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

by

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RESUME

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

ABSTRACT

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

INTRODUCTION

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

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

MATERIAL AND METHOD

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

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

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

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

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

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

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

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

RESULTS

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

DISCUSSION

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

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

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

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

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

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

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

CONCLUSION

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

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APPENDICE 1: Results of the offshore experiment

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

Layer 2-5 m	Sail	Motor	Pooled
Number of Obs.	6	6	12
Average	52.93	58.20	55.56
Variance	361.26	587.89	474.58
Std. Deviation	19.01	24.25	21.78

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

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

Hypothesis Test for H0: Diff = 0     Computed t = -0.42
            vs Alt: NE         Sig. Level = 0.68
        at Alpha = 0.01      so do not reject H0.
```

Layer 5-10 m	Sail	Motor	Pooled
Number of Obs.	6	6	12
Average	52.37	49.85	51.11
Variance	267.84	186.14	226.99
Std. Deviation	16.37	13.64	15.07

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

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

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

Layer 2-5 m	Sail	Motor	Pooled
Number of Obs.	6	6	12
Average	57.75	63.94	60.84
Variance	942.22	1285.06	1113.64
Std. Deviation	30.70	35.85	33.37

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

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

Hypothesis Test for H0: Diff = 0     Computed t = -0.32
                vs Alt: NE        Sig. Level = 0.754934
            at Alpha = 0.01      so do not reject H0.
```

Layer 2-5 m	Sail	Motor	Pooled
Number of Obs.	6	6	12
Average	60.45	66.62	63.53
Variance	1976.48	1633.37	1804.93
Std. Deviation	44.46	40.42	42.48

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

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

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

Total Layers 2-20m	Sail	Motor	Pooled
Number of Obs.	6	6	12
Average	223.50	238.603	231.05
Variance	6834.57	5475.03	6154.8
Std. Deviation	82.67	73.99	78.45

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

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

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

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

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

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

Confidence Interval for Variance: 0 Percent
Sample 1

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

APPENDIX 2: Results of the second coastal experiment.

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

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

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

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

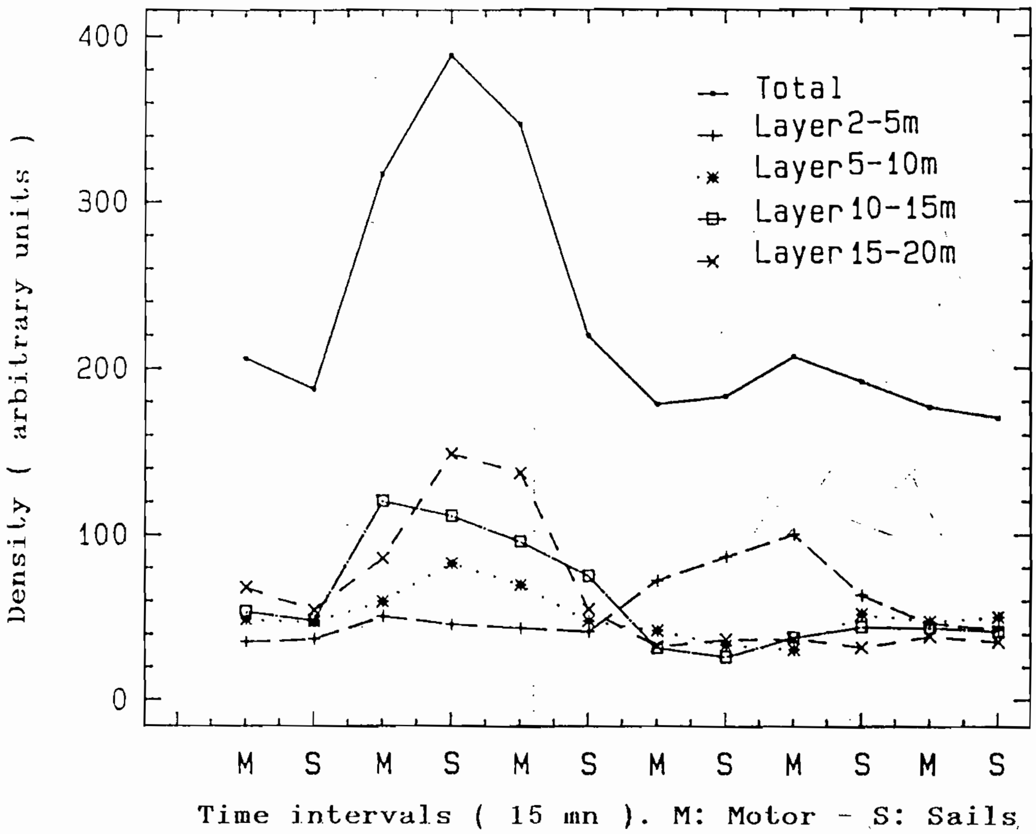

Fig 1. Time sequence plot (15 mn intervals from 21H00 p.m to 00H00 a.m) of densities observed during the offshore experiment at different depth.

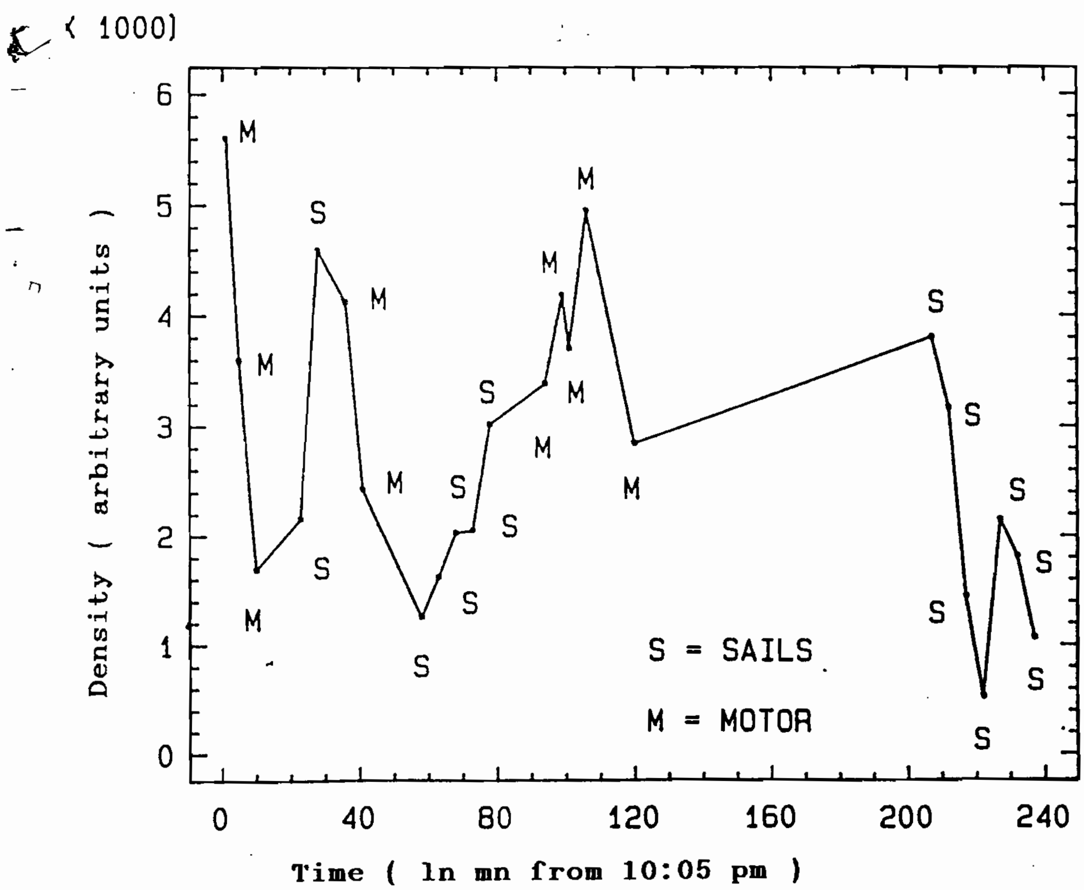

Fig 2. Time sequence plot (in minutes from 10H05 p.m) of total densities observed during the first coastal experiment.

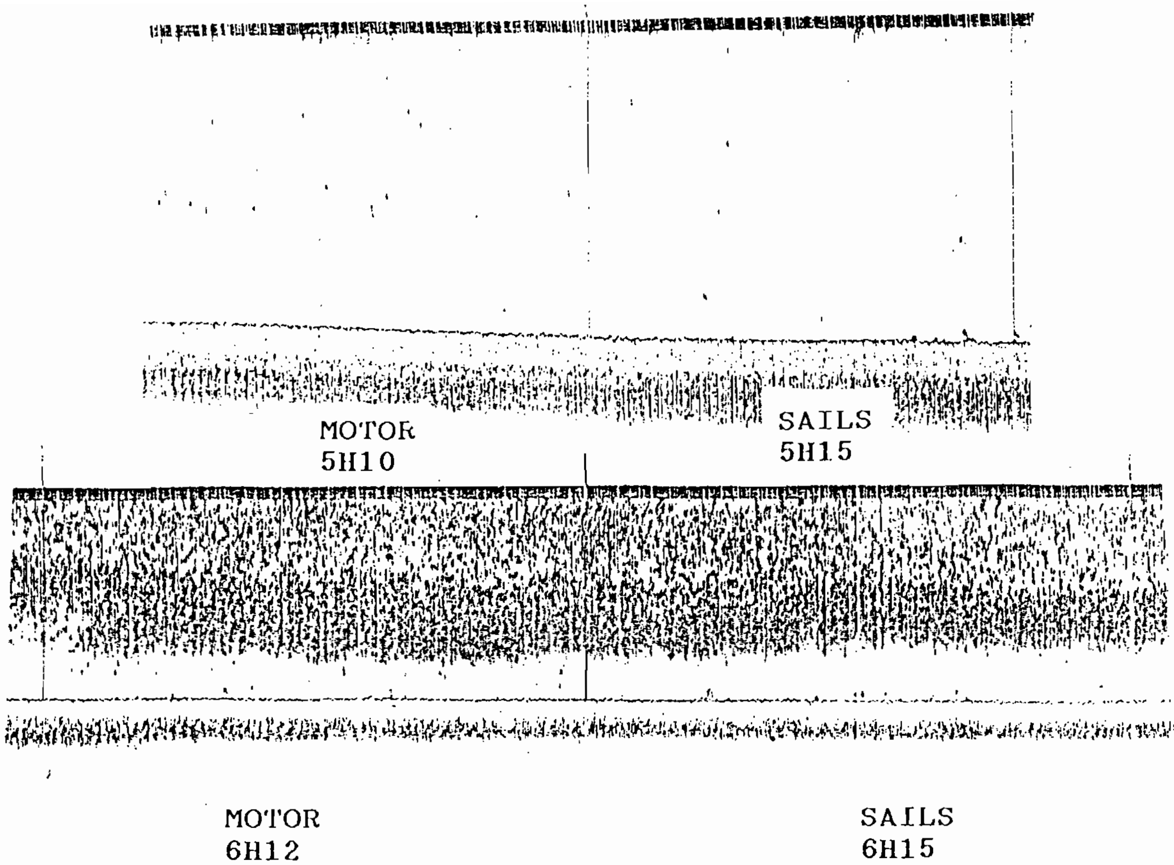

Fig 3. Echograms of layers and dispersed fish overpassed by the sail boat using alternately sails and motor during the second coastal experiment.

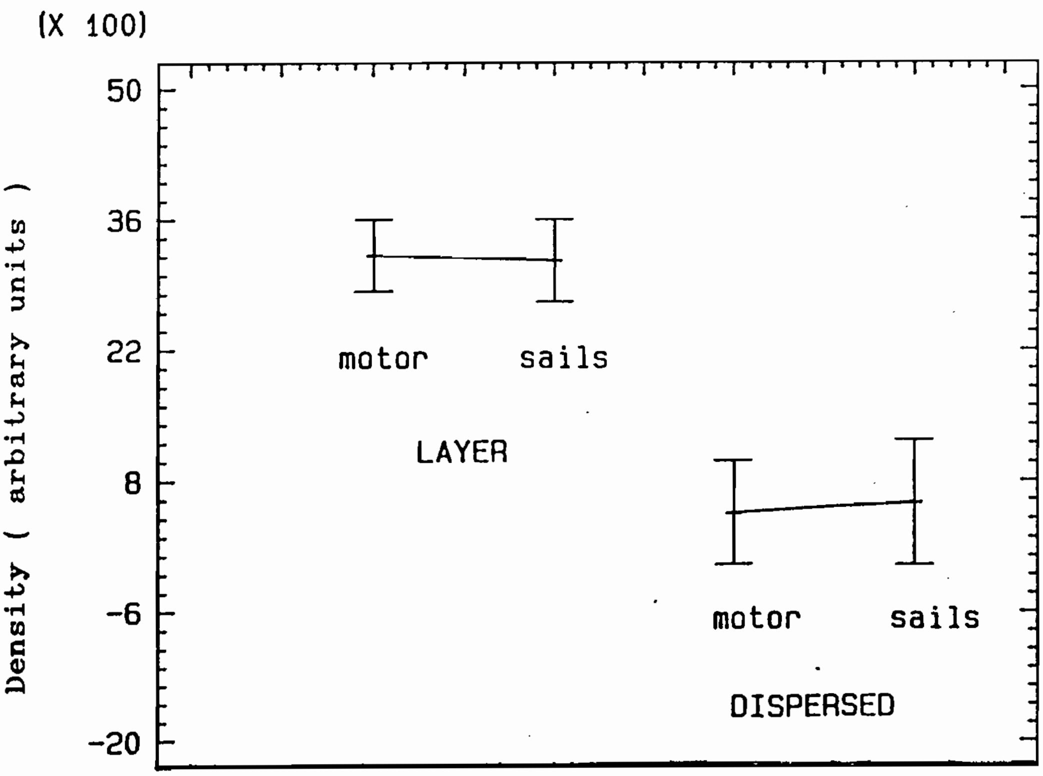

Fig 4. Second coastal experiment: 95 % confidence intervals of factor means density for sails versus motor and layer versus dispersed.

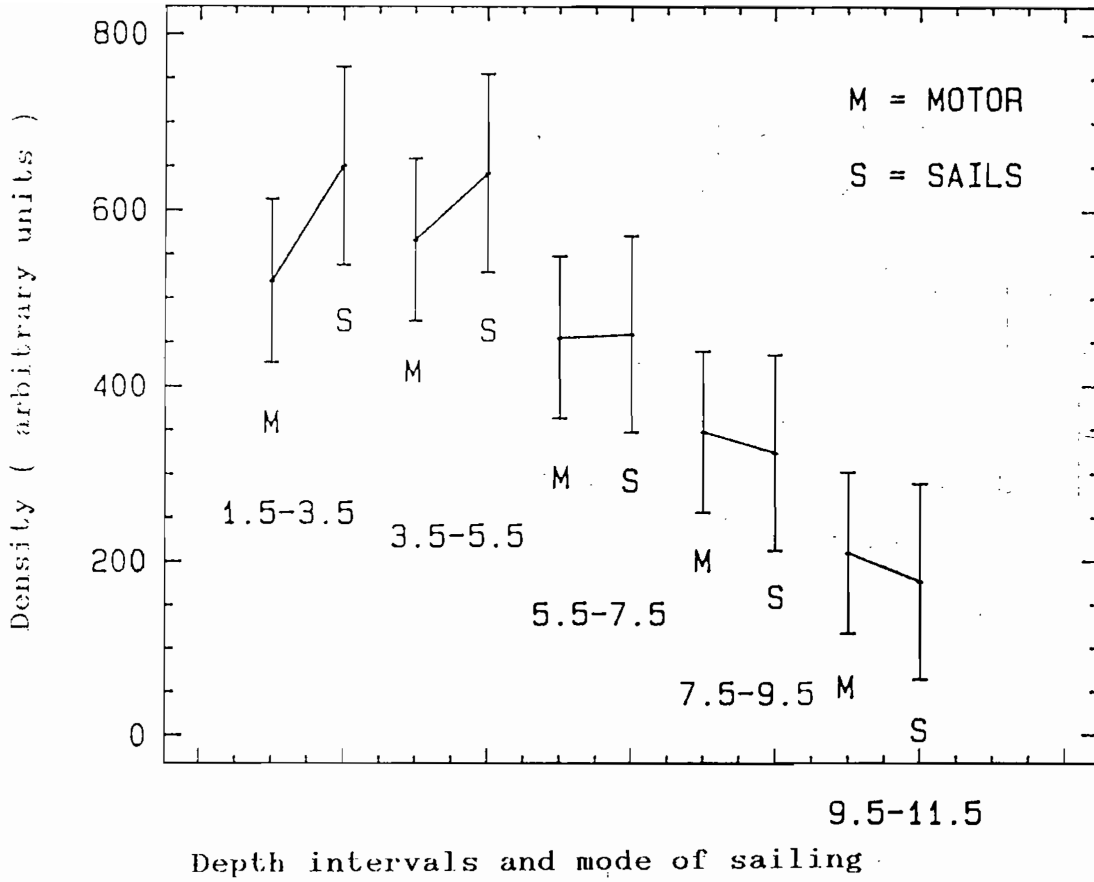

Fig 5. Second coastal experiment: 95% confidence intervals of factors means density for sails versus motor and for different depths.

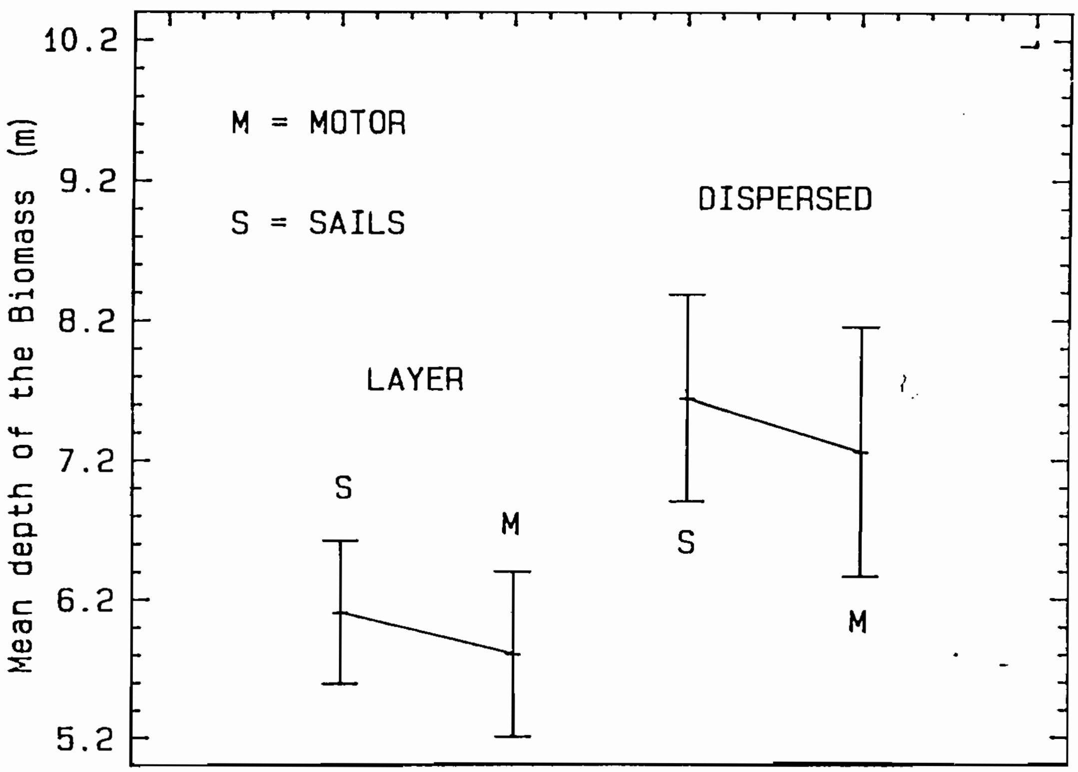

Fig 6. Second coastal experiment: 95 % confidence intervals of factor mean depth of the biomass for sails versus motor and layer versus dispersed.