OPTIMAL EFFORT AND SUSTAINABLE RENT IN THE PAPUA NEW GUINEA SURFACE TUNA FISHERY

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ABSTRACT

A static, multi species, multi gear type bioeconomic fishery model was developed and, with the use of parameters relevant to Papua New Guinea (PNG), was applied to the PNG surface tuna fishery. The rent maximising level of fishing effort on the current purse seine fishery was estimated to be 66 standard (1000-1500 GRT) purse seine vessels operating on a full-time basis. This indicates that there is the potential for economic overfishing, since 118 vessels currently have access to the fishery. In addition, it was established that a domestic pole-and-line industry could be re-established without significantly impacting upon the optimum size or profitability of the purse seine fishery. Based on the area that was fished in 1979, the results indicate an optimum of 44 pole-and-line vessels. However, the profitable operation of a pole-and-line fishery was found to depend critically on access to a market that affords price premiums for raw tuna, such as the Japanese fish market.

INTRODUCTION

By world standards, most island nations of the western Pacific are resource poor. In many of these island states, fisheries is a driving force to the economy generally, or at the very least, a driving force to the coastal regional economies. The most valuable fishery resource in the western Pacific is tuna, and the principal species are skipjack (*Katsuwonus pelamis*) and yellowfin (*Thunnus albacares*), which together comprise about 90 percent of tuna harvests in the western Pacific.

Historically, island governments have sought to benefit from their tuna resources in three principal ways:

(1) the negotiation of multilateral and bilateral access agreements with Distant Water Fishing Nations (DWFN's) operating within the exclusive economic zones (EEZ's) of Pacific island nations,
(2) the development of domestic fleets, and
(3) the establishment of tuna processing industries and transhipment facilities.

Of particular relevance with respect to 1) and 2) above is the estimation of the profitability of tuna fishing and the relationship between profitability and fishing effort.

In this paper a simple static bioeconomic model is developed and applied to the PNG surface tuna fishery. Controlling the level of fishing effort in order to maintain a high level of rent, ie., profitability, is assumed to be the operative goal of management. Section 1 contains a description of the PNG tuna fishery, and introduces some issues of current relevance to PNG and the wider western Pacific region. In section 2, a single species, single gear type yield model is developed, based on the model developed by Gulland (1969). The model is extended to include economic parameters so as to enable the calculation of fishery rent. In section 3, the single species, single gear type model is extended to describe a multi species, multi gear type fishery. In section 4, the single species model is applied to the PNG pole-and-line skipjack fishery, and the results are compared with empirical fishery statistics from the 1970's and early 1980's, when the fishery was in operation. In section five, the multi-species model is applied to the PNG purse-seine fishery. In section 6, the hypothetical interaction between a pole-and-line and purse seine fishery in PNG is analysed, based on the multi species, multi gear type model.

1. THE PAPUA NEW GUINEA TUNA FISHERY

Papua New Guinea is rich in fisheries resources. The PNG fishing zone is some 2.3 million square kilometres and includes the richest tuna fisheries in the central western Pacific. Estimates by the South Pacific Commission (SPC) of PNG's surface tuna fishery suggest a skipjack resource base of some 699,000 t and a yellowfin resource base of some 150,000 t. Annual production levels for skipjack and yellowfin are estimated to be 200,000 t and 60,000 t respectively (Hampton 1994).

The central western Pacific supplies about 40 percent of the world catch of tuna and tuna-like species. Although the catch has been variable, up to 50 percent of this has been taken in the PNG region. The development of this fishery is described in a number of places (see Kuk 1994, Doulman and Wright 1983, and Copes 1982).

Domestic Operations

Between 1970 and 1981, up to four domestic companies operated using pole-and-line vessels[1] in PNG Waters. Skipjack comprised on average 90 percent of the catch, while yellowfin comprised approximately ten percent. The existence of good supplies of baitfish around Raboul and Kavieng and abundant supplies of skipjack and yellowfin tuna in inshore waters was established in the 1960's. The relatively labour intensive pole-and-line vessels were the ideal choice at the time.

[1] There are three types of vessels generally used in tuna operations. Pole-and-line vessels are small, relatively labour intensive vessels that generally operate in inshore waters using live bait to catch tuna. Purse-seiners are highly capital intensive, netting tuna by surrounding schools with the net. The tuna is generally destined for canneries. Pole-and-line and purse seine vessels harvest the surface tuna stocks that are the focus of this paper. Longline vessels are capital intensive and use baited hooks and lines over one kilometre in length. They generally catch larger tuna that school in deep water, and these are sold for *sashimi*.

By 1981, the introduction of purse-seine technology and major upheavals in the international tuna market had made tuna operations very competitive internationally, world tuna prices had collapsed, much of the United States fleet were unprofitable and consequently for sale on the international market, and there was an over-supply of tuna. Only two companies remained in the industry in PNG: Star Kist-PNG (part of the Heinz food group), and New Britain Fishing Industries (NBFI), and both companies operated small pole-and-line vessels suitable for inshore fishing. In 1980, NBFI operated 12 pole-and-line vessels and one rarely used purse-seiner. Star Kist operated 36 pole-and-line vessels and four motherships. The catch was exported frozen from the mother ships or from shore handling facilities (Copes 1982). However, by 1983, both NBFI and Star Kist ceased operations, unable to compete in the very depressed international market.

The major problem for these companies was the restriction of pole-and-line vessels to inshore waters (they primarily operated around New Britain, northern New Ireland and New Hanover-Massau) and the expenditure of large amounts of effort in bait-fishing. The requirement for live bait meant that the fishing range was limited by the need to remain in proximity to bait-fish grounds. This was further exacerbated by the problem of high-bait mortality[2], and the biological and socio-political limitation of available bait-fish grounds. Purse-seine vessels were able to take large schools of skipjack (with associated juvenile yellowfin) in deeper waters far more economically than could the pole-and-line vessels.

The Distant Water Fishery

The DWFN's operate purse seiners primarily in the waters of PNG, the Solomon Islands and Micronesia. They target skipjack and yellowfin.

The purse-seine fleet has had a rapid growth in the PNG region, although not without significant conflict (Waugh 1989). United States vessels were first licensed to fish in 1982 and continue under the multilateral treaty with the South Pacific Forum. Since the implementation of the

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Up to 50 percent on capture and 100 percent with 24 hours (Wankowski 1980).

multi-lateral treaty in June 1988, the American purse seine fleet has had access to the Exclusive Economic Zones (EEZ's) of the 16 Pacific island countries party to the treaty, which is worth about $18 million per year to the region. Currently, 32 U.S. vessels have access to PNG waters.

Korean and Taiwanese purse-seiners began operations about the same time as US vessels, and currently have 29 and 43 purse seine vessels licensed to operate in PNG respectively. The Philippines currently have 10 vessels operating in PNG and there are 4 locally based and domestically licensed purse seiners.

While the purse-seine catch is off-loaded outside of PNG (mostly in Thailand) the establishment of a tuna cannery in Madang Province[3] will result in a proportion of the catch being off-loaded in PNG in the future.

Receipts from license fees are the principal gain to PNG from the distant water fishing. While there is year to year variation, revenue from license fees is currently about K13 million (Waugh 1993). Other assistance of a technological nature is probably not of great importance (Waugh 1987).

The difficulties of negotiating mutually acceptable fishing agreements are at the heart of the problem for all small island states. The very successful agreement with the United States was not achieved without considerable international turmoil, that included the arrest and impounding of a number of United States purse-seiners, trade embargoes, and large fines on vessel owners and skippers. The development of a domestic fleet would circumvent these problems, but raise other development and economic issues, especially in the light of the large amount of capital required, capital scarcity in PNG, the skills required and the high level of risk in an industry characterised by significant fluctuations in international tuna prices and large fluctuations in catch rates in different areas and over time.

[3] The cannery is currently under construction.

From an economic perspective, the decision whether to invest in domestic production or to sell fishing rights, and the value of those fishing rights needs to be assessed in terms of possible rent[4]. The level of rent depends in part upon the level of fishing effort applied to the fishery. Current methods of determining access fees in the western Pacific do not address the relationship between fishing effort and rent, and are based directly or indirectly on anticipated revenues[5], and hence fail to adequately incorporate fishing costs.

2. SINGLE GEAR, SINGLE SPECIES FISHERY MODEL

For a unit stock, calculation of fishing yield can made in terms of the yield of a single period class throughout its life. In the steady state, this will be equivalent to the yield in one period, from all period classes present in the fishery.

Typically, the period of reference chosen is one year, although for species that breed regularly throughout the year, such as skipjack, a shorter period is likely to be more appropriate. In each period, the number of fish alive, the number caught, losses from natural (non-fishery) causes, and the number remaining in the fishery at the beginning of the next period can be calculated. In addition, the yield in weight can be calculated as the product of the numbers caught and their average weight (Gulland 1969).

In order to obtain insight into the influence of various parameters upon the harvest (catch in numbers), it is useful to express the yield in algebraic form. The relevant terms are defined as follows[6]:

[4] Rent in this usage is defined as revenues in excess of fishing costs.

[5] In PNG licence fees are based mainly on a combination of (1) vessel type and size; (2) estimated catch rates; (3) duration of fishing trip and time spent in PNG waters; (4) Japanese (three month moving average) market prices adjusted for transport costs; and (5) estimated species composition of catch (Campbell and Nicholl 1994b).

[6] Note that we are considering the yield from a single period class throughout its lifespan.

N_t number of skipjack remaining in the fishery at time t.

R number of recruits ie. the number alive at time t_r

R' number remaining in the fishery at time t_c, at which they become vulnerable to the gear in use.

M instantaneous coefficient of natural attrition[6].

F instantaneous coefficient of fishing mortality.

Then for $t < t_c$

$$\frac{dN_t}{dt} = -MN_t$$

It follows that

$$N_t = Re^{-M(t-t_r)},$$

and

$$R' = Re^{-M(t_c-t_r)}$$

For $t > t_c$ when losses arise as a result of both fishery and natural causes

$$\frac{dN_t}{dt} = -(F+M)N_t$$

and

$$N_t = Re^{-M(t_c-t_r)-(F+M)(t-t_c)}$$

or

$$N_t = R'e^{-(F+M)(t-t_c)}.$$

The number of fish caught in the interval (t, t+dt) will be $Fn_t dt$, and hence the total number caught throughout the lifespan of a period class, H, will be given by the integral

$$H = \int_{t_c}^{t_\lambda} FN_t dt$$

Assumed to be independent of population size.

Including emigration and death from natural (non-fishery) causes.

where t_l is the ma … …e obtained. Hence

$$H = \int_{t_c}^{t_l} F R' e^{-(F+M)(t-t_c)} \, dt$$

or

$$H = R' \frac{F}{F+M} [1 - e^{-(F+M)(t_l - t_c)}]. \qquad (1)$$

If t_l is sufficiently large the equation reduces to

$$H = R' \frac{F}{F+M} \qquad (2)$$

This simplification is assumed in the following discussion.

Thus, fishing takes a proportion of the total numbers reaching the age of first capture, equal to the ratio of fishing mortality to total attrition. Equation 2 represents both the total catch of a single period class throughout its lifespan, and the total catch from the fishery (all period classes) in a single period. The model of Gulland is extended in the following way.

If the catch is multiplied by the average weight of fish, W, an expression for yield, Y, in terms of recruiting biomass, B, is derived.

$$Y = R^1 W \frac{F}{F+M} = B \frac{F}{F+M} \qquad (3)$$

where $B = R^1 W$

Three related measures that are often cited by fishery scientists are:

the catch per recruit $$\frac{H}{R} = \frac{F}{F + M} , \qquad (4)$$

the catch per unit effort $$\frac{H}{f} = R \cdot \frac{q}{F + M} , \qquad (5)$$

and yield per unit effort $$\frac{Y}{f} = B \cdot \frac{q}{F + M} , \qquad (6)$$

where f = fishing effort, q = catchability coefficient[1] and qf = F.

The ratio of fishing mortality to total attrition, termed the catch per recruit in equation 4, is also termed the harvest ratio. Analysis based on the Beverton-Holt yield per recruit model (Kleiber *et al.* 1983) suggests that harvest ratios in the vicinity of 0.5-0.7 would provide the maximum sustainable yield (MSY) in western Pacific skipjack fisheries. Assuming that the more conservative estimate of 0.5 is correct, an equation for the level of effort that will provide the MSY in the PNG fishery (f_{MSY}) can be derived as follows:

$$0.5 = \frac{F}{F + M} = \frac{qf}{qf + M}$$

Therefore

$$f_{MSY} = \frac{M}{q} , \qquad (7)$$

the ratio of the instantaneous coefficient of natural attrition to the catchability coefficient.

When the fishery is exposed to a constant level of fishing effort, the size of the resource at equilibrium, ie., the equilibrium, fishable biomass, P_e, can be derived:

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[1] The catchability coefficient is the fraction of the standing stock harvested by one unit of fishing effort (Tuna Programme 1983).

$$\frac{dP}{dt} = -(F + M)P + B$$

At equilibrium, $\frac{dP}{dt} = 0$, hence

$$P_e = \frac{B}{F + M} \qquad (8)$$

Thus yield (equation 3) is a function of equilibrium fishable biomass.

$$Y = F P_e \qquad (9)$$

In order to measure the rent generated by the fishery, two additional parameters must be included in the model: price per unit of biomass, P, and cost per unit of fishing effort, C. More formally:

$$\begin{aligned} Rent &= Revenue - Cost \\ &= PY - Cf \\ &= PB\frac{F}{F + M} - Cf \\ &= PB\frac{qf}{qf + M} - Cf \end{aligned} \qquad (10)$$

The level of effort that maximises rent can be obtained by differentiating rent with respect to effort, and setting to zero. Hence

$$\frac{d(Rent)}{df} = \frac{(qf + M)(PBq) - PBqf(q)}{(qf + M)^2} - C = 0$$

The above expression simplifies to a quadratic in f, and the solution f_{opt} is given by

$$f_{opt} = \frac{-2qM \pm \sqrt{(2qM)^2 - 4q^2\left(M^2 - \frac{(PBqM)}{C}\right)}}{2q^2}, \; f \geq 0 \qquad (11)$$

where f_{opt} is the level of effort that maximises rent.

Assuming that the parameters q, M and B are fixed and known, the ratio between P and C will determine the optimal level of effort. If both cost and price increase/decrease by the same proportion (leaving the ratio unchanged), neither the optimal level of effort nor the rent/rev % will change. However, the absolute value of the level of rent will vary by the same proportion as cost and price. The break-even cost price ratio (C/P break-even ratio), ie., the ratio between cost and price at which rent is zero, is a function of the level of effort, and can be derived as follows:

$$Rent = PY - Cf$$

When Rent = 0

$$PY = Cf$$

Hence

$$C/P_e = \frac{Y}{f} = \frac{qB}{qf + M} = \text{Yield per unit effort} \qquad (12)$$

Hence, the yield per unit effort can also be used to evaluate the cost price ratio at which the fishery rent will be zero, for a given level of effort.

If the prevailing cost price ratio is greater than the C/P break-even ratio for the given level of effort operating in the fishery, the model predicts that losses will be made (ie. rent will be negative) and vice versa. For a given level of effort, the percentage difference between the market price and the break-even price is equal to the rent as a percentage of revenue. (The break-even price is equal to the cost per boat-day divided by the C/P break-even ratio)

3. MULTI GEAR, MULTI SPECIES FISHERY MODEL.

Commonly in tropical fisheries, more than one species is harvested by a single fishing gear type. In western Pacific tuna fisheries, skipjack, juvenile yellowfin and smaller proportions of other species comprise single schools. Hence a single unit of fishing effort (eg. one boat-day, one purse-seine set) can result in a multi-species harvest. In addition, multi-species fisheries are often harvested by more than one type of gear.

The simple yield and rent models developed in Section 2 can be extended to accommodate a multi-species, multi-gear type model under the following assumptions: i) there are m species and n gear types, ii) t is sufficiently large for all species concerned, thus enabling equation 2 to be used as the base yield model[1], iii) the stock of each species is vulnerable to every gear type; and iv) species interactions are negligible.

Using the parameter symbols defined in Section 2, the following yield terms can be expressed algebraically. Let i = 1, ..., m denote the species type, and let j = 1, ..., n denote the gear type. Then equilibrium population of species i can be written as

$$P_i^e = \frac{B_i}{\sum_{j=1}^{n} F_{ij} + M_i} \qquad (13)$$

where $F_{ij} = q_{ij} f_j$.

The yield of species i harvested by gear j as

$$Y_{ij} = B_i \left(\frac{F_{ij}}{\sum_{j=1}^{n} F_{ij} + M_i} \right). \qquad (14)$$

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[1] A reasonable assumption for tuna fisheries provided the unit of time measurement is monthly or shorter, as is demonstrated in section 4.

The total yield of species i by all gear types as

$$Y_i = \sum_{j=1}^{n} Y_{ij} \quad , \tag{15}$$

The total yield by gear j, all species as

$$Y_j = \sum_{i=1}^{m} Y_{ij} \quad , \text{ and} \tag{16}$$

The total yield of all species by all gear types as

$$Y = \sum_{i=1}^{m} \sum_{j=1}^{n} Y_{ij} \tag{17}$$

Similarly, the yield per unit effort and the harvest ratio can be expressed algebraically:

The yield of species i per unit of effort by gear type j

$$YPUE_{ij} = \frac{Y_{ij}}{F_j} = B_i \left(\frac{q_{ij}}{\sum_{j=1}^{n} F_{ij} + M_i} \right) \quad , \tag{18}$$

The total yield per unit effort of gear type j

$$YPUE_j = \sum_{i=1}^{m} YPUE_{ij} \quad , \text{ and} \tag{19}$$

The harvest ratio (HR) for species i

$$HR_i = \frac{\sum_{j=1}^{n} F_{ij}}{\sum_{j=1}^{n} F_{ij} + M_i} \tag{20}$$

With the inclusion of price and cost parameters, the following revenue and rent terms can be expressed:

The revenue accruing to the owners of fishing gear j from the harvest of species i

$$Rev_{ij} = P_{ij} Y_{ij} = P_{ij} B_i \left(\frac{F_{ij}}{\sum_{j=1}^{n} F_{ij} + M_i} \right) ; \tag{21}$$

The total fishery revenue from the harvest of species i by all gear types

$$Rev_i = \sum_{j=1}^{n} P_{ij} Y_{ij} \ . \tag{22}$$

The total rent accruing to the owners of fishing gear j

$$Rent_j = \sum_{i=1}^{m} P_{ij} Y_{ij} - C_j f_j \ , \text{and} \tag{23}$$

Total fishery rent accruing to the owners of all gear types

$$Rent = \sum_{i=1}^{m} \sum_{j=1}^{n} P_{ij} Y_{ij} - \sum_{j=1}^{n} C_j f_j \tag{24}$$

As in the simple rent case, the C/P break-even ratio can be related to the yield per unit effort. Assuming that the price of each species, P_{ij}, is replaced by P_j, a weighted average price for gear type j[11], the C/P break-even ratio for gear type j can be written as

$$C_j / P_{j,b\text{-}e} = \sum_{i=1}^{m} YPUE_{ij} \ . \tag{25}$$

The construction of the model is reasonably straight forward and can be done using spreadsheet software. The spreadsheet format is particularly useful since it provides a flexible means of examining the impact of changes in parameter values upon the model. Assuming that all effort

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[11] It is not uncommon for juvenile yellowfin to remain undifferentiated from skipjack when purse seine of pole-and-line harvests are offloaded. In addition, the industry benchmark (4-7.5 lb) cannery price for purse seine tuna in the Pacific is the same for yellowfin and skipjack.

levels, with the exception of f_i (ie., a single gear type) are known and fixed, the spreadsheet can also be used to approximate the static optimum level of f_i.

The information requirements of the model are not extensive: biological and fishing data can be obtained from publications of the South Pacific Commission (SPC)[14], while economic data is available from a number of agencies including the Forum Fisheries Agency (FFA)[15].

While caution must be applied in the use of the model due to the numerous simplifying assumptions, it may nevertheless provide a useful insight into a range of issues including the relationship between effort and rent, the impact of various fleet structures and effort levels upon tuna stocks and upon the viability of the industry generally, interaction between fleets fishing the same tuna stocks, and the impact of price and cost changes upon fishery rents.

In the following sections, the simple and extended models are applied to PNG's surface tuna fisheries. The applications include two species: skipjack and yellowfin, and two gear types: pole-and-line and purse seine. However the variation in gear type need not be restricted to different types of fishing. The equations could, for example, be used to model a purse seine fishery comprising a range of vessel classes: 500 GRT vessels, 750 GRT vessels, 1000 GRT vessels and so on. This would require separate cost, price and catch capacity data for each vessel class.

The SPC is a regional research agency located in Noumea, New Caledonia. Biological data can be obtained from publications of the agency's Tuna and Billfish Assessment Programme, while fishing data is contained in the Tuna Fisheries Yearbook.

The Forum Fisheries Agency is a regional organisation located in Honiara, the Solomon Islands, that was established to coordinate fisheries management (principally for tuna) in the western Pacific.

4. PAPUA NEW GUINEA DOMESTIC POLE-AND-LINE SKIPJACK FISHERY

The following analysis is based on the single gear, single species model outlined in Section 2, and relates to the area that was fished commercially by PNG's pole-and-line vessels in the 1970's and early 1980's, although the parameter values relate specifically to the area that was fished commercially in 1979, principally the eastern Bismarck Sea, St George's Channel, and New Hanover-Massau. While skipjack comprised approximately 90 percent of the pole-and-line harvest during 1970-81, it is assumed to comprise 100 percent of the harvest in this section. The relevant parameters, their assigned values and sources are documented in Table 1.

Table 1. PNG skipjack yield model parameters and assigned values

Parameter	Units	Value	Reference
R^1	Fish/month	3823529	
B	t/month	13000	Derived from Kleiber et al. 1987
M	Per month	0.322	Derived from Kleiber et al. 1987
t_c	Months	8	Troedson and Waugh 1994
t_l	Months	60	Kearney 1989
q	Per boat-day	0.00009	Kleiber et al. 1987
f	Boat-days/month	0 to 3578	
W	t	0.0034	Troedson and Waugh 1994

The analysis was initially conducted over a range of effort levels, from 0 to 3,578 boat days/month (f_{MSY})[4], in steps of 200. At each level, values for the various bioeconomic measures derived in Section 2 were calculated, and are documented in Table 2. Each measure is discussed briefly in the following paragraphs.

The yield model is a static, equilibrium model. At each level of effort, there is an associated equilibrium fishable population and hence biomass (assuming constant average weight of fish). As the level of effort rises from 0 to 3,578 boat days/month, equilibrium biomass falls 50 percent, from 40,373 t to 20,186 t.

In their analysis of skipjack resources in the western Pacific, Kleiber *et al.* (1987) estimate the standing stock of skipjack in the PNG pole-and-line fishery to be 35,000 t, associated with an effort level of 644 boat-days/month ($F = 0.058$/month, $q = 0.00009$/boat-day). This is reasonably consistent with the present model, that estimates the biomass associated with 600 boat-days/month to be 34,574 t (Table 2). More precisely, the model estimates the equilibrium biomass associated with 644 boat-days/month to be 34,214 t, a discrepancy of 2.2 percent.

The maximum obtainable age, t_L (60 months), is sufficiently large relative to the age of first capture, t_c (8 months), to validate the use of equation 2 to model catch in numbers. Monthly catch rises curvilinearly with effort to a level of 1,911,824 individuals (6500 tonnes), when effort is 3578 boat-days/month. This is 50 percent of monthly recruitment, as is indicated by the corresponding catch per recruit figure.

Catch per unit effort and hence yield per unit effort decline with increasing effort, while the catch per recruit rises with increasing effort. Each individual is assumed to be 3.4 kilograms (the average weight), and hence yield (tonnes/month) is catch times 0.0034.

The level of effort that will provide maximum sustainable yield (equation 7) is calculated to be approximately 3,578 boat-days.mo^{-1}. The maximum sustainable yield is thus 6,500 tonnes.mo^{-1} (equation 3).

Table 2. PNG skipjack yield model: selected output

Fishing Effort (boat-days/month)	Equilibrium population (t)	Catch (fish/month)	Yield (t/month)	Catch per recruit (fraction of monthly recruitment caught)	Catch per unit effort (fish/boat-day)	Yield per unit effort (t/boat-day)
0	40373	0	0	0.000		
200	38235	202422	688	0.053	1012	3.44
400	36313	384489	1307	0.101	961	3.27
600	34574	549124	1867	0.144	915	3.11
800	32995	698716	2376	0.183	873	2.97
1000	31553	835237	2840	0.218	835	2.84
1200	30233	960328	3265	0.251	800	2.72
1400	29018	1075368	3656	0.281	768	2.61
1600	27897	1181520	4017	0.309	738	2.51
1800	26860	1279776	4351	0.335	711	2.42
2000	25896	1370987	4661	0.359	685	2.33
2200	25000	1455882	4950	0.381	662	2.25
2400	24164	1535097	5219	0.401	640	2.17
2600	23381	1609183	5471	0.421	619	2.10
2800	22648	1678623	5707	0.439	600	2.04
3000	21959	1743839	5929	0.456	581	1.98
3200	21311	1805207	6138	0.472	564	1.92
3400	20701	1863057	6334	0.487	548	1.86
3578	20136	1911824	6500	0.500	534	1.82

One means of determining the usefulness of the model is to compare it with empirical statistics. Table 3 documents relevant empirical statistics for the PNG domestic pole-and-line skipjack fishery for the period 1970-81. Average monthly effort during the period was 600 boat-days, while the average monthly yield was 1,990 t. A comparison with Table 2 indicates that this is reasonably close to the model prediction, an effort level of 600 boat-days/month corresponds to a harvest of 1867 t, a discrepancy of 6.2 percent.

Table 3. The PNG domestic pole-and-line skipjack fishery, 1970-81 (Lawson 1994).

	Vessel Numbers	Fishing effort (boat-days)	Skipjack catch (t)	Yield per unit effort (t/boat-day)
1970	5	511	2354	4.61
1971	29	4060	16862	4.15
1972	45	4950	11785	2.38
1973	43	7863	27300	3.47
1974	47	9408	40214	4.27
1975	48	6435	15625	2.43
1976	40	7901	24358	3.08
1977	31	9736	20106	2.07
1978	48	9941	45760	4.60
1979	45	8184	23976	2.93
1980	50	9484	30976	3.27
1981	44	7861	27207	3.46
Average	41.3	7194.5	23877	3.39
Average monthly*		600	1990	

* Assuming effort is distributed uniformly throughout the year.

Average yield per unit effort in the PNG fishery during 1970-81 was 3.39 t/boat-day, associated with an average effort level of 600 boat-days/month. According to the model, an effort level of 600 boat-days/month is associated with a yield per unit effort of 3.11 t/boat-day (Table 2), a discrepancy of 8.3 percent.

A comparison between the model estimates and empirical statistics indicates that, in terms of the relationship between catch and effort, the model is not an unreasonable representation of the fishery. Assuming that this is so, it is pertinent to analyse the conditions of optimality, ie., the optimal level of effort and subsequent yield in the fishery. In terms of economic efficiency, the optimal level of effort is that which maximises fishery rent. Optimal effort will be considered principally in terms of discrete boat units, where 1 boat unit is defined to be 14.5 boat-days/month. This value is derived from Table 3, where the average number of boats is 41.3 and the average monthly effort is 600 boat-days.

Campbell and Nicholl (1994a) estimate the cost of fishing effort for Japanese, 50-100 ton pole-and-line vessels operating full-time during the period 1979-80 to 1988-89. During the period, the cost per boat-day ranged from ¥467 thousand to ¥592 thousand with a reasonably level trend, the average being ¥524.7 thousand. At current exchange rates, this is approximately US $5 250.

The major selling points for Pacific skipjack are canneries located in Pacific Island nations and Thailand and the Japanese fresh and frozen tuna market. The leading Japanese discharge/market port for tuna in terms of volume is Yaizu port. Yaizu ex-vessel prices are considered to represent a benchmark for world tuna prices (Campbell and Nicholl 1994b). The 1989-93 average monthly price for pole-and-line caught skipjack at Yaizu was ¥238.12/kg which is approximately

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Most vessels operating in the fishery during 1970-85 were of this size (Wankowski 1980).

Calculation of cost per boat day involved using the method 'Return to Capital (A)' which is defined on page 42 of Campbell and Nicholl (1994).

An exchange rate of 100 Yen per US dollar is assumed in this paper.

US $2,380/t. Assuming that skipjack caught in PNG is shipped by sea freight to Japan[18], the net effective price is approximately US $2,000/t.

Given a fishing cost of US $5,250/boat-day and a skipjack price of US $2,000/t, the optimum level of effort is calculated to be 631.6 boat-days/month (equation 12), or, rounding to discrete boat units, 638 boat-days/month (44 boats). This level is close to the average level of effort applied to the fishery during 1970-81. At this level of effort, skipjack yield is 1967 t/month which is 30 percent of MSY, the YPUE is approximately 3.084 t/boat-day, and the rent is US $585,243/month (US $13,300/boat/month), which is 14.87 percent of revenue.

The C/P break-even ratio is approximately 3.084 when effort is optimal, and the break-even price is approximately US $1,702.53, which is 14.87 percent less than the market price. As noted in section 2, the percentage difference between the break-even price and the market price is equal to the rent/rev %.

Sensitivity Analysis

The following paragraphs examine the impact of variation in the parameters of the model upon monthly rent, rent/rev % and harvest ratio. The level of effort is fixed at the base model optimum of 638 boat-days/month.

Price and Cost: Table 4 documents the impact upon monthly rent and rent/rev % of changes in price and cost from the original levels. As noted in section 2, when the cost and price vary equally in proportion and direction, the absolute value of the level of rent varies by the same proportion, while the rent/rev % remains unchanged.

Both cost and price impact significantly upon the level of monthly rent and rent/rev %. A 20 percent decline in price causes monthly rent to fall to US $-201,706, while a 20 percent increase

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A small pole-and-line industry targeting the Japanese market was recently established in the Solomon Islands.

Freight costs are in the vicinity of US $ 350/t to US $ 400/t of fish.

As noted, it is numerically equal to the YPUE.

in cost causes monthly rent to fall to US $-84,657. If both price and cost are reduced by 20 percent, monthly rent falls to US $-871,606. The fishery could not continue to operate under such conditions in the long term. Price increases and cost decreases significantly improve rent and rent rev %. In either case, the variation in rent is significantly greater than the variation in the price and cost.

Table 4. Sensitivity analysis: price and cost

		RENT PER MONTH Change in price %				
		-20 %	-10 %	0 %	+10 %	+20 %
	+20 %	-871606	-478132	-84657	308817	702291
Change in	+10 %	-536656	-143182	250293	643767	1037241
Cost %	0 %	-201706	191768	585243	978717	1372191
	-10 %	133244	526718	920193	1313667	1707141
	-20 %	468194	861668	1255143	1648617	2042091
		RENT REV % Change in price %				
		-20 %	-10 %	0 %	+10 %	+20 %
	+20 %	-27.69	-13.50	-2.18	7.13	14.87
Change in	+10 %	-17.05	-4.04	6.36	14.87	21.97
Cost %	0 %	-6.41	5.42	14.87	22.61	29.06
	-10 %	4.23	14.87	23.39	30.35	36.16
	-20 %	14.87	24.33	31.90	38.09	43.25

Recruiting Biomass (B), Natural Attrition (M) and Catchability (q): Table 5 documents the impact upon monthly rent, rent/rev % and harvest ratio of a ten percent variation in B, M, and q. Each parameter is varied relative to the base model. Rent and rent/rev % vary directly with B and q, with variation in the range 44-67 percent. Rent and rent/rev % vary inversely with M, variation being in the range 49-62 percent. Hence, variation in the economic variables is at least four times greater than the variation in the biological and fishing parameters. Harvest ratio varies directly with q and inversely with M. Overall variation is similar for both (nine percent) and levels remain significantly less than those required for MSY.

Table 5. Sensitivity analysis: recruiting biomass, natural attrition and catchability

Parameter	Change in Parameter	Rent	Rent/Rev %	Harvest Ratio
B, M, q	0 %	585243	14.87	0.151
B	+ 10 %	978717	22.61	0.151
	- 10 %	191768	5.42	0.151
M	+ 10 %	277437	7.65	0.139
	- 10 %	950137	22.10	0.165
q	+ 10 %	914192	21.44	0.164
	- 10 %	246184	6.85	0.138

Age Of First Capture (t_c) and Maximum Age (t_l): The skipjack catch (H), as defined by equation 2, is a simplfication of equation 1, based on the assumption that the maximum age (t_l) is sufficiently large relative to the age of first capture (t_c), to render the term $e^{-(F+M)(t_l-t_c)}$ equal to zero. This assumption holds true in the base model, where $t_l = 60$ and $t_c = 8$. The greater the difference between t_l and t_c, the nearer the term approaches zero. Hence, only variation that reduces the gap between t_l and t_c need be considered.

An increase in the age of first capture by one year to 20 months, or a decrease in the maximum age by one year to 48 months reduces monthly harvest by one kilogram (0.00008 percent) at the optimum, which is not significant. Further increase in the age of first capture is likely to be beyond the scope of reasonable variation. A decline in the maximum age by 20 months reduces monthly harvest by approximately 14 kilograms (0.0012 percent). In terms of the impact upon the economic variables under consideration, this decline is not significant.

Hence, considerable variation in the maximum age of skipjack and in the age of first capture has no significant impact upon the yield, and consequently no significant impact upon the optimal level of effort in the fishery or the fishery rent. Any reasonable error in the measurement of maximum age or age of first capture should have no impact upon the results of the model.

5. PAPUA NEW GUINEA PURSE SEINE FISHERY

The following paragraphs document a two-species, single gear model of the PNG purse-seine fishery based on the model outlined in section 3. The purse-seiners are assumed to be US vessels of about 1000-1200 GRT, and the species harvested are skipjack and yellowfin. It is assumed that the maximum yellowfin age is significantly larger than the age of first capture to justify the use of equation 14 to model harvest levels. Biological parameters were provided by John Hampton, Principal Fisheries Scientist, SPC, Noumea. A weighted average tuna price was derived by applying the American Tuna Sales Association's (ATSA's) 1993/94 purse-seine tuna prices at Pago Pago[22] to the price averaging formula contained in McIlgorm (1989:146). A yearly average cost figure was derived from US purse seine cost data for the period 1979-89 contained in USITC (1990:7-9). The technique of linear regression was used to extrapolate a yearly average cost for 1994. Cost per boat-day was obtained by dividing the 1994 yearly average cost by 210, ie., one discrete boat unit is assumed to be 210 boat-days per year or 17.5 boat-days per month[23]. Catchability coefficients were determined by dividing 1989-93 average US purse seine YPUE (contained in Lawson (1994:63)) by the standing stock of each species[24]. Parameter values are documented in Table 6.

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[22] While current PNG access fees are based on Japanese (three month moving average) market prices adjusted for transport costs, we consider it more appropriate to base the rent calculation on Pacific cannery prices, the main major destination of US purse seine caught tuna.

Some variations to the published costs were made. License fees and interest costs were excluded since these are not part of the economic costs in a rent calculation. A five percent real opportunity cost of capital was included, which, based on a 1984-89 average US purse seine cost of 4,800,000, amounted to 240,000 annually.

[23] Industry sources indicate that reasonable operating levels are in the range of 200-240 fishing days per year.

[24] As noted, the catchability coefficient is the proportion of the standing stocking harvested by one unit of fishing effort.

Table 6. PNG Purse Seine Model: parameter values for skipjack and yellowfin.

Parameter	Units	Skipjack	Yellowfin
		$i=1, j=2$	$i=2, j=2$
B_i	t/month	202000	33000
M_i	Per month	0.26	0.181
q_{ij}	Per boat-day	0.000026	0.000052
P	US$/tonne	925	925
C_j	US$/boat-day	20000	20000

Table 7 documents selected output for the PNG purse seine model. Units for each term are as defined in section 4. Fishing effort ranges from 175 boat-days/month (10 boats) to 1750 boat-days/month (100 boats). Skipjack and yellowfin comprise roughly 70 percent and 30 percent of yield respectively, which is typical of western Pacific purse-seine fisheries. At each level of effort, more than twice the proportion of yellowfin recruits are harvested than skipjack recruits, as indicated by their respective harvest ratios. This indicates that yellowfin are more vulnerable to over-fishing in this fishery than are skipjack. Total yield increases from 5,054 t to 41,126 t, while total YPUE declines from 28.88 t/boat-day to 23.5 t/boat-day.

As effort levels increase from 175 boat-days/month to 1,750 boat-days/month, fishery rent per month initially increases to a level of US $3,837,433 when effort is 1,225 boat-days/month, and declines thereafter. Although not documented in Table 7, rent per month is maximum when fishing effort is 1,147 boat-days/month, or, rounding to discrete boat units, 1155 boat-days/month (66 boats). At the discrete optimum, monthly rent is US $3,851,929 (US $58,363 per boat), rent/rev % is 14.29, the C/P break-even ratio is 25.227, and harvest ratios for skipjack and

Table 7. PNG Purse Seine Model: selected output

Fishing Effort	175	350	525	700	875	1050	1225	1400	1575	1750
Boat Number	10	20	30	40	50	60	70	80	90	100
SKIPJACK										
P_e	763561	750650	738169	726096	714412	703098	692136	681511	671208	661211
Yield	3474	6831	10076	13215	16253	19195	22045	24807	27486	30085
YPUE	19.85	19.52	19.19	18.88	18.57	18.28	18.00	17.72	17.45	17.19
Harvest Ratio	0.017	0.034	0.050	0.065	0.080	0.095	0.109	0.123	0.136	0.149
YELLOWFIN										
P_e	173593	165663	158425	151794	145695	140068	134859	130024	125523	121324
Yield	1580	3015	4325	5525	6629	7648	8591	9466	10280	11040
YPUE	9.03	8.61	8.24	7.89	7.58	7.28	7.01	6.76	6.53	6.31
Harvest Ratio	0.048	0.091	0.131	0.167	0.201	0.232	0.260	0.287	0.312	0.335
TOTAL										
Yield	5054	9846	14401	18740	22882	26842	30635	34273	37766	41126
YPUE	28.88	28.13	27.43	26.77	26.15	25.56	25.01	24.48	23.98	23.50
Revenue	4674854	9107530	13320945	17334733	21165862	24829107	28337433	31702283	34933824	38041131
Cost	3500000	7000000	10500000	14000000	17500000	21000000	24500000	28000000	31500000	35000000
Rent	1174854	2107530	2820945	3334733	3665862	3829107	3837433	3702283	3433824	3041131
Rent rev %	25.13	23.14	21.18	19.24	17.32	15.42	13.54	11.68	9.83	7.99
C/P break-even	28.88	28.13	27.43	26.77	26.15	25.56	25.01	24.48	23.98	23.50

yellowfin are 0.104 and 0.249 respectively. As noted above, a weighted average price is used for skipjack and yellowfin. The break-even price is approximately US $793/t. In section 4, the break-even skipjack price for pole-and-line vessels was approximately US $1,700/t. Hence, the models are consistent with the fact that purse seine vessels are significantly more efficient than pole-and-line vessels.

Sensitivity Analysis

Following the procedure in section 4, the sensitivity of rent per month, rent/rev % and harvest ratio to changes in the model parameters is analysed in the following paragraphs. Effort is held constant at the base model optimum of 1,155 boat-days/month for all sensitivity analysis.

Price and Cost: Table 8 documents the sensitivity of rent per month and rent/rev % to changes in price and cost. Clearly, the variables in question and hence the model outcomes are highly responsive to variations in the price and cost parameters. As was the case for the pole-and-line fishery model, a 20 percent reduction in price or a 20 percent increase in cost will result in losses accruing to the owners of fishing vessels. This poses a significant problem to vessel owners, since over the past 10-15 years fishing costs have increased steadily, while tuna prices have remained relatively stable[*].

US purse seine cost trends are documented in USITC (1990:2-9). While there is reasonable year to year variation in purse seine tuna prices, the long term trends are relatively level. ATSA purse seine tuna prices at Pago Pago in the first half of 1994 were similar to prices in 1984. This is not true however of skipjack and yellowfin (purse seine caught) prices at Yaizu, which have declined over the past decade.

Table 8 Sensitivity analysis: price and cost

		RENT PER MONTH Change in price %				
		-20 %	-10 %	0 %	+10 %	+20 %
Change in Cost %	+20 %	-6158456	-3463263	-768071	1927122	4622315
	+10 %	-3848456	-1153263	1541929	4237122	6932315
	0 %	1538456	1156737	3851929	6547122	9242315
	-10 %	771544	3466737	6161929	8857122	11552315
	-20 %	3081544	5776737	8471929	11167122	13862315

		RENT REV % Change in price %				
		-20 %	-10 %	0 %	+10 %	+20 %
Change in Cost %	+20 %	[illegible]	-14.28	-2.85	6.50	14.29
	+10 %	17.85	-4.75	5.72	14.29	21.43
	0 %	-7.14	4.77	14.39	22.08	28.58
	-10 %	3.58	14.29	22.86	29.88	35.72
	-20 %	14.29	23.81	31.43	37.67	42.86

Recruiting Biomass (B), Natural Attrition (M), and Catchability (q): Table 9 documents the sensitivity of rent per month, rent/rev % and harvest ratio to changes in the biological and fishing parameters. As in section 4, each parameter is varied in turn relative to the base model. As would be expected, the impact on rent and rent/rev % of variation in skipjack parameters (B_1, M_1, q_{12}) is significantly larger than the impact of variation in yellowfin parameters (B_2, M_2, q_{22}), since skipjack comprises approximately 70 percent of the catch. A ten percent variation in the skipjack and yellowfin parameters causes rent per month to vary in the ranges 41-50 percent and 14-16 percent respectively.

Ten percent variation in skipjack mortality or catchability results in an eight to ten percent variation in skipjack harvest ratio, while a ten percent variation in yellowfin mortality or catchability results in a seven to eight percent variation in yellowfin harvest ratio. If a harvest ratio of 0.5 would provide the MSY for yellowfin (as is the case with skipjack) harvest ratios remain at reasonably safe levels for both species, within the range of documented variation However, it should be noted that yellowfin is a slow growing, long lived species compared with skipjack, and has a lower natural rate of attrition, and is therefore more vulnerable to overfishing than is skipjack

Table 9 Sensitivity analysis recruiting biomass, natural attrition and catchability

Parameter	Change in Parameter	Rent	Rent/Rev %	Harvest Ratio Skipjack	Harvest Ratio Yellowfin
B_1, M_1, q_1 B_2, M_2, q_2	0 %	3851929	14.29	0.104	0.249
B_1	+10 %	5786593	20.03	0.104	0.249
	-10 %	1917266	7.66	0.104	0.249
B_2	+10 %	4612459	16.64	0.104	0.249
	-10 %	3091400	11.80	0.104	0.249
M_1	+10 %	2260269	8.91	0.095	0.249
	-10 %	5757064	19.95	0.114	0.249
M_2	+10 %	3320768	12.57	0.104	0.232
	-10 %	4469331	16.21	0.104	0.269
q_1	+10 %	5568503	19.42	0.113	0.249
	-10 %	2099437	8.33	0.094	0.249
q_2	+10 %	4409091	16.03	0.104	0.267
	-10 %	3266295	12.39	0.104	0.230

6. PAPUA NEW GUINEA SURFACE TUNA FISHERY

In the following paragraphs, the potential interaction between a domestic pole-and-line fleet and a distant water purse seine fleet is analysed, based on the model developed in section 3. The economic feasibility of such an interaction and the impact upon the skipjack and yellowfin stocks are analysed.

It is assumed that both fleets range throughout the PNG fishery zone, and hence fish the same skipjack and yellowfin stocks. This implies an assumption that the restrictions upon the range of pole-and-line vessels that existed during the 1970's and early 1980's no longer apply. Two developments that would strengthen the validity of this assumption are: i) improved technology in bait capture and handling so as to significantly reduce the mortality of baitfish after capture, and ii) the discovery of new baitfish grounds or the development of known grounds that were previously unused or under-used.

Pole-and-line catchability coefficients were determined by dividing PNG pole-and-line YPUE data by the standing stock of each species. The remaining purse seine and pole and line fleet characteristics and selling arrangements are as defined in sections 4 and 5, with the additional assumption that the pole-and-line fleet is limited to 44 boats (the optimum determined in section 4). Table 10 documents the model parameters and their respective values. Units are as previously defined.

Socio-political problems led to the closure of some baitfish grounds to the pole-and-line fleet in latter half of the 1970's (Wankowski 1980).

While the number chosen is arbitrary, two justifications can be given for a limitation of vessel numbers. First, there is likely to be some form of quantity restriction in the Japanese selling arrangements. Second, the results in section 4 indicate that pole-and-line vessels could not operate profitably in PNG if a large proportion of the catch was sold to canneries.

Table 10 PNG surface tuna fishery model parameters and assigned values.

Parameter	Description	Value
B	Recruiting Biomass skipjack	202000
B	Recruiting Biomass yellowfin	33000
M	Natural Attrition skipjack	0.26
M	Natural Attrition yellowfin	0.181
q	Catchability skipjack, pole-and-line	0.000044
q	Catchability skipjack, purse seine	0.000026
q	Catchability yellowfin, pole-and-line	0.000023
q	Catchability yellowfin, purse seine	0.000052
P	Average Tuna Price pole-and-line	2000
P	Average Tuna Price purse seine	925
C	Cost per boat-day pole-and-line	5250
C	Cost per boat-day purse seine	20000
E	Fishing Effort pole-and-line	638

Table 11 documents selected output of the PNG combined surface fishery model. Purse Seine fishing effort ranges from 175 boat-days/month (10 boats) to 1,750 boat-days/month (100 boats). As was the case in the PNG purse seine model, skipjack and yellowfin comprise approximately 70 percent and 30 percent of the purse seine catch respectively, which is typical of catch proportions in western Pacific purse seine fisheries. Skipjack and yellowfin comprise respectively about 90 percent and ten percent of the pole-and-line catch, which was true on average of the PNG pole-and-line fleet during 1970-81.

Table 11. PNG surface tuna fishery model: selected output

PURSE SEINE										
Effort	175	350	525	700	875	1050	1225	1400	1575	1750
Boat Numbers	10	20	30	40	50	60	70	80	90	100
SKIPJACK										
P_c	755544	742901	730674	718843	707389	696294	685542	675117	665005	655191
Yield (P&L)	2121	2085	2051	2018	1986	1955	1924	1895	1867	1839
Yield (PS)	3438	6760	9974	13083	16093	19009	21835	24574	27232	29811
YPUE (P&L)	3.32	3.27	3.21	3.16	3.11	3.06	3.02	2.97	2.93	2.88
YPUE (PS)	19.64	19.32	19.00	18.69	18.39	18.10	17.82	17.55	17.29	17.03
Harvest Ratio	0.028	0.044	0.060	0.075	0.089	0.104	0.118	0.131	0.144	0.157
YELLOWFIN										
P_z	172263	164451	157317	150776	144758	139201	134055	129276	124826	120673
Yield (P&L)	253	241	231	221	212	204	197	190	183	177
Yield (PS)	1568	2993	4295	5488	6586	7600	8539	9411	10223	10981
YPUE (P&L)	0.40	0.38	0.36	0.35	0.33	0.32	0.31	0.30	0.29	0.28
YPUE (PS)	8.96	8.55	8.18	7.84	7.53	7.24	6.97	6.72	6.49	6.27
Harvest Ratio	0.055	0.098	0.137	0.173	0.206	0.237	0.265	0.291	0.315	0.338
COMBINED										
Rent	2527900	3325974	3912807	4307223	4525497	4581817	4488632	4256943	3896521	3416099
Rent/Rev %	26.96	24.32	22.03	19.89	17.83	15.84	13.88	11.96	10.06	8.18
P&L										
Rent	1397981	1304072	1214489	1128869	1046899	968302	892834	820279	750443	683152
Rent/Rev %	29.45	28.02	26.61	25.21	23.81	22.43	21.05	19.67	18.30	16.94
C/P break-even	3.72	3.65	3.58	3.51	3.45	3.38	3.32	3.27	3.21	3.16
PS										
Rent	1129919	2021902	2698319	3178354	3478599	3613515	3595798	3436664	3146078	2732946
Rent/Rev %	24.40	22.41	20.44	18.50	16.58	14.68	12.80	10.92	9.08	7.24
C/P break-even	28.60	27.87	27.18	26.53	25.92	25.34	24.79	24.28	23.78	23.31

As purse seine effort increases in steps of 175 from 175 boat-days/month to 1750 boat-days/month, total surface fishery rent and purse seine rent increase to a maximum when effort is 1,050 boat-days/month and subsequently decline. However, in terms of discrete boat units, the optimum levels of effort in the combined surface fishery and the purse seine fishery are not the same. From the standpoint of the combined surface fishery, the discrete optimum is 1,032.5 boat-days/month (59 boats). At this level of effort the monthly rent accruing to the owners of purse seine vessels is US $3,607,089 while monthly total fishery rent is US $4,583,106. From the standpoint of the purse seine fishery the discrete optimum is 1,120 boat-days/month (64 boats). At this level of effort the monthly rent accruing to owners of purse seine vessels is US $3,624086, while monthly total fishery rent is US $4,561,838.

Since both fleets are competing for the same tuna stocks, pole-and-line yields are dependant in part upon purse seine yields. This interaction stems from the structure of the model as determined by equation 14. Any variation in the instantaneous coefficient of fishing mortality from a single species/gear-type interaction (F_{ij}) will inversely effect the yield of that species by all other gear-types. This could result either from changes in harvesting efficiency, ie., changes in the catchability coefficient q_{ij}, or changes in the level of effort applied by gear type j, ie., changes in E_j. The effect of both changes is illustrated in the following paragraphs.

As is illustrated in Table 11, an increase in purse seine effort results in a decrease in pole-and-line yields (for a given level of pole-and-line effort). In consequence, pole-and-line rent declines as purse seine effort increases. Table 12 documents the impact of a change in harvest efficiency for one gear-type upon harvest and rent of both gear types. It is assumed that a change in harvest efficiency for one gear-type effects the catchability of skipjack and yellowfin for that gear-type equally. As can be seen, changes in pole-and-line catchability impact inversely upon purse seine harvests and vice versa, although compared with own-yield effects the cross-yield effects are small.

Table 12 Gear-type interaction through changes in harvest efficiency

Gear Type	Parameter	Change in Parameter	Pole-and-Line Yield	Pole-and-Line Rent	Purse Seine Yield	Purse Seine Rent
All	[illegible]	0%	2163	976017	26224	3607089
	[illegible]					
P&L	[illegible]	10%	2377	1404118	26201	3586013
		-10%	1948	547113	26247	3628203
PS	[illegible]	10%	2140	930946	28474	5688178
		-10%	2186	1022185	23916	1472480

Note Pole-and-line and purse seine effort levels are held constant at the combined surface fishery optimum of 638 boat-days/month and 1032.5 boat-days/month respectively.

CONCLUSIONS

From an economic perspective, the level of access fees and the intensity of resource use need to be assessed in terms of rent, and the relationship between rent and fishing effort. The model developed in sections 2 and 3 provides a means of assessing possible rents from a range of fishery structures, actual or hypothetical, and, under certain conditions, a means of determining optimal levels of effort.

When applied to the PNG surface tuna fishery, the model results suggest that domestic involvement in pole-and-line fishing could be re-established without significantly undermining the size or profitability of the purse seine fishery. Based on the area that was fished in 1979, the results indicate an optimum of 44 pole-and-line vessels. However, the profitable operation of a pole-and-line fleet depends critically on access to a market that affords price premiums for raw tuna, such as the Japanese market of Yaizu.

Based on the purse seine analysis, rents in the vicinity of 14 percent of revenue for US purse seine vessels operating in the PNG fishery are not unreasonable. Not surprisingly however, the accurate estimation of rent is dependent upon accurate parameter estimation, which demonstrates that continued biological research, the gathering of accurate fleet statistics and vessel costs, and tuna market studies are critical to good management.

Optimal purse seine effort is estimated to be 66 vessels of 1000-1200 GRT. Currently, 118 purse seine vessels have access to the PNG fishing zone. While many of these vessels may be smaller than the standard size used in the analysis, and may fish in the PNG zone for less than 210 days per year, the analysis suggests that there is a danger of economic overfishing given the current potential level of effort in the fishery. There is also the potential for biological overfishing of yellowfin stocks if effort levels continue to rise.

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