An analysis of the fishing capacity of the global tuna purse-seine fleet[1]

Chris Reid
Forum Fisheries Agency
PO Box 629, Honiara, Solomon Islands
E-mail: chris.reid@ffa.int
James E. Kirkley
College of William and Mary
Virginia Institute of Marine Science
School of Marine Science
Gloucester Point, VA 23062, USA
E-mail: jkirkley@vims.edu
Dale Squires
National Marine Fisheries Service
La Jolla, California, USA
E-mail: Dale.Squires@noaa.gov
Jun Ye
Department of Economics
University of California, San Diego, USA
E-mail: jye@weber.ucsd.edu

ABSTRACT

This paper presents the results of analyses conducted to measure tuna purse-seine fishing capacity in the eastern Pacific Ocean (EPO), western and central Pacific (WCPO), Indian and Atlantic oceans as part of FAO Project GCP/INT/851/JPN *Management of tuna fishing capacity: conservation and socio-economics*. The regional analyses were conducted using Data Envelopment Analysis (DEA), as recommended by the project's Technical Advisory Committee (TAC). The results of the regional analyses are then drawn together in an overview discussion of tuna purse-seine fishing capacity at a global level.

The level of aggregation and the period over which the DEA was conducted varied among the different regional purse-seine fisheries due to differing levels of data that were available for each of the fisheries. The DEA of the EPO and WCPO purse-seine fisheries were conducted at the vessel level during 1998-2002. The period over which the analysis was conducted was limited to 1998-2002, as limiting the number of years of analysis to the five most recent ones captures more recent fleet configurations, cost conditions and fishing patterns, and also helps to control for the potential shifts in capacity output due to technical change. Further, capacity for these fisheries was estimated under two measures: (1) under full variable input utilisation and maximum technical efficiency (TE) and (2)

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[1] The views expressed in this paper are those of the authors, and do not necessarily reflect the views of the U.S. National Marine Fisheries Service or the Forum Fisheries Agency or its member countries.

under full variable input utilisation, but with current levels of TE. The latter was done to try to account for variations in skipper skill levels in deriving estimated capacity output levels. In effect, it measures capacity utilisation purged for the effects of TE. The DEA of the Indian and Atlantic purse-seine fisheries were conducted at the fishery level during the 1981-2002 and 1991-2002 periods, respectively. This was done as the data available were extremely limited, and consequently the DEA could be conducted only at the fishery level as opposed to the vessel level. In order to ensure that sufficient observations were obtained it was therefore necessary to conduct the analysis over the whole period for which data were available

The results of the DEA for the EPO purse-seine fishery indicated that there was considerable excess capacity in the fishery, and that the largest contributor, by far, to excess capacity was Class-6 vessels, although there was excess capacity for Classes 2-3 and 4-5 vessels as well. It was estimated that across the fishery excess capacity, defined as capacity output, purged for TE, minus observed catch, increased from about 120 000 tonnes in 1998 to close to 200 000 tonnes in 2002, an increase approaching 63 percent in five years. For yellowfin and bigeye it was also estimated that excess capacity, defined as capacity output, purged for TE, minus combined maximum sustainable yield, climbed from an excess of about 11 percent in 1998 to an excess of almost 70 percent by 2002. Technical change was estimated on a cumulative basis to have increased by about 60 percent during 1998-2002 for the fishery as a whole. Thus "fishing power" or the state of technology increased considerably, and was an important factor in the exhibited increase in fishing capacity and excess capacity over this period.

For the western and central Pacific purse-seine fishery it was estimated that, on average, during 1998-2002 the purse-seine skipjack fishing capacity was around 306 000 tonnes (35 percent) per annum greater than the actual catch levels. However, it noted that when purging for TE excess skipjack fishing capacity was only 137 000 tonnes (16 percent) per annum greater than the actual catch levels. In other words, only around 40 percent of the potential increase in catches could be realised through increases in variable input usage, given the biomass, environmental conditions and state of technology that prevailed over this period. Estimated excess fishing capacity, purged for TE, was at its highest level in 2000. It was hypothesised that this may have been caused by low skipjack prices in the second half of 1999 and throughout 2000, resulting in vessels reducing the number of days spent searching and fishing.

For yellowfin and bigeye combined in the WCPO purse-seine fishery it was estimated that during 1998-2002 excess purse-seine fishing capacity was around 72 000 tonnes (29 percent) per annum greater than the actual catch. However, it noted that when purging for TE excess yellowfin and bigeye fishing capacity was only 31 000 tonnes (12 percent) per annum greater than the actual catch levels. In other words, only around 40 percent of the potential increase in catches could be realised through increases in variable input usage, given the biomass, environmental conditions and state of technology that prevailed over this period. It was also estimated that during 1998-2002, on average, fishing capacity, purged for TE, for yellowfin and bigeye combined was in excess of the average catches between 2000 and 2002 by 47 666 tonnes, or 20 percent, but that no excess capacity existed in the fishery in 2002 when measured against the average 2000-2002 catch levels.

From the DEA for the Indian and Atlantic purse-seine fisheries it appears that there is excess capacity in both oceans. The more serious level of excess capacity exists for the Indian Ocean fishery. It was estimated that, on an annual basis, there was approximately 61 000 tonnes of excess capacity in the Indian Ocean fishery. In comparison, the Atlantic Ocean fishery had approximately 29 500 tonnes of excess harvesting capacity. Alternatively, if Indian and Atlantic Ocean vessels operated efficiently, fully utilized their variable inputs and harvested the average annual reported level of landings, fleet sizes could be reduced, respectively, from 40 to 31 (22.5 percent) in the Indian Ocean fishery and from 53 to 46 (13.2 percent) in the Atlantic Ocean fishery. These estimates are considered extreme lower-bound estimates of capacity due to the limited number of observations and inadequate information for considering different modes and nations' fishing activities.

At a global level for skipjack it appears that fishing capacity peaked in 1999, then declined in 2000 and 2001 and then returned to 2000 levels in 2002. Excess capacity followed a similar pattern, with a significant rise in 1999, followed by a decline of more than 50 percent in 2000 and 2001 and then by a small increase in 2002. Excess capacity as a percentage of catch also peaked in 1999; however, from then until 2002 it was in continuous decline. From the estimates it appears that global purse-seine fishing capacity for yellowfin and bigeye was on a downward trend between 1998 and 2000, even though observed catch levels were rising, before increasing back to 1998 levels in 2001 as observed catch levels rose sharply and then declined again in 2002. Excess fishing capacity between 1998 and 2000 fell by over 40 percent, while excess capacity in 2001 was at levels similar to that seen in 1999. In 2002 excess capacity was less than those in 1998, 1999 and 2001, but greater than that in 2000.

Excess fishing capacity is a result of both technical inefficiency (or skipper skill) and under-utilisation of variable inputs. In other words, catches can be increased through either an increase in the efficiency of inefficient purse-seine vessels or through an increase in the utilisation of variable inputs such as increases in the numbers of days spent fishing and searching. In the analysis of the purse-seine fisheries of the EPO and the WCPO, fishing capacity, purged for TE, was also estimated. In both analyses under this measure, there was a significant reduction in the estimated level of fishing capacity. For the EPO, the estimated average excess capacity level, purged for TE, measured against the observed catches of skipjack and of yellowfin and bigeye combined during 1998-2002 were around half the level of the estimated excess capacity levels measured against observed catches. For the WCPO, average excess capacity level, purged for TE, measured against observed catches for skipjack and for yellowfin and bigeye combined during 1998-2002 were around 60 percent lower than the levels of the estimated excess capacity measured against observed catches. These results indicate that TE improvements (or increases in skipper skill levels) of inefficient vessels are required if capacity output levels are to be fully achieved.

1. INTRODUCTION

The Food and Agriculture Organization of the United Nations (FAO) is implementing a project on the management of tuna fishing capacity, FAO Project GCP/INT/851/JPN *Management of tuna fishing capacity: conservation and socio-economics*. The main objectives of the project are to identify, consider and resolve technical problems associated with the management of tuna-fishing capacity on a global scale, taking into account conservation and socio-economic issues.

The project's Technical Advisory Committee (TAC) met in April 2003. The TAC recommended that a data envelopment analysis (DEA) be undertaken to estimate the fishing capacity of industrial tuna fleets, including the purse-seine, pole-and-line and longline fleets. Subsequent to this it was decided that the analysis would be undertaken in a phased manner, with the analysis of purse-seine fishing capacity undertaken at the first stage and then, depending on the availability of appropriate data, the pole-and-line and longline fisheries at a later stage. This paper presents the results of the DEA of global purse-seine fishing capacity conducted at the regional level.

This paper is structured as follows. Section 2 provides an overview review of the definition of capacity and capacity utilisation (CU), as used in this report, and analytical methods used for measuring fishing capacity and excess (over-) capacity. In Sections 3 to 5 the methodology, data employed and results of the analyses conducted for the tuna purse-seine fisheries of eastern Pacific Ocean (EPO), western and central Pacific Ocean (WCPO), Indian Ocean and Atlantic Ocean are presented. Details of the analyses of the EPO conducted by Dale Squires and Jun Ye, the WCPO conducted by Chris Reid and the Atlantic and Indian Oceans conducted by James Kirkley are given in Sections 3, 4, and 5, respectively. Finally, in Section 6 the results of the regional analyses are combined in an overview discussion of tuna purse-seine fishing capacity at a global level.

2. OVERVIEW OF THE ANALYTICAL APPROACH

2.1 Capacity and capacity utilisation

Capacity is a short-run concept, where firms and industry face short-run constraints, such as the stock of capital or other fixed inputs, existing regulations, the state of technology and other technological constraints (Morrison, 1985). 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 based directly on microeconomic theory (Morrison, 1985).[2] The two notions of capacity are distinguished by how the underlying economic aspects are included to determine the capacity output.

In either approach, CU is simply actual output divided by capacity output (Morrison, 1985). 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 (Klein and Summers, 1966).

This paper, and those of FAO (1998), Kirkley and Squires (1999), FAO (2000) and Squires *et al.* (2003), focus upon the technological-economic measures of capacity, because the paucity of cost data in most fisheries mitigates against estimation of cost or profit functions to derive economic measures of capacity and CU. Similarly, the technological-economic approach is used by the United States (Corrado and Mattey, 1998) and most other countries to monitor CU throughout the economy.

The technological-economic capacity of a firm can be defined following Johansen's (1968, 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 (1984) provides a formal proof and discussion of plant capacity.

Capacity output thus represents the maximum production that the fixed inputs 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 (Klein and Long, 1973). 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.[3] This approach gives an endogenous output, and incorporates the firm's *ex ante* short-run optimisation behaviour for

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[2] In the economics approach, capacity can be defined as that output pertaining to one of two economic optimums: (1) the tangency of the short- and long-run average cost curves (Chenery, 1952; Klein, 1960; Friedman, 1963), so that the firm is in long-run equilibrium with respect to its use of capital, or (2), the tangency of the long-run average cost curve with minimum short-run average total cost curve (Cassels, 1937; Hickman, 1964).

[3] Klein and Long (1973, 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 U.S. 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 production technology, given full utilisation of the variable inputs under normal operating conditions.

The definition and measurement of capacity 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. Capacity is, therefore, the maximum yield in a given period that can be produced, given the capital stock, regulations, current technology and state of the resource (FAO, 1998; Kirkley and Squires, 1999). Nonetheless, annual climate-driven ocean variability is clearly a key factor affecting fisheries. The monsoon and El Nino-Southern Oscillation events provide clear examples, since the distribution and catchability of fish varies. As a consequence, and due to annual changes in the size and species mix of the resource stocks, the target level and capacity output from the stock-flow production process can vary annually, and even seasonally.

An additional factor that is important to consider is the source of variations in the level of technical efficiency (TE) at which a vessel operates. Pascoe and Coglan (2002) found that differences in vessel characteristics explained around one third of the variation in TE of English Channel trawlers, and attributed the remainder to unmeasurable characteristics, such as skipper skill and differences in technology that could not be quantified. Other studies (*e.g.* Kirkley, Squires and Strand, 1998; Squires and Kirkley, 1999) have also suggested that much of the difference in efficiency among vessels may be due to differences in skipper skill. As such, in this study, where data permits, fishing capacity is estimated under two different measures. First, as discussed previously, it is estimated under full-variable input utilisation and maximum TE. Second, it is estimated under full-variable input utilisation, but with current levels of TE. The latter was done to try to account for variations in skipper skill levels in deriving estimated capacity output levels; in effect, it measures capacity utilization (CU) purged for the effects of TE.

In fisheries and other renewable resource industries, excess capacity is often defined relative to some biological or bio-socio-economic reference point that 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 maximum sustainable yield (MSY) or the catch rate corresponding to the fishing mortality of an alternative harvest (FAO, 1998). The target level of capacity output was defined by FAO (1998, 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 utilized while satisfying fishery management objectives designed to ensure sustainable fisheries…"[4]. A similar conclusion was reached by FAO (2000). The target fishing capacity catch can be specified as, for example, MSY or maximum economic yield (MEY).

In this paper, however, we apply a different approach. Capacity and excess capacity are addressed primarily in terms of observed catch against capacity, or potential, catch,

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[4] Fishing capacity is generally defined by FAO (1998, 2000) 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 utilized, 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 utilizing 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.

assuming that the potential catch is sustainable. In addition, however, in the analysis of the EPO an examination of excess capacity with regard to the AMSY[5] for yellowfin and bigeye is presented, and in the WCPO analysis excess capacity is examined in the context of recent scientific advice that there be no further increases in fishing mortality on yellowfin and bigeye stocks.

2.2 Measuring capacity using data envelopment analysis

DEA is a mathematical programming approach introduced by Charnes, Cooper and Rhodes (1978). The DEA approach seeks to derive the most technically-efficient production frontier, from either an input or an output orientation, by constructing a piece-wise linear technology. Although capacity may be estimated by numerous methods (*e.g.*, a stochastic production frontier, peak-to-peak or surveys), we use DEA to estimate harvesting capacity for the EPO, WCPO, Indian Ocean and Atlantic Ocean. The estimation is restricted to a technological-economic approach in that the data are restricted to the physical quantity of inputs used in the production process and the physical quantity of output produced. The output-orientated approach of Färe (1984) is used in this study for estimating capacity. The output orientation seeks to determine the maximum expansion in outputs, given fixed input levels for some factors (fixed factors) and unrestricted levels for other factors (*i.e.*, the variable factors). The fixed factors limit total production. Although the variable factors are unrestricted, DEA permits the determination of variable input usage consistent with the levels determined by the fixed factors.

The original approaches of Charnes, Cooper and Rhodes (1978) and Färe (1984) provided estimates of TE consistent with the notion of TE offered by Farrell (1957) (*i.e.*, maximum expansion of output, given no change in inputs, or maximum reduction in inputs, given no change in outputs). The method of Färe (1984), later modified by Färe, Grosskopf and Kokkelenberg (1989), separates the factors of production into fixed and variable inputs, and subsequently solves a mathematical programming problem that permits the determination of a piece-wise production technology or frontier, which represents the efficient levels of output, given the fixed factors of production. The mathematical programming problem is the following:

$$
\begin{aligned}
& TE = MAX\ \theta \\
& \text{Subject to}\,\theta u_{jm} = \sum_{j=1}^{J} z_j u_{jm},\ m = 1,\ldots,M \\
& \sum_{j=1}^{J} z_j x_{jn} \le x_{jn},\ n = F_x \qquad\qquad [1] \\
& \sum_{j=1}^{J} z_j x_{jn} = \lambda_{jn} x_{jn},\ n = V_x \\
& z_j \ge 0,\ j = 1,\ldots,N
\end{aligned}
$$

where TE_{CAP} equals a measure of the potential expansion in outputs; 2 (2 ∃1.0) is the inverse of an output distance function; u_{jm} is the m^{th} output of the j^{th} producer or observation; x_{jn} is the nth input for the j^{th} producer; F_x and V_x, respectively, indicate vectors of fixed and variable factors; 8 is a measure of the optimum utilization of the variable inputs; and z is a vector of intensity variables that define the reference technology. If the value of 2 is 1.0, production is efficient and output cannot be expanded, and if [1]> 1.0, the potential output may be expanded by 2 - 1.0. Problem [1] imposes constant returns to scale; in our analysis we allow for variable returns to scale by imposing the constraint 3 z_j = 1.0.

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[5] AMSY is the Average Maximum Sustainable Yield and is an average over a number of years to account for fluctuations that may occur over time.

One limitation of problem [1] or the Färe, Grosskopf and Kokkelenberg (1989) model is that it imposes a radial expansion of outputs (*i.e.*, all outputs expand by the same proportion, 2 - 1.0). This limitation, however, can be easily resolved through the use of directional distance vectors, the Russell (1985) measure, or the slack-based approach of Cooper, Seiford and Tone (2000), all of which permit non-radial expansions of outputs. We consider the Russell measure because of its ease of estimation. The use of either directional vectors or the approach of Cooper, Seiford and Tone require considerably complicated estimation algorithms. The Russell measure (*RM*) is as follows:

$$
\begin{aligned}
&RM_{CAP} = \frac{1}{M} MAX \sum_{m=1}^{M} \theta_m \\
&\text{Subject to} \, \theta u_{jm} = \sum_{j=1}^{J} z_j u_{jm}, \; m = 1,\ldots, M \\
&\sum_{j=1}^{J} z_j x_{jn} \leq x_{jn}, \; n = F_x \qquad\qquad [2] \\
&\sum_{j=1}^{J} z_j x_{jn} = \lambda_{jn} x_{jn}, \; n = V_x \\
&z_j \geq 0, \; j = 1,\ldots, N
\end{aligned}
$$

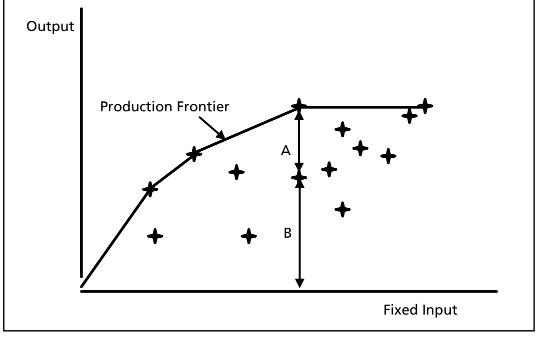
where *M* is the number of outputs, and the variables are the same as those previously discussed. The division by *M* ensures an overall efficiency score of 1.0 or greater. We also impose variable returns to scale.

The use of DEA to calculate fishing capacity output and CU is illustrated in Figure 2.1. 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 greatest for any given vessel size, assuming that the variable inputs are fully utilized (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 CU or CU = 1. When a vessel produces at less than full capacity, as represented by an output lying below the frontier in Figure 2.1, the CU is less than one, *i.e.* CU < 1. Thus, in Figure 2.1 B represents the size of the 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, the environment and the resource stocks, provided that the variable inputs (fishing effort) are fully utilized 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 utilized at the observed levels. Hence, the difference between capacity output and technically-efficient output is that variable inputs are fully utilized in the former and are utilized at the observed levels (which could be fully utilized) in the latter.

FIGURE 2.1

Data envelopment analysis



Alternative methods for measuring capacity and CU have been proposed in the literature, most notably duality-based measures using cost, profit or revenue functions (Morrison, 1985; Squires, 1987; Segerson and Squires, 1995a and 1995b; Färe *et al.*, 2002). Unlike duality-based econometric estimates of 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 can estimate primal measures of capacity in a multiple-product environment without imposing separability assumptions on the outputs (Segerson and Squires, 1990). 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, although there are several non-parametric tests that can be performed to test the results of DEA. 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. THE PURSE-SEINE FISHERY FOR TUNAS IN THE EASTERN PACIFIC OCEAN

In this section we focus attention on the purse-seine fishery for tunas in the EPO. We find that excess capacity exists for the EPO fishery with respect to yellowfin (YFT), skipjack (SKJ) and bigeye (BET) tunas caught in sets on dolphins, sets on floating objects and sets on unassociated schools.

3.1 Data and methodology

Capacity output, capacity output adjusted for TE and CU rates (observed output divided by CU or observed output divided by capacity output adjusted for TE) are estimated by DEA. We attempted to estimate the output-oriented non-radial method of Russell (1985), but the results were unsatisfactory. We instead estimated the output-oriented radial expansion approach, whereby all outputs were kept in fixed proportions as they were expanded, holding fixed factors constant and with full utilization of variable inputs. The CU rates are thus ray measures (Segerson and Squires, 1990).

The set- and vessel-level purse-seine data from the EPO tuna fishery were provided by the Inter-American Tropical Tuna Commission (IATTC) for 1980-2002. These data, by set and vessel, included landings of yellowfin, bigeye and skipjack tunas, vessel GRT and other measures of vessel size (cubic meters, net weight, or length, weight and depth in metres), trip lengths (days, arrival date minus departure date for trip), number of sets. Total is catch in tonnes, and is derived from observer data (or logbook data when observer date not available) raised to unloaded weight. All of these data were differentiated by mode of fishing, *i.e.* sets on fish associated with dolphins, sets on floating objects and sets on unassociated schools. The data were also differentiated by vessel size class (carrying capacity in tonnes) as follows: (1) 0-45 tonnes; (2) 45-91 tonnes; (3) 92-181 tonnes; (4) 182-272 tonnes; (5) 273-363 tonnes; (6) >363 tonnes. Biomass estimates for yellowfin, bigeye and skipjack tunas were provided by the IATTC (Maunder, 2003 personal communication; also see Maunder, 2002; Harley and Maunder, 2004 and Maunder and Harley, 2004).[6] Monthly sea-surface temperature data were obtained from Rayner *et al.* (2003) for 5°N to 20°N between the coast of the Americas and 120°W to try to capture environmental influences.

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[6] The estimates of biomass are for age 1 year and older. The 2003 assessments for which the yellowfin biomass comes from is at http://www.iattc.org/IATTC4thMeetingoftheScientificWorkingGroupENG.htm. The skipjack biomass is from stock assessment report 3. Bigeye is not from the assessment report 4, but from an updated assessment which the results are presented in the IATTTC status of the stocks.

Estimates of capacity outputs, allowing for variable returns to scale[7], were made at the set and vessel level by mode of fishing (dolphin, unassociated or floating object). Data for yellowfin and bigeye tunas were combined to reduce the number of zero-valued observations of bigeye (which is troublesome to the operation of the DEA program). Output or retained catches in the analysis was specified by species and method of harvest per set as follows: (1) yellowfin and bigeye tuna caught in sets made on dolphins; (2) yellowfin and bigeye tuna caught in sets made on unassociated schools; (3) yellowfin and bigeye tuna caught in sets made on floating objects; (4) skipjack tuna caught in sets made on dolphins; (5) skipjack caught in sets made on unassociated schools; and (6) skipjack caught in sets made on floating objects. The retained catches of other fish were negligible, and hence not considered in the analysis. The analysis estimated capacity output for all six outputs and three types of fishing, specifying a common harvesting frontier (*i.e.* the DEA models were run with all six outputs at once, rather than separately for each of the three types of fishing). To be able to accurately estimate capacity output by individual vessel for each of the different types of fishing, each of the six outputs in the DEA model were specified as average landings per vessel per set per year.

Biomass estimates for yellowfin and skipjack were 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 was captured by the GRT to allow for consistency with specifications for the other tuna purse-seine fisheries.

Although data were provided for 1980-2002, capacity output estimates were made only for 1998-2002. Limiting the analysis to the five most recent years captures more recent fleet configurations, cost conditions and fishing patterns, and also helps to control for the potential shifts in capacity output due to technical change. Limiting the number of years of analysis thus leaves differences in TE and variable input usage as the determinants of differences in observed output from capacity output (Färe, Grosskopf and Kokkelenberg, 1989). In addition, the technological-economic approach to capacity output is predicated on "normal practice" or "normal operating conditions" among the vessels, which is better given when the number of years is limited (*cf.* Corrado and Mattey, 1997).

Capacity output and TE were estimated separately for each of the following vessel size groupings: (i) classes 2 and 3 with 28 vessels; (ii) classes 4 and 5 with 43 vessels and (iii) class 6 with 188 vessels. There were no class-1 vessels in the data set. Classes 2 and 3 and classes 4 and 5 were combined to provide an acceptable minimum level of observations in each grouping.[8] The full five years of data were available for only 50 vessels.

The technological-economic measure of capacity output specifies full utilization of variable inputs. However, estimates of TE by DEA were made using the number of sets per vessel by each type of fishing by year as the variable input.

Estimates of ray CU, in which deviations from full CU are due to either low variable input usage or technical inefficiency, are given by θ in problem [1]. Estimates of ray CU purged for the effects of TE were given by the ratio θ_2/θ_1, where θ_2 is derived from problem [1], allowing for variable inputs that are not necessarily fully utilized and θ_1 is the θ in problem [1] when variable inputs are fully utilized (Färe, Grosskopf and Kokkelenberg, 1989). Thus, estimates of ray CU purged for the effects of TE are due to low variable input usage. As noted above, we have attempted to control for

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[7] Variable returns to scale were allowed by imposing the constraint $3\ z_j = 1.0$ in problem [1].

[8] An "insufficient" number of observations gives an estimated piece-wise linear frontier with more and/or longer linear segments and a less accurate measure of capacity output. Without enough "kinks" (from shorter and a larger number of segments) in the piece-wise linear frontier, the distance from an observed output to the frontier, where the observed frontier gives the capacity output, is reduced.

TABLE 3.1
Data used to estimate capacity for Class-2 and -3 vessels in the tuna purse-seine fishery of the EPO

Year	Set type	GRT	No. of vessels	Trip length (days)	Total no. of sets	Total landing (tonnes)		
						Yellowfin and bigeye	Skipjack	Total
By year								
1998	All	148	68	10 608	2 907	8 260	6 663	14 923
1999	All	152	63	10 397	2 655	17 678	10 796	28 474
2000	All	146	64	11 939	3 233	10 028	13 564	23 591
2001	All	161	51	10 410	2 481	13 759	7 500	21 258
2002	All	167	53	7 918	1 625	5 920	6 325	12 245
By year and set type								
2000	Dolphin	68	1	250	1	0	18	18
1998	Unassociated	153	25	5 539	2 370	6 839	4 271	11 110
1999	Unassociated	150	32	5 667	2 405	15 548	8 269	23 817
2000	Unassociated	153	32	6 336	2 946	9 115	10 590	19 705
2001	Unassociated	168	26	5 537	1 880	8 376	3 778	12 154
2002	Unassociated	172	25	4 178	1 248	4 853	5 045	9 898
1998	Floating object	158	19	4 323	537	1 421	2 392	3 813
1999	Floating object	161	23	4 259	250	2 131	2 527	4 658
2000	Floating object	148	25	5 134	286	913	2 955	3 868
2001	Floating object	154	21	4 724	601	5 383	3 722	9 104
2002	Floating object	169	22	3 527	377	1 067	1 279	2 347

Source: Inter-American Tropical Tuna Commission.
Note: There were no reported dolphin sets by Class-2 and -3 vessels in 1998, 1999, 2001 or 2002.

TABLE 3.2
Data used to estimate capacity for Class-4 and -5 vessels in the tuna purse-seine fishery of the EPO

Year	Set type	GRT	No. of vessels	Trip length (days)	Total no. of sets	Total landing (tonnes)		
						Yellowfin and bigeye	Skipjack	Total
By year								
1998	All	374	47	9 869	2 742	11 686	12 100	23 786
1999	All	350	50	8 560	2 655	22 858	17 153	40 011
2000	All	319	53	10 059	3 162	13 780	21 089	34 869
2001	All	377	63	11 749	3 100	26 301	10 722	37 022
2002	All	406	73	13 805	4 450	30 295	16 764	47 058
By year and set type								
2002	Dolphin	454	1	217	11	0	160	160
1998	Unassociated	366	23	5 075	2 269	7 659	9 588	17 248
1999	Unassociated	343	27	4 995	2 433	13 464	20 395	33 859
2000	Unassociated	318	27	5 739	2 867	16 824	12 015	28 839
2001	Unassociated	383	33	6 557	2 629	7 724	20 862	28 587
2002	Unassociated	410	38	7 633	3 850	12 363	26 513	38 876
1998	Floating object	401	20	4 369	473	4 440	2 098	6 538
1999	Floating object	387	18	3 237	222	3 689	2 463	6 152
2000	Floating object	334	21	4 287	295	4 265	1 765	6 030
2001	Floating object	388	25	5 081	471	2 997	5 439	8 436
2002	Floating object	429	30	5 913	589	4 400	3 622	8 023

Source: Inter-American Tropical Tuna Commission.
Notes: There were no reported dolphin sets by Class-4 or -5 vessels between 1998 and 2001.

deviations from full ray CU due to technical change in the later years by limiting the analysis to the last five years. We also attempted to control for deviations from full ray CU due to fluctuations in resource abundance and environmental conditions (which

TABLE 3.3
Data used to estimate capacity for Class-6 vessels in the tuna purse-seine fishery of the EPO

Year	Set type	GRT	No. of vessels	Trip length (days)	Total no. of sets	Total landing (tonnes)		
						Yellowfin and bigeye	Skipjack	Total
By year								
1998	All	1 036	362	88 984	21 211	279 749	119 093	398 842
1999	All	1 081	366	78 845	19 722	296 782	231 517	528 299
2000	All	1 116	366	80 958	18 198	320 733	169 121	489 854
2001	All	1 119	323	71 755	17 477	376 226	116 751	492 977
2002	All	1 179	333	77 196	20 379	395 408	134 087	529 495
By year and set type								
1998	Dolphin	1 025	81	10 942	19 863	158 868	5 044	163 912
1999	Dolphin	1 060	91	8 709	20 456	143 775	1 758	145 533
2000	Dolphin	1 136	91	8 876	20 033	150 934	387	151 321
2001	Dolphin	1 018	73	9 130	14 438	221 481	1 668	223 149
2002	Dolphin	1 073	77	11 169	15 761	278 318	2 841	281 159
1998	Unassociated	1 053	127	4 742	30 789	60 188	13 596	73 784
1999	Unassociated	1 087	133	6 063	28 039	60 794	52 819	113 613
2000	Unassociated	1 113	134	5 597	29 294	49 656	54 908	104 564
2001	Unassociated	1 141	127	3 041	28 904	49 476	7 834	57 310
2002	Unassociated	1 182	130	3 235	30 747	41 343	16 658	58 002
1998	Floating object	1 054	122	5 476	30 098	60 005	100 277	160 282
1999	Floating object	1 102	128	4 934	27 230	91 898	176 791	268 689
2000	Floating object	1 127	125	3 703	28 207	119 971	113 076	233 047
2001	Floating object	1 178	112	5 296	26 268	104 908	107 224	212 132
2002	Floating object	1 202	110	5 960	27 497	75 410	114 491	189 901

Source: Inter-American Tropical Tuna Commission.

shift the capacity output frontier in or out) by specifying biomass and sea-surface temperature.

Annual capacity output on a per-set and per-vessel basis was estimated and subsequently converted to total annual fleet activity for each vessel size class by multiplying the per-vessel and per-set estimates of capacity output by the number of vessels and sets in each year for each vessel size class.

Technological change can also increase fishing capacity. To begin to evaluate the effects of technical change, we estimate a Malmquist index of technological change for the Class-6 vessels, which gives us balanced panel data set of nine years with total number of data for 128 vessels for all three set types. We estimate the Malmquist index DEA model with constant-returns-to-scale, which basically uses the same output-oriented DEA model as that in our capacity estimation, with number of sets as variable input and the interaction term of number of sets and gross weight of the vessel added as another input. This gives a flow measure of capital services for the vessel, engine and gear. Four CU rates (also called output distance in this methodology) are calculated. We provide annual year-to-year estimates and chain or cumulative indices over the nine years.

3.2 Results

3.2.1 Overall levels of capacity in the tuna purse-seine fishery of the eastern Pacific Ocean

The results of the analysis indicates that substantial excess fishing capacity, defined as fishing capacity output minus observed output (retained catches), when measured as: (1) potential catch minus actual catch or (2) potential catch, purged for TE, minus actual catch exists for:

- Skipjack for all vessel classes and set types utilised by the respective vessel class;
- Yellowfin and bigeye combined for all vessel classes and set types utilised by the respective vessel class.

In short, tuna purse-seine vessels had the capacity to catch substantially more of all species during 1998-2002 than they actually caught. The greatest contributor, by far, to excess capacity was Class-6 vessels, although there was excess capacity for Classes 2-3 and 4-5 vessels as well (Table 3.5). Excess capacity for all species combined, purged for TE, fluctuated from a minimum of 120 420 tonnes in 1998 to a maximum of 208 162 tonnes in 1999, dipping in 2000 and steadily rising to 193 199 tonnes in 2001 and to 196 178 tonnes in 2002 (Figures 3.5 and 3.6). Across all vessels it is estimated, after accounting for TE, that during1998-2002 the combined catches of yellowfin and bigeye could have been 33 percent greater (Table 3.5, Figures 3.3 and 3.4) while those of skipjack could have been be 29 percent greater (Table 3.5, Figures 3.1 and 3.2).

FIGURE 3.1

Excess fishing capacity and excess fishing capacity purged for technical efficiency for the purse-seine fishery for skipjack in the EPO

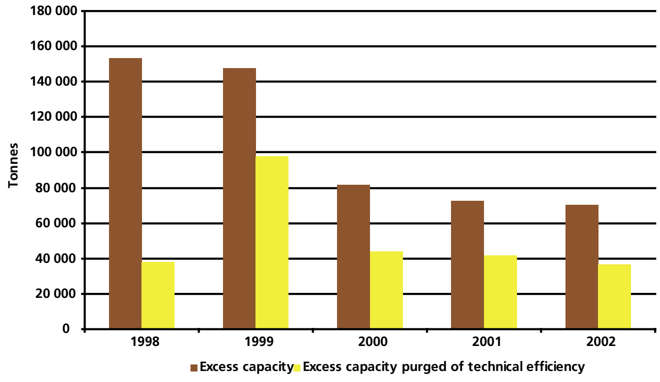


FIGURE 3.2

Observed catch, fishing capacity and fishing capacity purged for technical efficiency for the purse-seine fishery for skipjack in the EPO

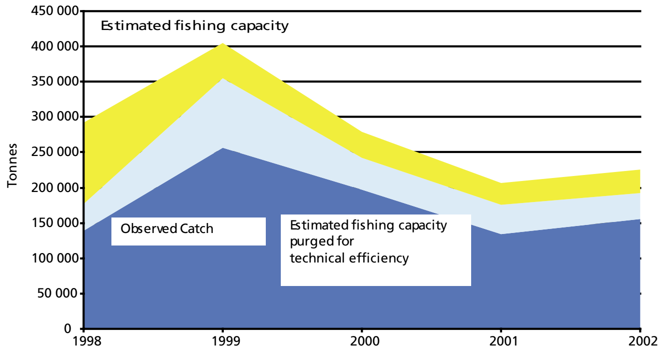
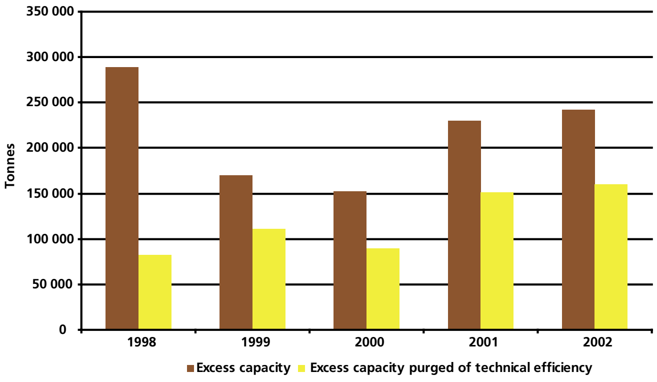


FIGURE 3.3

Excess fishing capacity and excess fishing capacity purged for technical efficiency for the purse-seine fishery for yellowfin and bigeye combined in the EPO



The CU rates for all species combined also indicate substantial excess capacity, defined as capacity output minus observed output, regardless of whether TE is purged (Table 3.7). (CU is defined as observed output divided by capacity output. CU ranges from 0 to 1, where 0 indicates no observed output and 1 indicates that observed output equals capacity output.) The CU for Class 2-3 vessels, purging TE from capacity output, averaged 67 percent, *i.e.* on average a vessel caught about two-thirds of its potential catch. Across all Class 2-3 vessels it is estimated, after accounting for TE, that the combined catches of yellowfin and bigeye could have been 51 percent greater, while those of skipjack could have been 39 percent greater (Table 3.5). The CU for Class 4-5 vessels, purging TE from capacity output, averaged 72 percent; *i.e.* on average a vessel caught slightly less than three-quarters of its potential catch. Across all Class 4-5 vessels it is estimated, after accounting for TE combined, that the combined catches of yellowfin and bigeye could have been 10 percent greater, while those of skipjack could have been 28 percent greater (Table 3.5). The CU for Class-6 vessels, purging TE from capacity output, averaged 75 percent, *i.e.* on average a vessel caught about three-quarters of its potential catch. Across all Class-6 vessels it is estimated, after accounting for TE, that the combined catches of yellowfin and bigeye could have been 34 percent greater, while those of skipjack could have been 29 percent greater (Table 3.5).

Excess capacity exists for all vessel size classes combined for all set types for yellowfin and bigeye tuna when measured as either: (1) potential catch, purged for TE, minus actual catch (Table 3.5, Figure 3.3), or as (2) potential catch, purged for TE, minus the combined AMSYs for both yellowfin and bigeye (Tables 3.6, Figure 3.7). Excess capacity for yellowfin and bigeye tuna *vis-à-vis* their combined AMSY was relatively small in 1998 at 37 167 tonnes, *i.e.* capacity output, purged for TE, was 37 167 tonnes, or almost 11 percent more than the combined AMSYs. Capacity output, purged for TE, rose to 92 518 tonnes, or almost 27 percent more than the combined AMSY in 1999. In 2000, capacity output, purged for TE, decreased slightly to 89 704 tonnes, or almost 26 percent more than the combined AMSYs. By 2001, however, capacity output, purged for TE, rose to 210 915 tonnes, or almost 61 percent more than the combined AMSYs. In 2002, capacity output, purged for TE, rose to 241 835 tonnes, or almost 70 percent more than the combined AMSYs. In all cases, Class-6 vessels contributed the lion's share of the excess capacity.

FIGURE 3.4

Observed catch, fishing capacity and fishing capacity purged for technical efficiency for the purse-seine fishery for yellowfin and bigeye combined in the EPO

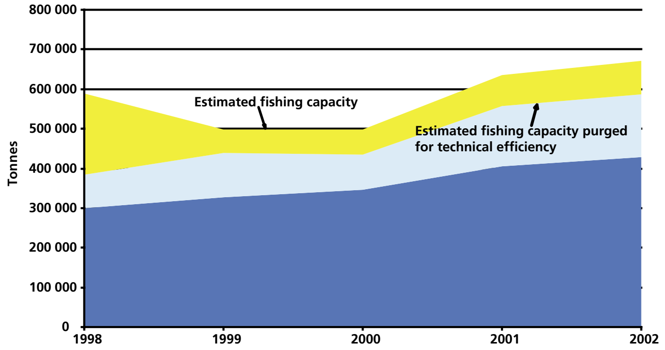


FIGURE 3.5

Excess fishing capacity and excess fishing capacity purged for technical efficiency for the purse-seine fishery for all species combined in the EPO

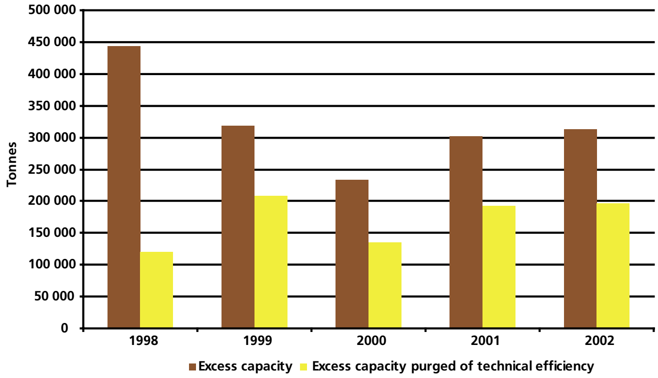
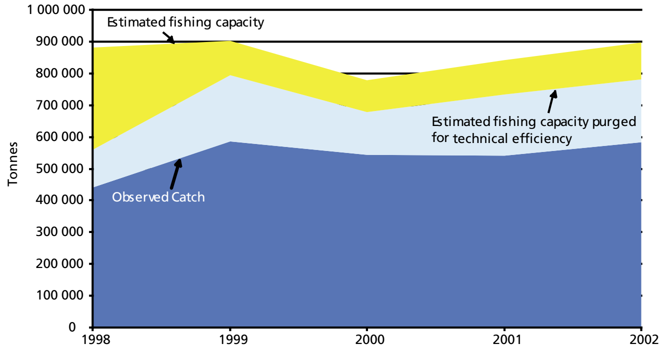


FIGURE 3.6

Observed catch, fishing capacity and fishing capacity purged for technical efficiency for the purse-seine fishery for all species combined in the EPO



In summary, by 2002 tuna purse-seine vessels had the capacity to harvest almost 70 percent more than the AMSYs for yellowfin and bigeye combined.

TABLE 3.4

Reported catch, estimated capacity and capacity purged for technical efficiency for the purse-seine fishery in the EPO.

Vessel class	Year	Reported catch (tonnes)						Fishing capacity (tonnes)						Fishing capacity purged for technical efficiency (tonnes)					
		Skipjack			Yellowfin and bigeye			Skipjack			Yellowfin and bigeye			Skipjack			Yellowfin and bigeye		
		Dolphin	Unasso-ciated	Floating objects	Dolphin	Unasso-ciated	Floating objects	Dolphin	Unasso-ciated	Floating objects	Dolphin	Unasso-ciated	Floating objects	Dolphin	Unasso-ciated	Floating objects	Dolphin	Unasso-ciated	Floating objects
Classes	1998	----	6 012	2 201	----	7 663	2 126	----	11 801	4 977	----	21 322	5 394	----	8 348	4 266	----	15 749	7 465
2 and 3	1999	----	6 444	1 992	----	7 303	1 361	----	14 715	4 360	----	18 065	4 948	----	9 768	2 470	----	11 580	5 096
	2000	18	5 817	2 317	0	9 664	2 041	18	13 347	4 725	0	22 024	4 638	18	8 475	2 674	0	13 150	5 652
	2001	----	6 467	1 696	----	10 230	779	----	11 200	4 100	----	16 981	2 471	----	7 759	1 615	----	12 494	4 356
	2002	----	5 934	1 415	----	8 306	1 567	----	12 619	3 959	----	16 493	4 507	----	7 756	2 168	----	10 682	4 538
	Av.	**18**	**6 135**	**1 924**	**0**	**8 633**	**1 575**	**18**	**12 736**	**4 424**	**0**	**18 977**	**4 392**	**18**	**8 421**	**2 638**	**0**	**12 731**	**5 421**
Classes	1998	----	7 659	4 440	----	9 588	2 098	----	16 858	8 167	----	20 140	4 395	----	9 915	6 159	----	11 682	2 886
4 and 5	1999	----	13 464	5 172	----	20 395	3 076	----	18 775	6 334	----	26 523	3 517	----	17 945	6 125	----	23 937	3 366
	2000	----	16 824	4 265	----	12 015	1 765	----	23 603	5 690	----	13 006	2 017	----	21 242	5 380	----	11 768	1 878
	2001	----	7 724	2 997	----	20 862	5 439	----	11 933	4 578	----	27 631	7 499	----	10 448	4 023	----	24 616	6 373
	2002	0	12 330	4 272	160	26 431	3 622	0	15 861	6 168	160	28 525	4 406	0	14 622	5 467	160	25 242	4 059
	Av.	**0**	**11 600**	**4 229**	**160**	**17 858**	**3 200**	**0**	**17 406**	**6 188**	**160**	**23 165**	**4 367**	**0**	**14 834**	**5 431**	**160**	**19 449**	**3 713**
Class 6	1998	5 044	13 596	100 277	158 868	60 188	60 005	8 341	27 241	215 115	300 663	110 248	127 811	6 287	17 281	125 844	200 974	73 840	73 756
	1999	1 758	52 819	175 308	143 775	60 794	91 285	2 364	75 097	283 217	207 942	86 925	149 876	2 205	66 485	249 450	187 020	76 618	133 513
	2000	387	54 908	113 076	150 934	49 656	119 971	525	79 842	151 329	222 651	75 926	158 323	499	71 140	132 170	200 407	66 451	139 363
	2001	1 585	7 673	105 875	216 583	48 180	103 634	2 593	10 843	161 598	347 537	72 673	160 706	2 255	9 674	139 122	307 197	64 133	140 473
	2002	2 763	15 893	113 021	272 926	40 211	74 840	4 241	22 619	160 512	451 035	61 137	104 007	3 796	19 520	138 517	399 297	53 821	92 393
	Av.	**2 307**	**28 978**	**121 511**	**188 617**	**51 806**	**89 947**	**3 613**	**43 128**	**194 354**	**305 965**	**81 382**	**140 145**	**3 008**	**36 820**	**157 020**	**258 979**	**66 973**	**115 900**

Notes: Actual output (retained catches in tonnes) from Inter-American Tropical Tuna Commission.

TABLE 3.5
Reported catch, estimated excess capacity and excess capacity purged for technical efficiency for the purse-seine fishery of the EPO

Vessel class	Year	Reported catch		Excess fishing capacity				Excess fishing capacity purged for technical efficiency			
		Skipjack	Yellowfin and bigeye	Skipjack		Yellowfin and bigeye		Skipjack		Yellowfin and bigeye	
		t	t	t	%	t	%	t	%	t	%
Classes 2 and 3	1998	8 213	9 789	8 565	(104)	16 927	(173)	3 335	(41)	10 225	(104)
	1999	8 436	8 664	10 639	(126)	14 350	(166)	3 957	(47)	5 386	(62)
	2000	8 152	11 705	9 938	(122)	14 958	(128)	3 318	(41)	4 120	(35)
	2001	8 163	11 009	7 137	(87)	8 443	(77)	2 337	(29)	3 101	(28)
	2002	7 349	9 873	9 229	(126)	11 127	(113)	2 778	(38)	2 976	(30)
	Average	8 077	10 208	9 102	(113)	13 161	(129)	3 145	(39)	5 161	(51)
Classes 4 and 5	1998	12 099	11 686	12 926	(107)	12 849	(110)	3 974	(33)	2 882	(25)
	1999	18 636	23 471	6 473	(35)	6 569	(28)	5 434	(29)	3 833	(16)
	2000	21 089	13 780	8 204	(39)	1 244	(9)	5 532	(26)	-134	-(1)
	2001	10 721	26 301	5 789	(54)	8 829	(34)	3 749	(35)	4 688	(18)
	2002	16 602	30 213	5 427	(33)	2 878	(10)	3 487	(21)	-752	-(2)
	Average	15 829	21 218	7 764	(49)	6 474	(31)	4 435	(28)	2 103	(10)
Class 6	1998	118 917	279 061	131 781	(111)	259 661	(93)	30 495	(26)	69 509	(25)
	1999	229 885	295 854	130 793	(57)	148 890	(50)	88 255	(38)	101 298	(34)
	2000	168 371	320 561	63 325	(38)	136 339	(43)	35 438	(21)	85 659	(27)
	2001	115 133	368 397	59 900	(52)	212 519	(58)	35 918	(31)	143 406	(39)
	2002	131 677	387 977	55 695	(42)	228 201	(59)	30 155	(23)	157 534	(41)
	Average	152 796	330 370	88 299	(58)	197 122	(60)	44 052	(29)	111 481	(34)
All vessels[a]	1998	139 229	300 536	153 272	(110)	289 437	(96)	37 804	(27)	82 616	(27)
	1999	256 957	327 989	147 905	(58)	169 809	(52)	97 646	(38)	110 517	(34)
	2000	197 612	346 046	81 467	(41)	152 541	(44)	44 288	(22)	89 645	(26)
	2001	134 017	405 707	72 826	(54)	229 791	(57)	42 004	(31)	151 195	(37)
	2002	155 628	428 063	70 351	(45)	242 206	(57)	36 420	(23)	159 758	(37)
	Average	176 702	361 796	105 165	(60)	216 757	(60)	51 632	(29)	118 745	(33)

Notes: Excess capacity output is defined as capacity output less observed output (landings) in tonnes.
Actual output (landings in tonnes) from Inter-American Tropical Tuna Commission.

3.2.2 The fishery by class-2 and -3 vessels

Potential catch exceeds actual catch for sets on unassociated schools and on floating objects for Class-2 and -3 vessels, *i.e.* there is excess capacity, regardless of whether capacity output is purged for TE (Table 3.4). (There were no dolphin sets for Class-2 or -3 vessels.) When TE is purged from capacity output for yellowfin and bigeye, this excess capacity is comparatively greater for sets on unassociated schools than for sets on floating objects, with an annual average about four times greater. Excess capacity for all set types for Class-2 and -3 vessels has been declined steadily during 1998-2002.

FIGURE 3.7
Combined AMSYs vs. fishing capacity purged for technical efficiency for the purse-seine fishery for yellowfin and bigeye in the EPO

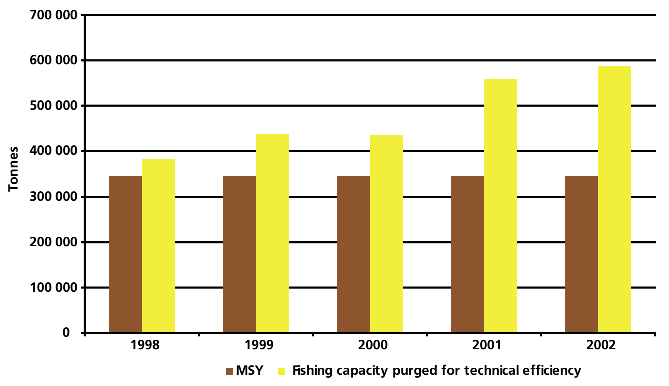


FIGURE 3.8

Annual year-to-year technical change class 6 vessels, all set types and species, 1994-2002

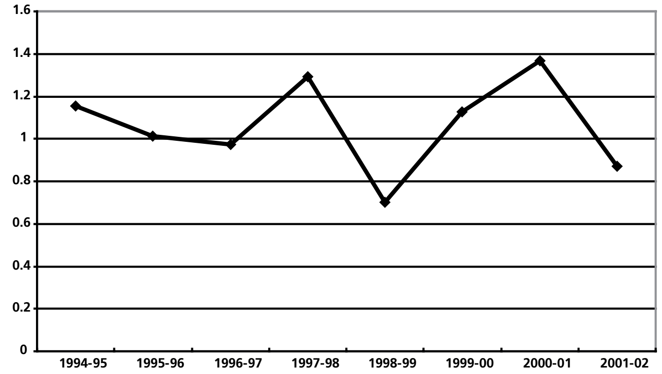
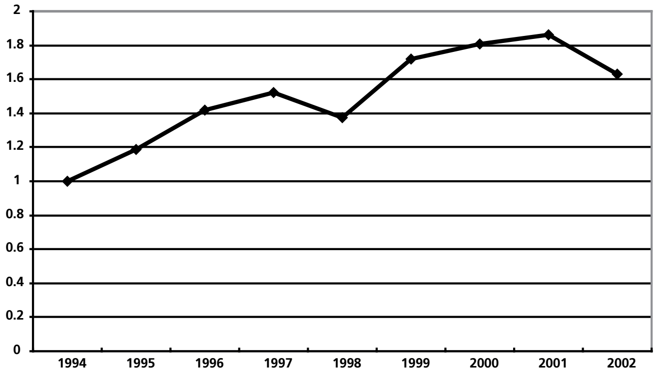


FIGURE 3.9

Cumulative (chained) technical change class 6 vessels, all set types and species, 1994-2002



3.2.3 The fishery by class-4 and -5 vessels

Potential catch exceeds actual catch for sets on unassociated schools and on floating objects for Class-4 and -5 vessels, *i.e.* there is excess capacity, regardless of whether capacity output is purged for TE (Table 3.4). (There was a negligible number of dolphin sets for this size category.) When capacity output is purged for TE for yellowfin and bigeye, this excess capacity is comparatively greater for sets on unassociated schools than for sets on floating objects, with an annual average about three times greater. For skipjack, this excess capacity also averages three times greater for sets on unassociated schools than for sets on floating objects. Excess capacity over all set types averages about three times greater for sets on unassociated schools than for sets on floating objects. The trend for excess capacity for all set types has been roughly downward during 1998-2002, but with considerable variability.

3.2.4 The fishery by class-6 vessels

Potential catch exceeds actual catch for sets on unassociated schools and on floating objects for Class-6 vessels, *i.e.* there is excess capacity, regardless of whether capacity output is purged for TE (Table 3.4). When capacity output is purged for TE for yellowfin and bigeye, this excess capacity can be ranked by set type, from most to least excess capacity as: dolphin sets, sets on floating objects and unassociated sets, school sets. For skipjack, this excess capacity is greatest for floating-object sets, intermediate for sets on unassociated schools sets and least for dolphin sets. Average excess capacity, purged for TE, is greatest for dolphin sets at 71 063 tonnes per year, intermediate for sets on floating objects at 61 462 tonnes per year and least for sets on unassociated schools at 23 009 tonnes per year. Excess capacity for all set types has been roughly upward over 1998-2002, but with considerable variability.

3.2.5 Technical change

Technical change on a cumulative basis for Class 6 vessels increased by about 60 percent for all set types, species during 1998-2002 (Figure 3.9). Thus “fishing power” or the state of technology increased considerably, and was an important factor in the exhibited increase in fishing capacity and excess capacity over this time period.

3.3 SUMMARY AND CONCLUSIONS

Excess capacity for all species combined, defined as capacity output minus observed output (retained catches), exists for all vessel size classes individually and combined for all set types (dolphin, unassociated, floating objects) for yellowfin and bigeye tuna

TABLE 3.6

Excess capacity for yellowfin and bigeye: capacity output purged for technical efficiency minus combined average maximum sustainable yield of yellowfin and bigeye for all vessels in the EPO

Year	Capacity output purged for technical efficiency *(tonnes)*				AMSY (YFT + BET) *(t)* (2)	Excess capacity (1-2) *(tonnes)*	Ratio (1/2)
	Classes 2-3	Classes 4-5	Class 6	All vessels (1)			
1998	20 014	14 568	348 570	383 153	345 986	37 167	1.107
1999	14 049	27 303	397 151	438 504	345 986	92 518	1.267
2000	15 824	13 646	406 220	435 690	345 986	89 704	1.259
2001	14 109	30 989	511 802	556 901	345 986	210 915	1.610
2002	12 849	29 461	545 510	587 821	345 986	241 835	1.699
Annual average	**15 369**	**23 194**	**441 851**	**480 414**	**345 986**	**134 428**	**1.389**

Notes: Excess capacity output is defined as capacity output, purged for technical efficiency, less combined AMSY for yellowfin and bigeye in tonnes. AMSYs from Inter-American Tropical Tuna Commission.

TABLE 3.7

Average vessel capacity utilisation and technical efficiency by vessel class

Vessel Class	Year	Capacity utilisation	Technical efficiency[a]	Capital utilisation without technical efficiency
Classes 2 and 3	1998	0.40	0.70	0.59
	1999	0.41	0.62	0.63
	2000	0.49	0.65	0.74
	2001	0.50	0.70	0.68
	2002	0.46	0.63	0.69
	All years	**0.45**	**0.66**	**0.67**
Classes 4 and 5	1998	0.46	0.61	0.76
	1999	0.71	0.92	0.71
	2000	0.72	0.92	0.73
	2001	0.60	0.89	0.65
	2002	0.72	0.91	0.74
	All years	**0.64**	**0.85**	**0.72**
Class 6	1998	0.52	0.65	0.78
	1999	0.67	0.89	0.75
	2000	0.68	0.89	0.76
	2001	0.63	0.88	0.71
	2002	0.65	0.88	0.72
	All years	**0.63**	**0.84**	**0.75**

Notes: a. Output-oriented technical efficiency for a vessel size class is measured relative to that vessel size class's own vessels' best-practice production frontier. Vessel size, biomass and sea-surface temperature are held fixed.

when measured as: (1) potential catch minus actual catch or (2) potential catch, purged for TE, minus actual catch. Excess capacity, purged for TE, for all vessel size classes has increased from about 120 000 tonnes in 1998 to close to 200 000 tonnes in 2002, an increase approaching 63 percent in five years. The largest contributor, by far, to excess capacity was Class-6 vessels, although there was excess capacity for Classes 2-3 and 4-5 vessels.

Excess capacity exists for all vessel size classes combined for all set types for yellowfin and bigeye tuna when measured as either: (1) potential catch, purged for TE, minus actual catch, or as (2) potential catch, purged for TE, minus the combined AMSYs for both yellowfin and bigeye.

For yellowfin and bigeye, combining over all set types and vessel size classes, excess capacity (defined as capacity output, purged for TE, minus combined AMSY) climbed from an excess of about 11 percent in 1998 to an excess of almost 70 percent by 2002. In all cases, Class-6 vessels contributed the lion's share of the excess capacity.

Technical change on a cumulative basis increased by about 60 percent for all set types, species and vessel size classes during 1998-2002. Thus "fishing power" or the state of technology increased considerably, and was an important factor in the exhibited increase in fishing capacity and excess capacity over this period.

In short, there is considerable excess capacity, whether measured relative to existing catches or AMSY. There is also considerable technical inefficiency and considerable increases in "fishing power" or the state of technology due to technical change, which, in turn, is an important factor in increases in fishing capacity.

4. THE PURSE-SEINE FISHERY FOR TUNAS IN THE WESTERN AND CENTRAL PACIFIC OCEAN

In this section, we focus attention on the purse-seine fishery for tunas in the WCPO. We find that fishing capacity exceeds observed catches for all major fleets, *i.e.* the purse-seine fleets of Japan, the Republic of Korea, the Philippines, Papua New Guinea, the Taiwan Province of China and the United States, and for the other fleets combined. We estimate that, on average, during 1998-2002 purse-seine skipjack-fishing capacity, purged for TE, was around 138 000 tonnes per annum greater than the actual catch levels. For yellowfin and bigeye combined we estimate that, on average, during 1998-2002 purse-seine fishing capacity, purged for TE, was around 29 000 tonnes per annum greater than actual catch levels.

4.1 DATA

Vessel level purse-seine catch (by species and set type) and effort (by days fished and searched[9] and number of sets made by set type) data by vessel flag for the WCPO tuna fishery were obtained from the Secretariat of the Pacific Community (SPC) for 1980-2002.[10] These data, which covered the operations of the purse-seine fleets of China, the Federated States of Micronesia (FSM), Kiribati, the Republic of Korea, the Marshall Islands, New Zealand, Papua New Guinea, the Philippines, the Solomon Islands, the Taiwan Province of China, the United States and Vanuatu throughout the WCPO, were obtained from vessel logbooks.

Data were also provided by the SPC for the purse-seine fleet of Japan; however, these data include only fishing activity in the Exclusive Economic Zones of countries other than Japan, which is only a portion of Japanese purse-seine operations. Data covering the fishing activities of the Japanese purse-seine fleet throughout the WCPO for 2000-2002 was obtained from the National Research Institute of Far Seas Fisheries (NRIFSF) of Japan. These data included catches by set type, the combined number days spent fishing and searching, and carrying capacities of the vessels, provided in ranges of 800 to 900 tonnes, 900 to 1000 tonnes, 1000 to 1100 tonnes, 1100 to 1200 tonnes, 1200 to 1300 tonnes, and 1300 to 1400 tonnes.[11]

Data on the activities of the Spanish and Australian purse-seine fleets were not available at the time that the analyses were undertaken.

While, for confidentiality purposes, the data provide by the SPC could not be attributed to individual vessels the SPC matched vessel characteristics taken from the Regional Register of the Forum Fisheries Agency (FFA) to the logbook data to allow for a data set for each vessel that included both catch and effort data and data relating to the characteristics of the vessel. The vessel characteristics provided were: GRT, storage capacity, length overall (LOA) and power of main engine. These data pertain

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[9] The number of days spent fishing and searching is provided as an aggregated total.

[10] Pers. com. Colin Miller, Fisheries IT Specialist, Secretariat of the Pacific Community.

[11] Pers. com. Naozumi Miyabe, Chief, Tropical Tuna Section, NRIFSF.

TABLE 4.1
Exploitable biomass and sea-surface temperatures

Year	Exploitable biomass (tonnes)			Sea-surface temperature
	Skipjack	Yellowfin	Bigeye	°F (°C)
1998	2 096 661	431 885	46 021	84.30 (29.1)
1999	2 663 134	323 635	45 113	83.80 (28.8)
2000	2 095 842	297 930	46 155	83.60 (28.7)
2001	2 054 939	297 187	47 710	84.90 (29.4)
2002	2 210 299	292 977	30 148	83.68 (28.7)

to the characteristics of the vessel at the time that they were obtained from the Regional Register, and thus do not capture changes in these characteristics of the period for which the analysis was conducted. Finally, in some cases the vessel characteristics for a vessel were not available[12] or were incomplete. The data set used in the analysis is based on the sample of vessels for which complete data sets were available. The number of vessels that formed the data set for each fleet grouping used in the analysis is provided in Table 4.2.

Exploitable biomass estimates for the purse-seine fishery for yellowfin, bigeye and skipjack tunas, which were provided on a quarterly basis by the SPC[13], are based on stock assessments undertaken for the 16th meeting of the Standing Committee on Tuna and Billfish of the SPC. The quarterly estimates were converted to annual estimates by averaging over a given year. Sea-surface temperatures taken at the time of each set of each vessel, in degrees Fahrenheit, are taken from the logbooks of United States purse-seine vessels. These data are collected jointly by the U.S. National Marine Fisheries Service and the Forum Fishery Agency. 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 fleets in the analysis, rather than just the United States vessels. The exploitable biomass and sea-surface temperature data used in the analysis are shown in Table 4.1.

For the analysis the data were grouped by fishing nations for the fleets of Japan, the Republic of Korea, Papua New Guinea, the Philippines, the United States, and the Taiwan Province of China. The remaining fleets were combined in a single group, as there were insufficient observations to allow the analysis to be undertaken at the individual fleet level.[14]

Average vessel data across groups for each of the variables used in the analysis are reported in Table 4.2.

4.2 METHODOLOGY

Capacity output, capacity output adjusted for TE and CU rates (observed output divided by capacity output or observed output divided by capacity output adjusted for TE) are estimated by DEA. We estimate fishing capacity using the output-oriented non-radial method of Russell (1985), assuming variable returns to scale.

For the reasons outlined in the EPO analysis, capacity output estimates, with the exception of those for the Japanese fleet, were made for the five-year period of 1998-2002.[15] For the Japanese fleet estimates were made for the three-year period of 2000-2002, as these were the only years for which data were obtained from the NRIFSF.

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[12] Not all vessel operating in the WCPO appear on the FFA regional register, for example, a portion of the New Zealand purse-seine fleet operates exclusive within New Zealand waters and are not on the register.

[13] Pers. com. John Hampton, Oceanic Fisheries Programme Manager, Secretariat of the Pacific Community.

[14] See footnote 7.

[15] See Section 3.

TABLE 4.2
Averages for vessel data used to estimate capacity in the purse-seine fishery of the WCPO

Flag	Year	Number of vessels	GRT	LOA (*metres*)	Engine size (*horsepower*)	Storage capacity (*cubic metres*)	Combined days fished and search	Reported catch per vessel by set type					
								Skipjack			Yellowfin and bigeye		
								Unasso-ciated	Floating objects	Other	Unasso-ciated	Floating objects	Other
Japan	2000	34	na	na	na	1 135	241	886	3 202	na	505	595	na
	2001	34	na	na	na	1 135	230	1 475	3 075	na	409	591	na
	2002	34	na	na	na	1 135	244	2 283	2 483	na	307	383	na
Republic of Korea	1998	27	1 027	62.64	3 645	1 301	257	3 499	1 789	131	1 824	341	24
	1999	25	1 025	62.79	3 633	1 318	281	2 929	1 163	264	867	328	96
	2000	26	1 024	62.69	3 632	1 312	233	3 784	930	81	908	161	10
	2001	26	1 024	62.69	3 632	1 312	251	3 898	835	159	1 251	68	99
	2002	26	1 024	62.69	3 632	1 312	255	4 023	1 848	290	551	139	28
Papua New Guinea	1998	11	952	58.28	2 905	673	161	374	401	1 762	160	133	645
	1999	12	920	61.08	2 902	692	151	176	956	1 221	93	151	447
	2000	17	959	60.43	2 887	737	166	1 050	919	1 116	338	180	357
	2001	18	879	59.06	2 748	684	250	1 579	985	828	475	347	456
	2002	22	912	59.19	2 735	764	210	1 121	1 105	1 479	218	200	825
Philippines	1998	9	955	56.34	2 816	718	203	119	1 280	1 529	72	401	408
	1999	9	955	56.34	2 816	718	226	162	1 547	1 352	12	386	372
	2000	9	978	57.27	2 894	737	225	170	1 277	1 317	45	473	404
	2001	9	945	57.79	2 994	782	242	270	1,158	747	208	734	414
	2002	12	949	59.19	3 145	853	173	124	749	489	60	263	133
Taiwan Province of China	1998	43	1 071	64.68	3 064	1 282	266	2 371	1 962	283	1 292	136	52
	1999	43	1 071	64.68	3 060	1 282	278	1 084	2 533	134	462	559	32
	2000	43	1 100	65.05	3 098	1 298	231	2 336	1 787	207	749	134	13
	2001	44	1 126	65.48	3 128	1 310	245	2 702	1 625	225	875	156	50
	2002	42	1 128	65.69	3 135	1 322	267	2 530	2 725	386	440	208	24
United States	1998	34	1 229	66.25	3 724	1 480	191	974	2 485	33	687	341	11
	1999	35	1 248	66.45	3 729	1 409	163	83	3 466	11	24	978	3
	2000	30	1 187	66.04	3 698	1 310	163	807	1 798	16	162	611	8
	2001	34	1 191	65.84	3 736	1 518	183	1 199	1 517	28	355	480	8
	2002	29	1 207	66.63	3 788	1 536	209	1 723	1 261	10	627	259	4
Others	1998	12	938	58.65	2 878	873	274	1 613	1 988	1 143	762	440	425
	1999	16	1 069	61.60	3 084	1 031	248	653	1 936	1 262	360	566	476
	2000	22	1 090	62.28	3 099	1 048	143	484	1 933	553	279	234	67
	2001	15	1 124	60.85	3 016	1 003	196	919	2 339	535	369	405	250
	2002	19	1 168	62.61	3 119	1 124	178	1 093	2 319	224	273	245	125

Note: For Japan catches reported by the NRIFSF as "free" sets are listed under "unassociated" sets in the table and those reported as "associated" sets are listed as "floating objects" sets.

Estimates of capacity outputs, allowing for variable returns to scale[16], were made at the set and vessel level by mode of fishing. Reports of yellowfin often include bigeye, as the two species are difficult to distinguish during the juvenile stages of their life cycle, so the data on the catches of the two species were aggregated. For all fleets, with the exception of the Japanese purse-seine fleet, output or catches in the analysis was specified by species and method of harvest as follows: (1) yellowfin and bigeye tuna caught in sets on unassociated schools; (2) yellowfin and bigeye tuna caught in sets on floating objects (FADS or flotsam); (3) yellowfin and bigeye tuna caught in other set types such as anchored FADs; (4) skipjack caught in sets on unassociated schools; (5) skipjack caught in sets made on floating objects and (6) skipjack caught in other set types. For the Japanese fleet the catches were specified as (1) yellowfin and bigeye tuna caught in free sets; (2) yellowfin and bigeye tuna caught in associated sets; (3) skipjack caught in free sets; (4) skipjack caught in associated sets. Free sets are the same as unassociated sets and associated sets are the same as floating-object sets as used previously. The reported catches of other fish were negligible, and hence not considered in the analysis. The analysis estimated capacity output for all six (four for the Japanese fleet) outputs and three (two) types of fishing specifying a common harvesting frontier (*i.e.* the DEA models were run with all six (four) outputs at once, rather than separately for each of the three (two) types of fishing). To be able to accurately estimate capacity output by individual vessel for each of the different types of fishing, each of the six (four) outputs in the DEA model was specified as catches per vessel per year.

The capital stock or capacity base of an individual vessel was specified by its GRT, storage capacity, LOA and engine power, except for vessels of the Japanese fleet, for which it was specified by the mid-point of the carrying capacity band in which it fell.

Biomass estimates for yellowfin and skipjack were 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 technological-economic measure of capacity output specifies full utilization of variable inputs. However, estimates of TE by DEA were made by using the annual numbers of days fished and searched as the variable inputs.

Annual capacity output on a per-vessel basis was estimated and subsequently converted to total annual fleet activity for each fleet group by summing over the individual vessels.

Finally, it should be noted that the catch estimates obtained from the logbook data and the data for the Japanese fleet provided by the NRIFSF differ from the SPC estimates of catches published in its *Tuna Fishery Yearbook*, as the logbook data are only one of many sources that are used to derive the published estimates. Given this, in Section 4.3.2 we combine the estimates derived from the DEA analysis and the SPC *Tuna Fishery Yearbook* catch estimates to obtain estimates of excess fishing capacity in the WCPO tuna purse-seine fishery.

4.3 RESULTS

4.3.1 DEA estimates

The results of the analysis indicate that substantial excess fishing capacity, defined as fishing capacity output minus observed output (landings), when measured as: (1) potential catch minus actual catch or (2) potential catch, purged for TE, minus actual catch exists for:

- Skipjack for all of the major fishing nations and for other fishing nations as a group for all set types; and
- Yellowfin and bigeye combined for all of the major fishing nations and for other fishing nations as a group for all set types.

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[16] Variable returns to scale were allowed by imposing the constraint 3 $z_j = 1.0$ in problem [1].

TABLE 4.3

Reported catches, estimated capacities and capacity purged for technical efficiency for the purse-seine fishing of the WCPO

Flag	Year	Reported catch (tonnes)						Fishing capacity (tonnes)						Fishing capacity purged for technical efficiency (tonnes)					
		Skipjack			Yellowfin and bigeye			Skipjack			Yellowfin and bigeye			Skipjack			Yellowfin and bigeye		
		Unassociated	Floating objects	Other	Unassociated	Floating objects	Other	Unassociated	Floating objects	Other	Unassociated	Floating objects	Other	Unassociated	Floating objects	Other	Unassociated	Floating objects	Other
Japan	2000	30 127	108 871	-	17 154	20 245	-	34 787	121 990	-	21 527	25 691	-	32 002	113 231	-	18 803	21 583	-
	2001	50 150	104 534	-	13 903	20 080	-	70 663	116 244	-	16 837	22 623	-	53 364	106 340	-	13 688	21 359	-
	2002	77 618	84 425	-	10 433	13 025	-	99 311	106 966	-	11 582	18 986	-	76 893	99 132	-	9 102	15 758	-
Republic of Korea	1998	94 483	48 308	3 530	49 235	9 201	635	113 580	66 135	3 795	59 765	13 649	809	111 050	64 635	3 644	59 091	13 034	737
	1999	73 214	29 069	6 605	21 682	8 206	2 400	131 708	50 417	7 279	24 381	8 595	2 624	86 623	33 873	6 798	23 490	8 417	2 469
	2000	98 372	24 187	2 105	23 601	4 188	270	136 581	35 759	4 169	26 998	6 645	683	132 587	34 437	3 233	25 957	6 224	481
	2001	101 349	21 719	4 140	32 535	1 761	2 570	124 056	24 233	4 447	35 958	2 028	2 829	117 230	23 199	4 380	34 784	1 914	2 755
	2002	104 588	48 040	7 535	14 327	3 610	740	133 744	56 250	8 288	17 360	4 214	919	113 385	51 801	8 058	15 396	3 858	788
Papua New Guinea	1998	4 116	4 406	19 378	1 756	1 458	7 096	17 490	9 679	22 242	2 873	2 862	8 550	17 080	8 091	22 140	2 777	2 275	8 443
	1999	2 108	11 477	14 656	1 110	1 815	5 367	16 805	29 959	19 549	1 978	2 273	8 795	7 658	23 378	18 302	1 400	2 187	8 185
	2000	17 852	15 625	18 969	5 740	3 063	6 067	27 756	18 462	22 353	8 019	3 482	7 091	26 861	18 415	22 353	7 319	3 415	7 036
	2001	28 416	17 735	14 899	8 555	6 240	8 215	32 807	22 803	15 826	9 757	6 722	8 491	31 928	19 370	14 987	8 905	6 612	8 391
	2002	24 664	24 320	32 546	4 787	4 396	18 156	30 973	41 291	39 909	5 401	4 762	20 778	29 712	38 962	38 603	4 698	4 703	20 188
Philippines	1998	1 072	11 521	13 765	645	3 611	3 673	1 994	14 355	17 369	1 159	5 011	5 346	1 702	14 099	15 411	885	4 649	4 506
	1999	1 458	13 924	12 167	112	3 470	3 350	2 101	15 621	13 605	315	4 706	4 684	1 458	13 970	12 250	119	3 480	3 367
	2000	1 531	11 495	11 853	408	4 257	3 639	2 595	13 692	13 396	757	5 893	5 341	2 145	13 546	13 008	594	5 762	4 919
	2001	2 433	10 418	6 721	1 870	6 606	3 729	2 563	12 352	7 175	1 891	9 041	4 879	2 478	10 687	6 455	1 871	6 900	3 763
	2002	1 488	8 984	5 872	717	3 157	1 598	1 499	9 570	6 727	859	3 702	1 790	1 488	8 984	5 872	717	3 157	1 598
Taiwan Province of China	1998	101 938	84 368	12 166	55 543	5 862	2 248	158 106	97 094	14 156	74 961	6 961	3 043	113 932	81 826	12 248	59 781	4 989	2 254
	1999	46 592	108 918	5 756	19 875	24 055	1 388	86 932	186 135	16 755	36 279	35 115	1 862	55 502	108 891	10 867	23 261	23 092	1 678
	2000	100 468	76 828	8 909	32 222	5 743	550	159 043	99 192	9 730	49 327	6 490	595	132 356	85 605	9 138	41 872	5 277	587
	2001	118 878	71 511	9 895	38 519	6 879	2 183	147 419	76 573	10 746	51 094	10 843	2 599	133 122	73 924	9 972	44 367	7 008	2 331
	2002	106 254	114 437	16 210	18 485	8 744	995	124 720	128 044	30 554	23 354	9 495	2 102	113 961	121 756	19 468	20 126	9 290	1 274
United States	1998	33 110	84 504	1 131	23 365	11 608	375	48 187	95 199	1 380	24 019	15 573	681	42 135	92 813	1 193	23 259	13 354	619
	1999	2 890	121 314	393	853	34 220	95	16 553	160 099	1 017	6 874	52 285	226	7 828	149 677	498	2 139	46 720	181
	2000	24 197	53 938	481	4 871	18 333	230	34 209	67 808	601	6 495	20 911	355	28 795	60 204	527	5 112	19 752	290
	2001	40 749	51 572	942	12 068	16 322	268	53 176	71 386	1 663	13 229	21 218	342	47 074	67 433	1 470	12 625	19 567	301
	2002	49 973	36 583	276	18 169	7 522	124	70 316	44 068	300	21 545	9 671	183	64 632	39 884	295	20 610	8 830	153
Others	1998	19 351	23 851	13 711	9 143	5 279	5 099	23 704	26 598	18 192	10 249	6 145	5 916	21 594	23 988	15 218	9 784	5 360	5 553
	1999	10 445	30 980	20 192	5 765	9 061	7 611	14 224	38 805	33 976	7 391	9 457	11 760	10 586	30 732	27 597	6 198	9 128	10 545
	2000	10 659	42 520	12 176	6 144	5 138	1 475	12 927	70 687	25 471	7 594	6 072	2 332	12 262	58 607	17 721	6 672	4 951	1 466
	2001	12 863	32 746	7 495	5 168	5 676	3 501	15 407	39 932	9 573	6 655	5 676	3 629	14 523	37 485	8 757	6 211	5 676	3 601
	2002	18 587	39 420	3 805	4 646	4 172	2 122	19 826	51 548	4 049	4 891	5 319	2 254	18 923	48 435	3 888	4 588	5 017	2 176

Note: For Japan catches reported by the NRIFSF as "free" sets are listed under "unassociated" sets in the table and those reported as "associated" sets are listed as "floating-object" sets.

During 1998-2002 excess capacity for skipjack, purged for TE, ranged from 8 percent of the observed catch for the Philippines' fleet to 35 percent of the observed catch for the Papua New Guinea fleet (Table 4.4). Excess capacity for skipjack, purged for TE, for the Korean, Taiwanese and United States fleets during 1998-2002 averaged 19, 10 and 20 percent of the observed catches, respectively. The estimates for the United States fleet are likely to be biased upward because some vessels of this fleet also operate in the EPO, and this is not accounted for in the analysis. For the other vessels as a group, it was estimated that excess capacity for skipjack, purged for TE, averaged 17 percent of their observed catch. For the Japanese fleet it was estimated that during 2000-2002 that the excess capacity for skipjack, purged for TE, averaged 6 percent of the observed catch

During 1998-2002 the excess capacity for yellowfin and bigeye combined, purged for TE, ranged from 9 to 17 percent, a significantly narrower range than that for skipjack (Table 4.4). The group of other vessels was estimated to have the lowest relative excess capacity for yellowfin and bigeye combined, purged for TE, at 9 percent of the observed catch, while the United States fleet was estimated to have the greatest, at 17 percent of the observed catch. Once again, the estimates for the United States fleet are likely to be biased upward for the reason given above. Excess capacity for yellowfin and bigeye combined, purged for TE, for the Taiwanese, Philippine, Korean and Papua New Guinea fleets during 1998-2002 averaged 11, 13, 14 and 15 percent of their observed catches, respectively. For the Japanese fleet it was estimated that during 2000-2002 the excess capacity for yellowfin and bigeye combined, purged for TE, averaged 6 percent of the observed catch.

The CU rates for all species combined also indicate significant excess capacity, defined as capacity output minus observed output, regardless of whether TE is purged (Table 4.5). (CU is defined as observed output divided by capacity output.) CU ranges between 0 and 1, where 0 indicates no observed output and 1 indicates that observed output equals capacity output. CU, purging TE from capacity output, during 1998-2002 averaged across all vessels in the respective fleets ranged from 0.81 for the Papua New Guinea fleet to 0.95 for the Philippines fleet. CU for all species combined, purged for TE, for the Korean, Taiwanese and United States fleets during 1998-2002 averaged 0.86, 0.91 and 0.86 percent respectively. For the reason previously mentioned, the estimates for the US fleet are likely to be biased downward. For the other vessels as a group it was estimated that CU for all species combined, purged for TE, averaged 0.88. For the Japanese fleet it was estimated that during 2000-2002 that CU, purged for TE, for all species combined averaged 0.95.

4.3.2 Using the DEA results and SPC catch estimates to estimate total excess fishing capacity in the WCPO

In this section the results of the DEA analysis are combined with the catch estimates in the SPC *Tuna Fishery Yearbook* to provide estimates of purse-seine fishing capacity and purse-seine fishing capacity, purged for TE, for all species combined and individually for skipjack and for yellowfin and bigeye combined. This is done because the DEA estimates derived in the previous section are based on logbook data, rather than unraised catch data.

These estimates were derived as follows. For each fleet and species grouping covered in the analysis the estimated catches from the SPC *Tuna Fishery Yearbook* were multiplied by the estimated excess capacity, expressed as percentages, obtained from the DEA analysis for the given fleet and species grouping. This was done for both fishing capacity and fishing capacity purged for TE. The resulting excess capacity estimates were then divided by the SPC *Tuna Fishery Yearbook* total catch for the fleets covered in the analysis and this percentage multiplied by the total WCPO purse-seine catch.

TABLE 4.4
Reported catch, estimated excess capacity and excess capacity purged for technical efficiency for the purse-seine fishery of the WCPO

Flag	Year	Reported catch		Excess fishing capacity				Excess fishing capacity purged for technical efficiency			
		Skipjack	Yellowfin and bigeye	Skipjack		Yellowfin and bigeye		Skipjack		Yellowfin and bigeye	
		tonnes	tonnes	tonnes	%	tonnes	%	tonnes	%	tonnes	%
Japan	2000	138 997	37 399	17 780	(13)	9 820	(26)	6 236	(4)	2 988	(8)
	2001	154 684	33 983	32 222	(21)	5 478	(16)	5 019	(3)	1 064	(3)
	2002	162 043	23 458	44 234	(27)	7 110	(30)	13 982	(9)	1 401	(6)
	Average	**151 908**	**31 613**	**31 412**	**(21)**	**7 469**	**(24)**	**8 412**	**(6)**	**1 817**	**(6)**
Republic of Korea	1998	146 321	59 104	37 188	(25)	15 119	(26)	33 009	(23)	13 758	(23)
	1999	108 888	32 376	80 516	(74)	3 224	(10)	18 406	(17)	1 999	(6)
	2000	124 664	28 139	51 844	(42)	6 186	(22)	45 593	(37)	4 522	(16)
	2001	127 208	36 945	25 529	(20)	3 869	(10)	17 600	(14)	2 508	(7)
	2002	160 163	18 765	38 119	(24)	3 728	(20)	13 082	(8)	1 277	(7)
	Average	**112 844**	**34 992**	**46 639**	**(35)**	**6 425**	**(18)**	**25 538**	**(19)**	**4 813**	**(14)**
Papus New Guinea	1998	27 899	10 309	21 511	(77)	3 975	(39)	19 412	(70)	3 185	(31)
	1999	28 242	8 293	38 071	(135)	4 754	(57)	21 095	(75)	3 479	(42)
	2000	52 445	14 870	16 125	(31)	3 722	(25)	15 184	(29)	2 900	(20)
	2001	61 050	23 010	10 386	(17)	1 961	(9)	5 235	(9)	899	(4)
	2002	81 531	27 339	30 642	(38)	3 603	(13)	25 746	(32)	2 250	(8)
	Average	**50 234**	**16 764**	**23 347**	**(46)**	**3 603**	**(21)**	**17 334**	**(35)**	**2 543**	**(15)**
Philippines	1998	26 358	7 928	7 361	(28)	3 588	(45)	4 855	(18)	2 111	(27)
	1999	27 549	6 932	3 778	(14)	2 773	(40)	129	(0)	35	(1)
	2000	24 880	8 305	4 804	(19)	3 687	(44)	3 820	(15)	2 970	(36)
	2001	19 573	12 204	2 518	(13)	3 607	(30)	47	(0)	330	(3)
	2002	16 343	5 471	1 453	(9)	878	(16)	0	(0)	0	(0)
	Average	**22 940**	**8 168**	**3 983**	**(17)**	**2 907**	**(36)**	**1 770**	**(8)**	**1 089**	**(13)**
Taiwan Province of China	1998	198 472	63 653	70 883	(36)	21 312	(33)	9 533	(5)	3 371	(5)
	1999	161 266	45 318	128 556	(80)	27 939	(62)	13 993	(9)	2 713	(6)
	2000	186 205	38 515	81 760	(44)	17 896	(46)	40 894	(22)	9 220	(24)
	2001	200 284	47 581	34 454	(17)	16 955	(36)	16 733	(8)	6 125	(13)
	2002	236 901	28 224	46 416	(20)	6 727	(24)	18 284	(8)	2 466	(9)
	Average	**196 626**	**44 658**	**72 414**	**(37)**	**18 166**	**(41)**	**19 888**	**(10)**	**4 779**	**(11)**
United States	1998	118 745	35 348	26 022	(22)	4 925	(14)	17 396	(15)	1 884	(5)
	1999	124 596	35 168	53 073	(43)	24 217	(69)	33 406	(27)	13 872	(39)
	2000	78 616	23 434	24 002	(31)	4 326	(18)	10 910	(14)	1 720	(7)
	2001	93 263	28 659	32 963	(35)	6 130	(21)	22 715	(24)	3 834	(13)
	2002	86 832	25 815	27 852	(32)	5 585	(22)	17 979	(21)	3 779	(15)
	Average	**100 410**	**29 685**	**32 782**	**(33)**	**9 037**	**(30)**	**20 481**	**(20)**	**5 018**	**(17)**
Others	1998	56 913	19 521	11 582	(20)	2 790	(14)	3 887	(7)	1 177	(6)
	1999	61 617	22 437	25 388	(41)	6 172	(28)	7 298	(12)	3 435	(15)
	2000	65 354	12 757	43 732	(67)	3 241	(25)	23 236	(36)	332	(3)
	2001	53 105	14 345	11 807	(22)	1 615	(11)	7 659	(14)	1 143	(8)
	2002	61 813	10 941	13 610	(22)	1 523	(14)	9 433	(15)	840	(8)
	Average	59 760	16 000	21 224	(36)	3 068	(19)	10 303	(17)	1 385	(9)
All vessels[a]	1998	574 708	195 863	188 427	(36)	45 265	(23)	82 891	(16)	15 800	(8)
	1999	512 158	150 524	333 572	(67)	70 586	(47)	86 464	(17)	24 901	(17)
	2000	671 161	163 419	240 019	(36)	46 222	(28)	143 289	(22)	22 491	(14)
	2001	709 167	196 727	162 333	(23)	45 522	(23)	71 298	(10)	18 052	(9)
	2002	805 626	140 013	214 540	(27)	29 272	(21)	94 020	(12)	11 352	(8)
	Average	714 718	181 623	240 343	(35)	50 361	(28)	98 957	(14)	19 246	(11)

Notes. As no estimates for the Japanese fleet are available for 1998 and 1999 all vessel figures for these years are exclusive of this fleet.

The derived estimates indicate that on average during 1998-2002 excess capacity for skipjack, purged for TE, was 137 452 tonnes, and was at its highest in 2000 at 188 991 tonnes and was at its lowest in 2001 at 89 088 tonnes. As indicated in Figure 4.1, excess capacity for skipjack, purged for TE, trended upward during 1998-2000, before declining significantly in 2001 and then increasing again in 2002. A possible driving force behind this pattern is the skipjack price fluctuations experienced over the period, with Bangkok skipjack prices plummeting to record lows in the second half of 1999 and remaining at these depressed levels throughout 2000 (Catarci, this collection). This price decline resulted in revenues below operating costs for some fleets, which led to some vessels tying up for prolonged periods and fishing fewer days than they would normally, particularly in 2000, as reflected in the number of days vessels in most fleets spent searching and fishing in total (Table 4.2) In other words, there was a reduction in the level of utilisation of variable inputs. In early 2001 the prices recovered to some degree, and prices throughout 2001 and 2002 remained significantly above the levels of the second half of 1999 and throughout 2000, and the average time vessels spent fishing and searching in total increased for all fleets except that of Japan, that was higher in 2001 than in 2000.

The derived estimates also indicate that on average during 1998-2002 excess capacity for yellowfin and bigeye combined, purged for TE, was 31 278 tonnes, and at its highest in 1999 at 43 873 tonnes and lowest in 2002 at 16 977 tonnes. As indicated in Figure 4.3, excess capacity for yellowfin and bigeye combined, purged for TE, rose in 1999, before declining continuously to its 2002 level.

TABLE 4.5

Average vessel capacity utilisation and technical efficiency

Flag	Year	Capacity utilisation	Technical efficiency	Capital utilisation without technical efficiency
Japan	2000	0.87	0.92	0.95
	2001	0.85	0.88	0.97
	2002	0.80	0.85	0.93
	All years	**0.84**	**0.88**	**0.95**
Republic of Korea	1998	0.80	0.96	0.82
	1999	0.66	0.76	0.88
	2000	0.74	0.97	0.77
	2001	0.85	0.95	0.89
	2002	0.82	0.89	0.93
	All years	**0.78**	**0.91**	**0.86**
Papua New Guinea	1998	0.67	0.96	0.70
	1999	0.55	0.85	0.65
	2000	0.82	0.99	0.82
	2001	0.89	0.95	0.94
	2002	0.80	0.96	0.83
	All years	**0.77**	**0.95**	**0.81**
Philippines	1998	0.80	0.93	0.86
	1999	0.88	0.88	1.00
	2000	0.85	0.98	0.88
	2001	0.88	0.88	0.99
	2002	0.95	0.95	1.00
	All years	**0.88**	**0.93**	**0.95**
Taiwan Province of China	1998	0.77	0.81	0.96
	1999	0.62	0.68	0.93
	2000	0.73	0.87	0.83
	2001	0.83	0.91	0.92
	2002	0.84	0.91	0.93
	All years	**0.76**	**0.83**	**0.91**
United States	1998	0.85	0.94	0.90
	1999	0.71	0.91	0.78
	2000	0.81	0.90	0.89
	2001	0.80	0.93	0.86
	2002	0.82	0.94	0.87
	All years	**0.80**	**0.92**	**0.86**
Others	1998	0.86	0.91	0.94
	1999	0.78	0.81	0.92
	2000	0.69	0.83	0.79
	2001	0.88	0.96	0.92
	2002	0.87	0.96	0.91
	All years	**0.80**	**0.89**	**0.88**

4.3.3 Estimated fishing capacity in the WCPO and sustainable fishing mortality on yellowfin and bigeye stocks

The Scientific Co-ordinating Group of the Preparatory Conference for the Commission for the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific recommended that there be no further increases in fishing mortality rates on yellowfin (particularly juveniles) and bigeye. Based on this recommendation, we compare estimated fishing capacity and fishing capacity, purged for TE. Against a target catch level set at the average yellowfin catch by purse seiners during 2000-2002.

Fishing capacity and fishing capacity purged for TE, for yellowfin and bigeye combined with average purse-seine catches during 2000-2002 are compared in Figure

FIGURE 4.1
Skipjack in the WCPO purse-seine fishery - Excess fishing capacity and excess fishing capacity purged for technical efficiency

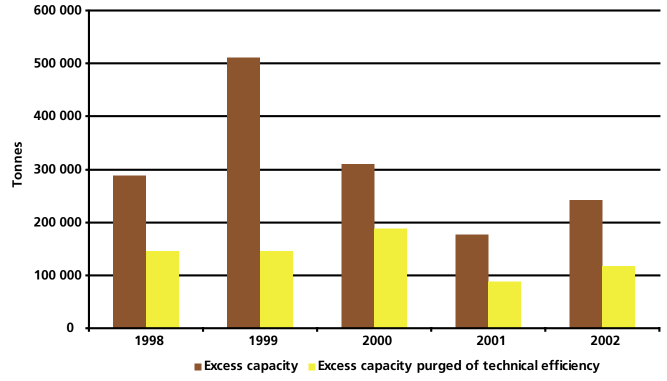


FIGURE 4.2
Skipjack in the WCPO purse-seine fishery - Observed catch, fishing capacity and fishing capacity purged for technical efficiency

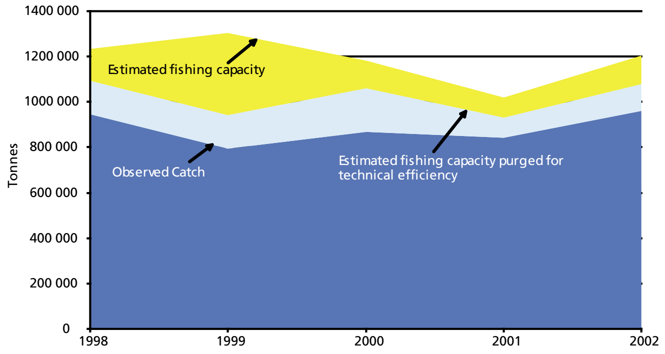
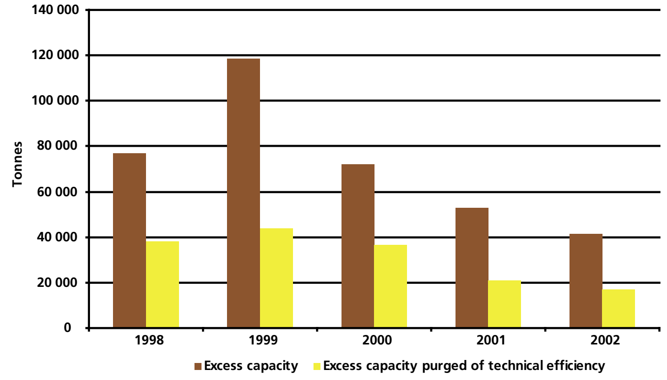


FIGURE 4.3
Yellowfin and bigeye combined in the WCPO purse-seine fishery-Excess fishing capacity and excess fishing capacity purged for technical efficiency



4.5. From this it can be seen that there was significant excess fishing capacity for yellowfin and bigeye when measured as fishing capacity minus average catches from 2000-2002 in the fishery from 1998 to 2002, although this excess capacity existed primarily in 1998 and 1999 and was very low in 2002. During 1998-2002 the average fishing capacity for yellowfin and bigeye combined was in excess of average catches between 2000 and 2002 by 88 762 tonnes or 38 percent.

It can be seen in Figure 4.5 that excess capacity for yellowfin and bigeye, when measured as fishing capacity, purged for TE, minus average catches from 2000-2002 existed in the fishery from 1998 to 2001, but in 2002 there was no excess capacity in the fishery. During 1998-2002 the average fishing capacity, purged for TE, for yellowfin and bigeye combined was in excess of average catches between 2000 and 2002 by 47 666 tonnes or 24 percent.

4.4 SUMMARY AND CONCLUSIONS

The analysis conducted for the WCPO suggests that excess fishing capacity exists for all major fleets, *i.e.* the purse-seine fleets of Japan, the Republic of Korea, the Philippines, Papua New Guinea, the Taiwan Province of China and the United States, and for the other fleets as a group.

It was estimated that on average during 1998-2002 purse-seine skipjack fishing capacity was around 240 000 tonnes (35 percent) per annum greater than actual catch levels. However, it noted that when purging for TE excess skipjack fishing capacity was only 99 000 tonnes (14 percent) per annum greater than the actual catch levels. In other words, only around 40 percent of the potential increase in catches could be realised through increases in variable input usage, given the biomass, environmental conditions and the state of technology that prevailed over this period. Estimated excess fishing capacity, purged for TE, was at its highest level in 2000. It was hypothesised that this may have been caused by low skipjack prices in the second half of

1999 and throughout 2000, resulting in vessels reducing the number of days spent searching and fishing (Catarci, this collection).

For yellowfin and bigeye combined it was estimated that during 1998-2002 excess purse-seine fishing capacity was around 50 000 tonnes (28 percent) per annum greater than the actual catches. However, it noted that when purging for TE excess yellowfin and bigeye fishing capacity was only 19 000 tonnes (11 percent) per annum greater than the actual catches. In other words, only around 40 percent of the potential increase in catches could be realised through increases in variable input usage, given the biomass, environmental conditions and the state of technology that prevailed over this period. It was also estimated that on average during 1998-2002 fishing capacity, purged for TE, for yellowfin and bigeye combined was in excess of the average catches between 2000-2002 by 47 666 tonnes or 24 percent, but that no excess capacity existed in the fishery in 2002, when measured against average 2000-2002 catch levels.

FIGURE 4.4

Yellowfin and bigeye combined in the WCPO purse-seine fishery-Observed catch, fishing capacity and fishing capacity purged for technical efficiency

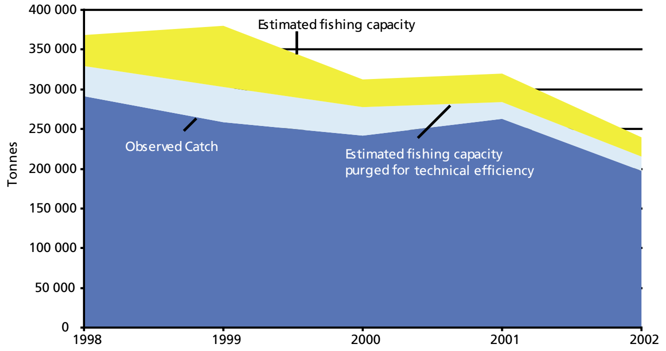
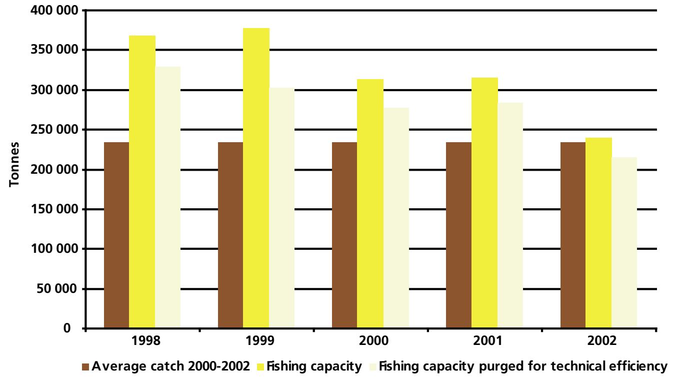


FIGURE 4.5

Yellowfin and bigeye combined in the WCPO purse-seine fishery-Average catch 2000-2002 vs. fishing capacity purged for technical efficiency



5. THE PURSE-SEINE FISHERIES FOR TUNAS IN THE INDIAN OCEAN AND THE ATLANTIC OCEAN

For the Indian and Atlantic Oceans we consider the Russell (1985) measure because of its ease of estimation, and impose variable returns to scale.

5.1 Data and methodology

Data was sought from around the world on fishing activity for the Atlantic and Indian Ocean purse-seine fisheries for tuna. Contacts were also made with ICCAT and the IOTC to obtain data. The data were determined to be inadequate for estimating capacity. Subsequently, data were obtained from Pallares et al. (2003) and Pianet et al. (2003) on the Indian and Atlantic Ocean fisheries, respectively. These data, however, were highly aggregated and inadequate for estimating capacity on a nation-by-nation basis or by fishing mode (*e.g.*, sets on floating objects vs. sets on unassociated schools). It was subsequently decided to estimate capacity using aggregate annual data on the catches of yellowfin, skipjack, bigeye, albacore and all other species combined, numbers of vessels, fishing days, searching days, carrying capacity, a weighted mean of GRT, using the mid-point of vessel tonnage classes, and number of sets. Data were then converted to a per-vessel basis by dividing by the number of vessels in each year. Data on the Atlantic fishery and Indian Ocean fisheries were available for 1991-2002 and 1981-2002, respectively (Tables 5.1 and 5.2).

TABLE 5.1

Data used to estimate capacity in the Atlantic tuna fishery

Year	Average GRT	Number of vessels	Days of fishing	Days of searching	Carrying capacity	Number of sets	Landings (tonnes)					
							YFT	SKJ	BET	ALB	Others	Total
1991	783	71	15 633	13 709	41 978	8 195	92 475	125 536	14 188	416	1 735	234 350
1992	804	65	17 454	15 886	44 091	6 975	96 705	87 243	18 230	2 518	1 254	205 950
1993	829	64	16 425	14 674	41 119	7 877	90 101	124 875	30 857	1 450	1 246	248 529
1994	800	59	15 904	14 231	40 833	7 663	88 062	105 633	32 378	1 079	2 239	229 391
1995	784	55	14 786	13 086	38 149	8 129	84 684	99 208	25 095	412	2 302	211 701
1996	775	54	14 671	13 116	35 641	7 705	82 476	83 928	25 006	258	3 799	195 467
1997	770	52	12 781	11 551	30 832	5 614	68 311	60 204	15 918	118	2 733	147 284
1998	1 005	44	12 585	11 215	29 784	5 898	73 338	56 438	12 622	434	3 065	145 897
1999	762	41	11 731	10 578	25 877	4 861	58 289	76 852	15 545	264	2 004	152 954
2000	730	41	10 576	9 394	27 385	5 122	64 047	64 625	13 752	32	1 741	144 197
2001	812	44	11 344	10 121	30 714	5 198	77 097	60 891	14 002	24	2 460	154 474
2002	801	41	9 823	8 816	25 036	4 324	74 094	47 900	14 230	39	1 008	137 271
Annual average	**805**	**53**	**13 643**	**12 198**	**34 287**	**6 463**	**79 140**	**82 778**	**19 319**	**587**	**2 132**	**183 955**

**Source*: Pianet *et al.* (2003)

TABLE 5.2
Data used to estimate capacity in the Indian Ocean tuna fishery

Year	Average GRT	Number of vessels	Days of fishing	Days of searching	Carrying capacity	Number of sets	Landings (tonnes)					
							YFT	SKJ	BET	ALB	Others	Total
1981	613	2	84	0	129	33	199	163	10	0	0	372
1982	681	4	256	221	820	105	1 028	1 027	8	0	0	2 063
1983	685	12	1 461	1 142	3 729	766	10 505	9 366	218	0	0	20 089
1984	847	47	8 041	6 502	23 642	3 491	56 456	41 884	3 561	558	0	102 459
1985	886	48	9 929	8 302	29 209	4 289	65 772	55 266	6 160	726	0	127 924
1986	863	35	8 597	6 907	25 562	3 904	68 610	60 483	9 951	179	0	139 223
1987	935	35	8 246	6 484	25 942	4 940	78 335	68 292	12 682	239	0	159 548
1988	973	40	9 135	7 244	31 550	5 638	112 780	82 822	13 812	266	0	209 680
1989	982	44	10 880	9 030	37 204	5 590	84 058	115 181	9 997	6	0	209 242
1990	1 015	46	10 628	8 880	34 525	5 911	101 070	87 932	10 489	317	0	199 808
1991	1 041	39	9 767	7 985	33 781	5 493	94 087	91 983	12 994	2 243	40	201 347
1992	1 095	39	9 944	8 162	35 061	6 227	91 172	102 569	8 326	3 256	0	205 323
1993	1 140	42	11 109	9 342	39 521	6 350	102 814	116 850	12 365	1 289	0	233 318
1994	1 133	42	11 061	9 228	40 113	7 051	98 623	144 492	13 767	2 574	1	259 457
1995	1 133	42	11 848	10 004	42 153	7 343	124 098	140 546	22 916	1 254	0	288 814
1996	1 174	47	12 380	10 510	45 384	7 733	112 501	124 998	21 755	1 526	1 286	262 066
1997	1 250	58	14 883	12 930	56 796	8 509	116 875	123 418	30 744	1 961	208	273 206
1998	1 226	53	14 648	12 667	54 669	8 300	89 193	132 073	24 945	1 376	0	247 587
1999	1 240	52	13 339	11 363	51 875	8 062	120 179	168 950	35 587	542	829	326 087
2000	1 267	50	12 635	10 657	52 740	8 132	130 717	170 793	25 519	1 162	2 779	330 970
2001	1 261	50	12 911	10 978	53 519	7 845	114 439	156 929	19 482	1 230	525	292 605
2002	1 284	49	12 864	10 851	55 410	8 356	130 187	212 173	26 943	703	5 379	375 385
Annual average	**1 033**	**40**	**9 757**	**8 154**	**35 152**	**5 639**	**86 532**	**100 372**	**14 647**	**973**	**502**	**203 026**

Source: Pallares *et al.* (2003)

TABLE 5.3
Reported and estimated capacity output (tonnes) for the Atlantic Ocean purse-seine fishery

Year	**Observed**						**Capacity**					
	YFT	**SKJ**	**BET**	**ALB**	**Others**	**Total**	**YFT**	**SKJ**	**BET**	**ALB**	**Others**	**Total**
1991	92 475	125 536	14 188	416	1 735	**234 350**	96 705	125 536	32 378	2 518	3 799	**260 936**
1992	96 705	87 243	18 230	2 518	1 254	**205 950**	96 705	124 969	32 378	2 518	3 799	**260 369**
1993	90 101	124 875	30 857	1 450	1 246	**248 529**	95 771	124 875	32 378	2 424	3 799	**259 247**
1994	88 062	105 633	32 378	1 079	2 239	**229 391**	91 103	114 435	32 378	1 955	3 799	**243 669**
1995	84 684	99 208	25 095	412	2 302	**211 701**	87 368	106 083	28 637	1 579	3 799	**227 466**
1996	82 476	83 928	25 006	258	3 799	**195 467**	86 434	103 995	27 702	1 485	3 799	**223 416**
1997	68 311	60 204	15 918	118	2 733	**147 284**	84 567	99 820	25 832	1 297	3 652	**215 167**
1998	73 338	56 438	12 622	434	3 065	**145 897**	77 097	83 116	18 351	546	3 065	**182 174**
1999	58 289	76 852	15 545	264	2 004	**152 954**	74 094	76 852	15 545	264	2 004	**168 759**
2000	64 047	64 625	13 752	32	1 741	**144 197**	74 094	76 852	15 545	264	2 004	**168 759**
2001	77 097	60 891	14 002	24	2 460	**154 474**	77 097	83 116	18 351	546	3 065	**182 174**
2002	74 094	47 900	14 230	39	1 008	**137 271**	74 094	76 852	15 545	264	2 004	**168 759**
Annual average	**79 140**	**82 778**	**19 319**	**587**	**2 132**	**183 955**	**84 594**	**99 708**	**24 585**	**1 305**	**3 216**	**213 408**

Unfortunately, the data were extremely limited in number of observations and detail, which might be important variables for estimating capacity (*e.g.*, fishing days and searching days on schools associated with floating objects and unassociated schools, or activities and summary statistics by nation). The number of observations was, in fact, too few to consider all inputs. Unlike statistics in which the required degrees of freedom are well established, there are no specific required degrees of freedom. It has been well established, however, that too few observations leads to problems in DEA because of its orientation to relative efficiency. A rough rule of thumb offered by Cooper, Seiford and Tone (2000) is that the degrees of freedom (n) for DEA should be as follows: $n \exists \max \{m \text{ x } s, 3(m + s)\}$, where n is the number of observations; m is the number of outputs; and s is the number of inputs. For the two data sets on the Atlantic and Indian Ocean purse-seine fisheries, we have five outputs and up to five inputs (average GRT, fishing days, searching days, carrying capacity and number of sets). We should, thus, have a minimum of 30 observations ($m \text{ x } s = 25$, and $3(5+5) = 30$). It was subsequently decided to use only average GRT per vessel per year and fishing and searching days per vessel per year. The GRT was considered as a fixed factor (*i.e.*, could not be easily changed), and fishing and searching days were considered to be variable factors.

In actuality, the DEA problem used to estimate capacity has only one factor of production (GRT). This is because capacity can be estimated without including the variable factors. The constraint introduced by 8 ensures unrestricted use of the variable factors, which is equivalent to excluding the variable factors from Problems [1] or [2]. We, nevertheless, have a potential problem with degrees of freedom relative to estimating capacity for the Atlantic Ocean purse-seine fishery.

Capacity on a per-vessel basis was estimated for both the Atlantic and Indian Ocean fleets and subsequently converted to total fleet activity by multiplying the per-vessel estimates of capacity by the number of vessels in each year. We stress that because of the limited degrees of freedom and the paucity of the data relative to detailed activities of the various nations and the modes of fishing, our estimates represent extreme lower-bound estimates of capacity for the Atlantic and Indian Ocean purse-seine fisheries.

5.2 Results

5.2.1 Overall levels of capacity in the tuna purse-seine fisheries of the Atlantic and Indian Oceans

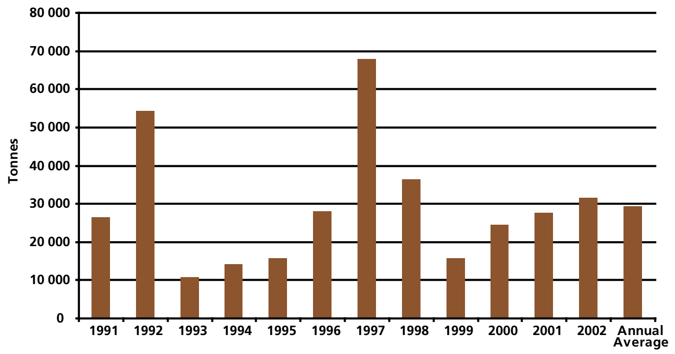
Estimates of capacity output on a per vessel basis for the Atlantic and Indian Ocean purse-seine fisheries suggest that both fisheries have some degree of excess capacity for all species (Tables 5.3 and 5.4). The highest degree of excess capacity (*i.e.*, capacity out-

TABLE 5.4
Reported and estimated capacity output (tonnes) for the Indian Ocean purse-seine fishery

Year	Reported						Capacity					
	YFT	SKJ	BET	ALB	Others	Total	YFT	SKJ	BET	ALB	Others	Total
1981	199	163	10	0	0	**372**	199	163	10	0	0	**372**
1982	1 028	1 027	8	0	0	**2 063**	3 324	2 962	327	0	0	**6 613**
1983	10 505	9 366	218	0	0	**20 089**	10 505	9 366	1 036	0	0	**20 907**
1984	56 456	41 884	3 561	558	0	**102 459**	92 568	83 765	12 549	1 911	0	**190 793**
1985	65 772	55 266	6 160	726	0	**127 924**	107 057	97 010	14 845	2 272	0	**221 184**
1986	68 610	60 483	9 951	179	0	**139 223**	72 604	65 739	9 951	1 517	0	**149 811**
1987	78 335	68 292	12 682	239	0	**159 548**	89 665	81 360	12 682	1 954	0	**185 660**
1988	112 780	82 822	13 812	266	0	**209 680**	112 780	102 418	16 102	2 497	0	**233 797**
1989	84 058	115 181	9 997	6	0	**209 242**	124 402	115 181	18 142	2 817	0	**260 542**
1990	101 070	87 932	10 489	317	0	**199 808**	131 331	129 000	20 559	3 206	0	**284 096**
1991	94 087	91 983	12 994	2 243	40	**201 347**	112 196	115 090	18 492	2 893	2 734	**251 404**
1992	91 172	102 569	8 326	3 256	0	**205 323**	113 968	127 024	20 706	3 256	0	**264 954**
1993	102 814	116 850	12 365	1 289	0	**233 318**	124 098	147 683	24 319	3 507	0	**299 606**
1994	98 623	144 492	13 767	2 574	1	**259 457**	124 098	145 976	24 002	3 507	3 578	**301 160**
1995	124 098	140 546	22 916	1 254	0	**288 814**	124 098	145 976	24 002	3 507	0	**297 582**
1996	112 501	124 998	21 755	1 526	1 286	**262 066**	138 871	174 343	28 899	3 924	4 320	**350 358**
1997	116 875	123 418	30 744	1 961	208	**273 206**	171 373	240 045	39 693	4 842	6 048	**462 001**
1998	89 193	132 073	24 945	1 376	0	**247 587**	156 600	212 248	35 491	4 425	0	**408 764**
1999	120 179	168 950	35 587	542	829	**326 087**	153 645	212 369	35 587	4 341	5 340	**411 283**
2000	130 717	170 793	25 519	1 162	2 779	**330 970**	147 736	211 624	34 219	4 175	5 349	**403 101**
2001	114 439	156 929	19 482	1 230	525	**292 605**	147 736	209 919	34 219	4 175	5 300	**401 347**
2002	130 187	212 173	26 943	703	5 379	**375 385**	144 781	212 173	33 534	4 091	5 379	**399 958**
Annual average	**86 532**	**100 372**	**14 647**	**973**	**502**	**203 026**	**109 256**	**129 156**	**20 880**	**2 855**	**1 729**	**263 877**

put minus observed output per vessel) occurred for skipjack and yellowfin for both fisheries, which also had the greatest landings of all four of the tuna species. For the Atlantic Ocean fishery during 1991-2002 the highest level of excess capacity relative to all species occurred in 1997 (Figure 5.1); the highest level of excess capacity for the Indian Ocean fishery also occurred in 1997 (Figure 5.2). The reason for this is unknown, but it may be a result of management or environmental conditions.

FIGURE 5.1
Annual and average annual excess capacity relative to all species caught in the Atlantic Ocean purse-seine fishery



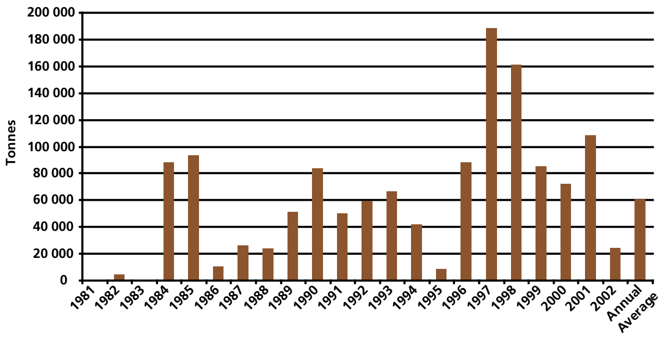
The Atlantic Ocean purse-seine fishery had the capability of harvesting 84 596 tonnes of yellowfin, 99 708 tonnes of skipjack, 24 585 tonnes of bigeye, 1 305 tonnes of albacore and 3 216 tonnes of other species per year (Table 5.3). Alternatively, the fleet had the capability to harvest 213 408 tonnes of all species combined. In comparison, the fleet had a reported average annual harvest of 79 140 tonnes of yellowfin, 82 778 tonnes of skipjack, 19 319 tonnes of bigeye, 587 tonnes of albacore and 2 132 tonnes of other species; the reported average annual harvest between 1991 and 2002 was 183 955 tonnes of all species combined. There was not, however, excess capacity for all species in all years. There was no excess capacity for yellowfin in 1992, 2001 and 2002; none for skipjack in 1991, 1993 and 1999; none for bigeye in 1994 and 1999; none for albacore in 1992 and 1999; and none for other species in 1996, 1998 and 1999.

The overall greatest level of excess capacity occurred in the Indian Ocean purse-seine fishery (Table 5.4). The estimated average annual capacity output between 1981 and

TABLE 5.5
Excess capacity and full-utilization levels of variable inputs per vessel in the Atlantic Ocean purse-seine fishery

Year	Number of vessels	Observed		Full-utilization		Excess Capacity (tonnes)					
		Fishing days	Searching days	Fishing days	Searching days	YFT	SKJ	BET	ALB	Others	Total
1991	71	220	193	246	224	60	0	256	30	29	374
1992	65	269	244	269	244	0	580	218	0	39	837
1993	64	257	229	269	245	89	0	24	15	40	167
1994	59	270	241	272	247	52	149	0	15	26	242
1995	55	269	238	274	249	49	125	64	21	27	287
1996	54	272	243	275	249	73	372	50	23	0	518
1997	52	246	222	276	250	313	762	191	23	18	1305
1998	44	286	255	286	255	85	606	130	3	0	824
1999	41	286	258	286	258	385	0	0	0	0	385
2000	41	258	229	286	258	245	298	44	6	6	599
2001	44	258	230	286	255	0	505	99	12	14	630
2002	41	240	215	286	258	0	706	32	5	24	768
Annual average	**53**	**259**	**232**	**274**	**248**	**104**	**322**	**100**	**14**	**21**	**560**

FIGURE 5.2
Annual and average excess capacity relative to all species caught in the Indian Ocean, purse=seine fishery



2002 for the Indian Ocean fishery was 109 256 tonnes of yellowfin, 129 156 tonnes of skipjack, 20 880 tonnes of bigeye, 2 855 tonnes of albacore and 1 729 tonnes of other species; the reported average annual landings were, respectively, 86 532 tonnes of yellowfin, 100 372 tonnes of skipjack, 14 647 tonnes of bigeye, 973 tonnes of albacore and 502 tonnes of other species. The average annual capacity output for all species was estimated to equal 263 877 tonnes, whereas the reported average annual total output was 203 026 tonnes. There was no excess capacity for yellowfin in 1981, 1983, 1988 and 1995; none for skipjack in 1981, 1983, 1989 and 2002; none for bigeye in 1981, 1986, 1987 and 1999; none for albacore for 1981-1983 and 1992; and none for other species in all years except 1991, 1994, 1996-1997 and 1999-2001.

5.2.2 The Atlantic Ocean fishery

In the Atlantic Ocean fishery, a vessel had, on average, the capability to harvest an additional 322 tonnes of skipjack and 104 tonnes of yellowfin per year (Table 5.5). The total average annual excess capacity per vessel between 1991 and 2002 was 560 tonnes They could do this by operating efficiently and making small increases in their fishing and searching days (the average annual number of fishing and searching days per vessel for the Atlantic fleet between 1991 and 2002 were, respectively, 259 and 232 days; the average annual level of fishing and searching days per vessel required to produce the capacity output were, respectively, 274 and 248 days). In general, the Atlantic Ocean purse-seine fleet could realize capacity output mostly by improving its efficiency (Table 5.6). The measure of CU adjusted for TE is quite close to one for most species and years, which indicates that gains in output could come mostly from operating more efficiently. The non-parametric Kruskal-Wallis test was conducted to determine the equality of observed and full-utilization levels of fishing and searching days; the equality was rejected at the 5-percent level of significance for both fishing

TABLE 5.6

Capacity utilization in terms of ratio of observed and technically-efficient output levels to capacity output levels in the Atlantic Ocean purse-seine fishery

Year	Capacity utilization—Observed/Reported output					Capacity utilization—Technically-efficient output				
	YFT	SKJ	BET	ALB	Others	YFT	SKJ	BET	ALB	Others
1991	0.96	1.00	0.44	0.17	0.46	0.96	1.00	0.95	0.70	1.00
1992	1.00	0.70	0.56	1.00	0.33	1.00	1.00	1.00	1.00	1.00
1993	0.94	1.00	0.95	0.60	0.33	0.98	1.00	1.00	0.86	1.00
1994	0.97	0.92	1.00	0.55	0.59	1.00	1.00	1.00	0.98	1.00
1995	0.97	0.94	0.88	0.26	0.61	1.00	1.00	0.99	0.95	1.00
1996	0.95	0.81	0.90	0.17	1.00	1.00	1.00	1.00	0.97	1.00
1997	0.81	0.60	0.62	0.09	0.75	0.98	0.91	0.89	0.77	0.86
1998	0.95	0.68	0.69	0.80	1.00	1.00	1.00	1.00	0.99	1.00
1999	0.79	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2000	0.86	0.84	0.88	0.12	0.87	1.00	0.84	0.94	0.43	0.87
2001	1.00	0.73	0.76	0.04	0.80	1.00	0.88	0.96	0.74	0.80
2002	1.00	0.62	0.92	0.15	0.50	1.00	0.62	0.92	0.15	0.50
Annual average	**0.93**	**0.82**	**0.80**	**0.41**	**0.69**	**0.99**	**0.94**	**0.97**	**0.80**	**0.92**

TABLE 5.7

Observed and full utilization fishing and searching days required to produce the capacity output in the Atlantic Ocean purse-seine fishery

Year	Number of vessels	Observed Levels		Full-utilization levels	
		Fishing days	Searching days	Fishing days	Searching days
1991	71	15 633	13 709	17 454	15 886
1992	65	17 454	15 886	17 454	15 886
1993	64	16 425	14 674	17 216	15 665
1994	59	15 904	14 231	16 023	14 559
1995	55	14 786	13 086	15 069	13 674
1996	54	14 671	13 116	14 831	13 453
1997	52	12 781	11 551	14 354	13 011
1998	44	12 585	11 215	12 585	11 242
1999	41	11 731	10 578	11 731	10 578
2000	41	10 576	9 394	11 731	10 578
2001	44	11 344	10 121	12 585	11 242
2002	41	9 823	8 816	11 731	10 578
Annual average	**53**	**13 643**	**12 198**	**14 397**	**13 029**

and searching days, which implies that producing the capacity output would require an increase in fishing and searching days. The CU values were quite low for other species and albacore, which is the likely reason why the observed number of fishing and searching days were not equivalent to the levels required to produce the capacity output.

In addition to improved efficiency in operations, the average annual capacity output for the fleet could be realized with only a very modest increase in fishing and searching days (Table 5.7). The analysis suggests that fishing days should be increased by a meagre 5.5 percent to realize the capacity output, and the number of days spent searching by the fleet should be increased by only 6.8 percent.

5.2.3 The Indian Ocean fishery

In the Indian Ocean fishery, a vessel had, on average, the capability to harvest an additional 504 tonnes of skipjack and 616 tonnes of yellowfin per year (Table 5.8), both of which are considerably greater than the levels of excess capacity for these two species in the Atlantic Ocean fishery. The total average annual excess capacity per vessel for 1981-2002 was 1 327 tonnes. Vessels could realize the capacity output mostly by operating efficiently and making small increases in their fishing and searching days (the average annual numbers of fishing and searching days per vessel for the Indian

TABLE 5.8

Excess capacity and full-utilization levels of variable inputs per vessel in the Indian Ocean purse-seine fishery

Year	Number of vessels	Observed levels		Full-utilization levels		Excess capacity (tonnes)					
		Fishing days	Searching days	Fishing days	Searching days	YFT	SKJ	BET	ALB	Others	Total
1981	2	42	0	42	0	0	0	NA	0	NA	0
1982	4	64	55	117	90	574	484	80	0	0	1 138
1983	12	122	95	122	95	0	0	68	0	0	68
1984	47	171	138	233	185	768	891	191	29	0	1 879
1985	48	207	173	242	193	860	870	181	32	0	1 943
1986	35	246	197	246	197	114	150	0	38	0	303
1987	35	236	185	236	188	324	373	0	49	0	746
1988	40	228	181	243	202	0	490	57	56	0	603
1989	44	247	205	247	205	917	0	185	64	0	1 166
1990	46	231	193	249	207	658	893	219	63	0	1 832
1991	39	250	205	251	208	464	592	141	17	69	1 284
1992	39	255	209	269	224	585	627	317	0	0	1 529
1993	42	265	222	282	238	507	734	285	53	0	1 578
1994	42	263	220	282	238	607	35	244	22	85	993
1995	42	282	238	282	238	0	129	26	54	0	209
1996	47	263	224	282	238	561	1 050	152	51	65	1 879
1997	58	257	223	282	238	940	2 011	154	50	101	3 255
1998	53	276	239	282	238	1 272	1 513	199	58	0	3 041
1999	52	257	219	282	238	644	835	0	73	87	1 638
2000	50	253	213	282	238	340	817	174	60	51	1 443
2001	50	258	220	282	238	666	1 060	295	59	95	2 175
2002	49	263	221	282	238	298	0	135	69	0	501
Annual average	**40**	**224**	**185**	**242**	**199**	**504**	**616**	**141**	**41**	**25**	**1 327**

TABLE 5.9

Capacity utilization in terms of ratio of observed and technically-efficient output levels to capacity output levels in the Indian Ocean purse-seine fishery

Year	Capacity utilization—Observed/Report output					Capacity utilization—Technically-efficient output				
	YFT	SKJ	BET	ALB	Others	YFT	SKJ	BET	ALB	Others
1981	1.00	1.00	1.00	NA	NA	1.00	1.00	1.00	NA	NA
1982	0.31	0.35	0.02	NA	NA	0.51	0.68	0.91	NA	NA
1983	1.00	1.00	0.21	NA	NA	1.00	1.00	1.00	NA	NA
1984	0.61	0.50	0.28	0.29	NA	0.97	0.98	0.99	1.00	NA
1985	0.61	0.57	0.41	0.32	NA	1.00	1.00	1.00	1.00	NA
1986	0.94	0.92	1.00	0.12	NA	1.00	1.00	1.00	1.00	NA
1987	0.87	0.84	1.00	0.12	NA	1.00	1.00	1.00	1.00	NA
1988	1.00	0.81	0.86	0.11	NA	1.00	0.99	1.00	1.00	NA
1989	0.68	1.00	0.55	0.00	NA	1.00	1.00	1.00	1.00	NA
1990	0.77	0.68	0.51	0.10	NA	0.99	0.99	1.00	1.00	NA
1991	0.84	0.80	0.70	0.78	0.01	1.00	1.00	1.00	1.00	1.00
1992	0.80	0.81	0.40	1.00	NA	0.99	1.00	1.00	1.00	NA
1993	0.83	0.79	0.51	0.37	NA	0.99	1.00	1.00	1.00	NA
1994	0.79	0.99	0.57	0.73	0.00	0.98	1.00	1.00	1.00	1.00
1995	1.00	0.96	0.95	0.36	NA	1.00	1.00	1.00	1.00	NA
1996	0.81	0.72	0.75	0.39	0.30	0.98	1.00	1.00	1.00	1.00
1997	0.68	0.51	0.77	0.40	0.03	0.98	1.00	1.00	1.00	1.00
1998	0.57	0.62	0.70	0.31	NA	1.00	1.00	1.00	1.00	NA
1999	0.78	0.80	1.00	0.12	0.16	0.98	1.00	1.00	1.00	1.00
2000	0.88	0.81	0.75	0.28	0.52	0.97	0.98	0.98	0.99	0.98
2001	0.77	0.75	0.57	0.29	0.10	0.98	1.00	1.00	1.00	1.00
2002	0.90	1.00	0.80	0.17	1.00	0.98	1.00	1.00	1.00	1.00
Annual average	**0.79**	**0.78**	**0.65**	**0.28**	**0.10**	**0.97**	**0.98**	**0.99**	**1.00**	**1.00**

TABLE 5.10

Observed and full-utilization fishing and searching days required to produce the capacity output in the Indian Ocean purse-seine fishery

Year	Number of vessels	Observed levels		Full-utilization levels	
		Fishing days	Searching days	Fishing days	Searching days
1981	2	84	0	84	0
1982	4	256	221	469	359
1983	12	1 461	1 142	1 461	1 142
1984	47	8 041	6 502	10 951	8 700
1985	48	9 929	8 302	11 636	9 287
1986	35	8 597	6 907	8 597	6 907
1987	35	8 246	6 484	8 246	6 568
1988	40	9 135	7 244	9 734	8 072
1989	44	10 880	9 030	10 880	9 030
1990	46	10 628	8 880	11 451	9 522
1991	39	9 767	7 985	9 795	8 127
1992	39	9 944	8 162	10 499	8 755
1993	42	11 109	9 342	11 848	10 004
1994	42	11 061	9 228	11 848	10 004
1995	42	11 848	10 004	11 848	10 004
1996	47	12 380	10 510	13 259	11 195
1997	58	14 883	12 930	16 362	13 815
1998	53	14 648	12 667	14 951	12 624
1999	52	13 339	11 363	14 669	12 386
2000	50	12 635	10 657	14 105	11 910
2001	50	12 911	10 978	14 105	11 910
2002	49	12 864	10 851	13 823	11 671
Annual average	**40**	**9 757**	**8 154**	**10 483**	**8 727**

Ocean fleet for 1981-2002 were, respectively, 224 and 185 days; the average annual level of fishing and searching days per vessel required to produce the capacity output were, respectively, 242 and 199 days). In general, the Indian Ocean purse-seine fleet could realize capacity output mostly by improving its efficiency (Table 5.9). The measure of CU adjusted for TE is quite close to one for most species and years, which indicates that gains in output could come mostly from operating more efficiently. The Kruskal-Wallis test was again conducted to determine the equality of observed and full-utilization levels of fishing and search days in the Indian Ocean fishery; results of the test could not reject the equality of reported and full utilization fishing and searching days. In other words, based on the non-parametric analysis, we conclude that the number of fishing and searching days required to produce the capacity output is equal to the reported or actual number of fishing and searching days. The exception is 1982, when the CU values were extremely low for yellowfin (0.51) and skipjack (0.68). The number of fishing and searching days would have had to increase 83.2 and 62.4 percent, respectively. Alternatively, we conclude that the capacity output could be realized mostly by improvements in TE only. In contrast to the Atlantic Ocean fishery, the CU values were quite high for other species and albacore.

Although results from the Kruskal-Wallis test suggest that realizing the capacity output requires only improvements in TE, there is still the possibility that gains could be realized by very small increases in fishing and searching days (Table 5.10). The analyses suggest that fishing days should be increased by a meagre 7.4 percent to realize the capacity output, and the number of days spent searching by the fleet should be increased by only 7.0 percent.

5.3 Summary and conclusions

Overall, it appears that there is excess capacity in the Atlantic and Indian Ocean purse-seine fisheries for tuna. The more serious level of excess capacity exists for the Indian Ocean fishery. It was determined that, on an annual basis, there was approximately 61 000 tonnes of excess capacity in the Indian Ocean fishery. In comparison, the Atlantic Ocean fishery had approximately 29 500 tonnes of excess harvesting capacity.

FIGURE 6.1
Skipjack in the global purse-seine fishery-Excess fishing capacity

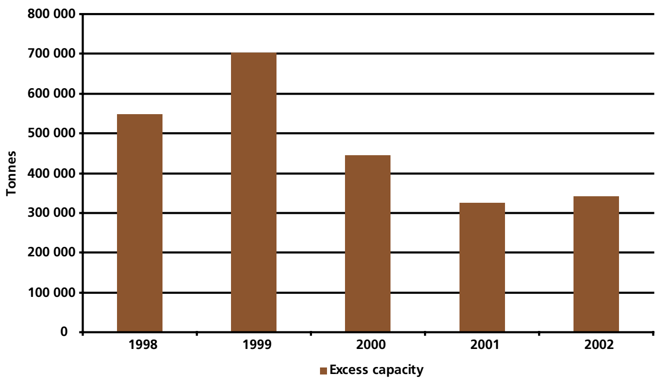


FIGURE 6.2
Skipjack in the global purse-seine fishery-Observed catch, fishing capacity and fishing capacity purged for technical efficiency

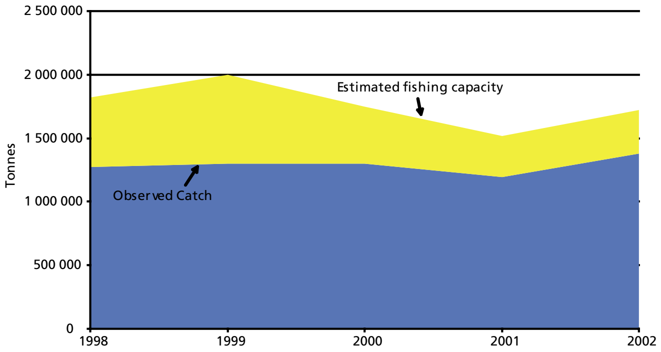
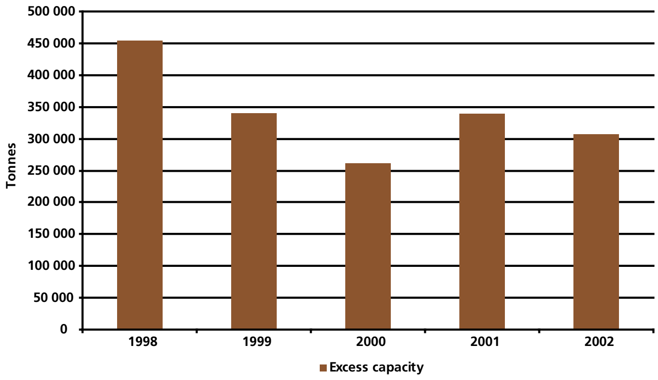


FIGURE 6.3
Yellowfin and bigeye combined in the global purse-seine fishery-Excess fishing capacity



Alternatively, if Indian and Atlantic Ocean vessels operated efficiency, fully utilized their variable inputs and harvested the average annual reported level of landings, fleet sizes could be reduced, respectively, from 40 to 31 (22.5 percent) in the Indian Ocean fishery and from 53 to 46 (13.2 percent) in the Atlantic Ocean fishery.

We stress that the estimates presented in this paper are extreme lower-bound estimates of capacity. The limited number of observations and inadequate information for considering different modes and nations' fishing activities limits the estimation of the frontier or piece-wise technology. Alternatively, if there are few observations for estimating the frontier, DEA will tend to recognize each firm as being technically efficient and operating at full capacity. In this case, the observed or reported output will equal the technically-efficient output level and the capacity output level.

6. GLOBAL TUNA PURSE-SEINE FISHING CAPACITY

The analyses presented in this paper provide estimates of fishing capacity for the tuna purse-seine fisheries of the EPO, WCPO, Atlantic Ocean and Indian Ocean.

Estimated total purse-seine catch, fishing capacity and excess capacity in the four regional fisheries for skipjack and for yellowfin and bigeye combined are provided in Figures 6.1-6.4 and Table 6.1. In examining these figures, it should be borne in mind that different analyses were applied in different regions due to data considerations and the fact that the estimates for the Indian and Atlantic Oceans are extreme lower-bound estimates of capacity. From the estimated global purse-seine fishing capacity for skipjack it appears that fishing capacity peaked in 1999, declined in 2000 and 2001 and then returned to 2000 levels in 2002. Excess capacity followed a similar pattern, with a significant increase in 1999, followed by declines in 2000 and 2001 of more than 50 percent and then a small increase in 2002.

TABLE 6.1

Observed global purse-seine catch and estimated purse-seine fishing capacity by ocean area

	1998	1999	2000	2001	2002
Eastern Pacific Ocean					
Skipjack					
Observed catch	139 229	256 957	197 612	134 017	155 628
Fishing capacity	292 501	404 862	279 079	206 843	225 979
Excess capacity	**153 272 (110)**	**147 905 (58)**	**81 467 (41)**	**72 826 (54)**	**70 351 (45)**
Yellowfin and bigeye					
Observed catch	300 536	327 989	346 046	405 707	428 063
Fishing capacity	589 973	497 798	498 587	635 498	670 269
Excess capacity	**289 437 (96)**	**169 809 (52)**	**152 541 (44)**	**229 791 (57)**	**242 206 (57)**
Western and Central Pacific Ocean					
Skipjack					
Observed catch	947 149	794 606	869 547	842 287	962 233
Fishing capacity	1 285 674	1 328 337	1 185 505	1 037 121	1 226 691
Excess capacity	**338 525 (36)**	**533 731 (67)**	**315 958 (36)**	**194 834 (23)**	**264 458 (27)**
Yellowfin and bigeye					
Observed catch	291 240	258 642	241 314	262 725	197 871
Fishing capacity	359 879	385 844	306 977	320 610	239 510
Excess capacity	**68 639 (24)**	**127 202 (49)**	**65 663 (27)**	**57 885 (22)**	**41 639 (21)**
Atlantic Ocean					
Skipjack					
Observed catch	56 438	76 852	64 625	60 891	47 900
Fishing capacity	83 116	76 852	76 852	83 116	76 852
Excess capacity	**26 678 (47)**	**0 (0)**	**12 227 (19)**	**22 225 (36)**	**28 952 (60)**
Yellowfin and bigeye					
Observed catch	85 960	73 834	77 799	91 099	88 324
Fishing capacity	95 448	89 639	89 639	95 448	89 639
Excess capacity	**9 488 (11)**	**15 805 (21)**	**11 840 (15)**	**4 349 (5)**	**1 315 (1)**
Indian Ocean					
Skipjack					
Observed catch	132 073	168 950	170 793	156 929	212 173
Fishing capacity	212 248	212 369	211 624	209 919	212 173
Excess capacity	**80 175 (61)**	**43 419 (26)**	**40 831 (24)**	**52 990 (34)**	**0 (0)**
Yellowfin and bigeye					
Observed catch	114 138	155 766	156 236	133 921	157 130
Fishing capacity	192 091	189 232	181 955	181 955	178 315
Excess capacity	**77 953 (68)**	**33 466 (21)**	**25 719 (16)**	**48 034 (36)**	**21 185 (13)**
All Oceans					
Skipjack					
Observed catch	1 274 889	1 297 365	1 302 577	1 194 124	1 377 934
Fishing capacity	1 873 539	2 022 420	1 753 060	1 536 999	1 741 695
Excess capacity	**598 650 (47)**	**725 055 (56)**	**450 483 (35)**	**342 875 (29)**	**363 761 (26)**
Yellowfin and bigeye					
Observed catch	791 874	816 231	821 395	893 452	871 388
Fishing capacity	1 237 391	1 162 513	1 077 158	1 233 511	1 177 733
Excess capacity	**445 517 (56)**	**346 282 (42)**	**255 763 (31)**	**340 059 (38)**	**306 345 (35)**

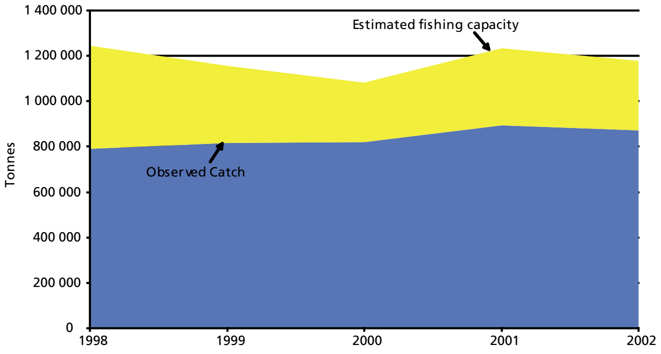
Note: Figures in brackets provide excess capacity as a percentage of observed catch.

Excess capacity, as a percentage of the catch, also peaked in 1999, and from then until 2002 it was in continuous decline.

It appears that global purse-seine fishing capacity for yellowfin and bigeye was on a downward trend between 1998 and 2000, even though observed catch levels were slowly increasing. In 2001 global purse-seine fishing capacity for yellowfin and bigeye, returned to 1998 levels and then declined again in 2002. Excess fishing capacity decreased by more than 40 percent between 1998 and 2000, and its level in 2001 was similar to that in 1999. In 2002 excess capacity was less than in 1998, 1999 and 2001, but greater than in 2000.

FIGURE 6.4

Yellowfin and bigeye in the global purse-seine fishery-Observed catch, fishing capacity and fishing capacity purged for technical efficiency



As stated previously, excess fishing capacity is a result of both technical inefficiency (or skipper skill) and under-utilisation of variable inputs. In other words, the catches can be increased either through an increase in the efficiency of purse-seine vessels or through an increase in the utilisation of variable inputs, such as increases in the numbers of days spent fishing and searching. In the analysis of the EPO and WCPO purse-seine fisheries, fishing capacity, purged for TE, was also estimated. In other words, it was assumed that TE (or skipper skill) remained constant and that fishing capacity could be increased only by increasing the levels of variable inputs employed. In both analyses under this assumption, there was a significant reduction in the estimated level of fishing capacity. For the EPO the estimated average excess capacity level, purged for TE, measured against observed catches for skipjack and for yellowfin and bigeye combined during 1998-2002 were around half the levels of the estimated excess capacity measured against observed catches. For the WCPO, average excess capacity level, purged for TE, measured against observed catches for skipjack and for yellowfin and bigeye combined during 1998-2002 were around 60 percent less than the levels of the estimated excess capacity measured against observed catches. These results indicate that increases in TE (or increases in skipper skill) of inefficient vessels are required if capacity output levels are to be fully achieved.

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