

Typology of fish aggregations observed around moored fish aggregating devices in Martinique during the DAUPHIN project

by
Mathieu Doray

During the first meeting of the WECAFC ad hoc working group on the development of sustainable moored FAD fishing in the Lesser Antilles, it was pointed out that there had been significant and fast development of the moored FAD fisheries in Martinique and Guadeloupe (Doray *et al.*, 2002b). The French Research Institute for the Exploitation of the Sea (IFREMER) initiated the DAUPHIN research project (acoustic study of the fishes aggregated around moored FAD in the Lesser Antilles and influence of fishing, environment and biology). This project aims at studying the fish aggregations, the environment and the fishing activities around moored FADs in Martinique in order to get first quantitative indicators of the sustainability of the moored FAD fisheries in the Lesser Antilles.

1. BACKGROUND OF THE “DAUPHIN” PROJECT

What was known about fish aggregations around moored FADs before the DAUPHIN project?

Studies on fish aggregated around moored FADs mainly focused on the individual behaviour of fish. Several studies were conducted: acoustic telemetry studies (Cayré and Chabanne, 1986; Holland, Brill and Chang, 1990; Cayré, 1991; Josse, Bach and Dagorn., 1998; Marsac and Cayré, 1998; Brill *et al.*, 1999; Dagorn, Josse and Bach, 2000), fishery statistics studies to describe the distribution and/or evolution of the composition of the catches (Cillauren, 1987; Kakuma, 2000) and tag and release programs to study the movement patterns, exchange rates, residence times and vulnerability of fishes within a network of artificial and natural FADs (Adam *et al.*, 2003). These studies provided valuable information at the scale of the individual fish (acoustic telemetry) and at the scale of the sub-stock (fisheries and tag and release data) but descriptions of the structure and dynamics of the fish aggregations around moored FADs were lacking. In Martinique, analysis of partial sampling of FAD catches had revealed that, based on weight, the three main species caught around moored FADs were the blue marlin (*Makaira nigricans*), the blackfin tuna (*Thunnus atlanticus*) and the yellowfin tuna (*Thunnus albacares*) (Doray, Reynal and Carpentier, 2002).

The first study of tuna aggregations around moored FADs was conducted in French Polynesia within the framework of the ECOTAP program (Josse *et al.*, 2000). The use of a scientific echosounder allowed for the first time to globally describe the distribution, density and dynamics of tuna aggregations around moored FADs. A typology of the fish aggregations encountered around moored FAD during the 87 acoustic surveys of the project is presented in Figure 1.

The artisanal moored FAD fishery mainly targets the “shallow schooling fishes” with trolling lines (25 percent of the catches) and the “deep scattered fishes” with vertical drifting longlines (85 percent of the catches) (Josse, Dagorn and Bertrand, 2000).

The aggregations that have been commonly observed in French Polynesia around moored FADs are the “deep scattered fishes” which are the primary target of the local artisanal fishery.

Dauphin project objectives

The DAUPHIN project has been designed to allow comparison with the study of the fish aggregations around moored FADs conducted within the framework of the ECOTAP project. The investigation tools and protocols are similar: the same kind of echosounder, parameters and survey patterns were utilized.

The DAUPHIN objectives are:

1. To define a typology of the fish aggregations observed around two moored FADs during one year in Martinique.
2. To describe the structure and the dynamics of the subsurface tuna aggregations observed around moored FADs. The aggregations will be studied in relation to their environment from small to medium spatio-temporal scales.
3. To study the impact of the Martinican artisanal fishery on the aggregations.

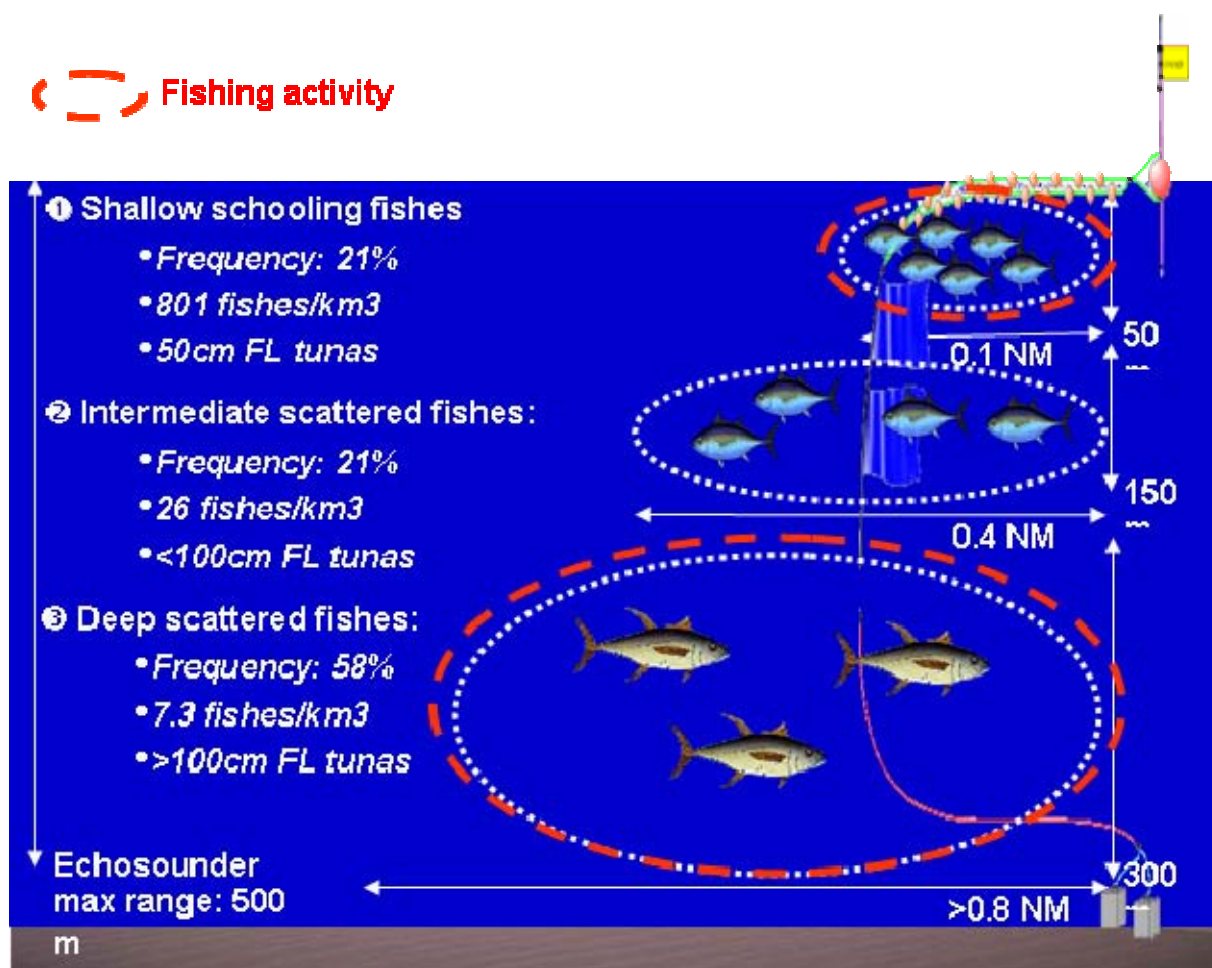


Figure 1: Fish aggregations and fishing activity around moored FADs in French Polynesia (redrawn from (Josse , Dagorn and Bertrand 2000)).

2. MATERIAL AND METHODS

2.1 Spatial and temporal scales

The data of the project have been collected during 16 monthly sea campaigns aboard the “Beryx” (skipper: P. Gervain) from January 2003 to April 2004. During this period, observers also embarked with commercial fishermen in order to sample their catches and to study their fishing strategies. Four moored FADs have been set within the frame of the project: three on the leeward coast of Martinique at a distance of 7, 20 and 25 nautical miles from the coast and one on the windward coast at 20 nautical miles. Two FADs located on the leeward coast at 7 nautical miles (coastal FAD) and 25 nautical miles (offshore FAD) from the coast have been particularly studied during the sea campaigns. The coastal FAD was a single head one whereas the offshore one had two heads (Reynal, Lagin and Gervain, this volume). Each of those FADs was surveyed for 60 hours during a sea campaign.

2.2 Complementary tools to finely describe the moored FAD system

2.2.1 Fishery acoustics

Fishery acoustics were the main investigation tool utilised during the DAUPHIN project. The Simrad EK60 scientific echosounder used during the sea campaign allowed to directly describe the structure and the density of the fish aggregations that passed under the boat. The other investigation tools were deployed according to this acoustic image of the aggregations around the moored FAD.

Acoustic equipment

Marine organisms do not reflect the infrasound produced by the echosounder with the same intensity. Reflection differs according to the size, the density of the marine organisms and the infrasound frequency. The echosounder was equipped with two frequencies (38 and 120kHz) so as to get complementary acoustic images of the moored FAD biotic aggregations. The echosounder maximum range also varies according to the frequency: the maximum ranges were respectively 600m at 38kHz and 200 m at 120kHz.

Three acoustic antennas (or transducers) were used: two transducers (38 and 120kHz, 6.9°) were directed vertically under the boat and the third one (120kHz, 2.5X10°) could be set from 0 to 90° below the surface. The echosounder parameters were those used in the ECOTAP program (Josse *et al.*, 1999). The echosounder was calibrated before each campaign using the standard procedure recommended by the manufacturer (Simrad, 2001).

Vertical acoustic “transects”

The “transect” used during vertical acoustic surveys was the “Star transect” designed in French Polynesia to observe fish aggregations around moored FADs (Josse *et al.*, 1999) (Figure 2).

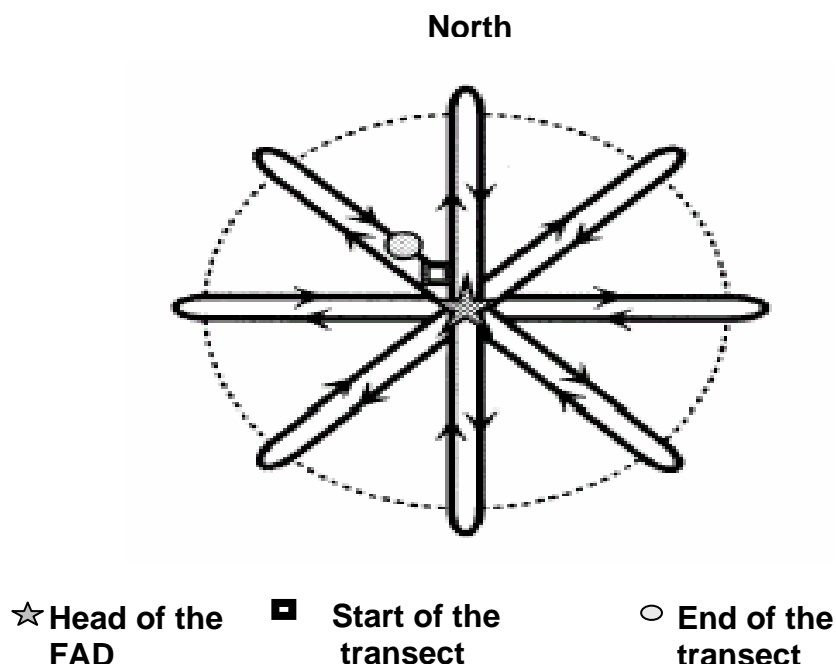


Figure 2: “Star transect” used during the vertical acoustic surveys of the DAUPHIN sea campaigns (Josse *et al.*, 1999).

The radius of the “transect” was at first the same as in French Polynesia: 0.8 nautical miles. Based on the results obtained, the radius was reduced to 0.2 nautical miles in order to observe the fish aggregations at a more appropriate spatio-temporal scale. 0.8 nautical miles “transects” were then still conducted but less frequently.

A 0.8 nautical miles “transect” was completed within 2 h at 6–7 knots, 0.2 nautical miles “transects” within 30 minutes at the same speed. Acoustic samples were collected each second on average. A 0.8 nautical miles “transect” allowed sampling a volume of 4 km³ in 38 kHz around the moored FAD.

Underwater video camera

An underwater video camera (Sony SST DC 50 AP) included in a hydro dynamical housing was lowered at the end of a cable over the tuna aggregations observed with the echosounder. The underwater video camera allowed to identify the fishes within the aggregations and to study their behaviour.

2.2.2 Experimental fishing

A small “portable” mesopelagic trawl was used to sample the prey items, micronekton (1–10 cm length), of the large predators.

To sample large predators (tunas, marlins, dolphinfishes) a 30 hooks horizontal surface longline was attached to the FAD at night. In addition a drifting gillnet was tested at night but unsuccessfully. Trolling lines were used during daytime.

The fishes caught were identified and measured in order to assess the species and the size classes of the fishes observed with the echosounder. Stomach contents and gonads were frozen to be analysed in the laboratory in order to study the nutrition and the reproduction of the large predators.

2.2.3 Abiotic environment monitoring

Several abiotic environment parameters were collected every 24 hours. A Seabird SBE19 CTD probe recorded temperature, salinity, dissolved oxygen, and light intensity from 0 to 600 m. The CTD was associated to an ADCP Workhorse 300 current meter that recorded the direction and the intensity of the current from 0 to 600 m.

2.2.4 Commercial fishing activities monitoring

The commercial fishing activities were monitored by observers aboard fishing boats, by phone surveys and by sampling of the commercial catches.

Aboard the commercial fishing vessels, several general descriptors of the trip were recorded (trip length, gas consumption, etc.) and all the catches were identified, localized with a GPS and measured. The stomach contents and gonads were sampled for further analysis. Indicators of the fisher strategy were also collected (number of gears deployed, gear description, etc.) (Reynal, this volume).

3. FIRST RESULTS

3.1 Data collection

Table 1 presents the data collected during the 16 DAUPHIN sea campaigns and the commercial fishing trips. At the beginning of 2003, four preparatory campaigns were devoted to adjust the equipment and the protocols. They were followed by 12 monthly routine data collection campaigns.

Table 1: Data collected during the DAUPHIN campaigns.

Acoustic data (h)	480
Video recordings (h)	40
CTD/current profiles	102
Fishes sampled	1400

The processing of the data has just been initiated and the results presented here are still preliminary. However, a first typology of the aggregations encountered around the moored FADs, based on the qualitative observations realized during the sea campaigns, can be presented here.

3.2 Typology of the diurnal biotic aggregations around moored FADs and relation to fishing activities in Martinique

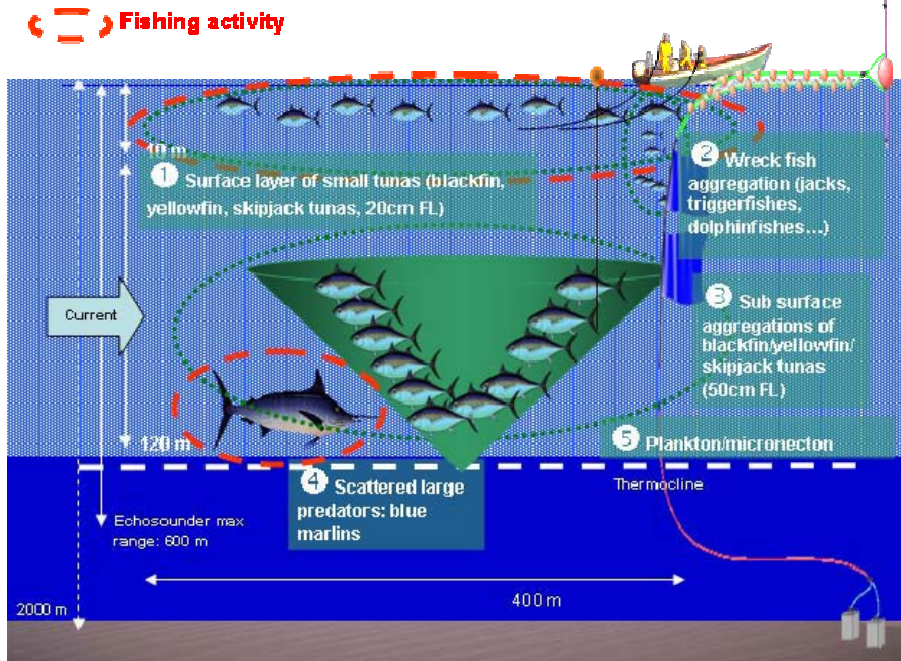


Figure 3: Diurnal fish aggregations, plankton/micronecton layers and fishing activity around moored FADs in Martinique

The fish biomass reaches a maximum during daytime and is mainly located up current, 150 m above and within a range of 400 m around the moored FADs.

Five types of aggregations have been observed around moored FADs in Martinique:

1. A surface layer (0–10 m) of small blackfin, yellowfin, skipjack and frigate tunas of 20 cm FL in average: This shallow aggregation cannot be observed with the echosounder but fishing data seem to indicate that its biomass is not very important. This aggregation is mobile and generally located up current.
2. An aggregation of wreckfishes (jacks, triggerfishes, dolphinfishes, etc.) located very close to the FAD rope at about 20 m depth: this aggregation has been well observed with the echosounder and its biomass is quite low.
3. A large subsurface (30–100 m) tuna aggregation distributed up to 400 m maximum upcurrent: most of the time, this aggregation seemed to be composed of 50 cm FL blackfin tunas. However, 50 cm FL skipjack tunas and probably some bigger yellowfin tunas have also been observed within those aggregations. This aggregation was detected very well by the echosounder. Its biomass represents about 95 percent of the estimated fish biomass aggregated around moored FADs.
4. Scattered large predators (blue marlins?) located near the subsurface aggregation of tunas: These isolated and highly mobile fishes that move near the surface are only partially sampled by the echosounder. However, their biomass seemed to be quite low.
5. Large plankton/micronecton layers generally distributed above the thermocline and widely spread around the FAD, out of the study area: These layers were well observed by the echosounder and their density varied according to nycthemeral and seasonal cycles.

The subsurface tuna aggregations represent about 95 percent of the total fish biomass, although they are nearly unexploited by the Martinican artisanal fishery. In fact, the vulnerability of the subsurface tunas to

the trolling lines used to catch the small tunas close to the surface and to the vertical drifting longlines used to catch large predators in depth seems to be very low at daytime. The commercial fishermen mainly catch a small amount of those 50 cm FL tunas at dawn and dusk and very seldom during daytime.

3.3 Typology of the nocturnal biotic aggregations observed around moored FADs in Martinique

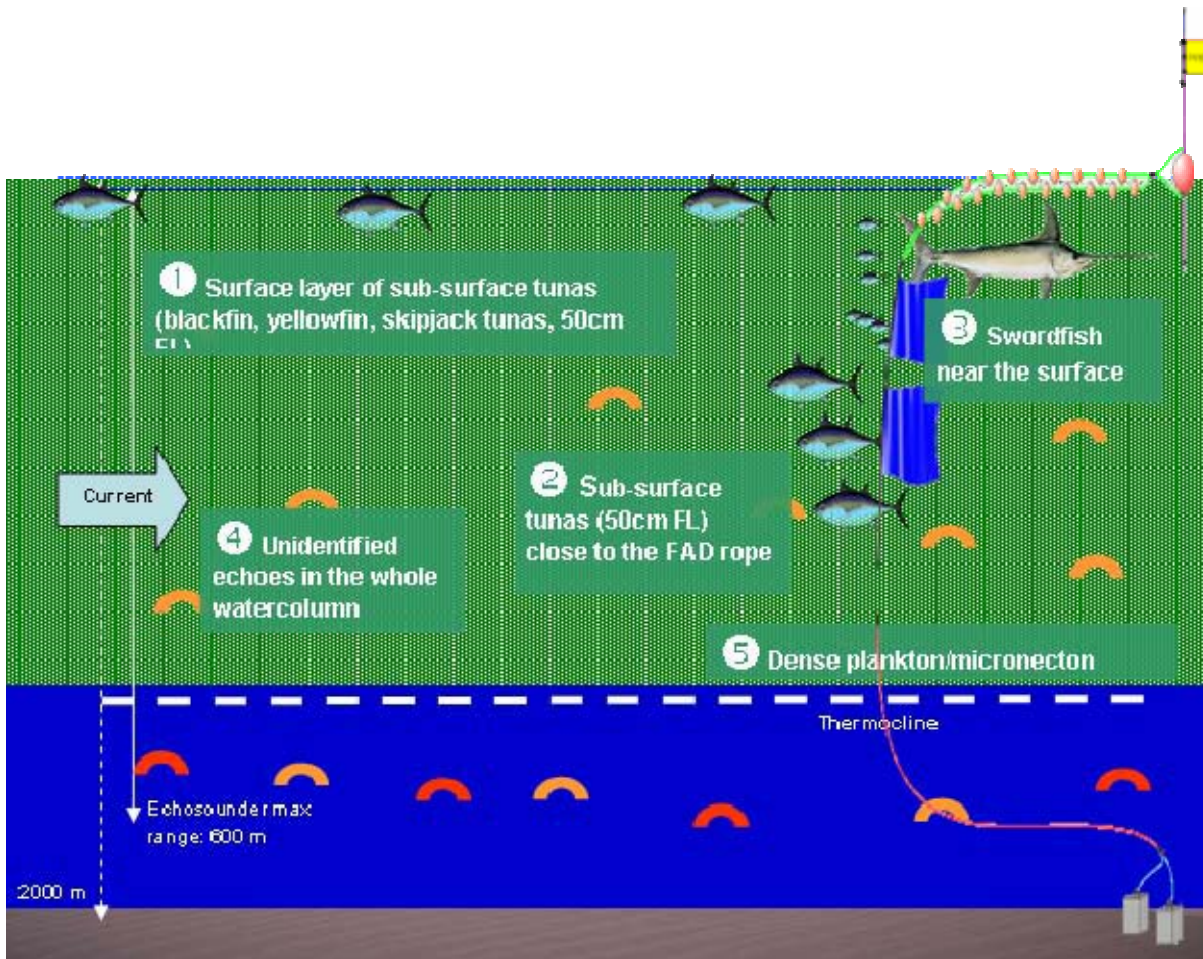


Figure 4: Nocturnal fish aggregations, plankton/micronekton layers around moored FADs in Martinique

The structure of the biotic aggregations changed a lot during transition periods.

In the afternoon, the subsurface tunas spread away and their biomass seems to be at a minimum after sunset. Then, they appear in the nocturnal catches of the surface longline, indicating that some of them are present close to the surface and near the FAD during the night (nocturnal aggregation, as type ❶ described above). Others form a small aggregation remaining very close to the FAD rope (nocturnal aggregation, type ❷). Unidentified individual acoustic targets (nocturnal aggregation, type ❹) have been observed every night.

Swordfishes (*Xiphias gladius*) have been rarely caught with surface longline (nocturnal aggregation, type ❸). Swordfishes are known to feed near the surface at night whereas they are located far deeper during daytime.

Deep plankton/micronekton layers went up to the surface every night after sunset, mixing with the diurnal layers (nocturnal aggregation, type ❺).

At dawn, the diurnal aggregations are quickly reconstituted. Commercial fishing only occurs at dawn and dusk.

4. DISCUSSION

4.1 Comparison of the Polynesian and Martinican moored FADs systems

The Polynesian moored FADs system is characterized by the presence of diurnal aggregations of deep (100–300 m) and scattered large tunas (>100 cm FL) which are generally distributed within a 0.8 nautical miles radius around the moored FAD. These fishes are the main targets of the local artisanal fishery.

In Martinique, the main diurnal aggregation is a subsurface (0–150 m) small tunas (50 cm FL) aggregation located up current and closer to the FAD, at a distance of up to about 0.2 nautical miles. Martinican artisanal fishermen hardly exploit the main fish aggregation observed around the moored FADs. Instead, they target large predators that are also attracted in smaller numbers by the FADs.

In both areas the biomass that is attracted by moored FADs mainly consists in tunas. However according to the region these tunas belong to different size classes and exhibit different aggregate patterns. These differences are related to the location of the devices and obviously to the local abundance of the tunas.

The type of exploitation of the fishes aggregated around moored FADs by artisanal fishermen also differs. In French Polynesia, fishermen mainly use deep lines (100–300 m) and target the deep scattered tunas composing the Polynesian main aggregation. In Martinique fishermen only prospect the subsurface layer (0–150 m) but without targeting the main Martinican aggregation of small subsurface schooling tunas.

4.2 Further description of the moored FADs system in Martinique

Following papers in this volume (Chanterelle, Doray and Fréjaville, this volume; Doray, this volume; Reynal, this volume) will focus on each of the types of diurnal aggregations and their exploitation by fishing, providing a preliminary description of the components of the moored FADs system in Martinique.

***Acknowledgements:** very special thanks to Paul Gervain and the “Beryx” crew for their invaluable assistance during the DAUPHIN sea campaigns. We also want to thank all the commercial fishermen who took part into the project. The author is also very grateful to Gerard van Buurt who kindly revised the English of the text.*

BIBLIOGRAPHY

- Adam, M.S., Sibert, J., Itano, D. & Holland, K. 2003. Dynamics of bigeye (*Thunnus obesus*) and yellowfin (*T. albacares*) tuna in Hawaii's pelagic fisheries: analysis of tagging data with a bulk transfer model incorporating size-specific attrition. *Fishery Bulletin* [Fish. Bull.]. 101: 215–228.
- Brill, R.W., Block, B.A., Boggs, C.H., Bigelow, K.A., Freund, E.V. & Marcinek, D.J. 1999. Horizontal movements and depth distribution of large adult yellowfin tuna (*Thunnus albacares*) near the Hawaiian Islands, recorded using ultrasonic telemetry: Implications for the physiological ecology of pelagic fishes. *Marine Biology* [Mar. Biol.]. 133: 395–408.
- Cayré, P. 1991. Behaviour of yellowfin tuna (*Thunnus albacares*) and skipjack tuna (*Katsuwonus pelamis*) around fish aggregating devices (FADs) in the Comoros Islands as determined by ultrasonic tagging. *Aquatic Living Resources* 4: 1–12.
- Cayré, P. et Chabanne, P. 1986. Marquage acoustique et comportement des thons tropicaux (albacore: *Thunnus albacares*, et listao: *Katsuwonus pelamis*) au voisinage d'un dispositif concentrateur de poissons. *Océanogr. Trop.* 21: 167–183.
- Chanterelle, J., Doray, M. et Fréjaville, Y. Ce volume. Etude préliminaire des couches micronectoniques de la côte sous le vent de la Martinique in Report of the Second meeting of the WECAFC Ad hoc Working Group on the Development of Sustainable Moored Fish Aggregating Device Fishing in the Lesser Antilles, FAO Fish. Rep. N°. Rome, FAO.
- Cillauren, E. 1987. The trolling fishery around the fish aggregating devices setted in Vanuatu. An example in the South West Pacific. PhD thesis Univ. Bretagne Occidentale: 205p.

- Dagorn, L., Josse, E. & Bach, P. 2000. Individual differences in horizontal movements of yellowfin tuna (*Thunnus albacares*) in nearshore areas in French Polynesia, determined using ultrasonic telemetry. *Aquatic Living Resources* 13: 193–202.
- Doray, M. This volume. First description of subsurface aggregations of small tunas observed around moored FADs in Martinique in Report of the Second meeting of the WECAFC Ad-hoc Working Group on the Development of Sustainable Moored Fish Aggregating Device Fishing in the Lesser Antilles, FAO Fish. Rep. N°. Rome, FAO.
- Doray, M., Reynal, L. et Carpentier, A. 2002. Evaluation de l'impact de la pêche associée aux DCP ancrés. Méthodes employées et premiers résultats aux Antilles françaises in Rapport de la 1ère réunion du groupe de travail FAO Petites Antilles pour le développement durable de la pêche associée aux DCP ancrés, FAO Fish. Rep. N°683, Supplement. Rome, FAO.
- Doray, M., Reynal, L., Carpentier, A. et Lagin, A. 2002b. Le développement de la pêche associée aux DCP ancrés en Martinique in Supplement to the Report of the First meeting of the WECAFC Ad hoc Working Group on the Development of Sustainable Moored Fish Aggregating Device Fishing in the Lesser Antilles, FAO Fish. Rep. N°683, Supplement. Port-of-Spain, FAO.
- Holland, K.N., Brill, R.W. & Chang, R.K.C. 1990. Horizontal and Vertical Movements of Yellowfin and Bigeye Tuna Associated with Fish Aggregating Devices. *Fish Bull.* 88: 493–507.
- Josse, E., Bach, P. & Dagorn, L. 1998. Simultaneous observations of tuna movements and their prey by sonic tracking and acoustic surveys. *Hydrobiologia [Hydrobiologia]* 371: 1–3.
- Josse, E., Bertrand, A. & Dagorn, L. 1999. An acoustic approach to study tuna aggregated around fish aggregating devices in French Polynesia: methods and validation. *Aquat. Living Resour.* 12: 303–313.
- Josse, E., Dagorn, L. & Bertrand, A. 2000. Typology and behaviour of tuna aggregations around fish aggregating devices from acoustic surveys in French Polynesia. *Aquatic Living Resources.* 13: 183–192.
- Kakuma, S. 2000. Current, catch and weight composition of yellowfin tuna with FADs off Okinawa island, Japan. In: M. Taquet (eds), *Tuna Fishing and Fish Aggregating Devices Symposium*, IFREMER, Actes Colloq. IFREMER, 28, 492–501.
- Marsac, F. et Cayré, P. 1998. Telemetry applied to behaviour analysis of yellowfin tuna (*Thunnus albacares*, Bonnaterre, 1788) movements in a network of fish aggregating devices. *Hydrobiologia* 371/372: 155–171.
- Reynal, L. Ce volume. Répartition spatiale des DCP dans les eaux martiniquaises et conséquences sur la pêche in Report of the Second meeting of the WECAFC Ad hoc Working Group on the Development of Sustainable Moored Fish Aggregating Device Fishing in the Lesser Antilles, FAO Fish. Rep. N°. Rome, FAO.
- Reynal, R., Lagin, A. et Gervain, P. Ce volume. Sites d'implantation et conception des DCP ancrés en Martinique in rapport de la deuxième réunion du groupe de travail FAO Petites Antilles pour le développement durable de la pêche associée aux DCP ancrés. Port-of-Spain, FAO.
- Simrad, 2001. Simrad EK60 Scientific echo sounder Instruction manual. Horten, Simrad Subsea A/S Norway.

First description of subsurface aggregations of small tunas observed around moored FADs in Martinique

by
Mathieu Doray.¹

1. MATERIAL AND METHODS: TOOLS TO DESCRIBE SUB SURFACE TUNA AGGREGATIONS

1.1 Fishery acoustics

The EK60 scientific echosounder was the main tool used to describe the subsurface tuna aggregations. The echosounder was equipped with two frequencies (38 and 120kHz) to get complementary acoustic images of the moored FAD biotic aggregations. The echosounder maximum range varied according to the frequency: the maximum ranges were respectively 600m at 38kHz and 200 m at 120kHz.

Three acoustic antennas (or transducers) were used: two transducers (38 and 120kHz, 6.9°) were directed vertically under the boat and the third one (120kHz, 2.5 x 10°) could be oriented from 0 to 90° below the surface. The echosounder parameters were those used during the ECOTAP program (Josse *et al.*, 1999). The echosounder was calibrated before each campaign using the standard procedure recommended by the manufacturer (Simrad, 2001).

Different types of acoustic transects were implemented:

1.2 Vertical beaming transect

This transect (Figure 1) has been adapted from the one designed in French Polynesia within the framework of the ECOTAP program (Josse *et al.*, 1999). Based on the results obtained, the radius of the transect has been reduced from 0.8 to 0.2 nautical miles in order to observe the fish aggregations at a more appropriate spatio-temporal scale. In fact the aggregations were located very close to the FAD and their structure could evolve quite rapidly. It was decided to reduce the area prospected and the time needed to complete a transect. A 0.2 nautical miles transect was completed within 30 minutes.

1.3 Other acoustic transects

A 120kHz 2.5 x 10° transducer was used to observe transversally and get a complementary sampling of the sub surface tuna aggregations. The transducer axis was set 30° under the sea surface and the boat described a rectangular transect around the tuna aggregation.

Vertical acoustic observations were realized when the boat was drifting over the tuna aggregations, during underwater camera recordings.

Vertical and radial acoustic observations of the tuna aggregations were also conducted when the boat was attached to the moored FAD.

North

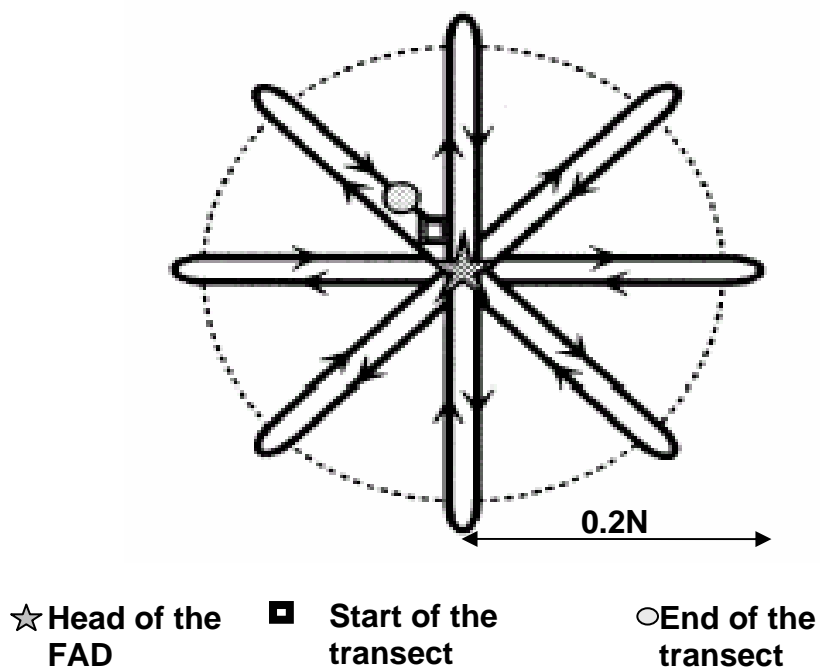


Figure 1: Star transect used during the vertical acoustic surveys of the DAUPHIN sea campaigns (Josse *et al.*, 1999).

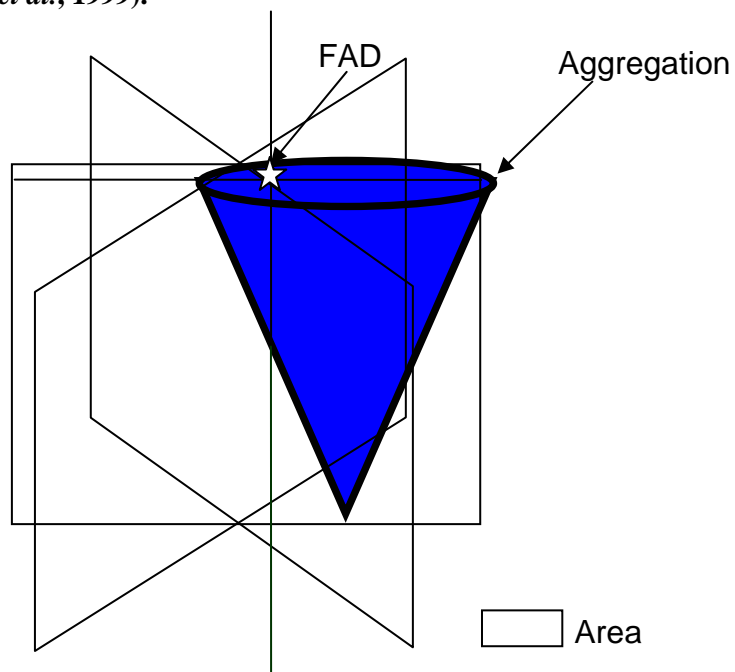


Figure 2: Sampling of a sub-surface tuna aggregation with a star transect and a vertical beaming echosounder.

The star transect in vertical beaming provides nine “slices” of the tuna aggregation describing its structure in four different directions (Figure 2).

1.4 Underwater video camera

An underwater video-camera (Sony SST DC 50 AP) included in a hydro dynamical housing was used to identify the fishes belonging to the subsurface aggregations and to observe their behaviour.

The camera was lowered at the end of a cable over the tuna aggregations detected with the vertical echosounder. Pictures were sent in real time by the camera through a coaxial cable to a monitor in the Beryx's deck.

A digital depth gauge was put in the field of the camera in order to adapt in real the immersion depth, according to the echosounder detections.

The camera was used either when the boat was drifting over the tuna aggregations or when the boat was attached to the moored FAD.

1.5 Experimental and commercial fishing

Experimental and commercial fishing catches were analysed to identify the fishes belonging to the subsurface aggregations and to study their nutrition.

A surface 30 hooks surface longline was attached every night to the FAD to sample the sub surface tunas scattered near the surface. Trolling lines were usually deployed from the Beryx during daytime. A surface drifting gillnet was also tested at night.

In an attempt to record as much as possible commercial catches made around the surveyed FADs during the sea campaign, observers directly sampled the catches aboard fishing boats and phone surveys were conducted after each campaign.

1.6 Vertical acoustic data processing

Shoal extraction

The aggregations were isolated from the surrounding micronektonic layers with the echo-integration by shoal module of the Movies + software (© 1997–2002, IFREMER). This module allows gathering of acoustic samples whose intensity is above a given threshold and which obey a certain law of contiguity. The set of acoustic samples which have then been defined is called a "shoal". Hence, the echo-integration by shoal allows reconstitution of fish schools which are generally characterized by a patchy structure on the acoustic images (or echograms). Movies + therefore provides a complete set of descriptors (location, density, morphology, etc.) for each shoal.

Individual target analysis

The Target Strength Analysis module of Movies + allows to analyse individual acoustic targets which can be isolated fishes like the "scattered predators" of fishes located at the periphery of the subsurface aggregations. The intensity of the individual targets (or Target Strength: TS) provides information about the size of the fishes and is needed to perform an acoustic density estimation of the aggregations.

Estimation of the fish density around the moored FAD

The echo-integration by shoals provides a global acoustic density of the aggregations. The acoustic density is attributed to sample cells, defined as in the ECOTAP study (Josse *et al.*, 1999). Each shoal acoustic density is weighed by the volume of the sampling cell to which it belongs. In fact the shape of the star transect causes an oversampling of the centre of the study area but the volume of the sampling cells increases from the centre to the edges and then counterbalances the sampling bias due to the geometry of the transect.

In each cell, the global acoustic density is divided by the average TS of the fishes in the aggregation to get an average number of fishes. A density, in number of fishes per m³, can also be calculated in function

of the volume of each cell. If the mean individual weight of a fish in the aggregation can be estimated from fishing data, one can calculate a biomass estimate for each sampling cell.

Total density, number of fishes and biomass estimates can then be calculated for angular, depth or distance strata or for the whole study area around the FAD.

2. FIRST RESULTS

2.1 Data collection

2.1.1 Acoustic data

The subsurface tuna aggregations have been observed around all of the moored FADs deployed within the framework of the DAUPHIN project (three on the leeward coast, one on the windward coast of Martinique).

Four hundred and eighty hours of acoustic surveys have been recorded during 516 star transects. A unique sub surface aggregation has been observed around each head of the moored FADs during nearly all of the diurnal surveys of the 16 sea campaigns. As the micronekton layers reflect less acoustic energy in 120kHz than in 38kHz, the subsurface tunas were best observed with the 120kHz frequency.

2.1.2 Underwater video recordings

Forty hours of video were recorded during the 16 sea campaigns. The camera allowed to record clear pictures of tunas up to a depth of 100 m, depending the light intensity and of the clearness of the water. It allowed to roughly identify the fishes (tuna like species) and to observe some behaviour.

2.1.3 Experimental and commercial fishing

It was very difficult to properly sample the fishes belonging to the subsurface tuna aggregations. The subsurface tunas are not easily caught with the line fishing methods currently employed in Martinique. New fishing techniques were tested (surface longline, drifting gillnets) but without convincing quantitative results.

Fourteen hundred fishes have been sampled, but very few of them belonged to the subsurface tuna aggregation.

2.2 Preliminary results

The preliminary results presented in this paper are derived from the data processing of 13 surveys conducted around a two heads offshore FAD in September 2003 and April 2004. Subsurface tuna aggregations were the only type of aggregations observed around the moored FAD during these campaigns.

2.2.1 Subsurface tuna aggregations dimensions

Table 1: Average morphologic descriptors of the subsurface tuna aggregations.

Average Lmax	217 m
Average Hmax	72 m
Average area	989 m ²
Average min depth	33 m
Average max depth	105 m

Table 1 presents the average main morphologic descriptors of the 13 subsurface aggregations processed for this paper. The aggregations are large (217 m x 72 m) and located in average between in the mixed layer, between 33 and 105 m.

Sub surface tuna aggregations position

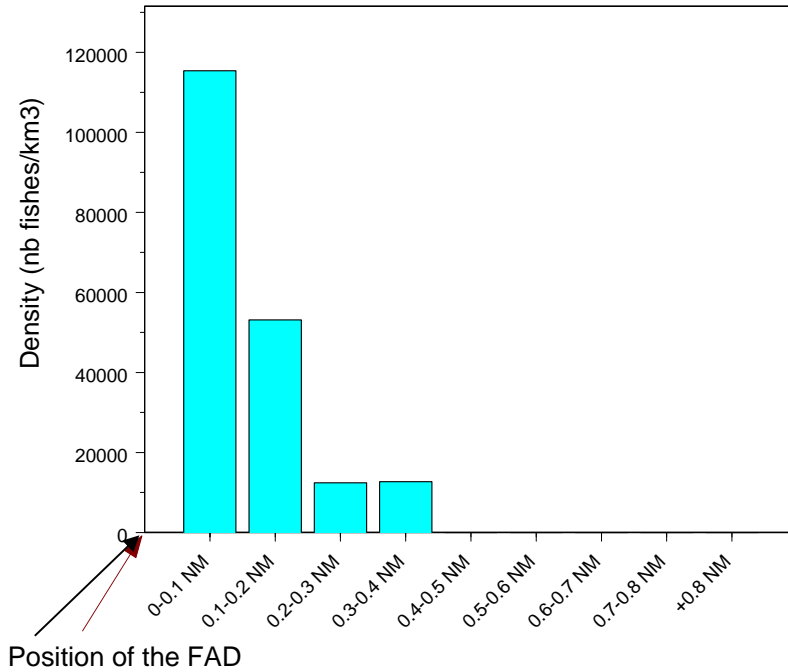


Figure 3: Position of the subsurface tuna aggregations relative to the head of the FAD.

Figure 3 presents the density of the subsurface tuna aggregations relative to the FAD head. Most of the fishes are distributed within 0.2 nautical miles from the FAD head, generally up current.

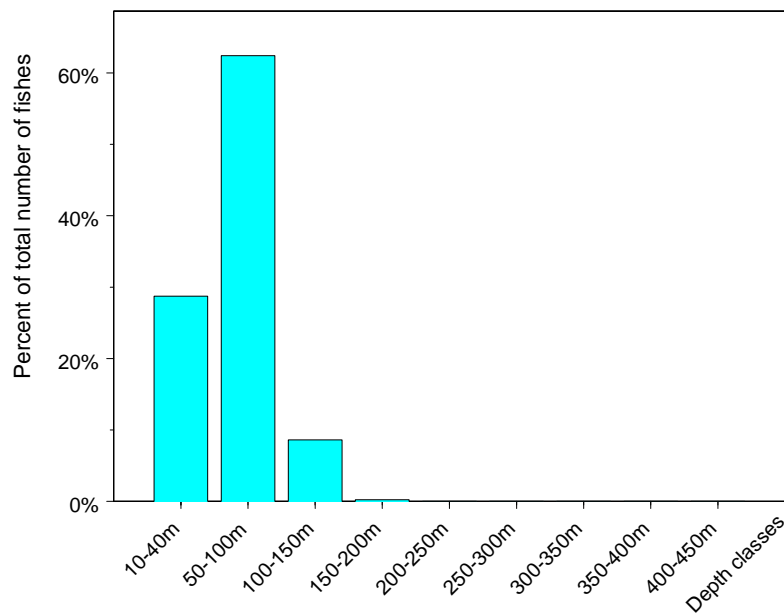


Figure 4: Depth of the subsurface tuna aggregations around moored FADs.

Figure 4 presents the percentage of the total number of fishes around the FAD for different depth ranges. All the subsurface tunas are distributed above 150 m, the majority being found between 50 and 100 m.

2.2.3 Subsurface tuna aggregations average daytime density

Table 2: Average density descriptors of the subsurface tuna aggregations.

Average number of fish	38 160
Average density (fish/km ³)	5 113
Average biomass (MT)	44
Max/min number of fish	181 413 / 5 917
Max/min density	23 619 / 770
Max/min biomass	140 / 4

Table 2 presents the average density descriptors of the sub surface tunas for the 13 surveys processed. The average density is high: 5 113 fishes/km³. These results are preliminary. The average biomass must be interpreted with caution because of the limited amount of data available to calculate it. Moreover, the methodology used does not provide confidence intervals of biomass estimates.

2.2.4 Sub surface tuna aggregations variability

The subsurface tuna aggregations are characterized by a high variability of their biomass, along nycthemeral cycles but also from one 24-hour cycle to another.

2.2.5 Nycthemeral cycles

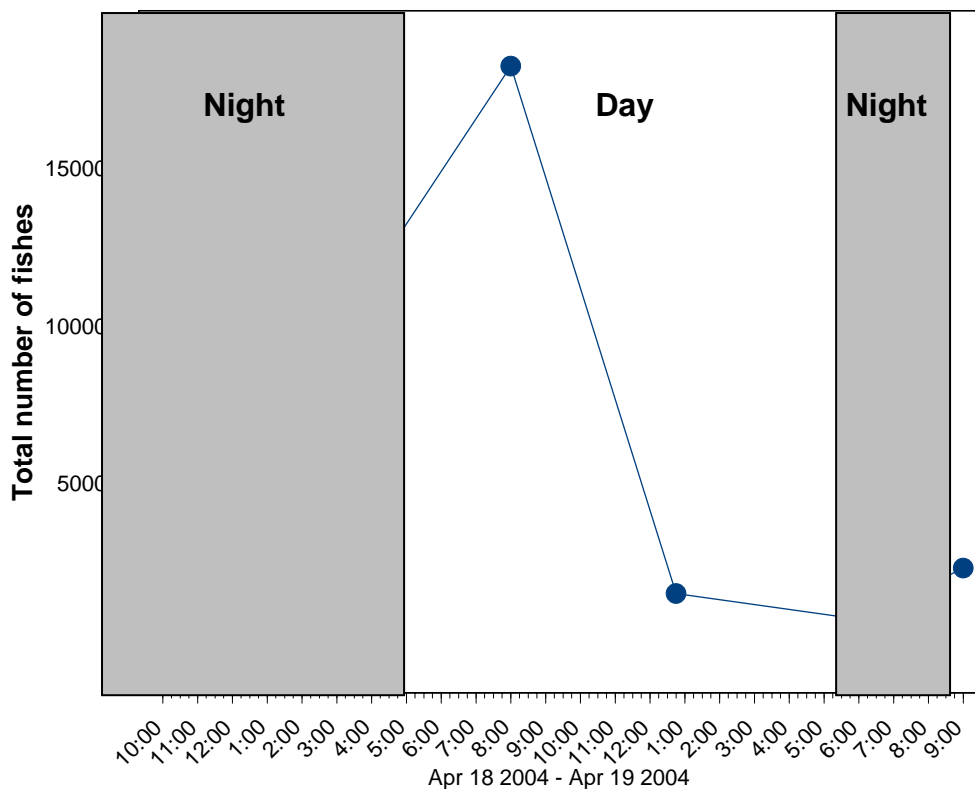


Figure 5: Nycthemeral cycle of the number of subsurface tunas aggregated around the moored FAD.

Figure 5 presents the classical nycthemeral cycle of the number of subsurface tunas aggregated around the moored FAD. The number of fish is the lowest at night and quickly increases at dawn to reach its maximum in the early morning. The maximum number of fish is reached in the early morning or later, by noon.

2.2.6 High fish density variations from day to day

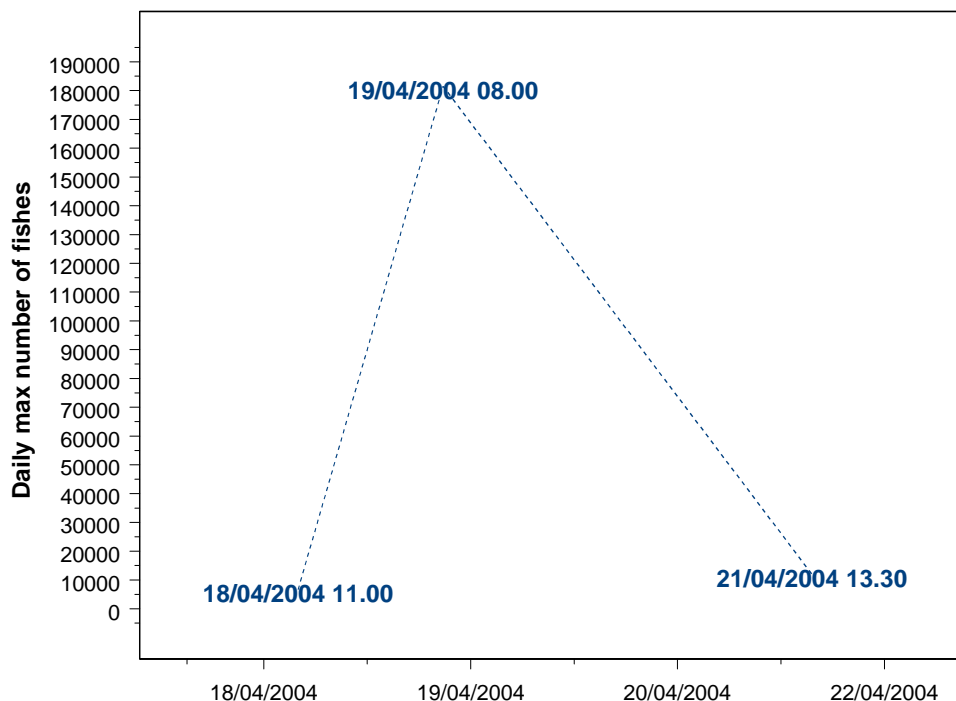


Figure 6: Variations of the maximum daily number of subsurface tunas around a moored FAD.

Figure 6 presents the variations of the maximum daily number of subsurface tunas around a moored FAD. There are considerable variations: the maximum number of tunas on 19 April is 30 times higher than the previous day and 15 times higher than two days later.

2.2.7 Complementary acoustic and underwater video observations of a blackfin tuna aggregation

The combination of acoustics and underwater video allowed us to efficiently observe both the structure and dynamics of the subsurface tuna aggregations.

Acoustics provided quantitative data on the shape, the position and the density of the aggregations whereas underwater video made it possible to roughly identify the fishes belonging to the aggregations and to corroborate some of the acoustic results. Video stood in for fishing which was poor during daytime and did not allow to identify the fishes of the aggregations.

It also confirmed the low density of the tuna aggregations which appeared in the acoustic echograms and density estimates. Hence, the mean density within the aggregations calculated for the April, 2004 campaign is 7.9 fish per m³ which is quite low compared to densities that can be observed in small pelagic schools for example (e.g. 99 fish/m³ for anchovy schools (Graves, 1977)). On video recordings also, the density of tunas in the aggregation appeared to be low with a weak swimming cohesion between fishes. It confirmed that the subsurface tunas form an “aggregation” and not a school which is a structure with much higher density and social cohesion.

3. DISCUSSION

3.1 Relations between subsurface tuna aggregations and environment

The data processed for this paper are derived from campaigns conducted in September, 2003 and April, 2004 around the offshore leeward moored FAD. The September campaign was characterized by an unstratified abiotic environment, weak currents, dense micronekton layers and the presence of large, dense and quite stable subsurface aggregations. On the contrary, the April campaign was characterized by a stratified abiotic environment, strong currents, light micronekton layers and more unstable and scattered aggregations, often observed around FAD heads which were submerged at 150 m depth. This may partially explain the high variability observed in the maximum daily biomass observed around the moored FAD in April.

More data processing is needed to study relations between the subsurface tuna aggregations structure and dynamics and their biotic and abiotic environment.

3.2 “Subsurface tuna aggregations” and “shallow schooling fishes”

As mentioned by Doray (this volume), the only other observations of fish aggregations around moored FADs were realized in French Polynesia (Josse *et al.*, 2000). A typology of the different aggregations observed around moored FADs was established in this study and compared to the aggregations observed in Martinique (Doray, this volume). The type of Polynesian aggregation that is most similar to the Martinican “subsurface tuna aggregations” is the “shallow schooling fishes” aggregation.

Table 3: Comparison of Polynesian “shallow schooling fishes” and Martinican “subsurface tuna aggregations”.

Type of aggregation	Shallow schooling fishes	Subsurface tuna aggregations
Geographic location	French Polynesia (Central Pacific)	Martinique (Western Central Atlantic)
Nb of surveys	87	13
Frequency of observations	21%	100%
Average density (fishes/km ³)	801	5113
Vertical distribution (m)	10-50	33-105
Horizontal distribution (NM)	0.1	0.2
Composition	50cm FL tunas	50cm FL tunas
Exploitation by fishing	provide 25% of catches	nearly unexploited

Table 3 presents a comparison between these two types of aggregations. Subsurface aggregation was always observed during the DAUPHIN campaigns and represented the majority of the fish biomass aggregated around moored FADs in Martinique. The shallow schooling fishes seemed to be less common in French Polynesia (frequency: 21 pour cent) and then generally less abundant than the subsurface tunas aggregation in Martinique. They also appeared to be distributed closer to the FAD and nearer to the surface. The two types of aggregations are supposed to be composed of tunas of the same size but with different dominant species (bigeye tunas in Polynesia, blackfin tunas in Martinique).

Further processing of the DAUPHIN data is needed to accurately compare the Polynesian and Martinican moored FAD systems.

Acknowledgements: The author is very grateful to Gerard van Buurt who kindly revised the English of the text.

BIBLIOGRAPHY

Doray, M. This volume. Typology of fish aggregations observed around moored FADs in Martinique during the DAUPHIN project in *Report of the Second meeting of the WECAFC Ad-hoc Working Group on the Development of Sustainable Moored Fish Aggregating Device Fishing in the Lesser Antilles*, FAO Fish. Rep. N°. Rome, FAO.

Graves, J. 1977. Photographic method for measuring spacing and density within pelagic fish schools at sea. *Fish. Bull. NMFS/NOAA* **75**: 230-234.

Josse, E., Bertrand, A. & Dagorn, L. 1999. An acoustic approach to study tuna aggregated around fish aggregating devices in French Polynesia: methods and validation. *Aquat. Living Resour.* **12**: 303-313.

Josse, E., Dagorn, L. & Bertrand, A. 2000. Typology and behaviour of tuna aggregations around fish aggregating devices from acoustic surveys in French Polynesia. *Aquat. Living Resour.* **13**: 183-192.

Simrad, 2001. Simrad EK60 Scientific echo sounder Instruction manual. Horten, Simrad Subsea A/S Norway.