PREDATORS AND PREYS : AN ACOUSTIC APPROACH

E. MARCHAL, E. JOSSE, A. LEBOURGES

ABSTRACT

Predators are seeking for congregated rather than scattered preys, and are schooling themselves most of the time. Studying relationships between predators and preys needs to identify them. Classical methods of investigation, such as the use of different kinds of net (plankton, midwater trawl) with a regular sampling grid, often fail to succeed in catching them, due to their very heterogeneous distribution. In contrast, acoustics allows us to « see » and to study them, thanks to the very good transmission of sound in the water. A good example of the way acoustics could be used to study predator-prey relationship is provided by a tuna fishery in the Equatorial Atlantic which exploits a seasonal tuna concentration. It was assumed that tuna find here an abundant food, supported by the very high percentage of a mesopelagic fish, *Vinciguerria nimbaria*, found in their stomach contents. However this fish is known as a dial migrator, diving to deep waters during daytime, where tuna could not catch them since they are view-feeders. Acoustic detection has proven that, in this case, this small fish could stay in the surface layers, aggregating in small schools at the thermocline level. In addition, acoustic tagging has shown that tuna were staying most of the time at this particular level. Finally, acoustic estimation of the packing density and the volume of these schools allows us to assume their actual role into the daily feeding of tuna.

KEYWORDS : predation and feeding, tuna, mesopelagic fauna, dial migrations, acoustic detection.

ABSTRAK

Sebagian besar tingkah laku pemangsa cenderung mencari mangsa yang mempunyai sifat berkelompok daripada mangsa yang sifatnya terpencar. Suatu telaah tentang hubungan mangsa dan pemangsa perlu diteliti secara terperinti. Penelitian dengan metode klasik seperti halnya dengan penggunaan berbagai macam jaring plankton maupun trawl pelagis melalui pengambilan contoh secara teratur sering kali menemui kegagalan dalam upaya mendapatkan data tersebut yang disebabkan oleh sebaran keberadaan yang sangat heterogen. Sebaliknya penggunaan metode akustik dapat memperlihatkan keberadaannya melalui proses pancaran suara dalam kolom air. Suatu hasil pengamatan yang sangat baik melalui metode akustik yang dapat bermanfaat bagi penelitian hubungan mangsa dan pemangsa telah dibuktikan pada perikanan tuna di perairan Ekuator Atlantik dimana kegiatan penangkapan tuna dilakukan secara musiman. Telah diduga bahwa keberadaan tuna tersebut berkaitan erat dengan melimpahnya makanan yang ditunjang oleh sangat tingginya keberadaan ikan mesopelagis, Vinciguerria nimbaria *sebagai preferensi makanan pada isi perut tuna tersebut. Jenis ikan mesopelagis ini dikenal sebagai jenis yang melakukan ruaya tegak harian, yang berada di perairan yang sangat dalam pada siang hari dimana tuna tidak dapat memangsanya. Pelacakan melalui teknik akustik menunjukkan bahwa jenis ikan berukuran kecil berada dilapisan permukaan dan berkelompok kecil pada lapisan termoklin. Ditunjang oleh hasil penelitian melalui teknik penandaan akustik (acoustic tagging) terlihat bahwa tuna sebagian besar waktunya berada pada lapisan ini. Akhirnya, pendugaan akustik melalui pekiraan kepadatan (packing density) dan volume kelompok ikan ini dapat dijadikan dasar peranan keberadaan jenis ini pada makanan harian ikan tuna.*

KATA KUNCI : pemangsa dan makanan, tuna, fauna mesopelagis, ruaya harian, akustik.

The predators must find their preys : they have advantage to seek for congregated rather than scattered preys, from the view point of energy consuming. Generally, the size of the preys is smaller than the size of their predators and these preys belong to a lower trophic level. If we take tunas as an example, they eat especially small fish which themselves consume essentially small shellfish such as copepods. What is true for the terminal predators is also true for their preys which behave usually also as predators, even if they may appear less active : so those small fishes will seek for layers and swarms of the zooplankton. We can practically say that the zooplankton also seek for concentrations of phytoplankton on which they feed. Certainly, the movements will be of much less amplitude and they will be mainly characterized by aggregations where the phytoplankton itself is concentrated by physical structures such as frontal zones, thermoclines or peripheral parts of upwellings.

So, whatever the trophic level concerned, we observe a great heterogeneity in the spatial distribution of organisms composing this level. Such an heterogeneity corresponds with a so-called « contagious distribution » by the statisticians and which, in the field of biology and behaviour, explains the fact that the main part of pelagic organisms form aggregations more or less structured. For a predator, living in schools, the concentration of its preys (or its food in a larger sense) plays a more important role than its average abundance, within certain limits, of course. In this matter, the fisherman is not very different from a « natural » predator since he seeks also for concentrations of schools.

But another consequence of that distribution concerns directly the scientific researcher : if he tries to collect the information according to a regular and systematic sampling, it is highly probable that he will miss the phenomenon he wants to study. Therefore it can be of a major interest to be able to « guide » the sampling pattern from direct observations of the aggregation phenomenon. In the aquatic environment, only acoustics enables such a remote observation. The tunas of the Equatorial Atlantic give us an example of its use, leading to elucidate the paradox of tuna concentrations in areas known as less productive.

FISHERY OF TUNAS IN EQUATORIAL ATLANTIC

Since about 15 years a seasonal fishery of tunas has been developed in a well-defined area of the equatorial Atlantic (Fig. 1), from 10° W to 20° W, between the equator and 5° N approximately (Fonteneau, 1994). The captures rapidly increased during the first years and then stabilized around 40 to 50,000 tons per year, with important inter-annual variation (Fig. 2). In fact, it concerns a multi-specific fishery with rather equivalent captures of skipjack *Katsuwonus pelamis* and yellowfin *Thunnus albacares*, with small quantities of bigeye *Thunnus obesus*). There is a clear seasonal influence upon captures : skipjacks compose the major part of the captures from November to January, then yellowfins from January to the end of March and bigeyes being scattered rather uniformly all along the fishing season (Fig. 3) which lasts about six months, from October to March.

THE PARADOX OF THE PRESENCE OF TUNAS

That area belongs to the equatorial current system. It takes advantage of a seasonal enrichment due to the development of an upwelling along the equator which lasts about 3 months during the boreal summer (from mid-June to about mid-September). During that period, the tuna fishery is inactive in the area, and apparently tunas are also in a very weak quantity. Therefore the fishery begins after that period of enrichment, with the delay of about 1 month after the end of upwelling.

Moreover, the friction between the opposite South and North equatorial currents produces a shearing wave which could lead to eddies and raising of water enriched with nutrients. That wave, particularly active in boreal summer when it can be seen on satellite pictures (Fig. 4), may continue during the following months to "fertilize" the area located North of the Equator (Morlière *et al.*, 1995).

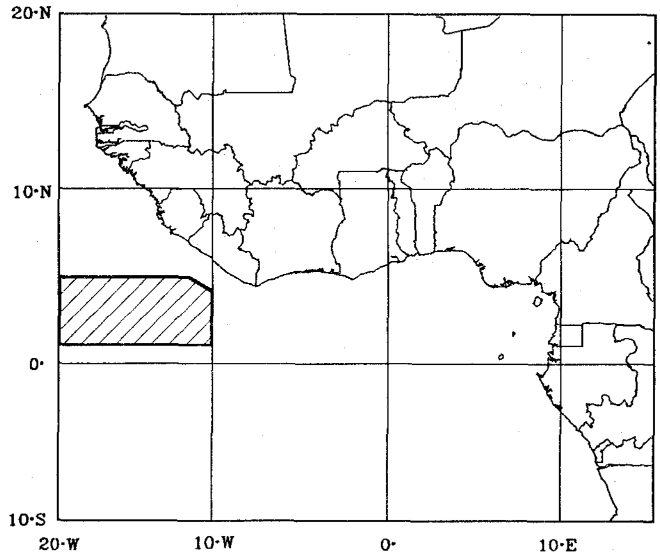

Figure 1 Location of the studied area (Fishing Area "Liberia").
Gambar 1 Lokasi penelitian (Daerah penangkapan Liberia).

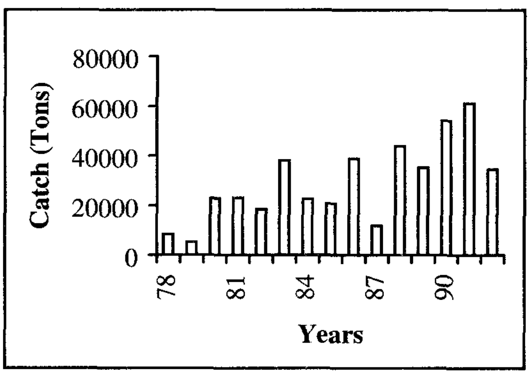

Figure 2 Annual total catches of tuna in the Liberia Area, 1978 to 1992.
Gambar 2 Hasil tangkapan tahunan ikan tuna di perairan Liberia pada tahun 1978 hingga 1992.

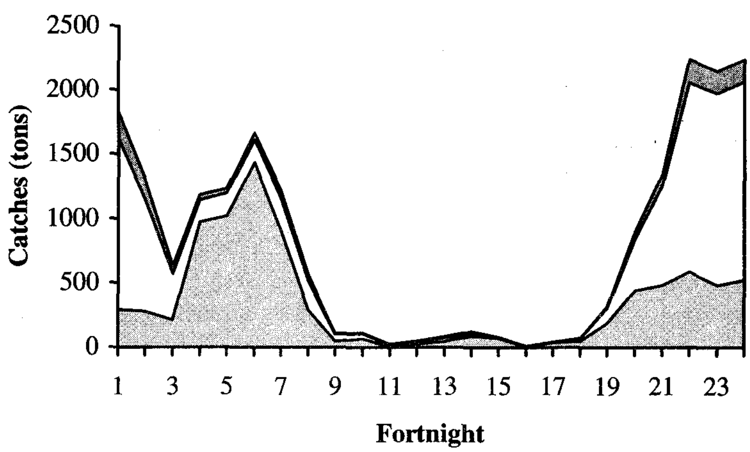

Figure 3 Average fortnightly catches of the 3 main species of tuna in the Liberia Area, during the same period.
Gambar 3 Rata-rata hasil tangkapan dua mingguan 3 jenis utama ikan tuna di perairan Liberia, pada kurun waktu yang sama.

Figure 4 **Satellite image showing a Long Wave north to the equator, underlined by a thermal front (Meteosat image, 07/07/94, UTIS, Dakar).**

Gambar 4 **Citra satelit memperlihatkan gelombang panjang utara ekuator dengan penekanan pada perbedaan garis suhu (Citra Meteosat, 07/07/94, UTIS, Dakar).**

Anyway, the epipelagic fauna has a very low abundance during the tunas fishery season, whereas tunas are "great eater". In fact, they have to constantly swim in order not to sink because they are lack of swimbladder (case of skipjacks), or they have one but not very developed (yellowfins), and they have anyhow negative buoyancy. Moreover, they swim rapidly, spending a lot of energy. On an average, a tuna consumes every day about 5% of his own weight (Olson and Boggs, 1986). It is generally accepted, and that has been confirmed by our own observations of stomach content, that tunas feed almost exclusively during day-time because they need to see their preys to catch them. The only important biomass of potential food is composed by mesopelagic organisms (mainly fish of the Myctophid families, Gonostomatids, etc., and Euphausiids). But those organisms, forming layers, perform dial vertical migrations from the surface during night-time to depths of 4 to 500 meters during day-time, as it has been observed in a close area (Marchal *et al.*, 1993) (Fig. 5). Here is one paradox of the feeding of tunas living in the high seas : the only abundant food seems to exist beyond their reach.

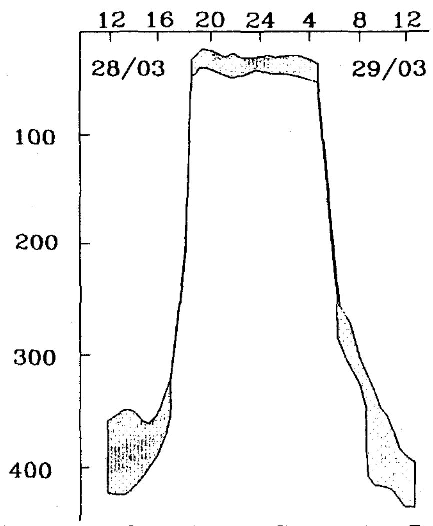

Figure 5 **Typical dial migration of the Sound Scattering Layer (SSL) as observed in the Equatorial Atlantic during 28-29 March 1976. Depth in meters on vertical scale, time in hours on the horizontal scale.**

Gambar 5 **Ruaya harian Lapisan Hamburan Suara (LHS) diamati pada perairan Atlantik Ekuator pada tanggal 28-29 Maret 1976. Kedalaman dalam meter dan waktu dalam jam.**

A study has been realized upon the diet of the tunas that are present in that area during the period of their concentration (Roger and Marchal, 1994) : the examination of the stomach content of the 2 major species caught during a research cruise performed in November 1992 (MICROTHON 03, R/V André Nizery) has shown that 73% of content volume was made up by a single species, *Vinciguerria nimbaria*, from the family of *Photichtyidae* (close to *Gonostomatidae*)[1]. This fish of small size, not exceeding 5 cm of length, is considered to belong to the mesopelagic fauna that perform dial migrations : actually, adults had rather never been caught during day-time within the surface layers of oceans (Blackburn, 1968). The fresh condition of *Vinciguerria*, found in the stomach of tunas caught during day-time, excludes a nocturnal feeding of tunas. We face then the following alternative : either the tunas were able to dive deeper than it was supposed and to seek for their preys at depths of 400 meters and so, in cold waters that do not fit their habitat, or the *Vinciguerria* could have stayed during day time within the surface layers, contrarily to previous observations. A bibliographical study of previous analysis of the stomach contents of open sea tropical tunas, has shown that, in fact, at least in the case of skipjacks, *Vinciguerria sp.* represented one of major constituents of their diet (Marchal and Lebourges, 1996).

During the same cruise, plenty of detections have been observed in certain areas of the prospected zone, particularly -- but not exclusively -- where tunas have been caught. Diurnal and nocturnal detections presented themselves in very different ways. Daily, they formed small schools, usually arranged in layers and, at 100%, constituted of adults *Vinciguerria nimbaria*, according to pelagic trawling (Fig. 6a). Nightly, the detection is more classical and appears as an almost continuous thin layer (10 to 15 meters approximately) situated rather at the same depth as the day-time schools, and containing large schools or swarms (Fig. 6c). Those swarms, sampled by pelagic trawling, were mainly composed of *V. nimbaria* : on an average 50% of captures, but certainly more into the swarm itself. According to temperature profiles carried out with a CTD probe, where those detections were present, the schools of Vinciguerria appear to be located essentially around the bottom of the thermocline (Fig. 6b).

However, previous observations made in the same zone, have shown that the schools of *Vinciguerria* were not exclusively seen at the level of thermocline, but were moving around within the surface layers during the day-time. It seems that, at the end of night, the *Vinciguerria* go up to the surface very rapidly towards the surface where they scatter, and then, at the very early morning, form schools which will go down towards the thermocline during the morning (Fig. 7); then, they stay there the rest of the time.

An observation of analogue behaviour has been done to a closely related species, *Maurolicus muelleri*, along the South African coasts. But unlike the *Vinciguerria*, they continue to go down in the morning towards the deeper part (Armstrong and Prosch, 1991).

In conclusion, those acoustic observations identified by trawlings, have clearly shown that the *Vinciguerria* schools could stay in the day-time at a depth accessible for tunas.

[1]The stomach content of tuna caught in the liberian area (november 1992) was represented at 73% by *Vinciguerria nimbaria*, 14% by other fishes, 11% by phronims, and 2% by cephalopods.

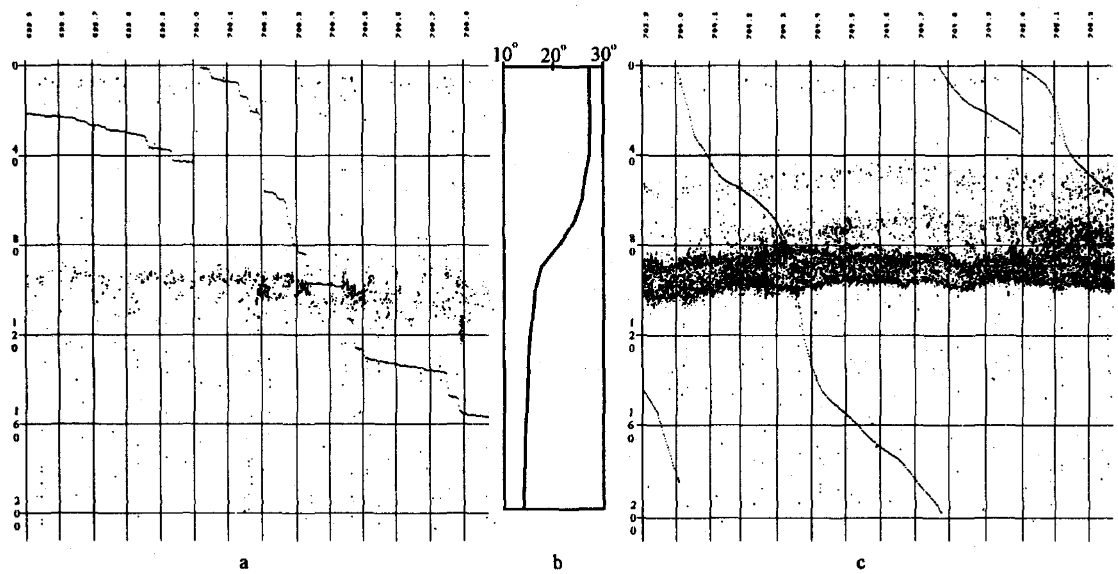

Figure 6 **Typical detection of *Vinciguerria nimbaria* and thermal structure : a/ daylight echogram showing small schools; b/ thermal profile, showing a well-marked thermocline between 60m and 90 m depth; c/ night echogram showing a scattering layer with swarms inside, at the bottom of the thermocline, about the same depth as during daytime.**

Gambar 6 **Keberadaan *Vinciguerria nimbaria* dan struktur suhu : a/ Echogram siang hari memperlihatkan kelompok-kelompok kecil ikan ; b/ penampang tegak suhu memperlihatkan lapisan termoklin pada kedalaman 60-90 m; c/ Echogram malam hari memperlihatkan adanya lapisan hamburan dengan pengelompokan didalamnya, dibawah lapisan termoklin pada kedalaman yang relatif sama pada siang hari.**

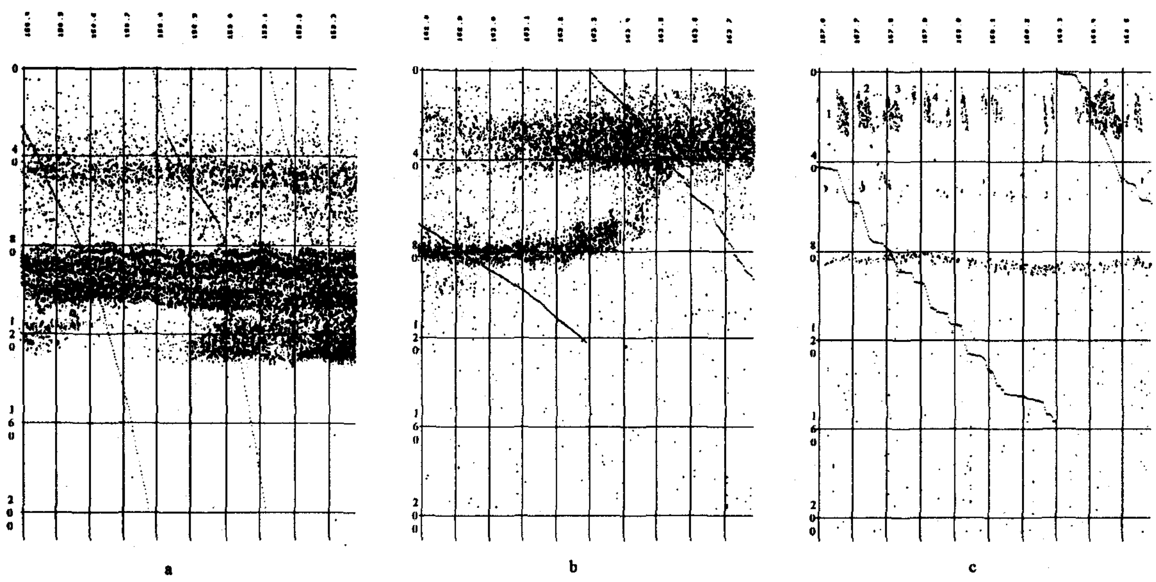

Figure 7 **Echograms showing the behaviour of *Vinciguerria* at the end of a night dark, dawn and early daylight).**

Gambar 7 **Echogram memperlihatkan perilaku *Vinciguerria* pada periode akhir malam hari menjelang pagi hari.**

In order to control more directly the behaviour of tunas and their capability of diving, 2 tunas have been marked acoustically during another cruise made in the same zone and at the same period, in November 1994 (MICROTHON 06). The mark consists of a small transmitter fixed on the fish's back and it can work for several days. It transmits, at regular intervals, the swimming depth of the fish : in addition, the orientation of the hydrophone, fixed on the ship or towed in a paravane, allows to determine approximately the direction of the fish compared to the ship. A skipjack and a yellowfin, both of about 50 cm of fork length (FL), were marked in the course of this experiment. Both of them did not go deeper than 80 meters, except a few very fast divings till 110 meters for the skipjack, and a little bit less for the yellowfin. The latter has shown a rather strange behaviour, going up and down regularly within the surface layer. Concerning the skipjack, it stayed much more stable and remained more or less within the range 50 to 70 meters depth during the 22 hours of its observation. A thermal profile shows that the thermocline was situated between 50 and 100 meters, with a strong gradient from 50 to 80 meters (Fig. 8).

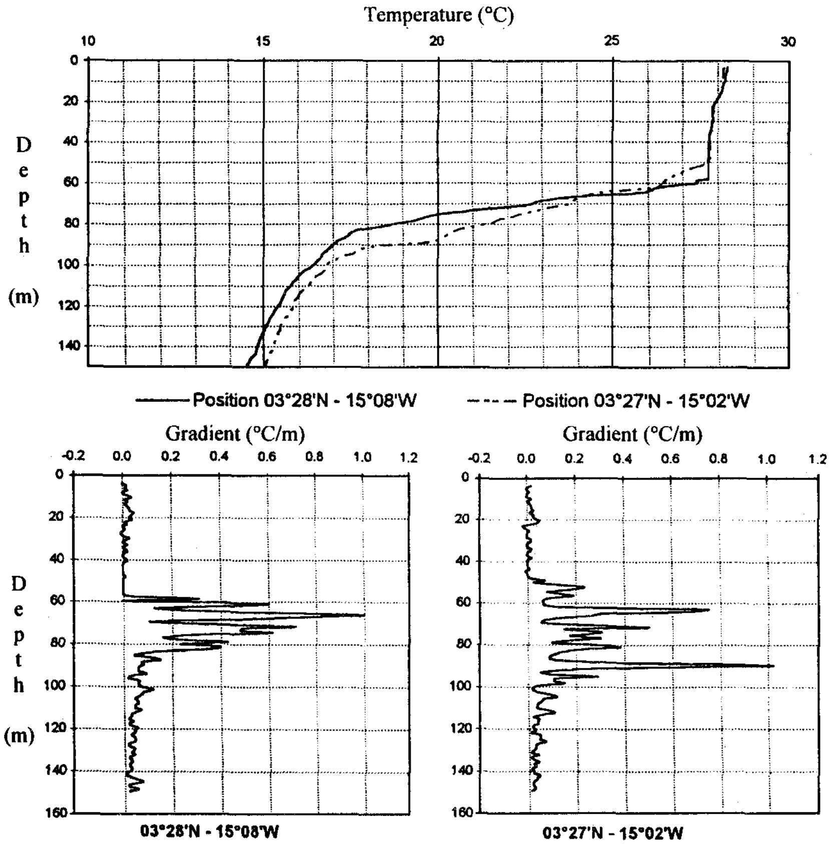

Figure 8 **Thermal profiles just before and after the acoustic tracking of the skipjack. Look at the very strong gradient between 60 and 80 m depth.**

Gambar 8 **Penampang tegak suhu sebelum dan sesudah jalur akustik tuna. Terlihat adanya gradien yang sangat nyata pada kedalaman 60-80 m.**

In the day-time, the skipjack was particularly stable and moving around between 60 and 70 meters, where the schools also present (Fig. 9). Other skipjacks caught in the same time than the marked fish, had their stomach full with *Vinciguerria*. It seemed then clearly that tunas present in that region, at least skipjacks and young yellowfins, stay in the supra-thermocline layer and by that way cannot reach the deep layers where the major part of the meso-pelagic organisms is located during day-time. But on the opposite, they feed actively on some meso-pelagic organisms which stay at day-time stay in the surface layer and particularly at the level of thermocline. Among those mesopelagic species behaving "abnormally" at least at certain periods, leaving their diurnal migrations, the fish Vinciguerria is largely in majority, but other species have shown the same behaviour and feed also tunas : notably the fish *Maurolicus muelleri*, a closely related species of *Vinciguerria*, and *Euphausia gibboides*.

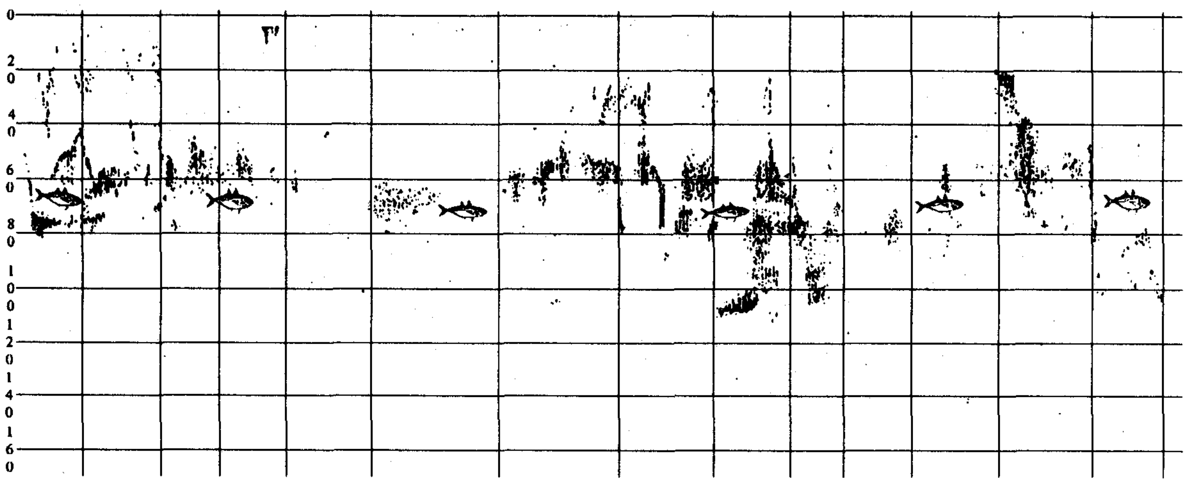

Figure 9 Echogram showing the schools with the track of the skipjack superimposed on it. Time 8:30 to 9:00 a.m.

Gambar 9 Echogram memperlihatkan *superimpose* antara kelompok ikan dan jalur tuna. Waktu : 8:30 - 9:00 a.m.

PACKING DENSITY OF SCHOOLS AND ITS IMPORTANCE FOR TUNAS

Acoustics can allow to evaluate the density of schools in number and weight, to estimate their volume and the biomass of fish that constitute them. For that purpose, we have to know the acoustic response of 1 fish, that is its Target Strength (TS), which depends of the fish size. There are several methods to measure it, one of the most pertinent being to measure the acoustic response of fishes kept alive in a cage or immobilized by thread. But those methods can not be applied to very small size fishes, fragile and moreover generally living rather deep. In this case, are arising problems related to the volume variation of the swimbladder. We have been able to realize a few TS measurements with a Dual-Beam echo-sounder that enables to calculate TS of single fish by comparing the echoes received on two beams presenting very different directivities.

The major problem with these *in situ* measurements is that we ignore the actual size of the fish being measured. However in the case of the *Vinciguerria*, there was a single mode in the size distribution, which can be accepted as the average size of the fishes. We could have then determined that the fishes of an average size of 47.5 mm of length of Standard Length (that is to say, 55.5 mm of Total Length) and a weight of 0.85 g presented an average TS of -59 dB (Fig. 10). That value is very close to another one calculated from an equation established for sprat, a small fish of very much like morphology, at the same frequency (120 kHz) and which is TS = -58,2 dB (Degnbol *et al.*, 1985).The other parameter that we need, in order to evaluate the average density of a school, is the average reverberation or volume scattering (Sv) expressed in dB per m^3. Average volume scattering for various types of schools is reported in Table 1, which contains also a few average geometric characteristics of those schools. The average Sv of schools that are supposed to be *Vinciguerria* has been found equal to -52,6 dB. The corresponding average packing density, d, is therefore calculated as follows :

$d = 10^{[(Sv-TS)/10]}$ =3.6 fishes per m^3,that is in weight : 0,85 g. x 3,06 g/m^3

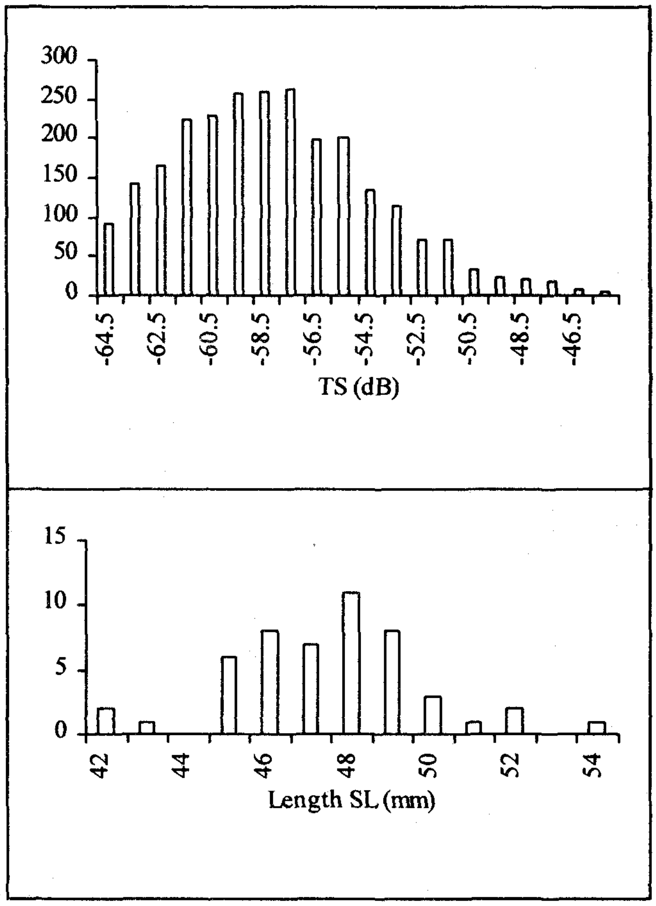

Figure 10 **Up : Target Strength (TS) histogram of assumed *Vinciguerria* from Dual Beam measurements. Down : size histogram of *Vinciguerria* caught in the same area.**

Gambar 10 **Atas : histogram besar ukuran (*Target Strength*) dari *Vinciguerria* dari pengukuran bim ganda. Bawah : histogram ukuran hasil tangkapan *Vinciguerria* pada daerah yang sama.**

Table 1 **Mean characteristics of different types of aggregations.**

Tabel 1 **Rata-rata karakteristik beberapa tipe kelompok ikan.**

Position	Type	D/N	Rv+ (dB)	Hmax (m)	Lmax (m)	Nb
Thermocline	Dense	N	-53.5	18 (18)	1800 (Est)	93
	Diffuse	J	-57.4	8 (4)	49 (24)	28
	Dense	J	-52.6	8 (5)	121 (209)	84
Surface layer	Diffuse	J	-58.7	10 (9)	66 (90)	56
	Dense	J	-52.4	23 (12)	128 (88)	12
	Very dense	J	-49.2	8 (1)	76 (14)	3

Rv+ : volume backscattering strength; Hmax : maximum height; Lmax : maximum length.
Nb : number of aggregations taken into account; D/N : day/night; Est : estimated value; standard deviations in brackets.
(+ Rv : volume backscattering strength; H max : tinggi maksimum; L Max : panjang maksimum; Nb : jumlah kelompok ikan terhitung; D/N : rasio siang malam; Est : nilai dugaan; simpangan baku di dalam kurung.)

That density may appear weak : it is true in comparison with schools of pelagic fishes (anchovy for example). However, that density corresponds, in terms of quantity, with Myctophids aggregations as they were observed during undersea diving. Thus, it has been estimated that the distance between 2 fishes, in such aggregations, was within the range from 2 m to 15 meters, which represents a density of 0.18, and therefore a number of 418 fishes per m^3 (Auster *et al.*, 1992). Another observation deriving from diving, mentioned 2.5 fishes per m^3 for a species of Myctophids within an aggregation, against 0.03 fish per m^3 beyond the aggregation.

The average dimensions of the « dense » schools in the thermocline attributed to Vinciguerria, are 120 metres long and 8.3 metres high. If we assume that these schools have a cylindrical form, we obtain an average volume of 93,870 m^3. This corresponds to an average school weight of 287,244 g or 287 kg. Knowing that the average weight of a 50 cm long tuna is about 2.5 kg and that, each day it eats 5% of its weight (see above), that is to say 125 g, such a schools, theoretically, can be sufficient to feed about 2,300 tunas during 1 day.

CONCLUSION

The main objective of this paper was to show how acoustic could be a precious tool to study predator-prey relationships because it allows to know the spatial structuration of preys and to study the behaviour of predators with regard to that structuration. But acoustics allows also to estimate the relationships between predator and prey abundances, at various spatial scales. Lastly, this method enables us to discover phenomena which cannot be seen through other ways, such as the « unexpected » behaviour of *Vinciguerria*, which certainly brings a major contribution to the concentration of tunas in that region.

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DISCUSSION

(Chairman Dr. FATUCHRI)

Dr. NURZALI

Q : - If we know the size of the prey stock, can we deduce the size of the predators ?

A : - Tuna is a migrating fish and in this area we found only a part of the stock. Tuna spend one part of their life in this region. Indeed, it is possible to predict the variations of the tuna stocks, from the variations of the prey stock (*Vinciguerria*), if we know the relationship between preys and predators.

Dr. NAINGGOLAN

Q : - My question is about the calibration of the equipment. Is it necessary to measure the beam pattern of the Dual-Beam transducer before Target Strength measurement or you just accept and apply the parameters given by the manufacturer ?

A : - It is always possible to do such calibration in the field. Actually, it needs work and time to perform this checking and it requires a special place with ideal condition to measure. The Project team used the manufacturer's data for the transducer's beam pattern. According to the directivity, I do not think that directivity changes with the time. The team regularly made calibration on the Source Level and the Sensitivity of the transducer and the equipment.

Dr. PASARIBU

Q : - Based on your own experience, which system do you prefer to use ? The Dual-Beam system or the Split Beam system ?

A : - Ten years ago, I would have said that Dual-Beam was better as the technological result of long experience. At the very beginning, the Split Beam encountered many problems. The Split Beam is nowadays better because this technique is less affected by the noise. Both systems have been improved. They can provide the possibility to track the fish. You can get, in this way, more precise Target Strength measurements.

Q : - In term of equipment, we must consider the problem of the fish orientation and localization in the beam. Can we be sure of the localization of the fish, using the Dual-Beam system, for example ? I feel that it is still questionable. For the Split Beam, it is said that the process based on the phase difference principle gives the orientation of the fish within the acoustic beam. There is not equivalent ability in the Dual-Beam system.

A : - The Split Beam allows you to know the true geographical position of the fish. This position is referred to X and Y coordinates related to the axis of the transducer and a third coordinate that we can call Z related to the transducer's face, that gives you complete positioning of the fish in the space. In the case of the Dual-Beam, the difference between the responses of the narrow and wide beams is simply used for the correction of the directivity. This technique does not localize the target in a coordinate system. The single information you can get, besides the directivity correction, is the depth of the target which, therefore, can be anywhere on a circle without any more detail to specify where its location is.

For precise measurement, it is interesting to track the fish. You can see if the fish is moving by following the Ts variations. In this case, nevertheless, neither the Dual-Beam, nor the Split Beam will give you the true TS value because both do not take into consideration the fish's attitude and its proper directivity neither. I will recommend to use the Split Beam for accurate measurements. About the dynamics of -160 dB praised by the manufacturer of the Split Beam, we can say that it is a nonsense and just a commercial promotion. Both methods give bias. In congress of Acoustics, we talk about these biases. It remains difficult for these systems to distinguish between fishes at the same depth.

As you can see in many examples, we often meet, at sea, very wide distribution that limits the use of the Dual-Beam and the Split Beam systems. You must be careful when using direct measurement with a very nice output supplied which gives you an average Target Strength or Backscattering Cross Section. Very often, the distribution is not very accurate; it is therefore better to extract the modal class, if possible and certainly more realistic than the average value.

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