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Strategy of Eel (*Anguilla anguilla* L.) Exploitation in the Thau lagoon

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Fisheries activity in the Thau marine lagoon (Mediterranean coast of France) rests mainly upon the eel, *Anguilla anguilla* L. It involves several types of gears: nets, traps and lines, that are used with varying frequencies in different areas at different parts of the year. We showed that the various types of gear select for different fish size classes, with each method focusing on a particular part of the eel stock, that lives at a particular depth. Data was collected weekly during 28 months. Time series analysis (contingency periodogram) made it possible to reveal significant periods of 6 and 12 months in the landings and in the fishing effort data series. Hypotheses about the influence of environmental determinants on the behaviour of fish and fishermen and on the interactions between them, and effects on landings, were tested using the method of path analysis; we found that effort is the most important determinant of landings, while temperature and lunar coefficient also have an effect. The resulting models differ depending on the type of gear under study: ' capêchades ' on the one hand, used mostly by occasional fishermen, and ' triangles ', ' brandines ' and longlines on the other, used mostly by resident fishermen.

Introduction

Eel is the most important commercial fish species in Thau, a Mediterranean lagoon in southern France. In 1982, a total landing of 136 tonnes was recorded. The lagoon is the centre of an intensive and diversified fishing activity, using a wide variety of gears. Except for Haon's paper (1979) on eel, information available on the fishing industry in the Thau lagoon is outdated: Gourret (1896*a*, 1896*b*, 1897), Sudry (1910), Petit and Doumenge (1955), Bonnet (1973).

An understanding of the fishing activity in the Thau lagoon must be based upon a study of the strategy of eel exploitation. The purpose of this paper is to analyse Thau eel fishing

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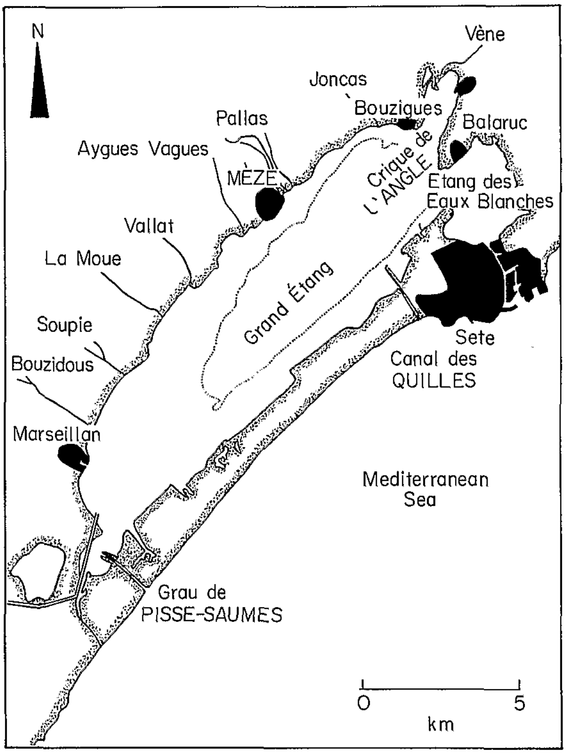


Figure 1. The Thau lagoon (Hérault, France).

activity, (1) by describing briefly the selectivity of fishing gears on green eel sizes; (2) then by pointing out the variations that occurred in the catches, between September 1981 and December 1983, considering fishing gears and types of eel (green or silver) on the one hand, and monthly fishing efforts on the other; (3) we will then search for periodic phenomena in the catches and in the number of fishermen involved, taking into account the main types of gears used, in order (4) to test hypotheses of explanation involving the climatic and astronomical factors that may affect both the catches and the fishing effort. In other words, we will examine to what extent catchability (which remains unmeasured) and fishing effort, which determine landings if we assume constant stock, may be determined by environmental factors; this will be done separately for different types of gear.

The Thau lagoon

The Thau lagoon, with a surface area of about 7500 ha, is located from 3°31′50″ to 3°42′30″ longitude east and from 43°20′ to 43°28′ latitude north (Figure 1). About 20 km long, it lies in a northeast/southwest direction and never exceeds 4·5 km in width. It is divided into two unequal parts: in the northeast, the ‘ Étang des Eaux Blanches ’ (600 ha) is shallow. The ‘ Grand-Étang ’ (6900 ha) in the southwest is more variable in depth, with shallow zones (such as the ‘ Crique de l’Angle ’, or ‘ Les Onglous ’ near the Pisse-Saumes channel) and deeper ones such as ‘ La Source de la Bise ’ (30 m deep). Mean depth is about 4·5 m.

Because it is shallow (which maximizes evaporation per unit volume), and because communications with the sea are important relative to the freshwater input from continental runoff, the Thau lagoon permanently retains strong marine characteristics.

Fishing gears

Lagoon fishing is as ancient as salt-works exploitation and dates back to the Gallo-Roman period at least. Methods remain quite traditional; the same fishing techniques have been used for the past hundred years (Gourret, 1897), and were modified only recently, where they were made more efficient with the introduction of nylon lines and motor boats. Examining documents about lagoon fishing (Gourret, 1897; San Feliu, 1973), one is surprised to find how many fishing gears were used in the past that are no longer in use today. Fishing techniques (active fishing gears, mostly) were left aside as the socioeconomic context of the activity became permanently modified.

In the lagoon, the main target species is eel. During the past few years, eel trade developed considerably with the expansion of its market in Italy. According to Haon (1979), Italy is the most important buyer of live eel from the Languedoc-Roussillon region, where eel represents 50% to 100% of the fishermen's income.

The fishing gears in use are adapted both to the eel and to the Thau lagoon. Most of them pertain to the trap net family. They differ in mesh size (Figure 2) and are used differentially through space and time: the ' capêchade ', equipped with three traps, is used around the year but only near the shore, in less than 1·5 m of water. The ' triangle ' is a fixed-spot gear. Locations are drawn at random yearly among fishermen. Equipped with seven traps, it is larger and has wider mesh then the ' capêchade '. It is used in the deeper parts of the lagoon (3 to 4 m), but remains attached to the shore. The ' triangle ' is used mostly during the spring (March to May) and fall (September to December). The ' gangui ', equipped with one trap only, is a fixed-spot gear used only in the Sète channels during fall and winter, when silver eel (migrating) moves to the sea. The ' brandine ' is used in the middle of the lagoon, and only in the deeper parts (4 to 7 m). Equipped with six traps, it is used during the spring and summer months.

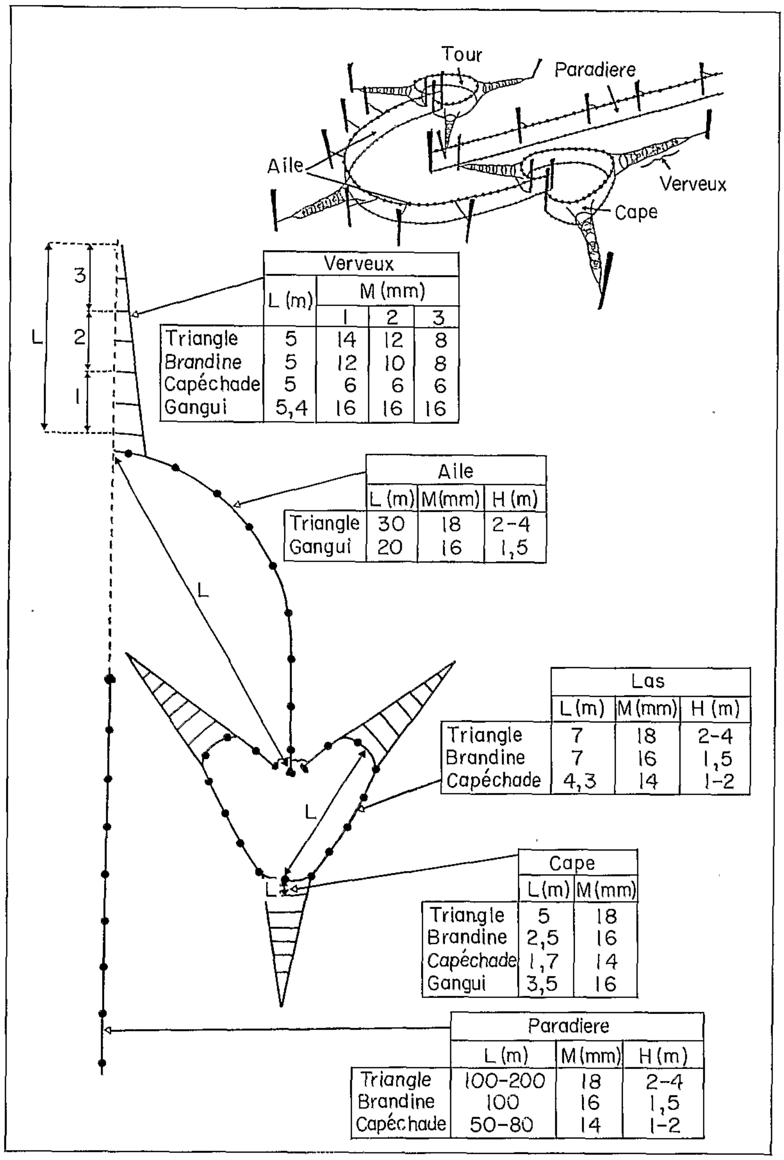
Other gears are used in a few locations; they are of the fishing-line type, such as the longline and the ' croc '. More detailed descriptions of the various fishing gears mentioned here can be found in Bach (1985) and in Bourquard (1985). Among the gears used in the Thau lagoon, the ' capêchade ', the ' triangle ' and the ' brandine ' are the most popular; they are well adapted to eel fishing.

Materials and methods

Data

Landings, fishing effort, length frequency data—Statistics on eel biomass from September 1981 to December 1983 for the Thau lagoon were obtained from the largest eel fishtrading company of the area. This firm deals with 50% to 75% of the eel caught in the French Mediterranean lagoons (Dérijard, pers. comm.). For the Marseillan area, we verified that all fishermen were selling their eel to that fishtrading company. Representatives of this firm, which for commercial reasons is well acquainted with the eel market, estimated that it handles between 80% and 95% of the catches of the whole lagoon.

Data, which were recorded from the fishermen's individual invoices, correspond to weekly or daily catches, depending upon the season. Each invoice contains the fisherman's name, the place and date where the catch was weighed, the mass of eel caught, and the purchase price per kilo. After investigating several other ways of acquiring data, we found this way of proceeding to be the only method for obtaining comparable, uniformly valid data.



	Verveux			
	L (m)	M (mm)		
		1	2	3
Triangle	5	14	12	8
Brandine	5	12	10	8
Capéchade	5	6	6	6
Gangui	5,4	16	16	16

	Aile		
	L (m)	M(mm)	H (m)
Triangle	30	18	2-4
Gangui	20	16	1,5

	Las		
	L(m)	M(mm)	H (m)
Triangle	7	18	2-4
Brandine	7	16	1,5
Capéchade	4,3	14	1-2

	Cape	
	L(m)	M(mm)
Triangle	5	18
Brandine	2,5	16
Capéchade	1,7	14
Gangui	3,5	16

	Paradiere		
	L (m)	M(mm)	H (m)
Triangle	100-200	18	2-4
Brandine	100	16	1,5
Capéchade	50-80	14	1-2

Figure 2. Measurements of gear elements and mesh size for the trap nets used in the Thau lagoon. L = length of element in m, M = mesh size (side of mesh) in mm, H = height of element in m. ' Verveux ' is a fyke net, ' aile ' is the wing, ' las ' is the fence of the enclosure, ' cape ' is the cape, and ' paradière ' is the leader. The basic gear is the ' capêchade ', made of three funnel nets in an enclosure, with a leader; the ' brandine ' consists of two ' capêchades ' linked by a leader; the ' gangui ' contains one funnel net with a wing on each side, while the ' triangle ', illustrated at the top of the picture, includes one ' gangui ', two ' capêchades ' and a leader.

Eel commercial value varies as a function of size and type, that corresponds to skin colour: green (freshwater), or silver (migrating). Since different fishing gears select for different types of eel (below), one can associate both a type of eel and its corresponding fishing gear to a selling price: the lowest price (10–13 FF kg^{-1}, depending upon the season) is paid for green eel caught by 'capêchades'. An intermediate price (12–16 FF kg^{-1}, depending upon the season) is paid for green eel caught by 'triangles', 'brandines' and longlines (bottom lines). The highest price (18–26 FF kg^{-1}, depending upon the season and the gear used) is for silver (migrating) eel caught mainly between October and January, using 'capêchades' and 'triangles'.

The invoice information made it possible to infer the following: (1) how much eel was caught during different time periods by each type of gear. For a weekly period, we consider that the last collection of eel by the wholesale fishmonger was done on a Saturday morning, regardless of the landing point. (2) How many fishermen were active during different time periods. The number of fishermen will be used to estimate fishing effort. The number of traps used in the lagoon would have been a better measure of fishing effort, but this information is very difficult to obtain and would have required frequent aerial surveys in order to follow the daily changes in fishing activity (changes in number and types of gear). The use of aerial surveys for this type of study is presently under consideration (Farrugio & Le Corre, 1985). (3) The type of eel caught, from which we inferred the dominant type of gear used.

After collection by a live-fish lorry, eels are stored in ponds, and divided according to the place of capture and the fishing gear used. Before resale, eels are gauged by sifting. In this study, eels caught in the Thau lagoon were measured using a galvanonarcotic tank (Gosset, 1974; Lamarque, 1976), before sifting by the fishtrading company.

Explanatory variables of the fishing activity—In order to explain the variance of landings, we related the fishing effort to two climatic factors (air temperature and wind speed) and one astronomical variable (the moon). Similarly, we tried to explain the variability of the fishing effort using these environmental variables. The choice of these explanatory variables is based upon the following hypotheses: (1) eel mobility, which is linked to its metabolism, is higher when the temperature of the surrounding water is high; consequently, chances for any given eel of encountering a fixed fishing trap are increased, so that we can expect catches to increase with temperature. (2) Strong wind is expected to have a negative effect on fishing effort. (3) It is well known that eels are nocturnal and move mostly at night. We can then expect them to be more capable of avoiding a fixed trap when moonlight is more intense, which corresponds to lower values of the lunar coefficient described below.

The climatic and astronomical variables were measured as follows. (1) Weekly average air temperature and wind speed were obtained from the records of the Fréjorgues (Hérault) meteorological station. For these two variables, we can assume that there is no great difference between the observations recorded at Fréjorgues and the situation on the Thau lagoon 30 km away. For other variables, such as wind direction, precipitations or cloud cover, differences might be more important because of a possible lagoon effect on these variables. Temperature and wind speed are recorded every 3 h; the respective weekly average values were calculated from these readings, from a Saturday at noon (day where eels are collected) to the following Saturday at noon. (2) The study period was divided into half-moon cycles (length of time between a full moon and a new moon night), of 14 or 15 nights long. We assigned an increasing value from 1 to 14 or 15 to each night for a given half-moon, where 1 is associated to the full-moon night and value 14 or 15 to the new moon (invisible); these values were added for each week. Larger values correspond to weeks with darker nights.

Data analyses

Length frequency differences among gears—First we checked whether all gears caught green eels of the same size. To do so, gears were first compared in terms of the variance of the lengths of eel they caught, using Bartlett's test; then, because there were significant differences among gear variances, the means of the lengths were compared using the nonparametric test of Kruskal-Wallis (Scherrer, 1984).

Eel catches and fishing effort time series—To analyse the green eel catch and fishing effort time series, we hypothesised the existence of cyclic phenomena embedded in the fishing strategy developed by the fishermen.

Most methods of periodic analysis require the data series to be long; as our series contained only $n = 122$ weekly observations spread over 28 months, we resorted to the contingency periodogram (Legendre *et al.*, 1981). This method makes it possible to analyse short data series; data can be quantitative, semi-quantitative or qualitative. In this method, all possible periods in the 'observation window', from a length of two observations up to $n/2$, are analysed in turn in a contingency table relating the various states of the variable to the length of the hypothesised period, and a contingency statistic B is computed; quantitative variables, as in the present study, are first divided into classes. Since they are related to chi-square ($\chi^2 = 2nB$), the values of B can be tested for significance. Legendre and Dutilleul (1992) present a comprehensive exposé of the contingency periodogram, and of other methods of time series analysis, written for fish biologists. Computations were done using program PERIOD from 'The R Package' (Legendre & Vaudor, 1991), available from the second author of this paper.

Relations among variables—As a first approximation to the relations among variables, two types of correlation coefficients were computed. Pearson's product–moment correlation searches for linear dependencies between variables, whereas Spearman's non-parametric correlation shows whether monotonic relations can be found. Partial parametric correlations were also calculated. These computations were carried out using the SPSS package. Since periodic data are by definition autocorrelated and that autocorrelation makes the tests of significance of correlation coefficients too liberal (Bivand, 1980; Legendre & Fortin, 1989), only those tests that reach the 0·01 probability level will be considered significant. The same rule will be applied to the partial correlation and path analysis results (below).

Variations in catches of green eels and in the fishing effort series were then interpreted through partial correlations, using climate (temperature, wind) and astronomy (moon) as independent variables. This analysis showed the dependency among the variables considered in this study, and allowed to test the significance of the causal relations among these variables. The choice of such a causal model always requires a set of hypotheses, that may be provided either by the body of ecological theory, or by some ecological information available from outside the data to be analysed (Legendre & Legendre, 1983).

Finally, catches and fishing effort variations were analysed by multiple regression with respect to hypothesised causal variables, and interpreted in a causal framework through the method of path analysis. Path analysis is a powerful tool which permits analysis of complex hypothesised cause-to-effect relationships and quantification of the relationships that are supported by the data; it was first developed for population biology (Wright,

TABLE 1. Statistics of the total length (in cm) distributions of green eels among dates for each type of fishing gear, for selected dates and locations. *n* = number of eels, *m* = mean of total length distribution (in cm), *s.d.* = standard deviation

Gears	Date	*n*	*m*	*s.d.*
'Capêchades'	7 March 83	374	20·93	5·40
	9 March 83	401	21·97	6·24
'Triangles'	9 December 82	597	33·42	5·74
	4 May 83	299	31·71	6·04
	6 May 83	409	35·21	8·13
	2 June 83	356	36·49	8·08
'Brandines'	11 April 83	208	38·75	6·85
	11 April 83	210	38·08	6·87
	27 April 83	188	37·37	5·50
	27 April 83	173	37·27	5·57
	30 April 83	244	35·74	4·35
Longlines	11 April 83	222	52·02	8·01
	13 May 83	63	52·08	9·84

1921), and is described in standard textbooks of biostatistics (Sokal & Rohlf, 1981; Legendre & Legendre, 1984); one may also consult Nie *et al.* (1975) or Asher (1976), among other texts. Path coefficients are *standard partial regression coefficients* that estimate the strength of the unique relationship between the various 'cause' and 'effect' variables (Sokal & Rohlf, 1981, section 16.3); in this study, the path coefficients are derived from simple or multiple linear regression coefficients, computed on the standardized variables. The linearity of the relations between the independent and dependent variables had been checked first.

Results

Comparison of length distributions of green eels caught by different gears

Table 1 shows that the means and standard deviations of the length distributions vary little among dates, within each type of fishing gear; this was confirmed by Kruskal-Wallis (for means) and Bartlett tests (for variances). The dates presented in Table 1 are those for which the fishmongers had saved specimens, for our study, caught with certainty by the various fishing gears listed. This result allowed us to pool data from different sampling dates, for each type of gear.

Then, comparisons were made among gear types, considering the means and variances of the pooled length distributions for each type of fishing gear (Figure 3). Looking at the results, (1) we found significant differences among the variances of the length distributions, using Bartlett's test ($P < 0{\cdot}01$). (2) Mean lengths also differ significantly among types of gear ($P < 0{\cdot}01$), as shown by a Kurskal-Wallis test; that test was used instead of a parametric analysis of variance because the data did not meet the condition of homogeneity of the within-group variances, as demonstrated in (1). So we can conclude that gear types are selective for different fractions of the eel stock, these fractions differing among gears in both mean and variance. The differences are likely to be partly the result of different mesh sizes: 6 mm in the 'capêchades', 8 to 12 mm in the 'brandines', and 8 to 14 mm in the 'triangles' (Figure 2).

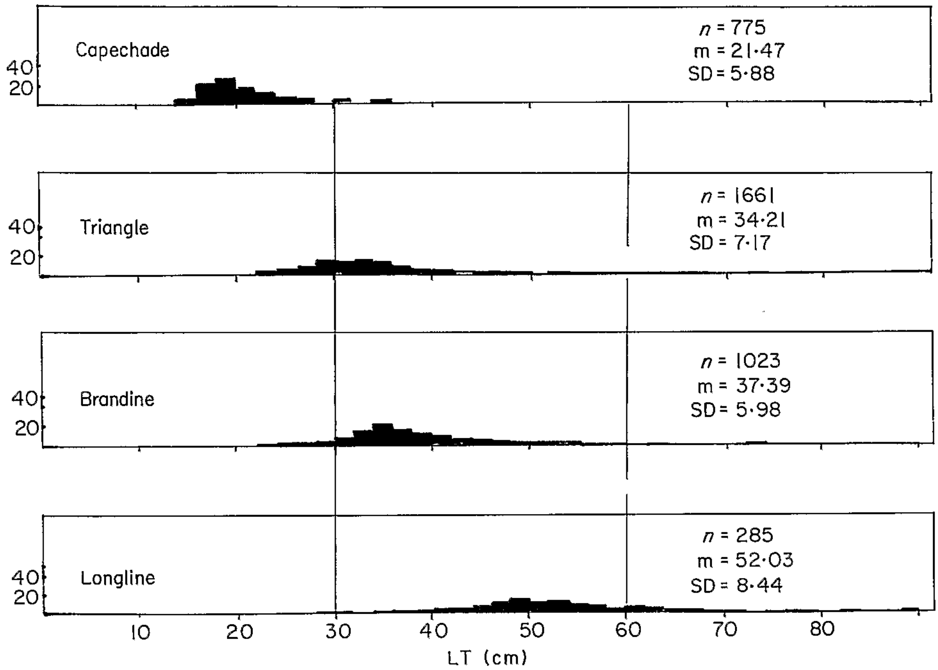


Figure 3. Pooled frequency distributions of total lengths (LT, in cm) of green eel caught in the Thau lagoon for each type of fishing gear. n = number of eel, m = mean length, *s.d.* = standard deviation.

Description of eel landings and of fishing effort

Silver eel and green eel catches—Looking at the monthly variations in eel landings from September 1981 to December 1983 [Figure 4(a)], we may consider two types of exploitation, depending on eel biology: silver eel (migrating, or ' downstream ') and green eel (which is the resident stock).

In November and December, landings mostly depend on silver eel catches; this is particularly true in December. The seasonality of silver eel catches reflects their biology, since they only turn silver and migrate during the fourth quarter of the year. Within-year fluctuations in the monthly catches of the silver eel are difficult to account for in terms of variations in stock vulnerability, however. Silver eel is caught with ' capêchades ', ' triangles ' and ' ganguis ', but fishermen may hold back their catches for quite some time, waiting for an increase in selling price. For this reason, only among-year comparisons are informative. Since we do not know the date of each catch, silver eel will be left out of the following analyses. Notice only that total landings of silver eel were roughly the same in 1981 and 1983, but lower in 1982. A possible reason for this decrease is the storm that hit the Mediterranean coast in November 1982 and caused very high fish mortality in the traps. These fish obviously could not be sold.

Considering the monthly variations of green eel landings, three characteristic periods can be recognised (Figure 4): during December, January and February, catches are always low. During March, April, May, August, September, October and November, catches are intermediate. By comparison, landings in July are very high (34·7 tonnes in 1982, 24·3 tonnes in 1983).

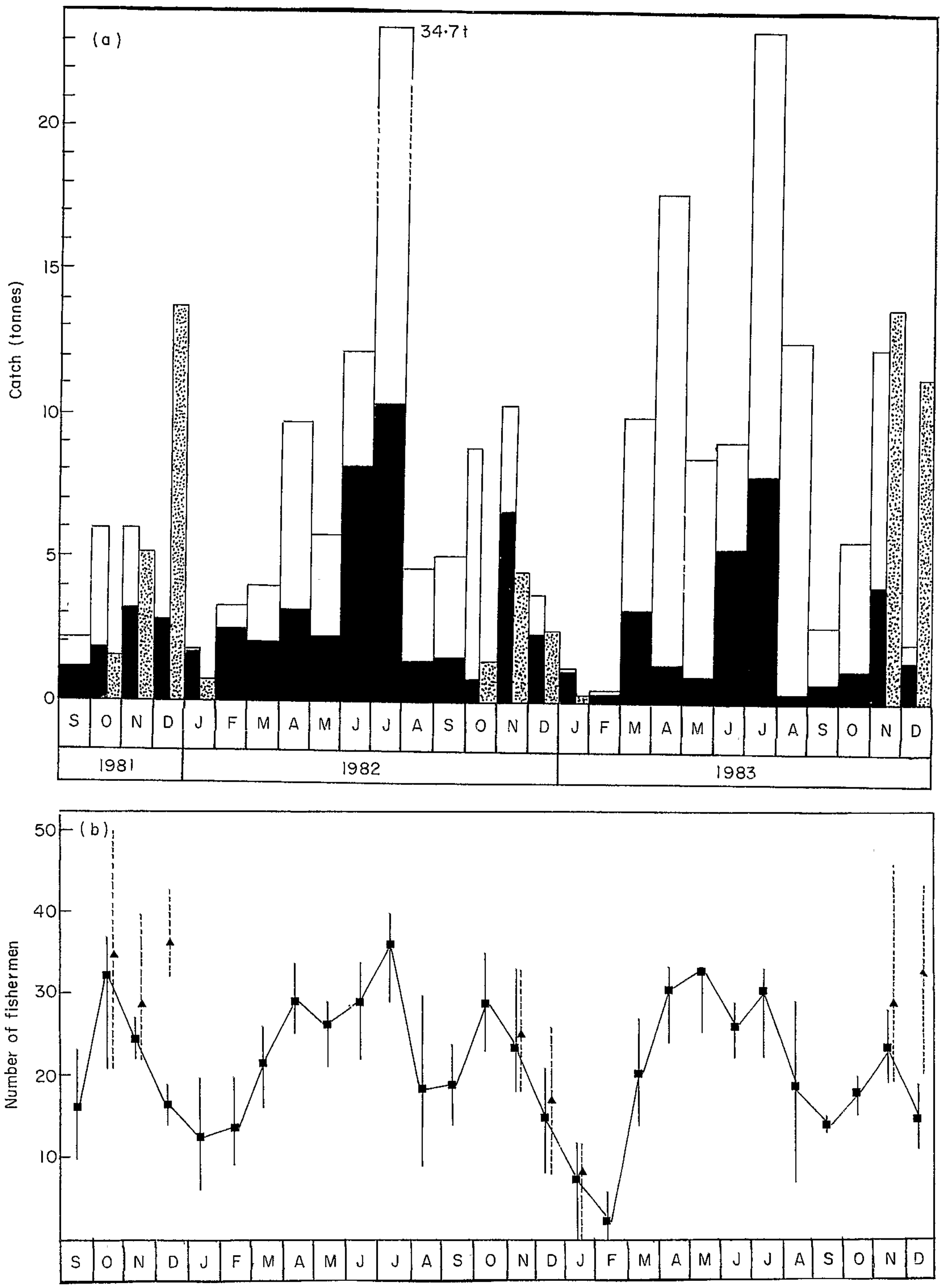


Figure 4. Eel landings from September 1981 to December 1983. (a) Monthly catches by eel types. □, green eels caught using 'triangle', 'brandine' and longline; ■, green eels caught using 'capêchade'; ▨, silver eel. (b) Monthly fishing effort, measured by the number of fishermen. ■, weekly average number of fishermen catching green eel; ▲, weekly average number of fishermen catching green and silver eel. —— and ---, extreme values.

Green eel catches increase regularly from January to April, decline in May, then go up to reach a peak in July. In August and September (except in August 1983) catches are similar to March, then they increase in October and November. Years 1982 and 1983 were characterized by roughly the same cycle.

If variations in monthly catches of green eel appear to be the same from year to year (periods of poor and large catches being the same), catches clearly differ among months. Several reasons can be invoked to explain these differences: (1) variations in fishing effort (number of active fishermen and number of gears used by them). (2) Variations in the meteorological conditions, that affect stock catchability. Accessibility being supposed constant, catchability only depends on vulnerability. (3) Variations in death rate in traps and stockpiling bags. We have seen this phenomenon mostly during the summer months, when temperature is high. Since these fish cannot be marketed, statistics for commercial catches underestimate real catches.

Fishing effort in terms of number of fishermen [Figure 4(b)]—Variations in the number of green eel fishermen are similar to those in green eel catches. Several phases can be identified: little activity in January and February of 1982 and 1983. Medium-size activity during March, April and May of 1982 and 1983; October, November and December of 1981, 1982 and 1983. High activity in June and July of 1982 and 1983. The rise in fishing effort during these months (particularly July) is less than that observed for catches.

If we consider monthly catches and monthly fishing effort profiles for the green eel, temporal variations in landings would seem to be caused by fluctuations in stock vulnerability, to which fishermen and fishing techniques adapt to a greater or lesser extent.

Green eel catches for each type of gear—Concerning individual fishing techniques [Figure 4(a)], changes in gears during the course of the year are not as noticeable as the variations in catches. Nevertheless, we notice that the months of January, February, June and July are characterized by a greater use of ' capêchades ' (particularly in June and July). Between August and October, there is a greater use of ' triangles ', ' brandines ' and longlines. In the period from March to May, the situation varies depending on the year. In 1982 for instance, ' capêchades ' seem to be more popular, unlike the same period in 1983 (particularly during April and May). These changes in fishing technique imply that fishermen seem to adapt to the variations of the stock vulnerability that follow seasonal changes in climate (wind conditions, precipitations, temperature, etc.). Unfortunately, the relationship between catchability and fishing effort (coupled with gear choice) cannot be investigated further without gathering extensive information from the fishermen about the type and number of gears they used.

Time series of green eel catches and of fishing effort, per fishing technique

Variations in monthly catches of green eel and in fishing effort [Figure 4(a,b)] clearly show that the eel fishery in the Thau lagoon is characterized at least by an annual periodicity; this is also the case with most fisheries in temperate climates. If these two periodic phenomena are in phase, the temporal fluctuations of catches may depend on the temporal fluctuations of fishing effort, and/or on the periodic behaviour of the resource vulnerability; both of these assumed causes may, in turn, be dependent upon climatic factors.

Time series analyses were carried out for series of weekly catches of green eel and for fishing effort, first for ' capêchades ', and then for ' triangles ', ' brandines ' and longlines together. The original and detrended data series are presented in Figures 5, 6, 7 and 8.

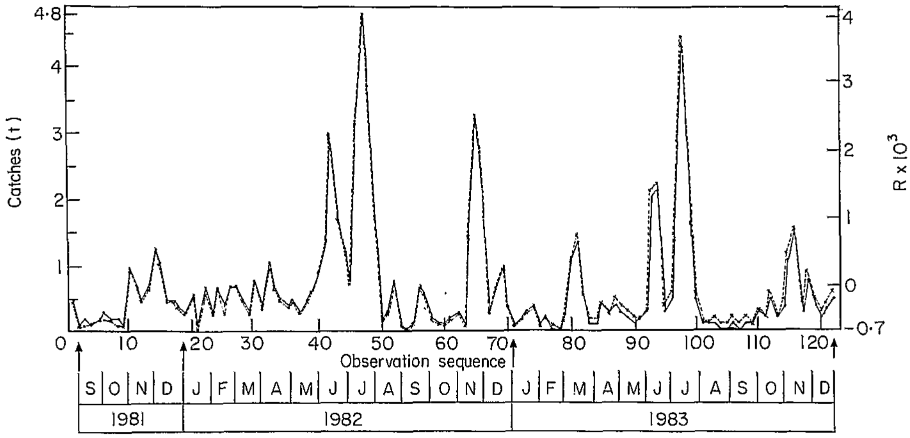


Figure 5. Time series of green eel catches (in tonnes) using ' capêchades ': original (——) and detrended (- - -) series. Right of the graph, ' R ' is the scale of the detrended data.

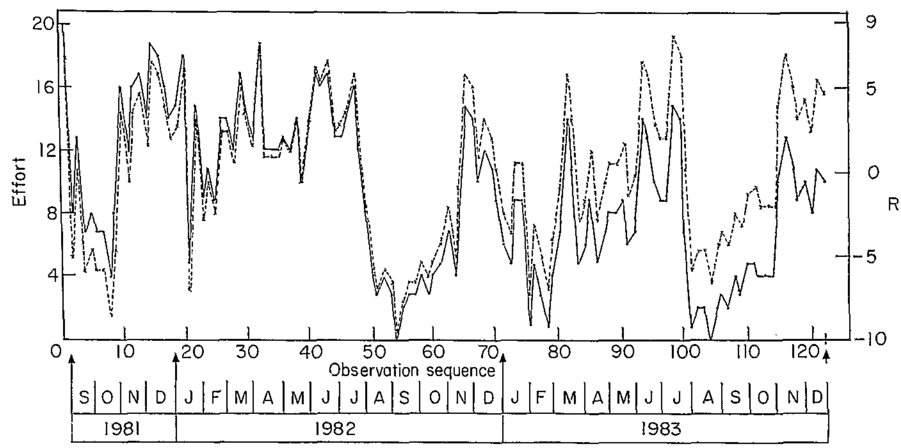


Figure 6. Time series of the fishing effort (number of fishermen) of ' capêchades ': original (——) and detrended (- - -) series.

Trends (tendencies) have to be removed from data series prior to periodic analysis. The presence of trends in our series was tested using Pearson's linear correlation coefficient, calculated between the values of the variable (catch or fishing effort) and the rank of the observations in the series. Results are reported in Table 2; they show that two of the series are characterized by a significant trend: a negative, highly significant linear trend is present in the ' capêchade ' fishing effort series (Figure 6), which means that the fishing effort has decreased markedly over the study period, without much of a corresponding effect on landings (Figure 5). A positive significant trend is found in the catches from ' triangles ', ' brandines ' and longlines (Figure 7), which means that landings from these fishing gears have increased over the study period, without a corresponding increase in effort (Figure 8); effort has actually slightly, though non-significantly, decreased (Table 2).

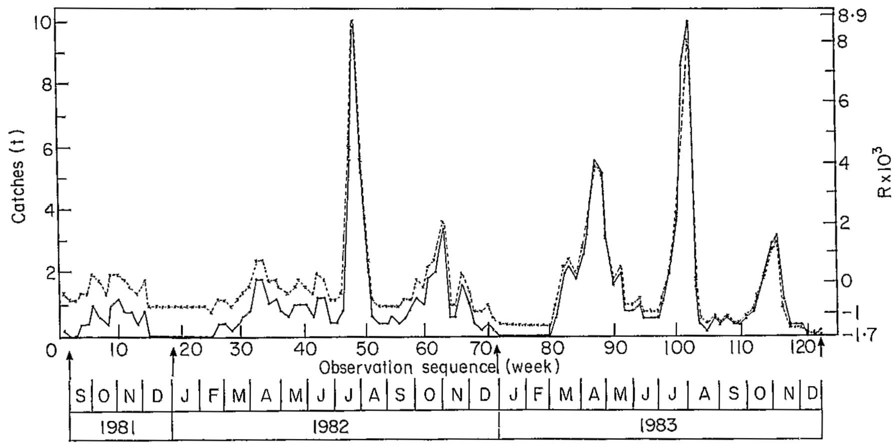


Figure 7. Time series of green eel catches (in tonnes) using 'triangles', 'brandines' and longlines: original (——) and detrended (- - -) series.

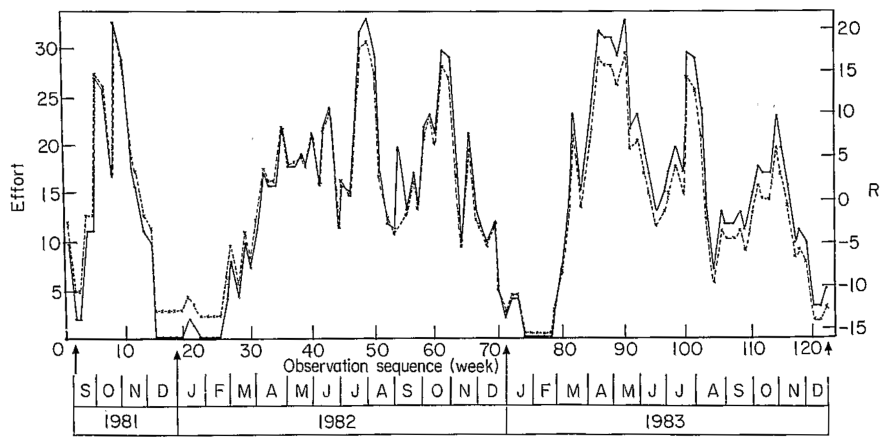


Figure 8. Time series of the fishing effort (number of fishermen) of 'triangles', 'brandines' and longlines: original (——) and detrended (- - -) series.

TABLE 2. Results of the trend analysis. Linear correlations between values of the variables and their ranks in the series test for the presence of significant trends; slopes across the *n* data points are measured by the linear regression coefficients

Series	*n*	Linear correlation	Significance (P)	Regression slope
Catches using 'capêchades'	122	−0·038	0·3389 (n.s.)	−0·903
Fishing effort of 'capêchades'	122	−0·453	0·0000[b]	−0·064
Catches using 'triangles', 'brandines' and longlines	122	0·210	0·0101[a]	10·363
Fishing effort of 'triangles', 'brandines' and longlines	122	−0·068	0·2284 (n.s.)	−0·017

[a]$0{\cdot}01 < P \leqslant 0{\cdot}05$; [b]$P \leqslant 0{\cdot}001$ (one-tailed test); n.s. = relationship not significant.

Because of these two significant results, the trends were removed by linear regression and residual values were computed for all four series (Figures 5–8), so as to make sure that all were stationary; detrending the two series with non-significant trends changes them very little, in any case.

'Capêchade' landings—The contingency periodogram of the residual series of weekly catches of green eels caught with 'capêchades' is presented in Figure 9(a) (full lines). This time series is characterized by two marginally significant periods, one at 17 weeks and the other at 25 weeks; at these two periods, the value of the periodogram statistic exceeds the critical value $B=\chi^2/2n$ for significance level 0·05. This is a case of multiple testing, however, since 61 tests are performed simultaneously in each periodogram. In such a case, a Bonferroni correction has to be applied to the significance level (Cooper, 1968; Miller, 1977). For all practical purposes, only the periods that are clearly significant will be retained; in that context, the periods of 17 and 25 weeks in the 'capêchade' landings do not qualify as significant. Furthermore, the lack of significance of B for the harmonics of these periods (harmonics 33 and 50 weeks for the period of 17 weeks, harmonics 50 weeks for the period of 25 weeks) show that this time series is not characterized by particularly strong periods.

'Capêchade' fishing effort—The contingency periodogram of this residual series is presented in Figure 9(a) (dashed lines). As with the residual series of catches, the marginally significant period observed at 17 weeks has to be discarded. On the other hand, the 26-week and 52-week periods are highly significant, the annual cycle being even more important than the 6-month period. In the two years and four months of data shown in Figure 6, the 26-week period is clearly visible in the lowest values of fishing effort (decrease or interruption of the fishing effort twice a year); it produces a response in the periodogram of landings, although that response remains not clearly significant.

'Triangle', 'brandine' and longline landings—The contingency periodogram of the residual series of weekly catches using 'triangles', 'brandines' and longlines is presented in Figure 9(b) (full lines). The shortest period found in this series is 13 weeks (about three months), which is not significant enough to be considered, and in any case not nearly as significant as the period of 26 weeks that follows. If the series was characterized only by a significant 13-week period, the values of statistics B for its harmonics at 26, 39 and 52 weeks would be about equally significant, while we notice that the 39-week harmonic is not significant. Therefore, we must consider that the series is characterized by one dominant period of 26 weeks (6 months).

'Triangle', 'brandine' and longline fishing effort—The periodogram of the residual series of fishing effort has much similarity with the one for the residual series of catches for these gears (Figure 9(b), dashed lines). The 26-week and 52-week periods are significant, with the 52-week period clearly dominant. Thus, there are two noticeable phenomena in this series: a 52-week period, characterized in particular by the lowest values in the series in Figure 8, and a 26-week period, characterized by lower fishing effort during mid-summer alternating with the already mentioned winter interruptions. The good correspondence between the two periodograms of Figure 9 indicates that the cycles observed in landings match the fluctuations of the fishing effort.

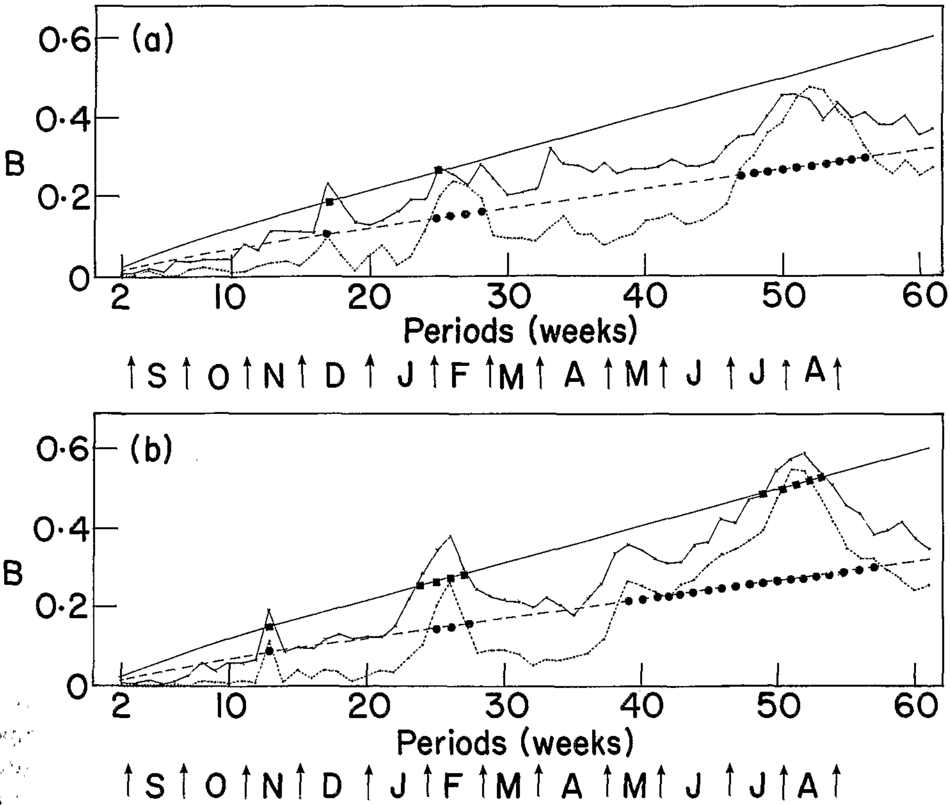


Figure 9. Contingency periodograms for the residual time series of weekly catches (——) and weekly fishing effort (- - -): (a) ' capêchades ', (b) ' triangles ', ' brandines ' and long-lines together. Abscissa: periods in weeks. Ordinate: contingency statistic *B*. Straight lines represent the limits of the 95% confidence intervals; values that exceed these limits are significant. Black squares indicate significant values in the catches series; dots identify significant values in the effort series.

Relations among variables

Table 3 shows that when the values of Pearson's linear correlation coefficients between variables considered in the analysis are significant, so are the values of Spearman's non-parametric correlations. This demonstrates that when relations exist among the variables to be included in the models, these relations are linear, which is a requirement of the modelling method that will be used in the Discussion. The only exception is the relation between ' capêchade ' catches and temperature, that will be discussed in more detail below. Furthermore, correlations among fishing effort, temperature, wind speed and lunar factor, to be used as independent (i.e., explanatory) variables in the models, are always lower than 0·3, so that there is no important collinearity among these variables; this requirement must be met in order to obtain stable estimations of the partial correlation, multiple regression, and path coefficients.

Discussion

Comparing the two periodograms (landings and fishing effort) for each gear or group of gears, it becomes obvious that the periods are by and large congruent; the only difference is

TABLE 3. Correlation coefficients (Pearson in the upper triangle, Spearman in the lower triangle) between catches, fishing effort, temperature, wind speed, and lunar coefficient (120 degrees of freedom)

	Catches	Effort	Temperature	Wind	Moon
(a) Weekly catches and fishing effort using 'capêchades'					
Catches	1·000	0·730[c]	0·096	−0·062	0·210[a]
Effort	0·504[c]	1·000	−0·180[a]	−0·025	0·077
Temperature	0·331[c]	−0·156[a]	1·000	−0·031	0·052
Wind	−0·045	−0·012	−0·065	1·000	0·114
Moon	0·182[a]	0·078	0·035	0·149	1·000
(b) Weekly catches and fishing effort using 'triangles', 'brandines' and longlines					
Catches	1·000	0·857[c]	0·247[b]	0·220[b]	0·160[a]
Effort	0·650[c]	1·000	0·255[b]	0·172[a]	0·079
Temperature	0·310[c]	0·350[b]	1·000	−0·031	0·052
Wind	0·189[a]	0·236[b]	−0·065	1·000	0·114
Moon	0·182[a]	0·113	0·035	0·149	1·000

One-tailed probability of independence of these variables: [a]$0{\cdot}01 < P \leqslant 0{\cdot}05$; [b]$0{\cdot}001 < P \leqslant 0{\cdot}01$; [c]$P \leqslant 0{\cdot}001$.

TABLE 4. 'Capêchade' landings: partial correlations between green eel catches, fishing effort (measured as the number of fishermen), temperature, average wind speed, and lunar coefficient

	Effort	Temperature	Wind	Moon
Catches (3, 117)[a]	0·592[c]	0·477[c]	−0·041	0·167[b]
Effort (2, 118)[a]		−0·162[b]	−0·036	0·089
Temperature (1, 119)[a]			−0·071	0·045
Wind (1, 119)[a]				0·152[b]

[a]Order of the coefficients and degrees of freedom. One-tailed probability of independence of these variables: [b]$0{\cdot}01 < P \leqslant 0{\cdot}05$; [c]$P \leqslant 0{\cdot}001$.

for the 'capêchades', where significant cycles were found for effort but not for landings. This means that the variations of these time series are largely identical. This result leads to the hypothesis that the periodicity observed for the series of catches is to a large extent associated with the periodicity of fishing effort. Using elementary statistical modelling techniques, we will first verify the hypothesis of 'causality' between the effort and landing variables, and then try to account for these periodicities in terms of environmental variables. The influence of environmental factors upon the vulnerability of a fish stock, or upon catches, has been evidenced in the past (Sutcliffe *et al.*, 1977; Mendelssohn, 1981, 1982; Fréon, 1984).

'Capêchades'

The matrix of partial correlations for 'capêchades' (Table 4) indicates which of the explanatory variables has a significant effect on catches; they are the effort, temperature, and lunar coefficient. Similarly, partial correlations show that temperature is the only explanatory variable in this study that weakly (if at all: see below) influences the effort variable, measured in terms of number of fishermen. These variables were assembled into a causal model [Figure 10(a)] and tested using path analysis.

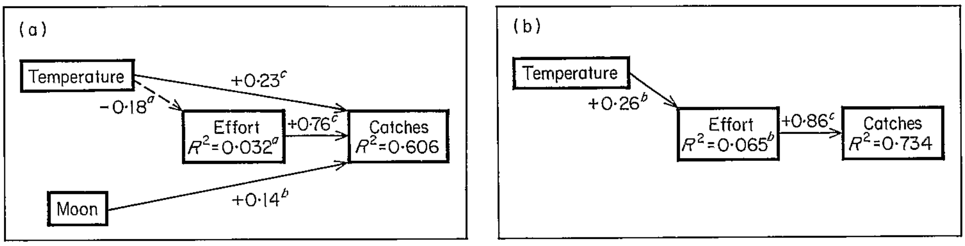


Figure 10. Causal relationships among variables most related to green eel catches. Path coefficients are shown on the significant causal arrows, and coefficients of determination (R^2) in the boxes with the dependent variables. Full lines: significant relations at the conservative 0·01% level ([b]$0{\cdot}001 < P \leqslant 0{\cdot}01$; [c]$P \leqslant 0{\cdot}001$); dashed: [a]$0{\cdot}01 < P \leqslant 0{\cdot}05$. (a) ' Capêchades ', (b) ' triangles ', ' brandines ' and longlines.

Effort, temperature and lunar coefficient jointly explain 60·6% of the catches' variance. Each of them has the expected effect, that is: catches increase with effort (which is the most important explanatory variable, with a path coefficient of 0·76), while landings also increase with temperature (positive path coefficient of 0·23) and with the lunar coefficient (positive path coefficient of 0·14); the signs of these coefficients are as hypothesised in the Methods section.

Notice that the non-significant simple Pearson correlation between temperature and catches, in Table 3(a), corresponds to two effects of temperature on catches that are both significant but of opposite signs: a direct positive path of $+0{\cdot}23$, and an indirect negative effect of $(-0{\cdot}18 \times 0{\cdot}76 = -0{\cdot}14)$. The negative effect is due to the fact that fishermen do not use ' capêchades ' during August, September and October (Figure 6). It is only in order to point out this double effect of the temperature variable on landings that the effect of temperature on fishing effort has been mentioned at all, since we stated in the Methods that no effect would be considered significant unless it passed the 0·01 significant level, in order to account for the liberalizing effect of temporal autocorrelation on statistical tests. In view of this double effect, one may wonder what is the influence of the lack of linearity observed between temperature and ' capêchades ' landings, that produces a Spearman correlation which is much higher than the Pearson linear correlation. To answer this question, let us assume for a moment that we have managed to find the non-linear transformation that linearizes all relations among the variables in Table 3(a); if we could do that, the Pearson correlations would become equal to the Spearman correlations. So, let us use the table of Spearman correlations and compute new path coefficients. The result is that the significant effects remain the same as depicted in Figure 10(a), the effect of temperature being split between a strong positive direct effect of $+0{\cdot}41$ and a weaker negative indirect effect of $-0{\cdot}09$.

' Triangles ', ' brandines ' and longlines

Path analysis [Figure 10(b)] shows that among the variables under study, fishing effort is the only significant determinant of landings using these gears. With a path coefficient of 85·7, effort explains 73·4% of the catches' variability.

Fishing effort is more clearly determined by an environmental variable than it was the case for ' capêchades ' effort. The explanatory variable is temperature, with a highly significant path coefficient of $+0{\cdot}26$. Average wind speed (correlation $+0{\cdot}172$ in Table 3(b); partial correlation $+0{\cdot}266$ in Table 5) has a sign opposite to the one of our one-tailed hypothesis, which predicted a negative relation, so that it is not significant by a one-tailed test.

TABLE 5. ' Triangle ', ' brandine ' and longline landings: partial correlations between green eel catches, fishing effort (measured as the number of fishermen), temperature, average wind speed and lunar coefficient

	Effort	Temperature	Wind	Moon
Catches (3, 117)[a]	0·581[d]	0·122	0·067	0·004
Effort (2, 118)[a]		0·378[d]	0·266[c]	0·069
Temperature (1, 119)[a]			−0·071	0·045
Wind (1, 119)[a]				0·152[b]

[a]Order of the coefficients and degrees of freedom. One-tailed probability of independence of these variables: [b]$0{\cdot}01 < P \leqslant 0{\cdot}05$; [c]$0{\cdot}001 < P \leqslant 0{\cdot}01$; [d]$P \leqslant 0{\cdot}001$.

Conclusion

Our study of the statistics on eels catches in the Thau lagoon has led to a number of findings showing how well the fishing techniques and the fishermen's strategies are adapted to eel behaviour and to the climatic conditions prevailing in the area.

Concerning fishing techniques, we have shown that each gear type is associated with a particular size of catches, their selectivity being related to mesh size. It can be concluded that the demographic structure of the eel stock extracted from the Thau lagoon depends on the fishing methods, each one focusing on a particular part of the eel stock. In turn, the use of each gear type depends on the activity level of the fishermen, market condition and environmental factors.

' Capêchades ' are mobile gears, easy to handle, which are used near the shore all year round, but mostly during June and July by occasional fishermen. ' Triangles ', ' brandines ' and longlines are fixed gears, used mostly by resident fishermen.

Considering a longer time scale, effort on ' capêchades ' has decreased significantly over the study period (1981–83) without much corresponding effect on landings. Landings from ' triangles ', ' brandines ' and longlines, on the contrary, have increased significantly during 1981–83, without a corresponding increase in number of fishermen.

Both the ' capêchades ' and the ' triangle ', ' brandine ' and longline effort time series are characterized by 6-month periods. There is a slight corresponding effect on ' capêchades ' landings, but this period is not statistically significant. In the case of ' triangles ', ' brandines ' and longlines, the significant periods are the same as in the effort series. During the winter months, after the silver eel season is over, only a few of the resident fishermen remain active. Green eel catchability is at its lowest; fishermen only use ' capêchades ', hoping to catch also some other species. During August and September, the opposite happens; resident fishermen are active and use mostly ' triangles ' and ' brandines '.

Effort, temperature and lunar coefficient jointly explain about 60% of the ' capêchades ' catches variance. Catches increase with the amount of fishing effort. This significant relation gives us some confidence in the number of fishermen as a way of estimating fishing effort, despite the fact that the number of ' capêchades ' per fisherman is not limited by legislation and can vary considerably; so, since that fishing gear is easy to handle, the number of nets in use can change from day to day. Temperature, which is an annual cycle indicator, is the only variable in the model that is related to the fishing effort. The relation is negative, which means that effort decreases when temperature increases. Indeed, when temperature rises, resident fishermen prefer to use ' triangles ' and ' brandines '; often, during these periods, only occasional fishermen continue to use ' capêchades '. Our lunar coefficient was designed in such a way that its value decreases when there is more moonlight; we observe indeed that eel catches increase with an increase in the lunar coefficient. This result supports our hypothesis that eel is more likely to avoid traps when there is moonlight. Most of the effort series' variability cannot be accounted for by the climatic variables used in this study; only 3·2% of the effort variance is explained by temperature. For this type of gear, it is evident that the important activity of occasional fishermen hides the real fishing strategy that would be displayed if only permanent fishermen had been considered in this analysis.

' Triangle ', ' brandine ' and longline landings are determined mostly by effort, with 73% of the landings' variance explained by effort. This value is higher than in the previous case for the following reasons. (1) ' Triangles ', ' brandines ' and longlines are mainly used by resident fishermen. (2) ' Triangles ' are fixed-location gears, and the number of ' triangle ' locations is the same for all fishermen in a given port (Mèze, Sète, Marseillan) of the lagoon, so that the number of nets depends on the number of fishermen. Temperature is the only environmental variable that partly explains effort; that relation is positive, resident fishermen making intensive use of ' brandines ' during periods of medium or high temperature. For that reason, the positive effect of temperature on landings is channelled through the effort variable.

In recent years, fisheries biologists have started to investigate environmental effects on fishing stocks; many examples can be found in the recent review ' Pêcheries Ouest-Africaines: Variabilité, instabilité et changement' (Cury & Roy, 1991). The term ' environment ' in fisheries biology does not cover only the physical variables, but also the social, economical and historical factors which are more difficult to apprehend in a quantitative study. Fishing mortality in monospecific or multispecific stocks depends on technical and tactical choices of fishermen, as a response to environmental variations (i.e., physical, social, economic conditions: Garrod, 1973). Recent studies in the context of fisheries management consider this adaptability of fishermen to their environment and to the resource (Hilborn, 1985; Allen & McGlade, 1987; Ecoutin, 1991, Laloë & Samba, 1991).

In the Thau lagoon, the alternative use of ' capêchades ', ' triangles ', ' brandines ' and longlines for eel exploitation gives evidence of the adaptability of fishermen. They optimize eel exploitation, in economic terms, with respect to (1) the variations of the physical environment, (2) eel behaviour, and (3) market strategies, including market-control practices such as the stockpiling of eels while waiting for an increase in sale price.

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