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

by

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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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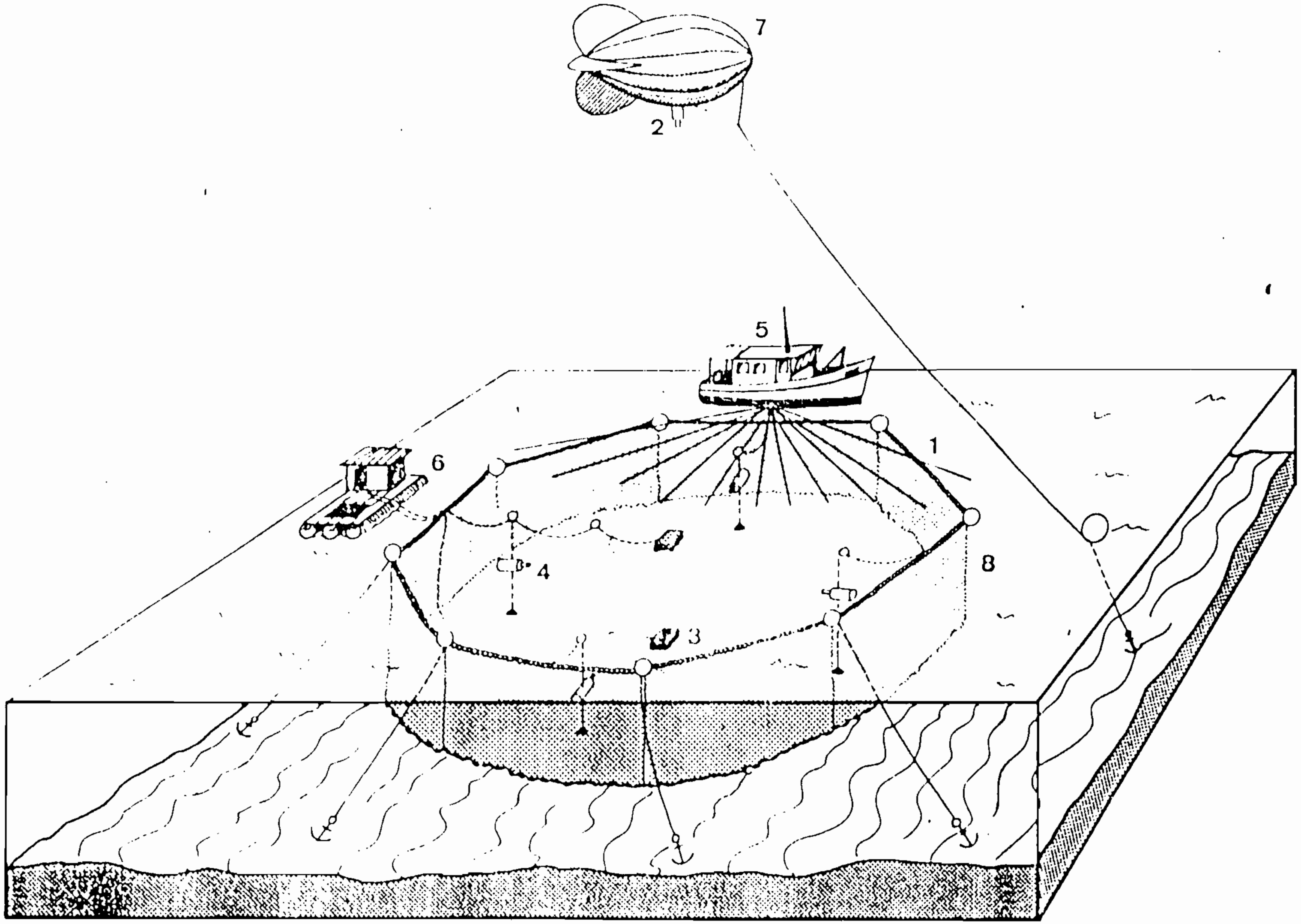

Figure 1. 'Mesocosm' installed in Martinique

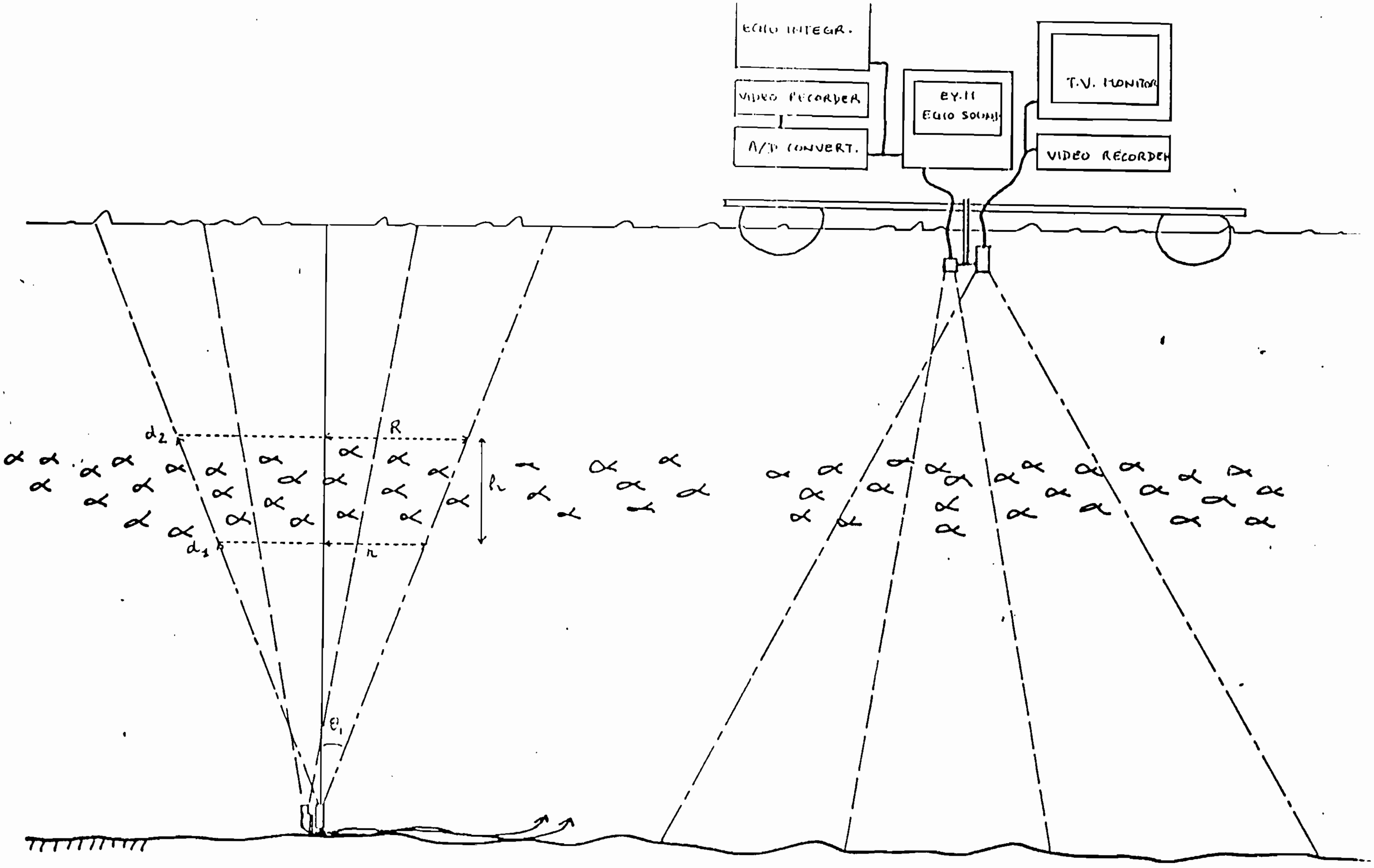

Figure 2. Description of the system used on an instrumented raft for TS measurements on fish in schools

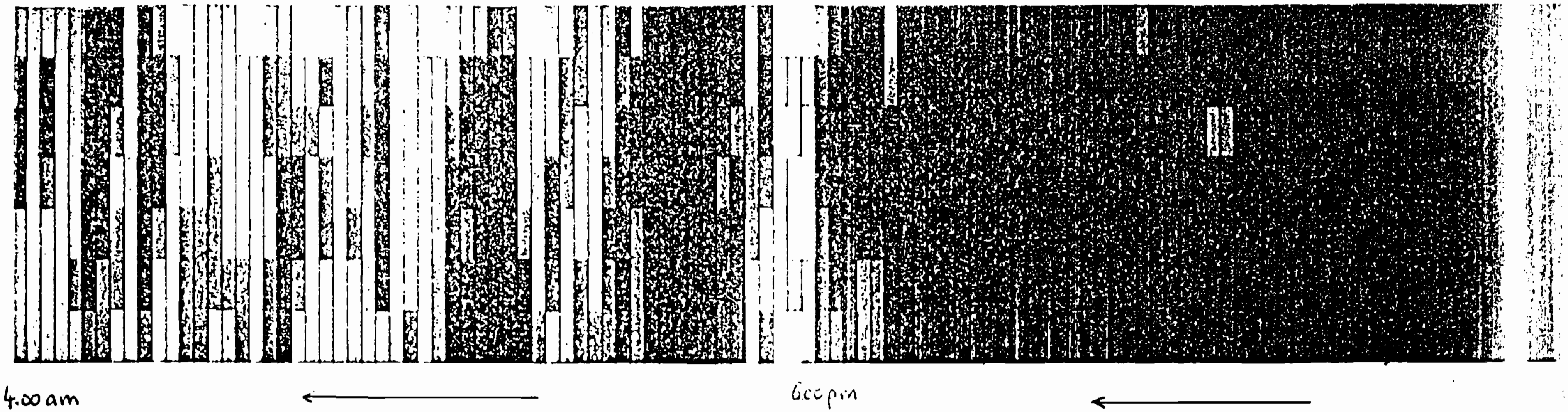

Figure 3. Evolution of the relative densities in a sardine school for 6 minutes intervals, in 1 meter layers (inside the mesocosm)

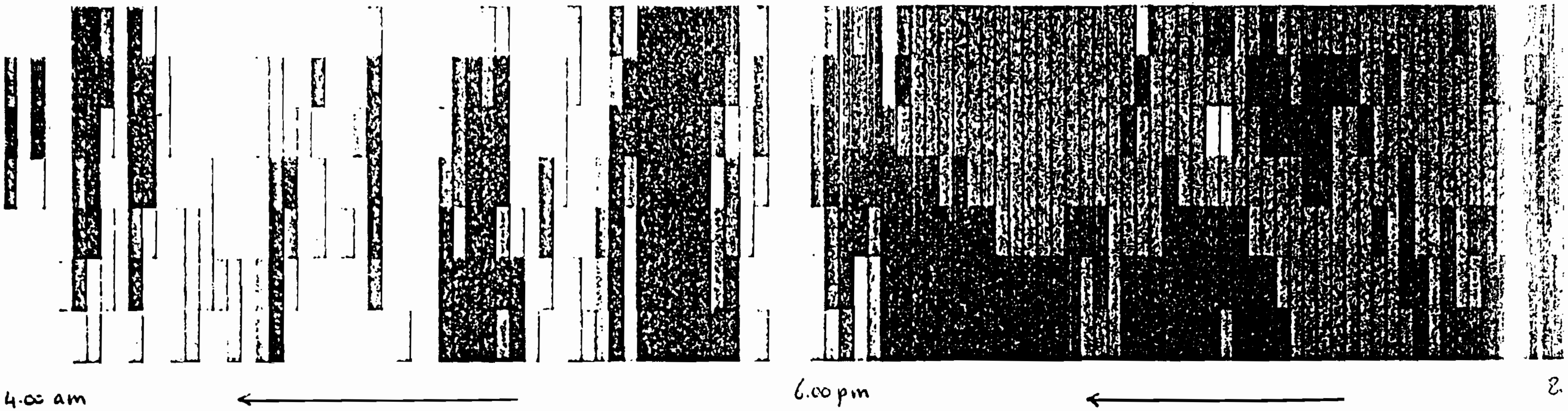

Figure 4. Evolution of the occurence index in a sardine school for 6 minute intervals in 1 meter layers (inside the mesocosm)

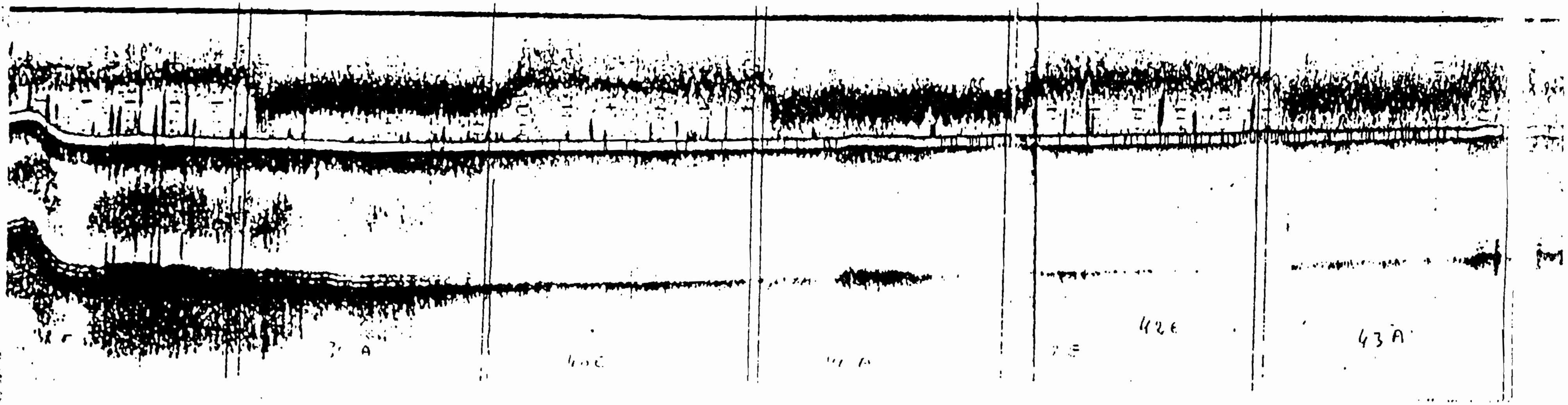

Figure 5. Example of echogram during the night, with lights switched on and of during 6 minute periods

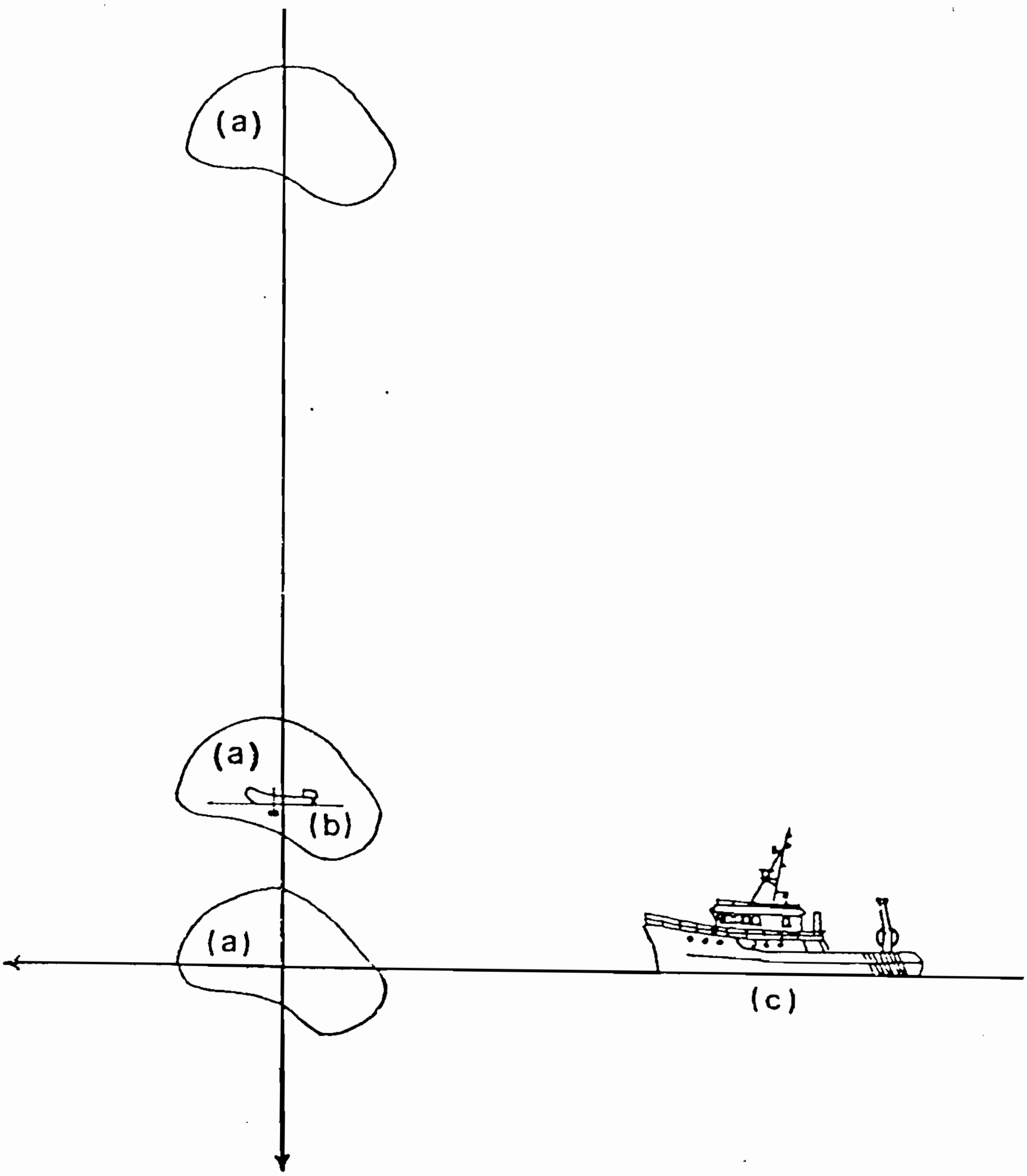

Fig. 6 - Description of the methodology used to compare the position and movement of a single school under natural and stressed conditions.