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CHANGES IN SCHOOL STRUCTURE ACCORDING TO EXTERNAL STIMULI

by

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RESUME

L'influence de stimuli visuels et auditifs, provenant d'un bateau de prospection ou de prédateurs, a été observée de jour sur des bancs de Clupeides tropicaux. Ces observations *in situ* ont été effectuées dans certains cas simultanément depuis un hydravion (ULM) et en plongée sous-marine. Dans d'autres cas on a effectué à partir d'un voilier motorisé des observations acoustiques d'un même banc lorsque le bateau se déplaçait sous-voile, puis au moteur. Il en ressort que la structure interne d'un même banc, sa forme extérieure et le volume qu'il occupe peuvent changer très rapidement dans des conditions naturelles ou en raison des perturbations provenant d'un bateau. Néanmoins, il est probable que, pour les bancs de surface pour le moins, la structure d'un banc stressé par le passage d'un navire ou la présence d'un prédateur présente 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 diffe- rent 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 successi- ve 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 pre- sented large vaccuoles of low density, specially in the left side of the diagram, which corresponds to the start of the cross sec- tion 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 agita- tion" 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 den- sity 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 consti- tution (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, op- posed 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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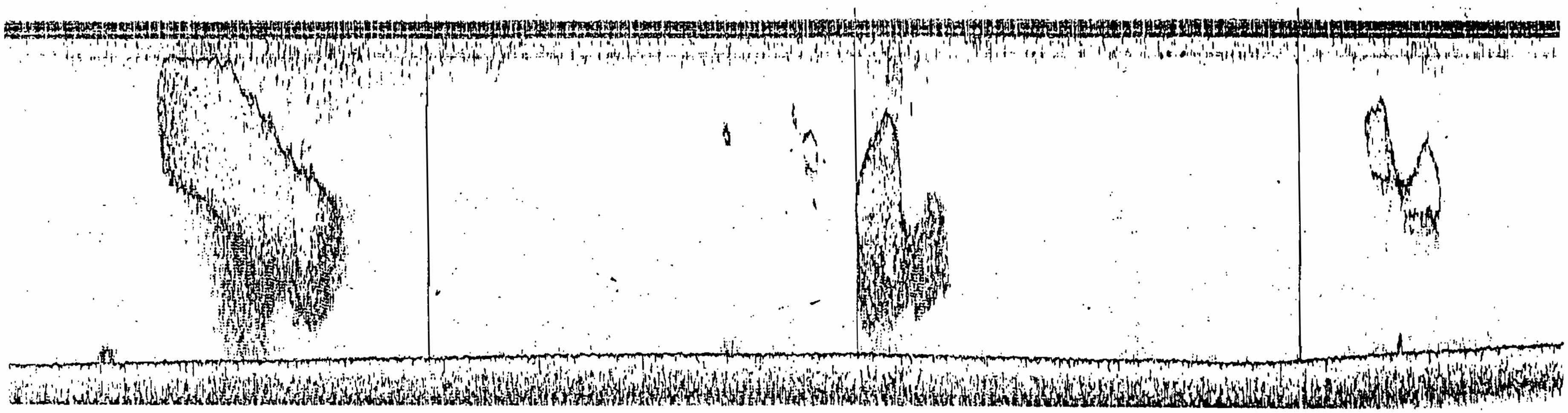

1 SAILS
0.r.p.m
1.5 Knot
9H10

2 MOTOR
850 r.p.m.
3.5 Knots
9H15

3 MOTOR
1500 r.p.m.
6 Knots
9H20

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

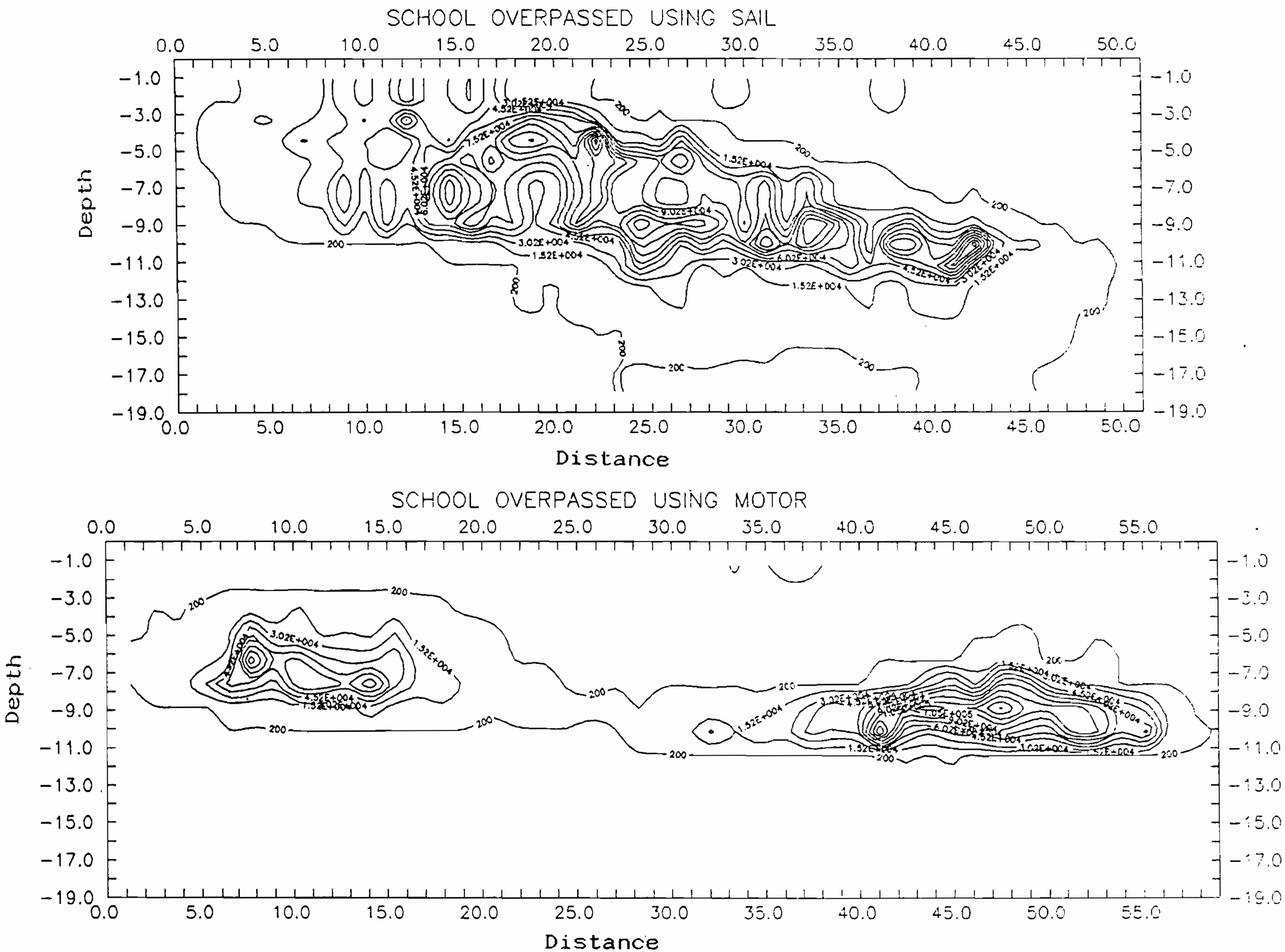

Fig 2. Internal structure (isodensity curves) of the school overpassed by the sail boat - using sails (echogram 1) - using motor (echogram 3).

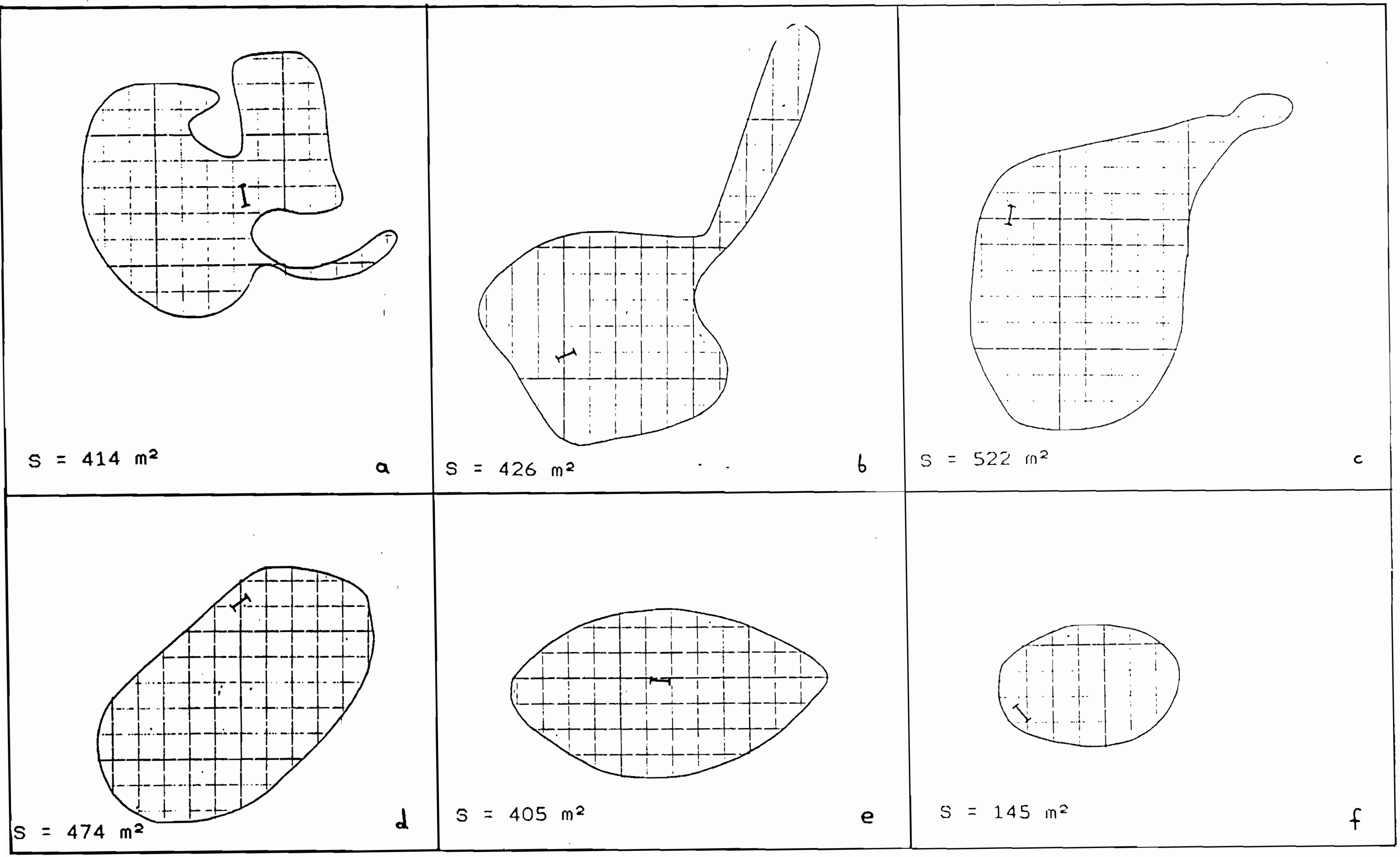

Fig. 3. Variation of school surface during a one hour aerial survey. |-| position and visible size (1.5 m) of the swimmer.

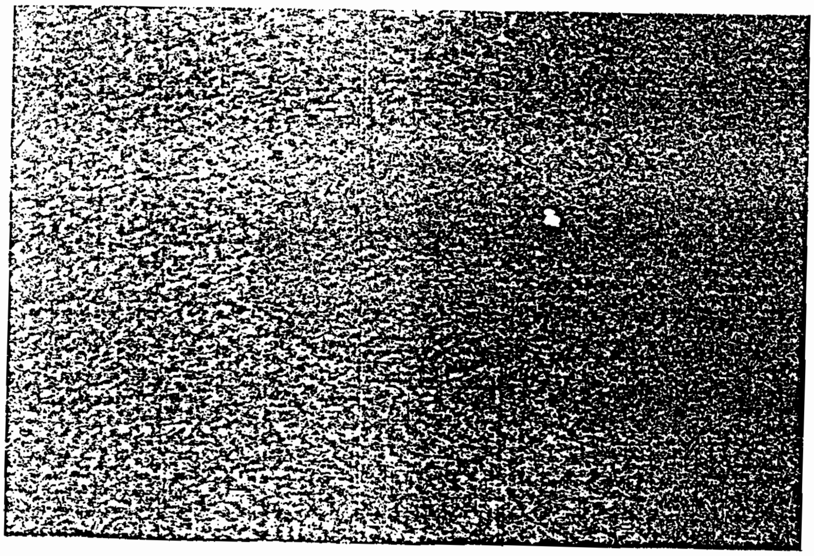

Photo 1 Egg-shaped structure of dense and homogeneous school during the first survey.

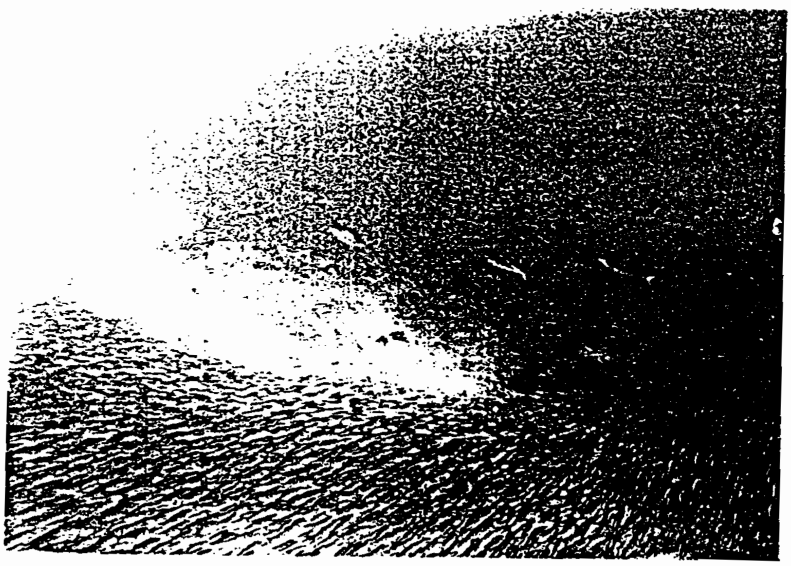

Photo 2. Underwater photography of flight reaction of the school to predators during the first survey.

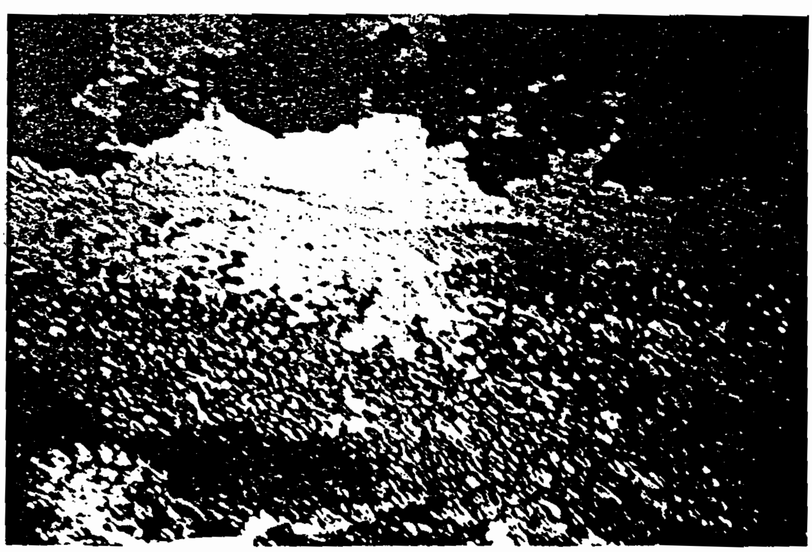

Photo 3. "Smoke like" structure of the school during the second survey.

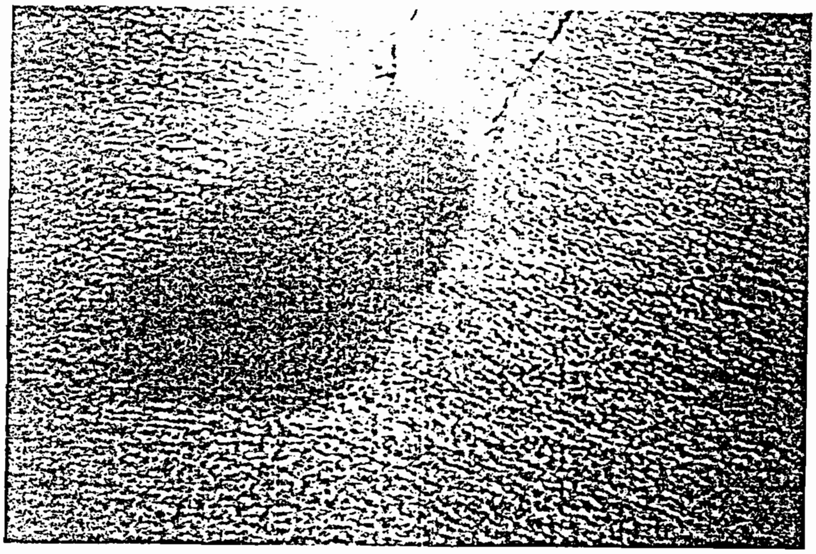

Photo 4. Egg-shaped and compact structure of the school during the second survey.

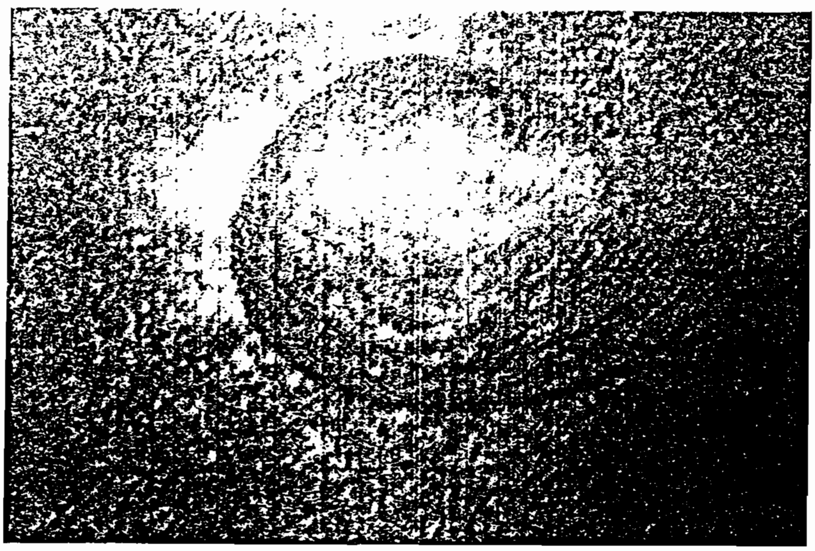

Photo 5. Defensive "mill " structure of the school during the second survey.

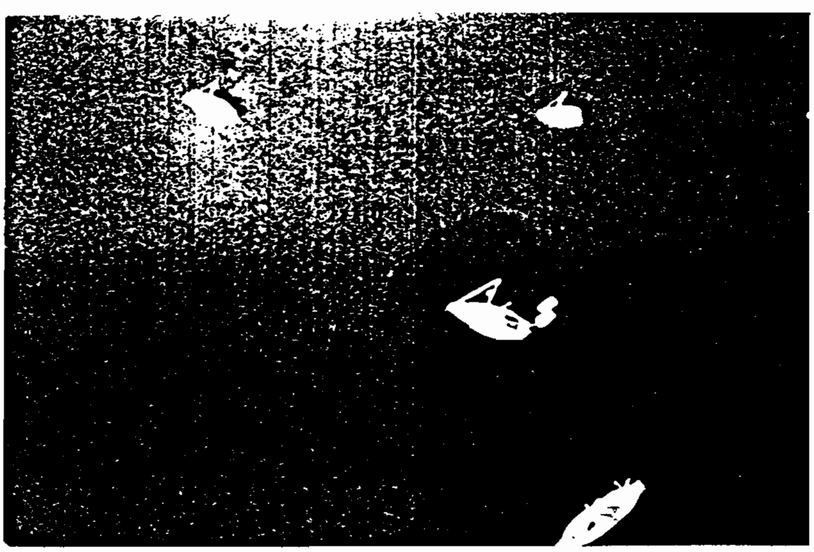

Photo 6. Circular and compact structure of the school at the end of the second survey.

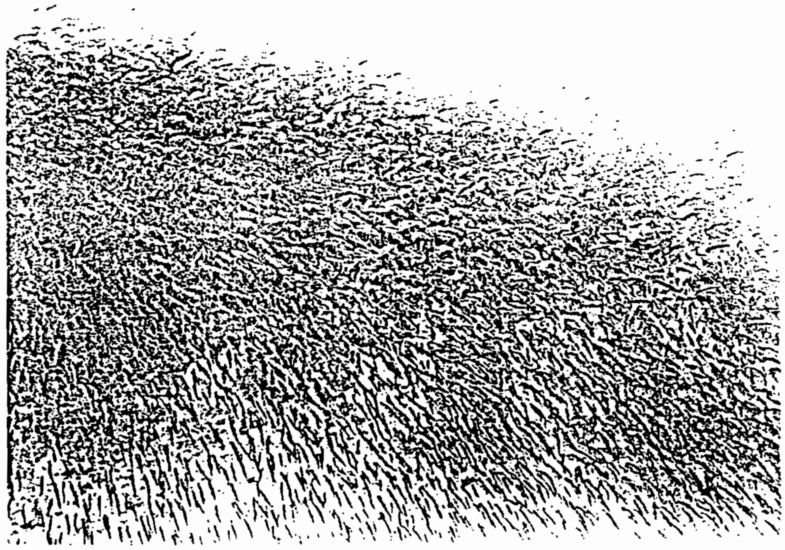

Photo 7. Underwater photography of fish in a circular and compact structure at the end of the first survey.

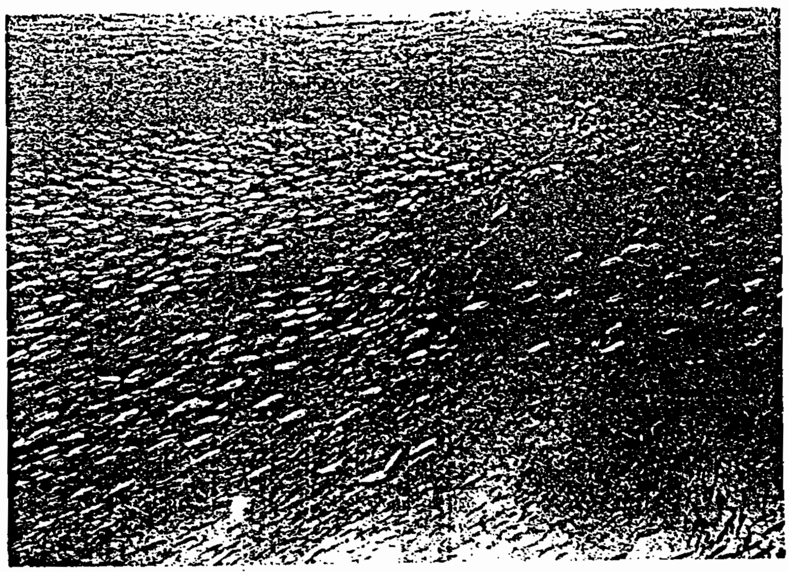

Photo 8. Underwater photography of column-shaped fish structure and large vacuoles during the first survey.

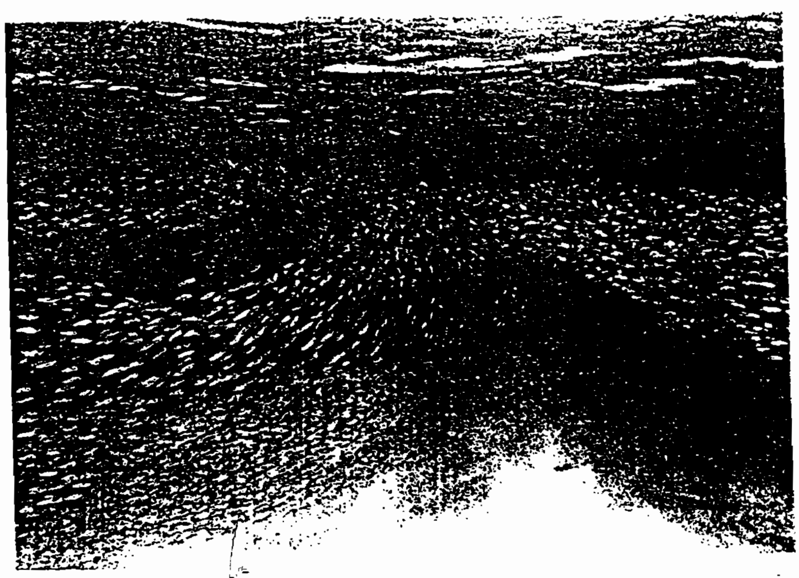

Photo 9. Underwater photography of column-shaped fish structure and large vacuoles during the first survey.