

Estimates of large-scale purse-seine and longline fishing capacity in the western and central Pacific Ocean based on stock assessments of target species

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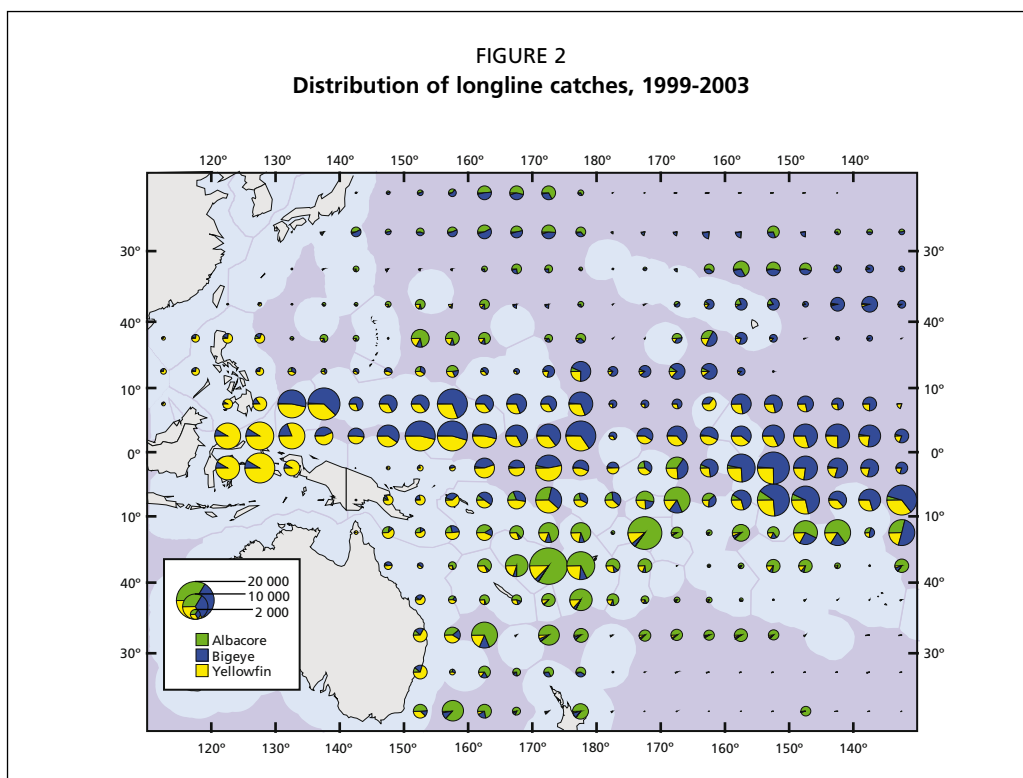
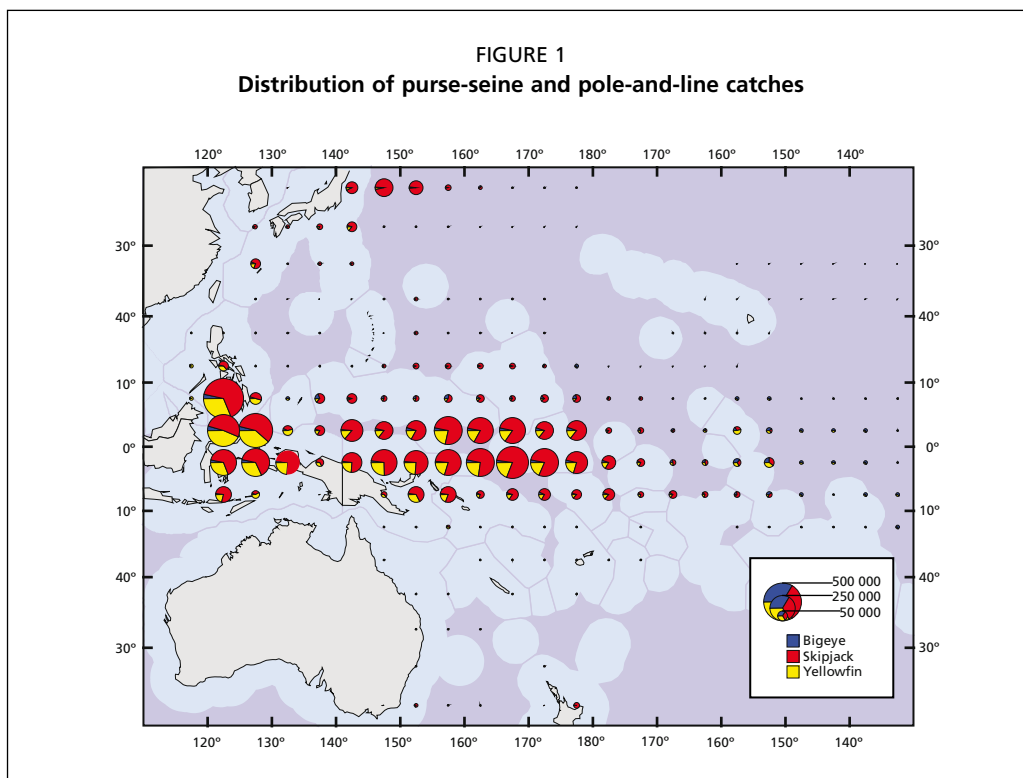
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ABSTRACT

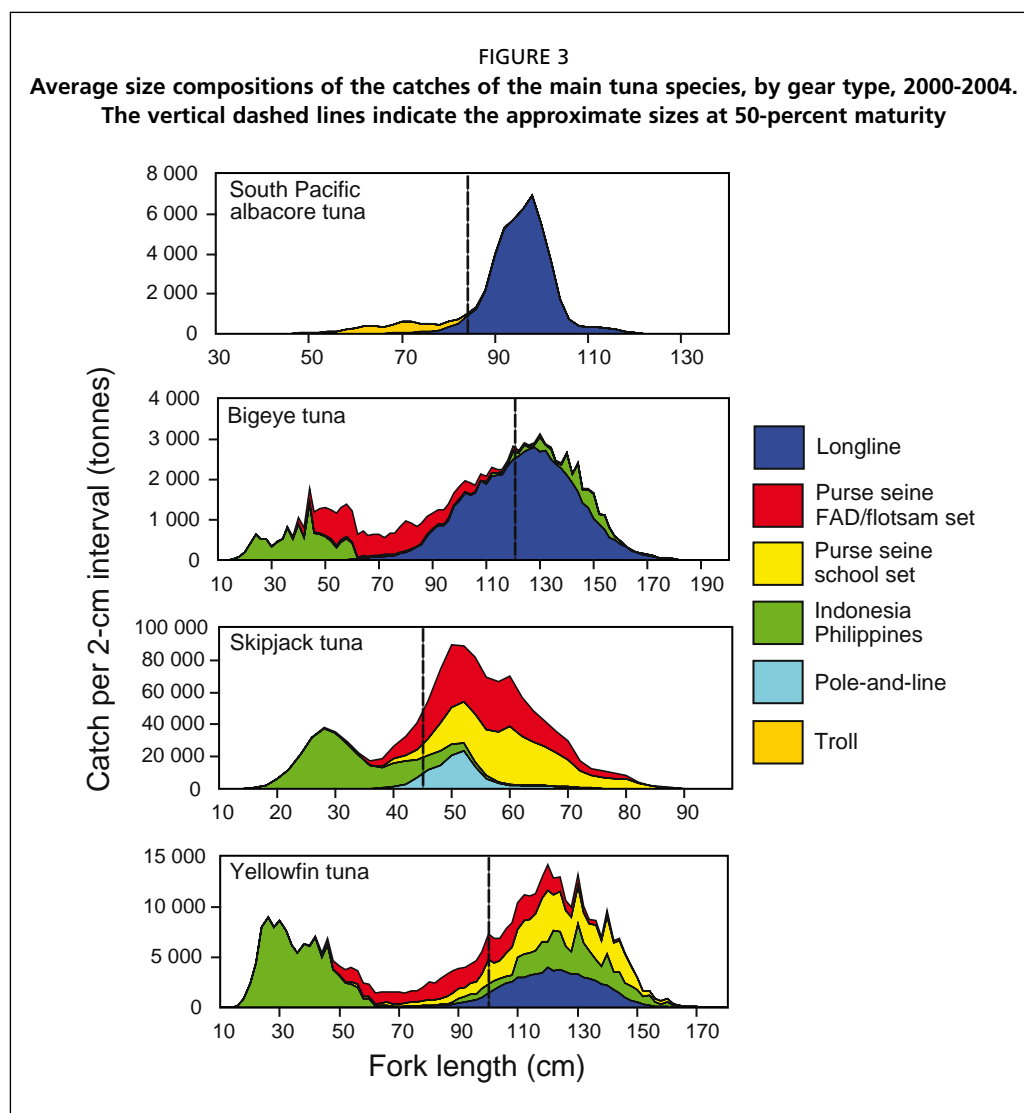
Tunas are exploited chiefly by purse-seine, longline and pole-and-line gear in the western and central Pacific Ocean. While it is relatively simple to specify capacity limits consistent with the stock status of the various species, there would be a number of difficulties in applying such an approach in practice. First, the multi-species nature of the purse-seine and longline fisheries and the differential stock status of the main species make it difficult, if not impossible, for single, gear-specific capacity limits, or, indeed, other broadly-specified effort-based measures, to equally address the stock status of all species simultaneously. Second, the problem of “effort creep” is significant for capacity and other effort-based management systems. If such measures are employed, it is essential that limits are regularly reviewed and, if necessary, adjusted downwards to counter “effort creep”. Third, the specification of capacity limits involves, either explicitly or implicitly, an allocation of those limits. Typically, this allocation is based on the current or recent average fishery composition. However, it is shown that altering the mix of gear types, and hence altering the overall size selectivity of the fishery, can have very different outcomes for stock status and productivity. Therefore, appropriate levels of fishing capacity in one component of the fishery will depend on the capacity in other components.

1. INTRODUCTION

The tuna fishery in the western and central Pacific Ocean (WCPO) is the largest of the world’s regional tuna fisheries, with recent annual catches of the main target species (skipjack (*Katsuwonus pelamis*), yellowfin (*Thunnus albacares*), bigeye (*T. obesus*) and albacore (*T. alalunga*) tuna) approaching 2 million tonnes (Appendix 1). The fishery is complex, employing multiple types of fishing gear that, in many cases, harvest the different species at different stages of their lives. The main fishing methods are longline, pole-and-line, purse seine and a variety of other types of net and hook-and-line gear. The fishery began in the 1950s, primarily as a longline fishery targeting larger albacore, bigeye and yellowfin tuna and a pole-and-line fishery targeting skipjack and albacore tuna in the western North Pacific. In the 1980s, purse seining, targeting skipjack and yellowfin tuna, began to outstrip longline and pole-and-line as the major gear type. Purse seiners also take a small, but significant, bycatch of bigeye tuna in the WCPO. Currently, purse-seine gear is responsible for approximately 60 percent of the total catch of all tunas and 75 percent of the catch of skipjack tuna in the WCPO. The catch



of tunas by purse seiners in recent years has consisted of about 68 percent skipjack tuna, 21 percent yellowfin tuna, 6 percent bigeye tuna and 6 percent albacore tuna. The purse-seine catch is concentrated in tropical waters (Figure 1). The longline catches of bigeye and yellowfin tuna occur mostly in tropical waters, and those of albacore tuna mostly in subtropical and temperate waters (Figure 2). A significant concentration of the catch by purse seines and a variety of net and hook-and-line gear types occurs in



the waters of Indonesia and Philippines (Figure 1). Much of the tropical fishery occurs in the exclusive economic zones (EEZs) of Pacific Island and Southeast Asian countries and territories.

The size compositions of the catches are strongly influenced by the fishing methods used (Figure 3). The smallest skipjack, yellowfin and bigeye tuna are taken by the domestic fisheries operating in Indonesia and the Philippines. The purse-seine fishery takes mainly adult skipjack tuna greater than 40 cm in length (from the tip of the snout to the fork of the tail; FL), juvenile (<100 cm FL) yellowfin, mainly in sets on fish-aggregating devices (FADs) and on flotsam, and adult yellowfin, mainly in sets on free-swimming schools (henceforth called “school sets”). The bigeye tuna captured by purse seiners are mostly juvenile fish (<120 cm FL) taken in FAD/flotsam sets. Longlines capture adult bigeye, yellowfin and South Pacific albacore tuna, and capture greater amounts of bigeye than any other gear. The FAD-based handline fishery in the Philippines and adjacent areas captures adult yellowfin and bigeye tuna similar in size to those caught by longlines.

The establishment of the Western and Central Pacific Fisheries Commission (WCPFC) in 2004 marks the beginning of formal international management of the fisheries in that region. Management measures must be adopted to address stock status issues (see Section 2), while also promoting sustainable utilization of the stocks and the pelagic ecosystem of which they are part. Initial management measures have included

a combination of fishing effort (days fished and days searched by purse seiners), catch (longline catches of bigeye) and fishing capacity (numbers of longline vessels fishing for albacore). In this paper, we attempt to estimate capacity limits (in terms of vessel numbers) that would be consistent with the 2005 stock assessments, focusing on the purse-seine and longline components of the fishery, and discuss various issues associated with the application of such measures.

2. STOCK ASSESSMENTS IN THE WCPO

Stock assessments of tunas in the WCPO are conducted, using MULTIFAN-CL, a statistical, length-based age-structured model. Most assessments incorporate spatial structure and multiple fisheries based on gear type (e.g. purse seine, longline), fishing method (e.g. purse seine FAD/flotsam and school sets) and region. Fisheries may have unique or shared characteristics of selectivity and catchability. A feature of the assessments is that catchability may be allowed to vary over time if that is considered appropriate.

Assessments are undertaken routinely for skipjack (Langley *et al.* 2005), yellowfin (Hampton *et al.* 2005a), bigeye (Hampton *et al.* 2005b) and South Pacific albacore tuna (Langley and Hampton 2005). Assessments of stock status are made using two principal biological reference points. The current (usually defined as an average over the most recent three years of the assessment, but excluding the last year) level of age-specific fishing mortality is compared with that estimated to produce the maximum sustainable yield (MSY), and the current biomass is compared to the equilibrium biomass at MSY. If $F_{current}/F_{MSY}$, overfishing is said to be occurring; if $B_{current}/B_{MSY}$ the stock is said to be in an overfished state.

Based on the 2005 assessments, overfishing was estimated to be occurring for yellowfin and bigeye tuna but not for skipjack or South Pacific albacore tuna (Table 1). None of the stocks was estimated to be in an overfished state.

TABLE 1
Biological reference points for the main tuna stocks of the WCPO, based on the 2005 base-case assessments

Stock	$F_{current}/F_{MSY}$	$B_{current}/B_{MSY}$
Skipjack	0.17	3.01
Yellowfin	1.22	1.32
Bigeye	1.23	1.25
South Pacific albacore	0.05	1.69

"Current" refers to the 2001-2003 period.

3. CAPACITY TARGETS CONSISTENT WITH STOCK ASSESSMENTS

Management measures are required to limit fishing mortality. It is theoretically possible, given suitable information on current levels of fishing capacity, to use the information from the stock assessments to derive appropriate levels of capacity for the major fleet categories fishing in the WCPO. In the following sections, we outline the various issues relating to the determination and application of capacity limits in the purse-seine, longline and other fisheries operating in the WCPO. We also look at the issue of fishery interaction and allocation, and how this may impact the estimation of capacity limits.

3.1 Purse-seine fishery

A possible methodology for relating stock assessment results to capacity limits in a simple sing-species fishery would be as follows:

- Assuming that fishing mortality is proportional to fishing effort, determine the level of fishing effort consistent with a target reference point. For example, if F_{MSY} is a target reference point, an appropriate level of effort would be

$$E_{MSY} = E_{current} \div (F_{current}/F_{MSY}) \quad (1)$$

where E = effort.

- A capacity limit consistent with E_{MSY} could then be determined, for example using an empirical relationship between fishing effort and fishing capacity. The relationship between WCPO purse-seine vessel numbers (capacity) and vessel days fishing and searching (effort) is shown in Figure 4.

In the case of the WCPO purse-seine fishery, there are several difficulties with such a simplistic approach. First, the fishery targets principally skipjack tuna, for which, according to the stock assessment, fishing mortality (and corresponding effort, capacity and catches) could be greatly increased. For example, the current (2001–2003 average) level of fishing effort of 40 949 days (equivalent to approximately 192 vessels based on the average days fished per vessel per year during 1992–2004 of 213 days) could be expanded six-fold by applying equation (1) to the skipjack stock status estimate. However, yellowfin tuna, which is a secondary target species, and bigeye tuna, which is essentially a bycatch species, are both currently being overfished (Table 1, Column 2). In the absence of any additional measures to mitigate fishing mortality of those species, an increase in fishing effort or capacity designed to increase the catch of skipjack tuna would result in further overfishing of yellowfin and bigeye tuna. On the other hand, if the simplistic procedure described above were applied using yellowfin and bigeye tuna stock status estimates, fishing effort and capacity would have to be reduced on the order of 20 percent (to 33 291 days and 156 vessels) to be consistent with F_{MSY} reference points for those species. Such a measure would be expected to slightly increase long-term average catches of yellowfin and bigeye tuna (according to the equilibrium yield model). However, it would be expected to reduce the average catch of skipjack tuna by approximately 20 percent because the skipjack yield-effort relationship is approximately linear at current levels of exploitation (Langley *et al.* 2005). Because skipjack tuna comprises the majority of the purse-seine catch (exceeding 1 million tonnes in 2004, Appendix 1), a reduction in fishing effort and catch of this magnitude would have significant economic ramifications, and therefore such an option is not politically acceptable.

A second difficulty is that a limit on the number of purse-seine vessels would not necessarily limit fishing effort, and therefore fishing mortality. The average number of days fished per vessel per year has tended to increase over time in the WCPO purse-seine fishery (Figure 4), fluctuating between about 180 and 230 days per vessel per year since 1992. The entry of larger vessels with greater carrying capacities into the fishery, more vessels being based in coastal states close to the fishing grounds, more modern unloading facilities, more options to select unloading ports and the use of at-sea transshipment and tendering could all allow vessels to spend more time per year fishing. At current levels of annual fishing effort per vessel, there would appear to be considerable potential to increase fishing effort even if the number of vessels was limited at the current level. If capacity limits were based on carrying capacity, rather than on vessel numbers, the capability to increase fishing effort would be somewhat more constrained.

A third difficulty is that even if fishing effort were constrained by capacity limitation, fishing mortality may still be increased by increased catchability (fishing mortality per unit of effort). Increased catchability might result from the adoption of new technology

FIGURE 4
Purse-seine effort (days fished and searched), numbers of vessels (Lawson 2005) and average days fished and searched per vessel

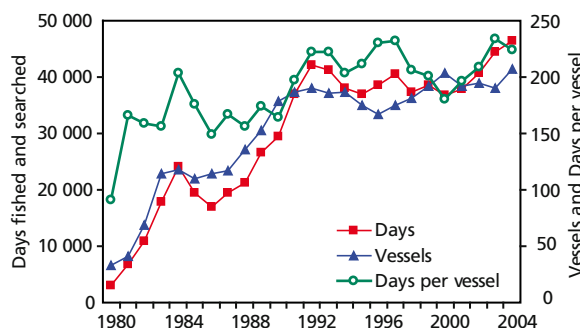


FIGURE 5
Estimated purse-seine fishing mortalities (F) and fishing mortalities per unit effort (catchability) for skipjack, yellowfin and bigeye tuna

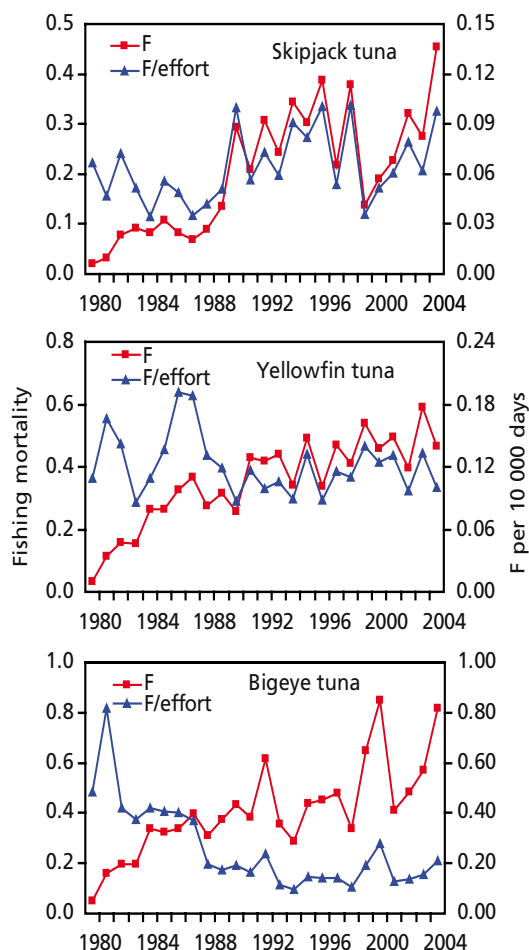
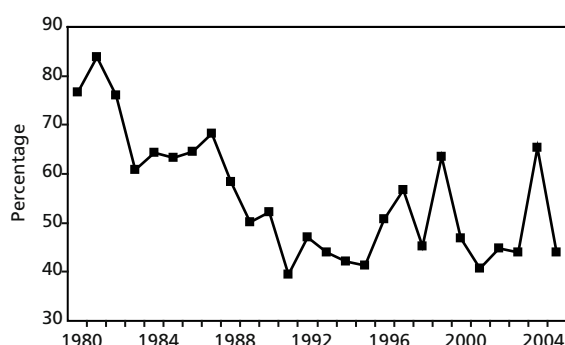


FIGURE 6
Percentages of FAD/flotsam sets in the total annual purse-seine sets in the fishery of the WCPO



that assists in the location and capture of tuna schools, such as the use of drifting or anchored FADs. Fishing mortality for the three species has increased over the past 25 years but catchability has shown less consistent variability (Figure 5).

For skipjack, catchability by purse seine is estimated to have increased in the late 1980s, decreased in the late 1990s and increased since that time. For yellowfin, catchability has been more stable over time, while for bigeye catchability is estimated to have decreased to the mid-1990s after which it tended to increase. Some of the variability in catchability is, no doubt, related to environmental variation. However, other changes are due to changes in the operational characteristics of the purse-seine fleet, in particular in relation to set type. For bigeye, set type is known to have a particularly profound effect on catchability and fishing mortality of bigeye tuna. The only significant purse-seine catches of bigeye tuna occur in FAD and flotsam sets, with only small catches occurring in school sets (Figure 3). In the early 1980s, the purse-seine fishery was highly dependent on FAD/flotsam sets (Figure 6).

With the arrival of United States vessels in the WCPO, the set-type profile of the fleet shifted more towards school sets, and by the early 1990s more than half of the total purse-seine sets were school sets. Since that time, the proportion of FAD/flotsam sets in any given year has varied from 40 percent to 65 percent of the total sets (Figure 6). The resurgence in FAD/flotsam sets in the past decade is due largely to the deployment of drifting FADs by purse-seine vessels. Drifting FADs may be located electronically, and in some cases may also transmit information on the size of tuna aggregations to assist vessel operators in FAD selection. These changes in the set-type characteristics of the fleet, and the use of high-technology FADs in particular, have been a major

factor influencing catchability and fishing mortality of juvenile bigeye tuna (Figure 5). In this case, it is clear that simple capacity limits, or even limits on fishing effort, will not necessarily control fishing mortality effectively. The number of FAD/flotsam sets,

rather than total purse-seine effort or capacity, will be the major factor influencing fishing mortality of bigeye tuna.

To summarize, there are three key difficulties that would need to be addressed in determining and applying purse-seine fishing capacity limits as a means of limiting fishing mortality:

- Capacity limits would not be able to recognise the differential stock status of skipjack tuna compared to yellowfin and bigeye tuna.
- Capacity limits may not limit fishing effort because of the potential of the fleet to increase the amount of fishing effort per vessel.
- Capacity limits may not limit fishing mortality because of increases in catchability over time.

The second and third issues above fall broadly into the category of “effort creep”. These might be dealt with through continual (downwards) adjustment of fishing capacity if annual assessments indicate increased fishing mortality per capacity unit. However, capacity limitation, or indeed fishing effort limitation alone, will not be able to deal with the issue of the multi-species nature of the fishery and differential stock status. Species-specific catch limitation or effort controls targeting FAD/flotsam sets would appear to be the only means of effectively dealing with this issue.

3.2 LONGLINE FISHERY

The longline fishery in the WCPO may be classified into two major groups: 1) large-scale vessels (typically greater than 24 m in overall length and equipped with superfreezing facilities, which makes their catches acceptable to the lucrative sashimi market) operating throughout the WCPO and targeting bigeye, yellowfin and, to a lesser extent, albacore tuna; and 2) vessels, commonly called offshore longliners (usually less than 24 m in overall length and without superfreezing capability) operating within restricted ranges of local fishing bases and targeting bigeye, yellowfin, albacore and, in some areas, broadbill swordfish (*Xiphias gladius*). (It should be noted, however, that in recent years the numbers of longliners less than 24 m in overall length have increased, and some of these are equipped with superfreezing facilities (Miyake 2007).) The large-scale longline fleet consists mainly of vessels from Japan, the Republic of Korea, the Taiwan Province of China and, more recently, the Peoples Republic of China. Offshore fleets are either flagged by the coastal states in which they are based or are foreign fleets originating in Japan, the Taiwan Province of China or the Peoples Republic of China but based in other coastal states under charter or other business relationships.

The species-targeting characteristics of these fleets are complex (Figure 2). In the equatorial WCPO (10°N–10°S), both large-scale and offshore longliners target primarily bigeye tuna, but also take significant catches of yellowfin tuna. At higher latitudes, catches of albacore tuna tend to dominate, although catches of other tunas, swordfish and striped marlin (*Tetrapturus audax*) may also be locally important. Most of the vessels operating in these areas are offshore longline vessels, although large-scale longliners may also operate there seasonally. The estimated numbers of longliners in each of these categories operating in 2001–2004 are shown in Table 2.

The methodology for estimating appropriate capacity limits outlined earlier for purse seiners could be applied to the longline fleets in Table 2. The large-scale and offshore equatorial longline fleets target primarily bigeye tuna, and therefore capacity

TABLE 2
Average estimated numbers of longline vessels operating in the WCPO during 2001–2004

Fleet	Equatorial	North Pacific	South Pacific	Total
Large-scale			788	788
Offshore	2,209	1,091	647	3,947

Source: Lawson (2005)

limits consistent with bigeye stock status would be the vessel numbers reported in Table 2 divided by 1.23, *i.e.* 640 large-scale and 1,796 offshore equatorial vessels.

The offshore fleet operating in the South Pacific targets primarily albacore. Biological reference points for South Pacific albacore indicate a lightly-exploited stock, mainly because longline gear targets the oldest age groups in the population (Langley 2006). While it is unlikely that fishing mortality on these age groups could be increased to the point that MSY-based reference points were threatened, the impact of the longline fishery on the longline-exploitable abundance of South Pacific albacore has been significant—an approximate 30 percent reduction from unexploited conditions in recent years (Langley and Hampton 2005). Estimates of appropriate levels of fishing capacity are needed, mainly on economic, rather than biological, grounds. Any large increases in vessel numbers would likely reduce the average catch-per-unit-of-effort of albacore and impact profits. While there may be potential for expanded fishing effort in some areas, a conservative overall fishing capacity target, in the vicinity of the current fleet size, is probably appropriate. It should also be noted that a component of the offshore fleet in the South Pacific targets other species, *e.g.* swordfish off eastern Australia and southern bluefin tuna off New Zealand. There may well be local issues associated with these fisheries that warrant a more cautious approach to management of fishing capacity.

Offshore longliners operating in the western North Pacific are a mixture of vessels of Japan and United States targeting bigeye, yellowfin, albacore, Pacific bluefin (*Thunnus orientalis*) and swordfish. The tuna-targeting and swordfish-targeting fleets are not identified in Table 2, but it would be possible to make this classification given access to complete catch statistics. If we take an approach consistent with that taken for the equatorial fleets, an appropriate limit for the tuna-targeting component of the western North Pacific offshore fleet would be the current fleet size divided by 1.23. A formal assessment of western North Pacific swordfish is yet to be undertaken, so it is not possible to nominate a capacity limit or target for the swordfish-targeting component of the fleet.

Some of the problems of using fishing capacity limits as a means of controlling fishing mortality identified for the purse-seine fleet are also issues for the longline fleets. The multi-species nature of the fishery and differences in stock status among species poses similar difficulties as for purse seiners. In this case, however, a main target species, bigeye tuna, is the species for which there are overfishing concerns. Yellowfin tuna, a secondary target species of all longline fleets, is also estimated to be subject to overfishing; however, the assessments indicate that the impact of longline catches on yellowfin tuna stock status is minimal. North Pacific albacore tuna is considered to be at least fully exploited, but, as noted above, MSY-based reference points indicate that South Pacific albacore tuna is lightly exploited. Unlike the purse-seine fishery, it is possible to identify components of the fishery for which differential measures might be applied. Separate capacity limits could be applied to equatorial large-scale and offshore longliners (targeting bigeye tuna), and to large-scale and offshore fleets targeting albacore and other species in the North Pacific and South Pacific, based on the areas of operation of those fleets. While this is certainly not a perfect means of identifying target species, it would allow capacity measures to at least approximately address the differential stock status of the species concerned.

If fishing capacity limits were used as a means of limiting fishing mortality of bigeye tuna, the issue of “effort creep” would have to be dealt with. As with purse-seine fishing, there have been developments in longline gear technology and deployment strategies that have improved the efficiency and productivity of the vessels, and it is likely that the catchability of target species has increased as a result. Therefore, it would be necessary to periodically revise capacity or other effort-based management measures in order to limit fishing mortality.

3.3 OTHER FISHERIES

Other significant fisheries in the WCPO include the domestic fisheries in the Philippines and Indonesia, the predominantly Japanese pole-and-line fishery targeting skipjack and North Pacific albacore tuna, and troll fisheries for North Pacific and South Pacific albacore tuna. At this time there is no compelling need for management measures for the pole-and-line fishery targeting skipjack tuna or the troll fishery targeting South Pacific albacore tuna. However, there is a case for limiting the capacity of the pole-and-line and troll fisheries targeting North Pacific albacore to approximately current levels due to the fully-exploited status of that stock (Stocker 2005).

The domestic fisheries in the Philippines and Indonesia record large catches of skipjack, yellowfin and bigeye tuna, consisting mostly of small juvenile fish (Figure 3). The impact of the catches of yellowfin and bigeye tuna on population biomass is substantial (Hampton *et al.* 2005a,b); therefore, management measures to control fishing mortality by these fleets would be necessary for effective stock-wide conservation. On the basis of the 2005 stock assessments, and applying across-the-board scaling of fishing mortality to achieve MSY-based reference points, fishing mortality (and fishing effort and fishing capacity) would have to be reduced in these fisheries on the order of 20 percent from the 2001-2003 average levels. However, it is not possible to nominate specific fishing capacity or effort targets, because of a lack of data on current and historical levels of fishing capacity and effort.

3.4 FISHERY INTERACTION CONSIDERATIONS

The design of fishery management measures for the tuna fisheries of the WCPO is complicated by the exploitation of the same stocks at different stages of their life histories in different regions by different fishing methods. Management measures should take into account the potential for interaction among the different components of the fishery, and, in particular, the fact that the appropriateness of a measure in any one fishery component depends on what measures are being applied simultaneously in other components.

In the examples so far given in this paper, we have simply applied a common scaling factor to current levels of fishing effort or capacity across fishery components to derive fishing effort and capacity limits that would be consistent with stock status estimates. In so doing, the current structure of the overall fishery, in terms of spatial distribution and relative levels of fishing by different size-selective gear types, has been maintained. Implicitly, this process allocates portions of the particular effort or capacity limit to fishery components based on their recent (2001-2003 in the case of the 2005 assessments) levels. This is a relatively simple and arguably objective way to proceed, but there may well be combinations of fishing levels across the different fishery components that would result in more favourable outcomes for both the stock and the fisheries overall. This can be illustrated in the cases of yellowfin and bigeye tuna. We have determined MSY , B_{MSY} and F/F_{MSY} for hypothetical fisheries comprising single components or combinations of components of the actual fishery (Table 3). MSY is estimated to be up to 90 percent greater for yellowfin tuna and up to 33 percent greater for bigeye tuna in situations in which the catch is composed mainly of larger fish (e.g. hypothetical fisheries 2, 4 and 6 in Table 3). Also, for these hypothetical fisheries, F/F_{MSY} at the current levels of effort would be considerably less than 1, so overfishing would not be occurring. In contrast, if the fishery were composed only of components targeting small fish (e.g. hypothetical fisheries 3 and 5 in Table 3), MSY and B_{MSY} would be reduced relative to the *status quo*.

These examples serve to illustrate that stock status reference points in complex fisheries are sensitive to the size composition of the catch, which in the case of the tuna fishery of the WCPO is determined mainly by the relative mix of different size-selective gear types. The implication for fishing capacity management is that the

TABLE 3
Comparisons of MSY , B_{MSY} and F/F_{MSY} for hypothetical fisheries consisting of one or more components

Hypothetical fishery	Yellowfin tuna			Bigeye tuna		
	MSY	B_{MSY}	F/F_{MSY}	MSY	B_{MSY}	F/F_{MSY}
1. All components as in 2001-2003	1.00	1.00	1.25	1.00	1.00	1.25
2. Longline, Philippines handline	1.91	1.12	0.08	1.33	1.03	0.32
3. Purse seine FAD/flotsam sets	0.88	0.71	0.12	0.40	0.63	0.24
4. Purse seine school sets	1.55	0.98	0.06			
5. Indonesia/Philippines small-fish gears	0.61	0.95	0.29	0.77	0.99	0.53
6. Longline, Philippines handline, purse-seine school sets	1.75	1.10	0.18	1.30	1.03	0.34

MSY and B_{MSY} are expressed relative to the values obtained for the full assessment, i.e. using the actual fishery composition for 2001-2003. F/F_{MSY} is the ratio of the fishing mortality in 2001-2003 for the component(s) specified to the F_{MSY} estimated for that (those) component(s) alone.

capacity limit for one gear type is dependent on the limits specified for other gear types. In the yellowfin and bigeye tuna examples, if effort (capacity) in the purse-seine FAD/flotsam component and/or the Indonesia/Philippines small-fish component is reduced, a greater amount of effort (capacity) in the longline component could be allowed, while maintaining the overall level of fishing mortality and biomass within MSY -based reference points.

4. DISCUSSION

This paper has outlined a relatively simple means of aligning fishing capacity limits to estimates of stock status of the main tuna stocks comprising the WCPO tuna fishery. However, several difficulties in applying such an approach to the WCPO tuna fishery have been identified.

The multi-species nature of the purse-seine and longline fisheries and the differential status of the principal stocks make it difficult, if not impossible, for single, gear-specific capacity limits, or indeed other broadly-specified effort-based measures, to address equally the status of all the stocks simultaneously. In the longline fishery, separate consideration of longline fleets targeting bigeye tuna in the equatorial WCPO and North and South Pacific albacore tuna at higher latitudes may be reasonably effective in dealing with this problem. In the purse-seine fishery, however, differential fishing mortality of juvenile yellowfin and bigeye tuna is strongly influenced by the number of FAD/flotsam sets. Traditional capacity-based measures, such as numbers or carrying capacities of vessels are non-specific with respect to set type, and therefore would not be effective in controlling fishing mortality of bigeye and yellowfin tuna without sacrificing a large amount of the catch of skipjack tuna. The current management measure put into place by the WCPFC limits purse-seine effort to specified numbers of days of fishing and searching by purse-seine vessels. This measure also is non-specific with respect to set type, and is not likely to be effective in the long term. Measures specific to FAD/flotsam sets, or catch-based measures specific to juvenile yellowfin and bigeye tuna, will ultimately be required to achieve the dual objectives of yellowfin and bigeye conservation and the desired level of skipjack exploitation.

The problem of “effort creep” is significant for capacity and other effort-based management systems. At given levels of capacity or fishing effort, fishing mortality may increase through increased catchability, usually associated with the adoption of new technology. An additional problem for capacity limitation by vessel numbers is the potential for vessels to increase their effort per unit time by a variety of means. This was one of the factors that prompted the Parties to the Nauru Agreement to move from a limit on vessel numbers to a limit on vessel days. (The Parties to the Nauru Agreement are the Federated States of Micronesia, Kiribati, the Marshall Islands,

Nauru, Palau, Papua New Guinea, the Solomon Islands and Tuvalu. Collectively, 75 percent of the purse-seine effort and catch occurs in their EEZs.) If capacity or other effort-based measures are employed, it is essential that limits are regularly reviewed and, if necessary, adjusted downwards to counter “effort creep”.

The WCPO tuna fisheries are complicated by multiple jurisdictions, multiple species and multiple size-selective gear types. For any given stock, MSY and associated biological reference points are sensitive to the composition of the fishery in terms of gear types (controlling overall size composition of the catch) in particular and in some cases to spatial and seasonal distributions of catch and effort. The implication of this is that the management measures in one component of the fishery will depend on measures applied to other components. Current stock assessments typically generate reference point estimates by scaling fishing mortality with the relative mix of gear types and the spatial and seasonal distributions of the fishery maintained at recent average levels. This procedure is implicitly allocating effort (or some other management variable) consistent with recent average conditions. Other allocations among gear types, areas and seasons will have different fishery outcomes and impacts on the stocks. Such alternatives might best be considered in the context of an explicit allocation procedure.

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APPENDIX 1
Estimated catches of the main species of tunas in the WCPO.

Year	Albacore tuna				Total
	Longline	Pole-and-line	Purse seine	Others	
1950	16 740	12 863	0	0	29 603
1951	11 408	14 500	0	0	25 908
1952	22 386	41 787	154	237	64 564
1953	23 627	32 921	38	132	56 718
1954	25 877	28 069	23	38	54 007
1955	21 188	24 236	8	136	45 568
1956	18 235	42 810	0	57	61 102
1957	24 117	49 500	83	151	73 851
1958	29 702	22 175	8	124	52 009
1959	26 635	14 252	0	67	40 954
1960	31 376	25 156	0	76	56 608
1961	32 599	18 639	7	268	51 513
1962	37 279	8 729	53	191	46 252
1963	26 370	26 420	59	218	53 067
1964	26 069	23 858	128	319	50 374
1965	28 342	41 491	11	121	69 965
1966	51 317	22 830	111	585	74 843
1967	57 903	30 481	89	525	88 998
1968	45 744	16 597	267	1 123	63 731
1969	37 909	32 148	480	935	71 472
1970	47 499	24 485	279	506	72 769
1971	44 286	53 451	1 751	308	99 796
1972	44 871	49 248	86	892	95 097
1973	59 707	62 026	262	1 018	123 013
1974	39 215	69 562	193	2 001	110 971
1975	30 926	48 032	153	1 040	80 151
1976	44 457	78 992	1 147	1 367	125 963
1977	48 488	35 385	611	1 664	86 148
1978	41 982	57 745	278	7 793	107 798
1979	36 189	45 611	131	4 796	86 727
1980	42 304	43 620	323	5 639	91 886
1981	47 109	26 235	246	13 117	86 707
1982	43 355	29 518	551	15 504	88 928
1983	36 271	19 997	224	7 986	64 478
1984	30 806	26 340	3 422	14 377	74 945
1985	37 880	21 346	1 538	17 275	78 039
1986	41 702	14 179	1 619	13 114	70 614
1987	33 340	19 274	1 445	13 248	67 307
1988	41 546	07 512	1 196	27 192	77 446
1989	29 608	11 208	2 120	47 541	90 477
1990	31 822	14 244	1 953	38 543	86 562
1991	35 118	06 577	3 518	17 337	62 550
1992	45 249	15 040	4 764	19 028	84 081
1993	55 941	12 919	1 680	5 520	76 060
1994	59 974	30 591	2 222	8 315	101 102
1995	60 869	23 143	1 279	9 055	94 346
1996	61 749	22 656	256	9 463	94 124
1997	72 742	35 063	1 099	7 852	116 756
1998	79 827	27 846	1 040	8 542	117 255
1999	68 391	55 122	6 445	4 937	134 895
2000	68 422	21 886	2 161	7 707	100 176
2001	78 336	29 309	979	6 960	115 584
2002	84 692	49 596	4 072	6 413	144 773
2003	79 200	34 731	837	7 712	122 480
2004	71 337	34 797	6 932	6 562	119 628

Year	Bigeye tuna				Total
	Longline	Pole-and-line	Purse seine	Others	
1950	18 244	646	0	0	18 890
1951	12 808	729	1 095	0	14 632
1952	24 355	2 100	1 039	0	27 494
1953	23 025	2 400	619	0	26 044
1954	16 204	2 100	360	0	18 664
1955	24 749	4 000	285	0	29 034
1956	28 342	4 400	908	0	33 650
1957	35 463	5 200	49	0	40 712
1958	44 390	4 200	48	0	48 638
1959	39 789	1 700	36	0	41 525
1960	42 147	1 500	58	0	43 705
1961	36 135	1 800	63	0	37 998
1962	34 206	800	173	0	35 179
1963	40 727	1 800	6	0	42 533
1964	29 339	1 100	231	26	30 696
1965	28 392	1 300	201	29	29 922
1966	30 748	1 100	9	87	31 944
1967	32 233	2 800	60	252	35 345
1968	25 698	2 300	183	204	28 385
1969	30 245	1 700	48	62	32 055
1970	34 965	1 600	560	2 968	40 093
1971	38 359	900	690	3 243	43 192
1972	51 040	1 762	672	3 690	57 164
1973	42 412	1 258	847	4 449	48 966
1974	45 653	1 039	1 121	4 987	52 800
1975	61 488	1 334	1 054	5 212	69 088
1976	73 325	3 423	1 081	4 354	82 183
1977	72 083	3 325	1 260	5 954	82 622
1978	56 237	3 337	1 051	4 331	64 956
1979	63 704	2 540	1 680	4 966	72 890
1980	61 824	2 278	1 737	4 565	70 404
1981	45 823	2 596	3 888	5 298	57 605
1982	47 886	4 108	5 114	4 875	61 983
1983	45 270	4 055	9 109	5 320	63 754
1984	51 889	3 465	8 633	5 593	69 580
1985	57 436	4 326	6 329	6 725	74 816
1986	55 804	2 865	7 222	6 949	72 840
1987	67 818	3 134	10 926	5 852	87 730
1988	66 521	4 125	7 821	6 838	85 305
1989	62 997	4 298	12 281	7 572	87 148
1990	75 262	3 918	12 001	9 264	100 445
1991	58 185	1 991	13 271	11 270	84 717
1992	73 773	1 757	20 044	8 453	104 027
1993	64 123	2 330	13 990	7 206	87 649
1994	72 528	2 951	10 580	9 692	95 751
1995	61 137	3 776	11 487	9 666	86 066
1996	50 298	3 864	21 143	11 001	86 306
1997	63 374	3 611	37 674	10 298	114 957
1998	82 739	2 446	24 428	12 424	122 037
1999	71 632	2 176	38 152	13 184	125 144
2000	71 263	2 988	31 946	14 183	120 380
2001	73 533	2 349	28 257	13 038	117 177
2002	88 249	2 805	28 461	14 970	134 485
2003	77 849	1 786	27 238	15 481	122 354
2004	84 611	1 809	26 975	16 104	129 499

Year	Skipjack tuna				
	Longline	Pole-and-line	Purse seine	Others	Total
1950	34	33 386	0	6 483	39 903
1951	12	96 214	1 748	8 602	106 576
1952	54	78 518	3 716	10 014	92 302
1953	1	65 546	3 371	11 403	80 321
1954	0	88 073	4 534	11 554	104 161
1955	157	92 524	2 906	12 664	108 251
1956	0	91 950	2 145	13 094	107 189
1957	17	92 156	2 813	11 955	106 941
1958	0	131 441	10 698	15 244	157 383
1959	33	145 447	16 941	14 853	177 274
1960	0	70 428	3 728	15 782	89 938
1961	0	127 011	11 693	18 032	156 736
1962	4	152 387	11 674	17 559	181 624
1963	0	94 757	9 592	18 354	122 703
1964	5	137 106	25 006	20 668	182 785
1965	11	129 933	4 657	20 459	155 060
1966	52	215 600	10 949	22 654	249 255
1967	124	168 846	10 931	24 621	204 522
1968	83	162 379	7 587	24 870	194 919
1969	154	168 084	5 057	30 008	203 303
1970	1 669	197 873	7 534	35 181	242 257
1971	1 526	180 945	13 769	32 361	228 601
1972	1 565	172 827	18 079	45 193	237 664
1973	1 896	253 217	19 271	53 929	328 313
1974	2 149	289 202	11 136	53 711	356 198
1975	1 934	218 271	13 579	54 553	288 337
1976	2 109	276 582	23 604	55 276	357 571
1977	3 142	294 641	35 320	69 473	402 576
1978	3 249	331 401	35 535	79 184	449 369
1979	2 208	285 859	59 367	65 412	412 846
1980	640	333 457	79 235	45 193	458 525
1981	800	294 292	90 206	50 421	435 719
1982	1 068	262 244	169 745	52 929	485 986
1983	2 147	299 762	319 025	56 658	677 592
1984	877	379 474	322 792	46 990	750 133
1985	1 210	250 010	293 744	55 486	600 450
1986	1 468	336 695	349 795	60 861	748 819
1987	2 363	262 466	363 206	53 265	681 300
1988	1 980	301 031	488 046	48 395	839 452
1989	2 580	289 706	472 376	50 508	815 170
1990	1 299	224 592	584 302	70 170	880 363
1991	1 549	282 397	755 019	67 509	1 106 474
1992	1 156	226 589	721 192	88 681	1 037 618
1993	1 069	270 671	569 364	74 055	915 159
1994	1 519	231 385	714 132	67 364	1 014 400
1995	1 415	266 736	698 570	89 398	1 056 119
1996	4 699	230 576	706 335	85 381	1 026 991
1997	4 819	250 685	634 417	86 527	976 448
1998	5 023	287 945	912 728	98 687	1 304 383
1999	4 232	293 269	760 951	98 477	1 156 929
2000	5 472	287 842	833 325	110 538	1 237 177
2001	5 447	228 336	812 499	89 823	1 136 105
2002	4 125	224 146	963 865	92 030	1 284 166
2003	4 543	247 291	941 261	101 970	1 295 065
2004	4 900	245 353	1 015 517	104 482	1 370 252

Year	Yellowfin tuna				
	Longline	Pole-and-line	Purse seine	Other	Total
1950	12 844	799	0	08 919	22 562
1951	8 862	900	938	10 415	21 115
1952	17 453	2 595	2 565	10 539	33 152
1953	23 139	5 228	1 260	10 871	40 498
1954	22 662	4 268	4 001	11 763	42 694
1955	22 800	3 983	2 944	12 633	42 360
1956	25 336	4 399	0 724	12 818	43 277
1957	41 911	1 669	1 496	13 481	58 557
1958	41 804	2 934	3 338	14 682	62 758
1959	42 802	4 119	4 316	15 673	66 910
1960	53 617	01 872	01 438	15 919	72 846
1961	52 717	03 259	02 777	17 044	75 797
1962	58 049	04 225	06 975	18 150	87 399
1963	55 673	02 071	02 277	18 676	78 697
1964	48 000	05 073	03 647	20 183	76 903
1965	49 238	03 434	03 752	20 958	77 382
1966	65 973	02 192	05 844	23 409	97 418
1967	36 799	03 125	03 428	26 303	69 655
1968	47 467	02 706	07 106	26 084	83 363
1969	51 939	02 714	03 857	26 609	85 119
1970	55 806	02 674	07 811	30 933	97 224
1971	57 766	02 866	09 150	32 894	102 676
1972	61 175	07 465	10 002	37 506	116 148
1973	62 291	07 458	14 798	43 828	128 375
1974	58 116	06 582	17 130	49 441	131 269
1975	69 462	07 801	12 893	51 029	141 185
1976	77 570	17 186	14 976	42 766	152 498
1977	94 414	15 257	15 515	58 070	183 256
1978	110 329	12 767	13 292	39 401	175 789
1979	109 043	11 638	28 163	49 565	198 409
1980	122 444	13 168	31 849	47 758	215 219
1981	94 665	19 269	59 463	54 082	227 479
1982	84 988	13 835	73 738	49 477	222 038
1983	86 187	13 266	105 773	53 872	259 098
1984	73 036	13 558	111 474	57 537	255 605
1985	76 117	18 156	100 425	66 686	261 384
1986	65 014	13 074	105 901	69 134	253 123
1987	76 695	13 243	155 400	60 659	305 997
1988	88 767	13 433	95 536	69 337	267 073
1989	68 474	15 169	159 263	73 824	316 730
1990	75 522	13 103	175 432	93 998	358 055
1991	62 314	12 921	214 488	111 177	400 900
1992	73 271	15 225	252 062	79 038	419 596
1993	67 173	12 698	238 477	71 183	389 531
1994	75 436	13 742	214 278	95 588	399 044
1995	81 113	15 050	184 475	97 468	378 106
1996	77 827	15 492	114 011	107 390	314 720
1997	70 656	12 362	246 382	102 189	431 589
1998	68 636	13 110	263 230	122 025	467 001
1999	61 384	13 817	212 185	134 007	421 393
2000	79 791	13 745	196 339	143 176	433 051
2001	75 497	12 163	210 055	129 293	427 008
2002	75 290	13 357	183 902	146 315	418 864
2003	74 359	12 039	205 168	155 108	446 674
2004	71 483	11 855	171 098	158 295	412 731

Year	Total tuna				
	Longline	Pole-and-line	Purse seine	Other	Total
1950	47 862	47 694	0	15 402	110 958
1951	33 090	112 343	3 781	19 017	168 231
1952	64 248	125 000	7 474	20 790	217 512
1953	69 792	106 095	5 288	22 406	203 581
1954	64 743	122 510	8 918	23 355	219 526
1955	68 894	124 743	6 143	25 433	225 213
1956	71 913	143 559	3 777	25 969	245 218
1957	101 508	148 525	4 441	25 587	280 061
1958	115 896	160 750	14 092	30 050	320 788
1959	109 259	165 518	21 293	30 593	326 663
1960	127 140	98 956	5 224	31 777	263 097
1961	121 451	150 709	14 540	35 344	322 044
1962	129 538	166 141	18 875	35 900	350 454
1963	122 770	125 048	11 934	37 248	297 000
1964	103 413	167 137	29 012	41 196	340 758
1965	105 983	176 158	08 621	41 567	332 329
1966	148 090	241 722	16 913	46 735	453 460
1967	127 059	205 252	14 508	51 701	398 520
1968	118 992	183 982	15 143	52 281	370 398
1969	120 247	204 646	9 442	57 614	391 949
1970	139 939	226 632	16 184	69 588	452 343
1971	141 937	238 162	25 360	68 806	474 265
1972	158 651	231 302	28 839	87 281	506 073
1973	166 306	323 959	35 178	103 224	628 667
1974	145 133	366 385	29 580	110 140	651 238
1975	163 810	275 438	27 679	111 834	578 761
1976	197 461	376 183	40 808	103 763	718 215
1977	218 127	348 608	52 706	135 161	754 602
1978	211 797	405 250	50 156	130 709	797 912
1979	211 144	345 648	89 341	124 739	770 872
1980	227 212	392 523	113 144	103 155	836 034
1981	188 397	342 392	153 803	122 918	807 510
1982	177 297	309 705	249 148	122 785	858 935
1983	169 875	337 080	434 131	123 836	1 064 922
1984	156 608	422 837	446 321	124 497	1 150 263
1985	172 643	293 838	402 036	146 172	1 014 689
1986	163 988	366 813	464 537	150 058	1 145 396
1987	180 216	298 117	530 977	133 024	1 142 334
1988	198 814	326 101	592 599	151 762	1 269 276
1989	163 659	320 381	646 040	179 445	1 309 525
1990	183 905	255 857	773 688	211 975	1 425 425
1991	157 166	303 886	986 296	207 293	1 654 641
1992	193 449	258 611	998 062	195 200	1 645 322
1993	188 306	298 618	823 511	157 964	1 468 399
1994	209 457	278 669	941 212	180 959	1 610 297
1995	204 534	308 705	895 811	205 587	1 614 637
1996	194 573	272 588	841 745	213 235	1 522 141
1997	211 591	301 721	919 572	206 866	1 639 750
1998	236 225	331 347	1201 426	241 678	2 010 676
1999	205 639	364 384	1017 733	250 605	1 838 361
2000	224 948	326 461	1063 771	275 604	1 890 784
2001	232 813	272 157	1051 790	239 114	1 795 874
2002	252 356	289 904	1180 300	259 728	1 982 288
2003	235 951	295 847	1174 504	280 271	1 986 573
2004	232 331	293 814	1 220 522	285 443	2 032 110