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Recent developments in the tuna industry

Stocks, fisheries, management, processing, trade and markets

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A tuna auction in Japan (courtesy of P. Miyake).

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by

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Preparation of this document

The Fisheries and Aquaculture Resources Use and Conservation Division (FIR) of the Fisheries and Aquaculture Department of the Food and Agriculture Organization of the United Nations (FAO) is responsible for all programmes and activities relating to management and conservation of fisheries resources. This paper was prepared as part of the FIR work programme to enhance the understanding of the tuna industry, addressing the situation concerning tuna stocks, fisheries, management, processing, trade and markets. It provides an update of the earlier FAO Fisheries Technical Paper No. 467 (2004) on "Historical trends of tuna catches in the world", extending it substantially into subjects not dealt with in that earlier paper.

The paper was prepared under the direction of Jacek Majkowski, Senior Fishery Officer, Marine and Inland Fisheries Service, FIR. The authors are: Dr Makoto Peter Miyake, Visiting Scientist at the National Research Institute of Far Seas Fisheries, Fisheries Research Agency, Japan; Dr Patrice Guillotreau, Visiting Researcher in Fisheries Economics at the Institut de Recherche pour le Développement (IRD) and Principal Lecturer at the University of Nantes, France; Dr Chin-Hwa Sun, Professor at National Taiwan Ocean University, Taiwan Province of China; and Dr Gakushi Ishimura, Assistant Professor at Hokkaido University, Japan. Dr Shelley Clarke, Visiting Researcher at Imperial College in London, United Kingdom, edited the paper.

Abstract

This paper provides an updated review of world tuna fisheries. Previous studies (Miyake *et al.*, 2004) discussed the historical development of tuna fisheries, described current world tuna fisheries, and explained the technological developments that have affected fishing operations. The current paper expands the discussion to include socio-economic aspects of the tuna industry as a whole, specifically including recent changes in processing, trade, marketing and consumer preferences.

The first half of the paper introduces the conditions under which the studies were made and the data sources. It first provides caveats and assumptions which are designed to prevent misunderstanding or misinterpretation when using the data. It then reviews the world tuna stock status based on the results of Regional Fisheries Management Organizations (RFMOs) scientific reviews. Even though the biomass of most of the world's tuna stocks is generally above but close to the reference point, for a few stocks fishing mortality is above the maximum sustainable yield level indicating that the stock is being overfished. World tuna fisheries (mostly longline, purse seine and baitboat [pole-and-line] fisheries) are reviewed from the standpoint of catches, technological developments and economics. Finally, tuna management measures taken by RFMOs are reviewed, including those used to mitigate bycatch. Gear and species interactions are specifically discussed in terms of allocations of the stocks between fisheries.

The second half of the paper analyses tuna trade, processing, markets, consumption, price and profits for *sashimi*, fresh tuna steak, *katsuobushi* (dried skipjack stick) and canned tuna. The marketing of *sashimi* has changed very substantially from an exclusive Japanese market to a global one. The marketing system is also changing, because instead of being sold in market auctions, entire catches are now bought by one dealer and sold to large supermarkets or other retailers. This trend has had a clear impact on price and has resulted in the reduction of landing values. In the fresh and frozen steak tuna industry, in general, the price of tuna per unit weight is far higher than for canned materials. Since the 1960s, the production of, and demand and market for, canned tuna has increased very rapidly, accompanied by the rapid development of purse seine fisheries in tropical waters. The largest consumer of canned tuna in the 1970s was by far the United States of America, but these levels have been exceeded by European Union markets in the last two decades. The relative importance of the major markets (the United States, the European Union and Japan) has been continuously declining as a percentage of the world market. These trends have been accompanied by the concentration of capital. Another major change has involved the relocation of tuna factories from developed countries to areas closer to raw materials. This also helped the industry by cutting labour and transshipment costs, and facilitated flexible export marketing. Production was formerly dominated by the United States but as production has declined, Thailand has become the top producer in the late 1990s, followed by Spain, as a result of newly developed canning materials in the form of loins.

In conclusion, because of the recent rapid increase in competition among fisheries, species, industries and even products (*sashimi*/fresh tuna vs. canned), the most important and most urgent issue is how to manage and allocate tuna resources among these competitors (e.g. using fishing capacity control measures and/or catch allocations). In order to achieve such an objective it is imperative that socio-economic and ecological considerations are integrated into decision-making processes alongside capacity and allocation issues. This study does not address the broad socio-economic importance of the tuna industry to the countries in which it operates, but this type of research will be necessary in future in order to solve current fishery management problems.

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Abbreviations and acronyms

ACP	African, Caribbean and Pacific
ALB	Albacore (*Thunnus alalunga*)
AMSY	average maximum sustainable yield
ARA	Amsterdam-Rotterdam-Antwerp
ATL	Atlantic Ocean
B	biomass
BB	baitboat (“baitboat” is used exclusively for “pole and line”)
BET	Bigeye tuna (*Thunnus obesus*)
BFT	(Atlantic) bluefin tuna (*Thunnus thynnus*); official FAO name is bluefin tuna but often referred to as Atlantic bluefin tuna
BFTSD	Bluefin Tuna Statistical Document
BFTSDP	Bluefin Tuna Statistical Document Program
BMSY	Biomass at MSY
CCSBT	Commission for the Conservation of Southern Bluefin Tuna
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CLIOTOP	Climate Impacts on Oceanic Top Predators
CLL	coastal small-scale longliners
CPCs	Contracting Parties, Cooperating non-Contracting Parties, Entities or Fishing Entities
CPUE	catch per unit of effort
CWP	Coordinating Working Party on Fishery Statistics
DLL	distant water longliners
E	East
EC	European Commission
EEZ	Exclusive Economic Zone
EPO	Eastern Pacific Ocean
EU	European Union
F	fishing mortality rate (or coefficient)
FAD	fish aggregating device
FAO	Food and Agriculture Organization of the United Nations
FAO/TAC	FAO Technical Advisory Committee on Fishing Capacity
FDA	Food and Drug Administration (United States)
FFA	Pacific Islands Forum Fisheries Agency
FOC	flag of convenience
GG	gilled and gutted
GILL	gillnet
GPS	Global Positioning System
GRT	gross register tonnage
GSP+	Generalised System of Preferences
HAND	handline
IATTC	Inter-American Tropical Tuna Commission
ICCAT	International Commission for the Conservation of Atlantic Tunas
IND	Indian Ocean
IOTC	Indian Ocean Tuna Commission
IPOA	International Plan of Action (adopted by FAO)
IRD	Institute of Research for Development

ISC	International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean
ISSF	International Seafood Sustainability Foundation
IUU	illegal, unreported and unregulated
JPY	Japanese yen
LL	longline
MED	Mediterranean Sea
MSC	Marine Stewardship Council
MSY	maximum sustainable yield
NMFS	National Marine Fisheries Service (United States)
N	North
NEI	nowhere else included (mostly “flag of convenience”)
NGO	non-governmental organization
OPRT	Organization for the Promotion of Responsible Tuna Fisheries
OTH	other gears
PAC	Pacific Ocean
PBF	Pacific bluefin tuna (*Thunnus orientalis*)
PNA	Parties to the Nauru Agreement
PPM	parts per million
PS	purse seine
RFMO	Regional Fisheries Management Organization
RP	reference point
S	South
SBF	Southern bluefin tuna (*Thunnus maccoyii*); official FAO code is SBF but often SBT is used
SC	Scientific Committee
SKJ	Skipjack tuna (*Katsuwonus pelamis*)
SPC	Secretariat of the Pacific Community
SPRT	sport (or recreational)
SSB	spawning stock biomass
SURF	surface gears
SWO	Swordfish (*Xiphias gladius*)
T	metric tonnes
TAC	total allowable catch
TAE	total allowable effort
TPC	Taiwan Province of China
TRAP	trap (or set-net)
TROL	troll
UNCLOS	United Nations Convention on the Law of the Sea
VMS	vessel monitoring system
W	West
WCPFC	Western and Central Pacific Fisheries Commission
WCPO	Western and Central Pacific Ocean
WTO	World Trade Organization
WTPO	World Tuna Purse Seine Organization
Y/R	yield per recruit
YFT	Yellowfin tuna (*Thunnus albacares)*

Executive summary

TUNA STOCK STATUS AND CHANGES IN FISHERIES

World tuna fisheries are reviewed in terms of commercially important species, by ocean and by major fishing gear types. In volume, the most important catches[1] are of skipjack tuna at 50.7 percent of the global total, particularly in the Pacific Ocean, followed by yellowfin tuna at 31.7 percent and bigeye tuna at 10.8 percent. Albacore and bluefin tunas – Atlantic bluefin,[2] Pacific bluefin and southern bluefin – are caught in much smaller quantities. The Pacific Ocean yields more than half of the world's tuna production (64 percent), followed by the Indian (25 percent) and Atlantic (11 percent) Oceans. The catch by purse seiners has increased very rapidly and now forms the majority of the total yield (from 300 000 tonnes in 1970 to 2.8 million tonnes in 2006). Longline used to be the dominant gear type but it is now rapidly losing its share (from 500 000 tonnes, 34 percent of the total in 1970, to 650 000 tonnes, 15 percent of the total in 2005), though coastal small-scale longlining is increasing.

Stock status is reviewed according to the most recent, formal assessments by each of the tuna Regional Fisheries Management Organizations (RFMOs). The review is based on two aspects: whether the biomass (or spawning biomass) is above or below the reference point (RP); and whether fishing mortality is higher or lower than the level equivalent to the sustainable yield (as represented by the RP, which is generally the maximum sustainable yield [MSY]). Catches of bigeye and yellowfin have continuously increased in the Indian and Pacific Oceans, whereas in the Atlantic they peaked in the 1990s and thereafter decreased or stabilized. Stock biomass of tropical tunas (bigeye, skipjack and yellowfin) is generally above but close to the RP, and the exploitation level is close to the MSY, except for skipjack which still appears to be underexploited. Current fishing mortality coefficients for bigeye and yellowfin are generally below the level of the RP, except those for bigeye in the Pacific Ocean and yellowfin in the Indian Ocean which are above the MSY level. The temperate tunas (albacore, southern bluefin, Pacific bluefin and Atlantic bluefin) are more heavily exploited. In particular, southern bluefin and Atlantic bluefin are both in an overfished state and are currently being overfished.

The technological and physical development of fishing gear and its deployment is continuously progressing. The most recent change with the greatest impact on fisheries was the introduction of fish aggregating devices (FADs) by the purse seine fleet. The recent increase in purse seine catches is directly related to the increase of small-sized tropical tunas caught in association with FADs.

At present, sets on FAD schools take most of the fish in the habitat developed under the FAD, hence the species and sizes are highly variable, including many non-target small tunas and other species. Since the stock size of bigeye is small compared to yellowfin and skipjack, the capture of juvenile bigeye underneath FADs has a more substantial impact on the stock. This has significantly altered the yield per recruit

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[1] Percentages represent the five-year average for 2001–2005 (see Section 4.1.2). Data for 2006–2007 were preliminary at the time this report was written.

[2] The formal taxonomical name is bluefin tuna. However, in order to avoid confusion with Pacific bluefin tuna, it is called "Atlantic bluefin" in this report.

(Y/R) of bigeye stocks as well as the allocation of stocks between longline and surface fisheries (particularly purse seine).

The greater use of at-sea transshipment (mostly by distant water longline fisheries) and increased use of supply vessels (by purse seine) have increased the fishing capacity of the fleets, even if the number and fish holding capacity of the fleet has been held constant.

The development of coastal fisheries, including coastal longline fisheries, is also an important feature of the last two decades. This is primarily related to the establishment of Exclusive Economic Zones (EEZs), but is also very closely linked to cost effectiveness and management schemes aimed at distant water fleets.

The establishment of tuna farms has also had a major impact on fisheries, particularly through changes in market price and trade and market structure. As a result of farming, fishing pressure has increased for both large and small fish.

TUNA MANAGEMENT

Scientists from the RFMOs use the most recent and best available data and information to evaluate the stocks and provide advice for management. Government representatives do not necessarily fully respond to such advice, but many actions have been taken including those responding to environmental or ecosystem concerns (mostly mitigation of incidental bycatch). The adoption and implementation of management measures has become more difficult in recent years due to the global excess fishing capacity. As tuna fisheries are multispecies and multigear, when a regulation is adopted spillover of fishing capacity inevitably occurs and thus global management of fishing capacity is an urgent need.

Management measures, including those to combat and eliminate illegal, unreported and unregulated fishing and other unauthorized activities, can have a negative effect on fishing efficiency. In particular, recent bycatch mitigation measures have had a major impact on fisheries in general, especially longliners. As a result, gains in fishing efficiency have slowed. This is important since it may cause scientists to overestimate increases in catchability, fishing efficiency and fishing capacity for recent years.

In conclusion, most of the long-term changes in the fisheries have acted to increase the fishing efficiencies of all fleets. However, many of the recent changes, particularly for longline fisheries (i.e. tuna stocks are approaching or exceeding their full exploitation level; Y/R is reducing due to increasing juvenile catches; the number of regulations is growing; obligations for bycatch mitigation are expanding; competition among gear types has been accentuated; and both global fishing capacity and operational costs have risen) have had a negative impact on tuna fisheries (e.g. reduced efficiency) and, if not decreased, at least slowed down the trend of increasing catchability.

OPERATING COSTS AND REVENUE

Fishery operating costs were analysed by expenditure item. Case studies for Japanese distant water longline, baitboat and purse seine fleets; the Japanese near-coastal longline fleet; and the Seychelles-based large-scale purse seine fleet were assessed. In general, the average purse seine operation produces a profit; however, the other distant water fisheries are operating almost at a loss. Even purse seine profits are shrinking due to the increasing cost of fuel, labour and materials, while landing values (revenue) cannot be increased. The fuel costs are significant and widely fluctuating. The recent rise in fuel prices did not have as large an effect on the European fleet as on other fleets, due to the favourable monetary exchange rates for euros (because oil prices are generally quoted in United States dollars). In the case of the Japanese fleets, labour costs are very substantial. Replacement of national crews by foreign crews, mostly Indonesian, provides some cost relief.

TUNA MARKET – *SASHIMI*

Tuna trade, processing, markets, consumption, price and profits are discussed for *sashimi*, fresh tuna steak, *katsuobushi* (dried skipjack stick) and canned tuna.

The *sashimi* market was almost exclusively centred in Japan, but it has recently expanded worldwide. The Japanese domestic supply is slightly above 200 000 tonnes (all tuna combined but excluding skipjack, in round weight), while about 400 000 tonnes of tuna are imported. (These figures are in round weight and thus different from most recorded trade or market statistics.) Except for small amounts of albacore, these fish are usually consumed in fresh form. Slightly less than 300 000 tonnes of skipjack are caught by national vessels and 100 000 tonnes are imported. More than a half of the skipjack are either for canning or *katsuobushi*. Both catch and imports of skipjack have decreased in recent years.

One major problem is that the statistics for markets, trade and production are generally in terms of processed products and it is difficult to relate these to round weight. The decrease in Japanese imports may well be due to the nature of the products imported: in recent years, more and more processed (reduced in volume) products have been imported, for example, *sashimi* sliced blocks rather than gilled and gutted fish.

The marketing of *sashimi* has changed significantly as well. Concentration of trade within a smaller number of dealers (traders), wholesalers and retailers is commonly occurring in parallel with a reduction in trade intermediaries. Instead of fish being sold in market auctions, entire catches are now bought by one dealer and sold by large supermarkets or other retailers. This trend has had a clear impact on price and has resulted in the reduction of landing values.

TUNA MARKET – FRESH AND FROZEN TUNA (NON-*SASHIMI*)

Many parts of the world, including southern Europe, Asia, the Pacific Island States and Japan, have a long tradition of consuming non-canned tuna. Recently, this type of consumption has expanded throughout the world, particularly in North America. One of the difficulties in assessing statistics for non-canned tuna is separating these quantities from canned materials and from *sashimi*. Uncertainty in product weights due to different processing forms is also a major issue for this review.

In general, the price of tuna per unit weight is far higher for fresh consumption than for canned products. In the United States, recent tuna imports for non-canning purposes ranged from 60 000 to 90 000 tonnes with an increasing trend, while domestic landing of such products ranges from 20 000 to 30 000 tonnes with a declining trend. Total consumption in the United States is estimated at 80 000 to 110 000 tonnes per year

TUNA MARKET – CANNED GOODS

Canning of tuna began as early as the late nineteenth century. Tuna was once a low-value substitute for other fish (e.g. salmon, sardines), but since the 1960s the production, demand and market increased very rapidly, accompanied by the rapid development of purse seine fisheries in tropical waters. World canned tuna production increased from about 200 000 tonnes (net weight) in the mid-1970s to over 1 million tonnes by the early 2000s. The United States was the largest producer in the 1970s, but now only American Samoa is still producing on United States soil, and there is no canning taking place in the mainland United States. As United States production has declined, Thailand, since the late 1990s, has become the top producer and is now responsible for almost 46 percent of the world production, followed by Spain (nearly 10 percent). The Spanish canning industry has been maintained through shipping of newly developed canning materials in the form of loins (cleaned, boiled and prepared, and ready for canning).

The largest consumer of canned tuna in the 1970s was by far the United States, followed by the European Union and Japan. Both the number of countries importing and exporting canned tuna has increased and the cumulative market share of the top three importing countries (North America, European Union and Japan) has dropped from 96 percent to 74 percent over the last three decades. The gradual expansion of the European Union has allowed it to maintain its market share at above half of the worldwide market; however, the relative importance of the United States market has been reduced by half over time.

The globalization of the canning industry in the last three decades is strikingly apparent. It has been accompanied by the concentration of capital into a small number of operators, in the form of fishing vessels, traders, wholesalers, canneries and/or retailers. This represents one method of reducing the costs of production. Another major change has been the relocation of tuna factories from developed countries to areas closer to raw materials. This has also helped the industry by cutting labour and transshipment costs and facilitated flexible export marketing. In some cases, the establishment of a canning industry has been a condition for obtaining fishing access to the EEZ. Also, the development of products with reduced transshipment costs for materials and lower production costs for industry has also been important (e.g. vacuum-packed *sashimi* blocks and loins).

On the part of retailers, there is a trend toward separation into two product classes of canned tuna, i.e. cheap private brands and expensive, sophisticated products. Naturally, the large wholesalers and retailers depend primarily on private brands. As a result, the value chain flows in reverse to the product flow, i.e. consumers decide the price and industry has to meet this requirement. Because of the globalization of the industry (market, processing and fishery), the key to its existence lies in trimming production costs at each stage and reducing margins between stages of the value chain as much as possible. In order to achieve this, the concentration of capital is occurring at each stage, including retail, wholesale, cannery, cannery supply, fresh fish markets, and the fishing industry itself. Cutting margins between these stages or skipping some of the stages has occurred in both the *sashimi*/fresh tuna and the canning industry. Development of private brands (labels) also serves this purpose.

The consumer market is susceptible to many factors. It can be easily influenced by the mass media or by public concerns at the time. The impact on the market can be unpredictably positive or negative. Therefore, there is always some risk involved for the entire tuna industry. Recently, there are fewer tariff-type trade barriers. This helps to cut production costs and increases the fluidity of trade in tuna products.

CONCLUSIONS

In conclusion, while tuna fisheries' efficiencies are being reduced by many new elements, the market is becoming increasingly dynamic. This results in higher competition among the fisheries, species, industries, and even between products – *sashimi* and fresh tuna vs canned. This scenario is analogous to that of a pie that has already expanded dramatically to its maximum but for which the number of pie consumers has also increased and is still increasing. At present, the most important issue is how to manage the number of potential pie consumers and how to distribute the pie among them (e.g. using fishing capacity control measures and/or catch allocations). In order to achieve such an objective, it is imperative that socio-economic and ecological considerations are incorporated into decision-making processes alongside capacity and allocation issues. This study does not address the socio-economic importance of the tuna industry as a whole to the countries in which it operates, but this type of research will be necessary in the future in order to solve current fishery management problems.

1. Introduction

Miyake, Miyabe and Nakano (2004) reviewed developments and changes in world tuna fisheries from 1950 through 2002. Miyake (2005a) analysed developments in fishing technology and their effects on fisheries, and Miyake (2005b) performed a similar assessment of longline fishing capacity. These studies were detailed and global in scope, but they were limited in one sense because they discussed changes in the fisheries only and focused mainly on the development of fishing technology. Although fishing methods are an essential factor in the fishing industry, there are many other factors which have induced important transitions.

This paper updates the previous studies and also includes a discussion of changes in the socio-economic environment, which have had significant impacts on tuna fisheries. Elements which are expected to have had very strong effects on the development of fisheries and which are included in this paper are:

- tuna stock status;
- developments in fishing technology;
- fishery management measures and compliance;
- fishing operating costs;
- interactions among various tuna fisheries;
- ecosystem considerations, including bycatch;
- developments in processing industries (canning, *sashimi*, fresh including steak forms, and others);
- transportation and trading systems; and
- world market and consumer preferences (demand and price).

Understanding the global, multigear and multispecies nature of the tuna fishery is critically important. Fishing fleets, including those of industrialized countries and often even including those composed of small vessels, have been operating using many different types of gear all over the world for many years. A vessel can fish in three oceans in any given year with any species of tuna as its target. Therefore, any management measure taken for a particular stock of tuna can cause a spillover of fishing capacity to other species and/or areas. The tuna market has also expanded and has become more complex and globalized: tuna commodities are traded throughout the world, the distribution system is very complicated, and consumers' preferences are both diverse and changing over time. Because all of these factors are closely and intricately interrelated, discussion of the entire system is not simple. Therefore, this paper first discusses each factor individually, then provides an overview of the tuna industry in its entirety, highlighting immediate management issues.

Regardless of whether its effects are direct or indirect, one of the most influential factors on the fishery is the natural environment. Despite the importance of this factor, this paper does not address this issue because many studies of this topic have already been conducted and it is also a major subject of research under the Climate Impacts on Oceanic Top Predators (CLIOTOP) programme.[1]

In analysing economic issues in this paper, values and costs are given in nominal values in most of the cases, i.e. notwithstanding some exceptions, which are annotated, they are generally not adjusted for inflation. Inflation rates vary among countries and stages of the value chain; therefore, incorporating these rates consistently throughout this analysis would in most cases be impractical.

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[1] See www.globec.org/structure/regional/cliotop/cliotop.htm

The shipbuilding industry is an important component of the tuna industry. In general, in the 1960s and 1970s, Japan led this industry, particularly in the longline sector. Since then, Spain has become the major builder of purse seiners, while the Republic of Korea and then later China and Taiwan Province of China have become major builders of longline vessels. Currently, Taiwan Province of China is a leading purse seine builder. This topic, though important, is not pursued further in this paper.

2. Definitions and sources

All catch data used in this paper derives from FAO database compiled from RFMOs' sources. As such, these data should be identical to those held by each RFMO. In the event of discrepancies, the original RFMO databases were used and thus referenced (see Section 4.1 for details). All catch data series run from 1950 through 2007 and consist of those data available as of 31 December 2008. The data for 2007, and possibly even for 2006, should be considered preliminary because some of these data had not yet been received by RFMOs from the flag states by the end of 2008. In such cases, the catch figures from previous years were simply carried over as placeholders. Although the data for 2007 are preliminary (i.e. often incomplete and/or subject to confirmation), any subsequent adjustments are expected to be minor relative to the macroscale overview of the fisheries presented in this paper. More details on data issues are provided in Section 4.1. Sources of information for tuna products, trade and markets are given in the sections in which the data are presented.

This paper covers tunas which are commercially important, i.e. Atlantic bluefin (BFT), Pacific bluefin (PBF) southern bluefin (SBF), albacore (ALB), bigeye (BET), skipjack (SKJ) and yellowfin (YFT). Billfishes (including swordfish) are not included. Abbreviations of frequently used terms, FAO species codes and fishing gear codes are listed at the beginning of this paper. Tuna stock separations (or definitions) used in this paper follow those used by the RFMOs.

In this paper, all data are provided in metric units (including data from the United States and the United Kingdom of Great Britain and Northern Ireland). All the catch or landing weights are given in live (or round) weight (often converted). However, in trade or market statistics, the data are the weight of processed products and, in most cases, the product forms are unknown. When the processed product forms were known, weight was either converted to round weight or stated in the units as given (e.g. gilled and gutted, filleted). When the processed product form was unknown, it was referred to as "processed weight". Therefore, processed weights reported in this paper are not directly comparable to catch or landing weights. In general, processed weight is about 80 percent of round weight in the case of fresh fish, but could be as low as 60 percent for canned material. If the products are vacuum-packed *sashimi* pieces, processed weight could be less than 40 percent of the round weight. Discrepancies such as these make comparing catch statistics with trade or market statistics very difficult. This issue is further discussed in Section 6.

Catch data, by FAO definition, includes discards (live or dead), but in practice reported catch data usually represents retained catches or landings only. Some longline fisheries targeting swordfish or sharks use gear specifications and operational patterns that are different from longline fisheries targeting tunas, but despite these differences they also catch major tuna species as bycatch. This tuna bycatch is included in the data presented in this paper as far as it is retained and reported even though the development of longline fisheries targeting swordfish or shark is not discussed in this paper.

In this paper, some data represent the results of various investigations made by the authors. When these are based on unofficial records, logbooks, censuses/surveys, sales slips and various other unpublished sources, they are referenced only as unpublished data.

3. Tuna stock conditions and scientific recommendations

3.1 DEFINITIONS

All the world’s tuna and tuna-like species are the subject of research and management by RFMOs. The major RFMOs responsible for this are the International Commission for the Conservation of Atlantic Tunas (ICCAT) for the Atlantic Ocean; the Indian Ocean Tuna Commission (IOTC) for the Indian Ocean; and the Western and Central Pacific Fisheries Commission (WCPFC) and Inter-American Tropical Tuna Commission (IATTC) for the Pacific Ocean. In the Pacific Ocean, another international organization, the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC) is responsible for the provision of conservation and management advice for North Pacific stocks, whose distributions cross the border of IATTC and WCPFC. All of the RFMOs described so far are area based. The only exception is the Commission for the Conservation of Southern Bluefin Tuna (CCSBT), which is species based, as there is only one stock of southern bluefin and it is distributed in three oceans (Atlantic, Indian and Pacific). Therefore, management of southern bluefin is undertaken by CCSBT, even though the other RFMOs are also responsible in principle. Since the major catch of southern bluefin occurs in the Indian Ocean, this paper discusses the southern bluefin catches in conjunction with the Indian Ocean.

The procedures and operating systems, as well as the management objectives defined by their conventions, differ among the RFMOs. The criteria used in this section follow the definitions of the RFMOs and therefore may differ from one another even if the species or stocks are the same. The definitions of stocks follow those by RFMOs and the findings on the status of each stock are those presented by the auxiliary scientific advisory bodies of the RFMOs with the exception of the North Pacific stocks (Pacific bluefin and North Pacific albacore), whose assessments are conducted by the ISC.

For each ocean, the most recent stock conditions (as of 1 June 2009), as agreed by the RFMOs and their scientific advice bodies, have been summarized into a simple table format. This paper does not intend to discuss biological stock conditions in detail. However, the uncertainties and conditions under which the RFMOs reached these conclusions (as described in each source report) should be always kept in mind.

Although there are many diagnostics for judging the stock conditions, the simplest criteria are used in this chapter: whether there is overfishing on a stock and whether a stock is in an overfished condition. In stock assessments, there are many uncertainties in the biological parameters and models used, e.g. in the data sets, in environmental factors affecting the stock abundance, and in changes in catchability and availability. Therefore, the medians from base case runs adopted by each scientific body are used. The annotation “overfishing occurring” refers to a situation in which the current fishing mortality rate (F) exceeds the level that maintains the stock biomass (or spawning stock biomass [SSB]) at the reference point (RP) (i.e. $F_{current} > F_{RP}$). “Overfished” status refers to a stock whose biomass (or SSB) has fallen below the level of the RP (i.e. $B_{current} < B_{RP}$).

It should be understood that under average conditions a stock which is not in an overfished condition and is not being overfished would stay above the RP. However, even for a stock that is not overfished, if overfishing is occurring, eventually the stock biomass will fall below the RP. On the other hand, an overfished stock may eventually recover to the RP if overfishing is not occurring, assuming the current biomass relative to the RP is not so low that it negatively affects the spawner/recruit relationship.

This section compiles the conclusions of the scientific advice on stock status given by the scientific advisory group to the RFMO Commissions for each stock in Tables 1, 2 and 3. If biomass and fishing mortality rate are above and below the RPs, respectively, green shading is used to indicate the good condition of the stock. When the median of the biomass and fishing mortality rate are within 10 percent (either above or below, respectively) of the RPs, yellow shading is used. If the median is more than 10 percent but less than 50 percent above or below the RPs respectively, orange shading is used to indicate a warning. When biomass is more than 50 percent lower or F is more than 50 percent higher than the RPs, red shading is used. In terms of stock management, red indicates that very strict regulations are essential even to maintain the present level of stock biomass (and even stricter regulations would be necessary for stock recovery); orange indicates that regulations are required for stock recovery; yellow indicates that management measures are required to maintain the current level of the stock; and green indicates that no regulations are required but that stock monitoring is advisable.

The recommendations are drawn from the scientific advisory groups (e.g. the RFMOs' scientific committees) as described above but do not necessarily reflect the decisions of the Commissions. The decisions of the Commissions are given in Section 5 in a simplified format. For example, the specification of "total allowable catch (TAC)" can range from a "fixed total allowable catch of X tons" to a general, and more ambiguous, recommendation such as "catch should not exceed MSY". This variability in the specificity of management decisions is particularly common in the case of total allowable effort (TAE). As effort is usually hard to define, the recommendations often take forms such as "F should not exceed the current level", which is generally interpreted to mean that the total catch (or individual national catch), or number of vessels, should not exceed the current level. As this paper does not intend to analyse management arrangements in detail, those who are interested in further information regarding these management recommendations should refer to the original reports by the RFMOs.

In this chapter, catches of each tuna stock are given in graphic format to provide an overview. Despite this summarized presentation, the sources and limitations of the data, as discussed in this section, should be kept in mind.

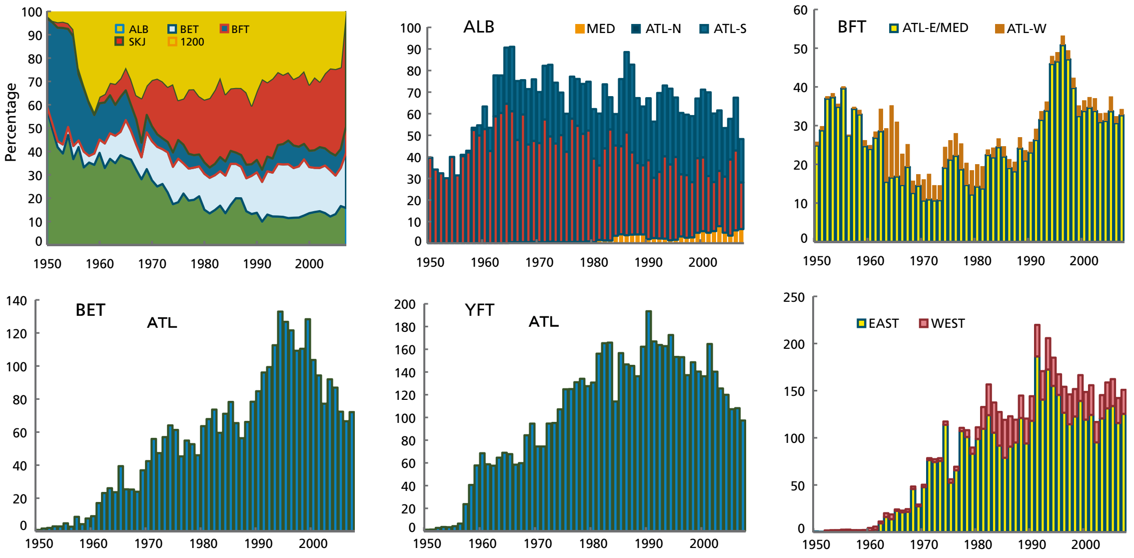
3.2 ATLANTIC OCEAN

Figure 1 gives the Atlantic Ocean tuna catches by species, subdivided into stocks. The only exception is the upper left panel which shows the species composition of Atlantic tuna catches in percentage. Catches of tropical tunas (yellowfin, skipjack and bigeye) in the Atlantic reached their peak in the 1990s and thereafter declined. This can be partly explained by the fact that stocks in the Atlantic reached their full exploitation status and management measures were introduced earlier there than in any other ocean, with the exception of the TAC/time closure in the Eastern Pacific Ocean in 1966. Later, the development of the Indian Ocean fishery absorbed the excess fishing effort from the Atlantic Ocean.

Management by quota has been in effect for Atlantic bluefin in the Western Atlantic Ocean since 1981 and in the Eastern Atlantic Ocean (including the Mediterranean) since 1994. Scientists estimate that between 15 000 and 30 000 tonnes of Atlantic bluefin in the Eastern Atlantic have not been reported in recent years. These estimates are not reflected in the catch figures themselves but are considered in the stock assessments as sensitivity analyses. Besides Atlantic bluefin almost all the tuna stocks in the Atlantic Ocean are under regulation of one type or another (catch, size, effort or time-area closures) and therefore cannot be considered to be unregulated (see

FIGURE 1

Species composition of Atlantic Ocean tuna catches (upper left panel) and catch by species by stock (remaining panels in thousand tonnes)



Note: MED = Mediterranean, ATL-N = North Atlantic, ATL-S = South Atlantic, ATL-W = West Atlantic.
Source: FAO and RFMO databases.

TABLE 1
Summary of stock status in the Atlantic Ocean

Stocks	$B_{current}$ / B_{MSY}	$F_{current}$ / F_{MSY}	Recommendation
ALB – N	0.81 (0.68–0.97)	1.5 (1.3–1.7)	TAC
ALB – S	0.91 (0.71–1.16)	0.63 (0.47–0.9)	TAC
ALB-Med	Unknown	Unknown	
BET	0.92 (0.85–1.07)	0.87 (0.70–1.24)	TAC
BFT – E[1]	High recruit 0.14	Reported catch 3.04	TAC/Size-limits/Time-area closure/Limit fishing capacity
	Low recruit 0.35	Estimated catch 3.42	
BFT – W[2]	High recruit 0.14 (0.08–0.21)	2.18 (1.74–2.64)	TAC
	Low recruit 0.57 (0.46–0.70)	1.27 (1.04–1.53)	
SKJ – E	High probability > 1	High probability < 1	None
SKJ – W	High probability > 1	High probability < 1	None
YFT	0.96 (0.72–1.22)	0.86 (0.71–1.05)	TAC

[1] SSB $_{2007}$/SSB$_{FMAX}$; F$_{2007}$/ F$_{MAX}$; High recruitment (1990s) and low recruitment (1970s) levels are assumed.
[2] Relative to MSY, which is calculated conditional on recruitment remaining at recent (1976–2004) levels.
Note: decimals of values coincide with these reported by each RFMO.

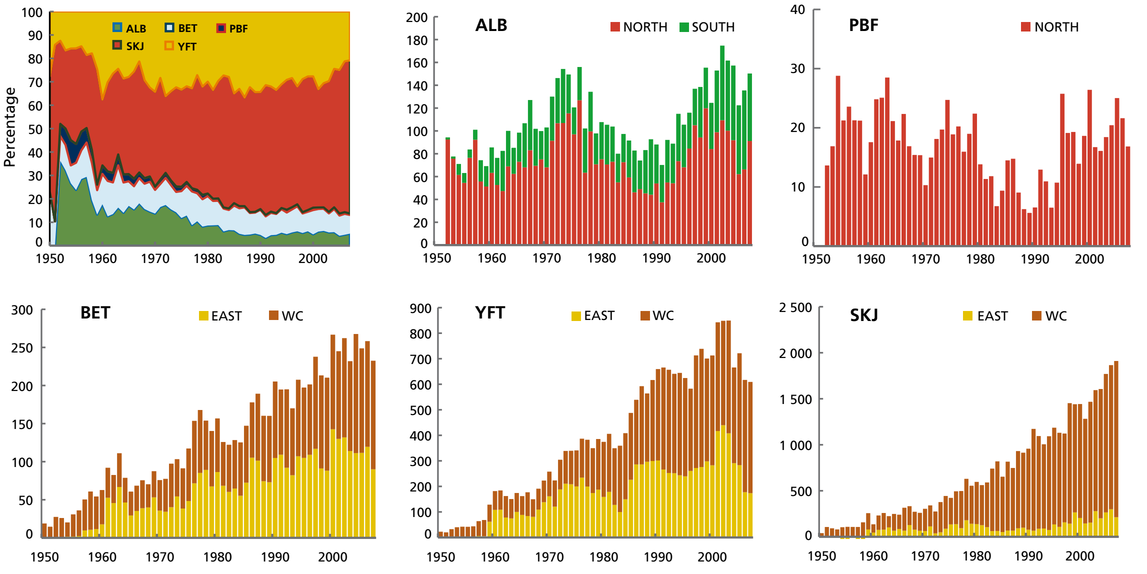
Section 5.1 for more detailed information). Table 1 provides a summary of the results of stock evaluations for the Atlantic tuna stocks based on ICCAT (2008) and using the ICCAT reference point of MSY.

3.3 PACIFIC OCEAN

Pacific Ocean catches by stock are given in Figure 2. The upper left panel shows the species composition. As will be discussed in Section 5, the Pacific catches of tropical tunas have maintained a nearly constant increase since 1950. On the other hand, relatively long-term cycles can be observed in the Pacific Ocean's temperate tuna (albacore and Pacific bluefin) catches. The ISC considers that these cycles represent regime shifts between high and low recruitment periods and that recent recruitments

FIGURE 2

Species composition of Pacific Ocean tuna catches (upper left panel) and catch by species by stock (remaining panels in thousand tonnes)



Note: WC = Western and Central Pacific.
Source: FAO and RFMO databases.

have been relatively high for both albacore and Pacific bluefin. Pacific bluefin is considered a North Pacific stock, and although there is a negligible amount of catch of this species in the southern hemisphere, all Pacific bluefin catches are discussed here as a North Pacific stock.

Table 2 provides a summary of the assessment results of the Pacific Ocean tuna stocks. Data for BET-East (E), YFT-E, and SKJ-E are taken from the conclusions of the IATTC and WCPFC scientific advisory groups; data for ALB-South (S), BET-WC (Western and Central), YFT-WC, and SKJ-WC are drawn from WCPFC (2008); and data for PBF and ALB-North (N) are drawn from ISC (2008). The reference point adopted by IATTC and WCPFC is MSY, whereas ISC does not yet have defined reference points. For this and other reasons, the stock evaluations of PBF and ALB-N are primarily based on current fishing mortality relative to various potential biological reference points.

TABLE 2

Summary of stock status in the Pacific Ocean

Stocks	$B_{current}$ / B_{MSY}	$F_{current}$ / F_{MSY}	Recommendation
ALB – N[1]	Likely >1.0	$F_{current}$=0.75 F_{MSY}	F to be reduced
ALB – S	1.26 (1.26–1.50)	0.44 (0.25–0.44)	
BET – EPO	1.01	1.234	Time closure for PS; quota for LL
BET – WCPO	1.37 (1.02–1.37)[2]	1.44 (1.33–2.09)	30% reduction of F
PBF[1]	$SSB_{current}$=$SSB_{average}$	Possibly $F_{current}\geq F_{RP}$	No increase in F
SKJ – EPO	Not estimated Probably >1	Probably < 1	
SKJ – WCPO	2.99	0.26	
YFT – EPO	0.96	0.89	Time closure for PS
YFT – WCPO	1.17 (1.13–1.42)	0.95 (0.56–1.10)	

[1] Point estimates are not provided. RP is not defined and various candidates are considered. Hence no clear cut median can be given.
[2] $SSB_{current}$/ SSB_{MSY} = 1.19 (0.76–1.20).

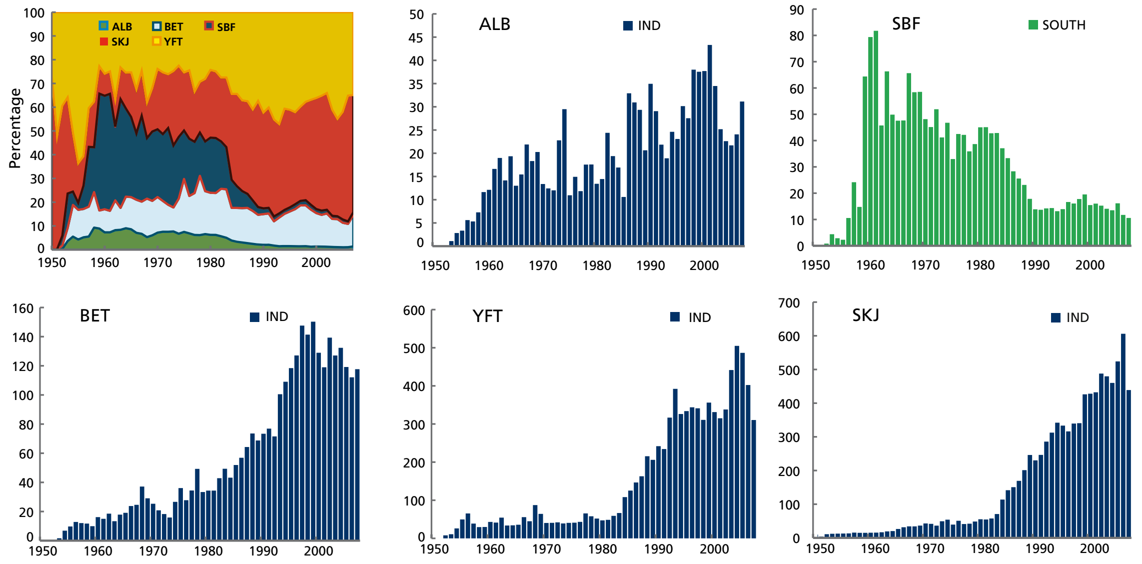
3.4 INDIAN OCEAN

Figure 3 provides an overview of Indian Ocean catches by species. The upper left panel shows the species composition of the Indian Ocean catch. As discussed in detail in Section 5, the Indian Ocean fishery is relatively new. Most of the stocks, particularly the tropical species, began to be exploited only in the 1980s and catches are still rapidly increasing, except for the last few years (data are preliminary). Because the fishing fleets operating in the Western Indian Ocean also operate in the Eastern Atlantic Ocean, the increasing catch in this area has clearly affected the Atlantic catches. This will be discussed further in a subsequent section of this paper.

Table 3 provides a summary of the results of assessments of the Indian Ocean tuna stocks. All data are sourced from IOTC (2008c), except for the southern bluefin data which derives from CCSBT (2008).

FIGURE 3

Species composition of Indian Ocean tuna catches (upper left panel) and catch by species by stock (remaining panels in thousand tonnes)



Note: IND = Indian Ocean (one stock).
Source: FAO and RFMO databases.

TABLE 3

Summary of stock status in the Indian Ocean

Stocks	$B_{current}$ / B_{MSY}	$F_{current}$ / F_{MSY}	Recommendation
ALB	> 1	0.48–0.90[1]	No recommendation
BET	1.34 (1.04–1.64)	0.81 (0.54–1.08)	Catch<MSY and Effort<2004
SKJ	Unknown (High probability >1)	Unknown (High probability <1)	No recommendation
YFT	1.13–0.93	0.9–1.60	TAC and Effort <2007
SBF	0.101–0.127[2]	Not reported	TAC

[1] Given as point estimates of exploitation (harvest) rates (h), $h_{current}/h_{MSY}$.

[2] $SSB_{current}/SSB_k$ (current SSB relative to the carrying capacity or unfished biomass).

4. Fisheries

4.1 OVERVIEW OF THE WORLD'S TUNA FISHERIES

4.1.1 Catch data sources and uncertainties

All the catch data used in Sections 3 and 4 are taken from the catches (landings) reported to, and published by, RFMOs as of the end of 2008. These data are stratified by species/stock, gear type and flag state, as well as by stock area. It should be noted that these data represent the best available scientific estimates of catch, rather than the data officially reported by national statistical offices.

The catch series begins in 1950. Prior to that time, catch data are highly uncertain as many countries were not reporting by area, species and gear type. In addition, once the Japanese fleet was released in 1952 from its post-war area restrictions, it spread across the world's oceans and began reporting catch data only in that year. This is important because Japanese catches comprised more than 50 percent of the world's tuna catches in these early years.

Furthermore, there are many uncertainties in catch data as reported by these RFMOs. These uncertainties arise mainly from:

(i) catches by vessels which are not on RFMO-authorized vessel lists;
(ii) under- or over-reporting by Contracting Parties, Cooperating non-Contracting Parties, Entities or Fishing Entities (CPCs);
(iii) estimation of coastal small-scale fisheries catches based on sampling, coverage of which varies from year to year;
(iv) loss of catch in the water before it is brought on-board (through depredation or for other reasons);
(v) lack of reporting of discards (live or dead);
(vi) reporting of processed weight instead of round weight;
(vii) species misidentification; and
(viii) unreported catches by recreational fishers.

Uncertainty sources (i) and (ii) are generally associated with fishery regulations, such as TACs, and are discussed in more detail in Section 5.1.6. Sometimes under- or over-reported quantities, or data on illegal, unreported and unregulated (IUU) catches which are lacking in their entirety, are estimated by the scientific advisory body of each RFMO. In most instances, these estimates are based on landing data from various ports where sampling is conducted and/or from trade data. With the permission of reporting nations, the RFMOs have adjusted the officially reported national catches for that quantity. However, in usual practice, circumstances do not permit such modification and only those catches officially reported by nations are included. Some RFMOs report these unreported or under-reported catches as "nowhere else included" (NEI) so that the sum of the catches would be closer to the true value.

The uncertainties related to small-scale coastal fisheries, i.e. (iii) above, for which the states do not have sufficient funds and/or capacity to collect adequate catch and size data on landings at their ports can be serious. Considerable effort has been made to remedy this situation through bilateral agreements between coastal states and developed countries and through some assistance provided by RFMOs. The problem is that the estimates are possible only for recent years, resulting in an apparent increase in catches which reflects merely an improvement in sampling coverage. On the other hand, many coastal states are developing tuna fisheries in their own waters and such fisheries are comprising an increasingly larger portion of world catches. As a consequence, the interpretation of catch trends in coastal fisheries requires special care and attention.

Uncertainty issues (iv) and (v) sometimes occur together. In the case of longlines, many fish that bite the hooks are lost for various reasons before they are brought on-board. Most of these losses are caused by depredation by sharks and/or marine mammals. Depredation rates have been studied systematically and reported by IOTC, and it was discovered that the rate of depredation increases as the catch rate decreases (IOTC, 2007a). Even when the fish are brought on-board, if the damage by shark depredation is high they are generally discarded. It is also known that some of the catches are lost before the nets are hauled up for "mysterious" reasons (Ward, Myers and Blanchard, 2004).

Discards of fish (v) are a substantial source of errors in catch estimates. In general, the logsheets require reporting of discards. However, for many fishers "catch" means only retained catch. Therefore, as described above, even depredated fish in longline fisheries which are brought on-board but discarded are frequently not reported. Also, some management regulations of RFMOs require release of some species, such as billfishes, before they are brought on-board. In earlier years, when catch rates were generally high, longliners retained preferred species and sizes and sometimes discarded low-grade or low-priced tuna. This is no longer practiced by longliners as the catch rates are low, and all fish caught contribute to the revenue so they are retained. However, in purse seine fisheries, particularly in the sets on schools associated with FADs, many fish that are well below the commercial size and/or those in poor condition (e.g. smashed) are discarded. Some regulations (e.g. in IATTC) require purse seiners to retain the entire catch unless it is unsuitable for human consumption, yet there are always some discards occurring and fishers frequently fail to report these discarded components of the catches.

Regarding uncertainty source (vi), in the past, official national statistics were often found to be in weight of processed fish rather than round weight. When such problems were discovered RFMO databases were modified for the entire data series of that country. In many of the cases this problem arises from a lack of communication between statistical departments and scientists.

Species misidentification, i.e. (vii) above, has many aspects. It sometimes represents intentional under-reporting of the regulated species and over-reporting of unregulated species. However, real difficulties in identifying juvenile yellowfin and bigeye do exist because, unfortunately, these two species look very similar in their juveniles stages and they are captured together from the same schools (particularly in FAD fishing). In addition, these juveniles have either no commercial value due to their extremely small size, or they are sold as mixed catch at the same price to the canning industry. Therefore, in the past, fishers generally reported them together as "tuna" or as "yellowfin". The uncertainty from this source has become more problematic as FAD fishing has increased the catch of small-sized tunas of mixed species.

Species misidentification was first recognized to be an issue in the Atlantic Ocean (Cayré and Fonteneau, 1984). Since then, reported catches by purse seine and later even baitboats have been modified on the basis of species composition sampling by on-board observers and/or sampling at landing ports. In oceans other than the Atlantic the problem was either considered not to be serious (until FAD fishing started) or not recognized to be a problem until much later (Lawson, 2008; Tomlinson, 2002 and 2004; Fonteneau, 2008). Much effort has been devoted to modifying the historical data based on available species composition data (Lawson, 2008). However, the mixing rates of the two species vary by relative stock size, school type, area, season and year. Therefore, with the exception of the Atlantic datasets, there are considerable uncertainties in the data before 2000.

4.1.2 Trends in the world tuna catches

By ocean

Figure 4 shows the world catches of major tuna species in weight by year (left panel) and by ocean (right panel). The pie chart within the figure represents the catch from each ocean in percentage for the five-year average of 2001–2005 (data for 2006 and 2007 are preliminary).

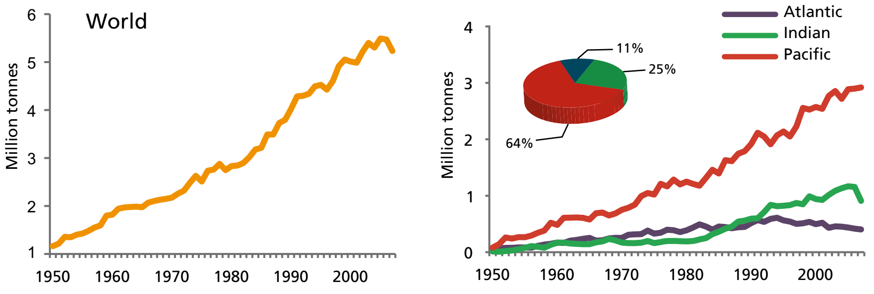
Global tuna catches have been constantly increasing in all but the last two years. Because the data for these two years are preliminary, there is a chance that catches in these years may have also continued the trend. The increase in catches was particularly noticeable in the 1980s and 1990s in the Pacific and Indian Oceans, and this is reflected in the global total. In contrast, Atlantic catches increased only until the early 1980s, but have since continuously declined. As a result, in recent years, 64 percent of the catch came from the Pacific Ocean, 25 percent from the Indian, and only 11 percent from the Atlantic (average of 2001–2005). More analysis and discussion of this subject is presented in Section 4.1.2.

By species

Figure 5 shows total world catches of tuna (in tonnes and in percents) by major species. Figure 6 disaggregates the catches by species and ocean. Please note that the scales on the y-axis differ among oceans and should be reviewed in conjunction with Figures 1, 2 and 3. From these figures, it is evident that the global tuna catch trends by species closely follow the trends shown for the Pacific as the Pacific catches are over 60 percent of the world total.

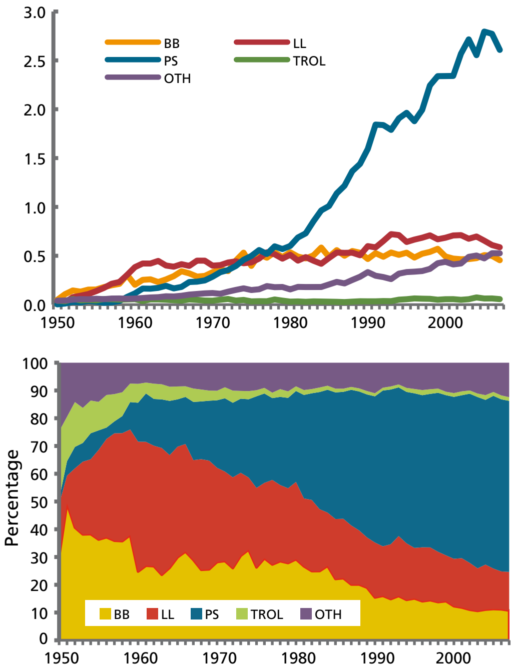
Global skipjack catches have been continuously increasing and in recent years reached 2.5 million tonnes, comprising over 50 percent of world tuna catches. The increase is particularly apparent in the Pacific Ocean, but the skipjack catch level in the other two oceans is close to that of yellowfin even in recent years. The difference between yellowfin and skipjack catches was small even in the Pacific until the mid-1990s, but thereafter the difference became much larger as the yellowfin catch declined. The global catch of yellowfin peaked in 2003 at about 1.3 million tonnes and is now trending downward. The global catch of bigeye increased gradually until the late 1990s, but since then has shown a slight downward trend.

FIGURE 4
World tuna catch in total (left panel) and by ocean (right panel), 1950–2007



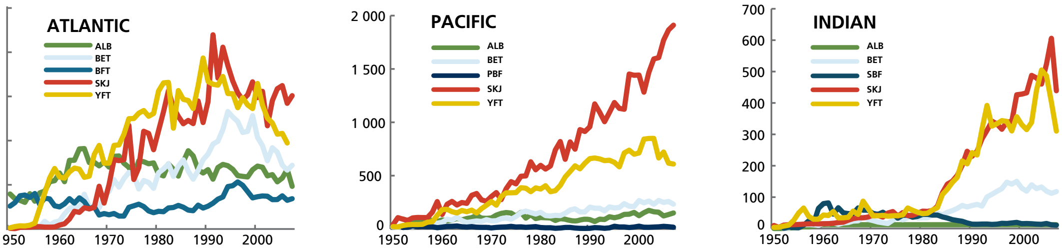
Note: The pie chart in the right panel represents the average share by ocean for the period 2001-2005.
Source: FAO and RFMO databases.

FIGURE 5
World tuna catch by species (upper panel in million tonnes) and share (lower panel), 1950–2007



Source: FAO and RFMO databases.

FIGURE 6
Catch (in thousand tonnes) of major tuna species by ocean, 1950–2007



Source: FAO and RFMO databases.

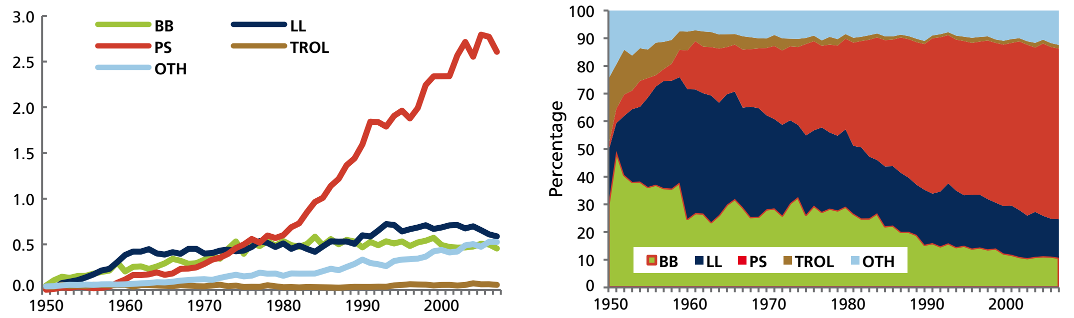
The catch of albacore has been relatively constant. In contrast, catches of Atlantic and Pacific bluefins have fluctuated widely between years and it appears that there are some long-term cycles in the catch quantities. Catch levels of southern bluefin and Atlantic bluefin are very much related to management measures, particularly since 2000. This will be discussed in Section 5.1.

By gear type

In Figure 7, world catches by major fishing gear types are shown in tonnes (left panel) and in percent (right panel). As illustrated in Figure 8, the importance of different gear types varies considerably among oceans.

FIGURE 7

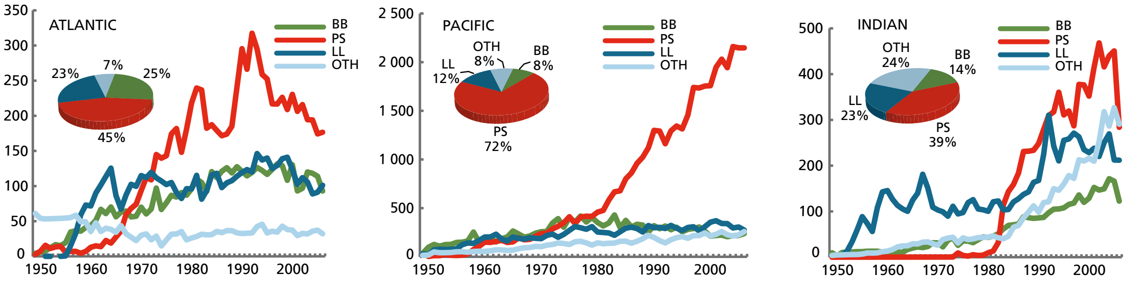
World tuna catch by gear type in catch weight (left panel) and share (right panel), 1950–2007



Source: FAO and RFMO databases.

FIGURE 8

Tuna catch (in thousand tonnes) by ocean and by gear, 1950–2007



Note: The pie chart represents the average share by gear type for the period 2001–2005.
Source: FAO and RFMO databases.

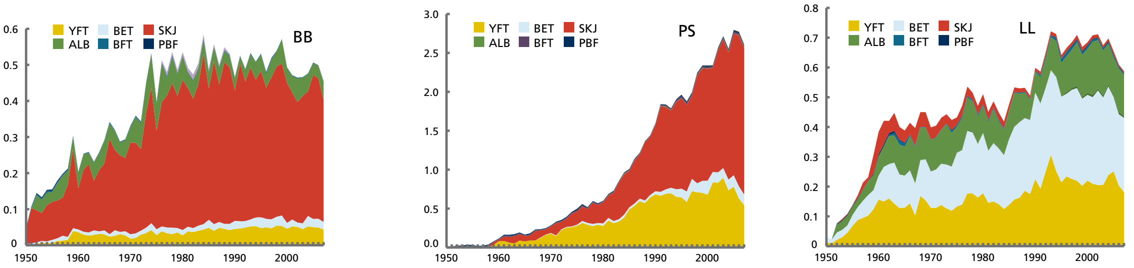
Since the beginning of the 1980s, the world purse seine catch has rapidly increased to nearly 3 million tonnes (or 70 percent of world tuna catches). This is particularly noticeable in the Pacific and Indian Oceans. In the Atlantic, purse seine catches peaked in the mid-1990s and thereafter started to decline (Figure 8).

Longlines and baitboats used to be the major fishing gear types worldwide (over 80 percent), but these have rapidly declined in share (currently about 10 percent worldwide) despite the fact that catch quantities have been slightly increasing or stable (Figure 7). This trend primarily reflects the situation in the Pacific Ocean, as over 60 percent of the world catch is taken there. Longline gear remains relatively important in the Atlantic and Indian Oceans (23 percent in each), while its share dropped to 12 percent in the Pacific (Figure 8). The catch of "other" and unclassified gear types increased very rapidly in the Indian Ocean (24 percent), representing either statistical improvement or an increase in the catch of coastal developing countries (see below and Section 4.2). These include unknown and small-scale coastal fisheries using a variety of gear types primarily composed of small traps, set nets, ring nets, small seiners, and possibly coastal gillnets.

The global catch by species for three major gear types is shown in Figure 9. It is clear that the catches by baitboats are almost exclusively skipjack with minor quantities of albacore, yellowfin and bigeye. In addition, considerable annual fluctuations in skipjack catches are apparent.

FIGURE 9

World catch (million tonnes) of major tuna species by baitboat (BB), purse seine (PS) and longline (LL), 1950-2007



Source: FAO and RFMO databases.

Purse seine catches were previously dominated by yellowfin, but since approximately 1990 the catch of skipjack substantially exceeded that of yellowfin and the proportion of skipjack in the purse seine catches is still increasing. Although not shown in this figure, these tendencies are particularly strong in the Pacific.

Longline catches show a change in target species with time. Until the mid-1970s, albacore, yellowfin and bigeye were caught in relatively similar quantities. Thereafter, bigeye and yellowfin were the most targeted species, while catches of albacore remained stable. This subject is discussed in detail in Section 4.2.3.

Despite the fact that it is not shown in Figure 9, the catch of albacore by troll gear is notable. Although the catches of Atlantic bluefin, Pacific bluefin and southern bluefin are too small to be shown in the figure, they are mostly caught by purse seine and longline and, to a lesser extent, by troll, trap and unclassified gear types.

By country

Figure 10 shows global catches of the major tuna species by the top ten countries/fishing entities. The upper panel shows the cumulative catch quantity in tonnes while the lower panel shows the same data in percent. The top ten countries/fishing entities were selected based on their average catches over the last ten years (1998–2007). Most of these countries/fishing entities catch tuna in the ocean closest to them, but some major tuna fishing fleets operate in more than one ocean. Figure 11 shows combined catches of major tuna species, disaggregated by the three oceans, for six countries/fishing entities (Japan, Taiwan Province of China, the Republic of Korea, Spain, France and China).

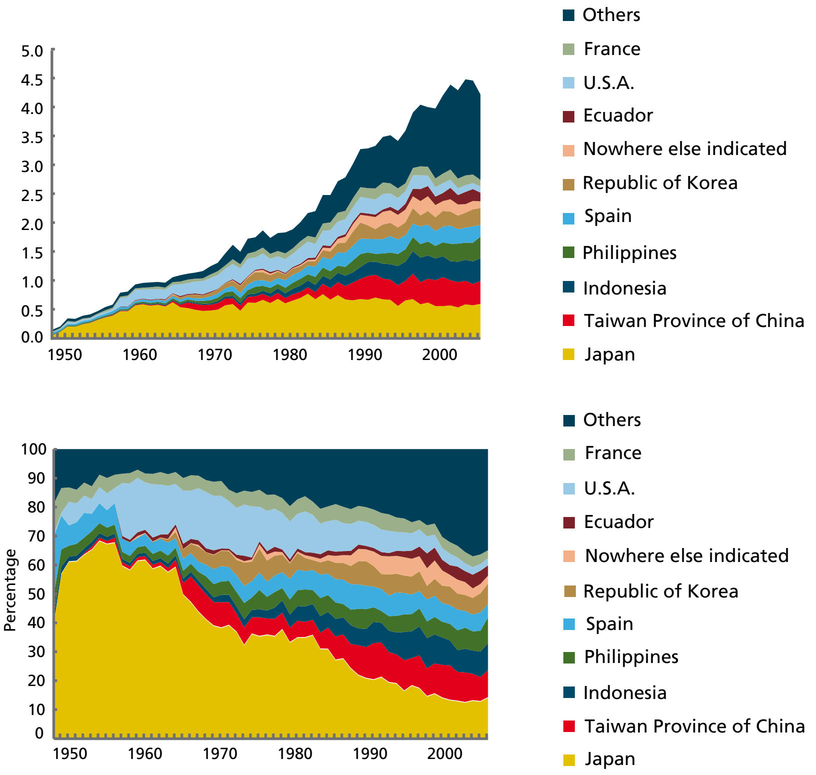
It is evident from this figure that the Japanese catch increased until the late 1960s in the Atlantic and Indian Oceans and in the Pacific until the mid-1980s, but thereafter declined or remained constant. At the same time, the global catch increased very rapidly thereby causing a sharp decrease in the relative importance of the Japanese catch from about 70 percent of the global total in the peak period of the late 1960s to 13 percent in recent years.

The United States also had similar trends. Catches peaked in the early 1960s and thereafter stabilized and declined in quantity, resulting in a rapid reduction in its proportion of the global catch.

In the meantime, Taiwan Province of China and the Republic of Korea developed their fisheries and have increased their catch quantities steadily until the present, maintaining a stable share as the global catch grew. In the early stages of these fisheries, both countries' major fishing grounds were the Indian and Atlantic Oceans. This is because their catches were mostly for export to the European Union and United States

FIGURE 10

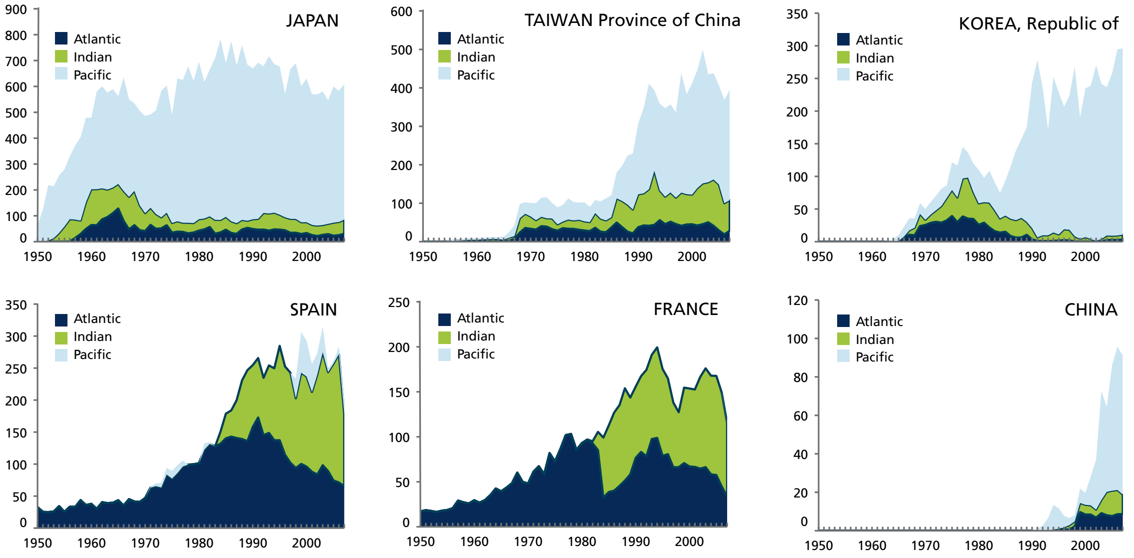
World tuna catch by country in weight (in million tonnes – upper panel) and share (lower panel), 1950–2007



Source: FAO and RFMO databases.

FIGURE 11

Catch of major tuna species by ocean for six major countries/fishing entities in thousand tonnes, 1950–2007



Source: FAO and RFMO databases.

BOX 1

Flag of convenience and IUU

The term "flag of convenience" refers, in principle, to any vessel registered to a country with an open registry rather than the country in which the vessel owner is based. In the 1960s and 1970s, some boat owners used flag of convenience registries for the sake of avoiding stricter maritime regulations by their home country (e.g. on navigation and crew), or to remain unencumbered by their home country's adoption of limited entry policies for fisheries. In addition, since the 1980s, many RFMOs have adopted various regulatory measures, which are only binding on CPCs. Vessel owners who wanted to escape being bound to such management measures reflagged vessels to non-contracting countries of the RFMOs. Although these are often referred to as flag of convenience arrangements, there are also legitimate vessels flying flags of convenience (e.g. cargo boats, etc.). In order to distinguish these vessels, the term "illegal, unreported and unregulated (IUU)" has been coined and is now commonly used. In its broadest definition, any vessels which do not obey regulatory measures, which are not controlled by their flag states, and/or are not reporting the required fishery information are IUU regardless of whether the vessels belong to CPCs or not. Under a narrower definition, IUU applies only to those fishing activities carried out by vessels which are not on RFMO-authorized vessel lists.

markets for canning. Recently, these longline fleets are primarily targeting *sashimi*-quality tuna for export to Japan. However, the majority of Korean operators have withdrawn from longline fishing in the Indian and Atlantic Oceans and have increased their focus on purse seine fisheries which are concentrated in the Pacific Ocean.

Spanish and French purse seine catches were limited to the Atlantic Ocean until the early 1980s, when fleets expanded their operations into the Indian Ocean. Spanish purse seine fleets expanded into the Pacific in the 1990s, but Spain's reported catch decreased because many of its vessels changed their flags to South American coastal countries or Pacific Island States. Catches by coastal developing states are discussed in the following section.

Since late 2008 many purse seine vessels fishing in the Western Indian Ocean have moved to the Atlantic or Pacific Oceans due to the expanding piracy in the most productive fishing area, i.e. between Somalia and the Seychelles.

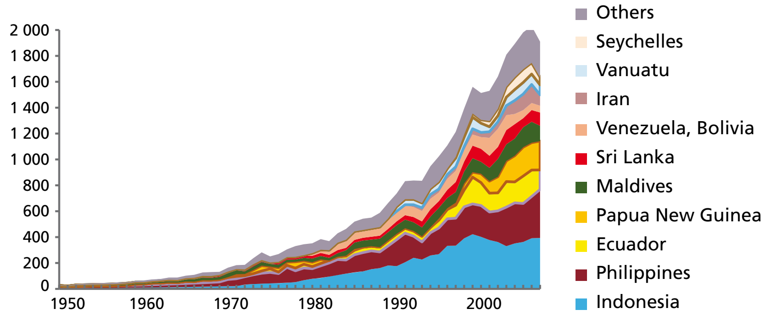
Coastal fisheries

Catches of the top ten developing coastal countries (based on the ten-year average of 1998–2007) are given in Figure 12. Gillett (2005, 2007) estimated the catches of non-industrial fisheries by region. The catches given here are significantly more than those estimated by Gillett (2005, 2007) because the definition of "coastal" used here is different. In order to avoid the inappropriate inclusion of countries with large and longstanding distant-water industrial tuna fleets (e.g. Taiwan Province of China) in this discussion, this paper uses the term "developing coastal states" to refer only to those countries with newly developed fleets.

Catches of developing coastal states were almost non-existent before 1980. However, they have increased at an accelerated rate since. Although some coastal states declared an extended jurisdiction beyond territorial waters in the 1950s and 1960s, rapid development of coastal fisheries was clearly sparked by agreement on the United Nations Convention on the Law of the Sea (UNCLOS) in 1982, which took effect in November 1994. At present, catches of developing coastal states total almost half of the world's tuna catches and four times more than the Japanese catch.

FIGURE 12

Catch of major tuna species by coastal developing countries in million tonnes, 1950–2007



Note: Bolivarian Republic of Venezuela and the Plurinational State of Bolivia are reported together to protect business confidentiality.
Source: FAO and RFMO databases.

These developing coastal countries' fleets are very diverse. Some fleets are multipurpose and of a truly artisanal and traditional coastal nature. Fishing gear types used by these fleets are categorized as unclassified. The fleets of Indonesia, the Philippines, the Maldives and Sri Lanka are composed of large artisanal fishing vessels. Many of these fisheries operate around anchored FADs (Babaran, 2006). One important issue associated with these fleets is the difficulty of obtaining accurate statistics (as discussed in Section 4.1.1).

Much of the increase in catches by developing coastal states is driven by large industrialized vessels (either longline or purse seine) built through the capital investment of fishery-developed countries. Many of these vessels can be considered flag of convenience, operating either under charter arrangements or in joint-venture type operations. Therefore, strictly speaking, these are not fleets which have been developed by the developing coastal states themselves. However, they are also not IUU fishing vessels because they are properly licensed, registered with RFMOs, and their catches are reported by the developing coastal states. Wherever national catch quotas are adopted, these vessels use the quota of the flag states. From a legal point of view they are legitimate fisheries of the coastal states, and hence they are permitted to, and likely to, fish both within and outside the EEZ of the developing coastal country to which they are now flagged. Some portion of the purse seine fleets of Ecuador, Vanuatu, Venezuela (Bolivarian Republic of), the Seychelles and Papua New Guinea fall into this category. Vanuatu and the Seychelles also have distant water longliners in this category (see Section 5.1.6).

There are also fleets which lie between these two extremes of small artisanal vessels and large flag of convenience vessels. These are small-scale longliners ≤ 24 metres in length originating from Taiwan Province of China. Most of them fish in Philippine, Indonesian and Thai waters (Gillett and McCoy, 2006; Gillett, 2005). Some of these vessels are 23.9 metres in length and hence are not bound by many of the management measures applicable to large-scale longliners despite the fact that they fish in exactly the same manner and have similar deep freezer capabilities.

Although Indonesia, the Philippines and possibly the Maldives have always had traditional coastal fisheries, the catch and share recorded by these countries only began increasing rapidly in the 1990s. While part of this increase is expected to be real, improvements in statistical record-keeping could be a contributing factor (particularly for Indonesia and the Philippines). The increase in the "other" countries' quantities and shares (Figure 10) implies either that tuna fisheries have been expanding worldwide, particularly among developing coastal states, or that more tuna resources in EEZs are now subject to exploitation.

General discussion of catches by ocean, gear type and species

The preceding discussion has presented the catches of major tuna species by ocean, species, gear type and country. This section combines this information to provide an overview of tuna fisheries at the present time.

World tuna catches have been increasing constantly and rapidly. Pacific catches dominate the world catch whereas Atlantic catches have been declining since 1990. The world catch increase is primarily attributable to purse seine catches in the Indian and Pacific Oceans.

Purse seine catches are comprised mainly of skipjack and yellowfin. The largest component of the increase in the world tuna catch consists of skipjack, particularly in the Pacific. Yellowfin catches are about equal to those of skipjack in the Indian and Atlantic Oceans, and thus yellowfin is a much larger component of the total catches in these oceans than in the Pacific.

Although longline and baitboat catches have stabilized in the last few decades, the share of these gear types' catch in the total has rapidly reduced as purse seine catches have expanded. Baitboats have consistently targeted mostly skipjack. The target species of longliners have varied over time: from the late 1960s yellowfin and albacore were the main targets but nowadays bigeye and yellowfin are the primary species sought.

The world tuna fishery used to be dominated by Japan and to a lesser extent by the United States. However, the United States' catch has fallen and the Japanese catch has stabilized in the last few decades, resulting in very rapid declines in their respective shares of the world catch. There has been a clear and rapid increase in catches, both in terms of weight and share, by developing coastal states such as Ecuador, the Philippines and Indonesia.

Geographic parameters for the Atlantic, Pacific and Indian Oceans (excluding the Antarctic Sea) are given in Table 4. The figures for total area, distance at the equator, and area between 20 degrees north and south latitude have been estimated by the authors, and although they are approximations they are useful as a general characterization of each ocean. The area between 20 degrees north and south latitude is considered to be the major fishing area for the tropical tunas, i.e. bigeye, yellowfin and skipjack, although these species, particularly bigeye, are also taken at depth by longliners in temperate waters. Skipjack is also known to make long migrations into temperate waters during the summer months. This distribution conforms to information on the nursery grounds for these species which are known to be in

TABLE 4

Comparisons of characteristics of oceans with catches of tropical (BET, SKJ, YFT) and temperate (ALB, SBF, PBF, BFT) tuna species

	OCEAN			
	Atlantic	**Pacific**	**Indian**	**Total**
Area (million km^2)	73	170	55	298
	24%	57%	18%	100%
Distance at the equator (km)	670	1 890	780	3 340
	20%	57%	23%	100%
Area between 20°N and 20°S	26	80	31	137
(million km^2)	19%	58%	23%	100%
Total tuna catches (1 000 tonnes)	460	2 754	1 065	4 279
	11%	64%	25%	100%
Tropical tuna catches (1 000 tonnes)	364	2 581	1 021	3 966
	9%	65%	26%	100%
Temperate tuna catches (1 000 tonnes)	96	173	44	313
	31%	55%	14%	100%
Tropical tuna catch/tropical area (tonnes per 1 000 km^2)	14.0	32.3	32.9	28.9

tropical waters. Catches given in the table are five-year averages for all gear types combined and consist of catches of tropical tunas representing bigeye, yellowfin and skipjack, and catches of temperate tuna representing albacore and Atlantic, southern and Pacific bluefins. The bottom row of Table 4 shows tropical tuna catch in tonnes per 1 000 km^2.

Although the area of each ocean does not necessarily correlate with its productivity, it is interesting to consider the relationship between area and tuna catch. The Pacific is the largest ocean by far with 57 to 58 percent of the total regardless of which parameter is considered. While the Pacific would thus be expected to dominate catches, its share is even greater than expected, particularly with regard to tropical species for which its catches are 65 percent of the total. The Indian Ocean's share is also proportionally higher than would be expected: it is only 18 percent of the total area and 23 percent of the tropical area, but its tropical tuna catches are 26 percent of the global total. In contrast, the Atlantic's share is 24 percent of the total area and 19 percent of the tropical area, but only 11 percent of the world's total catch and only 9 percent of the catch of tropical species.

Tropical tuna catches in tonnes per 1 000 km^2 of tropical area (Table 4) show almost equal values for the Pacific and Indian Oceans but considerably less than half of that for the Atlantic. The tropical tuna catches have increased nearly constantly in the Indian and Pacific Oceans, reaching their highest level in recent years. However, in the Atlantic Ocean, catches peaked in 1991 and thereafter declined. The Atlantic catch of tropical tunas during the peak period was 483 000 tonnes, or 18.6 tonnes per 1 000 km^2, which is still far less than the other two oceans.

High contributions of the Indian and Pacific Oceans may be related to the abundance of islands in their tropical waters. Both oceans include parts of Indonesia where many islands contribute to complex coastlines and high productivities. The Pacific also has many islands, particularly in the west, and over 80 percent of the Western and Central Pacific Ocean is included within the EEZs of states (mainly island states). On the other hand, the Atlantic has very few islands, with the exception of the Caribbean area, where tuna fisheries are not very well developed and/or not well represented in statistics.

The proportion of albacore caught in each ocean is 54 percent, 19 percent, and 27 percent for the Pacific, Atlantic and Indian Oceans, respectively, while the proportion of area in each of these oceans is 58 percent, 19 percent and 23 percent, respectively. Although the similarity of these figures may be merely a coincidence, they are worth noting for further study.

It is clear from these catch data that the Pacific is by far the most expansive ocean and the most productive for tropical tuna species. In the Atlantic, the production of temperate tunas is reasonably high compared to the total ocean area, but tropical tuna catches are far less than in the other two oceans in terms of both quantity and proportion. The fishery in the western tropical Atlantic has not been as well developed as in the other two oceans and may provide a possibility for further development in the near future. Progressive management measures taken by ICCAT to limit tuna catches, as described in Section 5.1, may be yet another reason for relatively lower catches in the Atlantic. With regard to other species, it is possible that albacore in the southern hemisphere is less exploited in the Pacific and Indian Oceans, as shown in Section 3.

4.2 CHANGES IN FISHERIES PRIMARILY RELATED TO TECHNOLOGICAL DEVELOPMENTS

4.2.1 Historical changes and their causes

This section briefly reviews a previous study by Miyake (2005a), which discussed three general types of technological developments that affect fisheries. These are developments which:

- increase fishing efficiency (i.e. increase the coefficient of catchability or q);
- increase economic gain, even if fishing efficiency is held constant; and
- make the fishing easier, safer and less labour intensive.

In general, fishing efficiency is constantly increasing, based on both technological development and fishers' increasing experience. The catch per unit of effort (CPUE), which serves as an index for stock abundance, is generally a function of catchability (unless it is standardized for changes in catchability using, for example, the depth of longline hooks). Therefore, in general, catchability (q) = fishing mortality (F) / effort, and following from that catch (C) $=q\times F\times N$, where N=stock size in number of fish, and $C/F=q\times N$. Interpreting changes in fisheries can have different consequences for stock assessment depending on whether the changes are related to real differences in efficiencies or only to economic motivation to fish. Miyake (2005a) discussed many technological and related developments which occurred for the fisheries during the period from 1950 to the early 2000s. A summary of the most important key changes and their consequences (as indicated by arrows) is given below.

General changes

(i) continuous improvement in fishing gear and procedures (net or line materials and gear construction, line/net casting and hauling) → higher fishing efficiency and less labour;
(ii) improvements in fishing vessels (motorization and increasing engine power, construction materials and increasing length and carrying capacity) which began at the end of the nineteenth century and continues today, especially in coastal fisheries → higher efficiency; and
(iii) improvements in navigational instruments (satellite positioning has become widely used since the mid-1970s) → safer operation and higher efficiency.

Longliners

(i) improvements in freezer systems (blast freezing replaced ice wells in 1953 → start of distant water fishing [maximization of economic gain]);
(ii) introduction of super freezers in the 1960s which allowed for the production of *sashimi*-quality tuna by distant water longliners → longline catches diverted from canning to *sashimi*;
(iii) introduction of line casting, bait attaching, and other similar devices in the 1960s → labour and cost savings; and
(iv) deployment of deep longlines in the 1970s for targeting bigeye → changes in fishing area and fishing time leading to economic gains.

Purse seiners

(i) invention of the power block resulted in a rapid increase in the number of modern purse seiners → replacement of baitboat fisheries in the late 1950s and 1960s;
(ii) rapid increases in fish holding capacity beginning in the 1960s and continuing to the present → longer cruises and more distant water fishing grounds;
(iii) various improvements in gear and procedures such as net pursing, catch brailing and storage, conservation of large catches through handling and freezing techniques, and rapid unloading beginning in the 1960s and continuing to the present → time, labour and cost savings;
(iv) improvements in fishing techniques (setting around dolphins, dolphin mitigation) → some gains in speed (e.g. setting around dolphins) but accompanied by some slowing down of operations due to required mitigation;
(v) improvements in searching and catch rates through the use of helicopters, bird radar, sonar, Global Positioning System (GPS) and GPS radio buoys → higher fishing efficiency; and

(vi) establishment of FAD fishing in the 1990s → higher fishing efficiencies and catch rates but also higher catches of juveniles and discards.

Further details on these and other technological changes in tuna fisheries can be found in Miyake (2005a); Ward and Hindmarsh (2006); Anon. (2008a); Itano (2004); Itano, Fukofuka and Brogan (2004); Itano (2007a, 2007b); and Suisanshinchosha (1970).

4.2.2 General review of recent changes

Since the 1980s, the causes of changes in the fisheries have become more complex. The following recent elements, in addition to the list given in 4.2.1, have affected fisheries through fishing technology and other factors (excluding socio-economic factors):

(i) improvements in the efficiency of FADs and the development of anchored or fixed FADs (see Section 4.2.6);
(ii) increased use of transshipment (see Sections 4.2.3 and 4.2.5);
(iii) changes in the relative importance of fishing gear types and target species (see Sections 4.2.6 and 4.2.7);
(iv) initiation of tuna farming activities (see Section 4.2.8);
(v) development of small-scale, coastal fisheries (see Sections 4.1.2, 4.2.3 and 4.2.7);
(vi) management measures (see Section 5.1); and
(vii) environmental considerations such as undesirable incidental catches and the introduction of various mitigation methods and techniques (see Section 5.2).

Up until the 1980s, most of the changes in fishing gear and techniques were designed to improve fishing efficiency and increase economic gains (i, ii, iii and iv above are in this category). However, this situation has changed very rapidly in the last two to three decades. The factors listed under (vi) and (vii) result in reduced fishing efficiency and economic gains. These two items will be discussed in Section 5. It is noted that factors (iii), (iv) and (v) are strongly linked to resource allocation issues and will generate profits for certain fisheries while having a negative effect on others. These factors are discussed in Sections 4.2.6 through 4.2.8.

4.2.3 Longline fisheries

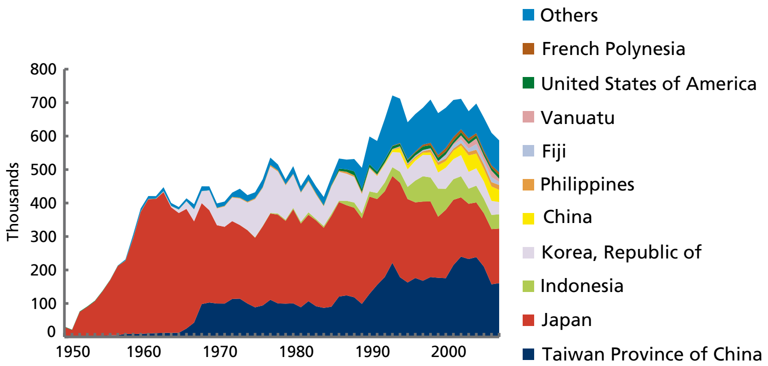
Trends in world tuna catches by longline fisheries were discussed in Section 4.1.2. Figure 8 shows these trends for each ocean. In the Atlantic and Pacific Oceans, longline catches have been at about the same level since the 1970s, but in the Indian Ocean longline catches have increased through the 1990s. In addition, the relative importance of longlines in the total catch was highest in the Indian Ocean (> 20 percent). As shown in Figure 9, the major catches in weight of longlines are yellowfin, bigeye and to a lesser extent albacore. However, in terms of price, the Atlantic, Pacific and southern bluefins are the most valuable targets (see Section 6.2).

Fishing fleets choose to undertake operations based on the combination of area, season and target species which will produce the highest profits for them. The most important factors in selecting fishing grounds, seasons and target species are the balance between the fish price and fish abundance among species/stocks and the operating cost. Such a balance changes from time to time. For example, when longliners were catching tuna for canning in the 1950s, they used to target species for which the catch rate was high, the fish price was the best and the fishing operations were easiest (i.e. albacore as a primary target and yellowfin as a secondary one). However, with the commencement of the *sashimi* market, the target changed to bigeye because the fish price was far better even though the catch rate was lower (see Section 6). Even now, some longliners, particularly those from Taiwan Province of China, fish for albacore because the catch rate of albacore is much higher than bigeye and thus offsets the lower albacore price.

Figure 13 gives the total longline tuna catches for the top ten countries/fishing entities. Ranks are based on average catches over the most recent ten-year period

FIGURE 13

Catch in thousand tonnes of major tuna species by longline for the top ten longlining countries, 1950–2007



Source: FAO and RFMO databases.

(1998–2007). These figures show that the previous dominance of the Japanese longline fleet has been reduced and now Taiwan Province of China is the top producer. Japan and Taiwan Province of China together catch more than one half of the world's longline catches. Catches by the Republic of Korea have declined substantially while Indonesian catches have increased significantly. Indonesian catches are mostly by small-scale, coastal longlines and the uncertainties discussed above for small-scale, coastal fisheries data apply to this fishery as well.

Although for longlines there have been some technological improvements in the last two decades, including greater freezing power and capacity (resulting in higher quality *sashimi*), and some changes in fishing depth, gear construction and bait choice (Ward, 2008), overall gains in efficiency have been relatively minor. In fact, in contrast to purse seiners, longline fishing efficiency was already nearly maximized in the 1990s.

Major changes in longline fishing operations which have increased fishing capacity include the widespread use of at-sea transshipment and the increasing number of hooks used per day. At-sea transshipment provides a substantial time savings for vessels which need not return to port to offload and resupply, thereby allowing a greater number of fishing days per year. However, in order to eliminate transshipment operations which facilitate IUU fishing, most RFMOs have implemented observer systems on transshipment vessels with costs borne by the fishery. Most of the Asian distant-water longliners make use of at-sea transshipment throughout the world, with the exception of the Western and Central Pacific Ocean where the fishing grounds are usually in relatively close proximity to the home ports.

Although the number of hooks per set is physically maximized at about 3 000, in the 1990s some longline vessels of the Taiwan Province of China started to operate three sets every two days instead of the traditional one set per day. In such cases, the number of hooks per set must be reduced (to about 2 000) in order to shorten the operation time, and hence the total number of hooks per day does not necessarily increase. However, operational efficiency increases with shorter lines. This type of operation requires more intensive labour inputs and, probably for this reason, this practice has not spread widely through longline fisheries (personal communication of the authors with fisheries scientists of Taiwan Province of China).

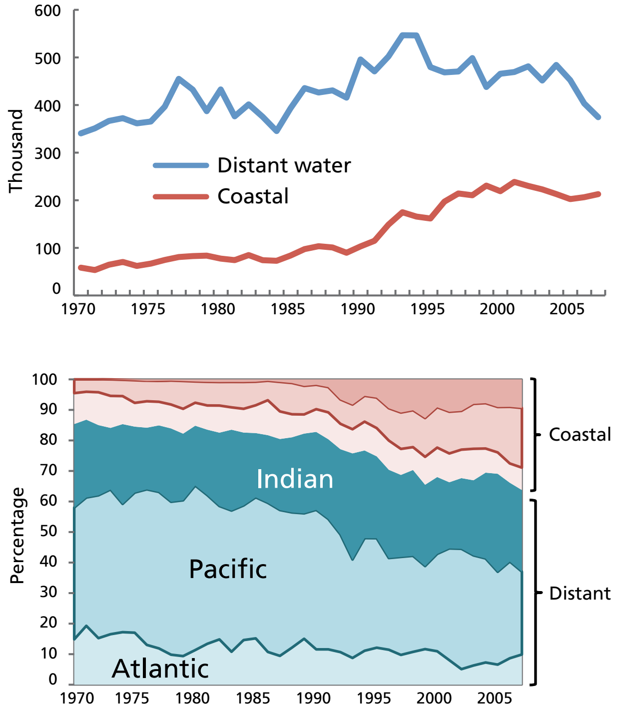
Most distant water longliners (see Box 2) have, over time, adopted operational patterns which result in reductions in fishing capacity, either in terms of reduced fishing efficiency and/or reduced economic gains, for the following reasons:

- most of the fishing crew are foreigners, who are less experienced in fishing, and/or have difficulties communicating with the captain/skipper;
- the average age of key crew members, particularly of captains/skippers, is rising and there is little recruitment of young people to the workforce;
- fishing grounds are becoming increasingly limited due to difficulties in negotiating EEZ access agreements with coastal states, and higher fuel costs;
- landing fees at foreign ports are increasing;
- observer programmes are placing demands on operations, either through fees which must be paid to participate in these programmes or in terms of reducing the number of crew members in order to provide sufficient bunk space for the observer;
- various mitigation measures for incidental catches of non-target species are now required (see Section 5.2);
- vessel monitoring system (VMS) has been introduced and there are now costs associated with operating, maintaining and upgrading the systems (as required by RFMOs); and
- large fish biomass and MSY has been reduced due to increased catches of small fish by other fishing gears (see Section 4.2.7).

Figure 14 shows the catch by distant water longline vessels and small-scale coastal longline vessels (see definitions in Box 2). The upper panel shows combined global catches in weight of major tuna species by these two fleets. The lower panel represents the percentage (by catch weight) of these two fleets by ocean. Since the early 1990s the coastal longline catches have increased rapidly while since the mid-1990s distant water longline catches have been declining. The share of the distant water longline catch in both the Pacific and Indian Oceans is declining rapidly. Conversely, most of the

FIGURE 14

Coastal and distant water longline catch of major tuna species worldwide in thousand tonnes (upper panel) and share by ocean for each category (lower panel), 1970–2007



Source: FAO and RFMO databases.

BOX 2

Definitions of distant water longliners (DLL) and coastal longliners (CLL)

There are no internationally accepted definitions for DLL and CLL. In this paper, DLL is used to refer to longliners generally (but not limited to) >24 metres in total length overall, with super-freezing facilities, and the potential to fish on the high seas and/or in the EEZs of foreign countries. CLL is used to refer to those vessels which fish only within their national EEZ. CLLs mostly use ice wells but may also have freezing facilities. CLLs also include some old ice-well boats >24 metres in overall length. Therefore, CLL may include both large old-type freezer longliners as well as very small artisanal longliners. There are many boats at the margins of this definition, for example, ice-well vessels fishing in foreign EEZs from a base in that foreign country. Some of these are considered here as DLL because of the difficulties of separating them from other DLL. However, in general, small longliners which fish in foreign EEZs with the flag of the coastal state are included in the CLL group (e.g. small longliners of Taiwan Province of China fishing in Indonesian waters with an Indonesian flag). The newly built longliners of 23.9 metres with super freezers are, in principle, included in DLL. Nevertheless, it is often very difficult to associate the coastal landings with the origin of the vessels. For all these reasons, the current division should be considered a practical but arbitrary one.

increase in coastal longline catches (upper panel of Figure 14) in recent years has been in the Indian Ocean and to a lesser extent in the Pacific Ocean. The increase of catches by coastal longliners has contributed to the increase in catches by developing coastal countries (Section 4.1.2).

The decrease in distant water longline catches is closely related to the reduction in longline fishing capacity under policies adopted by several distant water longline countries starting in the late 1990s, particularly involving policies to buy-back and scrap vessels. These policies are discussed in detail in Section 5.1.5.

In general, developing coastal states prefer to grant fishing rights in their EEZs to foreign vessels in the form of joint venture or flagging arrangements rather than by selling fishing access rights. This has encouraged the operation of small-scale longliners (e.g. with ice wells) flagged to coastal states, rather than distant water longliners under access agreements, in the longline operations of developing coastal states.

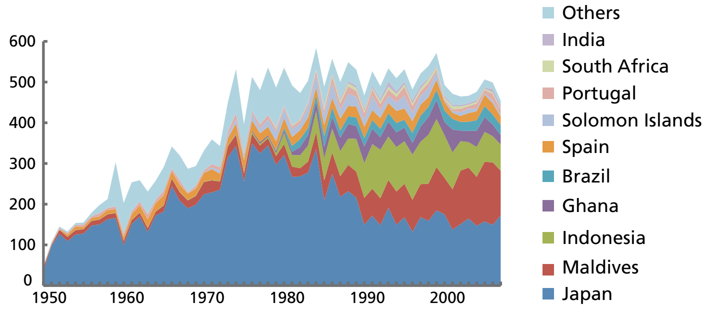
Although the structure of coastal longline fleets is very complicated, in general, the increase in coastal longline catches increases the supply of fresh fish to the market. This has been made possible, to a great extent, by the establishment of air shipping routes from various key ports (e.g. in Thailand, Indonesia, Malaysia, Singapore, Mexico, Spain and Italy) to consumer markets for fresh tuna (mostly Tokyo and Osaka [Japan] and Los Angeles [United States]. If such routes were not well established, the coastal longline catches would not have increased so rapidly (see Section 6.2).

4.2.4 Baitboat fisheries

Figure 15 shows baitboat (also known as pole and line) catches for the top ten countries based on average catches for 1998–2007. The major countries for this gear type are, in descending order by catch quantity, Japan, the Maldives, Indonesia, Ghana, Brazil and Spain. Among these, baitboat catches from the Maldives, Indonesia and Brazil are exclusively coastal, whereas the others are a mixture of coastal and high-seas operations. Ghanaian catches may include those by purse seine due to the fact that baitboats are often used as auxiliary boats for the purse seine fishery and receive a part of the purse seine catch as their share. Almost 75 percent of global baitboat catches are made by the top three countries. The major species caught by the top ten countries are skipjack,

FIGURE 15

Catch in thousand tonnes of major tuna species by baitboats for the top ten baitboat fishing countries, 1950–2007



Source: FAO and RFMO databases.

followed by yellowfin (Figure 9); Japan, Spain and Portugal also catch Atlantic bluefin, Pacific bluefin and/or albacore. South Africa and many countries in the southern hemisphere target albacore, which is locally a preferred target due to its higher price.

As was discussed in Section 4.1.2, baitboat catches have been nearly stable since the mid-1970s. However, the proportion of the total catch by country has changed considerably. Japan's catch was reduced almost by one half, with corresponding increases in baitboat catches reported by the Maldives and Indonesia.

Recent changes in baitboat operations are relatively minor, although it is possible that soaring fuel costs have limited distant water baitboat fishing grounds to more near shore areas. The most recent development is that some baitboat operations have established a *sashimi* market for high-quality frozen skipjack. Also, the increase in demand for soluble, powdered fish flavouring is probably the major factor supporting Japan's ability to maintain its baitboat fishery, even though these flavouring materials can also be provided by purse seine catches (see Section 6.4).

4.2.5 Purse seine fisheries

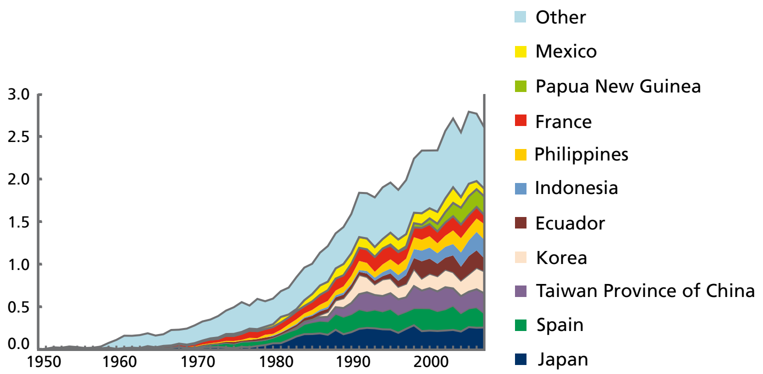
World purse seine catches are summarized in Section 4.1.2. Purse seine catches have continuously increased since the early 1980s, and at present they comprise 70 percent of all tuna catches. As discussed, the dominance of the purse seine fishery is due to rapid development of this fishery in the Indian and Pacific Oceans (Figures 7 and 8). The most important species in the purse seine catch is skipjack, particularly in the Pacific, followed by yellowfin (Figure 9).

Figure 16 presents the purse seine catch for the top ten countries/fishing entities as determined by average catches over the last ten years (1997–2006). The catches of Japan, Spain, Taiwan Province of China and the Republic of Korea are all at about the same level and have been stable since the mid-1990s. These four countries/fishing entities together take nearly half of the world's purse seine catches. Except for Spain, catches of these countries/fishing entities are almost all from the Western and Central Pacific Ocean. The catches by Ecuador and Indonesia have increased significantly in the last ten years. Some catches attributed to Ecuador, the Philippines and Papua New Guinea derive from vessels reflagged from, or joint ventures with, developed countries (e.g. Spain and Taiwan Province of China).

Technological development of fishing gear and its deployment is ongoing (Section 4.2.1). These developments are primarily aimed at improving fishing efficiency, shortening pursing and fish lifting time, and reducing labour input. Recent developments share many points in common with the factors described above for the longline fleet (Section 4.2.3), and while many developments have acted to increase fishing efficiency, several of them have had a negative effect, as follows:

FIGURE 16

Catch in million tonnes of major tuna species by purse seine for the top ten purse seine fishing countries, 1950–2007



Source: FAO and RFMO databases.

- fishing grounds are more restricted due to access agreements and/or management measures;
- fees for unloading at ports are higher;
- obligations resulting from observer programmes are increasing; and
- the number of required mitigation measures is rising (although it should be noted that requirements for mitigation of incidental bycatch are less for purse seines than for longlines with the exception of measures for dolphins and small tunas, particularly bigeye (see the next two sections).

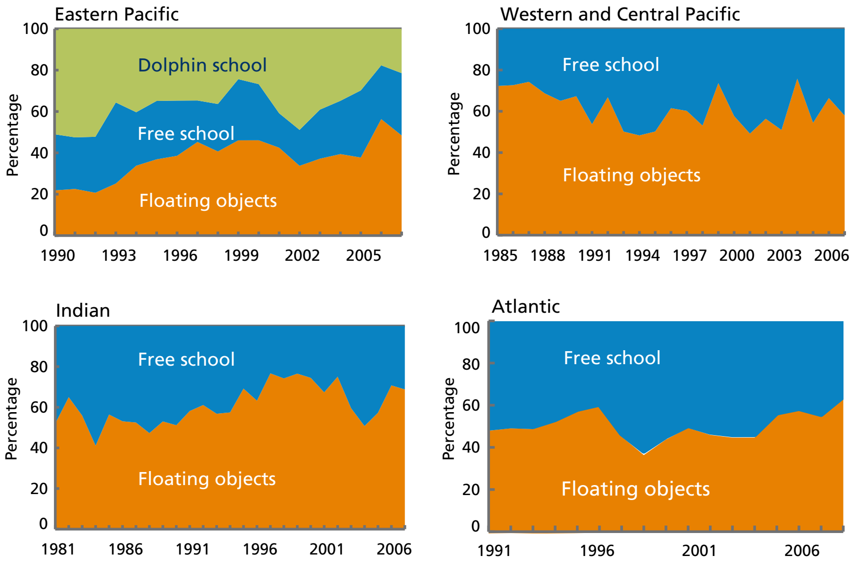
In many countries, including the European Union (EU), at-sea transshipments for purse seiners are prohibited by law. This is actually a major driving force toward building purse seiners with larger holding capacities, which also consequently results in increased fishing capacity. Even though the number of vessels (or number of fishing licences) may be limited, many older vessels are being replaced with new vessels with larger holding capacities.

One of the major changes for the purse seine fishery in recent years is the more efficient use of tender (or supply) vessels and/or reefers. As explained in detail in Section 4.2.5, the tender boats increase the fishing capacity without increasing the number of fishing licences. Reefers (transshipment vessels with fish in containers) are used in the same way for purse seiners as they are for longliners, most commonly in the Indian Ocean (Itano, 2007a; Itano, 2007b).

Another important factor is the spillover in purse seine effort from one region to another. This occurs, in most cases, as a result of management measures. For example, as most of the important Atlantic tuna stocks came under the quota system in the mid-1980s, many vessels spilled over into the Indian Ocean. Similarly, when the Eastern Pacific Ocean adopted a closed fishing season, some purse seine vessels moved into the Western and Central Pacific (IATTC, 2008). A more detailed discussion of this topic is found in later sections of this paper.

When discussing the development of purse seine fisheries, it is very important to examine the type of schools on which the sets are made. Figure 17 shows the proportion of purse seine catches in weight, by type of school for four ocean regions based on RFMO data (note that the periods covered differ among regions). In the Atlantic, the data cover only European Union purse seiners; minor catches made by other fleets and catches from the Western Atlantic are not included. For the other ocean regions, all catches by large purse seiners are included.

FIGURE 17
Share of purse seine catches deriving from different types of setting practices, by ocean



Note: Period covers various years.
Source: FAO and RFMO databases.

In this Figure "floating objects" includes schools associated with both natural logs and FADs. Until the early 1990s, these are understood to be all-natural logs. Disaggregated data for natural and man-made objects (FADs) are available for some areas, but even in recent years the data are not completely reliable and the boundary between these two categories is blurred because many additional features have been added to natural objects over time. The term "free schools" refers to fish found in the open ocean, not associated with dolphins or floating objects but possibly associated with seabirds.

A detailed discussion on this subject, particularly on FADs, is presented in the following section. However, it should be noted that operations on dolphin schools are observed only in the Eastern Pacific Ocean since tuna schools are associated with dolphins only in that region. When United States fleets were fishing in this area up until the 1990s, dolphin sets were declining, primarily due to mitigation efforts required as a result of pressure from environmental groups and the adoption of dolphin-free labelling schemes (Joseph, 1994; and see below). A secondary reason was the reduced abundance of yellowfin in the area and the reduction in the number of United States purse seiners operating in the area. When Mexico's fleet became the major fleet in this fishery, the sets on dolphin schools increased again.

4.2.6 Development of FADs and changes in target species

The thermocline in the eastern part of any ocean is shallow, permitting relatively small purse seines to be used for schooling fish. It is considered that such a shallow thermocline keeps the fish in the net near the surface during pursing the net. However, in the western part of the oceans, the thermocline is located at a greater depth and fishing operations similar to those used in the eastern part of the ocean fail to catch tuna. This phenomenon delayed the expansion of purse seine fishing. However, fishing operations on floating objects have been widely practiced in tropical areas for many years. In the Eastern Pacific Ocean, particularly in the Gulf of Panama off Ecuador where natural logs are found in abundance, log sets have been common since the purse seine fishery was initiated. The floating objects attract fish schools underneath them and those fish remain near the surface while setting and pursing the net. In the Western and Central Pacific Ocean, Japanese purse seining began in the 1960s by adapting a deeper and fast sinking seine and setting on tuna schools associated with natural floating objects. This system has been adopted by other fleets in the Western and Central Pacific Ocean as well as in the Western Indian Ocean since the early 1980s. Therefore, even before the introduction of FADs (in the 1990s), the proportion of catches from floating objects were high in these two areas.

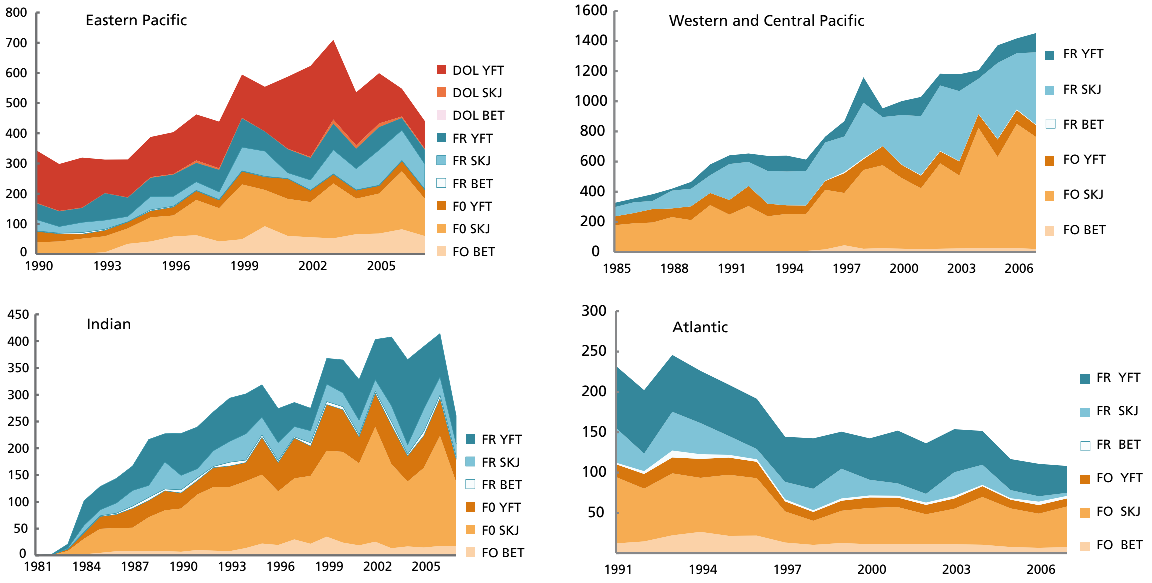
The development of FADs began with fishers attaching reflectors to the logs, and later radio buoys, GPSs and transmitters to track them. These efforts ultimately led to the development of FADs, i.e. man-made floating objects. Operations evolved year by year through fishers' effort to develop new structures and equipment in order to track FADs, attract more fish and estimate the abundance of fish under FADs (Itano, Fukofuka and Brogan, 2004). In addition, greater use of tender vessels, as discussed in the previous section, increased FAD fishing's operational efficiency.

The most recent developments include expansion of the use of anchored FADs, which are commonly found in the coastal waters of Papua New Guinea, the Philippines and Indonesia (Miyake, 2005a; Babaran, 2006). Due to the use of this type of FAD, catches by small-scale, coastal fisheries rapidly increased. In these operations, the target species are small pelagic fish of any kind including juvenile tunas.

Purse seine catches in weight of bigeye, skipjack and yellowfin and by school type are shown in Figure 18. This figure should be read in association with Figures 9 and 17. In Figure 18, catches from schools associated with dolphins are in red; free schools (unassociated schools) are in blue; and those from floating objects are in orange. The weight of catches from both free schools and floating objects increased in all of the ocean regions except the Atlantic. The rate of increase is much faster with floating

FIGURE 18

Purse seine catches in thousand tonnes of YFT, SKJ and BET by ocean and by type of setting practice, various years



Note: DOL = dolphin, FR = free, FO = floating object.
Source: RFMOs, personal communications.

objects, particularly since the early 1990s when FADs were introduced. In the Western and Central Pacific Ocean and Indian Ocean, the proportion of catches from floating objects was relatively high (70 to 80 percent) even before the introduction of FADs. On the other hand, in the Eastern Pacific Ocean, the share of floating objects used to be low but increased rapidly since the early 1990s from 20 percent to 50 percent, as catches from schools associated with dolphins declined. In the Atlantic, the proportion of catches taken in association with floating objects is relatively low (around 50 percent) throughout the period. While this may or may not be the result of regulatory measures taken by ICCAT to restrict FAD fishing, it is definitely related to the fact that purse seine fishing is restricted to the Eastern Atlantic because of the shallow thermocline, and thus less dependent on schools associated with floating objects as in the Western Atlantic where FADs are essential.

It is clear that catches from schools associated with dolphins are almost exclusively of yellowfin and include almost no bigeye. In free schools, yellowfin dominate in the Indian and Atlantic Oceans but skipjack-dominated catches are common in the Western and Central Pacific Ocean. In the Eastern Pacific Ocean free school sets, yellowfin were the major species in the past but in the last several years skipjack have dominated. In all of the regions, bigeye catches (in weight) from free school sets are almost negligible. In the catches associated with floating objects skipjack dominated in all of the areas. Yellowfin catches around floating objects are generally much less than skipjack. Bigeye catch around floating objects is higher than that of yellowfin in the Eastern Pacific Ocean, as was also the case in the early 1990s in the Atlantic.

4.2.7 Interactions between fishing gears and species

Tuna fisheries are characterized by their multispecies and multigear nature. This point was highlighted when purse seine catches increased substantially in recent years with the advent of FAD fishing. The key to success in any management plan is to treat all fisheries fairly, but this becomes increasingly difficult to achieve as the number of gear interactions rises.

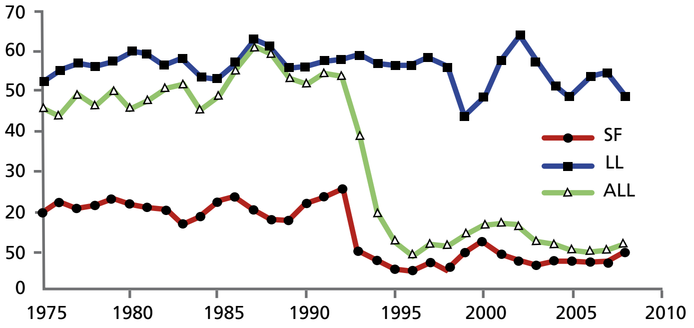
Before the beginning of purse seine FAD fisheries, purse seines and longlines were to some extent sharing tuna stocks with minimal interaction: longlines were targeting large-sized, deep water yellowfin and bigeye, while purse seines were targeting skipjack and relatively small-sized yellowfin in feeding schools near the surface. In the Eastern Pacific Ocean, dolphin school sets contained large-sized yellowfin but almost no bigeye. FAD fishing, in contrast, catches only small-sized tunas without discriminating between species. Under a FAD, a very specific ecosystem is formed and a set on a FAD school includes many non-target fish. Bigeye is one of the major species caught by FAD fishing. In relative terms, the amount of bigeye caught is similar to or less than the amount of yellowfin caught. However, because the stock size of bigeye is far smaller than the stock size of yellowfin, the impact of the purse seine catch on the bigeye stock is much more serious than it is on the skipjack and yellowfin stocks (Aires-da-Silva and Maunder, 2009; Miyake, 2005b; and IATTC, 2008).

The effects of gear interactions between purse seines and longlines on the bigeye stock is used here as a case study. Because bigeye is the major target of longliners, gear interactions have seriously affected the longline fishery in two ways: reduction of SSB and reduction of MSY.

As purse seine catch is almost exclusively juvenile bigeye, yield per recruit (Y/R) has reduced as purse seine catches have increased. This is clearly indicated in Figure 19 (reproduced with permission from Aires-da-Silva and Maunder, 2009), which shows the annual mean weights of bigeye caught by surface gear (almost all of which are purse seiners) and longlines, and the mean weight of the entire catch of bigeye in the Eastern Pacific Ocean. This figure clearly indicates that the mean weight of purse seine catches is declining each year (from 20 kg to <10 kg) while the mean weight in longline catches

FIGURE 19

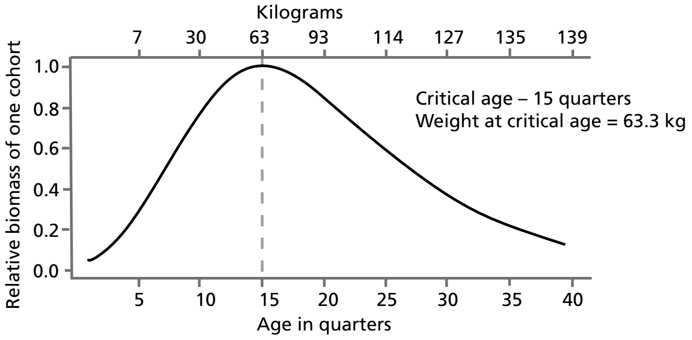
Average size of BET (body weight in kg) caught by surface gear (SF mostly purse seine), longline and all gear types combined (All) Eastern Pacific Ocean, 1975–2008



Source: Based on Aires-da-Silva and Maunder, 2009.

FIGURE 20

Distribution of biomass in a cohort of BET by age and size of fish



Source: Based on Maunder and Hoyle, 2006.

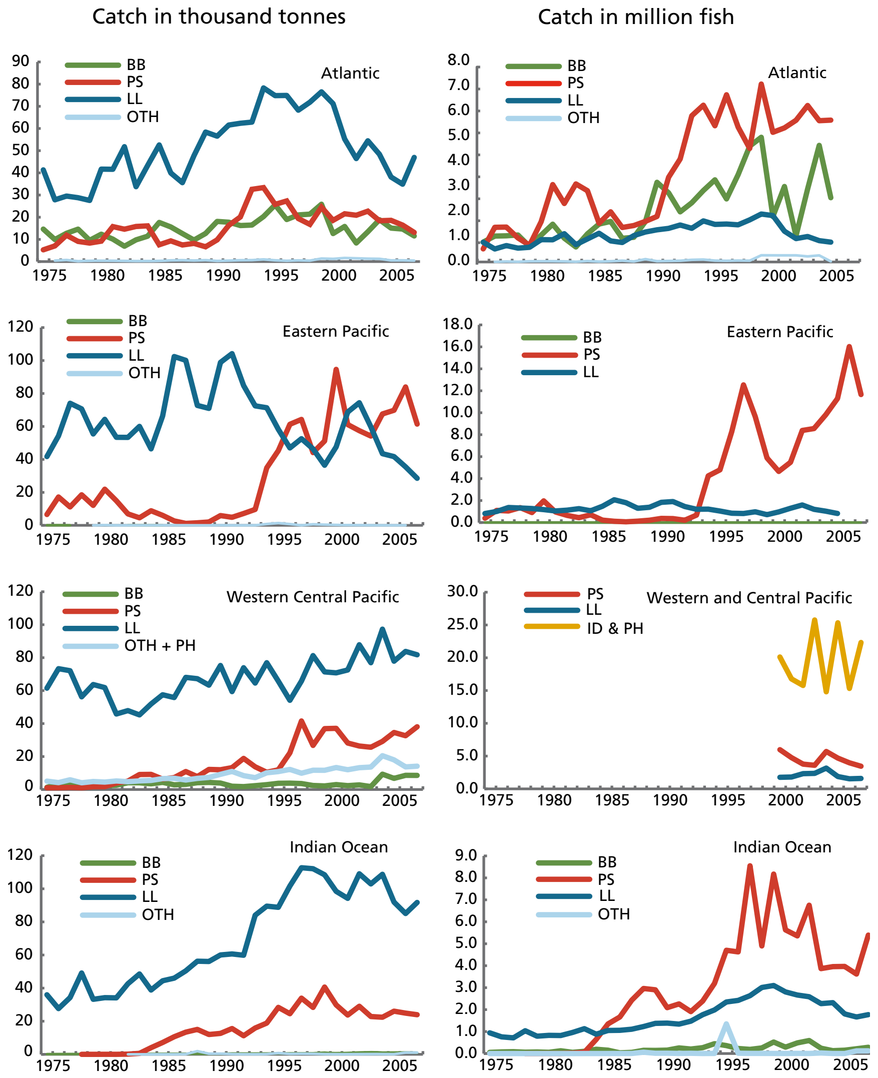
remains between 45 and 70 kg (annual fluctuations appear to be related to fluctuations in recruitment). The sharp decline in the mean weight of the total catch suggests that the relative amount of purse seine catch is increasing.

Given a certain recruitment, the biomass at an age (size) of a cohort of fish is determined by the balance between natural mortality and growth. Y/R is then dependent on the age-specific fishing mortality on this biomass-at-age structure. Figure 20 (Maunder and Hoyle, 2006) shows the relative biomass of one bigeye cohort by age (or size) estimated using recent fishing patterns (catch curves) and parameters applied in recent assessments. The maximum biomass of bigeye is obtained roughly at an age of 15 quarters (or 3 years, 9 months) and at 60 kg (relatively large as compared to 35 kg for yellowfin). Therefore, based on the data cited above, longlines are catching bigeye at its optimal size (Miyake, 2007). Although there are slight differences in biological parameters for bigeye between oceans, as the catch curves are similar, similar results would be expected for other oceans.

According to stock assessments conducted by RFMOs (see Section 3), most bigeye stocks' biomass is still above or near the MSY level; however, fishing mortality (F) is considerably higher than F at MSY. Figure 21 presents bigeye catches by gear type for four major ocean regions. The left column is presented in catch weight (tonnes), while the right column shows the catch in number of fish.

FIGURE 21

Catch of BET by ocean (Atlantic, Indian, Eastern Pacific and Western and Central Pacific) and by gear type (baitboat [BB], purse seine [PS], longline [LL], other [OTH], and Indonesia and Philippines fisheries [ID & PH]), 1975–2007

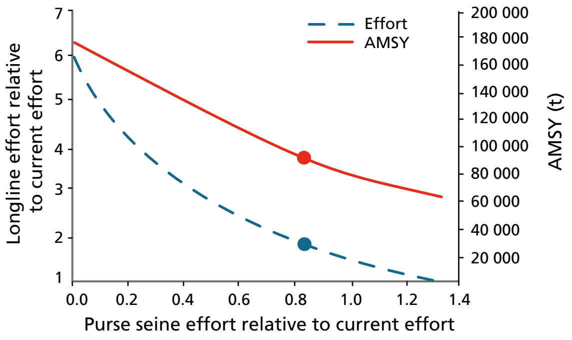


Source: RFMOs, personal communications.

In most cases, catches are considered in terms of weight. If that is the case, as discussed in Section 4.1.2, longline (including both distant water and coastal) catches have increased steadily at least until the mid-1990s in all areas. After that time catches continued to increase in the Western and Central Pacific Ocean but declined in other ocean regions. Particularly in the Eastern Pacific Ocean, longline catches of bigeye have declined rapidly since the early 1990s, coinciding with the introduction of FAD fishing and the rapid increase in purse seine bigeye catches. In 2000, purse seine catches of bigeye overtook longline catches of bigeye in the Eastern Pacific Ocean and have exceeded them ever since.

In the Atlantic and Indian Oceans, longline bigeye catches in weight started to decline in the late 1990s, which coincided with an increase and then peak in bigeye catches by purse seines (Figure 21). In the Western and Central Pacific Ocean, purse seine catches also increased rapidly in the mid-1990s, but longline catches of bigeye have not declined. In the Western and Central Pacific Ocean, the coastal fisheries of

FIGURE 22
Average maximum sustainable yield (AMSY) comparison between purse seine and longline effort



Source: Copied from IATTC, 2007.

Indonesia and the Philippines also catch large quantities of bigeye, but the catches of these fisheries are not well documented.

Stock impacts are generally better evaluated by number of fish, which are shown in the right panel of Figure 21. According to these data, in all ocean regions, purse seine catches in number of fish are far higher (two to more than ten times) than catches of longlines during the years in which substantial purse seine catches were made. In particular, in the Eastern Pacific Ocean in recent years, purse seine catches exceeded longline catches not only in number of fish but even in weight of catches. One of the reasons is the very high proportion of juvenile bigeye in the FAD fishery off Ecuador. In addition to this, some of Ecuador's purse seiners are now targeting bigeye even though bigeye remains only an incidental catch in other regions. These facts, in association with Figure 20 (which indicates that 1 kg of FAD catch is equivalent to more than 10 kg of longline catch), make it obvious that the current bigeye catch by purse seines, particularly on FADs, is affecting the bigeye stock to an equal or greater extent than the bigeye catch by longlines. In the Western and Central Pacific Ocean, much more of an effect on the bigeye stock is being exerted by the small-sized bigeye catches of the coastal fisheries off the Philippines and Indonesia, which are mostly conducted on anchored FADs.

Another important point is that the MSY itself is reduced when small-sized fish become abundant in the catches. Figure 22 (IATTC, 2007a) shows the average maximum sustainable yield (AMSY) for a given level of fishing effort (purse seines on the x-axis and longlines on the y-axis). The current situation is indicated by the position of the circles. If there were to be less purse seine effort and more longline effort, AMSY would increase. If there were to be no purse seine catch, the AMSY would be twice as large as it is now. If only longlines were to be catching bigeye in the Eastern Pacific Ocean, the calculated MSY would be about 130 000 tonnes, as compared with the current AMSY which is estimated at about 80 000 to 90 000 tonnes. However, it should be noted that it would require more than six times the current (2006–2007) longline effort to achieve that yield.

To sum up the current situation, in almost all oceans, FADs and some coastal fisheries (with anchored FADs) have caused a rapid increase in the catch of juvenile tunas. The catch of such small fish reduces the Y/R as well as the AMSY, both for yellowfin and bigeye. As a consequence, longlines which target spawning-size fish are disproportionately affected as the abundance of large fish declines. This is particularly problematic for bigeye since the total biomass is much smaller than for yellowfin and hence the proportion of the bigeye stock caught by FAD fishing taking small-sized fish

BOX 3

Bluefin farming

The term "bluefin farming" generally refers to bluefin (Atlantic, Pacific and southern) fattening operations. Juvenile or adult bluefins, which are lean in fat content, are generally captured by purse seines and kept in floating cages, fed excessively for a few months and then exported for the *sashimi* market. Purse seine-caught southern bluefin in Australia, Atlantic bluefin in the Mediterranean and Pacific bluefin off the west coast of the United States and near Japan were formerly very cheap products, used only for canning, in the production of "*mojama*" (a salted and dried form), or sold in local fresh fish markets. At that time, some post-spawning bluefins were exported to the Japanese market but were found to be unacceptable due to the low fat content.

Commercial bluefin farming began with Atlantic bluefin in Canada in the 1960s, and spread to Spain in the 1970s, to Australia for southern bluefin in the 1980s, and throughout the Mediterranean for Atlantic bluefin in the 1990s. Small-scale farming was also initiated in Japan with Pacific bluefin. These farmed products brought a good price (not as high as natural, high-quality bluefins but enough to turn a profit) and became very popular in the Mediterranean. In 2002, Mexico began Pacific bluefin farming in the Eastern Pacific Ocean. As a result of this expansion, the quantity of farmed Atlantic bluefin products increased rapidly, and the ex-vessel price of Atlantic bluefin in the Mediterranean as stock for the farms has soared.

In areas where only small bluefins are captured (e.g. Croatia and Japan), these fish can be held in cages for over a year until the fish reach the commercially acceptable size for the Japanese market.

is higher. Therefore, even if stock biomass is above or close to the MSY level, if the total fishing mortality (F) on the stock is excessively high, management to reduce F becomes necessary. This is particularly apparent in the Eastern Pacific Ocean and Western and Central Pacific Ocean.

The target species for purse seines are skipjack and yellowfin, except in Ecuador, where some vessels are targeting bigeye. Despite targeting strategies, when setting on FADs all species are caught together. This situation means that any regulations introduced to protect bigeye would affect the catches of skipjack and yellowfin, even if less stringent (in case of yellowfin) or no regulations (in the case of skipjack) are required for these species. For these reasons, species interactions such as those described in this section are important considerations when formulating management measures. The best solution for all fisheries would be to find a means of avoiding small fish and/or bigeye catches in FAD-related purse seine fisheries. These types of mitigation measures are discussed in Section 5.2.4.

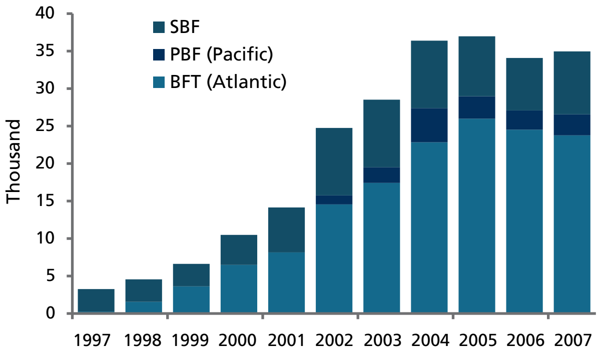
4.2.8 The development of tuna farming

Large-scale southern bluefin tuna farming started in Australia in the late 1980s and Atlantic bluefin began in the Mediterranean in 1997 (see Box 3). These operations developed rapidly and now farming has even been established in the Eastern Pacific Ocean for Pacific bluefin. The history and development of tuna farming activities are well documented in Miyake (2005c, 2007), and a general review of issues relating to Atlantic bluefin farming in the Mediterranean is provided in FAO (2005). As this is a very complicated subject, this section of the paper will only provide a brief summary of key issues. Economic and market analyses are presented in Section 6.2.

Figure 23 shows Japanese imports of farmed bluefin tunas. The country of capture is not shown as it can be different from the country of farming, because stocks of fish

FIGURE 23

Estimated imports (round weight in thousand tonnes) of farmed Atlantic bluefin, Pacific bluefin and southern bluefin tuna by Japan, 1997–2007



Source: Data provided by ICCAT Secretariat and Japanese custom statistics.

are frequently traded between countries and within the European Union. The data shown in the Figure are estimates based on ICCAT Bluefin Tuna Statistical Documents (BFTSDs) provided by the ICCAT Secretariat and Japanese custom statistics. As much as possible, incidents of double counting of the same fish during import and re-export have been eliminated. The data are in units of estimated round weight upon import. Estimating the live weight of the fish at the time of introduction to the farming cage is very difficult due to uncertainties in growth and mortality rates during the fattening process. As will be discussed in later sections, Japanese imports converted into round weight closely correspond to the estimates of the total farmed tuna output up until 2007 (source data provided by ICCAT).

According to official figures, Spanish production in live weight of Atlantic bluefin tuna in the Mediterranean ranges from 3 000 tonnes (2006) to 6 424 tonnes (2004). Since attaining these figures the production has declined over time. Production was valued at approximately 45 million euros according to the most recent official figures (assuming an average price of 15 euros per kg). Other earlier reports (2001–2002) quote prices at much higher levels: around 30 to 40 euros per kg for Spanish farmed tuna on the wholesale Japanese market and around 22 to 30 euros per kg for ex-farm prices (OFIMER, 2003). At that time, the turnover of the entire Spanish industry was estimated at 150 million euros, i.e. more than three times the current official figure. Most of the Spanish Atlantic bluefin products go to the Japanese market, which has diversified its supply sources in recent years and has accumulated substantial inventories in Japan as well as in Spain. It has been suggested that these factors explain the lower prices now obtained by Spanish farms (Jiménez-Toribio and García-del-Hoyo, 2007). Another factor is likely to be the appreciation of the euro relative to the Japanese yen.

A minor but increasing portion of farmed tuna is either exported to markets other than Japan or consumed in domestic markets (data source: ICCAT). Part of the reason for uncertainty surrounding this issue is that the ICCAT BFTSDs for trade to countries other than Japan appear to be incomplete. If farmed tunas are consumed without entering international trade, e.g. sales of fish within the European Union, they do not require ICCAT BFTSDs. Table 5 shows the numbers of farms and the total farming capacity for each Mediterranean farming country, as registered with ICCAT at the end of 2008. If all the cages are used to their full capacity, up to 58 000 tonnes of Atlantic bluefin can be produced (output). As described below, the amount of Atlantic bluefin needed as input to produce this amount (possibly 48 000 tones assuming a 25 percent

TABLE 5
Registered number and capacity of farming cages for BFT in the Mediterranean Sea

Country	Number of farm registries	Total capacity *(tonnes)*
Croatia	11	7 880
Cyprus	3	3 000
Spain	14	11 852
Italy	15	11 500
Malta	8	11 150
Libya	1	1 000
Morocco	1	300
Tunisia	4	2 400
Turkey	13	8 960
Total	**70**	**58 042**

increase in weight during farming as adopted by ICCAT) is substantially in excess of the BFT TAC adopted by the Commission. Therefore, the problem is very similar to that of fishing capacity as discussed in Section 5.1.5.

The development of tuna farming is important in two major ways. First, the fishing effort and catch of Atlantic bluefin has increased very substantially in the past few years. Current maximum fishing capacity for Atlantic bluefin is estimated to be over 60 000 tonnes, or 2.5 times the TAC (ICCAT, 2008). ICCAT has taken various measures to control both fishery and farming activities, but agreeing to management measures, and maintaining compliance with these measures, has been very difficult (see Section 5.1). Second, the sudden increase in the supply of tuna with a high fat content has destroyed not only the pricing system of the Japanese market but also the structure of the Japanese market and distribution system, which in turn has affected the tuna fishery as a whole, not only the fishery for Atlantic bluefin tuna. These issues are discussed in greater detail in Section 6.2.2 and 6.2.4.

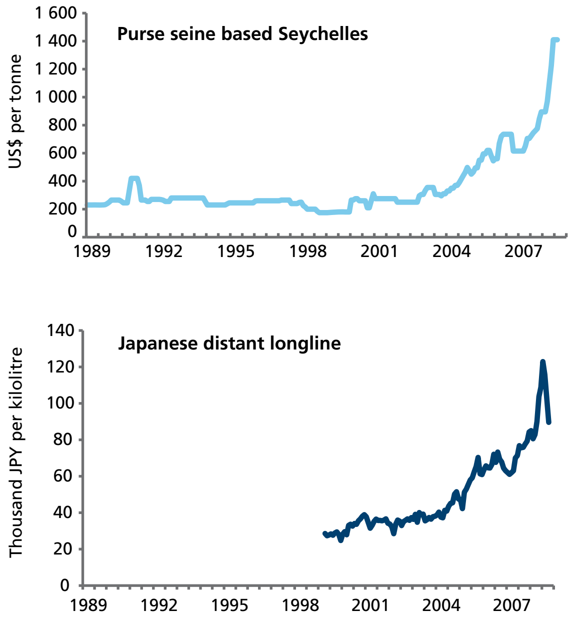
4.3 OPERATING COSTS

The difference between the revenue (i.e. landed values of the catch) and variable and/or fixed operating costs determines the amount of profit or loss to the fishery. Operational cost-effectiveness is therefore one of the most important factors affecting fisheries trends, but it is a difficult subject to tackle for three reasons:

- confidentiality of financial operations and data in the private sector;
- extreme variability in cost items among countries, areas, fisheries, years and even individual vessels; and
- the effects from other bio-, socio-, and economic factors including government subsidies, which may be direct or indirect.

The instability of the world monetary system is influencing many aspects of the tuna industry and is discussed in various sections of this paper. Operating costs are highly susceptible to such instability. There are three major currencies whose exchange rates influence the world tuna business, namely the United States dollar (US$), the European Union euro (euro) and the Japanese yen (yen or JPY). Comparisons of operating costs among various locations and fisheries depend on which currencies are arbitrarily chosen as the basis of the analysis. Such choices may or may not be representative of actual currency factors driving the complex international tuna market. These issues will be discussed in further detail in Section 6. Since the purpose of this paper is to provide an overview of current tuna fisheries, several case studies of typical fisheries are used in the following sections to provide a brief qualitative description of the operating costs of fishing activities.

FIGURE 24
Average price of fuel supplied to the purse seines based in the Seychelles, 1989–2009 (upper panel) and the Japanese distant water longline fishery, 1999–2008 (lower panel)



Source: Personal communications with Seychelles Fishing Authority and Japan Tuna Fisheries Cooperative Association.

4.3.1 Fuel price

The major variables influencing total fisheries operating costs are fuel and labour. Undoubtedly, the most important influence on the tuna fishing industry in recent years has been the exponential rise in the worldwide price of crude oil, reflected by increasing fuel (gasoline or diesel oil) price as shown in Figure 24. The upper panel shows the monthly unit fuel price for the purse seine fleet based in the Seychelles from January 1989 to June 2008 (personal communications with Seychelles Fishing Authority). The lower panel shows the average monthly unit fuel price paid by the Japanese distant water longline fleet from April 1999 to November 2008 (personal communications with Japan Tuna Fisheries Cooperative Association). The x-axes have been aligned for comparison between the two series. The Japanese price represents the average price of the domestic and foreign port bunkering and transshipment suppliers. Although not shown in this figure, the Amsterdam-Rotterdam-Antwerp (ARA) Gasoil Spot Price FOB (freight on board), a proxy for the world market, shows identical trends (ARA, unpublished data).

The reported reasons for the sharp increase in fuel prices in 2002–2008 are steady growth in demand by China and India and, probably more important, the overheating of investments in petroleum commodities by speculative investment funds. In September 2008, the collapse of the United States' bubble economy resulted in fuel prices falling from US$140 to US$35 per barrel by January 2009 (according to the ARA spot price).

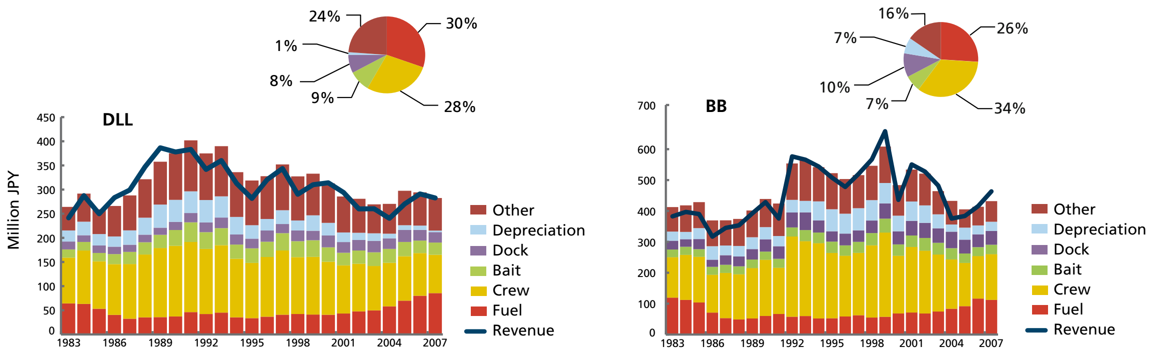
4.3.2 Case study 1: Japanese distant water longline and baitboat fisheries

The information for this case study derives from interviews with Japanese distant water longline and large-sized baitboat fishers (survey by the Japan Tuna Fishermen's Cooperative Association). Summary data for both fisheries are given in Figure 25.

The distant water longline data are stratified by target species and vessel size category, which makes them rather difficult to interpret. For the purposes of this paper a typical

FIGURE 25

Expenditure (columns) and revenue (line) of Japanese distant water longliners (left panel) and baitboats (right panel), 1983-2007



Note: Pie charts represent the share of expenditure on each item in 2007.
Source: Survey by the Japan Tuna Fishermen's Cooperative Association, unpublished data.

fleet is considered to be composed of vessels of about 300 gross register tonnage (GRT) targeting yellowfin and bigeye. Annual data shown in Figure 25 represent the average per vessel cost of a trip varying in length between 300 and 400 days, i.e. sometimes longer than one year. When a trip covered multiple years, it was assigned to the year in which it terminated. The number of trips in the sample for each year ranged from 30 to 110.

The baitboat data are derived from large vessels (>360 GRT) which make between six and ten trips per year. As there were data available for 20 to 30 vessels in each year, the total sample size in each year varied between 150 and 300 trips.

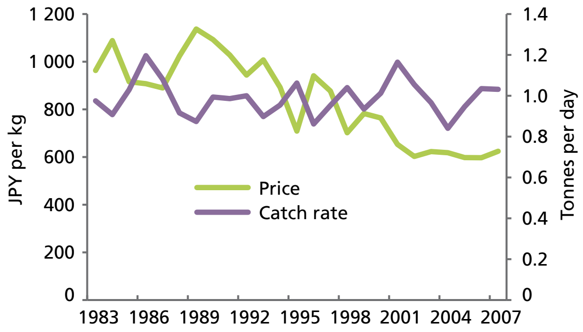
In both cases, revenue refers to total landing value. Crew costs include wages, crew transport, insurance and meals. Dock costs refer to all costs for maintenance and repair of vessels and fishing gear. Other costs include marine insurance, transshipment fees (only where applicable), port fees, and other miscellaneous costs. Only those costs related to fishing operations are assessed, for example, administrative costs, sales costs and bank interest are not included.

The results of the cost computations for 1983–2007 are shown in Figure 25 for distant water longliners (left panel) and baitboats (right panel). Pie charts inside each panel represent the share of the total for each item in 2007. The length of the bar for each year indicates the cumulative cost and the data series represented by the solid line shows the landed value of the catch (i.e. gross revenue). The average fishing cost (expenditure) and landed value of the catch (gross revenue) are similar, although gross revenue is slightly lower than expenditure, particularly in recent years and for the distant water longline fleet. If the results are considered in terms of net revenues, the discrepancy is even greater as overhead costs such as interest for capital and operating funds, and sales and administrative costs, need to be added to the expenditures. In other words, on average, the distant water longline fleets are operating at a loss. However, if fishers cease operations, all overhead costs become debt, and without further revenue deficits would become even greater. This situation begs the question of why the fleet has not become bankrupt. One explanation may lie in the fact that investment in fisheries is always speculative and, even though the average return on investment may be negative, occasionally a very high profit can be made. This may contribute to a willingness to continue operations rather than declaring immediate bankruptcy and incurring a large debt.

There are several other possible explanations for the apparently unprofitable situation, illustrated by Figure 25. First, as discussed in the following section,

FIGURE 26

Catch rates and landing prices for catches of the Japanese distant water longline fleet, 1983–2007



Source: Survey data by the Japan Tuna Fishermen's Cooperative Association, unpublished data.

depreciation costs are an accounting technique and not actually a real expenditure. Second, if vessels are part of a vertically integrated company, i.e. they are selling to a processor or broker which is part of the same company, the ex-vessel price is not a true market price, but instead should be viewed as a transfer price. The vessels may then be run at slight losses in order to insure a steady and reliable supply of fish to the integrated processing company. In spite of this possibility, it should be noted that most longliners are not integrated with land-based fish dealers. Finally, it may be the case that revenue might be under-reported to authorities.

The peak in operating costs for these fleets occurred in 1991 and trailed the peak in revenue by several years. Thereafter, a sharp decline in gross revenue was observed. Figure 26 compares landings (in tonnes) per trip-day and landing value per kg (i.e. ex-vessel price). Both of these data series are in processed weight (gilled and gutted, round or other forms) and do not account for species composition. Based on a comparison of Figure 26 and the left panel of Figure 25, it is clear that gross revenue reflects changes in fish price rather than the catch rate. As the fish price began to decline in the early 1990s reducing gross revenue, vessel owners started cutting expenditures as much as possible. In the distant water longline fishery, the largest savings were achieved by reducing labour costs by replacing Japanese fishing crews with foreign crews (mostly Indonesians). Fuel cost increased during this time (Figure 24) but its share of total expenditure has remained less than the cost of labour until very recently. In addition, depreciation has decreased as vessels became older.

For baitboats, both gross revenue and fishing expenditure per year per vessel are nearly twice as high as for distant water longliners. The discrepancy between the revenue and expenditure is also less for baitboats. Nevertheless, when considering the higher costs of distant water longliners versus baitboats, several important differences should be borne in mind. As explained above, the annual costs for longliners may actually be based on periods greater than one year, whereas for baitboats the figures are strictly annual data. Furthermore, longline vessels targeting Atlantic or Pacific bluefin tunas, even if for only part of the year, for example, until the vessel quota is reached, are economically slightly better off. There are also important operational differences such as the requirement for more skilled labour input on baitboats, which possibly reduces the opportunity for the use of less-skilled foreign crews. In contrast, maintenance and other expenditures for distant water longliners are higher because they are often incurred at foreign ports.

4.3.3 Case study 2: Japanese offshore longline fleet

This case study is based on vessels classified as offshore longliners due to their size rather than their actual fishing ground. According to Japan's fishing licensing system, longline vessels >20 GRT and <120 GRT, which target mainly tunas and tuna-like species (including billfishes), are categorized as offshore longline vessels. The fishing grounds of the offshore longline fleet are located almost exclusively in the Western and Central Pacific Ocean but are relatively close to the Japanese coast.

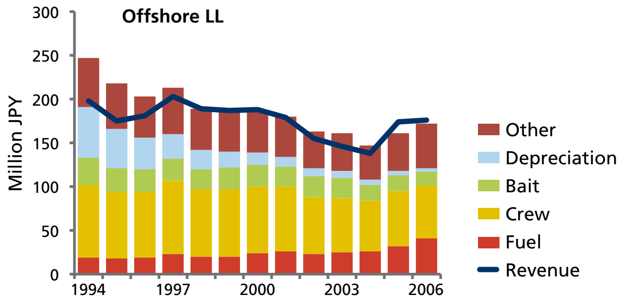
The annual cost and gross revenue (total annual landed value of the catch) data shown in Figure 27 derive from Japanese offshore longline vessels with holding capacities of around 120 tonnes, i.e. the top end of the size range for these vessels. For each year between 1994 and 2006, data from 20 to 40 such vessels were compiled and averaged (Ishimura and Yokawa, 2008). Note that the crew cost in this figure, as in the case of distant water longliners, includes wages, insurance and meals. The category of "other cost" includes all costs other than those for crew, fuel and bait. The proportions of fuel, crew and bait costs are very similar between distant water and offshore longliners.

Although these cost and revenue data provide a comprehensive financial profile of the hardships faced by this fleet in recent years, cost data must be carefully interpreted. One of the key issues is depreciation. Depreciation of durable equipment, including vessels and gear, was a substantial portion of the total cost in the early years (22.6 percent in 1994), but has been persistently declining over time. As explained with the case of distant longliners, this variable is only an accounting technique and does not represent real expenditure. Also, this effect is to be expected given that many of the vessels in this sample were built in the early 1990s and depreciation costs are calculated on the basis that durable equipment is arbitrarily considered to be partly used up each year until the end of its operational life. (In addition, the values of fixed assets are usually subject to property taxation and thus tax liabilities are reduced as asset values depreciate.) Vessel refurbishment costs and loan payments, which are included in the "other cost" category, were considerable portions of total costs from 1994 to 2001. The availability of alternative bait (e.g. Pacific sardine instead of saury or squid) and the introduction of foreign labour forces enabled a reduction in bait and crew costs of 50 percent between 1994 and 2006. In this sense, the situation for the offshore longline fleet was similar to that of the distant water longliners except that the reduction in labour costs is far greater for distant water longliners because a larger percent of the crew are foreign citizens.

The trend of increasing fuel cost over time is consistent with the aforementioned global fuel price rise. The increase in the fleet's total fuel costs from 26 million yen per year in 2004 to 41 million in 2006 changed its financial profile substantially as fuel costs

FIGURE 27

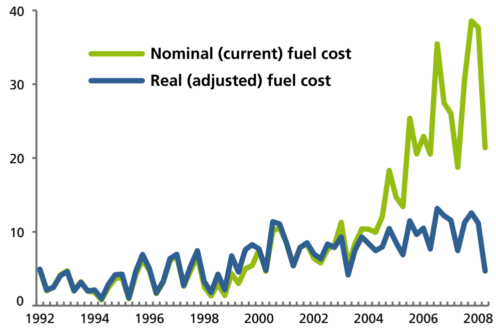
Expenditure (columns) and revenue (line) of Japanese offshore longliners, 1994–2006



Source: Authors' surveys.

FIGURE 28

Expenditure for fuel per trip (in million United States dollars) for the purse seine fleet based in the Seychelles, 1992–2008



Source: Personal communications with Seychelles Fishing Authority.

rose from 7 to 23 percent of the total operational cost between 1994 and 2006. Total revenue exhibits fluctuations over time but costs remained higher than revenues for this fleet except in recent years.

4.3.4 Case study 3: Seychelles-based European purse seine fleet

The recent trend of increasing fuel expenditure (Figure 28), caused by soaring fuel prices coupled with increasing fishing effort and larger vessel size, has been dramatic (personal communications with Seychelles Fishing Authority). The green line shows nominal expenses (in United States dollars) of fuel purchased by the entire European purse seine fleet landing at Victoria, Seychelles, from 1992 to 2008. The blue line gives real expenses (in United States dollars deflated by a fuel price index for the Seychelles using 2001 as the base year). The real impact of these rising prices on the profitability of the European fleets has probably been less than suggested by the nominal trend, given that the sales of frozen tuna are in euros, the fuel is purchased in United States dollar, and the euro has appreciated against the United States dollar in recent years.

The fuel (gas oil or diesel oil) expenditure represented an average of 60 percent of the total port call expenditures of the purse seine fleet landing or transshipping at Victoria, Seychelles, until 1999. This percentage increased to 70 percent in the following four to five years and reached as high as 92 percent in 2008. For purse seine fleets in general, regardless of size, in the 1980s and 1990s fuel costs represented an average of 20 percent of the total operating expenditure. In recent years, this amount increased to 50 percent or more for some vessels, a considerably higher percentage of the total expenditures than for either the Japanese distant water longline or baitboat fleets.

Fuel consumption varies according to the size and power of the purse seiner (Figure 29, upper panel). Average consumption is around 430 m^3 (i.e. 350 tonnes[2]) per trip of 45 days. At the peak price in September 2008, the fuel consumption per trip cost 250 000 euros. From a summer 2008 sample of 20 European purse seine vessels (survey by P. Guillotreau) operating in the Indian Ocean, a linear correlation was shown between power in kilowatt and fuel consumed in tonnes: every additional kilowatt increases fuel consumption by 160 kg per fishing trip. The relationship between the length of a boat and its fuel consumption appears exponential rather than linear (Figure 29, lower panel).

Figure 30 shows the estimated costs (expenditures) and gross revenue (sales value) obtained through a survey of 17 French purse seiners carried out in summer 2008, at

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[2] The appropriate coefficient to convert volume (in m^3) to weight (in tonnes) varies according to the type of fuel supplied, but in the Seychelles it is 0.815.

FIGURE 29

Relationship between purse seine fuel consumption per trip and power (upper panel) and between purse seine fuel consumption per trip and boat length (lower panel)

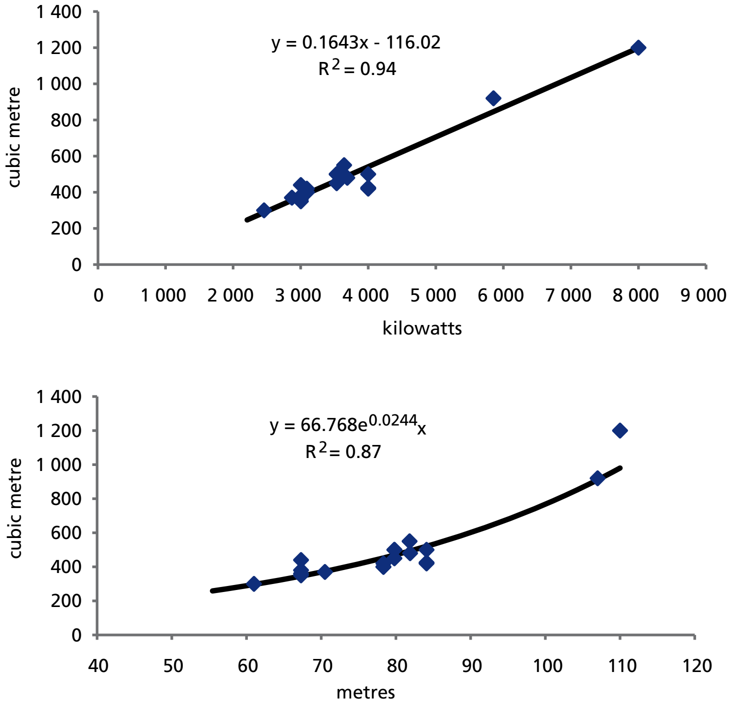
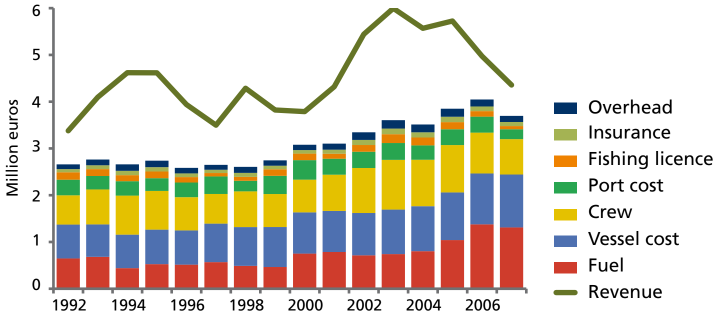


FIGURE 30

Estimated expenditure (columns) and revenue (line) for the purse seine fleet operating in the Indian Ocean, 1992–2007



Source: Personal communications with Seychelles Fishing Authority.

Victoria, Seychelles (survey by P. Guillotreau). The sales value was computed from French ex-vessel prices (SOVETCO, unpublished data) and catch and species composition data. Costs were estimated using data compiled by the Seychelles Fishing Authority for local economic spending by purse seiners. Local miscellaneous expenditures for port calls have been converted from Seychelles rupees into euros. Crew wages are determined based on a share-type contract under which wages depend on the total value of sales, the crew worker's position, and the characteristics of the vessel (GRT, fish carrying capacity and engine power). Access fees are estimated from the European Union–African, Caribbean and Pacific (ACP) fishing agreement rules (fixed value for a given number of base tonnes and 25 or 35 euros per additional tonne). The overhead (3 percent of sales value), insurance (2 percent) and survey costs were also estimated.

Data on some of the fixed costs (e.g. FADs, repair or maintenance of the engine, and/or fishing gear) were lacking and were thus not included; therefore, operating costs are underestimated to some extent. There were also many elements of operating costs which were not estimated (e.g. travel costs for crew, taxes). Furthermore, depreciation costs were not estimated and this may be the source of differences between the figures for this fleet and those for Japanese fleets (Sections 4.3.2 and 4.3.3). As a result of these biases, the profit (30 percent of the sales) is likely to have been overestimated, even though the magnitude of overestimation appears to be minor.

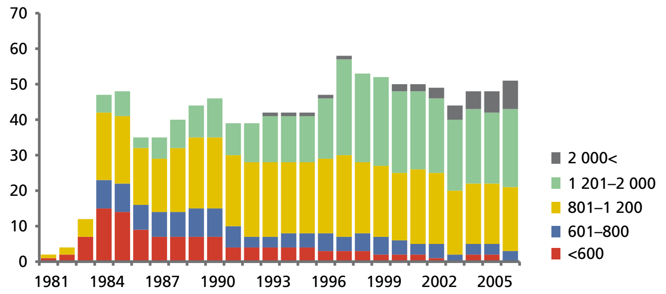
In recent years profit margins are decreasing due to rising fuel prices and, in 2007, lower catches in the Indian Ocean. In the latter part of 2008 and 2009, the operation of purse seines in the most productive area of the Western Indian Ocean became very difficult due to the piracy in the area, and this caused further reductions in catches.

Other factors acting to suppress profits are the increasing costs of constructing and maintaining more sophisticated FADs and greater competition among purse seiners. The French purse seine fleet dispatched 130 FADs annually, whereas the Spanish purse seine fleet released over 300 FADs (Moreno *et al.*, 2007). (It should be noted that costs and earnings may vary considerably between fishing companies.) The average size of fishing vessels has also increased significantly since the late 1990s, as shown by the composition of the fleet by carrying capacity class (Figure 31). The increase in catch, if any, with increasing size of a vessel is not likely to have compensated for this increase in capital expenditure.

The growing fishing effort (or fishing capacity) for this fleet has also been promoted by an increase in use of supply vessels (often called tender vessels), as illustrated in Figure 32. Supply vessels are exclusively used by the Spanish fleet. The use of supply vessels started in the mid-1990s and gradually increased until 2007 when 12 units were deployed (Delgado de Molina *et al.*, 2003; Moreno *et al.*, 2007). Some smaller Spanish purse seine vessels share a supply vessel among two or three purse seiners, whereas each purse seiner in the largest category has its own dedicated supply vessel. The role of the supply vessel is to search for fish schools and to manage the FADs for the mother vessel. This needs to be included as an additional cost for the European Union purse seine fleet, as each supply vessel employs around five to seven crew members, consumes about 80 000 litres of fuel per month, and carries a large amount of expensive electronic equipment. These costs are offset to a large extent by gains in fishing efficiency and catch rate.

FIGURE 31

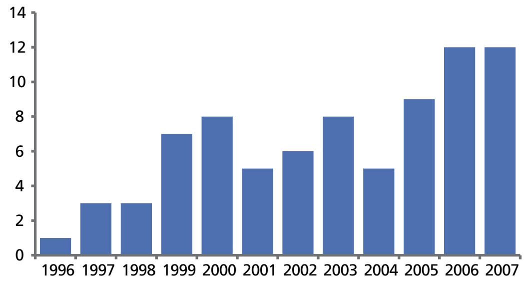
Number of purse seiners by size category of holding capacity (in tonnes) in the Indian Ocean (Spanish-, French- and Seychelles-flagged fleet), 1981–2006



Source: Data provided by IOTC.

FIGURE 32

Number of supply vessels operating in the Indian Ocean, 1996–2007



Note: Data are estimated based upon an assumption of one port call every two months.
Source: Data provided by the Seychelles Fishing Authority, unpublished data.

4.3.5 Case study 4: Japanese distant-water purse seine fleet

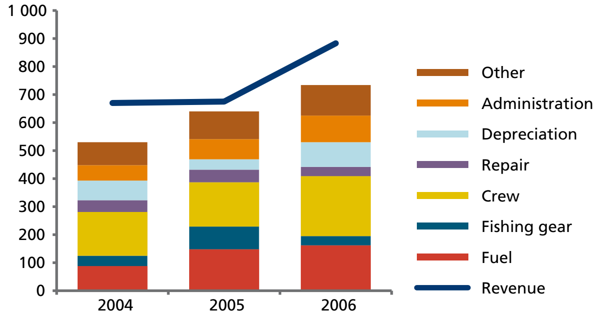
Figure 33 shows operating costs and gross revenue for the Japanese distant water purse seine fleet (Japan Far Seas Purse Seine Fishing Association, personal communication). By law, Japanese purse seiners are limited in size (as of the writing of this paper) to <500 GRT and these vessels fish almost exclusively in the Western and Central Pacific Ocean. Since all the land-based costs (e.g. administration and sales) are included in this data set, the difference between gross revenue and cost should fairly represent profit. However, as the data only cover a three-year period, it is too early to draw firm conclusions from these figures.

4.3.6 Comparisons of the balance between operating cost and revenue among various fleets

Figure 34 compares the cost composition and the gross revenue across the fleets in the case studies for 2006 (i.e. Japanese distant water longline, Japanese offshore longline, Japanese distant water purse seine, Seychelles-based French purse seine and Japanese baitboat fleets). Due to the substantial changes in the economic situation over time, this comparison may not reflect the current situation. In addition, relative rather than absolute comparisons are more meaningful given the variability in exchange rates and the differences in vessel size and target species. For this reason only the proportions of various costs in the total expenditure (i.e. cost shares) are shown and the gross revenue is given only as a percentage of the total operational cost.

FIGURE 33

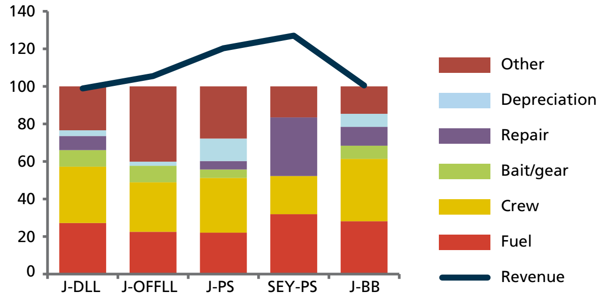
Estimated expenditure (columns) and revenue (line) in million yen for the Japanese distant water purse seine fleet, 2004–2006



Source: Data provided by the Japan Far Seas Purse Seining Fishing Association.

FIGURE 34

Comparison of expenditure (columns) and revenue (line) across various fleets



Note: Japanese distant water longline=J-DLL; Japanese offshore longline=J-OFFLL; Japanese purse seine=J-PS; Seychelles purse seine=Sey-PS; Japanese baitboat=J-BB).
Source: Various, see case studies above.

As explained under each case study, the itemization of costs is not consistent among these fisheries. For example, the case study of the Seychelles-based French purse seiners includes licence fees and other port entry costs in the repair costs, but does not include depreciation and gear costs in the overall operational cost. Hence, in this case the total operating cost is underestimated and the percentage of gross revenue to the total cost is overestimated. Even considering these limitations in the data, it is obvious that longliners and baitboats are operating at levels of very low or negative profit, whereas purse seiners are earning a profit. Another reasonable conclusion is that the revenue per unit cost of fuel appears to be higher for the Japanese fleets.

In terms of gear types, tuna caught by longliners would be higher in value per unit weight, whereas the landed quantity per unit cost of fuel would be higher for purse seiners. Because of these differences in profit margins (at least in part), the purse seine fleet is growing while the longline fleet, particularly in distant waters, is shrinking. In the purse seine fleet, the large fixed costs including vessel purchase price undoubtedly play a role in the increasing amount of effort, increasing catches and more generally in the increasing concentration in the purse seine catch-canning value chain. It should be noted, however, that the operation of purse seines is economically more risky than the operating of longlines as it represents a high-risk, high-return type of investment. For purse seine operations, the larger capital costs, larger catches and production scale, and potentially lower number of vessels in the fleet, all provide a greater potential for quasi-vertical integration whereby canners own all or part of a purse seine fishery.

5. Management-related issues influencing tuna fisheries

5.1 MANAGEMENT MEASURES AND COMPLIANCE

In this section, management measures currently adopted by RFMOs are briefly reviewed on a stock-by-stock basis for each ocean. As a general principle, the tables list only current regulations, but in some cases historical measures which have had major effects on the development of the fisheries have also been included as remarks. Any special exemptions for coastal, artisanal, minor and/or developing countries' fisheries which are included in management plans are not specifically mentioned in the tables.

In most cases the information is drawn from the most recent annual reports of the RFMOs or their scientific committees, but these reports however are not referenced individually. As this paper aims to present only a brief summary of management measures, those who are interested in further details should refer to the original RFMO recommendations and resolutions. This paper also does not provide an evaluation of whether the management measures are fully implemented or effective, except in cases where this information is widely available and the RFMOs, or their subsidiary bodies, have reported that the measures are not achieving their objectives.

5.1.1 Atlantic Ocean

Table 6 briefly summarizes the current management measures for Atlantic tuna stocks. TACs have been set for almost all Atlantic tuna stocks since the 1980s, and according to the reports of the ICCAT Compliance Committee (ICCAT Biennial Reports, 2008, 2009a, 2009b), they have been implemented and complied with. The exceptions to this have been in connection with the eastern Atlantic bluefin stock. TACs for this stock have been exceeded in some years, even according to the formal national catch reports (see Section 4.1.1), and there have also been important amounts of unreported catches estimated (ICCAT, 2009a).

Another case is the management measure instituting a minimum size limit of 3.2 kg for yellowfin and bigeye, which was shown through studies to have been widely flouted and was thus abolished. This minimum size limit did not affect any of the Atlantic tuna fisheries with the exception of the Japanese baitboat fleet based in Ghana which, as a result of this regulation, withdrew from this fishing ground and moved to Brazilian waters.

5.1.2 Pacific Ocean

Two RFMOs are directly involved in the management of tuna in the Pacific: IATTC and WCPFC. Northern albacore and Pacific bluefin, which are found in both Convention areas, are assessed by the ISC. Conservation and management recommendations by the ISC are reviewed by both IATTC and WCPFC, and efforts are made to harmonize management measures for these common stocks if adopted. Table 7 briefly summarizes the current management measures for Pacific tuna stocks.

The first management measures for tuna were taken in 1966 in the Eastern Pacific Ocean in the form of a yellowfin TAC with free competition, i.e. the quota was not apportioned by flag state or vessel. Under this measure, which was implemented until 1979, when the catch in the entire Eastern Pacific Ocean approached the TAC, the Director of Investigations of IATTC decided the date of closure. However, each vessel

TABLE 6
Regulatory measures currently applicable in the Atlantic Ocean (including the Mediterranean) – as of mid-2009

Stocks	Current regulations	Remarks
YFT	• Effective fish effort not to exceed 1992 level	
	• PS closure during November 0°–5°N 10°–20°W	• For BET but YFT included
BET	• TAC = 90 000 tonnes	
	• Number vessels < the average of 1991–1992	
	• LL vessels limited for China (45), Taiwan Province of China (98), Philippines (8)	
	• PS closure during Nov. 0°–5°N 10°–20°W	
SKJ	• No regulations	• BET time-area closure affects SKJ
ALB – North	• Number vessels < the average 1993–1995	
	• TAC = 30 200 tonnes for 2008, 2009	
ALB – South	• TAC = 29 900 tonnes until 2011	
BFT – East	• TAC 22 000 tonnes (2009),19 950 tonnes (2010), 185 000 tonnes (2011)*[1]	• TAC since 1995
	• Allocation to CPCs (and possibly individual quota for vessels <24 m)*	
	• Restriction on overage and underage permits*	• Current regulations:
	• For LL>24m, east of 10°W and south of 42°N closed June 1 – end of the year, west 10°W, north of 42°N closed February 1 – July 31*	• For LL>24m, east of 10°W and south of 42°N; June 1– December 31
	• For PS, no fishing from June 15 – April 15*[2]	• For PS, no fishing from July 1–December 31*
	• For BB and TROL, closed October 15–June 15*	• BB November 15 – May 15
	• For SPORT, closed October 15–June 15*	• Size > 30 kg (8 kg for BB in E. Atlantic, Adriatic for farming, Mediterranean artisanal coastal fisheries)
	• No aerial searching	
	• Size limit > 30 kg (8 kg for BB in E. Atlantic, Adriatic for farming, Mediterranean artisanal coastal fisheries)	
	• Fishing capacity limited to matching quota and the difference should be reduced to 20% by 2010*	
	• Catch document system	
BFT – West	• Country quota with TAC = 2 100 tonnes including dead discards*	• TAC since 1980
	• Size limit > 30 kg or 115 cm	
	• No fishing on spawning stock in Gulf of Mexico	

* These measures were adopted in 2008 and took effect in mid-2009.

[1] TAC revised to 13 500 tonnes in 2010 (November 2009).

[2] PS closure changed from June 15 to May 15 (November 2009).

that left port before the closure date was allowed to complete its trip. This measure had the unintended consequence of encouraging the construction of purse seiners with greater holding capacity.

For many years following 1979 no regulations were implemented because biomass was greater than B_{MSY}. One of the reasons for this is the curtailment of the United States' fleet's fishing operations under regulations relating to mitigation of dolphin mortality. Regulatory measures were introduced again in 2002, when TACs similar to those implemented during 1966–1979 were enacted. From 2004 to 2007, a closed period was introduced for the purse seine fleet – instead of a TAC – and a flag state quota for bigeye catch by longliners was set. In 2008, the Commission (IATTC) could not agree on management measures by consensus and only unilateral voluntary measures, similar to those applied in 2007, were adopted by CPCs. A new regulation was adopted in 2009, which applies for the period 2009–2011.

TABLE 7
Regulatory measures currently applicable in the Pacific Ocean – as of mid-2009

Stocks	Current regulations	Remarks
YFT–EPO	• For 2009: 59 days closure, either from 1 August to 28 September, or from 21 November to 18 January (2010) • For 2010: 62 days, either from 29 July to 28 September, or from 18 November to 18 January 2011 • For 2011: 73 days, either from 18 July to 28 September, or from 7 November to 18 January 2012 • The area surrounded by 96°–110°W and 4°N–3°S is closed from 29 September to 29 October	• (Until 2007) 42 days closure, 1 August to 11 September; or 20 November to 31 December • Retain all the catches
YFT–WCPO	• PS fishing shall reduce fishing mortality by 30% by 2011 in the area of 20°N–20°S: – In EEZ, PNA will close FADs fishing 1 August to 30 September and the same closure for non-PNA with observers or total closure – In high seas, the same as above with observers or total closure or reduction of catch quota by 10% in 2009 • No transfer of effort to other area • PS vessel days effort in high seas not to exceed 2004 or 2001–2004 average	• No increase of effort from current level • LL BET catch not to exceed 2001–2004 average for 2005-2008
BET–EPO	• For 2009: 59 days closure, either from 1 August to 28 September, or from 21 November to 18 January (2010) • For 2010: 62 days, either from 29 July to 28 September, or from 18 November to 18 January 2011 • For 2011: 73 days either from 18 July to 28 September, or from 7 November to 18 January 2012 • The area surrounded by 96°–110°W and 4°N–3°S is closed from 29 September to 29 October • The area surrounded by 96°–110°W and 4°N–3°S is closed from 29 September to 29 October	• (Until 2007) 42 days closure, 1 August to 11 September; or 20 November to 31 December, for PS • Retain all the catches • Country quota for LL (2001 level)
BET–WCPO	• PS fishing shall reduce fishing mortality by 30% by 2011 in the area of 20°N–20°S: – In EEZ, PNA will close FADs fishing 1 August to 30 September and the same closure for non-PNA with observers or total closure – In high seas, the same as above with observers or total closure or reduction of catch quota by 10% in 2009 • LL BET catch to be reduced by 30% (10% each year) by 1 January 2012; YFT catch not increased from 2001–2004 • No transfer effort to other areas • PS vessel days effort in high seas not to exceed 2004 or 2001–2004 average	• No increase of effort from current level • LL BET catch not to exceed 2001–2004 average for 2005–2008
ALB–N	• No increase of effort above current level	
ALB–S	• No increase of vessels south of 20°S from 2000–2004 level	
PBF	• No management measures	

In the Western and Central Pacific Ocean, a number of small island developing states collectively referred to as the Parties to the Nauru Agreement (PNA) enacted measures to limit the number of purse seiners that can operate in the EEZ of PNA members' states to 205. This measure was changed in 2007 to a Vessel Day Scheme (VDS), which limits the total number of vessel-fishing days in the area. The United States fleet is exempted from this system for the states with which a multilateral access treaty was agreed upon. Although the VDS is not a WCPFC management measure, under the Convention, the WCPFC member states must treat it as a binding measure (MRAG, 2006).

In 2005, WCPFC adopted a management measure which requires that effort and/or catches of bigeye and yellowfin should not exceed the current level (2002–2004). The first concrete management measure limiting tuna catches in the WCPFC Convention area was adopted in December 2008. The management measure is very complicated due to the need to respect the subregional agreements such as that of the PNA, but the overall intention is to reduce fishing mortality for bigeye by 30 percent within three years. Although the eventual effect of this regulation can only be evaluated with time, it is expected to have a major effect on various Pacific fisheries which have grown continuously over the last few decades. Furthermore, even though the primary objective is to reduce fishing mortality on bigeye, the measure, if properly complied with, will also have a substantial effect on catches of yellowfin and skipjack (see Section 4.2.7).

5.1.3 Indian Ocean

Table 8 briefly summarizes the current management measures for Indian Ocean tuna stocks. In the Indian Ocean, the IOTC meeting schedule is such that there is a greater lag between the provision of scientific advice and the adoption of management measures in this Commission than in other Commissions. This causes delays in decision-making by this Commission. In addition to this, although the stock status in the Indian Ocean is believed to be better than in other oceans (see Section 3.4), and although there are many regulations concerning capacity control and mitigation of incidental catches, no definite management measures such as TAC or effort control have been implemented.

5.1.4 General management measures

Many management measures have been adopted by RFMOs that are not directly related to the conservation of tuna stocks but nevertheless have an effect on tuna fisheries. Recently, there have been efforts to coordinate the scheduling of RFMO annual meetings thereby facilitating the diffusion of management measures taken by one RFMO into the others. This in theory should lead to greater compatibility in the management measures taken for the world's oceans. As fishing vessels are mobile, the adoption of management measures for one ocean but not for another will lead merely to a shifting of overfishing or overcapacity problems from one area to another. If management measures are adopted in two oceans but are not identical, this may also cause practical problems for fishing fleets moving between oceans (e.g. different VMSs). For these reasons, there is an ongoing effort among all tuna RFMOs to harmonize their management measures. These efforts include, *inter alia*, the Joint Meetings of Tuna RFMOs at Kobe, Japan, in 2006, and at San Sebastián, Spain, in 2009, as well as the FAO-Tuna RFMOs biennial meetings.

Table 9 describes the management measures adopted in each ocean in a qualitative manner. Although the information is highly summarized, more details can be found in other specific sections of this paper (e.g. fishing capacity, bycatch mitigation) and also in the original RFMO reports.

TABLE 8
Regulatory measures currently valid in the Indian Ocean – as of mid-2009

Stocks	Current regulations	Remarks
ALB	Number of SWO and ALB fishing vessels shall be held at 2007 levels	
BET	Limit catches to the recent levels. (Taiwan Province of China: 35 000 tonnes) since 2005	
SBF*	TAC and country quota	Voluntary catch limit (since 1984) and TAC by the Commission (since 1994)

*SBF: The management measures for SBF are by CCSBT and are valid worldwide.

TABLE 9
Other various management measures adopted by RFMOs

Items	Atlantic Ocean (ICCAT)	Eastern Pacific Ocean (IATTC)	Western and Central Pacific Ocean (WCPFC)	Indian Ocean (IOTC)	Worldwide for SBF (CCSBT)
Statistical document	BFT, BET*			BFT, BET*	SBF
Catch document	BFT				SBF (2010-)
Port inspection	Yes	Yes	Yes	Yes	Yes
At-sea inspection	Yes	Yes	Yes		Yes
Observer programme	Yes	Yes	Yes	Yes	Yes
Regional programme	Yes	Yes	Yes		
Transshipment	Yes	Yes		Yes	
Farming sites	Yes				
VMS	Yes	Yes	Yes	Yes	Yes
Fishing capacity control					
Vessel limits	Individual	Total fleet	Some	Total fleet	
Carrying capacity control		Vessel registry			
Vessel registry		Yes		Yes	
Positive vessel list	Yes	Yes	Yes	Yes	Yes
IUU vessel list	Yes	Yes	Yes	Yes	Yes
Mitigation					
Sharks	Fins<5%**	Fins<5%	Fins<5%***	Fins<5%	Fins<5%
Sea turtles	Release tool	Release tool	Release tool, Circle hook	Release tool	Release tool
Seabirds	Tori pole		Two types	Two types	Tori pole
Small tunas	Time-area closure	Full retention			
Others					

*Frozen but not for canning.
**Some species have to be released.
***Starts in 2011. Fins should be identifiable with matching carcass.

5.1.5 Fishing capacity

It is widely acknowledged that all tuna RFMOs are finding it more and more difficult to reach consensus on management measures. For example, IATTC adopted bigeye and yellowfin regulations for 2009–2011 only after failing to reach agreement in 2008. ICCAT also had great difficulty in adopting and implementing measures for the eastern stock of Atlantic bluefin, as did WCPFC in adopting the bigeye and yellowfin measure in 2008. The fundamental reason for such difficulties is the increasing fishing capacity which far exceeds the level necessary to harvest the world's tuna stocks at a sustainable level. Unfortunately, fishing capacity is often confused with fish carrying capacity. Fishing capacity is the capability of a fleet to catch fish relative to a reference point for tuna stocks. The most commonly used proxies for fishing capacity are, for longline fleets, the number of vessels and for purse seine fleets, the carrying capacity. The global increase in fishing capacity relates to the increase in the number of vessels and their size, as well as the increase in catchability due to technological advancement and at-sea transshipment.

The problem of excess fishing capacity has been recognized for over two decades. An International Plan of Action (IPOA) on fishing capacity was agreed upon by FAO in 1999 (Kirkley and Squires, 1999). However, progress with managing fishing capacity has been very slow, despite the fact that many studies of the issue have been conducted (e.g. Gillett, 2003; Joseph, 2003; Reid *et al.*, 2005; Miyake 2005b; Joseph, 2005; and Takase, 2005) and that FAO has created a Technical Advisory Committee on

Management of Tuna Fishing Capacity (the final report of this group was published as an FAO publication in 2005 [Bayliff, de Leiva Moreno and Majkowski, 2005]).

As reiterated throughout Bayliff, de Leiva Moreno and Majkowski (2005), modern fishing vessels are highly mobile. Thus, wherever regulatory measures are introduced, fleets have the potential to switch immediately to other less regulated fishing grounds or species (i.e. spillover effects). This is the reason that the management of fishing capacity must be considered on a global basis, and that harmonization among RFMOs is required.

FAO's Technical Advisory Committee on Management of Tuna Fishing Capacity: Conservation and Socio-economics identified that the current tuna fishing capacity is at least 30 percent higher than necessary to harvest a sustainable yield from current tuna stocks (Anon., 2007). The situation is further deteriorating due to the perpetual expansion of fishing fleets since the time of the FAO analyses, and the continuing exploitation of stocks at levels of fishing mortality higher than those corresponding to the MSY (see Section 3). The Committee recommended a moratorium on new vessels and rights-based management of fishing capacity, including development of an appropriate system to transfer capacity from developed to developing countries. This view has been further developed in several ways. In 2007, a meeting of the Joint Tuna RFMOs held in Kobe, Japan, emphasized the need to harmonize various management measures. Accordingly, many RFMOs either established an ad hoc group to study the management of fishing capacity and/or included this subject in their meetings' agenda. Also, many international meetings on this topic have been held, all of which supported the scheme and proposed further actions (e.g. IATTC and World Bank, 2008). However, these discussions usually focused on how to limit the number of vessels and/or fish-holding capacity without considering other aspects of the problem such as socio-economic issues.

As shown in Table 9, almost all the RFMOs have some kind of capacity control. These controls take many different forms, ranging from "the number of fishing vessels should not be increased from the current level" to a strict regional vessel registry system as adopted by IATTC in 2000. Another form of capacity control was adopted by IATTC in 2002 involving a limit of 158 000 m^3 for the total fish-holding capacity of the entire Eastern Pacific Ocean purse seine fleet.

In limiting the number of vessels, the IOTC is more advanced than the other RFMOs. It has not permitted any new entries into the fishery since 2003 unless the new entry is replacing a currently registered vessel (IOTC, 2008a). It should also be noted that in previous years the PNA agreed not to increase the number of purse seiners in their EEZs above 205 (see Section 5.1.2 and 5.1.4).

Several measures for the reduction of fishing capacity in longline fleets have been adopted by CPCs of the RFMOs, either individually or collectively. A programme to reduce longline fleets through buy-back and scrapping has been undertaken since the late 1990s by Japan, Taiwan Province of China, the Republic of Korea and later China and is described in Section 5.1.6 (IATTC and World Bank, 2008; Organization for the Promotion of Responsible Tuna Fisheries [OPRT][3]).

In the case of both IATTC and IOTC, there are two basic practical problems encountered when trying to reduce fishing capacity: small vessels, and discrepancies between the numbers of active and registered vessels. As management measures are generally applicable only to vessels >24 metres in overall length, smaller boats are excluded. Nevertheless, small vessels often represent a substantial portion of the total fishing capacity. In addition, in order to maximize potential fishing rights, CPCs tend to register all of the boats licensed to fish in the particular area, even if all of these vessels are not necessarily active. The inactive vessels offer a potential increase of

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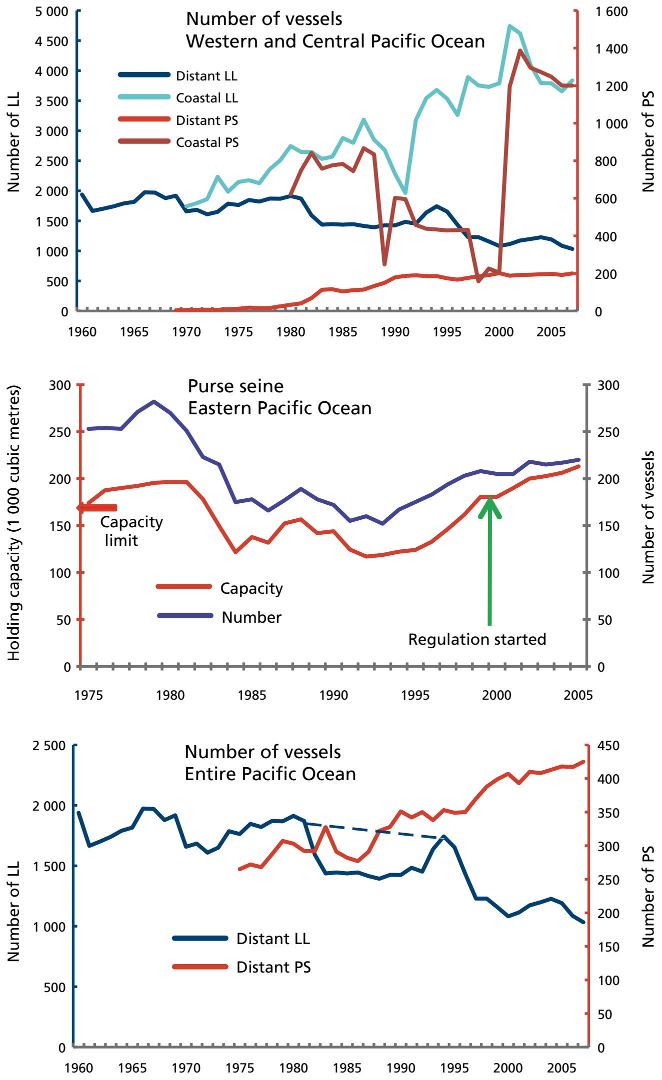
[3] See www.oprt.or.jp

fishing capacity when biological, social or economic conditions change. Both of these issues create problems for positive vessel lists as discussed below.

It is very difficult to estimate the number of fishing vessels actively fishing in an area. For the Indian and Atlantic Oceans only partial estimates are available. For the Eastern Pacific Ocean, estimates of active vessels are available for large purse seiners in terms of number and holding capacity in cubic metres (IATTC, 2008), while in the Western and Central Pacific Ocean, an estimate of the number of active coastal and distant water longliners and purse seiners is available (Lawson, 2008). The upper panel in Figure 35 shows the number of coastal and distant water longliners and purse seiners in the Western and Central Pacific Ocean based on SPC-OFP (2008) and Lawson (2009). Gillett (2007) also estimated the number of longline vessels and produced estimates

FIGURE 35

Pacific fleet size for the Western and Central Pacific Ocean (upper panel), Eastern Pacific Ocean (centre panel) and entire Pacific Ocean (lower panel)



Source: Data provided by RFMOs.

which are only slightly different from these data. The separation of coastal and distant water longliners is based on expert judgement using information on the number of vessels and trips per country, species composition and catch per vessel. The record of the number of distant water longliners and purse seiners is quite complete. The number of distant water longliners matches figures held by the Organization for the Promotion of Responsible Tuna Fisheries (OPRT); see the following section. From these data it is evident that the number of distant water longliners is decreasing while the number of purse seiners is rapidly increasing, confirming and explaining the increasing catch by purse seine vessels in the Western and Central Pacific Ocean.

In contrast, the number of coastal vessels, particularly purse seiners, is highly uncertain. Large fluctuations appear to represent differences in reporting rates rather than changes in fleet size. The middle panel shows the number and holding capacity of large purse seiners in the Eastern Pacific Ocean (IATTC, 2008). The vertical green line indicates the date of implementation of the regional fishing vessel registry system; the small red bar on the Y axis shows the agreed target capacity level. With reference to the increase in purse seine fish holding capacity as discussed in Section 4.2.5, it is important to note that larger vessels are not necessarily more efficient in fishing. According to IATTC (2008), the catch per m^3 of holding capacity is highest for vessels in the range of 1 100 to 1 500 m^3, although larger vessels may have a different type of advantage such as the capability to stay at sea for a longer period of time before filling up the fish wells, as discussed previously.

The lower panel shows the total number of distant water longliners and purse seiners in the entire Pacific. It was assumed that all the distant water longliners that were active in the Eastern Pacific Ocean also operated in the Western and Central Pacific Ocean, and hence were double counted when the numbers from the two registers were added. The figures for longliners were thus adjusted based on this assumption. For purse seiners, there may be approximately ten purse seiners which are double counted; therefore, without further investigation an assumption was made to count these vessels only once in this analysis.

In conclusion, the need for management of fishing capacity is widely recognized. The control of fishing capacity alone cannot solve all conservation problems, but it will facilitate the establishment of other regulations such as TACs and time-area closures. Furthermore, despite the necessity of rights-based approaches, developing a practical and effective system which allows for the smooth handover of rights held by current users to new users is likely to be fraught with difficulties. There is also the problem of allocation of rights between fisheries, e.g. between gear types. Resolution of these issues is likely to be the key factor influencing the tuna industry as a whole.

From the examination of information on catch trends by gear type, development of coastal or small scale fisheries, management measures taken for fishing capacity of various gear types and trends in fleet size and capacity (in terms of number of vessels and fish-holding capacity), it is apparent that distant water longline fishing capacity is declining while purse seine and coastal longline capacities are increasing. These trends would be expected to result in increasing catches of small fish, lower Y/R and MSY, and more difficult fishery management on a global basis for all stocks, with the exception of skipjack (see Section 4.2.7). Such trends are predicted based on the current environment, i.e. the low price for *sashimi* despite the high cost of its production and an increasing demand for canned products based on the high efficiencies associated with purse seine fisheries. However, if demand for canned tuna does not increase, and/or the price of *sashimi* goes up reflecting higher production costs and declining longline catch rates in the near future, the trends may be reversed.

5.1.6 IUU problems and trade measures

When ICCAT implemented several restrictive management measures in the 1980s, some fishing vessels of CPCs changed their flags to non-contracting parties, mostly with open registries, and continued unregulated fishing (Box 1). As the management measures were not binding upon the non-contracting states, this provided a useful opportunity for the operators to fish in an unrestricted manner and such flag of convenience (FOC) operations increased rapidly. Such operations came to be labelled as IUU fishing and the world became aware that IUU catches undermine the effectiveness of management measures, increase uncertainties in scientific research, and in the end endanger tuna stocks.

The bottom panel of Figure 35 shows the fishing capacity in the entire Pacific. The apparent decline in the number of distant water longlines during the early 1980s to late 1990s most likely represents a conversion of vessels to IUU fishing activities. The number of IUU distant water longliners at that time is estimated to be around 300 vessels (Miyake, 2005b), and if so, the actual number of distant water longliners did not decline so rapidly (dotted line in Figure 35).

Because ICCAT was the first RFMO to initiate strict tuna regulation (initially on Atlantic bluefin and bigeye catches in the 1980s and 1990s, respectively), the IUU fishing problem was first recognized as a serious problem by ICCAT. Since 1993, ICCAT has implemented a system referred to as the Atlantic Bluefin Statistical Document Program (BFTSDP). All of the ICCAT CPCs can only import BFT (at first it was in frozen form only, but later fresh forms were also covered) if accompanied by a document showing from which vessel the product originates, as certified by the flag state or its authorized agency. This system was expanded later to bigeye (although catches destined for canneries are exempted from the scheme) and swordfish. IATTC and IOTC have adopted similar systems.

The BFTSDP itself does not itself restrict the import of illegally caught products, but it does help to identify flag states which operate IUU vessels and to approximate the amount of such catches. In 1994, ICCAT adopted an Action Plan (implemented in 1995) which specified non-discriminatory trade restrictive measures that could be taken against the countries involved in IUU fishing, if steps to identify such activities are properly taken by the Commission and if flag states fail to rectify their IUU fishing activities. As a result, trade sanctions were adopted for several IUU vessel flag states. Such action was very effective in curbing IUU fishing activities. In 2007, ICCAT adopted a Catch Documentation Program for Atlantic bluefin to replace the BFTSDP. The new scheme not only covers all Atlantic bluefin trade but also applies to all catches of Atlantic bluefin which must be reported and checked at the point of landing.

Along with these actions to combat IUU fishing, distant water longline countries established the Organization for the Promotion of Responsible Tuna Fishing (OPRT), which coordinated the buy-back and scrap policy to reduce fishing capacity by major distant water longline countries (IATTC and World Bank, 2008; Box 4). Table 10 lists the number of distant water longline vessels of OPRT members. The total number of distant water longliners registered with OPRT had increased between 2001 and 2004, as IUU vessels were integrated into the system and legalized. Thereafter, the number of vessels started to decline due to the buy-back and scrap policy.

In conjunction with trade actions, ICCAT, and later all the other RFMOs, developed lists of IUU vessels. They adopted several conditions to identify, recognize, and list or unlist a vessel as an IUU vessel. For this purpose, the data collected from the BFTSDP was very useful. At year-end 2008, there were 22, 22, 3 and 2 distant water longline vessels on the ICCAT, IATTC, IOTC and WCPFC IUU vessel lists, respectively. Because more than ten vessels are duplicated among the lists, the actual number of IUU distant water longliners is likely to be less than 30.

BOX 4
Buy-back and scrap policy

A buy-back and scrap policy was adopted by Japan and later by Taiwan Province of China. It consisted of the following steps:

1. All flag of convenience (FOC) and/or IUU longliners owned or operated by Japanese or Taiwan Province of China nationals were re-registered to their home countries.
2. Both countries have limited entry systems. The limit was reduced, for example, by 20 percent in Japan. The government then repurchased the licences of those who volunteered to cease fishing so that total GRT was brought within the decreased limit. (Hence, the bought-back vessels did not add capacity to the national fleet.)
3. The funds for the buy-back were initially provided by government loans and ultimately by the contributions of boat owners who decided to continue fishing.
4. The vessels for which the licences were bought back were all scrapped.

In Japan, most of the buy-backs proceeded from Step 2, as very few FOC/IUU vessels were operated by Japanese owners. Japan also paid for the buy-back of Taiwan Province of China IUU vessels, which had been built in Japanese shipyards but were at the time operated by Taiwan Province of China owners and/or reflagged to Taiwan Province of China or to other countries.

In the end, about 15 percent of the total number of distant water longliners were scrapped. The Organization for the Promotion of Responsible Tuna Fisheries was established to promote this system and is now tracking and monitoring all the ex-IUU vessels reflagged to third countries, such as Vanuatu and the Seychelles. Those distant water longliners are now properly licensed by and reporting to the new flag states.

TABLE 10
Number of distant water longline vessels registered with OPRT by flag countries or fishing entity (as of March 2009)

	November 2001	March 2002	March 2003	March 2004	March 2005	March 2006	March 2007	March 2008	March 2009
Japan	495	490	495	473	434	381	363	360	254
Taiwan Province of China	562	562	599	597	600	526	420	392	369
Korea, Republic of	–	183	176	174	172	172	160	156	148
Philippines	–	6	17	17	18	26	28	28	26
Indonesia	–	–	14	14	14	14	15	17	17
China	–	–	–	105	113	113	117	121	136
Ecuador	–	–	–	–	5	4	4	4	5
Seychelles	–	–	–	–	–	–	–	27	27
Vanuatu	–	–	–	48	48	48	48	48	48
Fiji	–	–	–	–	–	–	–	–	19
Total	**1 057**	**1 241**	**1 301**	**1 454**	**1 425**	**1 305**	**1 176**	**1 153**	**1 049**

Meanwhile, the RFMOs recognized that some of the vessels that were not listed on the IUU vessel lists did not have authorization from CPCs to fish in the RFMO area. Therefore, it was decided to develop lists of legally authorized fishing vessels ("positive lists"). Consequently, all the RFMOs, in addition to adopting IUU vessel lists, have adopted so-called positive lists, which are lists of tuna fishing vessels that are authorized to fish by the flag states of CPCs of the RFMOs. Some RFMOs and some countries have adopted regulations that prohibit catches made by a vessel not included on the positive list from being imported. As discussed above, flag states tend to list all potential fishing vessels on the positive lists regardless of whether they are actively fishing, and thus the positive lists are not useful in estimating active fleet sizes.

5.2 ECOSYSTEM CONSIDERATIONS – BYCATCH[4] ISSUES

Since the late 1980s, global interest in ecosystems has been heightened and this has begun to have a major effect on tuna fisheries. This paper does not intend to present a detailed discussion of bycatch in terms of species, biology, ecology and interactions with the fisheries. However, the multispecies nature of tuna fisheries does not allow a simplistic focus on target species alone.

The first bycatch-related conflict with tuna fisheries was the issue of fishing on schools associated with dolphins in the Eastern Pacific Ocean (Joseph, 1994; Teisl, Row and Hicks, 2002). As a result of increasing interest in reducing incidental mortality of other species due to tuna fishing, FAO agreed to three IPOAs – on sharks, seabirds and turtles – in 1999. Since then, RFMOs have paid considerable attention to bycatch problems and initiated measures to mitigate incidental mortality to these animals even though RFMOs' Conventions do not clearly define responsibilities for conservation of most of these species.

Current management plans and research on mitigation for these marine animals are briefly summarized below. In addition, RFMOs are keenly interested in mitigation of small tuna catches of target species in order that these resources may be utilized more effectively. Therefore, research on mitigation of catches of small tunas is also summarized.

Table 9 provides a summary of management measures adopted by RFMOs. It should be noted that this paper does not aim to pass judgement on these management measures but only to report factual information about them.

5.2.1 Sharks

One key difference between shark bycatch and sea turtle and seabird bycatch is that sharks have been widely used as human food. In fact, many fisheries target sharks. The concern regarding sharks therefore is related to whether the catch is fully utilized and whether it is sustainable. For this reason, shark management plans include various aspects such as stock assessments, enforcement of full utilization requirements, and mitigation of undesirable and/or non-sustainable impacts.

Statistics on shark catches have been poor in all oceans because they are often considered bycatch and many of the reporting systems have allowed all shark species to be combined into a single reporting category. However, since the adoption of the IPOA-Sharks, many RFMOs have started to require reporting of catch statistics by species. Nevertheless, these data are expected to represent only retained catches of major species. Mining of historic catch data is difficult but has been attempted for some species (Nakano and Clarke, 2006). In addition, ICCAT shark stock assessments have used known ratios of shark and tuna catches from fleets which report sharks (ICCAT, 2007) as well as estimates based on shark fin trade data (Clarke, 2008) as alternatives to reported shark catch data. Despite the use of these techniques, shark stock assessments entail considerably more uncertainties than tuna stock assessments.

ICCAT has prohibited catches of certain species of elasmobranchs (sharks, skates and rays) which are considered to be overexploited. In addition to this, all tuna RFMOs have adopted measures stating that the whole carcass of sharks should be retained if the shark fins are retained. At present, most of these measures state that the fins must be less than 5 percent of the weight of sharks; however, the form of the shark weight, i.e. dressed versus live, varies among the measures. The appropriateness of the 5 percent

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[4] IATTC defines bycatch as anything caught and discarded. In this paper a more general definition is used, i.e. non-target fish (of species or size) caught during fishing activities regardless of whether they are retained, discarded or released alive.

fin to carcass ratio has been studied by various researchers (Kim *et al.*, 2007a; Hareide *et al.*, 2007; IOTC, 2007b; IOTC 2008b). The scientific conclusions so far are that one ratio such as 5 percent is not appropriate for all species, and that the appropriate ratio for any given species may vary with area and time, size of fish and the way the fins are cut. Some countries have adopted domestic regulations stating that no fins can be unloaded unless they are physically attached to the carcass. This type of regulation would have a major effect on distant water longliners operation and may cause dead discards of sharks to increase.

Another major issue for tuna fisheries is the damage to tunas caught on longline hooks by sharks. Depending on area and season, such depredation rates can be high and thus cause substantial losses to the value of the catch. For this reason there is much interest among fishers in finding ways to decrease shark depredation.

5.2.2 Sea turtles

Most of the information on the interaction of sea turtles with tuna fisheries is focused on longlines, despite the fact that they are also caught in purse seines. In the case of purse seines, the mortality appears low if the sea turtle is released. As many studies have been conducted on interactions between sea turtles and tuna fisheries, it is not possible to cite all of them here. Summaries and details of the studies can found in the reports of the working groups on ecosystem and bycatch of each RFMO (e.g. ICCAT, 2008, ICCAT, 2009b, IOTC, 2007b; IOTC, 2008b).

According to the various studies concerning longline fisheries, most of the incidental hooking of sea turtles occurs with shallow (<200 metres from the surface) hooks (particularly of longlines targeting swordfish). However, deeper hooks may also catch sea turtles as the hooks pass through the shallow layers during casting and hauling.

It has been demonstrated that circle hooks reduce sea turtle bycatch rates considerably from conventional J-shaped hooks and particularly reduce the mortality of sea turtles as they do not swallow the circle hooks as deeply as they do with the conventional "J" hooks (e.g. Itano, 2006). Various studies have indicated however that the catch rates of target species may also be affected by substituting circle hooks for J hooks. The effects are quite variable by area, time of day, season, size of hooks used and target species. Some investigations of circle hooks show higher catch rates for target tunas whereas others show lower rates for target species (e.g. Watson *et al.*, 2005; Ariz, *et al.*, 2008; Domingo *et al.*, 2008; Kim *et al.*, 2007b; IOTC, 2008b).

All of the RFMOs have adopted management measures requiring that tuna fishing vessels carry equipment to release hooked sea turtles with the minimum amount of damage. In addition, WCPFC adopted a measure in 2008 which states that swordfish longliners fishing in shallow (<100 metres) waters should use only large circle hooks and only whole finfish as bait. This regulation will be implemented in 2010. Thus far, no other RFMO has adopted any requirements for the use of circle hooks, but such requirements may be adopted in the near future.

Potentially, the effects of regulations requiring circle hooks on tuna fisheries would be that the catch rates of target species might be reduced, the baiting of hooks might take more time or become more complicated, and the cost of hook substitution could be an issue.

With regard to the purse seine fishery, IATTC adopted a regulation requiring that all sea turtles captured in purse seines must be immediately released to the sea.

5.2.3 Seabirds

As for sea turtles, most of the information on interactions of seabirds with tuna fisheries is focused on longlines, particularly at relatively high latitudes in both the northern and southern hemispheres. Overlaps in time and area between the distribution of seabirds and the distribution of the tuna fishery and the rates and depths of seabird

TABLE 11

Seabird mitigation options (one method has to be chosen from each column)

Column A	Column B
– Side setting with a bird curtain and weighted branch lines	– Tori line
– Night setting with minimum deck lighting	– Weighted branch lines
– Weighted branch lines	– Blue-dyed bait
– Tori line	– Deep setting line shooter
– Weighted branch lines	– Underwater setting chute
	– Management of offal discharge

hooking have been studied intensively and are well summarized in IATTC (2007) and Melvin and Barry (2006). The development of various mitigation methods has been incentivized because seabirds are unwanted bycatch. Due to the variability in seabird and tuna fishery interaction rates among areas/time periods, the mitigation measures adopted by various RFMOs also vary (Table 9).

The strictest measures have been taken by WCPFC (Table 11) and IOTC. For example, the CPCs will require their longline vessels to use at least two of several clearly defined mitigation measures (for example, the length of the Tori pole, i.e. a line with streamers). On the other hand, ICCAT and CCSBT require longliners to use Tori poles in certain designated fishing areas. IATTC has discussed this issue but has not yet adopted any regulations. These types of regulations have a negative effect on the efficiency of longlines, by restricting the duration of some operations and increasing operating costs.

5.2.4 Small tunas

Small tunas caught by purse seines, particularly from the schools associated with FADs, are discussed in many places in this paper (notably in Sections 4.2.6 and 4.2.7). There are two basic problems inherent in the catch of small tunas: a reduction of Y/R or MSY, and a high fishing mortality on bigeye, which is not the major purse seine target species. Restriction of fishing on FAD schools to protect small bigeye would affect purse seine catches of skipjack (and yellowfin), which in most cases do not warrant such management for their own sake.

A minimum size limit of 3.2 kg for yellowfin and bigeye was adopted by IATTC and ICCAT but was later rescinded as it was not effectively enforced. ICCAT has adopted area-time closures for FAD fishing and, more recently, limited all purse seine fishing to a smaller area. IATTC previously adopted a measure requiring full retention of all captured tuna, unless they were not fit for human consumption, but these regulations have been discontinued. There are no other regulations mitigating the catch of small fish.

Techniques to reduce or effectively mitigate the catches of small bigeye would benefit both longlines and purse seine fisheries as well as tuna resources. Hence, much research on this topic has been conducted, including:

- surveys on fish behaviour under FADs (Itano, Holland and Dagorn, 2006; Moreno *et al.*, 2007; Satoh *et al.*, 2008; Schaefer, 2008);
- methods to identify fish species in the school;
- type or construction of FADs (Schaefer and Fuller, 2008);
- gear characteristics (Cleridy *et al.*, 2007; Itano, 2006; Itano, 2007a; Itano, 2007b);
- fishing methods (e.g. depth of nets) (Itano, 2007b); and
- fish escaping racks (Anon., 2008b).

At present, no effective measures to fully mitigate the catch of small fish have been found. However, such research should be strongly encouraged for its ability to solve many of the problems facing bigeye stocks, to profit both longline and purse seine sectors, and to provide for a dramatic shift in tuna fishing operations.