Drifting FADs used in tuna fisheries: an ecological trap?

Francis Marsac, Alain Fonteneau, Frédéric Ménard
IRD, centre de Montpellier, laboratoire HEA, BP 5045, 34032 Montpellier Cedex 1, France
marsac@ird.fr

Abstract

This paper discusses the hypothesis that small tunas and the various species found in association with drifting FADs (such as "mahi-mahi", rainbow runner, wahoo, etc.) may be biologically trapped by such a strong association. Massive seeding of drifting artificial FADs was observed worldwide during recent years. In this hypothesis, we suggest that FADs may alter some biological characteristics of epipelagic populations associated with them: migration, growth, condition factors, predation and natural mortality. As FADs are most often used in the equatorial currents, they tend to exhibit zonal drift. Therefore, the associated populations would be artificially transferred from one part of the ocean to another, when they would show different movement patterns in the absence of FADs. Natural logs were probably beneficial in terms of ecology and evolution, because they tend to accumulate in convergence areas, most often considered as rich forage areas. Now, FADs are seeded in offshore areas, which are not necessarily favourable for tuna feeding. This apparently strong association between fishes and drifting FADs may then produce an unexpected biological impact on tuna populations and their associated fauna. The plan is to test this hypothesis in the Atlantic, developing an *ad hoc* research programme based on tagging, biological and physiological studies, in association to an analysis of high resolution fishery data before and after the development of the FAD fishery.

Introduction

Purse seine fishing on floating objects started in the Philippines during the late sixties. Networks of anchored rafts, dubbed payaos, had been deployed and were exploited by a tuna handline fishery. Some seiners started fishing operations around these FADs. This fishing mode turned to be very efficient and resulted in a drastic increase of catch during the following years. In 1972, more than 160000 t of tuna were captured around payaos (Marcille & Bour, 1981).

The use of drifting FADs in the purse seine fisheries is more recent: it has been initiated in the early eighties, during experimental surveys conducted by the Japanese organisation Jamarc in the Indian Ocean (Takahashi *et al.*, 1988; Watanabe *et al.*, 1988). Purse seiners had already taken advantage of the tuna aggregation around natural logs, first in the Eastern Pacific and Atlantic, and later in the Western Pacific and in the Indian Ocean. From Japanese surveys in the Indian Ocean, it was considered that the number of natural logs drifting in the fishery was not important enough to maintain this type of fishing for a large fleet. Therefore, the deployment of man-made rafts of different types (payao type, steel frames, wood frames, bamboos) was tested and studied as a response to this issue. The conclusions of these studies, along with other trials undertaken by the purse seine fleets, were satisfactory enough to introduce this new fishing method in the purse seine and baitboat fisheries. In the early nineties, this mutation was accomplished and the production using this technique took off and came in first position, ahead of the conventional fishing method on unassociated (free swimming) schools (Fonteneau *et al.*, 2000b).

In that way, fishing on FAD is a method enhancing the catchability of tuna stocks. Recently, observations on the decreasing size of tunas caught with FADs in the Atlantic focused the attention to the possibility that the aggregation of juvenile tunas under these FADs would be detrimental to some biological characteristics of the associated fishes, due to their great number deployed by the fishery. This hypothesis is a new way of seeing the impact of FADs with a number of potential consequences on the tuna populations. In this paper, important facts on FAD fishing are recalled and discussed with respect to this hypothesis.

Some facts on the association between tunas and floating objects

Drifting FAD fishing is now developed worldwide and is catching yearly over one million tons of tunas (Fonteneau *et al.*, 2000). When analysing the sizes of tunas caught by the different fisheries, it is striking to see the great similarity of the observations, suggesting that the underlying aggregation process is controlled by behavioural and physiological rules (fig. 1).

Several hypotheses were proposed to explain the aggregation on flotsam (Fréon & Misund, 1999). Among these, the "meeting-point hypothesis" states that a FAD enhances the formation of large schools, either from individuals or from small schools. A fish joining a greater group

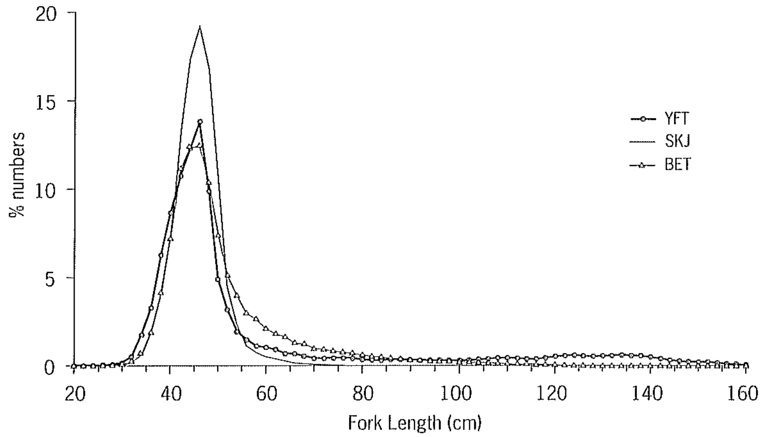


Figure 1
Average sizes of tunas, yellowfin (YFT), skipjack (SKJ) and bigeye (BET) (in numbers) taken under FADs (worldwide average, recent years).

will increase its probability of survival, until an optimal size is reached (Pitcher, 1986). Schooling process occurs mainly for species of similar sizes, which share the same habitat, have to face the same feeding requirements or share the same threats from the predators.
Tunas aggregated around FADs are mostly small size fishes (less than 70 cm). Adult yellowfin are also found around FADs, which produce a significant mode in weight, at 120-130 cm FL. Conversely, adult bigeye remain in the deep, and are less vulnerable to surface gears. Superimposing the size distributions (in numbers) of the three species exploited by the purse seiners, brings out a striking mode at 46 cm (fig. 1). Acoustic observations show a peculiar vertical distribution of tunas under a FAD, with small individuals of different species in the upper layer and large individuals scattered in the deeper layer (Cayré & Marsac, 1993; Josse *et al.*, 1999). The vulnerable fraction of this biomass to the gears is predominantly skipjack (58% of the catch, worldwide average 1994-1998, West Pacific excluded) and juvenile of yellowfin (27%) and bigeye (15%).

Artificial FADs and natural logs: a different oceanic distribution

An example is given from the East Atlantic surface fishery. Sets on natural logs and on unassociated schools showed distinct geographic distributions in the late seventies. Unassociated schools (fig 2b) were more abundant offshore (south of Equator), whilst the distribution of the natural logs reflected the physical properties of the environment, namely the proximity of great river mouths and the surface current pattern (fig. 2a). Various floating debris (bamboo packs, groups of branches, wooden logs) are washed up at sea by large rivers flowing across the equatorial forests (especially the Congo river), running into the Gulf of Guinea between 5°N and 5°S. The circulation of surface waters in the Gulf of Guinea is rather complex, with numerous small-scale vortex well described by drifting buoys (Piton & Kartavtseff, 1986). The eastern part of the Gulf of Guinea is therefore considered as a retention zone trapping drifting debris, which is enriched by seasonal coastal upwellings from July to September. The Lopez Cape used to be a productive fishing ground for the purse seine fishery during the seventies and the eighties. Lots of sets on natural drifting objects have been reported, producing more than 23% of the catch (Cayré *et al.*, 1988). In Ivory Coast and Ghana, biological production is also enhanced by upwelling, and the proportion of log catches amounted to 18% during the eighties. Offshore (0° to 5°N, 10°W to 20°W), a westward propagating eddy system generates a retention area where logs can be transported and trapped. In the 80s, the catch on natural objects reached 18.5% of the catch in this region which is enriched seasonally by waters advected from the equatorial upwelling (Menkès *et al.*, 1998). On the overall, natural logs tend to drift towards biologically productive areas. Conversely, very few natural logs were observed or fished in the offshore equatorial area, when unassociated schools were already fished in great numbers in this area.

In recent years, the distributions of FADs sets (fig. 2c) and free-swimming schools sets (fig. 2d) are very similar as the FAD fishing type has been developed offshore. Compared to the historical period, the artificial FADs concentrate high tuna biomass in non-conventional offshore areas, that are generally less productive ecosystems than the coastal ones.

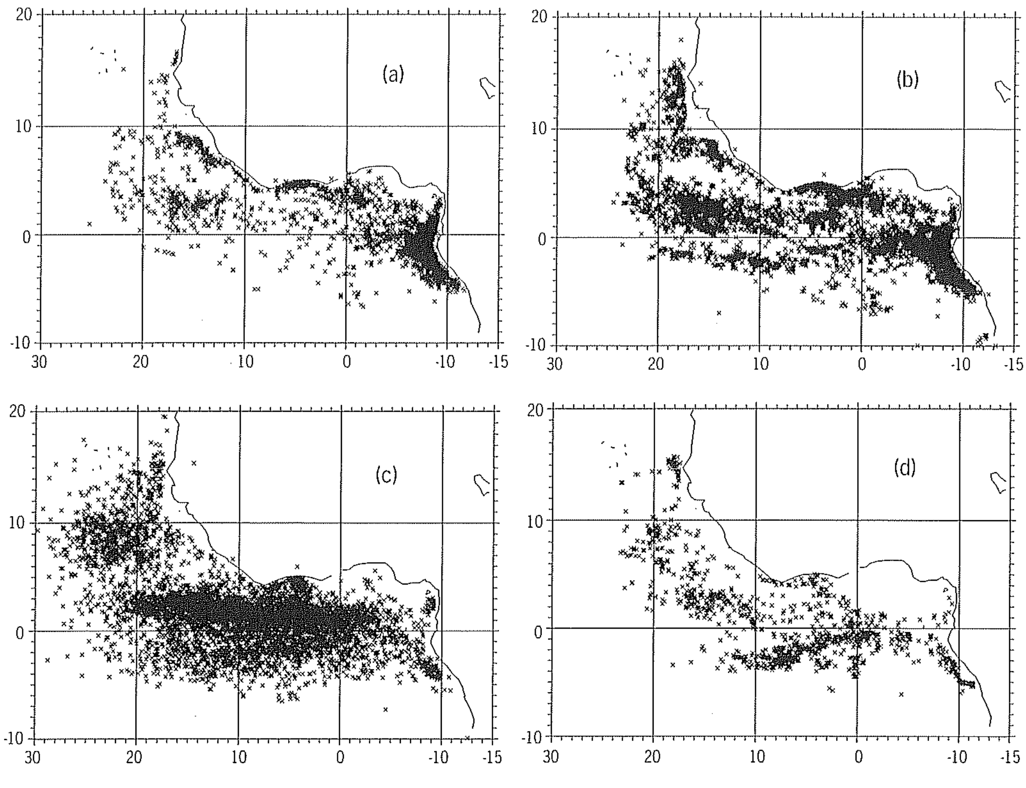


Figure 2
Comparative distribution of purse seine sets in two different periods of the fishery: 1976-1982 on natural logs (a) and unassociated schools (b); 1995-1996 on FADs (c) and unassociated schools (d).

An hypothesis based on a trapping effect of the FADs

The hypothesis of the FADs acting as an ecological trap is discussed in three related steps:
H1: the aggregation of small tunas under FADs is a fast, strong and long-lasting process;
H2: the large numbers of drifting FADs in the equatorial zone can alter the natural movements of this fraction of the tuna stocks;
H3: subsequently, drifting FADs affect negatively the growth and the natural mortality of small tunas which remain associated with FADs.

A fast, strong and long-lasting association

Experimental fishing surveys using FADs have shown a quick response of tuna schools in the aggregation. In the Eastern Indian Ocean, the Jamarc estimated significant amount of tuna (several tons, allowing a purse seine set) 7 days after deployment of the FADs (Watanabe *et al.*, 1988).

In the Atlantic, Bard *et al.* (1985) reported that a FAD had attracted a tuna school during the first hour following the deployment, and several of these FADs were colonised by tunas within one week.
It was also noted that the baitboat fishery operating in Senegal is exploiting schools that are concentrated during very long periods of time (several months) under the boats (Hallier *et al.*, 1998). Tagging undertaken in the MAC[1] programme has shown that the different species (skipjack, yellowfin, bigeye) associated with the "FAD-vessel" remain in similar proportions with time. Moreover, some observations suggest that the fidelity of the fishes to the "FAD-vessel" could be quite high. Most of the fishes tagged are recaptured several weeks later by the boat from which the fishes were released, and very few tag returns are recorded in the proximate purse seine fishery (20 miles away; Hallier, pers. comm.).
Tagging and recapture at the same FAD by the same vessel is a remarkable event, which has been observed for juvenile yellowfin during experimental cruises by the JAMARC in the Indian Ocean (Takahashi *et al.*, 1988). Results are summarised in table 1: the drift speed has been estimated around 0.4 to 0.6 knot for fishes recaptured after a maximum of 10 days at liberty. This speed estimate is consistent with the current drift (Equatorial Counter-Current) in the area studied (Central Indian Ocean). Two other fishes were recaptured after respectively 36 and 90 days. There is no evidence of a close and permanent association of the fish with the same object during the period at liberty. However, such results suggest that tunas did not undertake large oceanic movements as usually expected.

Table 1 - Tagging and recapture at the same FAD by the purse seiner *Nippon Maru* of the Jamarc, in the Indian Ocean (Takahashi *et al.*, 1988).

Tagging-recapture	Distance (nm)	Duration (days)	Drift speed (knot)	Size of fish (cm)
Feb. 16-18, 1988	29	2	0.6	52
Dec. 25-31, 1986	72	6	0.5	54
Feb. 4-12, 1987	77	8	0.4	50
Jan. 27-Feb. 6, 1987	144	10	0.6	51
Jan. 10-Feb. 15, 1984	?	36	?	52
Dec. 27, 1987-Mar. 27, 1988	?	90	?	54

Hampton & Bailey (1999) reported a tagging experiment carried out on a single log in the Western Pacific, demonstrating the dispersal of tuna from the log association after a few days. However, using a large tag-and-release data set for different types of association, the same authors acknowledge that the large movements exhibited by skipjack tagged at logs could be due to the association with the original log or with other logs that are drifting along substantial distances with the current.

1. MAC: research programme "Mattes Associées aux Canneurs" (tuna schools associated to baitboats) developed in Senegal between 1995 and 1999 by various Senegalese, Mauritanian and French research institutions.

Addressing the question of the FAD trapping effect on a long-term basis does not necessarily requires a long-lasting association to a single object. In fact, we consider that tunas may be trapped within oceanic areas characterised by high densities of FADs. Already, significant changes of species composition of tuna schools have been noticed: the number of mixed-species free schools which were fished in the 1980s have been reduced drastically in the recent years. Almost all the mixed-species schools are now observed in association with FADs (Fonteneau *et al.*, 2000b).
The observations above reported are not sufficient enough to validate a long-term association within a network of drifting objects. The fidelity of fish to logs or FADs has to be investigated using *ad hoc* methods.

A modification of the natural movements

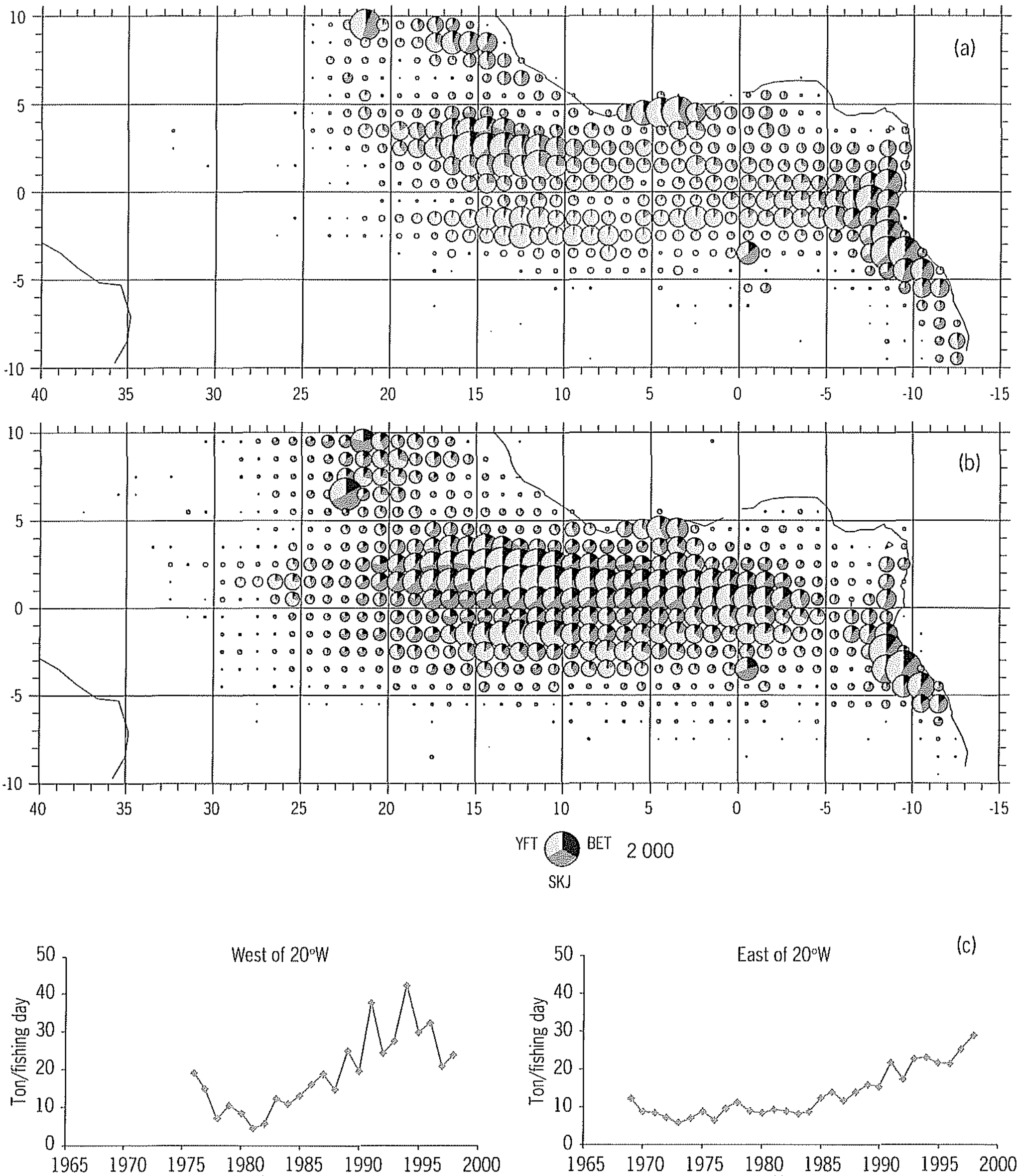
Large numbers of FADs are presently released at sea. In 1998, it has been estimated that an overall 3 000 rafts equipped with radio-beacons was monitored by the European purse seine fleets operating in the East Atlantic from Abidjan (Ménard *et al.*, in press). Other tuna fleets in Ghana (baitboats and purse seiners) are also using large numbers of artificial FADs (Bannerman, pers. comm.), so this number is likely to be underestimated. As shown earlier, the deployments are made in the offshore zones, along the equator, characterised by a westward transport (South Equatorial Current). Therefore, the tunas trapped at FADs in the east would drift zonally (to the west), whereas the trophic migrations are oriented poleward. In the example of the skipjack, the ICCAT international Skipjack Year Programme, in the early eighties, has revealed seasonal migrations from the Guinea Gulf to the more productive areas of Senegal (to the north) and Angola (to the south). If juvenile tunas remain trapped in the Equatorial network of FADs, they may show less migrations to the productive coastal areas which were an important component of their evolutionary and recent life cycle. Similar consequences might be expected for some species of the fauna which are associated to the FADs among tunas, such as "mahi-mahi" (*Coryphaena hippurus*) (Taquet *et al.*, 2000), rainbow runner (*Elagatis bipinnulata*), wahoo (g. *Acanthocybium* and *Scomberomorus*) and some species of sharks (*Carcharinus falciformis* and *C. longimanus*).
The two major points above mentioned were tested from the catch and effort data set of the purse seine fishery for the period 1969-1998:

- Westward extension of the purse seine fishing grounds

Prior to 1991, the purse seine catches in the equatorial region were essentially distributed east of the longitude 20°W (fig. 3a). Considering the area 0°-20°W/5°N-5°S, the species composition was dominated by large yellowfin south of the equator. The only significant proportion of skipjack in the catch was found south of Liberia (10°W-20°W) in relation to natural logs sets. After 1991, the fishing area stretches out as far as 30°W and the species composition east of 20°W includes a greater proportion of skipjack and bigeye than in the previous period (fig. 3b). The increase of these two species in the catch is a consequence of the fishing activity on FADs.

Time series of CPUEs for 1969-1998 are presented in figure 3c to compare the trends east and west of 20°W. The development of the FAD fishery in the early 1990s was followed by an increase of the CPUE in both areas; this increase showed a higher magnitude west of 20°W. This is likely to be a direct consequence of a greater vulnerability of the resource to the gear due to the school concentration at FADs. However, the assumption of an increased abundance west of 20°W by immigration of tuna associated with drifting objects cannot be rejected. Experiments at sea should be undertaken to test this assumption.

Figure 3
Geographic distribution of the catch (with species breakdown) in 1980-1990 (a), since the development of the FAD fishery (b), and corresponding CPUEs in east and west areas of 20°W (c).



• Density changes of skipjack in Senegal

Various indicators were calculated from the catch and effort statistics of the French and Spanish purse seine fleets, in order to assess the remote effects of the development of the equatorial FAD fishery on the dynamics of skipjack population during their summer migrations to the north. In the Senegal zone (10°-20°N, 15°-20°W), skipjack is the dominant species forming free-swimming schools. Before the 1990s, the purse seiners were operating south of 16°N. During recent years, the fishing grounds extended to the north (up to 20°N) to follow the seasonal migration of skipjack: the number of 1° squares producing more than 10 tons of skipjack has increased from 16 to 26 (fig. 4a). Despite this

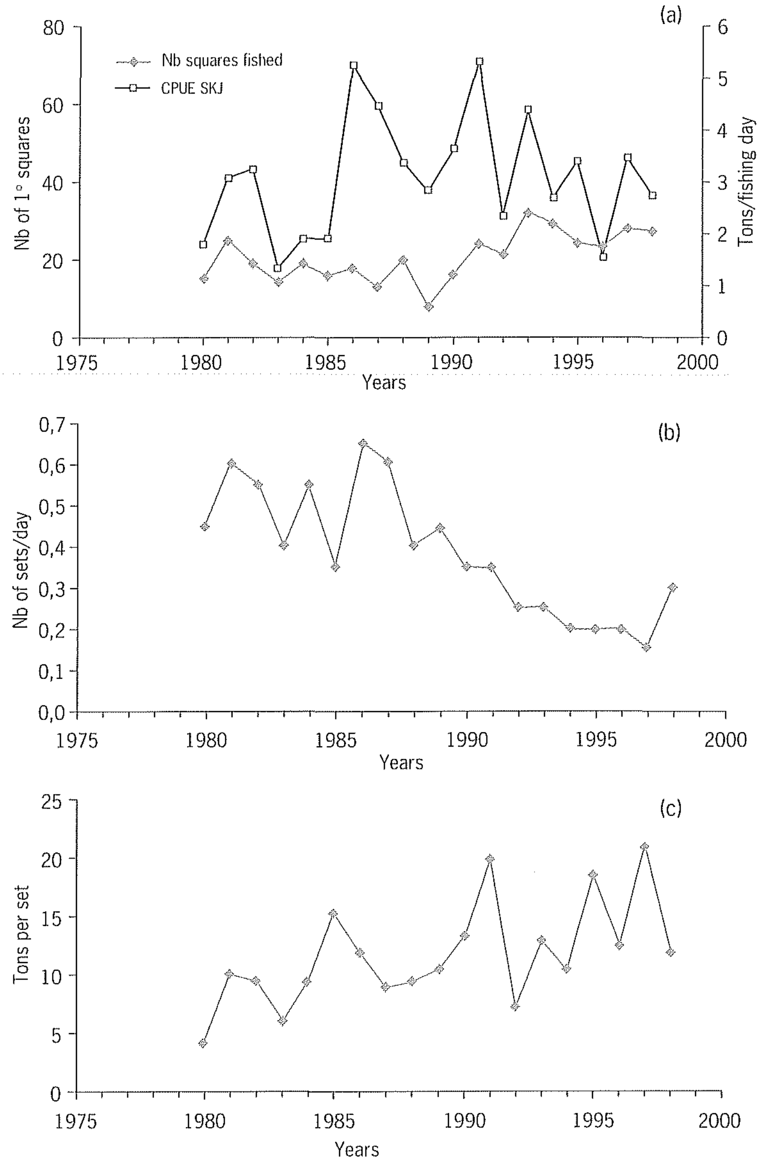


Figure 4
Indicators of density changes of skipjack in Senegal (10°N to 20°N, 15°W to 20°W): number of fished squares producing more than 10 tons of skipjack and CPUE (a), mean number of sets per day (b) and catch per positive set (c).

extension in potentially favourable fishing areas, the CPUE index has started to decline since 1991 (fig. 4a), after a period of positive trend during the eighties. Another indicator, the number of sets per day, started to decline in 1987-1988 and the decreasing trend has been regular until 1997 (fig.4b). In the period 1980-1985, there was an average of one set every two days, when it was only one set every five days in 1996. The changes in CPUE and number of sets per day could denote a decrease of the population abundance. Conversely, the catch per positive set (an indicator of the school size) has shown a positive trend since the early 90s (fig.4c), which is not in contradiction with the trends of the other indicators. In fact, if we consider density-dependent processes, the behavioural response of a population whose abundance is declining can be a greater concentration in a limited space, such as the formation of larger schools (Pitcher, 1986).

A modification of growth and natural mortality

Few studies have undertaken analyses of the diet of tuna based on the comparison between associated and non-associated fishes: tunas do not feed on fish associated with the anchored FADs (Brock, 1985) nor with the floating logs (Hunter & Mitchel, 1967). However, Yesaki (1983) found cannibalism of large yellowfin tunas on small conspecifics associated with FADs in the Philippines. In the framework of the Picolo[2] programme, studies of the tuna diet in the South Sherbro area (0-5°N, 10-20°W) taking into account the type of association, the species and the size, are underway. The rate of empty stomachs is very high for the tunas caught under drifting FADs (85% vs 25% for unassociated schools), and lower daily food rates are estimated for small-size tunas associated to FADs, showing that drifting FADs cannot have a forage function, but would rather be a refuge.

Morphometrics sampling has been set up during 1997 and 1998 in order to study the design of purse seine escapement grids (Gaertner *et al.*, 1999). For the present analysis, we used the body width of skipjack caught north of 5°N, as a function of body length (ranging from 36 to 55 cm) to estimate a condition factor taking into account the type of association (FAD-associated vs unassociated schools). Different linear models were fitted to the data: $y_{ij} = a_i x_{ij} + b_i + \varepsilon_{ij}$, with y and x respectively the body width and length of the fish j with the type of association i, and ε the residuals. Two separate slopes were not required ($p = 0.068$), and a simpler linear model with parallel regressions allowed to explain around 79% of the variation in the body width (tab. 2, fig. 5), showing that for the same length, body width is higher for unassociated tunas than for FAD-associated tunas. Figure 6 displays the fit of smoothing splines with approximately 20 degrees of freedom to the data: the smoothing of the FAD-associated data is almost always below the smoothing of the unassociated school data. This confirms the interpretation of the results

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obtained with the linear model analysis: skipjack associated with FAD show lower condition factors in this area than skipjack caught in free-swimming schools, which is in accordance with the lower daily food rates estimated on FADs. Such studies have to be more developed, focusing on other indicators of the condition factor, e.g. biochemical analyses of the muscles or stable isotope ratios.

Figure 5
Body width (cm) as a function of fork length (FL in cm) for skipjack tunas associated to drifting FADs and caught on unassociated schools north of 5°N.

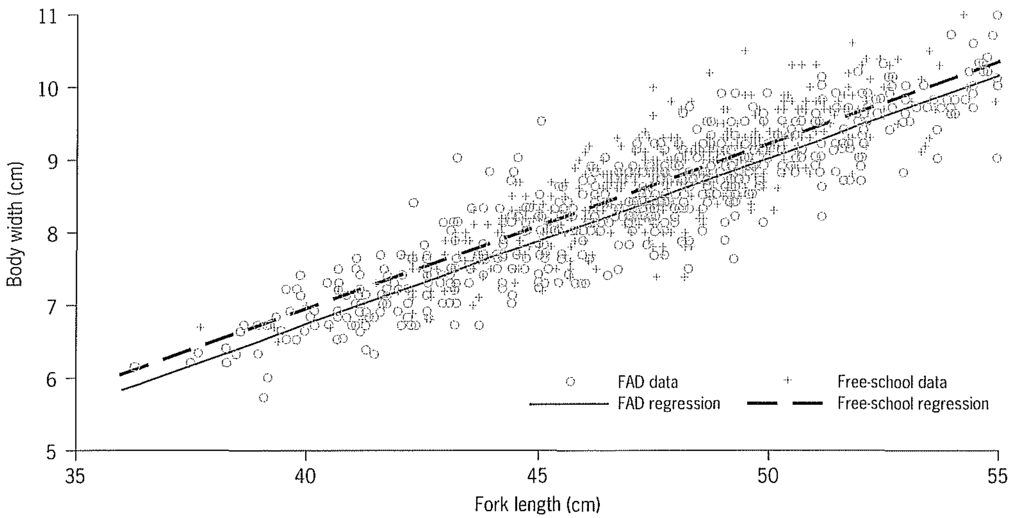

Figure 6
Smoothing splines with approximately 20 degrees of freedom fitted to the body width data for skipjack tunas associated to drifting FADs and caught on unassociated schools.

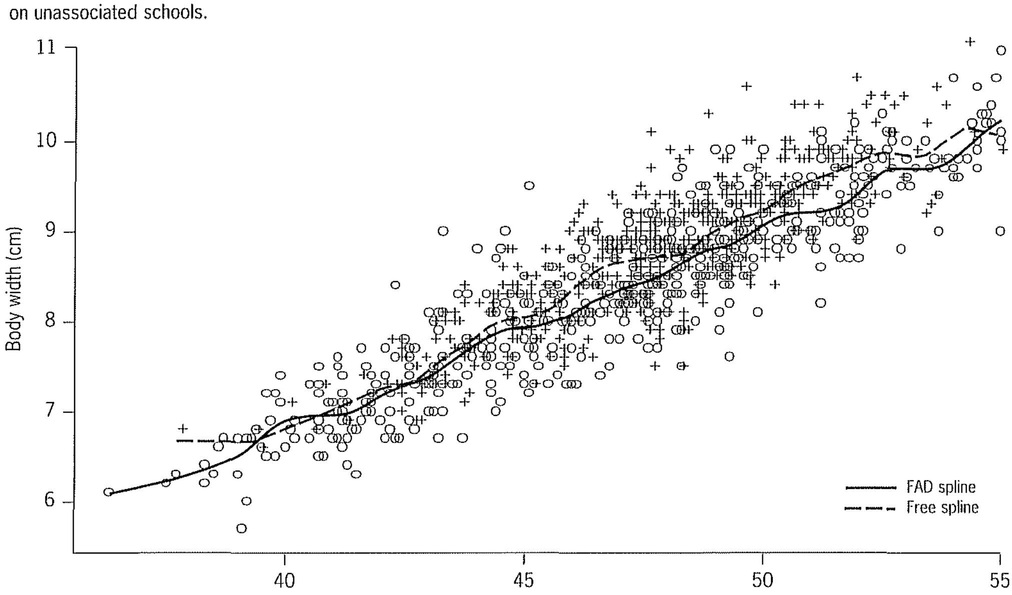

Table 2 - Analysis of variance table of the different linear models on the data of the body width versus the body length of skipjack tunas: $y_{ij} = a_i x_{ij} + b_i$, with y and x the body width and length respectively of the fish *j* with the type of association *i*.

Models	Df	Residuals sum of sq.	Test	F Value
M0: $y_j = a x_j + b$	999	191.52		
M1: $y_{ij} = a x_{ij} + b_i$	998	181.25	M1 vs M0	56.58
M2: $y_{ij} = a_i x_{ij} + b_i$	997	180.64	M2 vs M1	3.34

Significant changes in size and mean individual weight in commercial catches were observed during the recent period in the equatorial area, which may be due to the FAD fishing (fig. 7). The mean individual weight of skipjack in the South Sherbro area (0°-5°N, 10°W-20°W) shows a clear decreasing trend from an average 2.4 kg in 1981 to an average 1.8 kg in 1997 (25% decrease). As for yellowfin, considering both purse seine and baitboat fisheries and selecting the size of fishes taken at FADs (less than 60 cm), a decreasing trend has also occurred since the beginning of the eighties (2.3 to 2 kg, i.e.15% decrease). The decreasing mean weight of skipjack and yellowfin could be a consequence of a size overfishing (basic ICCAT hypothesis) combined with a slower individual growth rate. Another factor could also be considered, that is the greater proportion of small-size tunas landed in the recent years. The average weight being calculated from the sampling in port, we cannot exclude that this may play a role in the observed decreasing trend.

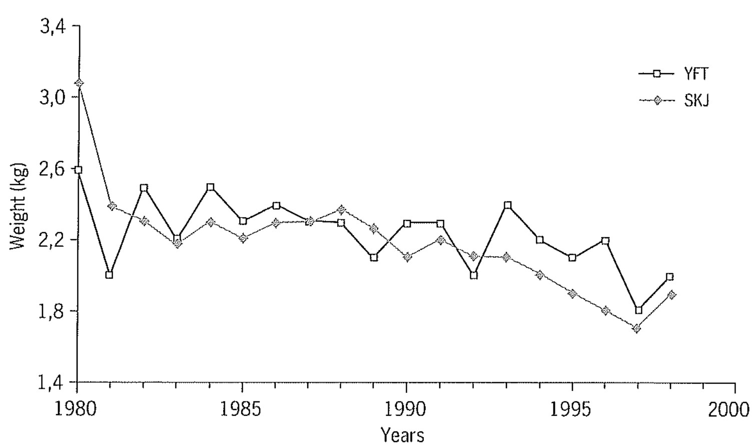

Figure 7
Average weight of tunas taken on FADs in the equatorial zone: juvenile yellowfin (< 60 cm FL) in the East Atlantic surface fishery and skipjack in the South Sherbro area (0°-5°N and 10°W-20°W).

Large tunas, billfishes and sharks which are potential predators of small tunas are frequently associated with FADs (Stretta *et al.*, 1996; Hallier & Parajua, 1999; IATTC, 1999). This FAD association of predators and preys may facilitate predation upon small tunas, and then may increase natural mortality (M coefficient) of small fishes living under logs.

Potential consequences in the perspective of stock assessment

Following this hypothesis, the effects of the FADs on the biological characteristics of associated species can be summarised in the following points:

- the combined effects of natural schooling behaviour and attractiveness to an anomaly of the environment would generate huge concentrations of juvenile tunas in association to FADs in areas where such types of schooling was not observed before;
- a great density of drifting FADs in an oceanic zone might trap a significant part of the populations of juvenile tunas and alter the natural movements towards the trophic areas in keeping large fraction of stocks in the equatorial zone;
- the growth rate of Atlantic skipjack tunas, was estimated to be higher in the tropical areas than in the equatorial zone (Bard & Antoine, 1986). During their life cycle, skipjack do show alternate movements between equatorial and temperate areas; their individual growth is an integration of the past feeding conditions and the energy spent to travel between these locations. Consequently, the lack of significant movements pole-wards could maintain large fraction of stocks to their low level of growth rate. Moreover, the concentration of fishes at FADs would also increase the competition for feeding and the potential predation by predators (Bakun, 1996). This reduced growth rate and the increased M would reduce the biological productivity of the corresponding populations.

The natural logs were considered as a positive way for small fishes to congregate and being transported in the converging zones where forage is also concentrated (Hall *et al.*, 1999). On the opposite, the dynamics of tunas associated with artificial FADs, as seen in the industrial surface fisheries, might have adverse effects on the biological features of the juvenile tunas. With respect to stock assessment, potential consequences of FADs are significant. The use of FADs is an important factor responsible of the increased efficiency of purse seiners worldwide. The effects of FADs on the fishing powers are difficult to assess precisely (Fonteneau *et al.*, 1998; IATTC, 1999; Gaertner & Marsac, 1999) but no attempt has been done so far to evaluate the potential effects of FADs on the biology of tuna.

How to test this hypothesis?

The East Atlantic industrial surface fishery is one of the fisheries where the transition between the different fishing modes is well documented. In addition, research programmes carried out in the past (early eighties) prior to the development of FADs provide a reference point allowing a valuable comparative analysis with the current situation.

A research programme could be proposed in initiating various methods:

- conventional tagging of small tunas in the FAD fishery area that would allow a comparison of the migration pattern with the historical tagging

programmes (International Skipjack Year Programme), a comparison of growth rates by area and the assessment of the fidelity of tunas to FADs, in the short and medium terms;
- acoustic tagging of FAD-associated tunas at a small-time scale, and dynamics of groups of tunas at a medium-time scale (using coded-pingers and hearing stations);
- biological analyses to address the trophic ecology of tunas between those associated to FADs for a significant amount of time, and the rather resident populations in forage-rich areas (as in Senegal). These analyses, using stable isotope ratios of carbon and nitrogen, can be complemented by the estimation of condition factors based on the chemical characteristics of the tuna flesh (fat content...). Such conditions factors should be compared between FAD-associated and free-school tunas.
- changes in size composition of the catches in the FAD fishery area, between historical and recent periods (for yellowfin, skipjack and bigeye).
- stomach contents of large predators (billfish, sharks, large tunas) taken under FADs.

The ICCAT Bigeye Tuna Year Programme, which is planned for a 3-year period starting with 1999 will cover part of the above listed issues.

Conclusion

The hypothesis of drifting FADs playing as an ecological trap for tunas in the offshore environment is worth to be further investigated. In this paper, we have tried to put together some facts which could suggest biological consequences of the recent and dramatic development of tuna fishing with drifting floating objects. On a more general point of view, this massive deployment of FADs could have serious implications in terms of evolution, ecology and conservation of resources, as this phenomenon is observed worldwide. Presently, the three parts of the ecological trap hypothesis are still speculative and should be seen as a basic framework. They provide guidelines that could be useful for initiating an *ad hoc* international research programme.

Bibliographic references

Bakun A., 1996. Patterns in the ocean. Ocean processes and marine populations dynamics. California Sea Grant College System. NOAA, 323 p.

Bard F.-X., Stretta J.-M., Slepoukha M., 1985. Les épaves artificielles comme auxiliaires de la pêche thonière en océan Atlantique. Quel avenir? Pêche Marit., 64(1291), 655-659.

Bard F.-X., Antoine L., 1986. Croissance du listao dans l'Atlantique Est. *In:* Proceedings of the ICCAT conference on the International Skipjack Year Programme. Symons P.E.K., Miyake P.M. & Sakagawa G.T. (eds), 301-308.

Brock R.E., 1985. Preliminary study of the feeding habits of pelagic fish around Hawaiian Fish Aggregating Devices, or can fish aggregation devices enhance local fish productivity? Bull. Mar. Sci., 37, 40-49.

Cayré P., Amon Kothias J.B., Stretta J.-M., Diouf T., 1988. Biologie des thons. *In:* Ressources, pêche et biologie des thonidés tropicaux de l'Atlantique Centre-Est. Fonteneau & Marcille (eds). FAO Fish. Tech. Pap., 292, 391 p.

Cayré P., Marsac F., 1993. Modelling the yellowfin tuna (*Thunnus albacares*) vertical distribution using sonic tagging results and local environmental parameters. Aquat. Living Resour., 6(1), 14.

Fonteneau A., Gascuel D., Pallarés P., 1998. Vingt-cinq ans d'évaluation des ressources thonières de l'Atlantique : quelques réflexions méthodologiques. *In:* Proceedings of the ICCAT Tuna Symposium, Beckett J.S. (ed). Collect. Vol. Sci. Pap. ICCAT, 50(2), 523-561.

Fonteneau A., Pallarés P., Pianet R., 2000a. A worldwide review of purse seine fisheries on FADs. *In:* Pêche thonière et dispositifs de concentration de poissons. Le Gall J.-Y., Cayré P., Taquet M. (eds). Éd. Ifremer, Actes Colloq., 28, 15-35.

Fonteneau A., Ariz Telleria J., Gaertner D., Nordstrom V., Pallarés P., 2000b. Observed changes in the species composition of tuna schools in the Gulf of Guinea between 1981 and 1999, in relation with the Fishing Aggregating Device fishery. Aquat. Living Resour., 13(4), 253-257.

Fréon P., Misund O., 1999. Dynamics of pelagic fish distribution and behaviour: effects on fisheries and stock assessment. Fishing News Books, 348 p.

Gaertner D., Dewals P., Marsac F., 1999. Relations biométriques utilisables dans les études sur l'échappement des juvéniles de thonidés tropicaux dans les sennes. Collect. Vol. Sci. Pap. ICCAT, 49(3), 323-332.

Gaertner D., Marsac F., 1999. Comparative analysis of the exploitation of bigeye tuna in the Indian and Eastern Atlantic Oceans with emphasis on purse seine fisheries. Working Parties on Tropical Tunas, Indian Ocean Tuna Commission, Seychelles, September 1999, WPTT/99/04, 28 p.

Hall M., García M., Lennert-Cody C.E., Arenas P., Miller F., 1999. The association of tunas with floating objects and dolphins in the Eastern Pacific Ocean. A review of the current purse seine fishery. *In:* Proceedings of the international workshop on the ecology and fisheries for tunas associated with floating objects. Scott M.D., Bayliff W.H., Lennert-Cody C.E. & Schaefer K.M. (comp.). Spec. Rep. I-ATTC, 11, 87-194.

Hallier J.-P., Parajua J., 1999. Review of tuna fisheries on floating objects in the Indian Ocean. *In:* Proceedings of the international workshop on the ecology and fisheries for tunas associated with floating objects. Scott M.D., Bayliff W.H., Lennert-Cody C.E. & Schaefer K.M. (comp.). Spec. Rep. I-ATTC, 11, 195-221.

Hallier J.-P., Diouf T., Bareck M.M., Foucher E., 1998. La pêcherie de canneurs à Dakar: une évolution remarquable pour assurer sa survie. *In:* Proceedings of the ICCAT Tuna Symposium. Beckett J. (ed.), Collect. Vol. Sci. Pap. ICCAT, 50(2), 673-701.

Hampton J., Bailey K., 1999. Fishing for tunas associated with floating objects: review of the Western Pacific fishery. *In:* Proceedings of the international workshop on the ecology and fisheries for tunas associated with floating objects. Scott M.D., Bayliff W.H., Lennert-Cody C.E. & Schaefer K.M. (comp.). Spec. Rep. I-ATTC, 11, 222-284.

Hunter J.R., Mitchel C.T., 1967. Association of fishes with flotsam in the offshore waters of Central America. Fish. Bull., 66, 13-29.

IATTC, 1999. Annual Report 1997, 310 p.

Josse E., Bertrand A., Dagorn L., 1999. An acoustic approach to study tuna aggregated around Fish Agregating Devices in French Polynesia: methods and validation. Aquat. Living Resour., 12(5), 303-313.

Marcille J., Bour W., 1981. La pêche des thons à la senne et à la canne dans l'océan Pacifique tropical. Trav. Doc. Inst. Fr. Rech. Sci. Dév. Coop., 134, 259 p.

Ménard F., Fonteneau A., Gaertner D., Nordstrom V., Stéquert B., Marchal E., (in press). Exploitation of small tunas by a purse seine fishery with Fish Aggregating Devices and their feeding ecology in an Eastern Tropical Atlantic ecosystem. ICES J. Mar. Sci.

Menkès C., Marchal E., Lebourges A., Biessy B., Morlière A., Dandonneau Y., Ballé J., Reverdin G., Champalbert G., Flament P., Kennan S., 1998. The Picolo programme: from instability waves to tunas in the Tropical Atlantic. Proceedings of the 23rd General Assembly of EGS. II: Hydrology, Ocean & Atmosphere. Ann. Geophys., 16 (suppl. 2), p. C 565.

Pitcher T.J., 1986. Functions of schooling behaviour in teleosts. *In:* The behaviour of teleost fishes. Pitcher T.J. (ed.). Croom Helm, London & Sydney, 294-337.

Piton B., Kartavtseff A., 1986. Utilisation de bouées dérivantes à positionnement par satellite pour une meilleure connaissance de l'hydrologie de surface du golfe de Guinée. Doc. Sci. Cent. Brest Orstom, 34.

Stretta J.-M., Delgado de Molina A., Ariz Telleria J., Domalain G., Santana J.C., 1996. Les espèces associées aux pêches thonières tropicales. Programme Union européenne. DG XIV, Bioeco/93/05 Orstom/IEO; Part 2, 58 p.

Taquet M., Reynal L., Laurans M., 2000. Do FADs influence the geographical distribution of dolphinfish *(Coryphaena hippurus)*. *In:* Pêche thonière et dispositifs de concentration de poissons. Le Gall J.-Y., Cayré P., Taquet M. (eds). Éd. Ifremer, Actes Colloq., 28, 528-536.

Takahashi M., Urakawa T., Kasahara F., Kanda A., 1988. Jamarc's activities on tagging of tunas in Indian Ocean. Expert consultation on stock assessment of tunas in the Indian Ocean, Mauritius, 22-27 June 1988. IPTP Collect. Vol. Work. Doc., 3, 208-223.

Watanabe Y., Tsunekawa T., Takahashi M., Tabuchi M., Sugawara T., 1988. Results on the experimental purse seine fishing with FADs in the Indian ocean by R/V *Nippon Maru*. IPTP Collect. Vol. Work. Doc., 3, 227-232.

Yesaki M., 1983. Observations on the biology of yellowfin and skipjack tunas in the Philippine waters. FAO/Indo-Pac. Tuna Dev. Manage. Program., IPTP/83/WP/7.