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SEASONAL AND INTERANNUAL VARIATIONS OF MEAN CATCH PER SET IN THE SENEGALESE SARDINE FISHERIES: FISH BEHAVIOUR OR FISHING STRATEGY?

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ABSTRACT

The annual c.p.u.e. and mean catch per set of the seiners working along the Petite Côte off Senegal from 1969 to 1987 have been studied using multivariate and time series analysis. The annual mean catch per set has decreased from 22 to 4 metric tons during this period.

This phenomenon may correspond both to a decrease in the proportion of the large schools in the stock, and to a real decrease of the overall abundance associated with a modification of fishing strategy: fishermen accept to catch smaller and smaller schools since larger schools are less frequently found. The increase in fishing effort and the variation of upwelling strength seem to govern these changes. The possibility of using the mean catch per set as an index of school size, and perhaps of abundance, is envisaged in the conclusion.

KEYWORDS

Schooling behaviour; catch/effort; Upwelling; Sardinella; Senegal.

INTRODUCTION

The industrial purse-seiner fishery of Senegal started in 1961 with one boat. After a period of learning and low effort, the number of boats increased irregularly from 2 boats in 1966 to 15-20 in 1985 (Boely and Chabanne, 1975; Fréon et al., 1978; Fréon, 1986). Recently, the fleet declined, mainly for economical reasons (old boats, competition with small-scale fishery).

The small-scale and artisanal fishery is much older, but catches of coastal pelagic species increased dramatically in 1972 with the introduction of the purse-seine on existing canoes (Fréon et al., 1978). This fishery provided more than 90% of the catches during recent years.

In both fisheries, which operate in partially overlapping fishing grounds, large variations of catches per unit of effort (c.p.u.e.) expressed in catch per search time, are observed at seasonal and interannual levels, largely because of fishing effort variations and environmental changes (Fréon, 1986). Both catch per set and c.p.u.e. show the same seasonal fluctuation and the same decreasing trend in the industrial fishery (Fréon, 1986). As the catch per set in such fisheries is more or less representative of the school size, the obvious question is: does the decrease of c.p.u.e. correspond to a decrease in the number of schools or to a decrease in their size, or both? In order to try to answer this question for the Sardinella spp. stocks off Senegal, an analysis of the bias in c.p.u.e. and school size as long-term indexes of abundance is performed, bearing in mind the influence of behavioral change in both fish and fishermen (i.e. changes in fish aggregation pattern or changes in fishing strategy).

The senegalese fisheries catch mainly young S. aurita and S. maderensis and more mature adult S. aurita and Carangidae. The mean time per trip is 10 hours, and zero to three successful sets are normally performed during this time period.

MATERIAL AND METHODS

Data on the industrial fishery were obtained from daily interviews with fishermen returning to the harbour or landing site after their daily trip. For the industrial fishery the rate of sampling is around 98% for catches and efforts, except in 1973 where it was lower than 80%; reliable and representative data are available from 1969. For the artisanal fishery, the annual data sets are complete only from 1977. Both series analyses stop in 1987, at the beginning of the industrial fishery collapse. In this paper, only the industrial fishery data are analyzed, except for total production modelling where total catches are considered.

Each record in the data files corresponds to the fishing operation of a single boat in a single area (except in 1976, a single area was fished during a trip in more than 95% of the annual observations). The catch per individual set is not recorded in the data files, but the numbers of successful and unsuccessful sets per trip/area are available. Therefore various indices of school size can be computed:

- the mean catch per total number of successful sets (c.p.t.s.s.); this provides the greatest possibility of underestimation of the school weight due to the possible saturation of boat-loading capacity when loading the last set;

- the mean catch per number of successful sets, selected for trips with only one successful set (c.p.s.s.1). About 37% successful sets are made during such trips. Except for very large schools, this index is designed to limit the saturation effect. It may underestimate the proportion of small schools.

- the mean catch per number of successful sets, selected for trips with only one successful set (as previously) and for the other trips when landings are obviously lower than boat-loading capacity (c.p.s.s.2). This index is used to overcome the previously mentioned possibility of underestimation.

The catch per time unit of searching and the catch per total time fishing (time searching plus time catching the fish) are considered the best indices of abundance for these fisheries, although not completely unbiased (Fréon, 1980). A summary of the available samples is presented in Table 1.

Table 1. Summary of available data for the industrial fishery from 1969 to 1987.

	Number of Sets	Number of trips
One successful set per trip	15 419	15 419
More than one successful set	26 276	11 672
Total successful sets	41 695	27 091
Unsuccessful sets	14 684	7 980
TOTAL sets	56 379	35 071

Other variables also recorded are: date, boat identification, weather at sea as declared by the captain, total time at sea, fishing area (20' latitude zones combined with choosen depth intervals), estimation of the landings, commercial categories (for each species). The time of day corresponding to each catch has been recorded since 1975. Appropriate meteorological data was available from the coastal station of Cap-Vert peninsula.

As most of the previous variables may be related directly or indirectly to the mean catch per set (size of the boat, temporal and spatial allocation of the fishing effort, etc), multivariate analyses were performed on the whole data set. Data was recoded in order to obtain a complete disjunctive table, then a factorial analysis performed from a Burt table (Benzecri, 1973).

RESULTS

General data set analysis

From the multivariate analyses (not shown), it is obvious that some significant changes occurred in the fishery during the period of study. Indexes of abundance and of school size both show a considerable decline (see below). The mean size of the boats, when weighted by their number of trips, did not change markedly (extreme annual values: 22.53 m in 1983 and 20.15 m in 1986). However, the range of boat sizes was greater in the eighties, owing to the arrival in the fishery of smaller boats (15-16m), operated by the government. The weather at sea varied considerably from year to year. According to fishermen interviewed, it was very bad in 1976 and from 1979 to 1986. Unfortunately this data is not always consistent by day or by area, nor is it correlated to meteorological data. The fishing area was slightly larger in the past. Fishing grounds were not as deep as those currently fished. During recent years, fishing operations more often took place later in the day or during the night (in comparison to the historical period). The proportion of different species in the catches changed from year to year, without clear long-term tendencies with the exception of a decrease in the young year-classes of S. aurita associated with an increase in the young year-classes of S. maderensis up to 1984, and a decrease of all other warm-season species (mainly Pomadasys spp., Chloroscombrus chrysurus and Ethmalosa fimbriata). The proportions of cold-season species (mainly Caranx rhonchus, Scomber japonicus, Trachurus spp., and the oldest year-classes of S. aurita) was subject to variation without visible trend (Table 2). Other variables concerning the fishing strategy did not change significantly.

Table 2. Proportion of the different species (%) landed by the industrial fishery from 1969 to 1987.
O-Sa: Old year classes of *Sardinella aurita*;
Y-Sa: Young classes of *S. aurita*;
Sm: *S. maderensis*; Cr: *Caranx rhonchus*;
Cc: *Chloroscombrus chrysurus*;
Ef: *Ethmalosa fimbriata*; Sj: *Scomber japonicus*;
Pspp: *Pomadasys spp* (mainly *P. jubelini*);
Tspp: *Trachurus spp.* (mainly *T. trecae*).

Year	O-Sa	Y-Sa	Sm	Cr	Cc	Ef	Sj	Pspp	Tspp	Oth.
69	40.0	13.4	25.7	7.1	4.2	0.9	0.0	7.5	0.1	1.1
70	29.9	18.9	24.4	9.2	3.9	1.0	0.3	10.4	0.1	1.9
71	59.2	6.6	14.2	0.9	0.2	4.0	0.0	15.0	0.0	0.0
72	62.6	6.2	17.8	4.7	0.2	1.0	0.0	7.1	0.0	0.4
73	48.5	4.5	26.2	4.2	2.2	0.4	0.3	6.5	0.5	6.7
74	30.6	21.5	29.2	5.3	2.0	0.5	0.3	3.8	3.5	3.3
75	32.9	7.6	31.0	5.3	0.7	0.8	9.8	1.7	5.4	4.8
76	28.2	18.4	37.5	6.0	0.5	0.4	0.2	1.2	3.5	4.1
77	28.8	19.6	33.3	6.0	1.0	0.9	0.2	2.9	2.0	5.3
78	27.8	29.2	24.4	7.2	1.0	0.0	0.2	3.5	1.2	5.5
79	29.2	22.5	33.1	6.4	0.9	0.0	0.6	1.0	0.5	5.8
80	20.9	31.4	31.5	9.5	1.2	0.0	1.0	0.3	0.5	3.7
81	21.9	27.8	34.5	8.2	0.5	0.0	3.0	0.3	2.1	1.7
82	9.2	15.3	50.4	14.4	0.7	0.2	1.7	1.4	3.5	3.2
83	9.3	19.1	51.4	5.5	0.8	1.4	5.5	0.1	5.1	1.8
84	15.8	9.1	49.0	1.4	0.9	2.4	9.4	0.9	5.5	5.6
85	47.9	8.8	32.4	1.0	1.8	0.0	0.5	0.6	3.6	3.4
86	35.8	7.8	38.6	2.0	1.0	0.1	4.6	0.0	3.2	6.9
87	55.7	6.0	28.3	0.1	0.6	0.0	4.4	0.0	2.5	2.4

Even though the factorial analysis is mainly a qualitative descriptive method, it indicates no important aspect of the above described long-term changes on annual abundance and school-size indexes; this despite strong seasonal or daily variable influences (example, weather at sea (Levenez, in preparation), hour of the catch, etc). The only exception is, to some extent, the influence of average boat size.

The comparatively weak influence of boat size and equipment on c.p.u.e. was mentioned in a previous study using only 1977 data (Fréon, 1980). Using the whole data set, the recent introduction of small boats shows the effect of boat size on different variables, especially on the mean catch per set. Therefore, the analysis was done using only medium-size boats (18 to 23 m), which represent the bulk of the fleet, except during the last years. Fortunately an old boat has been working continuously during the period studied, and its data have been processed separately; similar figures were obtained.

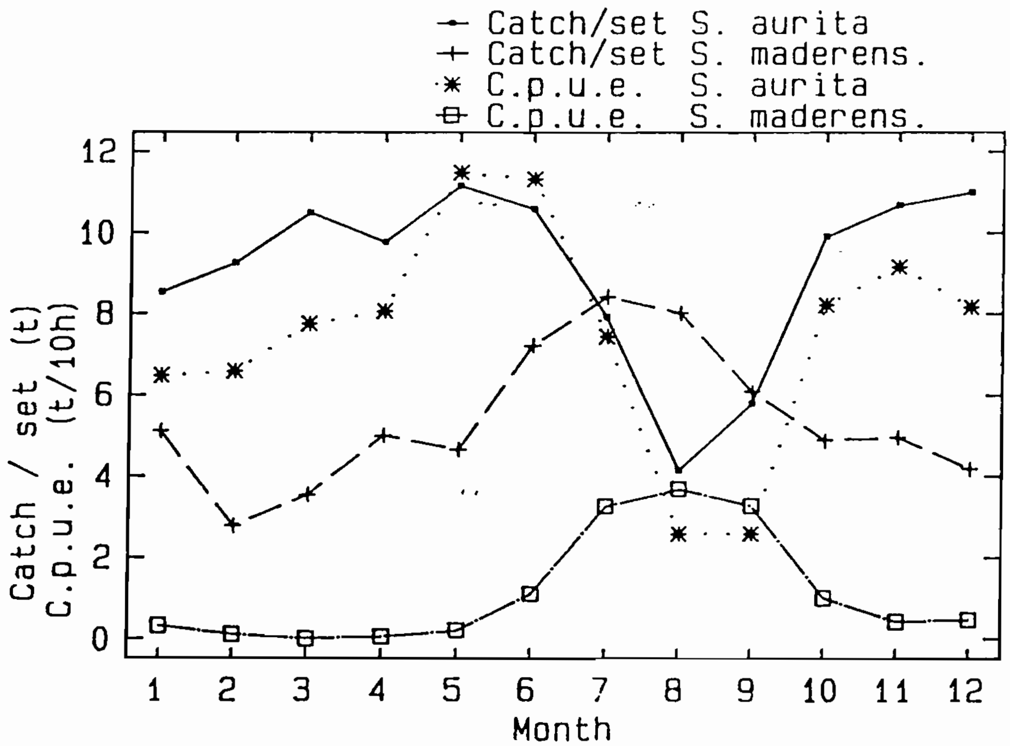

Fig. 1. Seasonal variations of the mean catch per set and of the c.p.u.e. (weight per time search) for S. aurita and S. maderensis computed from the 1969 to 1987 observations.

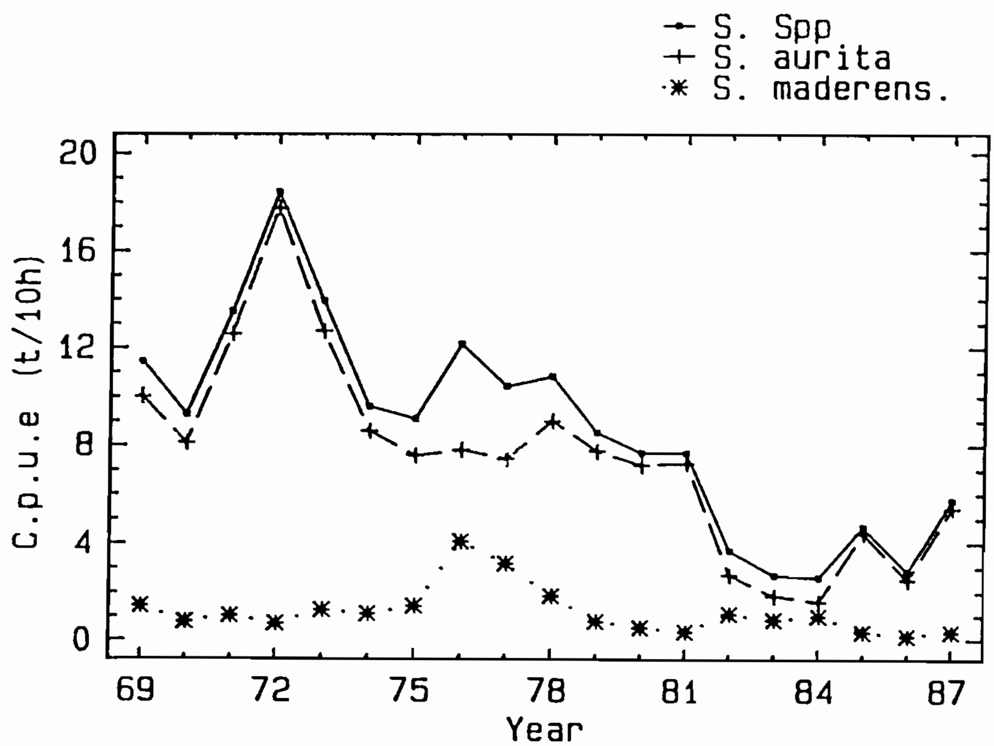

Fig. 2. Interannual variation of c.p.u.e. of medium size purse seiners from 1969 to 1987.

C.p.u.e. analyses

The c.p.u.e. of the industrial fishery shows large seasonal and interannual variations, mainly due to the two principal species of Clupeidae: *Sardinella aurita* and *Sardinella maderensis* (Fig. 1 and 2) which account for respectively 47% and 31% of the catches over the period studied. Such variations have already been explained by:

-the increasing fishing effort over this period (explaining the general decreasing trend in c.p.u.e.),

-the interannual fluctuations of the upwelling, shown in Fig.3 (explaining most of the abundance anomalies after suppression of effort effect),

-the seasonal fluctuations of the upwelling and the associated fish migrations and/or seasonal abundance variations.

From these observations a surplus production model including an upwelling index has been developed (Fréon, 1986).

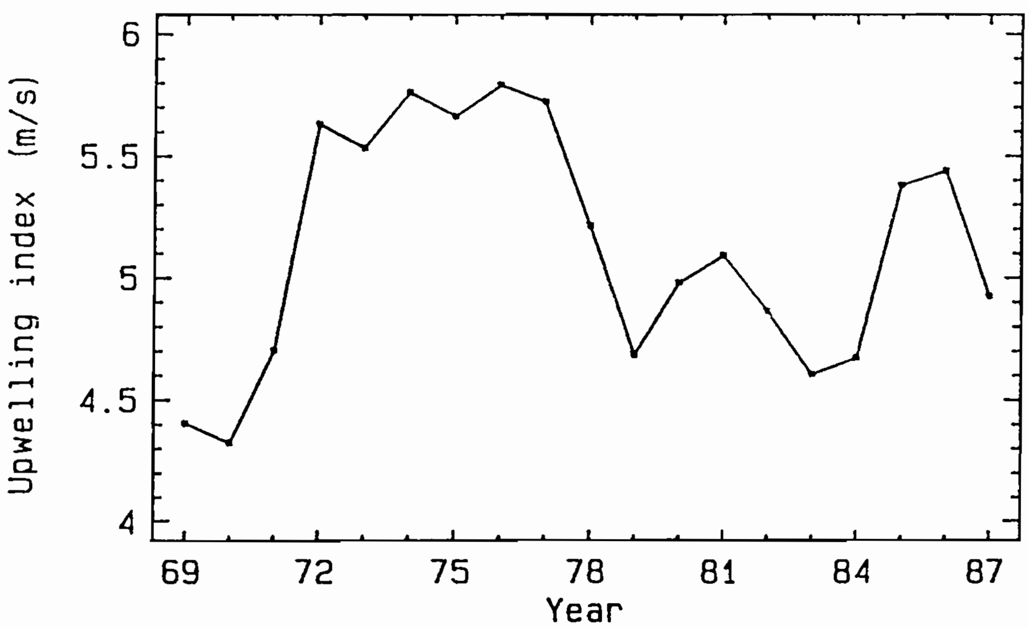

Fig. 3. Upwelling index from 1968 to 1987: mean wind speed from November to May (source: ASECNA).

School size index analyses

The catches per set (Fig. 4) and the c.p.u.e. (Fig. 2) exhibit similar trends, whether when considering the c.t.s.s. (decreasing from 22 to 4 metric tons; not shown), the c.p.s.s.1 or the c.p.s.s.2. Since the c.p.u.e. is the product of the mean catch per set (w) by the number of sets (n) per fishing effort (f) (c.p.u.e. = w n / f), the number of successful sets by time fished did not show a steady change during the period of observation. Only a slight increase of this value can be noted from 1970 (Fig. 5). The interpretation of *S. maderensis* figures is not so easy because this species is less abundant and often mixed with *S. aurita* in a single school (see below).

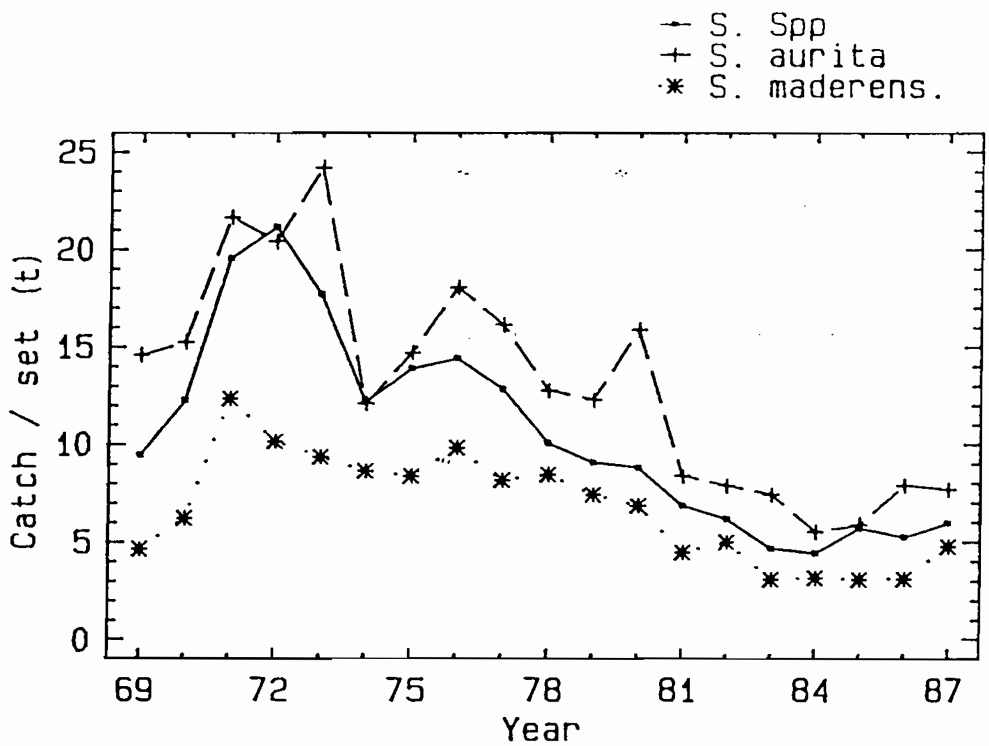

Fig. 4. Interannual variation of mean weight of catch per set c.p.s.s.2 (see text) of S.aurita, S. maderensis or of both species (1969-1987).

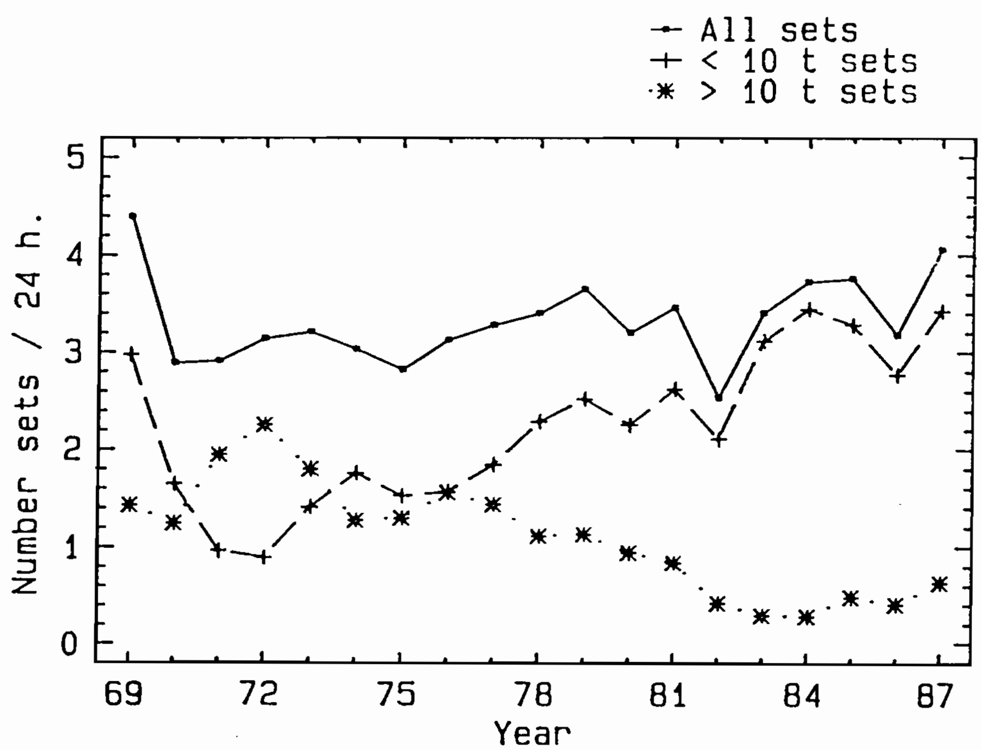

Fig. 5. Number of sets of Sardinella Spp. per 24 hour search for medium size seiners (1969-1987).

When looking at the evolution of set occurrence per time fished for each weight-classes separately, it appears that the decreasing trend in c.p.u.e. and catch per set is due both to an increase in the small schools occurrence in the catches (less than 10 metric tons) and to a decrease in the large and medium size schools (over 10 tons; Fig. 5).

The seasonal variation in the catch per set is, once more, related to the c.p.u.e. index (Fig. 1). A clear opposition between the two species of sardine can be observed: S. aurita is more abundant during the cold season and forms large schools between October and June; the largest schools of S. maderensis are observed between June and September. Such an opposition reflects the complementary demographic strategies developed by these two species in order to limit their competition. On these lines, Cury and Fontana (1989) stressed the differences in the reproductive strategies of these species which have very close feeding behaviours. Nevertheless, the competition does not seem to be completly avoided: the two species are often mixed in the same set, and probably in the same school (Fréon, 1984), especially during the warm season, where young spawners are caught (Table 3).

Table 3. Half Burt table showing the co-occurence of the two species of Sardinella in a single set, according to their body length group (empirical commercial categories by increasing size given by the fishermen, from I to VIII).

Species & Size	Sardinella aurita I	II	III	IV	V	VI	VII	VIII	Sardinella maderensis I	II	III	IV	V	VI	VII
S. aurita I	88														
II	0	86													
III	0	4	476												
IV	0	1	4	2608											
V	1	2	0	5	3314										
VI	0	0	0	0	5	305									
VII	0	0	1	8	2	0	3258								
VIII	0	0	0	0	0	0	0	136							
S. mader. I	42	5	10	9	6	0	0	0	89						
II	0	45	13	45	2	0	2	0	0	113					
III	36	11	210	164	175	4	3	3	4	3	641				
IV	2	14	108	1746	1487	50	132	44	2	0	7	4724			
V	0	2	9	110	1083	77	375	26	0	0	5	10	2103		
VI	0	0	0	5	34	63	7	0	0	0	5	6	11	121	
VII	0	0	0	6	4	0	99	0	0	0	0	0	0	0	120

DISCUSSION

Many factors can affect the recorded catch per set of a purse-seiner:

-the size of the net, and the boat-loading capacity, which can both lead to an underestimation of school size,

-the decision of the fisherman in shooting the net or not, according to his estimation of school size (especially for small schools), and to his hopes for subsequent fish-finding,

-the size of the schools on the fishing grounds (this is our main hypothesis). Changes in school size or form according to a circadian rhythm, to predation pressure or to environmental conditions, especially food density, are well documented (Kemmerer, 1980; Pitcher, 1986; Blaxter and Hunter, 1982). More debated is the influence of the fishing pressure on the school size (Nonoda, 1985).

It is obvious that the small senegalese purse-seiners are not able to catch or load the largest schools (40 to 100 tons according to boat size).From acoustic surveys we know that the mean size of schools in the area was around 10 tons in 1976 and that schools over 40 tons were infrequent (Gerlotto et al., 1976). In this paper we try to analyse the changes in the medium and small size of schools, where saturation effects do not occur.

When considering trips with a single successful set, the problem of saturation is limited. In consequence, the mean values of catch per set are higher and the differences between boats of different size are less marked.

The stategy of the fishermen may vary according to the fish abundance and possibly to its current market value. Especially for the first set of the trip, the fisherman will probably disregard small schools and shoot them only in case of low abundance, when expectation of a better finding is low. This phenomenon seems responsible for the increase in the number of schools smaller than 10 tons from 1972 to 1987 (Fig. 5). During this period, the conjunction of increasing effort and decreasing upwelling has reduced abundance. The problem is to discriminate the effect of fishing strategy from a possible direct effect of the environment or fishing pressure on the size of the schools present on the fishing grounds.

Another way to tackle the problem is to look at the evolution of large set occurrence. By exclusively selecting trips with a single successful set, we overcome not only the saturation problem but also remove most of the eventual influence of fishermen's behaviour: in any situation the fishermen will always prefer to shoot the large schools. It appears clear that the occurrence of schools over 30 tons decreased markedly during the 1972-85 period.

Of particular interest is the relatively high occurrence of small sets in 1969 and 1970 (Fig. 5). The situation was not similar to the mid-seventies period, even though identical values of catch per set were observed: the upwelling strength was at its minimum and fishing pressure was lower. The weakness of the upwelling seems the major event which explains the relative abundance of small sets during this period. A comparative study of the anomalies of cpue, catch per set and upwelling index was performed after removing the autocorrelation in the series by using the residuals of ARIMA models (Box and Jenkins, 1976). The study of the cross-correlation functions clearely indicates lagged relationship (from 2 to 14 month, according to the period of the year) between upwelling and c.p.u.e. series, and a weaker relationship between upwelling and catch per set.

Finally, it seems that both environmental conditions and exploitation level influence school size. The fishermen's strategy obviously overestimates decrease of mean school size when the size of the sets is analyzed, because they accept to shoot smaller schools in the case of low abundance. Nevertheless, if used carefully, the mean catch per set can provide a reliable index of mean school size and maybe of abundance, associated to the analyses of the number of schools per weight class detected per time unit. The smallest weight classes must be eliminated before analysis, and special attention must be paid to any changes in the fishery (gear, equipment, size of boat, time of fishing, market, etc).

Using the c.p.s.s.2 (after removing the sets of less than 2 tons) as an index of abundance for both species of Sardinella, a surplus production model including the upwelling index has been adjusted successfully (Fréon, this meeting). The theoretical effort index is in this case proportional to the number of sets, and it provides a more realistic picture of the evolution of fishing pressure than the results obtained by dividing the total catch by the c.p.u.e.. Nevertheless, further studies on the artisanal fishery (which seems to present a different pattern) and on other stocks are required before adopting such an abundance index.

CONCLUSION

In the senegalese fisheries, the mean catch per set presents large seasonal and interannual variations, mainly related to school size and secondarily to the fishermen's strategy as far as small sets are concerned.

For purse-seine fisheries of pelagic species, the time searching for fish is usually considered as the best effort unit to be used in c.p.u.e. calculation, as far as abundance index is concerned. Nevertheless the use of such an effort unit may introduce a bias in stock assessment, specially in the case of overexploited stocks of coastal pelagic fish where a reduction of the area of distribution is often observed. The analyses of the mean catch per set and of the number of sets do not overcome all the problems, but represents a complementary information for stock assessment. Moreover, the distribution of school weight is important in managing the fishery (size of gear, loading capacity of the boat).

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