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An analysis of fishing capacity in the western and central Pacific Ocean tuna fishery and management implications ☆

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Abstract

Recent increases in the volume of canning grade tuna caught in the Western and Central Pacific Ocean (WCPO) have led to concern about the increasing catching capacity of the fleet of purse seine vessels operating in the fishery. In this paper, data envelopment analysis is used to examine the current technical efficiency of the WCPO purse seine fleet, the potential catching capacity of the fleet and the excess capacity currently present in the fishery. These estimates are then used to examine possible implications of a move to a management regime based on limiting the total number of fishing days in the fishery.
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1. Introduction

The western and central Pacific Ocean (WCPO) tuna fishery is the largest tuna fishery in the world yielding an average annual total tuna catch of around 1.9 million metric tonnes (Mt) between 1997 and 2001. The fishery supplies around 50–70 per cent of the world supply of tuna used for canning, and about 30–40 per cent of Japan's sashimi market [1].

There are three major tuna fisheries located within the WCPO, a purse seine fishery, a pole and line fishery and a longline fishery. The purse seine and pole and line fishery catch is primarily used in the production of 'light meat'[1] canned tuna, although some of the catch is also used in the production of other tuna products such as *katsuobushi*. There are two components of the longline fishery, one targeting albacore for which the catch is primarily used in the production of 'white meat' canned tuna, and the other targeting yellowfin and bigeye, which is primarily sold as *sashimi* in Japan and to a lesser extent in the US and other markets.

The WCPO purse seine fishery, which is the focus of this paper, is the dominant fishery in terms of the volume of tuna landings within the WCPO, yielding catches of between 944,000 and 1,243,000 Mt of tuna annually between 1997 and 2001 [2]. The fishery is based

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[1] There are two major product forms of canned tuna, "light meat" and "white meat". About two-thirds of the world's surface tuna catch is processed into light meat canned tuna ranking it as the largest single tuna product. Skipjack and yellowfin are the major species utilised in the production of light meat canned tuna. White meat canned tuna is regarded as the gourmet product of US canned tuna consumption. Albacore is the only species allowed by US law to be labelled as "white meat" tuna.

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on the catching cannery grade skipjack (*Katsuwonus pelamis*), yellowfin (*Thunnus albacares*), and bigeye (*Thunnus obesus*) tunas. The fishery is the major source of the world supply of skipjack, accounting for about 40–50 per cent of global skipjack catches [3]. In 2001, the estimated ''delivered'' and ''ex-vessel'' value of the catch was around US$886 million and US$752 million, respectively [4].

The skipjack tuna stock, the most important species by volume of landing and with the largest stock size, appears to be in biologically healthy condition, with recent average levels of age-specific fishing mortality probably somewhat less than the corresponding maximum sustainable yield (MSY) levels [5]. The yellowfin stock is also at least moderately exploited, with recent average levels of age-specific mortality probably somewhat less than the corresponding MSY levels. Some concern has been expressed about the bigeye stock. Bigeye tuna are demonstrably slower growing, longer-lived, and therefore less resilient to fishing than skipjack and yellowfin tuna. Recent catch levels may be close to the maximum sustainable with the present age-specific exploitation patterns. In sum, the biological health of the fishery appears, on the whole, satisfactory.

While the biological health of the fishery appears on the whole satisfactory, the issue of the capacity of the WCPO purse seine fleet has recently attracted attention from both coastal states and distant water fishing nations (DWFNs). This attention is due to continued growth in catches in the fishery, the extremely low prices for canning grade tuna, particularly skipjack, experienced during much of 1999 and 2000 and in principle the agreement by the parties to The Palau Arrangement for the Management of the Western Pacific Purse Seine Fishery (The Palau Arrangement) to move to an effort control management regime based on effort day limits.

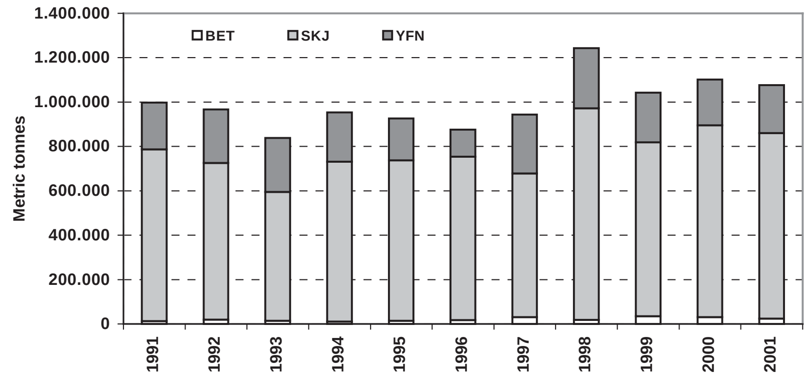
The Palau Arrangement, which entered into force in November 1995, seeks to conserve the tuna stocks and to improve the economic returns to the Pacific Island Parties (PICs) through access fees and local fishery development [6,7]. This unique agreement provides a mechanism whereby a group of coastal states, which are highly dependent on fisheries, can cooperatively manage their highly migratory fish stocks to further their economic and developmental objectives. The member nations are the Federated States of Micronesia, Kiribati, Marshall Islands, Nauru, Palau, and Papua New Guinea. The Solomon Islands and Tuvalu are signatories to the arrangement and have indicated that they will conduct themselves in accordance with the arrangement. Because approximately 70 per cent of the WCPO purse seine catches by all nations are harvested in the Forum Fishery Agency (FFA) exclusive economic zones, the FFA nations may have de facto control over the harvest levels through their licensing arrangements with all nations in the Palau Arrangement [7]. The Palau Arrangement thus allows the FFA member countries to exert, to a degree, management control over the WCPO purse seine fishery, including the adjacent high seas.

Under the Palau Arrangement, limits are placed on the total number of purse seine vessels allowed to be licensed within the zones of parties to the Nauru Agreement Concerning Cooperation in the Management of Fisheries of Common Interest (the Nauru Agreement) [6,7]. Specifically, the Twelfth Meeting of the Parties to the Nauru Agreement in Palau in May 1993 set the current level of 205 vessels. This limit effectively excludes other vessels from entering the fishery, since fishing on the high seas by itself is not economically viable.

The effectiveness of the Palau Arrangement in controlling growth in effort levels has been addressed in a number of reviews. A report by Kaufmann [8] stated that the Palau Arrangement had been ineffective at controlling the growth of fishing effort. The healthy state of the skipjack and yellowfin stocks in the region was attributed to the productivity of the resources rather than to any management initiatives. Geen and Bergin [9], in a review of management arrangements in the Western Pacific, suggested that while the Palau Arrangement provided Parties with the capacity to effectively exercise management control over the purse seine fishery, including in international waters, ''...this management control has been more potential than real. The Palau Arrangement has never been constraining on the numbers of vessels operating in the purse seine fishery''.

At the 4th Annual Meeting of the Parties to the Palau Arrangement held in Samoa in August 1999, Parties agreed to undertake a further comprehensive review of the Palau Arrangement and a review was subsequently commissioned. Following this directive, the FFA Secretariat obtained funding from the Asian Development Bank (ADB) to engage a consultant and to prepare a working paper looking at both short-term and long-term options to improve the Palau Arrangement as a tool for the management of the purse seine fishery in the western and central Pacific. The draft working paper was considered by the Parties at the 5th Annual Meeting of the Parties in Honiara in May 2000. As a result of this consideration the Parties decided that, ''In guiding the consultant in the preparation of a Final Report, Parties agreed that a long-term management system based on national limits on the number of purse seine days fished should be further developed.''

Following the presentation of the final report, the Parties decided in principle to move to an effort control management regime based on effort day limits. In doing so the Parties recognised that a number of issues would need to be further considered. These include, but are not restricted to: the need to consider the possible effect of displacing effort into the high seas and other EEZs and encouraging greater FAD use (which gives higher catch



Source: Lawson (2002)

Fig. 1. Western and central Pacific Ocean (WCPO), purse seine catch of bigeye, skipjack and yellowfin, 1991–2000. *Source*: Lawson [2].

rates) and the longer-term difficulties with effort management in terms of capital stuffing (substitution of unregulated for regulated inputs) and effort creep, including technological advances; the Total Allowable Effort (TAE) limit to be set; the allocation of the TAE between parties; the application of effort limits at the national level; transferability; access for regional vessels, and; monitoring and non-compliance.

In this paper, data envelopment analysis (DEA) is used to examine the technical efficiency of the WCPO purse seine fleet, the potential catching capacity per effort day of the fleet and the excess capacity present in the fishery over the period 1997–2000. Annual capacity and excess capacity are then addressed in terms of observed catch against capacity, or potential catch under observed levels of effort. These results are then used to estimate: potential annual catch levels under a TAE for the WCPO set at the average number of effort days observed over 1997–2000; and, at what level a TAE for the WCPO would need to be set if potential average annual catches were to be restricted to that observed over 1997–2000.

2. Catch and price trends for the western and central Pacific Ocean tuna purse seine fishery[2]

The purse seine fishery is the dominant WCPO fishery, in terms of the volume of tuna landings, contributing between 55 and 62 per cent of the total WCPO catch over the decade 1991–2000. The purse seine fishery is essentially a skipjack fishery unlike those of other oceans. The purse seine catch over the decade 1991–2001 is comprised, on average, of around 76 per cent of skipjack, 22 per cent of yellowfin and 2 per cent of bigeye. The purse seine catch of all species is primarily sold as frozen raw material for canning.

The WCPO purse seine fishery accounted for between 64 and 73 per cent of the total annual WCPO skipjack catch over the decade 1991–2001 and between 39 and 49 per cent of the annual global catch of skipjack over the period 1991–1999 [2,3].

Fig. 1 illustrates that purse seine catches increased dramatically in 1998 due to a surge in skipjack catches. In 1998, the purse seine skipjack was around 954,000 metric tonnes, which is around 47 per cent more than in 1997 and 23 per cent higher than the highest catch recorded prior to 1998, that is in 1991. In 1999, the purse seine skipjack catch fell by 18 per cent to around 785,000 metric tonnes, then increased by 10 per cent in 2000 to around 865,000 metric tonnes, before declining by 3 per cent in 2001 to around 836,000 Mt.

Annual yellowfin catches fluctuated considerably between 122,000 and 270,000 metric tonnes over the decade 1991–2001. Increases in the proportion of yellowfin tuna in the catch are often noted during El Niño years, with sharp reductions during La Niña years (1995/96 and to a lesser extent 1999/2000) (Fig. 1).

Increased bigeye tuna purse seine catches were observed in 1997 (31,337 Mt) and then again in 1999 (34,937 Mt) and 2000 (28,843 Mt), as a result of the increased use of drifting FADs since 1996.

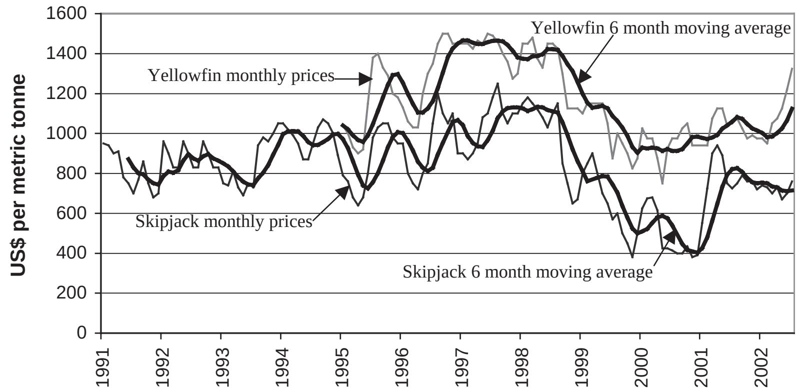
Bangkok is the primary destination for purse caught tuna from the WCPO and as such prices in this market provide a good indication of market trends for the fishery. Fig. 2 indicates that skipjack and yellowfin prices fell precipitously from the 3rd Quarter of 1988 to the end of 1999 and were low throughout 2000. Prices recovered to some degree in 2001, although they remained at the lower end of their trading range prior to the price collapse seen in 1998.

3. Overview of analytical approach

3.1. Capacity and capacity utilisation

Capacity is a short-run concept, where firms and industry face short-run constraints, such as the stock of

[2] Hunt [10], Aqorau and Bergin [6], Herrick et al. [11], Lodge [7], Van Santen and Muller [1], and Hampton et al. [5] provide excellent and comprehensive overviews and background.



Source: Forum Fisheries Agency (2002).

Fig. 2. Bangkok monthly skipjack (4–7.5 lbs) and yellowfin (20 lbs and up) prices (c&f). *Source*: Forum Fisheries Agency [4].

capital or other fixed inputs, existing regulations, the state of technology, and other technological constraints [12]. Capacity is defined in terms of potential output. This potential output can be further defined and measured following either a technological–economic approach or an economic optimisation approach directly based on microeconomic theory [12].[3] What distinguishes the two notions of capacity is how the underlying economic aspects are included to determine the capacity output.

In either approach, capacity utilisation (CU) is simply some base output—typically actual output—divided by capacity output [12]. In the technological–economic approach, a CU value less than one implies that firms have the potential for greater production without having to incur major expenditures for new capital or equipment [14]. The inverse of such a CU measure, $1/\mathrm{CU} = \mathrm{CU_I} = \mathrm{Y_C}/\mathrm{Y}$ (where I denotes inverse), thus indicates the amount output could increase if the existing capacity were to be used "optimally". For example, a value of 1.5 indicates that potential capacity output is 50 per cent larger than the current observed output.

This paper, Squires et al. [15], Kirkley et al. [16], Kirkley and Squires [17], the 1998 FAO Technical Working Group [18], and the 1999 FAO Technical Consultation [19] focus upon the technological–economic measures of capacity, because the paucity of cost data in most fisheries militates against estimation of cost or profit functions to derive economic measures of capacity and CU. Similarly, the technological–economic approach is the one used by the US Federal Reserve Board [20] and in most other countries to monitor CU throughout the economy.

The technological–economic capacity of a firm can be defined following Johansen [21, p. 52] definition of plant capacity as, "…the maximum amount that can be produced per unit of time with existing plant and equipment, provided the availability of variable factors of production is not restricted". Färe [22] provides a formal proof and discussion of plant capacity.

Capacity output thus represents the maximum production the fixed inputs or capacity base in general are capable of supporting. This concept of capacity conforms to that of a full-input point on a production function, with the qualification that capacity represents a realistically sustainable maximum level of output rather than some higher unsustainable short-term maximum [23]. In practice, this approach gives maximum potential output given full utilisation of the variable inputs under normal operating conditions, since the data used reflect normal operating conditions and existing market, resource stock, and environmental conditions.[4] This approach gives an endogenous output and incorporates the firm's ex ante short-run optimisation behaviour for the production technology given full utilisation of the variable inputs under normal operating conditions.

[3] In the economics approach, cost-minimising capacity is defined as the output level at which the short-run average cost curve is tangent to the long-run average cost curve [12,13].

[4] Klein and Long [23, p. 744] state that, "Full capacity should be defined as an attainable level of output that can be reached under normal input conditions—without lengthening accepted working weeks, and allowing for usual vacations and for normal maintenance." The US Bureau of the Census survey uses the concept of practical capacity, defined as "the maximum level of production that this establishment could reasonably expect to obtain using a realistic employee work schedule with the machinery and equipment in place" and assuming a normal product mix and down-time for maintenance, repair, and cleanup.

The definition and measurement of capacity and capacity output in fishing and other natural resource industries face a unique problem because of the stock-flow production technology, in which inputs are applied to the renewable natural resource stock to produce a flow of output. For renewable resources, capacity measures are contingent on the level of the resource stock, and in general on representing the capacity base in terms of the capital and resource stocks. Capacity output is, therefore, the maximum yield in a given period of time that can be produced given the capital stock or capacity base, regulations, current technology and state of the resource [17,18]. Nonetheless, annual climate-driven ocean variability is clearly a key factor affecting fisheries. The monsoon and El Niño-Southern Oscillation events provide a clear example. As a consequence, and due to annual changes in the size and species and age mix of the resource stocks, the target level and capacity output from the stock-flow production process can vary annually and even seasonally when there are strong seasonal effects such as El Niño-Southern Oscillation events.

In fisheries and other renewable resource industries, excess capacity is often defined relative to some biological or bio-socio-economic reference point, which accounts for sustainable resource use and a target resource stock size. Excess capacity, in a technological–economic approach, can be defined as the difference between capacity output and the target level of capacity output, such as MSY or the catch rate corresponding to the fishing mortality of an alternative harvest [18]. The target level of capacity output was defined by the 1998 FAO Technical Working Group as [6, p. 11], "Target fishing capacity is the maximum amount of fish over a period of time (year, season) that can be produced by a fishing fleet if fully utilised while satisfying fishery management objectives designed to ensure sustainable fisheries… ."[5] The 1999 FAO Technical Consultation on measuring fishing capacity reached a similar conclusion [19]. The target fishing capacity catch can be specified as MSY or as a sustainable economic yield.

[5] Fishing capacity is generally defined by FAO [18,19] as follows:

> Fishing capacity is the maximum amount of fish over a period of time (year, season) that can be produced by a fishing fleet if fully utilised, given the biomass and age structure of the fish stock and the present state of the technology. Fishing capacity is the ability of a vessel or fleet of vessels to catch fish, i.e. $Y_C = Y(E_C, S)$.

In this general definition, Y_C denotes current yield/catch, E_C denotes current effort, and S denotes stock size (biomass). Fishing capacity thus represents the maximum amount of fish caught by a fleet fully utilising its variable economic inputs under normal operating conditions, given the fleet's capital stock (vessels, gear, and equipment, including FADs), biomass, and harvesting technology. Normal operating conditions refers to those operating conditions faced by fishing vessels in the normal conditions of the time period in which they operate.

In this paper, however, we apply a different approach. Capacity and excess capacity are addressed in terms of observed catch against capacity, or potential, catch under observed levels of effort, assuming that the potential catch is sustainable. Given that the tuna stocks are in a reasonably healthy state as previously outlined this assumption appears reasonable.

3.1.1. Measuring capacity using data envelopment analysis

We apply DEA, a mathematical programming technique, as a practical approach to measure Johansen's definition of plant capacity as the maximal or capacity output per vessel per effort day. The DEA approach derives a deterministic production frontier describing the most technically efficient combination of outputs given the state of fishing technology, the fish stock, and unrestricted variable inputs. Färe [22] introduced this methodology as a means of measuring the technological–economic concept of capacity and CU for manufacturing firms, which was further developed by Färe et al. [24]. Kirkley and Squires [17] proposed DEA as a useful approach for assessing capacity in fisheries. The DEA approach distinguishes between variable and fixed factors and allows for multiple outputs and variable returns to scale.

The DEA approach calculates capacity output given that the variable factors are unbounded and the fixed factors, environmental parameters such as the resource stock and oceanic conditions, and state of technology constrain output. Capacity output corresponds to the output that could be produced given full and efficient utilisation of variable inputs and given the constraints imposed by the capacity base—the fixed factors, the state of technology, environmental conditions, and resource stock. In practice, because the data reflect both technological and economic decisions made by firms, the variable inputs correspond to full and efficient utilisation under normal operating conditions.

The Färe et al. [24] model posits that capacity at the plant (vessel) level can be estimated by partitioning inputs according to whether they are fixed (F_x) or variable (V_x) and then solving an output-oriented, DEA problem in which only fixed factors bind production. Assume that there are $j = 1, \ldots, J$ vessels producing M outputs (catches of different species) by means of both fixed and variable factors. Let u_{jm} equal the quantity of the mth output produced by the jth producer, and x_{jn} be the level of the nth input used by the jth producer. Eq. (1) gives the DEA problem to be solved, where θ is an output-oriented measure of technical efficiency (TE) and $\theta \geqslant 1.0$. Multiplying the observed output by θ gives an estimate of capacity output. The DEA problem is written as

$$
\begin{aligned}
&\mathrm{TE}_{\mathrm{oc}j} = \max_{\theta,\lambda,z}\ \theta \quad \text{s.t.} \\
&\theta u_{jm} \leqslant \sum_{j=1}^{J} z_j u_{jm},\ m = 1,\ldots,M,\ \ \sum_{j=1}^{J} z_j x_{jn} \leqslant x_{jn},\ n \in F_x; \\
&\sum_{j=1}^{J} z_j x_{jn} = \lambda_{jn} x_{jn},\ n \in V_x, \\
&z_j \geqslant 0, j = 1,\ldots,J, \ \text{and}\ \lambda_{jn} \geqslant 0, \\
&\sum_{j=1}^{J} z_j = 1.0, \qquad (1)
\end{aligned}
$$

where z is a vector of intensity variables that defines the reference technology given the observed inputs and outputs. These variables join the observed inputs and outputs to form the piecewise linear best-practice reference technology relative to which capacity is measured. CU is measured by the ratio of observed output to capacity output.

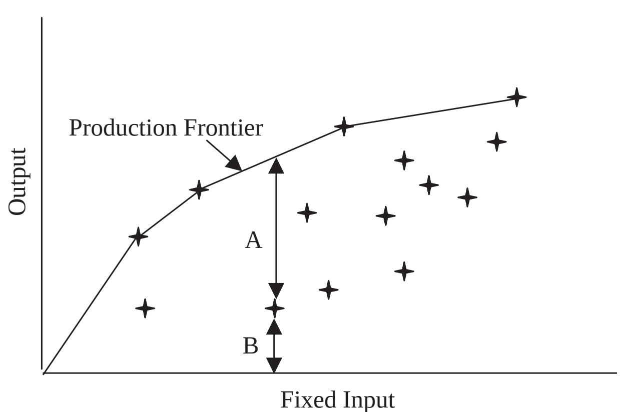


Fig. 3. Data envelopment analysis.

Fig. 3 illustrates the use of DEA to calculate fishing capacity output and CU. DEA, using the observed landings for different-sized vessels and a measure of the capital stock or fixed inputs, such as Gross Registered Tons (GRT), determines the output or landings that are the highest for any given vessel size assuming that variable inputs are fully utilised (variable inputs are thereby unconstrained) under normal operating conditions, where normal operating conditions are reflected in the data. DEA calculates a frontier or maximum landings curve, as determined by the best-practice vessels, which represents fishing capacity output. Landings directly on the best-practice production frontier represent full capacity utilisation (CU) or CU = 1. When a vessel produces at less than full capacity, as represented by an output lying below the frontier in Fig. 4, the CU is less than one, i.e. CU < 1. Thus, in Fig. 3, B represents the size of landings, A denotes the excess capacity (vis-à-vis observed production), $A+B$ denotes capacity output, and the ratio $A/(A+B)$ represents CU, so that CU < 1 in this case.

The production frontier, established by the best-practice vessels (the ones on the frontier) and estimated by DEA, gives capacity output, given the fixed inputs or capacity base, the states of technology and the environment, and the resource stocks, provided that variable inputs (fishing effort) are fully utilised under normal operating conditions. The production frontier (also called the reference technology), established by the best-practice vessels and also estimated by DEA, gives technically efficient output given the fixed inputs, states of technology and the environment, and resource stocks when the variable inputs are utilised at the observed levels. Hence, the difference between capacity output and technically efficient output is that variable inputs are fully utilised in the former and are utilised at the observed levels (which could be fully utilised) in the latter.

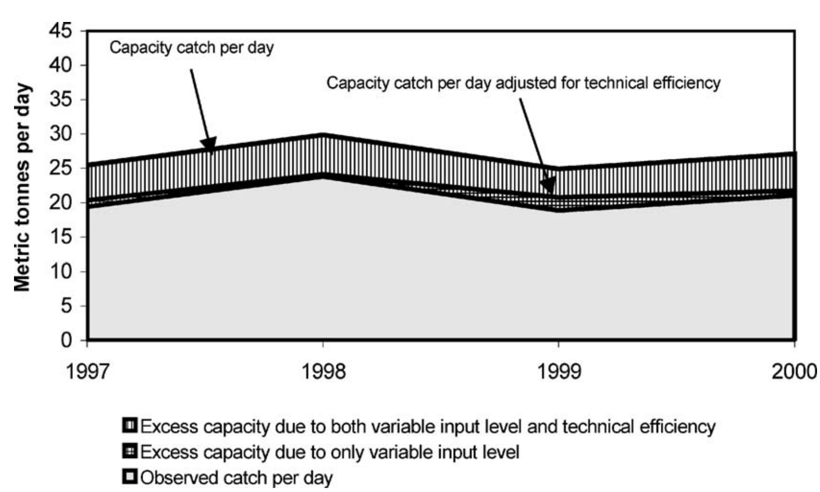


Fig. 4. Japan: per effort day observed catch, capacity and excess capacity.

Alternative methods for measuring capacity and CU have been proposed in the literature, most notably duality-based measures using cost, profit, or revenue functions [12,25,26]. Unlike duality-based econometric estimates cost, profit, or revenue functions, DEA does not impose an underlying functional form, so that estimation is not conditional upon the functional specification. Unlike the cost, profit, or revenue function approach, DEA estimates primal measures of capacity in a multiple-product environment without imposing separability assumptions on the outputs [27]. DEA can be used when prices are difficult to define, or behavioural assumptions, such as cost minimisation, are difficult to justify, or cost data are unavailable.

The DEA approach has limitations. First, it is a non-statistical approach, which makes statistical tests of hypotheses about structure and significance of estimates difficult to perform. Second, because DEA is non-statistical, all deviations from the frontier are assumed to be due to inefficiency. Third, estimates of capacity and CU may be sensitive to the particular data sample (a feature shared by the dual cost, profit, or revenue function approach).

3.2. Data

The analysis uses individual vessel-level data, much of which is summarised in Tables 1 and 2. The catch, days

Table 1
Mean observed catch per vessel per effort day fished by species, set type, and nation, 1997–2000

Nation	Year	Skipjack			Yellowfin and Bigeye			Total
		Unassociated sets	Log and FAD sets	Other sets	Unassociated sets	Log and FAD sets	Other sets	
FSM	1997	2.436	6.031	0.847	1.784	3.134	0.595	14.828
	1998	2.783	9.455	1.282	1.548	0.917	0.607	16.592
	1999	1.587	8.195	0.007	1.128	3.409	0.126	14.452
	2000	8.656	8.932	0.028	3.832	1.375	0.005	22.827
Japan	1997	2.322	7.899	0.873	2.285	5.677	0.380	19.435
	1998	4.845	11.513	2.739	2.774	1.646	0.294	23.811
	1999	2.123	10.062	1.806	0.794	3.468	0.612	18.865
	2000	2.591	13.612	1.609	0.859	2.209	0.171	21.052
Korea	1997	8.386	5.367	0.223	3.852	2.624	0.121	20.573
	1998	13.088	6.627	0.229	8.396	1.208	0.068	29.617
	1999	2.123	10.062	1.806	0.794	3.468	0.612	18.865
	2000	15.922	3.690	0.319	4.379	0.607	0.040	24.956
PNG	1997	0.000	0.999	3.315	0.000	0.727	2.095	7.135
	1998	8.901	1.086	9.030	4.400	0.364	3.207	26.988
	1999	0.000	1.072	9.010	0.000	0.468	3.799	14.349
	2000	0.000	13.266	0.290	0.000	4.784	0.044	18.384
Philippines	1997	0.151	4.987	2.935	0.023	2.947	1.313	12.356
	1998	0.222	5.424	8.659	0.126	1.646	2.604	18.680
	1999	0.265	5.039	6.441	0.011	1.826	1.757	15.339
	2000	0.154	4.164	6.146	0.029	2.240	1.534	14.266
Spain	1999	0.045	38.735	5.383	0.000	14.187	3.226	61.575
	2000	0.000	21.709	0.520	0.000	25.935	0.171	48.336
Taiwan	1997	4.593	4.096	1.564	2.678	1.456	0.335	14.722
	1998	9.128	7.383	1.040	5.183	0.461	0.195	23.391
	1999	3.852	9.432	0.546	1.682	2.108	0.110	17.729
	2000	11.086	7.683	1.016	2.430	0.485	0.038	22.737
US	1997	3.759	7.604	0.000	4.130	5.044	0.000	20.537
	1998	6.024	16.330	0.000	4.756	2.437	0.000	29.548
	1999	0.680	30.444	0.000	0.217	8.215	0.000	39.556
	2000	7.355	14.258	0.000	1.250	4.871	0.000	27.734
Vanuatu	1997	2.409	5.742	2.823	1.193	1.472	2.981	16.619
	1998	8.353	7.906	3.369	3.692	2.454	0.782	26.556
	1999	2.220	7.816	5.415	1.162	1.825	1.711	20.149
	2000	2.161	11.965	5.816	0.642	0.750	0.284	21.618

Table 2
Mean GRT, days fished, total sets, and sets per vessel per day fished by nation, 1997–2000

Nation	Year	GRT[a]	Days fished	Total sets	Sets per day fished
FSM	1997	868	179	199	1.114
	1998	868	273	290	1.063
	1999	868	211	231	1.095
	2000	1048	225	273	1.231
Japan	1997	362	137	154	1.122
	1998	362	115	137	1.184
	1999	370	134	139	1.036
	2000	369	106	111	1.051
Korea	1997	1090	260	321	1.241
	1998	1072	259	344	1.298
	1999	370	134	139	1.036
	2000	1073	233	332	1.408
PNG	1997	623	187	187	1.001
	1998	554	166	166	1.014
	1999	504	167	167	1.000
	2000	506	92	92	1.000
Philippines	1997	737	220	221	1.009
	1998	818	175	177	1.008
	1999	818	237	241	1.013
	2000	802	128	130	1.012
Spain	1999	2126	24	25	1.045
	2000	2273	28	29	1.030
Taiwan	1997	1063	277	289	1.041
	1998	1063	266	292	1.100
	1999	1063	287	299	1.041
	2000	1065	196	216	1.100
US	1997	1244	201	162	0.780
	1998	1272	165	130	0.807
	1999	1308	135	96	0.723
	2000	1360	137	109	0.814
Vanuatu	1997	899	291	324	1.119
	1998	899	326	365	1.132
	1999	899	323	343	1.067
	2000	899	152	158	1.074

[a] Carrying capacity not GRT for US fleet.

fished, number of sets by type of fishing and vessel size (GRT), for all fleets except the US fleet are obtained from the Oceanic Fisheries Programme of the Secretariat of the Pacific Community (SPC). The years during which a vessel fished were determined from logsheet data held by the Oceanic Fisheries Programme of the SPC. Because these data are incomplete, not all seiners that have fished in the WCPO are contained in the data set. The abundance data for biomasses of skipjack, yellowfin, and bigeye tunas are provided by the SPC. Sea surface temperatures in $^{\circ}$F are taken from daily fishing logbooks of US purse seine vessels. These data are collected jointly by the National Marine Fisheries Service and the FFA. Sea surface temperatures are recorded by set for each vessel. These temperatures are averaged (a simple or unweighted arithmetic average) over all sets, vessels, and areas to provide a mean annual sea surface temperature for the area fished in the WCPO. These temperatures are used for all vessels analysed, not just the US vessels (but most tuna purse seine vessels fish in the same or nearby areas). The biomass data were obtained from the Oceanic Fisheries Programme of the SPC [5].

The GRT values are those initially reported to the Forum Fishing Agency and are not always updated after the initial reporting. Hence, growth in vessel size may not be fully captured by the analysis. GRT was used rather than carrying capacity, since the latter is incompletely documented. However, GRT was unavailable for all of the US vessels during the period of the analysis, and hence carrying capacity was instead used.

4. Analysis

The fishing capacity analysis was conducted using DEA. As detailed in Section 3.2, to conduct the analysis variables were required to represent output, fixed inputs, and resource stock and environmental conditions.

Output or catch in the analysis was specified by species and method of harvest per day fished. They are: (1) yellowfin and bigeye tuna caught in sets made on unassociated schools; (2) yellowfin and bigeye tuna caught in sets made on logs or drifting rafts, Payaos, and FADs; (3) yellowfin and bigeye tuna caught in sets made on anchored rafts, Payaos, and FADs and in all other set types; (4) skipjack tuna caught in unassociated school sets; (5) skipjack tuna caught in sets made on logs, or drifting rafts, Payaos, and FADs; and (6) skipjack tuna caught in sets made on anchored rafts, Payaos, and FADs and in all other set types. Yellowfin and bigeye tuna were aggregated together as they are not always identified separately in logsheet and to reduce the number of zero-valued observations (which was troublesome to the operation of the DEA program).

Biomass estimates for skipjack, yellowfin and bigeye are used to specify stock conditions with sea surface temperature used to account for environmental conditions. Both of these variables were specified as non-discretionary or fixed (constrained) inputs.

The capital stock or capacity base of an individual vessel basis was captured by the vessel's Gross Registered Tonnage (GRT). The exception was the US fleet, for which carrying capacity was used due to unavailability of recent GRT data. GRT was specified as a fixed input.

The treatment of sets per day presented more difficulty in the analysis. Sets per day are dependent on the skill of the skipper in locating tuna, the state of technology, environment, resource abundance and availability, and the harvesting technique of the vessel, for example, setting on FADs versus setting on unassociated schools or floating logs. The harvesting technique may in turn be dependent upon economic forces such as market prices, as reflected in the data which revealed a shift away from FAD sets, which tend to catch smaller fish, toward unassociated school sets in latter years as prices fell and the relative premium for larger fish increased. In the analysis, therefore, two approaches were made toward the treatment of sets per day and TE. First, the number of sets per day was assumed to reflect both the variable input usage and technical inefficiency. Second, the number of sets per day was assumed to reflect only variable input usage, that is, the effects of technical inefficiency upon the level of fishing capacity were purged from the results (so that the number of sets is fixed).[6,7]

4.1. Empirical results

Tables 3 and 4 report the estimated average capacity catch by set type and species (and in total) per vessel per effort day for each fishing nation with and without the effects of technical inefficiency but retaining the effects of variable inputs. Thus, Table 3 reports the estimated capacity results with variable inputs and variable number of sets, that is the technically efficient level of capacity, while Table 4 reports the estimated capacity results with variable inputs and fixed number of sets, that is capacity is purged of technical inefficiency. Table 5 reports CU rates.

In Figs. 4–17, estimated fishing capacity output, observed catch, and excess capacity (the difference between capacity output and catch) on both a per effort day and annual basis over 1997–2000 for the different fishing nations with the exception of the Federated States of Micronesia and Vanuatu fleets are presented. The annual measure of capacity catch is measured by multiplying the estimated average capacity per effort day for each vessel by the number of observed effort days for that vessel and summing across all vessels in respective fleet. The reduction in effort days that is required to restrict catches to average 1997–2000 levels when all vessels work at full capacity is also estimated.

The data set for both the Federated States of Micronesia and Vanuatu fleets contained five or less vessels. Consequently, in using the DEA approach to derive a production frontier most or all of the vessels tend to lie on the frontier as reflected in the results (Tables 3 and 4) and CU tends to be close to or equal to 1 (Table 5).

4.1.1. Japan

4.1.1.1. Capacity due to both variable input usage and technical inefficiency. If the level of capacity catch is due to both the level of variable input usage and technical inefficiency, CU of the Japanese fleet ranged from 74 to 82 per cent over the period 1997–2000 (Table 5). On average over the 4-year period CU was 80 per cent. Thus, if all vessels worked at the full capacity level for their fleet, then the number of fishing days required to

[6] Strictly speaking, the number and types of sets per day may not fully capture all dimensions of fishing skill because of the choice of technique for fishing, such as log, school, or drifting FAD sets. Thus, (output-oriented) technical inefficiency is more than simply the distance from the best-practice production frontier associated with a given harvesting method due to the ability of a skipper and crew to locate fish, but also involves the choice of fishing technique, which our measure of technical inefficiency may not fully capture.

[7] Färe et al. [28] discuss the purging of technical efficiency to obtain an "unbiased" measure of capacity utilisation.

Table 3
Mean fishing capacity per vessel per effort day fished by species, set type, and nation, 1997–2000

Nation	Year	Skipjack			Yellowfin and Bigeye			Total
		Unassociated sets	Log and FAD sets	Other sets	Unassociated sets	Log and FAD sets	Other sets	
FSM	1997	2.960	6.653	0.850	2.102	3.358	0.597	16.520
	1998	2.780	9.453	1.280	1.547	0.917	0.607	16.584
	1999	1.587	8.193	0.007	1.127	3.410	0.127	14.451
	2000	8.655	8.933	0.028	3.833	1.375	0.005	22.829
Japan	1997	3.320	10.060	1.744	2.836	6.998	0.513	25.471
	1998	5.839	14.273	3.185	3.182	2.249	0.440	29.168
	1999	3.143	14.267	2.236	1.182	4.901	0.718	26.447
	2000	3.350	16.953	2.015	1.035	2.945	0.228	26.526
Korea	1997	11.323	6.608	0.248	5.172	3.352	0.128	26.831
	1998	15.209	7.301	0.252	9.976	1.384	0.078	34.200
	1999	3.143	14.267	2.236	1.182	4.901	0.718	26.447
	2000	19.081	4.283	0.398	5.836	0.972	0.050	30.620
PNG	1997	0.000	2.440	3.890	0.000	1.210	2.601	10.141
	1998	8.903	1.621	11.211	4.399	0.586	4.136	30.856
	1999	3.693	1.568	8.901	1.061	0.515	3.784	19.522
	2000	0.000	18.384	0.388	0.000	7.579	0.067	26.418
Philippines	1997	0.194	5.340	3.369	0.053	3.718	1.379	14.053
	1998	0.223	5.509	8.861	0.124	1.680	2.667	19.064
	1999	0.278	5.760	7.516	0.011	2.190	2.036	17.791
	2000	0.234	4.367	7.658	0.048	2.634	2.010	16.951
Spain	1999	0.045	65.445	5.383	0.000	21.060	3.226	95.159
	2000	0.000	23.891	0.581	0.000	29.001	0.179	53.652
Taiwan	1997	7.584	6.638	1.699	3.791	2.152	0.374	22.238
	1998	12.564	10.755	1.317	6.939	1.071	0.212	32.858
	1999	7.299	15.556	0.675	3.113	3.441	0.119	30.203
	2000	14.514	9.538	1.059	3.419	0.566	0.038	29.134
US	1997	5.578	10.569	0.000	5.132	6.740	0.000	28.019
	1998	8.344	23.164	0.000	6.262	5.440	0.000	43.210
	1999	1.381	45.154	0.000	0.281	11.762	0.000	58.578
	2000	12.514	18.359	0.000	1.656	6.449	0.000	38.978
Vanuatu	1997	2.412	5.812	3.071	1.201	1.482	3.069	17.047
	1998	8.902	8.499	3.556	4.367	2.883	0.815	29.022
	1999	2.243	8.421	6.224	1.164	1.946	1.894	21.892
	2000	2.162	11.964	5.818	0.642	0.750	0.284	21.620

take the observed catch over the period 1997–2000 would have been 80 per cent of the actual number of fishing days observed. Alternatively, if all Japanese vessels worked at their fleet's best-practice production frontier by using the appropriate level of variable inputs and were fully technically efficient, the fleet, working the observed number of days, could potentially have caught 25 per cent more over the period 1997–2000.

4.1.1.2. Capacity level due only to variable input usage and purged of technical inefficiency. Purging the effects of technical inefficiency or fishing skill gives an average CU of 95 per cent over 1997–2000 (Table 5). Thus, if all Japanese vessels worked at the full capacity level for their fleet, then the number of fishing days required to take the observed catch over the period 1997–2000 would have been 95 per cent of the actual number of fishing days observed. Alternatively, if all Japanese vessels harvested at their fleets' production frontier and worked the observed number of days, their total catch over 1997–2000 could potentially have been 5 per cent higher.

4.1.2. Korea

4.1.2.1. Capacity due to both variable input usage and technical inefficiency. If the level of capacity catch is due

Table 4
Mean fishing capacity per vessel per day fished, adjusted for technical efficiency by species, set type, and nation, 1997–2000

Nation	Year	Skipjack			Yellowfin and Bigeye			Total
		Unassociated sets	Log and FAD sets	Other sets	Unassociated sets	Log and FAD sets	Other sets	
FSM	1997	2.720	6.361	0.847	1.956	3.256	0.595	15.735
	1998	2.783	9.455	1.282	1.548	0.917	0.607	16.592
	1999	1.587	8.195	0.007	1.128	3.409	0.126	14.452
	2000	8.656	8.932	0.028	3.832	1.375	0.005	22.828
Japan	1997	2.407	8.246	0.898	2.416	5.959	0.399	20.325
	1998	4.889	11.683	2.776	2.803	1.670	0.298	24.119
	1999	2.233	11.304	1.867	0.826	3.901	0.635	20.766
	2000	2.621	13.991	1.730	0.871	2.355	0.185	21.753
Korea	1997	8.930	5.555	0.229	4.053	2.710	0.122	21.599
	1998	13.155	6.643	0.229	8.437	1.215	0.069	29.748
	1999	2.233	11.304	1.867	0.826	3.901	0.635	20.766
	2000	16.899	3.810	0.321	4.766	0.622	0.040	26.457
PNG	1997	0.000	0.999	3.315	0.000	0.727	2.095	7.136
	1998	8.901	1.086	9.030	4.400	0.364	3.207	26.988
	1999	0.000	1.072	9.010	0.000	0.468	3.799	14.439
	2000	0.000	13.266	0.290	0.000	4.784	0.044	18.384
Philippines	1997	0.151	4.990	2.935	0.023	2.948	1.313	12.360
	1998	0.222	5.424	8.659	0.126	1.646	2.604	18.681
	1999	0.265	5.039	6.441	0.011	1.826	1.757	15.339
	2000	0.154	4.177	6.147	0.029	2.248	1.536	14.291
Spain	1999	0.045	53.865	5.383	0.000	18.753	3.226	81.272
	2000	0.000	23.889	0.527	0.000	27.728	0.178	52.322
Taiwan	1997	4.881	4.253	1.702	2.840	1.526	0.350	15.552
	1998	9.517	7.594	1.128	5.388	0.476	0.203	24.306
	1999	4.117	10.460	0.621	1.832	2.388	0.116	19.534
	2000	11.427	7.886	1.022	2.478	0.493	0.038	23.344
US	1997	4.032	8.176	0.000	4.686	5.509	0.000	22.403
	1998	6.892	18.384	0.000	5.288	2.716	0.000	33.280
	1999	0.802	35.339	0.000	0.288	9.527	0.000	45.956
	2000	8.843	17.321	0.000	1.524	6.007	0.000	33.695
Vanuatu	1997	2.415	5.856	2.961	1.205	1.487	3.119	17.043
	1998	9.211	8.835	3.662	3.970	2.510	0.835	29.023
	1999	2.237	8.548	6.036	1.162	1.970	1.932	21.885
	2000	2.161	11.965	5.816	0.642	0.750	0.284	21.618

to both the level of variable input usage and technical inefficiency, CU of the Korean fleet ranged from 74 to 88 per cent over the period 1997–2000 (Table 5). On average over the 4-year period CU was 82 per cent. Thus, if all vessels worked at the full capacity level for their fleet, then the number of fishing days required to take the observed catch over the period 1997–2000 would have been 82 per cent of the actual number of fishing days observed. Alternatively, if all Korean vessels worked at their fleet's best-practice production frontier by using the appropriate level of variable inputs and were fully technically efficient, the fleet, working the observed number of days, could potentially have caught 22 per cent more over the period 1997–2000.

4.1.2.2. Capacity level due only to variable input usage and purged of technical inefficiency. Purging the effects of technical inefficiency or fishing skill gives an average CU of 95 per cent over 1997–2000 (Table 5). Thus, if all Korean vessels worked at the full capacity level for their fleet, then the number of fishing days required to take the observed catch over the period 1997–2000 would have been 95 per cent of the actual number of fishing days observed. Alternatively, if all Korean vessels harvested at their fleets' production frontier and worked

Table 5
Capacity utilisation and technical efficiency by nation, 1997–2000

Nation	Year	Capacity utilisation	Technical efficiency[a]	Capacity utilisation without technical efficiency
FSM	1997	0.93	0.97	0.96
	1998	1.00	1.00	1.00
	1999	1.00	1.00	1.00
	2000	1.00	1.00	1.00
Japan	1997	0.82	0.86	0.95
	1998	0.83	0.84	0.99
	1999	0.74	0.81	0.91
	2000	0.82	0.85	0.97
Korea	1997	0.79	0.83	0.96
	1998	0.87	0.88	0.99
	1999	0.75	0.83	0.90
	2000	0.88	0.93	0.94
PNG	1997	0.85	0.85	1.00
	1998	0.83	0.83	1.00
	1999	0.74	0.74	1.00
	2000	0.73	0.73	1.00
Philippines	1997	0.95	0.95	1.00
	1998	0.98	0.98	1.00
	1999	0.87	0.87	1.00
	2000	0.94	0.94	0.99
Spain	1999	0.75	0.90	0.78
	2000	0.88	1.00	0.88
Taiwan	1997	0.69	0.72	0.96
	1998	0.72	0.75	0.97
	1999	0.65	0.71	0.93
	2000	0.75	0.81	0.93
US	1997	0.75	0.83	0.91
	1998	0.74	0.85	0.88
	1999	0.80	0.94	0.86
	2000	0.80	0.94	0.85
Vanuatu	1997	0.98	1.00	0.98
	1998	0.95	1.00	0.95
	1999	0.94	1.00	0.94
	2000	1.00	1.00	1.00

[a] Output-oriented technical efficiency for a fleet is measured relative to that flag fleet's own vessels' best-practice production frontier. Vessel size is held fixed.

the observed number of days, their total catch over 1997–2000 could potentially have been 5 per cent higher.

4.1.3. Papua New Guinea

4.1.3.1. Capacity due to both variable input usage and technical inefficiency. If the level of capacity catch is due to both the level of variable input usage and technical inefficiency, CU of the Papua New Guinea fleet ranged from 73 to 85 per cent over the period 1997–2000 (Table 5). On average over the 4-year period CU was 82 per cent. Thus, if all vessels worked at the full capacity level for their fleet, then the number of fishing days required to take the observed catch over the period 1997–2000 would have been 82 per cent of the actual number of fishing days observed. Alternatively, if all Papua New Guinea vessels worked at their fleet's best-practice production frontier by using the appropriate level of variable inputs and were fully technically efficient, the fleet, working the observed number of days, could potentially have caught 22 per cent more over the period 1997–2000.

4.1.3.2. Capacity level due only to variable input usage and purged of technical inefficiency. Purging the effects of technical inefficiency or fishing skill gives an average CU of 100 per cent over 1997–2000 (Table 5). Thus, if all Papua New Guinea vessels worked at the full capacity level for their fleet, then the number of fishing days required to take the observed catch over the period 1997–2000 would have been the same as the actual number of fishing days observed.

4.1.4. Philippines

4.1.4.1. Capacity due to both variable input usage and technical inefficiency. If the level of capacity catch is due to both the level of variable input usage and technical inefficiency, CU of the Philippines fleet ranged from 87 to 98 per cent over the period 1997–2000 (Table 5). On average over the 4-year period CU was 94 per cent. Thus, if all vessels worked at the full capacity level for their fleet, then the number of fishing days required to take the observed catch over the period 1997–2000 would have been 80 per cent of the actual number of fishing days observed. Alternatively, if all Filipino vessels worked at their fleet's best-practice production frontier by using the appropriate level of variable inputs and were fully technically efficient, the fleet, working the observed number of days, could potentially have caught 7 per cent more over the period 1997–2000.

4.1.4.2. Capacity level due only to variable input usage and purged of technical inefficiency. Purging the effects of technical inefficiency or fishing skill gives an average CU of 100 per cent over 1997–2000 (Table 5). Thus, if all Filipino vessels worked at the full capacity level for their fleet, then the number of fishing days required to take the observed catch over the period 1997–2000 would have been the same as the actual number of fishing days observed.

4.1.5. Spain

4.1.5.1. Capacity due to both variable input usage and technical inefficiency. If the level of capacity catch is due to both the level of variable input usage and technical inefficiency, CU of the Spanish fleet ranged from 75 to 88 per cent over the period 1999–2000 (Table 5). On

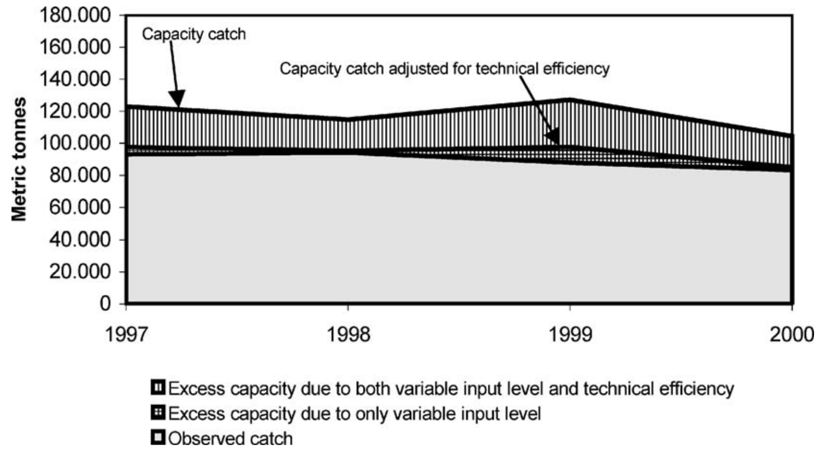


Fig. 5. Japan: annual observed catch, fishing capacity and excess capacity.

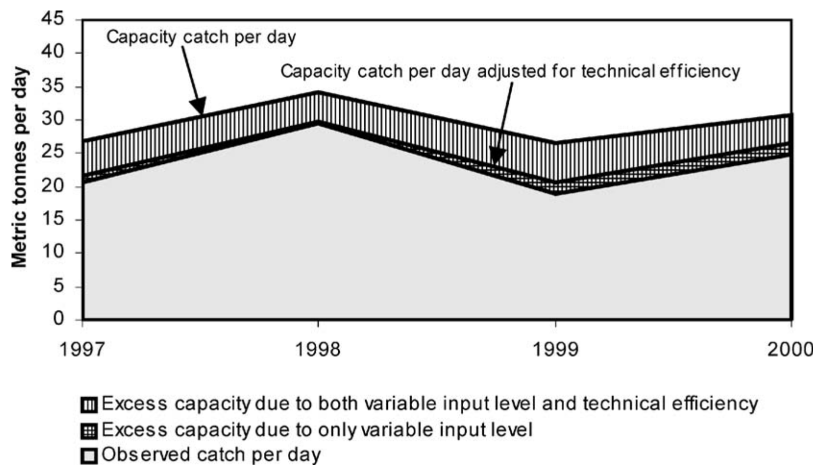


Fig. 6. Korea: per day observed catch, capacity and excess capacity.

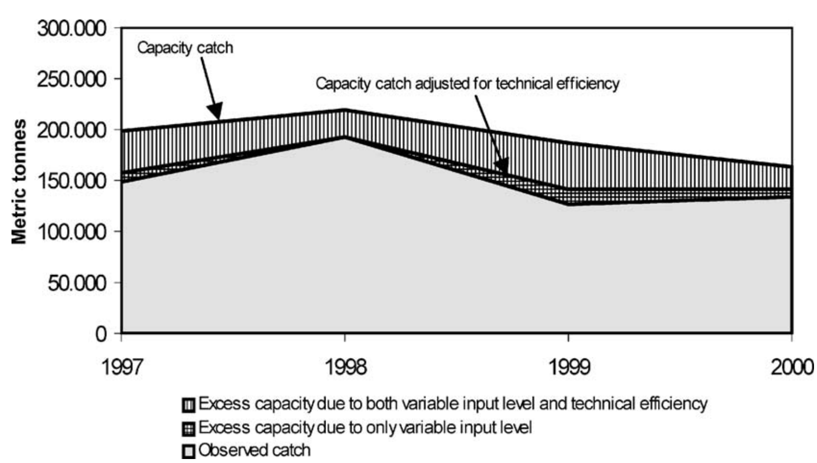


Fig. 7. Korea: annual observed catch, fishing capacity and excess capacity.

average over the 2-year period CU was 81 per cent. Thus, if all vessels worked at the full capacity level for their fleet, then the number of fishing days required to take the observed catch over the period 1997–2000 would have been 81 per cent of the actual number of fishing days observed. Alternatively, if all Spanish vessels worked at their fleet's best-practice production frontier by using the appropriate level of variable inputs

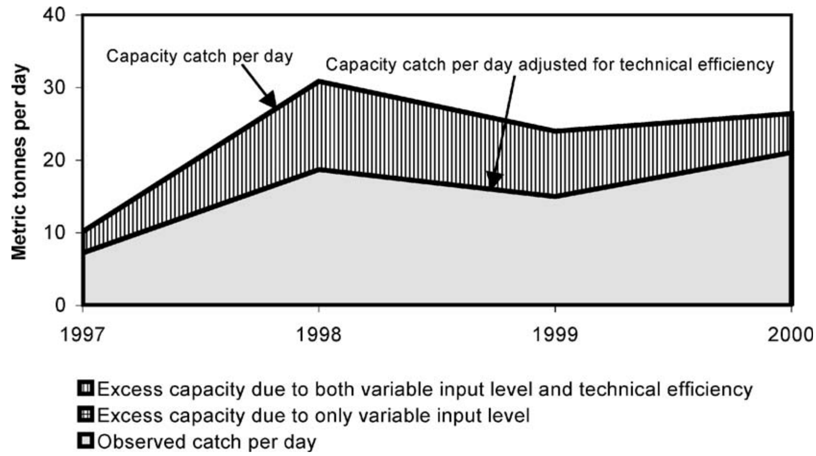


Fig. 8. Papua New Guinea: per day observed catch, capacity and excess capacity.

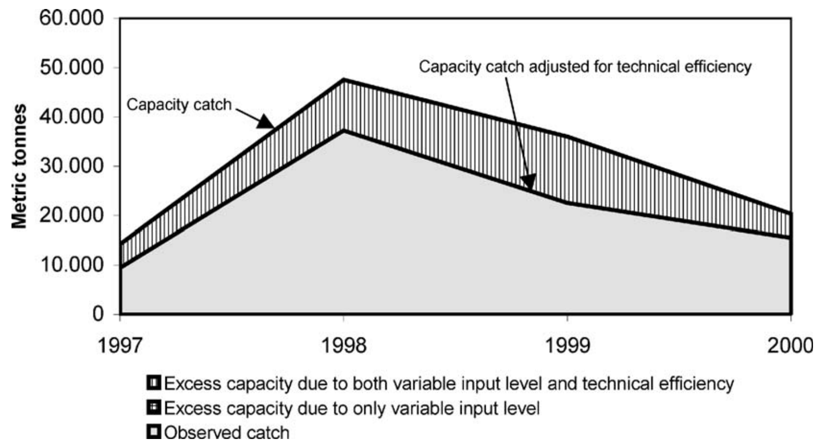


Fig. 9. Papua New Guinea: annual observed catch, fishing capacity and excess capacity.

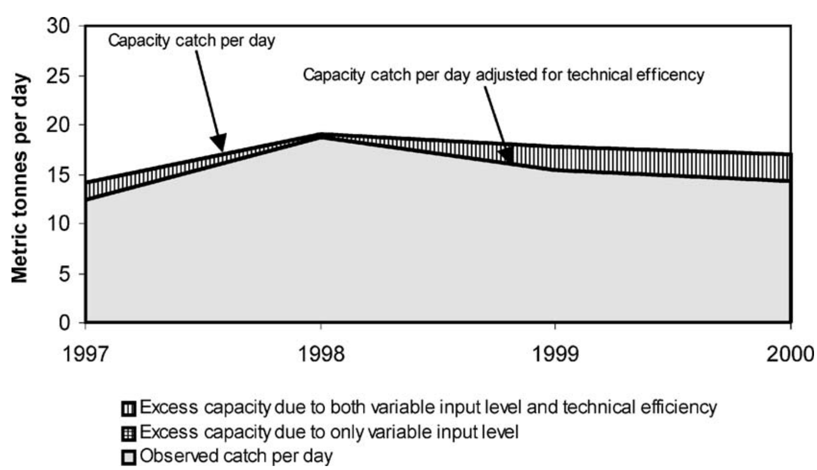


Fig. 10. Philippines: per day observed catch, capacity and excess capacity.

and were fully technically efficient, the fleet, working the observed number of days, could potentially have caught 23 per cent more over the period 1997–2000.

4.1.5.2. Capacity level due only to variable input usage and purged of technical inefficiency. Purging the effects of technical inefficiency or fishing skill gives an average CU of 83 per cent over 1999–2000 (Table 5). Thus, if all Spanish vessels worked at the full capacity level for their fleet, then the number of fishing days required to take the observed catch over the period 1997–2000 would have been 83 per cent of the actual number of fishing

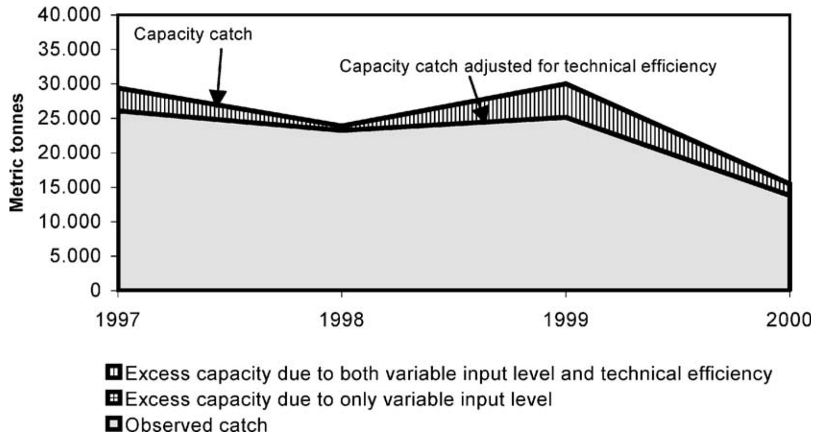


Fig. 11. Philippines: annual observed catch, fishing capacity and excess capacity.

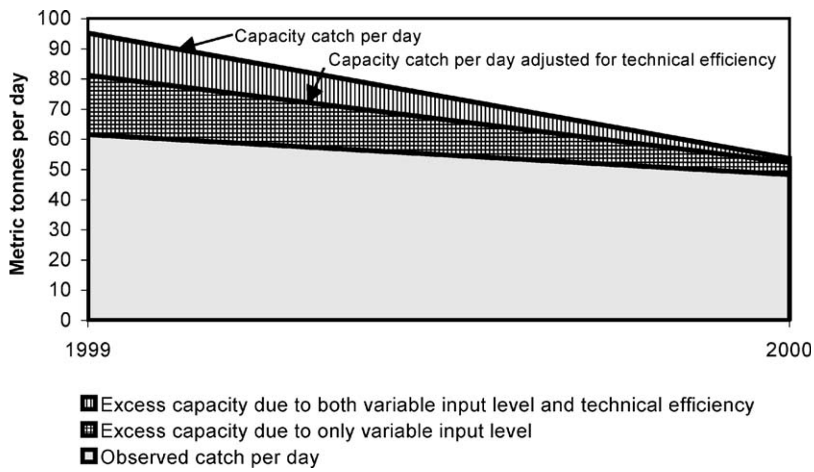


Fig. 12. Spain: per day observed catch, capacity and excess capacity.

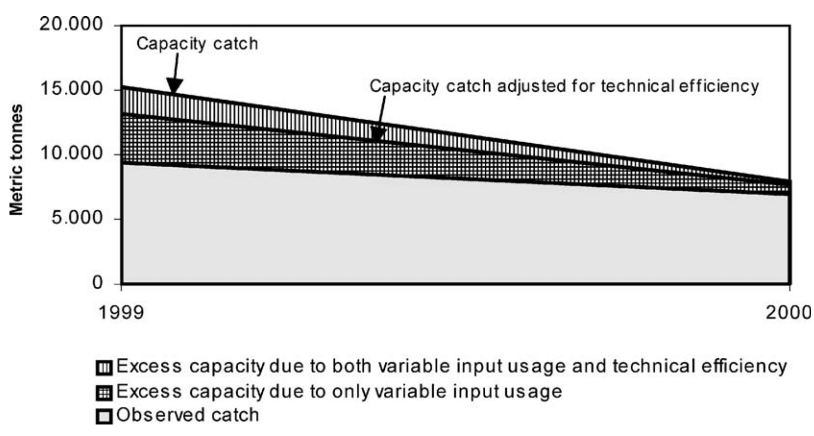


Fig. 13. Spain: annual observed catch, fishing capacity and excess capacity.

days observed. Alternatively, if all Spanish vessels harvested at their fleets' production frontier and worked the observed number of days, their total catch over 1997–2000 could potentially have been 20 per cent higher.

4.1.6. Taiwan

4.1.6.1. Capacity due to both variable input usage and technical inefficiency. If the level of capacity catch is due to both the level of variable input usage and technical inefficiency, CU of the Taiwanese fleet ranged from 65

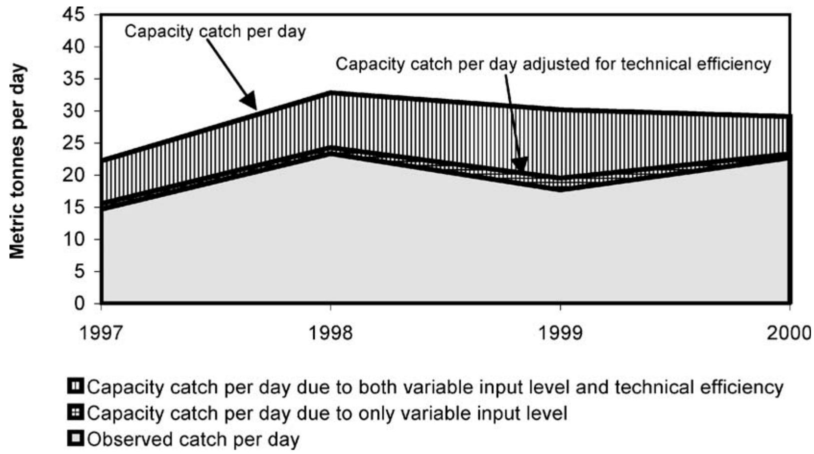


Fig. 14. Taiwan: per day observed catch, capacity and excess capacity.

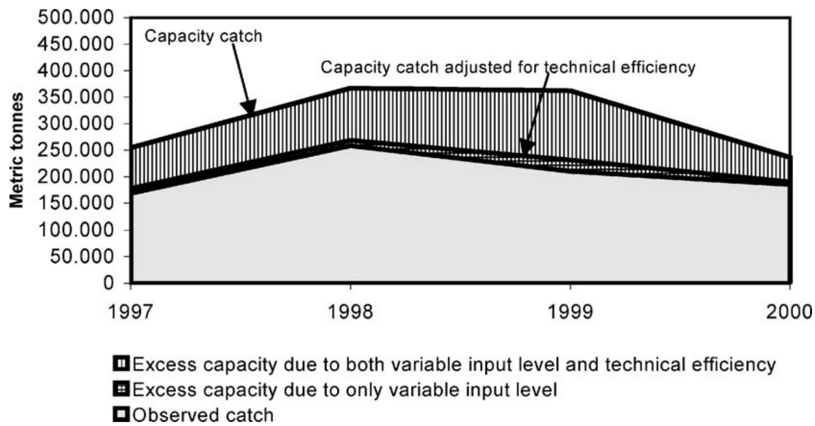


Fig. 15. Taiwan: annual observed catch, fishing capacity and excess capacity.

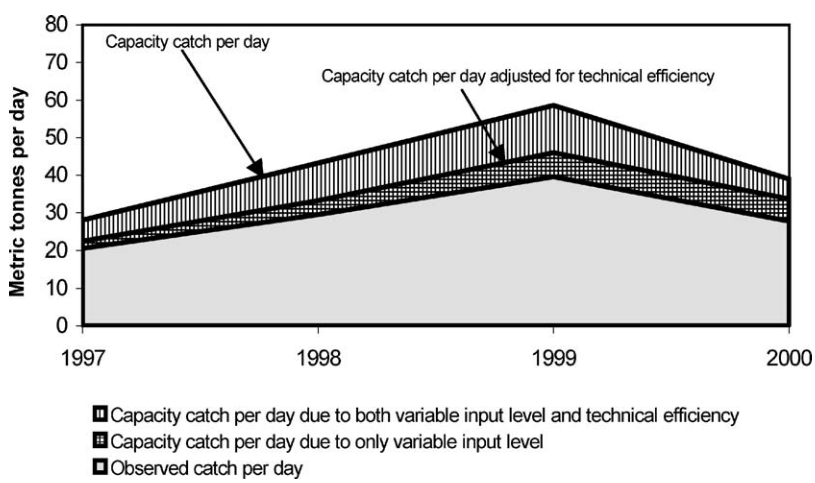


Fig. 16. US: per day observed catch, capacity and excess capacity.

to 75 per cent over the period 1997–2000 (Table 5). On average over the 4-year period CU was 70 per cent. Thus, if all vessels worked at the full capacity level for their fleet, then the number of fishing days required to take the observed catch over the period 1997–2000 would have been 70 per cent of the actual number of fishing days observed. Alternatively, if all Taiwanese vessels worked at their fleet's best-practice production frontier by using the appropriate level of variable inputs and were fully technically efficient, the fleet, working the

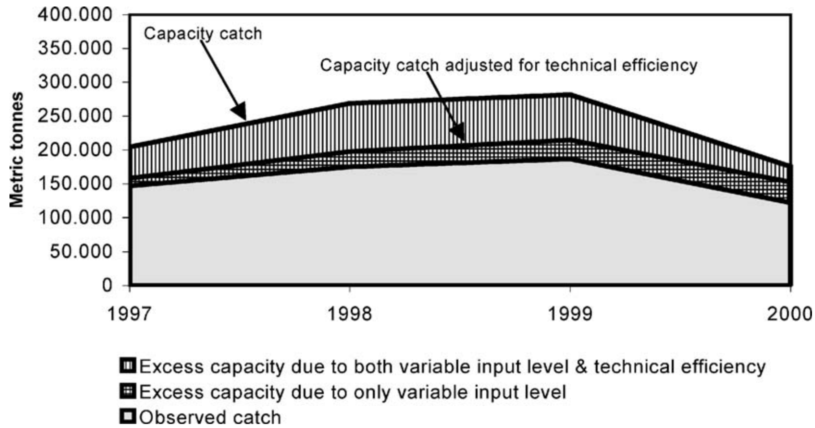


Fig. 17. US: annual observed catch, fishing capacity and excess capacity.

observed number of days, could potentially have caught 43 per cent more over the period 1997–2000.

4.1.6.2. Capacity level due only to variable input usage and purged of technical inefficiency. Purging the effects of technical inefficiency or fishing skill gives an average CU of 95 per cent over 1997–2000 (Table 5). Thus, if all Taiwanese vessels worked at the full capacity level for their fleet, then the number of fishing days required to take the observed catch over the period 1997–2000 would have been 95 per cent of the actual number of fishing days observed. Alternatively, if all Taiwanese vessels harvested at their fleets' production frontier and worked the observed number of days, their total catch over 1997–2000 could potentially have been 6 per cent higher.

4.1.7. US

4.1.7.1. Capacity due to both variable input usage and technical inefficiency. If the level of capacity catch is due to both the level of variable input usage and technical inefficiency, CU of the US fleet ranged from 74 to 80 per cent over the period 1997–2000 (Table 5). On average over the 4-year period CU was 77 per cent. Thus, if all vessels worked at the full capacity level for their fleet, then the number of fishing days required to take the observed catch over the period 1997–2000 would have been 77 per cent of the actual number of fishing days observed. Alternatively, if all US vessels worked at their fleet's best-practice production frontier by using the appropriate level of variable inputs and were fully technically efficient, the fleet, working the observed number of days, could potentially have caught 29 per cent more over the period 1997–2000.

4.1.7.2. Capacity level due only to variable input usage and purged of technical inefficiency. Purging the effects of technical inefficiency or fishing skill gives an average CU of 88 per cent over 1997–2000 (Table 5). Thus, if all US vessels worked at the full capacity level for their fleet, then the number of fishing days required to take the observed catch over the period 1997–2000 would have been 88 per cent of the actual number of fishing days observed. Alternatively, if all US vessels harvested at their fleets' production frontier and worked the observed number of days, their total catch over 1997–2000 could potentially have been 14 per cent higher.

4.1.8. All vessels

In order to obtain an indication of capacity output, excess capacity and CU for the WCPO purse seine fleet as a whole we derived a weighted average capacity output per effort day for all vessels in the sample. This was done by weighing the average capacity output per effort day for each fleet by the total number of observed effort days for the fleet.

4.1.8.1. Capacity due to both variable input usage and technical inefficiency. If the level of capacity catch is due to both the level of variable input usage and technical inefficiency, CU of the fleet ranged from 71 to 84 per cent over the period 1997–2000. On average over the 4-year period CU was 77 per cent. Thus, if all vessels worked at the full capacity level for their fleet, then the number of fishing days required to take the observed catch over the period 1997–2000 would have been 77 per cent of the actual number of fishing days observed. Alternatively, if all vessels worked at their fleet's best-practice production frontier by using the appropriate level of variable inputs and were fully technically efficient, the fleet, working the observed number of days, could potentially have caught 30 per cent more over the period 1997–2000.

4.1.8.2. Capacity level due only to variable input usage and purged of technical inefficiency. Purging the effects of technical inefficiency or fishing skill gives an average CU of 93 per cent over 1997–2000. Thus, if all vessels worked at the full capacity level for their fleet, then the number of fishing days required to take the observed catch over the period 1997–2000 would have been 93 per cent of the actual number of fishing days observed. Alternatively, if all vessels harvested at their fleets' production frontier and worked the observed number of days, their total catch over 1997–2000 could potentially have been 8 per cent higher.

5. Conclusions

Capacity catch per effort day or potential CPUE for all of the fishing nations and for the fleet as a whole increased from 1997 to 1998. When capacity catch is due to the levels of both variable input usage and technical efficiency (so that the number of sets per day can be varied), capacity catch per effort day slightly declined from 1998 through 2000. When capacity catch is due only to the level of variable input usage and the effects of technical efficiency are purged (so that the number of sets per day is fixed), capacity catch per effort day was about the same in 2000 as in 1998, with a slight dip in 1999. In summary, overall WCPO capacity or potential catch per effort day climbed from 1997 to 1998 and then was roughly constant thereafter (Fig. 18).

Annual excess capacity, measured as the difference between the annual capacity catch under observed effort days levels and actual catch over 1997–2000, is relatively high when capacity catch is due to both variable input usage and technical efficiency (that is, the number of sets per day can be varied), at an average of 23 per cent over 1997–2000 (Fig. 19). Thus, under this situation effort days could be roughly reduced by about 23 per cent across all fleets and potentially the fleet could catch the same amount in total. Alternatively, if all vessels worked at their fleet's best-practice production frontier by using the appropriate level of variable inputs and were fully technically efficient, the fleet, working the observed number of days, could

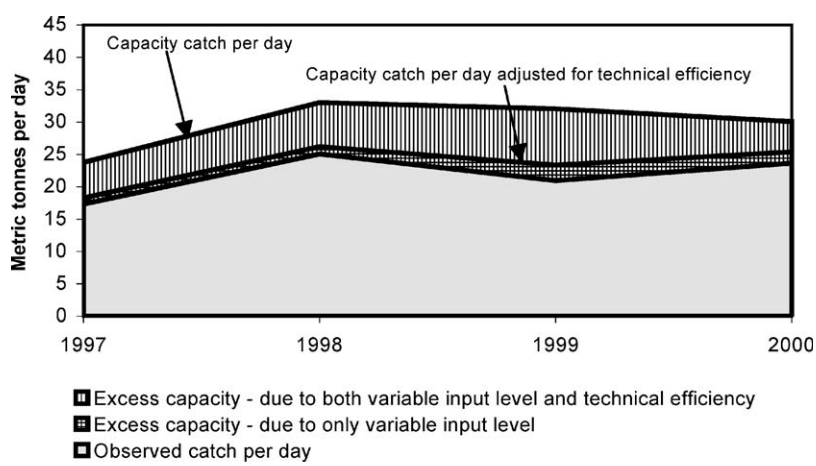


Fig. 18. All fleets: per day observed catch, capacity and excess capacity.

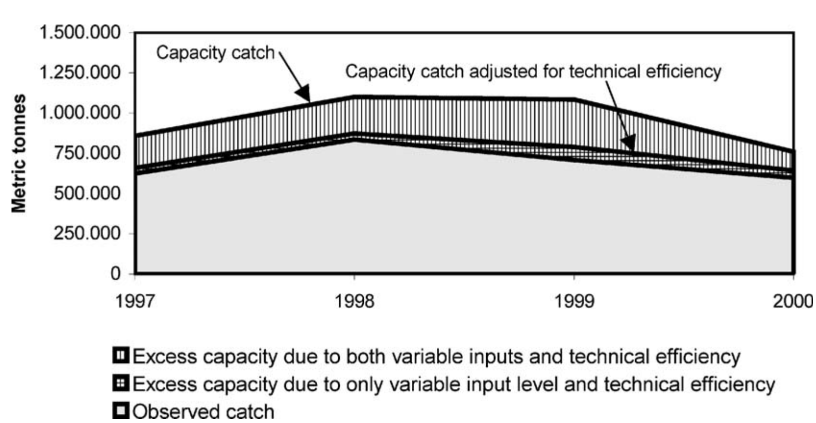


Fig. 19. All fleets: annual observed catch, fishing capacity and excess capacity.

potentially have caught 30 per cent more over the period 1997–2000.

When capacity catch is due solely to the level of variable input usage (the number of sets per day is fixed and technical efficiency has been purged), the excess capacity is substantially lower, with an average of 7 per cent. Thus, under this situation effort days could be roughly reduced by about 7 per cent across all fleets and potentially the fleet could catch the same amount in total. Alternatively, if all vessels harvested at their fleets' production frontier by using the appropriate level of variable inputs and worked the observed number of days, their total catch over 1997–2000 could potentially have been 8 per cent higher.

The results indicate that there is potential for catch levels to increase even without an increase in the number of days that vessels spend in the fishery, given the existing fleets and their sizes and the level of technical efficiency. The results also indicate that the extent of this increase is largely dependent on the ability of vessels not currently operating at full capacity to increase their technical efficiency, that is, to increase their catch by fishing with greater skill.[8] If vessels were able to move to their fleet's technically efficient production frontier it is estimated that catch per effort day could potentially have been around 30 per cent higher than that observed over the period 1997–2000. Thus, if an effort day regime was introduced into the fishery and the TAE was set at a level that was designed to limit potential average annual catches to that observed on average over the period 1997–2000, the TAE would need to be around 23 per cent lower than the observed average number of effort days. Alternatively, if the TAE was set at the average number of effort days observed over 1997–2000 the results indicate that the potential exists for catch levels to increase by about 30 per cent.

It may be difficult for vessels not currently operating at full capacity to increase their technical efficiency to that of vessels that are currently operating at full capacity. In this case, departures from full fishing capacity utilisation are due solely to variable input usage and the potential to reach the full 23 per cent increase will be significantly lower, although some potential will still exist. The results of this study indicate that in this situation, catch per effort day could potentially increase by around 7 per cent compared with that observed over 1997–2000 (and thereby conditional upon the states of technology, environment and resource stocks). In this situation if an effort day regime was introduced into the fishery and the TAE was set at a level that was designed to limit potential average annual catches to around that observed on average over the period 1997–2000, the TAE would need to be around 7 per cent lower than the observed average number of effort days. Alternatively, if the TAE was set at the average number of effort days observed over 1997–2000, the results indicate that the potential exist for catch levels to increase by about 8 per cent.

Additional issues and complications arise, however, for the TAE and regulatory regime, which extend beyond the scope of this paper and analysis. Technical change and productivity growth can expand fishing capacity beyond the levels observed over 1997–2000 by expanding the best-practice production frontier. Technical change in this fishery is comprised of process rather than product innovation. The most important sources of technical change and productivity growth are adoptions of vessel electronics and FAD fishing. FAD fishing can also be accompanied by an increased number of sets per day or per trip. In addition, a further source of capacity growth for the industry as a whole is entry into the fishery of larger, newer vessels along with "stretching" the existing vessels. An additional source of capacity expansion is posed by the use of fishing effort to capture variable input usage, since fishing effort as an aggregate or composite variable input does not incorporate the substitution of variable inputs.[9] In sum, there are several important sources of capacity expansion that extend beyond the scope of this paper and which must be considered by TAE management: technical change and productivity growth through adoption of electronics, FAD fishing, brailing systems, and other innovations;[10] entry in the fishery of newer (potentially embodying newer technology in the capital stock) and larger vessels; and expansion of the size of existing vessels through

[8] An additional issue arises through increasing fishing effort by increasing the number of sets per day. Effort is measured in the paper as days, but the number of sets per day can vary, in part as a result of the harvesting technique employed, for example whether the vessel is fishing on FADs or on logs or unassociated schools.

[9] Fishing effort is a composite or variable input whose formation as a consistent aggregate index requires a number of fairly stringent theoretical conditions [10,29]. The use of an aggregate does not allow for the substitution of inputs [30]. Finally, the number of days or sets or any other temporal unit is only a proxy variable which in turn introduces measurement bias.

[10] Purse seiners are equipped with sonar, bird radar, "X" Band navigational radar, short- and long-range radios, depth sounders, radio direction finders, omni-directional scanning sonar, selective call radio beacons with selective call radio direction finders, global positioning systems or GPS, tele-sounder, satellite weather display, and other electronic devices to help find tunas [14,24]. Although there have not been many advances in "new" types of electronics in the last decade, significant improvements have occurred in traditional gear, particularly for sonar systems that are now closely integrated with GPS and Doppler current readings and for SIMRAD sonar systems in attempts to integrate computers to assist with species and size discriminations (Itano). Another innovation is the introduction of Spanish style brailing (the catch and handling and processing system), in which catch are brailed directly to recirculating brine holds cooled to approximately -9°C by ammonia compressors and held in the same hold until unloaded or transhipped; this gives faster fishing operations and the potential for more sets per day and larger catches before spoilage (Itano).

"stretching" (which could also embody newer technology in the capital stock).

These sources of capacity expansion have important implications for a management regime entailing limits on effort-days and TAE. The above analysis of fishing capacity is static in the sense that it incorporated these additional sources of fishing capacity at the historically observed rates over this period. This analysis does not, however, allow for increases (or decreases) in the historically observed rates and is based on historical environmental and resource stock conditions. Even more importantly, the analysis does not account for future expansions in the best-practice production frontier, and hence expansions in fishing capacity. As a consequence, the approximate 7 per cent reduction in days fished to reduce excess capacity vis-á-vis the average 1997–2000 production level does not factor in "effort creep" and understates the reductions in effort that may be required in the future.

Finally, the analysis does not address a number of other issues relating to the implementation of an effort day management regime by the Parties to the Palau Arrangement, such as, the possible effect of displacing effort into the high seas and other EEZs. As such, the paper does not seek to address the question of what is an appropriate TAE limit under the Palau Arrangement. Rather the paper seeks only to provide a guide to the potential of the purse seine fleet to increase catch rates and the implications of this potential for an effort day management regime.

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