A worldwide review of purse seine fisheries on FADs

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Abstract

This paper develops a comparative overview of the development of Fish Aggregating Devices (or FADs) by the tropical purse seine fisheries in various ocean areas (Atlantic, Indian, Western and Eastern Pacific Oceans). First, a comparative review of fishery statistics is developed. Recent catches on FADs by purse seiners can be estimated at a level of one million tons yearly. This comparison allows to describe the fishing zones and catch trends over time, the species composition and size taken in the various FAD fisheries. Skipjack tuna is the dominant species in most FAD fisheries, but significant amounts of yellowfin and bigeye are also frequently taken under FADs. The paper also presents an overview of various observer data concerning the by-catches of the various fisheries using FADs. This comparison allows to estimate the total worldwide yearly by-catches at about 100,000 t, and their species composition in each ocean. The FAD technology used in the various oceans by purse seiners is described. The recent use of FADs by purse seiners has introduced major uncertainties in most stock assessments, because analyses are hampered by changes in the fishing effort in a FAD fishery, by changes in fishing zones and in sizes caught. As a last point, the management of FADs presently done or in view by the various tuna bodies are introduced. It appears that the present massive use of FADs worldwide is perhaps an unsafe fishing mode, which could produce serious overfishing of many stocks. There is then a consensus that the use of FADs needs to be controlled and limited to sustainable biological levels.

Introduction

Tuna fishing on flotsam has been used by most purse seine fisheries since the early sixties in coastal areas where drifting objects were abundant. This traditional fishery on flotsam (natural or man-made logs) was quite incidental in the Atlantic Ocean, but has always been very active in other areas such as Western Pacific or Indian Ocean. Since the late eighties, the purse seine fisheries using artificial FADs equipped with positioning devices have shown a massive development worldwide. As natural and artificial logs are not separated in the catch statistics, the term FAD will

be used in this text to describe any type of natural or artificial floating object. This paper aims to review and to compare the most recent information upon this new fishing mode and upon its potential effects on tuna stocks:
- species and sizes of tunas targeted under FADs in the various oceans;
- species and quantities of by-catches taken under these FADs;
- problems introduced by FAD fisheries in the tuna stock assessment;
- potential effects of this new fishing mode on the various tuna species and management prospects of FAD fisheries.

This work will be based on fishery data obtained, either from the published literature, or from data kindly provided by the IATTC[1] and the SPC[2] (cf. annex 1: data). All comparisons among FAD fisheries will be done between the Atlantic, Indian and Pacific Oceans, but the Pacific will be divided into its two eastern and western basins, separated at 150° West.

Trends and characteristics of purse seine FAD fisheries worldwide

Fishing zones on FADs

A map showing the average catches of purse seiners under FADs, by 5 degrees squares, during recent years (1994-1997) is given in figure 1. This figure shows that FAD fisheries are mainly distributed worldwide between 15°N and 15°S, the largest catches being taken in Western Pacific and to a lesser degree in the Western Indian Ocean and other

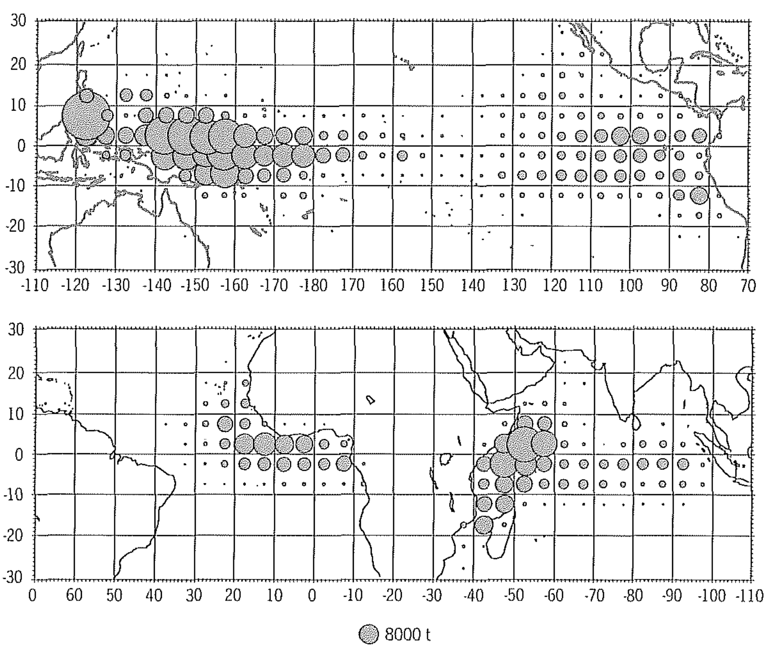


Figure 1
Estimated average catches of tunas by purse seiners on FADs by 5 degrees squares (period 1994-1997).

1. IATTC: Inter-American Tropical Tuna Commission.
2. SPC: Secretariat of the Pacific Community.

areas. This average fishing map shows well that both Indian and Pacific Oceans are now entirely exploited with FADs. In the Atlantic Ocean, only the eastern basin is exploited with FADs.

Catch trends and species composition

Tuna fisheries using FADs were developed actively worldwide in all oceans since the late eighties and early nineties: they are now catching an estimated weight of about 1 million tons of tunas yearly. The percentages of the purse seine tunas which were taken on FADs in each ocean during recent years 1994-1997 are given in table 1; table 2 gives the average species composition of tunas caught under FADs during the same period, in each area. They are primarily targeting skipjack tuna, which is everywhere the dominant species under FADs: skipjack catches amount for an average 63% of tuna FADs catches, and correspond to 55% of world skipjack catches by purse seiners.

Table 1 - Percentage of FAD-associated catches versus total tuna catches (yellowfin, skipjack and bigeye tunas) taken in each fishing zone on FADs by purse seiners during recent years (period 1994-1997).

Ocean	*Yellowfin*	*Skipjack*	*Bigeye*
Atlantic	22.1	68.1	84.1
Indian	52.1	80.7	85.4
Eastern Pacific	11.4	72.0	96.4
Western Pacific	21.4	55.2	66.5

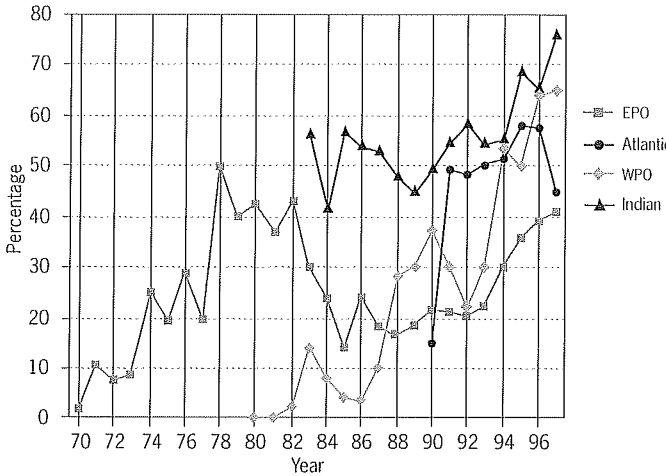
Table 2 - Average percentage of each species (yellowfin, skipjack and bigeye tunas) in the catches on FADs by purse seiners, in each fishing zone, during recent years (period 1994-1997).

Ocean	Yellowfin	Skipjack	Bigeye
Atlantic	33.7	56.5	9.7
Indian	22.1	61.2	16.7
Eastern Pacific	25.5	55.5	19.0
Western Pacific	20.8	77.9	1.3

This fishery is also catching significant quantity of yellowfin (an average 25% of tuna caught under FADs, 21% of yellowfin catches by purse seiners) and bigeye (12 and 66%). The comparison of the species composition of tuna catches under FADs shows quite minor differences between oceans. It can be noticed for instance that:

- in the Western Pacific, bigeye tuna caught under FADs may be less abundant than in other areas, but this low percentage could be due to a species identification bias (in the absence of a systematic species sampling);
- the FAD fishery contributes to a large proportion of yellowfin catches by purse seiners in the Indian Ocean (52% of total yellowfin catches), but only a small proportion in the Eastern Pacific (11%) (when the species composition of FAD-associated tunas is very similar);

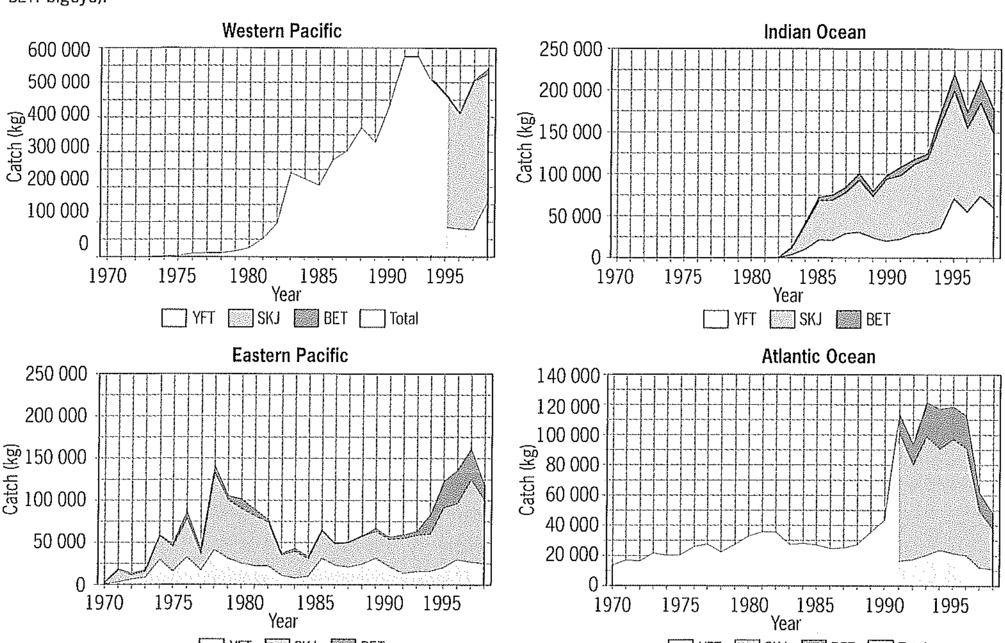
Figure 2
Estimated percentage of tunas caught by purse seiners under FADs in each of the four major fishing areas (EPO: Eastern Pacific Ocean, WPO: Western Pacific Ocean).



- the percentage of total catches taken during recent years under FADs is high in all oceans (fig. 2), the higher percentages being observed in the Indian Ocean (75% in 1997) and in the Western Pacific (65%), and the lowest in the Eastern Pacific (40%).

During recent years, each of the four fishing zones shows large increase of FAD-associated catches (fig. 3). However, both the number of purse seiners using FADs and the average number of FADs used by each purse seiner are poorly estimated by statistical agencies. It was recently estimated (Ménard *et al.*, 2000) that about 3 000 FADs were used permanently by the 45 purse seiners landing in Abidjan (i.e. an average of more than 60 FADs used by each purse seiner). Knowing that about

Figure 3
Estimated yearly tuna catches taken by purse seiners under flotsam and FADs (period 1994-1997) in each of the four major fishing zones (YFT: yellowfin, SKJ: skipjack, BET: bigeye).



500 industrial purse seiners are active worldwide, the total numbers of FADs used worldwide could probably be estimated in tens of thousands.

Sizes of tunas taken under FADs

Tunas associated with FADs are primarily of small sizes: the three tuna species targeted under FADs (skipjack, yellowfin and bigeye), show a similar mode at about 48 cm with a large majority of tunas caught under FADs at sizes less than one metre (fig. 4). The tuna sizes observed under FADs are quite similar for each species in the different fishing zones (fig. 5). It should be noted that significant weights of large

Figure 4
Average sizes of tunas, (yellowfin, skipjack and bigeye) taken by purse seiners under FADs (worldwide average, recent years).
(YFT: yellowfin, SKJ: skipjack, BET: bigeye).

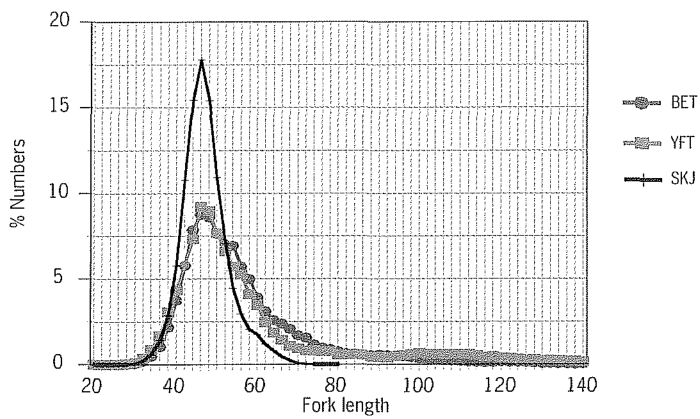
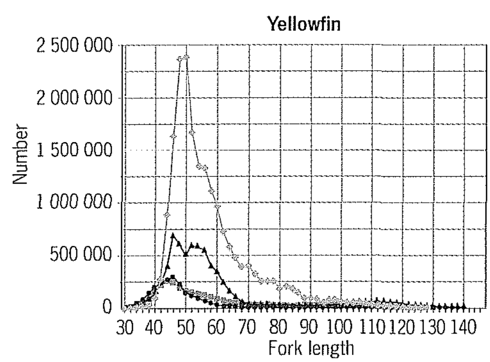
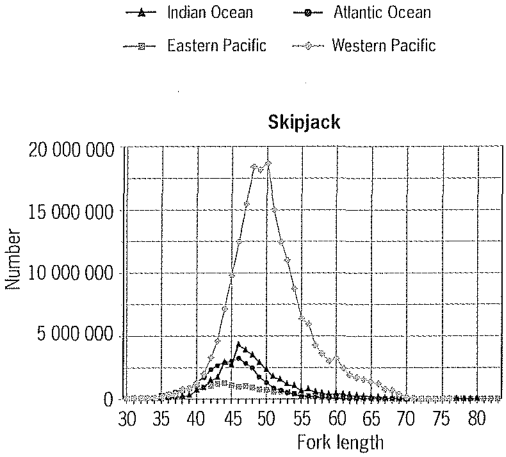


Figure 5
Average sizes of yellowfin, skipjack and bigeye, taken by purse seiners under FADs in each of the four fishing zones (recent years).





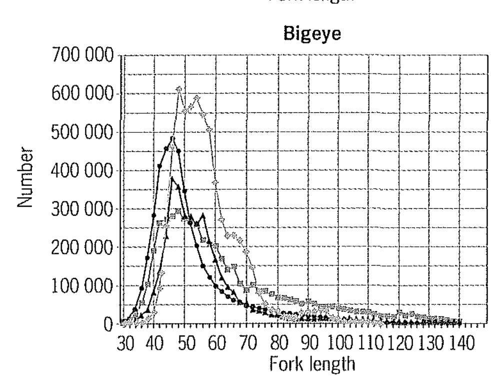
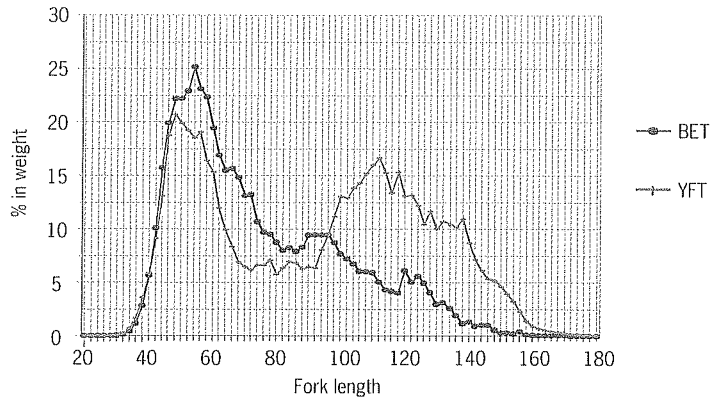


Figure 6
Average weight of yellowfin (YFT) and bigeye (BET) by 2 cm size classes taken by purse seiners under FADs (worldwide average, recent years).



yellowfin (and also to a lesser degree of large bigeye) are often taken under FADs (fig. 6) especially in the Western Pacific (fig. 5). This significant proportion of large yellowfin would explain why the yearly average weight of yellowfin caught under FADs is most often in a range between 5 and 10 kilogrammes.

However, some peculiarities are quite typical of the sizes taken in each area, for instance:

- the proportion of large yellowfin is greater in the Indian and Western Pacific Oceans;
- large skipjack are often taken significantly in the Western Pacific (and to a lesser extent in the Indian Ocean);
- large bigeye are often taken significantly in the Eastern Pacific;
- the proportion of very small tunas taken under FADs shows some differences among oceans (more discards in the Eastern Pacific), but part of this heterogeneity is probably due to variable rates of small tuna discarding. In general, discards of small tunas tend to be lower in the Indian and Atlantic Oceans because of the existence of local markets, in which undersized tunas are easily sold, and also because canneries are more flexible in some areas to buy these small tunas.

Some peculiarities of FAD sets

Three major peculiarities of FAD-associated sets have been commonly observed worldwide in all purse seine fisheries (Fonteneau, 1992):

- most FAD sets are done very early in the morning, before sunrise; as a consequence, most of the daytime can still be used to search for other tuna schools. However, there is also a tendency to increase the frequency of FAD sets during the day;
- positive sets done upon the same FAD are often observed during successive days (sometimes more than eight). In such case, there is a tendency to observe (1) a decrease of the average catch per set, (2) changes in the tuna species composition (in general a faster decrease of skipjack) and (3) changes in the average sizes of tuna caught (in general with an increasing average weight) (Ariz *et al.*, 1999);

- the rate of successful sets under FADs is always very high in all the oceans, above 90%, whereas about 50% of the sets done on free swimming schools are unsuccessful.

FAD technology

Similar design and size of FADs are used by all purse seine fisheries worldwide: FADs are most often built by the fishermen themselves (and without any technical or financial support from their States) with a bamboo framework (about 3 x 1.5 m), and they all carry a radio-location beacon and antennas, various systems being used. These location devices often allow to follow by satellite, permanently and in real time, the exact position of FADs and to analyse later these positions and the drift of FAD on a personal computer (on board or on shore). This analysis of FADs movement, associated to other satellite information (such as sea-surface temperature, waves, ocean color, etc.) will provide to the fishermen a better understanding of surface current patterns, fronts, eddies and convergences (which are useful to improve their searching patterns). Underwater nets are commonly attached under FADs. The length of these nets shows an increasing trend and can reach a depth of 50 m in the Eastern Pacific. The effectiveness of these larger nets to attract tunas has not been fully evaluated by scientists. There is also some indication that light sources associated to FADs are sometimes used at night (both underwater and surface lights), at least by some fleets, but the frequency of this use and its potential efficiency remain poorly documented. The use of bait fixed to the FAD in order to attract tunas was well described by observers in the Eastern Tropical Pacific, but it seems that this bait is not presently used in other fishing zones.

In some areas of the Western Pacific, anchored FADs are commonly used by purse seiners (Sibisopere, 2000). The amount of tunas taken by this fishing mode is quite high in Philippines and Solomon Islands or Indonesia, but it remains very rare or absent in other fishing zones. Supply vessels are also frequently used (mainly by Spanish purse seiners) in order to deploy and to maintain FADs, and to check permanently the quantities of tunas under its FADs. They will call a purse seiner from their company when they observe large amount of tunas under one of their FADs.

As a conclusion, it is quite clear that the FAD technology has been evolving very quickly worldwide and quite independently in each area (but always in order to improve the efficiency of FADs). However, fishermen often keep most of these changes secret, and the technical documentation available on drifting FADs is poor. It is then difficult first, to describe exactly all the characteristics of the FADs which are used, and second, to evaluate the importance of each new characteristics of these FADs and their effects on the various tunas species and sizes which are targeted. This efficiency may vary according to the ocean region as a function of its local environment.

Tuna stock assessment and FADs

A global problem

It is now quite clear for all scientists that the increased use of FADs has introduced worldwide major changes in the fishing patterns of most purse seine fisheries and consequently, in the exploitation of tuna stocks. Two examples, bigeye and skipjack stocks, are first analysed. This specific overview will be followed by a presentation of several problems which have been introduced in the stock assessment by the seeding of large numbers of FADs in the offshore pelagic areas: changes in the concept of fishing effort, changes in yield per recruit and other potential biological effects.

Bigeye and FADs

The massive development of fishery operations using FADs, in association with changes in the fishing technology (for instance the use of deeper nets described in the Atlantic by Gaertner & Sacchi, 1999), has produced worldwide a large increase of catches of small bigeye associated with FADs. This massive use of FADs has also produced a spectacular increase of bigeye fishing zones (with small bigeye being taken now in areas where they were not fished before, figure 7). This quick and unexpected change in the bigeye surface fisheries is a source of serious concern in various tuna commissions (IATTC, ICCAT, IOTC). As FADs fishery is catching small bigeye, when the longline fishery is catching only adults (fig. 8), there are two increasing concerns: first a short-term risk to reduce the yield per recruit, and second, a risk to face in the future a recruitment overfishing due to the recent FAD catches. This recruitment overfishing might be observed after a biological delay of about 3 to 10 years, a duration needed to reach a biological equilibrium of the spawning biomass (with a spawning stock too low to produce the historical recruitment of bigeye stocks). This recruitment overfishing has never been observed for any tropical tuna species, but there is a speculation that bigeye may face soon this situation because of the spectacular increase of juveniles catches since the early nineties (when catches of adults by longliners were also seriously increased). A first potential symptom of this excessive decline of the spawning stocks is given by the longline CPUE catching spawners. Surprisingly, this index shows a permanently decreasing trend in all oceans, for instance in the Atlantic and Indian Oceans (fig. 9), but at a quite constant rate during the period 1969-1997 (and without the spectacular decline which could be expected during recent years as a consequence of the large catches of juveniles by FAD fisheries). At this stage, there is still a serious concern with the increasing catches of bigeye by purse seiners on FADs, but these effects have not yet been demonstrated in any bigeye stock.

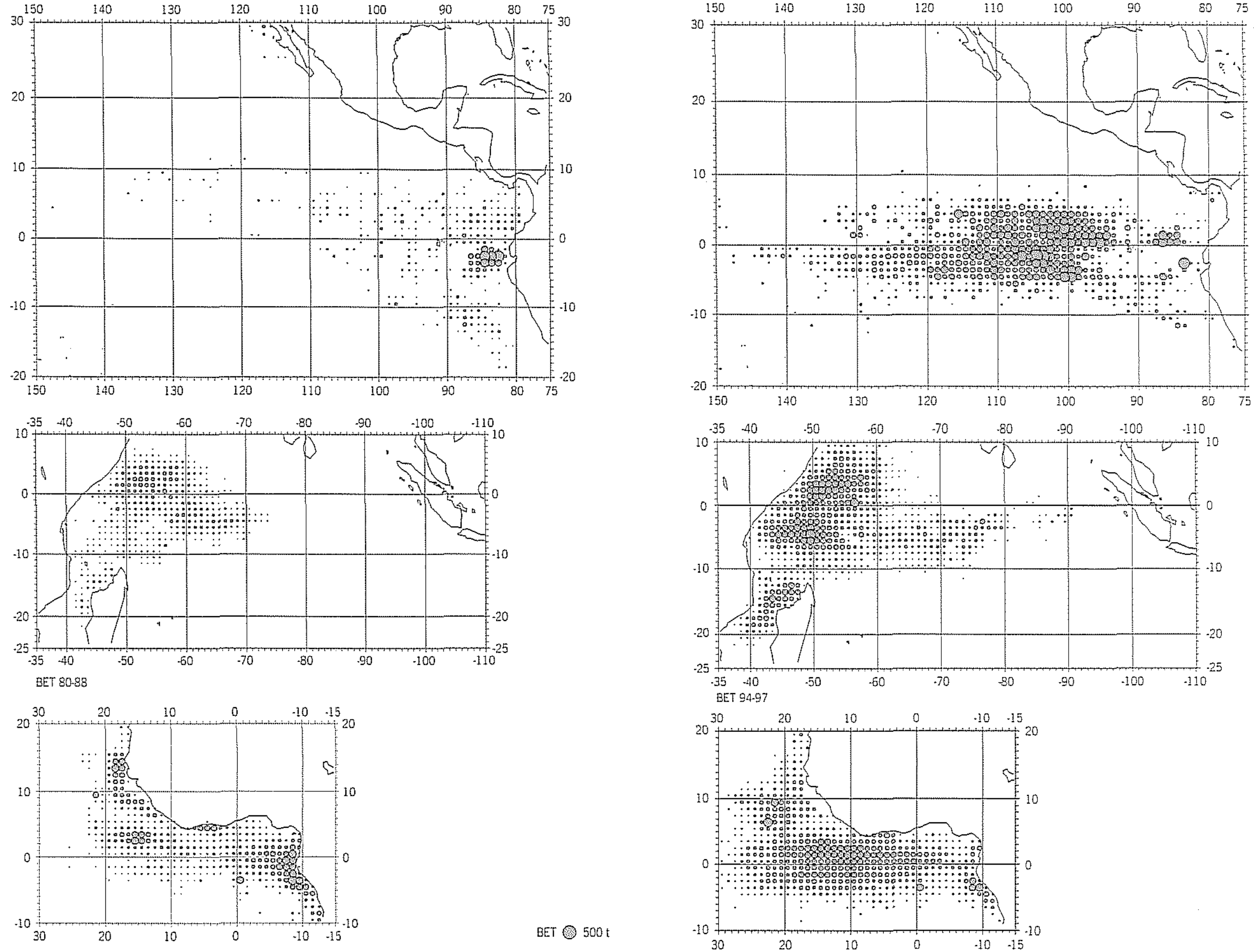


Figure 7 - Average catches of bigeye tuna by purse seiners in the Eastern Pacific, the Atlantic and the Indian Oceans before the development of FAD fisheries (period 1980-1988, left figures) and with FADs (period 1994-1997, right figures).

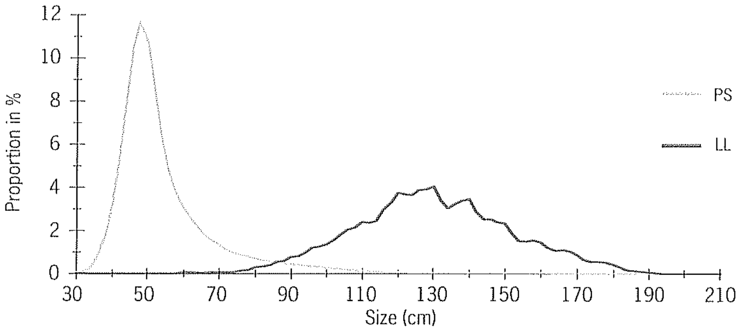


Figure 8
Sizes of bigeye tuna taken by purse seiners (PS, primarily under FADs) and by longliners (LL) in the Atlantic (period 1991-1997).

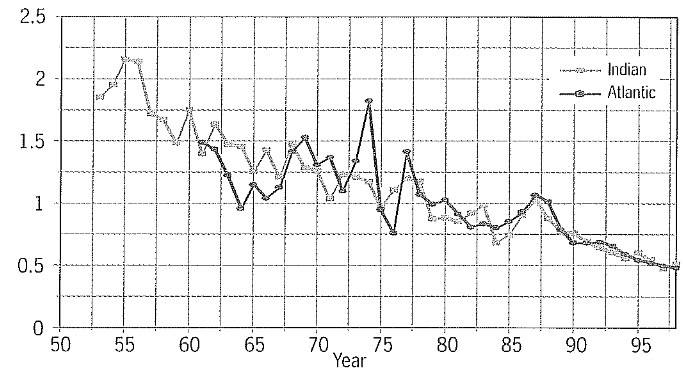


Figure 9
Index of abundance of adult bigeye tuna taken by Japanese longliners in the Atlantic and Indian Oceans (the two series of CPUE indices have been normalized to the same average).

FADs and Atlantic skipjack

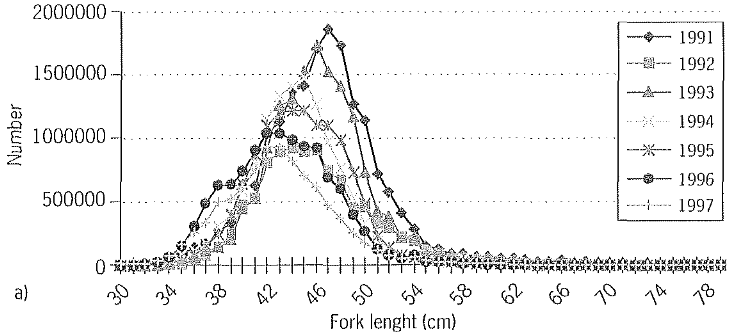
The massive use of FADs has produced worldwide a spectacular increase of skipjack catches. Skipjack stocks are most often estimated to be still underexploited by the different tuna commissions. Since 1990, this is no longer the case for Atlantic skipjack since the working group held by the ICCAT on this stock in 1999 (ICCAT, 1999). In the Atlantic, skipjack is the dominant species targeted by FAD fisheries. However, this increased fishing effort has produced a spectacular and unexpected decrease of skipjack catches (fig. 3), and also a significant decrease of average sizes in the major fishing zone on FADs (fig. 10). The ICCAT diagnosis was that Atlantic skipjack suffered during recent years growth overfishing, at least in the equatorial regions where the more active FAD fisheries were developed.

FAD, effort, CPUE and abundance

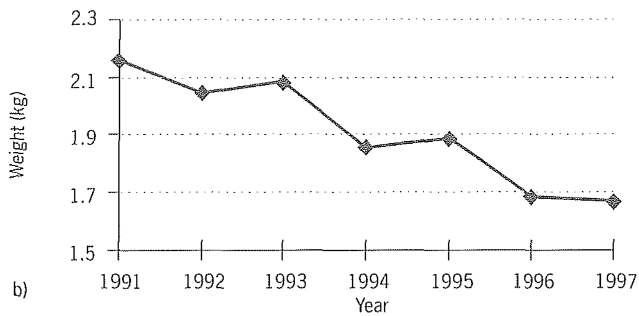
FADs equipped with sensors and radio-beacons have recently introduced a major change in the traditional concept of the purse seine fishing in which fishing effort was primarily a searching activity. Nowadays, when large numbers of FADs are deployed, searching time can no more provide a measure of fishing effort, because fishing effort is now a mixture of time periods devoted (1) to visit targeted FADs, or (2) to randomly search free schools. As a consequence, it is now very difficult to use the catch per unit effort or CPUE as an index of local abundance; this assessment problem is faced equally for both the FAD and the free-school fisheries, as log books never indicate times spent searching free schools or targeting FADs.

Figure 10
Yearly sizes of skipjack (fig. 10a) and yearly *average weight (fig. 10b)* taken by purse seiners in the equatorial area (Atlantic).

a)



b)



The average catch per set on FAD may become a better index of the local abundance for small tunas (assuming that there is a relationship between *the local biomass which is available in each strata and this catch per* set) but, this index would need more research. It would necessitate at least the knowledge of the number of FADs deployed in the area, because the biomass of tuna associated to each FAD will decrease while the numbers of FADs increases, assuming a given biomass in the area.

Changes in yield per recruit and natural mortality

One of the major difficulty presently faced by all tuna commissions is to estimate the long-term yield per recruit effect of drifting FADs fisheries for each tuna species. Any yield per recruit calculation needs a good knowledge of growth and natural mortality at all ages. Unfortunately, the natural mortality M estimated for juvenile tunas is poorly estimated for all tuna species and this uncertainty will largely condition most of the conclusions obtained from the analysis:

- If the actual M of juveniles is low (for instance the same as for the adults), then the massive use of FADs would, after several years (during their exploited life), produce a significant decrease of the yield per recruit. In this hypothesis, various bigeye stocks should soon face a significant decrease of their yield per recruit; they could also face an unknown risk *of recruitment overfishing* (when each of the cohorts exploited on FADs by the new fishery will be fully recruited in the adult stock).
- If juvenile M of tunas is high, for instance much larger than the adults one, the corresponding fishing mortalities of juveniles taken on FADs may still be quite low (even when large catches are observed). Such high

estimates of M were obtained for yellowfin by Hampton & Fournier (1999). For juvenile bigeye tuna less than one year old, yearly estimation of M over 4.0 is a very high level compared to the M=0.4 estimations for adult bigeye by Hampton (in Bertignac, 1999). For skipjack smaller than 30 cm M level estimation is over 2.0. In this case, the potential effect of FADs may be hardly visible for any tuna stocks unless when the adult stock is already very heavily fished.

The present uncertainties upon M are clearly so large that there is very little hope to evaluate precisely the changes in the yield per recruit due to increased FAD fishing. Intensive tagging of small tunas is probably the most efficient way to estimate this key biological parameter. In the absence of specific researches on natural mortality, the present large-scale increases of small tuna catches should be considered as an interesting (but not precautionary) overfishing experiment:

- if the present high catches are sustained, this would mean that natural mortality of juvenile is probably relatively high (or the recruitment much larger than presently estimated);
- if an overfishing does occur in the near future, growth or recruitment overfishing, this would probably means that natural mortality of juveniles was relatively low.

The full consequences of this experimental'overfishing will be apparent within few years.

Other potential effects of FADs on tuna stocks and fisheries?

There are probably also various other potential effects of FADs on the tuna resources including the following:

- Genetic erosion for some fraction of stocks which may show, in relation with their genome, a behaviour of strong association with FADs. This sub-population may then be eliminated by the selective pressure on FADs (Cury & Anneville, 1998; Allendorf *et al.*, 1986);
- Differential effects of FADs upon each of the major tuna species. Because of their different intrinsic potential to face growth and recruitment overfishing, the FAD fishery may introduce a specific advantage or disadvantage for each of the targeted species (yellowfin, skipjack or bigeye) and may accelerate the potential effects of fisheries in the pelagic ecosystems;
- FAD = ecological trap? This question is still pending (Marsac *et al.*, 2000), but several facts are consistent to support the hypothesis that the recent massive seeding of FADs in the equatorial areas could modify one or more biological characteristics of the concerned tropical tunas: movement pattern, growth and natural mortality. If this hypothesis is confirmed, all the analyses which are conducted presently under the assumption that these biological characteristics are constant, could be seriously biased (at an unknown level);
- Interaction between drifting and anchored FAD fisheries. The number of anchored FAD fisheries has increased recently in order to target tunas and associated species. There is then a potential interaction

between the offshore industrial fisheries using drifting FADs and the artisanal ones targeting tunas with anchored FADs. This could be the case when they are exploiting the same species in adjacent areas, such as in the Eastern Pacific, the purse seine fishery on FADs and the Polynesian FAD fishery. Taking into account the fact that the artisanal fisheries have very little or no alternative to catch their target species, this potential interaction would need to be carefully evaluated. This task was partly done during the recent FAO research project on tuna fisheries interactions (Shomura *et al.*, 1996); however, as this project was done at an early stage of the FAD fisheries, very few firm conclusions were obtained upon this topic.

Presently, none of these potential risks has been fully evaluated, but in the new context of precautionary approach, they should already be taken into account in the development of FAD fisheries, and further research should be developed in order to evaluate each of the risks involved in this FAD fishery.

Conclusion: tuna stock assessment and FADs

Unfortunately, the present biological knowledge and models do not allow making realistic projections of the potential effects of increased FAD fisheries. Therefore, it is necessary to monitor very closely, preferably in real time, any potential changes in the levels of catches, CPUE and sizes taken, for both FAD fisheries and the other ones. The three main tropical tuna species, skipjack, yellowfin and bigeye, should be monitored carefully, bigeye being probably the most sensitive species in this list, with perhaps a potential risk of recruitment overfishing, after an unknown but quite long-time lag.

This comparative follow-up and analysis of the changes occurring in the four ocean areas (Atlantic, Indian, Eastern and Western Pacific), should be a high priority and this analysis should preferably be conducted within a joint FAD research programme developed in a coordinated way by the various tuna bodies.

Potential effects of FADs on the pelagic ecosystem

Introduction

The FAD fishery by purse seiners is often catching (and often discarding) significant quantities of by-catches (tuna and other species). This overview will try to compare the rates of by-catches by the various purse seine fisheries using FADs worldwide. Two questions will be tackled:

- what are the by-catches and discards associated to FADs in the purse seine fisheries?
- what are the potential effects on the offshore pelagic ecosystems of this removal?

This overview is based upon data of variable sources and quality, all taken from the literature and from observer data (observations done during recent years, but not during the same period).

Quantitative estimates of by-catches

The species composition of by-catches appears to be quite similar in the four ocean areas (Atlantic, Indian, Eastern and Western Pacific) as shown in annex 2. Small tunas (skipjack, juveniles of yellowfin and bigeye, *Auxis, Sarda, Euthynnus*, etc.), rainbow runner *(Elagatis)*, billfishes (marlins and sailfishes), "mahi-mahi" (genus *Coryphaena*), triggerfish (genus *Balistes*), wahoo (genus *Acanthocybium*), sharks and few turtles are species most often found under FADs (fig. 11).

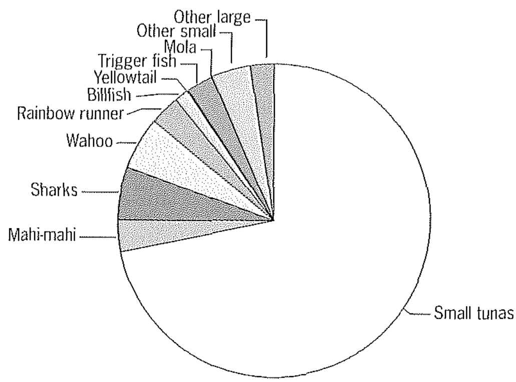
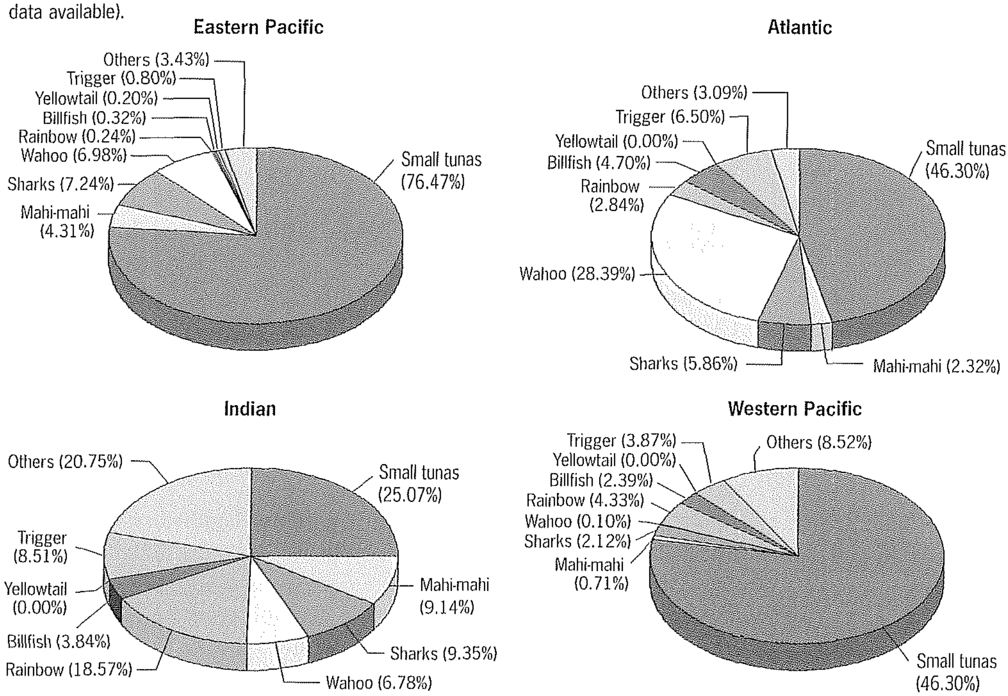


Figure 11
Estimated percentage of quantitative discards by purse seiners (worldwide), for the main groups of by-catches, on FAD schools (recent years, the periods are different in each ocean, as a function of observer data available).

It can be noted however that this associated fauna shows interesting differences in its species composition in each area (fig. 12). In various cases, it should be noted that this by-catch is often sold to local markets (Atlantic and Indian Ocean, Romagny *et al.*, 2000), when they are dumped dead at sea in other areas (Pacific Ocean, IATTC, 1999). This

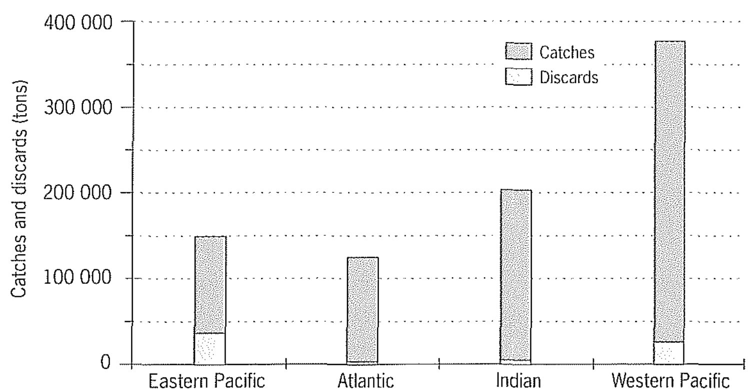
Figure 12
Estimated percentage of quantitative discards by purse seiners in each of the four fishing zones, for the main groups of by-catches, on FAD schools (recent years, the periods are different in each ocean, as a function of observer data available).



variable local market explains why discard rates are quite variable between oceans.

The average amount of by-catches taken on FADs are quite significant (an average of about 10% of the world tuna catches on FADs by purse seiners, figure 13), but the total weight of these by-catches remains moderate (e.g. about 100,000 tons yearly worldwide, mostly small tunas, on a total landed tuna catch of about one million tons). This by-catch can be considered as being quite minor in comparison with the very large size of the *equatorial pelagic ecosystems*, the *equatorial ecosystems* (as proposed by Longhurst, 1998) covering approximately 77 million square kilometres (respectively 13, 21 and 43 million square kilometres for the Equatorial Atlantic, Indian and Pacific Oceans). This also can be considered as a minor by-catch, for instance compared with total discards of shrimp fisheries (using trawls) estimated at 9.5 million tons yearly by Alverson *et al.*, 1994 (in a fishing area which is much smaller than the tuna fishing zone).

Figure 13
Estimated average catches of tunas taken under FADs by purse seiners and estimated by-catches in each of the four fishing zones (recent years, the periods are different in each ocean, as a function of observer data available).



As a consequence of this quite low level of by-catches, there is probably still a low or moderate impact of FAD fisheries on the pelagic ecosystems taken as a whole. However, the potential negative impact of FAD catches on some specific group of fishes (or some sensitive species) should be well-monitored. For instance, a given sub-population of hammer-head sharks, turtle or "mahi-mahi" could suffer at a local level an excessive fishing mortality which may be dangerous, either for the local artisanal fishery or for a local sub-population (Cury & Anneville, 1998). These *potential local problems should then be evaluated carefully, based on a permanent* analysis of observer and artisanal fishery data.

Only well-planned *ad hoc* observer programmes do allow to estimate the species composition and quantities of FAD-associated by-catches. Observer data should then be collected routinely on all major purse seine fleets in order to monitor carefully these by-catches and to incorporate those observations in databases that could be accessed and used by interested scientists. However, it should be noted that, because of the spatial and temporal stability of the FAD-associated by-catches, a quite low rate of observers (for instance between 5 and 10%) can probably allow to estimate quite precisely the by-catches of most species by fleet and region.

This low rate is probably valid at least when the observer data are well-stratified and extrapolated using this stratification, in association with the log book information. Lennert from the IATTC and Fonteneau obtained this preliminary, but very interesting and quite logical conclusion with a bootstrap analysis conducted with the IATTC observer data (coverage rate of about 100%). This very interesting result still needs to be validated for each of the major species, and to be published.

Management prospects of FAD fisheries

In the present context of precautionary management of fisheries, there is now an increasing international pressure to reduce the use of FADs by purse seiners. This tendency is logical, even though the negative long-term effects of FADs on tuna stocks and their ecosystems are still widely hypothetical. This trend to reduce the use of FADs is primarily targeting a safer management and a better conservation of tuna stocks. Even the fishermen themselves are fully aware of the potential danger of an excessive use of FADs: the moratorium on the use of FADs in the Atlantic was an initiative taken by the European Union fishermen. However, very few practical ways have been presently identified to efficiently reduce the use of FADs by purse seiners, and this reduction will be a difficult challenge for the various tuna commissions and for the purse seine tuna industry.

Most reduction in the use of FADs would produce large losses of catches, especially skipjack, but also of bigeye and yellowfin as well of non-tuna by-catches (which are becoming very interesting for many purse seiners in the Atlantic and in the Indian Ocean (Romagny *et al.*, 2000). Various potential measures are now studied by tuna commissions and tuna boat owner associations in order to reduce FAD fisheries, such as:

- A ban of the supply vessels (already done by the IATTC);
- Limiting the numbers of FADs deployed (as the present number of FADs used is still poorly estimated, this scheme may be unrealistic);
- Limiting the sizes of nets under FADs (such measure was envisaged by the IATTC, but it will be difficult to control and its potential effects are still unknown);
- Limiting the electronics used on FADs (again difficult to manage);
- Implementing catch quotas of small tunas taken on FADs (observers are needed on every purse seiner);
- Implementing Moratorium of FADs in well-selected strata (primarily strata with large catches of tunas on FADs), such as the management measure applied in the Atlantic since 1997 (observers are also needed, and the negative intrinsic effects of FADs may remain);
- Complete area closure (will be easy to manage when all boats will carry vessel monitoring system devices).

Most fishermen, scientists and fishery managers agree that the use of FADs should be limited at reasonable levels and closely monitored. One logical conclusion would be for instance that the use of FADs should have been permitted to increase more slowly, allowing scientists to evaluate empirically their risks. There are presently multiple uncertainties and difficulties, practical and political, to choose and to implement the management measures on FADs which would limit their negative impact, still allowing to catch large quantities of skipjack tunas, and of large yellowfin and bigeye.

Conclusion: drifting FADs and purse seine fisheries

This synthesis upon purse seine fisheries operating worldwide on FADs demonstrates the major importance of this fishing mode developed during the last ten years. This overview shows well the great similarities between the various FAD fisheries that are active worldwide:

- similar importance in terms of percentages of tunas caught on FADs;
- similar trends in their development during recent years;
- similar species composition and sizes of tuna taken under FADs;
- similar by-catches of associated fauna (in terms of their quantities and species composition).

It is also clear that the massive development of the FAD fisheries is presently introducing major uncertainties in most stock assessment studies done on tropical tunas. It is also raising serious potential problems concerning the conservation of tuna stocks, primarily bigeye tunas, but also skipjack in some areas. Many serious uncertainties also remain concerning the long-term effects of this recent development. There are first serious reasons to consider that this new fishing technique may have strong negative impact on the yield per recruit of some species (primarily bigeye, and to a lesser degree other species such as yellowfin). There is also serious concerns that an excessive use of FADs and an excessive catch of juveniles may produce at a longer term (for instance within 10 years or more) a dangerous decrease of tuna spawning stocks which could lead later to recruitment overfishing. This would be a critical situation, never observed until now for tropical tunas, which could reduce fishing activities at very low levels and during quite long periods. Furthermore, there is also serious concerns that the large numbers of FAD seeded may modify the biological characteristics of tuna species (changing their movement patterns, natural mortality and growth), independently of the level of tuna catches. The significant accidental mortality of by-catches species in most FAD sets can also be a legitimate source of worry, even though the total weight of these discards can be considered as quite low in comparison of the very large biomass of the oceanic ecosystems exploited by purse seiners. In the new context of precautionary management of exploited resources, the conclusion most often reached by fishermen, scientists and tuna commissions is that the use of FADs should be limited and controlled at reasonable and moderate levels, even though their real danger cannot yet be fully evaluated. This controlled activity would allow a sustainable exploitation of each targeted species (yellowfin, skipjack and bigeye) and would not

hamper the ecological equilibrium in the pelagic areas. Various actions have been already taken to limit the use of FADs or to reduce their efficiency, but there is no clear and optimal solution among the various management options that are presently taken or envisaged. In the new context of the precautionary approach applied to the management of fisheries, this limitation of FAD use by purse seiners should be an urgent goal, even though the real risks remain still quite uncertain.
A clear and firm conclusion from this study is that the problems of FADs, both scientific and management ones, should preferably be tackled at a worldwide scale. This recommendation is a logical one, taking into account the great similarities between tuna species, tuna fisheries and FAD trends worldwide. This international cooperation should lead urgently to an *ad hoc* world research programmes on FAD fisheries. This research should take into consideration, not only the drifting FAD fisheries, but also the combined rational use of drifting and anchored FADs, and the potential interaction between the two fisheries. This active international research should be based for instance on a very active cooperation between the tuna commissions (which has never been well developed in the past). The FAO and its Fishery department should preferably play an active role in this plan leading to a more sustainable exploitation of world tuna resources.

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Annex 1: Data and information used in this synthesis

The data and information used in this synthesis were obtained from diverse sources.

Most statistical data concerning the catch, efforts and sizes of tunas were obtained by direct contact to the various tuna bodies which are handling tuna data in the various oceans, namely:

- the ICCAT (International Commission for the Conservation of Atlantic Tunas) for the Atlantic data;
- the IOTC (Indian Ocean Tuna Commission) for the Indian Ocean data;
- the IATTC (Inter-American Tropical Tuna Commission) for the Eastern Pacific data;
- for the Western Pacific, data were provided by the SPC (Secretariat of the Pacific Community) and by the NMFS (National Marine Fishery Service, US fleet).

Some statistical informations used in this paper were also taken from the scientific literature published by these different organizations (these sources are quoted in the text).

The estimates of by-catches and discards were all taken from the published literature obtained from observer data. As the information concerning these by-catches are often given in numbers of fishes, they were first transformed into estimated weight (using the best available information upon the specific average weights). When necessary, these weights were also extrapolated to the total catches (knowing the total FAD catches and the ratio of by-catches versus tuna catches in the samples).

Annex 2: List of the major species associated to FADs

Tunas: skipjack (*Katsuwonus pelamis*), young bigeye (*Thunnus obesus*), young yellowfin (*Thunnus albacares*), "kawa-kawa" (*Euthynnus*) and bullet tuna (*Auxis*).

Wahoo (*Acanthocybium solandri*).

Dolphinfish or "mahi-mahi" (g. *Coryphaena*).

Sharks: silk shark (*Carcharhinus falciformis*), oceanic white-tip shark (*C. longimanus*) and hammerhead shark (g. *Sphyrna*).

Billfishes: blue, striped and white marlins (g. *Makaira* and g. *Tetrapterus*), sailfish (g. *Istiophorus*).

Pelagic triggerfish (g. *Balistes*).

Carangids: rainbow runner (*Elagatis bipinnulata*), yellowtail (g. *Seriola*) and carangids (g. *Caranx*).

Barracuda (*Sphyraena barracuda*).