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Exploitation of small tunas by a purse-seine fishery with fish aggregating devices and their feeding ecology in an eastern tropical Atlantic ecosystem

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We investigated the effects of a purse-seine fishery with drifting fish aggregating devices (FADs) in the South Sherbo area of the Equatorial Atlantic, located between 0–5°N and 10–20°W. There had been no surface fishing activity in the area until 1975. Since 1991, fishing operations on schools of tuna associated with FADs has become widespread and this offshore area has developed into a major fishing zone. Exploitation rates are high between November and January. The fishery exploits multispecies concentrations of skipjack (71%), bigeye (15%), and yellowfin (14%) tunas of similar size (mode: 46-cm forklength). The use of FADs increased the vulnerability of small tunas and induced changes in fishing patterns. The mean individual weight of skipjack caught has decreased since 1991, due either to overfishing or to a growth change. Data from scientific observers were used to estimate discards and by-catches generated by FAD fishing during 1998. Discards of tunas (including frigate and little tunas) represented 7.6% of the total catch. Other by-catch (dominated by wahoo, billfish, triggerfish, sharks, barracudas, and dolphinfish) represented 2.3%, including 0.4% discarded at sea. Stomach content analysis showed that a mesopelagic species, *Vinciguerria nimbaria* (Photichthyidae), which during daylight concentrated in the upper layers in dense schools, was the main prey of all small tunas. The South Sherbro area appears to have exceptional environmental conditions. It is suggested that the FAD fishery may have wide-ranging effects on the migration of tunas in general and on the productivity of the skipjack population in particular.

Key words: by-catch, discards, fish aggregating devices (FADs), feeding, mesopelagic fish, purse-seine fishery, tunas.

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Introduction

A tuna purse-seine fishery started to exploit the coastal area in the eastern tropical Atlantic at the beginning of the 1960s. Most offshore areas of the Equatorial Atlantic remained free of surface fishing gears until 1975, but a purse seine fishery developed between 1975 to 1990, targeting monospecific concentrations of large yellowfin tuna (*Thunnus albacares*). Since 1991, fishing on tuna schools associated with drifting fish aggregating devices (FADs) has become widespread (Ariz *et al.*, 1993). The South Sherbro area (SSA; 0–5°N and 10–20°W; Fig. 1) in the Equatorial Atlantic in particular developed into a major seasonal FAD fishing zone for skipjack (*Katsuwonus pelamis*), yellowfin and bigeye (*T. obesus*) tunas (Fonteneau, 1994; Ménard *et al.*, 1999). The fishery exploits predominantly small tunas (<5 kg) and generates discards and by-catches of small tunas and other pelagic species associated with the FADs. The SSA has some peculiar environmental features. Located north of the equatorial divergence, where strong upwellings occur during the boreal summer (from June to September), the area is characterized by seasonal oscillations, referred to as tropical instability waves (Legeckis, 1983). These involve three current systems: the South Equatorial Current, the North

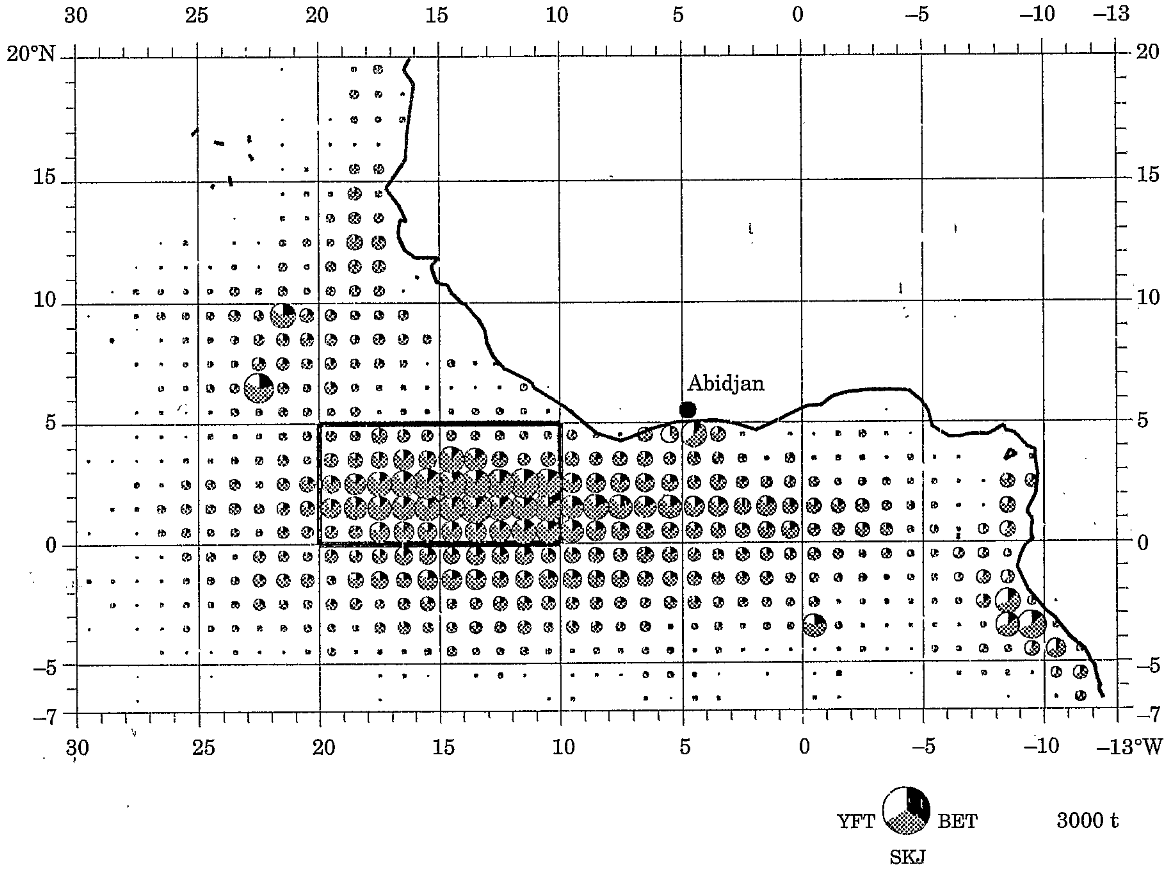

Figure 1. Mean annual catch (t) associated with FADs per 1° square of yellowfin (YFT), skipjack (SKJ), and bigeye (BET), 1991–1996. Area of each circle is proportional to the catch. The South Sherbro area is outlined.

Equatorial Counter Current, and the Equatorial Under Current (Morlière *et al.*, 1994). The high-energy oscillations are particularly marked in the SSA (Richardson and McKee, 1984); they affect the dynamics of the pelagic trophic web (Flament *et al.*, 1996) and probably play an important role in seasonally attracting concentrations of tunas. The physical and biological processes involved have been the topic of the multidisciplinary programme PICOLO conducted by the Institut de Recherche pour le Développement for 3 years and a large amount of information has been collected.

Our aims are (1) to give an overview of the FAD tuna purse-seine fishery in the SSA, (2) to estimate the by-catch using scientific observer data collected during 1998, and (3) to describe the feeding ecology of tunas associated with FADs based on stomach content data.

Materials and methods

Fishery data were obtained from logbooks of purse seiners operating in the Eastern Atlantic Ocean from 1991 to 1997. The species composition of the catches reported in the logbooks was corrected on the basis of port sampling, account being taken of the fishing mode associated with each set (Pallares and Petit, 1998). The rectangular FADs (3 × 1·5 m) are constructed of bamboo, with large pieces of old net hanging below for stability in the surface currents. They may stay adrift for up to 2 months. A radio buoy is attached and each vessel uses secret frequencies to locate its own floating objects (some are tracked by satellite). A preliminary estimate indicates that the total number of FADs with radio buoys used by the 45 purse seiners landing in Abidjan (Côte d'Ivoire) in 1998 might exceed 3000. The "FAD seeding" area ranges from 0 to 20°W and generally does not exceed 2°S as a southern limit, corresponding to the westward South Equatorial Current. The SSA represents a convergence area (just above the equatorial divergence) and most FADs drift through or stay within during their operational period. Data on dumping of non-target species are poorly reported in the logbooks. These accidentally caught species are either dumped at sea or kept on board to be sold at the local market in Abidjan. We used data obtained during the European Union bigeye research program by French scientific observers to estimate by-catch and discards generated by

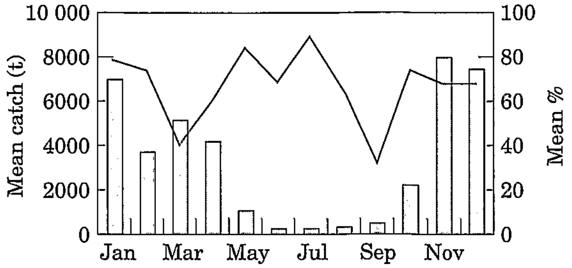

Figure 2. Monthly mean purse-seine catches in the South Sherbro area (bars) and proportion of FAD-associated catches (line).

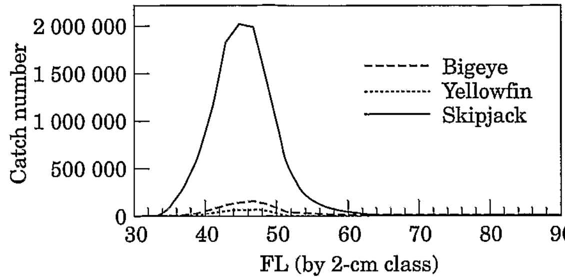

Figure 3. Size distribution of catches of skipjack and of yellowfin and bigeye tunas in 76 FAD-associated sets (FL: forklength, in 2-cm classes).

FAD fishing during 1998. Because of a FAD fishing moratorium determined by the main European purse-seine fleets for the Gulf of Guinea, FAD fishing was forbidden in the SSA during January, November, and December 1998. A total of 76 FAD sets have been analysed, including 20 sets with discards. For convenience, total catches were categorized within five groups: landings and discards of major tuna species, landings and discards of minor tuna species – including frigate tuna *Auxis* spp. and little tuna (*Euthynnus alletteratus*) – and other associated species that may also represent discards.

Samples of tuna stomachs from fish captured during FAD fishing operations in the SSA were collected by scientific observers on board some vessels, and at the port of Abidjan. The length of each fish sampled was measured and the stomach was preserved in formalin or deep-frozen. Stomach contents were sorted, identified to the lowest possible taxa, counted, and weighed.

Results

The tuna purse-seine fishery in the SSA is conducted mainly from October to April, but high catches are taken from November to January. During these three months, FAD sets represented about 70–80% of the total catch (Fig. 2), and exploited mixed concentrations of skipjack, bigeye, and yellowfin of similar size (around 46 cm forklength; Fig. 3). Although small tunas (<10 kg) constituted around 91% of the catches in weight, large yellowfin and bigeye were common. Mean FAD catch per fishing season represented 27 000 t of the total average catch of 40 000 t in the SSA (1991–1997). Skipjack (71%) was the main target followed by bigeye (15%) and yellowfin (14%). Catch per successful set often reached 100 t (mean: 35 t; median: 24 t).

Tuna discards were observed in 20 FAD sets (26%). Of the 905 t of the major tunas caught in the sets sampled, 6.2% were dumped dead at sea, whereas 16% of the 176 t of the minor tunas were discarded. The species composition of tuna discards (total 67 t) estimated from 18 sets showed that skipjack, frigate, bigeye, yellowfin, and little tuna represented 44%, 28%, 12%, 11%, and 5%, respectively. Tuna discards consisted mainly of small fish (mode: 38 cm). By-catches of other pelagic species (Table 1) were associated with 64 FAD sets (84%). Wahoo (*Acanthocybium solandri*), billfish (mainly *Makaira nigricans*), triggerfish (Balistidae), great barracuda (*Sphyraena barracuda*), dolphinfish (*Coryphaena* sp.), rainbow runner (*Elagatis bipinnulata*), kyphosidae, and sharks (mainly *Carcharhinus falciformis*) were the main groups in weight of the associated fauna. Most species (particularly billfish, wahoo, great barracuda, dolphinfish, rainbow runner) were kept on board: 17% in weight was discarded at sea, including 3.7% alive. The seven turtles reported were all thrown back into the sea alive. The main results of the observer data are displayed in Figure 4.

Of the 593 stomachs sampled in the SSA, 85% were empty. Stomach-content analysis was carried out for 572 tunas sampled, including 87 with non-zero stomach content weights (Table 2). The diet and the average weights of the stomach contents expressed as a percentage of the body mass of the predator varied little between different species in the same size range, but there were major differences between small and large yellowfin (Fig. 5). Fish were the main prey. Small tunas fed mainly on *Vinciguerria nimbaria* Jordan & Williams (Photichthyidae) and on cephalopods. Although the amount of undetermined fish was high (36% by weight for yellowfin <90 cm), *V. nimbaria* accounted for 40% by weight of the stomach content for tunas of the same size range (<90 cm). Large yellowfin tunas fed almost exclusively on Scombridae (i.e. frigate tuna and skipjack).

Discussion

Tunas, especially in the smaller size range, as well as other pelagic species tend to aggregate under floating objects, where they become less active and therefore easier to catch. The method of catching tuna associated with floating objects has probably been used in the Eastern Atlantic since the beginning of the purse-seine

Table 1. Numbers (N) and weights (W in t) of associated by-catch species in 76 sets in FAD purse-seine fishery, 1998.

Common name	Scientific name	Family	N	Wt
Wahoo	*Acanthocybium solandri*	Scombridae	1832	9.011
Blue marlin	*Makaira nigricans*	Istiophoridae	31	4.560
White marlin	*Tetrapturus albidus*	Istiophoridae	3	0.322
Atlantic sailfish	*Istiophorus albicans*	Istiophoridae	7	0.070
Billfish unspecified		Istiophoridae	1	0.045
Triggerfish	*Canthidermis maculatus*	Balistidae	1488	0.979
Triggerfish	*Balistes capriscus*	Balistidae	368	0.551
Triggerfish	*Abalistes stellatus*	Balistidae	710	0.391
Triggerfish	*Balistes punctatus*	Balistidae	206	0.103
Triggerfish unspecified		Balistidae	2890	2.890
Great barracuda	*Sphyraena barracuda*	Sphyraenidae	504	1.863
Rainbow runner	*Elagatis bipinnulata*	Carangidae	442	0.924
Blue runner	*Caranx crysos*	Carangidae	428	0.214
Cottonmouth jack	*Uraspis secunda*	Carangidae	85	0.190
Pilotfish	*Naucrates ductor*	Carangidae	1	0.001
Carangidae unspecified		Carangidae	2	0.001
Dolphinfish	*Coryphaena hippurus*	Coryphaenidae	230	0.842
Dolphinfish	*Coryphaena equiselis*	Coryphaenidae	19	0.083
Dolphinfish unspecified		Coryphaenidae	203	0.102
Yellow sea chub	*Kyphosus sectatrix*	Kyphosidae	700	0.405
Kyphosidae unspecified		Kyphosidae	950	0.475
Scalloped hammerhead	*Sphyrna lewini*	Sphyrnidae	5	0.235
Silky shark	*Carcharhinus falciformis*	Carcharhinidae	21	0.157
Oceanic whitetip shark	*Carcharhinus longimanus*	Carcharhinidae	1	0.045
Shortfin mako	*Isurus oxyrinchus*	Lamnidae	1	0.063
Shark unspecified			1	0.050
Serranidae family		Serranidae	408	0.204
Turtle	*Caretta caretta*	Chelonidae	3	0.120
Turtle	*Chelonia mydas*	Chelonidae	2	0.025
Turtle			2	0.043
Atlantic tripletail	*Lobotes surinamensis*	Lobotidae	86	0.166
Mola	*Mola mola*	Molidae	1	0.075
Manta ray	*Mobula mobula*	Mobulidae	1	0.050
Ray unspecified			1	0.008
Lambridae unspecified		Lambridae	20	0.010
Remora	*Remora remora*	Echeneidae	3	0.005
Exocoetidae unspecified		Exocoetidae	2	0.001
Total			11 657	25.279

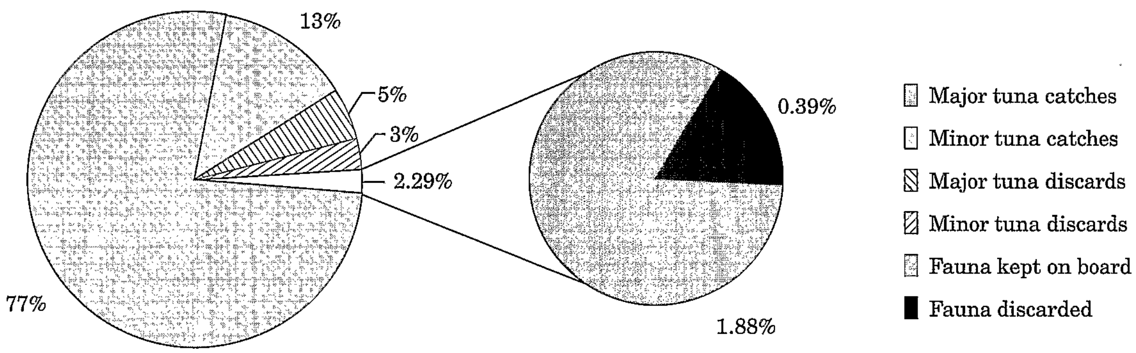

Figure 4. Proportions of catches and discards of major and minor tuna species and of associated fauna.

fishery, but was originally limited to natural objects. The use of FADs has increased the vulnerability of small tunas and the efficiency of purse seiners, and thus has modified fishing patterns. Furthermore, the large number of FADs in use may have a negative biological effect regardless of whether tunas are actually caught

Table 2. Number of stomachs investigated (N; e: empty; non-e: non-empty), minimum, maximum, and mean live weight of individuals sampled (Wt), and of stomach content live weight (SCW) of different species of tuna in the SSA.

Species	N e	N Non-e	Wt (kg) Min	Wt (kg) Max	Wt (kg) Mean	SCW (%) Min	SCW (%) Max	SCW (%) Mean
Skipjack	30	292	0.80	8.22	2.05	0	7.82	0.19
Bigeye	33	148	0.80	11.53	3.14	0	6.86	0.22
Yellowfin <90 cm	13	41	0.81	12.74	3.14	0	2.97	0.13
Yellowfin >90 cm	11	4	15.04	81.00	46.17	0	4.66	0.85

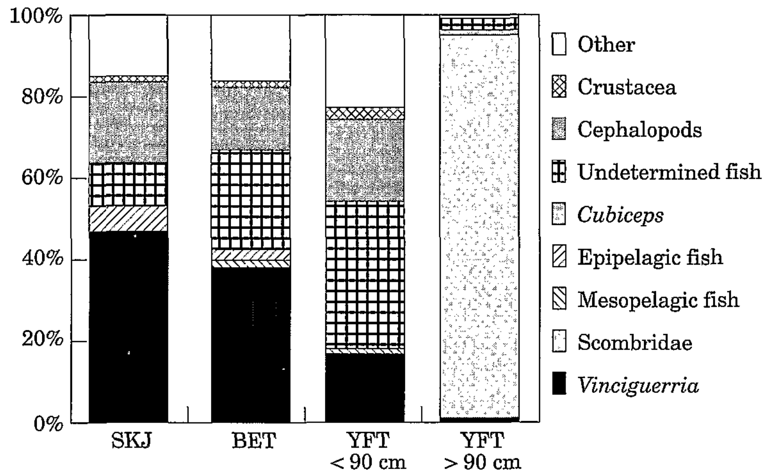

Figure 5. Prey composition of stomach contents in weight percentage for skipjack (SKJ), bigeye (BET), yellowfin (YFT; two size classes) sampled from FAD associated catches.

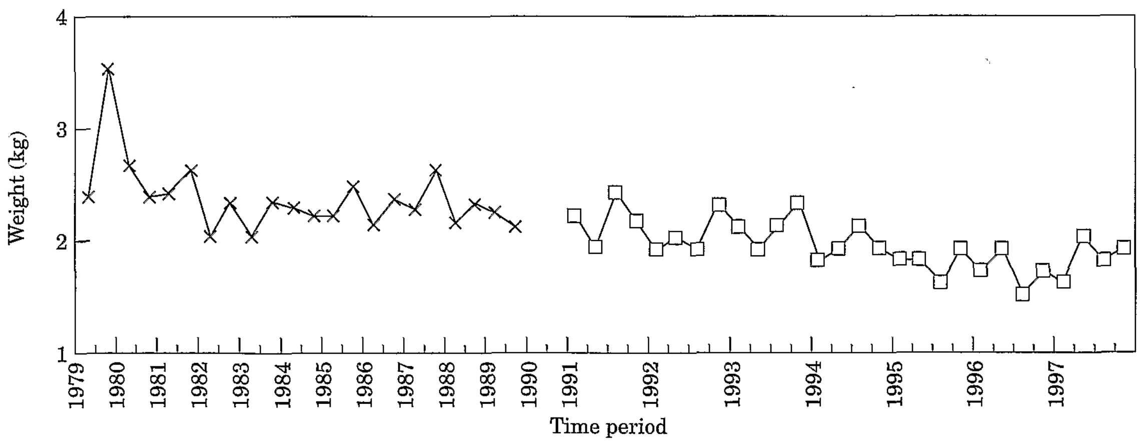

Figure 6. Variation in mean weight of skipjack in FAD-associated catches (for 1979–1990, means are given for October–January and February–April; for 1991–1997, quarterly means are given).

or not. The mean weight of skipjack caught in the SSA has decreased since 1991 (Fig. 6). This trend, which has not been observed in other areas, could be due to growth overfishing. However, it might also reflect a change in growth. We put forward the hypothesis that skipjack may become trapped under FADs in warm waters and poor trophic conditions, instead of moving towards productive and more favourable areas, such as Senegal or Angola as they did previously (Bard, 1986).

FADs do not seem to have a trophic function for tunas. Small tunas are concentrated under the objects during the night and may form free-swimming loose schools during the day to feed, according to the stomach samples, mainly on *V. nimbaria*, which are not associated with the FAD. This species has a maximum standard length of 55 mm, reaches maturity at 3–4 months and has a short life of up to 6–7 months. In the eastern tropical Pacific, *V. nimbaria* is considered a typical mesopelagic species, diving to depths of 500 m or more during the day, and common in the 0–90 m layer at night (Blackburn, 1968). However, the adult populations in the SSA exhibit unusual diel behaviour (Marchal and Lebourges, 1996): they concentrate in dense schools in the upper layers during the day, where they become available to tuna predation. Because this biomass must sustain the high concentrations of small tunas in the SSA, the species must be considered a major chain in the local food web. During the boreal summer (July to September, i.e., 4 months before the main fishing period), the productivity is maximal due to a strong equatorial divergence and a westward-propagating eddy system generated by tropical instability waves (Morlière *et al.*, 1994). The spawning success of *V. nimbaria* may be linked to the summer enrichment, and the number of successive cohorts that supply the biomass during the fishing period to its duration.

The available observer data are still imited, but our estimates of discards and by-catch are similar to those observed in the Pacific and in the Indian Ocean (Alverson *et al.*, 1994). Although they are low compared with many other fisheries, the impact of this tuna fishery on total mortality of associated species, some of which may be considered sensitive (e.g. sharks or turtles), remains unknown.

The SSA appears to be a geographical area subjected to a peculiar type of food web. Small tunas are supported by a limited number of forage fish species, strongly dominated by *V. nimbaria*. The FAD fishery may have a limited direct effect on the ecosystem, although the intensive use of floating objects could have a negative effect in terms of yield-per-recruit for bigeye and yellowfin (Ariz *et al.*, 1993). However, if the massive use of FADs in the area has led to a change in migration and growth patterns, this fishery may have a much greater impact on tuna productivity and on their geographical distribution.

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