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INFLUENCE OF HYDROLOGICAL AND CLIMATIC CONDITIONS ON DAILY CATCH PER UNIT EFFORT OF ATLANTIC SALMON (*SALMO SALAR* L.) WITH DRIFT GILLNET AT THE MOUTH OF THE ADOUR RIVER, FRANCE

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Abstract

Influence of river flow, tidal coefficient and wind direction on Atlantic salmon (*Salmo salar* L.) daily catch per unit effort (CPUE) at the mouth of the Adour river were analysed by the Correspondence Analysis and by the Generalized Linear Model. Catch and effort data were provided by logbooks from commercial fishermen. Scale reading of a stratified sample of the catch allowed partitioning of the fishing season (march-july) in two periods, corresponding to two different salmon types: multi-sea-winter salmon (march-may) and one-sea-winter salmon or grilse (june-july). For both periods, hydrological contrasts (high river flow combinated with spring tide) and sea winds contributed to high-level CPUE of salmon. However, relative influence of the hydrological conditions differed according to salmon type. Tidal coefficient was a primary source of variation of CPUE (in number of fish caught per fisherman) of multi-sea-winter salmon, with tidal flow and sea wind as secondary sources. As for grilse, river flow, which was lower than in spring, appeared to be more critical: CPUE level, calculated as the deviation between daily CPUE and a normal trend (in number of fish caught per fisherman), increased with increasing river flow ; tidal flow and wind direction appeared to be less influent.

Keywords

Salmo salar, Atlantic salmon, Salmonids, anadromous migration, catch, drift gillnet, river flow, tidal flow, wind direction, correspondence analysis, generalized linear model.

I. INTRODUCTION

Influence of environmental factors on anadromous migration of Atlantic salmon in estuaries and rivers has been analysed by many authors. Reviews can be found in BANKS (1969) and JONSSON (1991). However, most of those studies rely on:

- use of traps or automatic counters set on fish-passes or obstacles (JACKSON & HOWIE, 1967 ; SWAIN & CHAMPION, 1968 ; ALABASTER, 1970 ; HELLAWELL *et al.*, 1974 ; JENSEN *et al.*, 1986 ; JONSSON *et al.*, 1990)
- acoustic or radioelectric tracking in estuaries (STASKO, 1975 ; BRAWN, 1982 ; POTTER, 1988 ; PRIEDE *et al.*, 1988 ; SOLOMON & POTTER, 1988), in rivers (HAWKINS & SMITH, 1986 ; WEBB, 1989), or near spawning areas (WEBB & HAWKINS, 1989).

Thus, they provide information on individual behaviour of small numbers of fishes, or on obstacle passing. Moreover, these studies often cover only a short period of the year, or include all recruitment periods of the different sea-age-groups without distinction between salmon types.

For example, SMITH (1990) studied commercial net salmon catches at the Aberdeenshire Dee mouth. He showed significant negative linear correlations between daily values of catch and river flow, but did not take into account variations in fishing effort or in relative abundance of the different sea-age groups around the year.

Our study considered the first phase of the anadromous migration, *i.e.* the entry in the estuary of the Adour river (South-West of France). We used daily catch per unit effort (CPUE) with drift gillnet as an index of salmon abundance. We analysed covariations of daily CPUE and some hydrological and climatic factors (tidal flow, river flow, wind direction), during the recruitment periods of the two main salmon types (one- and two-sea-winter salmon) in the fishery at the river mouth.

II. SITUATION AND CARACTERISTICS OF THE SURVEY AREA

The Adour estuary, the mouth of which is situated in Bayonne (*fig.* 1), is the interference zone between the flow of the Adour-Gaves-Nive hydrographic system and the Atlantic tide.

We used catch and effort data and environmental data on the Adour river mouth during the years 1988, 1990, 1991 and 1992. According to the fishing days, the number of fishing boats in the fishery under study varied between two and twelve.

A. HYDROLOGICAL CONDITIONS

River flow is relatively high in the estuarine part of the Adour basin (between 100 and 450 m^3/s according to seasons), maintained as a result of the contribution of rivers with varied hydrological patterns (FISCHER, 1930 ; PARDE, 1968 ; PAGNEY, 1988).

During the years 1988 to 1992, the yearly mean daily flow at the river mouth was around 240 m^3/s, with extremal monthly values of 56 and 720 m^3/s. During spates, mean daily flow could reach 2000 m^3/s.

The fishing zone under study corresponds to the entrance to the commercial harbour of Bayonne. Its main characteristics are:

- the artificial narrowing of the river by dykes: river width is around 150 m between dykes at the river mouth, against 700 m around Saint-Bernard sand bank, some 300 m up river ;
- a depth maintained between 9 and 15 m (zero-level of sea charts) by regular dredging (ANON., 1991).

The fall of the river, combined with the great depth, leads to high speeds of water (*tab.* 1).

B. Tidal conditions

Tidal phenomenons in the Adour estuary have been described and quantified by LESBORDES (1979). Duration of tidal period is 12 h 25 min. At the river mouth, ebb and flow have the same duration, and tide height varies between 1.35 m in neap tides and 4.20 m in spring tides. During tides of maximum strength, around 30 millions cubic metres of sea water get in and out of the Adour estuary.

III. Material and methods

A. Collection of catch and effort data

Current data on commercial fisheries in the Adour estuary, and particularly on salmon fishing (*tab.* 2) come from:

- individual daily logbooks, indicating fishing zone, fishing effort, catch by species in weight and/or number ;
- and a sampling of the biometric and demographic characteristics of the catches: weight, length, scales and blood for age and sex determination.

Using the individual logbooks, we could discriminate the potential fishing days into three groups within the legal fishing season: days with null fishing effort, days with non-zero fishing effort and null catch, and days with non-zero catch.

Our study used observations and informations collected for the second and third groups of fishing days.

Levels of catch and fishing effort were very low in 1989, and many days of the fishing season saw no fishing effort at all. So this year was excluded from our analysis. Observations for the other four years (1988, 1990, 1991, 1992) amount to a total of 346 fishing days, including fishing days with zero catch.

In this study, the daily CPUE was calculated by dividing the total number of fish caught by the number of fishermen having fished that day.

B. Age determination for salmon catch

Two methods were used:

- scale-reading, for individual ageing of fish on which scale sample were collected, according to a generic methodology (ANON., 1984) adapted to the southern area of Atlantic salmon distribution (BAGLINIERE, 1985). Thanks to the time-stratification of the sampling, the results obtained with this method provided an age-weight key for the different periods of the fishing season ;
- this age-weight key allowed the assignment of a most probable sea-age to fish for which only individual weight and catch date were known. This method was proven consistent with scale-reading on test samples (CUENDE & PROUZET, 1992).

C. Partitioning of the fishing season

Age determination of catches aimed at dividing the fishing season into two periods corresponding to the recruitment of the two major types of salmon in the fishery at the mouth of the river: multi-sea-winter salmon (mainly 2-sea-winter salmon), and one-sea-winter salmon or grilse.

For each fishing year, we determined the approximate date until which 2-sea-winter salmon are largely the most numerous type and after which grilse become the salmon type with the largest relative importance.

This allowed us to take into account the possible disproportion between abundance levels of the salmon types, as well as differences in prevalent hydrological and climatic conditions.

D. Environmental variables

The astronomic tidal coefficient (TC) was provided by the French Hydrographic and Oceanographic Marine Service (Service Hydrographique et Océanographique de la Marine). It is expressed as a fraction (in hundredths) of the mean spring tide heigths in March and September in Bayonne harbour. Values range between 20 and 120.

River flow (RF) data, in m^3/s, were provided by gauging stations on the Adour river and its tributaries.

The National Meteorological Service provided data on wind direction (WD) from Biarritz airport monitoring station. Values are expressed in tens of angle degrees, according to the following convention: north = 0, east = 9, south = 18, west = 27.

E. Analysis of covariations of environmental variables and catch per unit effort

Separate analyses were conducted for each of the two salmon types.

1. *Statistical methods*

a) Correspondence analysis

A multiple correspondnce analysis (Benzecri, 1973 ; Jambu, 1989) was used to describe covariations of hydrological (RF, TC) and climatic (WD) factors and salmon catch. Lines of the observation matrix correspond to fishing days, and columns to classes of catch and environmental variables.

b) Generalized linear model

The generalized linear model (McCullagh & Nelder, 1989) was used to quantify the effects of hydrological and climatic conditions on salmon catch per unit effort with drift gillnet. This statistical technique does not belong to the traditional regression technique group, which are design to study continuous, or at least numerical, variables (Trexler & Travis, 1993). The classical linear model postulates that the error terms are normally distributed, with zero mean and constant variance. Yet, for many types of data, variance changes with the mean. Response-variable reexpression models suffer from several drawbacks. For example: loss of familiarity with the reexpressed variable, transformation not defined at the boundaries of the sample space.

The generalized linear model is an alternative response, a reparametrization inducing linearity and allowing non constant variance. It requires a link function describing relations between the mean and the linear predictors, and a variance function describing dependence of variance upon mean (HASTIE & PREGIBON, 1992).

When dealing with contingency tables, the generalized linear model can be used to model the probability distribution of a categorical variable, or a function of this probability distribution, as a function of set of categorical explanatory variables. Such an approach is presented in TENENHAUS *et al.* (1993).

Taking into account the number of our observations (1 observation = 1 fishing day), we built three-way contingency tables, with two environmental explanatory variables (hereafter noted A and B) and a salmon catch explained variable (noted C). Each entry of the three-way tables was the number n_{ijk} of fishing days for which we observed the combination of levels i, j and k for the categorical variables A, B and C respectively.

The total number of observations for a given combination AxB ($n_{ij.}$) being fixed, cell counts on the same row of the table are not independent. Thus, data can be analysed using a multinomial model (PLACKETT, 1981). A log-linear model was used to estimate the parameters of the multinomial model and the conditional probabilities $p_{k\cdot ij}$ to observe the level k of variable C under the combination of level i of variable A and level j of variable B.

Starting from a minimum model [A.B + C.(A+B)], interactions between variables were successively introduced. We selected the only predictors inducing a significant decrease of the deviance. The deviance (dev) is a statistic allowing comparison between the likelihood of the model under study and that of the saturated model (i.e. explaining perfectly the observed proportions $n_{ijk} / n_{ij.}$):

$$\text{dev} = -2 \,\text{Log}\, [\phi \text{ (partial model)} / \phi \text{ (saturated model)}]$$

where ϕ represents the likelihood (TENENHAUS *et al.*, 1993).

When the numbers of observations are high, the differences between two successive values of deviance are approximately chi-square distributed (MCCULLAGH & NELDER, 1989).

2. *PARTITIONING OF VARIABLES INTO LEVELS*

a) **Catch per unit effort variables**

Division into factor levels was made separately for each year and for each salmon type. Thus, we could take into account both the mean catch level for a given year and the seasonal variation of abundance between the salmon types.

(1) Multi-sea-winter salmon

We assumed that MSW fish abundance was uniformly distributed along the period of time corresponding to their maximum recruitment, and that variations in CPUE were mainly related to environmental factors, particularly those under study. The CPUE variable division into levels was made according to quartiles ("low", "medium", "high", and "very high" catch levels, coded as CPUE1 to CPUE4).

(2) Grilse

Observations on the Adour river as well as on neighbouring rivers (Nivelle river, Bidassoa river) lead us to assume that the arrival of grilse at the Adour estuary mouth followed a normal distribution along their recruitment period. Thus, entry of grilse in the estuary and CPUE were assumed to follow a normal trend. Deviations from that trend were assumed to be mainly related to environmental factors.

Estimators for mean μ and standard deviation σ of the normal distribution were respectively calculated, for each year, as the median day of the grilse recruitment period and the sixth part of this recruitment period duration, since interval $[\mu-3\sigma ; \mu+3\sigma]$ contains 99.72% of the individuals in a normal distribution (SOKAL & ROHLF, 1969).

We defined a new variable, coded as GRI, as the deviation between the observed CPUE for a given day and the normal value calculated for this same day.

Values of this GRI variable were divided into levels according to quartiles ("low", "medium", "high", and "very high" catch levels, coded as GRI1 to GRI4).

b) **Environmental variables**

Data sets of river flow (RF), tidal coefficient (TC) and wind direction (WD) were splitted into levels with equal numbers (*tab.* 3) for each recruitment period.

Low (TC1) and high (TC3) tidal coefficient levels correspond to neap tides (TC≤45) and spring tides (TC≥90) respectively.

Classes of wind direction were designed to reflect wind influence in concentrating or dispersing fresh water in the coastal zone near the river mouth and its contribution to the mixing of superficial layers of water.

IV. RESULTS

A. RECRUITMENT PATTERN OF DIFFERENT SALMON SEA-AGE GROUPS IN THE FISHERY

By-catch of Atlantic salmon are scarce out of the salmon legal fishing season, even during the sea lamprey (*Petromyzon marinus*) in February, or during the catch period of other marine species in August and September. Moreover, few salmon were caught before mid-March. For the years under study, transition between multi-sea-winter salmon period and grilse period lasted around ten days. The recruitment of MSW fish began by mid-March and ended during the first days of June. Grilse entered the fishery by the end of May. Assuming the normality of the grilse recruitment pattern, the mode of the distribution occured in the last days of June (except in 1988: mid-June), and the standard deviation varied between 10 to 16 days.

B. EFFECTS OF HYDROLOGICAL AND CLIMATIC FACTORS ON CPUE

1. *MULTI-SEA-WINTER SALMON SEASON*

a) Descriptive approach

The CPUE variable had a high contribution to axes 4 and 5, and a smaller one to axes 1 and 2 (*tab.* 4).

Projections of variable classes in factorial plane 1-2 (*fig.* 2) indicated that favourable conditions for catches of MSW salmon (CPUE3-CPUE4) were tides with high coefficient (TC3) in conjunction with high river flows (RF3). On the opposite, weak movements of sea water (TC1-TC2) and fresh water (RF1-RF2) seemed to induce low or medium catch levels (CPUE1-CPUE2). However, the river flow appeared to be only a secondary source of influence: classes of the CPUE variable were poorly discriminated on axis 3, to which the RF variable had a strong contribution (*tab.* 4).

Associations were aloso noticed between offshore winds (WD1) and the lowest catch level (CPUE1), and between west-north-westerly onshore winds (WD4) and the highest catch level (CPUE4).

b) Quantitative approach

(1) Tidal coefficient and river flow

Interaction between CPUE and tidal coefficient was the only significant one (*tab.* 5). Maximum estimated conditional probability was only 0.535, indicating that the effects of environmental factors under study were not very strong. Nevertheless, when displayed with tide levels arranged in ascending order, the matrix of estimated conditional probabilities showed a general trend: the probability to get "high" or very "high" catch levels increased with increasing tidal coefficient (*fig.* 3). High river flow acted as a secondary positive factor (though not significant), particularly in case of low tidal coefficient (TC1-RF3 combination for example).

These results appeared to confirm the descriptive approach by correspondence analysis. Moreover, they provided a hierarchy among relative inflence of sea water and fresh water movements.

(2) Tidal coefficient and wind direction

The deviance analysis of the model including tidal coefficient (TC) and wind direction (WD) as explanatory variables showed no significant effect (*tab.* 6).

2. *GRILSE SEASON*

a) Descriptive approach

Factorial plane 1-2 (*fig.* 4) showed a increase of relative catch level (GRI) with increasing river flow (RF) and tidal coefficient (TC). However, variable TC only had a low contribution to axes 4 and 5, unlike variable GRI (*tab.* 7).

Influence of wind direction (WD) could be understod as better catch (GRI3-GRI4) under winds from west to north (WD3-WD4), and lower catch (GRI1) under winds from south-south-east to west-south-west (WD2).

b) **Quantitative approach**

(1) Tidal coefficient and river flow

Unlike the case of multi-sea-winter salmon, the only significant interaction (*tab.* 8) was that of river flow with relative catch index (RF x GRI).

Effects of environmental factors under study on salmon catch were poorly marcked (maximum estimated conditional probability 0.426). Figure 5, with river flow levels arranged in ascending order shows that probability of higher catch levels improved with increasing river flow, while tidal coefficient plays a minor role.

(2) River flow and wind direction

No significant effect appeared in the analysis of deviance (*tab.* 9).

V. DISCUSSION

A. USE OF CATCH AND EFFORT DATA

1. *ADVANTAGES*

The use of catch per unit effort data as an index of abundance offers several advantages when compared to other methods:

- the observation period is the whole drift gillnet fishing season, and lasts over several months. It covers almost the entire period of Adour salmon return to their home river ;
- the observations consider a large number of fish, unlike studies based on acoustic or radio-goniometric tracking ;
- this method does not present the drawback of the delaying effect met in obstacle passing studies, during which salmon can wait for favourable conditions for weeks ;
- finally, unlike rod-and-line fishing, net fishing does not hinge on the agressive behaviour of salmon, but only on his movements in the estuary.

2. *DRAWBACKS*

However, CPUE index has its drawbacks:

- drift gill net only takes place during low slack water and flood tide, therefore no observation is possible during the other half of the tidal cycle. Nevertheless, different studies using tracking showed that movements against tidal currents are rare in coastal and estuarine waters (STASKO, 1975 ; HAWKINS *et al.*, 1979 ; POTTER, 1988 ; PRIEDE *et al.*, 1988) ;
- the main problem with CPUE index is not being able of distinguishing the part of the variability of the CPUE due to fish availability variations from that originating in catchability variations. This demonstrates the necessity of *in situ* studies to estimate the effect of each factor.

B. EFFECTS OF HYDROLOGICAL AND CLIMATIC FACTORS ON CPUE

The results obtained with the correspondence analysis (around 60% of inertia explained by the first 5 axes) and with the generalized linear model (maximum probabilities lower than 0.55) indicated that the relations appearing between salmon catch and the studied environmental variations were only general trends. This led to thinking that other factors affected this phenomenon.

However, for both salmon types (MSW and 1SW fish), high catch levels appeared to be associated with high river flow and high tidal coefficient, with sea winds playing a less significant part. Relative influence of factors varied according to the salmon type.

1. *INFLUENCE OF RIVER FLOW*

In the review by BANKS (1969), river flow was most frequently mentionned as a controlling factor for salmonid anadromous migration. Spates are said to induce Atlantic salmon concentration in coastal waters, near the river mouth, the anadromous migration taking place during the fall of water after the freshet (HUNTSMAN, 1939, 1948 ; HAYES, 1953 ; HARRIMAN, 1961 ; SWAIN & CHAMPION, 1968).

Spates induce physical and chemical modifications of estuarine water quality. These modifications being generally simultaneous, determining the respective part of effect due to each factor results difficult.

As a consequence, contradictory results were obtained when trying to determine the range of river flow values favourable to anadromous migration. In the river Coquet, salmon appeared to migrate in flows superior to the mean avalaible flow (ALABASTER, 1970). The situation was opposite, in the river Frome (HELLAWELL *et al.*, 1974).

High river flow or a rising of the river flow seemed to have a positive effect on:

- catch abundance (ALABASTER, 1970 ; STEWART, 1969) ;
- obstacle passing (ALABASTER, 1970 ; JENSEN *et al.*, 1986 ; JONSSON *et al.*, 1990) ;
- movements, as monitored by tracking techniques (POTTER, 1988 ; PRIEDE *et al.*, 1988 ; WEBB, 1989 ; WEBB & HAWKINS, 1989).

However, variations of river flow are not sufficient in explaining a salmon ascent. HELLAWELL (1976) showed that river flow variations were only a secondary factor, the main factor being the season of the year. But this could result from not taking into account difference in abundance, and thus in availability, of the different salmon types: river flow conditions showed as most favourable to salmon anadromous migration correspond to those observed during the recruitment period of the most abundant sea-age group.

Differences in response could be due to differences between hydrological patterns of the rivers under study. Moreover, some studies, in particular those using tracking techniques, are carried over during short periods only, unlike other studies lasting over entire years. Ranges of available flow and related effects are thus difficult to compare.

Effects of the Adour river flow on salmon catch are more prominent during the grilse recruitment period than during the MSW salmon recruitment period. Differences in available mean river flow could explained this observation: river flow is much lower in June and July than in the beginning of the fishing season, while ranges of tidal coefficient are similar (*tab.* 3). Freshwater flow could be a limiting factor for grilse ascent.

a) **Final orientation**

High river flow at the beginning of sping could enhance home river recognition by salmon. As a matter of fact, the importance of olfaction in guiding the salmon during its return migration has been emphasized in the hypothesis of olfactive precocious impregnation of fry or smolt (HARDEN JONES, 1968 ; HASLER, 1971 ; HANSEN *et al.*, 1989), as well as in the hypothesis of a innate genetic capacity to recognize specific pheromones (NORDENG, 1977, 1989 ; STABELL, 1984).

Yet, experiments by HANSEN *et al.* (1993) lend support to the hypothesis of an active search of their home river, appearing not to be based on a genetically fixed memory of specific pheromones. This hypothesis, close to that of SMITH *et al.* (1980), is in contrast with suggestions by SAILA & SHAPPY (1963) or JAMON (1990) on return migration being a random trial and error process.

When in coastal waters close to their home river, salmon would look for visual or olfactive guidance (HARDEN JONES, 1968 ; HASLER & SCHOLZ, 1983 ; HANSEN *et al.*, 1993). Then, in the estuary, they would wait for conditions propitious to their ascent (JONSSON *et al.*, 1990).

By greatly increasing presence of characteristical olfactive clues in coastal waters, spates could contribute to attracting salmon towards their home river mouth.

b) Anadromous migration and osmoregulation

When changing from salt water to fresh water, salmon undergoes important modifications of its osmoregulation processes. This requires a progressive adaptation, made easier by a low salinity gradient in waters close to the estuary mouth. The mixing of sea and river waters during spring tides and spates probably contributes to a better transition of fish between the two media. This has also been observed for the allis shad (*Alosa alosa*) in the same estuary (PROUZET *et al.*, 1994*a*).

c) Temperature and dissolved gases

An increased river flow, particularly during the spates of the Gaves rivers (tributaries of the Adour river running down from the Pyrenees moutain range), can induce a decrease in water temperature in and around the river mouth, as well as an increase of dissolved oxygen concentration.

A decrease of temperature has a positive effect on salmon ascent, as observed during artificial freshets by MENZIES (1939) and STUART (1962), and in uncontrolled conditions byPOTTER (1988), PRIEDE *et al.* (1988) and ALABASTER (1990).

On the other side, hypoxia can inhibate salmon movements in an estuary. In anaerobic conditions, salmon muscles produce lactic acid, inducing a decrease in pH, and a subsequent reduction of the blood oxygen carrying capacity. Dissolved oxygen requirements defined as optimal for Atlantic salmon vary greatly (ALABASTER & GOUGH, 1986 ; PRIEDE *et al.*, 1988).

A freshet can thus contribute to attracting salmon by improving estuarine water quality, particularly by increasing the dissolved oxygen concentration (CURRAN & HENDERSON, 1988 ; PRIEDE *et al.*, 1988).

In the Adour estuary, such an improvement could occur in June or July, during the grilse recruitment period. As a matter of fact, water quality could play an important part during this period, because of the generally low river flow and the rise in temperature in coastal waters (up to 22-23°C). However, by lack of dissolved oxygen measurements, we were not able to draw a conclusion on this particular point.

2. *INFLUENCE OF TIDAL FLOW*

According to MENZIES (1931) and HAYES (1953), spates contribute to salmon ascent in the river zone under tidal influence. MILLS (1968) suggested that they have no significant effect outside tidal waters.

Tracking experiments in coastal or estuarine waters (STASKO, 1975 ; HAWKINS *et al.*, 1979 ; POTTER, 1988 ; PRIEDE *et al.*, 1988) showed salmon movements with tidal currents, in a way named *tidal excursion behaviour* by SOLOMON & POTTER (1988). Ascents have been said to be stimulated by high tidal conditions (SWAIN & CHAMPION, 1968) and by increasing tidal amplitude (HAYES, 1953). On the opposite, in the Lune estuary, STEWART (1973) observed that salmon catch and ascents increased when tidal amplitude decreased.

At the mouth of the Adour estuary, tidal amplitude has a prevalent influence on salmon catch during spring months. During this period, river flow is not a limiting factor and the strong tides make upstream migration easier for salmon.

Moreover, these tides allow a greater overlapping of sea and rivers waters, favourable to the progressive adaptation of amphihaline fish to salinity changes.

3. *INFLUENCE OF WIND*

Influence of wind on salmon catch is known in an empirical way by fishermen (STASKO *et al.*, 1973). DAY (1887) observed that strong winds blowing up river had a positive effect on salmon ascent in the Severn river. Studies by HUNTSMAN (1939) and HAYES (1953) showed that onshore winds concentrated salmon near the river mouth and in the estuary and affected river ascent.

Yet wind seems to have only a minor influence on salmon catch, when compared to river flow or tide conditions. Onshore winds contribute to freshwater concentration along the coast. But in narrow channels like the one at the mouth of the Adour estuary, the sea winds create swell effects that make driftnet fishing difficult, particularly with the kind of small fishing boats used in that zone.

C. FURTHER RESEARCH

Designing contingency tables with more than two explanatory variables would require a large increase of the number of observations, to avoid table entries close or equal to zero.

In the Adour estuary, each salmon fishing year comprises around 160 legally open fishing days (from end of February to end of July). Yet, in February and March, and sometimes well into April, commercial fishing effort is rather aimed at sea lamprey, in a different river zone, further upstream (PROUZET *et al.*, 1994*b*). This reduces the number of salmon fishing days with driftnet at the mouth of the estuary. Moreover, observations on salmon fishing are divided into two periods corresponding to salmon types.

The possibility of a significant augmentation of the number of observations can only be contemplated on a long term.

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Table 1 - Comparisons of river falls near the mouths, and ebb and flow tide speeds in the Adour, Loire and Garonne estuaries (ANON., 1981 ; LESBORDES, 1979).

	river fall (cm/km)	tidal flow speed (m/s)	
		low slack water	high slack water
Adour	3.5	6-8	10-12
Garonne	1	5	15
Loire	2	4-6	6-10

Table 2 - Number of salmon caught by the Adour river drift gillnet fisheries, by year and by sea-age-group. The numbers of fish used for age determination is given between parenthesis.

	1988	1990	1991	1992
One-sea-winter salmon	551 (77)	1027 (209)	726 (163)	1506 (126)
Multi-sea-winter salmon	1748 (435)	473 (147)	374 (74)	924 (141)

Table 3 - Definition and extreme values of hydrological and climatic variable levels.

variable	code	levels		multi-sea-winter salmon lowest	multi-sea-winter salmon highest	one-sea-winter salmon lowest	one-sea-winter salmon highest
daily river flow (m^3/s)	RF	RF1:	low	102.3	245.1	55.4	102.7
		RF2:	moyen	245.2	274.5	102.8	210.5
		RF3:	high	274.6	1065.4	210.6	890.7
tidal coefficient (hundredths)	TC	TC1:	low	32	59	38	60
		TC2:	moyen	60	77	61	74
		TC3:	high	78	107	75	107
wind direction (tens of angle degrees)	WD	WD1:	N to SSE	0	15	0	15
		WD2:	SSE to WSW	16	26	16	26
		WD3:	W to WNW	27	30	27	30
		WD4:	WNW to N	31	35	31	35

Table 4 - Multi-sea-winter salmon. Eigen values associated with factorial axes, relative contributions of variables to factorial axes, and coefficients of variable classes in the linear equations of the axes.

		axis 1	axis 2	axis 3	axis 4	axis 5
Eigen values		0.36	0.32	0.30	0.27	0.26
relative contributions (%)	RF	19.1	16.7	59.2	0.7	14.5
	TC	25.7	46.5	7.6	4.3	19.2
	WD	24.6	12.7	26.0	51.5	22.6
	CPUE	30.6	24.1	7.2	43.5	43.7
coefficients in the linear equation	RF1	-0.463	-0.960	-1.505	-0.006	0.707
	RF2	-0.757	-0.057	2.120	0.204	0.338
	RF3	1.230	1.037	-0.584	-0.198	-1.059
	TC1	-0.585	1.816	-0.723	0.031	-0.615
	TC2	-0.868	-1.541	0.031	-0.520	-0.656
	TC3	1.390	-0.162	0.635	0.482	1.209
	WD1	-1.719	0.385	-1.347	-0.025	0.397
	WD2	0.696	-1.050	-0.398	0.925	0.915
	WD3	0.669	0.743	0.518	1.098	-1.545
	WD4	0.192	0.137	1.545	-2.717	0.138
	CPUE1	-1.720	0.973	0.891	1.657	0.759
	CPUE2	-0.136	-1.489	0.097	-0.148	-2.241
	CPUE3	0.238	0.815	-0.500	-1.943	1.114
	CPUE4	1.429	-0.257	-0.378	0.655	0.359

Table 5 - Multi-sea-winter salmon. Fitness statistics for a sequence of models. Deviance (dev), degrees of freedom (df), variation of deviance (Ddev), variation of degrees of freedom (Ddf), X^2 statistic (: significant at 0.05 ; ns: not significant).**

predictors	dev	df	Ddev	Ddf	X^2
minimum model	30.85	24			
			8.41	6	ns
+ RF.CPUE	22.44	18			
			12.52	6	**
+ TC.CPUE	9.92	12			
			9.23	12	ns
+ RF.TC.CPUE	0				

Table 6 - Multi-sea-winter salmon. Fitness statistics for a sequence of models. Deviance (dev), degrees of freedom (df), variation of deviance (Ddev), variation of degrees of freedom (Ddf), X^2 statistic (ns: not significant).

predictors	dev	df	Ddev	Ddf	X^2
minimum model	26.67	33			
			10.26	6	ns
+ TC.CPUE	16.41	27			
			3.11	9	ns
+ WD.CPUE	13.30	18			
			13.30	18	ns
+ TC.WD.CPUE	0				

Table 7 - One-sea-winter salmon. Eigen values associated with factorial axes, relative contributions of variables to factorial axes, and coefficients of variable classes in the linear equations of the axes.

		axis 1	axis 2	axis 3	axis 4	axis 5
Eigen values		0.34	0.32	0.31	0.27	0.25
relative contributions (%)	RF	35.2	10.0	30.1	14.6	4.2
	TC	21.0	37.2	23.3	2.1	2.3
	WD	21.2	21.0	42.0	31.1	32.3
	GRI	22.7	31.8	4.6	52.1	61.3
coefficients in the linear equation	RF1	0.081	0.668	-1.530	1.066	0.003
	RF2	-1.496	0.169	0.921	-0.661	-0.503
	RF3	1.413	-0.848	0.632	-0.421	0.500
	TC1	0.257	1.688	0.724	-0.404	0.403
	TC2	-1.181	-0.765	0.574	0.237	-0.301
	TC3	1.035	-1.001	-1.434	0.180	-0.108
	WD1	-0.539	0.907	-2.164	-0.213	-0.734
	WD2	0.953	-0.976	0.121	-1.871	1.733
	WD3	0.856	0.925	1.422	0.904	-1.271
	WD4	-1.181	-0.866	0.380	0.886	0.412
	GRI1	-0.025	1.877	-0.238	-1.296	0.823
	GRI2	-0.033	-0.112	0.414	2.365	1.966
	GRI3	-1.278	-1.118	-0.572	-1.080	-0.445
	GRI4	1.386	-0.565	0.422	0.077	-2.270

Table 8 - One-sea-winter salmon. Fitness statistics for a sequence of models. Deviance (dev), degrees of freedom (df), variation of deviance (Ddev), variation of degrees of freedom (Ddf), X^2 statistic (: significant at 0.05 ; ns: not significant).**

predictors	dev	df	Ddev	Ddf	X^2
minimum model	28.30	24			
			12.68	6	**
+ RF.GRI	15.61	18			
			4.30	6	ns
+ TC.GRI	11.32	12			
			11.32	12	ns
+ RF.TC.GRI	0				

Table 9 - One-sea-winter salmon. Fitness statistics for a sequence of models. Deviance (dev), degrees of freedom (df), variation of deviance (Ddev), variation of degrees of freedom (Ddf), X^2 statistic (ns: not significant).

predictors	dev	df	Ddev	Ddf	X^2
minimum model	29.77	33			
			5.11	6	ns
+ RF.GRI	24.66	27			
			6.45	9	ns
+ WD.GRI	18.21	18			
			18.21	18	ns
+ RF.WD.GRI					

Figure 1. Situation map. Main rivers: Adour (Ad), Bidassoa (Bi), Gave d'Oloron (GO), Gave de Pau (GP), Loire (Lo), Nivelle (Ni), Nive (Nv). Estuarine salmon drift gillnet fisheries (●●). Impassable dams (□). Tidal saline limit (/). Tidal dynamic limit (//).

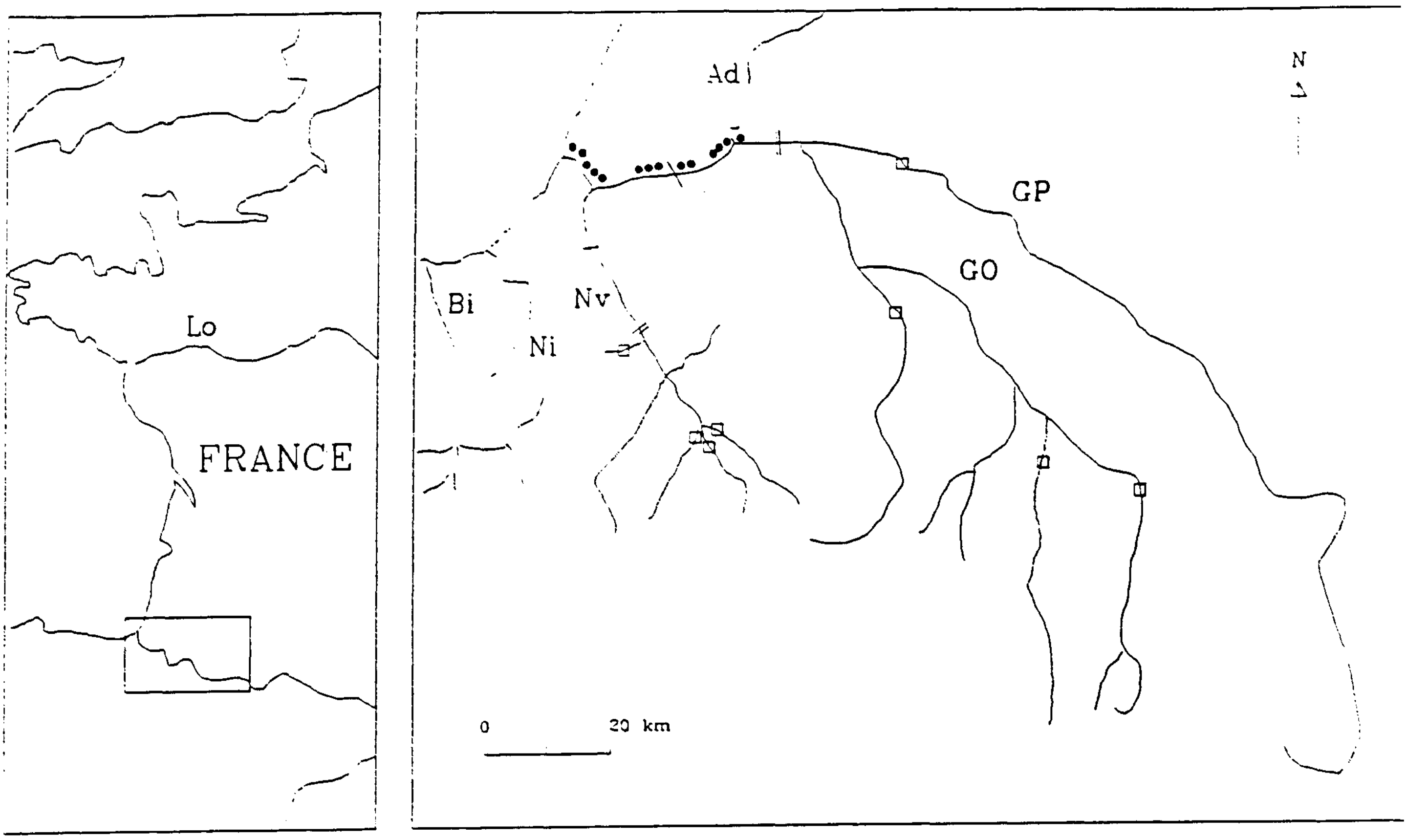

Figure 2. Multi-sea-winter salmon. Distribution of classes of variables in factorial space 1-2. Classes of increasing level of catch per unit effort (CPUE1 to CPUE4), increasing river flow (RF1 to RF3), increasing tidal coefficient (TC1 to TC3), and classes of wind direction (WD1 to WD4).

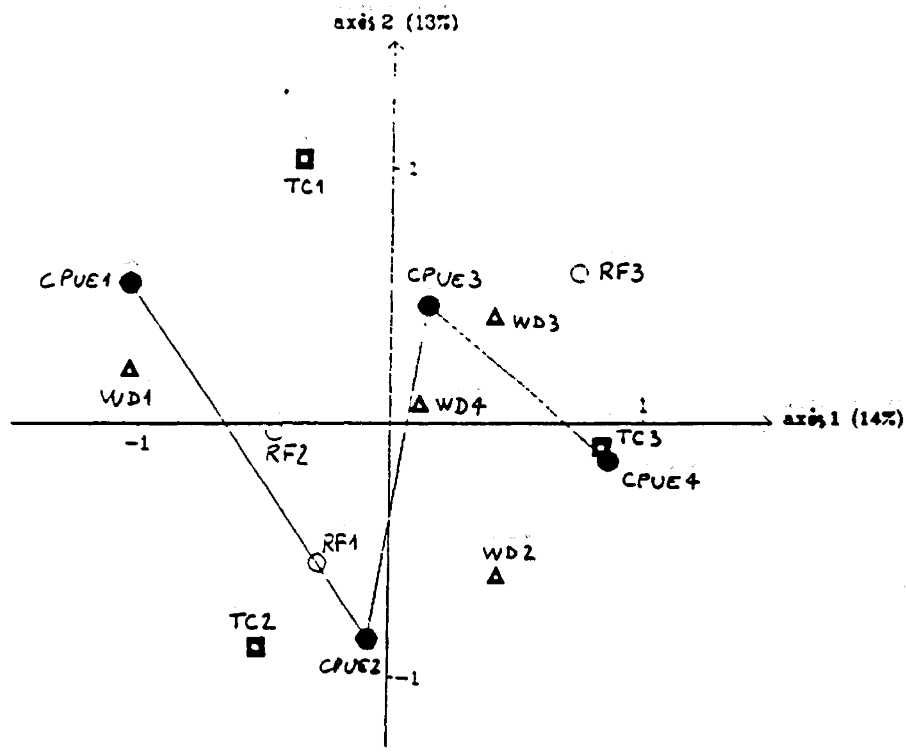

Figure 3. Multi-sea-winter salmon. Estimated conditional probabilities to get level *k* of catch per unit effort (CPUE) for level *i* of river flow (RF) and level *j* of tidal coefficient (TC).

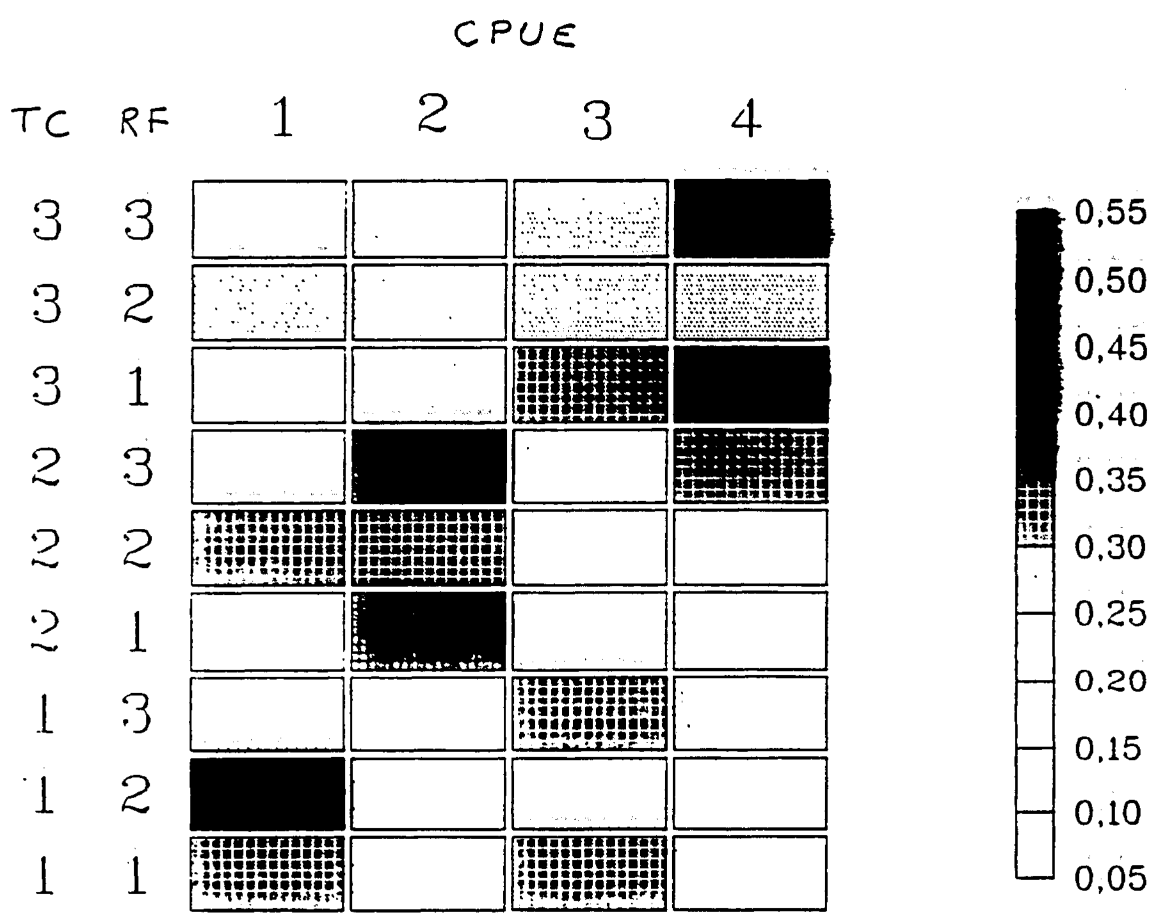

Figure 4. One-sea-winter salmon. Distribution of classes of variables in factorial space 1-2. Classes of increasing catch per unit effort (GRI1 to GRI4), river flow (RF1 to RF3), tidal coefficient (TC1 to TC3), and classes of wind direction (WD1 to WD4).

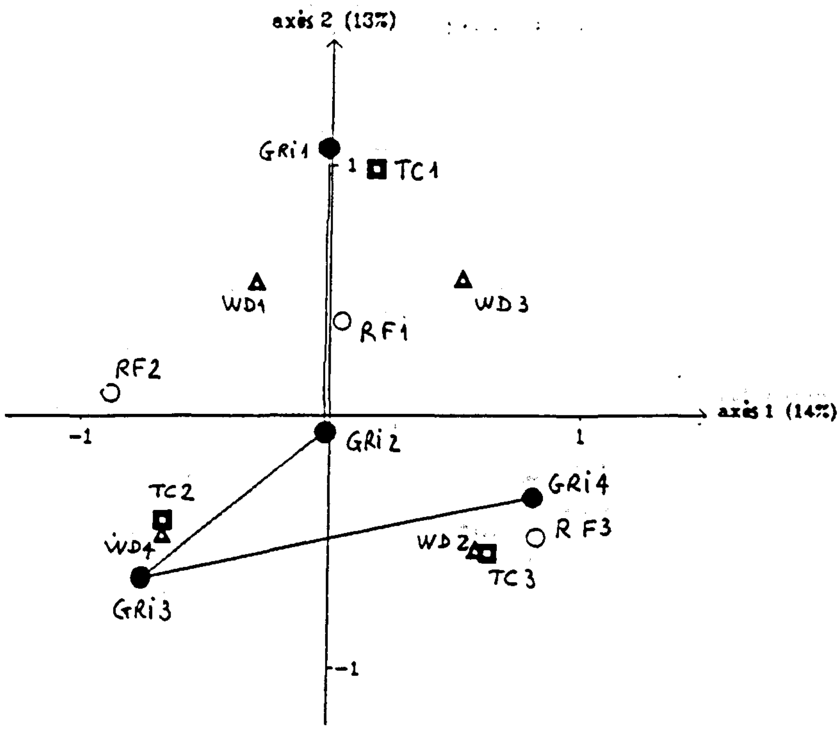

Figure 5. One-sea-winter salmon. Estimated conditional probabilities to get level *k* of catch per unit effort (GRI) for level *i* of river flow (RF) and level *j* of tidal coefficient (TC).