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Maximizing Resource Rent From the Western and Central Pacific Tuna Fisheries

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Abstract *Rent generated by the tuna fisheries occurring in the waters of Pacific Islands Nations is estimated for various levels and combinations of purse-seine, pole-and-line, frozen tuna longline, and fresh tuna longline fishing effort, using a multi-species, multi-fleet bioeconomic model. The underlying population model integrates available information on the population dynamics of skipjack, yellowfin, bigeye, and Southern albacore tunas in the Pacific Ocean. The economic model utilizes the most recent data on fishing effort costs for the purse seine, pole-and-line, and longline fleets operating in the western and central Pacific Ocean, along with recent estimates of prices by species, method of capture and market, and estimates of demand elasticities. The results of the model indicate that fishery rent could be increased substantially above the current level by decreasing the size of all fleets, with the possible exception of the tuna longline fleet. The results also suggest that the countries of the region could benefit significantly by changing the level and structure of access fees levied as a percentage of total catch revenue.*

Key words Bioeconomic model, Western Pacific tuna fishery.

Introduction

The substantial changes which have occurred in the level and composition of fishing effort in the western and central Pacific Ocean (WCPO) in the past 20 years have taken place in the context of an evolving management regime. However, manage-

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ment measures are still at a relatively early stage of development, and it is reasonable to describe the changes in effort levels which have occurred as market driven. It is well understood that following private market incentives in the exploitation of a fishery is likely to result in rent dissipation. The purpose of this paper is to estimate the level and composition of effort which maximizes fishery rent in the WCPO tuna fisheries, with particular emphasis on the returns to the countries of the region.

Background

Over the last 20–30 years, the tuna fisheries in the WCPO have undergone a period of rapid restructuring and expansion. Figure 1 shows the trends in the catches of the three major gear types over the period, and figure 2 shows the area covered by the WCPO. Most of the expansion in total catch can be attributed to a dramatic increase in the size of the purse-seine sector of the fishery, as shown in figure 1. The purse-seine fishery developed rapidly in the late 1970s and 1980s in response to an improved technological ability to fish the deeper thermocline found in the WCPO, poor fishing conditions in the eastern Pacific Ocean (EPO), and the emergence of the Korean, Taiwanese, and Japanese purse-seine fleets. In addition, in the early 1990s, there was a shift of US purse-seine fishing effort from the EPO to the WCPO in response to consumer boycotts of tuna caught with a dolphin bycatch—a problem encountered only in the eastern Pacific. The introduction of the 1990 Dolphin Protection Consumer Information Act in the United States prompted canneries to require that purse seine vessels fishing in the eastern tropical Pacific provide certification that their tuna catches were not taken in association with dolphins. This requirement gave added stimulus to the move from the eastern to the western Pacific (Sakagawa 1991).

In contrast, the pole-and-line fishery went through its growth phase in the early 1970s, with vessel numbers peaking in 1978, partially in response to growth of the canned tuna market, and partially in response to the Japanese government's subsidization of its distant water fleet. The subsequent decline of the pole-and-line fleet is mainly attributable to the emergence of the purse-seine fleet, which has been more efficient at supplying canning-grade tuna. However, some pole-and-line fleets, such as the Solomon Taiyo fleet, a joint venture between the Solomon Islands government and the Japanese Taiyo Fishing Company operating as a domestic fishery in the Solomon Islands, have remained viable, and vessel numbers remain constant for this fleet. Furthermore, the Japanese pole-and-line fleet appears to have stabilized after a period of large decline in vessel numbers. The ability to supply higher-value markets (Hand and Forau 1997b) and slight increases in productivity (Campbell and Hand 1998) have contributed to the improved viability of the Japanese fleet. The reluctance of some markets to accept purse-seine catch, due to perceptions of high dolphin bycatch, has also helped the pole-and-line fleets remain viable (Hand and Forau 1997b).

The longline fleet, which predominantly supplies the Japanese *sashimi* market, has declined in terms of its percentage of the total catch. However, because *sashimi* fetches prices much in excess of those paid for canning-grade tuna, revenues are almost as high as those of the purse-seine fishery. Longline catch peaked in 1980 (167,145 mt), and then went through a period of moderate decline, falling to a low of 85,841 mt in 1989. Then, from the early- to mid-1990s, there was a resurgence in the longline fleet, with catch rising to 145,647 mt in 1994. This increase in vessel numbers is mainly due to the improvement in airfreighting logistics for fresh tuna, which prompted a large influx of "fresh tuna" longline vessels.

Tropical tuna, due to their high fecundity, fast growth rate, high natural mortality, and weak stock-recruitment relationship are considered to be very productive and resilient to fishing. However, with the overall increase in fishing effort, resource owners throughout the region are aware of the need to manage the fishery in a sustainable fashion. Furthermore, questions of optimal fleet composition are being raised more frequently. Clearly, the question of fleet composition cannot be left to the harvesting sector (the supply side of the market) because of the well-known inefficiencies associated with the exploitation of common property assets (Gordon 1954).

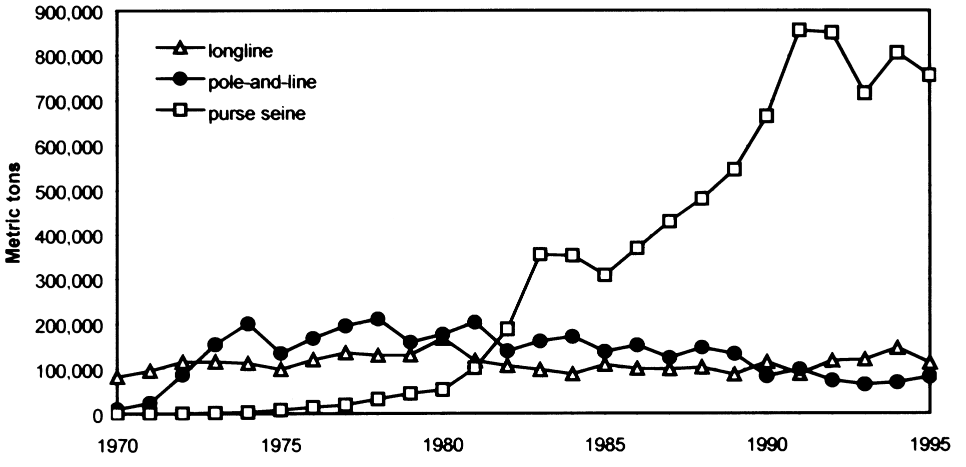

Figure 1. Annual Catch by Purse Seine, Longline and Pole-and-Line Vessels in the Western Pacific Tuna Fishery, 1970–95
Source: South Pacific Commission Yearbook 1995 (SPC 1996).

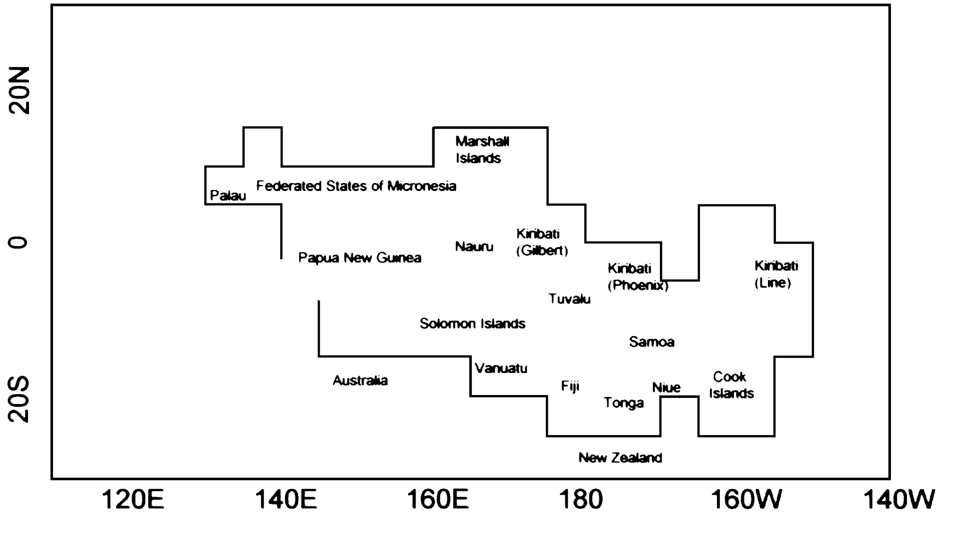

Figure 2. The FFA Region as Defined in the Model (dark line)

Some previous studies have partially addressed the issue of optimal fleet composition. Campbell (1994) and Campbell and Nicholl (1995) examined the effect of a hypothetical marginal reallocation of the yellowfin tuna stock from the purse-seine to the longline fishery, and Hampton *et al.* (1997) modelled the interaction between the purse-seine and pole-and-line fleets in the Solomon Islands Fishing Zone.

The study by Campbell (1994) was illustrative in nature and suggested that, using plausible values for economic and biological parameters, the benefits of a reallocation of the yellowfin tuna stock towards the longline fleet would outweigh the costs to the purse-seine fleet. The study by Campbell and Nicholl (1995) was more rigorous, incorporating detailed models of the production processes and costs of the multi-species purse-seine and longline vessels and utilizing biological parameters drawn from various sources. While it supported the conclusions of Campbell (1994), a critical parameter, measuring the change in longline yellowfin cost per unit effort (CPUE) in response to a change in purse-seine catch, was derived from time series data on catch and effort for the two fleets. This statistical association reflects natural fluctuations as well as the interaction of the two fleets. Furthermore, since it is a marginal effect measured at existing fleet levels, it is likely to be unreliable as a guide to what would happen if there was a substantial movement away from the current balance of effort between the two fleets. Hence, it can be argued that the indicative results of these two studies need to be tested against the predictions of a full-scale bioeconomic model before policy conclusions can be drawn.

The study by Hampton *et al.* (1997) is a bioeconomic model of the purse-seine and pole-and-line fisheries in the Solomon Islands Fishing Zone. While the model is at the required level of detail, it deals only with the exploitation of skipjack and yellowfin stocks in a single EEZ. It finds that the rent generated by the two fleets in the Solomon Islands could be increased by significantly increasing the level of purse-seine effort above the average level during the period 1989–91. However, the model ignores the effect on the region's longline fishery through the impact of additional purse-seining on stocks of adult yellowfin and bigeye tuna.

To assist in determining optimal fleet sizes, the present study, using a bioeconomic model of the WCPO tuna fishery, estimates the effect of changes in levels and composition of fishing effort in the waters of member countries of the Forum Fisheries Agency (FFA) on profitability of the fishery in that area. The FFA region is approximated by an area encompassing the EEZs of Pacific Island FFA countries at a 5˚ resolution, and, therefore, contains some small areas of high seas (figure 2). The FFA assists its members in bilateral and multilateral negotiations with distant water fishing nations wishing to exploit the region's tuna stocks and maintains a register of foreign fishing vessels that are permitted to operate in member countries' EEZs (Doulman and Terawasi 1990). Since the aim of the paper is to determine the potential value of the tuna fisheries in waters administered by the FFA, the eastern Pacific purse-seine fleet, the Japanese "north Pacific" pole-and-line fleet, and the portions of effort distributions of the other fleets occurring outside this region are automatically excluded from the economic calculations (but are accounted for in the biological model).

The FFA region was the area studied by Herrick, Rader, and Squires (1997) in their analysis of short-run profits that could be earned by the existing US purse-seine fleet if it operated under individual vessel quotas on catches of skipjack and yellowfin. The present model is more general in several respects: it includes the activities of all significant gear types operating in the region; it incorporates all significant tuna species; and it allows for changes in the level of effort of each gear type, and corresponding changes in stock densities and CPUE. Since the measure of profit is a long-run measure that includes profit from all significant tuna fishing activities, it is an appropriate guide to the optimal exploitation of the region's tuna resources.

The model accounts for a variety of fishery interactions. One of the most important occurs as a result of purse-seine vessels catching juvenile surface-swimming yellowfin, thereby reducing the number of mature yellowfin found in the mid-water strata and exploited by the longline fleet. Another significant interaction is between the pole-and-line and purse-seine fleets, as they both catch large quantities of skipjack. The main interactions are illustrated by the catch statistics reported in table 1.

Clearly, not all species have been caught in significant quantities by each of the fleets. For example, purse-seine vessels catch mainly skipjack and yellowfin, while longliners catch mainly albacore, bigeye, and yellowfin (the albacore catch is mainly taken in sub-tropical and temperate waters). However, the recent use of deeper fishing techniques has resulted in purse-seiners also catching increased quantities of juvenile bigeye. This interaction has also been included in the model and will, therefore, have an effect on optimal vessel numbers. It should be noted, however, that the extent of the bigeye interaction is, in fact, likely to be much greater than that shown by the model, simply because the model has been developed using data for the 1988–94 period, and purse-seiners have significantly increased their catch of bigeye since then (SPC 1998). Future updates of the model will incorporate catchability coefficients that are more representative of the greater purse-seine catch of bigeye and will better reflect the current interaction between purse-seine and longline catches of bigeye.

Population Dynamics Model

The tuna population dynamics model is a spatially disaggregated, multigear, multispecies simulation model. The model is age structured, to account for growth and gear selectivity, and includes tuna movement based on a diffusion-advection equation in which the advective term is proportional to the gradient of a habitat index. The model predicts the spatial distribution of spawning, the age-structured population, and the catch for various fishing fleets as a function of specified levels and distributions of fishing effort. Details of the structure of the population dynamics model are provided in Bertignac, Lehodey, and Hampton (1998), which deals with one species (skipjack) and two fleets (purse-seine and pole-and-line). A summary description of the expanded version of the Bertignac, Lehodey, and Hampton model used in the present study is provided below.

Species and Fleets Treated by the Model

Four tropical tuna species are included in the model—yellowfin (*Thunnus albacares*), bigeye (*T. obesus*), albacore (*T. alalunga*), and skipjack (*Katsuwonus pelamis*). Five different gear types, each with separate catchability and age-based selectivity coefficients, are included. They are: eastern Pacific purse seine, western

Table 1
Average Catch of Major Tuna Species by Gear Type in the SPC Statistical Area, 1988–94

Fleet	Albacore (mt)	Bigeye (mt)	Skipjack (mt)	Yellowfin (mt)
Purse seine	—	2,500	538,000	184,000
Longline	24,500	48,800	—	50,300
Pole and line	—	—	90,500	3,000

Source: South Pacific Commission Yearbooks 1988–94.

Pacific purse seine, frozen tuna longline, fresh tuna longline, and pole-and-line. As noted earlier, the eastern Pacific purse seine fleet is included in the biological model, since its effort affects the sizes of migratory stocks in the western Pacific, but is not included in the economic model, since the focus is on the FFA region.

The five gear categories have been further stratified on the basis of nationality, as described in the Harvesting Model section, reflecting the differences in productivity and cost structure among the diverse range of vessels operating in the fishery. A total of 16 different fleets are represented in the model. This differentiation of the fleets in terms of cost structure and prices is made to improve the accuracy of the profitability estimates. It will also enable more flexibility in examining the effects of different policy decisions, such as the licensing arrangements for particular fleets. However, we believe that the accuracy of all fleet-specific economic parameters is not sufficient to warrant the reporting of profit levels for each of the 16 fleets. Instead, profit for five general fleet categories is reported—the purse-seine fleet, the frozen *sashimi* longline fleet, the frozen albacore longline fleet, the fresh tuna longline fleet, and the pole-and-line fleet. The three categories of longline fleets serve different markets, and the frozen albacore fleet targets a different species than the frozen *sashimi* and fresh tuna longline fleets.

Monthly catch and fishing effort data for each fleet were obtained at 5˚ square resolution for the period 1988–94. Each fleet's total catch and effort in each 5˚ square over the period were computed for each month, and then scaled by the ratio of the 1996 catch or effort in that month to the total catch or effort in that month over the period 1988–94 to obtain annual distributions of catch and effort that summed to the observed 1996 levels. These reference distributions of catch and effort over the year and over the fishery are used to parameterize the model (see Parameterizing the Model section), and distribution of effort is also used in the simulations (see the Results section) to examine the bioeconomic effects of different levels of effort.

Spawning, Recruitment, and Movement

In most models of fish-population dynamics, spatial variation in the stocks is ignored. However, tropical tunas are highly migratory, and their densities vary strongly over space and time. It was, therefore, considered necessary to build a spatially disaggregated model which incorporates the movement and spatial distribution of the fish at all stages of their life history, as well as the spatial distribution of fleet-specific fishing effort. To do this, the entire Pacific Ocean between 45˚N and 45˚S at a spatial resolution of 5˚ of latitude by 5˚ of longitude and over monthly time intervals is considered.

Skipjack and Yellowfin

Spawning of skipjack and yellowfin was assumed to occur in a 5˚ square—month stratum if the mean sea surface temperature (SST) was more than 25˚C (skipjack) and 26˚C (yellowfin). Monthly average temperature data from the World Ocean Atlas (WOA) climatology were used for determining spawning areas (Levitus and Boyer 1994). For the first three months after spawning, larvae were assumed to be distributed passively by monthly average ocean currents (obtained from the general circulation model OPA developed by the Laboratoire d'Oceanographie Dynamique et de Climatologie, Paris). After this time, juvenile skipjack and yellowfin movement is based on a habitat index. The habitat index consists of two components — sea surface temperature and food availability. Food availability is based on the redistribution of average monthly primary production (chlorophyll) by average monthly ocean currents. It has been determined in a separate study (Lehodey *et al.* 1998), and is, thus, exogenous to the bioeconomic model. Movement is parameterized such that directed movement (or advection) tends to occur in the direction of positive habitat gradients. Conversely, greater undirected movement (or diffusion) occurs in areas of low habitat index. Such diffusive movement may be thought of as mimicking searching behavior. For full details of the parameterization of movement in relation to habitat index, see Bertignac, Lehodey, and Hampton (1998).

Bigeye and Albacore

For bigeye and albacore, which are primarily sub-surface tunas exploited by longliners, we have less understanding of their environment and how it influences their distribution. Therefore, we have opted for simpler hypotheses consistent with current understanding of the life histories of these species.

For bigeye, we assume that the distribution of spawning is limited to areas where the SST is >23˚C. As with skipjack and yellowfin, larvae are moved passively in ocean currents for the first three months. After this, they are assumed to move in a simple diffusive manner, which is the simplest hypothesis of a gradually dispersing population. For albacore, we have assumed that recruitment occurs in the region south of 30˚S, consistent with the results of other analyses (Fournier, Hampton, and Sibert 1998). Diffusive movement then occurs, with movement bounded in the north by the equator.

Mortality and Age Structure

Individual cohorts (quarterly in the case of skipjack, yellowfin, and bigeye; annual in the case of albacore) are tracked in the model, allowing the age structure of the populations at any point in time to be determined. The initial size of the cohorts is determined by the level of recruitment, after which time cohort attrition occurs due to natural and fishing mortality. The natural mortality rate is assumed to be constant in space and time.

The fishing mortality rate of a particular age class in a stratum is the sum across fleets of the product of fishing effort, the corresponding catchability coefficient, and the selectivity coefficient. The catch in the stratum is simply the product of the fishing mortality rate, the local population size, and the average weight for each age class (as determined by growth and length-weight relationships), summed over age classes.

Summary of Parameters of the Biological Model

The biological parameters in the population dynamics model are described in Bertignac, Lehodey, and Hampton (1998). The parameter values, together with their sources, are reported in table 2 to permit comparison with those used in the Bertignac, Lehodey, and Hampton (1998) model.

Table 2
Main Biological Parameters (and References) used in the Simulation Model

Parameter	Skipjack	Yellowfin	Bigeye	Albacore
Number of age classes	12 (quarter)	24 (quarter)	28 (quarter)	10 (year)
Growth parameters				
Linf	62.5 cm	190.0 cm	214.8 cm	121.02 cm
K	2.00 yr^{-1}	0.33 yr^{-1}	0.207 yr^{-1}	0.134 yr^{-1}
t_0	0.00	0.00	–0.12 yr	–1.922 yr
Weight-length				
A	4.82E-06	2.51E-05	1.97E-05	3.14E-05
B	3.37	2.94	3.02	2.89
Sources	Wild and Hampton (1994)	Suzuki (1994)	Miyabe (1994)	Labelle *et al.* (1993)
Mortality				
M	0.12 mth^{-1}	0.07 mth^{-1}	0.05 mth^{-1}	0.04 mth^{-1}
Sources	Hampton (1992)	Hampton (1992)	Miyabe (1994)	Fournier, Hampton, and Sibert (1998)
Recruitment				
SST limit for spawning	25˚C	26˚C	23˚C	N.A.
Sources	Schaefer (pers. com.)			
Stock biomass for tuning	≈ 1.8-2,500,000 t.*	≈ 1.4-2,000,000 t*	≈ 500,000 t.	≈ 450,000 t.
Sources	Hampton (1992)	Hampton (1992)	Miyabe (1994)	Fournier, Hampton, and Sibert (1998)
Movement				
χ (advection)	200,000 nm^2 index $unit^{-1}$ mth^{-1}	200,000 nm^2 index $unit^{-1}$ mth^{-1}	0	0
D (diffusion)	10,000 nm^2 mth^{-1} on average	10,000 nm^2 mth^{-1} on average	10,000 nm^2 mth^{-1}	10,000 nm^2 mth^{-1}

* For skipjack and yellowfin, only western tropical stock biomass is used in the tuning (20N-20S in latitude and up to 150W in longitude)

Harvesting Model

In a single species, single cohort, single gear type, and spatially aggregated context, the harvesting model would take the following form:

$$H = AEX \tag{1}$$

where: H is the monthly harvest in tons, E is the level of fishing effort in vessel-months, and X is the level of stock in tons. A is known as the catchability coefficient and describes the proportion of the stock that is taken by a single unit of fishing effort.

By adding some extra detail to the model, it is possible to represent the four different species (and a number of cohorts within each species), four different gear types, and account for some of the spatial heterogeneity inherent in the fishery. As discussed earlier, this level of disaggregation is important because it facilitates the modelling of interactions among gear types. The proportion of each cohort of each species represented in vessel catches varies across fleets. Catch by one fleet impacts stocks and affects other fleets' catch rates, total catch, and profit levels. To measure the impact of each fleet on other fleets, and to optimize the mix of fleets, it is necessary to use a disaggregated model. Including these factors in the harvest function gives the following functional form:

$$H_{a,s,r,m,g,f} = A_{s,g,f} S_{a,s,g} E_{r,m,g,f} X_{a,s,r,m} \tag{2}$$

where: a is age class, s is species, g is the gear type, f is fleet nationality, m is the month, and r is the region (5^{o} latitude by 5^{o} degree longitude grid). S is the selectivity coefficient, which modifies the catchability coefficient, A, to allow for the fact that catchability of juveniles of each species is different from that of adults. The selectivity coefficients are presented in figure 3.

Fishing effort is varied for the four fleet categories, which were identified earlier as operating in the FFA region. These fleet categories are: (*i*) Purse seine fleets: US, Japanese, Korean, Taiwanese, "other" western Pacific, and eastern Pacific fleets; (*ii*) Pole-and-line fleets: Japanese north (of 20˚N), Japanese south (of 20˚N), and domestic (*i.e.,* FFA member countries) pole-and-line fleets; (*iii*) Frozen tuna longline fleets: Japanese, Korean, and Taiwanese fleets; and (*iv*) Fresh tuna longline fleets: Japanese, Chinese, Taiwanese, and "other" western Pacific fleets.

The spatial distribution of effort of each fleet in each month is held constant at its 1988–94 average in the sense that the proportion of total fleet effort allocated to each region is maintained, although the total level of effort may be varied. The annual harvest of each species by each fleet is obtained from the harvesting model by aggregating across regions, months, and age classes.

Parameterizing the Model

The model has not yet been subjected to a comprehensive parameterization by fitting it to observed data at the best spatial and temporal resolution possible. As a first step, an approximate tuning procedure has been applied by adjusting the recruitment (or spawning) so that stock biomass estimates equal those obtained independently from tagging studies (skipjack and yellowfin) or other stock assessments (bigeye and albacore), and then adjusting catchability coefficients to levels such that estimated catches of each species by each fleet for the 1988–94 period approximate the reported catches. The recruitment and catchability coefficients obtained in this way and used in the bioeconomic simulations are reported in table 3.

Prices and Costs

Current tuna prices for all fleets are as reported in Hand and Forau (1997b), and costs are as reported in Hand and Forau (1997a). All values are in 1995 US dollars. The price received by each fleet for each species is a weighted average of the prices received for the various size classes of the species in the various markets served by the fleet. The cost of fishing effort includes the long-run opportunity cost of capital, but excludes access fees.

Current Prices

Purse-seine Fleets

Prices for all purse-seine fleets are US$1,000 per mt for bigeye, and US$1,063 per mt for yellowfin. Prices for skipjack for all purse-seine fleets, except Japan, are US$923 per mt. Average prices received for skipjack by the Japanese fleet are higher because higher-value markets are supplied. A weighted average of the prices received on these higher value markets of US$1,161 per mt is used (see Hand and Forau 1997b).

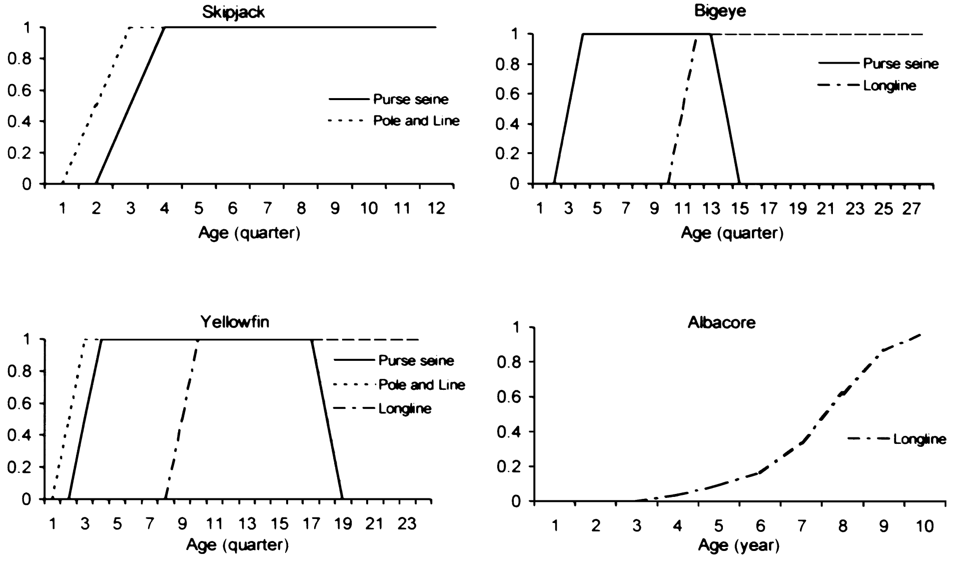

Figure 3. Selectivity Coefficients by Age Class, Species, and Gears Used in the Simulation
Note: The albacore coefficients are estimated from a stock assessment analysis (Fournier, Hampton, and Sibert 1998). For the three other species, selectivity coefficients are extrapolated from length-frequency distributions of catches by gears (SPC data) (see text for details).

Table 3
Catchability Coefficients for Each Fleet Included in the Simulation Model

Fleet	Skipjack	Yellowfin	Bigeye	Albacore
Purse seine				
United States	8.35E-04	7.39E-04	3.71E-05	0.00E+00
Japan	1.35E-03	1.23E-03	1.36E-04	0.00E+00
Korea	1.18E-03	1.31E-03	6.69E-07	0.00E+00
Taiwan	1.04E-03	9.61E-04	0.00E+00	0.00E+00
"Others"	9.71E-04	9.87E-04	8.08E-05	0.00E+00
Pole-and-line				
Japan north of 20° N	5.52E-04	1.88E-05	0.00E+00	0.00E+00
Japan south of 20° N	1.89E-04	1.98E-05	0.00E+00	0.00E+00
Other pole-and-line fleet	1.04E-04	3.17E-05	0.00E+00	0.00E+00
Frozen tuna longline				
Japan	0.00E+00	3.12E-06	2.19E-05	4.55E-05
Korea	0.00E+00	2.35E-06	1.69E-05	2.06E-05
Taiwan	0.00E+00	4.55E-07	1.23E-06	1.04E-04
Fresh tuna longline				
Japan	0.00E+00	2.20E-06	8.24E-06	3.22E-03
China	0.00E+00	2.50E-06	9.62E-06	0.00E+00
Taiwan	0.00E+00	3.16E-06	9.80E-06	3.66E-04
Other	0.00E+00	3.55E-06	3.43E-06	7.78E-05

Pole-and-Line Fleets

Japanese pole-and-line vessels supply skipjack and yellowfin to higher-value markets than their domestic counterparts (Hand and Forau 1997b), and, therefore, different prices are used for Japanese pole-and-line and domestic vessels' pole-and-line catch. The prices for the Japanese fleet are US$2,246 per mt, and US$4,196 per mt for skipjack and yellowfin, respectively, while the prices for the domestic fleets are US$982 per mt and US$898 per mt for skipjack and yellowfin, respectively.

Frozen Tuna Longline Fleets

Prices received for the catch of Japanese longline vessels are based on prices received at 42 Japanese ports, as reported in Hand and Forau (1997b). These prices are US$2,440 per mt for albacore, US$10,520 per mt for bigeye, and US$5,610 per mt for yellowfin. Due to the 4–5% tariff and preference for Japanese-caught tuna in the main *sashimi* markets of Japan, it is assumed that Korean and Taiwanese vessels receive 5% less for frozen longline catch than Japanese vessels. Taiwanese vessels also target albacore for the canned market, receiving US$2,280 per mt.

At this point, it should be noted that while the net of tariff prices of frozen and fresh longline-caught tuna supplied to the Japanese market by the Korean, Taiwanese, Chinese, and other fleets are the appropriate prices to use when calculating the private profits of these fleets, using these prices to calculate total fishery rent leads to a slight underestimate. The net of tariff prices is used to implement a non-negative profit requirement for each fleet. It should be borne in mind while interpreting the results of the simulations that the estimates slightly underestimate fishery rent.

Prices for bycatch are US$2,830 per mt for blue marlin, US$4,560 per mt for black marlin, US$5,880 per mt for striped marlin, US$6,050 per mt for swordfish, and US$1,850 per mt for sailfish (AFMA 1996). It is assumed that the CPUE of these bycatch species is constant—no population dynamics models for these species are developed. However, bycatch does contribute a significant amount of revenue which is attributed to fleets, for any effort level, on the basis of historical CPUE for these species. Japanese longliners have a much higher CPUE, and, therefore, value per unit effort, of bycatch species (US$44.43 per 100 hooks) than Korean vessels (US$17.10 per 100 hooks).

Fresh Tuna Longline Fleets

Prices received by Japanese fresh tuna longline vessels are based on prices received at Yaizu, as reported in Hand and Forau (1997b). These prices are US$2,980 per mt for albacore, US$9,460 per mt for bigeye, and US$7,830 per mt for yellowfin. It is assumed that Taiwanese, Chinese, and domestic FFA vessels receive 5% less than Japanese vessels.

Bycatch prices are the same as those used for longline freezer catch, and bycatch value per unit effort is calculated on the basis of these prices and historical CPUE. The following bycatch values of CPUE are assigned to the fresh longline fleets: US$54.01 per 100 hooks for the Japanese fleet; US$20.17 per 100 hooks for the Chinese fleet; US$18.62 per 100 hooks for the Taiwanese fleet; and US$25.39 per 100 hooks for the domestic fleets.

Price Elasticities of Demand

The WCPO currently supplies between 30% and 40% of the world's pole-and-line, purse-seine, and longline catches of tuna. Since some of the bioeconomic simulations will involve significant departures from current catch levels of species supplied to markets for canning (mainly by purse-seine and pole-and-line vessels) and for fresh and frozen tuna consumption (mainly by longline vessels), demand elasticities are used to allow market prices to vary according to quantities supplied. The elasticities take into account the price elasticity in the final demand market, the various markups on the price of raw tuna, the share of the WCPO in world catch, and the elasticity of supply from competing regions.

Demand elasticities are calculated for the catches of each of two types of fleets: those using purse-seine and pole-and-line gear, whose catch is destined for the canning market; and those involved in fresh and frozen longline operations, whose catch is mainly destined for the Japanese *sashimi* market. The following simple model can be used to estimate the elasticity of demand for raw tuna from either of these fleets. Let world demand be $Q = Q_f + Q_o$, where Q_f is sourced from the WCPO region and Q_o from other sources, and let the retail price be $P = P_r + P_p$, where P_r is the price of raw tuna, and P_p is the cost of processing and distribution. Assuming that the latter mark-up remains constant, the elasticity of demand for tuna products in the retail market can be expressed as:

$$e = -(dQ_f/dP_r + dQ_o/dP_r)(P_r + P_p)/(Q_f + Q_o)\,. \qquad (3)$$

Using this expression, the elasticity of demand for raw tuna from the WCPO region can be expressed as:

$$e_r = -(dQ_f/dP_r)(P_r/Q_f) = e_r(S_r/S_f) + e_{so}\left[(1/S_f) - 1\right] \tag{4}$$

where S_r is the share of the price of raw tuna in the price of tuna at the retail level, S_f is the share of the region's output in the world market, and e_{so} is the elasticity of the tuna supply from the rest of the world.

Using parameter values obtained from Campbell (1998), the elasticity of demand for raw tuna supplied to the canning markets by purse-seine and pole-and-line fleets operating in the WCPO is estimated to be 1.55, and that for fresh and frozen tuna supplied by the longline fleets is 2.53. Since albacore caught by the Taiwanese longline fleet is used for canning, these catches were grouped with the purse-seine and pole-and-line catches in calculating the price response.

A linear demand function was used to calculate the price responses in each of the two main markets:

$$p_{e,g,j} = p^{96}_{e,g,j} - p^{96}_{e,g,j} \cdot \varepsilon_j \left[\frac{(C_j - C^{96}_j)}{C^{96}_j}\right] \tag{5}$$

where $p_{e,g,j}$ is the current price for species e supplied by gear category g in market j, $p_{e,g,j}{}^{96}$ is the price in 1996, C_j and $C_j{}^{96}$ are the total catches supplied from the WCPO region to market j by all gear types, and ε_j is the elasticity coefficient, consisting of the inverse of the demand elasticity for raw tuna. Since the elasticity coefficients are based on point rather than arc elasticities of demand, the calculated price responses will only approximate the effects of changes in quantities supplied and will decline in accuracy the further simulated catches depart from current levels.

Costs

The basic unit of purse-seine and pole-and-line effort in the bioeconomic model is days fished; whereas for the longline fleets, it is hooks fished per day. Information on annual costs, number of days fished per year, and number of hooks fished per day is used to calculate the unit cost of effort of each fleet (Hand and Forau 1997a).

Purse-seine Fleets

Estimated total costs of fishing per day are US$19,417 for US purse seine; US$15,500 for Taiwanese purse seine; US$21,033 for Korean purse seine; US$23,607 for Japanese purse seine; and US$14,671 for domestic purse seine vessels.

Pole-and-Line fleets

Due mainly to large variations in size, there is a substantial difference in the cost of pole-and-line fishing between Japanese vessels operating the western and central Pacific and domestic vessels of FFA countries. The estimated total costs of fishing per day for Japanese vessels (North and South) and domestic pole-and-line vessels are US$9,134, US$14,500, and US$2,391, respectively.

Frozen Tuna Longline Fleets

Among the frozen tuna longline fleets included in the model—Japan, Korea, and Taiwan—data are available only for the Japanese cost of fishing. Data in Hand and Forau (1997a) are for the 100–200 and 200 GRT size classes. With a cost per day of US$8,533 for 100–200 GRT vessels and US$12,433 for 200-500 GRT vessels, and an average number of hooks per day of 2,811 and 2,949, respectively, the cost per hook for each size class was estimated at US$3.04 and US$4.22, respectively. A weighted average was then taken on the basis of 31% of hooks being set by the 100–200 GRT size class over the 1988–94 period and 68% being set by the 200–500 GRT class, giving a final cost per day of US$3.85 per hook for the Japanese fleet. The use of this cost figure for the Korean and Taiwanese fleets would lead to negative profits over the entire range of the fishery. In the absence of other information, we assumed costs of fishing which resulted in a break-even performance at the 1996 levels of effort and catch for these fleets. These break-even costs are US$3.35 per hook for the Korean fleet and US$1.05 per hook for the Taiwanese fleet.

Fresh Tuna Longline Fleets

Again, the only reliable cost data for this fleet category are for Japanese vessels. Hence, these data were used as a proxy for all of the fresh longline fleets except China, for which breakeven costs in 1996 are assumed.

It was necessary to convert cost per day for various vessel size classes to a weighted average cost per hook. The costs of fishing were US$4,853 per day for the 10–30 GRT size class, US$9,499 per day for the 50–100 GRT size class, and US$12 433 per day for the 200–500 GRT size class. The numbers of hooks per day for each fleet were 1,966, 2,312 and 2,640, respectively, over the 1988–94 period. This resulted in costs per hook of US$2.47, US$4.11, and US$4.71, respectively. Given that 94% of hooks were set by the 10–30 GRT class fleet, 5% by the 50–100 GRT class fleet, and 1% by the 200–500 GRT class fleet, the final weighted average cost of fishing was estimated at US$2.57 per hook. For Chinese vessels, the cost was set to US$2.80 per hook.

Results

Bioeconomic simulations were conducted on the basis of percentage changes in the 1996 level of fishing effort within the FFA region. Note that this is not the period for which the model is tuned (1988–94). Therefore, profit and catch are predicted, not actual. According to the FFA vessel register, 1996 vessel numbers equated to 182 purse seiners, 58 pole-and-liners, 642 freezer longliners, and 450 fresh longliners (Gillett 1997). These figures include only vessels that are licensed by at least one FFA member country. The effort levels of fleets operating in areas of the WCPO outside the FFA region were held constant at 1996 levels.

Three types of bioeconomic simulations were undertaken: (*i*) varying the 1996 effort levels within the FFA region for the four fleet categories by the same relative amounts; (*ii*) varying the effort levels of the individual fleet categories in sequence by set relative amounts; and (*iii*) using an optimization algorithm in which effort for each fleet category was varied simultaneously in order to maximize the value of an objective function (either the value of fishery rent or the returns to FFA member countries).

The simulations are employed to generate predicted values for all fleets in the regional fishery, of total revenues, total costs (exclusive of access fees and including a normal rate of return on capital), access fees, fishery rent (total revenues less total costs), and total private profit (net of access fees) of the combined fleets. Access fees are set at 4% of the gross value of the catch of each fleet, although Swan (1997) has estimated actual access fee revenues to be around 3.5% of gross value. FFA regional returns are measured as the sum of access fee revenues and the profits of local fleets such as the Solomon Islands purse seine fleet.

Effect of Changing the Overall Level of Fishing Effort

Table 4 shows the effect on total revenue, costs, and fishery profitability of changes in effort levels relative to 1996 levels in the FFA region. In this case, equivalent proportional changes in effort are made for all fleets represented in the model.

The results reported in table 4 indicate that annual fishery rent generated in the FFA region is around US$108 million per annum at the current effort levels. Fishery rent is fully dissipated at a level of effort 20–30% higher than the 1996 level; this level of effort is, therefore, the predicted open-access equilibrium level. Private profit falls to zero at an effort level 10–20% higher than the 1996 level as illustrated in figure 4. Both fishery rent and private profit are maximized at approximately 50% of the current effort level, with the private optimal effort level being marginally lower than the rent maximizing level because of the 4% royalty. The results suggest that higher access fees could be sustained at lower levels of effort.

Effect of Changing Effort of Individual Fleet Categories

We now examine the effects of changing the effort of one fleet (to 80%, 90%, 110%, and 120% of the 1996 level) on the profitability of that fleet and of the other fleets, holding the effort of the other fleets constant at the 1996 level. Consistent with the finding reported, above, that the overall level of effort is significantly above the optimal level, the profitability of each fleet, except the frozen tuna longline fleet, rises

Table 4

Annual Revenue, Costs,[a] Access Fees, Gross Profit,[a] and Net Profit[b] at Different Proportions of the 1996 Effort Levels

Percent of 1996 Effort	Revenue	Costs	Access Fees (4% of Revenue)	Fishery Rent	Private Profit
40	693	438	28	255	227
50	811	548	32	263	231
60	916	657	37	259	222
70	1,011	767	40	245	204
80	1,099	876	44	222	178
90	1,179	986	47	193	146
100	1,254	1,095	50	158	108
110	1,323	1,205	53	118	66
120	1,389	1,315	56	74	19
130	1,450	1,424	58	26	–32

Note: Figures are in 1995 $US million.
[a] Exclusive of access fees.
[b] Inclusive of access fees.

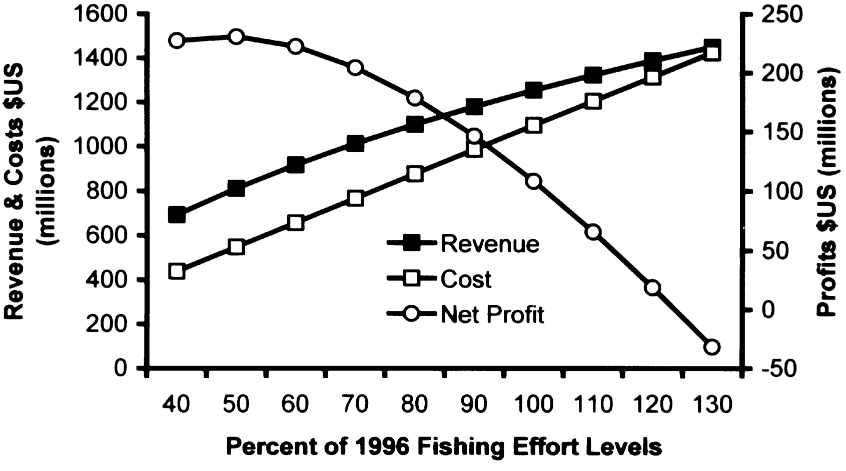

Figure 4. Fishery Profitability for a Range of Proportional Changes in Fishing Effort (1996 levels)
Note: Profit is net profit assuming an access fee of 4% of revenue.

(falls) as its effort level falls (rises). The effects of the effort level of a given fleet on the profitability of other fleets can be interpreted as estimates of the "marginal bioeconomic interaction" between the fleets. The effects of changing purse seine, pole-and-line, frozen tuna longline, and fresh tuna longline effort are shown in figures 5–8, respectively. The following observations can be made regarding the extent of bioeconomic interaction among the fleets: (*i*) increases in purse seine effort have negative impacts on fresh tuna longline profitability, but relatively little effect on pole-and-line and frozen tuna longline profitability. Purse seiners catch juvenile yellowfin and bigeye in fishing areas favored by the fresh tuna longline fleets, but are less active in areas preferred by the frozen tuna longline fleets. Since pole-and-line fleets catch mainly skipjack, which is in plentiful supply, the purse seine skipjack catches have little impact on the profitability of the pole-and-line fleet; (*ii*) increases in pole-and-line effort have relatively little impact on the profitability of the other fleets, because pole-and liners catch mainly skipjack tuna, which is in plentiful supply; (*iii*) increases in frozen tuna longline effort have a strong negative impact on fresh longline profitability because of their impact on the levels of migratory stocks, but little impact on the profitability of the other fleets, which depend on different species or age classes; and (*iv*) increases in fresh tuna longline effort have relatively little impact on the profitability of the other fleets. While the fresh tuna longline fleet targets the same species as the frozen longline fleet, it operates in different areas and on a smaller scale.

Optimizations

It is clear from figures 5–8 that some strong bioeconomic interactions exist among the four fleet categories being considered. This suggests that it may be possible to increase fishery rent, or some other measure of economic performance, by varying the mix of effort levels. To consider this, the simulation model was interfaced with a Simplex optimization algorithm to attempt to locate an optimum level and mix of gears given the objective of maximizing fishery rent in the long-run, or maximize the returns to the FFA region under the current fee structure. Several constraints were placed on each optimization to prevent it, entering an unreasonable domain. These were: (*i*) effort multipliers (defined as one plus the proportionate change in effort relative to the 1996 level) must remain positive; (*ii*) the global profitability of each fleet over the entire geographical range of its activities (*i.e.*, including operations outside the FFA area) must remain positive; and (*iii*) the population biomass of each of the four species must not fall below 40% of their virgin levels (determined by the equilibrium population in the absence of effort).

The latter constraint was applied in order to impose a reasonable conservation guideline (or limit reference point) on the stocks. Each combination of effort values was applied for 15 years from the initial state (1996) in order to attain an approximate equilibrium. Conditions at equilibrium (*i.e.*, in year 15) were then used to compute the variables for the optimization.

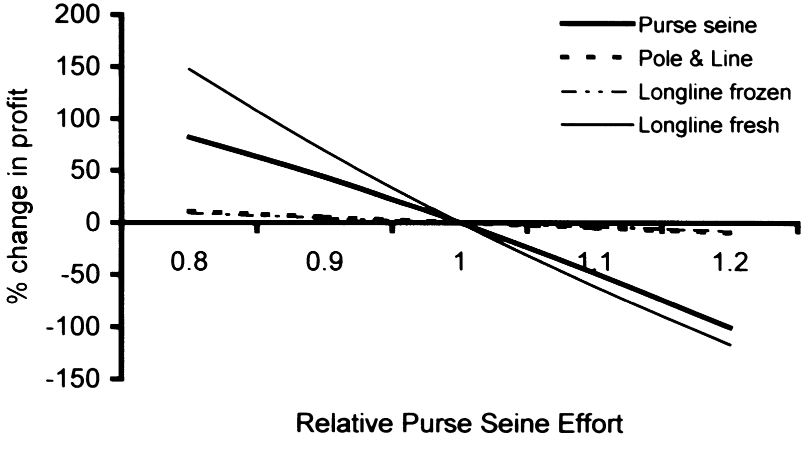

Figure 5. The Effects of Changes in Purse Seine Effort (relative to the 1996 level) on Net Profit (*i.e.*, after 4% access fees have been paid) of the Four Fleet Categories

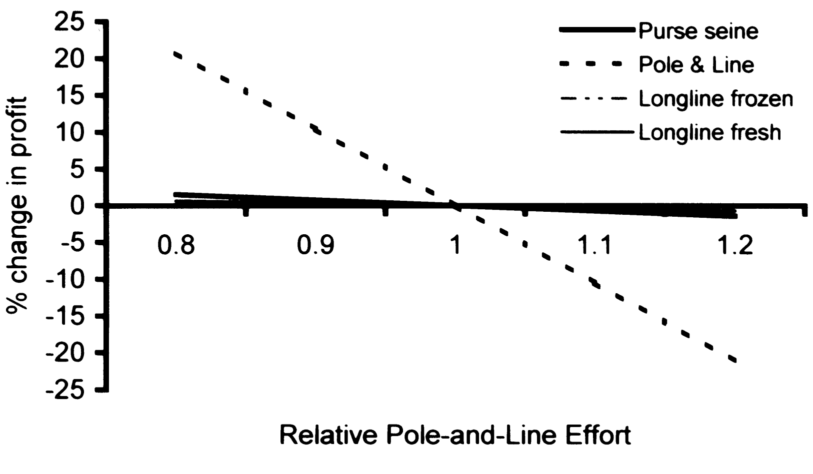

Figure 6. The Effects of Changes in Pole-and-Line Effort (relative to the 1996 level) on Net Profit (*i.e.*, after 4% access fees have been paid) of the Four Fleet Categories

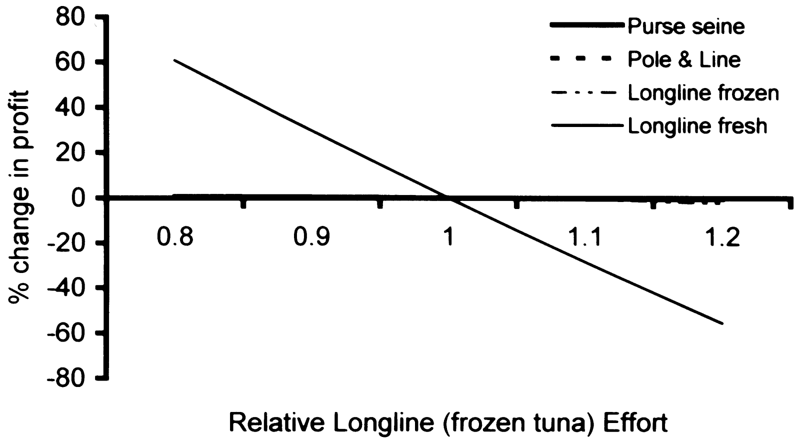

Figure 7. The Effects of Changes in Frozen Tuna Longline Effort (relative to the 1996 level) on Net Profit (*i.e.*, after 4% access fees have been paid) of the Four Fleet Categories

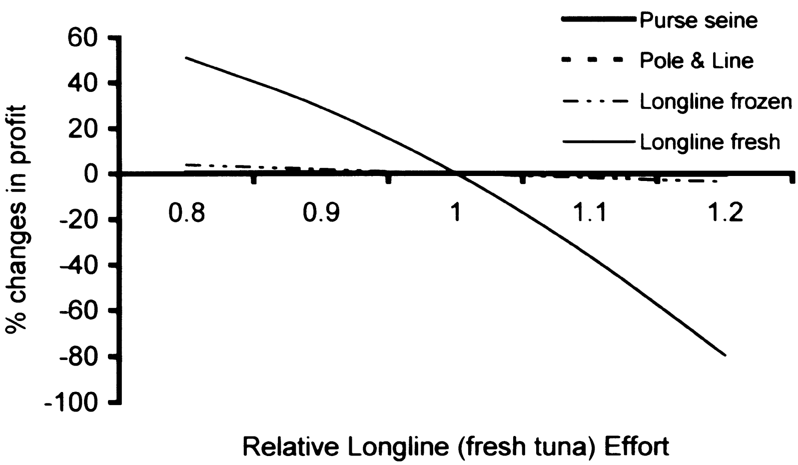

Figure 8. The Effects of Changes in Fresh Tuna Longline Effort (relative to the 1996 level) on Net Profit (*i.e.*, after 4% access fees have been paid) of the Four Fleet Categories

In conducting the optimizations, the frozen tuna longline fleet was separated into two components impacting different fish stocks and markets: the frozen *sashimi* longline fleet, consisting mainly of Japanese and Korean longliners, targets bigeye and yellowfin tuna for the *sashimi* market; and the frozen albacore longline fleet, consisting mainly of Taiwanese longliners, targets albacore for the canned tuna market. There are, therefore, five fleets for which optimal levels of effort have to be determined—purse seine, pole-and-line, frozen *sashimi* tuna longline, frozen albacore longline and fresh tuna longline. Several optimizations were carried out, as described below.

Optimization 1: Maximizing (a) Fishery Rent and (b) FFA Returns, with Fixed Prices

These optimizations were conducted in order to estimate levels of fishing effort of the various fleets corresponding to fishery rent maximization in the FFA region and to maximization of the return to the FFA countries. The latter return is calculated as 4% of the gross revenues of the distant water fishing nation (DWFN) fleets plus the profits of the domestic fleets. It must be emphasized that, in Optimization 1b, the maximization of FFA returns is constrained by the maintenance of the current fee structure, which, it is argued later in the paper, is suboptimal from the regional viewpoint.

Optimization 1a maximized annual fishery rent generated in the region at an estimated US$311 million, more than twice the value for 1996 (table 5, Rent Maximization). The maximum was obtained by reducing fishing effort for all fleets except the fresh and frozen tuna longline fleets, which were increased significantly. The pole-and-line and frozen albacore longline fleets were virtually eliminated from the rent maximizing solution. In Optimization 1b, the maximization of regional returns increases the effort of groups of fleets in which some of the domestic fleets participate. In particular, this is the case for the fresh tuna longline fleet, which increases by a factor of 5 (while that of the DWFN frozen tuna longline fleet is curtailed), and that of the pole-and-line fleet, which more than doubles. This results in the relative shares of access fees and domestic fleet profits in total FFA region receipts going from 67% and 33%, respectively, in a 1996 type situation, to 57% and 43% at the optimum. The predicted receipts of US$81.6 million for the FFA countries can be compared with the predicted level under the 1996 effort levels of US$69.6 million, implying a 17% increase.

Optimization 2: Maximizing (a) Fishery Rent and (b) FFA Returns, with Variable Prices

These optimizations are similar to optimizations 1a and b, with the exception that prices are allowed to vary as a function of quantity of the various tuna species of tunas supplied to the two different markets. The demand function described in the Price Elasticities of Demand section was included in the optimization procedure to provide a simple, linear link between prices by species and gear categories and total catches supplied to each market.

The revenue, cost, and rent comparisons are given in table 6. The main effect of the variable as compared with fixed prices in the regional rent maximization is that fresh and frozen longline effort is curtailed, with the former falling substantially. In the case of the regional return, constrained by the current fee level and structure, the price effects act in the expected directions, making longlining relatively less attractive from a regional perspective. However, the increase in the price of canning tuna causes a marked shift in the balance of effort in this fishery towards purse seining, as compared with the fixed-prices case.

The catches of each species for 1996 and those associated with the optimal solutions discussed above are given in table 7. While there is some redistribution of catches among fleets, resulting in lower purse seine catches and higher fresh tuna longline catches, total catch levels under the optimized effort levels are considerably lower than those that existed in 1996. While catch levels in 1996 are believed to be sustainable (although there is some uncertainty regarding bigeye), the lower catches under the optimized effort levels would afford the stocks an even greater degree of protection from overfishing. We stress, however, that the lower catches associated

Table 5
Optimized Effort Levels, Revenue, Cost, Rents, and FFA Returns (1995 $US million) by Fleet, with Fixed Prices, and with Comparison to the 1996 Situation (Optimizations 1a and 1b)

	1996				Rent Maximization				FFA Returns Maximization		
Fleet	Rev.	Cost	Rent	Effort	Rev.	Cost	Rent	Effort	Rev.	Cost	FFA Return
Purse seine	724.0	630.1	93.9	0.35	400.0	223.0	177.0	0.004	7.7	3.0	0.7
Pole-and-line	42.1	55.0	–12.9	0.00	0.0	0.0	0.0	2.13	114.9	117.3	5.8
Frozen sashimi tuna longline	313.3	243.5	69.8	1.43	447.4	348.4	99.0	0.71	237.4	171.8	9.5
Frozen albacore longline	18.8	20.8	–2.0	0.07	1.5	1.5	0.1	0.23	4.5	4.7	0.2
Fresh tuna longline	155.5	146.0	9.5	1.30	225.7	190.4	35.4	5.43	921.7	793.2	65.4
Total	1,253.8	1,095.4	158.3		1,074.7	763.2	311.4		1,286.3	1,090.1	81.6

Table 6

Optimized Effort Levels, Revenue, Cost, Rents, and FFA Returns (1995 $US million) by Fleet, with Variable Prices, and with Comparison to the 1996 Situation (Optimizations 2 a and 1b)

	1996				Rent Maximization				FFA Returns Maximization		
Fleet	Rev.	Cost	Rent	Effort	Rev.	Cost	Rent	Effort	Rev.	Cost	FFA Return
Purse seine	724.0	630.1	93.9	0.39	499.7	244.6	255.2	0.58	588.6	366.0	46.5
Pole-and-line	42.1	55.0	–12.9	0.00	0.0	0.0	0.0	1.81	90.7	99.8	5.0
Frozen sashimi tuna longline	313.3	243.5	69.8	1.11	368.8	270.8	97.9	0.44	156.1	108.1	6.2
Frozen albacore longline	18.8	20.8	–2.0	0.14	3.5	2.8	0.7	0.00	0.0	0.0	0.0
Fresh tuna longline	155.5	146.0	9.5	0.52	95.2	75.3	19.9	1.71	281.4	250.0	19.7
Total	1,253.8	1,095.4	158.3		967.3	593.6	373.7		1,116.9	823.9	77.5

Table 7
Catches by Species and Fleet for 1996 in the FFA Region Under the Optimum Effort Regimes: SKJ=skipjack, YFT=yellowfin, BET=bigeye, ALB=albacore

Fleet	1996				Optimization 1a				Optimization 2a			
	SKJ	YFT	BET	ALB	SKJ	YFT	BET	ALB	SKJ	YFT	BET	ALB
Purse seine	545	182	2	0	286	115	1	0	306	122	1	0
Pole-and-line	19	1	0	0	0	0	0	0	0	0	0	0
Frozen sashimi tuna longline	0	13	21	2	0	23	28	3	0	18	24	3
Frozen albacore longline	0	1	0	5	0	0	0	0	0	0	0	1
Fresh tuna longline	0	7	9	2	0	12	11	3	0	5	5	2
Total	565	204	32	9	286	150	40	7	306	145	30	5

Note: Figures are in thousand mt.

with the optimized effort levels result because the model predicts increased rent at lower effort, not because the stocks need to be rebuilt for purposes of biological conservation.

Conclusions

On the basis of the bioeconomic simulations discussed in the results, some preliminary conclusions can be drawn about the rent maximizing level of effort in the WCPO tuna fisheries, the optimal fleet composition, and the access fee structure that will maximize returns to the resource-owning countries.

In the section on the Effect of Changing Effort of Individual Fleet Categories, it was found that fishery rent generated in the FFA region was maximized when total fishing effort was reduced to around 50% of its 1996 level. While a reduction of this scale lowers total revenues to two-thirds of the 1996 level, total harvesting costs fall to half of the 1996 level. The reduction in harvesting cost is achieved partly by reducing total catch, but also through the lower unit cost of catching fish resulting from the higher fish stocks in the new, long-run equilibrium. These results are consistent with the prediction of the simple Gordon-Schaefer bioeconomic model (Gordon 1954; Schaefer 1957), generating a quadratic yield-effort curve, that the rent maximizing level of effort will be 50% of the “bionomic,” or open-access, equilibrium level. While the WCPO tuna fishery is a managed, rather than open-access, fishery, the management regime is relatively new. It follows the 1982 UNCLOS declaration which gave the countries of the region the right to determine the rate of exploitation of the resource. As a consequence of this recent development, the management infrastructure—the research base, decision-making processes, monitoring, and enforcement procedures—is still evolving. For this reason, the current level of effort appears to be closer to open-access equilibrium than to the rent maximizing level. It should be emphasized that the results suggest economic, rather than biological, overfishing. While current levels of effort do not appear to threaten the viability of fish stocks, they appear to be excessive in the sense that reductions in effort will reduce costs by more than the reduction in revenue.

In the section on the Effect of Changing Effort of Individual Fleet Categories, marginal changes were made to the effort level contributed by each fleet, while effort levels contributed by the other fleets were held constant at 1996 levels. Consistent with the finding that overall levels of effort are too high, it was found that each fleet's profitability fell/rose as its effort level was increased/decreased. Of most interest are the bioeconomic interactions among fleets, summarized in figures 5–8. Two significant interactions were revealed. Increases in the level of purse-seine effort have a significant negative effect on the profits of the fresh tuna longline fleet, which is consistent with the findings of earlier studies (Campbell 1994; Campbell and Nicholl 1995), but little impact on pole-and-line or frozen longline profitability. Second, increases in frozen tuna longline effort have a significant impact on the profits of the fresh tuna longline fleet, but little impact on the profitability of the pole-and-line or purse-seine fleets. There appears to be no significant bioeconomic interaction between the purse-seine and pole-and-line fleets. This might appear surprising, given that both fleets are heavily dependent on the skipjack stock. However, the skipjack catch is thought to be low relative to the sustainable potential, and the results reported in this paper are consistent with those of an earlier study by Hampton *et al.* (1997).

The existence of significant interaction among important sectors of the industry raises the possibility that the structure of the fleet, as well as its overall level of effort, is suboptimal. An optimization algorithm was used to find the rent maximizing fleet levels in the FFA region subject to population biomass constraints on stock levels and non-negative private economic profit constraints on the fleets. This optimization procedure virtually eliminated the pole-and-line and frozen albacore longline fisheries completely, and reduced purse seine effort to less than 50% of the 1996 level. Total revenues fell to around 85% of the 1996 level, and costs fell to 70%. Fishery rent more than doubled, and the return to the FFA region, under the existing fee structure, rose by 39%.

As noted in the section on "Price Elasticities of Demand," the WCPO provides around one-third of the world supply of fresh and frozen tuna and tuna for canning. Significant changes in the supply of tuna from the region can be expected to affect world prices of these products. In particular, a shift in the balance of the fishery away from canning tuna (supplied by the purse seine, pole-and-line, and frozen albacore longline fleets), and towards longline-caught tuna for the fresh and frozen markets will tend to raise the world price of canning tuna and lower the price of longline-caught tuna. When these effects were introduced into the optimization model by means of demand elasticities, the results of the rent maximizing model were generally less dramatic than those of the fixed-prices model. Revenue from sales of canning tuna from the region fell to two-thirds of the 1996 level, while revenue from tuna supplied to fresh and frozen markets remained roughly at the 1996 level. The higher price received for canning tuna resulted in a relatively small frozen albacore fleet remaining viable. However, the main difference between the fixed and variable prices model was a significant contraction of the fresh tuna longline fleet. A 50% reduction in overall costs, reflecting a significant reduction in overall effort, coupled with a shift of emphasis towards longlining, results in a four-fold increase in rent as compared with the 1996 level.

A principal concern of fishery managers is with the returns to the resource owning nations. It was noted that a notional 4% of the catch value was used as a guide to determine access fee levels, but that actual returns are closer to 3.5%. It is evident from the results of the simulations that the fisheries could generate higher access fee revenues in a competitive environment. Fishery rent is around 13% of revenue at the 1996 levels of effort, and 30% and 40% in the fixed and variable price simulations, respectively. Furthermore, rent as a proportion of revenue, calculated at the rent maximizing levels of effort, varies significantly across fleets. For example, in the variable prices model, rent is 50% of revenue for the purse seine fleet, 27% for the frozen *sashimi* longline fleet, 20% for the frozen albacore fleet, and 21% for the fresh tuna longline fleet.

If the resource-owning nations could capture a significant share of fishery rent by means of access fees, it appears that it would be to their advantage to alter both the level and structure of the fees. Fees as a percentage of catch value could be raised for all fleets, and a fee structure that recognizes the different revenue and cost structures of different fleets could be introduced. In a competitive environment, the introduction of higher access fees, and differential fees according to profitability, would lead to the kind of changes in total and relative effort levels suggested by the results of the optimization model. It must be recognized that the fishery rent estimates reported in this paper are those in a new, long-run equilibrium after a period of adjustment, and that short-run adjustment costs, including the cost of investing in fish stocks, have not been taken into account. Since the adjustment period would be relatively short, incorporating these costs, as has been done elsewhere (Hampton *et al.* 1997), would be unlikely to change the conclusions materially.

The rent calculations used in the simulation model do not capture all of the changes in net economic benefits likely to result from changing effort levels in the FFA area. Some of the increase in the profits of the regional fisheries calculated in Optimization 2a consists of a transfer of the region's tuna harvest from consumers to producers. The percentage price changes of canning and *sashimi* tuna can be calculated by weighting the individual species price changes by the species shares in the catches reported in table 7. The price of canning tuna rises, on average, by 17.14% and that of *sashimi* tuna falls by 1.28%. Using a simple formula for consumer surplus change, incorporating these price changes with the revenue estimates reported for the initial situation and under Optimization 2a in table 6, it can be calculated that the loss to consumers of canning tuna is US$104 million, and the gain to consumers of *sashimi* products is US$6 million per year. The net loss to consumers of US$98 million must be set against the US$215 million additional profit earned by fleets operating in the FFA region, as compared with the 1996 situation (see table 6). Fleets operating in other regions, such as the EPO and the Indian and Atlantic Oceans, may be affected by changes in world tuna prices resulting from significant changes in catches in the FFA area. However, gains and losses to these fishing fleets will be mostly offset by losses and gains to consumers of tuna products as a result of the price changes.

Other possible changes in net benefits include changes in rents captured by domestic labor and land, or by government through taxes on inputs, although more detailed research on one of the region's fisheries suggests that indirect benefits from this source may be relatively small (Hampton *et al.* 1997). Changes in effort levels and fleet composition, such as a significant reduction in pole-and-lining or fresh tuna longlining, may reduce the levels of such benefits. Fleets operating in regions contiguous to that of the FFA area may accrue some slight benefit in the form of higher catch rates as a result of higher stock levels. In the short-run, vessels in fleets which experience a significant reduction in access to the FFA region may suffer losses which are not accounted for in the long-run rent maximization calculation.

A primary reason for the substantial reduction in purse-seine effort required for maximization of the joint profit of the combined fleets operating in the region, is the current level of purse-seine catches of juvenile yellowfin and bigeye tuna, which reduces the recruitment of these species to the adult stocks exploited by the longline fleets. These catch predictions are determined by the catchability coefficients that were estimated during the parameterization of the harvesting model. If purse-seiners could change their fishing practices to increase the share of skipjack in their catch and reduce the share of yellowfin and bigeye, the optimizations would not require such significant reductions in the purse-seine fleet. In a study of targeting behavior by U.S. and Japanese purse-seiners, Campbell and Nicholl (1994) found some evidence that the proportion of juvenile yellowfin in the catch was, to a certain extent, a choice variable, at least for U.S. purse seiners. If conditions of purse-seine access to the region could be devised which resulted in purse-seiners taking a smaller proportion of juvenile yellowfin and bigeye in their catch, the joint profit maximizing solution might call for less than a 60% reduction in purse-seine effort below the 1996 level.

It should be emphasized that the results obtained from the optimization models are indicative only. In particular, the effects of changes in harvest levels on tuna prices are difficult to predict. The results should be seen as suggested directions for change—towards longlining and away from purse seining, towards higher access fees, and towards differential access fees as a percentage of catch value. The immediate reaction to a proposal to increase access fees might be concern that the DWFN fleets will substantially reduce their operations in the region. This concern may be misplaced in the sense that it is the reduction in fishing effort, mainly by the purse seine fleet, that sets the conditions for enhanced profitability and potentially higher access fee revenues.

Finally, it should be stressed that the model used to generate the profitability results can be improved in many ways, and that subsequent versions of it may produce different estimates of gross profit. For example, instead of using historical proportions to determine the monthly spatial effort distribution of each fleet, a search model similar to that developed by Campbell and Hand (1999), could be used to reallocate effort from month to month according to a profitability criterion. This could result in even higher estimates of fishery rent at the optimum effort level. Nevertheless, the model supports the tentative conclusions of earlier work, based on less detailed and reliable evidence, and it seems unlikely that the directions of change it suggests will be altered as a result of further research.

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