

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

by

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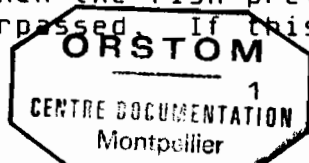
ABSTRACT

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 vessel passing over a school. The methodological approach involves 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 vacuoles, 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 is 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 Sardinella aurita 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 in situ 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 absorption, 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 successively by a drifting dinghy and immediately 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 beginning 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 numbers 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.



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 mentioned by several authors recorded by Pitcher and Partridge (1979). The mean density inside a school can change according to the season (Olsen, 1981) or circadian 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 vacuoles 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





which were insonified. In these conditions and under the previous assumption, the tilt angle  $\theta$  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  $\theta$ ,  $V_h$  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 Sardinella aurita (one must keep in mind that the gravity 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 Sardinella aurita, 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 insignificant loss (Foote, 1983).

But if we consider now the mean values of the gravity centre movement (instead of its 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 Sardinella aurita. 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) mentioned 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 resource is essential for stock management purposes. The observed distribution of the schools (fig. 15) suggest that most of the resource 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 to 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 discrepancies with similar studies carried out on temperate species.

The internal school structure is heterogeneous, including large vacuoles, 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 too 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 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.

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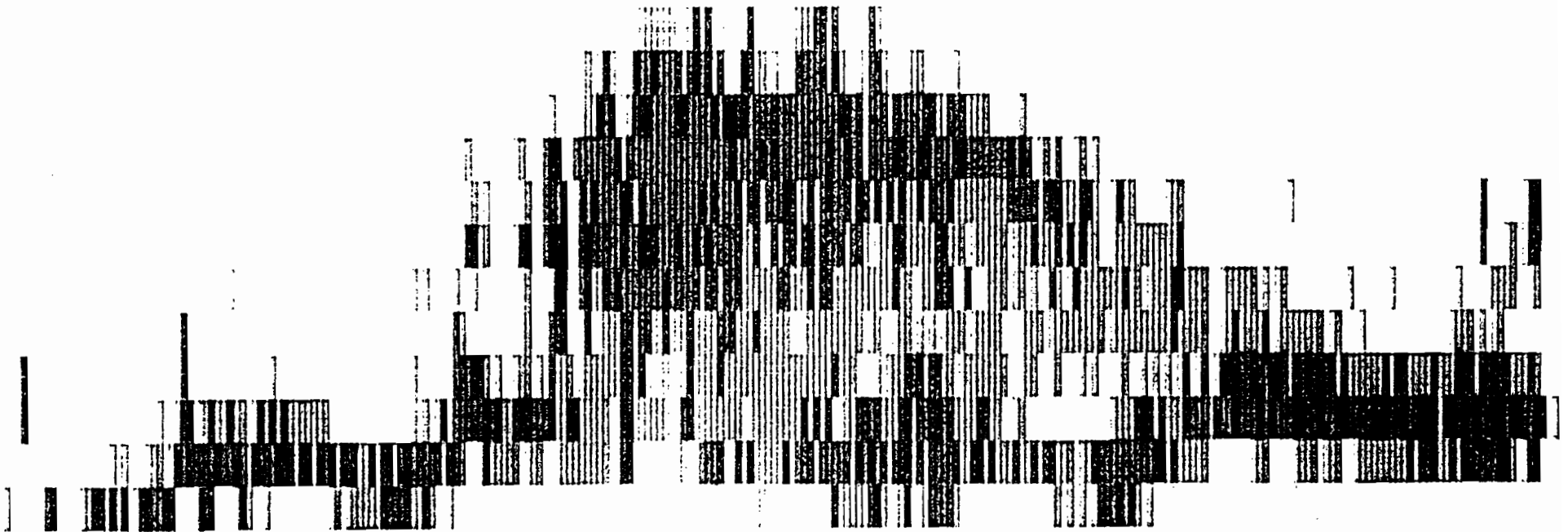
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bl. 3: Simulation of systematic sampling in the "Cariaco school"

<u>Trial number</u>	<u>Sampling rate</u>	<u>N</u>	<u>Mean</u>	<u>6</u>
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	5 766
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).







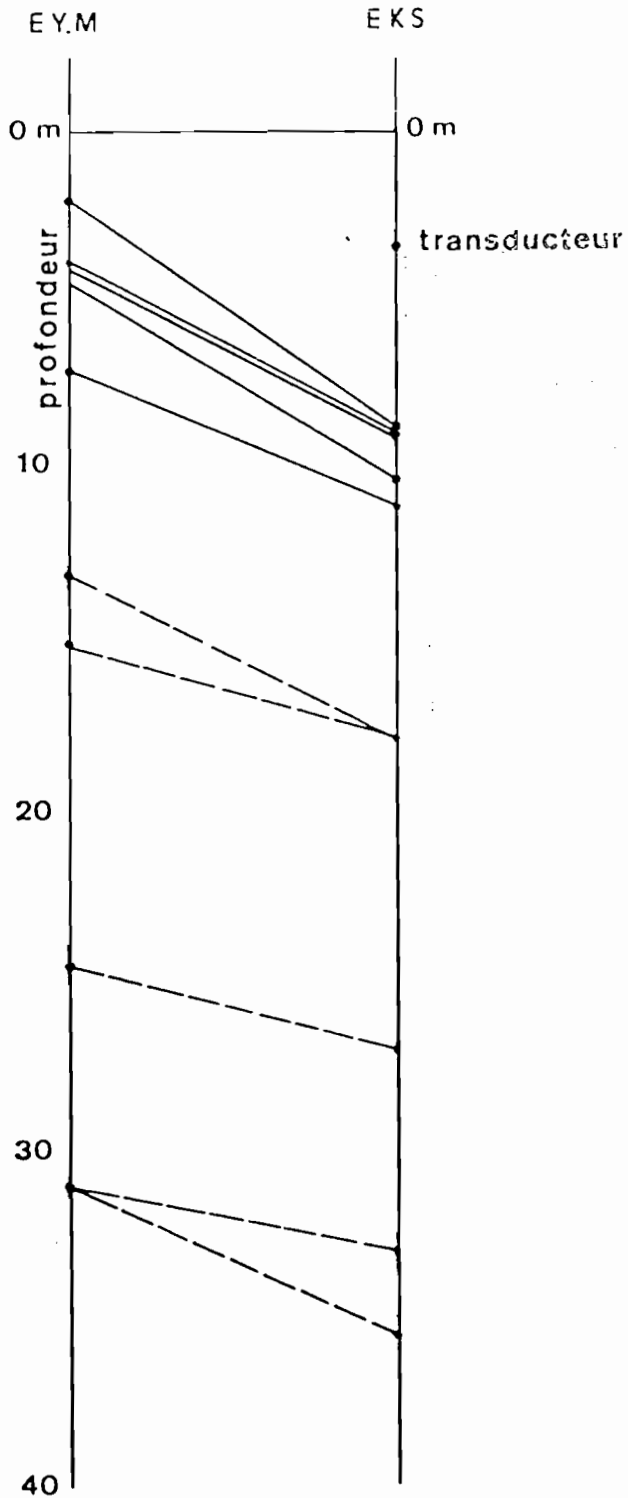
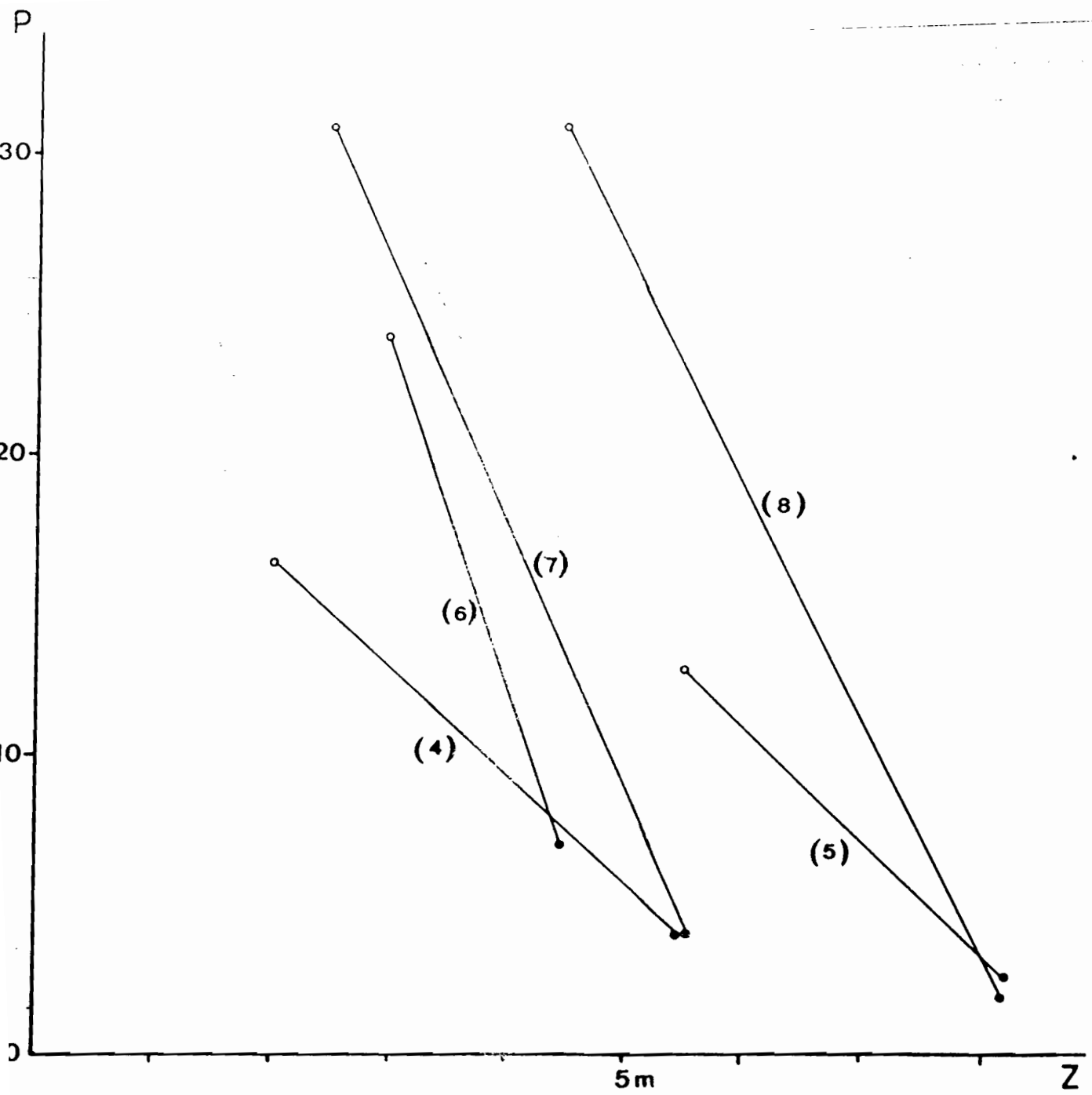


Fig. 3 - Evolution des profondeurs des sommets (—) et des bases (----) des bancs observés successivement sous la petite embarcation (EYM) et sous le N/O NIZERY (EKS).

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

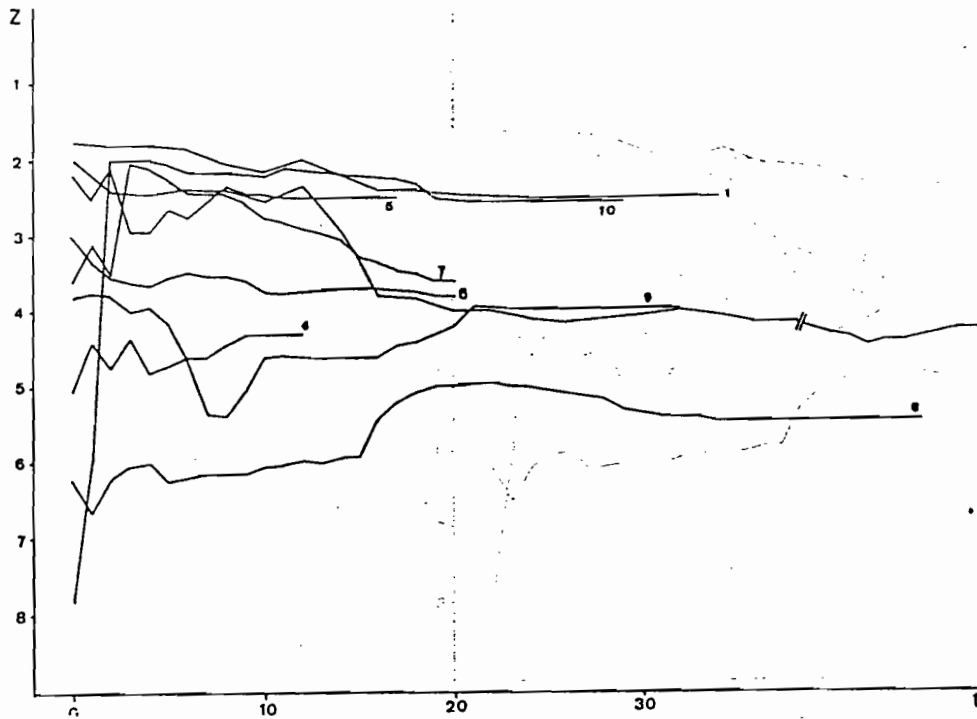


Fig. 5A - Evolution émission par émission (t) de la profondeur (z) du centre de gravité des bancs en mètres (par rapport au transducteur).

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

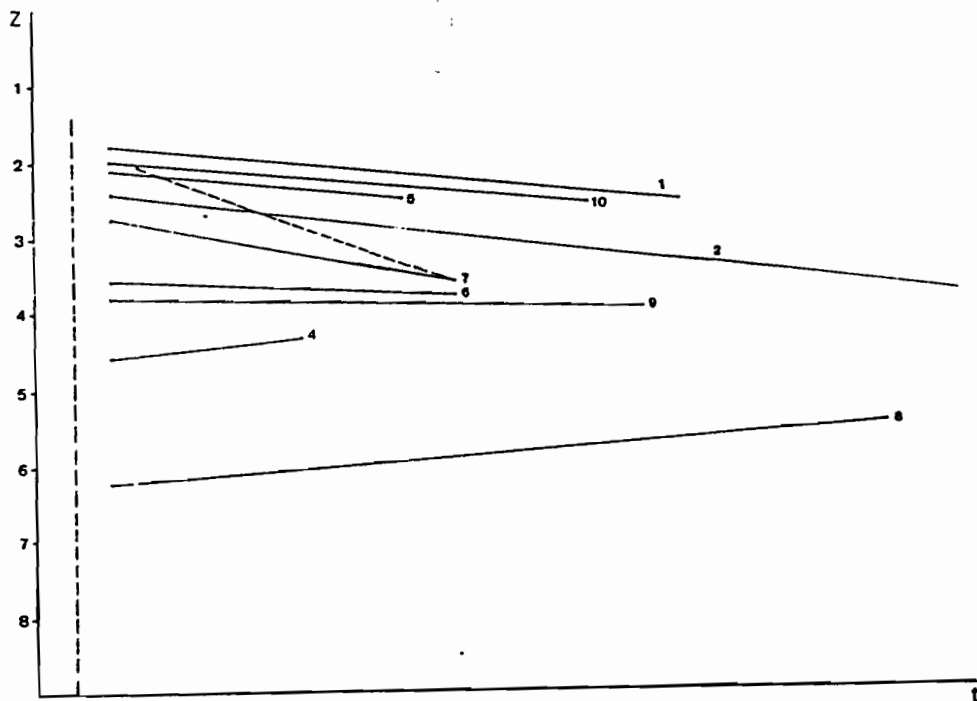


Fig. 5B - Représentation de la tendance moyenne de plongée pour chaque banc.

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

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

Figure 6 - Principe de transformation des couches

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









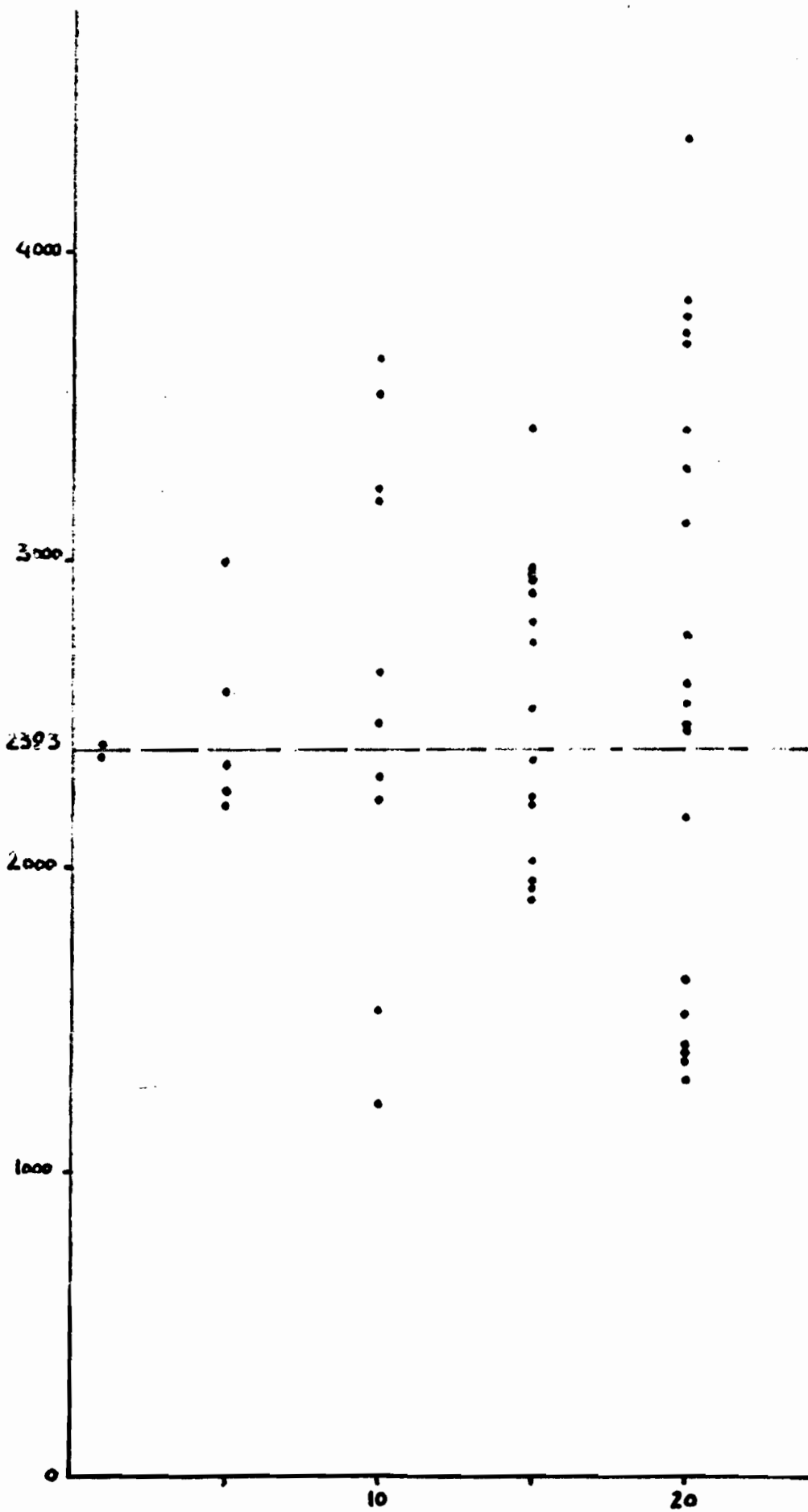
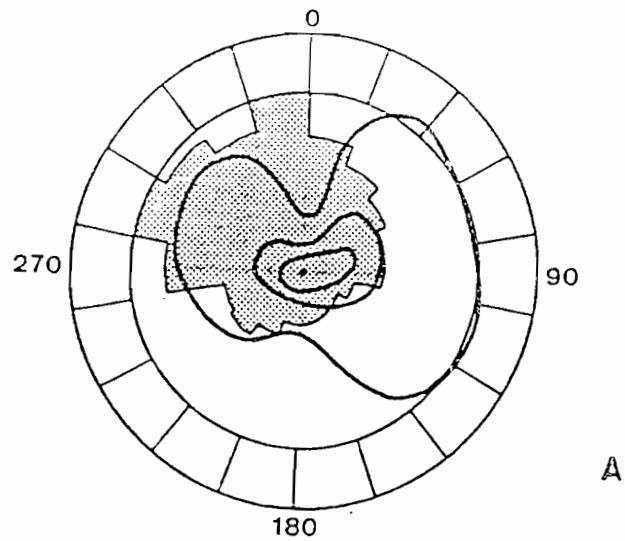
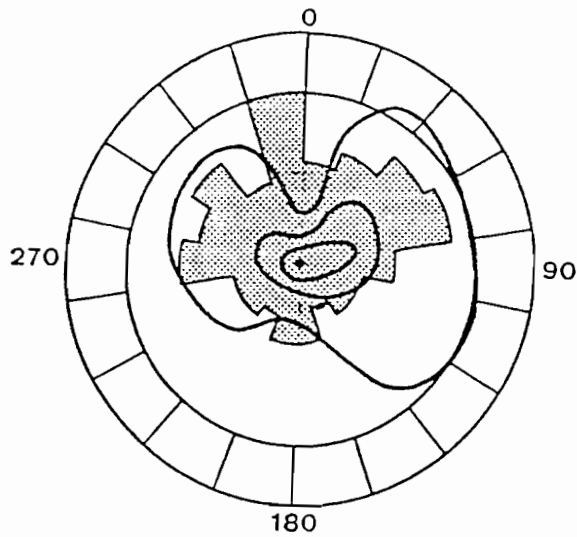


FIGURE 10. Evaluation of the sea urchin index (Y-axis) against the relative biomass evaluation according to sampling level. (Reference line = 2393 units).



A



B

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).

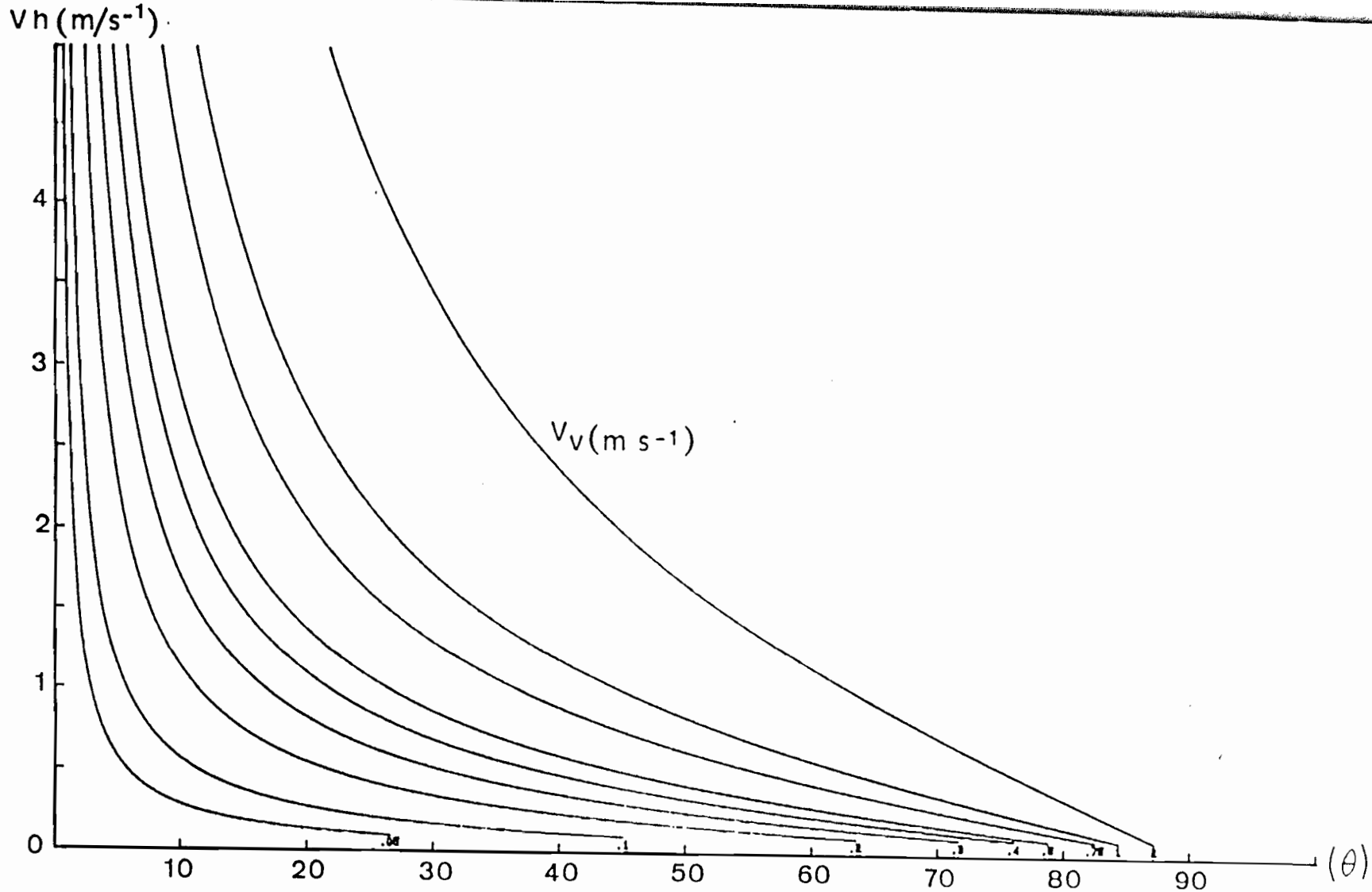


Fig. 12 - Relation entre angle du poisson ( $\theta$ ),  
Vitesse horizontale de fuite ( $V_h$ ) et  
vitesse verticale de plongée ( $V_v$ )

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

