1, c_2, c_3, m_1, m_2, m_3, q_1, q_2, q_3, y_1, y_2, y_3, α, γ, and δ are coefficients to be estimated, Pt is a dummy variable taking the value 1 if the longline was patrolled and zero otherwise, Z_1, Z_2, and Z_3 are dummy variables representing the 12–50, 50–100, and >100 n.mi. zones from the coast (with the default value of the dummy representing the 0–12 n.mi. zone), C_1, C_2, and C_3 are dummy variables representing the vessel classes multipurpose vessels, trawlers, and purpose built vessels, respectively (with the default value of the dummy representing planing longliners), M_1, M_2, and M_3 are dummy variables representing the new moon, first quarter, and full moon respectively (with the default value of the dummy representing the last quarter), Q_1, Q_2, and Q_3 are dummy variables representing the April–June, July–September, and October–December quarters, respectively (with the default value of the dummy representing the January–March quarter), Y_1, Y_2, and Y_3 are dummy variables representing the years 1988, 1989, and 1990, respectively (with the default value of the dummy representing 1987), $\ln(E)$ is the natural logarithm of the number of hooks fished in the day, T is a temperature-related variable which measures stock availability, and St represents soak time and U is a random error term assumed to have zero mean and constant variance.

The Australian vessels primarily harvest yellowfin tuna. Researchers have determined upper and lower bounds for water temperatures where they are known to range, and fishermen search for a level of sea surface temperature (SST) which they believe maximizes the chance of locating fish. In this study, the optimum water temperature was assumed to be 21.5°C. If yellowfin tuna stocks tend to be most abundant in waters of 21.5°C, then it can be assumed that the further the actual SST is from this value, the lower the stock level. A crude indicator of the stock level available to a vessel is given by $1/\exp(\gamma T)$ where T is the absolute value of the difference between the actual SST and the optimal temperature. If a vessel is fishing waters at 21.5°C the stock indicator takes on a value of unity; this value declines exponentially as the water temperature diverges from the optimum. Since the larger the value of T the lower is the stock assumed to be in the vicinity of the vessel, it would be expected that the estimated value of γ, the coefficient on T, would be negative.

The equation is first estimated by Ordinary Least Squares (OLS) using all the observations in the sample. Tests indicated the presence of heteroscedasticity in the sample, and standard data transformations were performed in an unsuccessful attempt to eliminate this problem. In the presence of heteroscedasticity in the sample, the OLS coefficient estimators are unbiased but the estimated t statistics are biased. The sample is then divided into northern and southern subsamples, and a log likelihood radio test is used to determine whether the production processes in the north and south are the same. This test indicated that the northern and southern zones should be regarded as distinct fisheries. The northern and southern samples were then examined to determine whether any groups of variables could be excluded as having an insignificant effect on yellowfin tuna catch. It was found that in the northern fishery, yellowfin tuna catch did not vary significantly with distance from shore, and this set of variables was dropped from the model. In the southern fishery, it was found that yellowfin tuna catch was not significantly affected by distance from shore, vessel class, or moon phase, and these variables were dropped from the model.

Results

Since the northern and southern fisheries were found to have different characteristics, results will be reported for each. Table 1 reports the coefficients estimated for each of the independent variables in final versions of the estimating equations, together with t statistics. Coefficient estimates which are significantly different from zero at the 1%, 5%, and 10% levels of significance are marked by asterisks. As mentioned above, these tests of significance may not be reliable because of the problem of heteroscedasticity.

Discussion

In the initial estimations it was found that moonphase and class of vessel had no significant effect on yellowfin tuna catch in the southern fishery, and these variables were omitted from the final specification of the southern model. Patrolling the longline was found to have no significant effect on yellowfin tuna catch in the northern fishery and this variable was also omitted. Distance from shore was found to be significant in neither fishery, suggesting that performance is influenced by local availability of fish rather than choice of fishing ground.

The coefficients on the year dummies indicate that 1988 and 1990 were particularly good years for the northern fishery, whereas 1989 and 1990 were good for the southern fishery. The fluctuations from year to year are quite significant: for example, the 1989 yellowfin tuna vessel catch level in the southern fishery was more than double that in the base year, holding all other factors constant. These annual fluctuations are partly explained by movements of the East Australia Current. The coefficients on the seasonal dummies suggest that there is little seasonal variation in yellowfin tuna catches for given levels of effort in the northern fishery, whereas in the southern fishery performance in the first quarter of the year is markedly below that in the rest of the year. This pattern is consistent with anecdotal evidence and can be attributed to movements in the East Australian Current (DPIE[2]).

The results indicate that patrolling the longline in the southern fishery increases yellowfin tuna catch by 16%, holding all other factors constant. A 1% increase in soak time was found to increase yellowfin tuna catch by 0.2% in the northern fishery, and 0.08% in the southern fishery. These results perhaps reflect the fact that longer soak times (11.23 h avg.) backed up by patrolling the longline are the norm in the southern fishery, whereas the northern fishery employs shorter soak times (5.96 h avg.). When a hook encounters a tuna, the bait is either removed or the fish hooked. In either case, the hook ceases to fish. Patrolling the line to remove hooked fish and/or rebait will significantly increase catch if there is a significant probability that the rebaited hook will encounter another fish. Since tuna travel in schools, the probability of rebaited hook encountering another fish depends on the probability of the longline encountering another school. It may be that short soaktimes used in the northern fishery make probability of the longline encountering a second school of tuna fairly low. The use of the shorter soaktimes in the north, despite the apparent benefit of an increase in soaktime, may be due to technical factors such as strong currents which rapidly move the line from its point of setting.

The results suggest that in the northern fishery purpose-built longliners and trawlers have a significant catching advantage over multipurpose vessels and planing longliners. For example, holding all other factors constant, a purpose-built longliner will have a 64% higher yellowfin tuna catch, and a trawler a 33% higher yellowfin tuna catch than a planing longliner. Against this advantage in yellowfin tuna catch performance must be set any disadvantage in terms of higher costs of operating these vessels. However, a survey by Campbell and McIlgorm (1992) revealed that the cost per unit of effort for planing longliners was around 1.8 times that of multipurpose vessels and trawlers. Cost data were not available for purpose-built vessels.

SST recorded by fishermen constituted a significant variable in both fish-

Table 1.—Results of the regression for the period 1987–90.[1]

Variable	North	South	Variable	North	South
A (Constant)	0.874** (2.28)	0.756* (2.57)	q_2 (Season 2)	0.285*** (1.72)	0.382* (5.17)
a (Patrol)	N/A[2]	0.151* (3.50)	q_3 (Season 3)	−0.235 (−1.36)	0.365* (5.80)
m_1 (New moon)	0.107 (1.42)	N/A	y_1 (1988)	0.464* (5.04)	0.285* (4.16)
m_2 (First phase)	−0.104 (−1.36)	N/A	y_2 (1989)	−0.036 (−0.47)	0.766* (12.22)
m_3 (Full moon)	−0.047 (−0.62)	N/A	y_3 (1990)	0.263* (3.19)	0.488* (7.09)
c_1 (Multipurpose)	0.077 (0.89)	N/A	δ (lnSt)	0.201* (4.12)	0.08* (2.88)
c_2 (Trawlers)	0.285* (4.28)	N/A	α (ln effort)	0.724* (11.65)	0.535* (10.59)
c_3 (Purpose built)	0.498** (2.37)	N/A	γ (Temperature)	−0.106* (−4.39)	−0.068* (−3.65)
q_1 (Season 1)	−0.141 (−0.79)	0.407* (7.83)	Summary statistic: R_2 north = 0.267, south = 0.138. Sample size (n) = 1,412 (north) and 2,448 (south).		

[1] * = t significant at 1% level, ** at 5% level, *** at 10% level (t ratios in parenthesis).
[2] N/A = not applicable.

eries. In the north an additional 1° more or less than the optimal temperature reduced yellowfin tuna catch by 11%, whereas in the south the estimated reduction is 7%. This confirms the view that local movements of yellowfin tuna stocks are influenced by water temperature variations, and that information on water temperature is important in the conduct of the fishery.

The constant term in each production function represents the log of catch for base values of the dummy variables, without taking into account the effects of soak time, water temperature, and local stock depletion caused by the level of individual vessel effort. It can be used to calculate a base level of yellowfin tuna catch per unit of effort (CPUE) in each fishery for assigned values of the soak time, temperature, and effort variables. When effort and soak time are assigned their mean values, water temperature assumes its optimal value, and all dummy variables are set equal to zero, it can be estimated that 277 hooks set in the northern fishery yield 201 kg of yellowfin tuna and 345 hooks in the southern fishery yield 59 kg. The corresponding CPUE estimates are 0.73 kg per hook in the north and 0.17 in the south. This comparison understates the relative performance of the southern fishery since, as can be seen from the positive signs of the coefficients of the season and year dummies, the base period chosen for the comparison is the worst season in the worst year of the sample for the southern region. However, the comparison can also be carried out for the best season in the best year for each region, and allowing vessels in each region to adopt those fishing practices identified by the analysis as advantageous. When this is done the CPUE is 2.53 kg in the north, and 0.64 kg in the south. Thus the northern region appears to have a fourfold advantage over the south in terms of CPUE.

The coefficient on the log of effort is an estimate of the percentage increase in yellowfin tuna catch per vessel in response to a 1% increase in the level of effort. Again the comparison of the northern and southern fisheries favors the north: a 1% rise in vessel effort produces a 0.72% rise in yellowfin tuna catch in the northern fishery and a 0.54% rise in the southern fishery.

The comparison of the northern and southern fisheries suggests that a shift of vessel effort from the south to the north would increase total yellowfin tuna catch. This result may reflect the fact that the southern fishery is operating close to the limit of the distribution of yellowfin tuna in the South Pacific Ocean.

Conclusion

In summary, the analysis of the 1987–90 sample provided some evidence of seasonal and annual fluctuations in performance: season 2 (July–September) was clearly best in the north, whereas season 4 (January–March) was clearly worst in the south; 1987 and 1989 were the worst years in the north, and 1987 was the worst in the south. Moon phase was of no significance in the south and of little significance in the north.

Some fishing practices appeared to provide a relative yellowfin tuna catching advantage. The use of trawlers and purpose-built vessels provided higher catch rates in the north, holding other factors constant. Patrolling the longline resulted in a significantly higher catch in the south but not in the north. Soak time is important in both fisheries, but more so in the north where there appear to be significant gains to longer soak times; these apparent gains might be offset by operational difficulties resulting from drifting of the longline. In both regions of the fishery placing the longline in waters close to 21.5°C results in significantly higher catch rates.

Overall, the northern region seemed to provide significantly higher yellowfin tuna CPUE. Furthermore, the predicted response of catch to an increase in effort per vessel was more favorable in the north than the south. This suggests that consideration might be given to developing the northern fishery further.

Acknowledgments

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