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Acoustic Selectivity in Tropical Tuna (Experimental Purse-seine Campaign in the Indian Ocean)

by
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1. INTRODUCTION

The target species of Spanish tuna purse-seiners are Tropical tuna: yellowfin (*Thunnus albacares*) and skipjack (*Katsuwonus pelamis*), the secondary species being bigeye (*Thunnus obesus*). The fleet operates in the intertropical waters of the three oceans, and annual catches amount to around 250,000 tonnes.

Tropical tuna caught by purse-seine are mainly obtained through two types of set: over free schools and over artificial floating objects. Furthermore, a characteristic fishery has been developed in the Pacific Ocean in association with yellowfin and dolphins.

Fishery over free schools or with natural floating objects was traditional until the appearance of fishing over artificial floating objects, which evolved between the mid eighties and early nineties. Currently, catches obtained with either mode of fishing are around 50% (considering the Atlantic, Indian and eastern Pacific Oceans). Although fishing over floating objects has increased seine efficiency and, subsequently, the catches (principally of skipjack), the large-scale use of objects has had several effects on the fishery that were not customary until objects were introduced: on the one hand, the capture of numerous accessory species and, on the other, the presence and capture of specimens of young tropical yellowfin and bigeye. The latter is not a target species and is barely caught when the fishery is performed over free schools.

The impact of this mode of fishing on the ecosystem and the exploitation profile that it generates have meant that fishing over floating objects marked with buoys is a cause for concern for the various RFOs responsible for assessing and managing tuna stocks, and in whose sphere recommendations have been gathered regarding the need to improve knowledge about this mode of fishing, with a view to assessing its real impact on stocks and to drafting appropriate management measures.

From the perspective of resource management and given the continuous increase of fishing pressure on such resources, the General Secretariat of Maritime Fisheries in Spain, the Albacora company, and the Spanish Oceanographic Institute (IEO) have embarked on a line of research, through an experimental fishery Pilot Action, aimed at determining the size and constitution of schools by species and size prior to fishing, with a view to establishing guidelines and criteria that will enable more selective fishing regarding the size and species caught.

2. OBJECTIVES

The objectives planned for this Pilot Action were:

- Identification of the different species and sizes of tuna using acoustic methods,
- Behaviour of tuna and accessory species when aggregating around floating objects.

3. MATERIAL AND METHODS

Data was collected for six months, from 15 May to 15 November 2005, and the working area was the western Indian Ocean. The scientific follow-up of the Pilot Action was undertaken by the tuna team from the Oceanographic Centre in the Canaries, while the Oceanographic Centre in the Balearics analysed the echo sounder data.

3.1. Vessels

Acoustic data was collected on a Spanish tuna purse-seiner and a support vessel, whose characteristics are given in Table 1.

3.2. Acoustic data and acoustic equipment

The vessels were fitted with the following equipment:

The tuna purse-seiner was supplied with:

- 1 SIMRAD SP90 scanning sonar,
- 1 SIMRAD ES-60 echo sounder with GPS feed, working with 3 frequencies (120, 50 and 200 kHz). Frequency 120 directed towards the seabed (operating frequency) and the other two frequencies with the transducer located on one side of the hull, aimed at an oblique angle (we have not worked with data from the latter two),
- Radio buoys,
- Radio buoy control monitors,
- WILSON connexion.

The support vessel was equipped with:

- 1 SIMRAD SP90 scanning sonar,
- 1 SIMRAD ES-60 echo sounder with GPS feed with one frequency (120 kHz) (Figure 1),
- Radio buoys,
- Radio buoy control monitors,
- WILSON connexion.

3.2.1. Echo sounder

Data collection using the ES-60 echo sounder was mainly undertaken by the support vessel, while the purse-seiner was responsible for fishing for species identification.

The echo sounder's raw files (*.raw) were obtained using the system software (ES-60). The files were processed using the acoustic data post-processing programme *Sonar Data Echoview.*

3.2.1.1. Protocol for echo sounder data collection at sea

The working plan designed for data collection included the decision to deposit objects by following the fleet's customary procedures.

The support vessel would follow up one of the objects by remaining alongside for at least two days, and during this time, the observer would decide whether to continue or to move to another object. On arriving at the object, the support vessel would undertake three double transects in different directions, as close as possible to the object in question (Figure 2). This operation would be repeated three times by day and twice at night in order to observe the evolution of the fish shoal. All the objects visited were to be sampled, with or without tuna aggregation.

In the event of no set over a sampled object, it would be left and revisited seven to fourteen days later. The working range was fixed at a depth of 0 to 200 m. While moving between objects, the vessel would carry out systematic surveys to measure plankton that would serve as a basis on which to assess the wealth of the ecosystem.

The purse-seiner had to perform sets over several objects, when appropriate; however, a minimum number of associated sets with the support vessel was decided. These sets were to be undertaken immediately after the support vessel had explored the school. Two sets per week for the six months' duration of the experiment was the minimum number of sets—48 associated sets were to be obtained by the end. Half (24 sets) would be subjected to supersampling on land. These sets should not produce discards and should not be taken into consideration if fish had managed to escape. The purse-seiner would also collect acoustic data, on arrival at a concentration of tuna and during the fishing operation.

For each set, observers estimated the accessory catches and performed a random sampling for size on the commercial catch. They also sampled accessory species, giving priority to turtles, followed, in this order, by sharks, swordfish and other fish.

3.2.1.2 Setting

An echo sounder must be duly calibrated before acoustic data of a certain species can be analysed. Although it is advisable to adjust the settings before work begins for this kind of study, on this occasion, calibration was done halfway through the experiment, when both vessels were in port. Both ES-60 echo sounders were successfully adjusted.

3.2.1.3 TS determination

Three thresholds were considered for TS estimation: -40, -38 y –36 dB. Threshold –38 dB was based on previous studies undertaken over tuna in French Polynesia (A. Bertrand thesis). These thresholds enable echo elimination from noise (undesired→hydrodynamic) or from small species, such as bait or small pelagics, as seen in Figure 3. In this figure, where no fish appear, the bottom left-hand window shows a histogram (grey bar) belonging to hydrodynamic noise.

Mean TS data for each fishery were used to create tables to show the dominant species (number of specimens), average size (cm) and TS obtained for each of the three thresholds, which produced four different parameters (K1, K2 , K3 and K4) explained below:

- K1: in this case the mean TS value was based on the average size from the species sampling (e.g. skipjack) performed on board or on land.

TS = 20 log L + K (general formula).

$K1 = TS\_{mean} - 20 \log L\_{average\ size}$. (finding the value of K1)

- K2: the average size used to obtain mean TS was taken from the category of the dominant species in the catch. This average size was calculated from the mean weight of the category, by applying the size-weight ratio for the species.

- K3: this value is obtained when changing the value obtained in K1 to 25 log. Midttum (1984) proposes this ratio for physoclistic fish like tuna:

TS = 25 log L + K.

$K3 = TS\_{mean} – 25 \log L\_{average\ size}$

- K4: changing the K2 value to 25 log.

The reason for calculating K3 and K4—in other words changing to 25—is simply to obtain data comparable to other measurements.

3.2.2 Sonar

The omnidirectional sonar used was the SIMRAD multibeam sonar, model SP90 (Figures 4a and 4b). This type of sonar is commonly used by the tuna fishing fleet and often by vessels fishing for small pelagics. This type of device generally detects large schools of fish.

Omnidirectional sonar data were logged directly on board, thanks to recent technological advances included in the latest generation sonar, which facilitate direct access to the acoustic system signal. Signal access is reached in two ways: through raw data leaving the central unit and through the screendump—a graphical representation (image format, generally Windows bitmap). Figure 5 shows a summary diagram of the setup made on board the purse-seiner and support vessel.

3.2.2.1 Protocol for sonar data collection at sea

On arrival at an object, sonar and echo sounder data should be collected simultaneously for as long as possible, before commencing star-shaped sampling for echo sounder data acquisition.

Once star-shaped sampling has begun for echo sounder data collection, the sonar must remain switched off for the entire duration of the process, due to interference between both devices.

Sonar data analysis programme

INFOBANCS 2.0 (Brehmer and Gerlotto, 2000) was the programme used to analyse omnidirectional data for the Pilot Action. This programme processes video information from the sonar. Analysis is standardised and compares data acquired from several fisheries or object searches, suppressing or minimising measurement errors induced by the sonar operator (Brehmer and Gerlotto, 2000). Apart from compatible measurements, this programme is interesting for obtaining an identical sampling protocol. All distance calculations are based on classic Euclidean formulas. In our work, we study the kinematics of pelagic fish schools and echo-trace characteristics, in relation to commercial fishing results (Figures 6 and 7).

3.3. Observers

Scientific observers were trained beforehand by the IEO in systematic and methodological aspects, and in the use of specific software for entering observer data from the tuna purse-seiners.

Furthermore, two courses—one in La Coruña port and another on board one of the vessels participating in the project—were given by qualified personnel so that observers could learn to handle acoustic instruments.

4. Results

Tables 2, 3 and 4 give the distance covered, the number of observation days and the number of grid squares visited, per month, for each of the purse-seiners. Tables 5 and 6 show the total distance covered and the observation days, per month, for both support vessels. These tables help to situate the time-space strata studied during the project.

4.1 Echo sounder

The only acoustic data used in this study were taken from the support vessel, since data collected by the purse-seiner during fisheries was not apt for our purposes.

11 associated fisheries (Table 7)—those performed over an object acoustically sampled beforehand—were carried out in September and October, between parallels 5ºN and 6ºS and meridians 45º - 60º E (Figures 8 and 9).

Of these 11 associated fisheries, only six were sampled using the echo sounder just before fishing, as pointed out in the protocol (see methodology) (Table 8). One of them (set 53) had a defective echogram, which could not be used. In the 5 remaining fisheries, acoustic data from fish aggregation under the object were collected by the support vessel in three different samplings (morning, afternoon and night), the day before the fishery. In three of these sets, sampling was performed in the direction of the current (Figure 10), without three double transects around the object. The following day, the object was fished for species identification at the same time as some sampling took place.

When the support vessel performed acoustic sampling over an object, the tuna shoals responded in several ways. Sometimes, the fish dispersed (Figures 11, 12, 13 and 14). These figures show four consecutive vessel runs over the same object. The fish grouped beneath the object slowly dispersed after each run until they disappeared. Other behaviour observed in this study was that the fish—normally detected in a 60 metre radius around the object—followed the vessel when it passed overhead for a distance of around 500 metres (Figure 15). Finally, on other occasions the fish did not move from where they were detected.

Skipjack was the most abundant species in specimen numbers for 9 catches of these associated fisheries, and yellowfin for 1 (Table 9).

When analysing the maximum and mean TS for these regions, the maximum TS was seen to be influenced on occasions by other accompanying species (sharks, etc.), which modified the results. Therefore, we opted to work with the mean TS.

Using the analysis of the mean TS detected by echo sounder, we observed that the TS detected do not exceed –32 dB when the most abundant species caught is the skipjack (Figure 16), as shown in the histogram that appears in the figure.

The average sizes of the skipjack catch samplings performed on board and on land are very uniform. Almost all fisheries have an average size of around 51 cm in total length (Table 10), except for two (sets 33 and 55) that give somewhat larger average sizes (56 and 58 cm).

In addition to using the average size of the catch sampling, we also used the average sizes corresponding to the commercial categories of the species (depending on the mean weight) that appeared in the catch. We applied the size-weight ratio of each tuna species to calculate average size (Tables 11, 12, 13 and 14).

When yellowfin is the majority species in the catch, the TS logged in the echo sounder histogram give higher values (Figure 17), exceeding –32 dB, owing to the larger size of this species' specimens. In the figure, we can see how echo traces corresponding to this species are located between 50 and 150 m depth.

By applying algorithms to determine the TS of a species, we obtain the values shown in Table 15, where we can observe the results of the TS obtained for the 10 sets analysed for the three tuna species under study.

By taking the situations of –40 dB (regarding the threshold) and the average size of the species sampling undertaken on board as optimum—changing to 25 log (K3)—we obtain the following TS for skipjack:

$$TS\ skipjack = 25 \log L - 73.72$$

We have insufficient data for the other two species—only one set for each of them—to deduce a final TS.

4.2 Sonar

Data obtained

3 minutes is the average sonar log (ranging between 30 seconds and 37 minutes). Several sonar images could not be exploited as they presented numerous parasites or strong interference from other acoustic instruments. However, most data are exploitable (Figures 18 and 19).

Data analysis

The data analysed focussed on associated fisheries between the purse-seiner and the support vessel. These criteria restrict the analysis to 11 selections, of which 8 cases have been processed (Table 16), since the fisheries performed on 07/09/2005 and 08/09/2005 are lacking in sonar data.

School size and acoustic intensity

Main sonar detection enables two kinds of analysis that describe the length or width of the beams, as well as the acoustic intensity of the encoded return signal, in three modes (1: weak, 2: average, 3: strong). A graph with three variables has been created for each school. All morphological observations have been decomposed for an elementary statistical analysis: mean calculation, minimum and maximum value. Results are given in Table 17 (Figure 20 contains an example).

School swimming speed

A Euclidean calculation—an orthonormal location composed of the change between two geographical marks—is used to correctly measure fish school speed aided by sonar images. There is no complete sequence of sonar image from the purse-seiner with these two marks. On the contrary, the sequence of selected sets performed in association by the support vessel (Table 7) is perfect. Figures 21 and 22 show fish school displacement depending on vessel position. For the first, calculations for this tuna school (set 23: skipjack, 49.76 cm) were made over 19 observations undertaken in 191 seconds of observation. School exploration speed (from position 1 to position 19) is 0.26 $m.s^{-1}$, the mean instant speed observed in a time interval of 10 seconds is 1.84 $m.s^{-1}$ (minimum 0.04 $m.s^{-1}$, maximum 4.19 $m.s^{-1}$ and standard error 1.29). The route of the school shows no specific direction; however, it does not follow vessel drift (surface current). Characteristic images of fish schools are given in Figures 23 and 24.

5. DISCUSSION

5.1 Echo sounder

Protocol for data collection: Data collection at sea explained at the beginning of this report (obtaining acoustic logs (echograms) from objects using the echo sounder to immediately proceed to fishing the school collected under the object) has only been achieved on very few occasions, since vessel skippers complained of fish fleeing when the vessel passed over them.

The protocol was established by taking the acoustic techniques used for detecting small and medium size pelagics (sardines, anchovies, mackerel, etc.) by way of example. In these cases, after obtaining logs or echograms from the shoals of these species in a specific area (e.g. the continental shelf in the Spanish Mediterranean), the shoals are fished for species identification.

Since this was the first time that acoustic techniques using commercial vessels and over floating objects were applied to large pelagics such as tuna, we attempted to find the best way of collecting useful acoustic data for analysis without hindering catch success. This led to some flexibility when applying the data collection protocol.

For this reason, the number of associated sets obtained at the end of this Pilot Action was very low (11 sets) in comparison with the minimum number planned (see section on methodology).

The number of sets in which acoustic star-shaped sampling was undertaken over the object were also very limited, since skippers opted to sample in the direction of the current, without bothering the fish.

Acoustic data collection speed: The initial sampling protocol (see methodology) specified that acoustic data should be collected at a speed of 8-9 knots. However, the data were taken at a lower speed—3-4 knots. The proximity of the transducer to the vessel hull caused hydrodynamic noise (bubbles from the hull that interfere with the active surface of the transducer), which masked fish echo traces if the vessel travelled too fast. On occasion, this acoustic tracking speed caused fish to disperse or follow the vessel, which meant that the skippers did not allow the support vessel to operate before performing the set.

The acoustic data obtained at this speed (3-4 knots) were valid for analysis. We do not know, however, whether data collection at greater speed (8-9 knots) would affect species behaviour.

SIMRAD ES-60 echo sounder: The model of echo sounder chosen for this Pilot Action proved to be a good instrument for this kind of experiment. It is a low cost, user-friendly echo sounder that allows for data files to be obtained in *.raw format and then processed in the same way as data obtained using more sophisticated scientific echo sounders.

In this Pilot Action, the sounders were well calibrated, which meant that no further modification to the data analysed was required.

Operating frequency of 120 kHz: the choice of operating at this frequency with a split beam transducer during data collection for this Pilot Action has certain advantages, if we consider that both the size of the transducer and the cost are lower when compared, for example, with a frequency of 38 kHz. This makes it easy to install in a commercial fishing vessel, without too many complications.

As for the suitability of this frequency for detecting the three species of tuna under study (skipjack, yellowfin and bigeye), in the absence of data or echograms taken at other frequencies, we cannot determine if it is a better or worse option for species detection. In experiments carried out with small and medium size pelagics, it has been proven that species with a natatorial bladder, such as the sardine (*Sardina pilchardus*) or anchovy (*Engraulis encrasicolus*), are better detected with a 38 kHz frequency, while species that have no natatorial bladder, such as mackerel (*Scomber scombrus*), are better detected with a 120 kHz frequency. In this case, of the three tuna species studied, two have a natatorial bladder (yellowfin and bigeye) and one does not (skipjack). For this study, only data obtained at a frequency of 120 kHz were available, but frequency 38 KHz might have been more convenient for yellowfin and skipjack. For this type of experiment, it would be ideal to work with multifrequency so as to compare echograms of the same species detected at different frequencies and deduce algorithms for species identification (virtual echograms), by means of a post-processing programme.

TS detection thresholds: the thresholds chosen for analysing the TS of these tuna species (-40, -38 and -36 dB) were based on the tuna bibliography consulted (A. Bertrand thesis). Studies about tuna undertaken in French Polynesia considered –38 dB as the ideal threshold for this kind of work. However, in the light of this study, we believe that we should reduce this threshold to –42 dB.

Echo trace analysis: in order to correctly identify the echo traces of the fish aggregated beneath an object detected with the echo sounder, we need to catch the fish. In this experiment, the fishing gear is the purse-seine and the fishing manoeuvre is performed over aggregations of fish detected beneath the object. The purse-seine gear used works from the surface to approximately 140 m depth. Consequently, we analysed the echo traces of the echograms that appeared at this range of depth (between 0 and 140 m).

The TS concordance of the species (K1 and K2) taken by different methods confirms that the estimation of species categories that appear in the catch is very close to reality.

In K1, the average size of the species used is that obtained in the size sampling performed on board and in port. K2 uses the average size of the most abundant category in the catch, obtained by applying the size-weight ratio.

Skipjack TS Determination: the species for which the highest number of associated sets was achieved, and subsequently the greatest volume of data for study, was the skipjack. The average sizes obtained from skipjack catch samplings were very homogenous (51 cm average size, except for one set, which gave 56 cm). Concordance of the TS obtained for sets of similar average sizes appears to confirm data validity. Moreover, it would be interesting to obtain TS values of catches containing different average sizes, in order to cover a wider range of sizes and thus deduce a more robust TS regression line.

Differentiation between skipjack and yellowfin using TS histogram: the preliminary findings of this study establish the possibility of using the echo sounder TS histogram to differentiate between skipjack (not exceeding –32 dB) and yellowfin specimens (exceeding –32 dB, since specimens are larger). However, we must emphasise that, in the situations studied in this Pilot Action, sizes of both species were very different: skipjack sizes gave averages from 51 to 57 cm, while yellowfin sizes showed averages of 1 m in length. Consequently, what we actually detected with the TS were different size ranges (small and large), rather than different species. We need to study the data in greater depth to obtain more conclusive results.

In the event of skippers choosing in future to use the TS histogram to differentiate between these two species (or sizes), they are advised to ask the manufacturer to calibrate the echo sounders before use.

None of the sets analysed gave bigeye as the dominant species, and consequently no analysis could be made to obtain specific TS values for this species.

5.2. Sonar

Data obtained from the sonar were generally high quality. Raw data was not exploited in the absence of an adapted programme, but the quality of the images compiled allows for a fine level of analysis. A programme for raw data analysis should be finished by the end of 2006 (Anonymous, 2003, 2004).

The absence of parameters is observed over some sonar images, giving rise to numerous problems when situation data are analysed, which would require improvement for future work. Moreover, a detailed follow-up of temperature and salinity would improve medium-dependant acoustic equations.

We observe that the automatic tracking mode is regularly used when the purse-seiner performs fishing operations. The information obtained by the kinematic analysis algorithm of the schools has yet to be analysed, but this analysis may well provide interesting information. Furthermore, a more in-depth analysis of school echo traces and size would be necessary. The aggregatory dynamics of the different species hampers the possible recognition of fish school echoes according to species.

These are preliminary results and do not offer all the acoustic information gathered throughout this Pilot Action.

In conclusion, we can say that this is the first time that a database of these characteristics has been included in a scientific project. This Pilot Action has demonstrated the possibility of using commercial vessels as logistic support for fishery research. Nevertheless, in the case of the tuna fishery and contrary to previous studies, fleets are modern (already equipped with the acoustic detection material required for our study case) and the number of vessels is limited. An ongoing register of fishing vessels would be possible in the short term, which would facilitate complete monitoring and numerous studies about the dynamics of tuna behaviour in particular.

We have classified the sonar echo traces according to two types of structure: large compact schools, apparently of skipjack, made up of several small schools where the distance from the nearest neighbour is lower than the maximum size. Furthermore, yellowfin schools appear to have a different structure to skipjack schools, though these results are very preliminary, since we have only worked with a single yellowfin school.

However, the analysis of school characteristics is insufficiently discriminatory for a final conclusion about the specific recognition of types of tuna school structures, unless it can be matched with an analysis of TS provided by the echo sounder. This apparently necessary work must remain for the future.

Finally, the possibility of creating an “expert system” seems possible, which would lead to improved selectivity within the tuna fishery, based on echo sounder and sonar data.

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Midttum 1984

	Year	Tonnage	HP	Lenght
Albacora Quince	1983	1507	4580	86
Albacán	1991	1516	4023	77
Taraska	1999	311	1400	36
Zahara Tres	2004	165	650	35

Table 1. Characteristics of the four vessels used in the Pilot Action

	May	June	Julay	August	Septeber	October	November	Total
Albacan	2980	4643	4846	5576	4137	4483	2644	**29309**
Albacora 15	1021	4147	3116	4974	5278	4408	2415	**25359**

Table 2. Distance covered (in nautical miles), per month, for both purse-seiners

	May	June	Julay	August	Septeber	October	November	Total
Albacan	21	30	31	31	26	25	22	186
Albacora 15	7	24	22	26	29	22	15	145

Table 3. Observation days for both purse-seiners.

	May	June	Julay	August	September	October	November
Albacan	18	50	44	57	26	49	15
Albacora 15	13	55	39	66	47	51	29

Table 4. Number of 1º x 1º grid squares covered by the two purse-seiners.

	Distance covered
Taraska	26871
Zahara Tres	28430

Table 5. Distance covered (in nautical miles) for both support vessels

	May	June	Julay	August	September	October	November	Total
Taraska	15	30	31	31	30	29	19	185
Zahara Tres	16	30	24	32	30	31	16	179

Table 6. Observation days, per month, for both support vessels

Set	Date	Time set (GMT)	Object type	Position	YFT (Tn)	SKJ (Tn)	BET (Tn)	*A. Thazard* (Tn)	Total
23	03/09/2005	3:36	FAD-P021	0º 00' S / 50º 01' E	12	86	2	0.03	100.03
24	04/092005	2:24	FAD-137S	0º 13' S / 49º 38' E	20	133	7	0	160
26	07/09/2005	2:26	FAD-021P	2º 44' N / 49º 46' E	4	64	1	0	69
27	08/09/2005	2:20	FAD-S137	2º 39' N / 49º 27' E	2	2	1	0	5
33	16/09/2005	3:38	FAD-S145	6º 36' S / 46º 30' E	25	5	0	0	30
38	19/09/2005	3:31	FAD-P174	0º 44' S / 46º 44' E	8	43	4	0	55
39	19/09/2005	7:55	FAD-P193	1º 01' S / 46º 50' E	4	13	3	0	20
52	27/09/2005	2:47	FAD-S194	6º 26' N / 54º 20' E	37	109	14	0	160
53	27/09/2005	7:08	FAD	6º 27' N / 54º 05' E	11	33.5	2	0	46.5
54	14/10/2005	2:22	FAD-P156	9º 24' N / 57º 02' E	6	14	10	0	30
55	15/10/2005	2:03	FAD-P180	9º 15' N / 57º 10' E	14	56	5	0	75

Table 7. Sets performed in association between the Albacora 15 and the Taraska during the Pilot Action and analysed in our study.

Nº SET	Date	Ecosounder sampling
23	03/09/2005	Previous day, three Ecosounder sampling morning-afternoon-night
24	04/09/2005	Previous day, three Ecosounder sampling morning-afternoon-night
26	07/09/2005	Previous day, three Ecosounder sampling morning-afternoon-night
27	08/09/2005	Previous day, three Ecosounder sampling morning-afternoon-night
33	16/09/2005	One sampling before set
38	19/09/2005	Previous day, three Ecosounder sampling morning-afternoon-night
39	19/09/2005	One sampling before set
52	27/09/2005	One sampling before set, in the current sense
53	27/09/2005	One sampling one hour before set
54	14/10/2005	One sampling before set, in the current sense
55	15/10/2005	One sampling before set, in the current sense

Table 8. Characteristics of the acoustic sampling undertaken by the support vessel prior to the sets.

SET	Date	% YFT	% SKJ	% BET
23	03/09/2005	7.9	91.6	0.5
24	04/09/2005	7.6	90.4	2.0
26	07/09/2005	5.8	93.5	0.7
27	08/09/2005	11.7	88.7	1.7
33	16/09/2005	83.1	11.0	5.8
38	19/09/2005	13.0	76.3	10.8
39	19/09/2005	14.2	66.4	19.4
52	27/09/2005	20.6	72.5	6.9
53	27/09/2005	20.2	78.0	1.7
54	14/10/2005	20.6	61.6	17.7
55	15/10/2005	10.6	85.5	4.0

Table 9. Percentage abundance based on the number of specimens sampled in the different catches for the target species.

SET	Date	Average lenght (cm) YFT	Nº indiv. sampl.	Average lenght (cm) SKJ	Nº indiv. sampl.	Average lenght (cm) BET	Nº indiv. sampl.	Total indiv. sampl.
23	03/09/2005	51.2	82	49.8	953	43.6	5	1040
24	04/09/2005	74.6	80	50.7	950	68.9	21	1051
26	07/09/2005	63.2	66	51.2	1072	46.4	8	1146
27	08/09/2005	44.7	21	52.0	156	50.3	3	180
33	16/09/2005	101.8	128	58.7	17	59.3	9	154
38	19/09/2005	87.1	140	50.7	822	60.1	116	1078
39	19/09/2005	70.9	36	51.1	168	61.4	49	253
52	27/09/2005	60.9	218	50.8	767	46.7	73	1058
53	27/09/2005	83.2	93	52.6	359	55.1	8	460
54	14/10/2005	53.9	64	50.4	191	65.2	55	310
55	15/10/2005	67.3	40	56.4	324	63.3	15	379

Table 10. Average sizes of the size distributions obtained in associated sets for the three target species.

Commercial category		Average weight (Kg.) category	Average lenght (cm) category
Inferior 1.8 Kg.	1	1	37.7
Superior 1.8 Kg.	2	1.9	45.9
Entre 1.8-4 Kg.	3	2.9	52.3
Entre 1.8-6 Kg.	4	3.9	57.2
Entre 4-6 Kg.	5	5	61.8
Entre 4-8 Kg.	6	6	65.3
Entre 6-8 Kg.	7	7	68.5

Table 11. Average sizes for the various commercial skipjack categories.

Commercial category		Average weight (Kg.) category	Average lenght (cm) category
Inferior 3 Kg.	1	2	46.7
Entre 3-10 Kg.	2	6.5	69.4
Entre 11-30 Kg.	3	20.5	102.1
Entre 3-30 Kg.	4	16.5	94.9
Entre 31-50 Kg.	5	40.5	128.3
Entre 11-50 Kg.	6	30.5	116.7

Table 12. Averages sizes for the various commercial yellowfin categories.

Commercial category		Average weight (Kg.) category	Average lenght (cm) category
Inferior 3 Kg.	1	2	45.0
Entre 3-10 Kg.	2	6.5	66.8
Entre 11-30 Kg.	3	20.5	98.3
Entre 3-30 Kg.	4	16.5	91.4
Entre 31-50 Kg.	5	40.5	123.5
Entre 11-50 Kg.	6	30.5	112.3

Table 13. Average sizes for the various commercial bigeye categories.

SET 23				
Category	YFT	SKJ	BET	Total general
1	6	6	2	14
2	5	-	-	5
3	1	-	-	1
4	-	80	-	80
Total	12	86	2	100
SET 24				
Category	YFT	SKJ	BET	Total general
1	10	3	4	17
3	4	-	-	4
4	6	130	3	139
Total	20	133	7	160
SET 26				
Category	YFT	SKJ	BET	Total general
1	4	3	1	8
4	-	61	-	61
Total	4	64	1	69
SET 27				
Category	YFT	SKJ	BET	Total general
1	1	-	-	1
2	1	-	1	2
4	-	2	-	2
Total	2	2	1	5
SET 33				
Category	YFT	SKJ	BET	Total general
1	1	-	-	1
2	4	2	-	6
4	14	3	-	17
7	6	-	-	6
Total	25	5	0	30
SET 38				
Category	YFT	SKJ	BET	Total general
1	2	1	-	3

Category	YFT	SKJ	BET	Total general
2	1	-	4	5
3	1	-	-	1
4	-	42	-	42
5	3	-	-	3
7	1	-	-	1
Total	8	43	4	55

SET 39

Category	YFT	SKJ	BET	Total general
1	1	2	1	4
2	2	-	2	4
4	-	11	-	11
5	1	-	-	1
Total	4	13	3	20

SET 52

Category	YFT	SKJ	BET	Total general
1	11	6	9	26
2	21		5	26
3	5			5
4		103		103
Total	37	109	14	160

SET 53

Category	YFT	SKJ	BET	Total general
1	1	3	2	6
2	3	2.5		5.5
3	4			4
4		28		28
5	3			3
Total	11	33.5	2	46.5

SET 54

Category	YFT	SKJ	BET	Total general
1	1	1	1	3
2	5	-	7	12
3	-	-	2	2
4	-	13	-	13
Total	6	14	10	30

SET 55

Category	YFT	SKJ	BET	Total general
1	1	1	1	3
2	5	-	1	6
3	3	-	3	6
4	-	55	-	55
5	5	-	-	5
Total	14	56	5	75

Table 14. Distribution of the tonnes caught in the respective commercial categories according to species for the eleven associated sets.

SET 23 SKJ	Average length (cm)	Threshold	K1	K2	K3	K4
	49.8	-40 dB	-68.53	-69.74	-77.02	-78.52
	% individuals	-38 dB	-67.14	-68.35	-75.63	-77.13
	91.6	-36 dB	-65.67	-66.88	-74.16	-75.66

SET 24 SKJ	Average length (cm)	Threshold	K1	K2	K3	K4
	50.7	-40 dB	-68.50	-69.55	-77.03	-78.33
	% individuals	-38 dB	-67.38	-68.43	-75.91	-77.21
	90.4	-36 dB	-66.12	-67.17	-74.65	-75.95

SET 26 SKJ	Average length (cm)	Threshold	K1	K2	K3	K4
	51.2	-40 dB	-69.68	-70.64	-78.22	-79.42
	% individuals	-38 dB	-68.23	-69.19	-76.77	-77.97
	93.5	-36 dB	-66.55	-67.51	-75.09	-76.29

SET 27 SKJ	Average length (cm)	Threshold	K1	K2	K3	K4
	52.0	-40 dB	-69.68	-70.64	-78.22	-79.42
	% individuals	-38 dB	-68.23	-69.19	-76.77	-77.97
	88.7	-36 dB	-66.55	-67.51	-75.09	-76.29

SET 33 YFT	Average length (cm)	Threshold	K1	K2	K3	K4
	101.8	-40 dB	-73.75	-73.15	-83.79	-83.03
	% individuals	-38 dB	-72.37	-71.77	-82.41	-81.65
	83.1	-36 dB	-71.08	-70.48	-81.12	-80.36

SET 38 SKJ	Average length (cm)	Threshold	K1	K2	K3	K4
	50.7	-40 dB	-67.67	-68.72	-76.20	-77.50
	% individuals	-38 dB	-66.51	-67.56	-75.04	-76.34
	76.3	-36 dB	-65.52	-66.57	-74.05	-75.35

SET 39 SKJ	Average length (cm)	Threshold	K1	K2	K3	K4
	51.1	-40 dB	-69.50	-70.49	-78.04	-79.27
	% individuals	-38 dB	-67.88	-68.87	-76.42	-77.65
	66.4	-36 dB	-66.12	-67.11	-74.66	-75.89

SET 52	Average length (cm)	Threshold	K1	K2	K3	K4

SKJ	50.8	**-40 dB**	-68.19	-69.22	-76.72	-78.00
	% individuals	**-38 dB**	-66.87	-67.90	-75.40	-76.68
	72.5	**-36 dB**	-65.82	-66.85	-74.35	-75.63
SET 54 SKJ	**Average length (cm)**	**Threshold**	**K1**	**K2**	**K3**	**K4**
	50.4	**-40 dB**	-67.39	-68.50	-75.90	-77.28
	% individuals	**-38 dB**	-66.79	-67.90	-75.30	-76.68
	61.6	**-36 dB**	-65.16	-66.27	-73.67	-75.05
SET 54 YFT	**Average length (cm)**	**Threshold**	**K1**	**K2**	**K3**	**K4**
	53.9	**-40 dB**	-71.38	-73.58	-80.04	-82.78
	% individuals	**-38 dB**	-70.17	-72.37	-78.83	-81.57
	20.6	**-36 dB**	-69.16	-71.36	-77.82	-80.56
SET 54 BET	**Average length (cm)**	**Threshold**	**K1**	**K2**	**K3**	**K4**
	65.2	**-40 dB**	-71.25	-71.47	-80.33	-80.59
	% individuals	**-38 dB**	-70.47	-70.69	-79.55	-79.81
	17.7	**-36 dB**	-69.25	-69.47	-78.33	-78.59
SET 55 SKJ	**Average length (cm)**	**Threshold**	**K1**	**K2**	**K3**	**K4**
	56.4	**-40 dB**	-69.33	-69.45	-78.08	-78.23
	% individuals	**-38 dB**	-68.34	-68.46	-77.09	-77.24
	85.5	**-36 dB**	-67.25	-67.37	-76.00	-76.15

Table 15. Different TS values obtained at various thresholds of the majority species for the different associated sets.

N° Set	Date	YFT %	SKJ %	BET %	Total Tm	Time GMT	Boat
23	03/09/2005	37,05	**61,52**	1,43	139,8	04:00	Taraska
24	04/09/2005	12,50	**83,13**	4,38	160,0	02:00	Albacora
26	07/09/2005	5,80	**92,75**	1,45	69,0	-	No data
27	08/09/2005	**40,00**	**40,00**	20,00	5,0	-	No data
33	16/09/2005	**83,33**	16,67	**0,00**	30,0	03:37	Albacora
38	19/09/2005	14,55	**78,18**	7,27	55,0	03:29	Albacora
39	19/09/2005	20,00	**65,00**	15,00	20,0	07:47	Albacora
52	27/09/2005	23,13	**68,13**	8,75	160,0	02:43	Albacora
53	27/09/2005	23,66	**72,04**	4,30	46,5	06:58	Albacora
54	14/10/2005	20,00	46,67	**33,33**	30,0	02:20	Albacora
55	15/10/2005	18,67	**74,67**	6,67	75,0	02:01	Albacora
Total	11	182,8	558,5	49	790,3	-	8

Table 16. Fishery selected for analysis with the sonar and echo sounder, with the catches of the three mains tuna species (YFT: yellowfin, SKJ: skipjack and BET: bigeye)

Date	Lw Medium	Lw Maximum	Lw Minimum	Cw Medium	Cw Maximum	Cw Minimum
03/09/2005	37.44	56.27	8.84	143.34	192.33	111.96
09/04/2005	35.81	65.65	4.07	100.82	185.92	57.17
16/09/2005	38.04	102.13	7.1	95.60	163.24	38.18
19/09/2005	58.95	121.52	14.11	121.51	265.64	49.39
19/09/2005(2)	57.08	120.63	15.88	206.32	550.28	77.18
27/09/2005	71.71	310.19	11.81	236.39	390.74	53.54
27/09/2005(2)	31.1	85.3	3.53	189	491.08	44.59
14/10/2005	67.13	121.52	29.19	119.48	240.18	74.52
15/10/2005.	149.02	324.95	2.37	211.97	380.10	40.52

Table 17. Size of the fish schools observed with the omnidirectional sonar for each day of fishing. The Lw and Cw values are taken from the length and breadth of the beam.

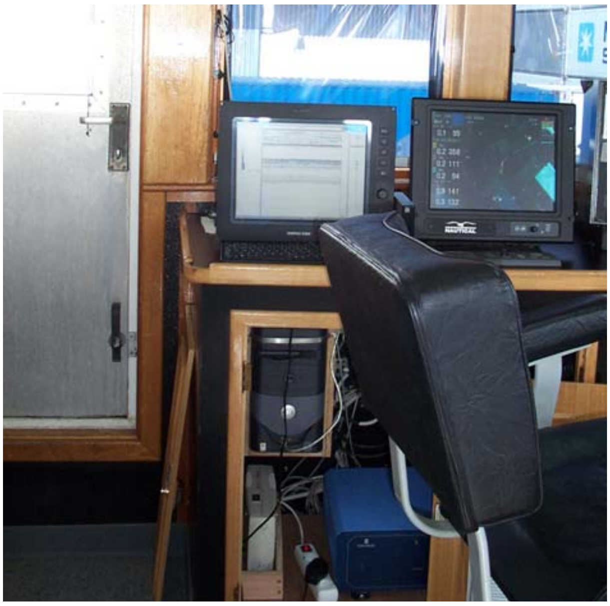


Figure 1. Partial view of the equipment installed on the bridge of the Taraska, and the SIMRAD ES-60 echo sounder with GPS feed.

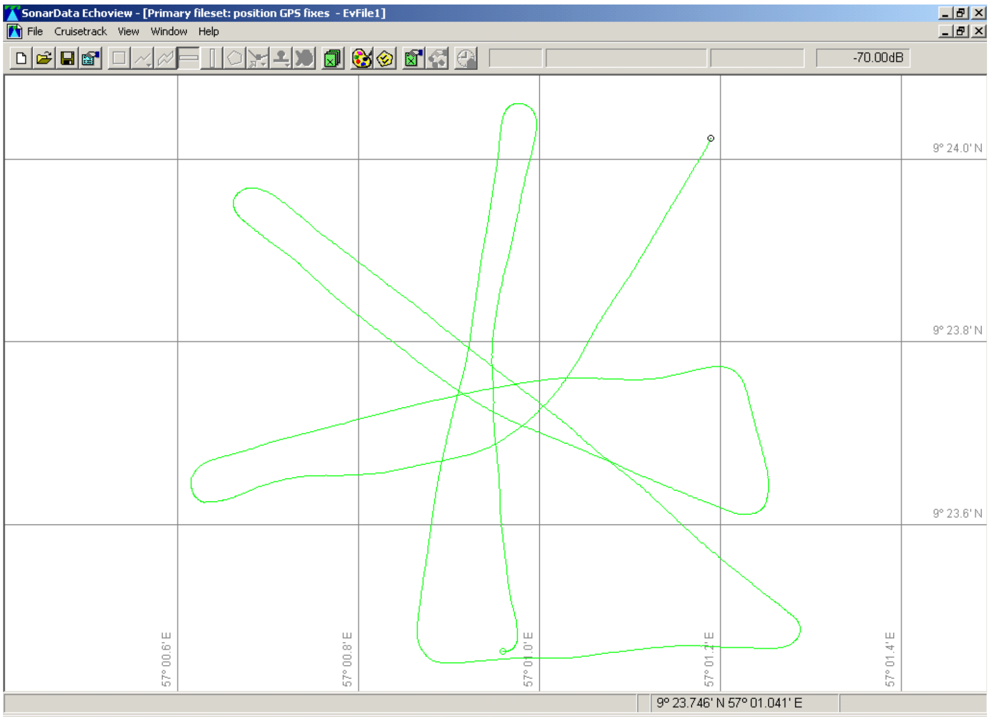


Figure 2. Example of a star-shaped sampling route over an object, performed by the support vessel. Three double rectilinear transects (return) and an approximate length of 0.3 nm around the object are observed.

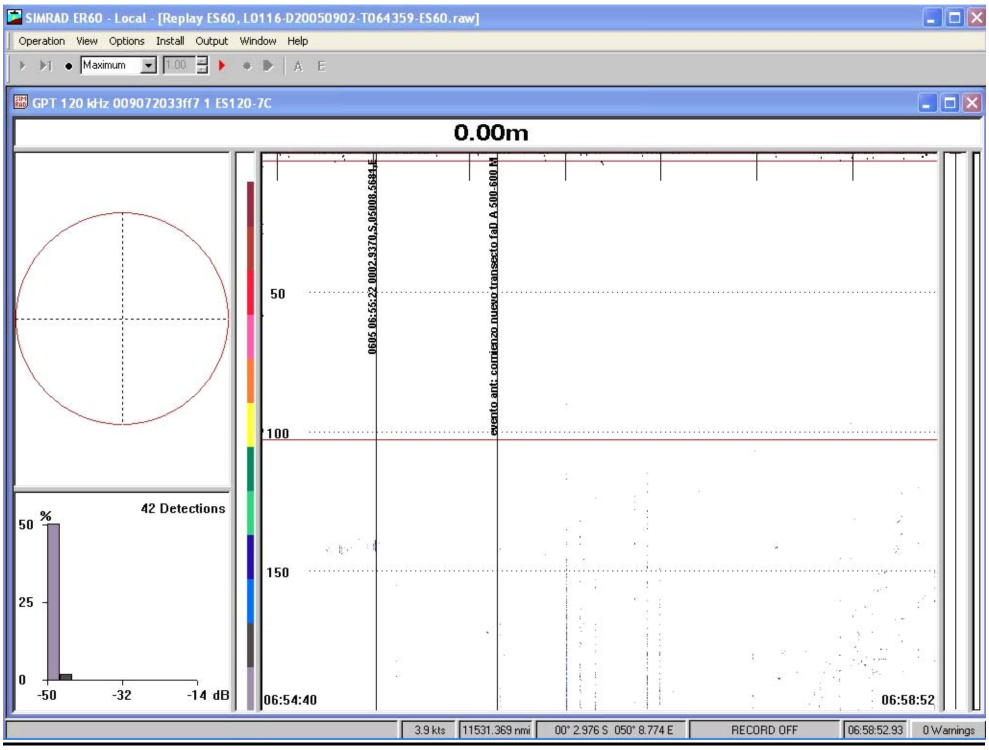


Figure 3. Example of histogram, due to noise from unwanted species (grey threshold bar -50 dB in the bottom left-hand window) such as small pelagics, known as “bait”, or other hydrodynamic noise.

Figure 4a and 4b. Site of omnidirectional sonar on board a fishing vessel: the sonar is generally located in the prow of the vessel (a). Example of fish school detection with the aid of omnidirectional type sonar (b).

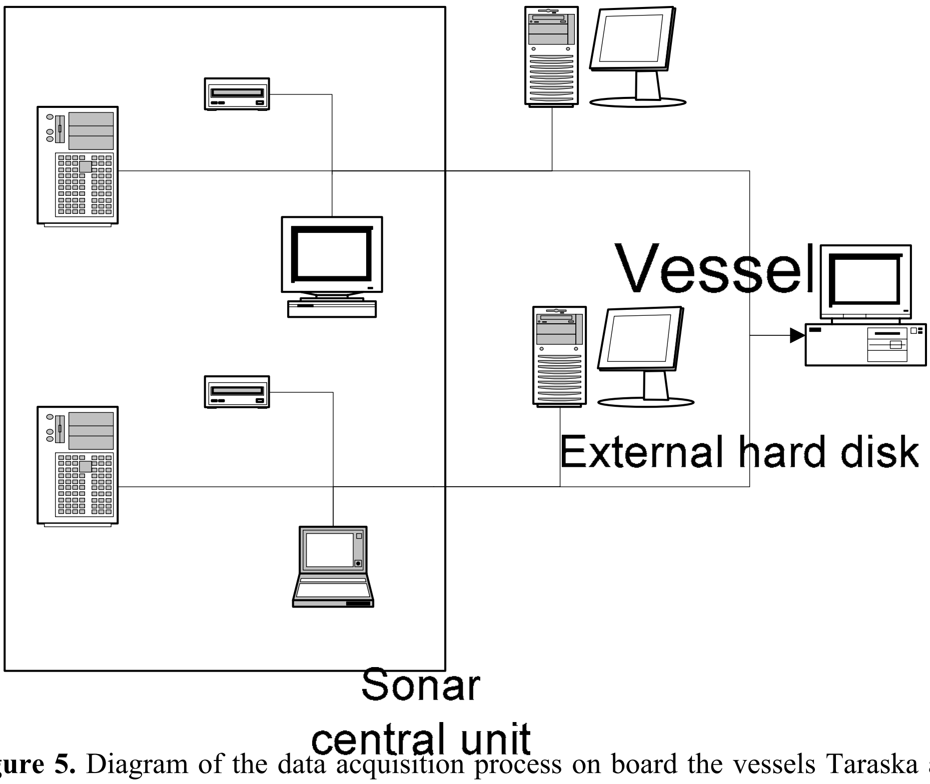


Figure 5. Diagram of the data acquisition process on board the vessels Taraska and Albacora 15, and analysis (information extraction by specific programmes) of the data obtained in the pilot action table.

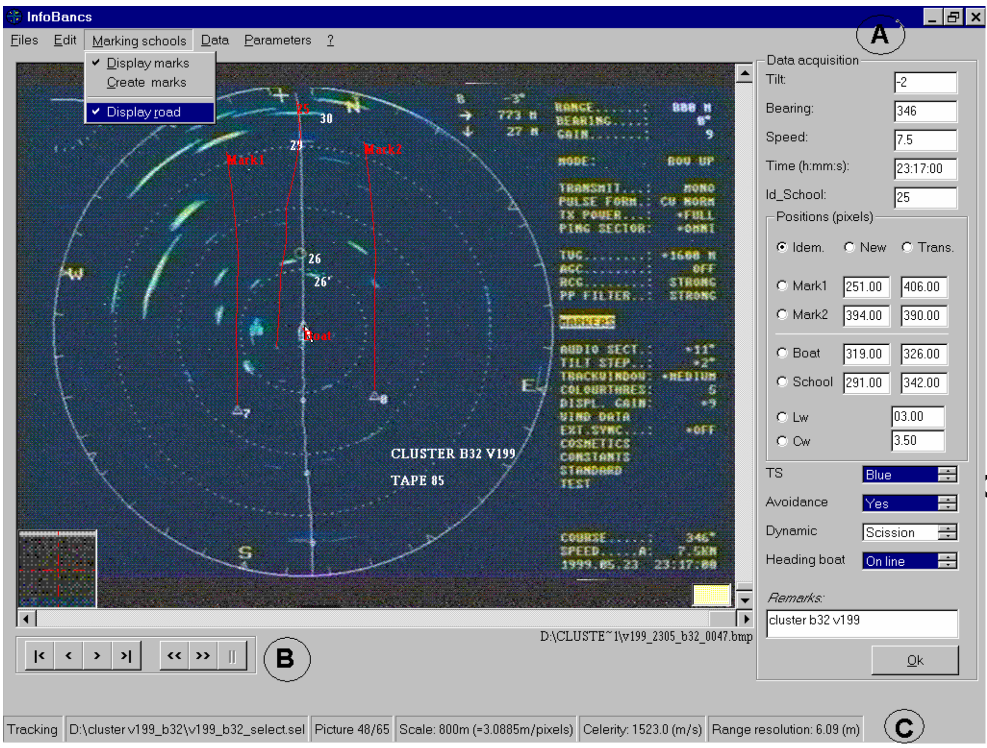


Figure 6. The programme used to analyse sonar data was Infobancs 2.0 (Brehmer *et al.* 2006).

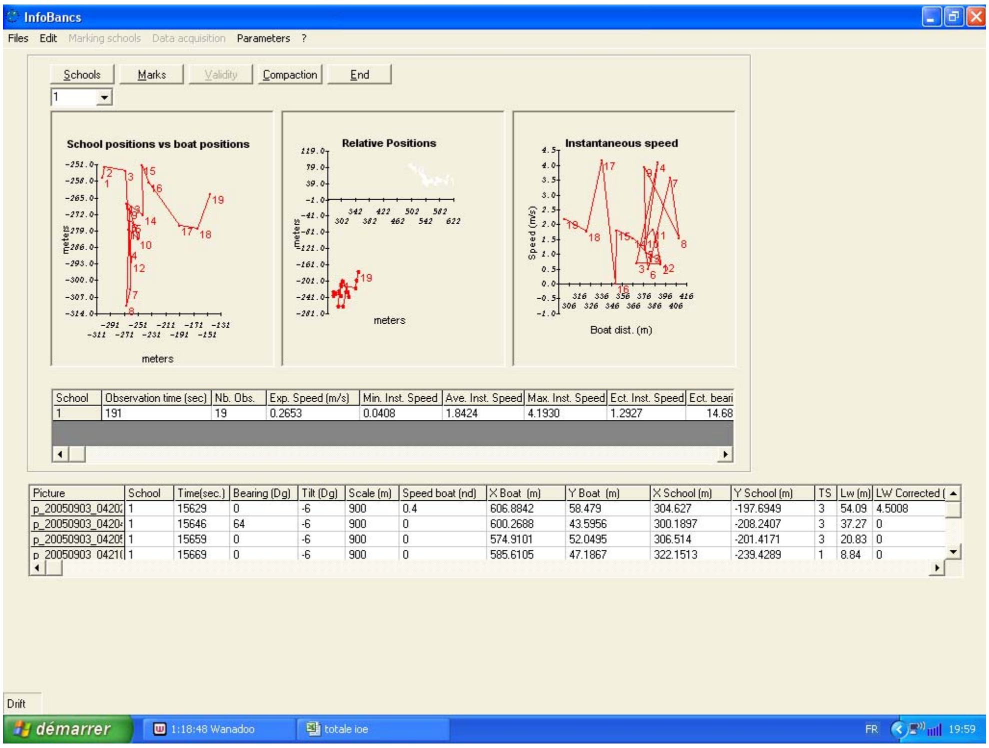


Figure 7. Infobancs kinematic analysis module in drift mode. Example of school observed by the Taraska on 03/09/2005.

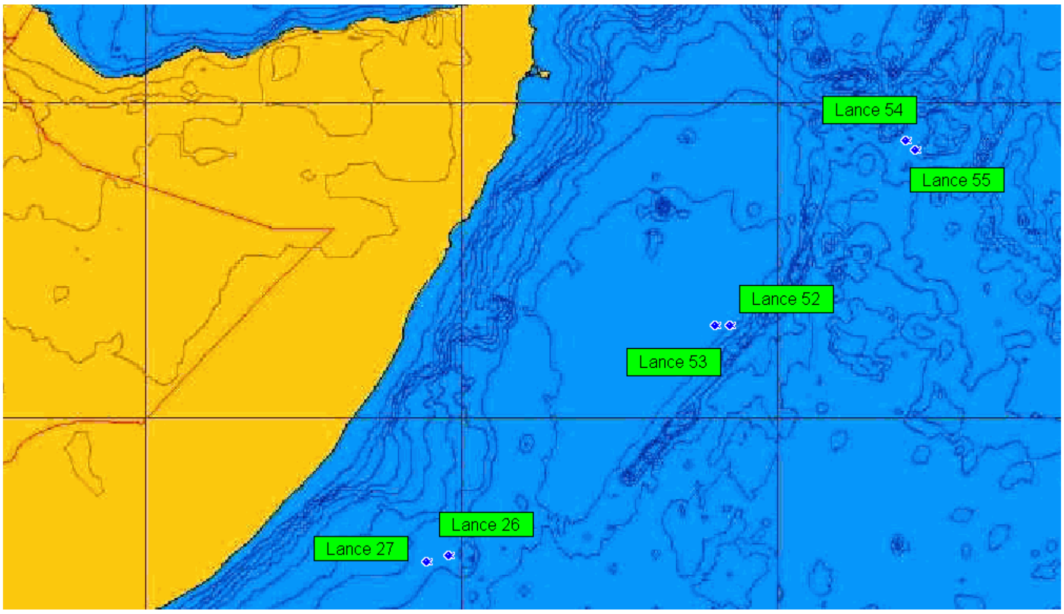


Figure 8. Geographic location of 6 associated sets (26, 27, 52, 53, 54 and 55), approximately located between parallels 5º N and 5º S, and between meridians 45º and 60º E.

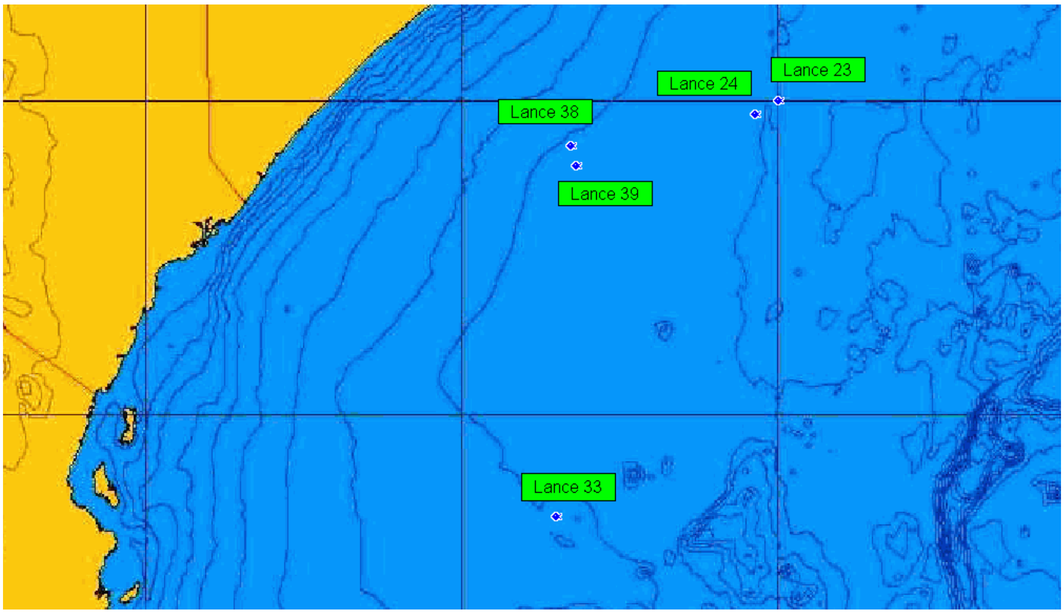


Figure 9. Geographic location of the remaining associated sets—specifically sets 23, 24, 33, 38 and 39—including between parallels 0º and 6º S, approximately, and between meridians 45º and 50º E.

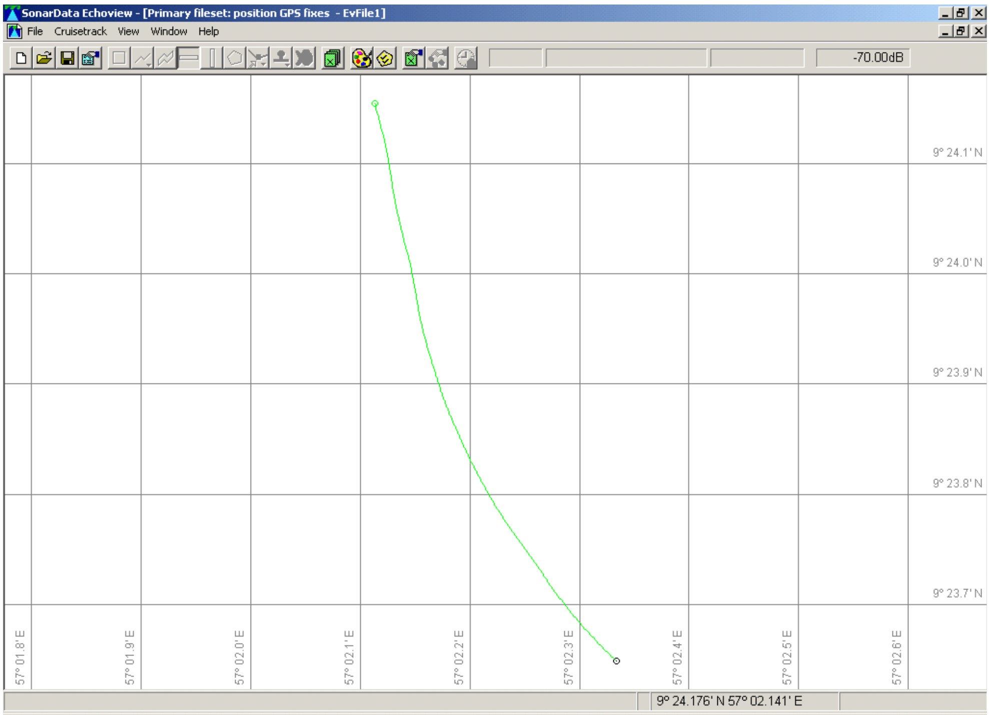


Figure 10. Example of a sampling route over an object following the current (adrift) performed by the support vessel before the purse-seiner Albacora 15 commenced fishing.

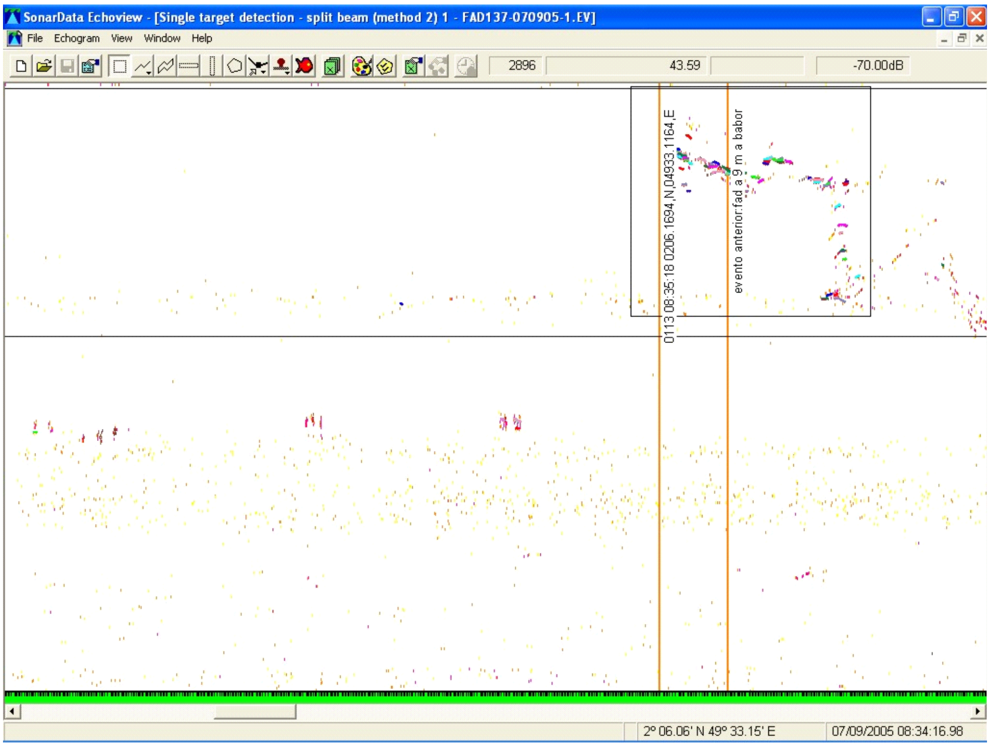


Figure 11. Example of tuna aggregation (region outlined by a square) detected by the echo sounder after the first star-shaped sampling run over an object (the two orange vertical lines indicate the object's geographical position) at a distance of 9 nm to port.

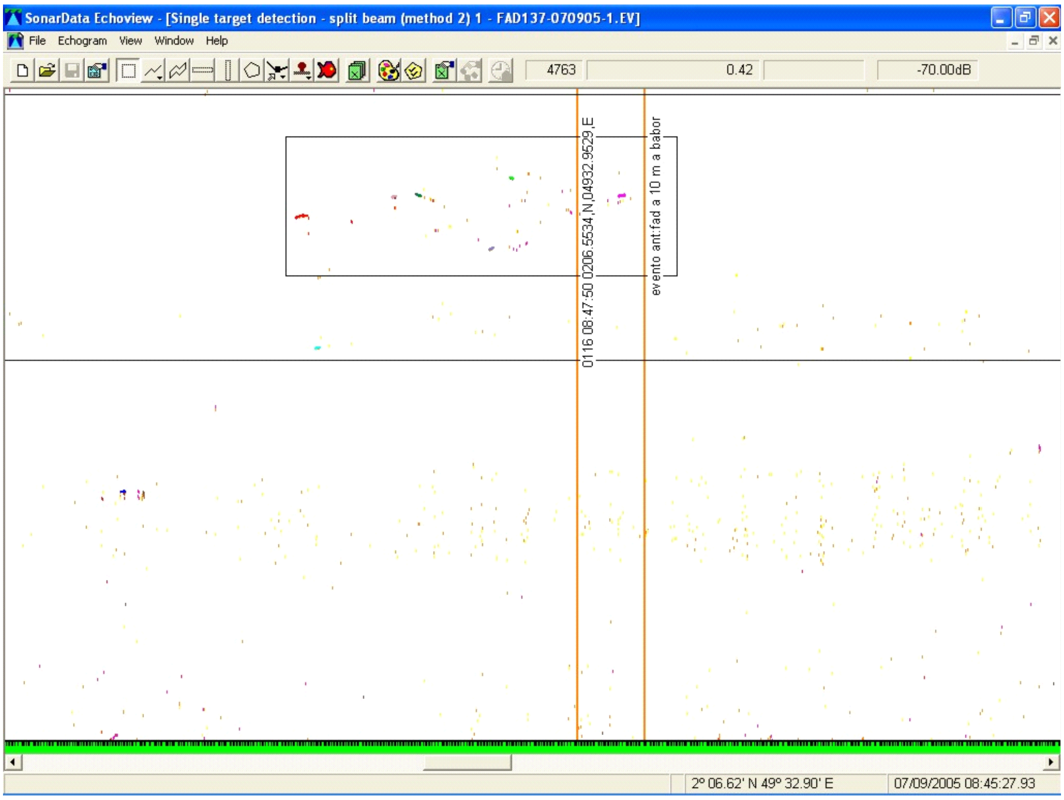


Figure 12. Example of tuna aggregation (region outlined by a rectangle) detected by the echo sounder after the second star-shaped sampling run over the same object as in the previous Figure, at a distance of 10 nm to port.

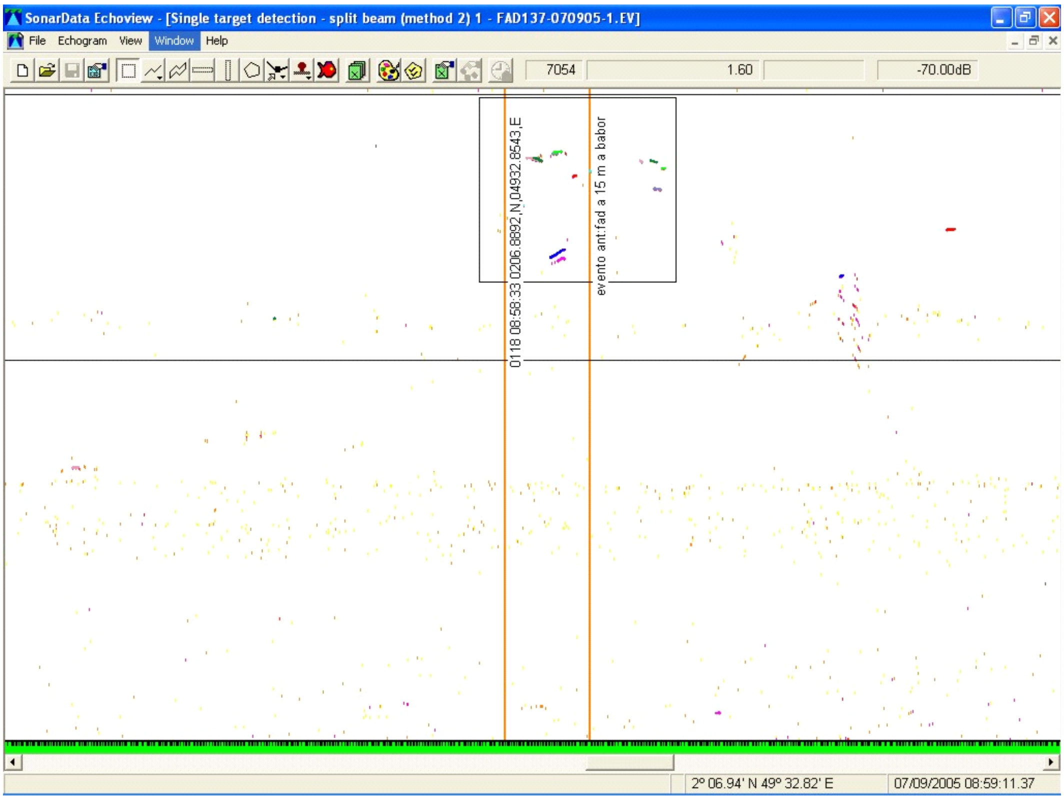


Figure 13. Example of tuna aggregation (region outlined by a square) detected by the echo sounder after the third run of star-shaped sampling over the same object as in the previous Figures, at a distance of 15 nm to port.

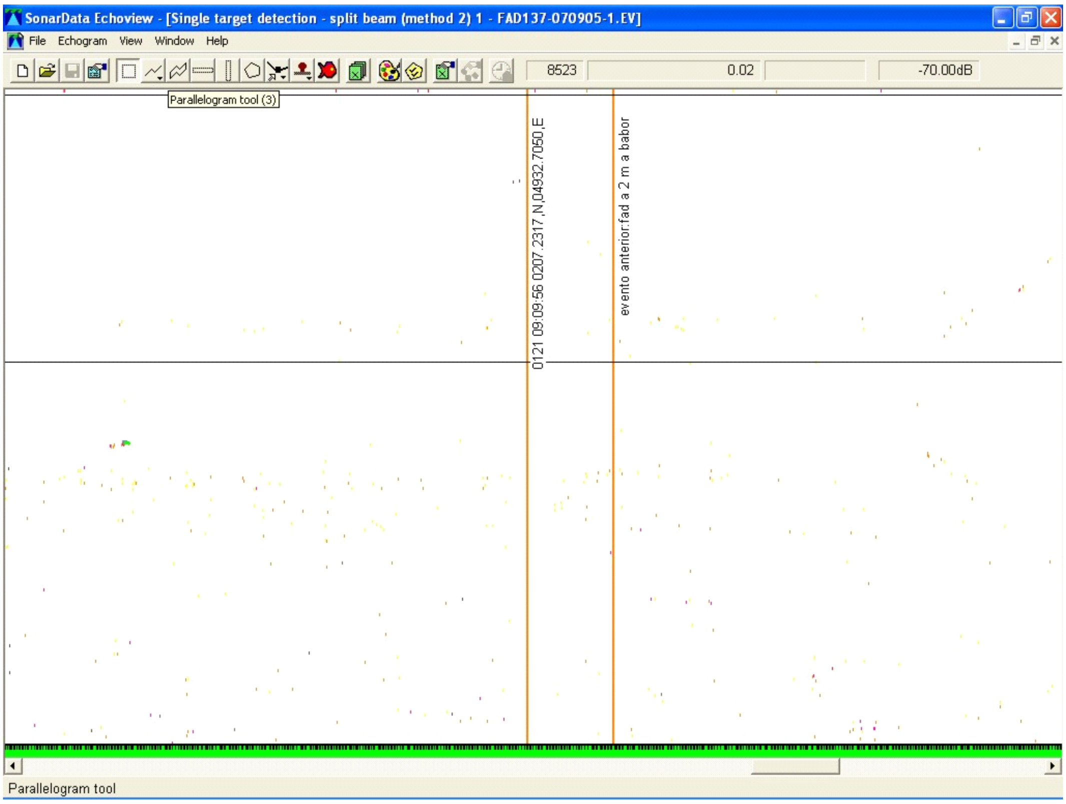


Figure 14. Example of tuna aggregation dispersal (no region can be outlined) detected by the echo sounder after the fourth star-shaped sampling run over the same object as in the previous Figures, at a distance of 2 nm to port.

Figure 15. Example of an echogram showing a group of tuna located under an object following the vessel for approximately 500 m.

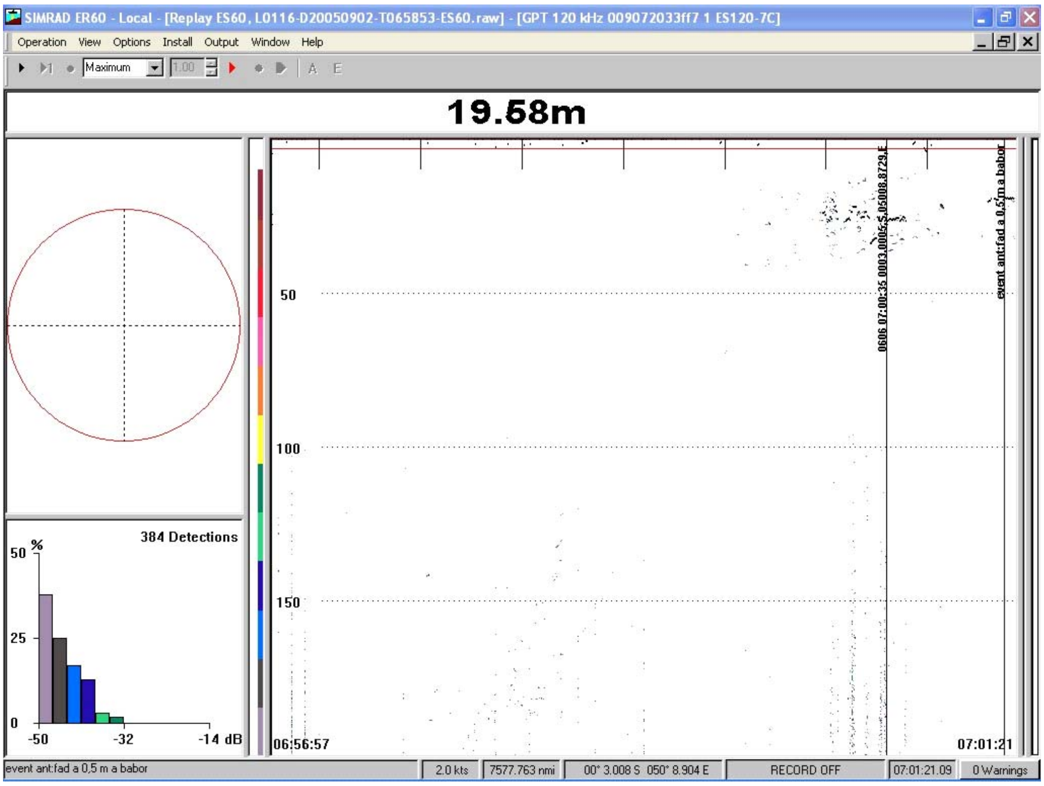


Figure 16. Example of a histogram (bottom left-hand window) belonging to a fishery where skipjack was the main species. The echoes (TS) of 384 fish detected with the echo sounder under the object do not exceed the threshold of –32 dB.

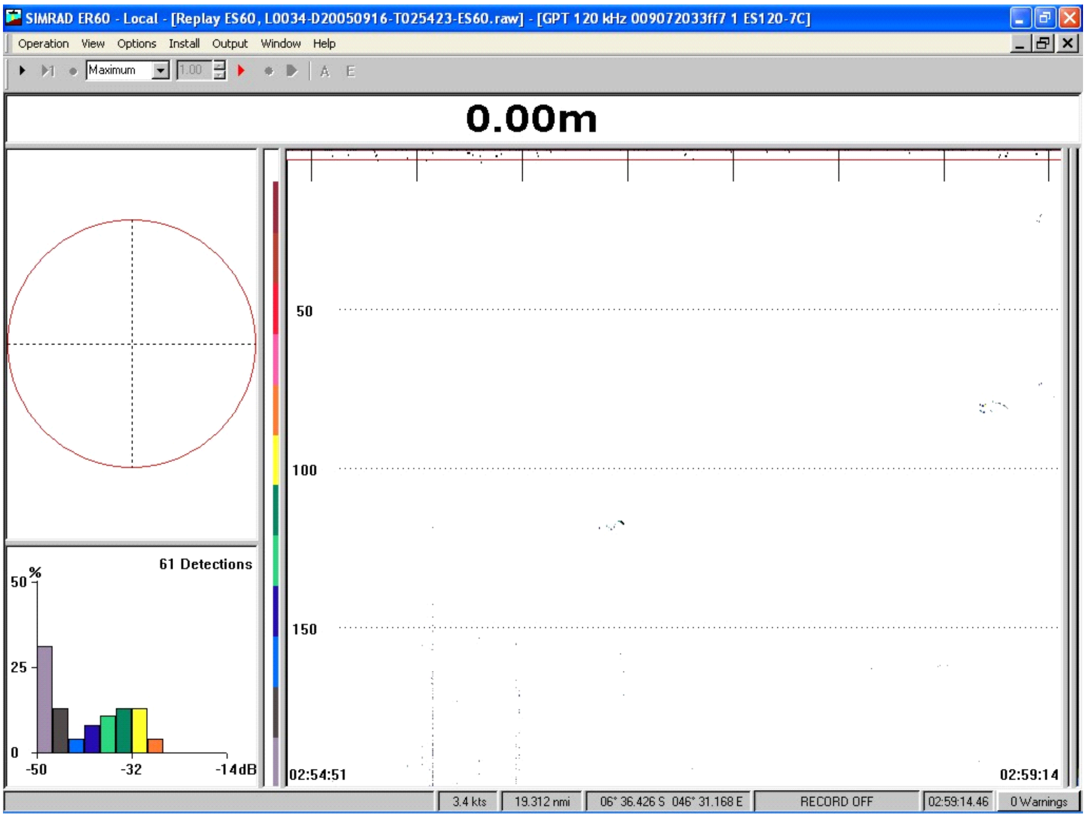


Figure 17. Example of histogram (bottom left-hand window) belonging to a fishery where yellowfin was the main species. The echoes (TS) of 61 fish detected with the echo sounder under the object exceed the threshold of –32 dB.

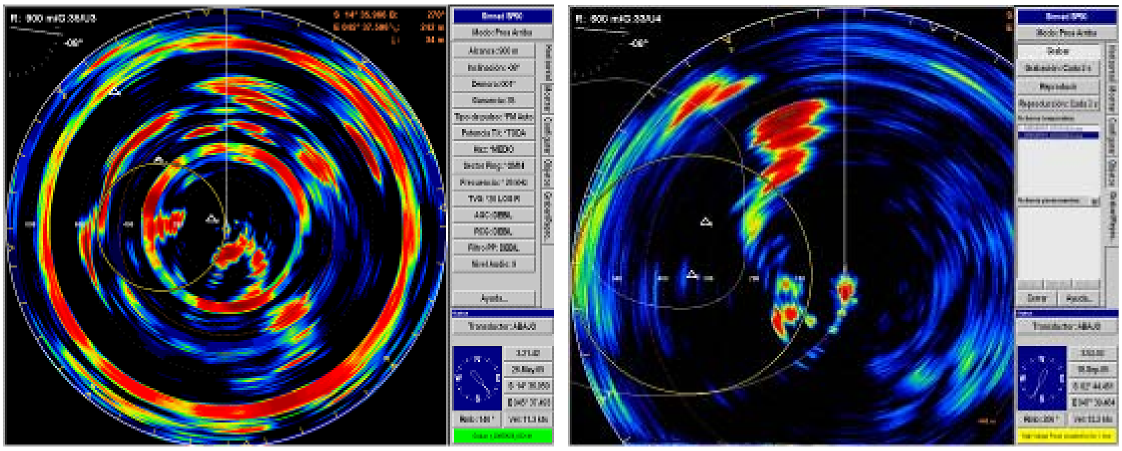


Figure 18. Sonar image presenting very characteristic, strong acoustic interference (A) in concentric circles. In (B), problems were due to reverberation and signal attenuation.

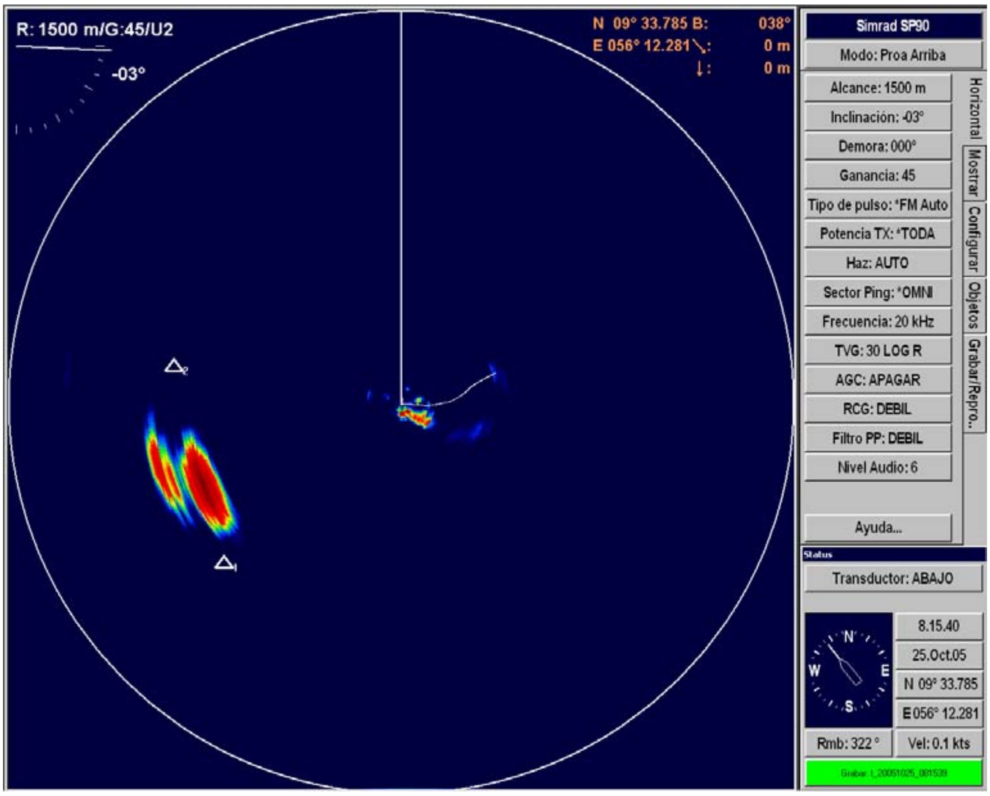
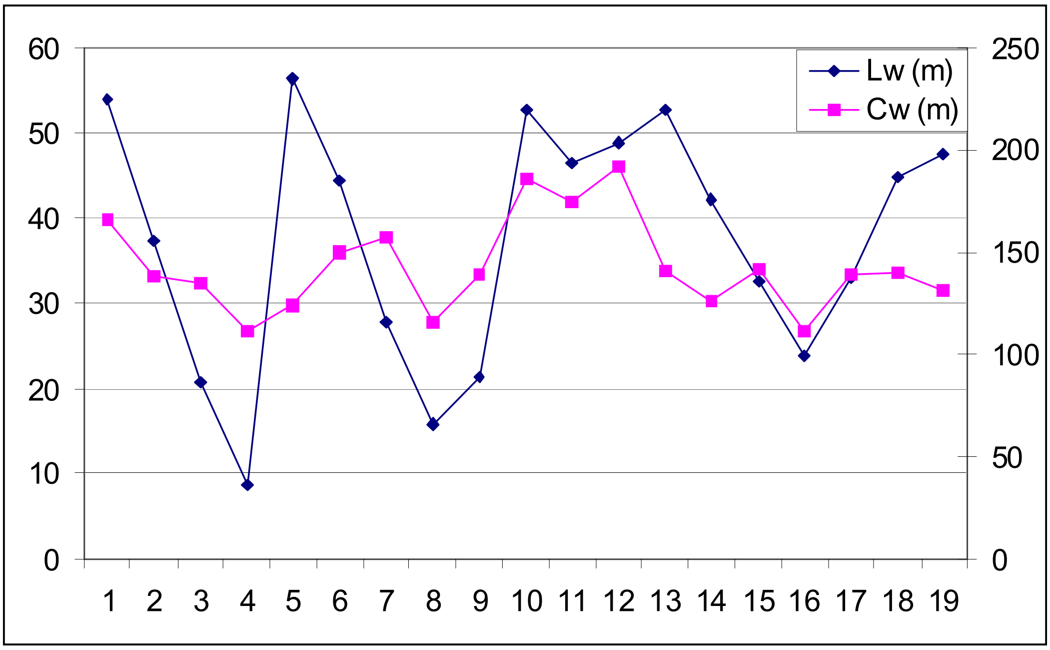


Figure 19. Omnidirectional sonar output picture from the Taraska. Interference with detection is not total—logging took place next to an object detected alongside a school of tuna. The parameters generally used in observations made at sea are given to the right of the image.



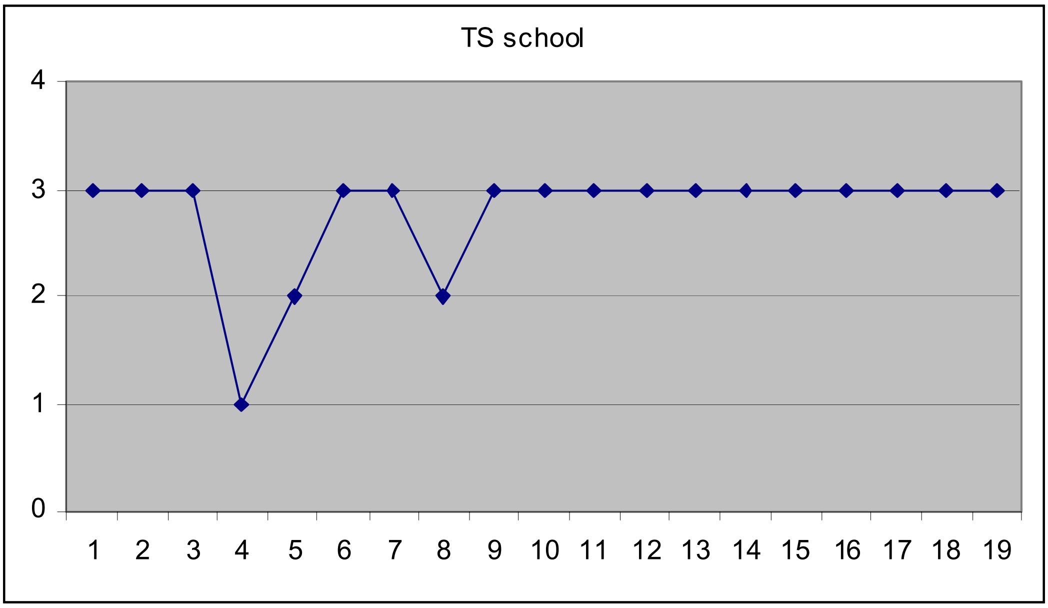
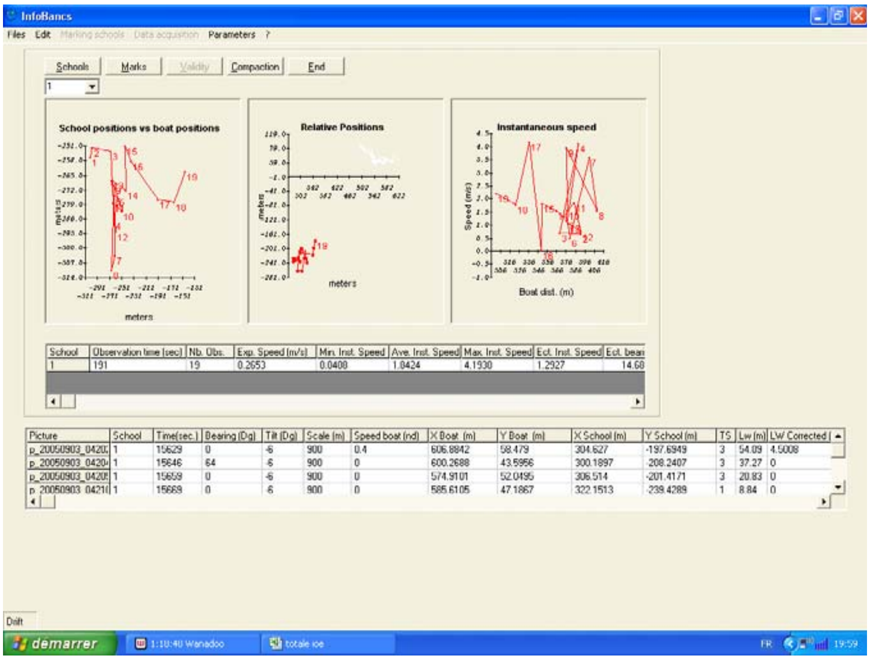
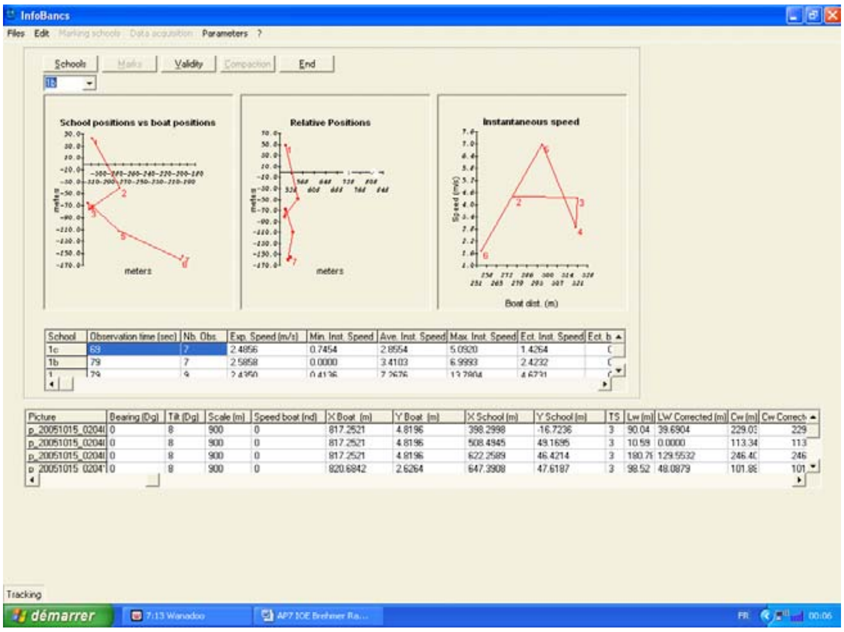


Figure 20. Variations in acoustic signal intensity (TS school, 1 weak, 2 average, 3 strong) and the Lw and Cw sizes (in metres) of the school of fish detected during the logging sequence on 03/09/2005.



School	Observation time (sec)	Nb. Obs.	Exp. Speed (m/s)	Min. Inst. Speed	Ave. Inst. Speed	Max. Inst. Speed	Ect. Inst. Speed
1	191	19	0.2653	0.0408	1.8424	4.193	1.2927

Figure 21. Information about fish school displacement speed, obtained by analysing the omnidirectional sonar data. Recording of a school of skipjack by the Taraska on 03/09/2005, during an operation adrift. (Exp.: speed of exploration; Inst.: instant speed over a constant time interval).



School	Observation time (sec)	Nb. Obs.	Exp. Speed (m/s)	Min. Inst. Speed	Ave. Inst. Speed	Max. Inst. Speed	Ect. Inst. Speed
1c	69	7	2.49	0.75	2.86	5.09	1.43

Figure 22. Information about fish school displacement speed, obtained by analysing the omnidirectional sonar data. Recording on 15/10/2005, during an operation adrift. (Exp.: speed of exploration; Inst.: instant speed over a constant time interval).

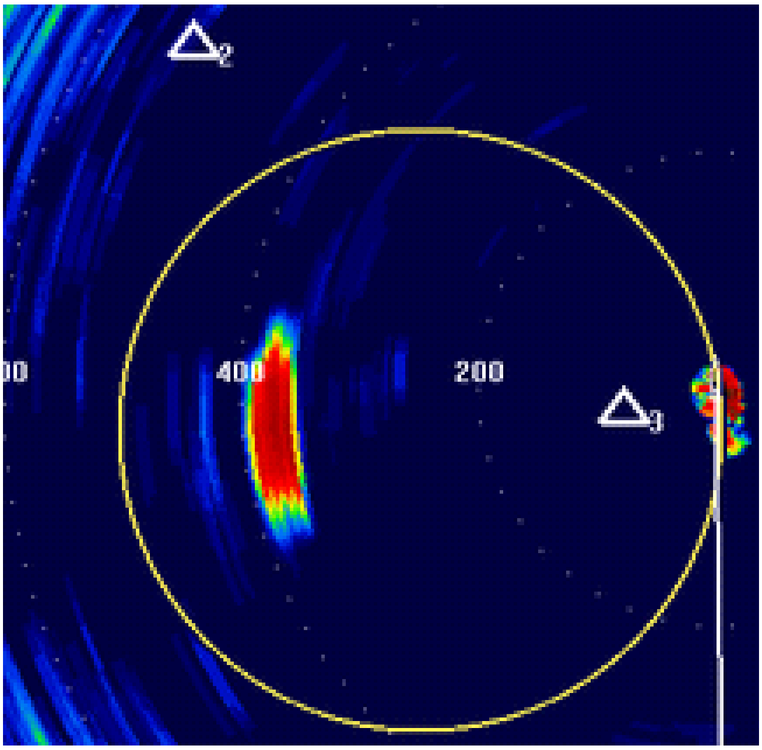


Figure 23. Echo trace of a tuna school observed by the Taraska on 03/09/2005, during an operation with the vessel adrift.

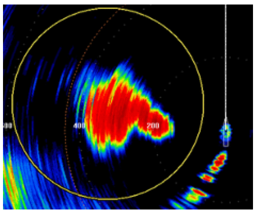
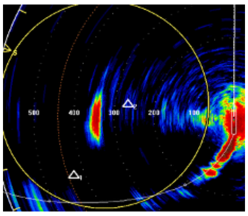
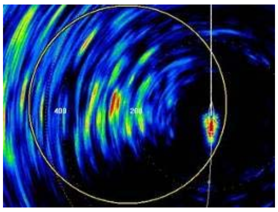
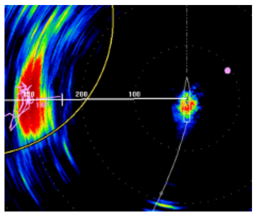
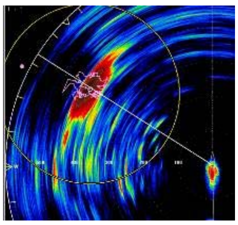
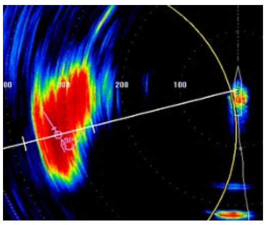
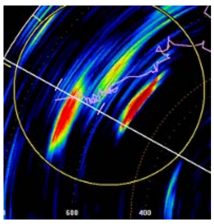
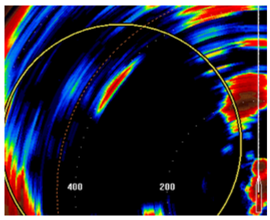
15/10/2005	04/09/2005	16/09/2005	19/09/2005
			
19/09/2005	27/09/2005	27/09/2005	14/10/2005
			

Figure 24. Echo traces of fish schools in 8 fishery operations on the Albacora 15 (selected by the angle of pitch). On 16/09, 83% yellowfin; skipjack is mainly present for the entire remaining fishery operations. The fish school is situated in the orange circle.