POLE DE RECHERCHE OCEANOLOGIQUE ET HALIEUTIQUE CARAIBE

COLLECTED REPRINTS OF THE MAIN CONTRIBUTED PAPERS OF EICHOANT PROGRAM (Evaluation of Behaviour Influence on Fishery Biology and Acoustic Observations in Tropical Open Sea) PRESENTED DURING CONGRESSES FROM 1/1/87 TO 4/30/90.

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IFREMER
INSTITUT FRANÇAIS DE RECHERCHE

UAG
UNIVERSITE

ORSTOM
INSTITUT FRANÇAIS DE RECHERCHE SCIENTIFIQUE

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OF EICHOANT PROGRAM

(Evaluation of Behaviour Influence on Fishery Biology
and Acoustic Observations in Tropical Open Sea)

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COMPILATION DES PRINCIPALES COMMUNICATIONS
DU PROGRAMME EICHOANT

(Evaluation de l'Impact du Comportement en Halieutique
et sur les Observations Acoustiques en milieu Naturel Tropical)

PRESENTÉES A DES CONGRES ENTRE LE 1/1/87 ET LE 30/4/90.

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GERLOTTO, F., C. HERNANDEZ CORUJO, and R. CLARO - 1990. A methodology for acoustic assessment in very shallow waters (less than 8 m). CIEM/ICES Working group on Fisheries Acoustic Science and Technology Rostock, April 1990:: 14 p.

GERLOTTO F. and E. MARCHAL - 1987. The concept of Acoustic Populations : its use for analyzing the Results of Acoustic Cruises. Internat. Symp. Fish. Acoustic, Seattle. Washington, june 22-26, 1987: 30 p.

SIMARD Y. and F. GERLOTTO - 1990. Exploration of the applicability of geostatistics in fisheries acoustics. CIEM/ICES Working group on Fisheries Acoustic Science and Technology Rostock, April 1990: 27 p. (également présenté au ICES workshop on applicability of spatial statistical techniques to acoustic survey data. Brest, 4-6 avril 1990 sous le titre: Applications of geostatistics to fisheries acoustics: exploration of difficulties with two typical data sets from artic and tropical waters).

SORIA M. - 1990. Study of learning capabilities of tropical clupeoïdes using artificial stimuli. CIEM/ICES Working group on Fisheries Acoustic Science and Technology Rostock, April 1990: 10 p.

FREON P.- 1989. Seasonal and interannual variations of the mean school weight in the senegalese sardine fisheries: effect of the behavior of fish or fishermen? International Symposium on the Long-term Variability of Pelagic Fish Populations and their Environment. 14-18 nov. 1989, Sendai, Japan: 11 p.

PREFACE

Ce document réunit les principales communications des chercheurs travaillant dans le programme EICHOANT (Evaluation de l'Impact du Comportement en Halieutique et sur les Observations Acoustiques en milieu Naturel Tropical) présentées à différents congres ou entre le 1/1/87 et le 30/4/90. Cette compilation nous a semblé nécessaire dans la mesure où ces documents ne sont pas facilement disponibles et où ces résultats ne sont pas pour l'instant publiés sous une autre forme. En effet, le programme EICHOANT s'est trouvé au cours de cette période dans une phase intensive de terrain durant laquelle seul ce type de publication était à la fois possible (car rapide) et nécessaire (afin de prendre date dans un domaine en pleine évolution).

D'autres communications (ou rares publications) ont été réalisées au cours de cette période. On en trouvera la liste exhaustive dans le tableau présenté ci-dessous. Les travaux ne figurant pas dans la presente compilation sont, pour l'essentiel, des communications à des groupes de travail du CIEM (Conseil International pour l'Exploration de la Mer; ICES en anglais) qui ont été reprises dans des communications présentées lors des réunions statutaires de cet organisme. On y trouvera également quelques travaux situés en marge de la problématique de EICHOANT.

PREFACE

This document is a reprint of the main contributed papers presented during congresses by scientists of the EICHOANT program (Evaluation of Behaviour Influence on Fishery Biology and Acoustic Observations in Tropical Open Sea), from 1/1/1987 to 4/30/1990. The edition of these collected reprints was necessary because on the one hand these papers are not easily available and, on the other hand, the results of our studies are not yet published elswhere. The EICHOANT program is still in a period of intensive data collection and the contributed papers give the opportunity of a fast publication.

Some other contributed papers (or in some cases publications) were written during this period. A complete list is available in the table presented further. The papers which are not in the present collected reprints are mainly contributed papers to ICES working groups (International Concil for the Exploration of the Sea, FAST and FTFB working groups) whose results are usually reported in the contributed papers presented during the ICES statutory meeting. Some other papers deal with subjects indirectly related to EICHOANT topics.

TABLEAU DE CLASSIFICATION DE L'ENSEMBLE DES PUBLICATIONS DES CHERCHEURS DE L'EQUIPE EICHOANT

du 1/1/87 au 30/4/90

(Classification table of the whole set of EICHOANT

papers from 1/1/87 to 4/30/90)

PRESENTATION

Le tableau ci-dessous présente l'ensemble les publications des chercheurs travaillant dans le programme EICHOANT entre le 1/1/87 et le 30/4/90 (seules deux publications antérieures à 1987, mais rentrant dans la problématique du programme, ont été rajoutées). Les communications compilées dans le présent document sont indiquées par un astérisque en marge. De plus, le tableau présente cinq entrées:

N - Numéro d'ordre dans le tableau (ordre conventionnel).

A - L'action de recherche EICHOANT concernée par la publication;

I - Le niveau d'intérêt scientifique de la publication;

O - Le niveau de diffusion du support de publication;

R - La référence scientifique de la publication;

Actions de recherche EICHOANT

0 - Hors programme EICHOANT (7 publications).

A - Etalonnage et évaluation des erreurs et biais en écho-intégration (13 publications).

B - Adéquation de la méthode d'écho-intégration aux biotopes insulaires (4 publications).

C - Structure et stabilité des bancs et agrégations (7 publications).

D - Mise au point ou utilisation de méthodologies nouvelles (6 publications).

E - Impact de l'apprentisage sur l'évaluation des stocks (1 publication).

F - Influence du comportement sur les résultats de la dynamique des populations (2 publications).

Niveau d'intérêt scientifique de la publication

0 - Résultats repris dans une publication de synthèse, ou travail traduits dans une autre langue (9 publications).

1 - Intérêt moyen (12 publications).

2 - Grand intérêt ou synthèse (13 publications). Les publications de synthèse portent les numéros d'ordre suivants: 9, 18, 24, 25, 28.

Niveau de diffusion du support de publication

0 - Littérature grise, diffusion limitée aux demandeurs (rapports de contrats en particulier): 4 publications.

1 - Communication à des groupes de travail, diffusion limitée aux experts internationaux des domaines acoustique et comportement liés à l'halieutique (exemple: groupes de travail du CIEM): 14 publications.

2 - Communication à des congrés, diffusion assez large au delà des spécialistes (exemple: réunions statutaires du CIEM): 15 publications.

3 - Publication dans une revue: 1 publication.

TABLEAU DE L'ENSEMBLE DES PUBLICATIONS DU PROGRAMME EICHOANT

(Classification table of the whole set of EICHOANT papers)

N	A	I	D	R
1	B	0	0	Anonyme - 1987. Campagne Prosantil (N/O ANDRE NIZERY 1/6-15/6/1987) Rapport Scientifique ORSTOM Fort-de-France: 14 p. + Annexes.
2	0	1	0	FREON P. - 1987. Les ressources pélagiques en Martinique. In: Table ronde sur la pêche; 23-24 nov. 1987. Conseil Régional de la Martinique: 7 p.
3	D	1	1	FREON P. - 1988. A methodology for visual estimation of abundance applied to flyingfish stocks. 41st GCFI annual meeting. San Thomas US Virgin Islands nov. 1988: 38 p.
4	OF	2	2	FREON P. - 1988. Introduction of environmental variables into global production models. In: Larraneta M.G. and Wyatt T. (eds), International Symposium on Long Term Changes in Marine Fish Populations. Consejo Superior de Investigaciones Cientificas: 32 p.
5	O-E	2	2	FREON P. - 1989. CLIMPROD: a fully interactive expert-system software for choosing and adjusting a global production model which account for changes in environmental factors. International Symposium on the Long-term Variability of Pelagic Fish Populations and their Environment. 14-18 nov. 1989, Sendai, Japan: 10 p.
6 *	F	2	2	FREON P.- 1989. Seasonal and interannual variations of the mean school weight in the senegalese sardine fisheries: effect of the behavior of fish or fishermen? International Symposium on the Long-term Variability of Pelagic Fish Populations and their Environment. 14-18 nov. 1989, Sendai, Japan: 11 p.
7	A-C	0	1	FREON P. and F. GERLOTTO - 1988. Influence of fish behaviour on fish stock abundance estimations. ICES, Working group on Fisheries Acoustic Science and Technology, Ostende, Belgique, mai 1988. 7 p.
8	O	0	1	FREON P. and F. GERLOTTO - 1988. A methodology for <u>in situ</u> measurement of mean target strength in small schools. ICES, Working group on Fisheries Acoustic Science and Technology, Ostende, Belgique, mai 1988 ; 5 p.

N	A	I	D	R
9 *	ACD	2	2	FREON P. and F. GERLOTTO - 1988. Methodological approach to study the biases induced by the fish behaviour during hydro-acoustic surveys. Réun. Cons. Int. Explor. Mer, Bergen Sept. 1988, C.M. 1988/B:52,: 16 p.
10	0	2	2	FREON P., GOBERT B. et MAHON R. (à paraître). Synthèse régionale sur la recherche halieutique et les pêcheries artisanales dans la Caraïbe insulaire. In: Durand J.R. et Weber J. (eds). Compte rendu du Symposium: La Recherche Face à la Pêche Artisanale. ORSTOM/IFREMER, Montpellier, Sept. 1989: 47 p.
11 *	A	1	1	FREON, P., F. GERLOTTO and M. SORIA, 1990. Evaluation of the influence of vessel noise on fish distribution as observed using alternately motor and sails aboard a survey vessel. ICES/FAST W.G., Rostock, april 1990 : 15 pp ICES/FAST W.G., Rostock, april 1990: 15 p.
12 *	C	1	2	FREON P., M. SORIA and F. GERLOTTO, 1989. Short-term variability of <u>Sardinella aurita</u> aggregations and consequencies on acoustic survey results. ICES 77th Statutory Meet. La Haye, Oct. 1989: 16 p.
13 *	C	1	1	FREON, P., M. SORIA and F. GERLOTTO, 1990. Changes in the fish school structure according to external stimuli. ICES/FAST W.G., Rostock, april 1990: 10p.
14	B	1	2	GERLOTTO F. - 1985. L'hydroacoustique appliquée aux stocks tropicaux insulaires (à travers l'exemple d'une prospection dans les Antilles Françaises en septembre 1984). Comm. 38th annual Gulf. caribbean Fish. Inst., Martinique, nov. 1985 : 21 p.
15	A	1	3	GERLOTTO F. - 1987. Medicion de las caracteristicas acusticas de algunos peces tropicales. Mem. Soc. la Salle Cienc. Nat., 47 (127-128), enero/dic. 1987, contrib. 131 : 149-167.
16	0	1	2	GERLOTTO F. - 1987. Los avances tecnologicos y metodologicos en el campo de la hidroacustica aplicada a la biologia pesquera. Simposio sobre recursos vivos y pesquerias en el Pacifico Sudeste. CCPS, Vina del Mar, Chile, 9-13 mayo 1987: 40 p.
17	A	0	1	GERLOTTO F. - 1988. Mesure du comportement diurne de plongée des bancs de <u>Sardinella aurita</u> devant un navire de prospection acoustique. ICES, Working group on Fisheries Acoustic Science and Technology, Ostende, Belgique, mai 1988 : 27 p.

N	A	I	D	R
18	A	2	1	GERLOTTO F. - 1989. Choix d'une stratégie d'échantillonnage et de stratification en écho-intégration. ICES/FAST Work. Group Meet. Dublin, Ireland, 26-28 april 1989: 38 p.
19	A	0	2	GERLOTTO F. - 1989. Choice of a strategy for sampling and stratifying the fish concentrations in tropical echo integration. ICES 77th Statutory meet., La Haye, Oct. 1989: 24 p.
20	A	1	2	GERLOTTO F., C. BERCY and B. BORDEAU - 1989. Echo Integration Survey around off-shore oil-extraction platforms off Cameroun : Observation of the repulsive effect on fish of some artificially emitted sounds. Progress in Fisheries Acoustics, Lowestoft, march 1989 : 10p (in press).
21	B	1	0	GERLOTTO, F., R. CLARO, P. COTEL, C. HERNANDEZ CORUJO, y J.P. GARCIA ARTEAGA - 1989. Adaptación y aplicación de métodos hidroacústicos para la evaluación de la ictiomasa en las condiciones de la plataforma cubana. Inf. Expedición Conjunta ORSTOM/Inst. Oceanol. Ac. Ciencias Cuba, nov. 1989 : 16 p. + fig.
22	A	0	0	GERLOTTO F. et P. COTEL - 1989. Bioacoustique marine appliquée à la répulsion des poissons près des plateformes pétrolières. Campagne ELFBIO. Tome II: Description par écho-intégration des biomasses halieutiques et de leurs mouvements liés aux stimuli sonores près des plateformes. Rapport de fin de contrat ELF/SEREPCA 88/07: 96 p.
23	C	0	1	GERLOTTO F. and P. FREON - 1988. School structure observed in some clupeid species. ICES/CIEM, Working group on Fisheries Acoustic Science and Technology, Ostende, Belgique, mai 1988: 11 p.
24 *	AC	2	2	GERLOTTO F. and P. FREON - 1988. Influence of the structure and behaviour of fish school on acoustic assessment. Réun. Cons. Int. Explor. Mer, Bergen Sept. 1988, C.M. 1988/B:53: 28 p.
25 *	A	2	1	GERLOTTO F. and P. FREON - 1990. Review of avoidance reactions of tropical fish to a survey vessel. CIEM/ICES Working group on Fisheries Acoustic Science and Technology Rostock, April 1990: 10 p.
26 *	B	2	1	GERLOTTO, F., C. HERNANDEZ CORUJO, and R. CLARO - 1990. A methodology for acoustic assessment in very shallow waters (less than 8 m). CIEM/ICES Working group on Fisheries Acoustic Science and Technology Rostock, April 1990:: 14 p.

N	A	I	O	R
27	D	0	1	GERLOTTO F. and E. MARCHAL - 1985. The concept of Acoustic Populations as an Aid for Biomass Identification . Comm. ICES/FAST Working Group, Tromso, 22/24 may 1985: 7 p.
28 *	D	2	2	GERLOTTO F. and E. MARCHAL - 1987. The concept of Acoustic Populations : its use for analyzing the Results of Acoustic Cruises. Internat. Symp. Fish. Acoustic, Seattle. Washington, june 22-26, 1987: 30 p.
29 *	A	1	1	GERLOTTO F., D. PETIT and P. FREON - 1990. Influence of the light of a survey vessel on TS distribution. CIEM/ICES Working group on Fisheries Acoustic Science and Technology Rostock, April 1990: 10 p.
30	0	2	2	GINES Hn. y F. GERLOTTO - 1988. Diez anos de echo-integration en EDIMAR referida a la sardina del oriente venezolano (Sardinella aurita). Congreso Iberoamericano y del Caribe, Punta de Piedras, Venezuela, mayo 1988. Comm. 001: 30 p.
31 *	A	2	2	LEVENEZ J.-J., F. GERLOTTO et D. PETIT - 1987. Réactions à la lumière d'espèces pélagiques côtières tropicales et conséquences sur les estimations d'abondance par écho-intégration. Internat. Symp. Fish. Acoustics, Seattle, Washington, june 22-26, 1987: 16 p.
32	0	1	2	LLANO M. CARDENAS J., MAYZ L., GUEVARA P., ARMAS A., FREON P., KIMBERLEY M. y ABU-JABER N. - 1989. Elementos biogénicos de los sedimentos de la fosa de Cariaco y los recursos icticos del Nororiente Venezolano. In: Congreso Latinoamericano sobre ciencas del mar, Cumana, Octubre 1989 (sous presse).
33 *	D	1	1	SIMARD Y. and F. GERLOTTO - 1990. Exploration of the applicability of geostatistics in fisheries acoustics. CIEM/ICES Working group on Fisheries Acoustic Science and Technology Rostock, April 1990: 27 p. (également présenté au ICES workshop on applicability of spatial statistical techniques to acoustic survey data. Brest, 4-6 avril 1990 sous le titre: Applications of geostatistics to fisheries acoustics: exploration of difficulties with two typical data sets from artic and tropical waters).
34 *	E	2	1	SORIA M. - 1990. Study of learning capabilities of tropical clupeoïdes using artificial stimuli. CIEM/ICES Working group on Fisheries Acoustic Science and Technology Rostock, April 1990: 10 p.

*** Publication figurant dans cette compilation (paper in this collected reprints)**

ICES 1988

C.M. 1988/B:52
Ref. H
Sess. P

METHODOLOGICAL APPROACH TO STUDY BIAS INDUCED BY FISH BEHAVIOUR DURING HYDRO-ACOUSTIC SURVEY

by

Pierre Fréon & François Gerlotto
Pôle de Recherche Océanologique et Halieutique Caraïbe
ORTOM, BP 81, 97256 Fort-de-France Cédex,
Martinique (French W.I.)

ABSTRACT

A methodology is proposed for studying fish school behaviour, in order to quantify its influence on stock abundance estimations using acoustics. Observations take place in situ or inside a large net, set in shallow waters. This enclosure (up to 70 m diameter) is installed in areas where transparent waters allow the use of optical devices in addition to the acoustic equipment.

The first studies concern the internal school structure and its modification when influenced by a vessel, the vertical school avoidance and the mean target strength measurement inside small schools. Some of the preliminary results are given in an other communication (Gerlotto and Freon, this meeting).

RESUME

Les auteurs presentent une serie d'outils methodologiques mis au point pour l'etude du comportement des bancs de poissons, afin de quantifier l'influence de ce comportement sur les etudes de stocks, en particulier l'estimation des biomasses des populations mesurées par echo-integration. Les observations s'effectuent in situ ou a l'interieur d'un enclos en filet de grandes dimensions (plus de 70 m de diametre), installe dans une zone peu profonde. La zone est choisie en raison de la transparence de l'eau, ce qui permet l'emploi d'appareils de visualisation directe (camera sous-marines) en plus des equipements acoustiques.

Les premieres etudes concernaient la structure interne des bancs et ses modifications en fonction de l'influence du passage d'un bateau, la quantification de l'évitement vertical et les mesures de TS à l'intérieur de bancs de petites dimensions. Les résultats préliminaires de ces travaux sont détaillés dans un autre document (Gerlotto et Fréon, ce congrès).

I. INTRODUCTION

Fish behaviour studies in relation with fisheries started many years ago with the aim of improving fishery technology. Avoidance and escapement observations have been carried out for several decades making it possible to build more efficient or more selective fishing gear, according to the needs of fishermen or fishery managers. However, as far as fishery biology is concerned, the influence of the numerous behavioural parameters has been considered either very recently or not at all, although it is predominant in three main fields:

(1) Behaviour can be modified by learning in relation with a fishery, and thus introduces a biases in the abundance estimation when c.p.u.e. is used as abundance index.

(2) Changes in behaviour can be induced by the scientific observer and/or his observation tools. This mainly concerns the acoustic survey method: the interpretation of acoustic data requires quantification of the behavioural effects with respect to the oceanographic vessel, first described by Olsen (1980) and more recently by various participants of the Seattle meeting (Anonymous, 1987). The main parameters to identify and measure are in this case: the fish avoidance caused by the stress from the vessel (noise, light, shadow ...) and the fish tilt angle inside the acoustic beam, induced by these stimuli.

(3) Natural behaviour quantitatively influences the scientific observations of the fishery activity, and then the validity of production models. The structure of schools and concentrations must be known, as well as their temporal and spacial variability. Studies have already been carried out on this topic (Lebedev, 1967; Radakov, 1973) but little quantitative work is available with the exception of some small schools in tanks. For designing and processing acoustic surveys, it is necessary to have reliable knowledge of the tridimentional structure of schools and concentrations, as well as their time evolution. Such data provide a better estimation of the biomass and of its confidence limits (Aglen, 1983; Gerlotto and Stequert, 1983). As shown in the pioneer work of Cushing (1977) the density inside large schools is not homogeneous, contrary to the common belief resulting from visual observations on small schools. Our preliminary studies indicate that a vertical density gradient is frequently observed, well as discontinuity inside the school (Gerlotto and Freon, this meeting).

With the goal of evaluating the effect of fish behaviour on the results of previous traditional studies, the program EICHOANT was developed in 1986 in the Caribbean. For the time being, EICHOANT (Evaluation of the Behaviour Influence on Fishery Biology and Acoustic Observations in Tropical Open Sea) is carried out on the island of Martinique (French West Indies) and the oriental part of Venezuela where the program is conducted in cooperation with FLASA (La Salle Foundation of Natural History). The points (2) and (3) have only been studied at this time and their methodology is presented in this paper. This methodology concerns both _in situ_ observations and observations inside a large enclosure.

II. METHODOLOGY INSIDE AN ENCLOSURE

II.1. Places of observation and equipment

Off the coast of Venezuela, a seasonal upwelling allows the presence of a large stock of _Sardinella aurita_, but induces a low water transparency permitting mainly observations with acoustic devices. Around Martinique, some bays provide good working conditions (high transparency, low current, protection from the wind) allowing the installation of a "mesocosm" for visual and acoustical observations. This installation (fig. 1) consists of a 70 m diameter, 15 m height circular net, set on shallow grounds. Small pelagic schools, from 100 kg to several metric tons, are encaged in the net. Underwater camera, aerial camera as well as vertical and horizontal sonars are used to observe and quantify school behaviour.

The Simrad EYM narrow beam transducer (22°, 70 kHz) and an Osprey video underwater camera were supported by a buoy at 1 m below the surface and maintained upon the deepest part of the enclosed area. Generally the excellent weather conditions provide a reasonably stable position of the equipment. The Agenor (IFREMER/ORSTOM) echo integrator is used on real time to provide 6 mn interval integrated values, or later in the laboratory to process transmission by transmission the data recorded on a DAT tape-recorder in the field.

Visual observations are made using the wide angle camera coupled to the transducer as mentioned above, which is connected to a video tape recorder equipped with a precise revolution counter and allowing a performant slow motion and frame by frame play-back. A microphone is also connected for eventual comments and for checking the synchronisation between tape and video recording. A 6 meter tube ended by a one meter graduated bar is used for calibrating the size of the video pictures according to the depth and to the monitor screen size (fig. 2). Another method is to take into account the physical caracteristics of the lens and monitor, as it has been done for photographic camera by Yarvik and Murav'yev (1982).

The array of video cameras set around the net and on the bottom can provide informations on the fish movements inside the net. When the fish are schooled, it can also be localized inside the net by using an omnidirectional sonar or an aerial camera (blue-print project). Other observations are done by a free diver using a Nikonos V photo camera.

A 60 watt underwater loud speaker Aquavox can be used to emit natural or atificial sounds in order to stress or to attract the fish.

All the processing equipment is installed either on a research vessel anchored close to the net or on a large instrumented raft, providing a support for the transducer and the camera which remains more stable and shallow than it would be on a vessel (at least in the coastal area where the experiment was carried out).

Preliminary information has been collected on a small school (100 kg) of Clupeid *Harengula jaguana* and Carangid *Decapterus punctatus* in Martinique. In Venezuela, the same equipment has been used to observe a 5 ton school of *Sardinella aurita*.

II.2. Examples of bias measurement

This installation can be used to study the influence of external parameters related to scientific surveys or to fisheries, and to quantify them. For instance, the sound attenuation within concentrations mentioned by Röttingen (1976) and observed by Olsen (1987) in schools, can be studied in detail from specific schools already well-described. The influence of visual or auditive stimuli on the fish movements and density can also be studied using this approach. More specifically, the influence of the tilt angle distribution on the mean volume backscattering strength (Buerkle, 1983; Foote, 1980) can be measured.

Circadian rythms in fish behaviour are well documented (Ali, 1980; Pitcher, 1986). Nevertheless, the common dispersion behaviour of the schools during the night is not supported by all observations and it seems that fish are able to school under very low light level (Glass and Wardle, 1986). For instance, the 5 ton school of *S. aurita* observed during 20 hours showed stable integrated values during the day and extremely large fluctuations during the night with some values close to zero (fig. 3). These low values correspond to a complete absence of the school below the transducer during the 6 mn records, while during the day the school was permanently under the transducer, as indicated on the echograms. The same behaviour was observed on another school recorded during six hours (4.00 p.m. to 10.00 p.m.). The location of the school during the night has not be investigated, but the most interesting point in this experiment is the the analysis of the very high values observed immediatly after the sunset (about four times the day values). These values cannot be explained by a higher occurence of school during the 6 mn interval. In fact the echogram analysis indicated in both cases (day and sunset) a permanent presence of the school. This is confirmed by the analysis of the mean densities per sample above a 50 mv threshold, which also indicates very high densities (table 1; fig. 4), and by the analysis of some samples of emissions. Therefore it is clear that the mean density of the school increases dramatically after the sunset. More detail on the internal structure of this school are given by Gerlotto and Fréon (this meeting). However, the influence of the net, even in such a large enclosure, cannot be ignored and complementary in situ observations must be implemented.

III METHODOLOGY IN SITU

III. 1 TS measurement

Different methods of TS measurement have been already performed on single fish (caged, tethered or wild in situ) or on number of live fish in a cage (Johannesson and Mitson, 1983; Foote, 1987). Each method presents its own advantage and limitations. The three main problems to solve are:

(1) to perform the measurement on fish behaving as closely as possible to their natural behaviour and physiological condition,

(2) to take into account the effect of the transducer beam pattern,

(3) to take into account the bias introduced by high fish density (acoustic shadowing or re-radiation) when school echoes are integrated.

During the last decade the scientific effort was oriented toward the resolution of only one of these three problems at once, by measuring in situ individual wild fish when distributed in low density (dual beam or split beam) or by measuring fish in a small cage. Olsen (1986) intended to estimate the sound attenuation under a large herring school, but as far as we know, very few attempts of TS measurements have been done on wild concentrations, although this seems possible when certain conditions are satisfied. In this case, the above mentionned three problems are all overcome.

Using Johannesson & Mitson's (1983) notation, where S_v is the mean volume back-scattering strength, we get:

$$S_v = 10 \log \rho_v + TS \text{ dB} \qquad (1)$$

where TS is the mean target-strength and ρ_v the mean density expressed in number of fish per cubic meter. If certain conditions are satisfied, the mean density ρ_v of a thin fish layer can be estimated using a sounder and a camera. This can be done considering the volume V of the truncated cone delimited on the one hand by the camera field of view and on the other hand by the upper and lower limits of the layer (d_1 and d_2), obtained from the sounder (fig. 2). So we get:

$$h = d_1 - d_1$$
$$r = tg\ \theta_1\ d_1$$
$$R = tg\ \theta_1\ d_2$$

$$V = \pi \frac{h}{3} (R^2 + r^2 + Rr)$$

If the layer density is likely homogeneous and presents a fairly constant thickness, and if the mean depth of this layer is rather constant during a few seconds, then some sampled views can be used for estimating the mean density inside the volume V. For instance on a stable 30 second sequence the sampling frequency could be of one frame each second. The frame by frame system of the video recorder can be used, or a digitalized picture can be analysed on a computer.

The species composition and the mean fish length can be estimated either by fishing or by using the video for measuring the fish on the monitor and calculating the rising factor from the calibration results and according to the mean depth given by the sounder. If the layer thickness is too high and introduces a large variability of the apparent lengths measured on the screen, then only the largest fish can be measured, considering that they are located in the upper part of the layer (such a method supposes a narrow distribution of the body lengths and tilt angles inside the schools). Other approaches can be developped using stereo camera or a second video camera (or photo camera) with a large focal lens providing a narrow depth of field.

In this last case, a narrow interval of depth can be sampled inside the layer by measuring only the fish presenting a good resolution. The calibration of this second camera must be achieved under identical conditions to those taking place during the experiment on the school (turbidity, light intensity and direction), using the same graduated tube or better a dead fish. This will provide both the precise mean depth of sampling and its range.

For instance, if the transducer and the camera lens are properly choosen in order to have the angle θ of the lens much greater than the mean angle of the transducer beam at -3 dB, therefore the S_v values can be assumed to be representative of the mean acoustic response of the transducer for a given depth, when the layer is observed on the whole screen surface.

Some experiments were conducted after fixing the camera and the transducer on the raft, but others were realized with these devices fixed on the bottom and oriented toward the surface. According to the depth of the layer and to the water transparency, one or the other method is suitable. If the fish directivity diagram is supposed to present a vertical axis of symmetry -as usually admitted- then the results must be consistent. Observations from the bottom present three advantages: first the camera and the transducer are absolutely stable and provide less variable data, second the pictures are perfectly contrasted ("shadow show") and third there is absolutely no influence of the equipment on the fish behaviour.

Knowing S_v and o_v, TS can be easily calculated.

The two main advantages of this approach are first the completely natural behaviour in our experiment and second a more random distribution of the fish with respect to the transducer beam pattern.

This methodological approach cannot be applied to all species and biotopes. It is essentially adapted to some coastal pelagic species (or small demersal species living in schools), living in transparent water. The following conditions must be satisfied:

(1) distance between the fish layer (or school) and the set camera-transducer inside a 2 to 12 meter interval, i.e. the layer must be close enough to the bottom or to the surface,

(2) water transparency enabling one to count fish using the camera,

(3) layer or school not too thick or too dense

(4) homogeneous density of the fish layer, without "vacuoles", and presenting a rather stable thickness,

(5) if the camera must be used from the surface, shallow ground and homogeneous sea bed color providing a good contrast with the fish.

Further experiments carried on inside the enclosure on the same school should provide estimations of the measurement variability and indication on the repetitivity of the behaviour influence on the TS.

III.2 Avoidance reactions

Two kinds of experiments on avoidance reactions have been done: first reproducing a standard survey routine and changing alternatively on parameter (i.e. boat speed, light on board) from one ESDU to the other, second, special experiments on a prelocated school or concentration.

Concerning the first kind of experiment, the influence of the light on board has been studied during 8 hours with the main light of the bow alternatively switched on and off every 6 mn (Levenez et al. 1987). The echograms and analysis indicated clearly a strong vertical avoidance of the fish layer which dive 30 to 40 seconds after switching the light on and exhibited an increase of its thicknes (fig. 5). Surprisingly, the integrated values did not indicate a significant difference between the two sets of data, suggesting that the avoidance reaction is in this perticular case strictly vertical:

-mean integrated values of 40 ESDU with light on: 1995
-mean integrated values of 42 ESDU with light off: 2057

An accessory but interesting result of this experiment concern the few schools observed at night on the bottom under the layer: they apparently also react to the light by a decrease of their high and a probable increase of internal density.

The second type of experiment is derived from Olsen (1979). At night, in order to measure an eventual lateral avoidance of the fish, a small boat was stopped over a large fish layer, waiting for the passage of the research vessel steaming as close as possible to it. The acoustic signals are recorded on both embarcations with periodic signal of synchronization communicated by radio. Different trials have been done at different speed for the main vessel and with all the possible combinations of light switched on or off on each embarcation. All the data are not yet processed.

By day, The experiments were performed on surface schools easy to detect with the eyes: a dinghy carrying the acoustic equipment (EYM and recorder) was placed on the route of a moving school and stopped waiting for the passage of the school under it. Then the research vessel (24 m) was called by radio and passed over the same school a few minutes later, recording the reaction of this school when disturbed by the vessel (fig. 6). This methods allows one to measure the diving behaviour of the school under the vessel, which in turn permits an estimation of its tilt angle (Gerlotto and Freon, this meeting).

IV. CONCLUSION

It has long been known that fish behaviour probably has a great impact on the results of acoustic surveys. Nevertheless, it has been necessary to wait for technological improvements of the observation tools before being able to sucessfully measure this impact. These tools are of two kinds: acoustic (multi-beam sonar, dual-beam and split-beam sounders, etc) and optic (photography as well as underwater cameras, digital process of the pictures, etc). In some favourable conditions the use of both systems is possible, this is particularly the case of tropical waters (transparency, temperature, open sea conditions, etc...)

The methodology presented here has already been applied on some pelagic fish in the caribbean and has made it possible to obtain some results on the biases due to behaviour changes when the fish are disturbed by the observer. In fact it seems that these biases are not so important as had been supposed, and this could indicate that the results of former surveys are not so bad.

Another point is that in favourable conditions the optical observations are very useful for confirming the accuracy of the acoustic data. The routine use of this equipment could be helpful in tropical waters, keeping in mind that it would be performed with a special methodology that has not yet been totally realized.

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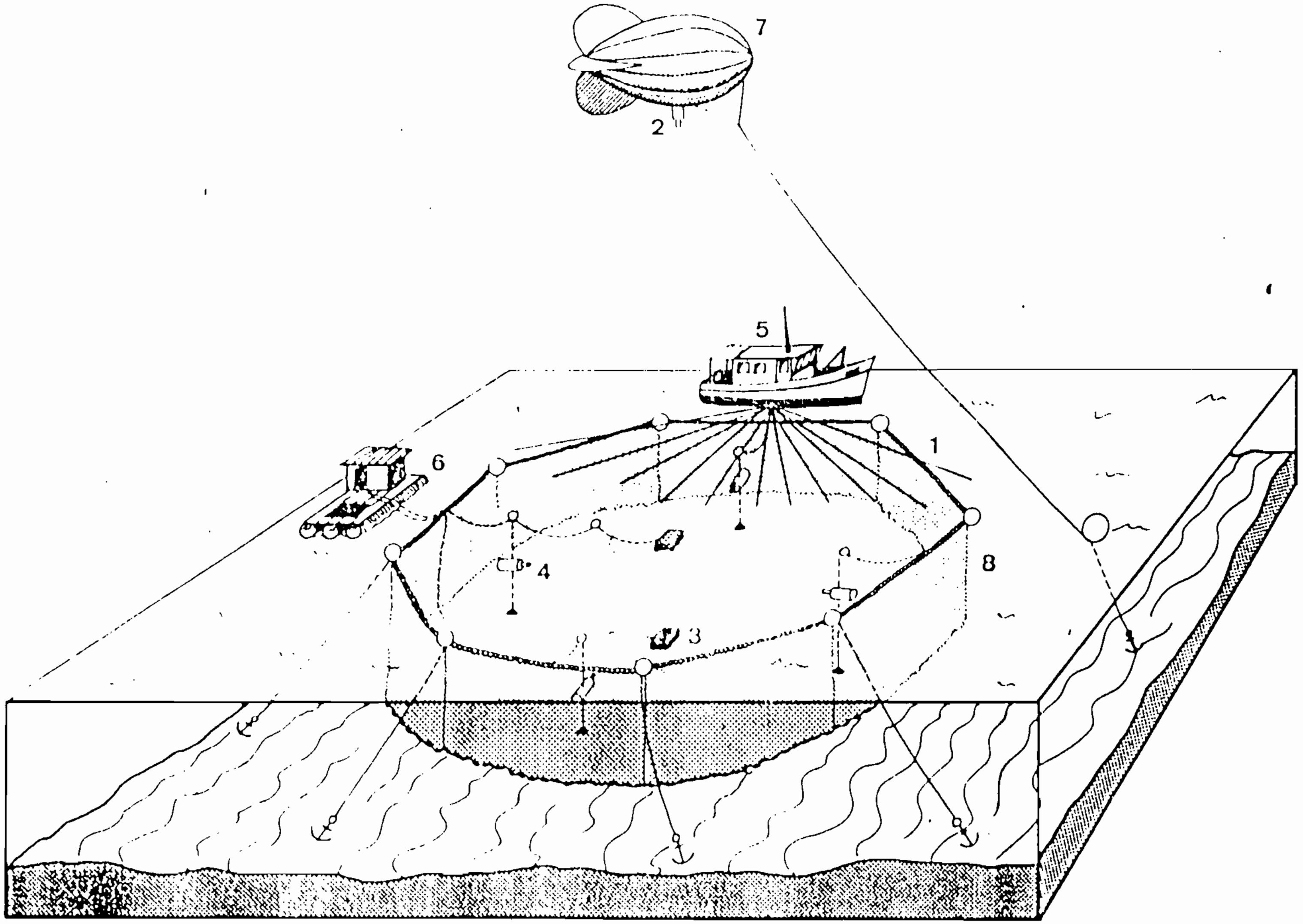

Figure 1. 'Mesocosm' installed in Martinique

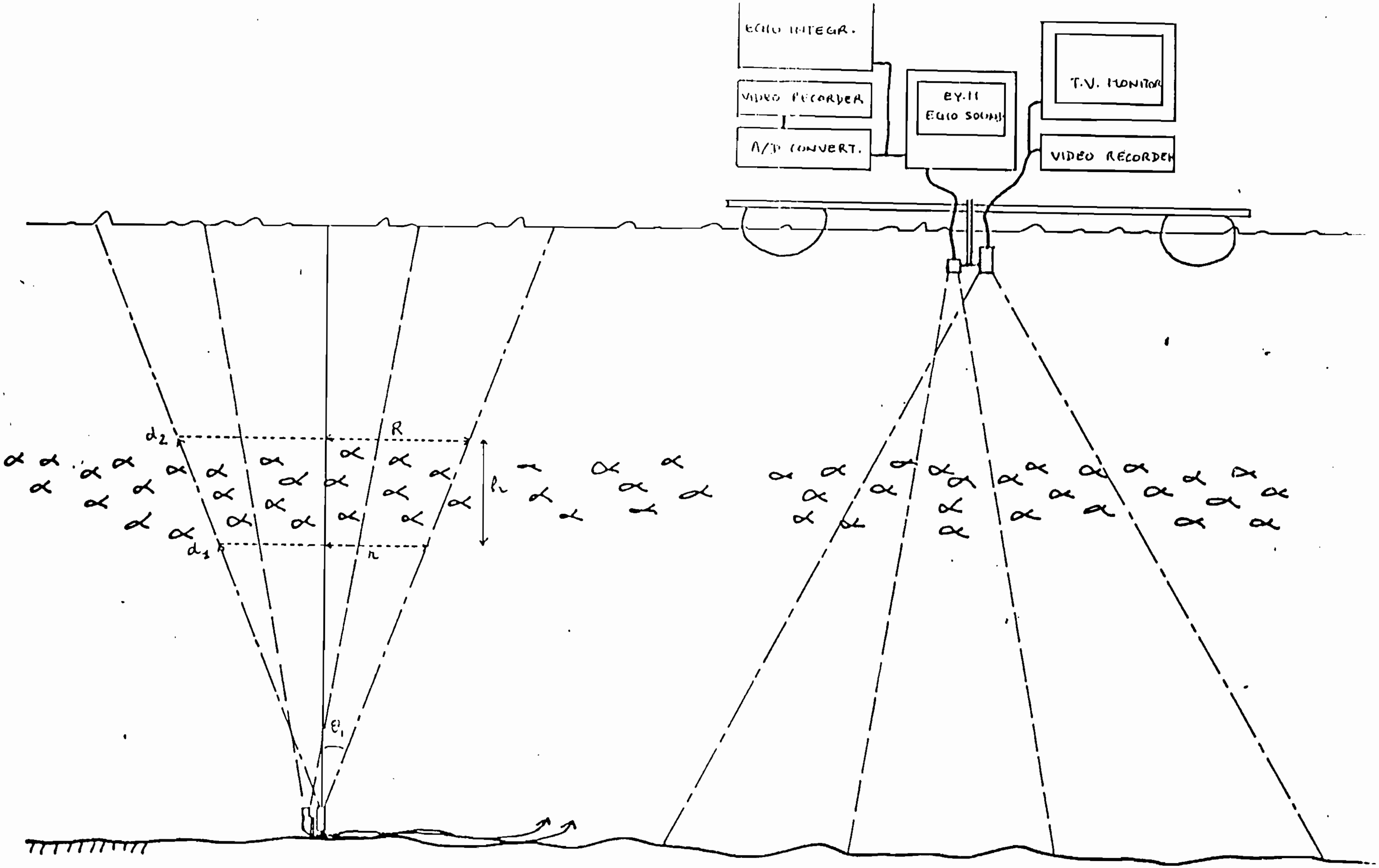

Figure 2. Description of the system used on an instrumented raft for TS measurements on fish in schools

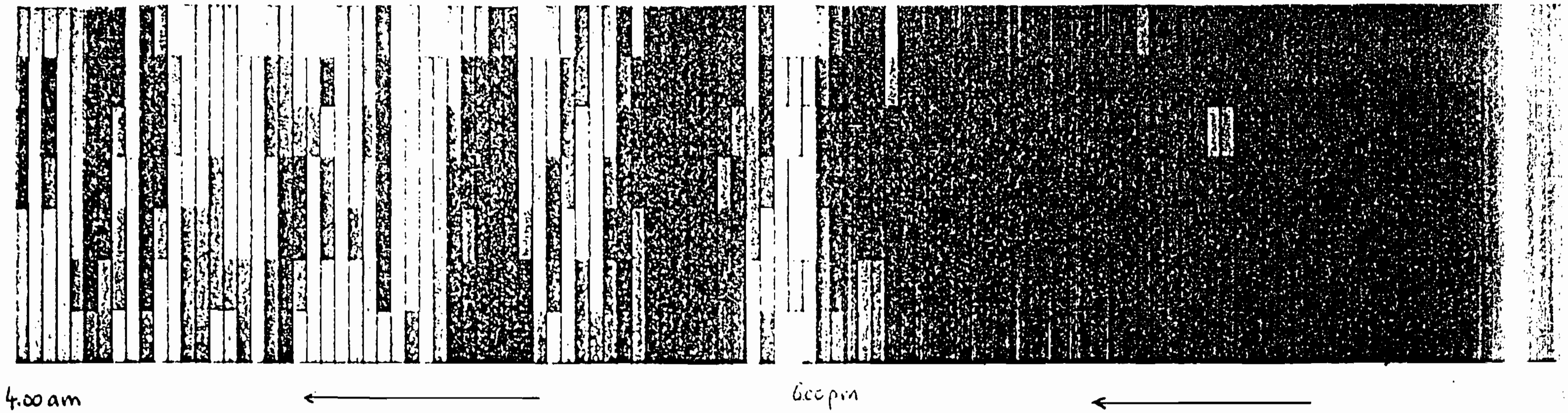

Figure 3. Evolution of the relative densities in a sardine school for 6 minutes intervals, in 1 meter layers (inside the mesocosm)

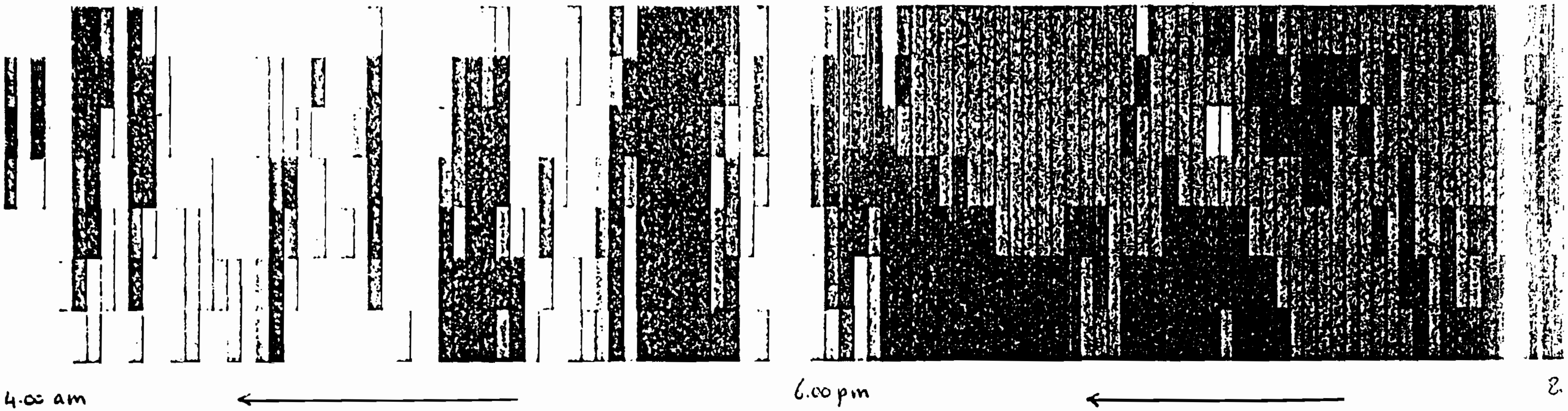

Figure 4. Evolution of the occurence index in a sardine school for 6 minute intervals in 1 meter layers (inside the mesocosm)

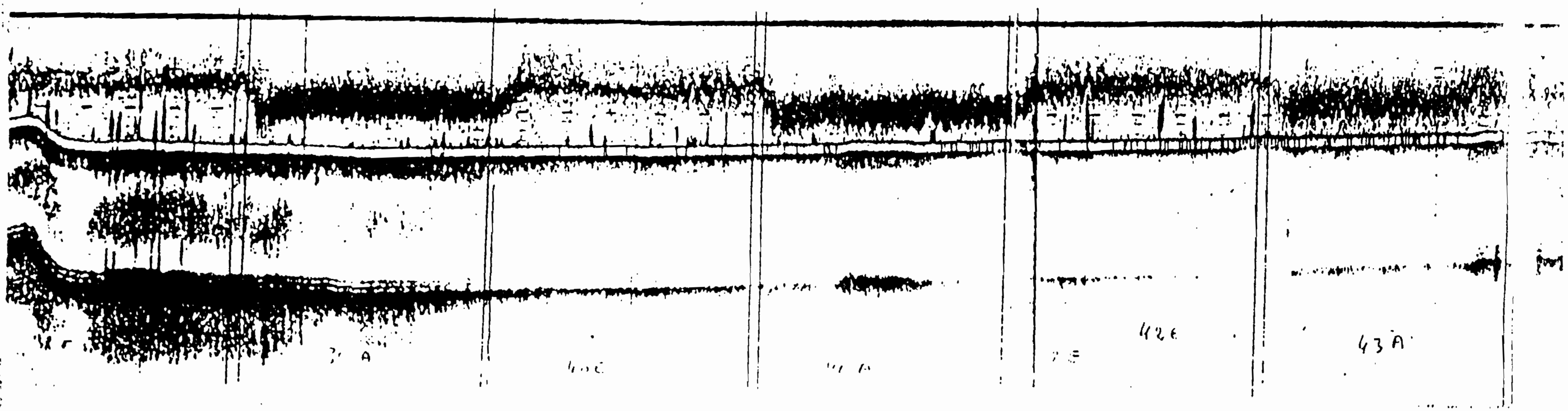

Figure 5. Example of echogram during the night, with lights switched on and of during 6 minute periods

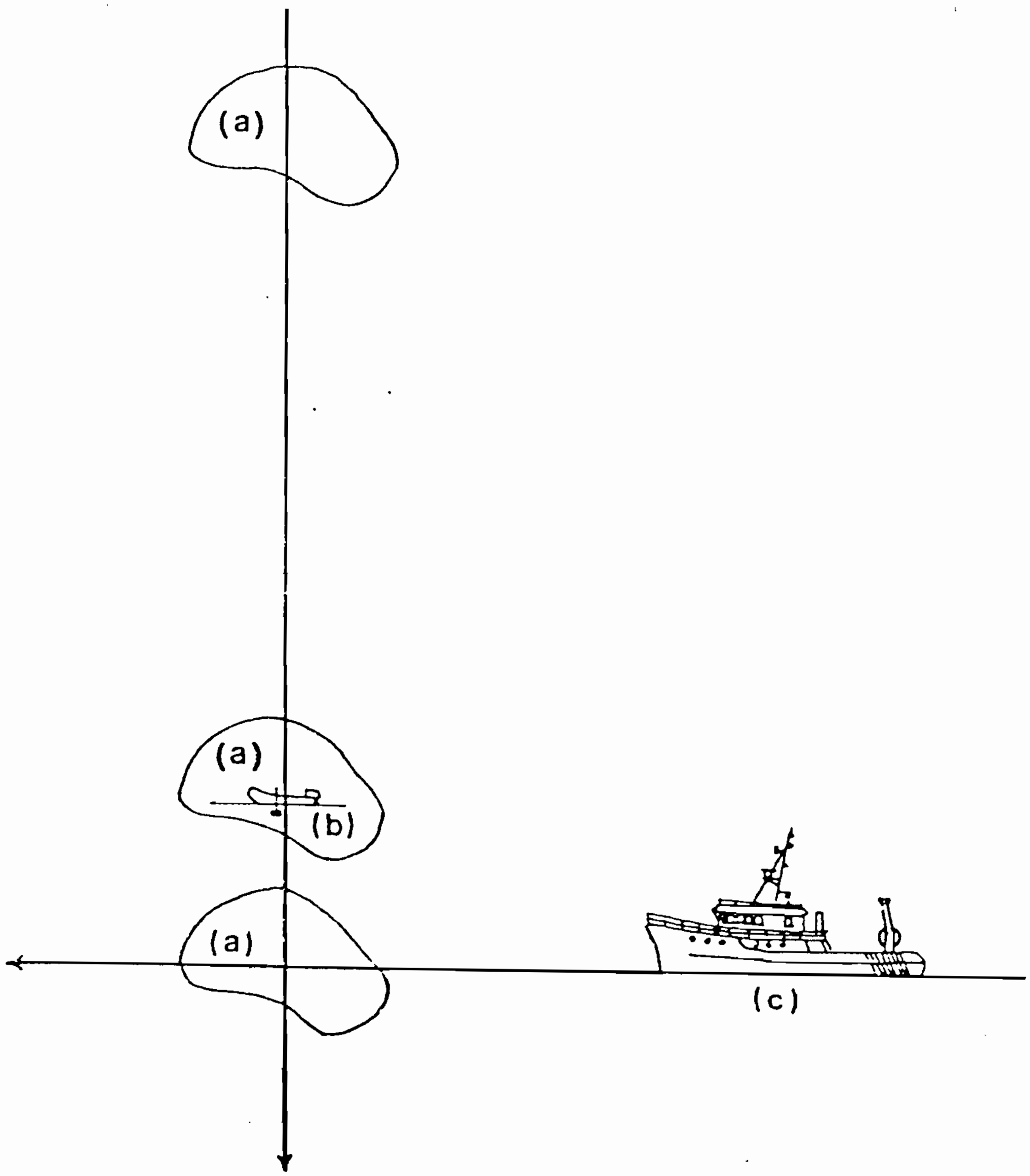

Fig. 6 - Description of the methodology used to compare the position and movement of a single school under natural and stressed conditions.

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INFLUENCE OF THE STRUCTURE AND BEHAVIOUR OF FISH SCHOOL ON ACOUSTIC ASSESSMENT

by

François Gerlotto & Pierre Fréon
Pôle de Recherche Océanologique et Halieutique Caraïbe
ORSTOM, BP 81, 97256 Fort-de-France Cédex,
Martinique (French W.I.)

ABSTRACT

The study of the internal school structure and behaviour of pelagic fish provides interesting information in relation to acoustic surveys, specially when comparing the undisturbed structure to the structure observed under a vesse passing over a school. The methodological approach envolves *in situ* observations as well as observations carried out on encaged fish. It combines visual and acoustic technics, described in another communication (Fréon and Gerlotto, this meeting).

The internal school structure is heterogeneous, including vaccuoles, and changes when the school is overpassed by a vessel by day. In this latter case a compression of the upper layer of the school is observed. The influence of this school structure on the variability of the density estimation has been studied. For the surface schools, the usual rate of sampling (90 transmissions/s at 8 to 10 knots) may be too low for some heterogeneous schools. Other consequences of the school structure on acoustics has been discussed.

The diving reaction of *S. aurita* under a vessel seems rather limited in comparison to herring schools. This reaction in only sensible in the first 20 m and its mean amplitude is only 5 m. It seems that this amplitude is inversely proportional to the initial school depth. Such a limited amplitude allows one to estimate that the fish tilt angle is lower than 10° when the school is overpassed. Therefore the underestimation of density is probably negligible.

The propeller noise in front of a vessel is attenuated by the hull and the resulting funnel-shaped acoustic shadow should be responsible for the limited lateral avoidance reaction observed when the fish previously located on the vessel route is overpassed. If this result is confirmed, it

could invalidate the use of lateral towed body close to the hull.

RESUME

L'évaluation de la précision des résultats de prospection acoustiques passe entre autres par l'étude de la structure et du comportement des bancs pélagiques, aussi bien dans des conditions naturelles que lorsqu'ils sont perturbés par le passage d'un navire observateur. Cette étude est effectuée par l'intermédiaire d'observations acoustiques et optiques, réalisées sur des bancs libres ou en enclos.

La structure interne des bancs est hétérogène, combinant zones denses et vacuoles, et peut changer lorsqu'un bateau passe au-dessus d'eux. Dans ce cas on observe une compression de la partie supérieure des bancs. L'incidence de ces structures sur la variabilité des estimations de densité est étudiée: dans les conditions normales de prospection, le taux d'échantillonnage (90 émissions/mn, 8-10 noeuds) peut être trop faible sur certains type de bancs superficiels.

Les réactions de plongée de <u>Sardinella aurita</u> sous un bateau semblent assez limitées, inférieures à celles des harengs, par exemple. Cette réaction n'est sensible que dans les 20 premiers mètres, et son amplitude moyenne est d'environ 5 mètres. Dans ces conditions on a calculé que l'impact de l'angle de plongée sur les mesures de TS des poissons est négligeable.

Le bruit de l'hélice est en partie masqué sur l'avant par la coque du bateau, formant un cône d'ombre acoustique qui canaliserait les poissons et qui expliquerait le faible évitement latéral de ceux situés exactement sur la route du bateau. Si cette observation est confirmée, elle peut remettre en cause la validité des résultats obtenus à l'aide d'un transducteur remorqué latéralement près du bateau.

I. INTRODUCTION

Different school characteristics may have an important influence on acoustic survey results, such as: their distribution, shape, behaviour, sound attenuation, shadow effect, etc.

The study of the internal school structure of pelagic fish would in these conditions provide interesting informations in relation to acoustic surveys, specially when comparing the undisturbed structure to the structure observed under a research vessel passing over a school. These studies are part of the EICHOANT program where the methodological approach involves <u>in situ</u> observations as observations carried out on encaged fish. The methodology, combining visual and acoustic technics, is described in an other communication (Fréon and Gerlotto, this meeting).

II. SCHOOL STRUCTURE OF UNDISTURBED FISH

II.1. In situ results

Acoustic observations of two schools of sardine (one of Sardinella aurita off Venezuela, the other of S. maderensis off Cameroun) were recorded under a drifting dinghy. The data of each transmission were integrated separately. The first school was observed for 87 seconds and 264 transmissions were recorded. The school structure presented strong density variations in space as shown in fig. 1, where each rectangle represents the density inside a one metre layer for one transmission. The average density is higher on the lower part of the school, and some "vacuoles" appear at different layers.

The second school of S. maderensis shows a different structure, more homogeneous in global density, but still irregular in structure (fig. 2). The sampling rate was two times lower than when observing the venezuelian school and only 86 transmissions were recorded.

One must keep in mind that these results may present bias owing to some acoustic limitations, such as absorbtion, sampling overlapping, multiple reflections, fish behaviour (tilt angle, bubbles release, etc.) which have to be taken into account (Mac Lennan and Forbes, 1982). The visual observations enables one to overcome some of these limitations.

The reality of apparent vacuum structures inside a school has been confirmed by visual observations on Harengula jaguana observed in free undisturbed schools. In fact the true observed structure looked more like intricated twisted columns crossing each other, than real spherical holes. More over, important density variations were observed on free S. aurita and Decapterus punctatus schools appeared neat differences in the interfish distance between the rear and the front part.

II.2. Encaged school structure

Evidently an encaged school may have a different behaviour than a free one. Considering this fact, the cage was built as wide as possible, but it is important to keep this point in mind.

A 5 ton school of S. aurita, encaged in a 35 m diameter surrounding net set close to the beach on a 12 m depth ground were studied for 20 hours in Venezuela. The methodology and the global results will be presented by Fréon and Gerlotto (this meeting). The daytime acoustic data, analysed transmission by transmission, indicates an heterogeneous vertical distribution of the fish inside the school (table 1). Visual observations confirm the presence of vacuoles and column structures as noted on free H. jaguana schools. This would enable one to suppose at a first approximation that there are no heavy differences, as far as density structure is concerned between free schools and those encaged in a sufficiently wide enclosure during the day (night behaviour has to be studied in more detail).

III MODIFICATION OF SCHOOL STRUCTURE AND BEHAVIOUR BY A SURVEY VESSEL

III.1. Vertical migration of a disturbed school

Five schools were observed succesively by a drifting dinghy and immediatly after passed over by a research vessel according to the methodology already described. Their vertical distribution is presented in table 2 and figure 3.

SCHOOL #	4	5	6	7	8	Mean
UNDISTURBED						
Top	4	2.5	7	4	1.8	3.85
Bottom	16.5	13	24.5	31	31	23.20
Extension	12.5	10.5	17.5	27	29.2	19.35
DISTURBED						
Top	9.5	10.7	11.5	9.5	10	10.25
Bottom	18.5	18.5	27.5	33.5	35.5	26.7
Extension	9.0	7.8	16.0	24.0	25.5	16.45
MEAN DIVE						
Top	5.5	8.2	4.5	5.5	8.2	6.4
Bottom	2.0	5.5	3.0	2.5	4.5	3.5
Mean	3.75	6.85	4.0	4.0	6.35	4.99

Table 2. Location of the top and bottom of the five observed schools (in metres below the surface)

Three conclusions can be drawn from these observations:

- all the schools dived before the boat passage, without exception, and the mean dive is 5 m;

- The school nearest to the surface dived deeper

- in addition to the vertical migration a compression of the school was observed: the upper part dived deeper than the lower part (6.4 m and 3.5 m respectively). Therefore it seems that the fish reaction follows a gradient of intensity according to the distance of the stimulus (fig. 4).

A second measure of the vertical avoidance is obtained by processing transmission by transmission the acoustic records when overpassing a school at a lower speed (4 knots) than the usual survey speed. The real gravity centres of 9 school were calculated from the density by layer (fig. 5A). The same global result as previous was observed: the surface schools present a stronger reaction towards the boat (fig. 5B).

Knowing that the interval between to consecutive transmissions is 0.33 s, the diving speed of the surface school has been estimated at 0.1 m/s. Another interesting point is the difference in the displacement of the gravity centre during the vessels passage: the gravity centre presents large amplitude movements at the begenning of the vessel passage and then is more stable during the second part.

III.2. Internal structure of the disturbed schools

Secondly the density inside the school was investigated. In order to limit the influence of the external shape of the school, we defined the upper part of the school the first layer with fish detection, and then the following layers received the numers 2, 3, 4, etc. Then all the transmissions having the same number of layer were placed on a same line in order to get an homogeneous presentation of all the results (fig. 6). Nevertheless, the densities of the different schools in layer 1 cannot be taken into account because this layer is in general completely unoccupied by the fishes.

Two different types of density distribution can be observed. On figure 7 an unimodal distribution may be seen where the highest density was observed in the upper layers (with exception of layer 1). This case concerns 7 of the 10 recorded schools, with very similar distributions. On figure 8 the density inside the 3 remaining schools looks different, apparently bimodal. In fact this last schools represent a particular case because their bottom was reaching the sea bed and then their vertical migration was naturally limited.

It is interesting to compare the results of disturbed schools to the undisturbed school of the same species observed in the same area. The data of the venezuelian school presented in figure 1 was processed in the same way and it can be seen on figure 9 that the density distribution obtained here was completely different. Of course, before drawing up any conclusions, further observations need to be carried out specially on undisturbed school.

IV. DISCUSSION

The heterogeneity of densities inside a fish school has been already mentionned by Cushing (1977) who studied the horizontal distribution of the fish inside sprat and sandeel shoals, using a scanning narrow beam sonar. This heterogeneity has two main consequences with respect to acoustic survey: first it increases substantially the confidence limits of the abundance estimation if the sampling rate is too low, second it invalidates some approaches of school biomass or density estimations based on school size or on average interfish distance.

IV.1. Influence of the sampling rate

It is well known that during the daytime surveys, most of the biomass of pelagic species is detected in schools. Sometimes more than half of the estimated biomass of survey results of the density and dimension measurement from a few large schools, which only represents a few minutes of insonification over a cruise of several days. In such cases, it is important to verify that the sampling rate of the school is high enough to provide a reasonable confidence limit of the schools biomass. This problem is decisive for schools located close to the surface, i.e. in the upper part of the selected scale.

In order to investigate this point, we have simulated different sampling rates on the venezuelian school and studied the variability of the results. Considering the high speed option used on the EY-M in this experiment (about 180 transmissions per minute) and the relatively low displacement of the fish with respect to the transducer (between 0.5 and 1 m/s), it can be assumed that the sampling rate was very high. During a routine survey the sampling rate is necessarily lower owing to the boat velocity and to the lower number of transmission per second.

The different systematic sampling rates were obtained by using successively one transmission every 2, 5, 10, 15, 20 of the 264 transmissions data set. The results indicate a relatively stable mean and standard deviation up to a 1/10 rate of sampling, then the values present a higher variability (table 3, fig. 10). In usual conditions of an acoustic survey (8-10 knots, 90 transmissions/mn), the same school would have been sampled at a 1/10 rate and the estimation would have been acceptable. Nevertheless this point has to be taken into consideration for measuring the precision of schooling stock evaluations, as we are usually close to situations where data begins to present a rather important variability.

IV.2. School volume and biomass

In order to overcome the limitations of the vertical sounder when used for acoustic survey (avoidance, limited sampled volume) different authors tried to estimate the abundance by using the number and size of schools detected by a lateral or multibeam sonar (Lamboeuf *et al.*, 1982; Misund and Ovredal, 1988). The combination of horizontal sonar and vertical sounder can also be used to estimate the fish density or the mean volume back scattering strength when one of these two parameters is already available (Misund and Beltestad, 1988). Estimations of fish density inside layers were obtained by combining acoustic and photographic measurements (Buerkle, 1987), or using the relationship between average interfish distance and average fish length (Serebrov, 1976; Misund and Beltestad, 1982). These methods are based on the assumption that the mean density of a school detected by a sonar is the same as when detected by a sounder, and/or on the assumption that the interfish distance is homogeneous.

Numerous potential reasons of failure from these two assumptions have been identified by Misund and Ovredal (1988). Our results confirm the limits of these approaches, at least in the particular case of our observations (species, environment). The homogeneity of interfish distance was generally observed on small schools in a tank (Van Olst and Hunter, 1970; Weihs, 1973) but it seems that this regular structure is relevant *in situ* only at a first order scale of the school, which presents several lacunae as mentionned by several authors recorded by Pitcher and Partridge (1979). The mean density inside a school can change according to the season (Olsen, 1981) or circandian cycles (Fréon and Gerlotto, this meeting), and to external stimuli such as the approach of a vessel. In such cases the interfish distance and/or the size of the lacunae can change. This phenomenon probably explains most of the differences between estimations of fish density inside schools or layers based on homogeneous fish spacing and estimations based on vertical sounder data. The first one underestimates the real density because the vaccuoles are not taken into account, the second provides overestimated values because the density artificially increases in the upper part of a disturbed school (at least during the day). A secondary effect of this contraction of the upper layer is a probable increase of multiple scattering effect which may "shadow" the lower part of the school (Rottingen, 1976; Olsen,1986).

IV.3. Vertical avoidance, tilt-angle and bias

The main aim of the study is to identify eventual bias in biomass estimations by acoustic and then to propose some corrections. The modelisation of fish behaviour with respect to the vessel distance proposed by Olsen *et al.* (1983) is difficult to apply with our data set, due to the lack of information (vessel noise, etc...). Moreover the results obtained in Venezuela are somewhat different from those of other authors. If the general avoidance pattern is similar to the observations made on other Clupeoids such as herring (Olsen *et al.*, 1983; Misund, 1987) or sardine (Diner and Masse, 1987), the diving reaction concerns only the surface school in Venezuela. Over 20 m the fish reaction is unsignificant, whereas Olsen *et al.* (1983) observed fish diving up to 40 m using a boat similar to ours. Moreover, in our case the fish reaction is only important in the upper part of the school. From these facts the opportunity for a correction of the data is now envisaged.

In order to estimate the mean tilt angle of the fish when diving, this angle has been considered as the result of its horizontal and vertical speeds. The maximum horizontal speed has been estimated at 4 knots from the pelagic net data and bibliographic sources (Hara, 1987; Misund, 1987). Then the assumption that most of the school flights are in the prolongation of the boat route axis was made. This assumption is based on three arguments:

(1) if, following Olsen (1979), the propeller noise is considered as the main stimuli, the distribution of sound pressure obtained by Urick (1975) shows that the fish schools located exactly in front of the boat are "trapped" inside the acoustic shadow of the hull: when trying to escape laterally, they are deflected by an increasing noise gradient (fig. 11.)

(2) the previous point is strengthened by the results obtained by Misund (1987) when measuring with a multibeam sonar the mean horizontal flight angle of 43 schools 0.5 to 3 minutes before passing them over. Although the schools detected by the sonar more than a minute before being overpassed were probably not able to detect the shape of the sound pressure distribution, the mean flight direction fit more or less the diagram of sound pressure. Moreover Misund (1987) points out that during the few last seconds preceding the ship's passage, the lateral avoidance would be very low because only 2 of the 43 overpassed schools were not detected by the vertical sounder.

(3) Levenez *et al.* (1987) observed a strong diving reaction of *Sardinella aurita* layers due to the lights during experiments by night in Venezuela. Nevertheless this vertical avoidance was not linked to a decrease of the biomass, suggesting that the fish remain inside the acoustic shadow of the hull.

These observations do not imply that there is no lateral school aviodance, which may occur relatively far from the vessel and lead to a complete absence of detection through the vertical sounder (Olsen, 1987; Diner, 1987). In fact we have been exclusively interested in the schools which were insonified. In these conditions and under the pervious assumption, the tilt angle o of the fish is given by the simple equation:

$$\theta = \text{arc tg } \left(\frac{V_v}{V_h}\right)$$

where V_h = horizontal flight speed
V_v = vertical diving speed

The relationship between the variables θ, V_h and V_v is given in the figure 12.

The data presently available does not allow a modelisation of the diving reaction according to the initial depth of the school, from the vessels noise, vessels speed, etc.. Therefore, the present analysis is limited to the estimation of the tilt angle in order to see if it may lead to an underestimation of the biomass. The only data already useable according to our methodological approach are the measures of the gravity centre displacement (fig. 5A) because we don't know the time spent by the school diving during the first experiment. In our observations the maximum instantaneous speed of diving is around 0.3 m/s. According to the horizontal component of the movement, the fish tilt angle would fluctuate from 17°, for 1 m/s, to 10°, for 2 m/s which is considered as the maximum flying speed for <u>Sardinella aurita</u> (one must keep in mind that the gavity centre displacement represents an indirect estimation of the fish migration, supposing that an undisturbed school did have an horizontal distribution of the gravity centre on successive vertical cross-sections).

Referring to results obtained on herring, whose anatomy is close to <u>Sardinella aurita</u>, it appears that a 17° tilt angle led to a 20 dB lost for a 27 cm fish when using a 120 kHz frequency. Contrarily tilt angles lower than 10° led to unsignificant loss (Foote, 1983).

But if we consider now the mean values of the gravity centre movement (instead of it instantaneous values as previous), we can see that even for the surface school the mean vertical speed is only 0.1 m/s. At this vertical speed, an horizontal speed lower than 0.3 m/s would be required in order to obtain a tilt angle greater than 10°. The estimated horizontal speed of the schools leads to a tilt angle lower than 5°, which has a negligible influence on density estimations.

Nevertheless, some uncertainty remains on the usual horizontal flying speed of <u>Sardinella aurita</u>. Wardle (1977) noted that outburst speed of small fish can reach 25 body length which would give more than 5 m/s for a 22 cm fish (mean size of our fish), while other references recorded by Holliday (1977) mentionned a range of 8 to 12 body length. This author measured outburst speeds of 2.4 m/s on a undetermined school which mean fish length was estimated at 29 cm.

IV.4. Avoidance and vertical school distribution

The vertical mapping of school is one of the results of acoustic survey and can be of primordial interest in some cases. For instance the artisanal sardine fishery in the gulf of Cariaco (Venezuela) uses surrounding nets allowing only the catch of coastal surface schools. Therefore the precise vertical mapping of the ressource is essential for stock management purposes. The observed distribution of the schools (fig. 15) suggest that most of the ressource is located between 20 and 40 m in depth, and therefore inaccessible to the fishermen. Before asserting this conclusion, the influence of the vertical avoidance on the results must be taken into account.

From our preliminary results (fig. 3 and 4) it seems that the diving reaction is inversely proportional to the initial depth of the school and become negligible over 20 m. Even though our data does not allow a modelisation of the behaviour, we applied a preliminary rough correction consisting in a reduction of 5 m of the depth of detection for the school located in the 0 t 20 m layer.

Although these results cannot be generalized, in the particular case of the sardine stock of Venezuela the vertical avoidance does not seem to represent a major source of bias. The main problem now is to investigate if the importance of horizontal avoidance at a large distance from the vessel is responsible for a significant underestimation of the biomass. The difference between night and day mean density suggests that by day this phenomenon is important, but probably less in Venezuela than in other tropical areas, such as Western Africa.

V. CONCLUSION

The observations made on tropical clupeoids schools indicate some similarities and some discrepencies with similar studies carried out on temperate species.

The internal school structure is heterogeneous, including large vaccuoles, and may change when the school is overpassed by a vessel by day. In this latter case a compression of the upper layer of the school is observed. This school structure has a consequence on the variability of the density estimation, specially for the surface schools. The usual rate of sampling (90 transmissions/s at 8 to 10 knots) may be to low for some heterogeneous superficial schools.

The heterogeneity of the school structure leads to difficulty for the estimations of school biomass based on external volume (multibeam sonar) and density estimations using visual counting or a distribution model.

The diving reaction of S. aurita seems rather limited in comparison too herring schools. This reaction is only sensitive in the first 20 m and it mean amplitude is only 5 m. It seems that this amplitude is inversely proportional to the initial school depth. Such a limited amplitude allows one to estimate that the fish tilt angle is lower than 10° when the school is overpassed. Therefore the underestimation of density is probably negligible.

Although we have not enough data to confirm this affirmation, it seems interesting for us to present the following hypothesis: the propeller noise in front of a vessel is attenuated by the hull and the resulting funnel-shaped acoustic shadow should be responsible for the limited lateral avoidance reaction observed when the fish previously located on the vessel route is overpassed. This phenomenon could explain the surprising differences between the apparently reasonnable detections recorded by night on a fish layer when the hull transducer is used, meanwhile a lateral transducer records very poor detections. In this last case it is likely that the fish previously located inside the vessel route present a strong lateral avoidance. This hypothesis, if confirmed, would invalidate the use of lateral towed body close to the hull.

All these observations must be confirmed by further experiments. An interesting point to examine is the reason for the specificity of our results. Different speculative hypothesis can be made: the environment (clear and warm water), the species or the low rate of artisanal explotation of the stock could explain the differences with other areas. In addition to the well documented influence of the visibility (Pitcher, 1986), Wardle (1977) pointed out a potential influence of the water temperature on the fish outburst speed. The eventual influence of fish learning (Marler and Terrace, 1987) on the avoidance reaction could be investigated by a comparative study in Senegal and Venezuela where the same species of sardine is found in a similar environment but with a tradition of industrial fishing only in Senegal. In Venezuela the absence of sardine industrial exploitation-could enable the fish to associate the noise of a vessel to a danger because the artisanal fishermen use only outboard engines.

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85	0	1497	2291	954.7	5642	6231	3558	4158	0
86	0	559.4	4947	5219	3096	1714	6773	5494	0
87	0	316.2	959	4433	5636	7425	3413	10550	1254
88	0	5563	2824	1174	7220	13170	6033	3541	240.1
89	0	1677	4753	942.3	5098	7113	5104	9710	186.1
90	0	11720	11540	2157	8472	10900	6509	13010	0
91	0	1939	11080	4674	1602	3821	11050	12960	414.8
92	1163	7553	9751	1923	654.4	10490	7615	8295	672.4
93	0	3477	5030	2522	547.7	9950	13720	12660	2202
94	0	3461	1026	2796	199.7	1996	982.5	10340	1537
95	3209	10300	15970	9153	4248	5004	6486	15590	1440
96	5819	3042	3098	5010	4613	7756	12150	13010	838.8
97	253.7	10600	8914	7030	6899	7432	16230	11400	917.3
98	568.9	6579	3038	6953	1794	5247	9238	6097	1144
99	67.6	7221	4697	6241	5090	2752	5276	5917	1025
100	508.1	12460	9646	10210	7219	5917	4283	11600	220.9
101	1481	7131	13570	3231	6904	3671	12650	11510	848.5
102	3162	5554	3993	3209	5428	8578	1405	6512	230.4
103	492.1	15970	10830	10610	7726	6675	11140	10670	
104	0	2462	5579	9054	4011	9756	11990	11750	1020
105	0	6083	4971	6543	8099	9771	4479	4644	244.1
106	0	3820	9229	4145	8282	9365	6995	12370	0
107	62.5	1558	2709	6586	2073	7323	3914	4293	0
108	0	2248	10300	4155	14490	8057	7126	5536	1060
109	84.1	4367	6021	3447	15580	11530	3517	4534	76.4
110	0	3649	2752	2904	1592	2922	6451	2503	1591
111	0	3321	4347	4966	8225	2736	1339	8253	476.1
112	115.6	8040	5747	2546	2219	8260	5975	7559	773.9
113	290.9	8134	2502	5557	3004	4187	8313	7573	211.6
114	0	1793	6297	5437	3768	3615	2432	4226	0
115	369.9	1529	4903	3025	2395	10150	5005	4060	250.9
116	350.5	883.7	1670	5573	5753	14410	10920	6457	211.2
117	0	9703	6950	2787	717.1	740.2	6753	4526	1563
118	337.6	3746	5532	1272	3656	4045	8119	9632	
119	283.6	3051	6695	2853	1920	3065	2330	3226	1022
120	0	670.2	2025	2144	9799	3561	1425	2957	220.4
121	0	2504	5955	7523	1366	2455	4473	2173	525.1
122	2305	2577	1275	1540	4916	11770	8411	7701	
123	1305	4842	5060	3766	2798	4453	1201	6166	547.6
124	4933	1569	1695	7039	10130	6595	8208	9592	
125	225.4	2825	4020	7040	6391	4213	2298	5641	490
126	0	316.1	1140	718.1	2602	562.2	3011	3303	129.6
127	0	5099	1778	2687	1123	3977	8341	1377	122.5
128	7397	7434	2899	3360	4556	5624	14440	6712	0
129	751.2	5572	4970	4299	5284	12140	5023	1771	396.9
130	6156	6495	-2400	2960	3633	1286	5037	1822	260.1
131	0	5564	5144	1632	232.9	3215	8867	11060	697
132	0	6695	6925	4161	11720	2322	13680	9576	1512
133	146	5723	926.5	2402	9123	5757	11560	14620	1849
134	5888	3413	5552	2362	5880	2677	6316	5303	1038
135	0	3055	9176	4042	3320	1025	8858	4607	384.4
136	0	2163	7746	2533	6379	866.9	8722	9013	360
137	305	1566	2260	2638	4924	3245	7714	8476	462.4
138	0	2877	5725	2466	7445	5699	12190	11190	448.9
139	748.5	748.5	312.3	1884	1531	618.5	887.9	9552	968.4
140	436.9	1406	2370	363.7	654.3	4218	5205	1556	1344
141	308.6	1463	2909	988.3	2001	2316	11520	4937	168.1
142	84.1	4035	4915	1123	5519	6842	14250	5329	122.5

Table 1. vertical distribution of relative densities measured transmission by transmission inside an encaged sardine school, by day (densities obtained in 1 m layers).

bl. 3: Simulation of systematic sampling in the "Cariaco school"

Trial number	Sampling rate	N	Mean	σ
1	2	131	2 381	3 829
2	2	131	2 384	3 818
3	5	53	2 329	4 376
4	5	53	2 199	3 457
5	5	53	2 231	3 440
6	5	53	2 582	4 294
7	5	53	2 994	5 053
8	10	27	2 227	5 168
9	10	27	2 303	5 156
10	10	27	1 227	1 437
11	10	27	1 535	2 039
12	10	27	2 461	3 872
13	10	26	2 625	3 756
14	10	26	3 201	4 577
15	10	26	3 233	4 561
16	10	26	3 666	5 663
17	10	26	3 547	6 074
18	15	18	2 348	3 452
19	15	18	1 931	3 072
20	15	18	1 892	3 066
21	15	18	2 518	4 940
22	15	18	2 797	5 562
23	15	18	2 943	4 247
24	15	18	1 950	2 819
25	15	18	2 213	3 677
26	15	18	2 903	4 569
27	15	18	3 431	5 768
28	15	17	2 949	6 358
29	15	17	2 966	6 351
30	15	17	2 017	3 258
31	15	17	2 228	3 404
32	15	17	2 740	3 801
33	20	14	2 593	3 639
34	20	14	1 369	1 768
35	20	14	1 528	1 932
36	20	14	1 644	1 906
37	20	14	2 176	3 192
38	20	13	3 858	4 827
39	20	13	2 450	3 318
40	20	13	2 441	3 323
41	20	13	3 423	5 980
42	20	13	4 383	7 521
43	20	13	3 134	7 266
44	20	13	3 309	7 218
45	20	13	1 290	1 544
46	20	13	1 418	2 244
47	20	13	2 768	4 611
48	20	13	1 392	1 675
49	20	13	2 543	3 931
50	20	13	3 747	5 172
51	20	13	3 798	5 560
52	20	13	2 712	4 334

Figure 1. Vertical density structure of a *Sardinella aurita* school (Gulf of Cariaco, Venezuela).

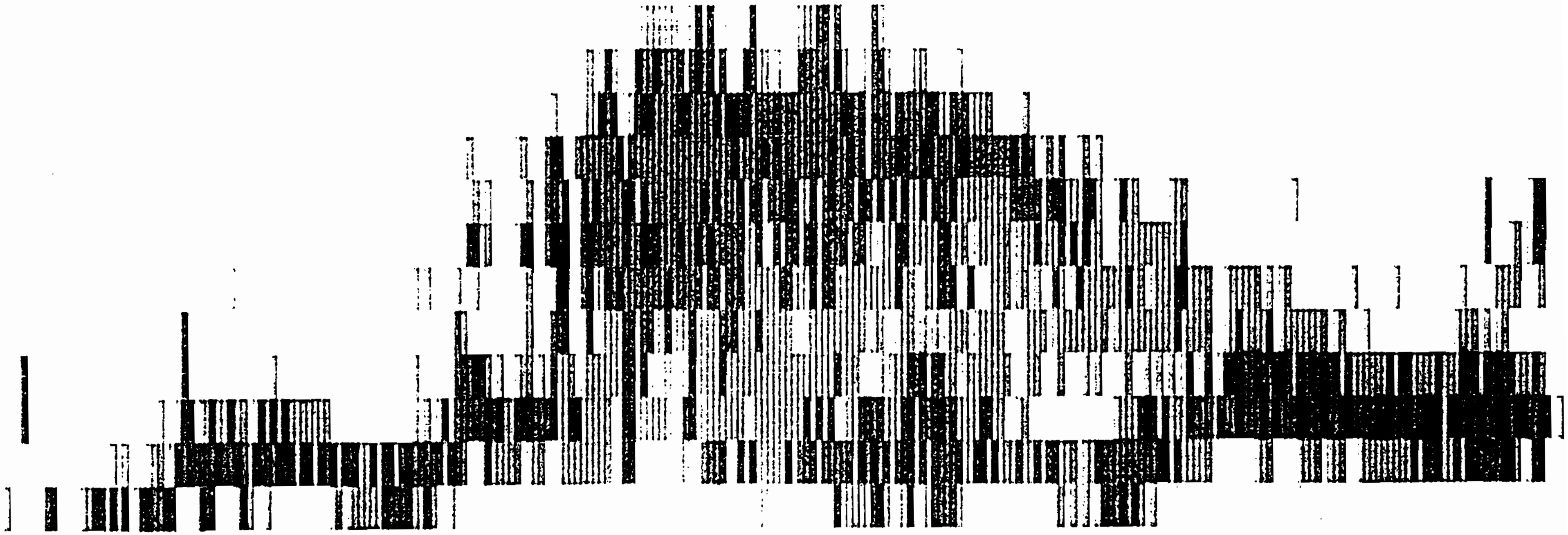
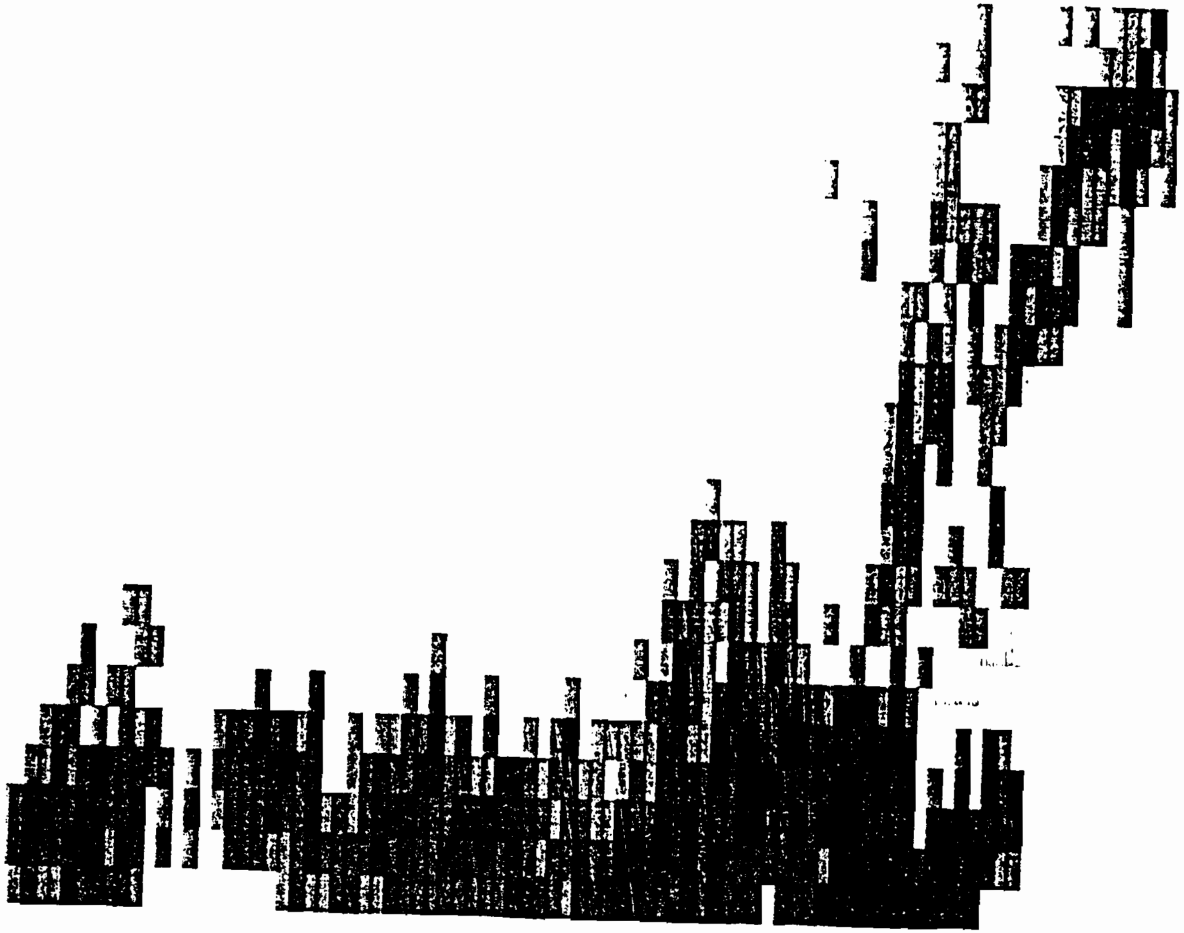


Figure 2. Vertical density structure of a *Sardinella maderensis* school (Gulf of Cariaco, Venezuela).



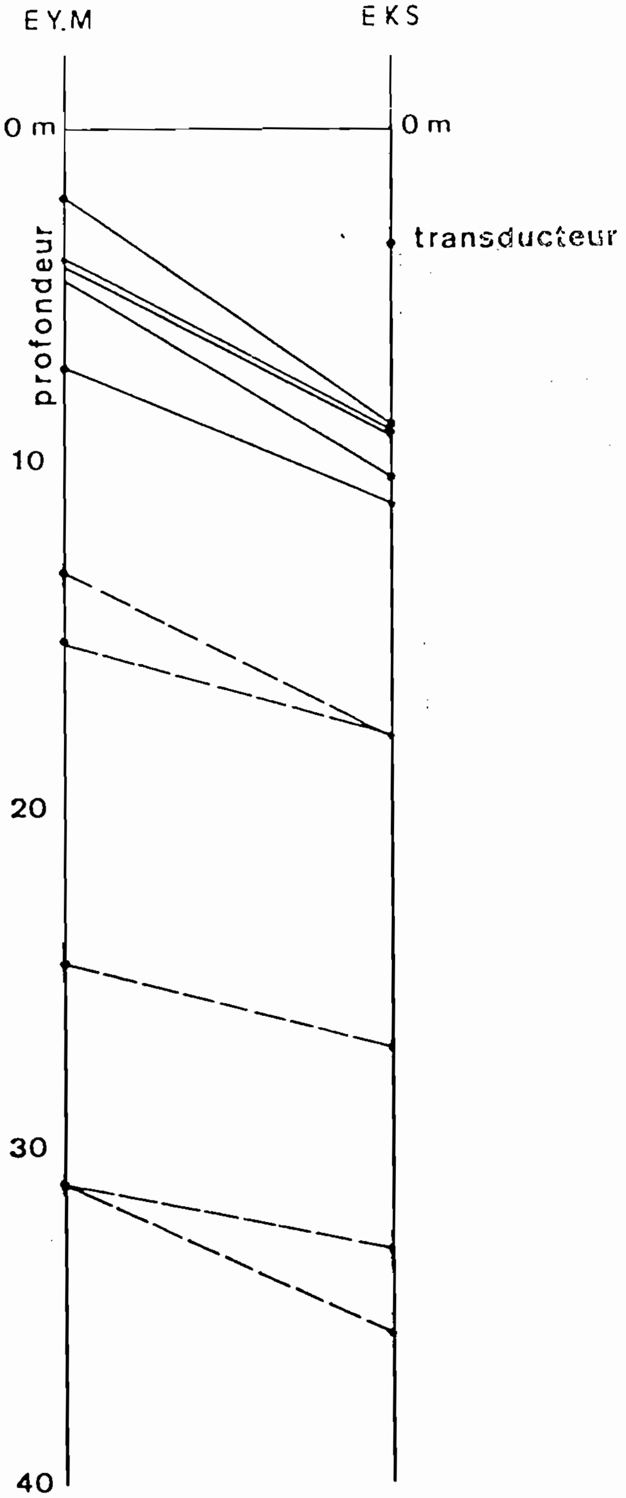
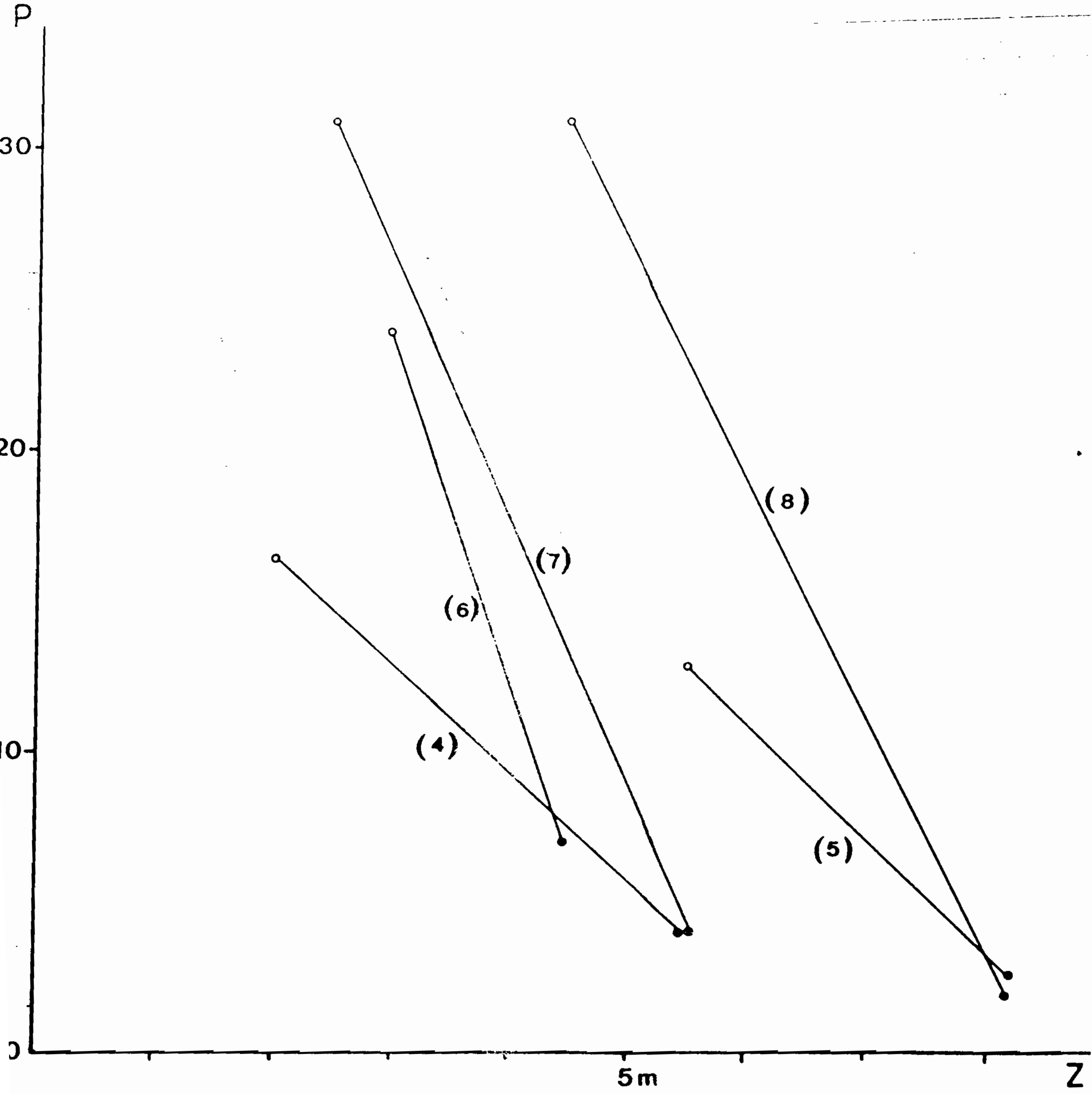


Fig. 3 - Evolution des profondeurs des sommets (———) et des bases (----) des bancs observés successivement sous la petite embarcation (EYM) et sous le N/O NIZERY (EK5).

Figure 3. Evolution of the mean depth of the top (________) and the bottoms (------) of some sardine schools observed successively under the dinghy (EYM) and the research vessel (EKS)



Fi g. 4 - Relation entre profondeur de départ (P) et ampleur de la plongée (z)

sommet du banc
base du banc

Figure 4. Relation between the depth of a school and the range of the dive for some schools

. top of the school
o bottom of the school

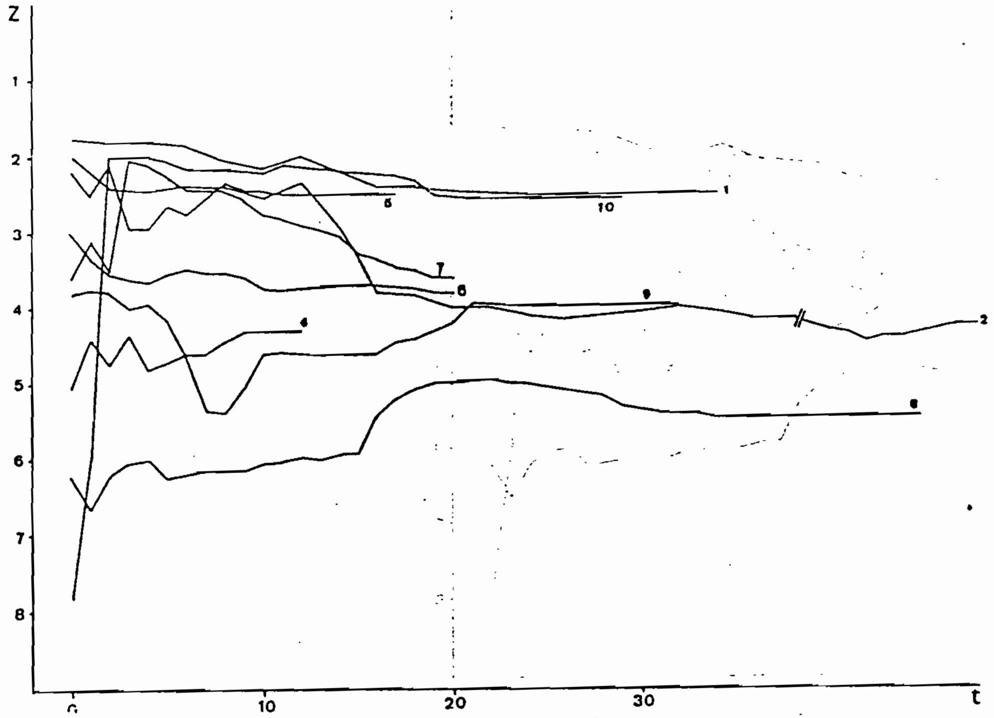


Fig. 5A - Evolution émission par émission (t) de la profondeur (z) du centre de gravité des bancs en mètres (par rapport au transducteur).

Figure 5a. Evolution, transmission by transmission, (t) of the gravity center's depth (z) of the schools (in meters from the transducer).

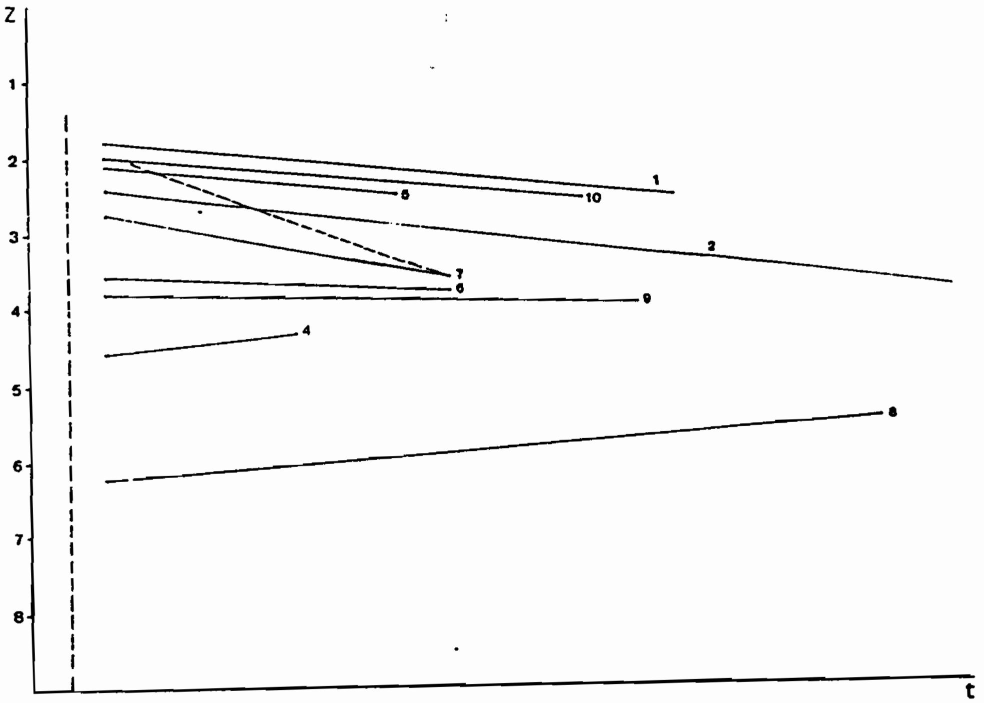


Fig. 5B - Représentation de la tendance moyenne de plongée pour chaque banc.

Figure 5b. Representation of the dive tendency for each school.

1	2	3	4	5	6	7
		1	1			
		2	2			
	1	3	3			
1	2	4	4	1		
2	3	5	5	2		
3	4	6	6	3		
		7	7	4	1	
		8	8	5	2	1
			9	6	3	
			10	7		

1	2	3	4	5	6	7	n° émission	
1	1	1	1	1	1	1	1	
2	2	2	2	2	2		2	
3	3	3	3	3	3		3	
	4	4	4	4			4	couche
		5	5	5			5	
		6	6	6			6	
		7	7	7			7	
		8	8				8	
			9				9	
			10				10	

Figure 6 - Principe de transformation des couches

Figure 6. Scheme of the conversion method (cf text)

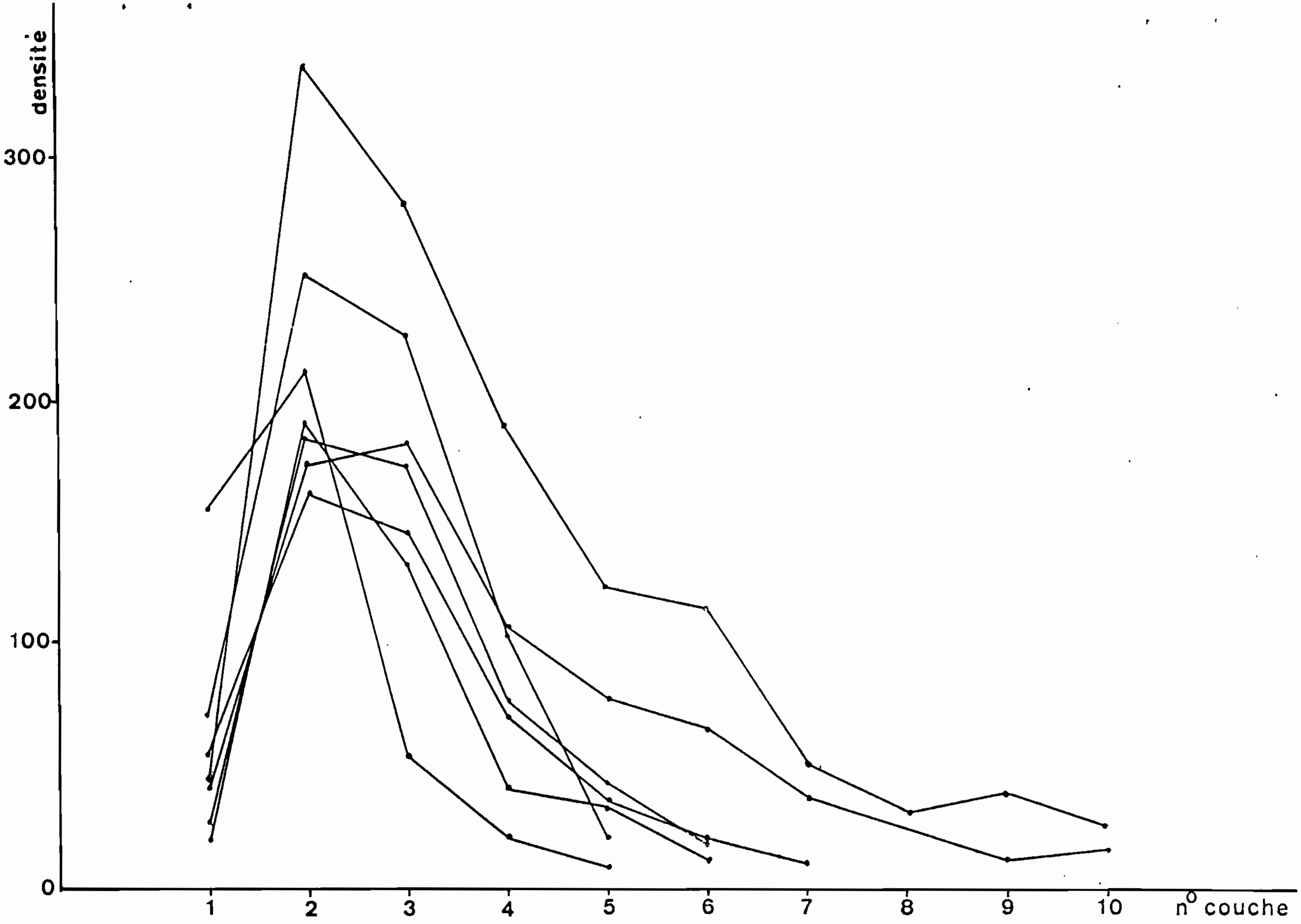


Fig. 7 - Densité moyenne relative dans les bancs pélagiques par couche de 1 m

Figure 7. Mean relative density in the pelagic schools, for each one-meter layer.

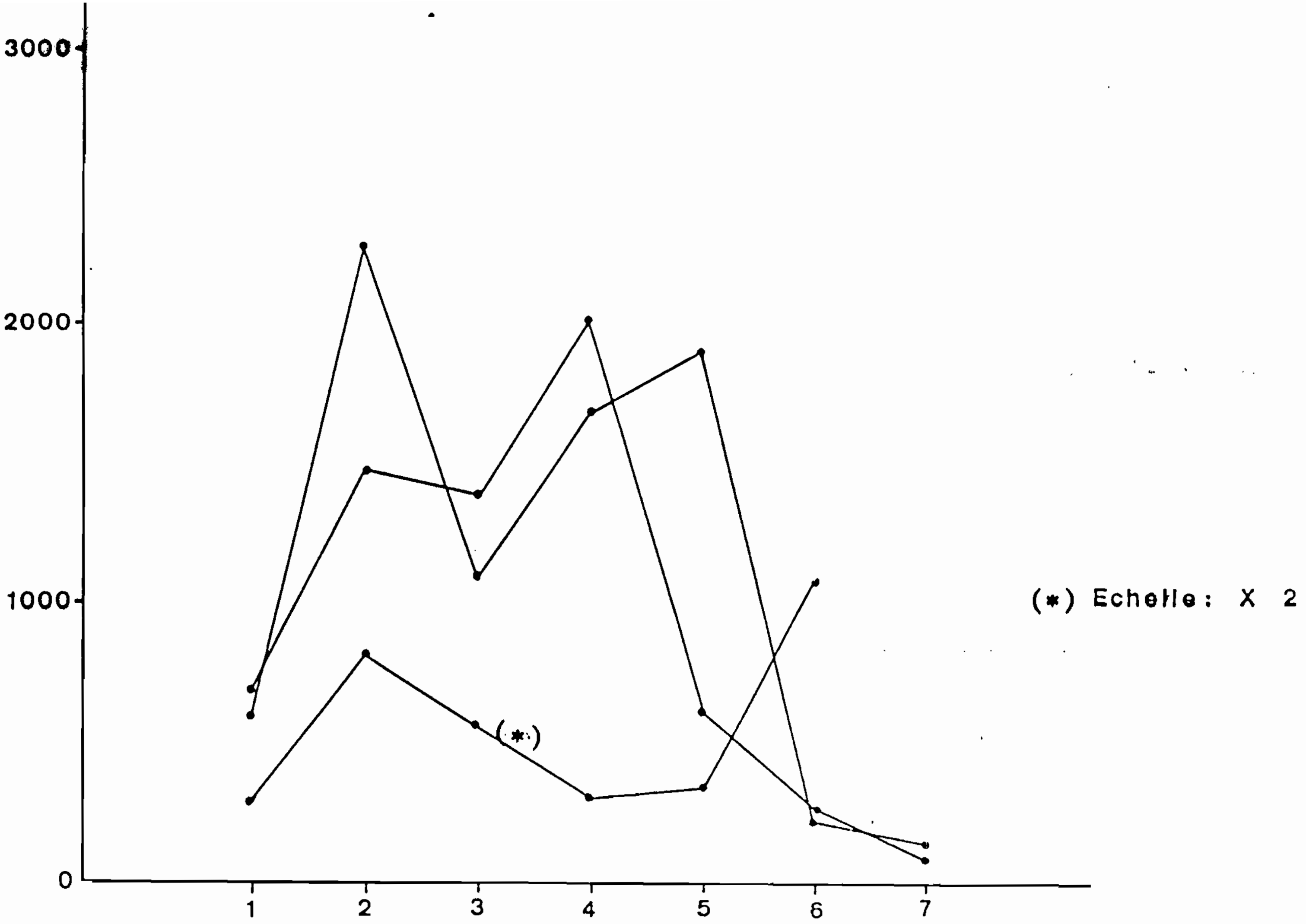


Fig. 8 - Densité moyenne relative dans les bancs "semi-pélagiques" par couche de 1 m.

Figure 8. Mean relative density in the "semi pelagic" schools for each one-meter layer.

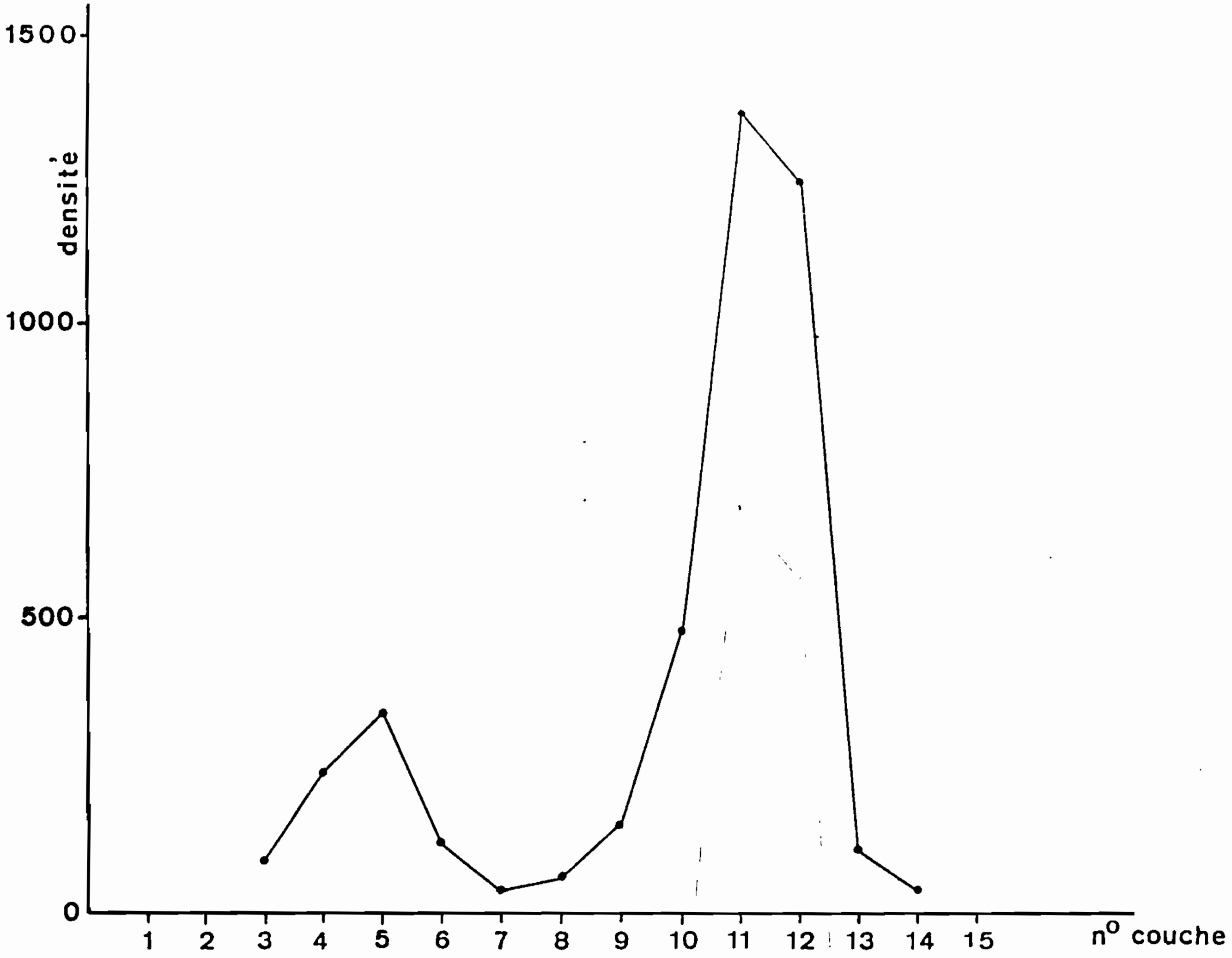


Fig. 9 - Densités moyennes par couches de 1 m dans un banc de sardinelles non perturbé, Vénézuéla.

<u>Figure 9</u>. Mean relative density in a non perturbed school for each one-meter layer.

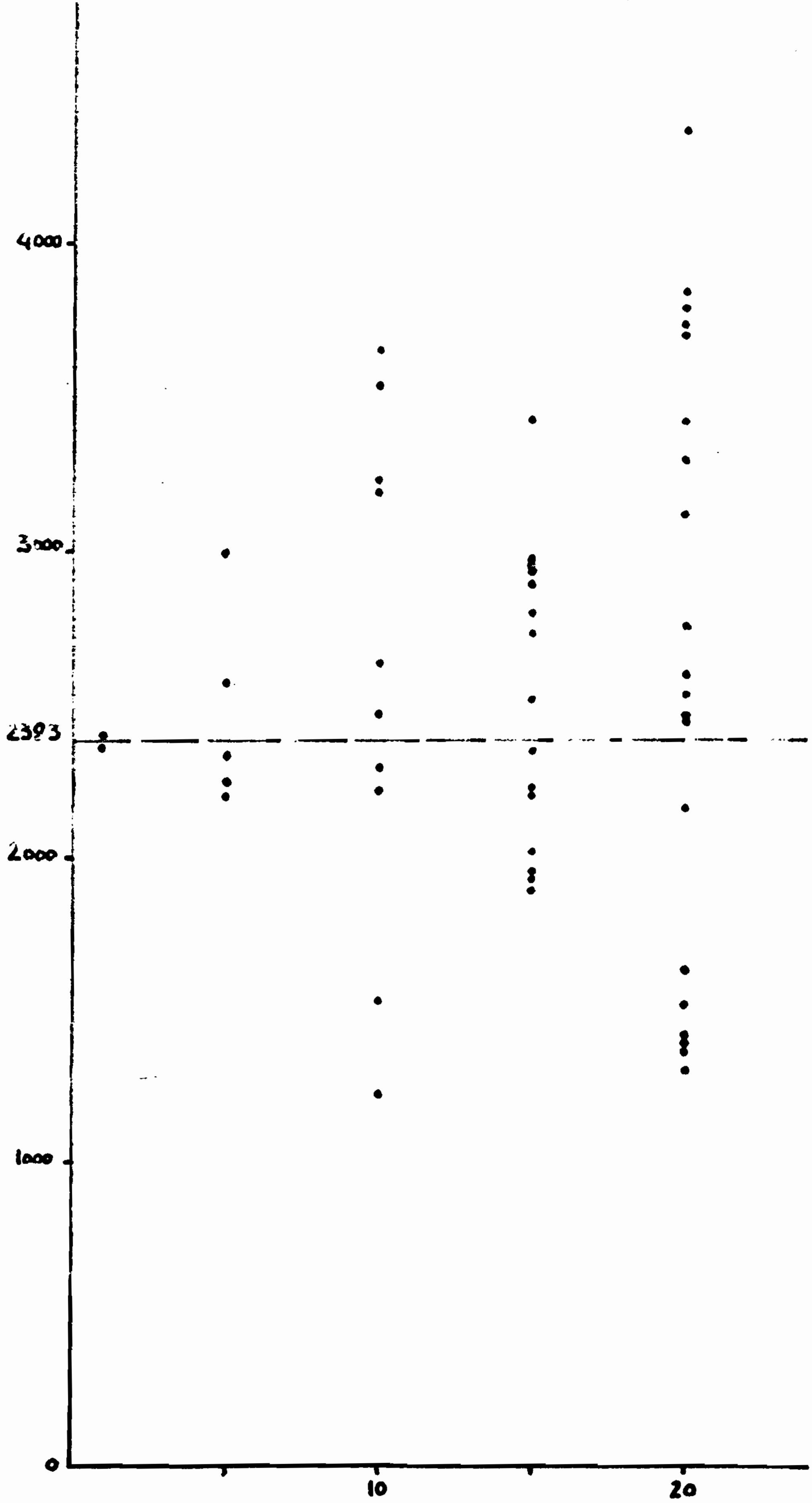


Figure [illegible]. Evolution of the [illegible] biomass [illegible] in the relative biomass evaluation according to sampling level [illegible]

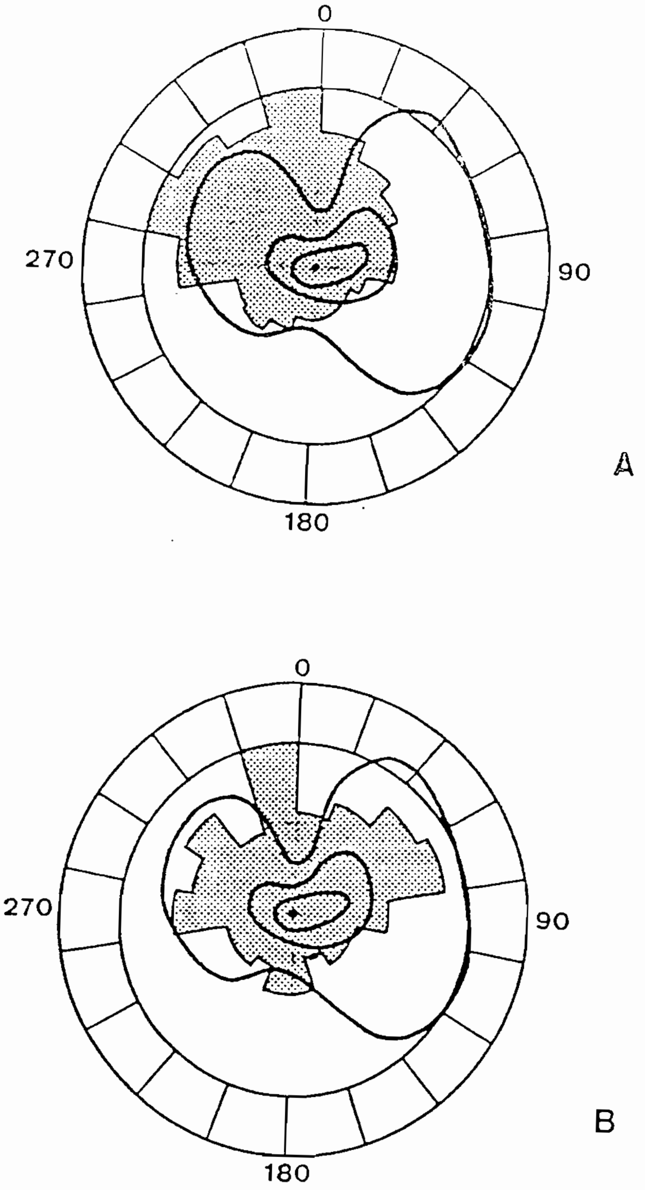


Fig. 11 - Relation entre bruit du navire et évitement des bancs

—— Gradient de pression sonore (d'après URIK, 1975)

▨ Proportion des bancs en évitement dans le secteur considéré (d'après MISUND, 1987)

A : bancs capturés à la senne
B : bancs libres

Figure 11. Sound pressure around a boat (from Urick, 1975), and (a) distribution of radial swimming direction for circled schools. (b) corresponding distribution for passed-over schools (from Misund, 1987).

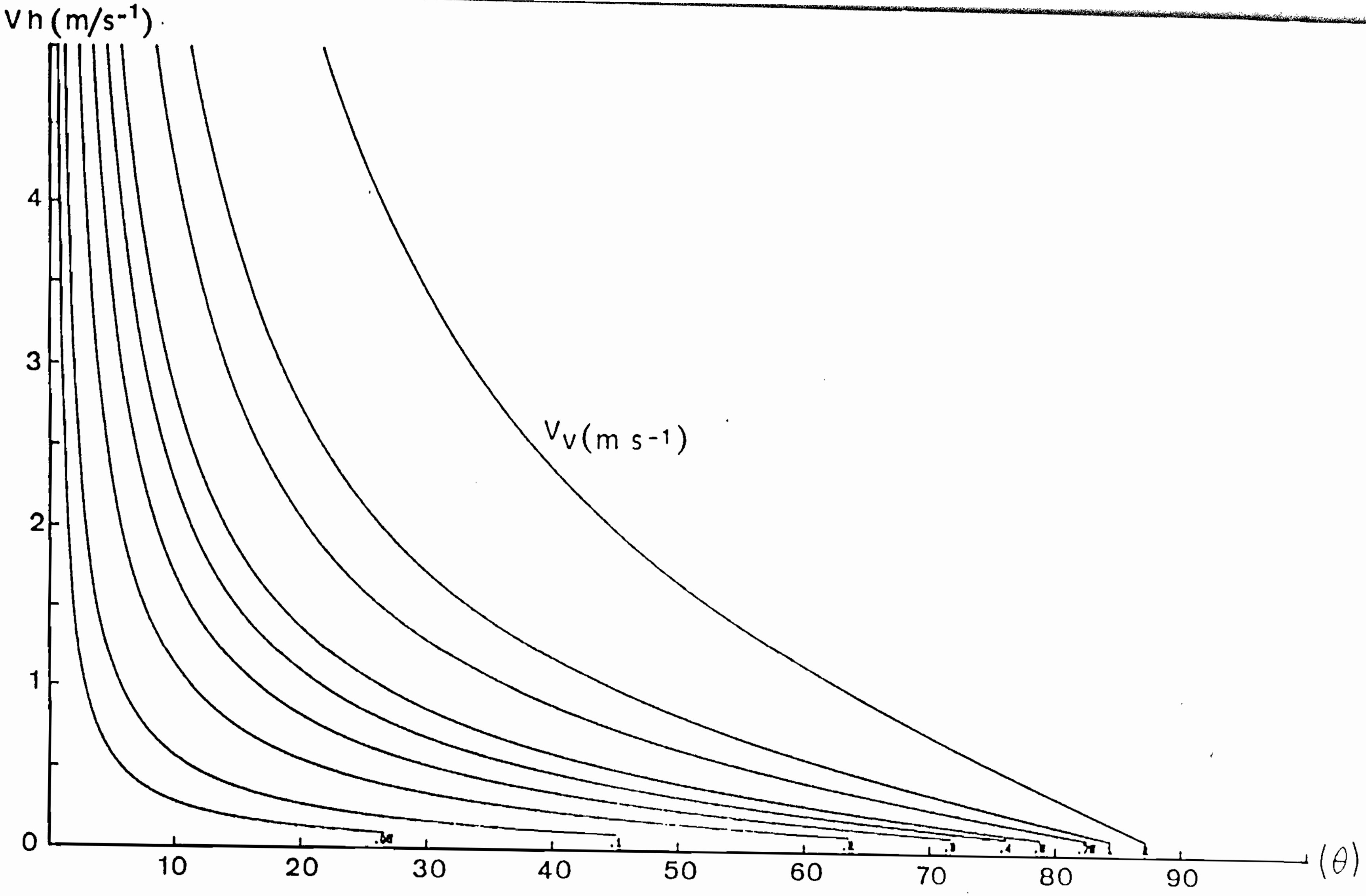


Fig. 12 - Relation entre angle du poisson (θ), Vitesse horizontale de fuite (Vh) et vitesse verticale de plongée (Vv)

Figure 12. Relation between vertical speed (v), horizontal speed (h) and tilt angle (θ) for *S. aurita* schools.

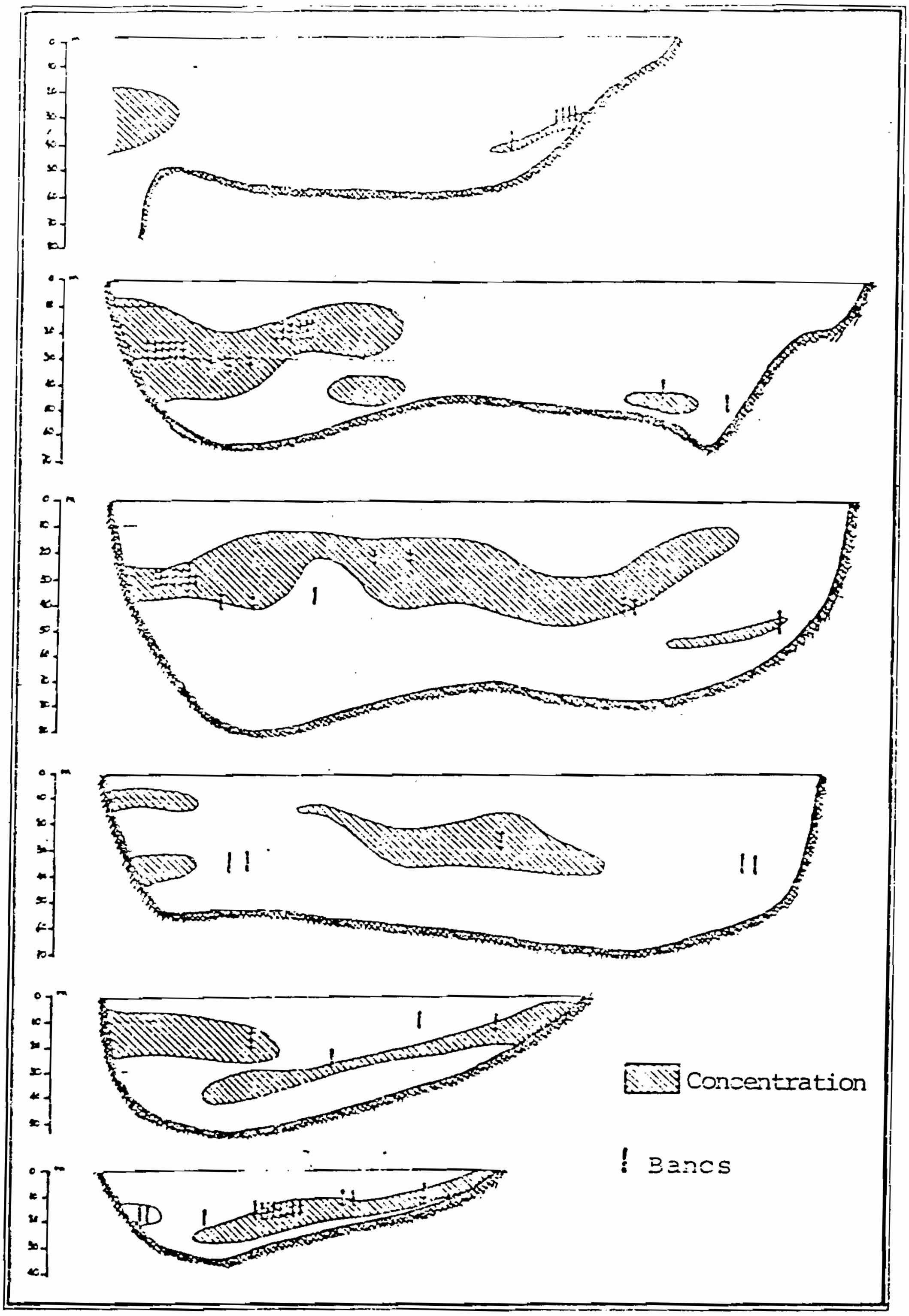


Fig. 13 - Répartition verticale diurne des concentrations et des bancs dans le Golfe de Cariaco.

Figure 13. Day vertical distribution of scattering layers and schools in the gulf of Cariaco.

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Session O

SHORT-TERM VARIABILITY OF SARDINELLA AURITA AGGREGATION AND CONSEQUENCIES ON ACOUSTIC SURVEY RESULTS

by

Pierre Freon, Marc Soria and François Gerlotto
Pôle de Recherche Océanologique et Halieutique Caraïbe
ORSTOM, BP 81, 97256 Fort-de-France Cédex,
Martinique (French W.I.)

ABSTRACT

A single fish assemblage of _Sardinella aurita_ was tracked over 24 hours by a research vessel equipped with acoustic devices in order to study the short-term variability of its distribution pattern in the Gulf of Cariaco (Venezuela).

Obviously the studied assemblage did not follow the usually observed aggregation pattern, considered to depend mainly on the light intensity. Nor did the mean depth of the biomass correspond exactly to the usual diurnal cycle pattern. Dense schools were observed during the first night in absence of moonlight; they dove from 15 to 35 m depth in the morning, but came back close to the surface (19 m) early in the afternoon and remained dense during the following night.

Furthermore the fish assemblage apparently presented a contagious structure most of the time, with an increasing density from the periphery (dispersed fish and/or small schools) to the center (large schools or aggregation).

Practical conclusions are drawn from these observations, specifically on the survey design (oversampling strategy on densest areas) and on the data analysis (inaccuracy of the night/day data split in some cases).

I. INTRODUCTION

The distribution pattern of coastal pelagic species, and especially of clupeoids, is usually documented as: deep schools regrouped in concentrations during the day, and surface layers during the night (Woodhead, 1966). Such a pattern, combined with the different avoidance behaviours observed between day and night periods, is generally one of the main reasons alleged to explain night-day differences in biomass estimates. Nevertheless, during acoustic survey this usual distribution is not always observed, and the relationship between the different distribution modes (school, layer, concentration) is not always clear, nor are the factors governing the changes observed in the structures.

Interpretation of the usual acoustic survey data when dealing with this topic is not easy because it is difficult to distinguish temporal effects from the spatial ones. In order to overcome this difficulty, we tried to follow the same fish assemblage during 24 hours, as did Buerkle (1986) on the Nova Scotia herring stock. The objectives of the study were:

- try to find any objective acoustic criterium allowing classification of the echos into different categories (schools, concentrations, layers, dispersed fish),

- following the nycthemeral evolution of the distribution pattern, in terms of aggregation mode and depth,

- in conclusion, infer from these observations some practical conclusions about the survey design.

II. MATERIALS AND METHODS

In order to facilitate the localisation and the tracking of the aggregation, a rich, confined and well-known area was selected for the study (Gines and Gerlotto, 1988): the Gulf of Cariaco (Venezuela), a 30x8 n.m. area, open to the sea by a relatively narrow mouth and having steep edges and a 50 m mean depth (fig. 1). On 26th and 27th November 1988, a preliminary 24 hour survey of the whole Gulf located the richest zone. Then a 1.5x3.5 n.m. rectangular track, located in the middle of this zone was performed 13 times from the 27th at 10:00 pm to the 28th at 11:00 pm. According to the apparent horizontal migration of fish (corresponding to similar previous observations) this rectangle was shifted four times to the south-west and once to the east during the study, as shown in figure 2.

The R/V La Salle (120 feet) was used for the survey, at a speed of 6.5 knots. A Simrad EY-M 70 kHz echo-sounder was connected to AGENOR, a digital echo-integrator. The integrator data were sent to a computer for automatic storage. A digital audio tape recorder was used for recording the sounder signal (DAT Sony). The transducer was fixed lateraly to the hull. A 3 mn time interval and 10 vertical layers (2-5 m; 5-10 m; 10-15 m; 15-20 m; 20-30 m; 30-40 m; 40-50 m; 50-60 m; 60-70 m; 70-80 m) were used for integration and a 50 mv threshold was retained. AGENOR provided the number of samples above the threshold per layer inside each ESDU, which allowed computation of the density by sample above the threshold (DSAT) as described by Marchal (1988).

No fishing operations were conducted during the survey, but according to the commercial landings and to the echogram characteristics, the bulk of the biomass consisted of small _Sardinella aurita_ (fork length: 12 cm), while the scattered bottom targets were recognized as catfish (_Bagre marinus_; 15 to 20 cm f.l.).

The detection was classified in six groups according to the echogram analysis: dispersed pelagic fishes, dispersed catfishes, pelagic layers, small schools with clear limits, large concentrations with uncertain limits, plankton. Most of the time, only one dominant group was observed by stratum (i.e. a 3 mn interval in one layer). Only on four occasions were two important groups of detection observed in the same stratum and the corresponding density was arbitrarily split in two equal parts.

III. RESULTS AND DISCUSSION

Echograms classification

In order to check the statistical significance of the echogram classification, the mean DSATs of dispersed fish, schools and concentrations were compared. These means are significantly different (p = .05), before and after logarithmic transformation (table 1).

However, the three distributions show important overlaps, especially schools and concentrations, suggesting that these two structures have the same internal density most of the time and differ mostly in size and shape. Nevertheless a more detailed analysis must be carried on from recorded signal, because DSAT is dependant on the threshold retained, on the depth (Marchal, 1988) and on the ESDU length. Other objective criteria characterizing the dimensions an density of the detection could also be used (Azzali, 1982; Rose et Legget, 1988; Souid, 1988).

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Log DSAT for:	Dispersed	Concentration	School
Sample size	743	194	141
Average	-0.835	1.28	1.57
Standard deviation	1.198	0.84	1.12
Minimum	-2.878	0.008	0.01
Maximum	4.280	3.719	4.08
Skewness	0.980	0.480	0.57
Kurtosis	0.823	-0.523	-0.71

DSAT for:	Dispersed	Concentration	School
Sample size	743	194	141
Average	1.202	5.26	9.52
Minimum	0.056	1.00	1.00
Maximum	72.2667	41.21	59.08

Table 1: Summary statistics of the Densities per Sample Above the Threshold (DSAT) for dispersed fish, concentrations and schools (crude and log-transformed data).

Biomass distribution

The bulk of the biomass (89%) was detected above 50 meters depth, and was represented mostly by concentrations and schools, and secondarily by dispersed sardines, except at the beginning and at the end of the survey where typical deep anchovy layers were observed. The biomass detected in the deepest layers (over 50 m) was clearly separated from that in the upper ones and represented 99% of the total after removing that of the anchovies and catfishes. Moreover no significant exchanges between the deepest layers and the upper ones seemed to occur. Therefore, only the first 7 layers are considered in this paper.

All the high densities were first observed close to the South-west corner, then on the South-east corner as well, along a 1.5 to 3 n.m. distance. An increase of the mean surface density by rectangle was observed during the study (fig. 3).

Short-term evolution of the distribution pattern

The mean depth of the biomass increased from 17 to 35 meters during the first part of the day, decreased in the afternoon, then remained more or less stable at 19 meters (fig. 4).

The dispersed fish were only important during the first part of the first night, while the schools and the concentration represented the bulk of the biomass (fig. 5). Surprisingly the schools were only predominant during the morning and were responsible for the increase of the mean biomass depth. No apparent nyctemeral cycle appears in the time-plots of depth or density, and the moonlight variation does not explain this result.

The usual figure (dispersed at night and in school at day) was only applicable during the first half of the study. From rectangle #6 (9:00 am) a typical macro-structure was observed which remained more or less the same up to the end of the observation (10:00 pm): a large central concentration surrounded by schools and/or by dispersed fish (figs. 6a and 6b). This typical structure was sometimes uncomplete on one side (fig. 6c).

The increase of the total biomass detected by rectangle (fig. 3) can be explained by two factors. Firstly, an increase of the number (one then two) of macro-structure cross-sections by rectangle, and secondly, by a slight increase of the internal density of these detections, especially during the second part of the study. In order to give a more realistic figure of the changes in the aggregative structure, the data have also been split into macro-structure cross-sections in figures 7 and 8. The number of single macro-structures observed remain uncertain (one large or two small), but does not seem essential owing to the similarity of the echograms.

A progressive shift in the position of the cross-sections during the study (fig. 9) may partially explain the observed changes in the echograms and mean densities (figs. 3 and 8). The localisation of the nucleus of the macro-structure along the survey would explain the predominance of dispersed fish at the beginning of the study, then of schools and, finally, of concentration.

It remains clear that other experiments are necessary to validate the reliability of this distribution, and to determine its limits of application (fish size, species, area, season, etc). A first element of confirmation is yet available. The day following this study, we studied the internal structure of the main concentration and observed the same echogram pattern. From 5:30 pm to 11:00 pm we repeated the rectangle experiment in order to verify if schools and concentration were still present as on 27th, or absent as on 26th at the beginning of our first study. We found similar structures to those observed on 27th (fig. 10). Nevertheless the increasing tendency of the mean density by rectangle was observed one more time, suggesting that some changes in the aggregation mode occured.

CONCLUSION

Obviously the observed macro-structure did not follow the normally observed aggregation pattern. Even though our experimental survey design did not completely overcome the problem of distinguishing between spatial and temporal effects, it seems that during this particular observation, the aggregative behaviour was not completely dependent on the light intensity. Possibly it was governed by a longer time period of evolution. Nor did the mean depth of the biomass correspond completely to the usual nycthemeral pattern (see Woodhead (1966) for similar examples). These observations suggest that the usual split of acoustic survey data in day-time and night-time series before processing could be done using criteria other than day and night periods.

The well-documented contagious structure of fish distribution was again confirmed, and the increasing density of the macro-structure, from the periphery to the center, is an additional argument in favor of over-sampling the areas of highest density located during a routine survey (Gerlotto, this meeting). Such an oversampling methodology must be carefully designed in order to avoid overestimation if the area assigned to the nucleus is overestimated, or under estimations if the dense nucleus is not found. Owing to the usual inversed binomial distribution of the density, it must be noted that the magnitude of an overestimation of the biomass would be much more important than the magnitude of an underestimation.

Even though the preliminary survey covered the entire Gulf twice, by day and by night, using a 5 n.m. inter-transect distance, the highest densities per ESDU were much lower than those observed during the rectangle experiment. The data are not completely evaluated but it is obvious that the total biomass estimated through this preliminary survey for the whole Gulf is lower than the biomass estimated inside one of the last rectangles. This confirms the necessity of over-sampling around the highest detection after a preliminary survey in this area.

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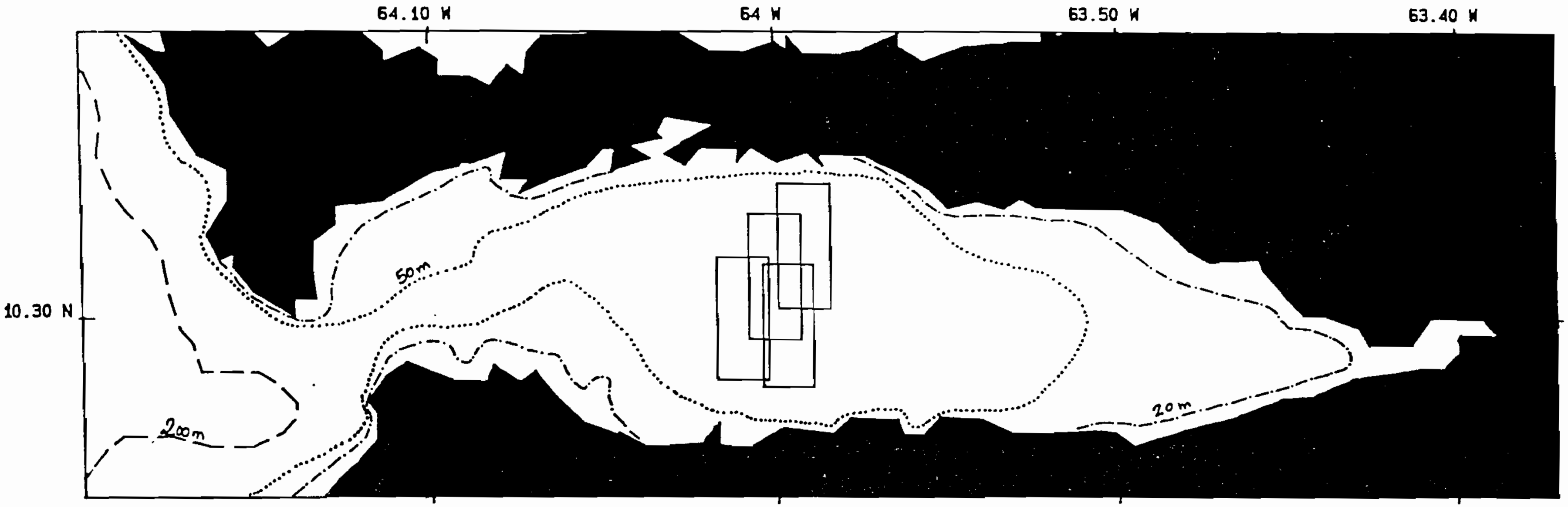


Fig. 1. Gulf of Cariaco (Eastern Venezuela): position of some rectangular tracks performed by the R/V LA SALLE

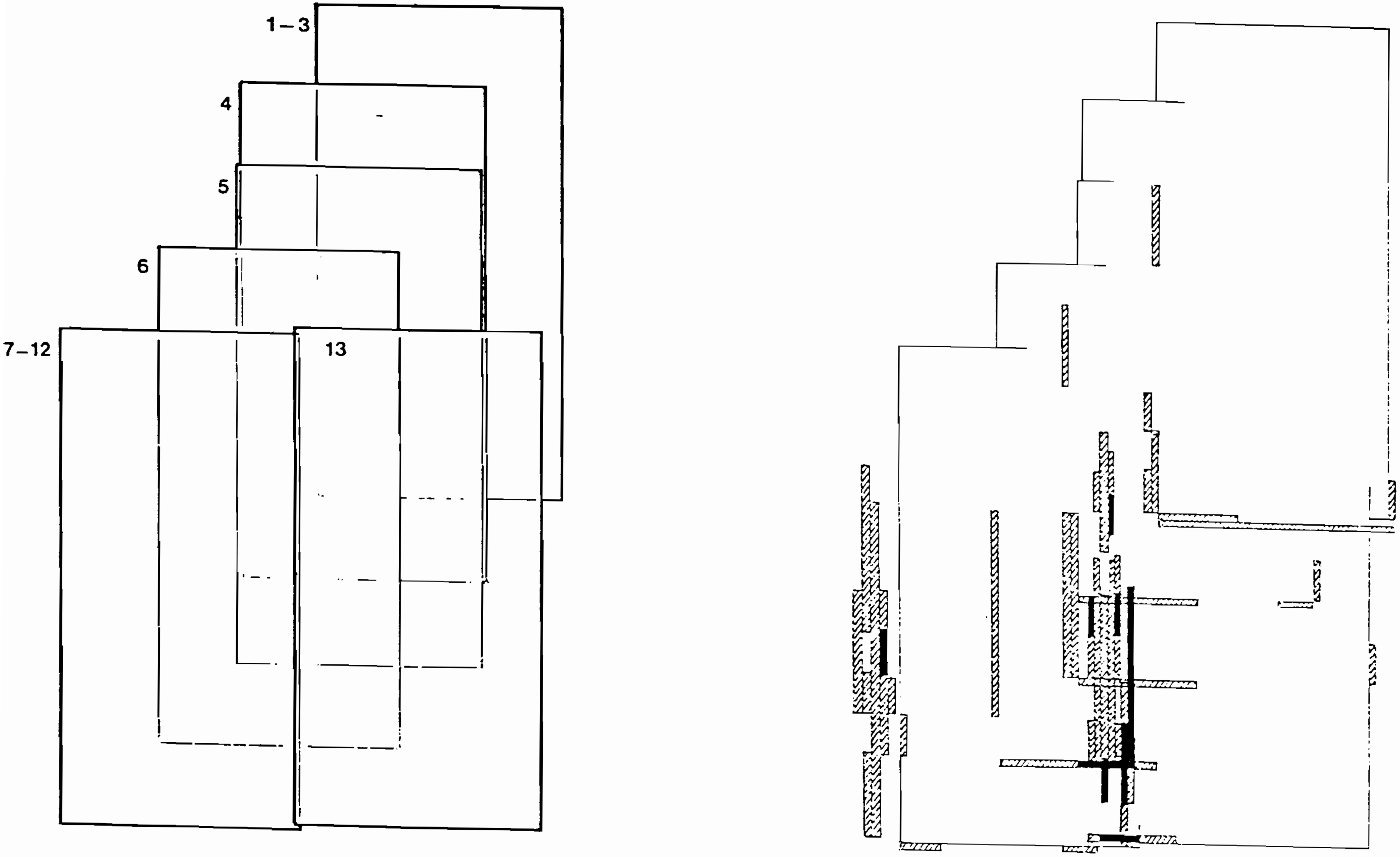


Fig. 2a. Successive positions of the rectangular tracks performed by the vessel (from 1 to 13).

2b. Location of the highest surface densities (SD):

■ $SD \geq 10^5$ ▨ $SD < 10^5$

Fig 3. Evolution of the surface density from rectangle 1 to 13

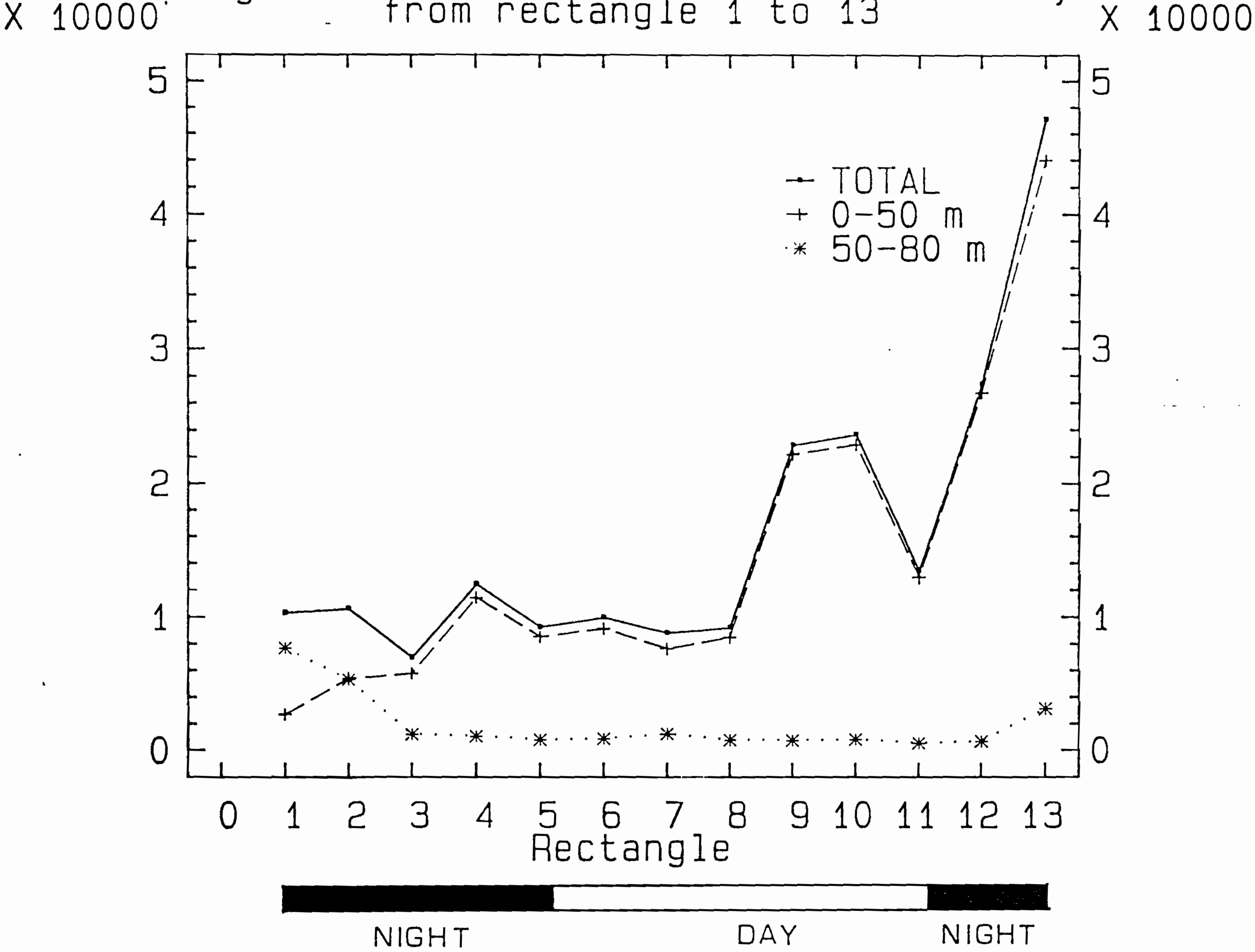


Fig 4. Mean depth of the detections from rectangle 1 to 13

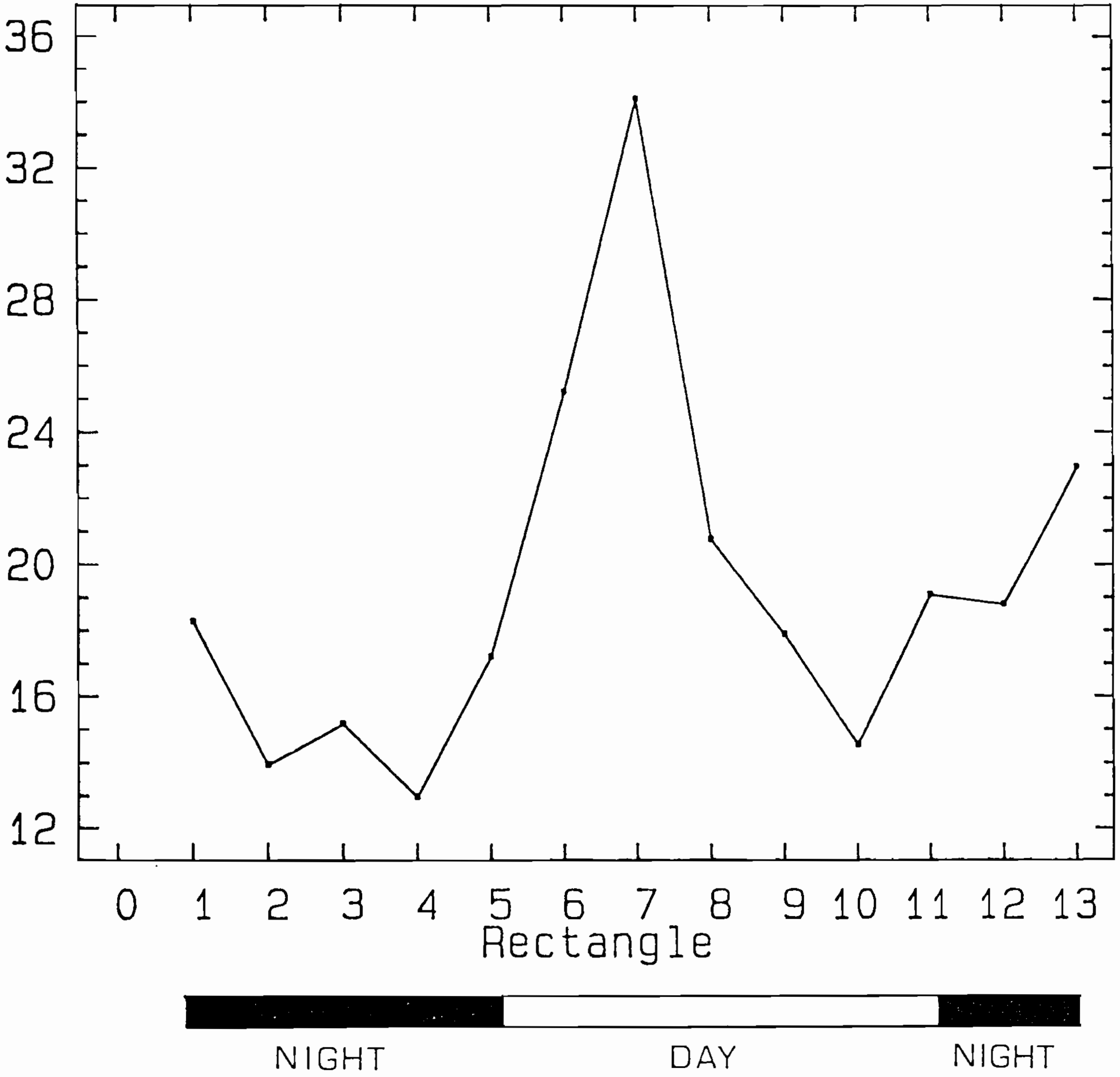
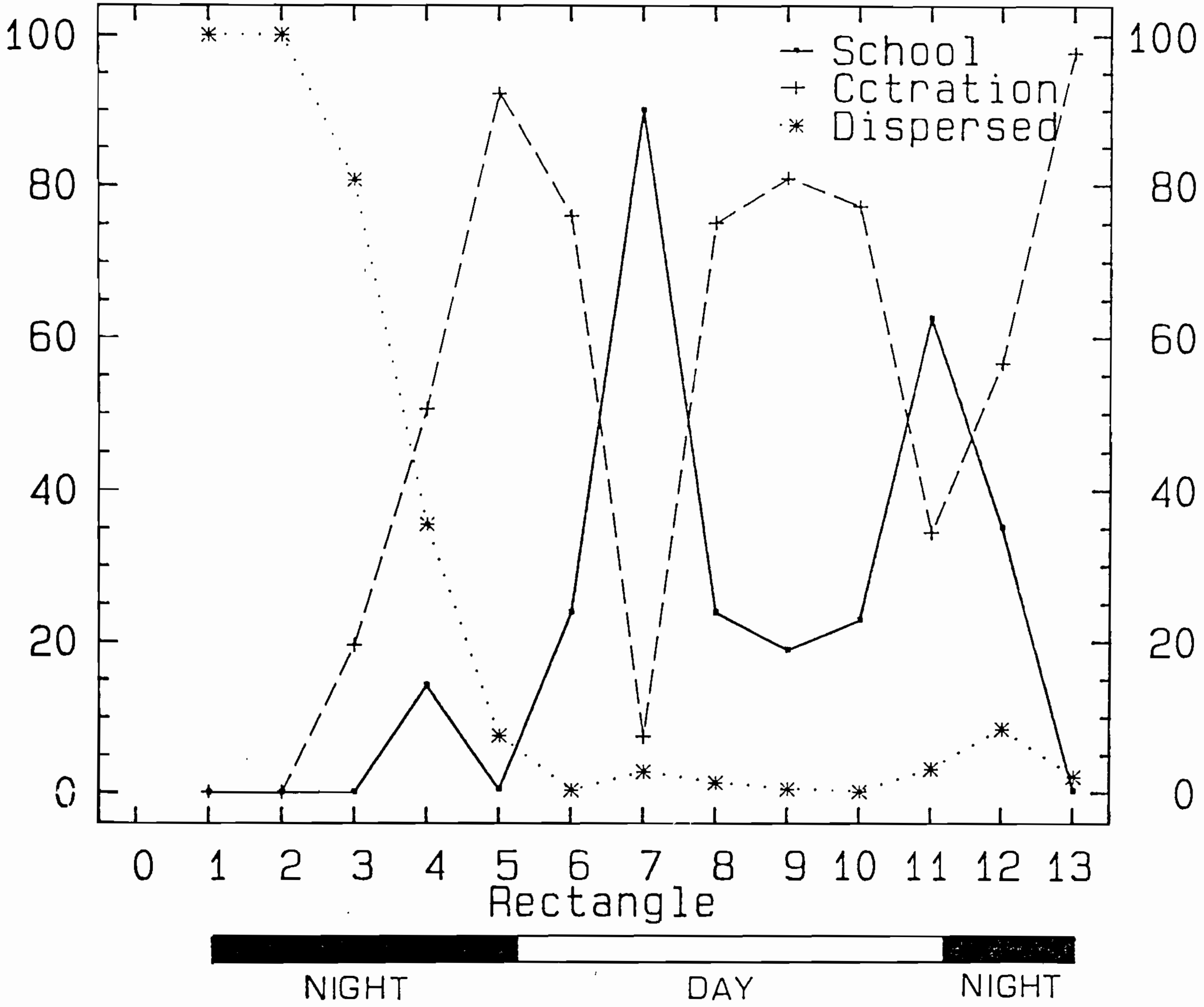


Fig 5. Proportions of dipersed fish, schools and concentrations. Rect 1-13



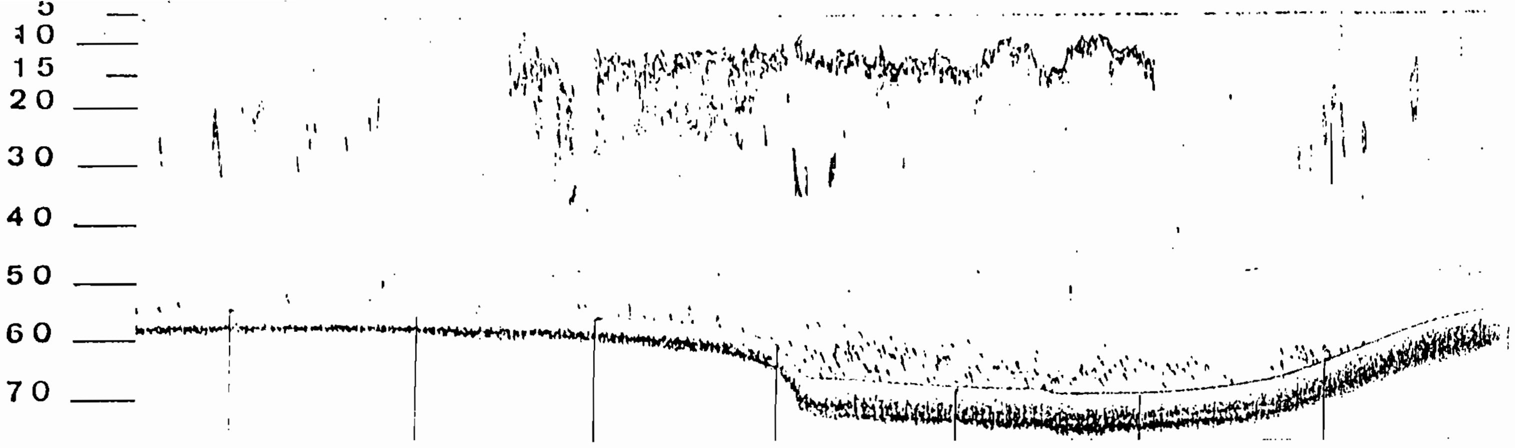


Fig 6a: Concentration surrounded by schools.

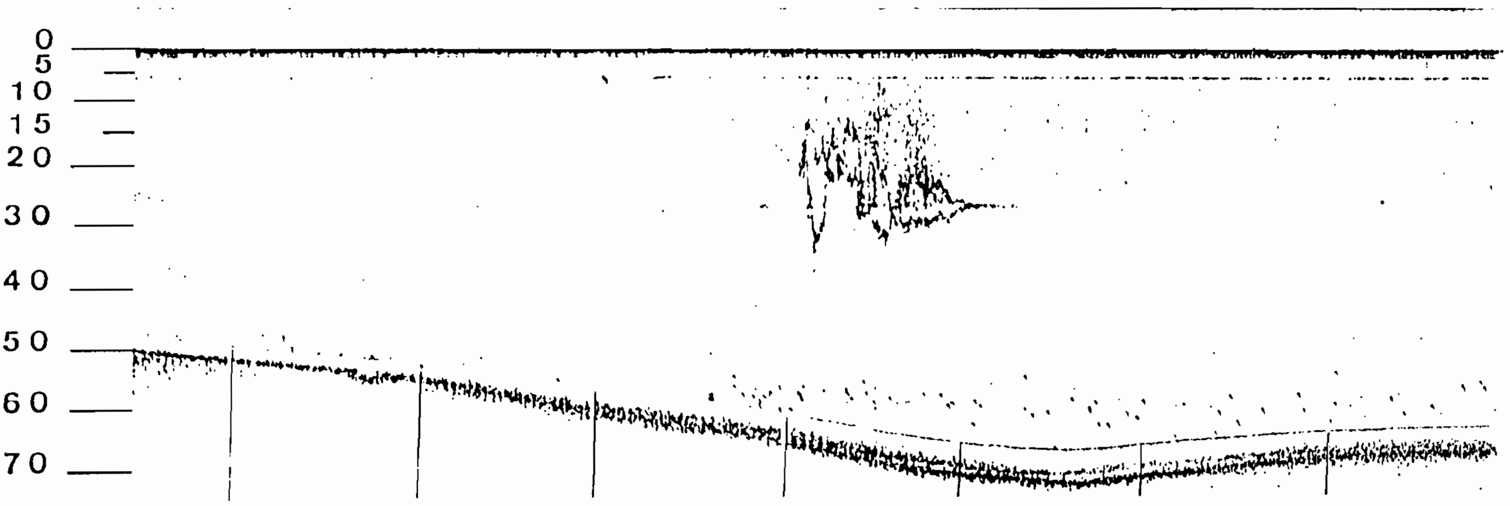


Fig 6b: Concentration surrounded by dispersed fish.

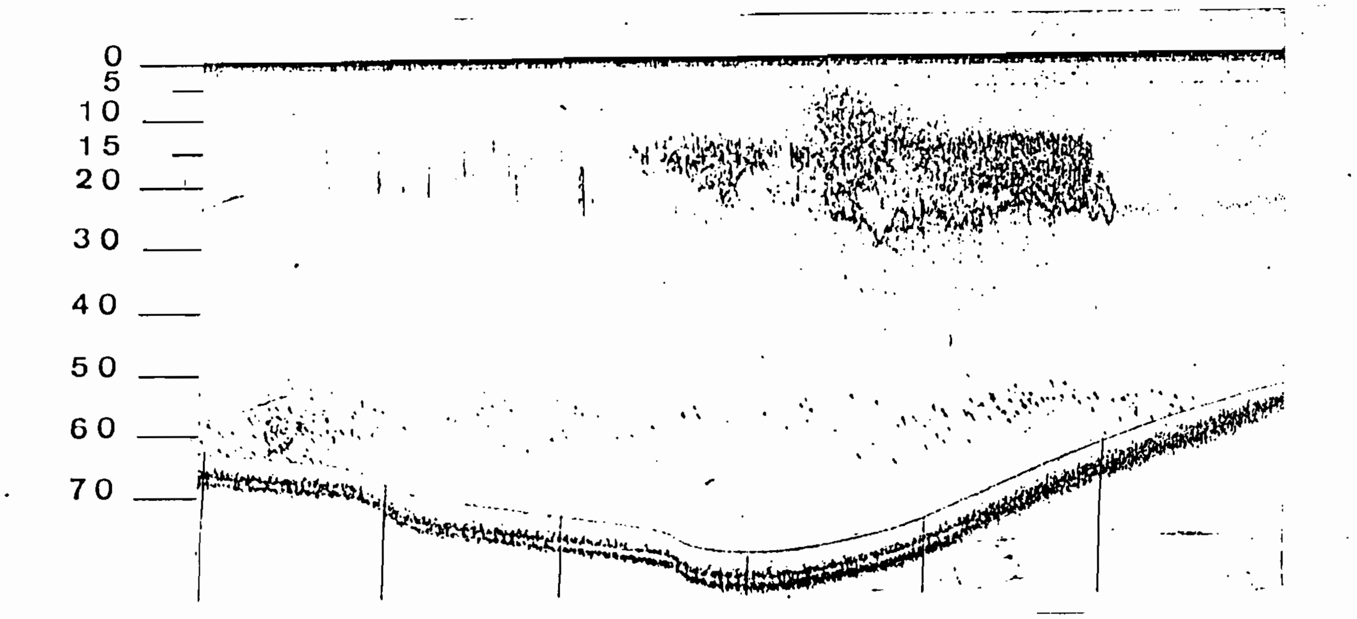


Fig 6c: Concentration with dispersed fish and schools on one side

Fig 7: Biomass from Macro-structure 1 to 21

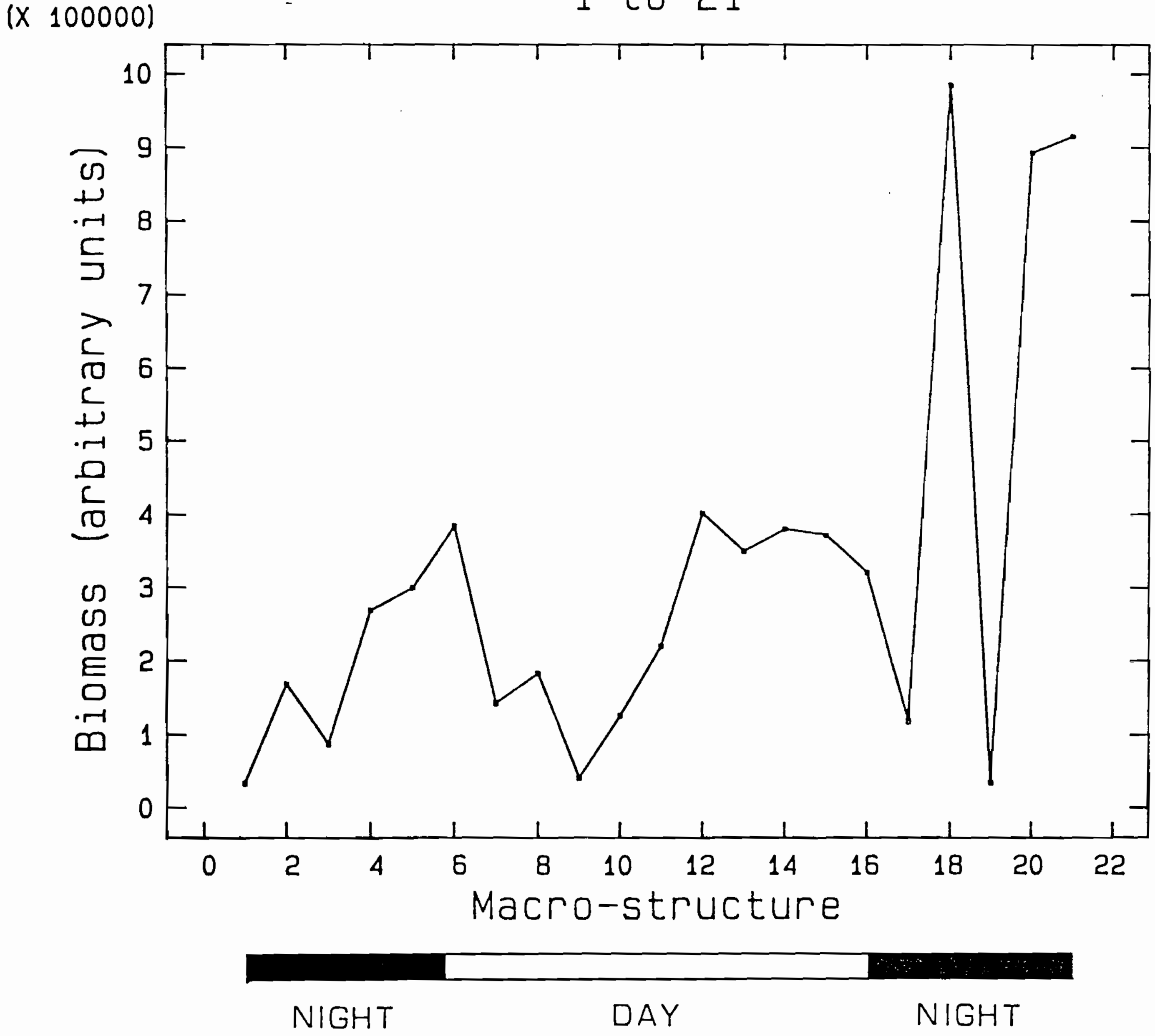
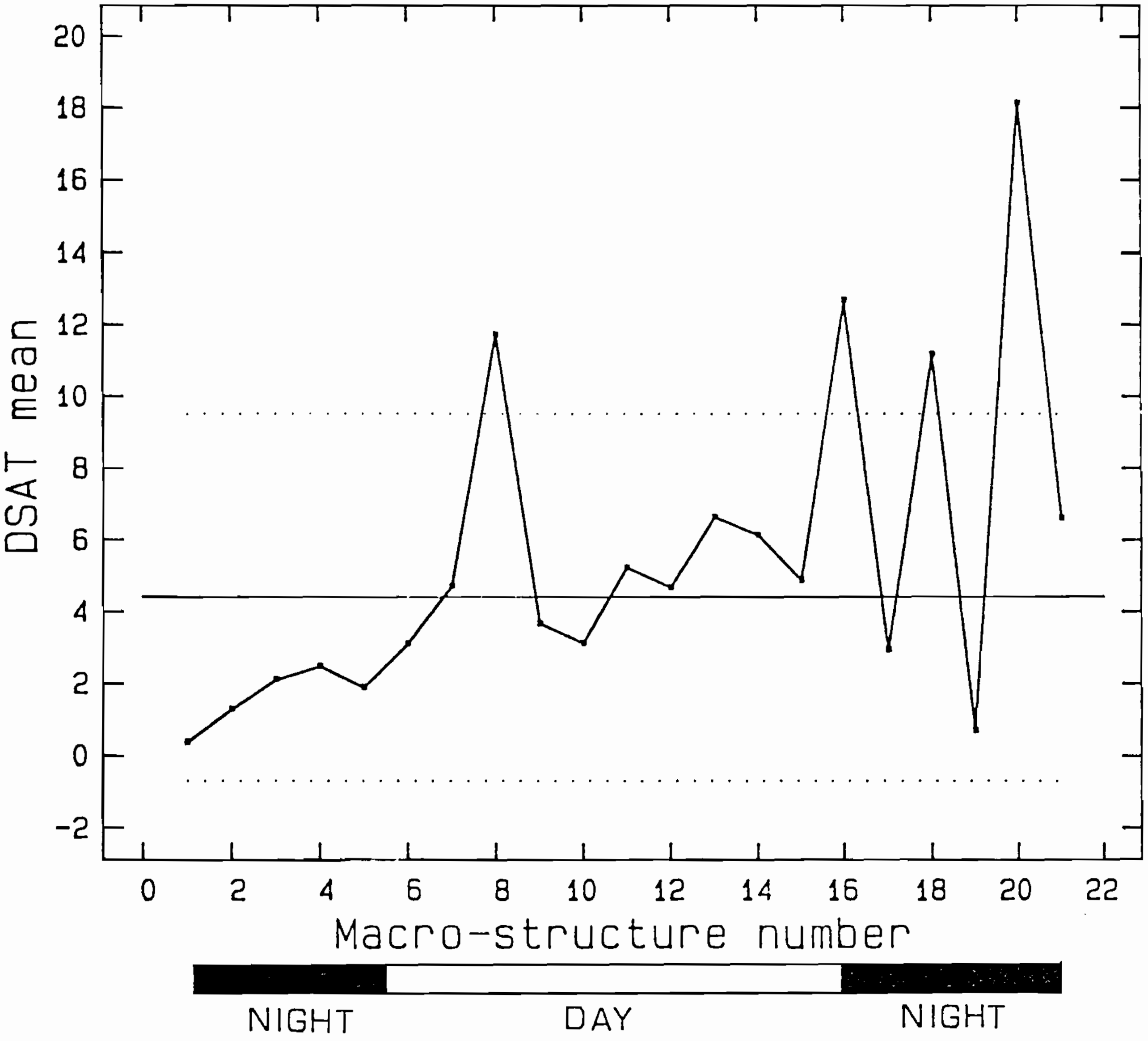


Fig. 8: Density by Sample Above the Threshold from macro-structure 1 to 21



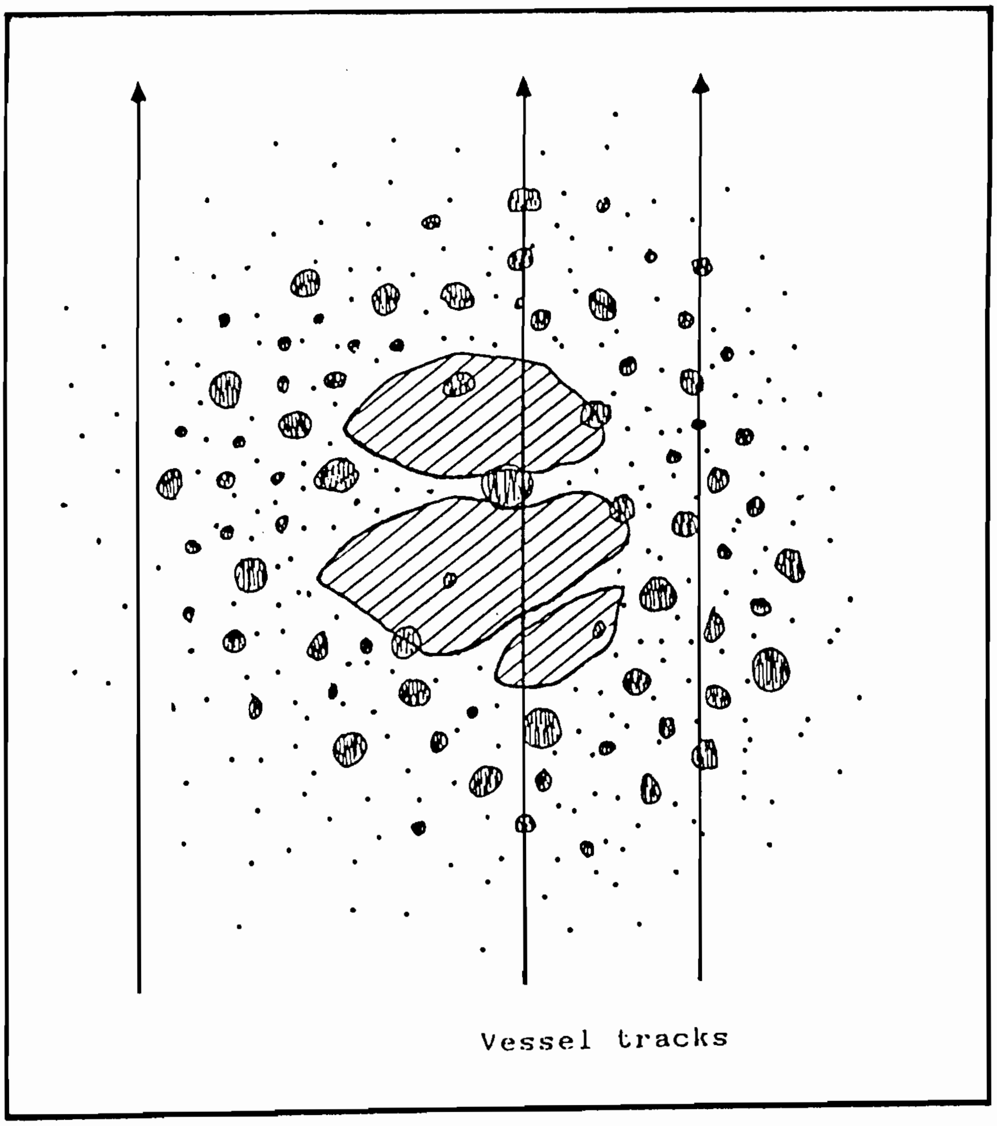


Fig. 9 Schematic representation of a macrostructure as observed through 3 different cross sections by the vessel.

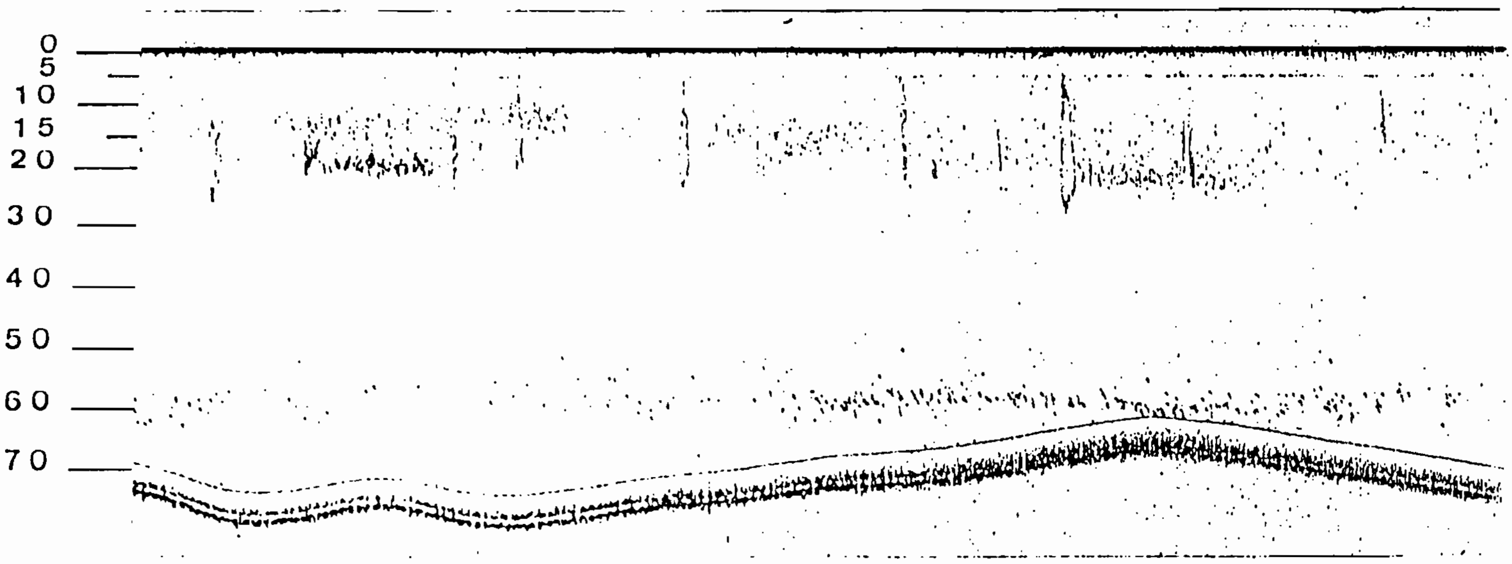


Fig 10a: 2nd Experience: NOV 29. 7H30 PM. Dense schools observed by night.

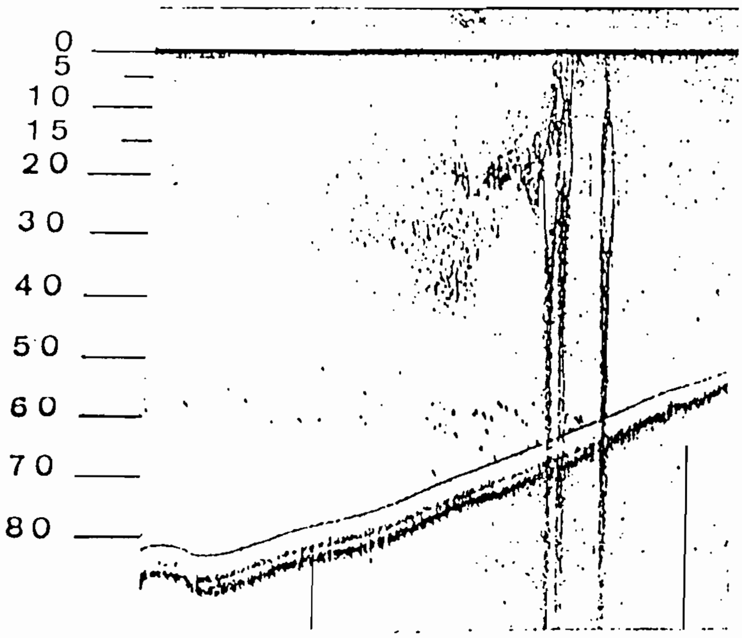


Fig 10b: 2nd Experience: NOV 29. 9H00 PM. Dense schools observed by night.

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REACTION OF TROPICAL COASTAL PELAGIC SPECIES TO THE ARTIFICIAL LIGHTING AND IMPACTS ON THE ESTIMATIONS OF ABUNDANCE BY ECHO-INTEGRATION

BY

Jean-Jacques LEVENEZ (1), François GERLOTTO (2)

and

Didier PETIT (3)

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(1) ORSTOM, CRODT-ISRA, B.P. 2241, Dakar Sénégal.
(2) ORSTOM, Centre ORSTOM de Fort de France, B.P. 81, 97201 - Fort de France.
(3) ORSTOM, IFREMER, B.P. 337, 29273 Brest Cedex

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ABSTRACT

The study of the fish behaviour in a tropical environment and its consequence on the estimates of the biomass from echointegration techniques have been conducted on both sides of the Atlantic, in Senegal and Venezuela. Three series of experiments realized nightly at 15 to 30 meters depth have shown that when the lights are lit up on the running research vessel, the fishes dive or/and spread but the consequences, as far as echointegration is concerned, depend on the species of fish and on th speed and the direction of the lighting on the boat : when the lights are focused only laterally (Senegal) the biomass estimates can decrease by a dramatic factor while, if the lights enlight forewards (Venezuela) the fishes are deeper but more or less stabilized before being insonified, hence without direct consequences ont the biomass evaluation.

RESUME

Des études sur le comportement du poisson en milieu tropical et ses conséquences sur les estimations de biomasse par echo-intégration ont été menées de chaque côté de l'Atlantique,au Sénégal et au Vénézuela. Trois séries d'observations réalisées de nuit à des profondeurs comprises entre 15 et 30 mètres ont montré que lorsque les lumières de pont sont allumées sur les bateaux de recherches, les poissons plongent et/ou s'écartent, mais que les conséquences, en ce qui concerne les évaluations de biomasse, dépendent des espèces, de l'orientation de l'éclairage du bateau et de la vitesse de ce dernier. Quand les lampes éclairent latéralement (Sénégal) les évaluations de biomasse peuvent être grandement sous-estimées, tandis que si les lumières sont focalisées vers l'avant (Vénézuela) les poissons plongent mais sont relativement stabilisés avant d'être insonifiés, et par conséquent cet effet ne biaise pas les estimations d'abondance.

INTRODUCTION

The effects of artificial light upon fish concentrations have been studied from the beginning of the hydroacoustics research. HODGSON and RICHARDSON (1949) and RICHARDSON (1952) have shown that the depth of a fish concentration could be modified using the illumination of a lamp. VERHEIJEN (1959) has published results of this impact of artificial lights on the behaviour of sardines, from which it is evident that this species dives when the lamps are switched on. The same type of behaviour has later been observed on other species in a temperate environment. The tropical environment has been less studied ; however, we can find, in OVTHINNIKOV et VOSMITTIEL (1971), the results of visual observations made from a drifting research vessel along the west african continental shelf and around the Canary Islands ; they note in particular, for Sardinella maderensis that "after having switched on the white lights, a big quantity of fish has disappeared", and for Sardinella aurita that, "after suddtently having switched on the submarine lamps, the fish went deeper and a significant time lapse (20 à 25 min.) was needed before they returned fo the illuminated area.It is moreover known, and this has in particular been discussed by OLSEN (1971 an 1979), that certain species have a strong tendency to withdraw when a boat approaches and this is due to the low frequency noise generated mainly by the propellers.

In the tropical environment where the echo-integration is increasingly developing, it was, first in a very global way, necessary to measure the impact of these different behaviours, results of visual and auditive stimuli, on the estimations of abundance by the acoustic method. Three series of experiments have been conducted, two in Senegal and one in Venezuela, and the results are shown in this paper.

1 . MATERIEL AN METHOD

In Senegal (map 1), the observation have been carried out from the R.V. Laurent Amaro, a research vessel with a stern trawl equiped with a Biosonic 120 kHz echosounder and integrator. Its bridge spoligths (?) are facing backwards and the towed transducer is at the adge of their direct lighting area (fig. 1).

The first series of observations was done during the nights in the Goree bay (map 1) with 15 m depths and waters with abundant juvenile sardines, which serve as bait for the tuna bait boat based in Dakar.

It needed the technical support from the R.V. Cauri which served as assistance versel ; this latter was anchored and held, at about 30 m distance, a raft with a week signalling light, which supported the 120 kHz transducer and a small diving lamp installed in order to fix the fish under the raft (fig. 2). The R.V. Laurent Amaro passed just beside this raft several times at different speeds and with the bridge lit up or not ; and the reactions of the fish were observed directly on the echograph and recorded on cassette for later processing in the laboratory.

The second series of observations took place in the northern Casamance area (map 1) at depths of 25 m. While the vessel advanced at its usual cruising speed, that is 8 knots, the lights on the bridge were on and off alternatively with a 1 minute periodicity, this time lapse corresponding to a distance of 247 m. The reactions of the fish were observed on the echograms.

In Venezuela, the experiments were carried out from R.V. Capricorne, at approximately 25 m depth, where a control catch identified anchovies and 15 to 20 % Sardinella aurita. The vessel, which was equipped with a SIMRAD sounder and an AGENOR integrator used a speed of 4 and then 7,5 knots.Its bridge projector (500 w), situated in the front, was alternatively switched on for 6 minutes and them switched off for 6 minutes, this time lapse corresponding in this case to a distance of 1389 m. This illumination was not particularly focused towards the sea. The other lights on the R.V. Capricorne were turned off or

carefully covered except for the navigation lights. The behaviour of the fish was observed on the echograms and the echoes integrated during each of these 6 minutes sequences.

2 . RESULTS

2.1. IN SENEGAL

2.1.1. First experiment

Approximately 30 minutes after the installation of the experimental device, the recorded echoes on the sounder abord the R.V. Cauri showed a stable situation, where the concentration of small sized fish was very dense and homogeneous between the beginning depth of observation and 1 to 2 m above the bottom. The fish were clearly more dispersed near the bottom. (Fig. 3A).

When the research vessel passed without lights just beside the raft, no apparent reaction of the fish was noted independant of the speed of the boat (fig. 3B and 3C). The noise did in this particular case not have any determinating consequences on the behaviour of the fish.

On the contrary, when the vessel had the lights on the bridge switched on, it was noted that :

- when it passed at a speed of 8 knots, and as soon as the area of direct illumination of the lights of the bridge reached the observation raft, an immediate decrease of the apparent densities, characterized by an absence of echoes at approximately half the observation depth and a strong decrease of the densities of the other half, was observed.

- When it passed at low speed (0.5 to 1 knot), the observations show the same immediate dispersion of the fish near the surface, rapidly followed by an apparent upwards movement of the fish near the bottom. The situation takes much longer to become stable as though a part of the fish had followed the area illuminated by the boat (fig. 3E).

2.2.2. Second experiment

This experiment, carried out in the operational conditions of the acoustic surveys, confirms (fig. 4) that the fish have an immediate reaction to the luminous stimuli, and a sudden illumination causes them to dive according to our observations 10 to 12 m, which leads to a general concentration of the fish close to the bottom.

It also shows that, on this type of fish concentrations, the reactions are reproductible with, the fish diving to the same depth at the arrival of the illuminated vessel as can be noted from the sequences 14 and 15 of figure 4, or staying at the same level when the bridge of the boat is not illuminated (for example : sequences 16 and 17 of fig. 4).

2.2. VENEZUELA

The reaction pattern of the fish is the same in Venezuela as in Senegal (fig. 5), that is, they dive when the vessel

switches on the lights, but contrary to the situation in Senegal, where the reaction is immediate and total, a transition phase with a duration of 30 to 40 seconds was observed in Venezuela. This transition phase is shorter when the speed of the vessel is high (fig. 6 : 1 and 2).

On the other hand it can be noted that the fish nearest the surface dive 5 to 8 m and the part of the fish situated further down dive 12 to 18 m.The amplitude of this migration also depends on the speed of the boat (fig. 6 : 1 an 2) ; and there is consequently an apparent increase in the extension of the concentration which is correclated to a decrease in its density.

If can als o de noted, referring to figure 5, that the fish do not dive all the way to the bottom, contrary to what was observed about the R.V. Laurent Amaro (fig. 4).

The integrations of these fish concentrations have as results the following global relative values :

- mean of 40 "illuminated" sequences = 1995
- " " 40 "non-illuminated" " = 2057.

There is flues in this case no significant influence by the lithting on the two estimations of the density.

On the contrary, a clear alternate change of the values between the integrated layers during 2 successive sequences was noted, with a maximum amplitude of 20 m (Fig. 7).

DISCUSSION

The small variation of the intensity of echoes recorded during a passage of the R.V. Laurent Amaro without lights near the raft seems to indicate that the species of fish observed, especially small sardines, have only a week reaction to the noise of the boat; but the presence of a submarine lamp installed under the raft to locate the fish could have disturbed their behaviour.

Thus it is difficult to make a definite conclusion on this point.

A big difference between observations done in Senegal and Venezuela concerns the reaction of fish to light. On the first case the reaction is violent when the lighting is lateral while in the second case one notices a response time of 30-40 seconds with lighting directed fowards an orientation which lets one suppose that the fish has already gone down and is stabilised at the moment insonified ; however, this is not the case. A greater turbidity of the water in Venezuela and/or a weaher power of the lights of the R.V. Capricorne could explain the apparent showness of the reaction,but it probably is due to a slow swimming speed of the fish.

One sees that the superficial part of the layer goes down from 5 meters when the boat sails at 7.5 knots, but is sinks at 8 meters when the boat sails at 4 knots. On the other hand, the lower limit of the layer of fish sinks 14.5 meters in the first case and only 10.5 meters in the second.

Many hypothses can be famulated regarding the specific differential sensitivity to boat noise and te sound and light stimuli combined, but lack of precise information doesn't support them. Thus, it is difficult to known even though global estimations of density are identical for illumination and extinguishing if the fish have had enough time to stabilize their depth upon the arrival of the boat.

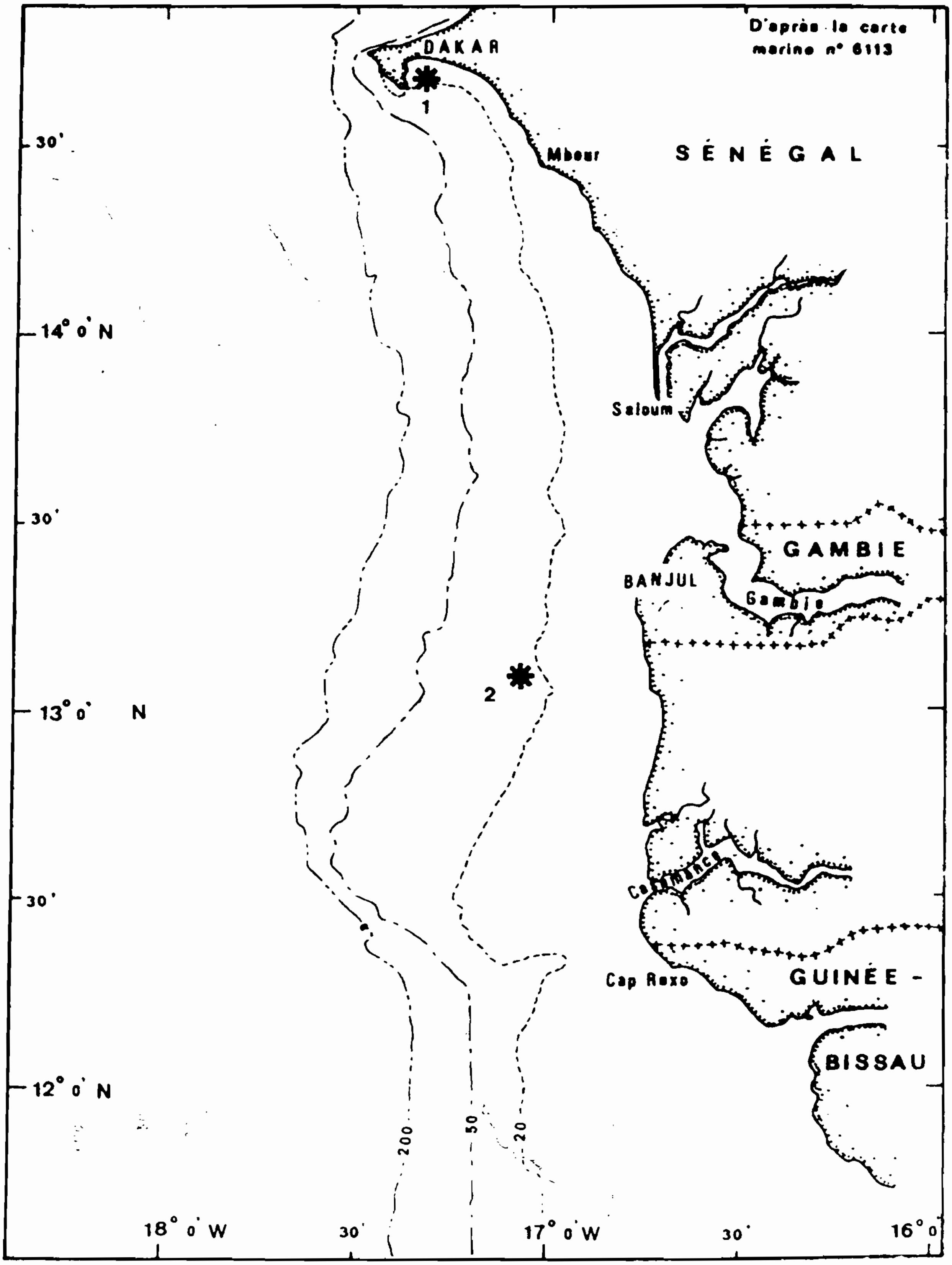
This would intense the accuracy of these estimations. The geatest density of concentration when the light is turned on only characteries multispecific detections (at least anchovy and Sardinella aurita according to results of fishery operations) hairly swimming speeds and reactions to different stimuli. The fact that they don't go down to the bottom could be in past linked to the boat's of the leater and the power of the lighting which permits the fish to escape from the bright stimulus before they teach the level of the bottom.

On the other hand, in conditions observed in Senegal the light makes these fish bunch up toward the bottom,consequently the density of the concentrations diminished from 10-12 meters;the decrease not necessarily correctated to an augmentation of density. In this way one can see it on the echograms, which means that the fish escaped laberally in relation to the ship and/or that it has an orientation in relation to the horizontal which expresses weaker index of reflextion. Moreover, the fractions of fish which doing to the bottom escape the integration zone which leads to a large underestimation of densities.

CONCLUSION

On the three series of experiments presentes here, the influence of artificial light on tropical fish behaviour is considerable.

If in the example of prolonged stationary illumination, fish are generally attracted, a violent illumination makes them move away from the light source at first. The second case, which conserns more exactly echo-prospection compaigns, should be seriously taken into consederatin for it is the case for experiments done in Senegal. It can lead to a serious underestimation of biomasses. Quantative studies in this area are thus recommended to reduce as much as possible sources of bias in the evaluation of biomass in stocks of tropical coastal fish. In the absence os such studies it is undoubledly preferable to do night compaigns in tropical areas with a minimum of light on research vessels.



Carte 1 :-

Geographical area of the observations in Sénégal

1°) Bay of Goree

2°) Northwest Casamance

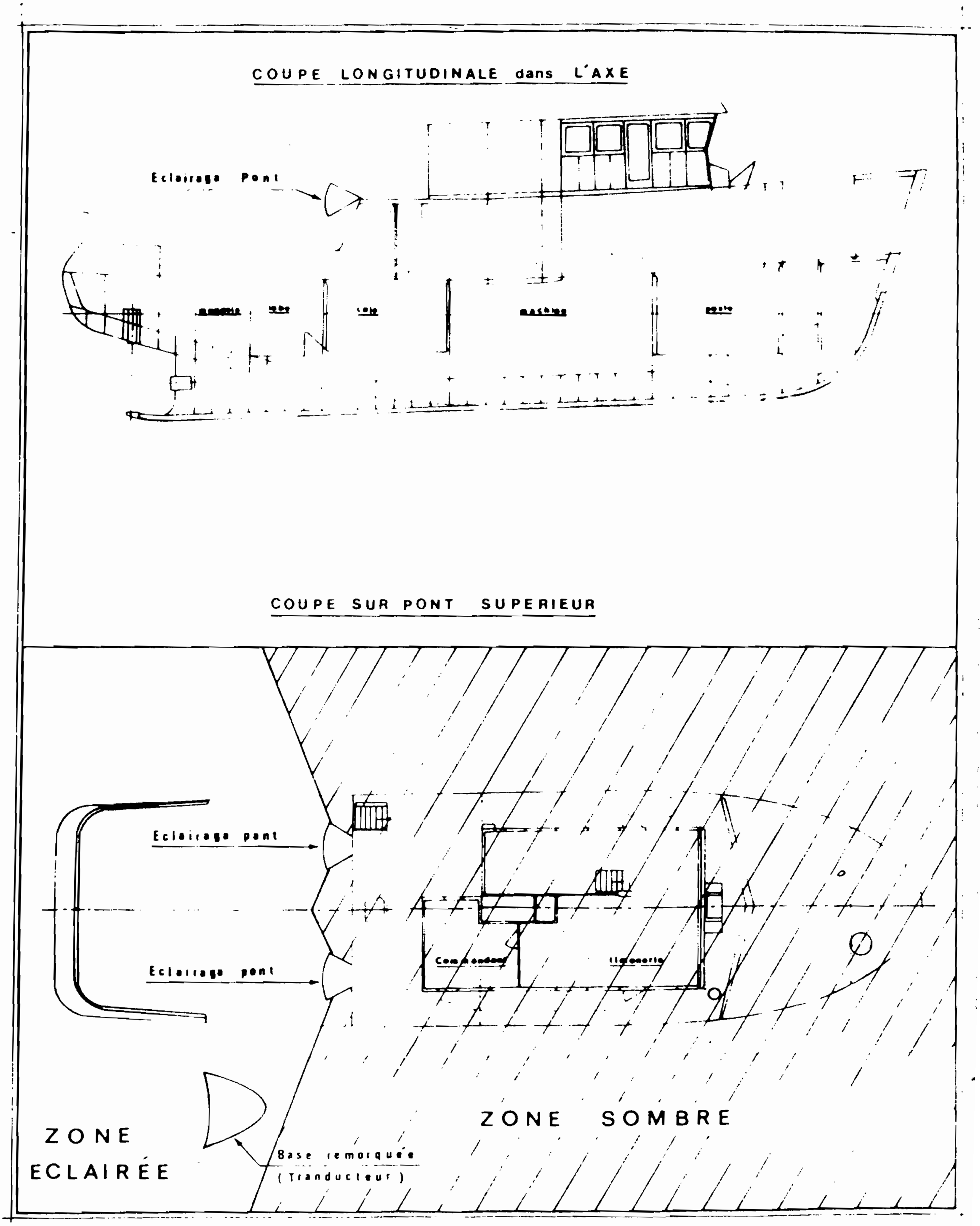


Figure 1.- : R.V. Laurent Amaro
Position of the lightspots

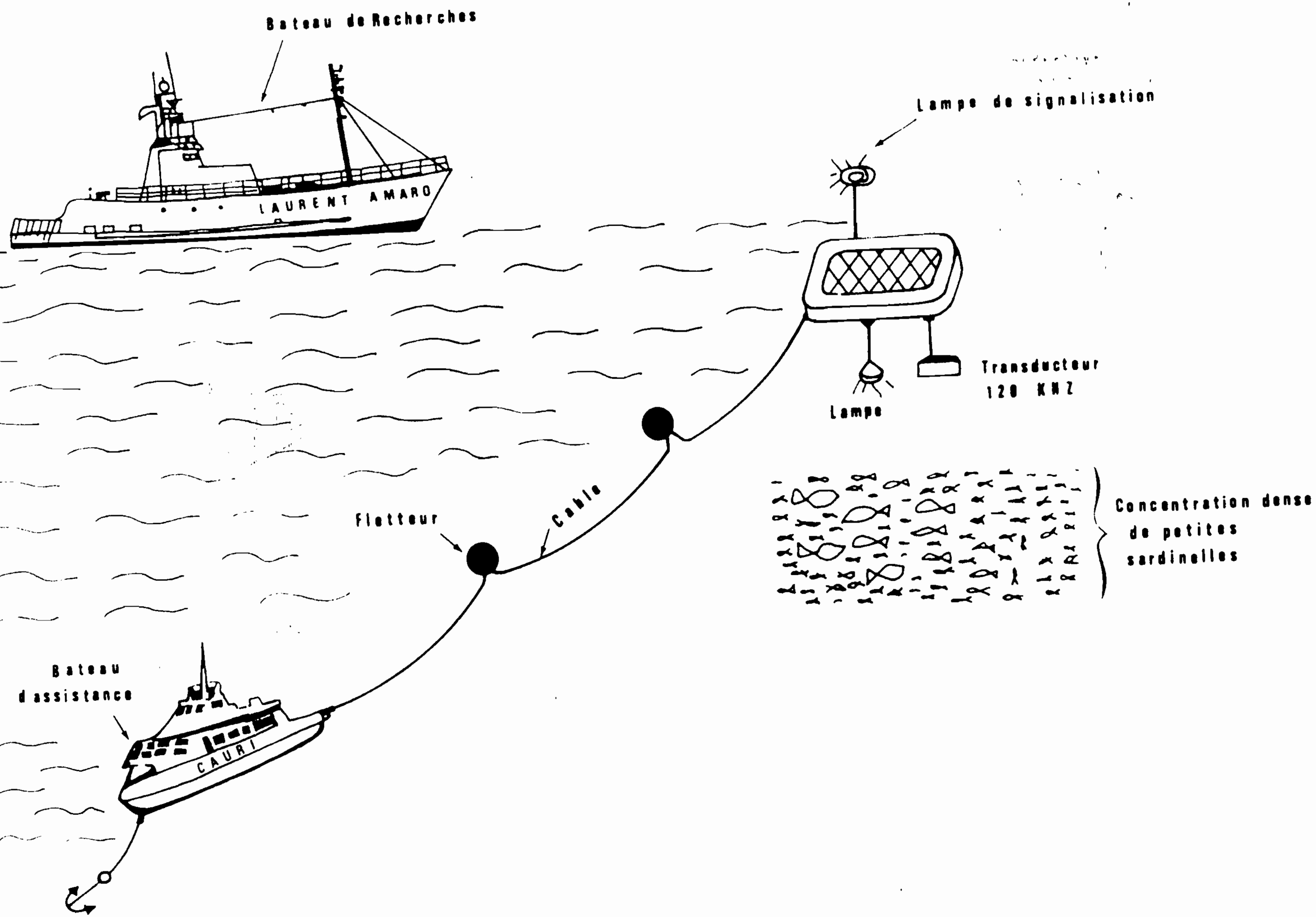


Figure 2.- : Experimental set up for fish behaviour observation

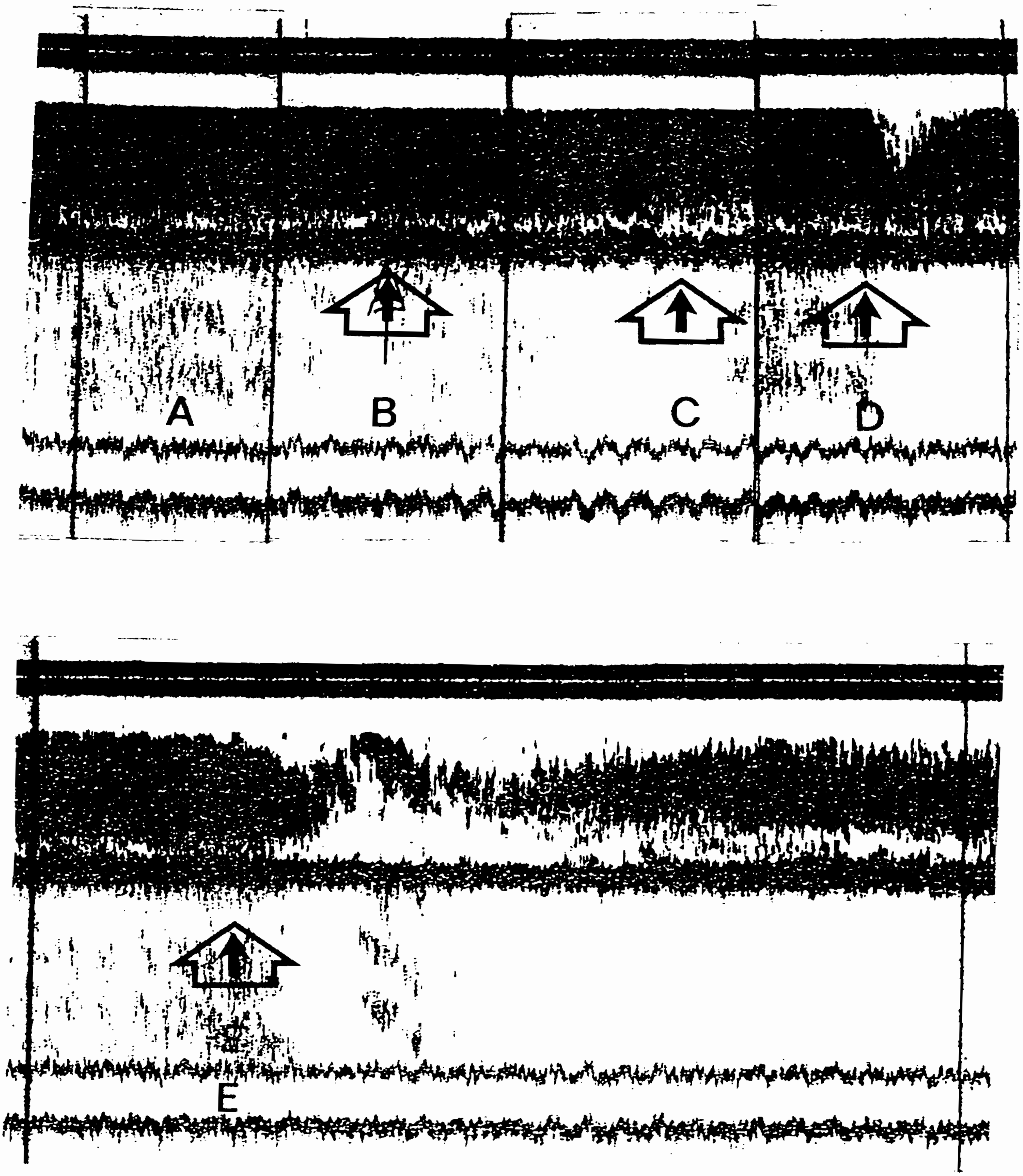


Figure 3.- : Echogrammes showing the fish behaviour to the lighting (See explanations in the text).

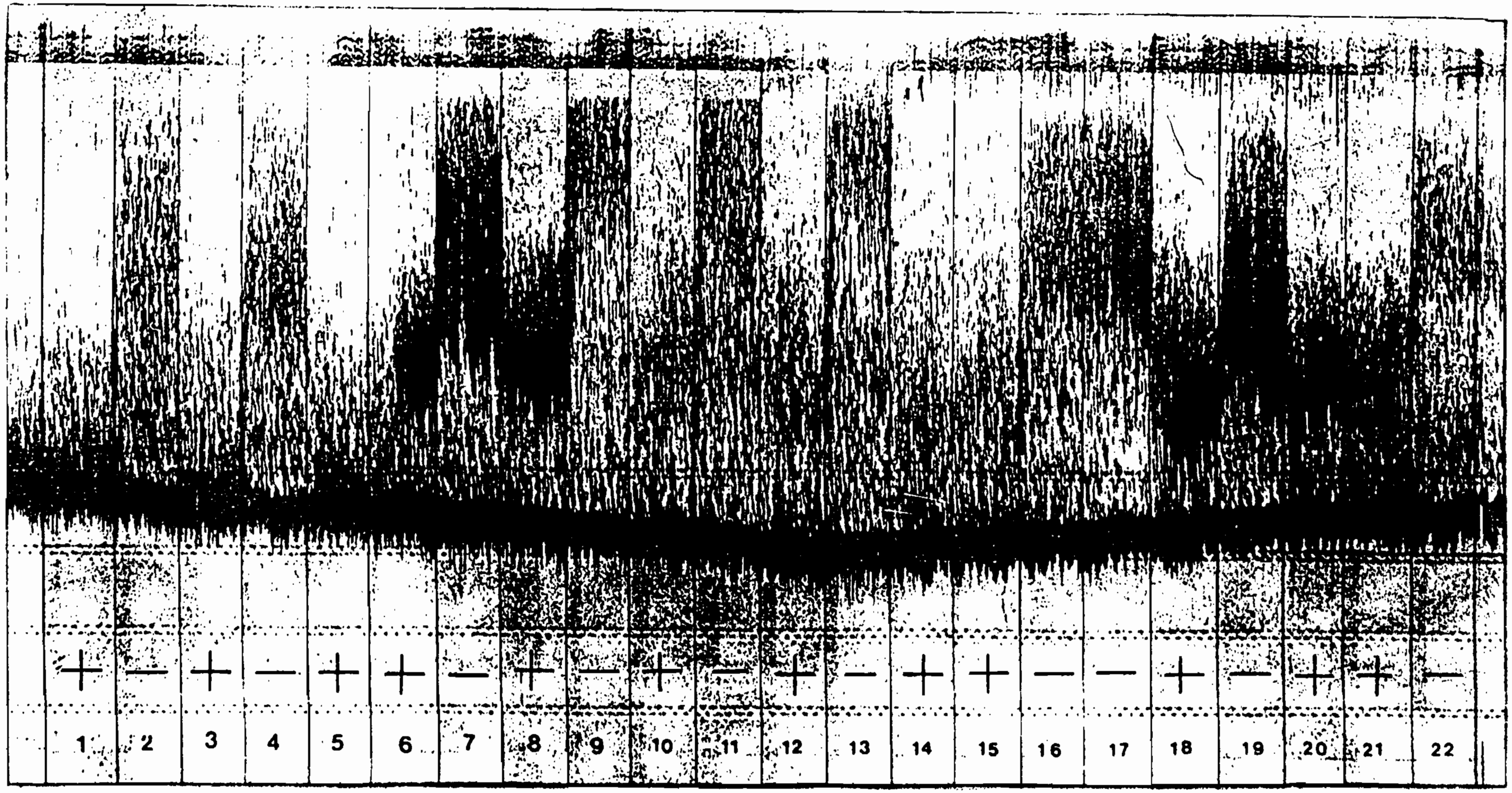


Figure 4.- : Fish reaction to the light :
Northwest Casamance arrea 25 m. depth.
+ = With light
- = Without light

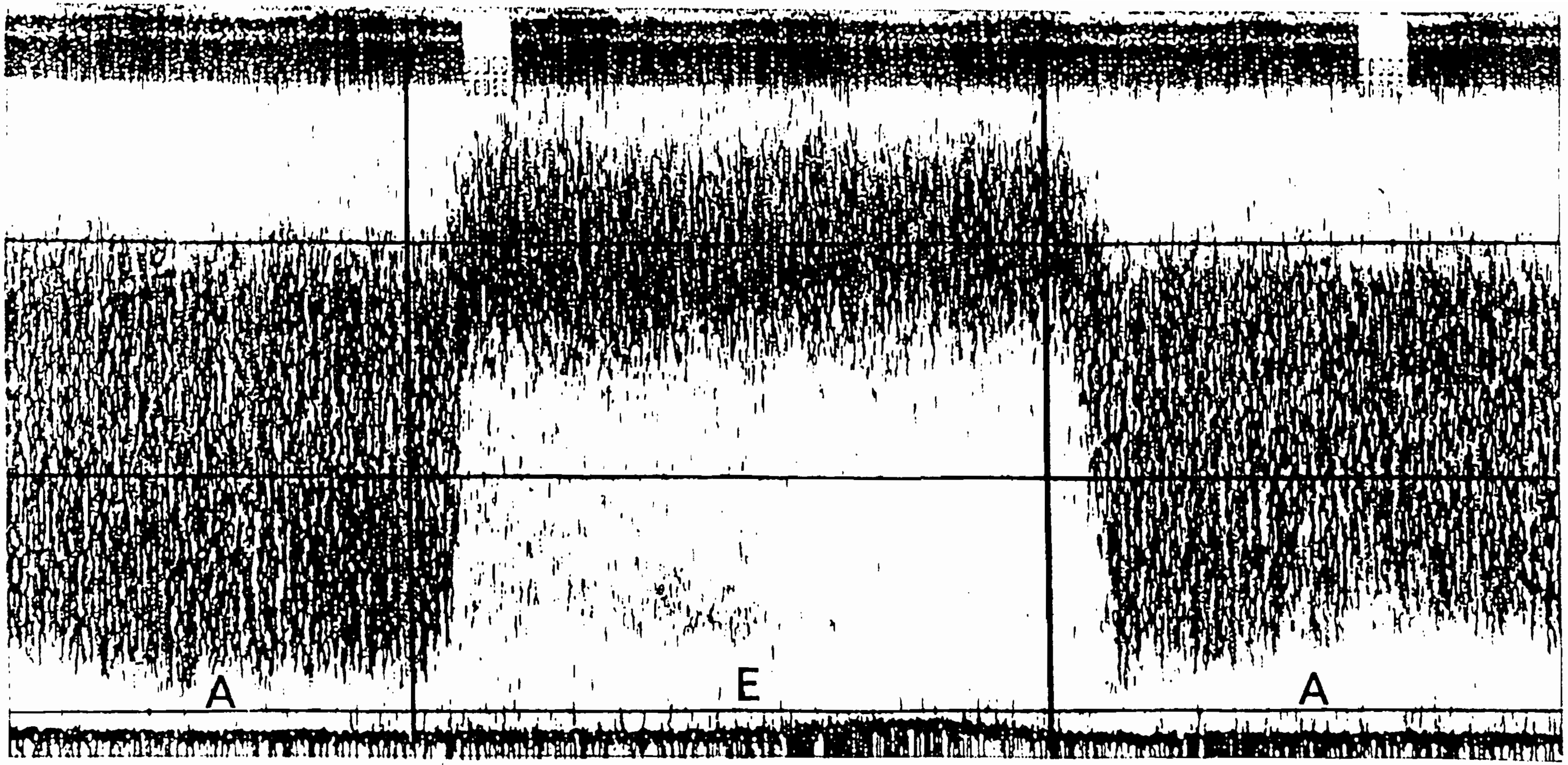


Figure 5.- : Fish reaction to the light in Venezuela
R.V. Capricorne speed : 7.5 Knots
A = With light
E = Without light.

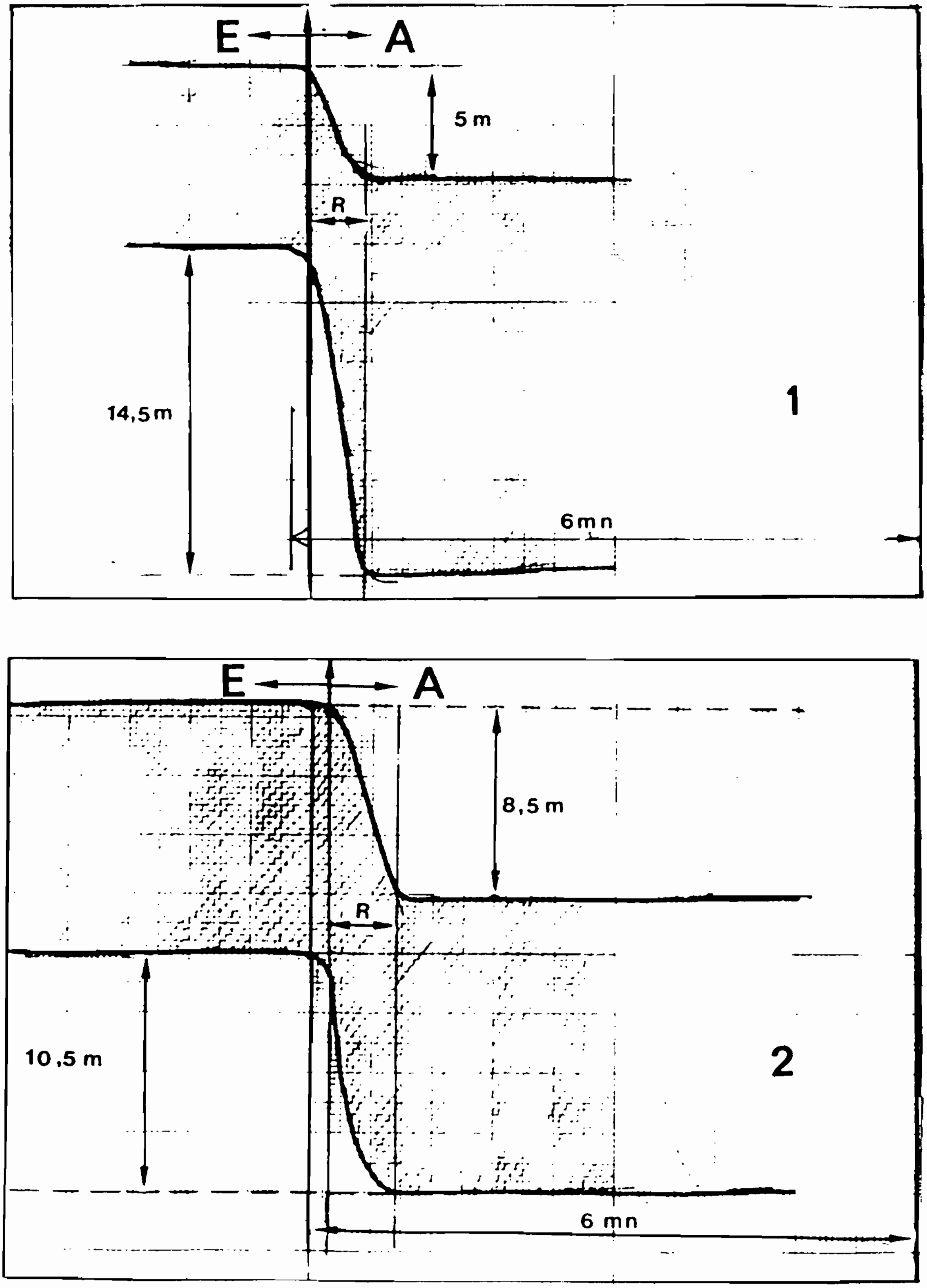


Figure 6.- : Changes in a scatlered fish lager
Caracteristics during the experiments
1 Speed = 7.5 knots ; 2 Speed = 4 knots
A = Nith light
E = Without light

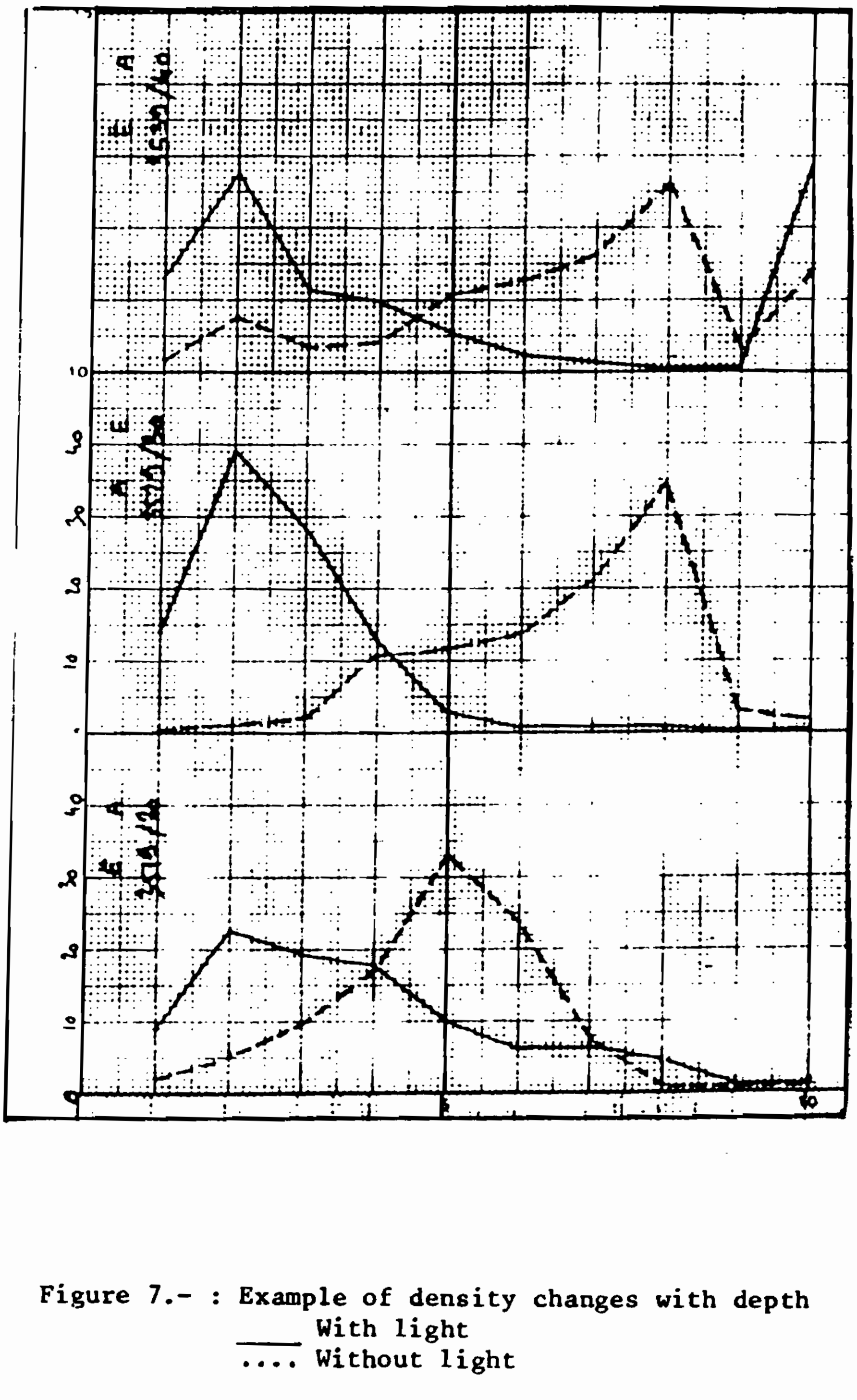


Figure 7.- : Example of density changes with depth

____ With light

.... Without light

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INFLUENCE OF THE LIGHT OF A SURVEY VESSEL ON TS DISTRIBUTION

(Influence de l'éclairage d'un navire de recherches en prospection acoustique sur la distribution des TS)

by

F. GERLOTTO (1), D. PETIT (2), and P. FREON (1)

(1): ORSTOM, BP 81, 97256 Fort-de-France, Martinique (FWI)
(2): ORSTOM, centre IFREMER, BP 71, 29263 Plouzané, France

RESUME

Des mesures d'écho-intégration et de TS "in situ" effectuées de nuit à l'aide d'un sondeur à faisceaux concentriques ont permis de vérifier l'effet de l'éclairement d'un navire de prospection sur les distributions bathymétriques des poissons. Deux résultats principaux ont été obtenus:

- les poissons des couches supérieures, contrairement à ce qu'avaient montré d'autres expériences dans la même zone, n'ont pas plongé lors des périodes éclairées, mais ont en partie évité latéralement le bateau, l'importance de cet évitement étant apparemment à relier à la taille et/ou à l'espèce des poissons;

- si l'on ne tient pas compte de la disparition des cibles les plus importantes, les niveaux de réflectivité moyens n'ont pas varié entre périodes obscures et éclairées, ce qui confirmerait l'hypothèse que les poissons sont polarisés par le bruit d'un navire et se trouvent généralement en position horizontale lors de son passage.

ABSTRACT

Some "in situ" measurements performed with a "dual-beam" echo sounder by night have permitted to evaluate the influence of the light of a boat on the inclination and avoidance of fish. Coupled with echo integration data, the results lead to the two following conclusions:

- the fish of the upper layers, contrarily to former experiments,

did not dive vertically when the boat passed over them, but tended to avoid laterally her route, the avoidance reaction being apparently in relation to the length and/or the species of the fish;

- when not taking into account the disappearance of the biggest targets, the mean backscattering cross section did not vary significantly whether the ship light was switched on or off. This phenomenon confirms the hypothesis that the fish are polarized horizontally by the noise before the ship overpasses them.

INTRODUCTION

Some former observations of the behaviour of the fish (LEVENEZ et al., 1987) showed two rather contradictory phenomena:

- the fish reacts very strongly to the light of a survey vessel by a neat diving behaviour, as shown in fig. 1.

- in spite of this avoidance reaction, the global density did not vary: the gravity centre of the biomass may change, but considering the total water column, it appeared clearly that all the biomass remained present.

These observations lead to the following hypothesis: the fish are probably polarized in horizontal position by the noise of the ship (warning situation), a rather long time before she passes upon them, and is insonified in this position; in this condition, if the echo sounder is using a TVG function, the depth of the gravity centre has no influence on the density evaluation, and therefore the actual condition of lighting (and noise) of the ship has no effect on density estimation. Another consequence of this fact is that the TS data of the fish would be similar by day and by night, the tilt angle of the fish depending probably on the noise of the ship (and its initial depth) and not on its natural behaviour.

We tried to test such an hypothesis using TS measurements on the fish "in situ". The results of these observations are presented in this work.

1. MATERIAL AND METHODS

1.1. Description of the survey methodology

The area of the study was the northern part of the gulf of Cariaco (eastern Venezuela), where some important sardine (Sardinella aurita) concentrations were found during a previous general survey (fig. 2). The experimental survey were performed using zig-zag transects. A 500 W light was fixed above the towed body of the transducer on the left side of the vessel, and alternately switched on and off every 6 mn, using the same experiment protocole as was used in a former experiment (LEVENEZ et al., 1987). The speed of the survey was around 5 knots, which fitted in the range of that of the above mentioned experiment. During the survey TS values were measured and processed by 6 mn ESDUs, as well as echo integration evaluations. The weather was cloudy, but the full moon was visible from time to time. The experiment took place from 8:00 pm to 11:45 pm.

1.2. TS Measurements

We used a dual beam echosounder type BioSonics 102, 120 kHz, aboard the R/V André Nizery (25 m stern trawler). The settings of the sounder are presented in table 1.

Receiving sensibility (cal. range 40 log R) :		-173.54
Source level :		221.63 dB
Threshold large beam :		100 mV rms
narrow beam :		50 mV rms
Selection criteria for individual targets		
- 6 dB :	min.	0.5 ms
	max.	0.7 ms
- 12 dB :	min.	0.5 ms
	max.	0.8 ms
- 18 dB :	min.	0.5 ms
	max.	3.0 ms
echoes records from 5 m below transducer up to the bottom		

Table 1. Settings for TS measurements
(Tableau 1. Réglages du sondeur lors des mesures de TS)

We are not able to present in this paper the absolute TS values, as the results of the calibration are not yet available. The results are expressed in relative back scattering cross section values.

1.3. Echo integration measurements

The echo integrator used was an AGENOR digital echo integrator. The data were regrouped in the same 6 mn ESDUs as for the TS measurements, using the (20 log R) TVG setting of the 102 BioSonics sounder. Agenor allows the use of 10 layers, which were adjusted by 5 meters intervals, from the surface to the bottom, the 9th layer being adjusted from 40 to 50 m and the 10th from 50 up to the bottom. A 50 mv threshold was selected, with a 0 dB gain.

2. RESULTS

2.1. Description of the echograms

The first part of the survey was performed on low density concentrations, and were not included in the data processing. We used the second part of the survey, from 9:30 pm.

During this survey the fish did not present the usual spatial distribution, and some big schools were recorded (fig. 3). This unusual behaviour is probably due to the moonlight conditions. Anyway, we were obliged to remove 9 ESDUs from the data set (4 in light-on situation, 5 in light-off).

Once this "cleaning" of the data performed, the 28 remaining ESDUs show a rather homogeneous situation, the biomass being represented by scattered fish all over the water column (fig. 4). Contrarily to the situation observed in 1987, no obvious vertical movement is visible on the echogram. It is also interesting to notice that in the deepest layers the single target show a "climbing" tendency, which could indicate either an upward migrating behaviour or a slight inclination of the transducer.

2.2 Echo integration results

a). Horizontal analysis.

The succession of the global fish density for each ESDU is presented in fig. 5, the data of light-on and light-off sequencies being separated. Except in two couples of data, the light-off values are higher than the light-on, the mean difference being 50 % . Nevertheless, when we apply statistical significance tests on this set of data, we may see that the difference between light-on and light-off data is not considered as significant at the 95 % level. Considering the high degree of variability of the set of data, and the fact that we do not use real couples of values, we must be very careful when extracting conclusions from these kind of observations.

b). Vertical analysis

The difference on the 28 unpaired values of density in the upper layer (13 light-off, 15 light-on) is very important (54 %) but not significantly different from zero (for $P = 0.05$) owing to the large variability of the data. A log-transformation was used to obtain the homogeneity of the variances. A t test on 21 paired values of contiguous ESDUs allowed for a decrease in the variability of the difference between means, and therefore indicated that this difference is significantly different from zero (for $p = 0.01$).

Comparing the mean values of integration for each layer, we may observe that this clear difference between the light-on and light-off data of the shallow layers (depth less that 20 m) does not appear in the deep layers (more than 20 m): the biomass difference already noted appears exclusively in the upper layers: it seems that the light has no effect at depths lower than 20 m. The figure 6 shows clearly that in this case there is no vertical diving avoidance.

2.3. Back scattering cross section results

a) target counting

When considering all the data from 9:19 pm to 11:45 pm (fig. 7), we obtain more or less the same kind of results as in fig. 5 : the number of individual targets as counted by the dual-beam system is generally lower in the light-on periods than during the light-off. This could be due either to a escapement of the fish or to a compacting behaviour which would reduce the number of avaliable individual targets for the dual-beam echo-sounder. When comparing the echograms, we may suppose that lateral escapement is the main responsible factor.

Then we counted the targets within the superior and the inferior level (fig. 8): the results are parallel to those of echo integration: the number of target decreases in the upper layer (5 to 17 m) while it remains approximately constant in the lower strata (17 to 30 m).

b. TS variations

When considering the average back scattering cross sections (fig 9), we can see that contrarily to the average densities, the individual echoes remain much more constant. There is still a lower level of the values when the light is on, but not so evident and important as on the density measurement.

If we observe the data separately by 2 meter layers, we may see one more time the same difference between the upper and lower layers (fig. 10): all the difference between the data of the ESDUs is due to differences in the upper layer.

It is not yet possible to discriminate between the two hypothesis above mentioned, i.e. lateral escapement or tilt angle variation, which one is responsible of the variations in the density. In order to make such a discrimination, we draw the frequency histograms of the backscattering cross sections in the shallow and deep layers (fig 11): we can see that the modal values are identical in all the cases, and that the decrease of the mean in the shallow layers is due to the absence of the biggest targets (which are suspected to represent a different species, probably predators, as Carangids, barracudas, etc..).

DISCUSSION

The first observation we can extract from this work is that the behaviour of the fish is depending on many factors: the species concerned, environmental variables, artificial stimuli, and may be different from a survey to the other in certain cases. The usual diving behaviour we have observed several time in this area (and included a few days after this experiment) was not present during this small survey. This could probably be linked to the unusual concentration of big night schools.

Therefore the decrease of the global densities could be due to either lateral escapement or changes in the tilt angle of the fish. If we consider that on the one hand the number of present targets decreased in the same way as the global density, and on the other hand that the observed decrease of the mean back scattering cross section was mainly due to the lack of the biggest targets, we can conclude that the decrease of the biomass in this experiment is explained by lateral escapement, the big fish escaping more than the small ones.

Finally a third conclusion on these data, when comparing to the other identical experiments we have performed in this area (vertical avoidance), is that, as there was no difference in the mean back scattering cross section of the fish whether the light were switched on or off (once removed the values of the big targets), the fish were most probably always in an horizontal position when overpassed by a survey vessel: the behavioural scheme would be the following:

- the fish perceives the noise of the boat at a long distance and moves to an horizontal "warning" position.

- when the light is perceived, and according to other behavioural parameters (moon light ?), it choses a spatial "secure place", either by diving or through a lateral escapment. This behaviour takes place before the boat passing over the target; when it occurs, the fish is already in this "secure position", and consequently is still horizontal.

CONCLUSION

The phenomena described explain why in former surveys we have not seen biomass differences between light-on and light-off data.

Moreover, it leads to the following conclusion: the TS values obtained with a cage, and the integration constant calculated by this way must take into account the values for horizontal fish more that those for other tilt angles. In this case, we may consider that it is prefereable to use the results of cage experiments performed by day than by night. The visual control (video camera) of the position of the fish being evidently indispensable.

It allows us also to compare directly the "in situ" TS values obtained by day and by night, without having to apply on them any tilt angle correction (at least for the upper layers).

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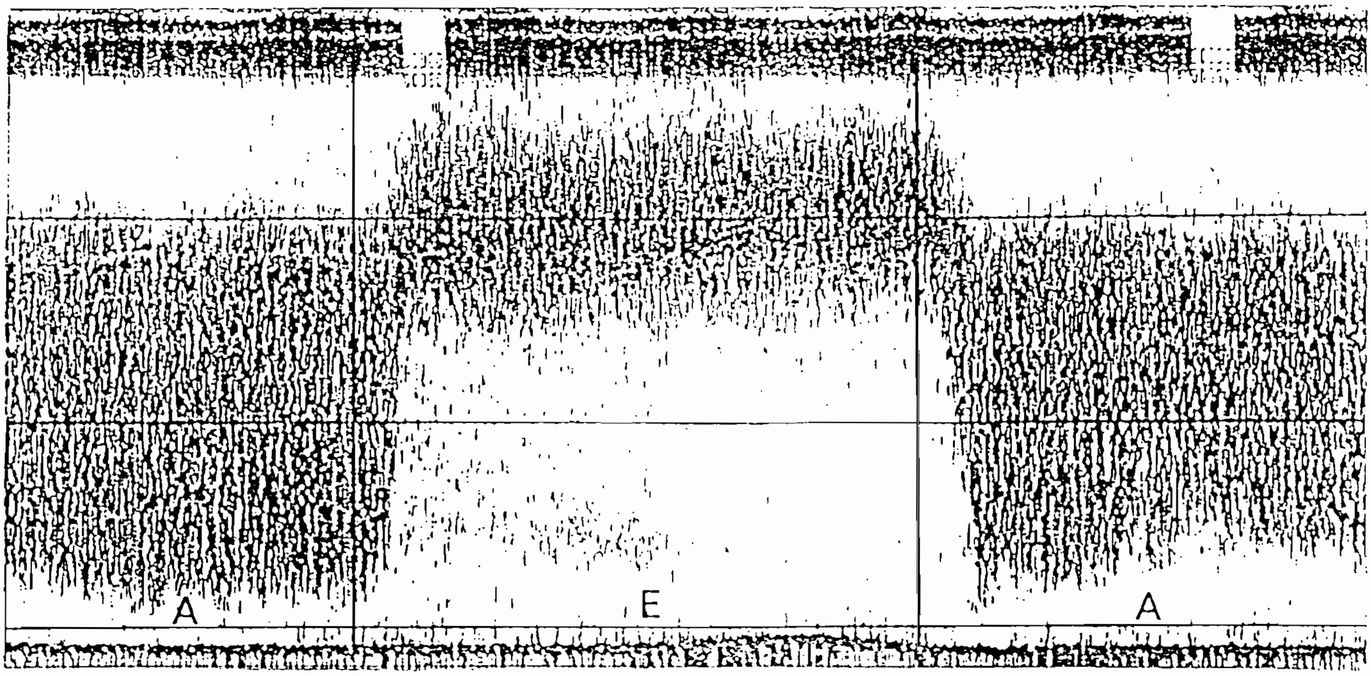


Fig. 1. Example of avoidance reactions of the fish to the light
A = light on E = light off
(from LEVENEZ <u>et al.</u>, 1987)

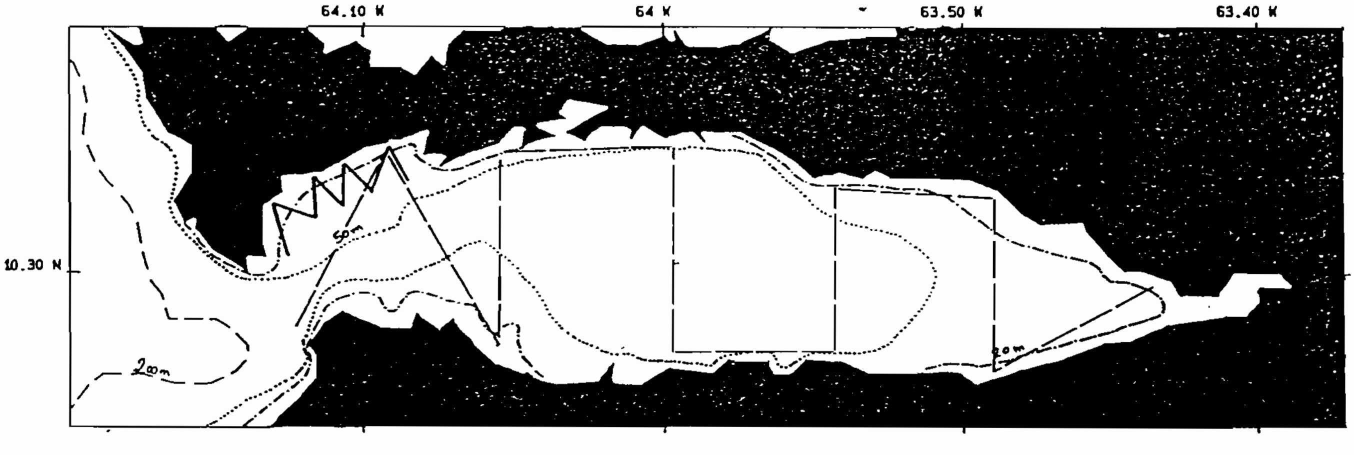


Fig. 2. Prospection and experiment transects in the Gulf of Cariaco (Eastern Venezuela)
- - - prospection ——— experiment

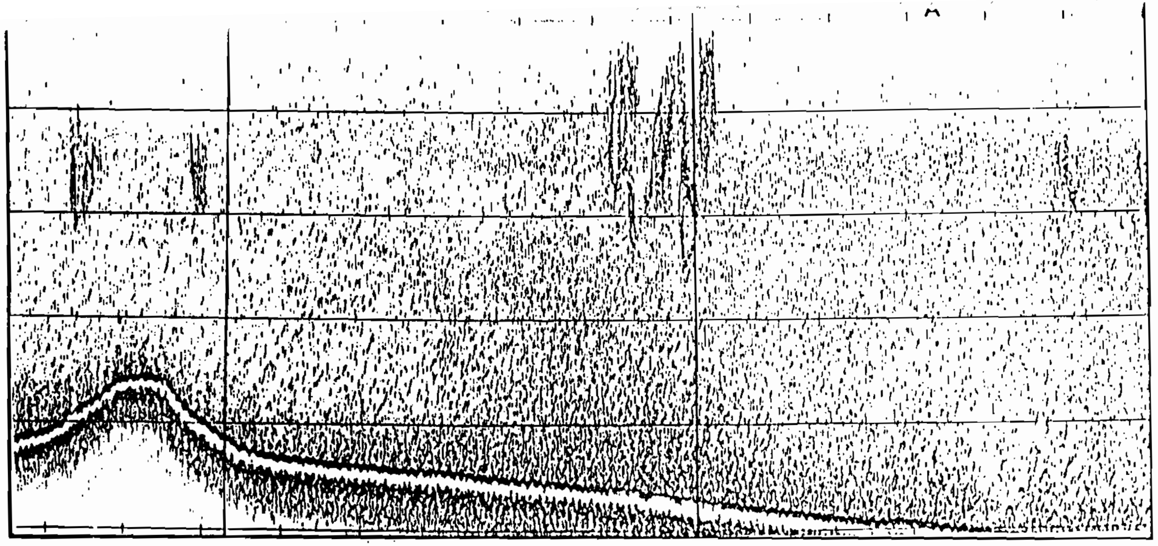


Fig. 3. Echogram of some schools observed by night in the area of experiment (paper scale 0/50 m)

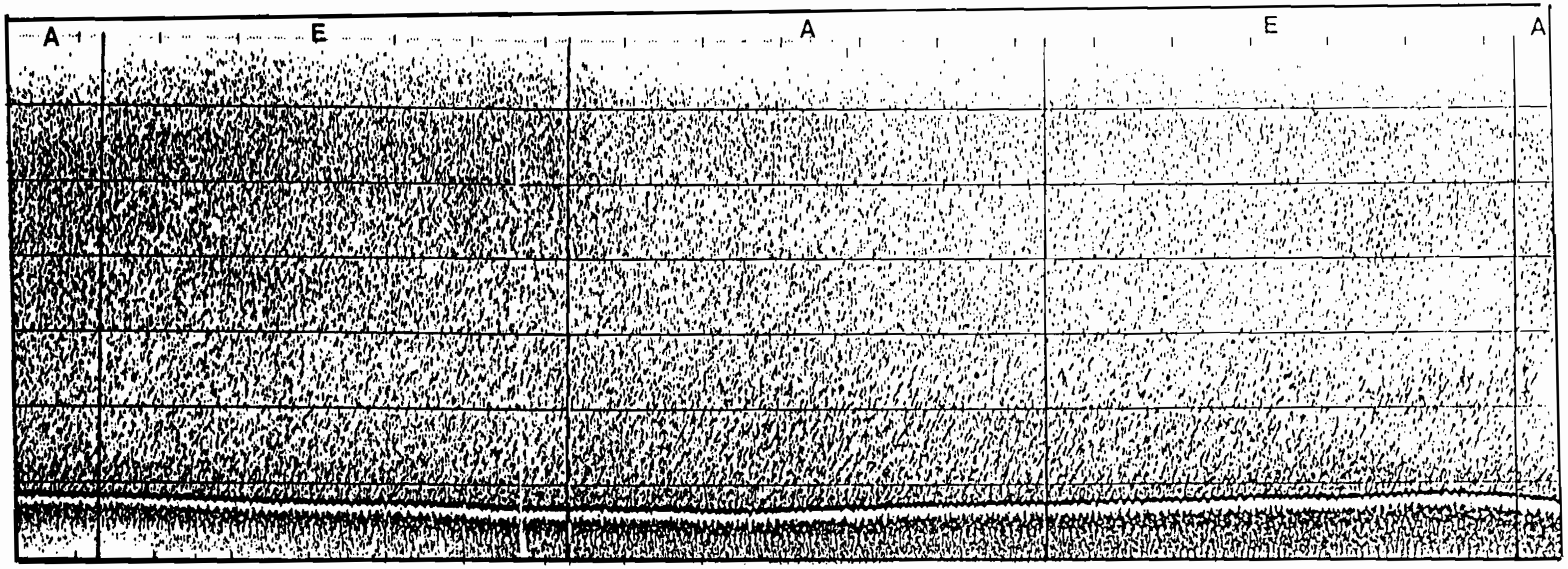
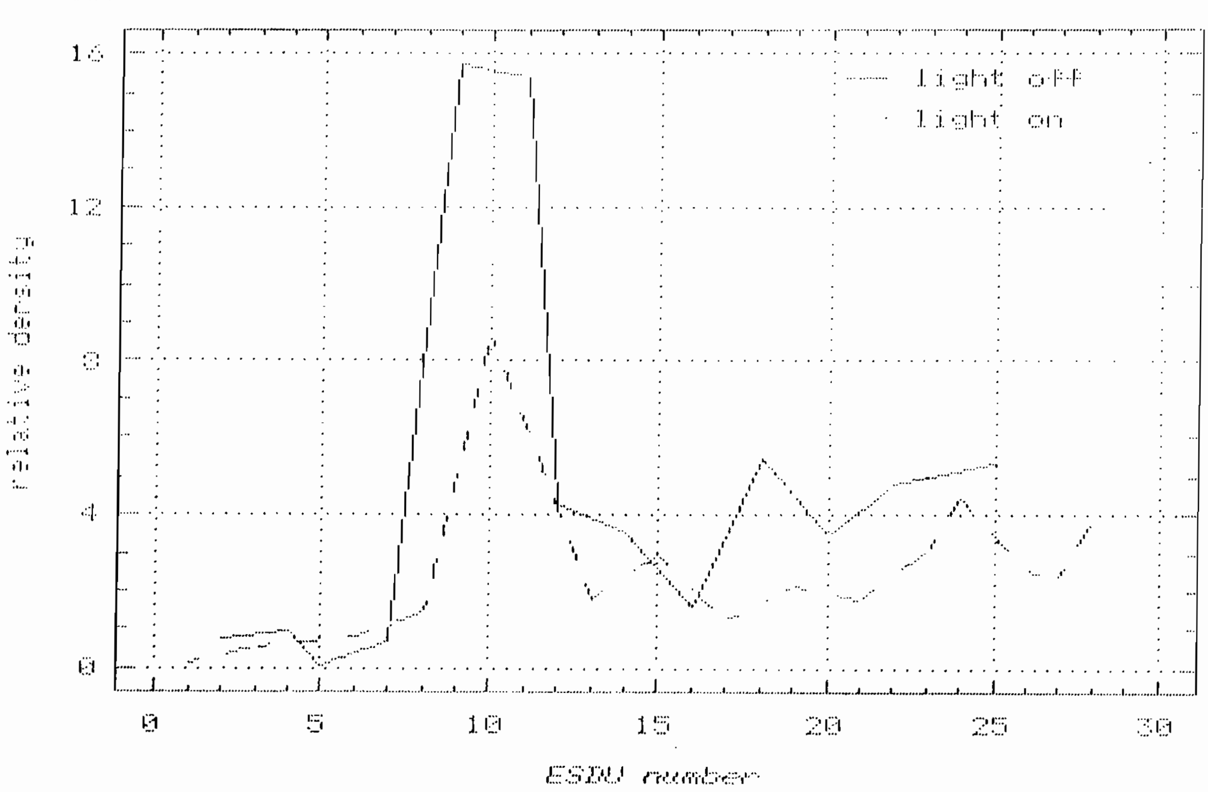


Fig. 4. Example of some light-on/light off ESDUs
A = light on E = light off (scale 0/70 m)

Fig. 5. Evolution of the total density
EICHOANT, feb. 1990



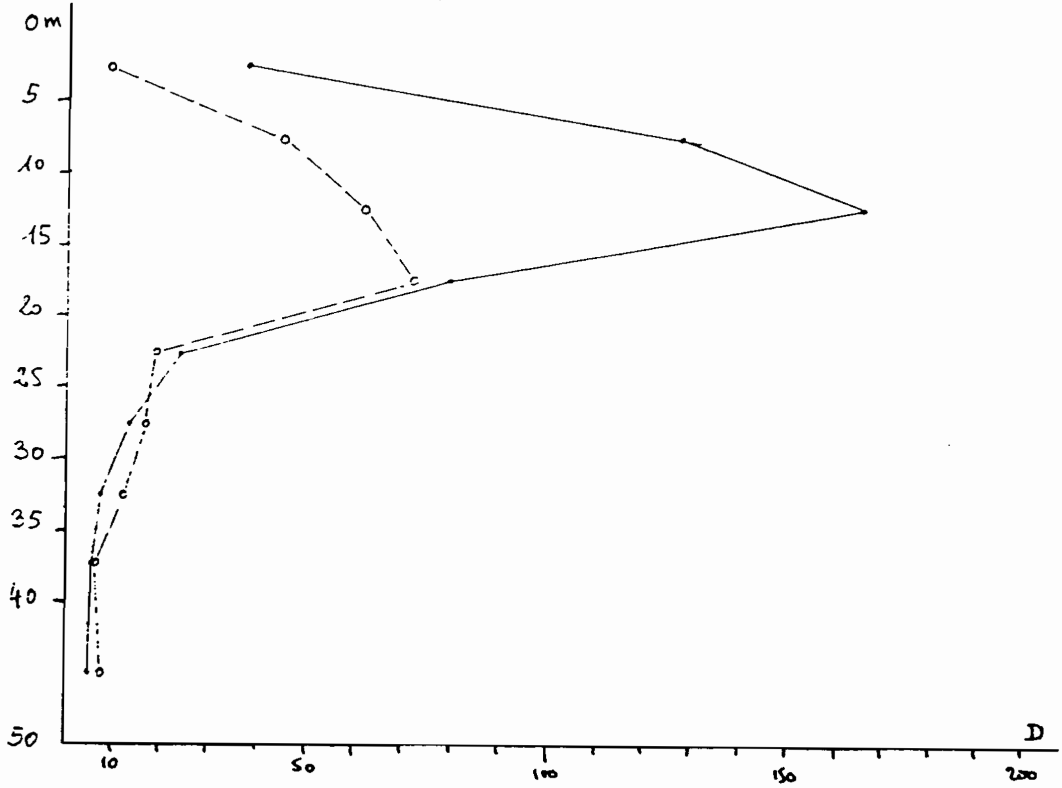


Fig. 6. Mean variation of the density by 5 meter layers in relative units.

o- - -o light on ●——● light off

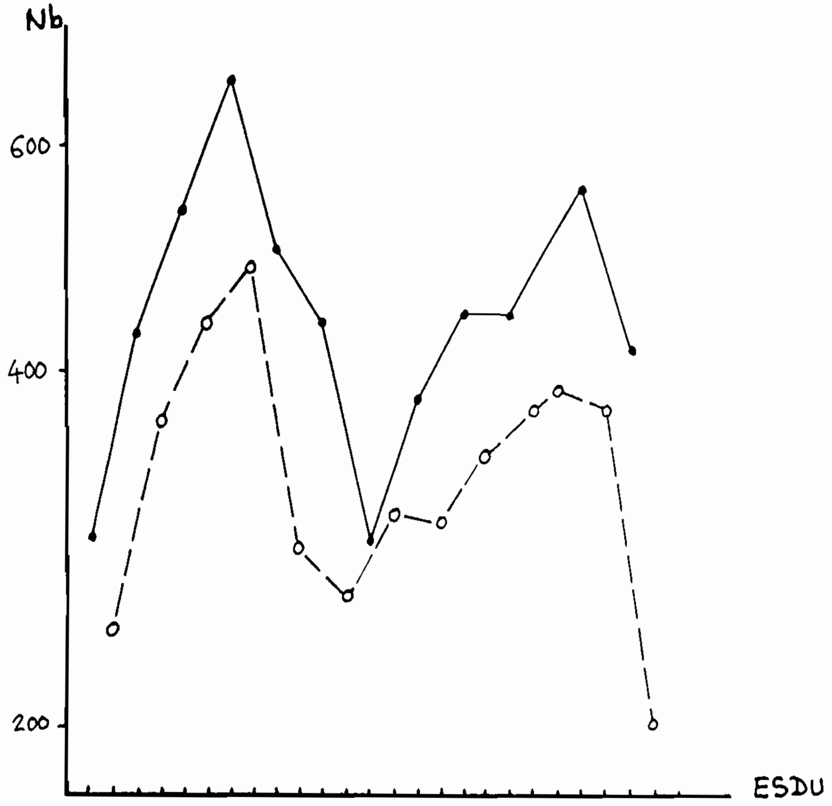


Fig. 7. Number of individual target observed through dual-beam results for each ESDU

○ - - - ○ light on ●——● light off

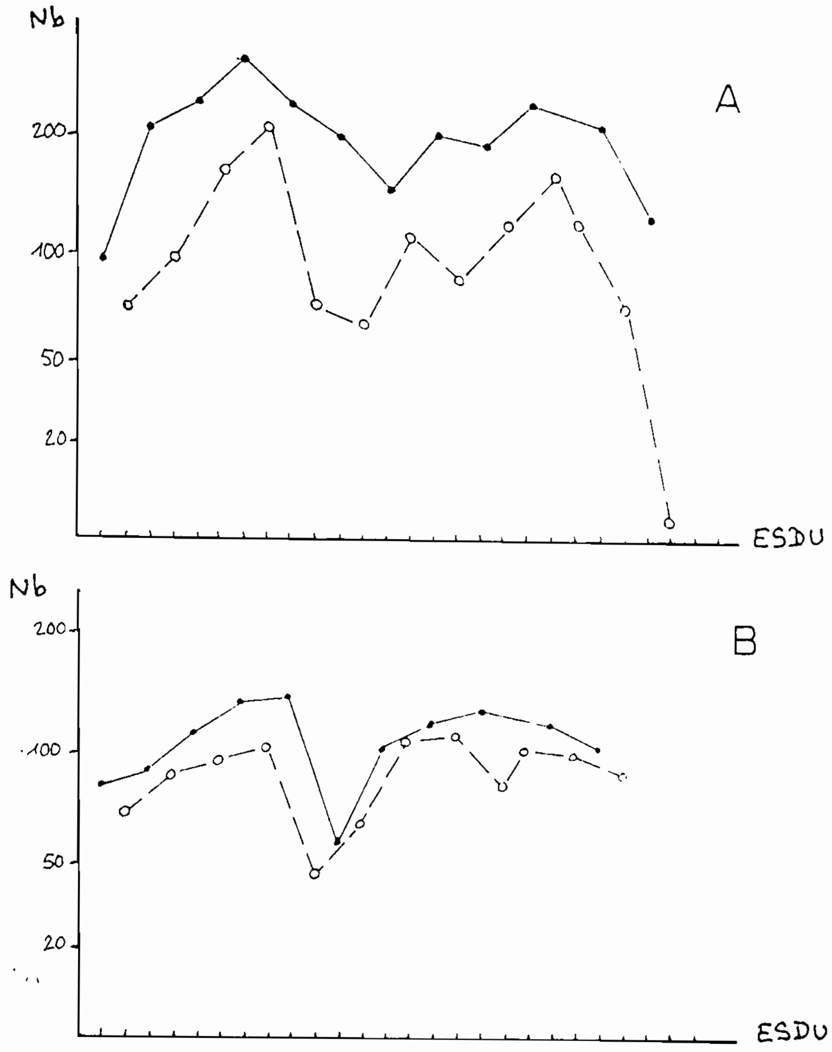


Fig. 8. Number of individual targets observed through dual-beam results for each ESDU and:

A = for the upper layer (5/17 m)

B = for the lower layer (17/30 m)

○ ○ light on ●——● light off

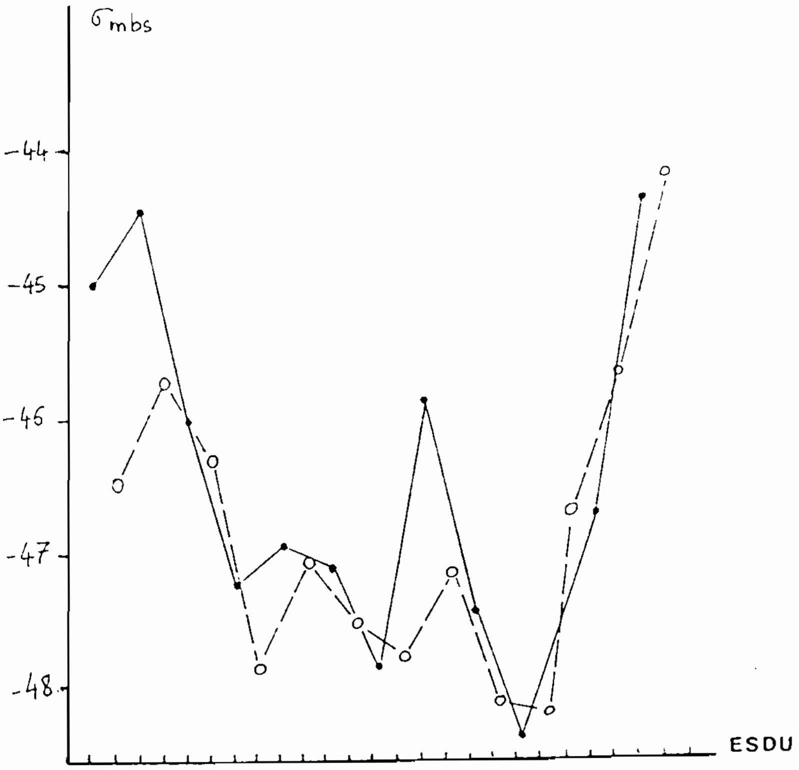


Fig. 9. Variation of the mean back scattering cross section for each ESDU

o- - -o light on ●——● light off

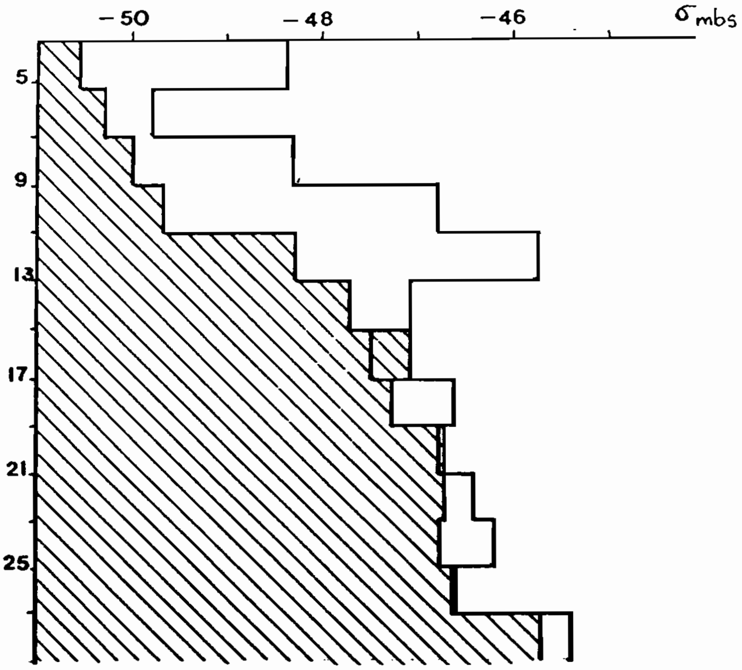


Fig. 10. Mean value of the mean back scattering cross section by 2 meter layers (all ESDUs included)

light on ▨ light off ☐

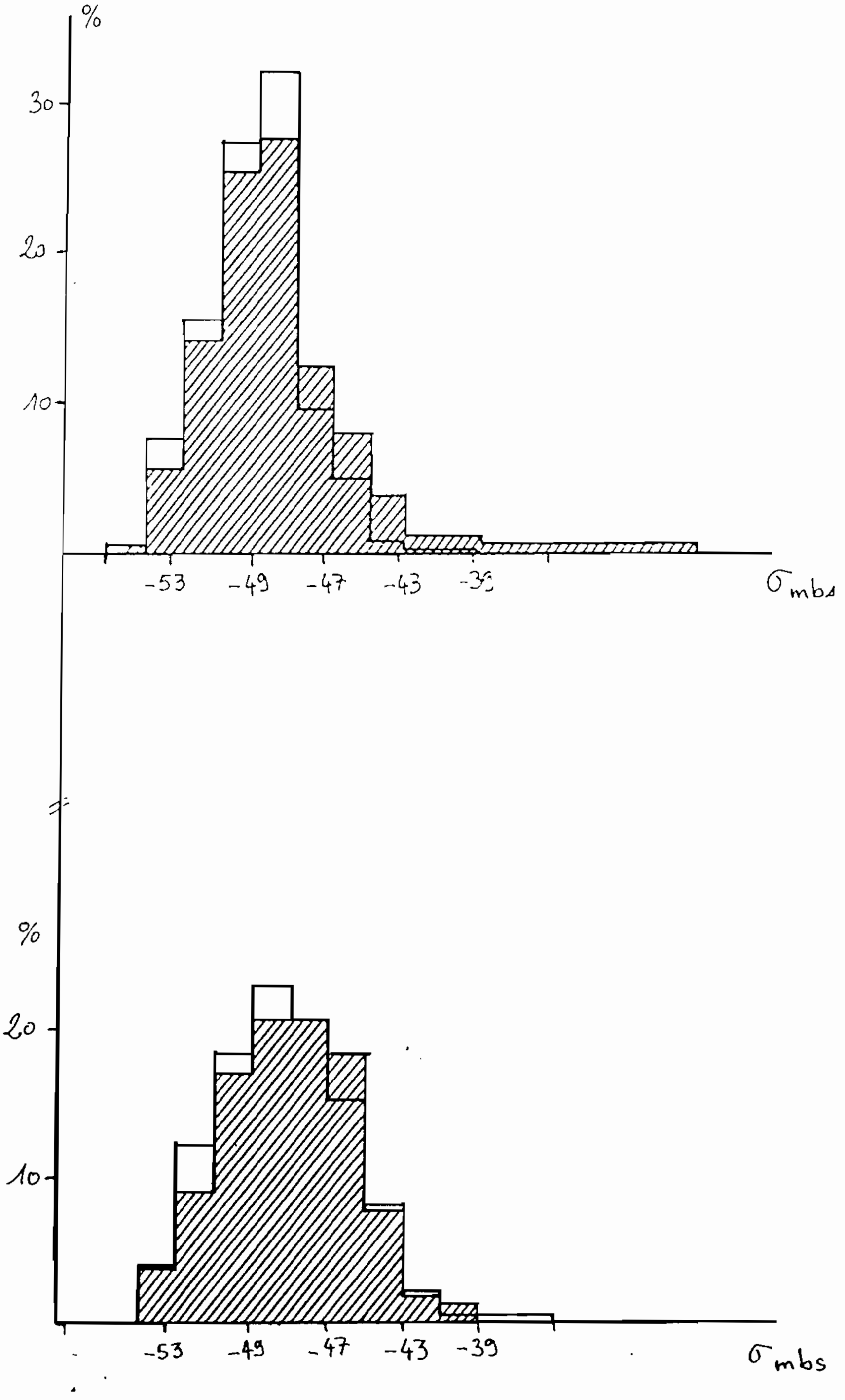


Fig. 11. Frequency histogram of the back scattering
cross sections of all the targets observed
A = upper layer (5/17 m)
B = lower layer (17/30 m)
light on ▨
light off ☐

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Joint FAST/FTFB
Working Group
Rostock, April, 1990

EVALUATION OF THE INFLUENCE OF VESSEL NOISE BY NIGHT ON FISH DISTRIBUTION AS OBSERVED USING ALTERNATELY MOTOR AND SAILS ABOARD A SURVEY VESSEL.

by

P. FREON, F. GERLOTTO and M. SORIA

ORSTOM, BP 81, 97256 Fort-de-France, Martinique (FWI)

RESUME

L'influence du bruit du moteur d'un bateau de prospection sur les poissons a été étudiée en utilisant alternativement la navigation sous voile et au moteur à bord d'un voilier de 16 mètres équipé d'un moteur diesel inboard de 116 cv. Trois expériences ont été realisées de nuit sur deux types de population de poissons tropicaux: l'une au large sur des poissons dispersés (probablement des poissons volants et des Myctophydés de la DSL), l'autre sur une couche de poisson pélagiques côtiers (probablement de jeunes Clupéidés et quelques mulets). Dans les trois cas on a observé aucune différence significative de l'influence du bruit du moteur sur la densité, et seulement une faible réaction d'évitement vertical (plongée inférieure à un mètre) s'est produite.

ABSTRACT

The influence of the motor noise of a vessel on fish distribution has been studied by using alternately motor and sail on a survey vessel. The vessel was a 16 meter overlength sailing-ship, equipped with a 116 hp diesel inboard engine. Three experiments were conducted by night on two kinds of tropical fish population: one offshore on an assemblage of dispersed fish (probably flying-fish and myctophydae of the DSL), the other on a layer of coastal pelagic fish (probably young Clupeids mixed with some mullets). In all cases no significant influence of the engine noise was observed on the density and a only a weak vertical avoidance (less than one meter) occurred.

INTRODUCTION

The influence of the vessel stimuli on the fish behaviour is one of the central question adressed to scientists using acoustic survey for stock assessment (Olsen, 1987). Such an influence is supposed to be responsible for underestimations of density owing to lateral or to vertical avoidance reactions (in this last case a change in the fish tilt angle, and therefore in its target strength is incriminated). The vessel noise, and more specifically the propeller noise, is incriminated as the principal stimulus governing fish avoidance (Olsen and al, 1983).

In order to quantify the importance of this behaviour on density estimations, some experiments have been conducted by night with a sailboat using alternately sail and engine during the echo survey.

MATERIAL AND METHOD

The boat used was a 16 meter overlength quetch, equipped with a 116 hp diesel motor. In order to limit the heel, leading wind sailing trims were retained. It has been controlled that the heel did not overpass 3° (generally from 0° to 2°), and therefore its effect on TS can be supposed negligible.

A 70 Khz Ey-M Simrad portative echo-sounder was installed on board with its 11° transducer mounted starboard, at 7 meters from the stem and at 1,5 meter under the surface. The signal was recorded on a portative digital recorder and processed later in the laboratory with a digital echo-integrator AGENOR.

Two kinds of experiments were conducted. One took place offshore in the Western part of Martinique (French West Indies), during the 27-28 november 1989 night of the new moon. It concerned a scattered fish layer (probably flying fish in the first 15 meters and Myctophydae of the DSL below this depth). The two other experiments took place in coastal waters of Venezuela (Gulf of Cariaco and Southern part of Coche island) during the night, from the 22nd to 23rd June 1989, and for three nights from february 13th to 16th 1990. The moon was at three quarters during these last experiments. For the first experiment the moon rose at the beginning of the observation period and the weather was relatively clear. During the second coastal experiment, contrarily to the fisrt one, most of the observations were done during the hours of low moonlight intensity (before moon rised or with cloudy weather). The depth of the bottom was around 40 meters in the first experiment, over 500 meters in the second and from 12 to 21 meters (generally 17) in the third one.

In all the experiments, sails and engine were used alternately at time intervals varying from, 3 to 15 minutes according to the variability of the detection. A single time interval of 15 mn was used for the offshore experiment conducted along a single transect, meanwhile 3 to 6 mn time intervals were used for the other experiments. In these two experiments a short transect across the distribution area of a limited layer were repeated several times and two methods were used:

- in some cases the distribution area was crossed using alternately sails and motor when sailing down-wind, and only the engine when sailing head to wind, therefore the experiment provided more samples with motor than with sails;

-in other cases the whole distribution area was crossed only using sails (down-wind) and then only the motor (head to wind), providing the same number of samples with engine as with sails. As far as possible the vessel speed when using the motor was adjusted to the speed of the previously elapsed time using sails (generally between 3 and 4 knots). Nevertheless, for some hours during the night between the 14th-15th February, a weak wind imposed a very low speed (1.5 to 2 knots), impossible to sustain with the motor.

Owing to variability of the fish distribution in the last experiments, a selection of the usable data set was necessary. First of all, the low densities found before entering in the layer and after overpassing it were eliminated from the data set. In a few cases, some bottom schools were observed and the corresponding data were deleted.

The first step in data processing was to compare the mean density of the whole intervals with sails, to the whole intervals with motor. This method presents the advantage of allowing the use of all available data, specially when motor data are more abundant (see before). Nevertheless, the high spatial variability may limit the power of such an analysis. In order to overcome this problem, the second step was to compare paired samples of adjacent observations with sails and motor. As no obvious engine influence appeared from the first analysis or when reading the echograms, it was decided to retain the paired samples when the echograms looked similar and homogeneus, especially the short time intervals in the middle of the layer. This choice is of course subjective, but a repetition of the selection by two scientists has shown a good consistency.

RESULTS

The offshore experiment indicates that the density varied reasonably (factor 2 between, lowest and highest values) and progressively from one 15 mn time interval to the other (fig. 1). The same remark applies to the different depth intervals. A two sample test considering two independent samples indicates no significant differences between the sample where the motor was used compared to those where sails were used, even using a 99% confidence interval (Appendice 1, table 1). A paired t test gave the same results (Appendice 1, table 2). On the contrary, another experiment on this same fish assemblage, conducted in the following hours, indicated a strong reaction of the fish to an artificial light alternately switched on and off (Gerlotto *et al.*, 1990).

The first experiment on coastal pelagic fish is not so easy to interpret because a larger spatial variability was observed (factor 10; fig. 2). When using a one factor ANOVA (which is equivalent to a two sample test in this particular case), a significant difference appears between the means of samples with sails and those with motor (table 1). Nevertheless, the fish density was highly variable and a two factor ANOVA, including a repetition factor in the middle of the experiment, shows that the spatial variation explains most of the variability and that the motor effect is not significant (table 2).

Table 1: One-way analysis of variance for the first coastal experiment.

Source of variation	Sum of Squares	d.f.	F-ratio	Sig. level
Between groups	12367264	1	9.68	.0051
Within groups	28109793	22		
Total (corrected)	40477057	23		

Level	Count	Mean	Stnd. Error (internal)	Stnd. Error (pooled s)	99% Confidence intervals for mean	
SAIL	14	2189.1	296.5	302.1	1337.4	3040.9
MOTOR	10	3645.2	366.9	357.5	2637.4	4653.0
Total	24	2795.8	230.7	230.7	2145.3	3446.3

Table 2: Two-way analysis of variance for the first coastal experiment.

Source of variation	Sum of Squares	d.f.	F-ratio	Sig. level
MAIN EFFECTS	18502400	4	3.595	.027
SAIL/MOTOR	987036	1	.767	.403
REPETITION	6135136	3	1.590	.229
2-FACTOR INTERACTIONS	103103.68	2	.040	.961
RESIDUAL	21871554	17		
TOTAL (CORR.)	40477057	23		

The second experiment on coastal pelagic fish provides the highest number of data, collected over three nights (presently only 80% of the available data are analysed). As the observations applied obviously on the same fish layer, the whole set was used in a first step (186 observations). The only subdivision used was between dispersed fish and layer, the latest providing the highest densities (fig. 3).

The results of the ANOVA performed on the total density (fig. 4; table 3 and appendix 2) indicated that the difference between intervals when using the motor and those using sails is small (1.8 %) and not significantly different from zero (P=.05). The homogeneity of the variance is verified and the distribution of residuals is acceptable. A t test on the means of 47 paired values gave the same results (difference = 7.4%; P=.05).

Table 3: Two factor analysis of Variance of total density in the second coastal experiment.

Source of variation	Sum of Squares	d.f.	F-ratio	Sig. level
MAIN EFFECTS	14081536	2	20.627	.000
LAYER/DISPERSED	13534512	1	39.652	.000
SAILS/MOTOR	456432	1	1.337	.249
2-FACTOR INTERACTIONS	61170	1	.179	.6771
RESIDUAL	62123189	182		
TOTAL (CORR.)	76265895	185		

The same analysis was performed for the five 2 meter intervals of depth between 1.5 and 11.5 meters (not enough representative data were available for the deepest layers). Even though none of the differences between sequencies with and without sails is significantly different from zero (P=.05), there is a consistency in the results, strongly suggesting a downward shift of the biomass during the sequencies with motor compared to those with sails (fig. 5). A t test on the 47 means of paired data lead to the same results for any layer (P=.05).

The two factors ANOVA performed on the mean depth of the biomass does not indicate significant differences between sequencies with sails and motor when using the whole data test (fig. 6; table 4 and appendice 2). Nevertheless, a t test performed on 37 paired values concerning only layers indicated that there was a difference of -0.52 meter between sequencies with sails and motor, which was significantly different from zero for P=.01 (the density in dispersed fish sequency was too low for estimating a representative mean depth).

Table 4: Two factors analysis of variance for mean depth in the second coastal experiment.

Source of variation	Sum of Squares	d.f.	F-ratio	Sig. level
MAIN EFFECTS	97.1	2	12.5	.0000
LAYER/DISPER.	91.4	1	23.4	.0000
SAILS/MOTOR	4.9	1	1.3	.2650
2-FACTOR INTERACTIONS	.0720	1	.018	.8935
RESIDUAL	710.2	182		
TOTAL (CORR.)	807.3	185		

DISCUSSION

Even though the data processing is not completly acheived, it is obvious that in these experiments the influence of the motor and propeller noise on the density -if any- was very low, suggesting that no important lateral avoidance occurred, or at least that the avoidance would be the same with or without engine.

The influence on the mean depth of the biomass is demonstrated, but remains limited (less than one meter). It suggests that the engine noise was responsible for a vertical avoidance reaction, or at least that when sailing with sails if such a reaction occured, it was accentuated by the motor noise.

The hypothesis underlaying these results are not obvious. On the one hand, a decrease in the density could be expected when the motor was used owing to lateral avoidance reaction; Gerlotto and Fréon (1988) proposed an interpretation of such a low avoidance by the effect of the acoustical shadow of the hull which is funnel-shapped; therefore the fish could be funnelled under the hull. On the other hand, if the fish was stressed when the motor was used and not with sails, the mean tilt angle should be higher in this later case and therefore lower densities would be expected (supposing no lateral avoidance). Our results indicated that the fish were stressed by the noise of the engine and/or the propeller because it dived, but as no difference in density was observed, it was supposed that the fish were also stressed without motor noise. The fact that the propeller was freely rotating when using the sails could explain this fact.

An opposite explanation could be that the fishes were weakly stressed by the motor and propeller noise. Two reasons can be invoqued.

Firstly, the relatively low noise level of the boat when using it 110 hp motor at half of its power (800 r.p.m.) which could lead to a low stress and/or a short duration of this stress. Moreover, the relatively low speed of the boat, compared to the usual speed used during acoustical surveys, could also limit the stress intensity. It has been demonstrated (Hering, 1968; Olsen, 1969) that the fish react to noise according to its gradient in time (which gives an indication of the speed of the noise source displacement) and not only to its mean level. In order to control the influence of these two factors (level and gradient) a short experiment was conducted during the night of 16th-17th february using alternately two motor "regime": 750 r.p.m. (around 3.5 knots) and 1400 r.p.m. (around 6 knots). Unfortunately not enough data were available to draw any conclusion from this experiment owing to the spatial variability of the density.

Secondly, the noise level of the motor is supposed to be high enough but fish are not sufficiently organised to interact in group behaviour reactions. Indeed, during the night the fish were in layer structure or scattered. Thus, their visual isolation and the lack of organisation could deprive them of synchronized reactions (flight or avoidance). In this case the "wave of agitation" described by Radakov (1973) inside a school should be impossible. Consequently we could obtain the same densities in the deepest layers when the motor or the sails were used. However, in the upper layer the fished slightly dived when the boat used it's motor. It must be recorded that the surface bioluminescense induced by the hull in the night represented a strong visual stimulus (and may have reduced the level of visual isolation between fishes). Thus, the fishes have been able to associate the noise of the motor to a visual stimulus as it has not been possible for the ones of the deeper and darker layers (the turbidity was relatively high in this coastal area).

This last remark can be connected with the general diagram of fish behaviour to external stimuli presented by Gerlotto and Fréon (this meeting) and with the observations of Glass and Wardle (1989) on the difference of reaction of fish to a trawl according to the light level intensity. These last authors mentionned that the fish in absolute darkness did not react to the the noise of the trawl but only react by a startle reaction when struck by the net. Moreover, experiments on fish conditioning suggest that fish conditioned by a noise to react to a gear, require the visual clue of this gear, even passive, to react to the auditive stimulus (Soria, this meeting).

CONCLUSION

The three experiments using alternately sail and motor during the night indicated clearly that the differences in the fish avoidance reactions -if any- was weak: less than one meter concerning the vertical avoidance and no significant lateral avoidance. These surprising results could appear as good news as far as acoustical surveys are concerned. Nevertheless various interpretations are possible and such findings could result from the low noise level of the sailer when using it's motor, and/or to the relatively low speed during the experiment. Further experiments are necessary to give a definitive conclusion on the avoidance reaction of the fish to a survey vessel, specially TS measurements (Gerlotto and Freon, this meeting).

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APPENDICE 1: Results of the offshore experiment

Table 1: Two-sample analysis results of the offshore experiment (for layers from 2 meter to 20 meters depth, and total of these layers).

```
---------------------------------------------------------------------------
 Layer 2-5 m                Sail             Motor            Pooled

 Number of Obs.             6                6                12
 Average                    52.93            58.20            55.56
 Variance                   361.26           587.89           474.58
 Std. Deviation             19.01            24.25            21.78

 Difference between Means = -5.27
 Conf. Interval For Diff. in Means:           99 Percent
 (Equal Vars.)     Sail - Motor:   -45.14   34.61      10 D.F.
 (Unequal Vars.)   Sail - Motor:   -45.65   35.12     9.5 D.F.

 Ratio of Variances = 0.61
 Conf. Interval for Ratio of Variances:   95 Percent
 Sail ÷ Motor:   0.086          4.392        5 D.F.

 Hypothesis Test for H0: Diff = 0       Computed t = -0.42
                vs Alt: NE          Sig. Level = 0.68
             at Alpha = 0.01        so do not reject H0.
---------------------------------------------------------------------------
 Layer 5-10 m               Sail             Motor            Pooled

 Number of Obs.             6                6                12
 Average                    52.37            49.85            51.11
 Variance                   267.84           186.14           226.99
 Std. Deviation             16.37            13.64            15.07

 Difference between Means = 2.52
 Conf. Interval For Diff. in Means:           99 Percent
 (Equal Vars.)     Sail - Motor: -25.06 30.09     10 D.F.
 (Unequal Vars.)   Sail - Motor: -25.26 30.29   9.7 D.F.

 Ratio of Variances = 1.43
 Conf. Interval for Ratio of Variances:   95 Percent
 Sail ÷ Motor: 0.20    10.28        5 D.F.

 Hypothesis Test for H0: Diff = 0   Computed t = 0.29
                vs Alt: NE       Sig. Level = 0.778
             at Alpha = 0.01     so do not reject H0.
```

```
----------------------------------------------------------
 Layer 2-5 m            Sail          Motor         Pooled

 Number of Obs.         6             6             12
 Average                57.75         63.94         60.84
 Variance               942.22        1285.06       1113.64
 Std. Deviation         30.70         35.85         33.37

 Difference between Means = -6.18
 Conf. Interval For Diff. in Means:        99 Percent
 (Equal Vars.)     Sail - Motor: -67.26    54.89     10 D.F.
 (Unequal Vars.)   Sail - Motor: -67.58    55.22    9.8 D.F.

 Ratio of Variances = 0.73
 Conf. Interval for Ratio of Variances:   95 Percent
 Sail ÷ Motor: 0.103   5.240     5 D.F.

 Hypothesis Test for H0: Diff = 0    Computed t = -0.32
                 vs Alt: NE       Sig. Level = 0.754934
             at Alpha = 0.01     so do not reject H0.
----------------------------------------------------------
 Layer 2-5 m            Sail          Motor         Pooled

 Number of Obs.         6             6             12
 Average                60.45         66.62         63.53
 Variance               1976.48       1633.37       1804.93
 Std. Deviation         44.46         40.42         42.48

 Difference between Means = -6.18
 Conf. Interval For Diff. in Means:        99    Percent
 (Equal Vars.)     Sail - Motor: -83.93    71.58      1 D.F.
 (Unequal Vars.)   Sail - Motor: -84.09    71.74    9.9 D.F.

 Ratio of Variances = 1.21
 Conf. Interval for Ratio of Variances:  95      Percent
 Sail ÷ Motor: 0.076   19.196      5 D.F.

 Hypothesis Test for H0: Diff = 0     Computed t = -0.25
                vs Alt: NE       Sig. Level = 0.81
            at Alpha = 0.01     so do not reject H0.

----------------------------------------------------------
 Total Layers 2-20m     Sail          Motor         Pooled

 Number of Obs.         6             6             12
 Average                223.50        238.603       231.05
 Variance               6834.57       5475.03       6154.8
 Std. Deviation         82.67         73.99         78.45

 Difference between Means = -15.1067
 Conf. Interval For Diff. in Means:        99 Percent
(Equal Vars.)     Sail - Motor:   -158.69 128.48     10 D.F.
(Unequal Vars.)   Sail - Motor:   -159.08 128.87    9.9 D.F.
```

```
Ratio of Variances = 1.25
Conf. Interval for Ratio of Variances:  95 Percent
Sail ÷ Motor:

Hypothesis Test for H0: Diff = 0      Computed t = -0.33
                vs Alt: NE          Sig. Level = 0.745629
             at Alpha = 0.01        so do not reject H0.
----------------------------------------------------------
```

Table 2: One-sample analysis results of the difference in the paired values of the offshore experiment (Motor - Sail).

```
                Number of Obs.          11
                Average                 13.23
                Variance                4114.1
                Std. Deviation          64.14

      Confidence Interval for Mean:     99     Percent
                                     -48.08   74.53     100.F.

      Confidence Interval for Variance:        0       Percent
                Sample 1

      Hypothesis Test for H0: Mean = 0         Computed t = 0.68
                      vs Alt: NE          Sig. Level = 0.51
                   at Alpha = 0.01        so do not reject H0.
```

APPENDIX 2: Results of the second coastal experiment.

Table 1: Means for total density in time intervals using sails and motor, classified according to the detection (layer or dispersed fish).

Level	Count	Mean	Stnd. Error (internal)	Stnd. Error (pooled s)	95% Confidence for mean	
LAYER	127	3184.7	177.2	149.2	2890.3	3479.3
DISP.	59	497.1	59.9	218.9	65.0	929.2
MOTOR	108	2314.5	199.9	161.8	1995.2	2633.9
SAILS	78	2356.8	239.3	190.4	1981.0	2732.6
LAYER/MOTOR	73	3207.8	229.1	196.8	2819.3	3596.2
LAYER/SAILS	5	3153.7	281.5	228.9	2702.1	3605.4
DISP./MOTOR	35	451.5	73.5	284.3	-109.5	1012.5
DISP./SAILQ	24	563.7	101.4	343.3	-113.8	1241.1
Total	186	2332.2	23.3	123.3	2088.9	2575.6

Table 2: Means for the mean depth of the biomass in time intervals using sails and motor, classified according to the detection (layer or dispersed fish).

Level	Count	Mean	Stnd. Error (internal)	Stnd. Error (pooled s)	95% Confidence for mean	
LAYER	127	5.97	.102	.175	5.63	6.32
DISP.	59	7.49	.400	.257	6.98	7.99
MOTOR	108	6.60	.203	.190	6.23	6.98
SAILS	78	6.25	.233	.224	5.81	6.69
LAYER/MOTOR	73	6.10	.136	.231	5.64	6.56
LAYER/SAILS	54	5.80	.153	.269	5.27	6.33
DISP./MOTOR	35	7.64	.520	.334	6.98	8.30
DISP./SAILS	24	7.26	.637	.403	6.46	8.05
Total	186	6.45	.145	.145	6.17	6.74

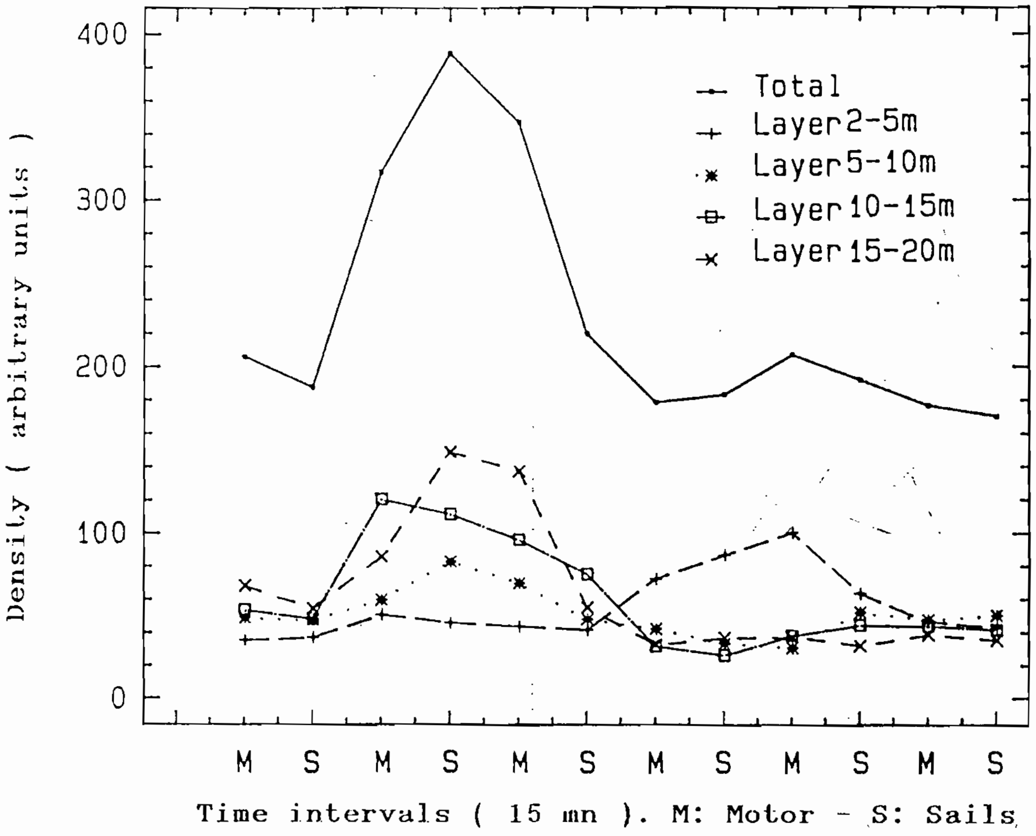

Fig 1. Time sequence plot (15 mn intervals from 21H00 p.m to 00H00 a.m) of densities observed during the offshore experiment at different depth.

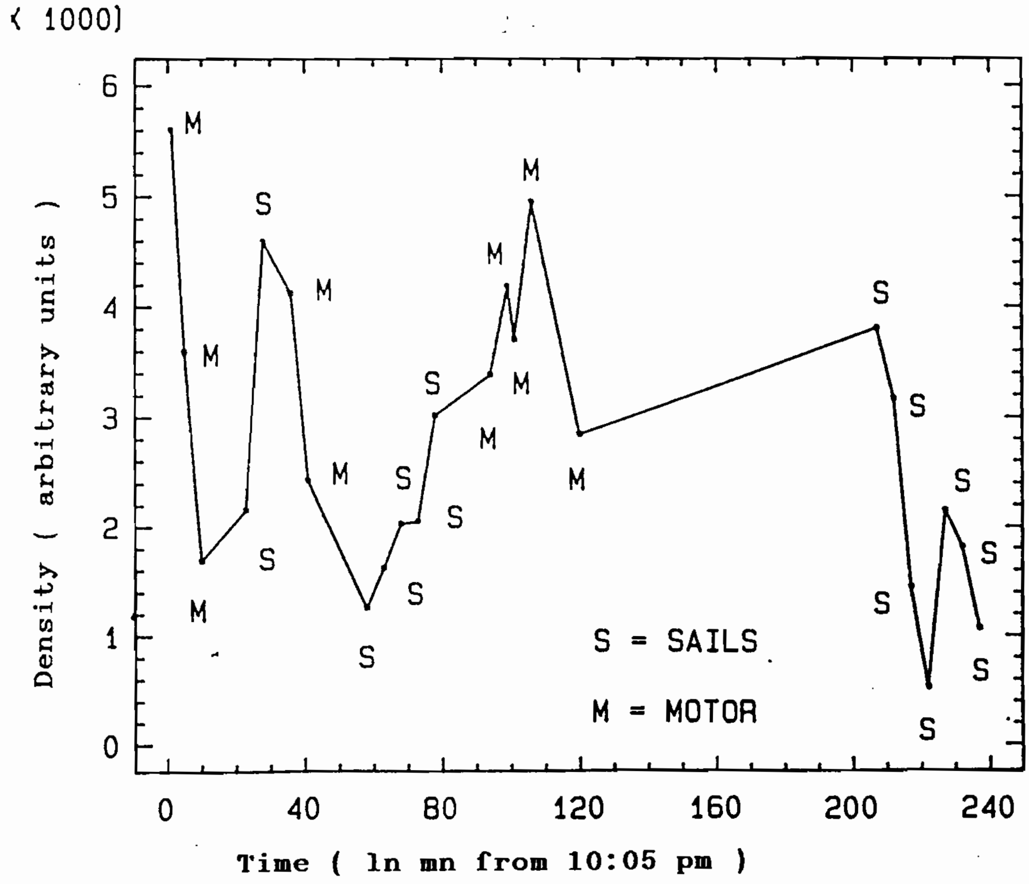

Fig 2. Time sequence plot (in minutes from 10H05 p.m) of total densities observed during the first coastal experiment.

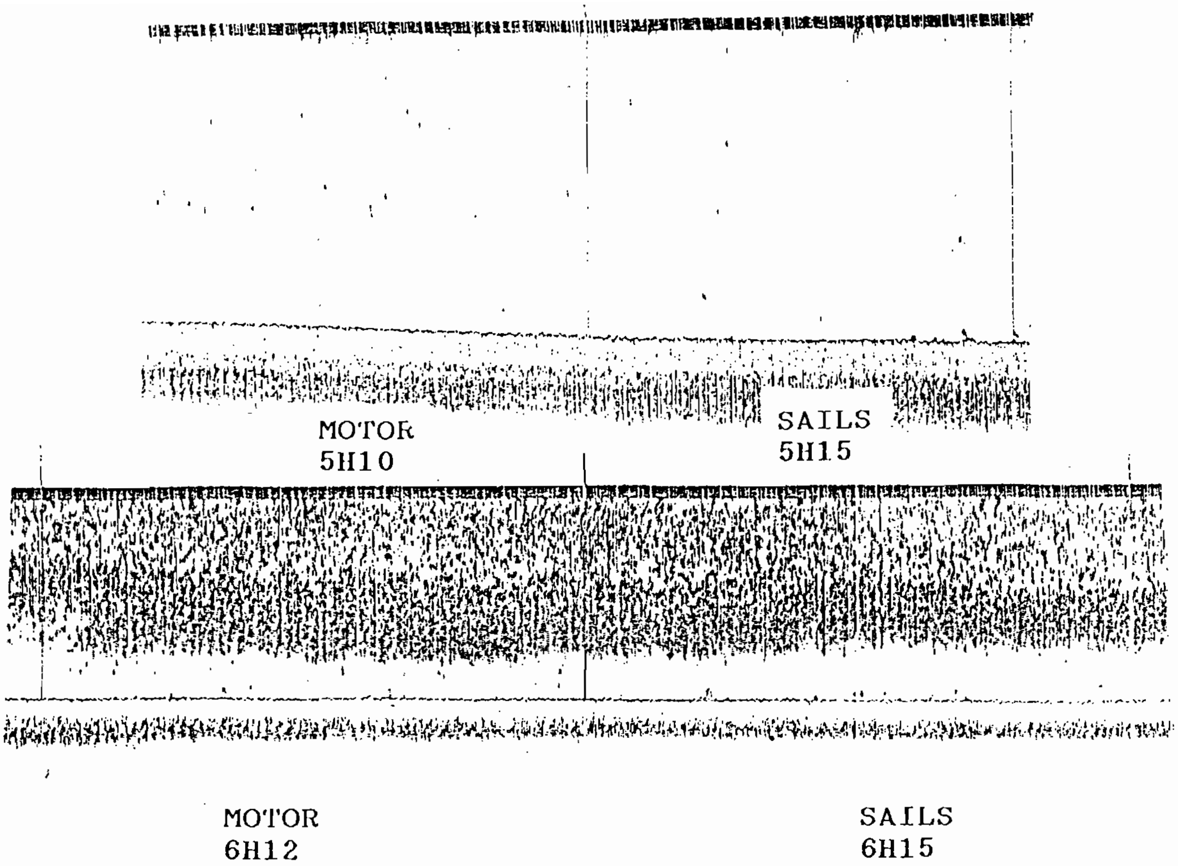

Fig 3. Echograms of layers and dispersed fish overpassed by the sail boat using alternately sails and motor during the second coastal experiment.

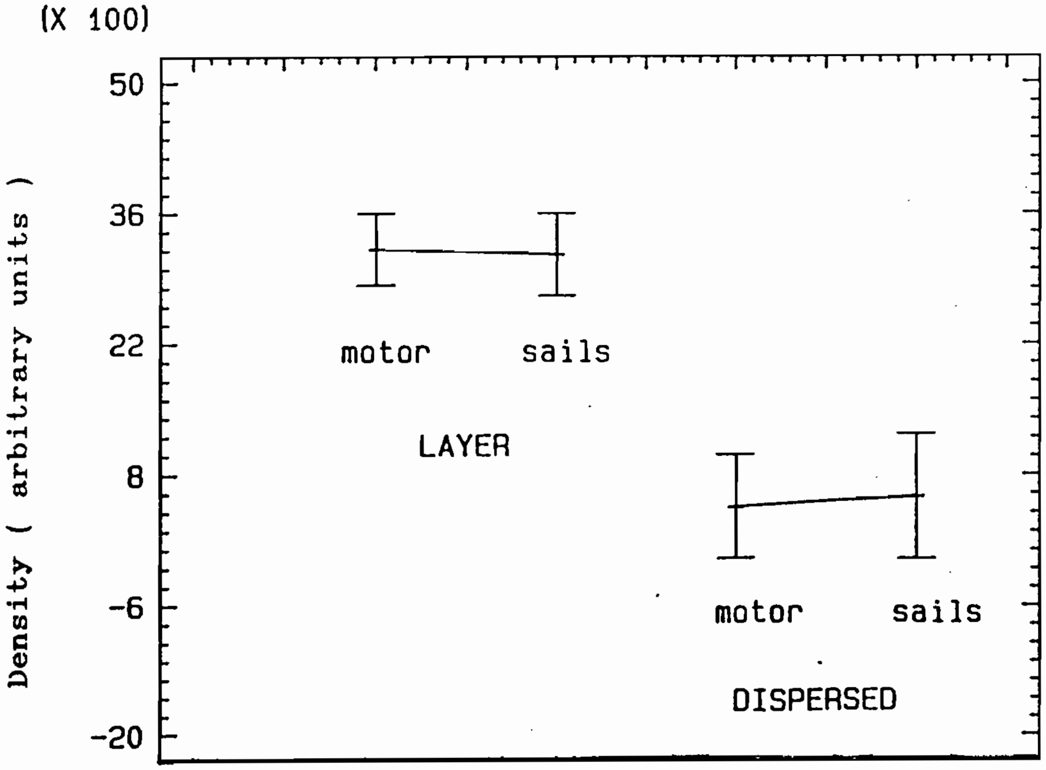

Fig 4. Second coastal experiment: 95 % confidence intervals of factor means density for sails versus motor and layer versus dispersed.

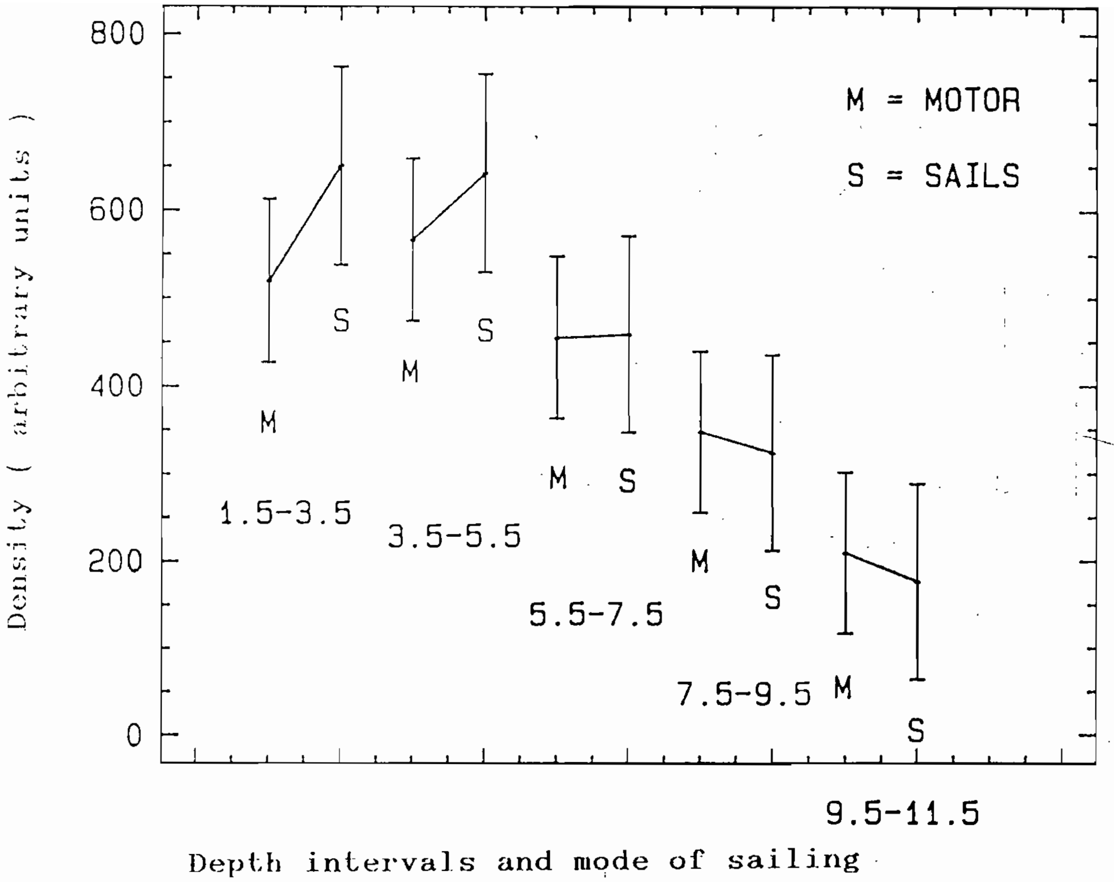

Fig 5. Second coastal experiment: 95% confidence intervals of factors means density for sails versus motor and for different depths.

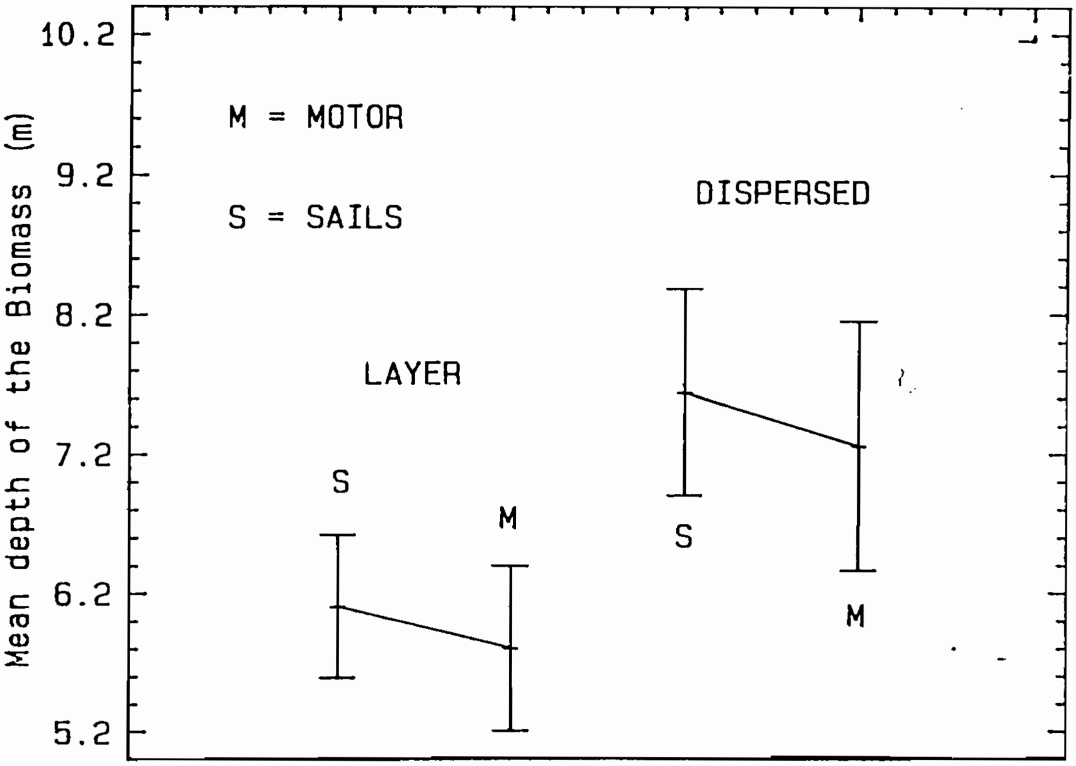

Fig 6. Second coastal experiment: 95 % confidence intervals of factor mean depth of the biomass for sails versus motor and layer versus dispersed.

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CHANGES IN SCHOOL STRUCTURE ACCORDING TO EXTERNAL STIMULI

by

P. FREON, M. SORIA and F. GERLOTTO

ORSTOM, BP 81, 97256 Fort-de-France Cedex, Martinique (FWI)

RESUME

L'influence de stimuli visuels et auditifs, provenant d'un bateau de prospection ou de predateurs, a ete observee de jour sur des bancs de Clupeides tropicaux. Ces observations *in situ* ont ete effectuees dans certains cas simultanement depuis un hydravion (ULM) et en plongee sous-marine. Dans d'autres cas on a effectue à partir d'un voilier motorise des observations acoustiques d'un même banc lorsque le bateau se deplaçait sous-voile, puis au moteur. Il en ressort que la structure interne d'un même banc, sa forme exterieure et le volume qu'il occupe peuvent changer tres rapidement dans des conditions naturelles ou en raison des perturbations provenant d'un bateau. Neanmoins, il est probable que, pour les bancs de surface pour le moins, la structure d'un banc stresse par le passage d'un navire ou la presence d'un predateur presente certaines constantes.

ABSTRACT

The influence of visual and auditive stimuli coming from a survey vessel or predators was observed by day on tropical Clupeids schools. In some instances, these *in situ* observations were done simultaneously from a ultra-light motorized seaplane and by a diver. In other instances a motorized sail boat was used for performing acoustical observations of a single school when overpassed first using sails and then motor. As a result, the internal structure of a school, its external shape and its volume may change rapidly according to external perturbations which can be either natural or coming from a boat. Nevertheless, it seems li-

kely that for surface schools at least the structure of a stressed school is rather constant.

INTRODUCTION

The internal structure of a fish school can be generally described by three groups of parameters:

-The mean density of the whole school (in terms of number of fish per cubic meter or Kg/m^3).

-The arrangement of individual fish inside this structure (homogeneity of the density, variations in the relative position of the fish, variation in the relative and absolute tilt angles, etc).

-The external shape of the school (which is usually linked to the internal structure).

These parameters are probably governed by numerous internal factors (i.e. relative to the fish itself, such as maturation stage) or external ones. This last group of factors can be divided in two subgroups: environmental conditions (for instance, temperature, light intensity, availability of preys, etc) and external stimuli (such as visual or auditive stimuli coming from a natural predator or from a vessel).

All these internal and external factors probably interact in a complex way, and therefore modelizing the fish school structures and behaviours -or generally speaking pelagic fish behaviour- represent a challenge which unfortunately is presently out of our reach. This paper intends to give some pieces of information in changes in fish school structure of tropical pelagic species according to two sources of external stimuli: predator and vessel.

This information, even though representing small pieces of the puzzle, seems interesting to take into account in the case of acoustic survey because the internal structure of schools is suspected to introduce some bias in the biomass estimation or in the species identification.

Some hydro-acoustic observations on a school were carried out by day from a vessel using alternately sails and motor. Visual observations, both underwater and aerial, were also made.

I - MATERIAL AND METHODS

I.1. Hydro-acoustic observations

A sail boat of 16 meter overlength, motorized by a 116 hp inboard diesel motor, was used during this experiment, carried out on the 15th of February 1989 at 9:05 a.m. in the south of

Coche island (Venezuela) were the depth was 19 meters. The same single school was overpassed three times consecutively at a few minutes interval. This surface school was initially detected by sight and overpassed at 1.5 knots using sails the first time (in fact, as the wind was very weak, the motor was also used for impulsing the boat and it was stopped around 100 m before reaching the school). The second time the school was overpassed, the motor was running at 800 r.p.m. (around 3.5 knots), and the third time at 1400 r.p.m. (around 6 knots).

A E-YM Simrad portable sounder (70 KHz) was used with its narrow beam transducer (11°) installed starboard at 7 m from the stem and at 1.5 m under the sea surface. The signal was recorded on a portable digital recorder DAT (Sony). The power of this equipment was supplied by a 12 volts battery, and therefore the electric plant of the boat was stopped in order to limit the noise level.

Later in the laboratory the signal was processed for each individual transmission by the echo-integrator AGENOR, using 1.4 m depth intervals of integration.

1.2. Visual observations

In Martinique (French W.I.) schools of Harengula clupeola are usually observed in coastal areas by day, in shallow waters over seagrass beds. This structure is considered as defensive meanwhile during the night the fish emigrate offshore and disperse for foraging (Silva Lee, 1974). The schools are usually small compared to other clupeoids (from one to 5 tons). The high transparency of the water in the shallow bay of Grande Anse allows for visual observations both underwater and aerial (Fréon and Gerlotto, 1988). As this species is not exploited and the area is a seaside touristic resort, the fish are used to the swimmers and are not afraid of them as long as they keep swimming at the surface.

On February 28th and May 9th, 1989, a school of H. clupeala was observed and photographed at the same time under water by a swimmer and from an ultra-light airplane flying between 60 an 90 meters of altitude. A Nikonos V with a 28° lens was used for the underwater sights and a reflex camera with a 70-200° zoom and a polarizing filter was used in the airplane. The sensitivity of the films was respectively 100 and 400 ASA for underwater and aerial sights. Even though the relatively high sensibility retained for aerial photography allowed for high speed of obturation, the quality of the photos were not always perfect owing to the unstability of the small airplane during the windy season. Nevertheless, from these photos taken more or less from the vertical position above the school, it was possible to estimate the surface it occupied by using the size of the swimmer as a reference in the calculation of the scaling factor.

II - RESULTS

II.1. Hydroacoustic observations

The school overpassed three times shows a reduction of its cross-section, both in the vertical and horizontal dimensions (after applying a scaling factor proportional to the vessel speed). Moreover the mean depth increased, specially from the first cross section to the second, owing to the diving of the surface fish (which was visible above the transducer from the boat during the first cross section, and disappeared completely later, even around the boat). In the last cross section the school seemed to split into two "sub-schools" at slightly different depths (fig. 1).

As the volume occupied by a school is often irregular and as the sounder provides a distribution only in two dimensions, the observed differences could be due to a different location of the cross section inside the school and/or to a real change in its shape and location, during the time elapsed between two successive cross sections. Despite an important saturation of the sounder (gain 7 on a scale of 10), the analysis of the signal allowed confirmation that the school really increased its internal mean density. The mean density of the samples low-pass filtered to eliminate the samples above a threshold (here 50 mV) provides a good indication of the level of dispersion of the individuals (Marchal, 1988); it was calculated at 381 (arbitrary units) in the first cross section and 659 in the third one (owing to a technical problem, the signal of the second cross section was not recorded). Moreover, the internal structure of the school shows a high variability in both figures but in different ways (fig. 2). During the supposed unstressed cross section the structure presented large vaccuoles of low density, specially in the left side of the diagram, which corresponds to the start of the cross section by the vessel. The right part is denser and deeper. This may reflect the beginning of a diving avoidance reaction which could be due to a contagious and fast propagation of "wave of agitation" inside the school (Radakov, 1973) initiated by the arrival of the hull and the keel in the field of vision of the first fish encountered at the surface, after they were overpassed by the transducer. This phenomenon could be accentuated by the fact that the boat speed fell during the first cross section (boat forging ahead).

During the third cross section the distribution of the density was different from the first one. The surface of the area of low density was smaller than previously and concerned first of all the "neck" between the two "sub-schools" in course of constitution (fig. 2). The distribution of the density is much more structured, with two maximal values in the centre of each "sub-school" and a strong gradient of density around these points, opposed to the 11 maximal points of concentration (plus 7 secondary points) in the first cross section.

II.2. Visual observations

External shape of the schools

The one hour observation of the first survey of a school indicated that the shape of a school and the horizontal surface it occupied is highly variable in time, as mentionned by other authors (Bolster, 1958; Hara, 1985; Squire, 1978). The surface varied from a range of 1 to 4 (fig. 3) and the observed shape can be subdivided in two types:

-amiboïde type when the school looked slack and unstructured (fig. 3a to 3c);

-egg-shaped type when the school is homogeneous and dense (fig. 3d to 3f; photo 1). The simultaneous underwater observations indicated that this type of shape corresponded to the arrival of a group of predators: Elagatis bipinnulatus (photo 2).

Internal structure of the schools

The second survey of a school gave the same kind of results: at the beginning of the observation the school presented an irregular shape, but in addition the irregularities of its internal structure were perceptible from the airplane (owing to a better quality of the photographs) and provided "smoke-like" pictures (photo 3). During the middle of the survey, the school was crossing the bay and presented a compact structure and egg-shaped limits, with a denser nucleus in the centre (photo 4). A few minutes later the shape was the same but the internal structure was at the opposite of the previous sight: irregular with a low density in the centre and a high density at the periphery, suggesting a circular movement (photo 5) typical of the defensive "mill" structure (Pitcher, 1986). The last sight (photo 6) represents a typical egg-shaped and compact structure.

No predators were observed by the diver in this case but owing to the limited field of view in the water and to the high speed of displacement of the school, their presence cannot be totally excluded. Another explanation to the change observed in the school behaviour could be the influence of the airplane shadow and/or noise, flying at low altitude (Hara, 1985). At the end of the one hour survey, the school presented again a typical egg-shaped limit and a compact internal structure (photo 7).

Concomitant underwater sights confirm the differences in the internal structure which was dense and with a regular interfish distance (at least in the field of view of the camera) or made of inter mingled fish columns separated by large vaccuoles (photos 8 and 9).

Even though these photos were made on another Clupeids species, they confirm the acoustic observations made in Venezuela on sardine or anchovy.

III - DISCUSSION

The pionneer studies on the internal structure of schools were performed in tanks and concerned few examplars of fish. From such observations it was concluded that the relative position of individuals in a school presents a diamond like structure which is supposed to be favourable to swimming performances from an hydrodynamic point of view (see for example Weihs, 1973; Breder, 1976). Such a regular structure is not always confirmed by <u>in situ</u> observations of large schools, at least when using a large scale of observation for the whole school description. In temperate areas, the heterogeneity in the density distribution of wild schools was already observed by Cushing (1977) using a multibeam lateral sonar. From <u>in vitro</u> observations, Pitcher and Partridge (1979) mentionned that an increase in swimming speed produces more compact schools but from the variability of their results they suggest that the "arousal level can generate equally large differences". The present results validate this hypothesis.

Previous observations of the internal structure of stressed and unstressed fish schools were carried out by our team in Venezuela using a different experimental protocol (Fréon and Gerlotto, 1988): the unstressed schools were observed using an adrift dinghy, and stressed schools were observed with a 24 m overlength research vessel. The results indicated also that the internal structure of school was highly variable with vaccuoles of very low density and area of high concentration, specially for the unstressed schools. The stressed schools presented generally a higher density in the upper part (Gerlotto and Fréon, 1988). As other experiments of the same authors indicated that those surface schools were diving when the reasearch vessel was approaching, it was suggested that the higher density of the upper part of the school reflected a compression in this area in response to a higher stress. Some exceptions were observed for the schools laying near the bottom, and the interpretation was the limitation of the vertical avoidance possibility for the lowest part of the school. It seems that in the present experiment using sails and motor, such a case occured because the lowest part of the school, when initially observed, laid at only 3 m above the bottom (if we suppose it did not dive at all during the first cross section). Therefore, the same gradient in density was observed in the upper and lower part of the stressed school. The vertical avoidance was limited and associated to a lateral avoidance, probably resulting in the constitution of two schools.

The heterogeneity of the schools at a large scale, specially when unstressed, does not mean that the diamond like structure is never observed <u>in situ</u>. In fact at a smaller scale this structure appears even when vaccuoles are observed: the fish around the empty area seems regularly spaced (photo 9).

A recent research field in acoustic is the automatic identification of the species of a school from its characteristics measured by acoustic (shape, depth, density, etc). The first results which seem promising (Azzali, 1982; Rose and Legget, 1988; Souid, 1988), could appear in contradiction with our results indicating a high variability of the internal school structure for the same species. In fact this contradiction could be only appearent: if we consider that a research vessel always stresses the schools, their characteristics could be much more homogeneous than in natural situations.

The consequencies of the heterogeneity in school structure on the minimal rate of sampling was previously studied in unstressed schools (Gerlotto and Fréon, 1988). The results indicated that the possibilities of undersampling was low in usual survey conditions. The fact that stressed schools show a more homogeneous internal structure must reduce the confidence interval of sampling results. The most important sources of bias by day are probably the saturation and shadow effects on large and strongly stressed surface school and their avoidance reaction.

IV - CONCLUSION

The present observations confirm previous results on the spatial and temporal heterogeneity of the internal school structures. The effect of an acoustical and/or visual stress on a school by day is not only an avoidance reaction (vertical and/or lateral) but also an increase in density resulting from the collapse of the vaccuoles and the decrease in the inter-individual distance. Considering the fact that usually tropical pelagic schools are rather small, this last behavioural response is favourable both to sampling and to species identification by acoustic devices; when schools are bigger, this behaviour leads to underestimation due to acoustic shadows and saturations.

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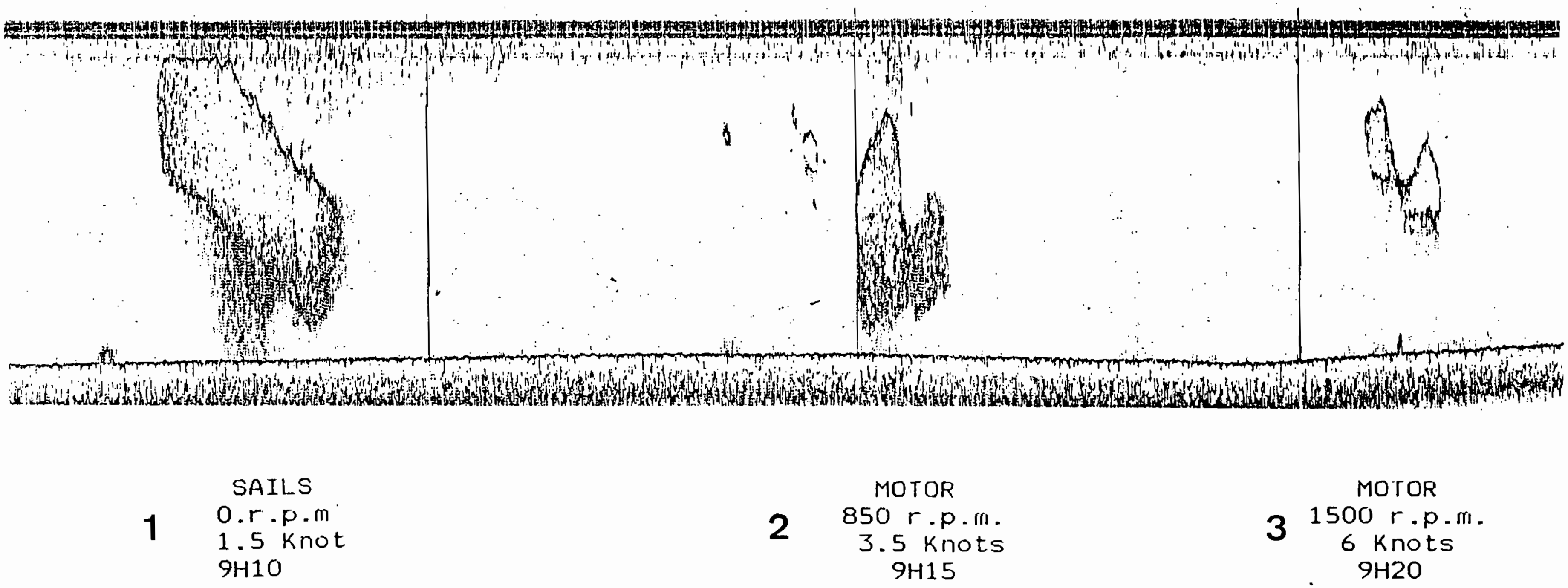
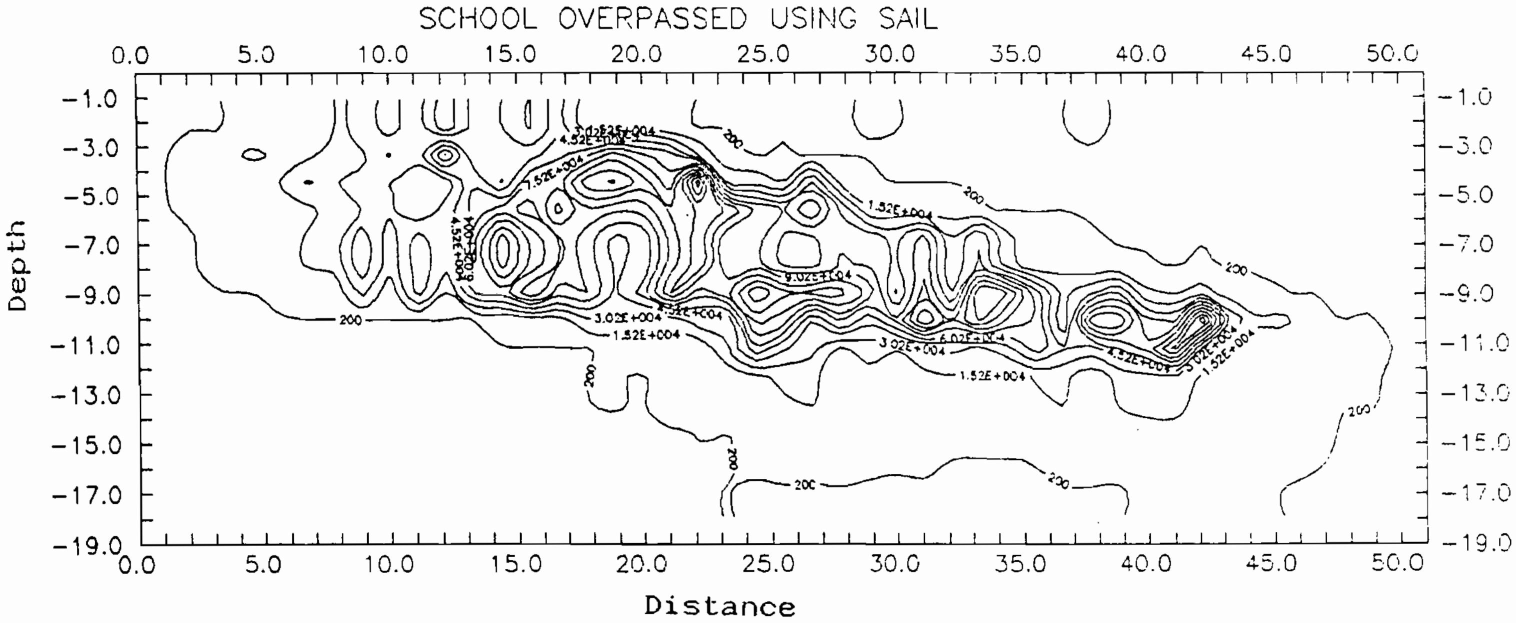


Fig 1. Echogram of the free school overpassed three times by the sail boat using first sails and two different motor speeds.



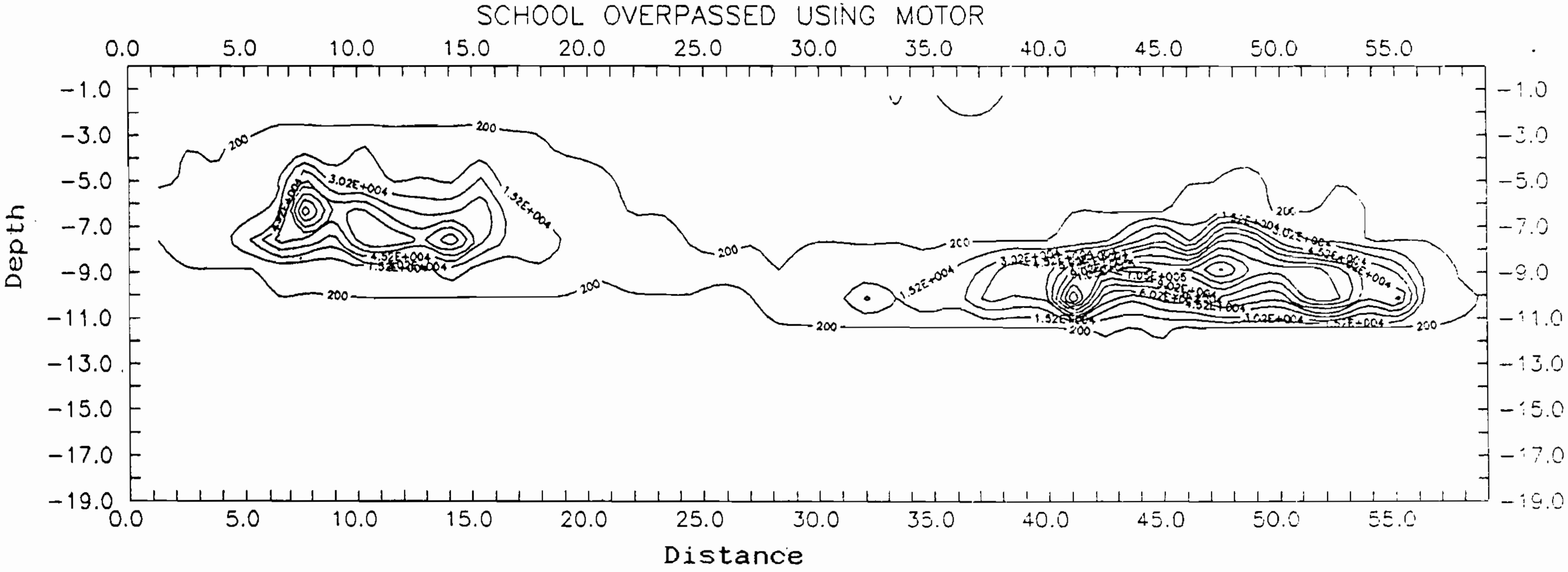


Fig 2. Internal structure (isodensity curves) of the school overpassed by the sail boat - using sails (echogram 1) - using motor (echogram 3).

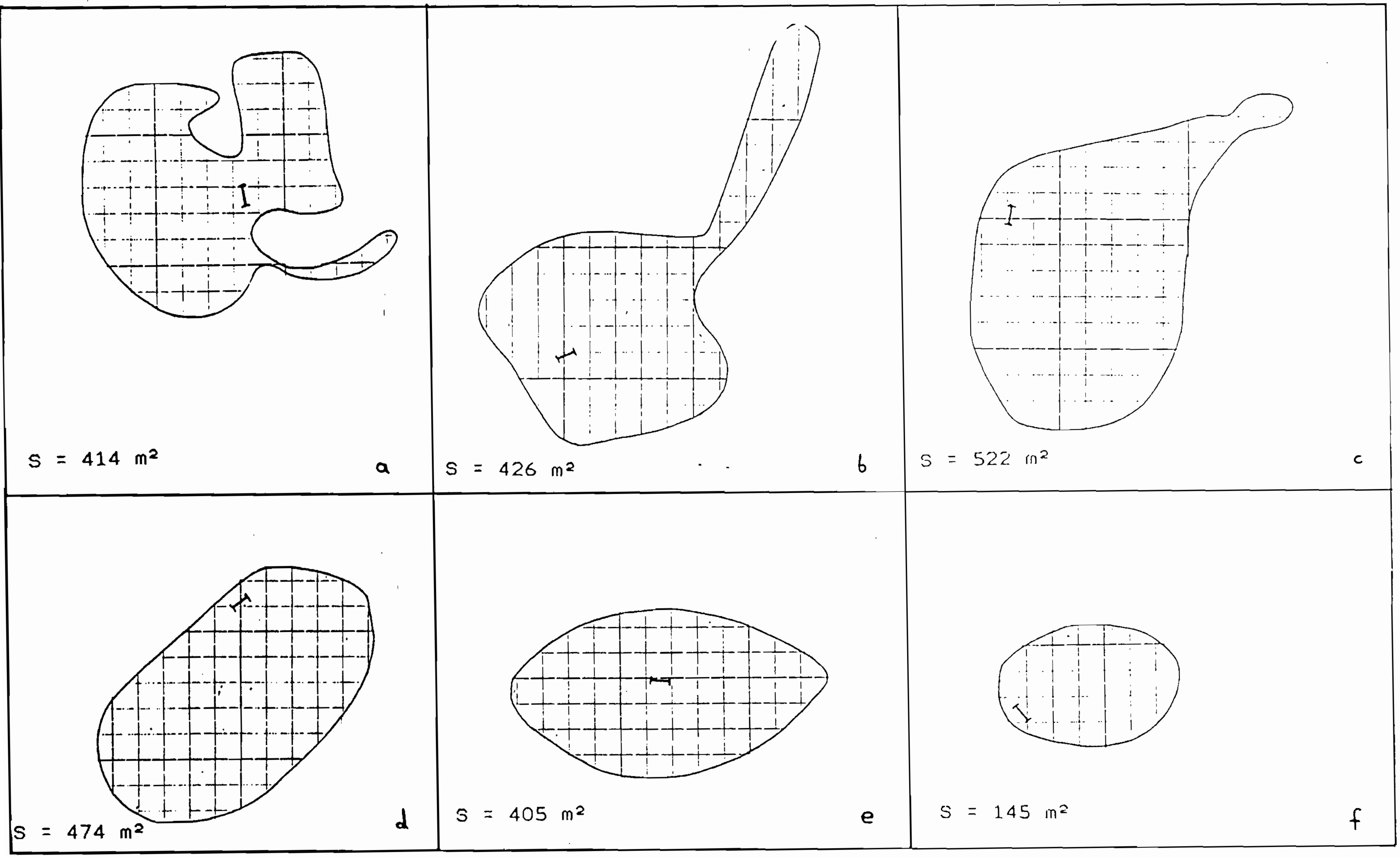


Fig. 3. Variation of school surface during a one hour aerial survey. |-| position and visible size (1.5 m) of the swimmer.

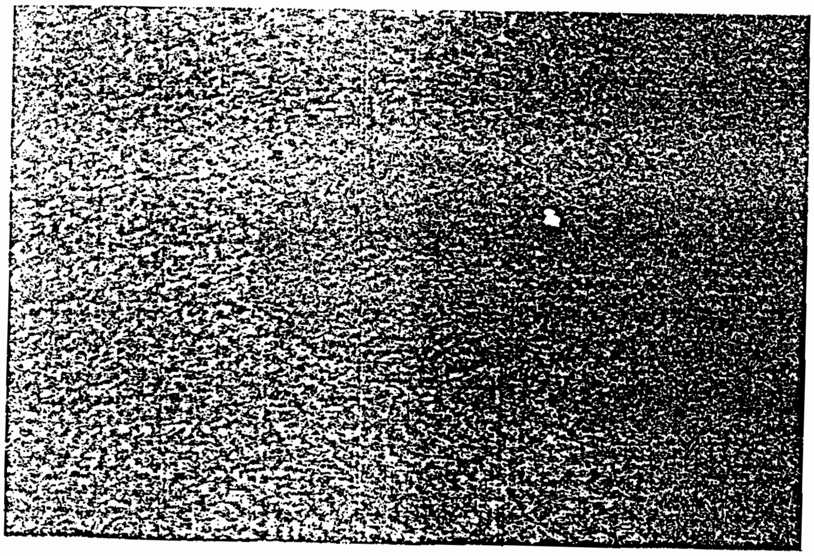


Photo 1 Egg-shaped structure of dense and homogeneous school during the first survey.

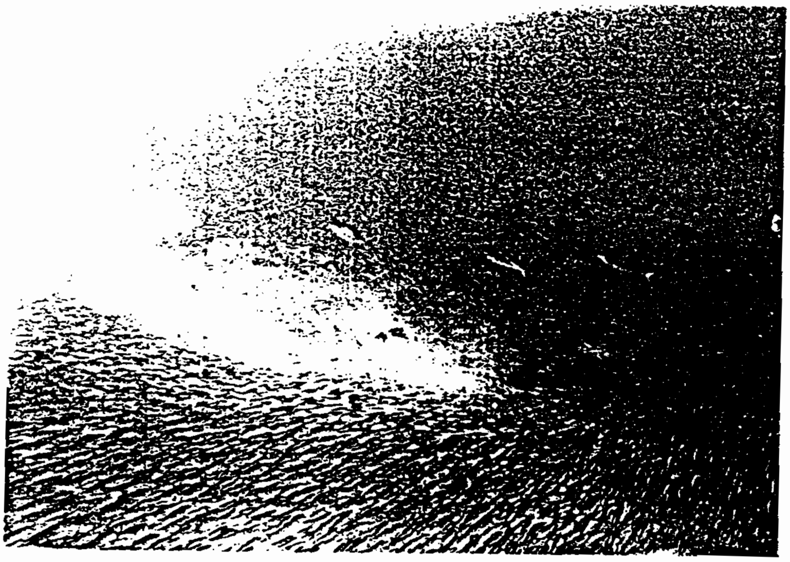


Photo 2. Underwater photography of flight reaction of the school to predators during the first survey.

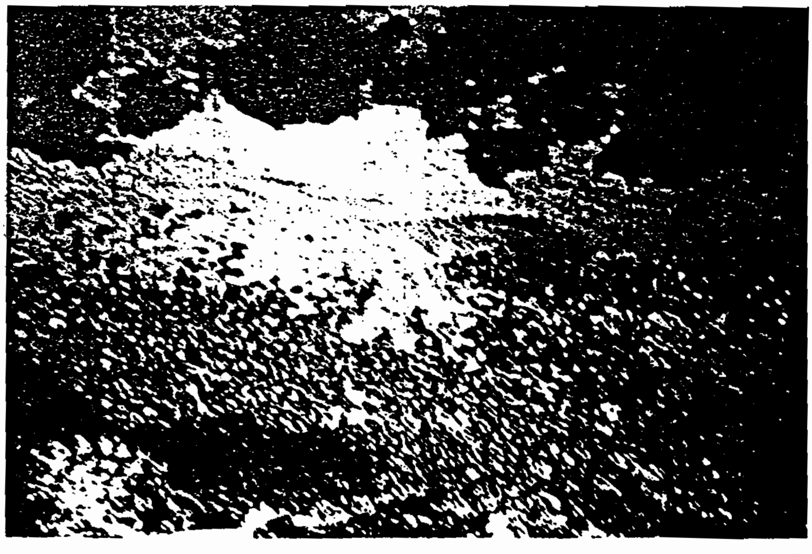


Photo 3. "Smoke like" structure of the school during the second survey.

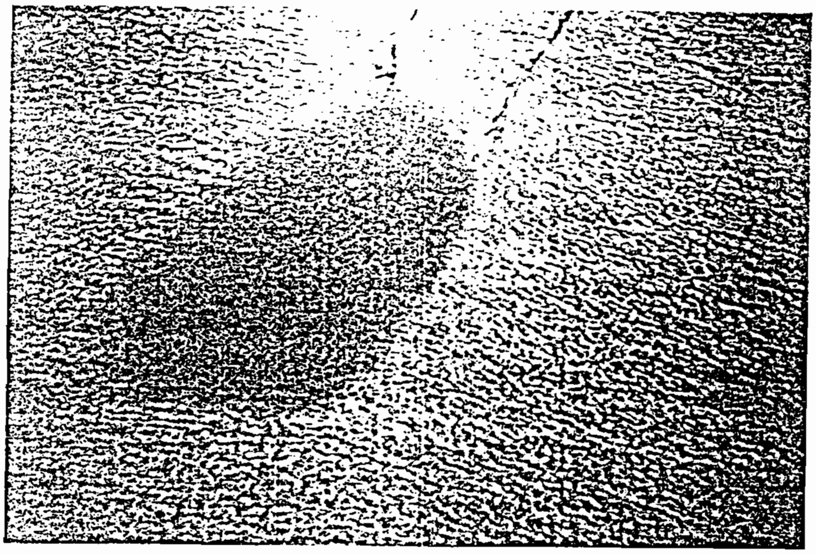


Photo 4. Egg-shaped and compact structure of the school during the second survey.

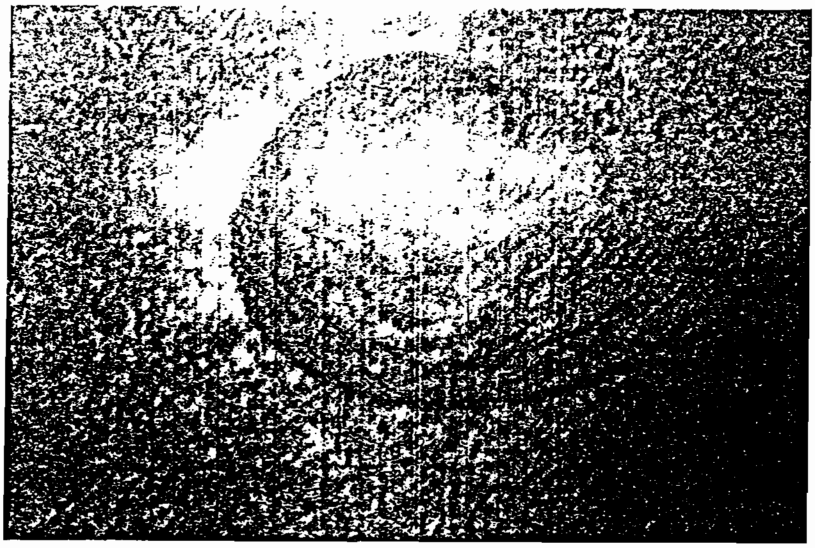


Photo 5. Defensive "mill " structure of the school during the second survey.

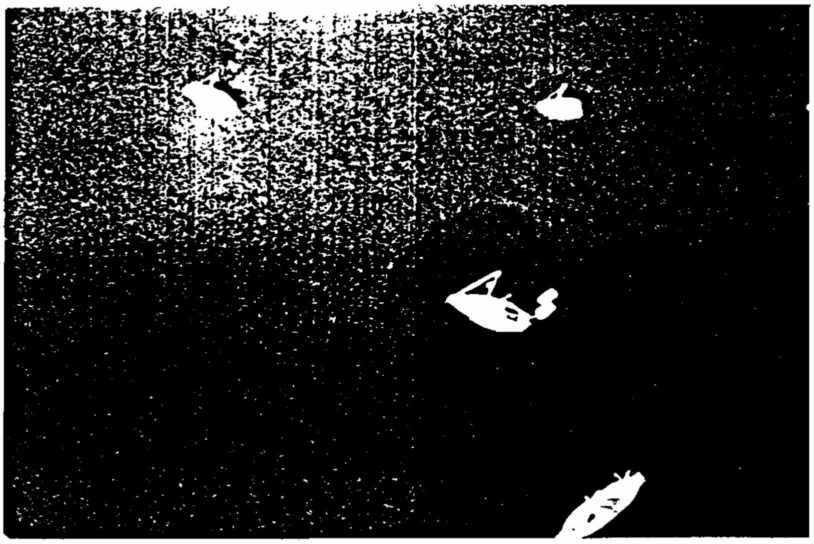


Photo 6. Circular and compact structure of the school at the end of the second survey.

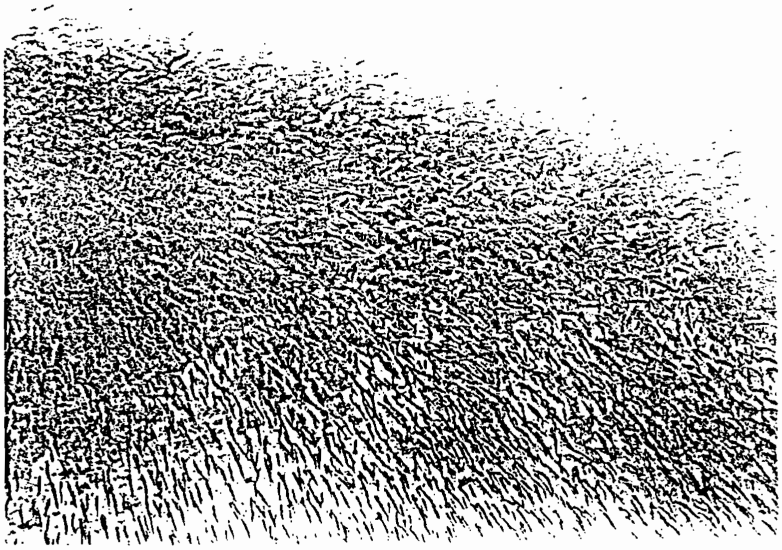


Photo 7. Underwater photography of fish in a circular and compact structure at the end of the first survey.

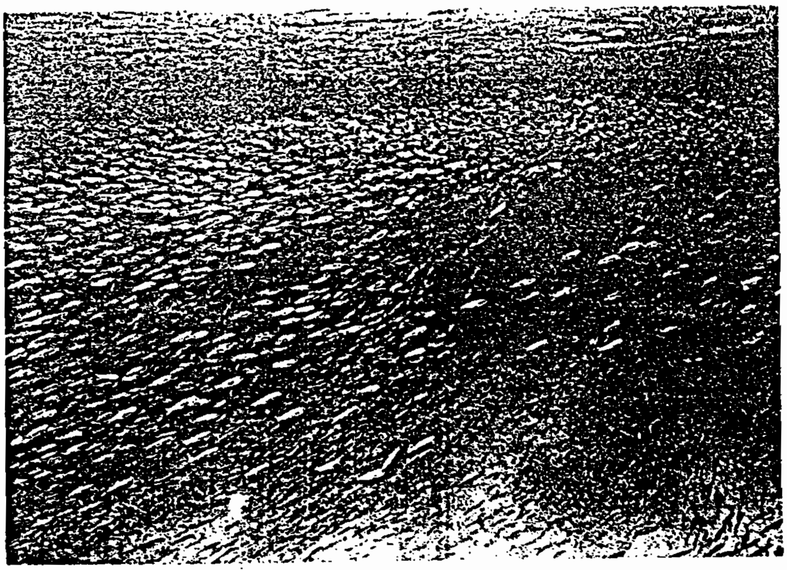


Photo 8. Underwater photography of column-shaped fish structure and large vacuoles during the first survey.

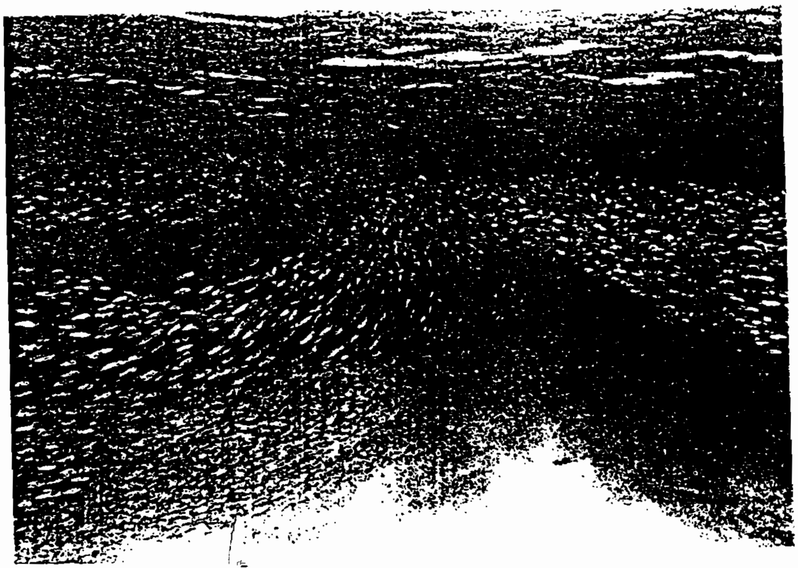


Photo 9. Underwater photography of column-shaped fish structure and large vacuoles during the first survey.

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REVIEW OF AVOIDANCE REACTIONS OF TROPICAL FISH TO A SURVEY VESSEL

(Revue des réactions d'évitement des poissons tropicaux au passage d'un navire de prospection)

by

F. GERLOTTO and P. FREON

(ORSTOM, BP 81, 97256 Fort-de-France, Martinique, French W. I.)

RESUME

Les réactions des poissons pélagiques tropicaux au passage d'un navire de recherches sont décrites en fonction de l'impact qu'elles peuvent avoir sur les résultats des prospection acoustiques. Deux composantes principales sont décrites: déplacement du poisson latéralement ou en plongée, et situation dans les trois dimensions.

Une description empirique des influences des divers stimuli d'un navire sur les poissons est proposée: les trois stimuli pris en compte sont le bruit, l'éclairement d'un navire la nuit et la vision de la coque le jour, l'importance de la réaction des poissons est estimée inversement proportionnelle à la portée du stimulus.

ABSTRACT

The reactions of pelagic tropical fish to the presence of a survey vessel are listed and related to the type of stimulus emitted by the boat. They are described according to the impact they present on the result of acoustic surveys. The two main kinds of reactions are: lateral or vertical avoidance (dynamic behaviour) and instantaneous spatial position of the fish (tilt angle).

An empirical evaluation of the influence of the three principal stimuli emitted by a boat is proposed. Those stimuli are the global noise of the vessel, its lights by night, and the vision of the hull by day. The magnitude of the reaction of the fish seems inversely proportional to the range of these stimuli.

INTRODUCTION

The reactions of the pelagic tropical fishes towards the crossing of a vessel can show some very diverse aspects depending on the species, the type of stimulus, etc..., but as far as their impact on acoustic data is concerned, they present two principal components:

- the instant position of the fish: touches uniquely the tilt angle of the fish within three dimensions, at the precise moment where it crosses the axe of the acoustic beam of a sounder.

- the dynamic of the displacement: represents all the displacements of the fish within three dimensions, which can be attributed to the irruption of a survey vessel. Each of these two components which can provoke some important biases in the density evaluation will be analysed separately for day and night surveying in order to take into account their specificity. The effects will be studied at different distances from the boat. Finally the ethological components having an influence on the anatomical characteristics of the fishes (swimbladder) will not be studied here, although we know that they can play an important role in the biases that the behaviour induces in the acoustic evaluations.

DYNAMIC BEHAVIOUR

A. NOCTURNAL BEHAVIOUR

In order to simplify, we will only envisage the case of scattered fishes although schools could be observed by night too (FREON et al., 1988; WOODHEAD, 1966).

At night the behaviour is perturbed by two stimuli: noise and light of the vessel. Noise is perceptible at long distances (to the order of 10^3 m); as far as light is concerned, it can be perceived depending on the movement of the surface from some 10 to probably more than a 100 metres.

Reaction to noise

Fish are very perceptible to noise (OLSEN, 1971). This sensitiveness has several consequences.

- **at long distances**, a slow displacement can be observed, fishes have a tendancy to flee from emission points. This phenomenon observed and described in northern areas (MISUND, 1987) was confirmed by the measures of biomass around a noise source transmitting near a oil-extraction platform in tropical waters (GERLOTTO et al, 1989). We have no direct informations on this spparticular behaviour, but indirect observation on long periods. Fig 1, for instance, shows the progressive diminution of the density on a 26 hour period of insonification. We did not perform measurements by night during this experiment, but we can observe that the density remained as low in the morning than the day before: the fish concentrations did not come back by night in the insonified area.

- **at shorter distances**, the results are a lot more complex and often contradictory.

  * at short distance and a reduced scale of time (ship's passage) a distinct movement of the biomass cannot be detected. An experiment using the protocole of OLSEN et al. (1983) did not show obvious avoidance reactions of the fish (fig. 2, "S+L-"), contrary to what the authors were able to observe in the Nordic waters.

  * vertically under the boat no variation of density was observed linked to the noise of the vessel (Fig. 3, from FREON et al., 1990): the use of a sail boat sailing alternately with sails and motor did not show any significant differences in the densities measured.

Reactions to the light

It is difficult to evaluate the impact of the boat's illumination at long distances. We measured the fish reactions at two levels:

- **at short distances**: we observed a displacement exactly identical to that described by OLSEN et al. (1983) for noise: in opposite direction to that of the source, in the three dimensions. In an identical experiment as that described above, but with all the lights switched on, a diminution of the density and a shifting of the target towards the bottom was noted (fig. 2, "S+L+").

- **under the survey vessel**: the reaction to the light inside the vertical sound beam is very clear, although it can change in intensity according to the species and/or the dimensions of the fish. The results taken from LEVENEZ et al. (1987) display very clearly the displacements of the fish vertically (fig. 4). In return two points are to be noted for this experiment:

  * there were no obvious variation in the total density in spite of the evident balancing of the superior and inferior layers.
  * the structures were stabilized at the time the boat overpassed the fish.

A conclusion for these phenomenons (at least for the species observed) is that under the environmental conditions of this experiment, the fish located in the vertical plane of the vessel's course are "trapped" by the cone of the acoustic shadow created by the hull (fig. 5, from GERLOTTO and FREON, 1988).

Curiously, during another experiment in the same area and using the same protocole (GERLOTTO et al., 1990), the vertical avoidance looked much smaller than in the first one, and a relatively small -but evident- lateral avoidance could be observed in the upper layers (0/17 m). It is probably possible to correlate this lateral avoidance to the size of the fish, the biggest escaping while the small ones stood in the route of the vessel.

These two observations look somehow contradictory, but it was observed also that the scattering behaviour of the fish were distinct: we observed some big night schools during the second one while almost no school were recorded in the first experiment. This could show that the environmental conditions were distinct (moon light, bioluminescence, for instance), and that this natural behaviour has to be taken into consideration.

B. DIURNAL BEHAVIOUR

In this case we are only interested in the schools of fish which essentially form the pelagic biomass.

In the day time two stimuli prevail:

- the noise, identical to that at night

- the visual stimulus. In this case it concerns the direct vision of the hull. It is only effective at around 10 metres and certainly not above 50 m, even in clear transparent tropical waters. Therefore it acts only at weak distances, contrarily to the nocturnal illumination where the pinpoint source can be perceived at a greater distance. At the present time we do not have enough experimental results allowing for the separation of the effects of the auditive and visual stimuli, but some preliminary results on the shape of schools should indicate that the impact of the visual stimulus alone gives rather different results if they have been recorded with the boat using sails or motor.

1. Behaviour at a long distance.

The stress is of the same nature as in the night (noise at long distance). The only data on this subject that we have at our disposal is that observed under oil-extraction platforms (fig.1). We observed the same diagram of slow radiated escape at the same distance as that at night which has been described elsewhere by diverse authors for cold waters (see for instance OLSEN, 1987). In warmer areas, we can cite the work of NEPROSHIN, 1979.

2. Behaviour at short distances.

- lateral avoidance. It was observed but not measured; particularly in the surface layers, and manifests at the immediate proximity of the boat: therefore it appears to be tied to the presence of the hull in the field of vision (included in certain occasions the vision of the superstructures across the surface, which in certain cases may be visible in front of the hull). It is clear that this avoidance leads to a very high underestimation of the biomass, which in certain cases can almost totally disappear.

- vertical avoidance. We measured for the sub-surface schools observed a moderate vertical avoidance (fig. 6) that we globally evaluated at a dive of 5 m for the school included between the surface and 20 m deep (GERLOTTO and FREON, 1988). An observation on a single school overpassed three times by the sail boat (1: sails; 2: motor; 3: motor) suggested that the visual stimulus alone was responsible for a diving reaction at the very last moment (observable on the echogram), meanwhile the existence of the auditive stimulus (motor) showed an earlier reaction (FREON _et al._, 1990).

It is suitable to add the variations of structure induced by the ship's crossing to this global displacement. We have been able to notice in particular that a school has a tendency to compress more in it's higher parts than in it's lower parts. Figure 7 shows the difference between a "natural" structure of a surface school and a "stressed" structure.

INSTANT POSITION

A. NOCTURNAL BEHAVIOUR.

The static behaviour of the fish acts on the TS: more the position is different from the horizontal position, more the TS weakens. The evaluation of this component of the induced behaviour is indispensable for two reasons: first it determines which TS value must be applied to the data for a transformation in biomass estimations, then it gives one of the factors allowing the comparison of the data collected during day and night.

We have not carried out measurements of the angular position of the undisturded tropical pelagic fishes. There exists two sources of information in the litterature on this position. By photographic observation (BUERKLE, 1983; AOKI and INAGAKI, 1986), and observing caged fish.

Although sometimes discrepancies are observed, it is interesting to note that most of the time the results coincide. It has been found for the fish "in situ" an average angle of 12 degrees in comparison to the horizontal which corresponds on the TS graph to a decrease of about - 6 dB in comparison to the nominal value, and the measurements in the cage gave, for example, a difference of - 5 dB between the day and night for the herring (EDWARDS and ARMSTRONG, 1989), or - 7 dB for _Sardinella aurita_ (GERLOTTO, 1987)

Having only the data obtained by a sounder, we tried to determine the impact of noise and light on the angular position of the fish by using them alternately or together.

We assumed that the passage of a lighted vessel at normal speed of surveying represented a "maximum stress". Hypothetically we admit that the fish in a situation of maximum stress is polarized with regard to the source of the stimulus; it's position can either be horizontal, in "alert", or slanted agreeing to the model suggested by OLSEN _et al_. (1983). We have studied the following cases:

- **variation of the noise level**. There is practically no observable variation of the density or the position of concentration (FREON et al., 1990), but this result has to be confirmed through additional experiments using higher levels of noise.

- **variation of the light level under constant noise**. We have already noted that two cases were observed: depth detections very different, with a constant total density, and slight variation of the density with no apparent movement of the concentration depth. In this late case, measurements of TS by "dual beam" were carried out (GERLOTTO et al., 1990), and showed that the fish which remain below the boat do not present any change in their TS whatever the lighting of the boat is.

- **variation of light without noise**. Although this case may not be susceptible to appear in normal conditions of surveying, experiments were carried out with a sail boat, but the results obtained are not clear enough at the moment to extract any conclusion (FREON et al., 1990).

All these observations lead to suppose that the hypothesis of an inclination with regard to the source is not plausible: the fish have apparently reached a zone of refuge where they are equilibrated from the maximum stress (noise and light). It is difficult to imagine why they would dive in two steps, first to avoid the light before the boat passes, then vertically under the boat to avoid the noise.

It seems also difficult to retain the hypothese of fish in their natural non-stressed position under a noisy unlighted boat: in this case one should obtain a mean TS and therefore an apparent density of fish under the influence of a light, stronger than those in obscurity. This is not the case. Therefore it can be concluded that by night under a survey vessel fish are in a polarized position of alert as in the daytime.

This conclusion conflicts with certain contradictory observations (no change of measured density in function with noise variation) which must be raised before confirmation.

B. DIURNAL BEHAVIOUR.

We have seen that the sub-surface schools dive about 5 m under the boat. Here also one can assume that the dive is carried out either before or during the vessel's crossing. The observation of the surface lateral avoidance allows for the leaves to think that the dive is carried out at the last moment, therefore vertically to the vessel. In this case the fish present a clear inclination with regard to the vertical. Measurements of diving speed of the school gravity centre allow the drawing of a graph giving the diving angle in function of the speeds of the horizontal escape and the vertical diving (fig. 8, from GERLOTTO and FREON, 1988). In these regular conditions, this angle seems reduced (between 5 and 10 degrees).

BALANCE AND CORRECTIVE FACTORS

A proposed synthesis of the avoidance reactions of the fish is presented on figure 9, where the basic hypothesis is the following:

The strength of the stimulus is more or less inversely proportional to the range at which it can be perceived by the fish. The sound perceived from a great distance (to the scale of 10^3 m) induce precocious reactions but of a weaker strength. Punctual lighting of a vessel by night, less perceptible (to the scale of 10^2 m) induces a more sudden reaction. The sight of a boat's hull, which is only possible at a very short distance (about 10 m), is the cause of extremely violent reactions.

We have not defined on the vertical axis of the graphic the units of the fish reaction, as we were not able to measure an objective parameter representative of the perturbation of the fish (rate of heartbeat, adrenaline rate, swimming speed, etc...). Therefore we have placed arbitrarily three remarkables points.

- **beginning of the aversion reaction** (observed day and night). Corresponds to the point where a fish reacts to a stimulus. We saw that with noise, this point was reached at long distance. Therefore it is rather low. It can be linked to the polarizing behaviour, the fish being supposed to take the horizontal position to move. Clearly it corresponds to the auditive stimulus.

- **beginning of the escape reaction** (observed by night). This can be observed by night when a boat passes from a state of obscurity to a state of illumination. We saw that fishes react rapidly, but without their structures (school, layers, etc...) losing cohesion. Apparently this level of reaction is not reached if noise is the only stimulus, light is necessary.

- **beginning of the panic stage** (observed by day). It could concern the physiological passage from the normal fish swimming in aerobic conditions (even rapid) to that of the use of the anaerobic physiological process in burst swimming. In the case of acoustic prospection, it seems only to be reached by schools in lateral avoidance at the proximity of the hull, when the visual stimulus is received (vision of the hull). This visual stimulus may be evidently present by day, but also by night when the bioluminescence is high enough.

The objective of these observations is to allow us to employ some adapted survey methodology and apply corrective factors to the data.

The main adaptations concerning the survey methodology are the following:

- dual survey of an area, one by night and one by day, with separate data processing;

- special attention to the lighting conditions of the vessel by night, which must be as dark as possible;

- separate analysis of the school data and the scattered fish data;

- separation in the analysis of the results of the upper layer (i.e. < 20 m) and the lower one (> 20 m).

We intented to obtain some corrective factors, although it is impossible to consider that we can calculate a universal factor: we have seen that according to the environmental conditions the actual reaction of the fish may change. Nevertheless some rough corrective factors may be applied:

- correction of the mean depth of the schools: when a school is recorded in the upper layer (< 20 m), its mean "natural" depth is considered 5 m higher than the recorded one;

- the mean tilt angle of the fish in the upper layer is considered always horizontal.

- schools are classified according to their height and density in transparent, semi-transparent and opaques, and different correction are applied on their biomass estimation.

CONCLUSION

It can be seen that once certain rules are established, particularly the complete separation in the analysis of data between day and night, the selection of a lighting level for the boat, the separate study of the schools, etc..., the behaviour of the tropical fish does not present a major handicap to the research.

We have not studied here the quantitative behaviour of lateral avoidance of the schools, or certain natural components of the behaviour like the occupation of the surface layer inaccessible to the sounder, and those functions of the behaviour operating on the physiological characteristics of the fish, but these components evidently should be taken into account.

Finally it must not be forgotten that the natural behaviour may also interact with the stressed behaviour: at certain times of the day and certain periods of the year, the natural behaviour may be much stronger than the stressed one and the fish do not react in the usual way to a survey vessel. These relations might be studied too.

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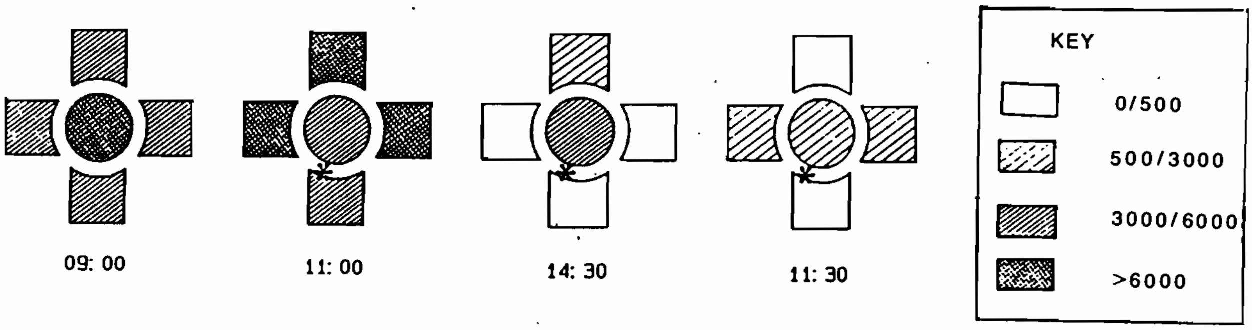
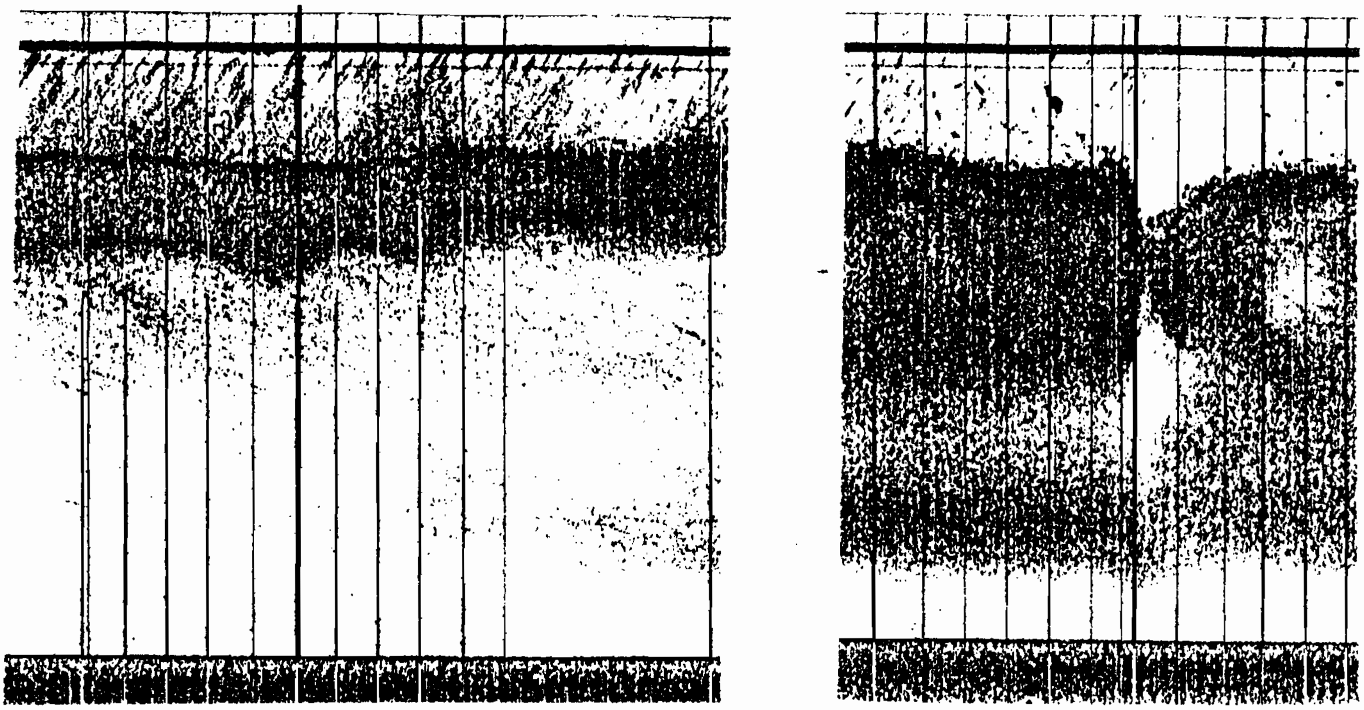


Fig. 1. Influence of a 250 Hz emission on fish density (in relative units) around an oil-extraction platform during 26 hours.
* point of emission


S+L-

S+L+

Fig. 2. Avoidance reactions of the fish close to the route of a survey vessel sailing at 8 knots.
(S+L+) : light on (S+L-) : light on
time between two thin lines : 30 sec.
thick line : crossing of the survey vessel

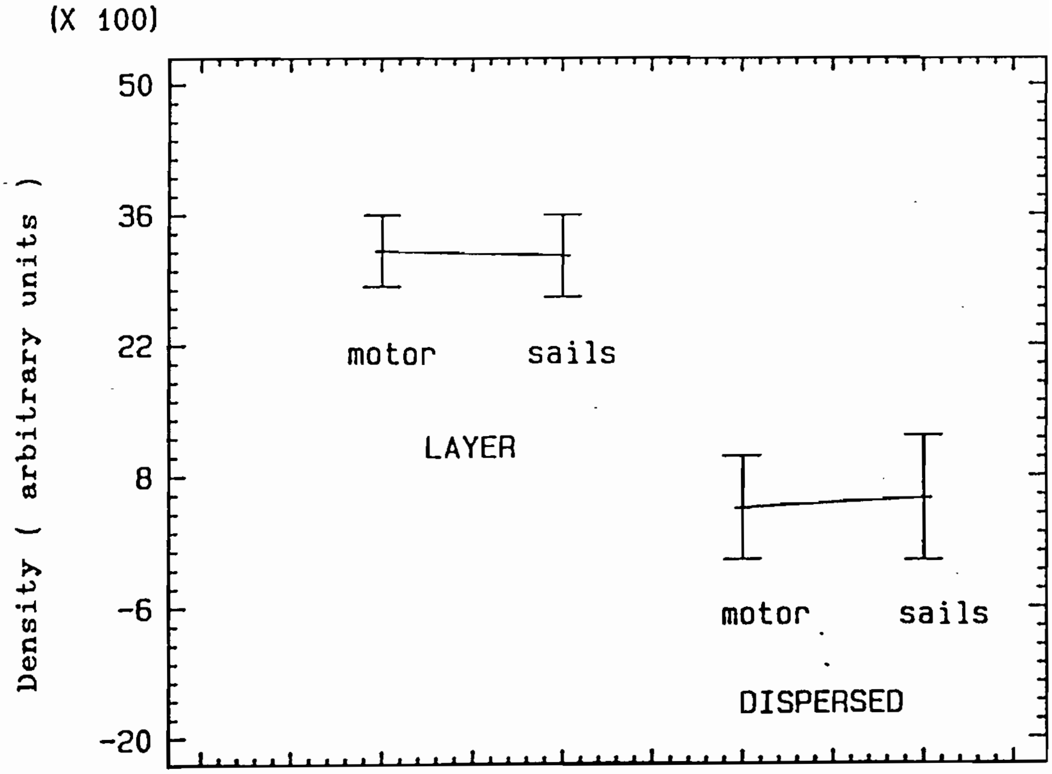


Fig. 3. 95% confidence intervals of factor mean density for sails versus motor and layer versus dispersed from FREON et al., 1990

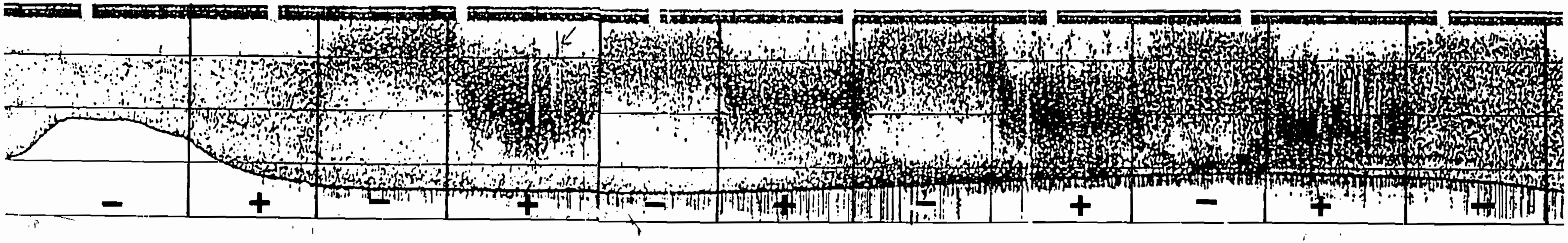


Fig. 4. Observed diving reactions of fish with a lighted boat
(from LEVENEZ et al, 1987).
+ light on − light off

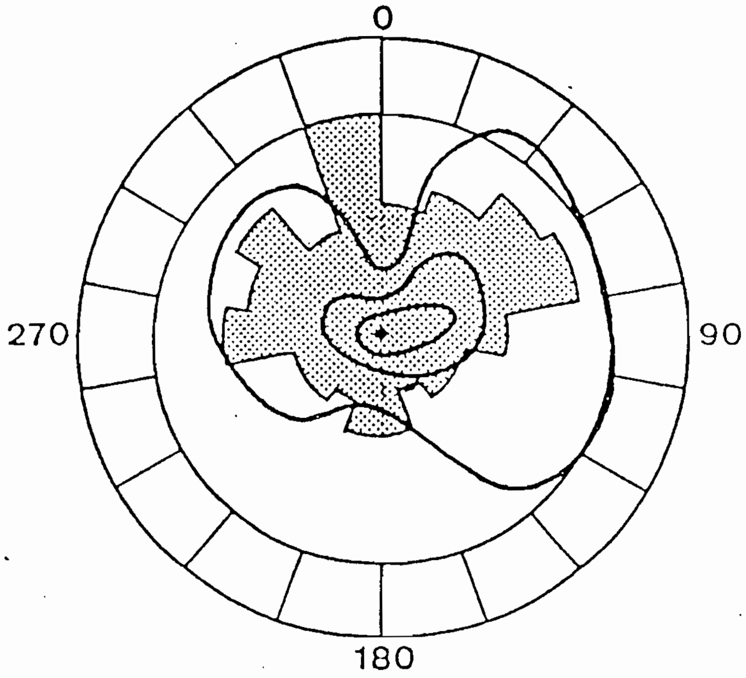


Fig. 5. Relation between vessel noise and school avoidance
(from GERLOTTO and FREON, 1988)
sound pressure lines (from URICK, 1975)
proportions of escaping schools
by 20° sectors (from MISUND, 1987)

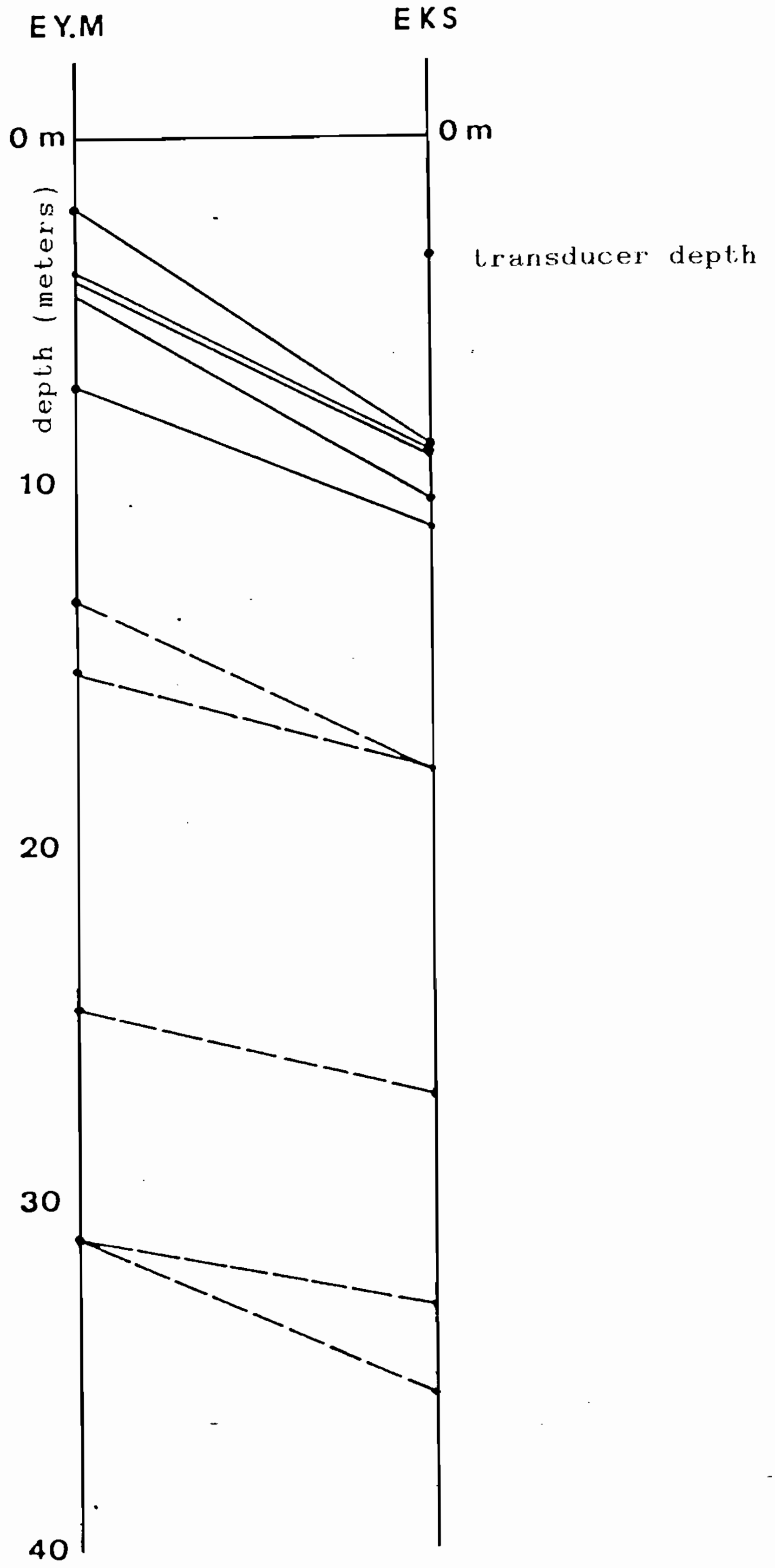


Fig. 6. Evolution of the depth of the tops (————) and bottoms (- - - -) of schools observed successively under unstressed conditions (EYM) and stressed conditions (EKS)

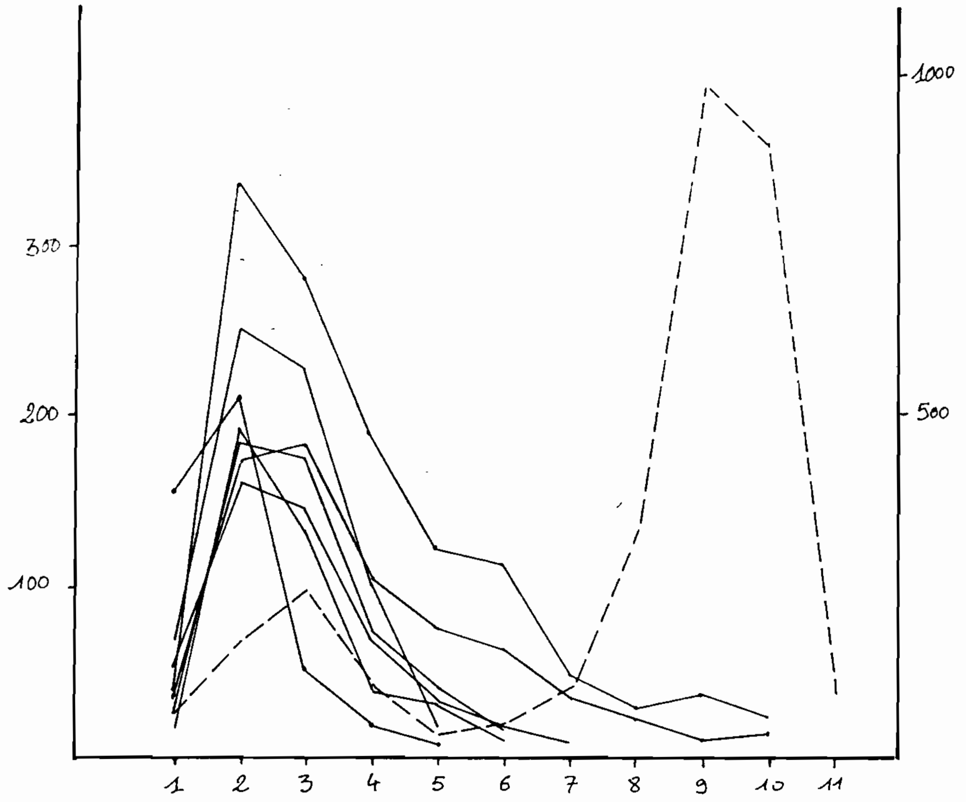


Fig. 7. Mean relative density per 1 m layer of "stressed schools" (———) and "unstressed schools" (- - -) from GERLOTTO and FREON, 1988

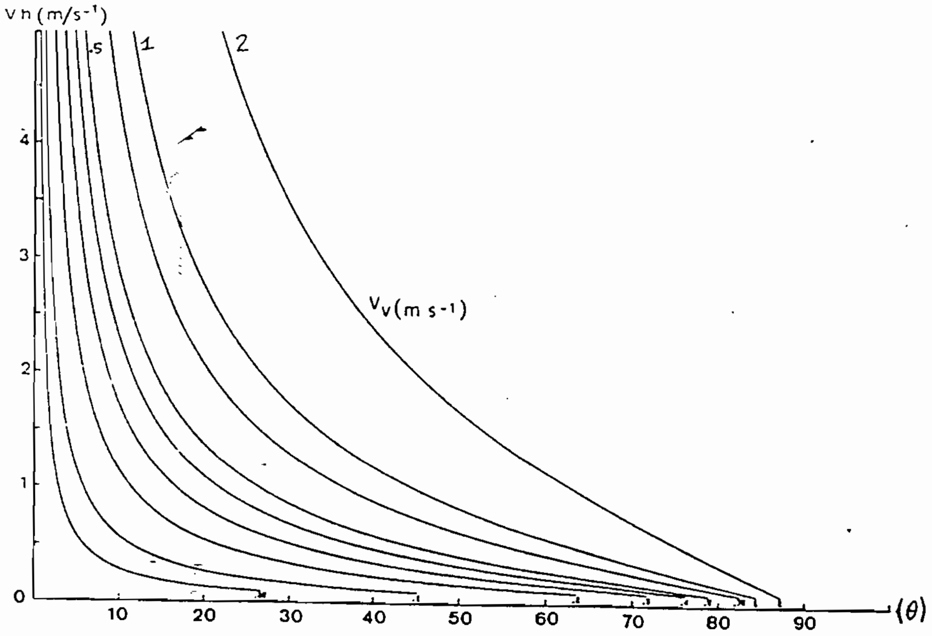


Fig. 8. Relation between fish tilt angle (Θ), horizontal flight speed (V_h), and vertical flight speed (V_v)

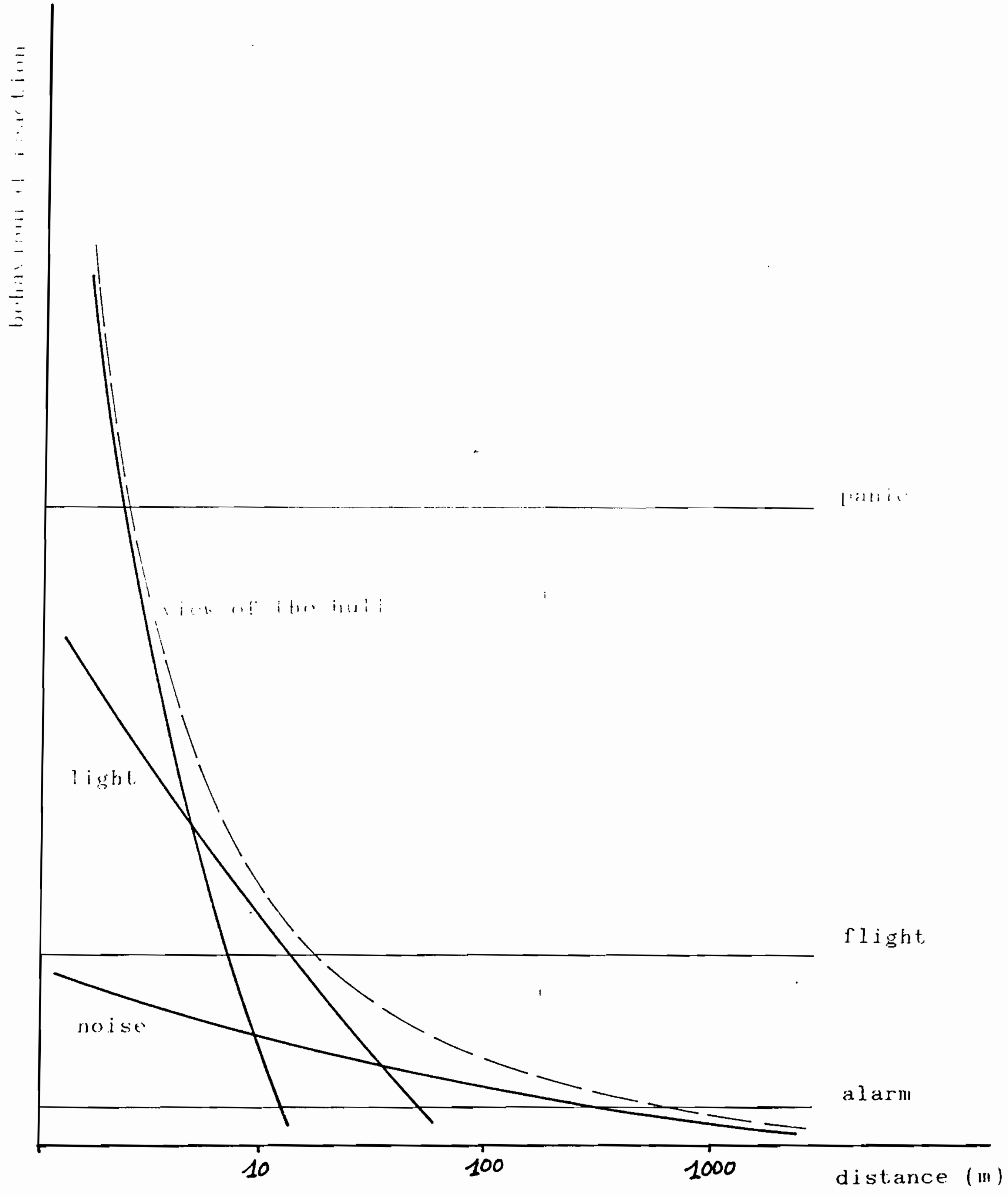


Fig. 9. Schematic synthesis of the reactions of fish to various stimuli according to their ranges

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A METHODOLOGY FOR ACOUSTIC ASSESSMENT IN VERY SHALLOW WATERS (LESS THAN 8 M)

by

F. GERLOTTO (1), C. HERNANDEZ CORUJO (2) and R.CLARO (3)

(1): ORSTOM, B.P. 81, 97256 Fort-de-France, Martinique (FWI)
(2): Academia de Ciencias, Rama Pesca, Habana Vieja, Cuba
(3): Instituto de Oceanologia, 1ra #18406 Playa, La Habana, Cuba

RESUME

Une méthodologie de prospection acoustique et de traitement des données pour l'évaluation des biomasses est proposée pour les systèmes lagonaires tropicaux, à fond plat, profondeurs faibles (de 3 à 8 m) et houle réduite. Les méthodes de mesure de l'angle d'échantillonnage et de déconvolution des TS "in situ" sont adaptées de la littérature pour ce cas particulier. L'application de cette méthodologie au golfe de Batabano (Cuba) montre que les meilleures évaluations de biomasses sont obtenues par comptage, et que la précision des mesures dépend étroitement des conditions extérieures: prospection de nuit exclusivement, mer plate et absence de lune.

ABSTRACT

A methodology for acoustic assessment and data analysis is proposed for the case of tropical island lagoons, with flat and very shallow bottom (3 to 8 meters), and low swell. Methods of measurement of the sampling angle and TS "in situ" deconvolution have been adapted from the litterature for this particular case. The application of the methodology to the Gulf of Batabano (SW of Cuba) shows that the best biomass evaluations are obtained by fish counting, and that the precision of the results is directly depending on external weather conditions : prospection exclusively by night, no swell, no moon light.

INTRODUCTION

The shelf of tropical islands presents usually two kinds of bathymetric structures: on the one hand, a lagoon, with very shallow waters, with flat sandy bottom including in some places circular coral reefs, and limited by the island coast and on the peripheral by mangrove on small islands and long and thin coral reefs; on the other hand, a very narrow shelf from 10 to 500 meters, all around the island. Each of these systems presents particular ecological characteristics and different fish populations, which present usually the common particularity to have a rather low density, the fish being concentrated in a few places by day and very scattered by night (fig. 1).

As far as acoustic assesment is concerned, both types of fish distribution do not permit to apply conventional methods, and appropriate methodologies are required. We present in this communication the methodology that has been developped for the first ecosystem, through the example of a survey program of the Gulf of Batabano, SW Cuba.

1. CHARACTERISTICS OF THE AREA

The Gulf of Batabano is a flat area of more than 20 000 km^2, with a mean depth of 6 meters (EMILSON and TAPANES, 1971), limited in the north by the island of Cuba, in the SW by the Juventud Island, and in the S and SE by a line of keys (low island covered with mangrove) and coral reefs (fig. 2). The bottom consists generally of muddy sand covered with a phanerogame, *Thalassia testudinum*. In some places circular coral grounds may be found inside the gulf.

The fishery is exploiting several families: Lutjanidae, Serranidae, Pomadasyidae, some typical coral families and spiny lobsters.

The fish live in two main groups:

- group depending on coral reefs: the fish live around the coral reefs by day and are scattered all over the *Thalassia* bed by night. This group is formed of the families mentioned above.

- group depending on mangroves: the fish, mainly small Clupeids (*Harengula spp*, *Opisthonema oglinum*, *Jenkinsia lamprotenia*) and juveniles of the other groups, live inside the mangrove by day and move to the grass bed by night, where they may be found either scattered or in small schools according to the light of the moon.

The climatic conditions within the gulf may be found very favourable in some periods of the year (no swell, no wind, low currents, etc).

2. MATERIAL AND METHODS

The choice of the material will depend of the following constraints:

- survey in very shallow waters (3 to 8 m), making necessary:
    - use of a small shallow-draught boat;
    - sounder with small blind-zone and TVG useable in the first meters below the transducer
    - large-beam transducer, for obtaining the highest sampling

- use of small boat:
    - equipment with independent electric power-supply;
    - favourable weather conditions;
    - transducer to be put close to the surface.

- fish behaviour:
    - survey exclusively by night;
    - survey during new moon and complete darkness.

- work on large areas:
    - a rather big ship is needed for life and work base
    - need of a positionning system, include aboard the small boat.

We have used the following material:

- echosounder EY-M SIMRAD, 70 kHz, with 22° transducer (1);
- portable digital tape recorder DAT (Sony) (1);
- echo integrator AGENOR (2);
- computer Toshiba T 5100 (2);
- boats: a 6 meter plastic motorboat, with flat hull (draught less than 50 cm), and a 25 m research vessel (R/V Triton)

The survey grid was the following: the transects are performed at 4 knots aboard the motorboat, and only the echo sounder and the tape recorder are used. The position of the small boat is obtained by reference to the big one, which is placed in some pre-defined points. The recorded data are processed during the day aboard the big vessel.

The transducer is placed on the fore part ov the motorboat (fig. 3), and is fixed as close to the surface as possible according to wave noise.

3. PRINCIPLES OF THE EVALUATIONS

The fish are extremely scattered. In these conditions the only reasonable method for biomass evaluation is the fish counting, but the conversion of the densities in number of fishes per cubic meter in densities in tons per square kilometer needs two precise informations about:

- the sampled volume;
- the TS distribution "in situ".

A. Measurement of the sampled volume

Most of the methods existing (EHRENBERG, 1983; MARCHAL, 1983) and particularly the so-called "duration-in-beam" method (THORNE, 1988) use the number of echo received from a single fish, in order to determine the actual angle of the beam, according to the mean TS of the fishes and the threshold of the receiver. Unfortunately this kind of method is impossible to apply on our results, because usually the fish is too close to the transducer to give more than a single echo.

Therefore we have been oblige to adapt the usual method in the following manner:

the calibration standard sphere has been moved horizontally below the transducer at constant slow speed along a line that crossed the beam axis. This operation has been repeated several times, for each gain value of the echo sounder, in order to give curves of the relations between voltage response and beam angle for various TS values.

Once determined the mean beam angle, the sampling volume is easily obtained using classical calculations (FORBES and NAKKEN, 1972; JOHANNESSON and MITSON, 1982, for instance).

B. Correction of the TS "in situ" measurement

We have adapted a method derived form the "deconvolution method" presented by CRAIG and FORBES (1969). The principle is the same as described by these authors (see also FORBES and NAKKEN, 1972), but the equations have been slighty changed in order to eliminate the negative results.

We have used the directivity diagram of the large beam transducer of the EY-M sounder given by SIMRAD. The angle of the beam for each 1 dB step has been measured manually, and used in the equations in the following way.

Let us suppose for instance that we have three sets of TS values, **High**, **Medium** and **Low**, and that N_h is the number of high TS, N_m the number of medium TS and N_l the number of low TS, and three strata in the directivity diagram, for instance -30 dB (angle θ_1), -20 dB (angle θ_2) and -10 dB strata (angle θ_3). N_l is the sum of the big fish in the -30 dB stratum plus the number of medium fish in the -20 dB stratum plus the number of small fish in the -10 dB stratum. N_m is the sum of the medium fish in the -10 dB stratum plus the big fish in the -20 dB stratum, and N_h is the number of big fish in the -10 dB stratum. In these conditions the total number B of big fish is:

$$B = \left[N_h \frac{A_1}{A_1} \right] + \left[N_m \frac{A_2 - A_1}{A_2} \right] + \left[N_l \frac{A_3 - A_2}{A_3} \right]$$

where A_i is the surface delimited by the angle θ_i

Once B obtained, and after removing the number of big fish TS in each strata, it is possible to calculate the number of medium fish as:

$$M = \left[N_m \frac{A_2}{A_2} \right] + \left[N_1 \frac{A_3 - A_2}{A_3} \right]$$

Then, removing the medium fish TS in each strata, gives us the number of small fish S.

C. Absolute biomass estimation

This estimation is done using the following data:

- D_r, number of fish in the unit volume;
- W_r, mean weight of a single fish.

The evaluation of D_r is obtained using the actual volume sampled and the total number of echoes counted on the echogram:

$$D_r = N/V$$

The calculus of the mean weight needs the TS values of a fish to be converted in length; then we have to convert the length distribution in weight distribution.

We have very few informations on the TS of tropical fish (LEVENEZ, 1987; GERLOTTO, 1987), and according to the fact that the only data on the species distribution come from the fishery and ecological studies (CLARO *et al.*, 1990), we have assumed that the use of the equation of LOVE (1971) was the most adequate transformation method:

$$TS = 19.1 \log L + 0.9 \log \alpha - 23.9$$

where L = length of the fish, and α = wave length of the sounder.

The transformation of the length distribution in weight distribution has been achieved using informations coming from the Department of Ichtyology of the "Instituto de Oceanologia" of Cuba (CLARO *et al.*, 1990), which are detailed in the table 1.

For each length class the L/W relationship of the most common species has been selected as the most representative.

4. RESULTS

We have applied the methodology in 6 different places on the Gulf of Batabano, using either parallel or zig-zag transects. The mean depth of the areas observed varied between 3.9 and 5.5 meters and the number of fish counted between 2.66 and 11.04 per km (table 2).

The results of these surveys were employed to test the validity of the methodology (fig. 4).

A. Measurement of the beam angle

The results of the measurements for the large beam transducer of the EY-M echo sounder are presented on the figure 5. According to the threshold used in echo counting (.15 V rms), and to the TS values (from -30 to -50 dB), this gives a mean beam angle of 30 °. We have assumed that the beam pattern was regularly conical. At a speed of 4 knots (2.00 m/s) and a transmission ping rate of 3/s, the overlapping between two transmissions begins at a depth of approximately 1.15 m. As the blind depth of the sounder has been observed to be 1 m, that means that there is a non-overlapped layer of 15 cm at 1 m below the transducer. With a 30° angle, this represents a volume of $v = 0.027\ m^3$ per transmission. In these conditions we can calculate easily the actual sampling volume V knowing the mean depth H, the length of the unit distance L and the half beam angle α :

$$V = D \left[(v * 3) + (H^2 * tg\alpha - z^2 * tg\alpha) \right]$$

where H = total depth
z = superior limit of the overlapped sector (in this case, z is considered as a constant, and equal to 1.15 m)
D = total distance of the transect
α = 1/2 beam angle

In some cases an other correction has to be add : when the wave noise is present on the surface layers, it makes it impossible to recognise the echoes of the fish to those of air bubbles, and consequently the upper limit of the observed volume has to be lowered. In this case the overlapped zone disappears (v = 0) and z is increased in the above mentioned equation. This gave for the actual sampled volume of the 6 experiments the values presented in the table 2.

B. Distribution of TS

It is important, before to use the EY-M echo sounder for "in situ" TS collection, to measure precisely the TVG function. We [illegible] a classical way from 100 to 1.5 m. Then due to the fact that we need to know the values of the TVG in very shallow depth, we have measured it using a standard sphere, from 5 to 0.90 m. The results show that the TVG is efficient until 1 m depth, but the data are overestimated in small distances (fig. 6). As the TS are measured within these small depths, a correction factor should to be applied. An other way consists in measuring (SL+VR) at these low depths. We have obtained (SL+VR) at 3.5 m and assume that this value is useable for the small depths without corrections.

We may then calculate the TS distribution (fig. 7)

C. Biomass evaluations

The biomass evaluation has been used in this experiment to test the applicability of acoustic assessment to the Gulf of Batabano: the annual catch in this area is well known, and gives a good idea of the actual biomass (PAEZ COSTA, 1989). The mean catch is evaluated as around 0.8 metric ton/km^2/year in this kind of ecosystem. Considering that the total catch is 75 000 t and that the MSY calculated is evaluated to 80 000 t, we may assume that the density in the Gulf would be between 1.5 and 3.0 t/km^2.

After deconvolution, the TS histogram has been converted in a length histogram. Although we did not calculate the mean weight using the mean length, it is interesting to note that this mean length is 17.2 cm, which correspond reasonably to the population structure of the area as known from cathc data. The calculus of the mean individual weigh gives 217 g.

It is then easy to calculate the densities of each area sampled (table 2). These densities vary between 541 and 1980 kg/km^2.

5. DISCUSSION

We can see that the densities calculated through echo counting and TS measurements are lower than expected, but fit in the (ordre de grandeur). Various points are to be taken into consideration.

- TVG measurements. We must measure with better precision this point, which may input errors in the TS values.

- Fish behaviour. The survey has been performed during full moon, and a strong avoidance reaction of the fish was suspected. The next surveys will be performed in new moon periods.

- Weather conditions. They were rather favourable at the beginning of the survey, but changed during the work, and obliged us to eliminate a part of the data. This point is also to be taken into consideration when performing a cruise.

- Finally we have surveyed a very small part of the gulf and a correct evaluation will necessitate a more general grid.

Nevertheless it seems that under these conditions an evaluation of the fish abundance would be possible.

An other point interesting concerns the equipment. The echosounder EY-M gives rather good results and its TVG seems good enough, but the echogram is very difficult to read and the discrimination between fish echo and other signals is not easy. It will be indispensable to use a scale magnifier to count in good conditions the total fish echoes.

CONCLUSION

The acoustic survey of fish biomass in very shallow waters may give useable results using echo counting, and under favourable weather, light and behavioral conditions.

The most difficult point is to obtain unbiased values of TS, especially when using single beam echo sounder. In any case, if the data are collected aboard a small vessel and recorded for further processing, it is absolutely indispensable to use digital recorder, the analog tape recorder qualities being too low for these measurements. It is clear too that the equation of LOVE would be replaced by the actual TS data of the observed fish.

A special attention must be paid in the transformation length-weigth: in areas with various species present, the best way is to calculate a different relationship between length and weigth for eack length class, according to the specific composition.

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Table 1. Distribution of the main species for each length class

Length class	Species	L/W rel.
2-4 cm	*Jenkinsia lamprotaenia*	x
4-12 cm	*Harengula* spp *Haemulon* spp (juv.)	x
13-20 cm	*Haemulon* spp *Lutjanus synagris* *Lutjanus griseus*	x
21-41 cm	*Lutjanus griseus* *Caranx* spp. *Calamus* spp.	x
> 41 cm	*Lutjanus analis* *Caranx* spp. *Sphyraena* spp. Scombridae	x

L/W rel. = length/weight relationship of the species considered as representative of the length class

Table 2. Biomass evaluation for each experiment Gulf of Batabano, october 1989

Exp	1	2	3	4	5	6
date	12/13	13/14	14/15	15/16	16/17	17/18
H	5.5	4.7	4.3	4.9	4.4	3.9
z	1	1	2	1	1	1
D	11112	44448	40744	20372	12408	33336
V	84556	241041	158192	120958	58212	119326
N	39	213	233	225	33	189
dens.	550	902	1330	1980	541	1340

H : mean total depth (m)
z : blind zone (m)
D : total distance (m)
V : total sampled volume (m^3)
N : number of fish
dens : mean density (kg/km^2)

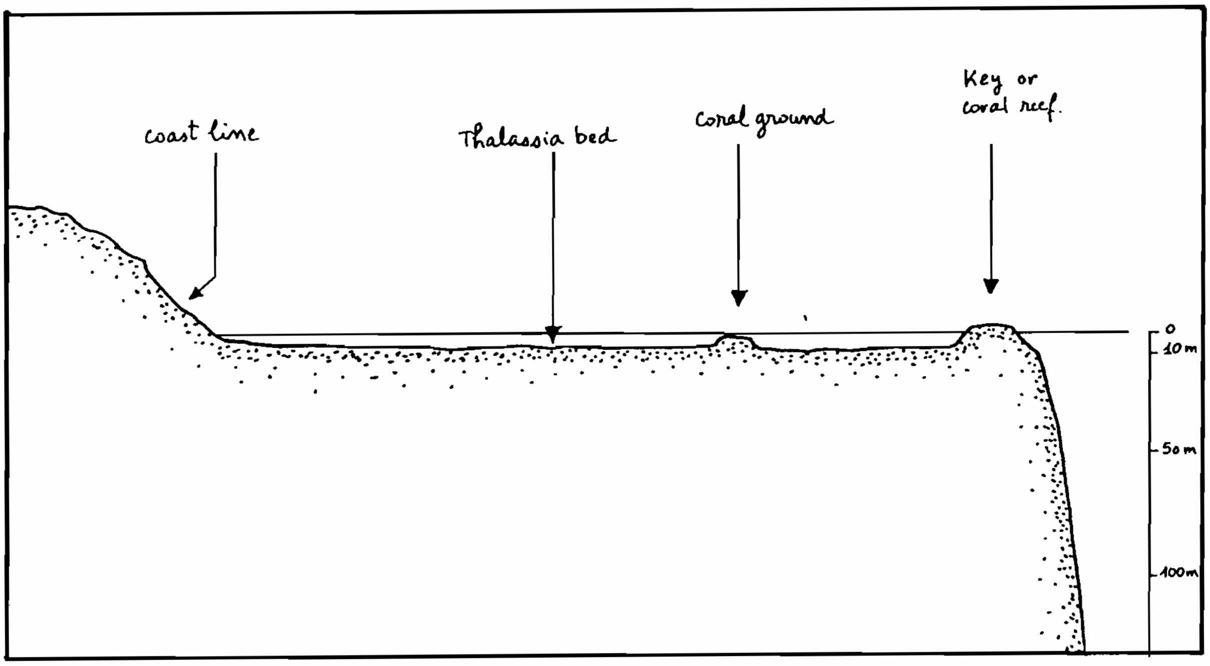

Fig. 1. Bathymetry of the Gulf of Batabano

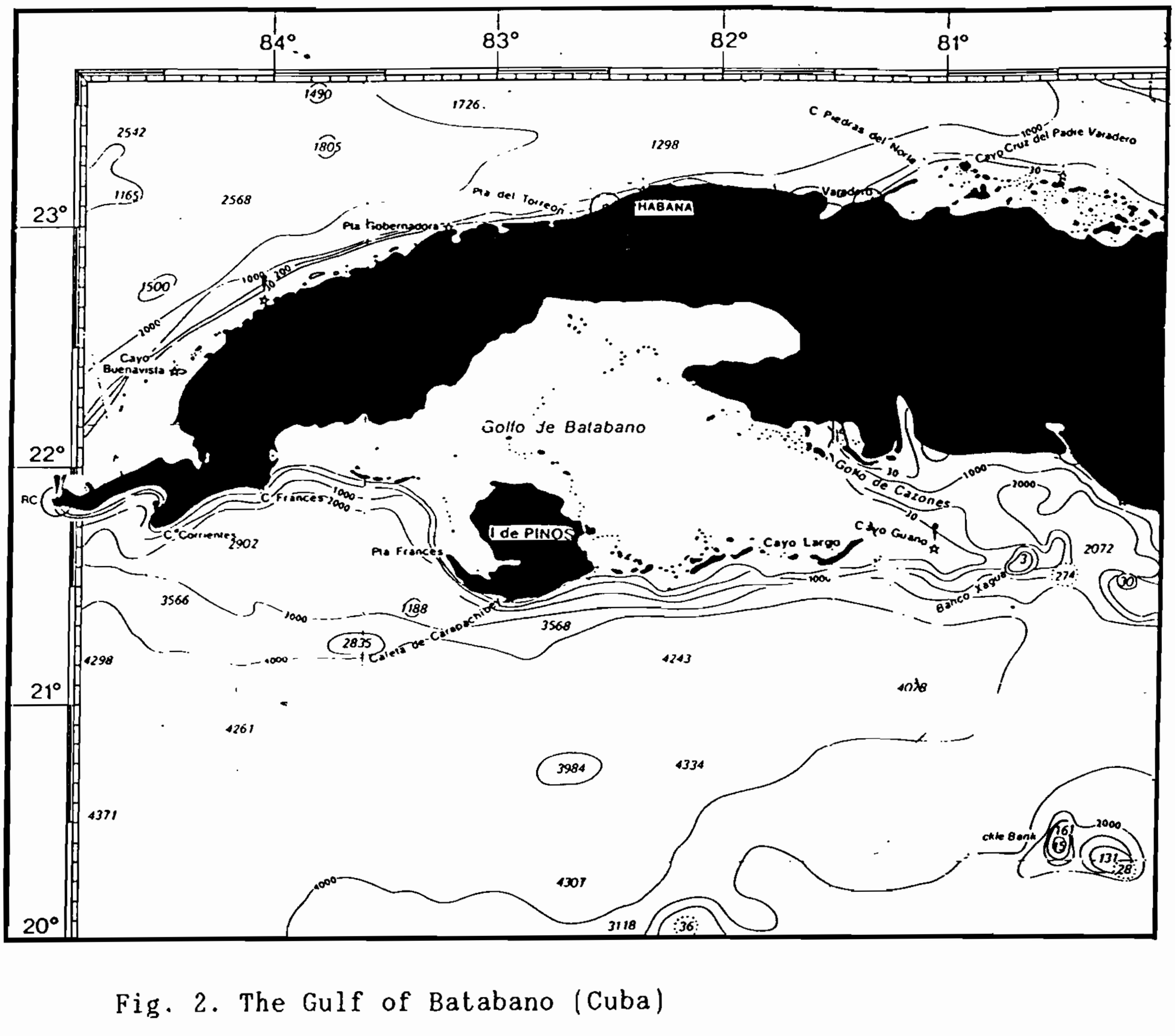

Fig. 2. The Gulf of Batabano (Cuba)

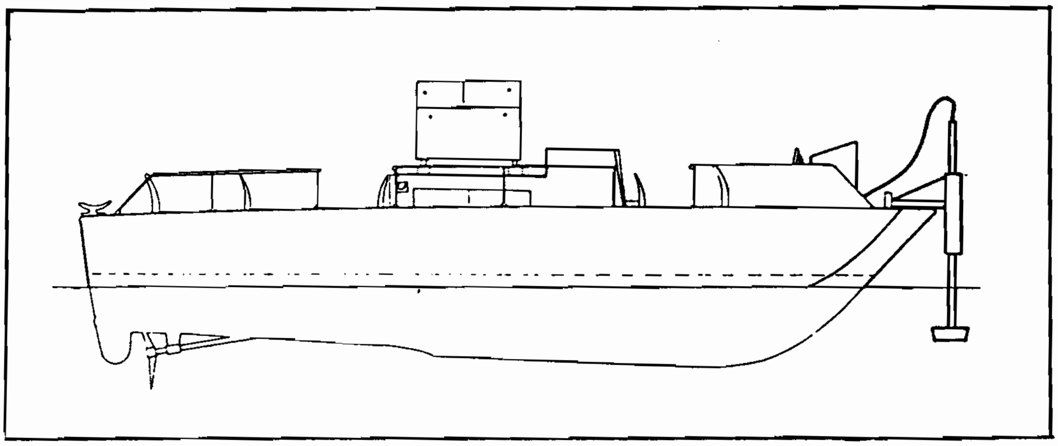

Fig. 3. Installation of the EY-M transducer aboard the motorboat

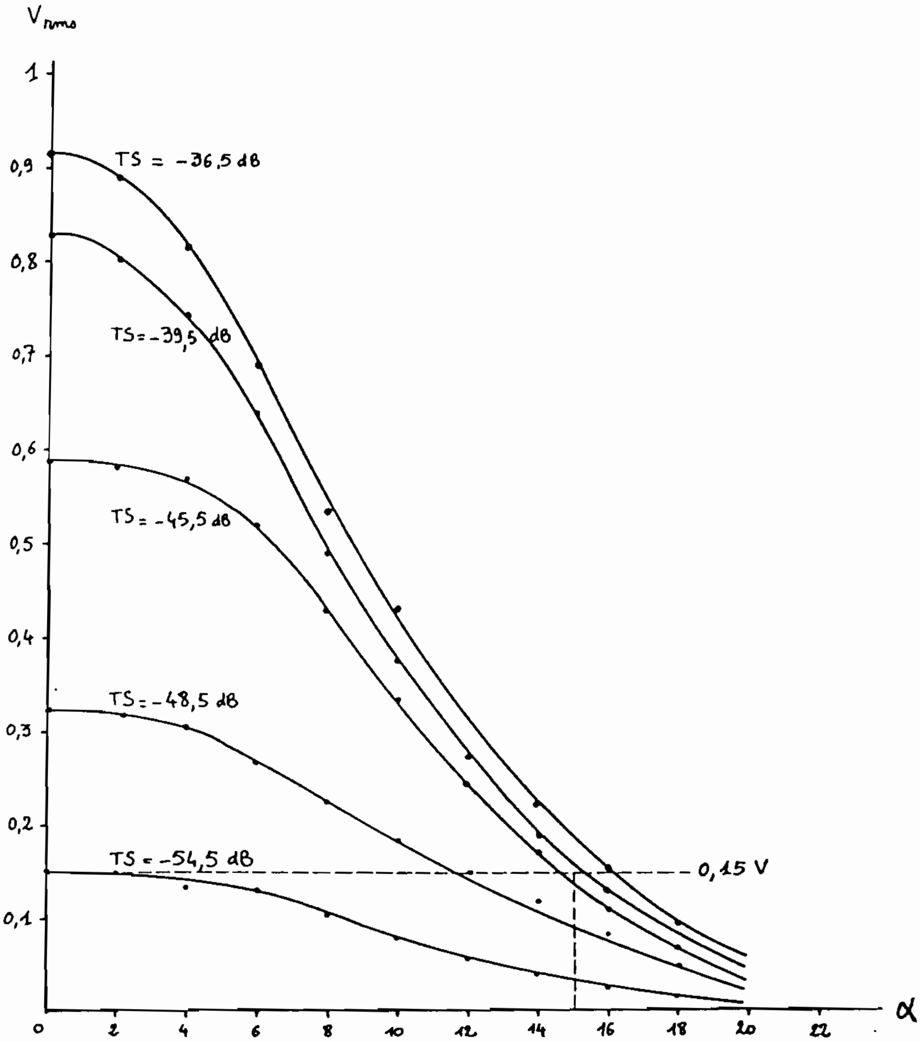

Fig. 4. Relation between beam angle and threshold for various TS

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The Concept of Acoustic Populations: Its Use for Analyzing the Results of Acoustic Cruises.

by

François Gerlotto and Emile Marchal

ORSTOM
213, rue La Fayette
75010 Paris, France

Abstract

One of the more critical limitations in the use of acoustics to assess the fish stocks concerns the difficulty in identifying precisely the surveyed populations. Information given by fishing operations are often insufficient, especially where there are many different species, as is usually the case in temperate and tropical areas.

This paper deals with the concept of "acoustic population" defined as a group of detections with rather homogeneous acoustic characteristics. The characteristics are provided by: -simple analysis of echograms (day/night counting of schools, type of schools, type of scattered fish, etc..); -integrated echo signals by categories (day, night, pelagic, demersal, etc..); -volume reverberation (average value of the layer and of the sample above a threshold).

The use of this concept is supported by the hypothesis of a correlation between observed acoustic characteristics and anatomic and behavioural characteristics of the surveyed population, leading to the conclusion that an "acoustic population" represents a true natural community. Therefore it should be possible to substancially reduce the number of fishing operations by a fine stratification of the sampling. Mapping the population is made using factor analysis on all the relevant acoustic data.

The comparison between data from fishing surveys and acoustic surveys conducted from 1982 to 1986 in Venezuela shows a good fit between the maps of natural communities and acoustic populations. Finally the weight of some acoustic parameters is tentatively assessed.

The authors conclude that the routine use of this method when the populations are multispecific may help to identify and to map more precisely the main natural communities living in such areas.

Résumé

L'une des limites les plus sérieuses à l'évaluation des stocks de poissons réside dans la difficulté à identifier précisément les populations: à peu près utilisable sur des groupes formés de peu d'espèces, la pêche de contrôle fournit des informations insuffisantes dès que l'on étudie des stocks multispécifiques (cas des zones tempérées et tropicales).

Les auteurs présentent dans cet article le concept de "population acoustique": il s'agit d'ensembles de détections présentant des caractéristiques acoustiques à peu près homogènes. Ces caractéristiques sont tirées des analyses simples des échogrammes (nombre de bancs de jour, de nuit, pélagiques, démersaux, types de dispersions, etc..), des valeurs d'écho-intégration (biomasses moyennes de jour, de nuit), et des valeurs particulières issues de l'analyse du signal (TS, densités par échantillon, par échantillons supérieurs au seuil, etc..).

L'utilisation des résultats s'appuie sur l'hypothèse que les caractéristiques acoustiques d'un stock sont liées aux caractéristiques anatomiques et éthologiques globales des espèces composant ce stock, et donc qu'une population acoustique représente bien une communauté naturelle. La confirmation de cette hypothèse permet alors, par une stratification fine, de réduire notablement l'échantillonnage par pêche. La cartographie des populations acoustiques s'effectue à l'aide d'analyses factorielles sur l'ensemble des différents paramètres acoustiques.

La comparaison entre les résultats de pêches exploratoires et de campagnes de prospection acoustiques effectuées entre 1982 et 1986 au Vénézuéla a permis de voir que les cartographies des communautés naturelles et des populations acoustiques coïncidaient remarquablement.

Enfin une tentative d'évaluation des importances respectives des différents paramètres acoustiques entrant dans la définition des populations acoustiques est présentée.

Les auteurs concluent que l'application systématique du concept de population acoustique sur des zones à stocks multispécifiques peut être une façon d'identifier et de cartographier précisément les principales communautés naturelles de ces régions, et donc d'améliorer notablement la précision des évaluations sur ces populations.

1. Introduction

Acoustic stock evaluation methods have greatly improved over the last few years, by using microprocessors that allow the digitalization of the received acoustic signals and the quick and precise analysis of the contained information (see for example the bibliographic list established by Venema, 1985).

Nevertheless the identification of the observed populations still depends on fishing operations, with all the bias and errors such methods could entail. This fact may considerably reduce the precision of the results, especially in tropical regions where these populations are very intricate. It is obvious that a good evaluation of a survey result precision is needed (Shotton and Bazigos, 1984). Several methods have been proposed to evaluate and reduce the observed variance (Shotton, 1981; Barbieri, 1981, etc...), but all of them indicate that a good stratification of the observed area is required. Such a stratification can be based on various criteria: biological and ethological (Laloe, 1985; Gohin, 1985), bathymetric (Shotton, 1981), depending on the population distribution (Aglen, 1983; Gerlotto and Stequert, 1983) or on the delimitation of homogeneous populations (Barbieri, 1981). This shows how useful an automatic, non fishing-dependent, stratification method might be.

2. Definition of the "Acoustic Population" concept

A natural fish community may be defined as a group of species mixed in more or less constant proportions, each species being characterized within the community by its individual mean length and weight and its behaviour. The determination of these criteria and the distribution of this community may be obtained by fishing operations which give (if the fishing gear is non-selective):

- a catalogue of the present species;
- the species proportions;
- the individual mean length and weight.

Acoustic populations are defined from the following hypothesis: behaviour, taxonomic and biometric characteristics of the fish inside a natural community are sufficiently typical and permanent to allow their resultant to characterize this community. In this case the community can be described by all the acoustic observations that depend on these behaviour, taxonomic and biometric characteristics, their synthesis representing the so-called "acoustic population".

Such a concept has been approached by various authors: Azzali (1982) distinguishes five parameters to identify species: vertical extension, horizontal extension, formation coefficient, day time, group shapes. Nion and Castaldo (1982) separate an anchovy population in five groups: superficial schools (day), superficial schools (night), deep schools (day), scattered fish (night).

We propose here to generalize this method by using all the parameters likely to help to characterize a community. These parameters come from two origins: visual analysis of echograms and electronic processing of the acoustic signals. We present the following list:

- TS mean values and histograms;
- day and night variations of each parameter;
- individual echoes distributions;
- type of fish aggregation (pelagic, demersal, schools, scattered...)
- global fish density (echo integration);
- variation of target distributions (school/scattered, pelagic/demersal)

It could be possible to include in this list some abiotic characteristics, being some communities related to particular ecosystems (hydrology, sedimentology, bathymetry). Nevertheless in this study we shall only take acoustic data into account.

If the former hypothesis is confirmed, a fish community can be correctly represented by an acoustic population index. In this case we are justified in using acoustic populations to post-stratify a surveyed area: acoustic samples are many more numerous than fishing samples, so it seems that using acoustic populations distribution instead of natural community mapping would improve significantly the precision obtained by stratificating area.

In order to confirm this hypothesis we have studied two natural communities and their corresponding acoustic populations, and evaluated the fitness existing between them.

3. Equipment and methods

3.1. The surveys.

We have conducted this study in two different regions in Venezuela: the Gulf of Venezuela in the West and the "Oriente" in the East. (fig. 1). Six surveys were performed in these two regions, the characteristics of which are summarized in table 1. Four of them (FALCON 1 to 4) were done in the Gulf of Venezuela, and two in the Oriente (ECHOVEN 1 and 2).

Fishing and acoustic data were obtained in separate surveys in the West: FALCON 1 was a fishing survey and FALCON 2 to 4 acoustic surveys. In the East, ECHOVEN 1 did not cover the complete zone and no fishing has been done, so we data of this survey are not included in the present study, although neat acoustic populations have been observed during this cruise (Gerlotto and Marchal, 1985). ECHOVEN 2, which covered completely the eastern area, was a mixed fishing and acoustic survey.

3.2. Equipment.

Two boats have been employed: R/V La Salle (39 m) in the Gulf of Venezuela and R/V Capricorne (46 m) in Oriente.

- FALCON 1. The fishing has been done using a semi-pelagic trawl, in fishing operations between one and three hours long.

- FALCON 2 and 3. During these acoustic surveys, the echosounder was a SIMRAD 120 kHz EK/S, and the echo-integrator a SIMRAD analogic QM 2.

- FALCON 4. The equipment was the same as during FALCON 2 and 3, with the exception of the integrator, a digital AGENOR (Protechno). During FALCON 2 to 4, although they have not been used in the present work, a few fishing operations took place, with the same net as during FALCON 1: their results showed that the communities observed during FALCON 1 did not change significantly until FALCON 4.

- ECHOVEN 2. The fishing was done with a pelagic trawl (8 m mesh size in the mouth). The echo sounder was a SIMRAD EK400, used at the 120 kHz frequency, and the integrator a digital AGENOR.

3.3. The data.

Depending on the surveys, different types of data have been analyzed (table 2), according to the following list:

(a). fishing: yield (catch/hour)
(b). number of pelagic schools per Elementary Sampling Distance Unit (ESDU) by day;
(c). number of pelagic schools per ESDU, night;
(d). number of demersal schools per ESDU, day;
(e). number of demersal schools per ESDU, night;
(f). mean density/ESDU, day;
(g). mean density/ESDU, night;
(h). number of samples above the threshold/number of samples (E+/E), day
(i). E+/E ratio, night;
(j). density/E+ (high, medium, low), day;
(k). density/E+ (high, medium, low), night.

The definition of data (h) to (k) is given by Marchal and Gerlotto (1987). Lacking the necessary equipment, we have not been able to collect sufficient "in situ" TS values to include this type of information in this work.

3.4. Data processing

The data obtained for each ESDU (in all the cruises, ESDU are six-minutes intervals, corresponding more or less to one nautical mile (N.M.) at 10 knots) are gathered in geographic squares (15x15 N.M. in the Gulf of Venezuela, 10x20 N.M. in Oriente) (fig. 1). These empirical dimensions are supposed to be sufficient to consider that the squares are independent (McLennan and McKenzie, 1985).

Each square was considered as an individual; we used factorial analysis as processing device. In fact we used it as a cluster method, in order to classify all the squares in a non-subjective way, as far as possible.

The groups of squares are then mapped in order to observe possible homogeneous regions according to the parameters introduced. This analysis is done first of all on the fishing data, to map the existing natural communities (if any), then on the acoustic data to extract acoustic populations: the corresponding maps are finally compared.

4. Results

4.1. Gulf of Venezuela

4.1.1. Fishing. The Gulf is divided in 28 squares. Four of them have not been prospected acoustically, and will not appear in the maps. Sampling consists of one trawling in each square. The trawling results are presented in table 3, where the data are converted in species percentage of the total catch weight.

The direct observation of table 3 shows that two specific groups are present in the gulf, one in the lower part of the Gulf (SW) and the other one in the mouth (NE). Fig. 2 presents the distribution of the most representative species.

That observation can be confirmed by the factorial analysis of the data of table 3. Figure 4, which shows the distribution of the squares on axes 1 and 2, permits to define five main groups of points, named A to E. Mapping these points (fig. 6A) reveals that the two main regions observed on table 3 are clearly circumscribed (sectors A and C). Sector D will not be studied further, as we have no acoustic data in squares 24, 25, 26. Finally sectors B and E appear geographically as intermediary zones between sectors A and C.

4.1.2. Acoustic data. As presented in table 2, two kinds of data have been used in the gulf of Venezuela. All the data are summarized in table 4 and presented in the figures 2 and 3. The results of the factorial analysis are given in fig. 5. On this figure the number of each square is affected by a letter related to the corresponding natural community of fig. 6A. Figure 5 enables one to identify three groups:

- group (a), rather well individualized: squares 5, 6, 8, 9
- group (b), not so neat: squares 4, 13, 14, 19
- group (c), with a rather arbitrary limit: squares 22, 23, 27, 28.

Although the other points look too central to be non-subjectively separated, it is interesting to note that the points around group (a) belong to the natural community A, as the squares of this group (squares 7, 17, 18). The same observation can be arrived at group (c): squares 2, 3, 21. They are presented with the letter group in parenthesis on fig. 6B.

The other squares are presented with an X. Finally fig. 6B shows, as fig. 6A, two main populations, on the SW and on the NE of the gulf, with intermediary squares that cannot be gathered with these populations.

4.2. Oriente.

Oriente has been divided in 10x20 N.M. "squares", 55 of them having been prospected and included in this analysis.

4.2.1. Fishing. It was not done in the same way as the Gulf of Venezuela, for two reasons: on the one hand, because one cannot use the pelagic trawl in a completely random sampling as one can when using a bottom trawl, and on the other hand because, as the trawling took place during the acoustic survey, it depended on the selected route. 30 trawlings were carried out on detections (fig. 10), three of them have been eliminated (no catch): numbers 23, 27, 30. The rasult of the catches (in species percentage of the total catch) are summarized in table 5.

Following the same method as for FALCON 1, we have applied a factorial analysis on the data, but after ignoring all the species which appeared only once in the catches and those which always represented less than 1 % of the catch (as it is difficult to know the actual representativity of these species in a pelagic trawl catch).

The factorial analysis results are presented on fig. 7: three main groups (A, B, C) and a little one (D) can be distinguished on the distribution of the squares along axes 1 and 2. Observing now the distribution on axes 2 and 3, we can see that a sub-group appears, formed with some points from group B. This new group is called B' in figure 7B.

Mapping these groups gives an idea of the communities that are present in Oriente (fig. 11):

- community A: essentially composed of Sardinella aurita, it covers exactly an up-welling region (Fukuoka, 1963).

- community B': it is formed of a great number of species, especially Carangidae (Chloroscombrus chrysurus, Vomer setapinnis, Caranx spp), and those Clupeids present in low salinity waters (Opisthonema oglinum principally). All the trawlings of this group took place in the gulf of Paria, which is characterized by extremely low salinities, less than 20 %., the gulf being situated at the mouth of the Orinoco River (fig. 8).

- communities B, C and D cannot be easily defined. So we can only observe that group C is formed of the trawlings that caught mackerel (Scomber japonicus). Group B and D would require a finer analysis to be defined in community terms, and we only will consider them (together with group C) as an intermediary mixed community.

It is then possible to consider that the factorial analysis on trawling data made it possible to separate three communities in Oriente: the up-welling sardine community, the gulf of Paria community and an intermediary/peripherical community.

4.2.2. Acoustic data They are detailed in table 6, and the main part of them is presented in fig. 9. The factorial analysis is presented on fig. 10. The distribution of the squares on axes 1 and 2 shows two rather well individualized groups: A (squares 4, 6, 30) and B (squares 10, 31). Two other groups, called A' (squares 8, 41) and B' (squares 5, 9, 25, 32, 37, 38), less clearly individualized, may be observed. The other points cannot be individualized on axes 1 and 2.

Looking at axes 2 and 3, we can see that groups B and B' may be gathered, as well as groups A and A'. A third group is extracted from the central points: group C (squares 15, 17, 18, 20).

Finally the acoustic data analysis may show four acoustic populations:

- population A: squares 4, 6, 8, 30, 41;
- population B: squares 5, 9, 10, 25, 31, 32, 37, 38
- population C: squares 15, 17, 18, 20;
- population D: all the other squares.

The map of these populations shows a good consistency in the data (fig. 11):

- populations A and B cover almost exactly the Sardinella area, A being formed of the squares where the sardinella population looked the densest;

- population C covers a great part of the gulf of Paria;

- finally population D covers an intermediary zone, where no dominant species can be observed.

5. Discussion

Although it gives many information, factorial analysis in not an entirely reliable method, as it does not preclude subjective interpretation. In the case of its application on tropical fish communities, if we consider the fact that there is a very important number of parameters, often contradictory, which influence the characteristics of these communities, one cannot expect to find results enabling one to isolate these populations without any risk. That point is actually the reason why devices for the identification of populations are required in tropical surveys, even if these devices are not completely error-free.

In order, first of all, to test the concept in different situations, we selected two examples which were calculated with data extracted from different sources: four separated surveys extended over several years,using an analogic echo integrator and a bottom trawl in the case of the gulf of Venezuela; a single mixed acoustic/trawling survey,using a pelagic trawl and a digital echo integrator in Oriente.

It is also to be noted that these two regions are rather ecologically distinct: there is not a big sardine stock in the West as it appears in Oriente, and the peripherical systems of the two regions (Maracaïbo lagoon in the Gulf of Venezuela, Orinoco in Oriente) are completely different.

All these observations confirm the idea that stratification and mapping of the acoustically surveyed stocks by the way of acoustic populations seem consistent and should give usually good information, at least in the case of tropical populations.

Then, in order to see wether some subjectivity had been introduced in our interpretation, we carried out a little test on one of the acoustic data sets (ECHOVEN 2), using on the data a cluster analysis (fig. 12A). The obtained dendrogram reveals two things:
(1) except in a few cases, the squares are not strongly discriminated by a cluster method: this was expected.
(2) nevertheless, the classification obtained is rather close to that obtained through the factorial analysis, as is made clear on fig. 12B

These observations lead to the following conclusion:
(a): it seems that acoustic populations are a useable tool for community identification;
(b): in order to obtain the best discrimination of these acoustic populations, the different kinds of data available should be tested, because it is probable that all of them do not have the same significance. A little example is given below.

We have introduced with table 4 data those of the 7 most representative species of FALCON 1, and calculated the correlation matrix on the complete set (table 6). If we consider the correlations between acoustic data and specific catches, we can see that on 140 calculated correlations, 36 are significant at the confidence level 0.1. If one wishes to be more precise, it is possible to classify the data in three groups:

- data without any significant correlation with the fish;
- data with at least one significant correlation at level 0.1 (r=0.3233)
- data with at least one significant correlation at level 0.05 (r=0.3809)

These groups are presented in the following table:

group	type of data
0 corr.	DJF2, DJF3, BFJF2, BFJF3, BFNF3
corr (0.1)	DJF4, DBJF2, DBJF3, DBNF2, BFNF3
corr (0.05)	DNF2, DNF3, DNF4, BPJF2, BPNF2, BPNF3, DBNF3, DE1F4, DE2F4, DE3F4

(the names of the variables are explained in table 2)

This classification shows some points:

- the day-density values have no -or little- correlation with species distribution, while on the opposite the night-density values show a high correlation.

- the school data are more difficult to analyze: some of them look highly correlated with the distribution (number of pelagic schools), others have a low correlation (school densities), and the number of demersal schools seems to have no correlation at all with the distribution of species.

- the densities per sample above the threshold are, with the night densities, the most correlated parameter.

All these observations show that a more precise study of the significance of each acoustic parameters and of their influence on the acoustic populations elaboration has to be done.

Finally another point should be calculated, i.e. the gain in precision that a stratification through acoustic populations could give compared with a general study or a systematic stratification.

Conclusion

The analysis of acoustic data from the surveys in Venezuela made it possible to build in a rather satisfactory way maps of acoustic populations which were practically identical to the natural community maps of the same areas obtained through exploratory trawling.

This observation seems to be a good demonstration that the initial hypothesis, i.e. that a fish community can be represented by the acoustic data collected upon it, is very probably correct. In these conditions a closer analysis of the collected signals would permit:

- to obtain a good mapping of these communities, with many more values than a trawling survey could ever give, and consequently to rationalize the sampling time;

- to stratify or post-stratify in an automatic way, through the acoustic populations, the studied area, and to greatly decrease the variance in results of an hydroacoustic survey.

The last point is the following: an hydroacoustic survey generally gives one important result: the global biomass value. In fact the processed data could give much more than this single, low-precision, result. The maps obtained with all the other acoustic results bring a lot of information as far as the identification of communities, the behaviour, and the fishery biology are concerned. This type of information does not present the drawback of absolute density values, because it can be used directly in relative terms, and is consequently much more accurate.

Acknowledgments

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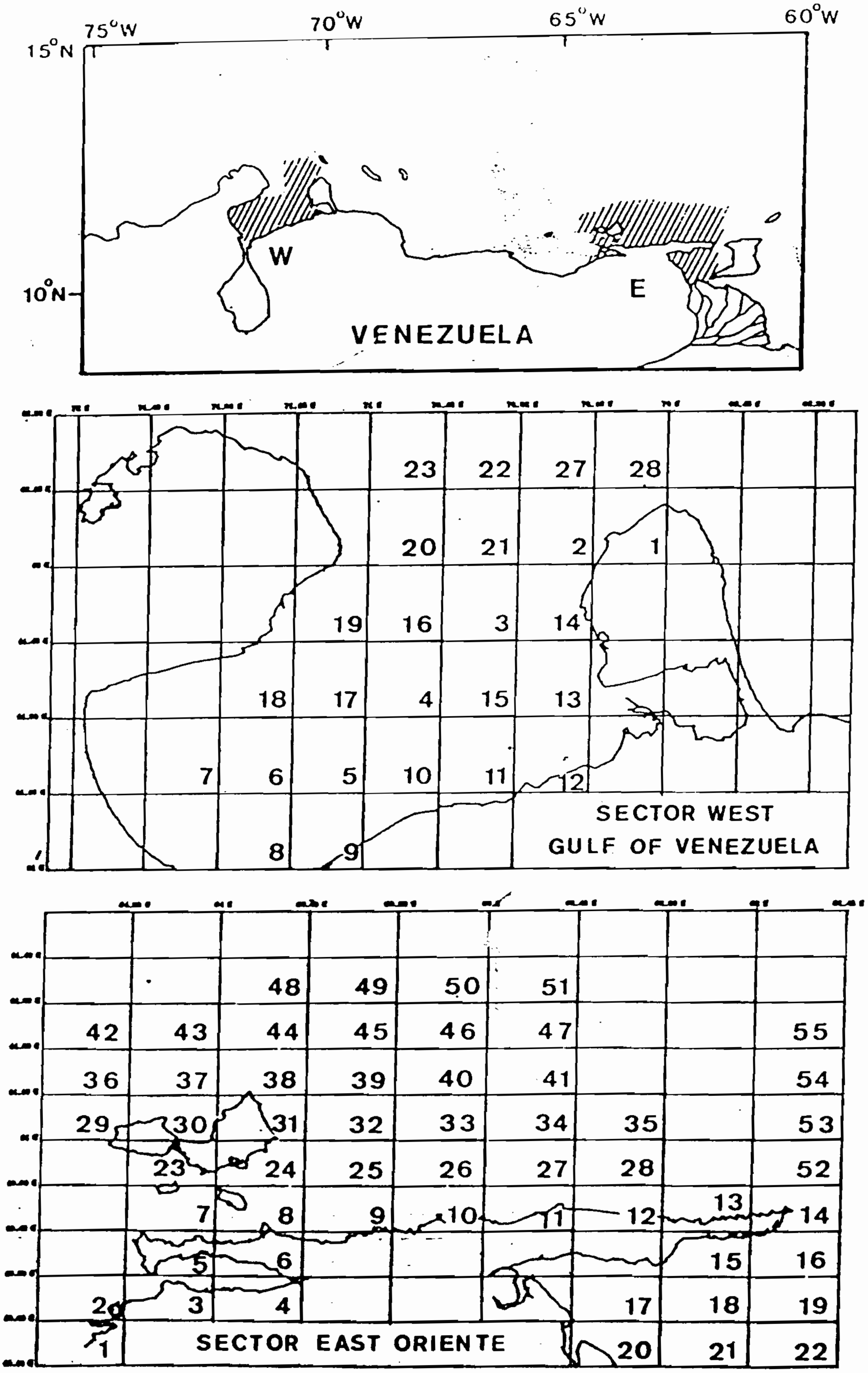
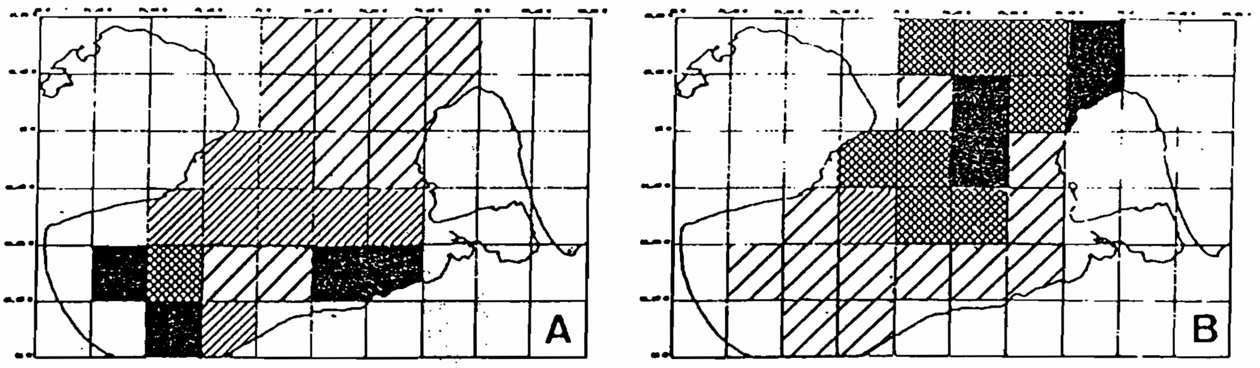
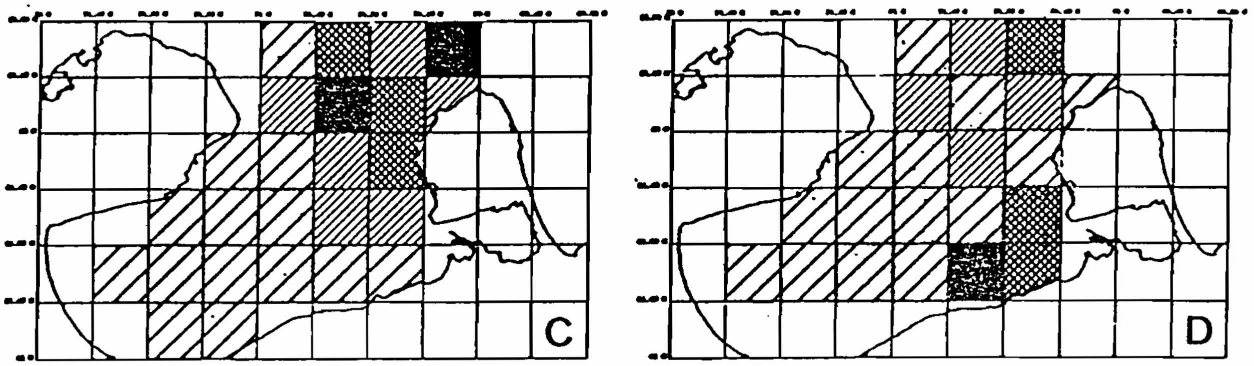


Fig. 1 : General map of Venezuela Coast and surveyed sectors, with numbered squares



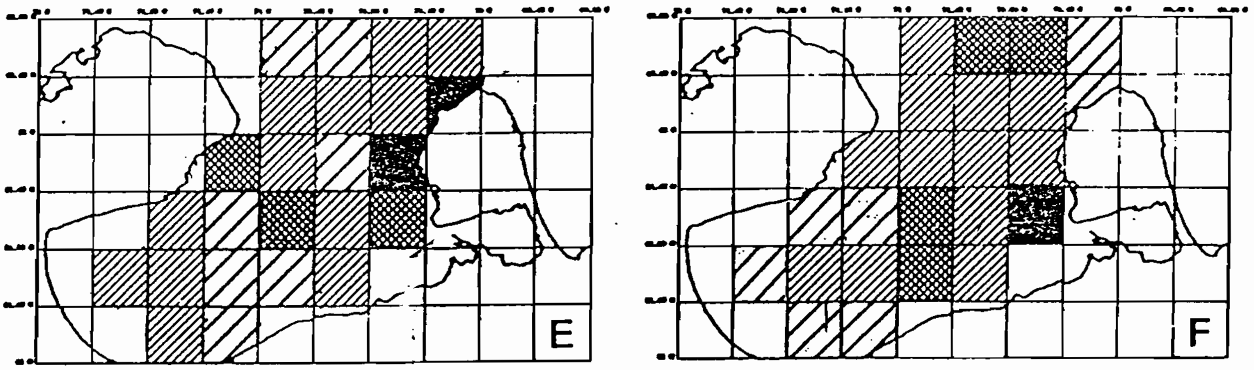
Chloroscombrus chrysurus

Lutjanus spp.



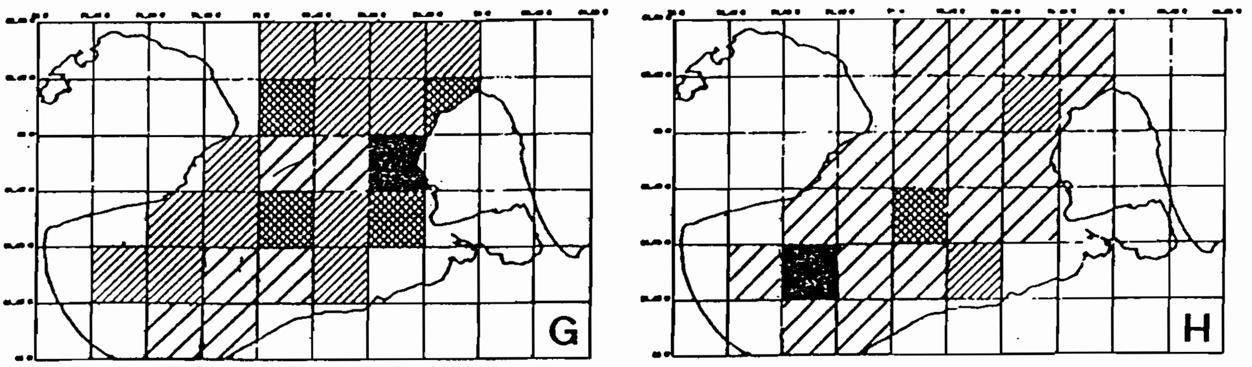
Priacunthus arenatus

Pomadasydae



day density

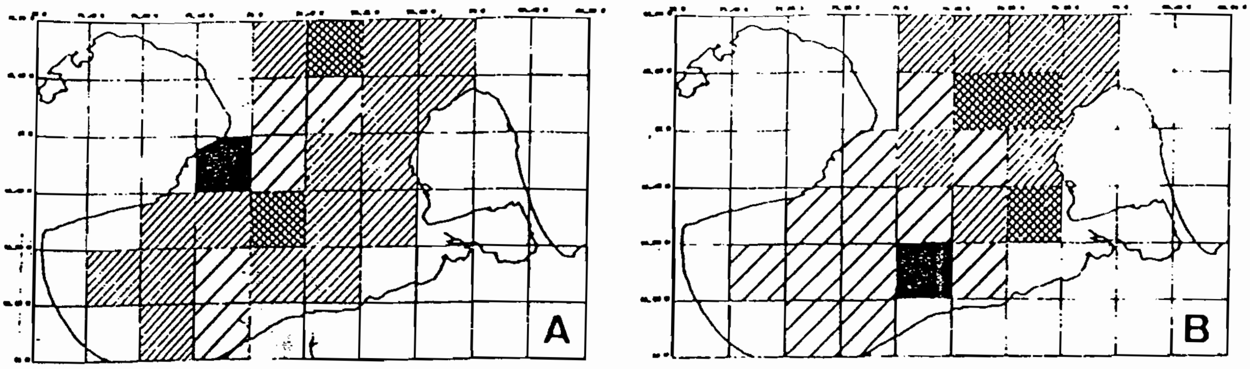
night density



school day density

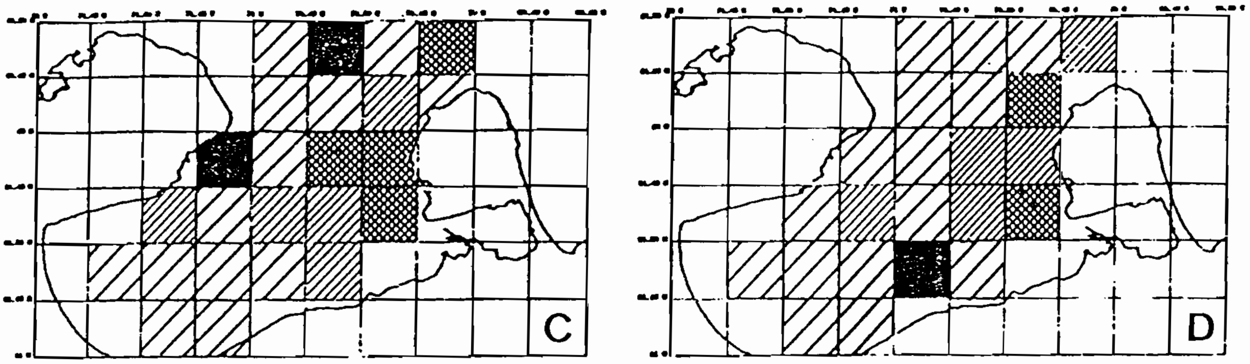
school night density

Fig. 2 - A,B,C,D : FALCON 1, examples of fish distribution
E,F,G,H : FALCON 2, examples of acoustic parameters distribution



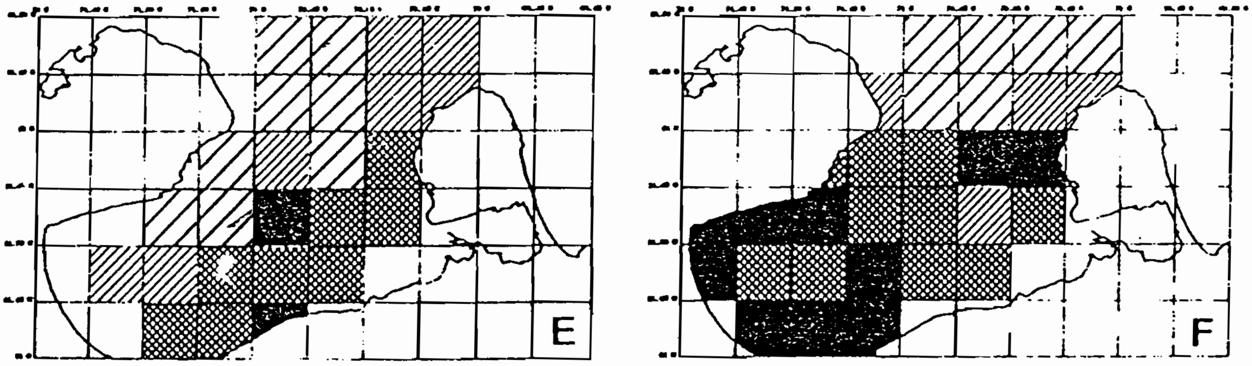
global density (day)

global density (night)



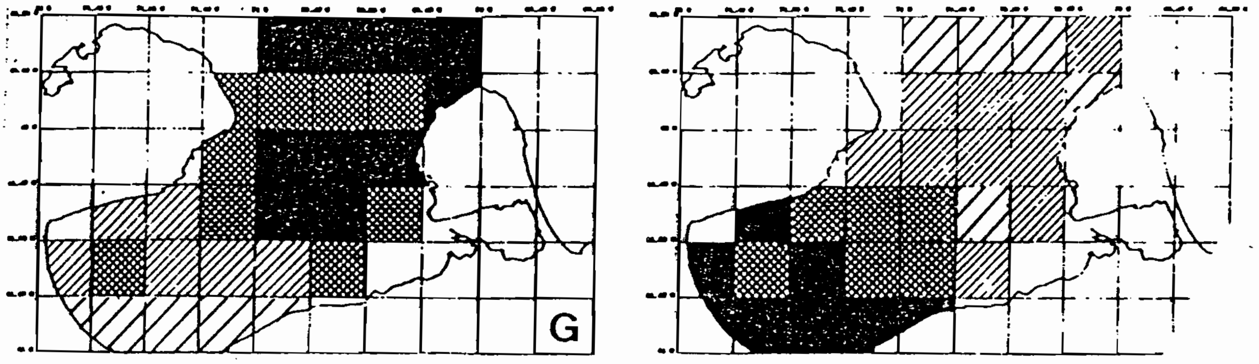
school density (day

school density (nigth)



global density (day)

global density (night)



Density /E+ (low)

Density/E+ (medium)

Fig. 3 - A,B,C,D : FALCON 3, examples of acoustic parameters
E,F,G,H : FALCON 4, examples of acoustic parameters

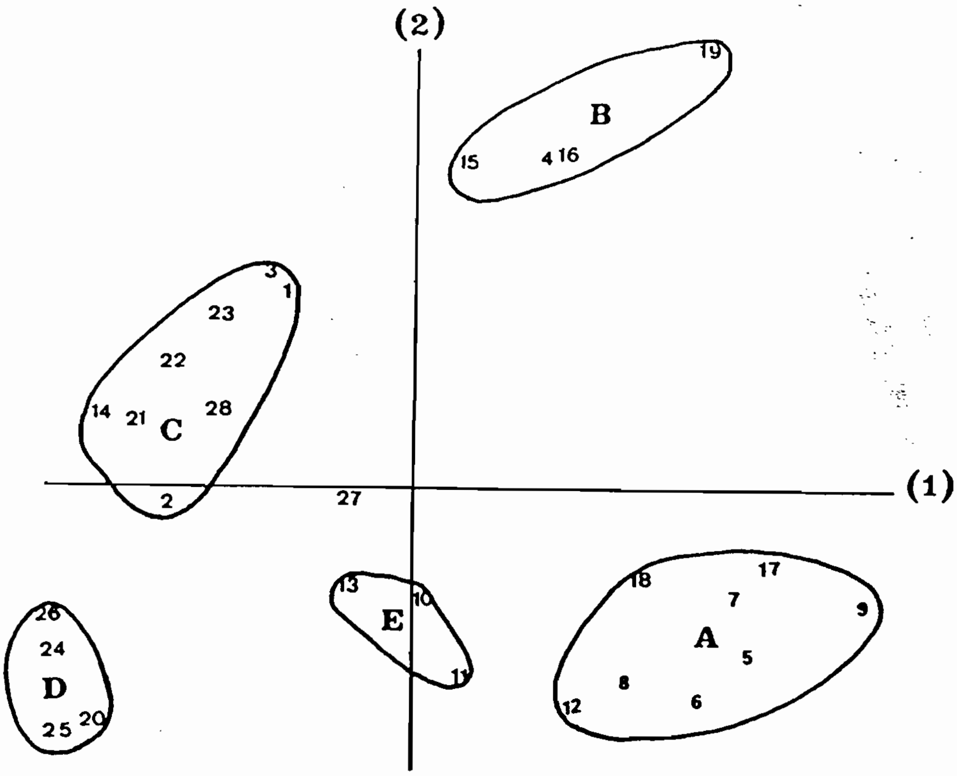


Fig. 4 - Factorial analysis on trawling data (FALCON 1)
distribution of the squares on axes 1 and 2
% inerty of axes 1 to 3 : 46.1 ;14.2 ; 8.7

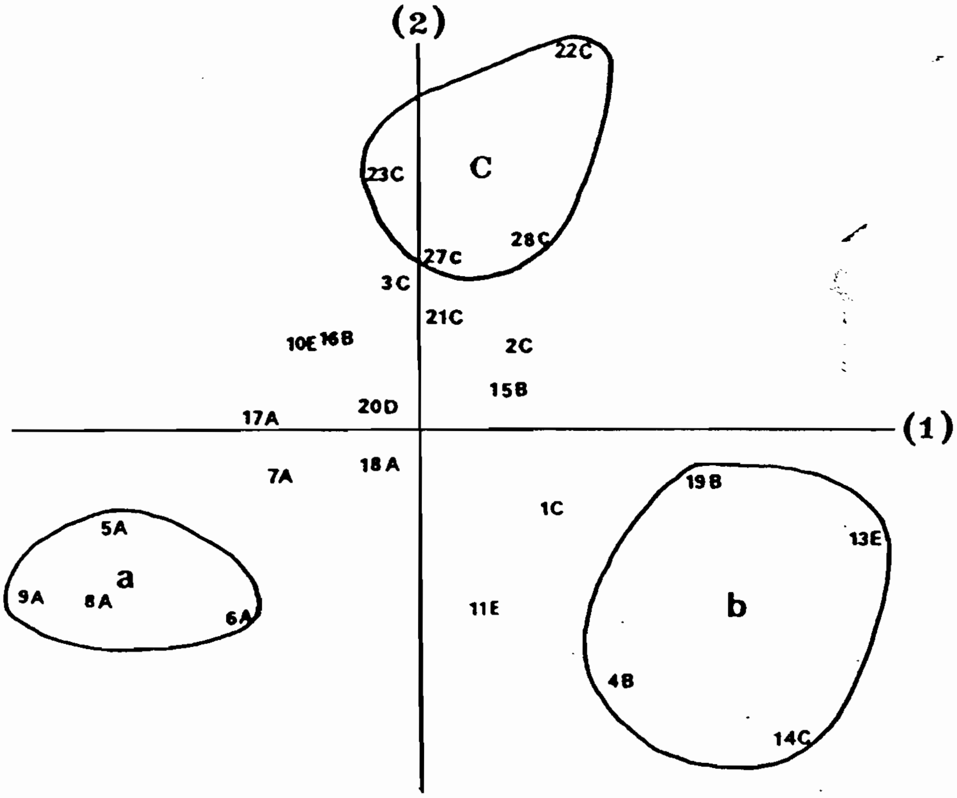


Fig. 5 - Factorial analysis on acoustic data (FALCON 2-4)
distribution of the squares on axes 1 and 2
% inerty of axes 1 to 3 : 26.9 ; 16.9 ; 13.9

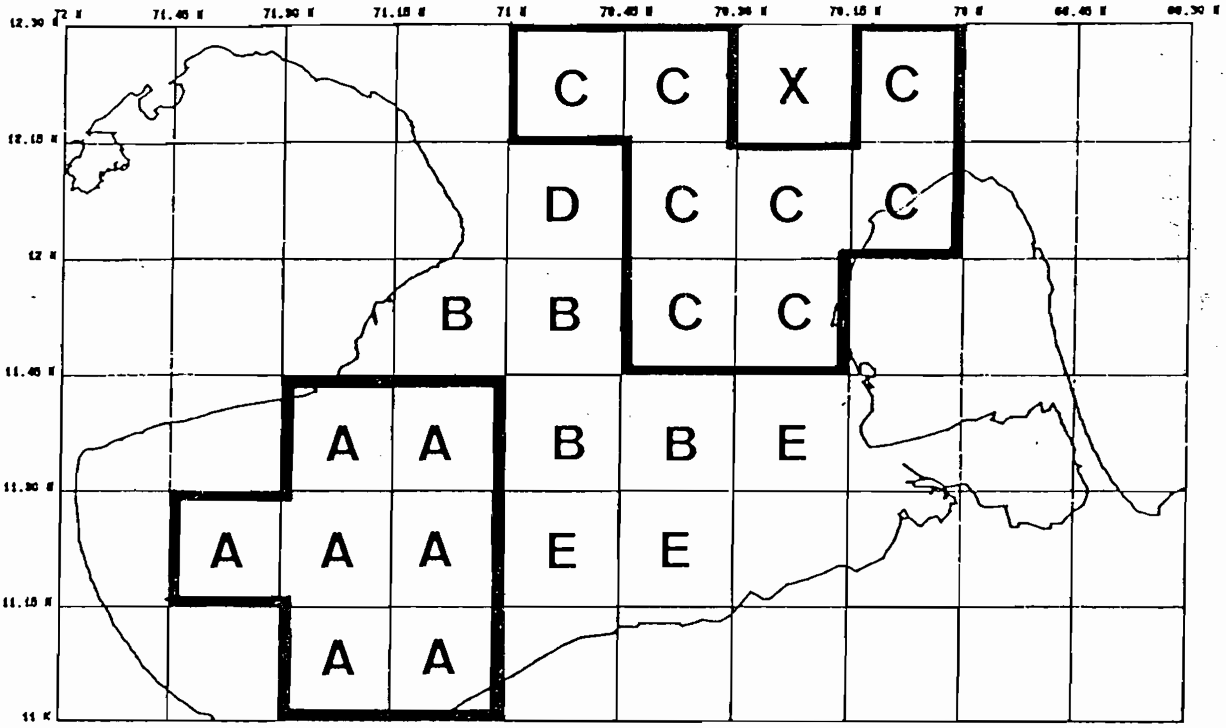


Fig. 6A : Map of natural communities, FALCON 1

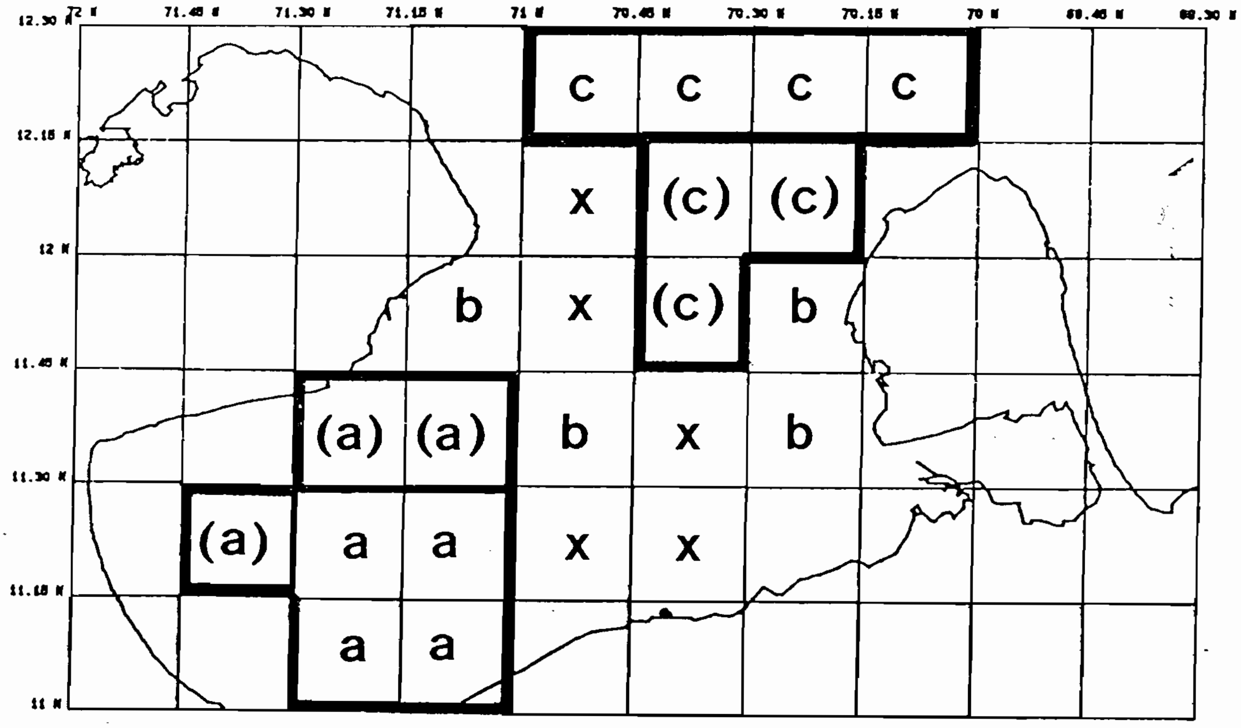


Fig. 6B : Map of acoustic populations, FALCON 2 to 4

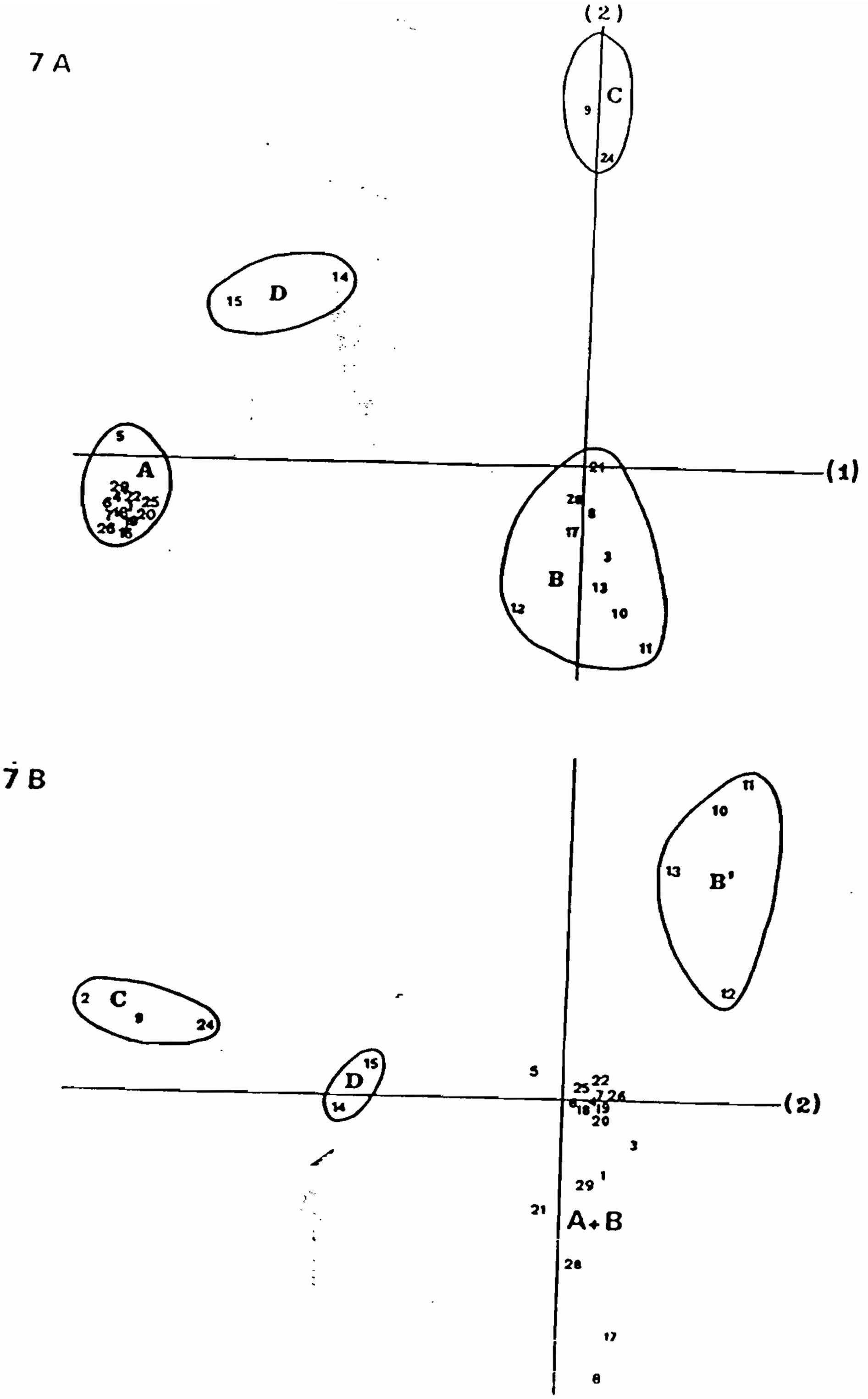


Fig. 7 : Factorial analysis on trawling data (ECHOVEN 2)
7A : trawlings distribution on axes 1 and 2
7B : trawlings distribution on axes 2 and 3
% inerty on axes 1 to 5 : 50.5 ; 10.3 ; 6.5 ; 5.1 ; 5.0

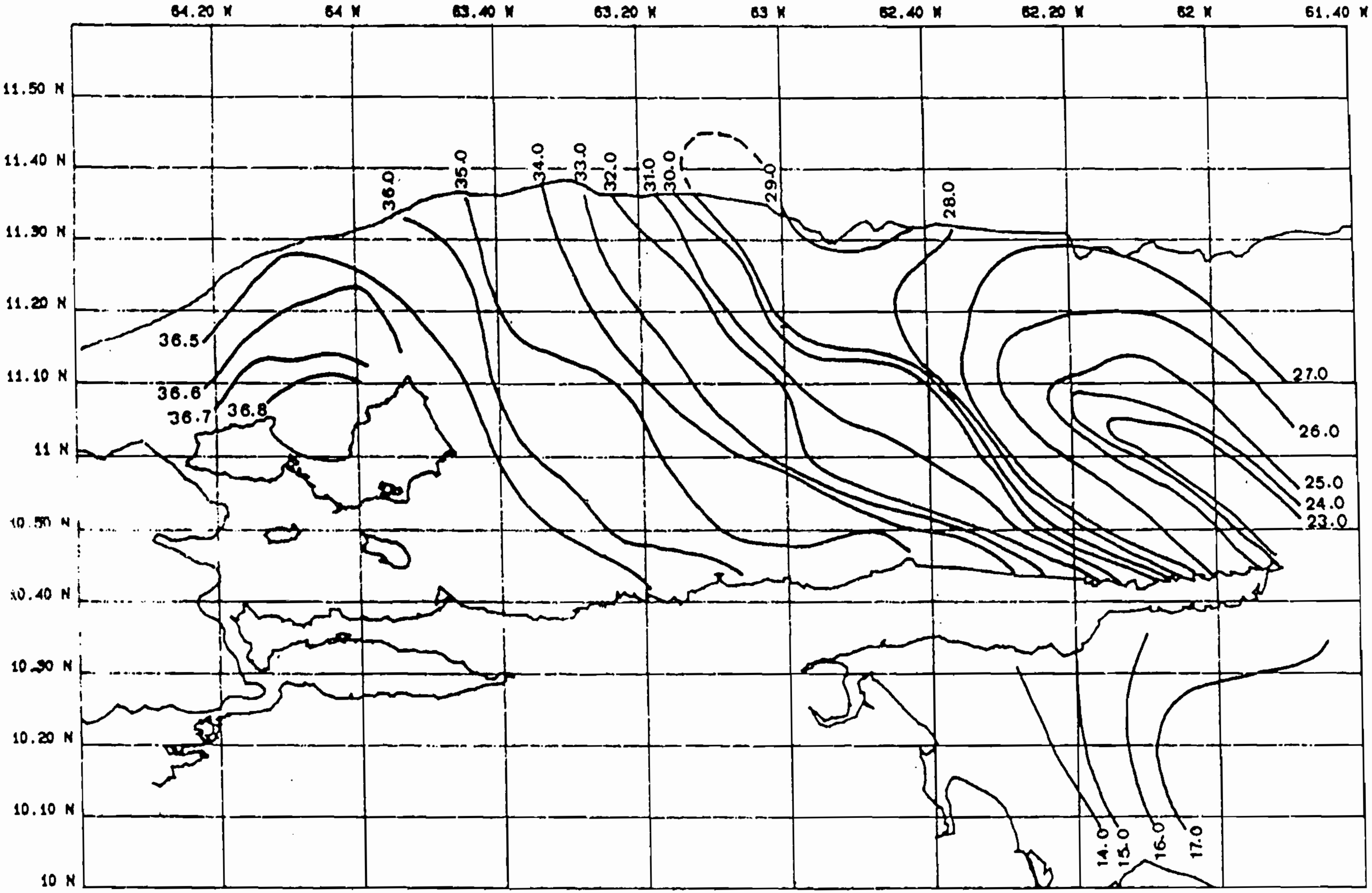
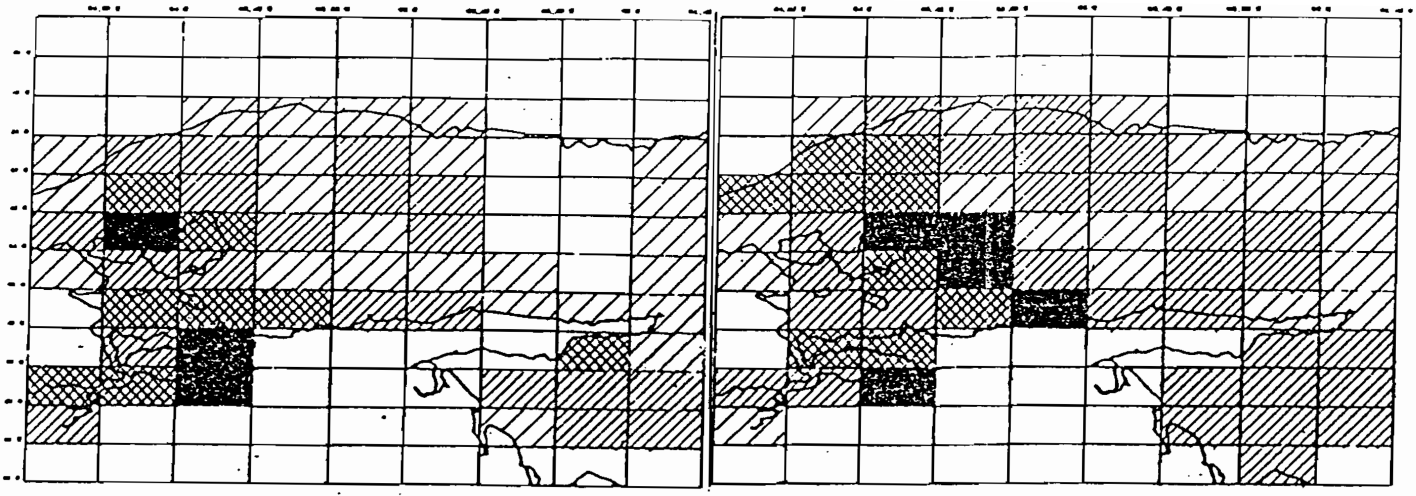
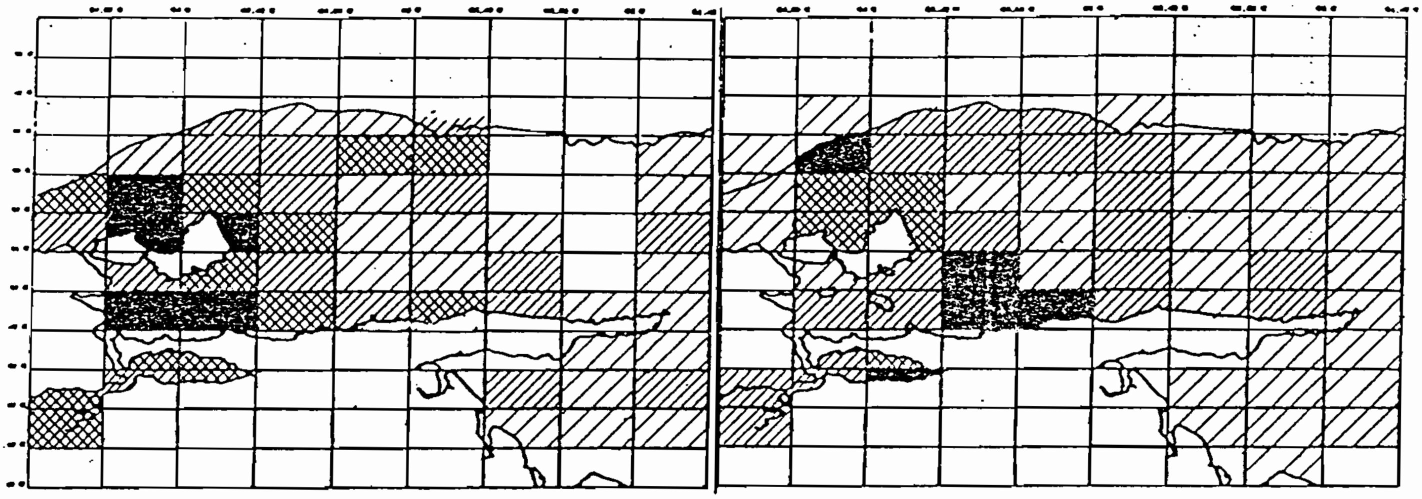


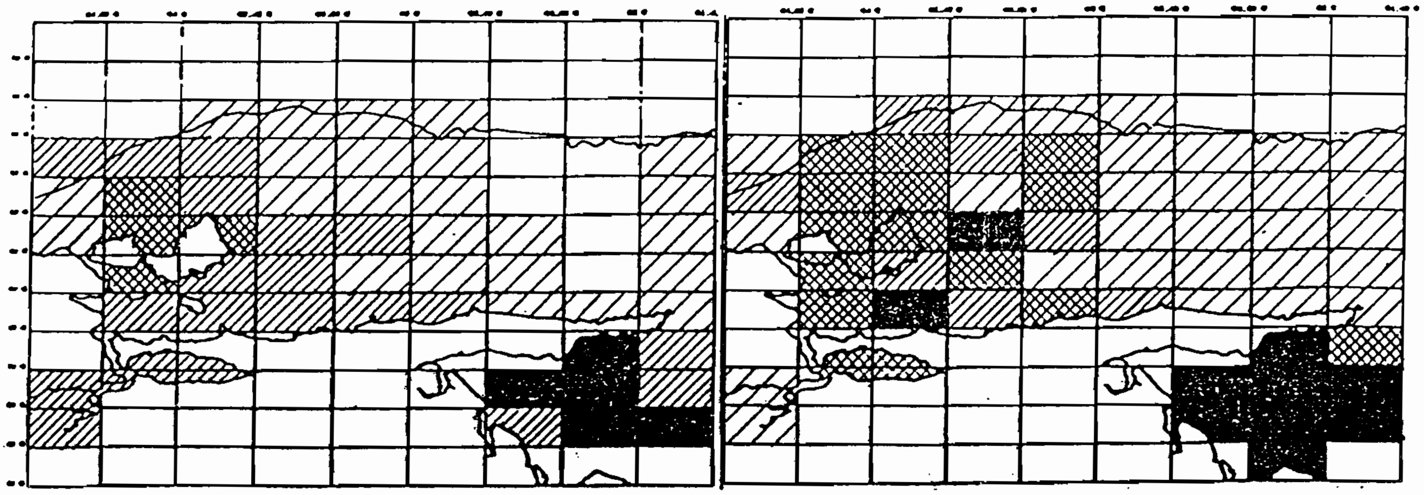
Fig. 8 : Map of surface salinity (ECHOVEN 2).



Global density (day) global density (night)



mean number of schools/ESDU (day) mean number of schools/ESDU (night)



E+/E (day) E+/E night)

Fig. 9 - ECHOVEN : examples of acoustic parameters distribution

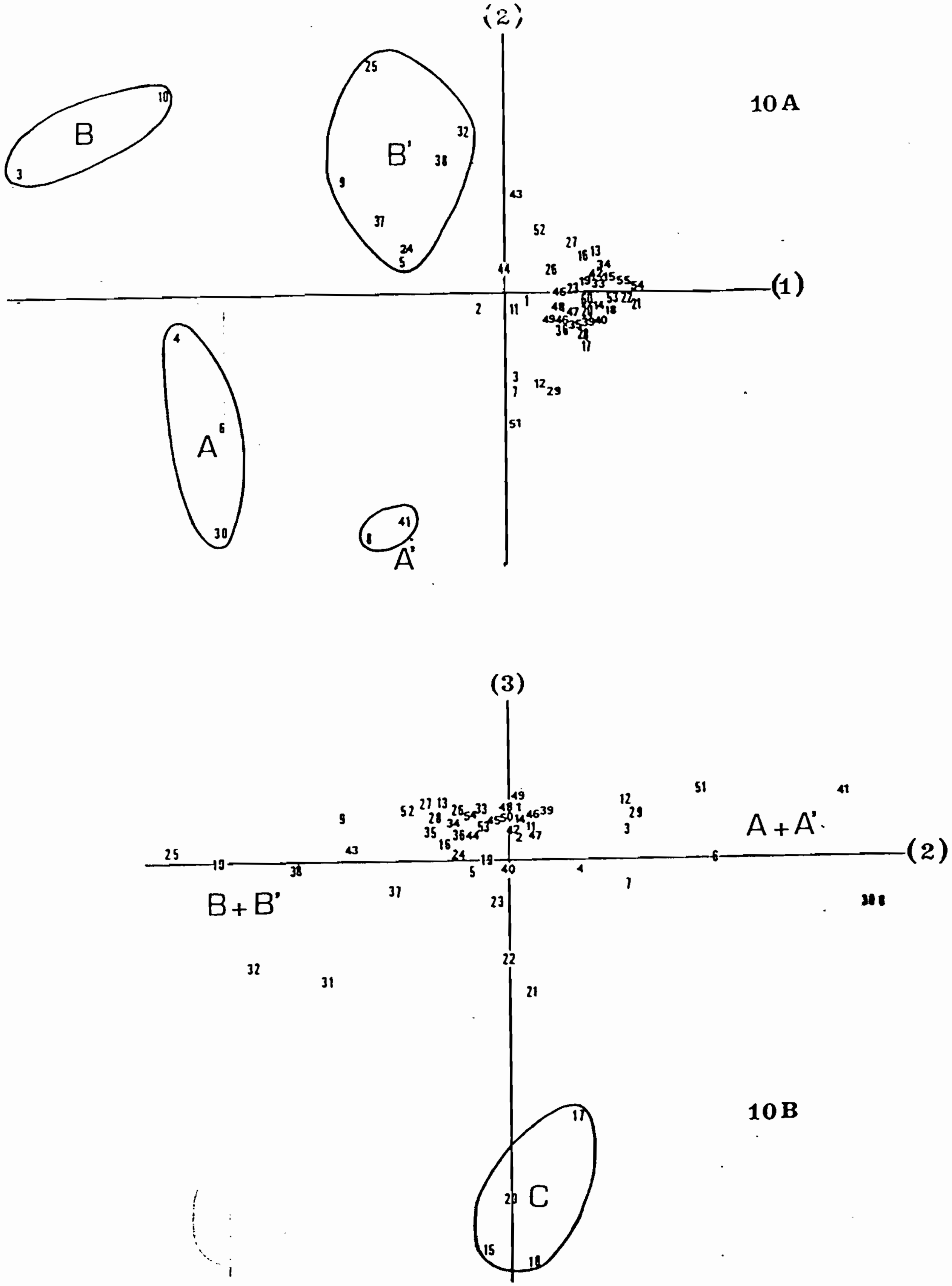


Fig. 10 - Factorial analysis on acoustic data (ECHOVEN 2)
10a : squares distribution on axes 1 and 2
10b : squares distribution on axes 2 and 3
% inerty on axes 1 to 5 : 41.2 ; 19.5 ; 12.9 ; 7.1 ; 6.3

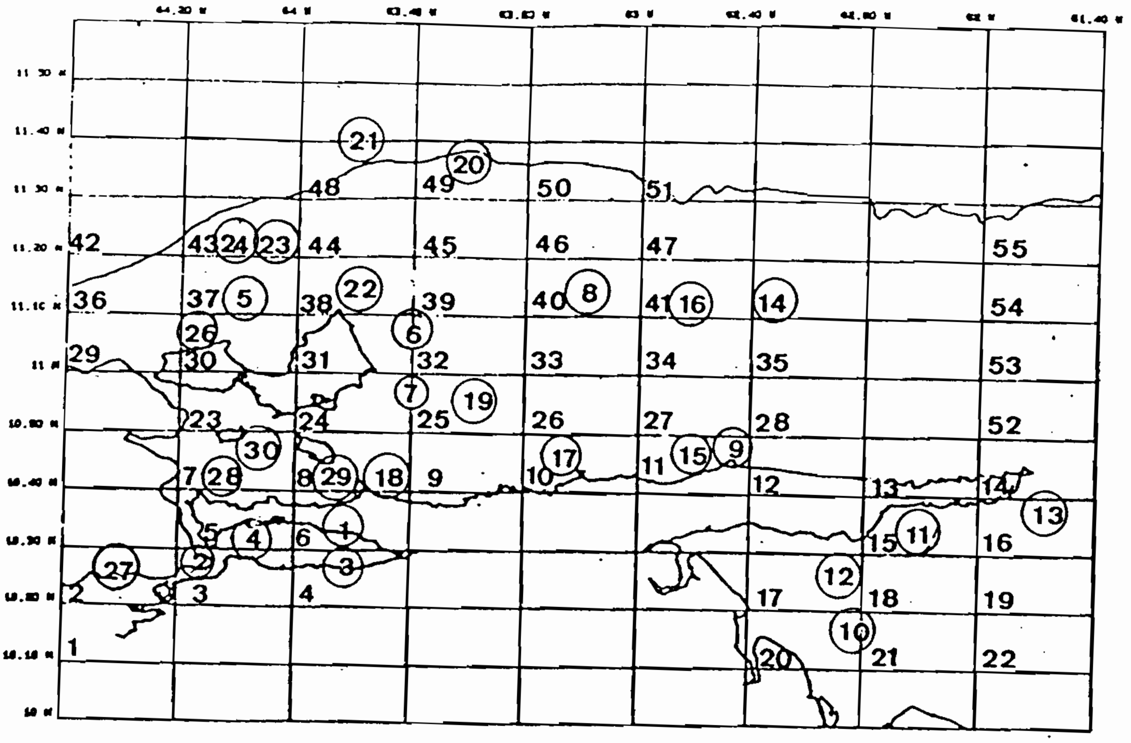


Fig. 11A : Position of trawlings (ECHOVEN 2)

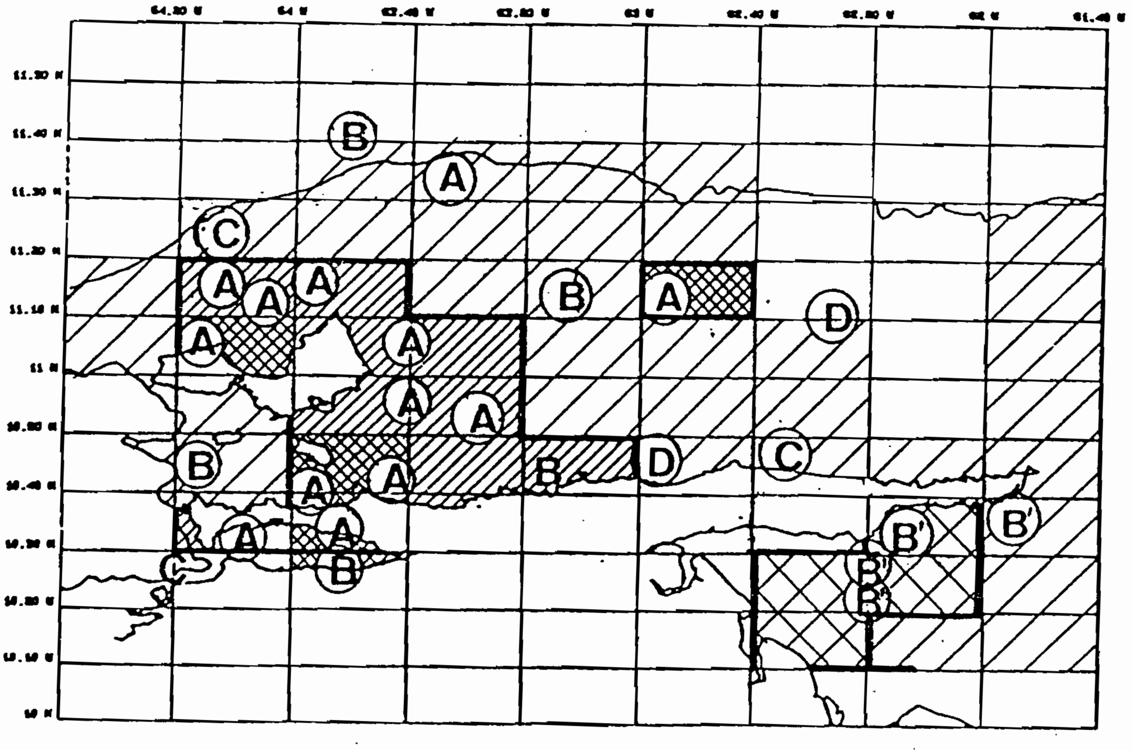


Fig. 11B : Distribution of natural communities
(A to D)

Ditribution of acoustic populations

▩	▨	⊠	▧
A	B	C	D

Survey name	FALCON 1	FALCON 2	FALCON 3	FALCON 4	ECHOVEN 2
Beginning End	15/8/1982 25/8/1982	3/5/1983 20/5/1983	30/1/1984 12/2/1984	31/10/1985 12/11/1985	10/8/1986 11/9/1986
Vessel	LA SALLE	LA SALLE	LA SALLE	LA SALLE	CAPRICORNE
Sounder Frequency	EK/S 120 kHz	EK/S 120 kHz	EK/S 120 kHz	EK/S 120 kHz	EK400 120 kHz
Integrator	QM II	QM II	QM II	QM+AGENOR	AGENOR
Area prospected	Gulf of Venezuela	Gulf of Venezuela	Gulf of Venezuela	Gulf of Venezuela	Orient
Nb ESDUs	-	2300	2244	1800	4000
Trawl Nb stations	bottom 28	bottom -	bottom 11	bottom 14	pelagic 30

Table 1. Specifications of the surveys in Venezuela

Survey name	FALCON 1	FALCON 2	FALCON 3	FALCON 4	ECHOVEN 2
Beginning	5/8/1982	3/5/1983	30/1/1984	31/10/1985	10/8/1986
End	25/8/1982	20/5/1983	12/2/1984	12/11/1985	11/9/1986
Vessel	LA SALLE	LA SALLE	LA SALLE	LA SALLE	CAPRICORNE
Sounder	EK/S	EK/S	EK/S	EK/S	EK400
Frequency	120 kHz	120 kHz	120 kHz	120 kHz	120 kHz
Integrator	QM II	QM II	QM II	QM+AGENOR	AGENOR
Area prospected	Gulf of Venezuela	Gulf of Venezuela	Gulf of Venezuela	Gulf of Venezuela	Orient
Nb ESDUs	-	2300	2244	1800	4000
Trawl	bottom	bottom	bottom	bottom	pelagic
Nb stations	28	-	11	14	30

Table 1. Specifications of the surveys in Venezuela

Survey	FALCON 2	FALCON 3	FALCON 4	ECHOVEN 2
Density/ESDU, day	DJF2	DJF3	DJF4	DSJ
Density/ESDU, night	DNF2	DNF3	DNF4	DSN
Density/sample above the threshold, day high; medium; low				D+J.H D+J.M D+J.L
Density/sample above the threshold, night high; medium; low				D+N.H D+N.M D+N.L
Density/sample above the threshold, day+night high; medium; low			DE3F4 DE2F4 DE1F4	
School density, day	DBJF2	DBJF3		
School density, night	DBNF2	DBNF3		
Schools number per ESDU, day				B/S.J
Schools number per ESDU, night				B/S.N
Pelagic schools number, day	BPJF2	BPJF3		
Pelagic schools number, night	BPNF2	BPNF3		
Demersal schools number, day (BFJ)	BFJF2	BFJF3		
Demersal schools number, night (BFN)	BFNF2	BFNF3		
Samples above threshold/ total samples, day (E+/EJ)				E+/EJ
Samples above threshold/ total samples, night (E+/EN)				E+/EN

Table 2. Types of acoustic data introduced in the acoustic populations analysis

Trawl number => species v	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Lutjanus analis	42.1	0	14.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	26.8	0	0	0	18.3	0
Lutjanus aya	0	0	0.3	3.2	0	0	0	0	0	0	0	0.3	0	0	13.6	0	0	0	0	1.9	12.1	0	12.1	0	3.7	0	0	0
Lutjanus synagris	14.0	0	23.4	13.0	0	0	0	0	0	0	0	0	0	0	13.6	25.3	4.6	0	14.6	0	6.1	11.4	6.7	0	0	0	9.0	5.2
Lutjanus maximus	3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11.7	0	0	0	2.7	0	0	0	1.5	0
Lutjanus griseus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.7	0
Calamus sp	17.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	37.0	3.6	0	6.7	3.4	0	6.8	9.0	5.2
Priacanthus aren.	3.7	38.2	2.9	0	0	0	0	0	0	0	0	0	4.3	38.5	9.1	0	0	0	0	18.5	36.4	11.4	0	0	0	27.0	1.5	15.7
Haemulon spp	0	0	2.9	0	0	0	0	0	0	0	0	0	5.8	0	0	0	0	0	0	37.0	0	4.5	0	16.9	15.9	6.8	3.0	0
Salmonete	0	3.1	0.3	0	0	0	0	0	0	0	0	0.3	1.4	2.6	0	0	0	0	4.9	0	1.8	4.5	0	6.1	0	4.7	0.3	0
Trachurus lathami	3.7	0	0	0	0	0	0	0	0	0	0	0	1.4	2.6	2.3	0	0	0	0	1.9	0	1.1	0	2.7	22.4	13.5	0	7.9
Pristipomoides m.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	27.3	28.4	40.3	16.9	11.2	16.9	0	20.9
Rhomboplites aur.	8.5	15.3	0	0	0	0	0	0	0	0	0	0	1.4	2.6	2.3	0	0	0	0	1.9	12.1	4.5	3.4	50.7	46.7	20.3	0	5.2
Scomber japonicus	0	7.6	23.4	0	0	0	0	0	0	0.4	0	0.3	11.6	38.5	9.1	0	0	0	0	0	0	15.9	0.7	0	0	3.4	0.3	0.5
Sardinella aurita	1.8	6.1	29.2	0	0	0	0	0	0	6.3	0	0	29.0	0	0	0	0.9	0	0	1.9	0	1.1	0	0	0	0	0,3	0
Selar crumenopht.	0	11.5	2.9	0	0	0	0	0	0	0.4	0	0	0	12.8	0	6.3	0	0	0	0	0	0	0	3.4	0	0	0	2.6
Sphyraena spp	0	3.8	0	32.5	0	0	0	0	0	4.2	0	0	0	0	6.8	25.3	0	0	0	0	0.6	17.0	0	0	0	0	0	36.6
sharks	5.5	0	0	13.0	0	0	0	0	0	0	0	0	0	0	0	0	0.9	0	0	0	0	0	0.7	0	0	0	0	0
cornua	0	0	0	0	0	0	2.8	0	0	0	0	0	0	0	0	0	0	5.7	1.5	14.6	0	0	0	0	0	0.7	0	0
Micropogon sp	0	0	0	0	18.5	18.1	11.3	14.9	37.5	4.2	0	0	0	0	13.6	12.7	22.0	7.7	24.3	0	0	0	0	0	0	0	0	0
Opisthonema ogl.	0	0	0	2.6	37.0	0	4.0	0	12.5	0	0	13.8	14.5	0	0	1.3	0	0	12.6	0	0	0	0	0	0	0	0	0
Curbinata sp	0	0	0	0	0	0	2.8	1.5	2.5	0	0	0	0	0	0	1.3	13.7	63.9	4.9	0	0	0	0	0	0	0	0	0
Curvina sp	0	0	0	26.0	0	24.1	28.2	1.5	25.0	0	0	0	0	0	0	0	13.7	0	1.0	0	0	0	0	0	0	0	0	0
Chloroscombrus ch.	0	0	0	3.2	3.7	24.1	16.9	59.7	12.5	0	20.0	74.4	1.4	0	4.5	12.7	0.9	1.3	1.0	0	0	0	0	0	0	0	0	0
Dasyatis sp	0	0	0	0	0	20.5	0	0	0	0	0	0	0	0	0	0	0	0	5.1	1.0	0	0	0	0	0	0	0	0
Peprilus mono	0	0.8	0	6.5	3.7	0	5.6	0	0	0	0	0	0	2.6	22.7	12.7	0	6.4	9.7	0	0	0	0	0	0	0	0	0
Bagre spp	0	0	0	0	37.5	0	16.9	0	0	0	0	0	0	0	0	0	0.9	7.7	0	0	0	0	0	0	0	0	0	0
Trichiurus lept.	0	7.6	0	0	0	1.2	11.3	14.9	7.5	0	5.0	5.5	0	0	2.3	1.3	36.6	6.4	0	0	0	0	0	0	0	0	0	0
Orthopristis rub.	0	6.1	0	0	0	12.0	0	0	0	0	75.0	5.5	29.0	0	0	0	0	0	0	0	0	0	0	0	0	0	54.1	0
Vomer setapinnis	0	0	0	0	0	0	0	0	2.5	0	0	0	0	0	0	1.3	0	0	0	0	0	0	0	0	0	0	0	0
Scomberomorus spp	0	0	0	0	0	0	0	7.5	0	84.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 3. Results of FALCON I trawlings (species % of total catch weight).

Square Nb	DJF2	DNF2	DBJF2	DBNF2	BPJF2	BPNF2	BFJF2	DFNF2	DJF3	DNF3	DBJF3	DBNF3	BPJF3	BPNF3	BFJF3	BFNF3	DJF4	DNF4	DE1F4	DE2F4	DE3F4
1	898	100	28.21	0	0.66	0	0.07	0	417	275	0	0	0	0	0	0	1600	189	93.5	0	3.0
2	119	268	1.90	0.53	0.17	0	0.08	0	163	770	6.19	17.39	0.06	0.04	0.03	0	244	206	94.0	2.2	3.3
3	86	119	0	0	0	0	0	0	391	73	6.20	0.97	0.06	0.03	0	0	42	13722	98.0	2.0	0
4	514	260	29.19	14.29	0.32	0.11	0.08	0	650	0	6.58	0	0.03	0	0	0	18538	1888	99.0	0.7	0.3
5	100	200	0	0	0	0	0	0	30	36	4.20	203.60	0	0	0	0	14	15	80.0	9.8	10.2
6	300	212	2.31	53.64	0	0	0.08	0	2327	15	0	0.20	0	0	0	0	0	842	80.5	16.1	4.4
7	308	78	3.27	0	0.02	0	0	0	367	0	0	0	0	0	0	0	200	8649	92.9	6.1	1.4
8	106	25	0	0	0	0	0	0	200	0	0	0	0	0	0	0	4000	12779	66.6	31.4	2.0
9	53	7	0	0	0	0	0	0	150	0	0	0	0	0	0	0	7269	13338	68.9	17.9	13.2
10	57	265	0	0	0	0	0	0	346	1176	0	117.5	0	0.06	0	0	83	8896	81.9	11.8	6.3
11	207	228	3.57	2.07	0	0.03	0.14	0.03	220	0	7.00	0	0.15	0	0	0	3670	3688	95.2	4.8	0
12	(no acoustic data on this square)																				
13	665	2921	20.29	0	0.24	0.17	0.12	0	262	461	16.19	15.69	0.19	0.06	0.05	0.01	52	34	94.5	3.6	1.9
14	949	148	54.65	0	0.65	0	0.07	0	425	233	10.00	1.48	0.13	0	0	0.11	3064	13905	97.9	1.3	0.9
15	12	139	7.32	0	0	0	0.12	0	106	144	0.71	3.46	0.12	0.03	0	0	3705	660	97.7	0	2.3
16	181	227	0	0	0	0	0.05	0	10	113	0	0	0	0	0	0	118	4052	99.3	0.7	0
17	76	89	1.21	0	0.03	0	0	0	310	44	0	0.15	0	0.02	0	0	7	5358	95.4	2.0	2.6
18	336	84	3.33	0	0.13	0	0	0	241	0	9.75	0	0.16	0	0.03	0	0	11536	89.0	11.0	0
19	411	100	4.00	0	0.42	0	1.00	0	4541	92	407.41	0	0.08	0	0.08	0	11	2202	96.4	2.4	1.2
20	288	105	24.12	0	0.06	0	0.03	0	10	76	0	0	0	0	0	0	0	90	93.6	3.3	3.1
21	133	205	4.17	0	0.24	0.09	0.08	0	33	400	0	0	0	0	0	0	5	43	98.3	1.7	0
22	61	273	3.48	0	0	0	0.08	0	867	153	66.67	0	0	0	0	0	0	22	100.0	0	0
23	55	191	0.91	0	0	0	0.02	0	214	147	0	0	0	0	0	0	4	13	100.0	0	0
24	(no acoustic data on this square)																				
25	(no acoustic data on this square)																				
26	(no acoustic data on this square)																				
27	136	273	3.57	0	0	0	0.08	0	242	286	0	0	0	0	0	0	100	51	98.1	0	1.9
28	277	100	0.48	0	0	0	0.07	0	255	332	3.68	10.00	0.05	0.16	0	0	100	48	98.0	2.0	0

Table 4. Summary of acoustic data collected during
surveys FALCON 2, FALCON 3, FALCON 4.
(names of data detailed in table 2)

Trawl number => species v	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Sardinella aurita	66.7	0	0	99.5	75.0	30.0	95.3	0	1.0	0	0	0	0	5.0	3.6	78.5	1.2	99.0	100	98.7	0	98.0	0	0.6	99.7	98.0	0	0	58.3
Anchoa spp	13.3	0	0	0.3	0	0	0	0	0	0	0	3.1	1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	69.0	16.7
Anchoviella spp	0	0	0	0.2	0	60.0	0	0	0	0	0	0	0	0	0.6	0	0	0	0	0	0	0	0	0	0	0	0	0	16.7
Trachurus lathami	0	37.5	0	0	0	0	0	0	75.0	0	0	0	0	2.5	2.9	5.0	0	0	0	0	0	0	0	4.4	0	0	0	0	3.3
+Harengula clup.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	87.5	0	2.4	0	0	0	0	0	0	0	0	0	0	0	1.8
Opisthonema ogi.	0	0	0	0	0	0	0	0	0	4.5	21.6	3.1	15.0	0	0.2	0	1.2	0	0	0	0	0	0	0	0	2.0	0	0	1.2
Sphyraena picud.	13.3	0	0	0	0	0	0.7	25.0	1.0	0	0	0	0	0	0	0	23.7	0	0	0	0	0	0	0	0	0	0	1.0	0.8
Bagre marinus	0	0	0	0	0	0	0	0	0	22.7	2.7	3.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2
Vomer setapinnis	0	0	0	0	0	0	0	0	0	1.5	10.8	12.5	62.5	0	0.2	0	0	0	0	0	0	0	0	0	0	0.1	0	0.1	0.2
Chloroscombrus ch.	0	0	0	0	0	0	0	0	0	1.5	8.1	3.1	2.5	0	0	0	2.4	0.1	0	0	0	0	0	0	0	0	0	5.0	0
+Elops saurus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8.0	0
Orthopristis rub.	0	0	10.0	0	0	0	0.5	0	0	0	0	0	0	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	15.0	0
Trichiurus lept.	0	0	1.5	0	0	0	0.1	0	0	7.6	1.4	3.1	0.5	5.0	0.8	0	2.4	0	0	0	6.7	0	0	0	0	0	0	0.1	0
+Alectis scylaris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.8	0
Peprilus paru	0	0	0	0	0	0	0	1.0	0	15.2	2.7	0	0.5	2.5	1.1	0	2.4	0	0	0	0	0	0	0	0	0	0	0	1.0
+Lile piquitinga	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.0	0	95.0	0.9	0	0	0	0
Scomber japonicus	0	50.0	0	0	15.0	4.0	0.1	0	23.0	0	.0	0	0	2.5	0.2	0	0	0.9	0	1.0	0	0	0	0	0.1	0	0	0	0
Euthynnus allet.	0	0	0	0	0	0	0.3	0	0	0	0	0	0	0	0	10.0	0	0	0	0	0	0	0	0	0.1	0	0	0	0
+Priacanthus aren.	0	0.5	0	0	0	0	0	0.9	0	0	0	0	0	0	0	0.5	0	0	0	0.2	0	0	0	0	0	0	0	0	0
Etrumeus teres	0	0	0	0	0	0	0	0	0	0	0	0	0	1.3	0	0	0	0	0	0	66.7	0	0	0	0	0	0	0	0
+Nealotus tripes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10.0	0	0	0	0	0	0	0	0
+Gempylus serpens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16.7	0	0	0	0	0	0	0	0
Selar crumenopht.	0	0	0	0	5.0	0	0	1.0	0	0	0	0	0	0	0	0	0	0	0	0.2	0	0	0	0	0	0	0	0	0
Archosargus unim.	0	0	15.0	0	0	0	0.2	0	0	0	0	0	0	0	0.3	0	0	0.1	0	0	0	0	0	0	0	0	0	0	0
+Lagocephalus laev.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0
Cynoscion leiar.	3.3	0	2.0	0	0	0	0	0	0	0	0	6.2	0	0	0	0	4.1	0	0	0	0	0	0	0	0	0	0	0	0
+Lobotes surinam.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0	0	0	0	0	0	0	0	0	0	0	0
+Mugil brasiliens.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	59.5	0	0	0	0	0	0	0	0	0	0	0	0
+Pellona harroweri	0.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0.4	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0
Decapterus spp	0	0	0	0	0	6.0	2.7	0	0	0	0	0	0	1.3	0	5.5	0	0	0	0	0	0	0	0	0	0	0	0	0
+Balistes vetula	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0
+Hemicaranx ambl.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
+Pomatomus saltat.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
+Macrodon ancylod.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Upeneus parvus	0	0.3	0	0	0	0	0	0	0	0	0	0	0	5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
+Rhomboplites aur.	0	0	0	0	0	0	0	0	0	0	0	0	0	75.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Caranx hippos	0	0	0	0	5.0	0	0	0	0	22.7	5.4	0	15.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oligoplites palom.	0	0	0	0	0	0	0	0	0	22.7	21.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
+Mugil trichodon	0	0	0	0	0	0	0	0	0	0	0	53.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Arius proops	2.0	0	50.0	0	0	0	0	0	0	0	5.4	6.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
+Ophioscion punct.	0	0	0	0	0	0	0	0	0	0	0	6.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
+Saurida brasil.	0	0	0	0	0	0	0	0	0	0	1.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carcharhinus spp	0	0	0	0	0	0	0	10.0	0	0	10.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
+Haemulon boschmae	0	0	0	0	0	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eugerres plumieri	0.3	0	20.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
+Centropomus paral.	0	0	1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
+Fistularia sp.	0	5.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
+Calamus penna	0.7	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
+Haemulon aurolin.	0	6.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scomberomorus mac.	0	0	0	0	0	0	0	2.0	0	1.5	8.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 5. Results of ECHOVEN 2 trawlings (species in % of total catch)
Species names with + : not included in analysis

Acoust. D. Square nb	DSJ	DSN	E+/EJ	E+/EN	D+J.H	D+J.M	D+J.L	D+N.H	D+N.M	D+N.L	B/S.J	B/S.N
1	297	73	13	8	92.0	6.5	2.0	97.1	2.9	0	0.77	0.41
2	792	706	52	21	91.5	6.3	2.2	93.5	2.9	3.6	1.77	0.04
3	891	563	18	157	84.1	9.1	8.9	99.0	0.5	0.5	0.45	0.12
4	3832	5155	29	147	68.2	10.0	21.8	83.2	5.2	11.7	1.44	1.63
5	495	2373	41	313	86.4	8.3	5.4	88.9	4.5	6.6	1.14	0.76
6	4921	1602	50	179	67.0	12.8	20.2	88.5	6.4	5.1	1.85	1.09
7	642	436	69	384	87.0	10.1	2.8	99.4	0.5	0.1	2.02	0.02
8	1385	715	62	672	60.9	26.1	13.0	98.9	0.6	0.4	2.90	0.11
9	798	1526	14	50	90.0	4.2	5.8	85.7	11.4	2.9	0.86	1.95
10	351	3661	30	246	79.3	13.5	7.2	71.1	11.3	17.5	0.21	3.25
11	473	391	20	95	90.4	6.0	3.6	95.3	3.9	0.8	0.71	0.03
12	14	113	0	16	83.3	0	16.7	100.0	0	0	0.20	0
13	28	39	1	2	100.0	0	0	98.4	1.6	0	0	0.39
14	14	42	0	6	95.6	2.2	2.2	100.0	0	0	0	0
15	591	384	783	890	100.0	0	0	98.3	1.7	0	0	0
16	32	161	39	171	98.8	0.6	0.6	96.4	2.9	0.7	0	0
17	137	371	300	1454	90.6	7.8	2.4	100.0	0	0	0.12	0
18	430	620	669	1389	96.2	1.7	2.2	99.6	0.4	0	0	0
19	99	195	49	259	97.3	0	2.7	98.5	1.5	0	0.15	0
20	42	547	91	2776	94.3	5.7	0	97.3	2.7	0	0	0
21	214	201	266	617	94.8	5.2	0	100.0	0	0	0.03	0
22	245	114	245	381	98.2	1.8	0	100.0	0	0	0	0
23	415	166	144	259	96.7	1.3	2.0	97.5	2.0	0.5	0.40	0
24	88	2589	27	75	87.5	14.3	0	87.2	9.0	2.6	1.60	0.38
25	36	5133	17	175	100.0	0	0	80.6	11.5	7.9	0.13	1.74
26	40	184	10	36	95.2	3.2	1.6	95.2	4.8	0	0.09	0
27	9	62	3	11	100.0	0	0	95.0	3.8	1.2	0	0.06
28	9	146	2	14	100.0	0	0	95.1	0	4.9	0.28	0
29	154	36	10	28	87.5	6.3	12.5	100.0	0	0	0.50	0
30	8164	282	125	101	66.5	16.8	16.8	92.9	5.8	1.3	2.86	0.67
31	1914	15058	123	271	72.8	16.0	11.1	68.9	8.2	23.0	3.72	1.38
32	52	13175	39	578	100.0	0	0	74.4	15.4	10.3	1.00	0.03
33	25	41	51	61	97.0	3.0	0	98.4	1.6	0	0.06	0
34	73	68	10	21	100.0	0	0	98.3	1.7	0	0	0.07
35	1	201	1	13	100.0	0	0	96.3	1.5	2.2	0	0
36	24	2562	4	30	100.0	0	0	99.2	0.8	0	0.72	0
37	1707	2839	106	142	97.8	2.2	0	88.9	7.0	4.1	2.75	1.13
38	180	2148	63	125	100.0	0	0	85.2	4.9	9.9	0.97	0.72
39	29	22	5	30	93.2	3.4	3.4	100.0	0	0	0.29	0
40	62	411	2	466	93.8	3.1	3.1	98.9	1.1	0	0.07	0
41	141	108	7	41	54.5	36.4	9.1	97.7	2.3	0	0.44	0.05
42	23	37	11	15	94.4	5.6	0	100.0	0	0	0	0
43	98	1645	34	159	100.0	0	0	94.6	4.8	0.6	0.04	1.61
44	154	1046	17	163	91.7	7.1	1.2	95.2	3.4	1.4	0.39	0.78
45	29	301	2	84	94.4	5.6	0	97.4	2.6	0	0.36	0.12
46	463	235	8	116	93.0	3.5	3.5	98.6	1.4	0	0.52	0.04
47	15	123	1	44	94.1	5.9	0	100.0	0	0	0.56	0.35
48	24	187	1	38	94.5	5.3	0	98.3	1.7	0	0.35	0.08
49	4	44	0	10	92.3	7.7	0	98.9	0	1.1	0	0.17
50	26	186	1	28	96.4	3.6	0	100.0	0	0	0.06	0.10
51	14	5	0	1	75.0	25.0	0	100.0	0	0	0.50	0
52	9	149	0	5	98.0	2.0	0	91.2	3.3	5.5	0	0
53	10	4	2	1	100.0	0	0	100.0	0	0	0.44	0
54	0	46	0	5	100.0	0	0	98.6	1.4	0	0	0
55	0	24	0	4	100.0	0	0	100.0	0	0	0.10	0

Table 6. Acoustic data used in the analysis (ECHOVEN 2)
DSJ = global density, day; DSN = global density, night
E+/EJ (N) = samples above the threshold/total samples, day (night)
D+J.H (M;L) = Density/E+ by day, high (medium; low)
D+N.H (M;L) = " " by night, high (medium; low)
B/S.J (N) = Number of schools per ESDU (x10000), day (night)

	TRIC	SCOM	PRIA	LUTJ	CHLO	CLUP	DJF2	DNF2	DBJF2	DBNF2	BPJF2	BPNF2	BFJF2	BFNF2	DJF3	DNF3	DBJF3	DBNF3	BPJF3	BPNF3	BFJF3	BFNF3	DJF4	DNF4	DE1F4	DE2F4	DE3F4
POMA	.0075	.0401	.0924	-.0984	.1172	.2530	0.0000	.4683	.1336	.0551	-.1187	.4342	.1143	.6499	.0347	.0735	.2195	.0939	.4083	.0601	.2111	.0727	.0609	-.1782	.1652	-.3395	-.1758
TRIC		.3433	-.4143	-.3730	.7360	-.2829	-.2246	-.5729	-.2546	.1075	.3643	-.0652	-.0652	.3346	-.0989	-.3832	-.3346	-.0893	-.0220	-.1118	-.1709	-.2077	.0401	.3337	-.3696	.4488	.1970
SCOM			-.5064	-.4259	.5071	.0557	-.0566	.1284	-.1284	.3550	.1519	.1754	.1535	.3271	.1935	.0972	-.1309	.3002	.1626	.1603	-.1209	-.1117	.2517	.2648	-.2228	.3323	.0854
PRIA				.5155	.5276	.1343	.1988	.2254	.3382	-.1903	.2889	.1155	0.0000	-.1615	-.0796	.4735	.3769	.2108	.0369	.3562	.2386	.2696	-.2130	-.5519	.4286	-.4720	-.3487
LUTJ					.4894	-.0149	.0809	.0917	0.0000	-.1172	.1176	.0157	.0783	-.2118	.2182	.2275	.2469	-.0644	-.1003	.1593	.0799	-.2893	-.3628	-.5399	.6825	-.6169	-.5508
CHLO						-.2663	.0482	-.3276	-.1638	.3098	-.1830	.2052	.0746	.4609	.1106	-.4692	-.1687	-.2809	.1572	-.2408	-.1569	-.1306	.2944	.4176	-.4190	.5113	.1326
CLUP							-.1638	.4335	-.1858	-.2012	.0122	.0635	.0635	-.2071	-.0006	.1758	.1598	.4345	.0642	.3118	.1312	.0404	.0650	.2501	.0124	-.0063	.0804
DJF2								.0630	.7559	.1310	.8944	.2582	.5809	0.0000	.2848	.0572	.2408	-.0589	.3482	-.1180	-.0712	.5480	.2646	.0433	.3027	-.2059	.0503
DNF2									.2143	.1485	.0563	.4392	.2196	0.0000	.2422	.5192	.3822	.4009	.1974	.3345	.3229	.2485	.2400	-.2946	.3432	-.3503	-.2281
DBJF2										.1485	.7888	.2928	.4392	0.0000	.2422	.0649	.2730	0.0000	.2961	-.0669	.0807	.6214	.0600	-.2455	.4576	-.3503	0.0000
DBNF2											-.0146	.2790	.1775	.2010	.1923	-.1996	-.0875	-.1042	.0085	-.1536	-.0874	-.1130	.2755	.0829	-.0941	.3616	.0914
BPJF2												.2309	.5196	-.1615	.3025	.1152	.3338	.0527	.3114	-.0132	.0478	.5637	.1183	.0290	.2933	-.1957	.0112
BPNF2													.3500	.4663	.0276	.1552	.0933	0.0000	.3708	.0229	-.0276	.1273	.3280	-.0503	.0781	-.0199	-.2143
BFJF2														.0933	.3861	.0443	.3544	.0685	.3877	-.0229	.1103	.2547	-.0205	0.0000	.1563	-.1595	.0390
BFNF2															.0129	-.1757	.0435	-.1277	.4087	-.1172	-.0900	-.0594	.2103	.0704	-.0182	-.0651	-.0454
DJF3																-.0948	.6660	.0378	.3254	.0347	.4829	.0176	-.0622	-.0208	.2640	-.1787	-.2444
DNF3																	.0269	.6981	-.0523	.4990	.1498	.2117	.0863	-.3848	.1862	-.3691	-.1835
DBJF3																		.1788	.6098	.2706	.6454	.3444	-.1185	.0047	.3680	-.3366	-.3906
DBNF3																			.2308	.7823	.0378	.2906	.2245	.0689	0.0000	-.0273	.0800
BPJF3																				.2234	.1766	.3863	.1382	.3223	.1317	-.1546	-.2430
BPNF3																					-.0158	.0727	.1171	-.1322	.1116	-.0661	-.1224
BFJF3																						.0176	-.3109	-.1873	.0916	-.2667	-.3519
BFNF3																							.2871	.2670	.1741	-.0889	.1364
DJF4																								.4022	-.2002	.3147	.5071
DNF4																									-.5210	.6672	.3872
DE1F4																										-.8220	-.5214
DE2F4																											.4448

Table 7. Correlation matrix on FALCONs data.
Acoustic data names explained in table 2
POMA = Pomadasidae; TRIC = Trichiurus lepturus;
PRIA = Priacanthus arenatus; SCOM = Scombridae; LUTJ = Lutjanidae
CHLO = Chloroscombrus chrysurus; CLUP = Clupeidae;

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Working paper

EXPLORATION OF APPLICABILITY OF GEOSTATISTICS TO FISHERIES ACOUTICS

by

YVAN SIMARD[1] AND FRANCOIS GERLOTTO[2]

1 : Institut Maurice LAMONTAGNE, Pêches et Océans Canada
C.P. 1000, Mont-joli, Québec G5H-3Z4, Canada

2 : Centre ORSTOM de Fort-de-France, B.P. 8006
97256 Fort-de-France, Martinique

RESUME

L'applicabilité de la géostatistique pour l'analyse de données d'écho-intégration est explorée à l'aide de deux ensembles de données provenant des eaux côtières du nord de la Norvège et du Vénézuéla. Les écarts aux conditions de stationnarité et les variations temporelles des structures spatiales sont examinées en portant une attention spéciale aux effets de : (1) l'utilisation des données brutes ou transformées en unités logarithmiques, (2) l'exclusion ou l'inclusion des séries de zéros, (3) différences jour/nuit dans les structures spatiales, (4) double échantillonnages et (5) différentes communautés de poisson. Tous ces facteurs affectèrent fortement la forme des variogrammes calculés, et conséquemment les estimations de biomasse qui en étaient reliées. L'utilisation de la géostatistique pour l'analyse des structures spatiales, l'estimation ou la cartographie de la biomasse en écho-intégration doit donc être effectuée avec précautions. Des recommandations sont suggérées et les aspects demandant plus de recherche sont soulevés.

ABSTRACT

The applicability of geostatistics to analyze fisheries acoustics echo-intégration data is explored with two typical data sets from coastal waters off northern Norway and Venezuela. Departures from stationarity conditions and temporal variations of the spatial structures are examined with special attention to the effects of : (1) using of raw or logtransformed data, (2) exluding of including the series of zeros, (3) day and night differences in the spatial structure (4) revisiting some sampled areas and (5) different communities of fishes. All these factors strongly affected the shape of the variogram computed, and consequently the biomass estimations also. Care should thus be taken when using geostatistics to analyze the spatial structures map or compute biomass estimations. Some recommandations are suggested and questions needing more explorations are pointed out.

INTRODUCTION

The echo-integration technique (Burczinski 1982) produces dense series of biomass estimates of pelagic or demersal fishes along routes surveyed by research vessels. The biomass is generally integrated over distance intevals of 1-5 nautical miles. Because of the continuous sampling serial autocorrelation is present in the data collected. This hinders data analysis with classical statistics, which require independence of the samples. Some methods have been suggested to minimize the effect of spatial autocorrelation to allow the use of classical statistics (Williamson 1982, Maclennan and Mackenzie 1988). A alternative methods using the autocorrelation structure through the Theory of regionalized variables (Matheron 1965, 1971) have been tried a few times in mid-1980s' (Gohin 1984, 1985 ; Laloe 1985 ; Guillard et al, 1987). but they have not stimulated a large interest until recently. The present paper explores the applicability of these geostatistical methods for spatial structures analysis and biomass estimation in fisheries acoustics.

Using geostatistics in fisheries acoustics presents two main potential interests. The first one is for analyzing the spatial structures of fish biomass that can be inferred from the characteristics of the structural functions (e.g David 1977 ; Sokal 1986) such as : the range of autocorrelation, the shape of the variogram, the sill level, the relative importance of the variability at various scales. The second one is for the estimation of local or global fish biomass in presence of spatial autocorrelation and for "optimal" "objective" mapping through kriging. This information can then be used for designing optimal sampling strategies.

The application of geostatistics to model spatial process relies on some basic assumptions about the studied variable. First, its structure is assumed to be stable in time, at least at the studied time scale. This might be true for mining deposits but it is not so for the distribution of fishes in a given environment, where variations of locations and activities are expected to occur over a wide range of time scales, hours, days, weeks etc... Second stationarity of the spatial process is assumed : this means that this spatial process must have some homogeneity and should be repeatable in space. Under the intrinsic hypothesis, the increment of the values of samples depend only on their relative spatial orientation, there is no trend or if there is one it can be modeled by the intrinsic random functions (David 1977 ; Clark 1979 ; Delhomme 1978). These stationarity conditions are far from the expectations from acoustics data. Complex spatial inhomogeneities are the rule in fish distribution data, which besides often include extremely high values (outliers), representing significant portions of the total biomass, or large proportion of total number of samples with no biomass. The present contribution explores how theses various assumptions are satisfied in two sets of data from tropical and arctic waters. Other specific objectives were to check the effects of : (1) using raw or log-transformed data, (2) excluding or not the series of zeros in the computation of the variogram (3) day and night differences in the spatial structures, (4) revisiting some sampled areas, (5) different communities of fishes on the spatial structures.

METHODS

The first data set has been collected in February-mar 1989 from northern Norway between latitudes 62 N and 64 N and longitudes 4 E and 8 E. The echo (m of backscattering cross section per square nautical miles) of pelagic fishes were collected at intervals of 1? nautical miles along the cruise tract (fig. 1). This data set has been provided by K. Foote (Institute of Marine Research. P.O. Box 1870, Nordnes, [illegible] Bergen, Norway).

The second data set comes from a survey realized in August 1985 off the east coast of Venezuela between latitudes 10 N and 12 N and longitudes 65.5 W and 61.5 W. The acoustic system was composed of a sounder SIMRAD EK-400, 120 KHz, a digital echo-integrator AGENOR. The echos were integrated at intervals of 0.8 nautical miles and expressed in relative units, directly proportional to the backscattering cross-section per area unit. The daytime transects were revisited at night in order to cover the whole area twice, once by day and once by night (fig 10). Some areas visited by day or by night were revisited with additional transects, and the transects located in the Gulf of Cariaco were more closely spaced than elsewhere. characteristics of the echos were computed per stratum of [illegible] min. lat. by 20 min. long . and analized by hierarchical clustering to identify the various homogeneous acoustic populations (Fig. 17 ; Gerlotto and Marchal 1987), which corresponded to different species communities as indicated by pelagic trawl samples (n = 30).

The numerical analysis was done with a combination of the following spatial analysis packages. GEO_EAS (Environmental Protection Agency USA) was used for computing histograms and variograms and for kriging. SURFER (Golden Sofware, G[illegible] Colorado, USA) did the contouring, 3-dimensional plots and [illegible] interpolation by the inverse square distance or by kriging using a variogram with linear model. Some variograms were also computed from an ORSTOM internal package.

RESULTS

NORTHERN NORWAY DATA SET

The echos from this area were characterized by a large proportion of zeros (60%). The distribution of positive echos over the whole area was lognormal but showed substantial spatial variations some areas having larger proportions of low or high echos indicating non-homogeneity (fig. 2). The time sequence plot of the echos (fig.3) were marked by 4 sharp peaks isolated from the rest of the series and serial autocorrelation at small scales was evident. Correlograms indicated that the correlation coefficient as well as the length of significant autocorrelation changed with the type of data pre-treatment used (Fig 4). This was also observed on the variograms (fig. 5), the range of autocorrelation, the levels of the nugget and the sill changing when the data were logtransformed or were excluding the zeros. The variograms computed per transects (fig.6) also presented large differences among them and were strongly affected by zeros. So were the variograms per strata (fig.7 and 8) indicating that the structure of echos was not homogeneous over the whole sampled area. The maps of echos obtained from various kriging options and from interpolation according to the inverse square distance method (fig.9) presented significant differences among them. Lognormal kriging with variograms including (ln x+1 Fig. 9) or excluding (ln x, fig 9) the zeros gave very different estimates. The estimates obtained when the zeros are considered in computing the variogram are systematically higher than the other options and seem erroneous. Lognormal kriging is very sensitive to the level of the sill of the variogram (Armstrong and Boufassa 1988) with may explain the high estimates obtained. The kriged maps from raw data gave similar results, the option including the zeros showing the highest peaks however. The linear kriging option of surfer (x lin. fig.10) produced a map slightly differing from the latter two, and which showed notable differences from the map obtained by the inverse square distance method (x 1/d . fig 10).

COASTAL VENEZUELA DATA SET

The sampling design in this region included significant proportions of revisited areas in both the day or the night surveys (fig. 10). Also contrasting with the other data set, the proportion of zeros was low (< 5%). The histograms of logtransformed daytime data per stratum (fig.11) evidenced significant spatial variations of the echo distribution. The logarithmic transformation failed to normalized the data in most cases. The corresponding histograms for the night survey (fig.12) were clearly different, the distributions being less skewed towards low echos and generally centered on similar means. Even though spatial variations were presents they were smaller than during the day. Variograms per strata (fig.13 and 14) also exhibited spatial variations and those of the daytime survey systematically showed higher sills and nugget as expected from the histograms. The effect of revisiting sampled areas on the variograms was tested for the Gulf of Cariaco data (fig. 15). This two-way sampling design greatly altered the variograms notably by raising the nugget and the variance at small scales. This was especially evident in the night variograms for the whole region sampled (fig. 16). The inclusion of even a small sub-area with such revisited data can drastically change the variogram as shown in fig. 16 when the revisited data of the Gulf of Cariaco are included in the computed variogram. Different community of fishes having their own acoustic signature (sensu Gerlotto and Marchal 1987, from cluster analysis of acoustic data) and species composition also appeared to be characterized by different variograms (fig. 17).

CONCLUSION

The above results clearly showed that typical fisheries acoustic data are not always well adapted for geostatistical analysis. Care should therefore be taken when using such methods. Deviations from stationarity conditions resulted in different variograms depending on (1) which area of the studied region was considered and (2) the type of data used, which could include or not the series of zeros and which could be transformed or not. Since the variogram is the basic tool in geostatistics, the variability presents some concerns : what data should be considered when computing the variogram and when kriging and what transformation should be used ? How biomass mapping and global estimation should be performed, globally or by fusion of homogeneous strata ? How to consider the outliers adequately ? Should lognormal kriging, relative kriging or other types of kriging be used ?

Other problems with the method are related to the dynamic behaviour of fishes : their day/night cycle of activity and distribution pattern, their displacements, and the species composition of the communities. The day and night survey off Venezuela clearly showed that the distribution patterns of fish echos changed with the day/night cycle. To maximize stationarity day and night data should not be mixed, because they corresponds to different spatial organizations of fishes. This finding imposes some constrains to sampling strategies, by limiting the effective of work per day and the size of the surveyed area. Night echos were more homogeneous at all scales and over the whole region than those during the day which favours the use of night data for geostatistical analysis.

Since fishes are not sessile organisms but they continously move in their environment, this violates basic condition of geostatitics. Revisiting previously sampled locations should be avoided if the revisited data are to be considered simultaneously with the original data for the geostatistcal analysis. Such strategy would result in significant increases of the variance, particularly at small mean scales, and give erratic variograms, as was shown in the survey off Venezuela. The use of both revisited and one-way data requires strategies of data analysis differing from the standard procedure. This observation stresses the importance of well ordered transects designs in the time-space domain, i.e. the area covered should be swept in order during the survey, with noroutes back already sampled area or too close to them. For example long transects tightly spaced could generate a high nugget on the variogram if the fishes seen on one transect are not seen on the adjacent transects because they have moved away. The transects design must therefore be adapted to the relative speed of survey compared to the fish displacement speed. Zig-zag transect design seems well-adapted to these sampling contrains because the samples are well ordered in time-space ; the closer they are in space, the closer they are in time and vice-versa.

It seems that different fish communities have different spatial organisation, from the variograms computed for the "accoustic populations" off Venezuela. To maximize stationarity, it would therefore be appropriate to stratify the region according to the different fish communities and then to study the strata separately.

Finally we have not considered the problem of anisotropy, because the data were not ideal for such an anlysis, but this must be done. Is anisotropy important ? What controls anisotropy ? Bottom topography ? Water masses ? Distance from the coast ? These are questions that should be addressed.

ACKNOWLEDGMENTS

We are grateful to K. Foote for making available the data set of northern Norway.

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FIGURE CAPTIONS

Figure 1. Map of the area sampled in northern Norway, with samples locations (crosses) along the cruise tract and gross contours (100, 2100, 4100) of echo (m per naut. mi.). Scale in km.

Figure 2. Histograms of the natural logarithm of echos in northern Norway data set for the whole area sampled and for the sub-areas marked by an X on the map.

Figure 3. Time-sequence plot of echos from northern Norway data set.

Figure 4. Correlograms of echos from the northern Norway raw (x) and logtransformed (ln) data including or excluding the zeros. Lag = time sequence.

Figure 5. Variograms (semi-variance vs distance in km) of northern Norway raw (x) and logtransformed (ln) data including or excluding the zeros.

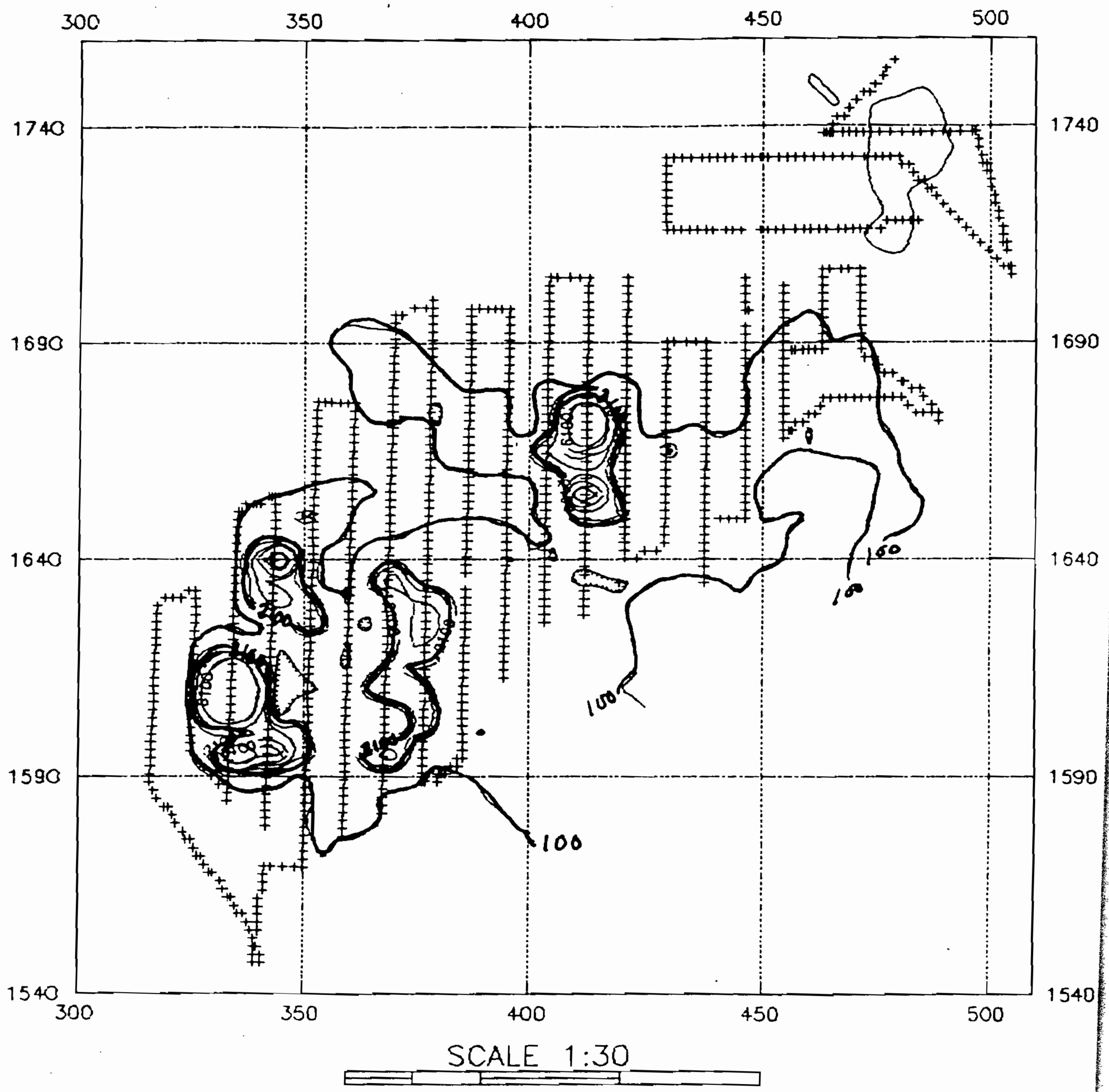
Figure 6. Variograms (semi-variance vs distance in km) of three different transects (pointed on the map) in northern Norway logtransformed (ln) data including or excluding the zeros.

Figure 7. Variograms (semi-variance vs distance in km) per stratum (X on the map) in northern Norway logtransformed (ln x+1) data including the zeros.

Figure 8. Variograms (semi-variance vs distance in km) per stratum (X on the map) in northern Norway logtransformed (ln x) data excluding the zeros.

Figure 9. Three-dimensional maps of kriged estimates and of interpolated values according to the inverse square distance for northern Norway raw (x) and logtransformed (ln) data. The grid mesh size was 5 X 5 km, the search circle radius was 15 km, searching by quadrants a maximum of 8 points. The top 4 maps used the corresponding variograms presented on fig. 5. The zeros were always considered for interpolation at the kriging step, even though the variograms of x > 0 and ln x used did not include them. The bottom 2 maps were obtained from SURFER, by kriging using a linear variogram (x lin) or by interpolation according to the inverse square distance method.

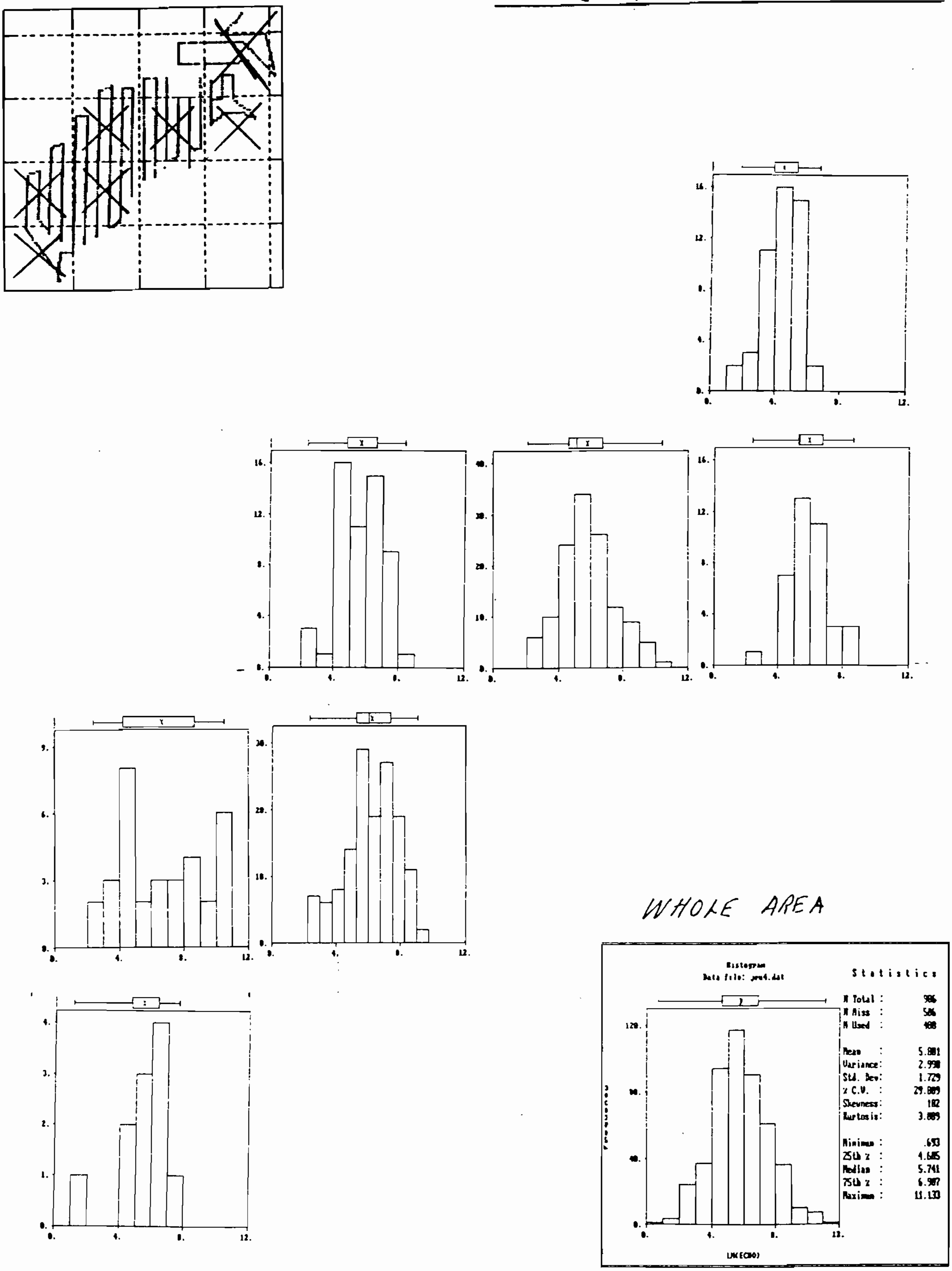
Figure 10.	Maps of the sampled area off Venezuela by day and by night, with the sample locations (dots) along the cruise tract. The grid rectangles are 10 min. lat. by 20 min. long.
Figure 11.	Histograms of the natural logarithm of echos during daytime from the Venezuela data set for the strata marked by an X on the inserted map.
Figure 12.	Histograms of the natural logarithm of echos during daytime from the Venezuela data set for the strata marked by an X on the inserted map.
Figure 13.	Variograms of the natural logarithm of echos during daytime from the Venezuela data set for the strata marked by an X on the inserted map. Note : Y scale = 0 - 20.
Figure 14.	Variograms of the natural logarithm of echos during the night from the Venezuela data set for the strata marked by an X on the inserted map. Note : Y scale = 0 - 10.
Figure 15.	Day and night variograms of the natural logarithm of echos from the Venezuela data set for the Gulf of Cariaco sampled one-way or revisited (two-way). Note the different scales of semi-variance.
Figure 16.	Variograms of raw (x) or logtransformed (ln) echos during the night from the Venezuela data for the whole region sampled one-way or revisited (top), or for the whole region sampled one-way but including or not the revisited data of the Gulf of Cariaco (bottom). Note the different scales of semi-variance.
Figure 17.	Variograms of the natural logarithm of echos during the night from the Venezuela data set for the groups stratat presenting similar acoustic signatures and species composition identified on the inserted map resulting from the cluster analysis. Note : the different scales of semi-variance.



Simard and Gerlotto. FIG. 1.

SET 4, NORWAY

LN(X) ZEROS EXCLUDED

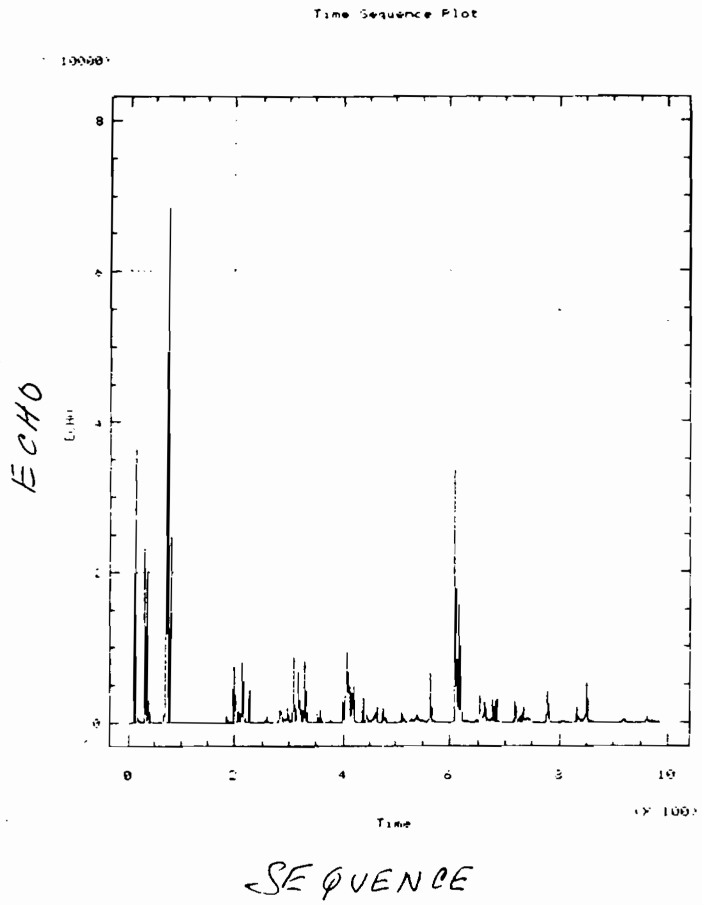


```
Statistics
N Total :     986
N Miss  :     506
N Used  :     480

Mean    :   5.801
Variance:   2.990
Std. Dev:   1.729
% C.V.  :  29.809
Skewness:    .102
Kurtosis:   3.089

Minimum :    .693
25th %  :   4.685
Median  :   5.741
75th %  :   6.907
Maximum :  11.133
```

Simard and Gerlotto. FIG. 2.



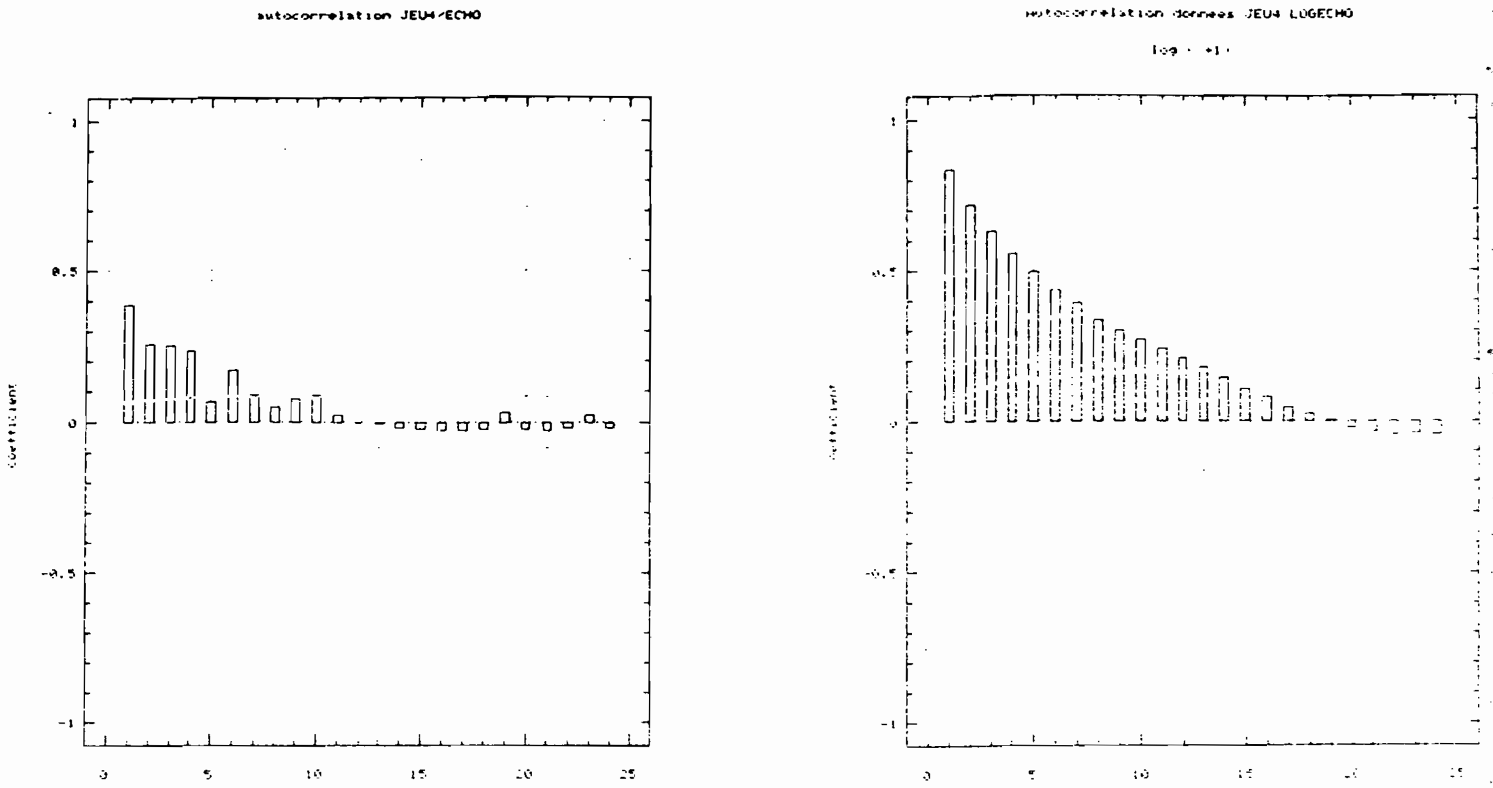
Simard and Gerlotto. FIG. 3.

AUTOCORRELATION: DATA SET NO 4, NORWAY

ALL DATA

(x)

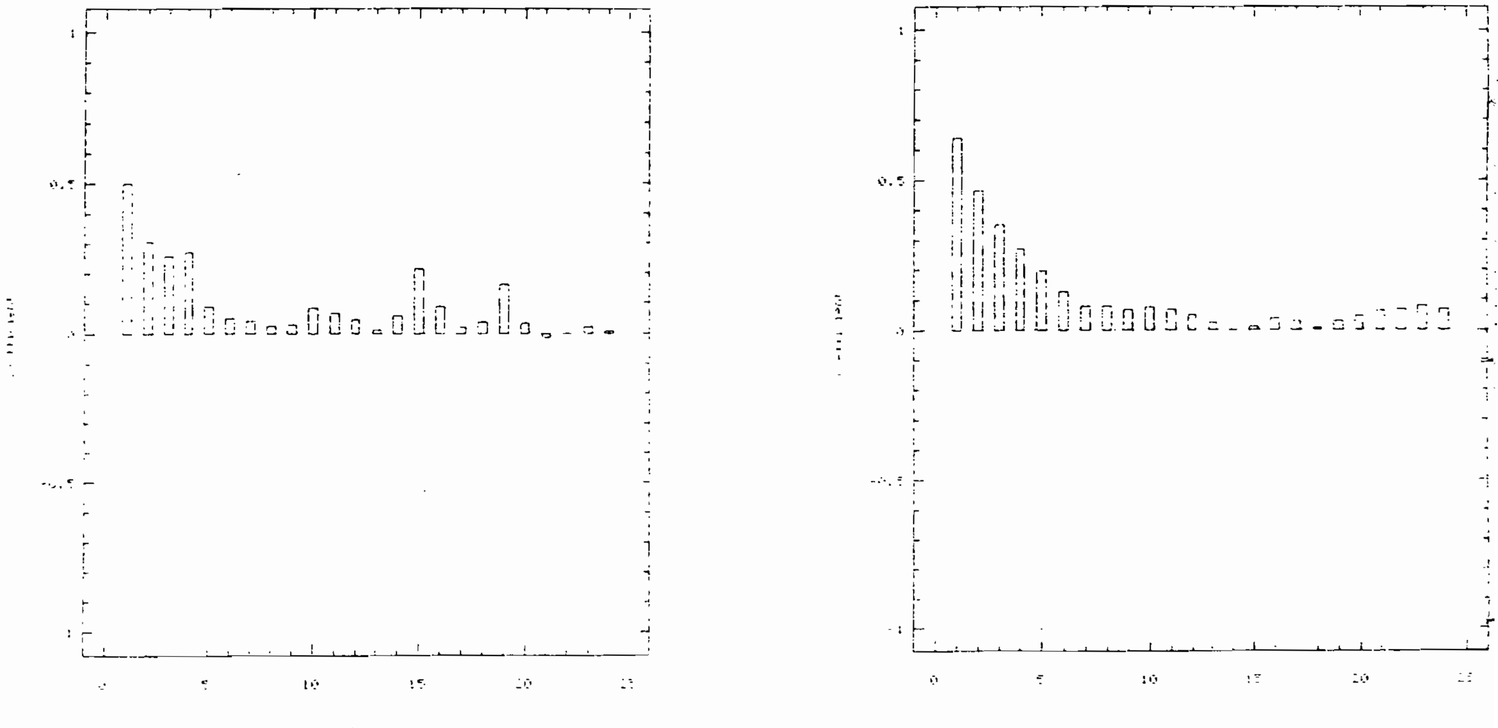
Ln (x+1)



WITHOUT ZEROS

(x > 0)

Ln (x)



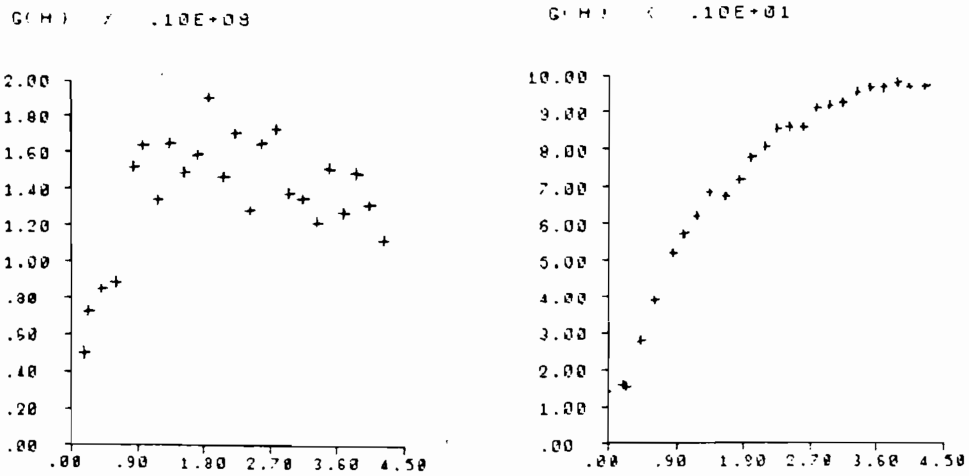
Simard and Gerlotto. FIG. 4.

SET 4, NORWAY

ALL DATA

(x)

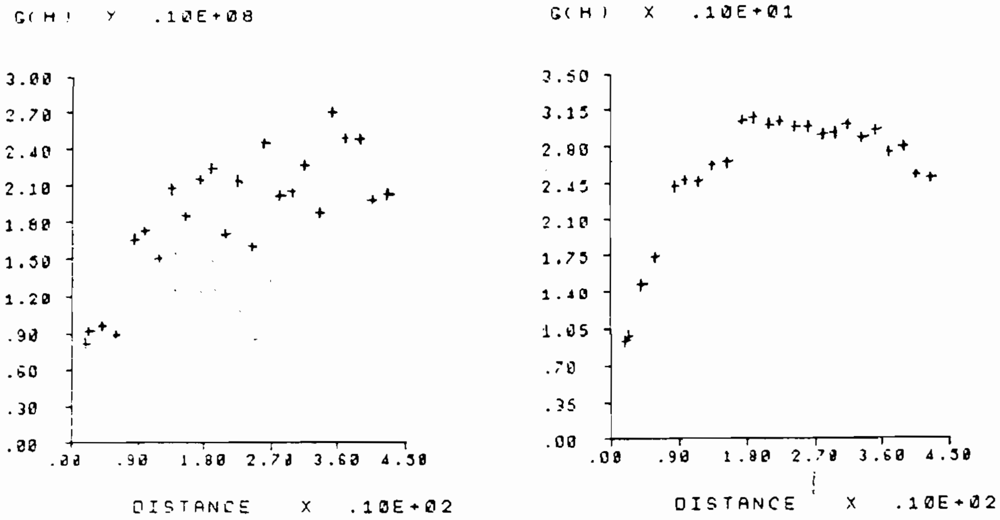
Ln(x+1)



ZEROS EXCLUDED

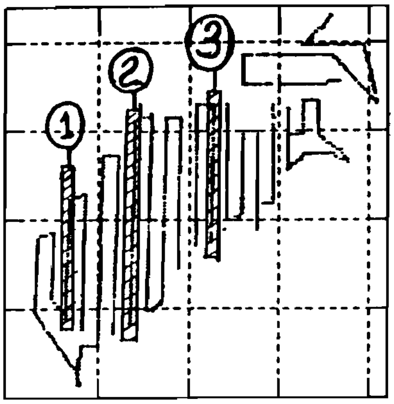
(x > 0)

Ln(x)

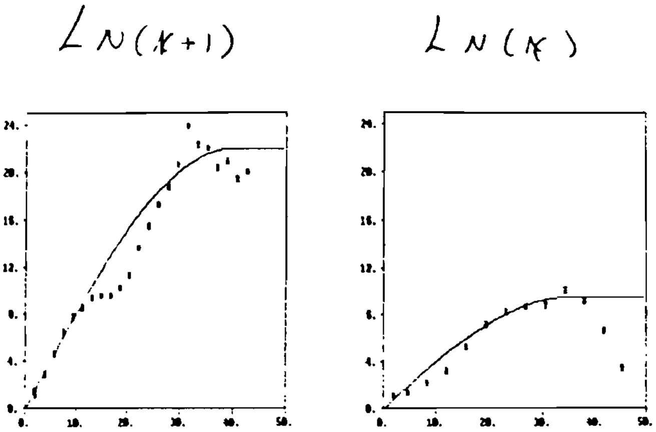


Simard and Gerlotto. FIG. 5.

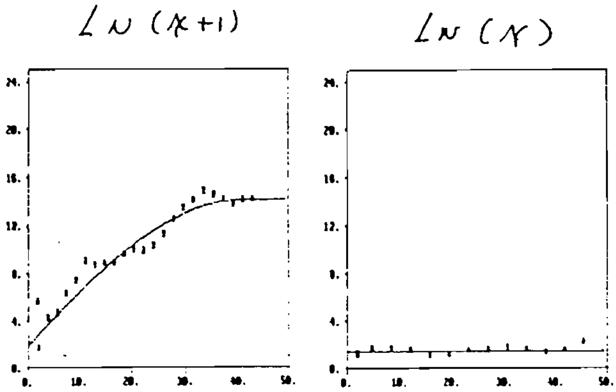
SET 4, NORWAY



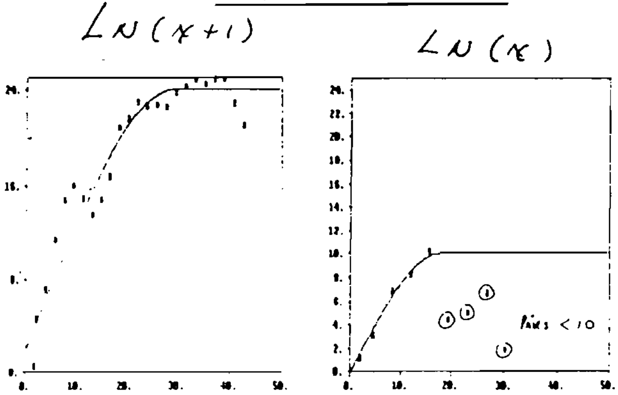
TRANSECT 3



TRANSECT 2



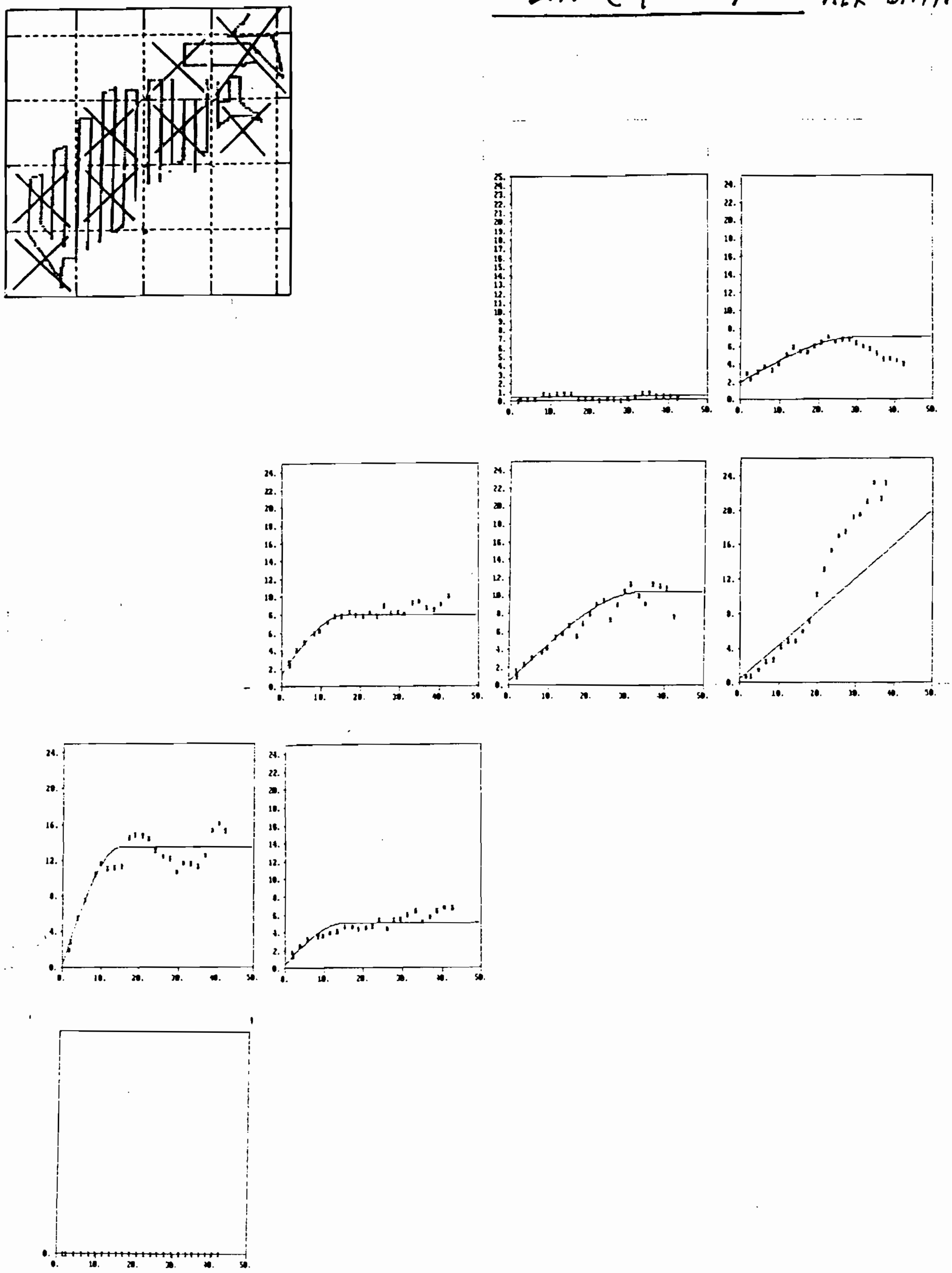
TRANSECT 1



Simard and Gerlotto. FIG. 6.

SET 4, NORWAY

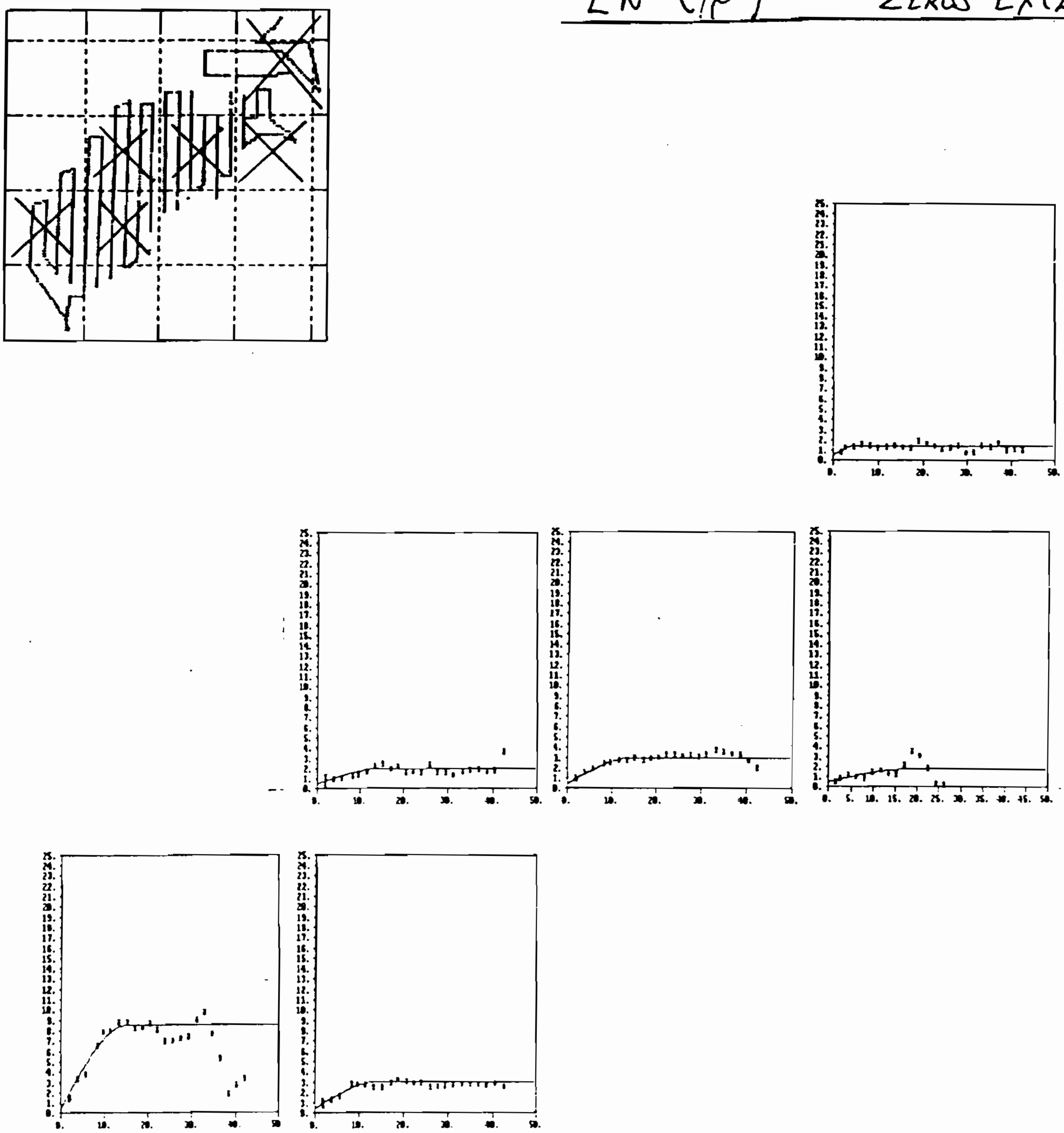
Ln (x+1) ALL DATA



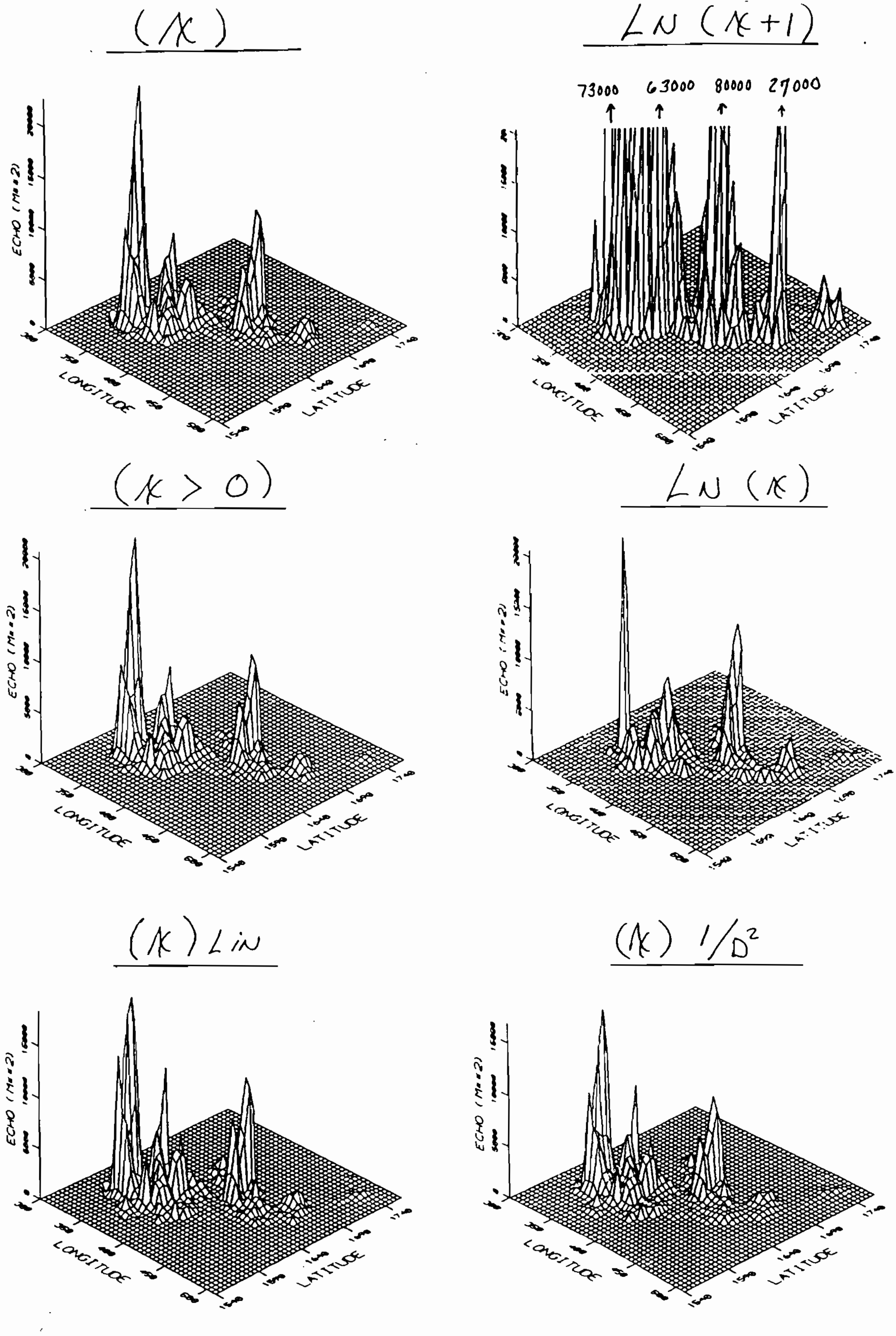
Simard and Gerlotto. FIG. 7.

SET 4, NORWAY

Ln (N) ZEROS EXCLUDED



Simard and Gerlotto. FIG. 8.


(x)

Ln (x+1)

(x > 0)

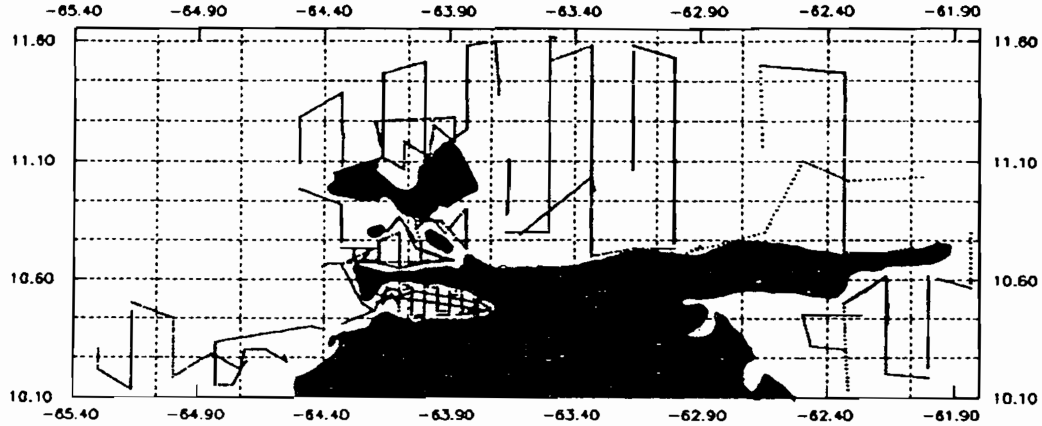
Ln (x)

(x) Lin

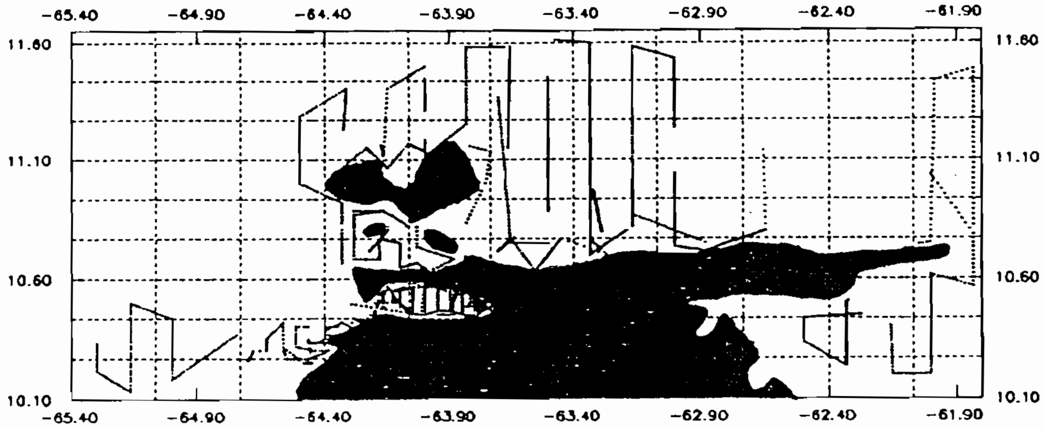
(x) $1/D^2$

Simard and Gerlotto. FIG. 9.

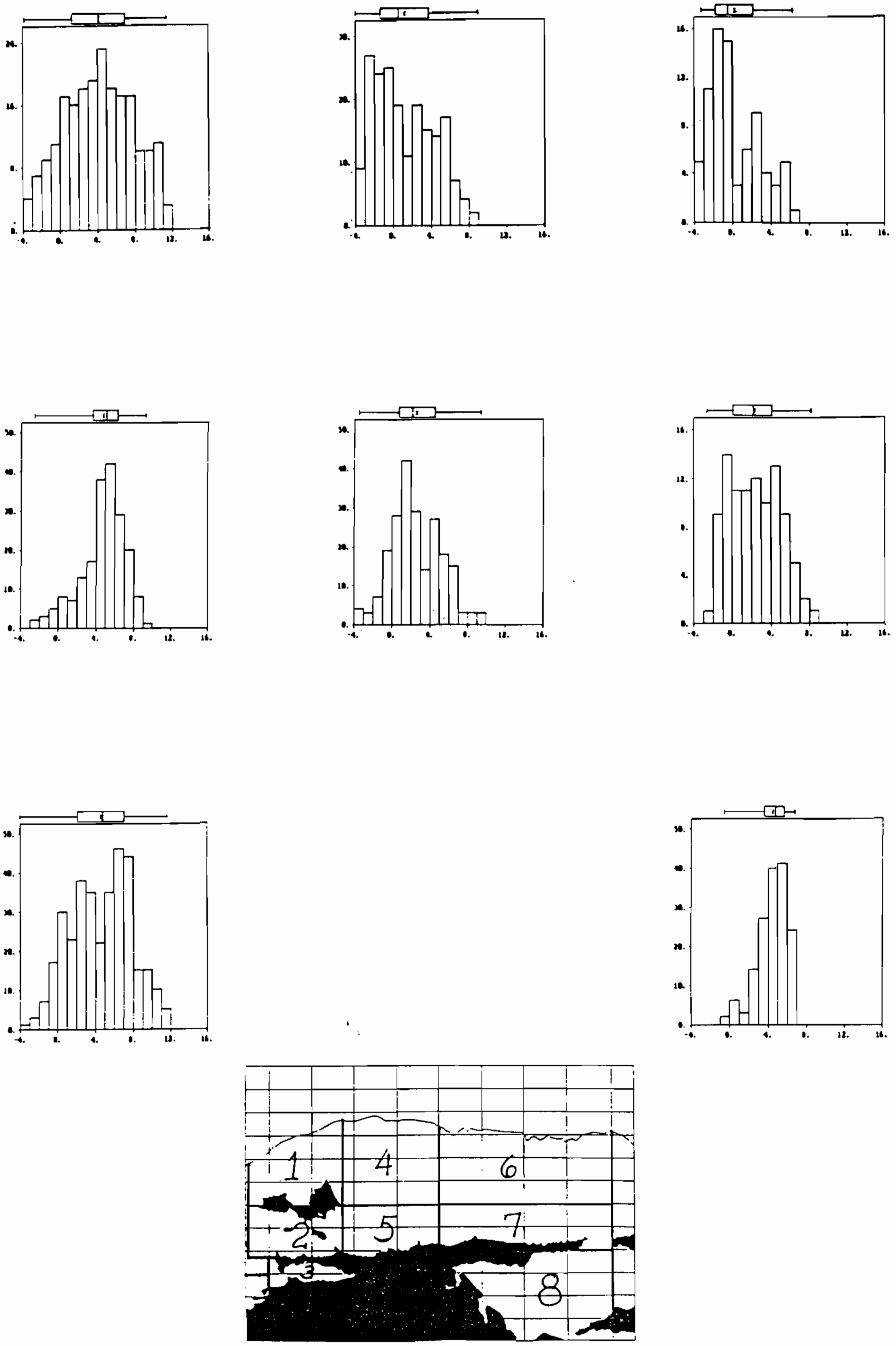
ECHOVEN NIGHT TRANSECTS



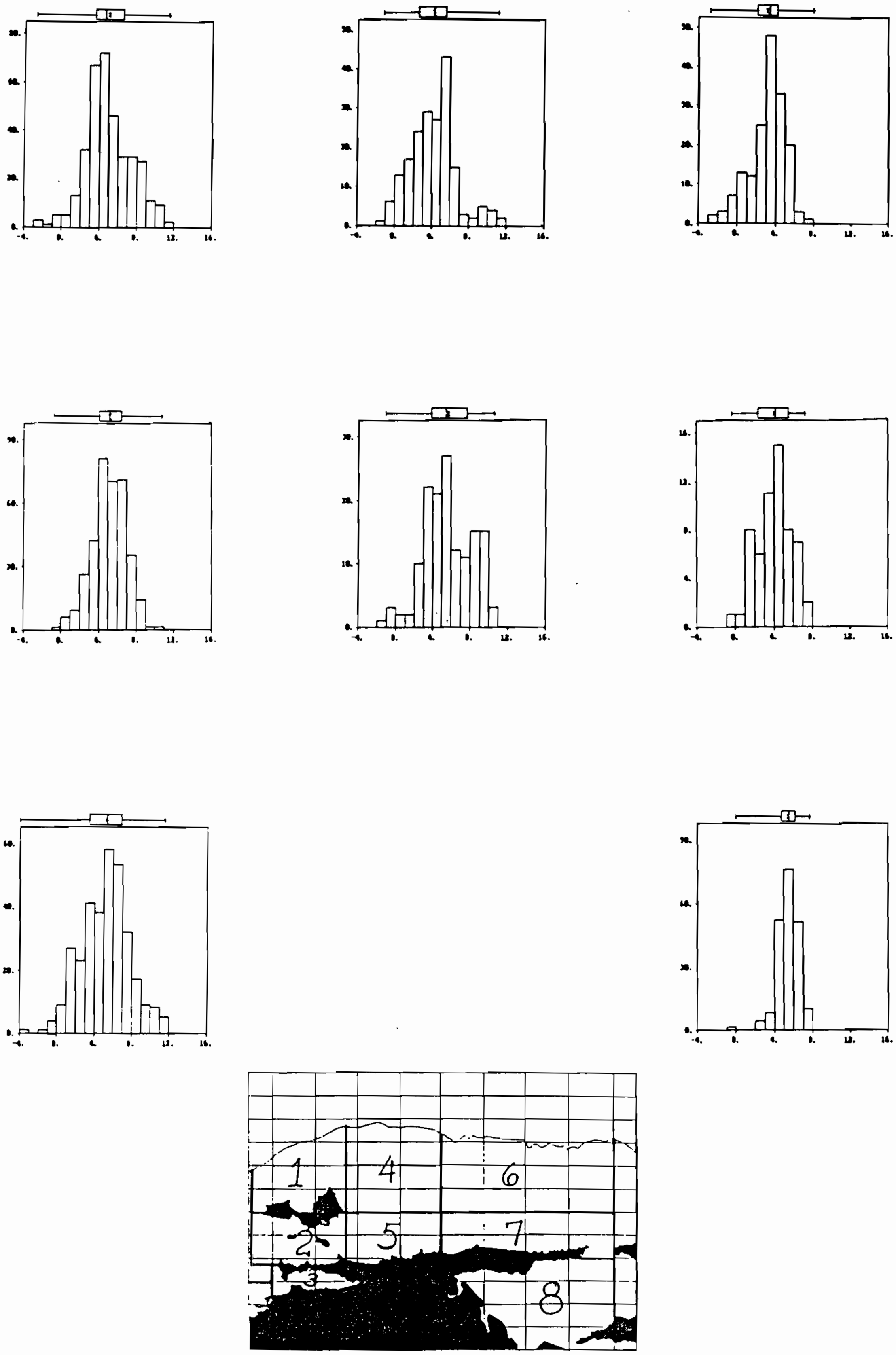
ECHOVEN DAYTIME TRANSECTS



Simard and Gerlotto. FIG. 10.

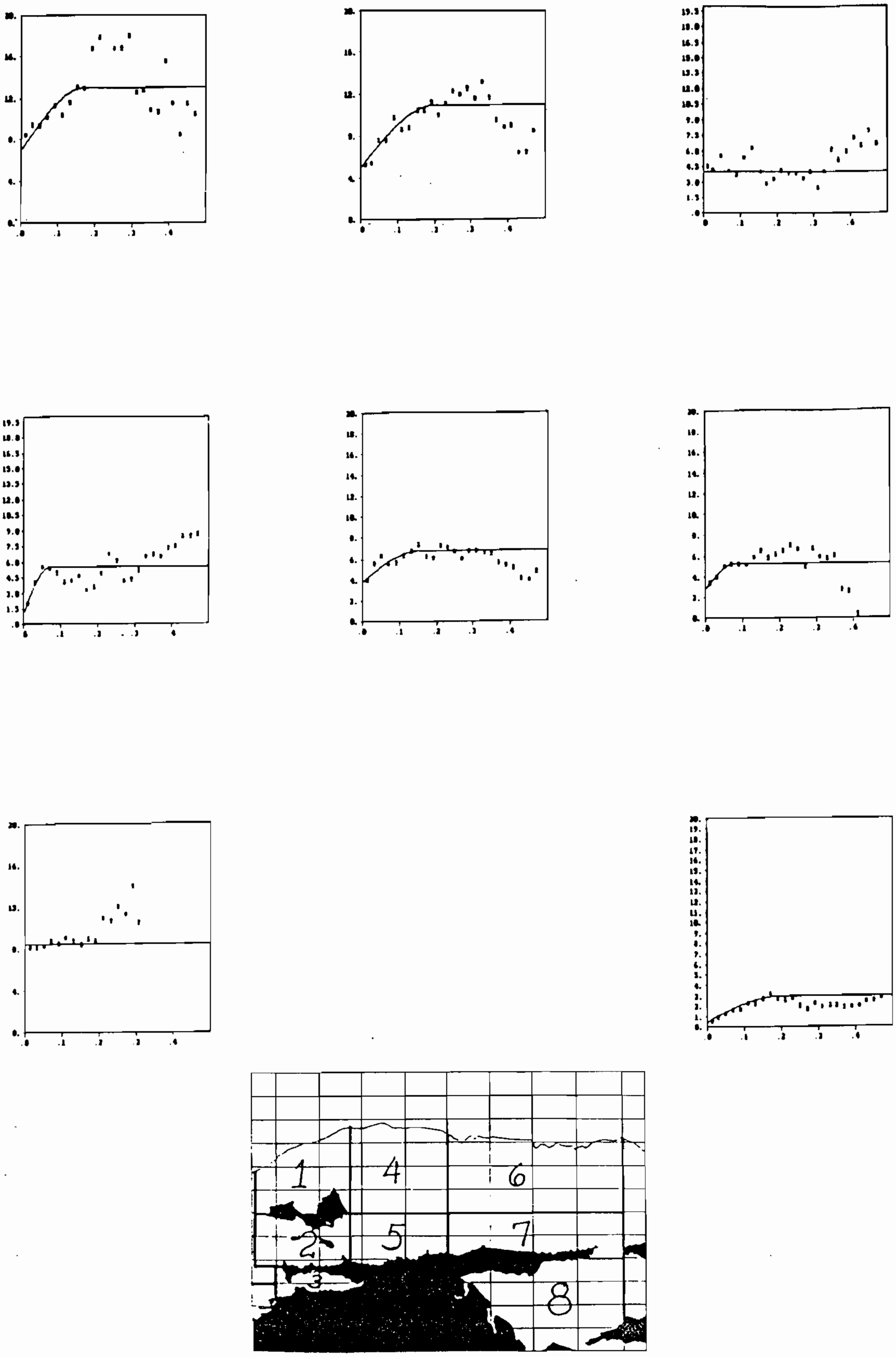


Simard and Gerlotto. FIG. 11



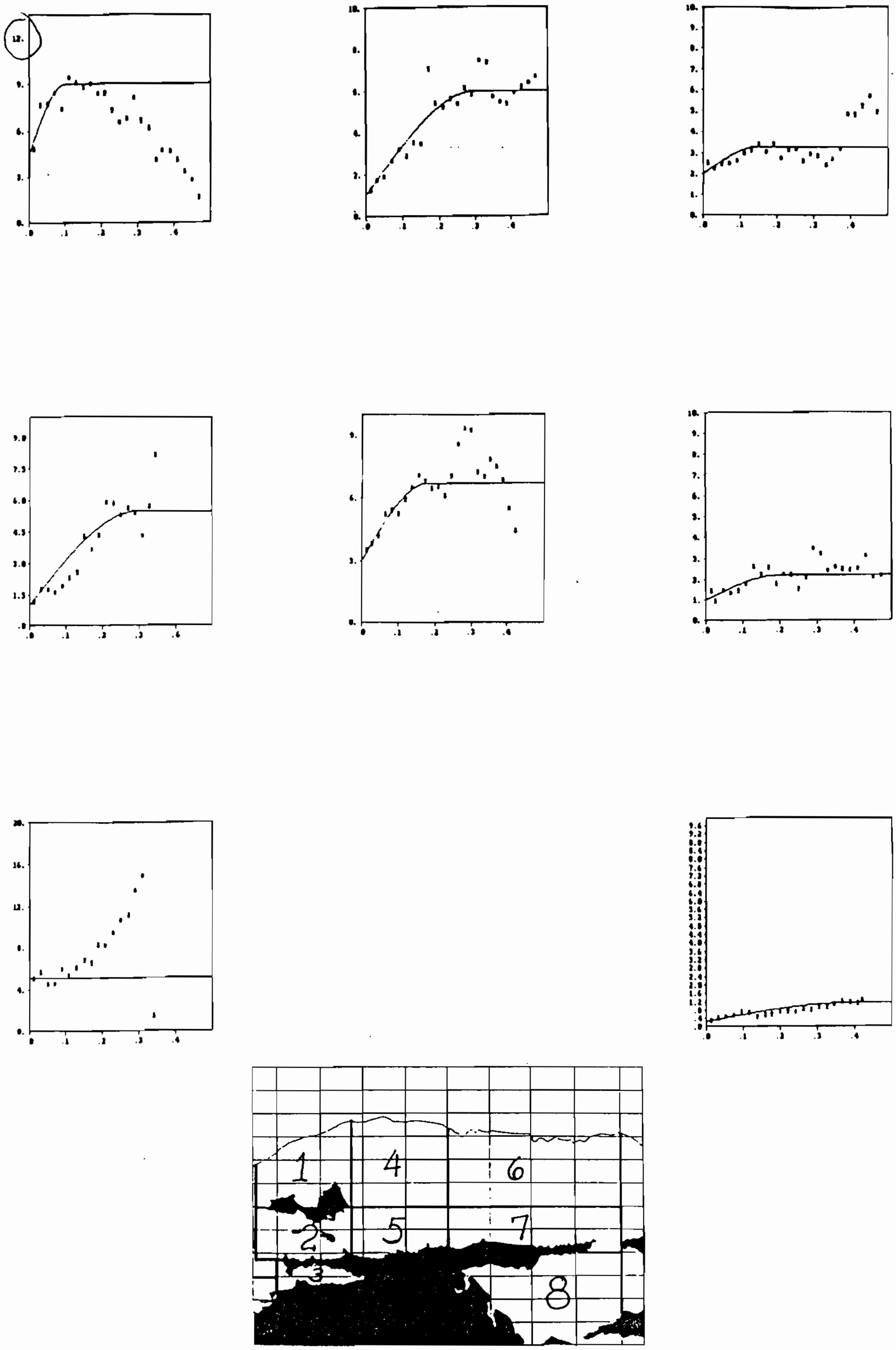
Simard and Gerlotto. FIG.

DAYTIME



Simard and Gerlotto. FIG. 1

NIGHT



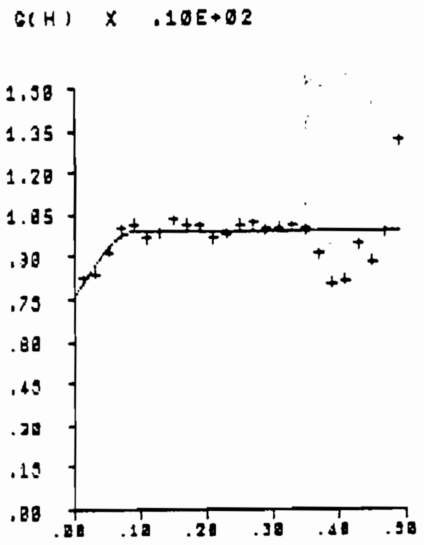
Simard and Gerlotto. FIG. 14.

[illegible] CARIACO

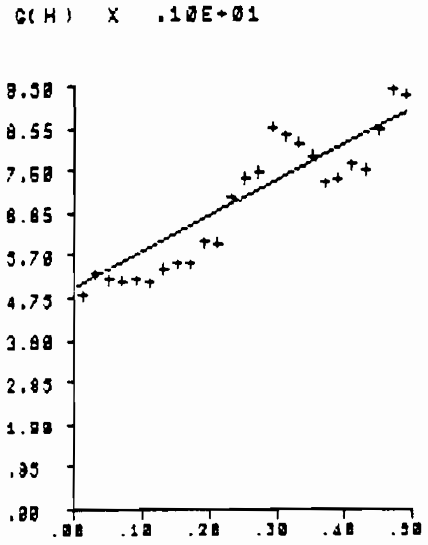
DAY

NIGHT

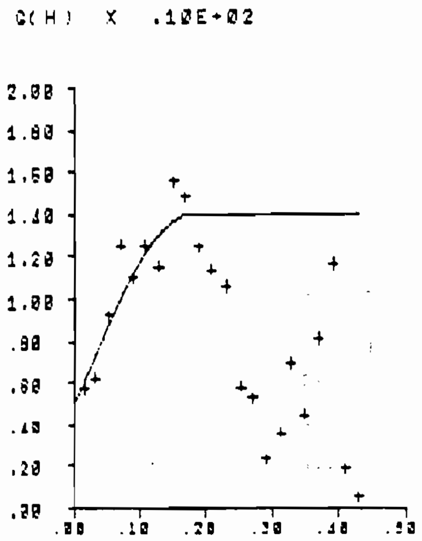
TWO-WAY



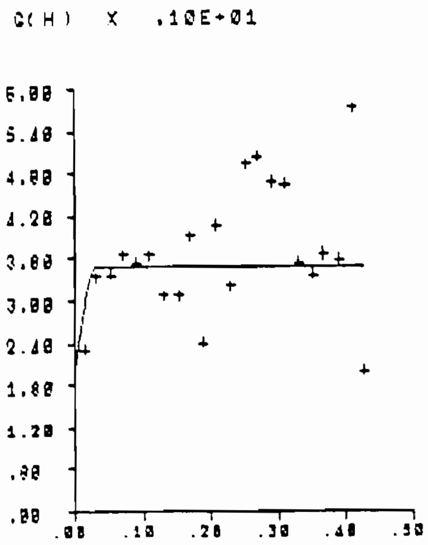
TWO-WAY



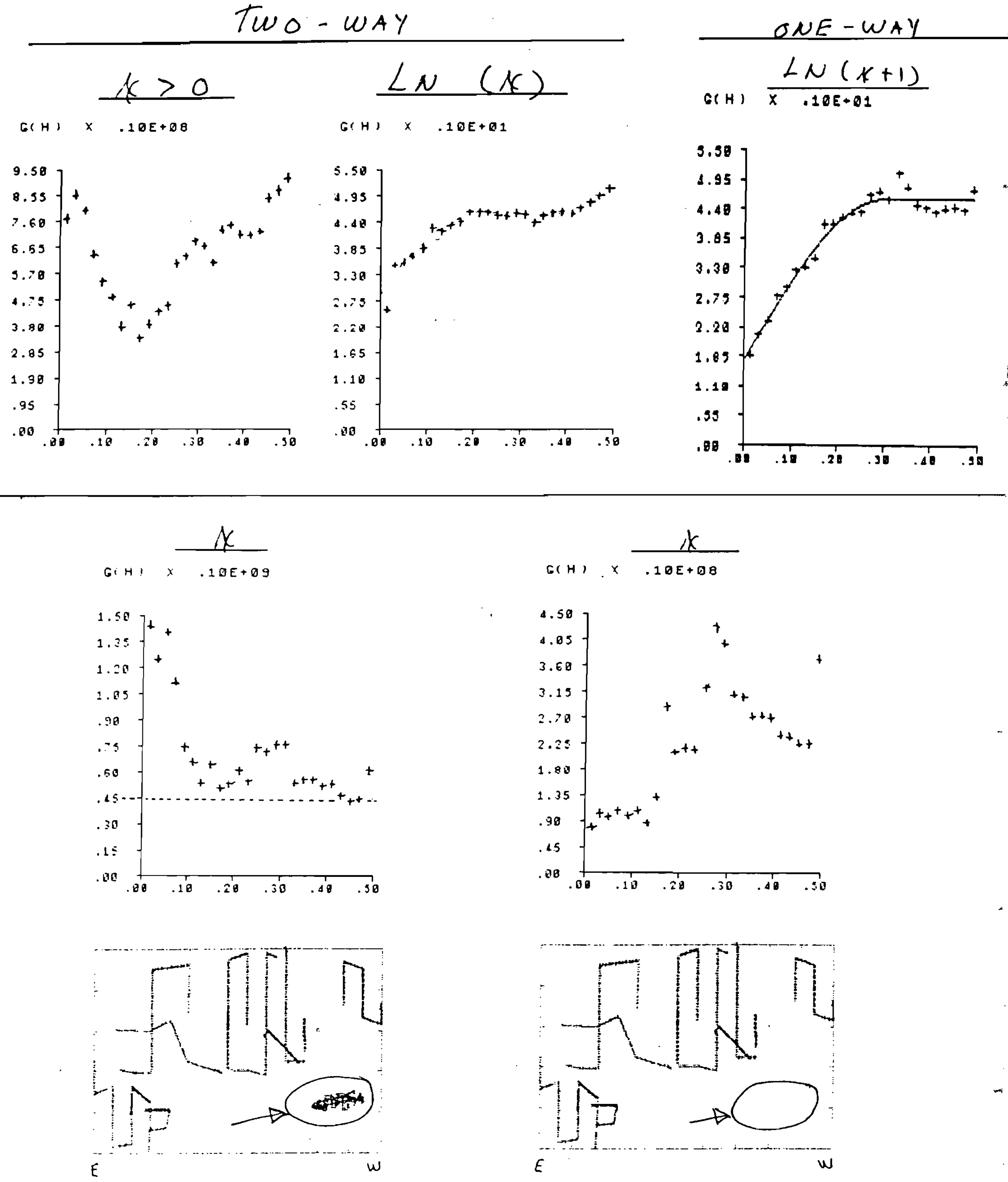
ONE-WAY



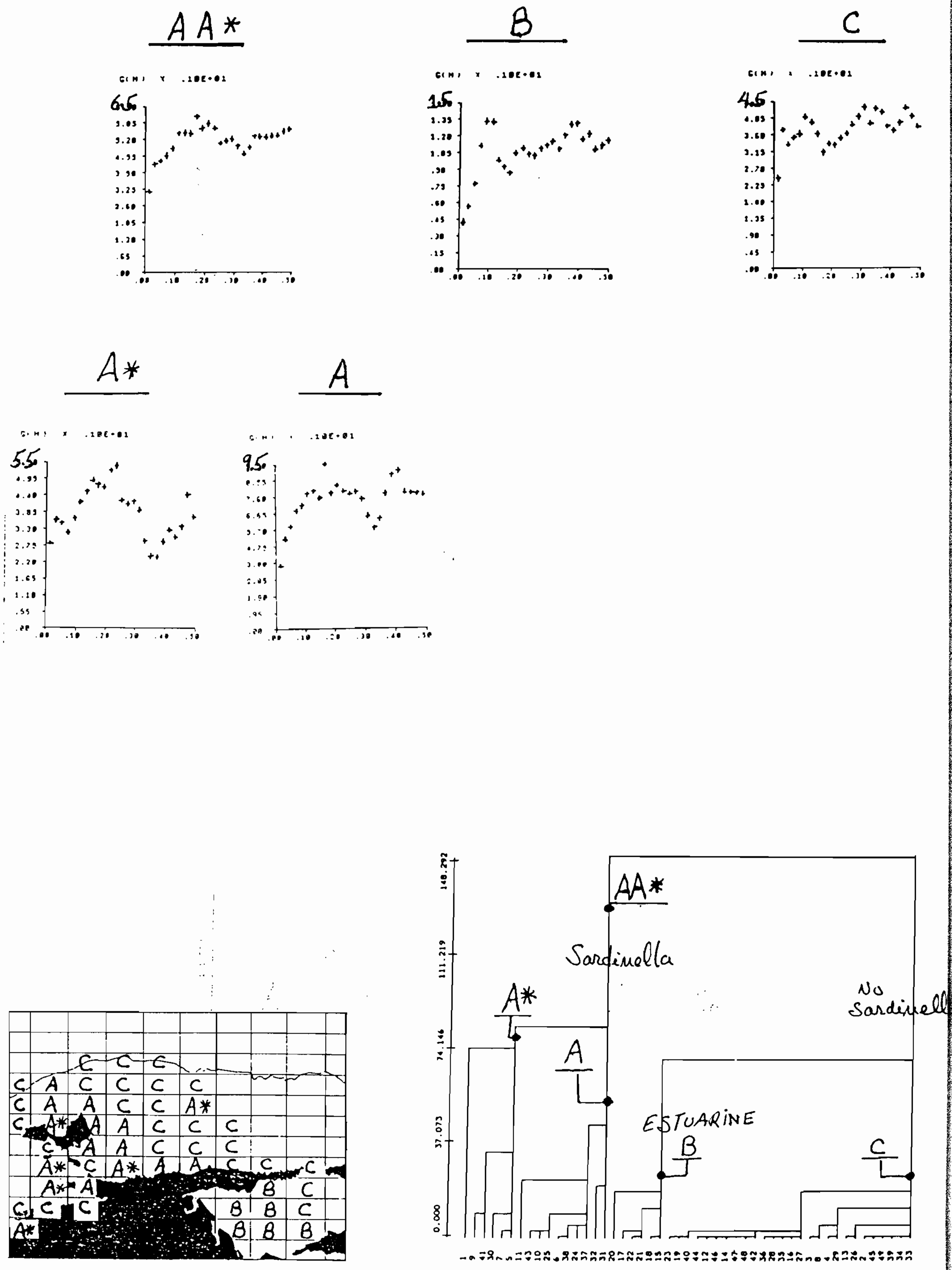
ONE-WAY



Simard and Gerlotto. FIG. 15.



Simard and Gerlotto. FIG. 16.



Simard and Gerlotto. FIG.

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Fisheries Technology and
Fish Behaviour Working Group
Rostock, April 1990

STUDY OF LEARNING CAPABILITIES OF TROPICAL CLUPEOID USING AN ARTIFICIAL STIMULUS

by

M. SORIA

ORSTOM, B.P. 81, 97256 Fort-de-France, Martinique (FWI)

RESUME

Nous avons étudié dans des conditions expérimentales l'apprentissage et le conditionnement de petits poissons pélagiques à un stress. Les poissons peuvent être conditionnés et peuvent, apres conditionnement, entrainer des réactions dans un banc de poissons naifs. Nous discutons ensuite de l'influence possible des comportements observés sur la capturabilite.

ABSTRACT

We have studied in experimental conditions the learning and conditioning capabilities of small tropical pelagic fishes on a stress. The fish can be stress-conditioned and those fish can lead to reactions in a "naïve" fish school. We discuss these results and the influence of these behaviours on fish catching.

INTRODUCTION

In order to better surround the importance of individual behaviour of pelagic fishes in the formation, the structure and the reactions of a school, and in order to better define the problems met during their catch, we have studied in experimental conditions the learning and conditioning capabilities of a coastal tropical clupeoid fish: *Opisthonema oglinum*.

The hypothesis is:

Previously stress-conditioned fishes (Pavlovian Conditioning) introduced in a school of "naïve" fishes (non conditioned) can induce alarm or flight reactions in the whole school by contagious effect (Levin and Grillet 1988).

METHODOOLOGY

1. Catching fishes and experimental structure.

The fishes were caught by day in front of the station with a little lift net. Fishing was executed without handling the fish and without emerging them. The fish were carried to the experimental area under smooth anesthesia and heavy oxygenation. A prophylactic antiseptic treatment was applied during the first few days to prevent a bacterian proliferation in the tanks.

Two sets of thirty fish of 15 cm mean length were caught in this way and brought separately and successively into two joined tanks of four meters in diameter and 1.6 high. These two twin tanks in open circuit were strictly identical in shape and colour. The first tank in which takes place the conditioning and the experimental phasis was fitted out with an underwater loudspeaker, a sliding and rigid net laid down on the bottom, and a video camera above. The second tank was bare.

2. Experimental protocol. (Diagram 1.)

The first set of fish were placed in the second tank to be kept on acclimating phasis. These acclimated and non-conditioned fish will be called "naïve" fish. The second set, was introduced in the first tank. During three days of acclimatation, a serie of three sound pulses of five seconds duration and at a frequency of 2500 Hz was emitted in an erratic way (Scharz and Greer 1984). Therefore, we should confirm that this sound didn't involve any fish reactions. Then, we associated these transmitted pulses with a stress. This stress consisted of hoisting the net close to the surface. We could consider the conditioning phasis ends when all the fish reacted to the first sound pulse. We want to determine throughout this phasis, how many repetitions are required for this conditioning.

During the experimental phasis, one part of these conditioned fish was joined with the naïve fish in the second tank, the other part is released. Then, we observed how naïve congenerics react to the flight behaviours of conditioned fish when the sound pulses occur. In the second phase, we removed this dual school back to the first tank in order to measure a possible tank effect.

3. Behaviour criteria held.

Each record of ten minutes was divided into three periods: before, during and after the inductive factors (sound pulses only or sound pulses followed by the stress). For each period, the cohesion and the activity of the school were measured through eight behavioural criteria.

The cohesion and stability criteria of a school are in decreasing order:

- the structure in MILL where the fish swim slowly in circles. This structure is considered as a behavioural form of protection. It is a good index of stability and defence of a school.

- the structure in SLACK SCHOOL where the interindividual distances are approximately equal to the body length and where the swimmming speed is slow.

- the structure in DENSE SCHOOL where the interindividual distances are short and the swimming speed is faster than in a slack school.

- the DISPERSION where no fish swim in the same direction in group.

The activity behaviour criteria of the school are in decreasing order:

- the ALARM REACTION which affects only one fish and which doesn't induce reaction towards the other.

- the FLIGHT REACTION WITH REGROUPING.

- the FLIGHT REACTION WITH DISPERSION.

We measured the occurences and the durations for each criterion in each period and also the same thing for the sum of all the reactions.

RESULTS

1. Acclimatization phasis.

First, we noticed that no mortality and no unexpected behaviours occured during the experiment. Therefore, we consider that the fish have adapted correctly to their captivity.

The tests on fish during each sound pulse show that the reaction is low and decreases during this phasis. The last three tests show no reactions on any pulse. Therefore, the sound pulse is considered as a neutral stimulus.

2. Conditioning phasis.

In order to follow the evolution of conditioning, we set up a table of weighting factor taking into account both the reaction ways (increasing from agitation to flight and dislocation) and the running number of sound pulse (increasing factor from pulse 3 to pulse 1). These values are shown in the table 1.

The reaction curve rises up to the maximum at the end of the phasis (Fig.1). The fish react earlier and earlier to the stimuli. The evolution of reaction ways is gradual in the case of the first sound: at first, alarm reactions occur with excitement, then flight reactions with a dislocation of the structure, and finally flight reactions with regrouping. During the same phasis at the moment of pertubation, both the duration of mill structure and the regrouping flight reaction increase. (Fig.2 and 3).

Then, the conditioning should be accomplished at the same time by an increase of the individual sensibility to the stress and an increase of school stability, it's cohesion and defence.

3. Experimental phasis.

With the same criteria used during the conditioning phasis, we analysed the reactions of the mixed school on the stimuli. They were null and void during the first phasis when the fish were introduced into the first tank. On the other hand, we observed flight reactions and dislocation at the beginning of the second phasis when we put the fish back into the second tank. These reactions whittled down quickly until they just became individual alarm reactions in the end. (table 2). During the same phasis, at the moment of pertubation, the duration of dispersion decrease while the duration of mill structure increase. (Fig 4 and 5).

In first analysis, it seems that the reaction of the mixed school is low. This school acquires a strong stability and cohesion at the end of this phasis.

DISCUSSION

The first question is: can the fish be conditioned? i.e., in our experimental conditions, are they able to recognize a sound emitted in the water and associate it with a further event (here: a stress)?

In the case of a positive response, the following questions are:

- how is this association (stimulus-stress) self made ? i.e., how does the reaction to the stimuli evolve during the conditioning phasis ?

- how many repetitions does it take for this conditioning ?

The results show that the conditioning of fish is possible. The interesting fact is that the conditioning to a stress doesn't lead to panic in individuals but to a strengthening of the school cohesion in their flight reactions. This panic might be obtained with a stronger intensity of the stress and with a longer conditioning duration. In any case, we did not obtain a stabilization of the reactions at the end of the conditioning phasis. Therefore, a stronger conditioning should require more than fifteen repetitions.

In the second part of the experience, we tried to answer the following questions:

- Do the conditionned fish introduced into a "naïve" fish school react to the conditioning stimuli?

- If so, how long do they react ? - Do the flight reactions of the conditioned fish induce a reaction in the whole mixed school? - What are these reactions?

At the begining of the experiment, when we add a part of the conditioned fish with the naïve fish, we do not observe any reaction from the mixed school. To account for this result we may consider the following explanations. First, the stability and the cohesion of the school are so strong that the conditioned fish are completely wrapped up in the naïve school and cannot react to the stimuli. This is speciallv plausible because the school are usually in mill structure. The formation of this structure was described first by Breder (1951). It happens frequently after a short period of "confusion" in which the school is temporarily disrupted, with fishes pointing in all directions. We think for this reason that this structure ensures good protection for all the congenerics . In this case there is a huge school inertia, and the group effect is preponderant in front of the individual effect.

Secondly, the conditioned fish hear the stimulus but do not react because they are not in their own tank. So, in a second phasis, we put the whole school back into the conditioning tank. During this the second phasis, at the beginning, the school reacted to the stimuli then this reaction decreased rapidly. This second phasis demonstrated that the previously stress-conditioned fish were still conditioned because they react to the stimuli. Then, they were able to induce a flight regrouping reaction of the mixed school although the mill structure should set oneself against it.

In this case, the individual effect is preponderant in front of the group effect but, the flight regrouping reaction appeared during the first four sets of sound pulses after a great part of the presumedly stress-conditionned fish reacted. At the end of the experiment we recorded alarm reactions from some of the fish which did not induce flight reaction of the school. Therefore, we presume that a threshold proportion of the group must be stressed in order to induce a flight reactions of the whole school. That means that the leading reaction inside a school requires a threshold proportion of conditioned fish. In our experiment, this threshold is only reached when all the stress-conditionned fish react.

If the reaction decreases rapidly it may be due to the short time of conditioning or the weakness of the stress (in order to avoid hurting them, the fish were not emerged).

To explain the differences between the two tanks, we can assume that a visual relay is required to recall the conditioning to the previously stress-conditioned fish. Without this relay, they cannot react and so, do not lead the whole school. In our experiment, this visual relay could be the net laid down on the bottom.

CONCLUSION

The conditioning of a fish school is possible under experimental statements. We have seen that the essential statements for learning and conditioning are a sufficient intensity of the stimuli and a relatively high number of repetitions. Without these statements conditioning should be impossible in the natural environmemt. These conditions are found in intensive fishing areas where a lot of ships sail, fish and trawl. Therefore, we shall have to observe in other experiments if the increase of both intensity and duration of the stimuli could induce a better learning and conditioning.

In our experiments the leading of naïve fish by conditioned fish seems to require a visual relay in front of the strong inertia of the school. To examine this hypothesis we could put another net on the bottom of the second tank (previously bare tank) before the experiments and observe the reactions of the mixed school. In the natural environment these kind of mixed schools should exist. Indeed, we can imagine that inside the distribution zone of a fish stock, there is a restricted exploitation area (which could be for example the nursery) where we can find more conditioned fish than in the nearby areas. By means of migrations inside the distribution zone, these conditioned fish can mix with naïve fish. So, the catchability of fish inside these stocks could be lower than in "wild" stock.

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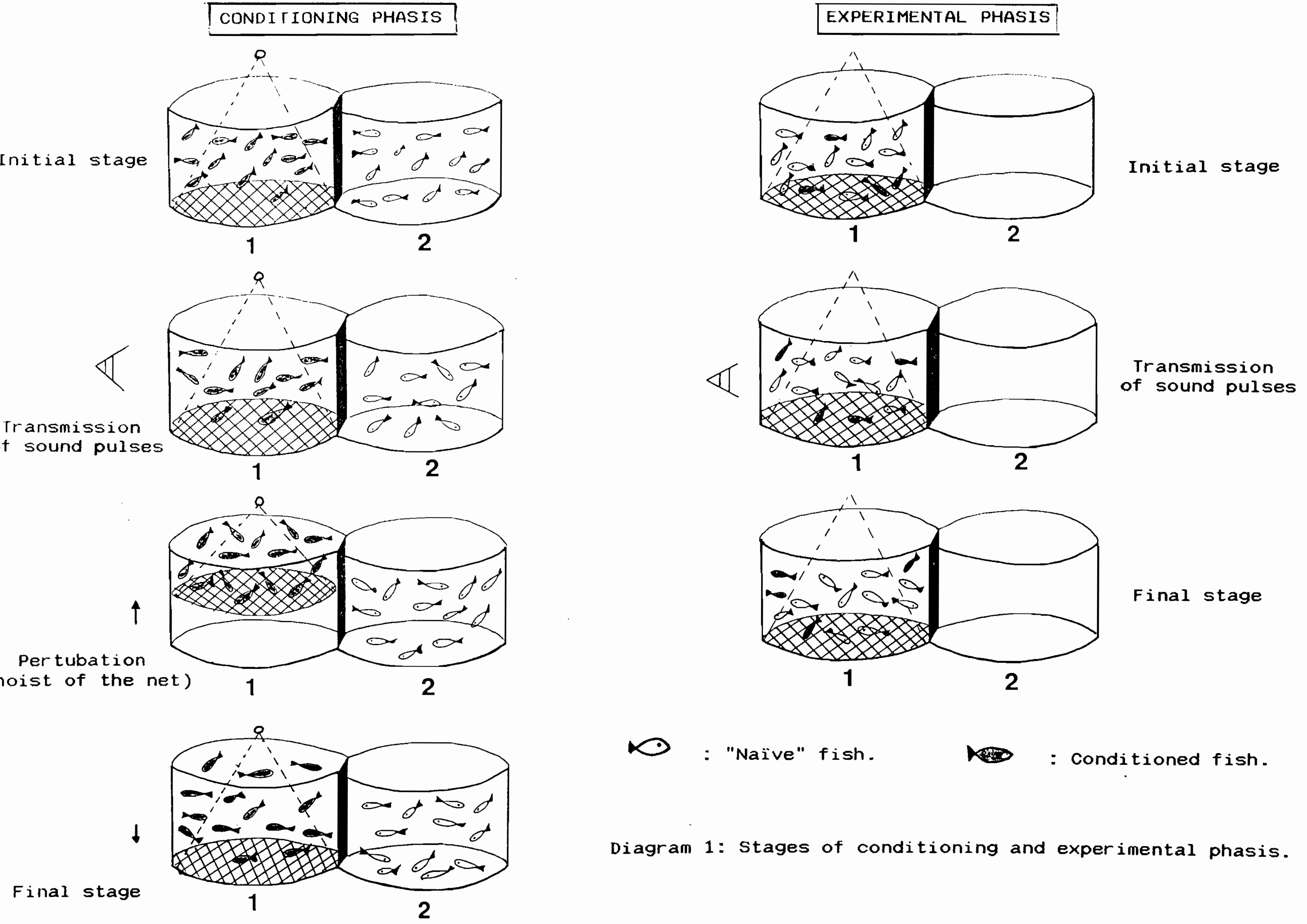


Diagram 1: Stages of conditioning and experimental phasis.

Fig. 5. TVG for EY-M large beam transducer
Cuba, october 1989

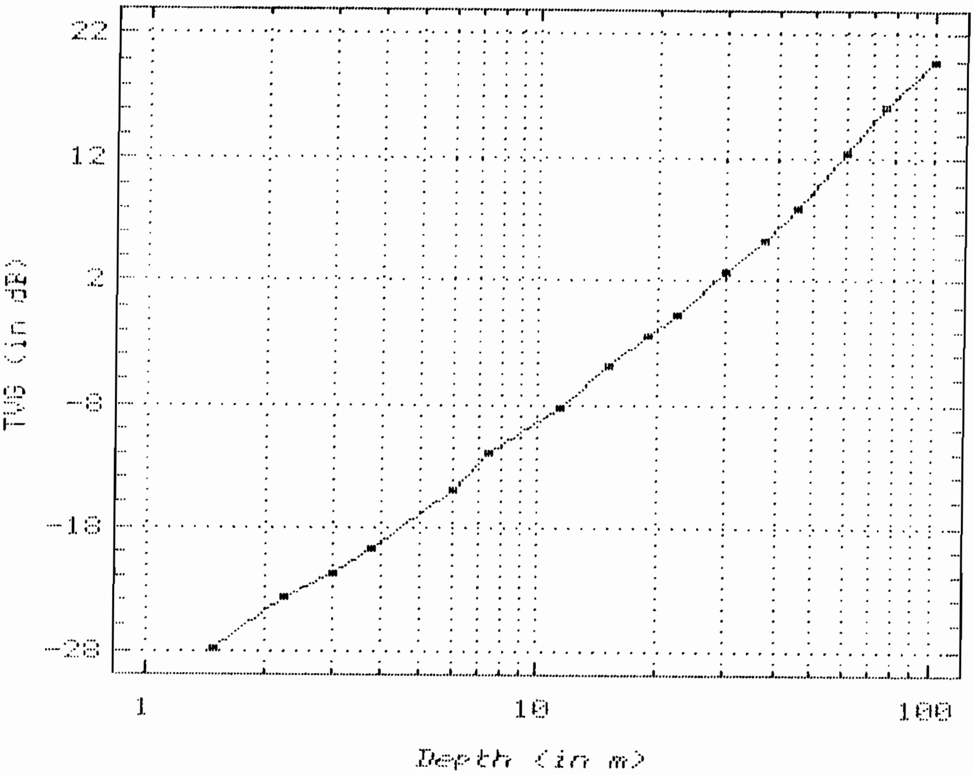


Fig. 6. Frequency Histogram of Fish echoes
Gulf of Batabano, oct. 1989

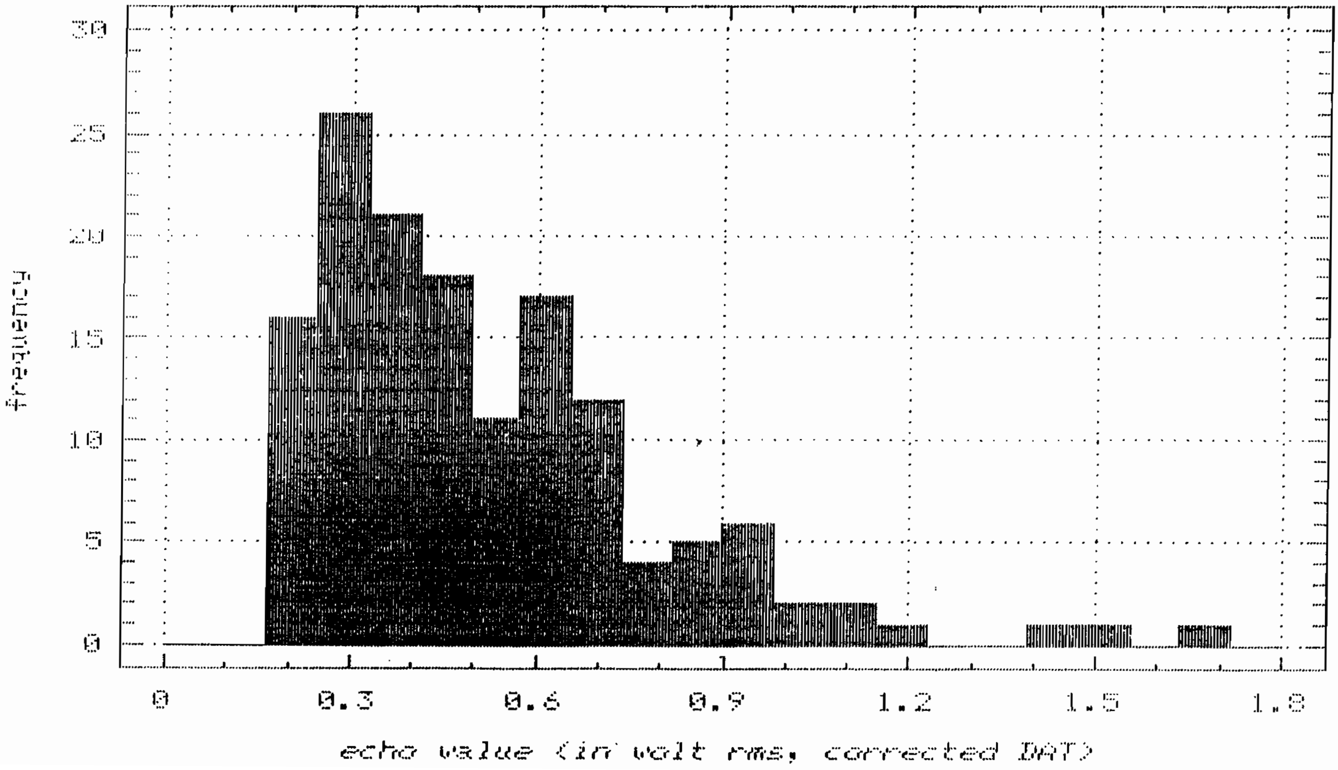


Fig. 7a. Frequency Histogram of fish TS
Gulf of Batabano, oct. 1989

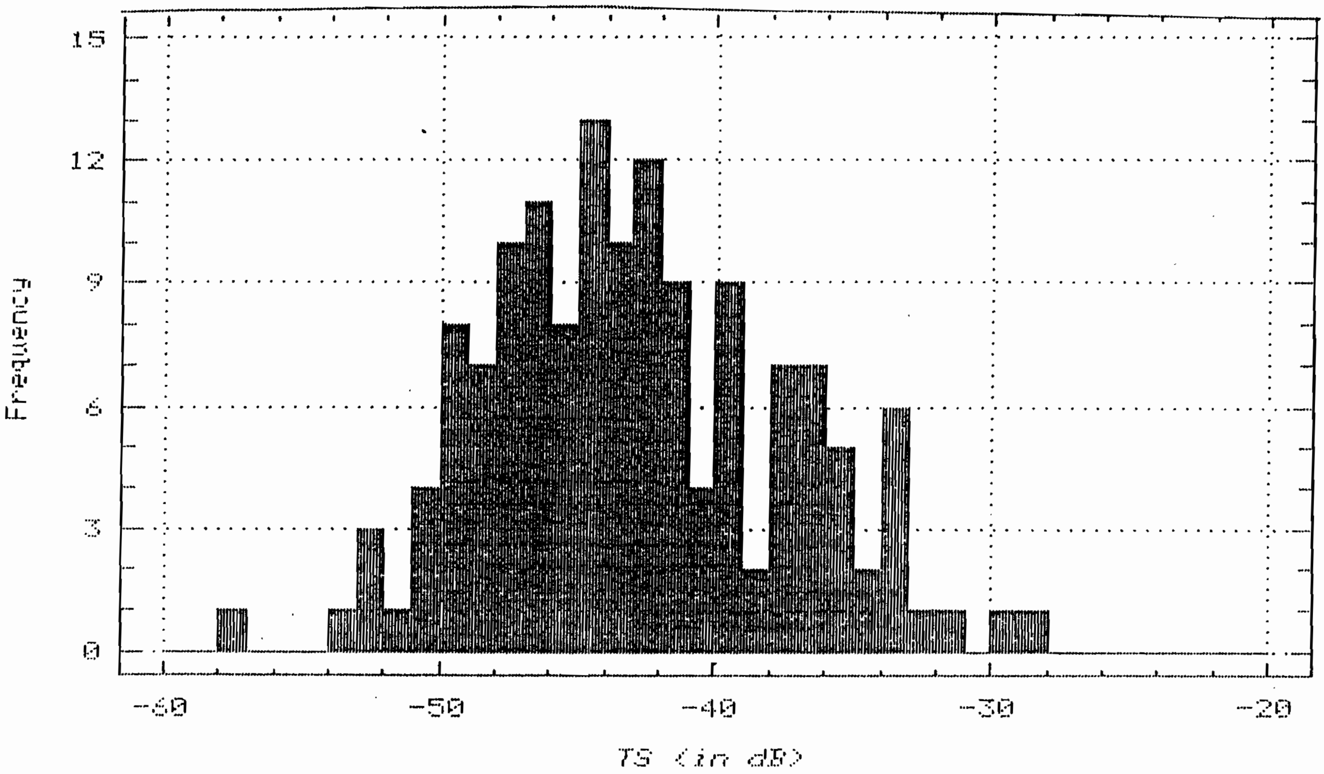
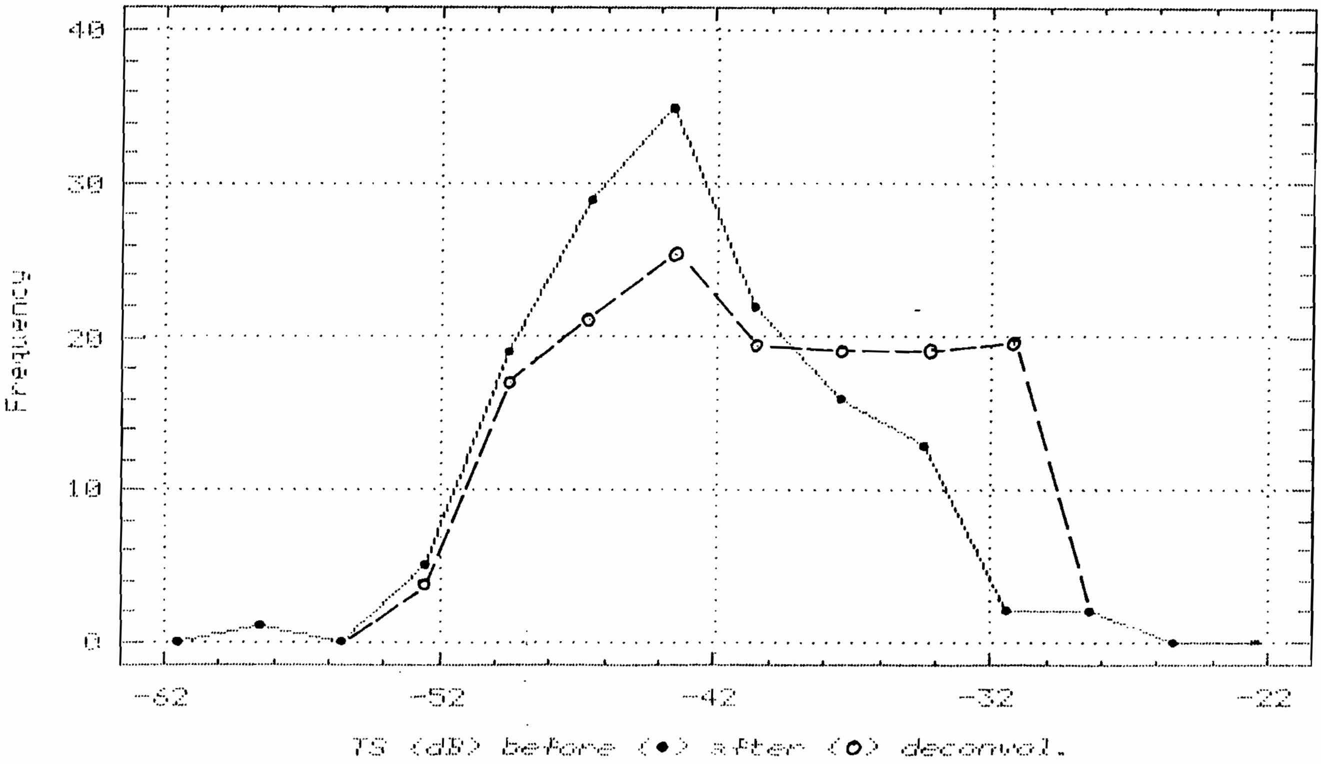


Fig. 7b. Frequency Polygon of fish TS
Gulf of Batabano, oct. 1989



	SOUND PULSE 3	SOUND PULSE 2	SOUND PULSE 1
FLIGHT AND DISLOCATION	4	8	12
FLIGHT ***	3	6	9
DISLOCATION **	2	4	6
AGITATION *	1	2	3

Table 1. Scale of values of the conditioning in terms of reaction ways and reaction time.

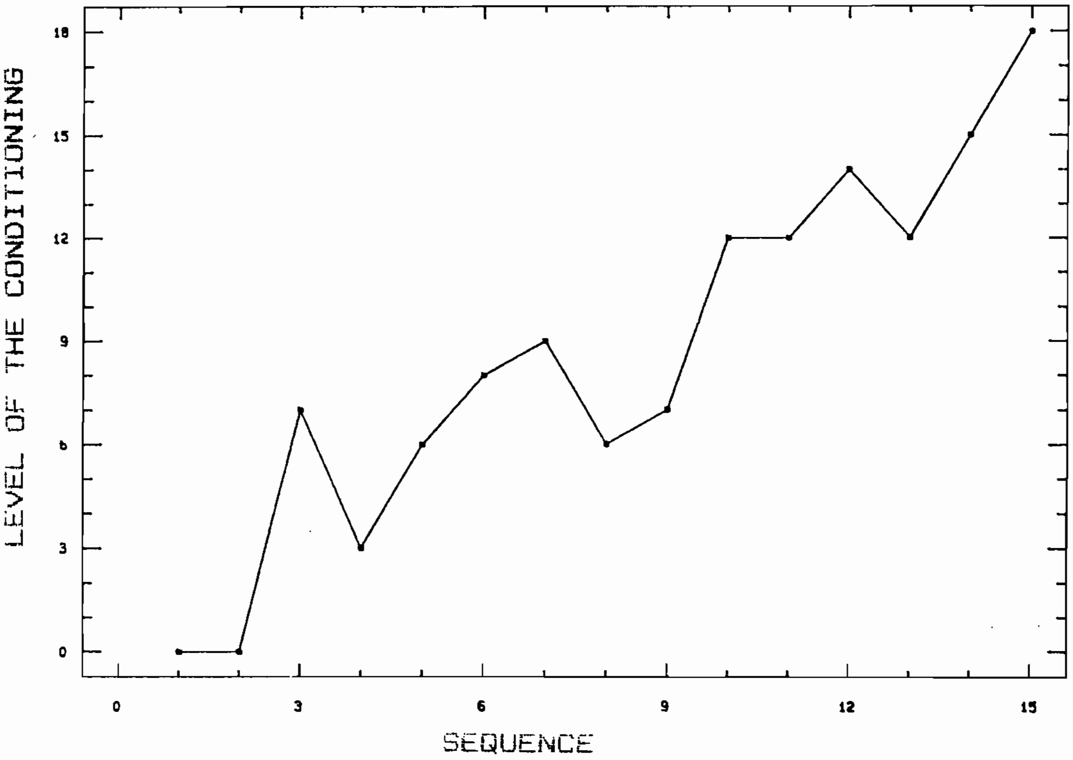


Fig 1. Evolution of the reaction during the conditioning phasis at the moment of the pertubation.

REPETITION	SOUND PULSE 1	SOUND PULSE 2	SOUND PULSE 3
1	/	**	***
2	***	***	***
3	/	/	**
4	/	/	**
5	/	/	/
6	/	*	*
7	/	/	/
8	/	/	/

Table 2. Levels of reaction during the second part of the experimental phasis.

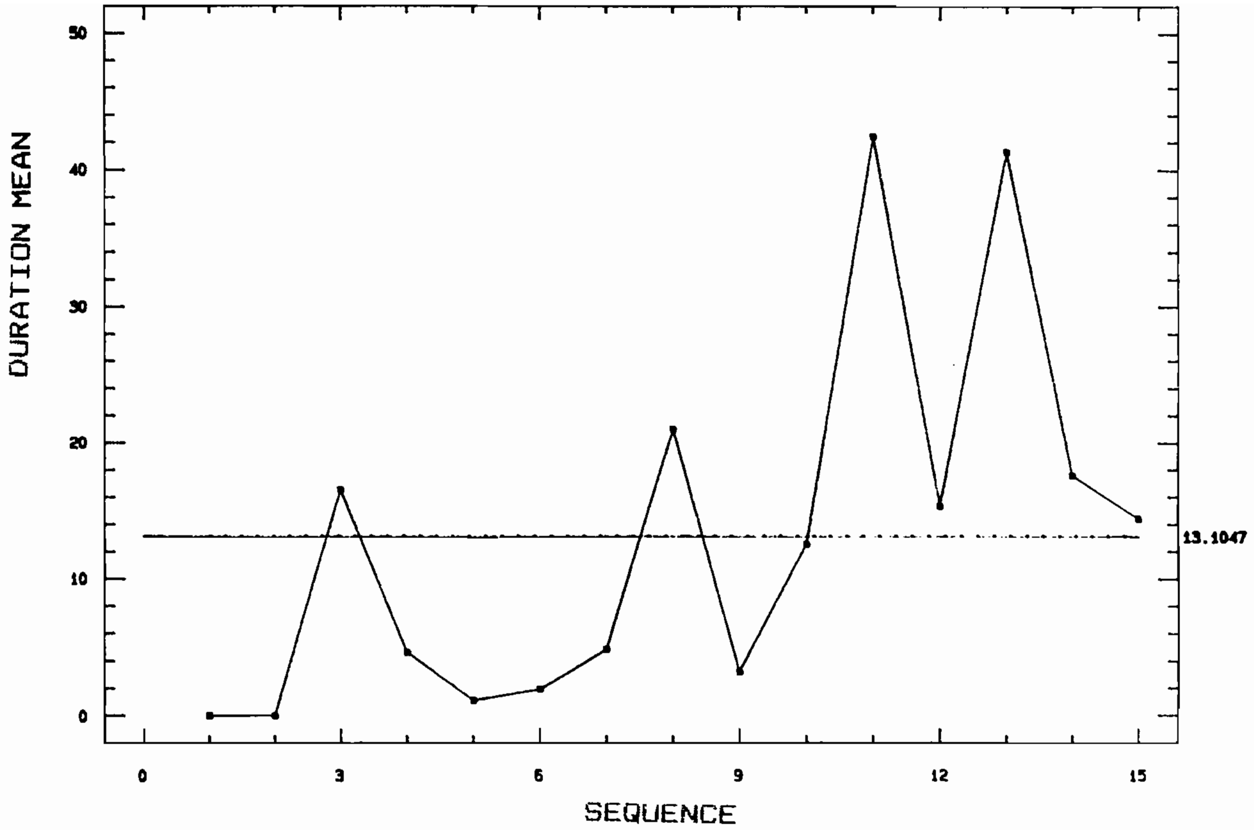


Fig 2. Evolution of the MILL structure duration during the conditioning phasis in the periode of pertubation

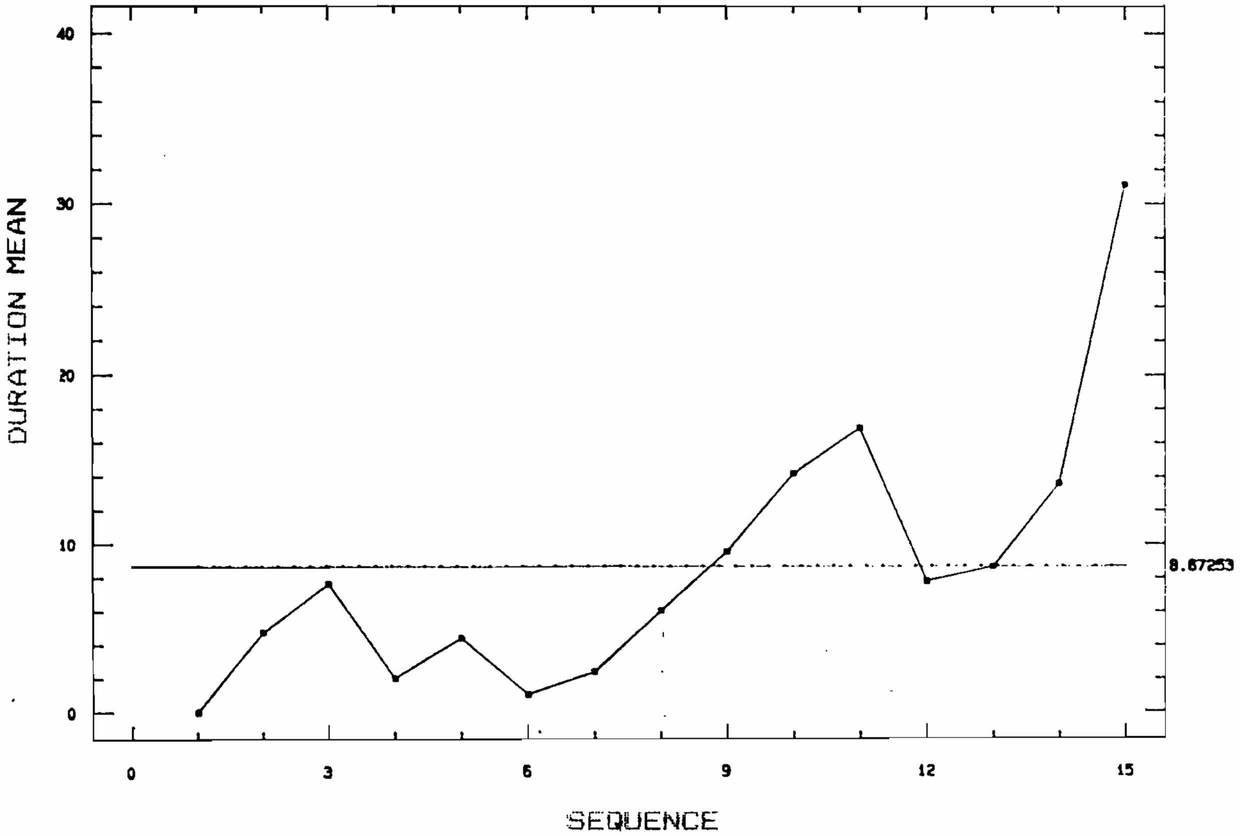


Fig 3. Evolution of the regrouping flight reaction during the conditioning phasis in the periode of pertubation.

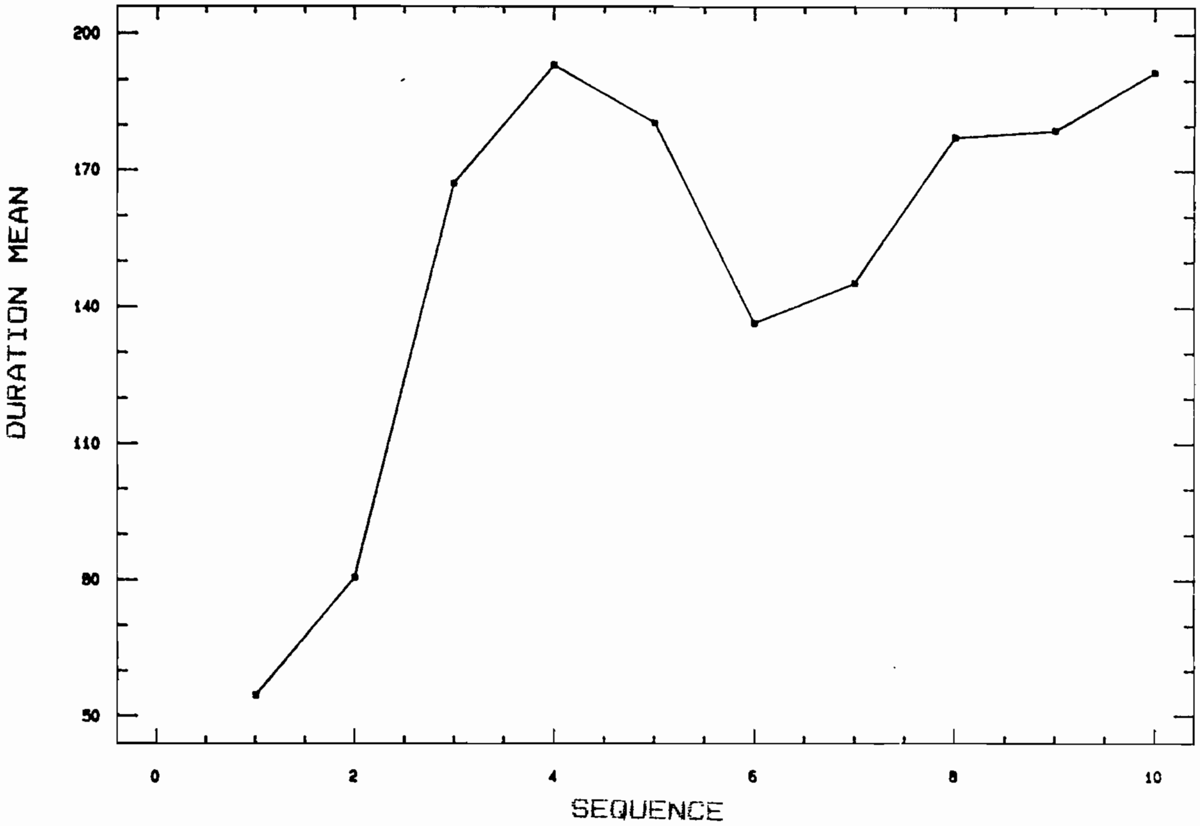


Fig 4. Evolution of the MILL structure duration during the experimental phasis in the periode of pertubation.

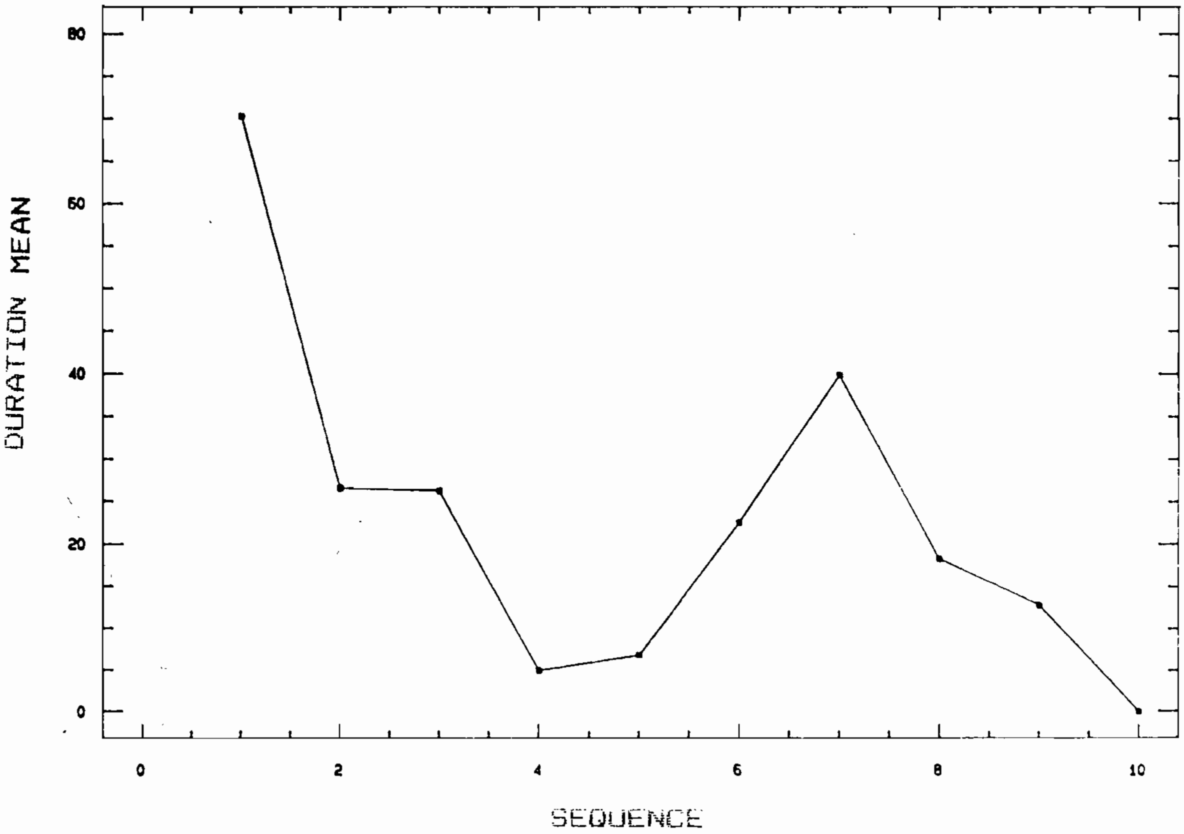


Fig 5. Evolution of the dispersion during the experimental phasis in the periode of pertubation.

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STUDY OF LEARNING CAPABILITIES OF TROPICAL CLUPEOID USING AN ARTIFICIAL STIMULUS

by

M. SORIA

ORSTOM, B.P. 81, 97256 Fort-de-France, Martinique (FWI)

RESUME

Nous avons étudié dans des conditions expérimentales l'apprentissage et le conditionnement de petits poissons pélagiques à un stress. Les poissons peuvent être conditionnés et peuvent, apres conditionnement, entrainer des réactions dans un banc de poissons naifs. Nous discutons ensuite de l'influence possible des comportements observés sur la capturabilite.

ABSTRACT

We have studied in experimental conditions the learning and conditioning capabilities of small tropical pelagic fishes on a stress. The fish can be stress-conditioned and those fish can lead to reactions in a "naive" fish school. We discuss these results and the influence of these behaviours on fish catching.

INTRODUCTION

In order to better surround the importance of individual behaviour of pelagic fishes in the formation, the structure and the reactions of a school, and in order to better define the problems met during their catch, we have studied in experimental conditions the learning and conditioning capabilities of a coastal tropical clupeoid fish: *Opisthonema oglinum*.

The hypothesis is:

Previously stress-conditioned fishes (Pavlovian Conditioning) introduced in a school of "naïve" fishes (non conditioned) can induce alarm or flight reactions in the whole school by contagious effect (Levin and Grillet 1988).

METHODOLOGY

1. Catching fishes and experimental structure.

The fishes were caught by day in front of the station with a little lift net. Fishing was executed without handling the fish and without emerging them. The fish were carried to the experimental area under smooth anesthesia and heavy oxygenation. A prophylactic antiseptic treatment was applied during the first few days to prevent a bacterian proliferation in the tanks.

Two sets of thirty fish of 15 cm mean length were caught in this way and brought separately and successively into two joined tanks of four meters in diameter and 1.6 high. These two twin tanks in open circuit were strictly identical in shape and colour. The first tank in which takes place the conditioning and the experimental phasis was fitted out with an underwater loudspeaker, a sliding and rigid net laid down on the bottom, and a video camera above. The second tank was bare.

2. Experimental protocol. (Diagram 1.)

The first set of fish were placed in the second tank to be kept on acclimating phasis. These acclimated and non-conditioned fish will be called "naïve" fish. The second set, was introduced in the first tank. During three days of acclimatation, a serie of three sound pulses of five seconds duration and at a frequency of 2500 Hz was emitted in an erratic way (Scharz and Greer 1984). Therefore, we should confirm that this sound didn't involve any fish reactions. Then, we associated these transmitted pulses with a stress. This stress consisted of hoisting the net close to the surface. We could consider the conditioning phasis ends when all the fish reacted to the first sound pulse. We want to determine throughout this phasis, how many repetitions are required for this conditioning.

During the experimental phasis, one part of these conditioned fish was joined with the naïve fish in the second tank, the other part is released. Then, we observed how naïve congenerics react to the flight behaviours of conditioned fish when the sound pulses occur. In the second phase, we removed this dual school back to the first tank in order to measure a possible tank effect.

3. Behaviour criteria held.

Each record of ten minutes was divided into three periods: before, during and after the inductive factors (sound pulses only or sound pulses followed by the stress). For each period, the cohesion and the activity of the school were measured through eight behavioural criteria.

The cohesion and stability criteria of a school are in decreasing order:

- the structure in MILL where the fish swim slowly in circles. This structure is considered as a behavioural form of protection. It is a good index of stability and defence of a school.

- the structure in SLACK SCHOOL where the interindividual distances are approximately equal to the body length and where the swimmming speed is slow.

- the structure in DENSE SCHOOL where the interindividual distances are short and the swimming speed is faster than in a slack school.

- the DISPERSION where no fish swim in the same direction in group.

The activity behaviour criteria of the school are in decreasing order:

- the ALARM REACTION which affects only one fish and which doesn't induce reaction towards the other.

- the FLIGHT REACTION WITH REGROUPING.

- the FLIGHT REACTION WITH DISPERSION.

We measured the occurences and the durations for each criterion in each period and also the same thing for the sum of all the reactions.

RESULTS

1. Acclimatization phasis.

First, we noticed that no mortality and no unexpected behaviours occured during the experiment. Therefore, we consider that the fish have adapted correctly to their captivity.

The tests on fish during each sound pulse show that the reaction is low and decreases during this phasis. The last three tests show no reactions on any pulse. Therefore, the sound pulse is considered as a neutral stimulus.

2. Conditioning phasis.

In order to follow the evolution of conditioning, we set up a table of weighting factor taking into account both the reaction ways (increasing from agitation to flight and dislocation) and the running number of sound pulse (increasing factor from pulse 3 to pulse 1). These values are shown in the table 1.

The reaction curve rises up to the maximum at the end of the phasis (Fig.1). The fish react earlier and earlier to the stimuli. The evolution of reaction ways is gradual in the case of the first sound: at first, alarm reactions occur with excitement, then flight reactions with a dislocation of the structure, and finally flight reactions with regrouping. During the same phasis at the moment of pertubation, both the duration of mill structure and the regrouping flight reaction increase. (Fig.2 and 3).

Then, the conditioning should be accomplished at the same time by an increase of the individual sensibility to the stress and an increase of school stability, it's cohesion and defence.

3. Experimental phasis.

With the same criteria used during the conditioning phasis, we analysed the reactions of the mixed school on the stimuli. They were null and void during the first phasis when the fish were introduced into the first tank. On the other hand, we observed flight reactions and dislocation at the beginning of the second phasis when we put the fish back into the second tank. These reactions whittled down quickly until they just became individual alarm reactions in the end. (table 2). During the same phasis, at the moment of pertubation, the duration of dispersion decrease while the duration of mill structure increase. (Fig 4 and 5).

In first analysis, it seems that the reaction of the mixed school is low. This school acquires a strong stability and cohesion at the end of this phasis.

DISCUSSION

The first question is: can the fish be conditioned? i.e., in our experimental conditions, are they able to recognize a sound emitted in the water and associate it with a further event (here: a stress)?

In the case of a positive response, the following questions are:

- how is this association (stimulus-stress) self made ? i.e., how does the reaction to the stimuli evolve during the conditioning phasis ?

- how many repetitions does it take for this conditioning ?

The results show that the conditioning of fish is possible. The interesting fact is that the conditioning to a stress doesn't lead to panic in individuals but to a strengthening of the school cohesion in their flight reactions. This panic might be obtained with a stronger intensity of the stress and with a longer conditioning duration. In any case, we did not obtain a stabilization of the reactions at the end of the conditioning phasis. Therefore, a stronger conditioning should require more than fifteen repetitions.

In the second part of the experience, we tried to answer the following questions:

- Do the conditionned fish introduced into a "naïve" fish school react to the conditioning stimuli?

- If so, how long do they react ? - Do the flight reactions of the conditioned fish induce a reaction in the whole mixed school? - What are these reactions?

At the begining of the experiment, when we add a part of the conditioned fish with the naïve fish, we do not observe any reaction from the mixed school. To account for this result we may consider the following explanations. First, the stability and the cohesion of the school are so strong that the conditioned fish are completely wrapped up in the naïve school and cannot react to the stimuli. This is specially plausible because the school are usually in mill structure. The formation of this structure was described first by Breder (1951). It happens frequently after a short period of "confusion" in which the school is temporarily disrupted, with fishes pointing in all directions. We think for this reason that this structure ensures good protection for all the congenerics . In this case there is a huge school inertia, and the group effect is preponderant in front of the individual effect.

Secondly, the conditioned fish hear the stimulus but do not react because they are not in their own tank. So, in a second phasis, we put the whole school back into the conditioning tank. During this the second phasis, at the beginning, the school reacted to the stimuli then this reaction decreased rapidly. This second phasis demonstrated that the previously stress-conditioned fish were still conditioned because they react to the stimuli. Then, they were able to induce a flight regrouping reaction of the mixed school although the mill structure should set oneself against it.

In this case, the individual effect is preponderant in front of the group effect but, the flight regrouping reaction appeared during the first four sets of sound pulses after a great part of the presumedly stress-conditionned fish reacted. At the end of the experiment we recorded alarm reactions from some of the fish which did not induce flight reaction of the school. Therefore, we presume that a threshold proportion of the group must be stressed in order to induce a flight reactions of the whole school. That means that the leading reaction inside a school requires a threshold proportion of conditioned fish. In our experiment, this threshold is only reached when all the stress-conditionned fish react.

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To explain the differences between the two tanks, we can assume that a visual relay is required to recall the conditioning to the previously stress-conditioned fish. Without this relay, they cannot react and so, do not lead the whole school. In our experiment, this visual relay could be the net laid down on the bottom.

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The conditioning of a fish school is possible under experimental statements. We have seen that the essential statements for learning and conditioning are a sufficient intensity of the stimuli and a relatively high number of repetitions. Without these statements conditioning should be impossible in the natural environmemt. These conditions are found in intensive fishing areas where a lot of ships sail, fish and trawl. Therefore, we shall have to observe in other experiments if the increase of both intensity and duration of the stimuli could induce a better learning and conditioning.

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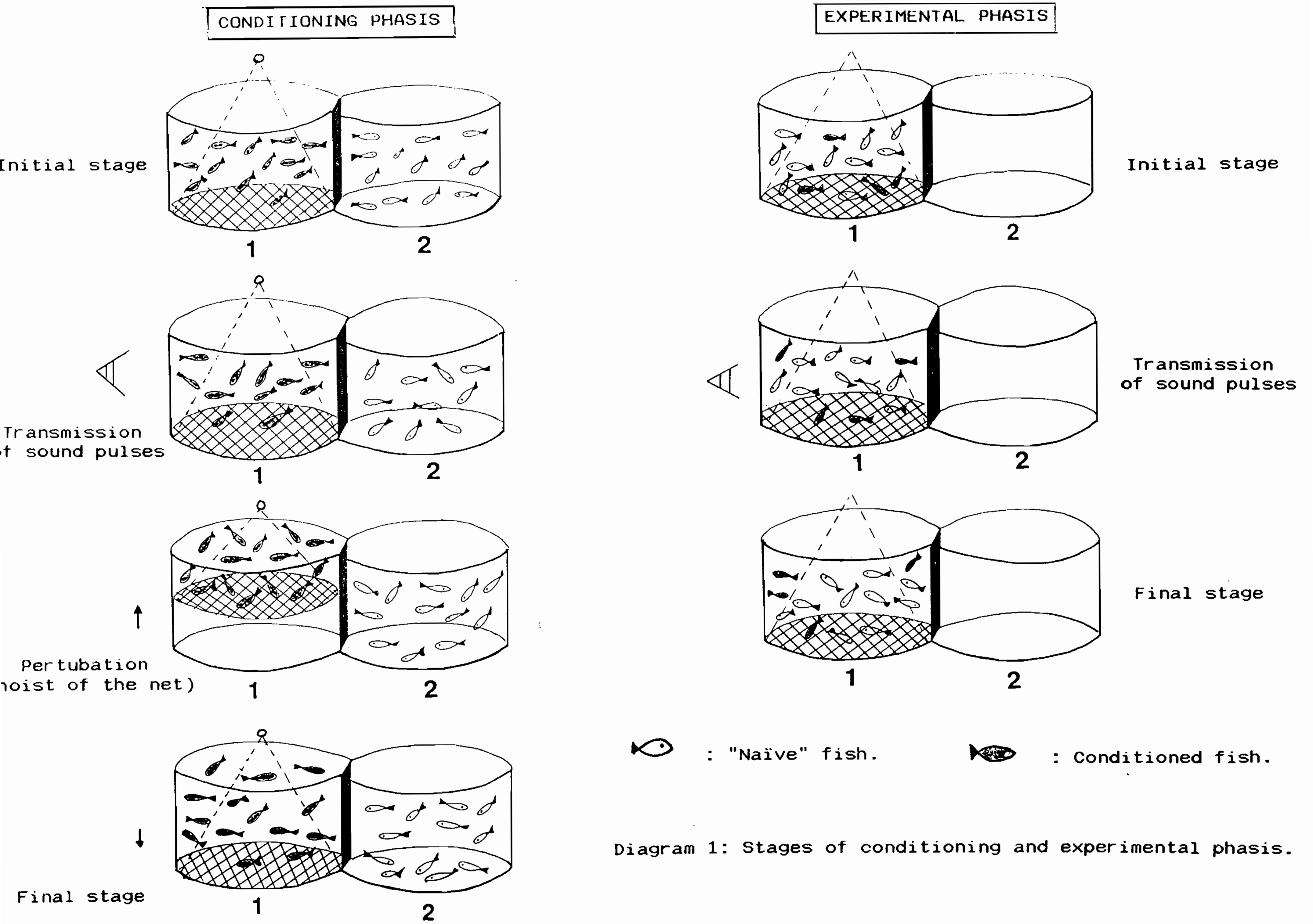

Diagram 1: Stages of conditioning and experimental phasis.

	SOUND PULSE 3	SOUND PULSE 2	SOUND PULSE 1
FLIGHT AND DISLOCATION	4	8	12
FLIGHT ***	3	6	9
DISLOCATION **	2	4	6
AGITATION *	1	2	3

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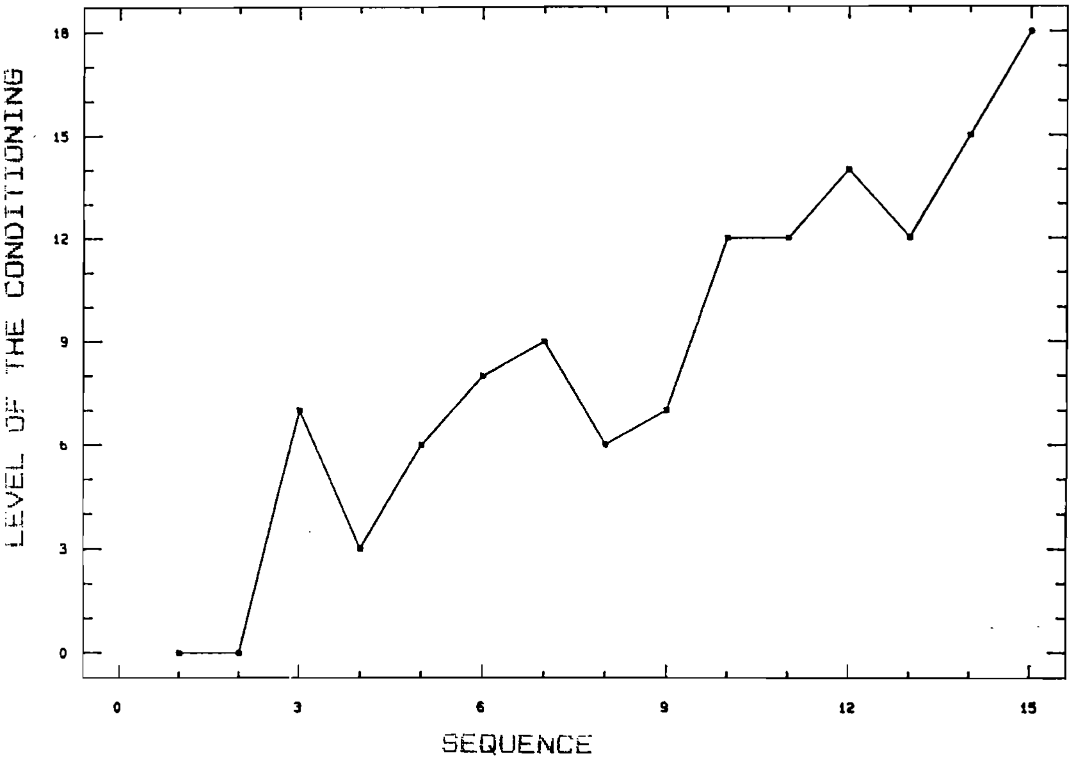

Fig 1. Evolution of the reaction during the conditioning phasis at the moment of the pertubation.

REPETITION	SOUND PULSE 1	SOUND PULSE 2	SOUND PULSE 3
1	/	**	***
2	***	***	***
3	/	/	**
4	/	/	**
5	/	/	/
6	/	*	*
7	/	/	/
8	/	/	/

Table 2. Levels of reaction during the second part of the experimental phasis.

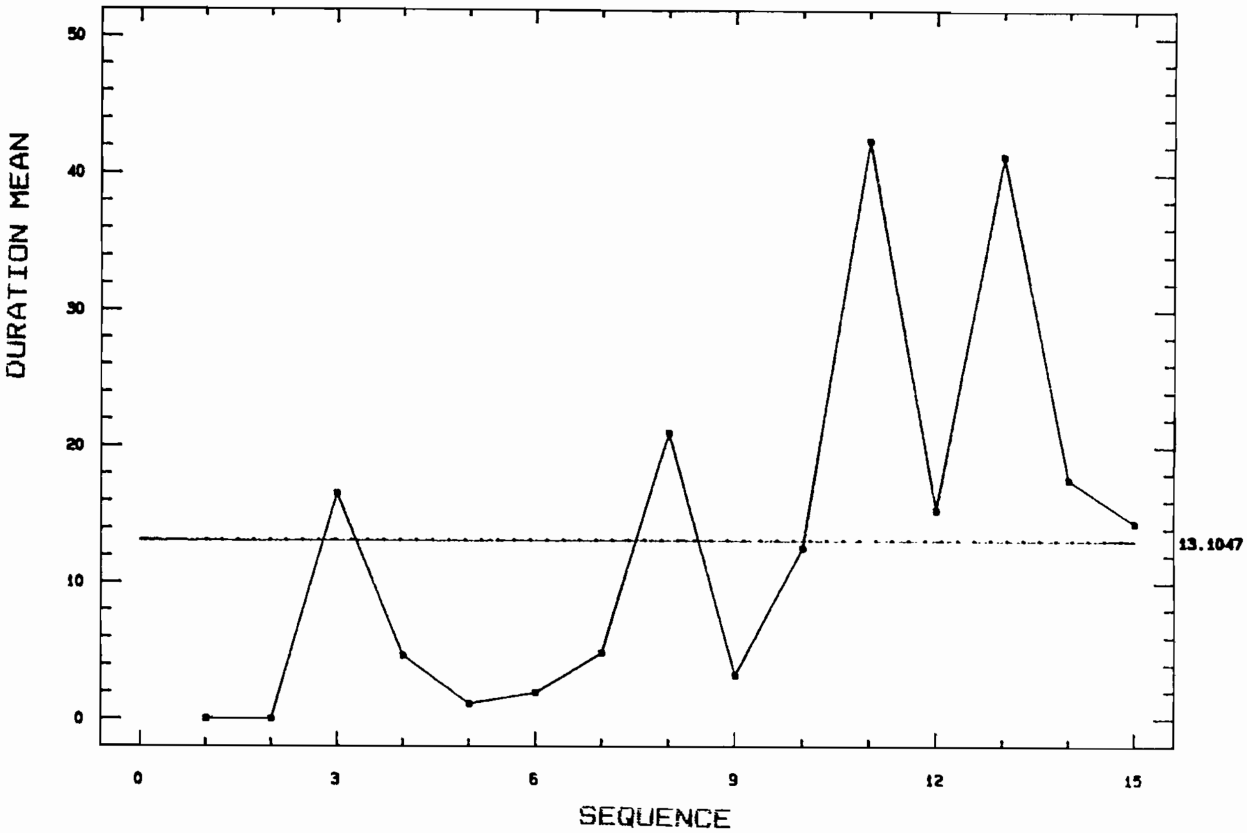

Fig 2. Evolution of the MILL structure duration during the conditioning phasis in the periode of pertubation

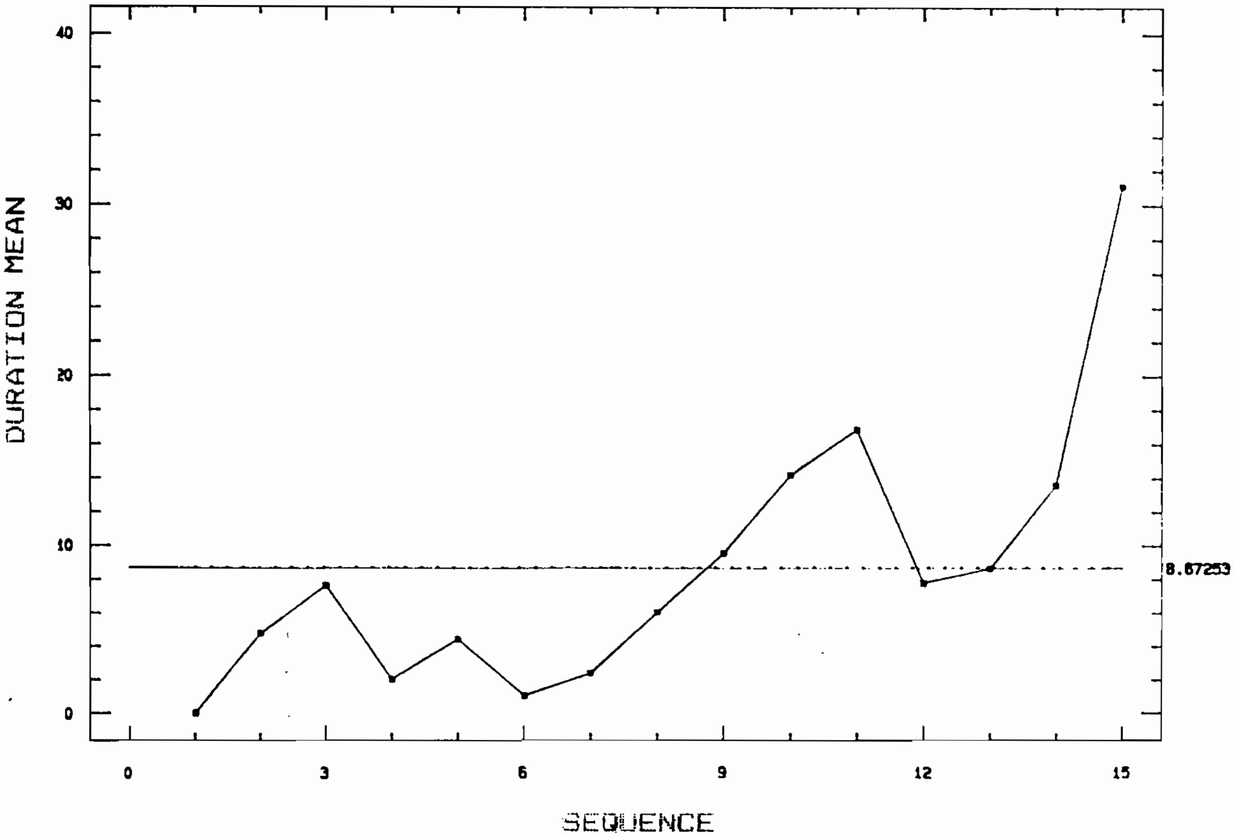

Fig 3. Evolution of the regrouping flight reaction during the conditioning phasis in the periode of pertubation.

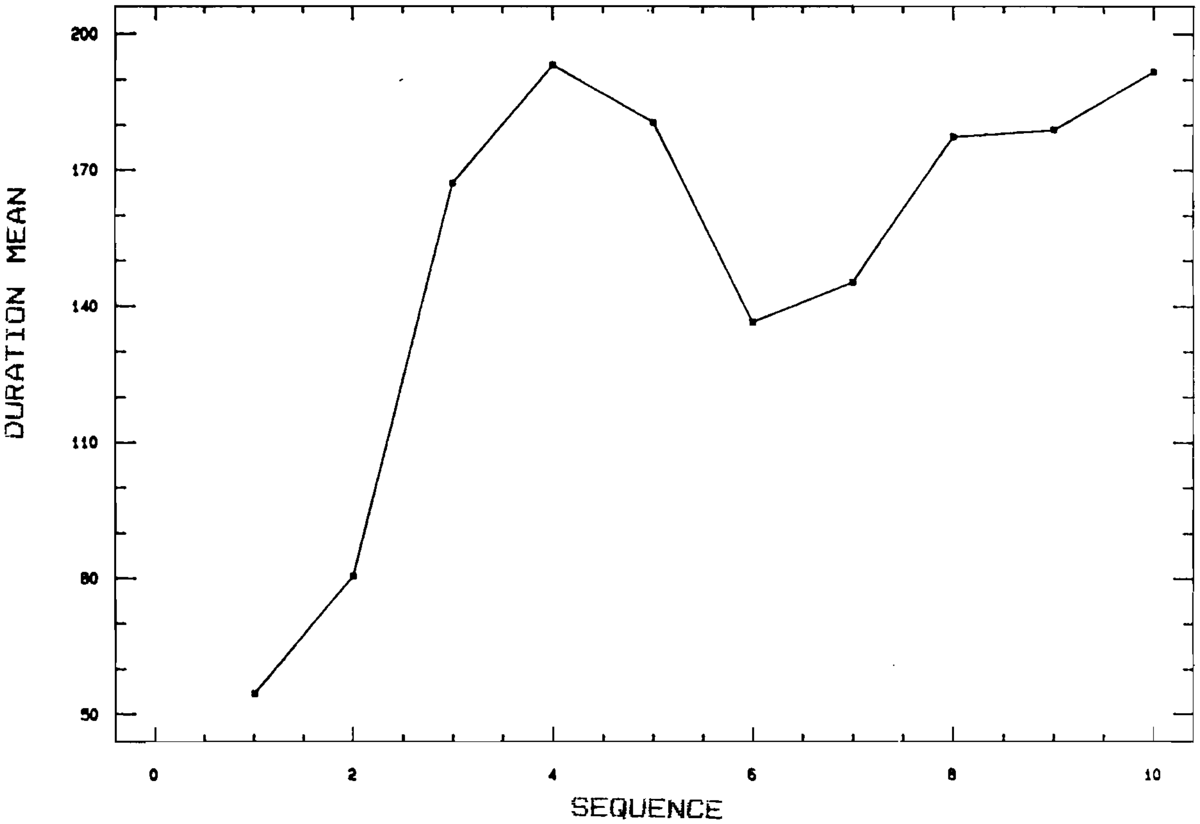

Fig 4. Evolution of the MILL structure duration during the experimental phasis in the periode of pertubation.

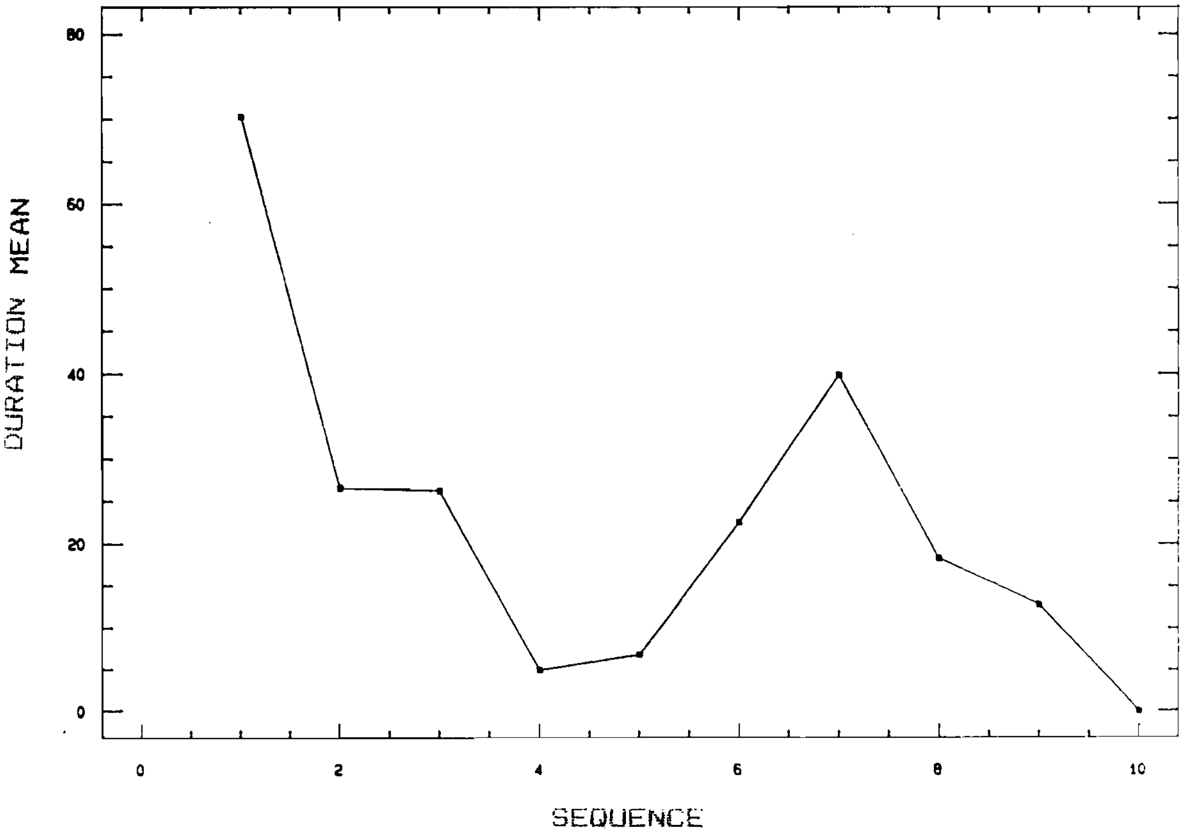

Fig 5. Evolution of the dispersion during the experimental phasis in the periode of pertubation.

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SEASONAL AND INTERANNUAL VARIATIONS OF MEAN CATCH PER SET IN THE SENEGALESE SARDINE FISHERIES: FISH BEHAVIOUR OR FISHING STRATEGY?

P. FREON

ORSTOM, Pôle Caraïbe, BP 81, 97256 Fort-de-France
Cédex, Martinique (French West Indies), France.

ABSTRACT

The annual c.p.u.e. and mean catch per set of the seiners working along the Petite Côte off Senegal from 1969 to 1987 have been studied using multivariate and time series analysis. The annual mean catch per set has decreased from 22 to 4 metric tons during this period.

This phenomenon may correspond both to a decrease in the proportion of the large schools in the stock, and to a real decrease of the overall abundance associated with a modification of fishing strategy: fishermen accept to catch smaller and smaller schools since larger schools are less frequently found. The increase in fishing effort and the variation of upwelling strength seem to govern these changes. The possibility of using the mean catch per set as an index of school size, and perhaps of abundance, is envisaged in the conclusion.

KEYWORDS

Schooling behaviour; catch/effort; Upwelling; Sardinella; Senegal.

INTRODUCTION

The industrial purse-seiner fishery of Senegal started in 1961 with one boat. After a period of learning and low effort, the number of boats increased irregularly from 2 boats in 1966 to 15-20 in 1985 (Boely and Chabanne, 1975; Fréon <u>et al.</u>, 1978; Fréon, 1986). Recently, the fleet declined, mainly for economical reasons (old boats, competition with small-scale fishery).

The small-scale and artisanal fishery is much older, but catches of coastal pelagic species increased dramatically in 1972 with the introduction of the purse-seine on existing canoes (Fréon <u>et al.</u>, 1978). This fishery provided more than 90% of the catches during recent years.

In both fisheries, which operate in partially overlapping fishing grounds, large variations of catches per unit of effort (c.p.u.e.) expressed in catch per search time, are observed at seasonal and interannual levels, largely because of fishing effort variations and environmental changes (Fréon, 1986). Both catch per set and c.p.u.e. show the same seasonal fluctuation and the same decreasing trend in the industrial fishery (Fréon, 1986). As the catch per set in such fisheries is more or less representative of the school size, the obvious question is: does the decrease of c.p.u.e. correspond to a decrease in the number of schools or to a decrease in their size, or both? In order to try to answer this question for the Sardinella spp. stocks off Senegal, an analysis of the bias in c.p.u.e. and school size as long-term indexes of abundance is performed, bearing in mind the influence of behavioral change in both fish and fishermen (i.e. changes in fish aggregation pattern or changes in fishing strategy).

The senegalese fisheries catch mainly young S. aurita and S. maderensis and more mature adult S. aurita and Carangidae. The mean time per trip is 10 hours, and zero to three successful sets are normally performed during this time period.

MATERIAL AND METHODS

Data on the industrial fishery were obtained from daily interviews with fishermen returning to the harbour or landing site after their daily trip. For the industrial fishery the rate of sampling is around 98% for catches and efforts, except in 1973 where it was lower than 80%; reliable and representative data are available from 1969. For the artisanal fishery, the annual data sets are complete only from 1977. Both series analyses stop in 1987, at the beginning of the industrial fishery collapse. In this paper, only the industrial fishery data are analyzed, except for total production modelling where total catches are considered.

Each record in the data files corresponds to the fishing operation of a single boat in a single area (except in 1976, a single area was fished during a trip in more than 95% of the annual observations). The catch per individual set is not recorded in the data files, but the numbers of successful and unsuccessful sets per trip/area are available. Therefore various indices of school size can be computed:

- the mean catch per total number of successful sets (c.p.t.s.s.); this provides the greatest possibility of underestimation of the school weight due to the possible saturation of boat-loading capacity when loading the last set;

- the mean catch per number of successful sets, selected for trips with only one successful set (c.p.s.s.1). About 37% successful sets are made during such trips. Except for very large schools, this index is designed to limit the saturation effect. It may underestimate the proportion of small schools.

- the mean catch per number of successful sets, selected for trips with only one successful set (as previously) and for the other trips when landings are obviously lower than boat-loading capacity (c.p.s.s.2). This index is used to overcome the previously mentioned possibility of underestimation.

The catch per time unit of searching and the catch per total time fishing (time searching plus time catching the fish) are considered the best indices of abundance for these fisheries, although not completely unbiased (Fréon, 1980). A summary of the available samples is presented in Table 1.

Table 1. Summary of available data for the industrial fishery from 1969 to 1987.

	Number of Sets	Number of trips
One successful set per trip	15 419	15 419
More than one successful set	26 276	11 672
Total successful sets	41 695	27 091
Unsuccessful sets	14 684	7 980
TOTAL sets	56 379	35 071

Other variables also recorded are: date, boat identification, weather at sea as declared by the captain, total time at sea, fishing area (20' latitude zones combined with choosen depth intervals), estimation of the landings, commercial categories (for each species). The time of day corresponding to each catch has been recorded since 1975. Appropriate meteorological data was available from the coastal station of Cap-Vert peninsula.

As most of the previous variables may be related directly or indirectly to the mean catch per set (size of the boat, temporal and spatial allocation of the fishing effort, etc), multivariate analyses were performed on the whole data set. Data was recoded in order to obtain a complete disjunctive table, then a factorial analysis performed from a Burt table (Benzecri, 1973).

RESULTS

General data set analysis

From the multivariate analyses (not shown), it is obvious that some significant changes occurred in the fishery during the period of study. Indexes of abundance and of school size both show a considerable decline (see below). The mean size of the boats, when weighted by their number of trips, did not change markedly (extreme annual values: 22.53 m in 1983 and 20.15 m in 1986). However, the range of boat sizes was greater in the eighties, owing to the arrival in the fishery of smaller boats (15-16m), operated by the government. The weather at sea varied considerably from year to year. According to fishermen interviewed, it was very bad in 1976 and from 1979 to 1986. Unfortunately this data is not always consistent by day or by area, nor is it correlated to meteorological data. The fishing area was slightly larger in the past. Fishing grounds were not as deep as those currently fished. During recent years, fishing operations more often took place later in the day or during the night (in comparison to the historical period). The proportion of different species in the catches changed from year to year, without clear long-term tendencies with the exception of a decrease in the young year-classes of S. aurita associated with an increase in the young year-classes of S. maderensis up to 1984, and a decrease of all other warm-season species (mainly Pomadasys spp., Chloroscombrus chrysurus and Ethmalosa fimbriata). The proportions of cold-season species (mainly Caranx rhonchus, Scomber japonicus, Trachurus spp., and the oldest year-classes of S. aurita) was subject to variation without visible trend (Table 2). Other variables concerning the fishing strategy did not change significantly.

Table 2. Proportion of the different species (%) landed by the industrial fishery from 1969 to 1987.
O-Sa: Old year classes of Sardinella aurita;
Y-Sa: Young classes of S. aurita;
Sm: S. maderensis; Cr: Caranx rhonchus;
Cc: Chloroscombrus chrysurus;
Ef: Ethmalosa fimbriata; Sj: Scomber japonicus;
Pspp: Pomadasys spp (mainly P. jubelini);
Tspp: Trachurus spp. (mainly T. trecae).

Year	O-Sa	Y-Sa	Sm	Cr	Cc	Ef	Sj	Pspp	Tspp	Oth.
69	40.0	13.4	25.7	7.1	4.2	0.9	0.0	7.5	0.1	1.1
70	29.9	18.9	24.4	9.2	3.9	1.0	0.3	10.4	0.1	1.9
71	59.2	6.6	14.2	0.9	0.2	4.0	0.0	15.0	0.0	0.0
72	62.6	6.2	17.8	4.7	0.2	1.0	0.0	7.1	0.0	0.4
73	48.5	4.5	26.2	4.2	2.2	0.4	0.3	6.5	0.5	6.7
74	30.6	21.5	29.2	5.3	2.0	0.5	0.3	3.8	3.5	3.3
75	32.9	7.6	31.0	5.3	0.7	0.8	9.8	1.7	5.4	4.8
76	28.2	18.4	37.5	6.0	0.5	0.4	0.2	1.2	3.5	4.1
77	28.8	19.6	33.3	6.0	1.0	0.9	0.2	2.9	2.0	5.3
78	27.8	29.2	24.4	7.2	1.0	0.0	0.2	3.5	1.2	5.5
79	29.2	22.5	33.1	6.4	0.9	0.0	0.6	1.0	0.5	5.8
80	20.9	31.4	31.5	9.5	1.2	0.0	1.0	0.3	0.5	3.7
81	21.9	27.8	34.5	8.2	0.5	0.0	3.0	0.3	2.1	1.7
82	9.2	15.3	50.4	14.4	0.7	0.2	1.7	1.4	3.5	3.2
83	9.3	19.1	51.4	5.5	0.8	1.4	5.5	0.1	5.1	1.8
84	15.8	9.1	49.0	1.4	0.9	2.4	9.4	0.9	5.5	5.6
85	47.9	8.8	32.4	1.0	1.8	0.0	0.5	0.6	3.6	3.4
86	35.8	7.8	38.6	2.0	1.0	0.1	4.6	0.0	3.2	6.9
87	55.7	6.0	28.3	0.1	0.6	0.0	4.4	0.0	2.5	2.4

Even though the factorial analysis is mainly a qualitative descriptive method, it indicates no important aspect of the above described long-term changes on annual abundance and school-size indexes; this despite strong seasonal or daily variable influences (example, weather at sea (Levenez, in preparation), hour of the catch, etc). The only exception is, to some extent, the influence of average boat size.

The comparatively weak influence of boat size and equipment on c.p.u.e. was mentioned in a previous study using only 1977 data (Fréon, 1980). Using the whole data set, the recent introduction of small boats shows the effect of boat size on different variables, especially on the mean catch per set. Therefore, the analysis was done using only medium-size boats (18 to 23 m), which represent the bulk of the fleet, except during the last years. Fortunately an old boat has been working continuously during the period studied, and its data have been processed separately; similar figures were obtained.

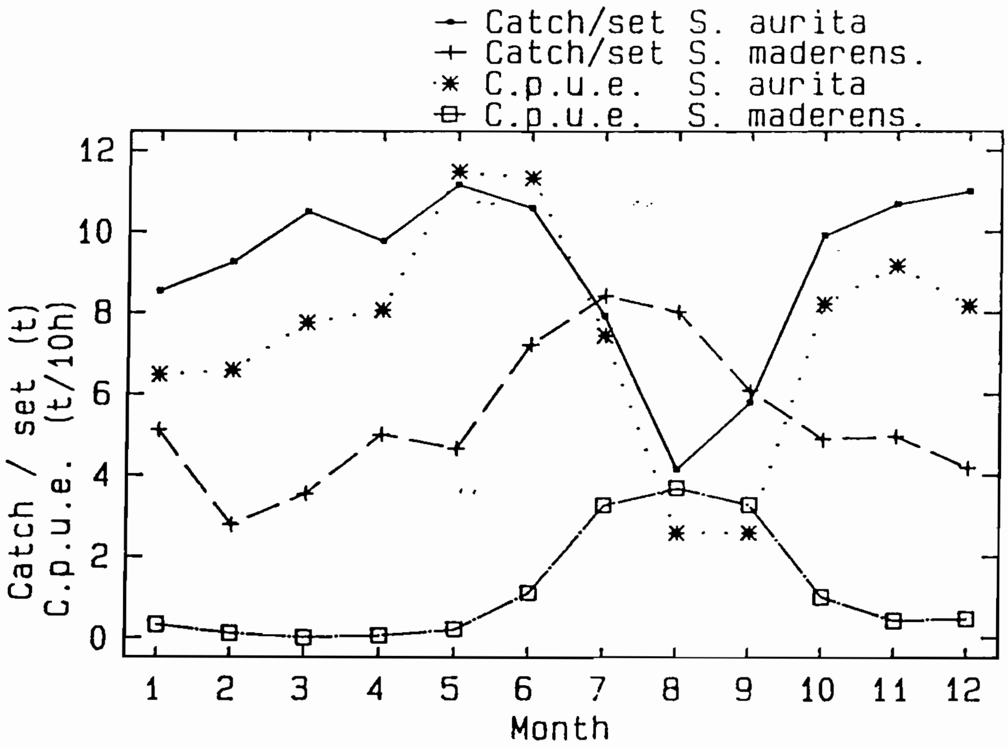

Fig. 1. Seasonal variations of the mean catch per set and of the c.p.u.e. (weight per time search) for S. aurita and S. maderensis computed from the 1969 to 1987 observations.

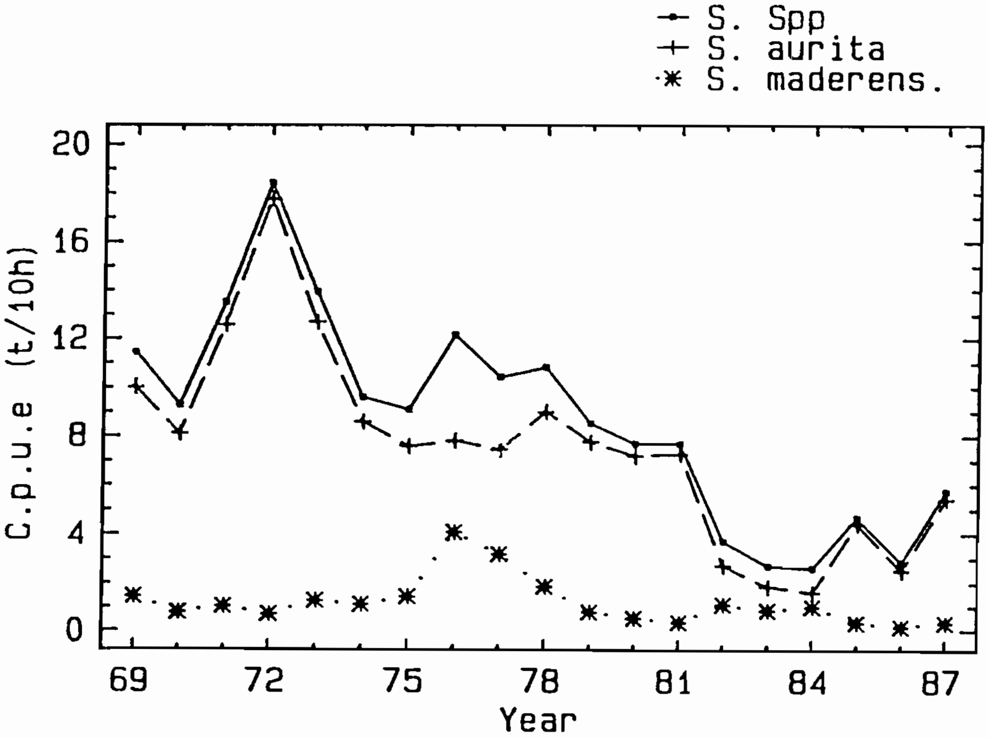

Fig. 2. Interannual variation of c.p.u.e. of medium size purse seiners from 1969 to 1987.

C.p.u.e. analyses

The c.p.u.e. of the industrial fishery shows large seasonal and interannual variations, mainly due to the two principal species of Clupeidae: <u>Sardinella aurita</u> and <u>Sardinella maderensis</u> (Fig. 1 and 2) which account for respectively 47% and 31% of the catches over the period studied. Such variations have already been explained by:

-the increasing fishing effort over this period (explaining the general decreasing trend in c.p.u.e.),

-the interannual fluctuations of the upwelling, shown in Fig.3 (explaining most of the abundance anomalies after suppression of effort effect),

-the seasonal fluctuations of the upwelling and the associated fish migrations and/or seasonal abundance variations.

From these observations a surplus production model including an upwelling index has been developed (Fréon, 1986).

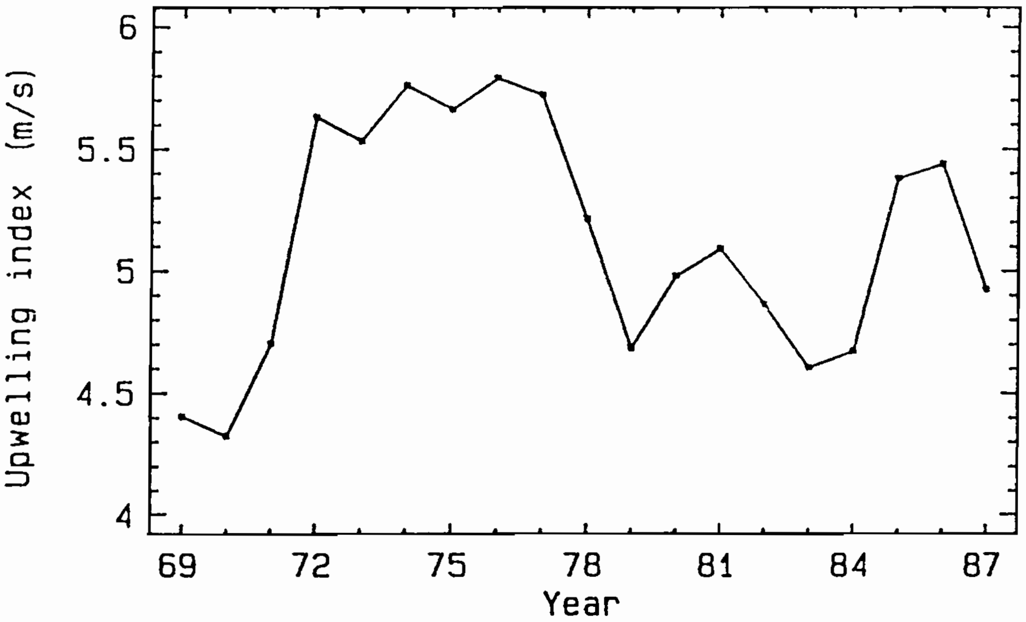

Fig. 3. Upwelling index from 1968 to 1987: mean wind speed from November to May (source: ASECNA).

School size index analyses

The catches per set (Fig. 4) and the c.p.u.e. (Fig. 2) exhibit similar trends, whether when considering the c.t.s.s. (decreasing from 22 to 4 metric tons; not shown), the c.p.s.s.1 or the c.p.s.s.2. Since the c.p.u.e. is the product of the mean catch per set (w) by the number of sets (n) per fishing effort (f) (c.p.u.e. = w n / f), the number of successful sets by time fished did not show a steady change during the period of observation. Only a slight increase of this value can be noted from 1970 (Fig. 5). The interpretation of <u>S. maderensis</u> figures is not so easy because this species is less abundant and often mixed with <u>S. aurita</u> in a single school (see below).

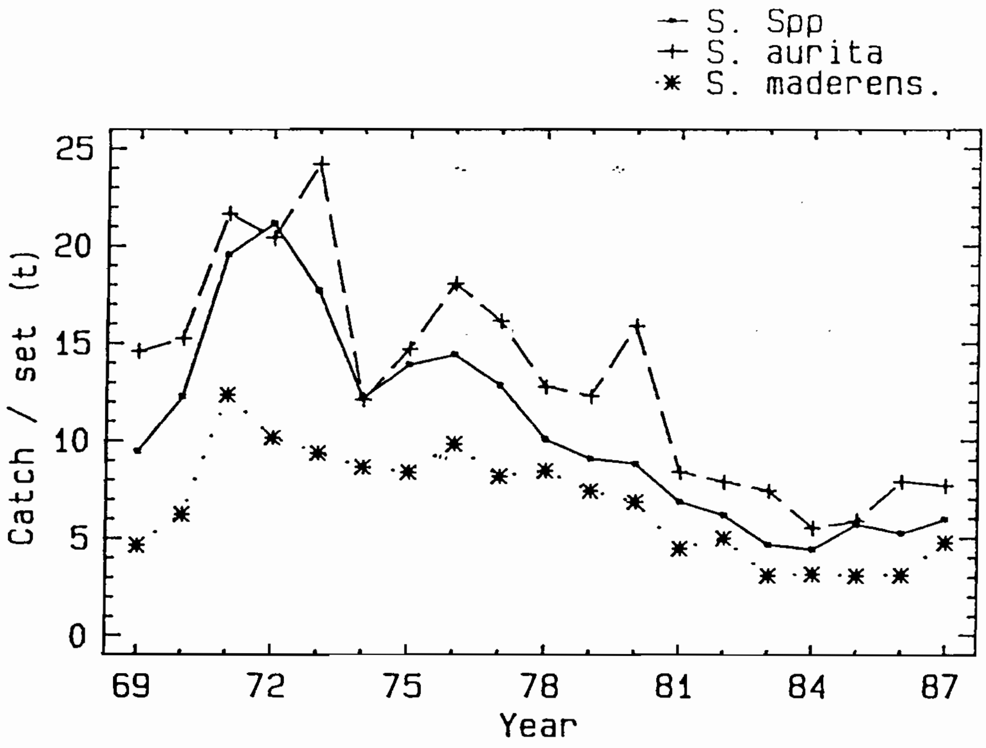

Fig. 4. Interannual variation of mean weight of catch per set c.p.s.s.2 (see text) of S.aurita, S. maderensis or of both species (1969-1987).

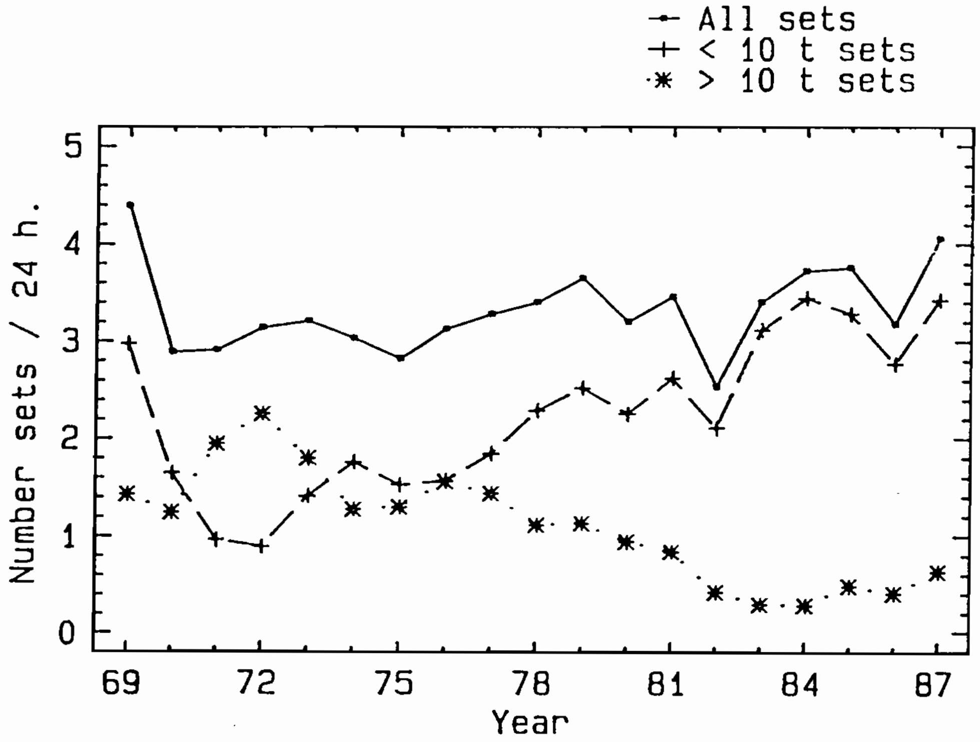

Fig. 5. Number of sets of Sardinella Spp. per 24 hour search for medium size seiners (1969-1987).

When looking at the evolution of set occurrence per time fished for each weight-classes separately, it appears that the decreasing trend in c.p.u.e. and catch per set is due both to an increase in the small schools occurrence in the catches (less than 10 metric tons) and to a decrease in the large and medium size schools (over 10 tons; Fig. 5).

The seasonal variation in the catch per set is, once more, related to the c.p.u.e. index (Fig. 1). A clear opposition between the two species of sardine can be observed: *S. aurita* is more abundant during the cold season and forms large schools between October and June; the largest schools of *S. maderensis* are observed between June and September. Such an opposition reflects the complementary demographic strategies developed by these two species in order to limit their competition. On these lines, Cury and Fontana (1989) stressed the differences in the reproductive strategies of these species which have very close feeding behaviours. Nevertheless, the competition does not seem to be completly avoided: the two species are often mixed in the same set, and probably in the same school (Fréon, 1984), especially during the warm season, where young spawners are caught (Table 3).

Table 3. Half Burt table showing the co-occurence of the two species of *Sardinella* in a single set, according to their body length group (empirical commercial categories by increasing size given by the fishermen, from I to VIII).

Species & Size		*Sardinella aurita*								*Sardinella maderensis*						
		I	II	III	IV	V	VI	VII	VIII	I	II	III	IV	V	VI	VII
S.	I	88														
	II	0	86													
a	III	0	4	476												
u	IV	0	1	4	2608											
r	V	1	2	0	5	3314										
i	VI	0	0	0	0	5	305									
t	VII	0	0	1	8	2	0	3258								
a	VIII	0	0	0	0	0	0	0	136							
S.	I	42	5	10	9	6	0	0	0	89						
m	II	0	45	13	45	2	0	2	0	0	113					
a	III	36	11	210	164	175	4	3	3	4	3	641				
d	IV	2	14	108	1746	1487	50	132	44	2	0	7	4724			
e	V	0	2	9	110	1083	77	375	26	0	0	5	10	2103		
r	VI	0	0	0	5	34	63	7	0	0	0	5	6	11	121	
.	VII	0	0	0	6	4	0	99	0	0	0	0	0	0	0	120

DISCUSSION

Many factors can affect the recorded catch per set of a purse-seiner:

-the size of the net, and the boat-loading capacity, which can both lead to an underestimation of school size,

-the decision of the fisherman in shooting the net or not, according to his estimation of school size (especially for small schools), and to his hopes for subsequent fish-finding,

-the size of the schools on the fishing grounds (this is our main hypothesis). Changes in school size or form according to a circadian rhythm, to predation pressure or to environmental conditions, especially food density, are well documented (Kemmerer, 1980; Pitcher, 1986; Blaxter and Hunter, 1982). More debated is the influence of the fishing pressure on the school size (Nonoda, 1985).

It is obvious that the small senegalese purse-seiners are not able to catch or load the largest schools (40 to 100 tons according to boat size).From acoustic surveys we know that the mean size of schools in the area was around 10 tons in 1976 and that schools over 40 tons were infrequent (Gerlotto <u>et al.</u>, 1976). In this paper we try to analyse the changes in the medium and small size of schools, where saturation effects do not occur.

When considering trips with a single successful set, the problem of saturation is limited. In consequence, the mean values of catch per set are higher and the differences between boats of different size are less marked.

The stategy of the fishermen may vary according to the fish abundance and possibly to its current market value. Especially for the first set of the trip, the fisherman will probably disregard small schools and shoot them only in case of low abundance, when expectation of a better finding is low. This phenomenon seems responsible for the increase in the number of schools smaller than 10 tons from 1972 to 1987 (Fig. 5). During this period, the conjunction of increasing effort and decreasing upwelling has reduced abundance. The problem is to discriminate the effect of fishing strategy from a possible direct effect of the environment or fishing pressure on the size of the schools present on the fishing grounds.

Another way to tackle the problem is to look at the evolution of large set occurrence. By exclusively selecting trips with a single successful set, we overcome not only the saturation problem but also remove most of the eventual influence of fishermen's behaviour: in any situation the fishermen will always prefer to shoot the large schools. It appears clear that the occurrence of schools over 30 tons decreased markedly during the 1972-85 period.

Of particular interest is the relatively high occurrence of small sets in 1969 and 1970 (Fig. 5). The situation was not similar to the mid-seventies period, even though identical values of catch per set were observed: the upwelling strength was at its minimum and fishing pressure was lower. The weakness of the upwelling seems the major event which explains the relative abundance of small sets during this period. A comparative study of the anomalies of cpue, catch per set and upwelling index was performed after removing the autocorrelation in the series by using the residuals of ARIMA models (Box and Jenkins, 1976). The study of the cross-correlation functions clearely indicates lagged relationship (from 2 to 14 month, according to the period of the year) between upwelling and c.p.u.e. series, and a weaker relationship between upwelling and catch per set.

Finally, it seems that both environmental conditions and exploitation level influence school size. The fishermen's strategy obviously overestimates decrease of mean school size when the size of the sets is analyzed, because they accept to shoot smaller schools in the case of low abundance. Nevertheless, if used carefully, the mean catch per set can provide a reliable index of mean school size and maybe of abundance, associated to the analyses of the number of schools per weight class detected per time unit. The smallest weight classes must be eliminated before analysis, and special attention must be paid to any changes in the fishery (gear, equipment, size of boat, time of fishing, market, etc).

Using the c.p.s.s.2 (after removing the sets of less than 2 tons) as an index of abundance for both species of Sardinella, a surplus production model including the upwelling index has been adjusted successfully (Fréon, this meeting). The theoretical effort index is in this case proportional to the number of sets, and it provides a more realistic picture of the evolution of fishing pressure than the results obtained by dividing the total catch by the c.p.u.e.. Nevertheless, further studies on the artisanal fishery (which seems to present a different pattern) and on other stocks are required before adopting such an abundance index.

CONCLUSION

In the senegalese fisheries, the mean catch per set presents large seasonal and interannual variations, mainly related to school size and secondarily to the fishermen's strategy as far as small sets are concerned.

For purse-seine fisheries of pelagic species, the time searching for fish is usually considered as the best effort unit to be used in c.p.u.e. calculation, as far as abundance index is concerned. Nevertheless the use of such an effort unit may introduce a bias in stock assessment, specially in the case of overexploited stocks of coastal pelagic fish where a reduction of the area of distribution is often observed. The analyses of the mean catch per set and of the number of sets do not overcome all the problems, but represents a complementary information for stock assessment. Moreover, the distribution of school weight is important in managing the fishery (size of gear, loading capacity of the boat).

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POLE DE RECHERCHE OCEANOLOGIQUE ET HALIEUTIQUE CARAIBE

Cette entité scientifique est née en 1985 de la mise en commun des capacités locales de recherche de l'IFREMER (Institut Français pour l'Exploitation de la Mer), de l'ORSTOM (Institut Français de Recherche Scientifique pour le Développement en Coopération) et de l'UAG (Université des Antilles et de la Guyane).

Son objectif est de :

- promouvoir, mettre en œuvre et coordonner les recherches concernant le milieu, la gestion des ressources vivantes, le développement et l'aménagement de leur exploitation dans la zone caraïbe ainsi que la connaissance et la conservation des écosystèmes.

Ses recherches portent, actuellement, sur l'étude des écosystèmes marins, l'évaluation et l'aménagement des pêcheries artisanale et industrielle, l'aquaculture des mollusques, crustacés et poissons.

Ses laboratoires se situent en Guadeloupe, Guyane et Martinique et des chercheurs du Pôle peuvent être accueillis dans différents laboratoires par des équipes de pays voisins dans le cadre d'accords bilatéraux de coopération *(voir en dernière page la liste des laboratoires et antennes).*

This scientific entity was born in 1985, resulting from the local association of three national research institutes : IFREMER (Institut Français de Recherche pour l'Exploitation de la Mer), ORSTOM (Institut Français de Recherche Scientifique pour le Développement en Coopération) and UAG (Université des Antilles et de la Guyane).

Its aim is to advance, realize and coordinate the research concerning the physical oceanography, the managment of living ressources, the development and planning of their use in the caribbean area as well as the understanding and protection of their ecosystems.

Its research programs deal with : the study of marine ecosystems, the evaluation and planning of the small scale and industrial fisheries and the aquaculture of molluscs, crustaceans and fish.

The laboratories belonging to this group are situated in Guadeloupe, French Guyana and Martinique, but the scientific teams can be based in other laboratories of neighbouring countries through cooperative joint-ventures. *(See laboratories index on the last page).*

Esta entitad nació en 1985 de la confluencia de las capacidades locales de investigación del IFREMER (Institut Français pour l'Exploitation de la Mer), del ORSTOM (Institut Français de Recherche Scientifique pour le Développement en Coopération) y de la UAG (Universidad de las Antillas y la Guyana francesas).

Su objetivo es promover, realizar y coordinar las investigaciones tocantes al medio, a la administración de los recursos vivos, al desarrollo y al fomento de su explotación en el área del Caribe así como al conocimiento y a la conservación de los ecosistemas.

Sus investigaciones actuales conciernen el estudio de los ecosistemas marinos, las evaluaciones y ordenación de las pesquerias artesanal e industrial, el cultivo acuatico de los moluscos, crustáceos y peces.

Sus laboratorios se ubican en Guadalupe, Guyana y Martinica y sus investigadores pueden laborar en varios laboratorios con equipos cientificos de los países vecinos en el marco de convenciones bilaterales de cooperación. *(Ver la lista de los laboratorios en la ultima pagina.)*