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Identification and spatial stratification of tropical fish concentrations using acoustic populations

François Gerlotto

ORSTOM, Centre de Montpellier, B.P. 5045,
34032 Montpellier cedex 1, France.

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Abstract

One of the main limitations in acoustic stock assessment is fish identification. We propose here a new method for identifying several communities of tropical fish within a surveyed area. This method, called "Acoustic Populations", consists in splitting a study area in systematic regular strata such as geographical rectangles, and calculating for each stratum a set of acoustic parameters that can be easily obtained with conventional acoustic equipment, and have a discriminant power, such as target strength, mean density, confidence interval and dispersion indexes. It is based on the fact that the biological (specific diversity, physiology) and ethological (gregarism, migrations, etc.) characteristics of fish communities have a particular influence on the echoes recorded, which become characteristical and thus are able to discriminate acoustically several populations. An example of application of the method is given for Eastern Venezuela, and the use of the results for mapping, evaluation and stratification of acoustic data is discussed.

Keywords: Acoustics, echo-integration, stratification, stock identification.

L'identification et la stratification des concentrations de poissons tropicaux par le biais des populations acoustiques

Résumé

L'une des limitations les plus importantes dans l'application des méthodes acoustiques d'évaluation des stocks réside dans la difficulté à identifier correctement les espèces dans des communautés multispécifiques, en particulier dans les zones tropicales. Ce travail présente une méthode permettant l'identification de communautés distinctes dans une zone tropicale par l'utilisation de paramètres acoustiques facile à obtenir à partir de matériel de prospection courant, tels les index de réflexion des cibles, les densités moyennes, les indices de dispersion, etc. La méthode est fondée sur les différences qui apparaissent d'une communauté à l'autre au niveau des caractéristiques biologiques (diversité spécifique, physiologie) ou éthologiques (grégarisme, migrations, etc.). Ces différences induisent des effets différents sur les échos enregistrés. Ceux-ci, répartis par strates rectangulaires, permettent par leur pouvoir discriminant de regrouper les rectangles en populations distinctes. Un exemple de l'application de cette méthode sur les stocks du Venezuela oriental est présenté. Nous discutons l'application de cette méthode et l'utilisation des résultats en termes d'identification et de stratification des données acoustiques de densité.

Mots-clés : acoustique, écho-intégration, stratification, identification.

INTRODUCTION

Acoustic fish stock assessment is an indirect method, as it measures echoes from fish, and not the fish themselves. The transformation from echo distribution to fish population distribution requires several pieces of information. First the proportionality between fish echoes and fish biomass must be demonstrated, which has been already done (Foote, 1982). Then the identification of fish species is indispensable, in order to determine the specific biomass. This information is obtained by way of direct observation, such as trawl fishing, or in some cases through the study of commercial catches.

This is often the weak point of acoustic studies, even in the case of "northern areas" (Nakken and Ultang, 1983; Rose, 1992) where fish communities are composed of a small number of species. This objective is almost impossible to achieve when considering tropical communities, which are highly multispecific. Roman (1980), for instance, numbers 15 Clupeidae, 15 Engraulidae, 29 Carangidae, and several species of other families in the pelagic community of Eastern Venezuela. This example shows that, even when the species are gathered into a few homogeneous groups (Stroemme and Saetersdal, 1989), fishing results are often unable to give a reliable picture of species proportions.

Several acoustic methods have been designed in order to overcome this limitation. A synthesis is given by Simmonds *et al.* (1992). These authors divide the available methods into three main categories.

1. Use of wide band echo sounders

The pulse emitted is modulated along a wide band of frequencies and the spectra of the echoes are analysed. Each species typically presents a characteristic spectrum, due to anatomic differences, which allows identification of targets. Such methods have been developed by Simmonds and Armstrong (1987); Lebourges (1990); Zakharia and Sessarego (1982); Bjorno and Kjaergard (1986), etc. The results are encouraging, but at present the equipment required is experimental and the number of species discriminated remains lower than 4. The method is not yet usable in a routine survey.

2. Automatic analysis of the echoes

Selected discriminant characteristics of the echoes of scattered fish or of a single school are used for identification. Such a method has been successfully used by Rose and Leggett (1988) on 3 species. The addition of other species within this protocol has also been described (Rose, 1992). Souid (1988) has applied it to separate schools up to 3 species, by way of the geometrical characteristics of the school. We may cite also Giryn *et al.* (1981). These methods do not require specialized echo sounders and are applicable in routine surveys (Scalabrin and Massé, 1993). Nevertheless their applicability to more than 3 or 4 species has not yet been demonstrated.

3. Indirect methods

These use both acoustic characteristics of the echo and geometrical information on the concentration, to identify the aquatic communities. These methods have been applied by Azzali (1982), on the Adriatic sardine; Nion and Castaldo (1982), on the Pacific anchovy; Vray *et al.* (1982) on Salmonids of Lake Annecy. To date they have been applied exclusively to simple stocks, although they may be applied to more complex systems. They require no particular material.

Methods 1 and 2 are unlikely to be suitable for tropical stocks, as it has not yet been proved that they could be applied to multispecific communities: the highest number of species discriminated by such methods does not exceed 5 or 6 (Rose, 1992). On the contrary, an adaptation of method 3 seems possible, as long as we do not require identification at the species level to delimit communities. It is such an adaptation that is presented in this paper.

THE CONCEPT OF ACOUSTIC POPULATION

Fish do not occupy space at random. Each species and each community tends to use space in a particular way. Such spatial behaviour should make it possible to extract from the echoes more than the simple value of density (Souid, 1988; Rose and Leggett, 1988). Spatial structures have been used as the basis for some of the identification methods. A limitation of these methods is that the fish may not occupy space always in the same manner (Fréon *et al.*, 1990; Scalabrin and Massé, 1993). When considering communities instead of species, and a single survey instead of permanent characteristics, these limitations disappear: we consider global variations and not specific characteristics. Using this observation, we have created a more generalized concept, called "acoustic populations" (Gerlotto and Marchal, 1987). Basically, an acoustic population is a population of echoes which may be gathered in a single group owing to their common characteristics. Then the key point is to consider if this acoustic population is correlated with a natural community that it could describe.

Numerous species of tropical fish are gathered into coherent communities according to different environmental factors: upwellings, bottom types, trophic systems, water temperature and salinity, and productivity. Such a community may be defined as a group of species gathered in constant proportions (during the time of a single survey), each species being characterized within the community by its demographic structure, its biological and physiological conditions and its behaviour. As far as acoustics are concerned, the echoes represent the synthesis of these characteristics. Therefore an acoustic population is defined from the following hypothesis: the biological and behavioural characteristics of the species that constitute a community are sufficiently permanent and typical so that their synthesis may characterize the community. In this case the community may be described by the acoustic data that depend on these characteristics, and the synthesis of the acoustic data represents the acoustic population.

Principles

The echo of a fish depends on both biological and behavioural characteristics of that fish.

– *Anatomy*

This is the main factor, as the echo is dependent on the dimensions and consistency of the target. Many workers have presented the relationship of fish anatomy and target strength. Among them we may cite Foote (1980) and Foote and Ona (1985) who calculated the correlation between target strength and the dimensions of the swimbladder of the fish. The target strength may be also influenced by the shape of the scales, the skeleton, and above all the length of the fish (Love, 1971).

– *Physiology*

It has also a strong influence on the target strength of the fish through the changes in the consistency of the flesh and organs. Ona (1987) presents the variability of the target strength according to characteristics in the main physiological characteristics of the fish: changes in the volume of the swimbladder due to the depth, the stomach content, the reproduction stage, the proportion of fat tissues in the body.

– *Fish position*

According to the position of the fish, the echo may be quite different: the target strength depends on the tilt angle of the fish (Nakken and Olsen, 1977). This tilt angle changes according to the species (He and Wardle, 1986) and the hour of the day (Buerkle, 1983; Aoki and Inagaki, 1986). Finally the single echo depends on the packing density of the fish, which may produce a phenomenon of acoustic shadowing (Röttingen, 1976; Foote, 1982; Toresen, 1990; Appenzeller and Leggett, 1992).

– *Fish distribution*

The fish may gather in different ways: dense schools, shoals, layers, scattered all over the water column or in preferential depths (demersal, pelagic), with circadian changes. These situations are easy to observe on the echograms and may be analyzed.

MATERIAL AND METHODS

We applied the concept of "acoustic population" to Eastern Venezuela (*fig.* 1), using the data of a survey ("*Echoven* 2") performed from 12 August to 11 September 1986. This area is characterized by a rather large and regular continental shelf, with mean depth 50 metres, limited on the east by the brackish waters of the Orinoco River, on the west by the Cariaco deep (around 1 500 m) and on the north by the 200 m depth line. This area presents a high primary production, due to the presence of several upwellings along the coast of the continent as well as the islands. The fish biomass, evaluated around 1.2 million tons during this survey, is principally due to a large stock of Spanish sardine (*Sardinella aurita*), representing 800 000 tons (Gerlotto and Elguezabal, 1986; Stroemme and Saetersdal, 1989; Cardenas, 1992).

Material

The scientific equipment was as follows.

– An echo sounder SIMRAD, EK 400, 120 kHz. The time variable gain (TVG) function was adjusted at 20 log R.

– A digital echo integrator AGENOR, processing the data within 10 vertical layers. A threshold of 50 mV was adjusted. The sampling distance or elementary sampling distance unit (ESDU) was defined as the distance covered by the vessel in 6 minutes, *i.e.* around 0.7 nautical mile, at a speed of 7 knots.

– Salinity/temperature sensors: surface temperature were recorded continuously and surface salinity each hour along the transects. Only surface measurements were performed.

– Pelagic trawl. We have used a 10 m vertical opening trawl, with 8-metre meshes in the mouth and 15 mm in the codend (this trawl is especially adapted to the catching of small Clupeidae). The sampling using this trawl was decided according to the acoustic observation: fishing was decided in both cases of high apparent abundance of fish or appearance of new kinds of detection.

The survey strategy was to cover the whole area with parallel equidistant transects, once by day and once by night (*fig.* 2), and to go back on the upwelling areas as well as on those areas where high densities were observed. The coverage was lower on the eastern part of the area (one transect each 20 mile instead of 10) due to the previous observation that the fish biomass in this part of the area is almost negligible.

Method

Once the concept of "acoustic population" is defined, the methodology is as follows.

– A set of discriminant acoustic characteristics is selected and the data are collected during the survey;

– These characteristics are grouped in elements of surface, such as rectangles of determined dimension (MacLennan and MacKenzie, 1988; Gerlotto, 1989).

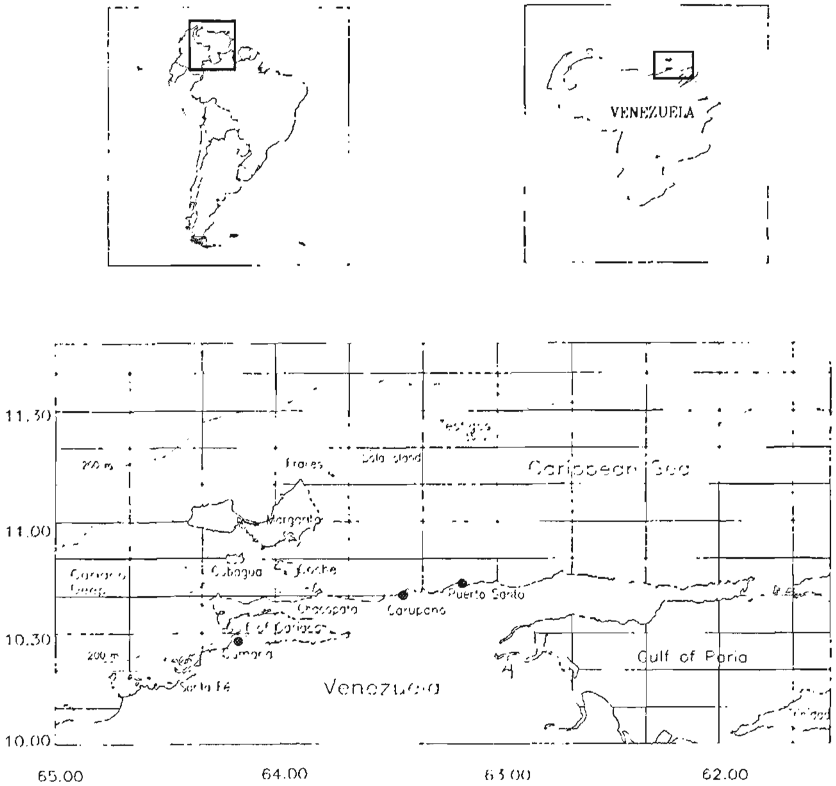

Figure 1. – Study area (Eastern Venezuela).

– A hierarchical classification is calculated on the rectangles as individuals, using the data sets of each rectangle as variables. This calculation separates the rectangles into several acoustic populations.

– The acoustic populations are mapped and all the information available on species proportions (such as scientific and commercial fisheries) are used to "translate" the acoustic populations into the corresponding natural communities.

The first step is to select a set of discriminant characteristics. Almost all the acoustic data may give valuable information, so we have to define which ones are the main characteristics. The two main criteria are the following: they must be easy to collect during routine survey without specific equipment and they must be logically connected to a main biological or behavioural characteristic of the community. We decided to use only acoustic data. Other parameters, such as mean depth, distance from the coast or hydrology, may be used, in order to explain the distribution of the populations.

The main biological and ethological characteristics that have an influence on the communities are: (1) anatomy of fish and species proportions, (2) concentration on special areas (spawning areas, hatcheries, feeding grounds, physiological preferences), (3) situation in the water column, (4) gregarious or solitary behaviour, (5) pelagic or demersal behaviour, (6) circadian rhythms.

Each of these characteristics may be related to a corresponding acoustic characteristic.

(1) *Anatomy and species proportions.* The most obvious criterion is the target strength distribution *in situ.* When the acoustic equipment used does not provide this information, correlated data may be used. Following Marchal (1988), we can take advantage of the sampling of the signal that any digital echo integrator is doing to transform an analogic signal to digital. In the case of the digital sampling of the echo integrator AGENOR that we have used, as in most of the cases, the sampling frequency is 7.5 kHz, therefore a sample represents a 10 cm high layer. We can use the "ratio of density per positive sampling", which is the ratio of the densities calculated by an echo integrator to the number of digital samples of the acoustic signal where the calculated density is above a defined threshold, which is correlated to the structure of the aggregation and to the weight of single fish.

(2) *Concentration on particular areas.* The most evident criterion is the mean density per ESDU (elementary sampling distance unit).

(3) *Position in the water column.* The occupation of space (layers, dispersed, in schools or shoals) may be represented simply by the ratio of the "positive samples" to the total number of samples (Marchal, 1988): this ratio gives the number of elementary samples which contain targets (above a

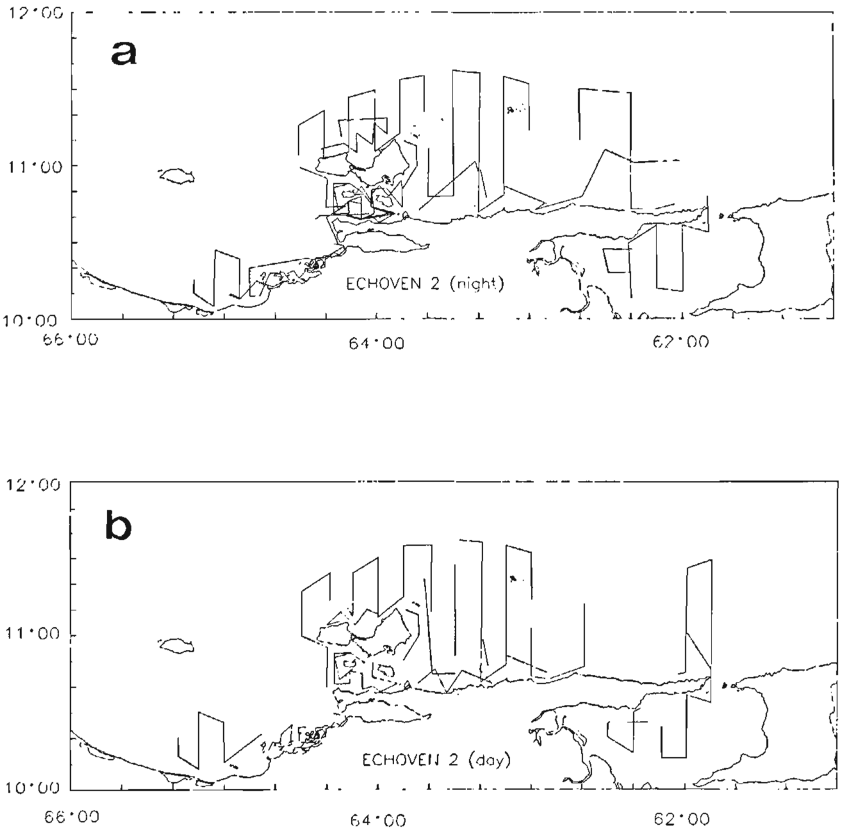

Figure 2. – Transect design during "*Echoven* 2" survey (night (a) and day (b) considered separately).

given threshold) compared to the total volume of water.

(4) *Gregarious or solitary behaviour.* We consider that a good representation of this behaviour is the confidence interval of the densities within the strata (rectangles): the most concentrated is the fish, the most heterogeneous is the area, and the highest is the confidence interval.

(5) *Pelagic/demersal behaviour.* We use the number of pelagic and demersal schools per ESDU. The mean density of the schools can be used also, but we did not consider it on our example.

(6) *Circadian behaviour.* We consider the ratio between the parameters already presented collected by day and by night.

RESULTS

Hydrological characteristics

The map of surface salinities shows clearly the limits of the influence of the Orinoco River in the eastern part of the area (*fig.* 3). The Gulf of Paria appears as a particular area, more similar to a brackish lagoon than to an oceanic gulf. The temperatures show a similar structure, with visible upwellings along the coast of Carupano and in the North of Margarita.

Fishing

30 pelagic trawlings were performed in the area, 27 of which resulted in catches (*fig.* 4). The results of the trawlings show high concentrations of Spanish sardine around the upwelling areas, and their absence in the other regions. The fauna of the Gulf of Paria is completely different from that of other areas (*table* 1). These catch results need some discussion.

– *Representativity of the catch.* It is known that a pelagic trawl does not catch all the species, for several reasons: first it is usually designed for some particular target species and sizes (Pope *et al.*, 1975). Second, usually once a school is caught, the trawl is unable to proceed with fishing efficiently. The first species caught is over-represented and the specific proportions are not realistic in a single sample. Extrapolation of the results to a large area must be done with caution (Simmonds *et al.*, 1992).

– *Description of specific distribution.* Specific mapping is not possible but for the most common species. We show in *figure* 4 *a* where the fishing samples are located and if *Sardinella aurita* were

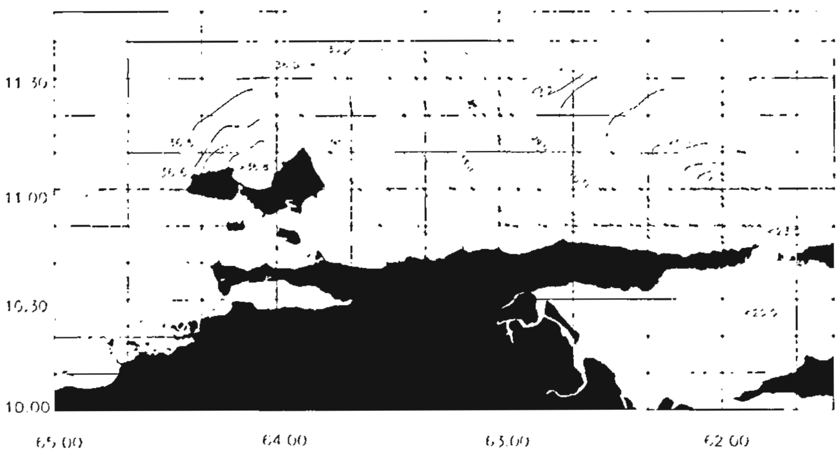

Figure 3. – Surface salinity structure observed during "*Echoven* 2" survey.

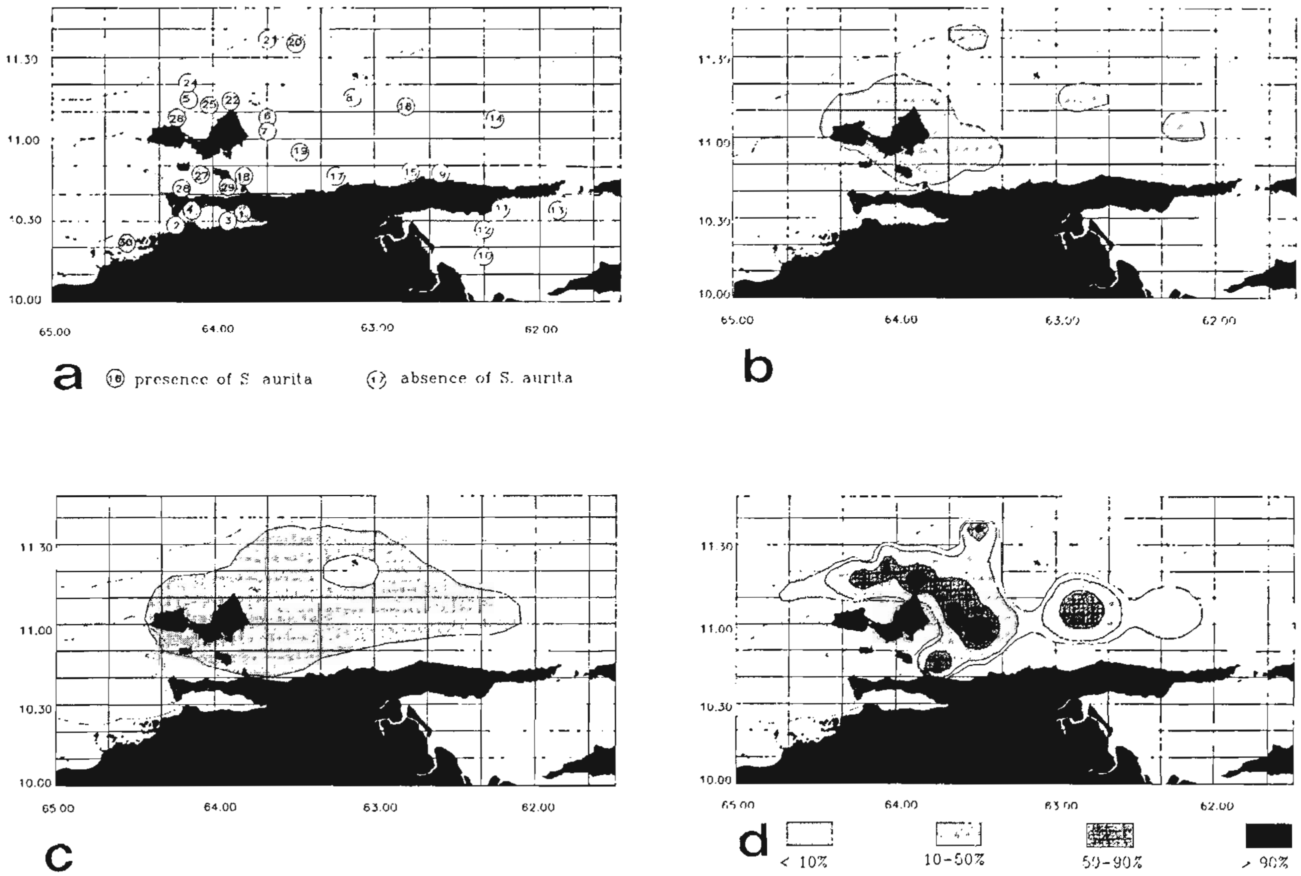

Figure 4. – Some examples of sardine distribution mappings. a: location of the fishing samples. grey circle: sardine caught in the sample; white circle: no sardine caught. the number inside circle represents the sampling item, b: mapping of the sardine area under "pessimistic hypothesis" (sardine nowhere except where caught), c: mapping under "optimistic" hypothesis (sardine everywhere except where not caught), d: mapping using SURFER (density in % of sardine in the catch).

caught. As an example, we have drawn several maps of this sardine distribution according to two extreme hypotheses: an "optimistic" hypothesis (*fig.* 4 *c*), where it is assumed that sardines are everywhere except in those places where they have not been caught, and a "pessimistic" hypothesis (*fig.* 4*b*) where, on the contrary, sardines are exclusively located on those areas where they have been caught. Of course

Table 1. – Detail of the catches (%) during "*Echoven* 2" survey. The positions of the trawl operations are indicated on *figure* 4 *a*.

Trawl no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	24	25	26	28	29
Carcharhinus sp.	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
Elops saurus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0	0	0	8.0	0
Sardinella aurita	66.7	0	0	99.5	75.0	90.0	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	0.6	99.7	98.0	0	58.3
Harengula clupeola	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	1.8
Opisthonema oglinum	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	2.0	0	1.2
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	95.0	0.9	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
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
Anchoa sp.	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	69.0	16.7
Anchoviella sp.	0	0	0	0.2	0	0	0	60.0	0	0	0	0	0	0	0.6	0	0	0	0	0	0	0	0	0	0	0	16.7
Saurida brasiliensis	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
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
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	0.2
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
Sphiraena picudilla	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	1.0	0.8
Mugil brasiliensis	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
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
Centropomus parallelus	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
Priacanthus arenatus	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
Pomatomus saltatrix	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
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	4.4	0	0	0	3.3
Selar crumenophtalmus	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
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	0.1	0.1	0.2
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	0.8	0
Decapterus sp.	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
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
Oligoplites palometa	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
Hemicaranx amblyrhynchus	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
Chloroscombrus chrysurus	0	0	0	0	0	0	0	0	0	1.5	8.1	3.1	2.5	0	0	0	2.4	0	0	0	0	0	0	0	0	5.0	0
Lobotes surinamensis	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
Rhomboplites aurorubens	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
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
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
Haemulon aurolineatus	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
Orthopristis ruber	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	15.0	0
Cynoscion leiarchus	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
Macrodon ancyclodon	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
Ophioscion punctatus	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
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
Archosargus unimaculatus	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
Upeneus parvu	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
Trichiurus lepturus	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	0.1	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
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
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	0.1	0	0	0
Scomberomorus maculatus	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
Euthynnus alleteratus	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	0.1	0	0	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	1.0
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
Lagocephalus laevigatus	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

these hypotheses are "extreme", and are described in order to show the two most different maps. More realistically, we have also calculated the distribution of sardine by the use of a mapping software, using "standard" hypothesis (isotropic distribution, contagiousness represented by a factor $1/x^2$: *fig.* 4 *d*) (SURFER, Golden Software Inc., 1990). The results of these hypotheses show that the result of mapping may differ according to the anisotropic and contagious characteristics that are assumed. One should add this source of variation to the errors on the fishing.

Distribution of the densities (fig. 5)

The bulk of the biomass is concentrated along a curve line beginning at the north of Margarita and finishing close to the continent in front of Carupano.

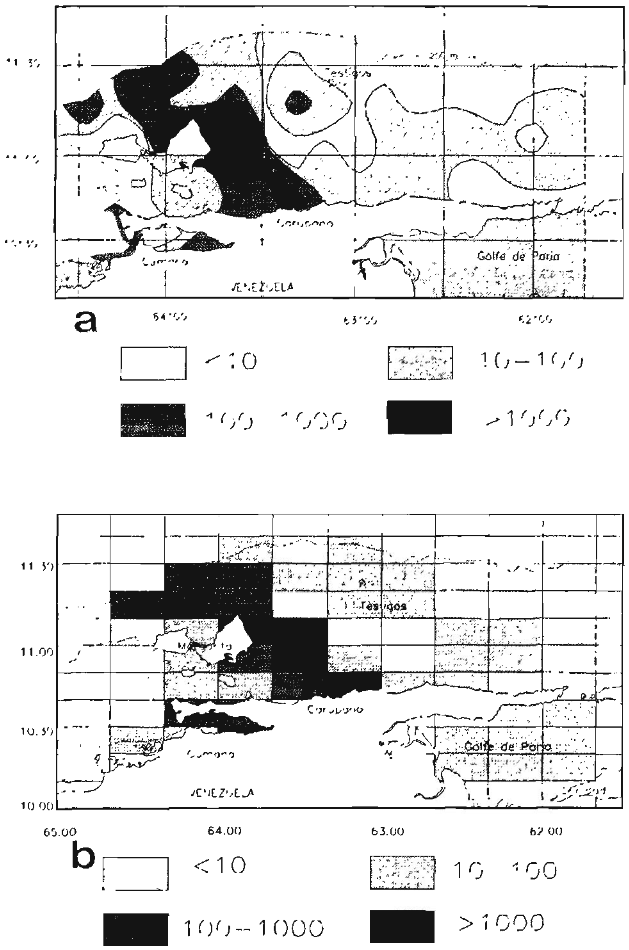

Figure 5. – Global biomass distribution observed during "*Echoven* 2" survey in relative units of density per elementary sampling distance unit (ESDU). a: mapping using SURFER, b: mapping using 10×20 nautical miles rectangles.

The map of the mean densities (*fig.* 5 *a*) is not totally satisfactory, because it is drawn using a simple hypothesis (*i.e.*, anisotropy along a straight East-West line). It may be better to present the density data within 10×20 miles rectangular strata, dimensions which correspond to the autocorrelations (*fig.* 5 *b*).

The acoustic populations

We calculated the parameters previously described for each one of the 50 rectangles where acoustic sampling was performed (*i.e.* day and night transects, more that 10 ESDU for each period) (*table* 2, *fig.* 6 *a*). The rectangles are considered as individual. The variable are as follows.

– *Ratio of density per positive samples.* The variable (DEP) is the mean value of this ratio for all the ESDU within the rectangle. DEP must usually be considered individually (or in histogram), and the mean value has no meaning (Marchal, 1988). Therefore, we present the proportions (in %) of low, medium and high DEP per ESDU for each rectangle DH (high) are defined as the DEP representing schools, concentrated layers or large fish; DM (medium), scattered and medium fish; DL (low), plankton layers and/or scattered small fish. Night (n) and day (d) data are considered separately.

– *Mean density.* We calculated the mean density D for all the ESDU within a rectangle. Two variables are obtained, one representing the density by day (Dd), the other, the density by night (Dn).

– *Situation in the water column.* Mean value of the ratio of positive sample to the total number of samples, for all the ESDU. Two variables are obtained, one for the night data (EEn) and one for the day data (EEd).

– *Confidence interval of the densities.* As the histogram of the ESDU is highly asymmetrical, we prefer to employ the coefficient of variation (CV=σ/mean 100.) for all the ESDU of a rectangle.

– *Number of schools.* It is the mean number of schools per ESDU, separating day (Sd) and night (Sn) schools.

A hierarchical classification is calculated on this data set (euclidian distance, weighted for the variables, aggregation using the criterion of the variance). The dendrogram (*fig.* 6 *b*) shows that the individuals (*i.e.* the rectangles) may be divided into two main groups, each one being also divisible into two subgroups. Thus, we may define 4 acoustic populations from the data of "*Echoven* 2". The mapping of these acoustic populations shows their consistency (*fig.* 6 *c*). The first division into two main groups (*AA** and *BC*) is closely related to the presence (*AA**) or absence (*BC*) of the sardine stock. Within the group "without sardine" (*BC*), we may observe that group *B* is gathering the rectangles of the Gulf of Paria. That acoustic population is quite individualized and homogeneous. The other subgroup (*C*) is geographically less homogeneous: it gathers most of the rectangles in the east of the shelf, and others in various areas around the other acoustic populations. This group *C* could be defined negatively, as the group "without sardines".

The group *AA**, that we could define as the group "with sardines", is also formed of two subgroups.

– Population *A*. It represents the rectangles where the mean density is the highest, but not only them: population A is also seen along the eastern coast of the continent.

– Population *A**. It is smaller than population *A* and geographically less homogeneous. The differences between *A* and *A** are due to differences in mean density: although all the rectangles of *A** belong to the sardine area, their mean density is lower than those of *A*. The rectangle 41 (*fig.* 6 *a* and *c*) is particularly interesting: it is isolated in the centre of the platform inside population *C*, and as far as density is concerned does not differ from the rectangles of that population. Actually, it fits on one of the

Table 2. – Parameters used for each rectangle (50), "d" or "n": by day or by night. D: mean density (in relative units), EE: ratio (positive samples/total number of samples)×10^3, DH: percent of high values of ratio density to positive samples, DM: percent of medium values ratio density to positive samples, DL: percent of low values ratio density to positive samples, S: mean number of schools per ESDU (elementary sampling distance unit), CV: coefficient of variation (100×σ/m).

Rect.	Dd	Dn	EEd	EEn	DHd	DMd	DLd	DHn	DMn	DLn	Sd	Sn	CV
c1	297	73	13	8	92.0	6.5	2.0	97.1	2.9	0.0	0.77	0.41	64.7
c2	792	706	52	21	91.5	6.3	2.2	93.5	2.9	3.6	1.77	0.04	35.9
c3	891	563	18	157	84.1	9.1	8.9	99.0	0.5	0.5	0.45	0.12	51.2
c4	3832	5155	29	147	68.2	10.0	21.8	83.2	5.2	11.7	1.44	1.63	39.8
c5	495	2373	41	313	86.4	8.3	5.4	88.9	4.5	6.6	1.14	0.76	58.7
c6	4921	1602	50	179	67.0	12.8	20.2	88.5	6.4	5.1	1.85	1.09	44.0
c7	642	436	69	384	87.0	10.1	2.8	99.4	0.5	0.1	2.02	0.02	34.7
c8	1385	715	62	672	60.9	26.1	13.0	98.9	0.6	0.4	2.90	0.11	29.0
c9	798	1526	14	50	90.0	4.2	5.8	85.7	11.4	2.9	0.86	1.95	39.0
c10	351	3661	30	246	79.3	13.5	7.2	71.1	11.3	17.5	0.21	3.25	27.3
c11	473	391	20	95	90.4	6.0	3.6	95.3	3.9	0.8	0.71	0.03	22.9
c13	28	39	1	2	100.0	0.0	0.0	98.4	1.6	0.0	0.00	0.39	85.0
c14	14	42	0	6	95.6	2.2	2.2	100.0	0.0	0.0	0.00	0.00	32.8
c15	591	384	783	890	100.0	0.0	0.0	98.3	1.7	0.0	0.00	0.00	27.6
c16	32	161	39	171	98.8	0.6	0.6	96.4	2.9	0.7	0.00	0.00	27.2
c17	137	371	300	1454	90.6	7.8	2.4	100.0	0.0	0.0	0.12	0.00	10.0
c18	430	620	669	1389	96.2	1.7	2.2	99.6	0.4	0.0	0.00	0.00	12.3
c19	99	195	49	259	97.3	0.0	2.7	98.5	1.5	0.0	0.15	0.00	7.4
c20	42	547	91	2776	94.3	5.7	0.0	97.3	2.7	0.0	0.00	0.00	6.0
c21	214	201	266	617	94.8	5.2	0.0	100.0	0.0	0.0	0.03	0.00	13.8
c22	245	114	245	381	98.2	1.8	0.0	100.0	0.0	0.0	0.00	0.00	5.0
c23	415	166	144	259	96.7	1.3	2.0	97.5	2.0	0.5	0.40	0.00	19.7
c24	88	2589	27	75	87.5	14.3	0.0	87.2	9.0	2.6	1.60	0.38	34.8
c25	36	5133	17	175	100.0	0.0	0.0	80.6	11.5	7.9	0.13	1.74	37.2
c26	40	184	10	36	95.2	3.2	1.6	95.2	4.8	0.0	0.09	0.00	96.5
c27	9	62	3	11	100.0	0.0	0.0	95.0	3.8	1.2	0.00	0.06	34.1
c28	9	146	2	14	100.0	0.0	0.0	95.1	0.0	4.9	0.28	0.00	27.9
c29	154	36	10	28	87.5	6.3	12.5	100.0	0.0	0.0	0.50	0.00	56.7
c30	8164	282	125	101	66.5	16.8	16.8	92.9	5.8	1.3	2.86	0.67	41.8
c31	1914	15058	123	271	72.8	16.0	11.1	68.9	8.2	23.0	3.72	1.38	49.2
c32	52	13715	39	518	100.0	0.0	0.0	74.4	15.4	10.3	1.00	0.03	81.8
c33	25	41	51	61	97.0	3.0	0.0	98.4	1.6	0.0	0.06	0.00	63.2
c34	73	68	10	21	100.0	0.0	0.0	98.3	1.7	0.0	0.00	0.07	49.9
c35	1	201	1	13	100.0	0.0	0.0	96.3	1.5	2.2	0.00	0.00	31.7
c36	24	2562	4	30	100.0	0.0	0.0	99.2	0.8	0.0	0.75	0.00	34.9
c37	1707	2839	106	142	97.8	2.2	0.0	88.9	7.0	4.1	2.75	1.13	51.7
c38	180	2148	63	125	100.0	0.0	0.0	85.2	4.9	9.9	0.97	0.72	60.6
c39	29	22	5	30	93.1	3.4	3.4	100.0	0.0	0.0	0.29	0.00	68.4
c40	62	411	2	466	96.9	3.1	3.1	98.9	1.1	0.0	0.07	0.00	11.6
c41	141	108	7	41	54.5	36.4	9.1	97.7	2.3	0.0	0.44	0.05	69.8
c42	23	37	11	15	94.4	5.6	0.0	100.0	0.0	0.0	0.00	0.00	22.6
c43	98	1645	54	159	100.0	0.0	0.0	94.6	4.8	0.6	0.04	1.61	41.6
c44	154	1046	17	163	91.7	7.1	1.2	95.2	3.4	1.4	0.39	0.78	29.5
c45	29	301	2	84	94.4	5.6	0.0	97.4	2.6	0.0	0.36	0.12	40.6
c46	463	235	8	116	93.0	3.5	3.5	98.6	1.4	0.0	0.52	0.04	24.8
c47	15	123	1	44	94.1	5.9	0.0	100.0	0.0	0.0	0.56	0.35	28.1
c48	24	187	1	38	94.7	5.3	0.0	98.3	1.7	0.0	0.35	0.08	25.3
c49	4	44	0	10	92.3	7.7	0.0	98.9	0.0	1.1	0.00	0.17	52.9
c50	26	186	1	28	96.4	3.6	0.0	100.0	0.0	0.0	0.06	0.10	81.2

few places where sardines have been caught in this area. On the contrary, rectangle 49 which is situated on a place where sardines have been caught, does not belong to *AA**, which is satisfactory, considering that usually no catch of sardine take place in this area: the fishing of this species in this sector is exceptional.

DISCUSSION

The mapping of acoustic populations appears as very coherent compared to the natural communities. The fish of the Gulf of Paria are perfectly separated, which indicates that this area should be studied apart. It is interesting to point out that the rectangle of the

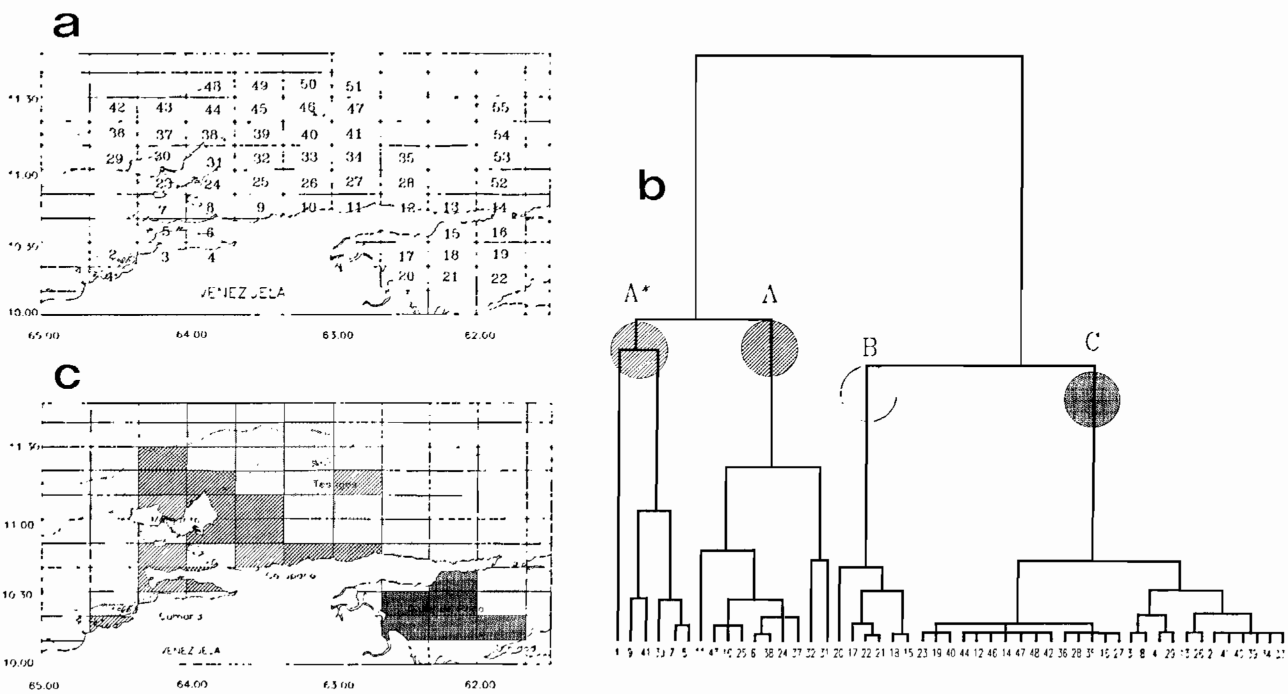

Figure 6. – Hierarchical classification of the rectangles and mapping of the acoustic populations. a: rectangle items used in the hierarchical classification, b: dendrogram of the rectangles, c: mapping of the acoustic populations in Oriente, the intensity of grey colour of the rectangles (6 *c*) corresponds to that of their respective population (6 *b*).

mouth of the Gulf, where the depth is great (more than 100 m) and from where oceanic waters are entering, are distinct from the rectangles inside the Gulf.

Nevertheless the most interesting points concern the sardine population. We can compare the maps of acoustic populations (*fig.* 6 *c*), salinity (*fig.* 3) and fishing (*fig.* 4).

Acoustic populations and fishing data

The two maps (*fig.* 6 and 4) are globally similar, but present interesting differences.

– The catches along the shelf border induce an extension of the drawing of the sardine distribution along the 200 m depth line. We know, from other sources of information (commercial fishery, former surveys, etc.) that this area does not usually contain sardines: during this survey their abundance was too weak to have an influence on the acoustic data. They did not appear in the acoustic population.

– The catch map presents an extension on the centre of the shelf (east of 62°30′W), which is much smaller on the acoustic population map: rectangle 41 (*fig.* 6 *a* and *c*) is the only one which appears in this area belonging to *A**.

– The population *A** is not well represented in the catch map, which confirms that *A** concerns the sectors with low densities of sardines.

– The biggest difference between the maps concerns the coastal area around Carupano: it is included in population *A* and is completely out of the sardine area in the catch map.

Acoustic population and hydrology

The comparison of the two maps show a very good overlapping of population *AA** and high salinity areas (*fig.* 3 and 6 *c*).

– The Gulf of Paria appears once more as a completely distinct ecosystem.

– The limit of oceanic water (*i.e.* above 35°/₀₀) is precisely the limit between population *C* and populations *AA**. The coastal zone around Carupano is an oceanic area, which correspond to the population *A* as observed on the map of acoustic populations.

– The upwelling areas correspond to *A**, and the neighbouring areas to *A*.

– The rectangle 41 (*fig.* 6 *a* and *c*) is the only one which has an unexpected behaviour: being out of the oceanic waters, it belongs to *A**. We have no hypothesis for explaining that point, but we may note that rectangle 41 is situated on a shallow bank, which may have a particular ecology.

The acoustic populations describe the fish distribution better than the catch data (*fig.* 6) because they allow inclusion in one of the populations of the areas not subjected to fishing sampling. Moreover, the acoustic interpretation appears to represent the true fish distribution to a greater extent that does the fishing data. For instance, the fact that a very important coastal fishery of sardines is situated along the coast of Carupano allows one to consider that this area belongs to the sardine zone, which appears on the acoustic populations map but not on the fishing map.

CONCLUSION

Application of the concept of acoustic populations on the data of a survey in Eastern Venezuela has allowed a discrimination between 4 populations, the reality of which has been corroborated by the observation of hydrological data as well as scientific and commercial fishings. The maps of these populations have been analysed and show a better validity than maps of fish distribution by catch analysis. This method seems to be particularly helpful for tropical research, where the species are too numerous to be identified separately.

One other application of acoustic populations could be the definition of strata: these maps are rather independent from the density data, but are contemporaneous with the survey, which could overcome some of the strong limitations Jolly and Hampton (1991) point out when stratifying the data of acoustic surveys.

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