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Use of estuarine and freshwaters habitats and the way that freshwater and diadromous fish use them

Changes in recruitment of Atlantic salmon (*Salmo salar*) population in the River Oir (Lower Normandy, France): relationships with the characteristics of spawners and with the stream modification

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The River Oir is a small tributary of the Sélune (Armorican massif) and is used as a spawning area by the Atlantic salmon (*Salmo salar* L). Since 1985, the population dynamics of its salmon population have been studied from a data set regarding parr density, number and age structure of migrating fish (smolts and adults). Parr densities (1.5 to 17.4 fish/100 m² of suitable habitat) and smolt production (0.25 à 9.2 fish/100 m²) fall within the range of values of other nearby rivers but vary strongly according to the year and to the cohort. These fluctuations of abundance are linked to the number and to the size of spawners (with a strong decrease of multi-sea winter fish) and to the possibility for the adults to reach the best spawning grounds, depending on discharge conditions.

The fluctuations are also related to highly variable survival rates from egg to smolt (0.044 to 1.07%). Moreover**,** these survivals are much lower than in rivers non impacted by human activities. The highest mortality occur between the egg and the 0+ stage (97.5 to 99.9%) and especially during the under gravel phase. During this phase, mortality depends on the type of substrate (granite or schist) and is increased by the strong variability of the discharge, and by the number and the strength of spates occurring in late autumn and winter, because of silt deposition on the spawning beds. On the study period, annual recruitment has resulted in an insufficient renewal of the salmon population some years.

Key words: Atlantic salmon, survival, abundance, anthropogenic impact, silt deposition

Introduction

Due to its geological and hydro-climatic characteristics, the Armorican Massif, which comprises Brittany and Lower Normandy, has a strong proportion of salmonid rivers and is the French area with the greater number of salmon rivers. The Atlantic salmon lives in 25 main rivers which are 30 to 75 km long (Fontenelle *et al.,* 1980), and about 80 % of the French yearly rod and line salmon catches are made in Brittany and Lower Normandy.

Most of these salmonid rivers have a small stream order. They have peculiar physical and chemical characteristics (relatively steep slope, good water quality, suitable water temperature), a high heterogeneity and a small overall resilience. Their fish assemblages have been the most studied of all biotic compartment and are relatively well known. The fish component has a low diversity and includes two salmonid species: the Atlantic salmon (*Salmo salar*) and the brown trout (*Salmo trutta*), which have basic ecological requirements in relation to the good overall quality of the habitat and an important common biological feature: a large ontogenetic spatial niche (diadromy/migration).

These ecosystems are sensitive to the anthropic pressures, some of which are old (hydraulic and hydroelectric energy) while others are more recent (agriculture). The modifications of the physical and of the agronomic structure of the drainage area strongly perturb the various biotic compartments and influence the abundance of fish populations, more particularly trout and salmon, be it by direct (toxicity) or indirect effects (habitat modifications).

Since 1985, a research programme on salmonids population dynamics has been carried on the River Oir, a tributary of the Sélune, Lower Normandy. It has permitted to acquire a long series of data (17 years) on the ecological characteristics and on the colonization strategy of the salmon on this river. The present paper analyses in a synthetic way the data series obtained, with two main objectives: (1) assess the status of the population and the level of the river productivity; (2) analyse the factors of variation taking into account the impact of man activities on the watershed and large scale changes in the abundance and in the composition of salmon populations observed in the species range. This analysis follows a general description of the River Oir watershed and of the ecological characteristics of the salmon population.

General description of the River Oir watershed

Geographical and physical characteristics (Fig. 1)

The River Oir is a tributary of the River Sélune. The River Sélune flows into the English Channel in the Bay of the Mont Saint-Michel and shares a common estuary with the

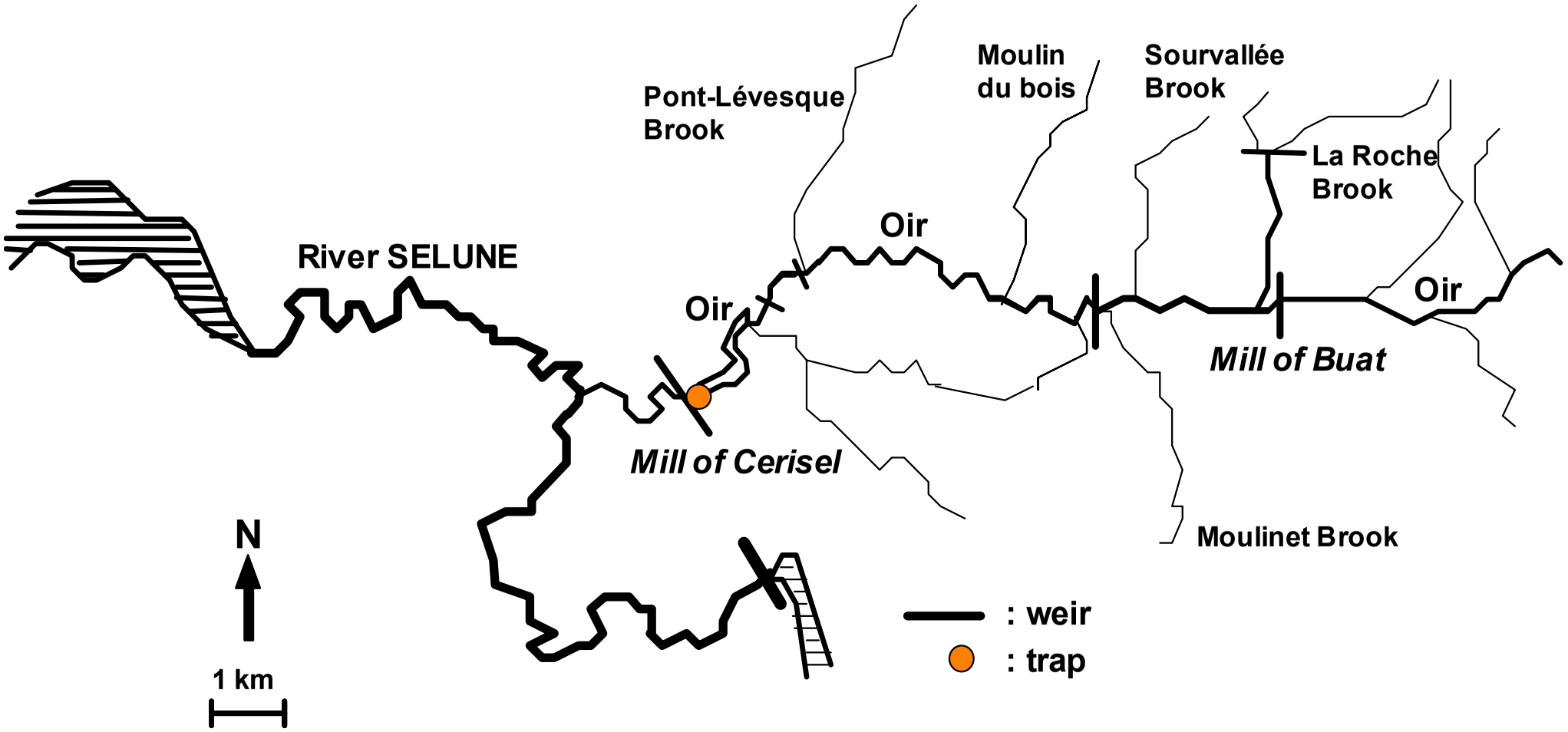

Figure 1. The River Oir water system

River Sée. The River Oir confluence is situated in the estuarine part of the Sélune, only 8 kilometers from the mouth. It is 19.5 km long and has an average slope of 11 ‰. Its watershed, 87 km² wide, is made of schists with a few enclaves of granite and has an oceanic climate (Baglinière *et al*., 1988). Water temperatures fluctuate between 3 and 19°C during the year and hardly ever exceed 20°C on a given day.

The study zone is located between the mills of Cerisel and of Buat. At Cerisel, two upstream and downstream traps) are installed and operated all year long, allowing to control the adult salmon and smolt migration. The mill of Buat, 12.5 km upstream from Cerisel, can be a serious obstacle for the migration of the adults, provided it can only be crossed during important flows (Baglinière *et al*., *ibidem*). There is another weir in the middle of the study zone that can prevent any access of the adult salmons to the upper basin and to the La Roche Brook during low flow conditions. The River Oir has several tributaries in the study zone, of which the most important are Bois Tyrel, L'Arçonnière, La Roche, Sourvallée, Moulinet, Moulin du Bois and Pont-Lévesque Brooks. The five last brooks have been investigated, particularly La Roche Brook.

The human activities likely to have an impact on the water system are mainly agricultural (permanent and cultivated grasslands, pastures and fodder cultures), the few existing villages being very small. Recent analysis of the physico-chemichal composition of the River Oir and of some of its tributaries show a slightly alcaline pH and a high concentration of dissolved oxygen. The nitrate concentrations are close to or above 30 mg/L. (Tab. 1). At last, an important silt deposition is observed on the river bottom of the Oir and of some of its tributaries (particularly the Moulinet Brook), resulting from an erosion of the steep banks and of the watering-places.

Table 1. Physico-chemical characteristics of the River Oir and of some of its tributaries in April 1997 (Giovanni, unpublished data).

Location	NO3- mg/L	NO2- mg/L	NH4+ mg/L	PO4 3- mg/L	pH	O2 mg/L (%)	T°
Oir (middle course)	37	0.24	0	0.07	7.12	11.8 (113)	
Oir (at Cerisel)	36	0.23	0.01	0.04	7.83	14 (130)	12.4
La Roche Brook	50	0.25	0	0.02	7.15	11.8 (111)	13
Moulinet Brook	31	0.22	0.02	0.01	7.12	11.8 (118)	13
Pont-Lévesque Brook	27	0.25	0	0.02	7.70	12.5 (118)	13.1

Data on the contamination of the water system (herbicides and heavy metals) remain fragmentary but their analysis showed that:

- the herbicide concentration (triazines and isoproturon), measured in spring and at the end of summer are relatively low on the whole and lower than the detection threshold in 85 % of the samples collected (Tab. 2).

Table 2. Herbicides concentration in the River Oir in spring and summer 1997 (Giovanni, unpublished data). In italics: values only measured once.

Localization	Triazines (ng/L)		Isoproturon (ng/L)	
	minimum	maximum	minimum	maximum
Above Montigny (upper course)	<25	260	<50	150
Confluence La Roche Brook - Oir	<25	300 (*1100*)	<50	180
Confluence Moulinet Brook - Oir	<25	220 (*1700*)	<50	(*200*)
Confluence Marcilly Brook - Oir	<25	250	<50	150
Above Cerisel	<25	(*800*)	<50	(*500*)

- the heavy metals are found in the sediments. Some values of copper and lead measured in winter and in summer exceed the upper limit of the class 1 ("good") in the quality grid of the Water Authorities (Anonymous, 1997), and even the upper limit of class 2 for copper (Tab. 3).

Fish community

The Atlantic salmon and the brown trout inhabit the River Oir. The trout is present under the marine and freshwater forms, the two being impossible to distinguish at the juvenile stage (Baglinière *et al.*, 2000). The other species include three diadromous fish, the European eel (*Anguilla anguilla*), the sea lamprey (*Petromyzon marina*) and the river lamprey (*Lampetra fluviatilis*) as well as small resident fish like the bullhead (*Cottus gobio*), the stone loach (*Neimacheilus barbatula*), the minnow (*Phoxinus phoxinus*), the brook lamprey (*Lampetra planeri*) and the gudgeon (*Gobio gobio*). The total species richness of this river system is ten but has never exceeded seven in any electro-fishing sample. It decreases from the lower to the upper stretches and is much smaller on the tributaries (between 2 and 4). Nevertheless, this species richness is increased in some places by non-native species such as the pike (*Esox lucius*), the perch (*Perca fluviatilis*), the roach (*Rutilus rutilus*) and the common carp (*Cyprinus carpio*), coming from man-made ponds.

Table 3. Contamination of the sediments of the River Oir by heavy metals

Station	Year	Zn (mg/kg)	Pb (mg/kg)	Cd (mg/kg)	Cu (mg/kg)	Source
La Roche Brook	1998	82	18	0.54	12	Massa, 2000
	1999	72	17	0.15	11	
Moulinet Brook	1998	90	17	0.33	16	
	1999	106	20	0.27	24	
Bois Tyrel Brook	2000	43	13	0.13	7	U3E INRA unpublished data
	2000	59	15	0.38	10	
Marcilly Brook	2000	57	19	0.10	8	
Oir - 1	2000	64	16	0.25	9	
Oir - 2	2000	87	17	0.16	12	
Oir - 3	2000	94	16	0.2	15	
Oir - 4	2000	57	16	0.13	14	
Oir - 5	2000	59	15	0.19	11	
Quality threshold						
T1 (risk of chronicle effect on sensitive species)		124	4.1	0.7	1.9	Anonymous, 1997
T2 (risk of chronicle effect on the abundance of species)		271	41	4.2	19	

Data analysed

The salmon populations have been studied since 1985, by electro-fishing for resident juveniles and by trapping of the downstream migrating smolts and of the upstream migrating adults at the Mill of Cerisel (Fig. 1). The sampling effort for electro-fishing has strongly increased during the last years of monitoring, giving then a wider vision of the state of the populations on the main course and on the majority of the tributaries. As a matter of fact, the monitored surface on the Oir was less than 3,000 m² before 1995 and has varied between 11,874 and 22,500 m² since 1996, whereas the number of tributaries fished has shifted from one (La Roche Brook) to six (La Roche, Sourvallée, Moulinet, L'Arçonnière, Moulin du Bois and Pont-Lévesque Brooks).

Thus, the analysis of the data has been carried on taking into account the spatio-temporal evolution of resident juveniles densities, the evolution of the number of migrating juveniles and adults, the age structure and the rates of survival (egg to alevin, to emerging fry, to 0+ parr and to smolt). According to the case, the analysis uses the data gathered during 17 years (distribution by habitat, number of juvenile and of adult migrants,

estimation of the egg deposition) or those collected since 1996, which have led to a better view of the distribution and of the abundance of the salmon in the water system.

General presentation of the salmon population

Nearly all the salmon spawners enter the Oir in autumn shortly before the reproduction which essentially takes place in December. The Oir only serves as a spawning area for the Sélune, so rod and line fishing is forbidden by prefectoral decree.

The estimated number of adult salmons has varied from 47 (in 1991) to 491 (2001) individuals. The majority (90.6 % on average) of spawners were not born in the River Oir (minimum 42.2 %, maximum 100 %). The adult population mainly comprises grilses (one-sea winter fish), 88 % on average from 1985 to 2001. Whatever the year, the males account for the larger proportion (59.8 %) but the females are prevailing among the multi-sea winter fish (68.9 %) and among the multiple spawners (87.5 %). The grilses include a majority of cocks (64.8 %). There is a narrow relationship between the female fork length (Lf in mm) and its fecundity (F) expressed as the number of ovules:

$F = 22.93\ Lf - 9844.1$, $n = 78$, $r^2 = 0.69$, $p<10^{-2}$

The females of grilse and of two sea-winter salmons have respective average fecundity of 4.691 (± 367) and 7.965 (± 627) ovules (Prévost *et al.*, 1996).

In general, the juveniles are mainly present in the principal river and are rather rare in the tributaries, with the exception of the La Roche and Pont-Lévesque Brooks. Theses two brooks, especially the first one, are regularly ascended by adult salmons. Juveniles have also been found some years on the Moulin du Bois Brook (Fig. 1). On the Oir, the juveniles preferentially colonize shallow habitats, with high current speed (40 to 50 cm/sec) and coarse substrate (riffles) (Fig. 2). Densities in riffles are generally five times higher than in run habitats. This observation confirms the method proposed by Prévost and Porcher (1996) which consists in adding only 20% of the run areas to the riffles and rapids to estimate the total area of smolt production in the water system. The observations made in the Oir are in agreement with the general strategy of spatial colonization found in other rivers (Baglinière and Champigneulle, 1982; Heggenes *et al.*, 1999). The very strong relationship between the habitat and the salmon juvenile has allowed to establish a reliable method of estimation of the smolt production based on the ecological and biological characteristics of the autumnal juvenile population (Baglinière *et al.*, 1993).

The juveniles migrate towards the sea in spring and are mainly one year old (average: 88.5 %) because of a high growth rate.

Evolution of the abundance of salmon juveniles

Density and distribution of resident juveniles

The mean density in the Oir basin (7.0 ind./100 m² in 17 years) is above the average observed in other rivers of similar size of the Armorican Massif at the same period. As a matter of fact, 59 % of the mean yearly densities of these rivers are smaller than in the River Oir which is, however, from 2 to 5 times smaller than what is observed on the best salmon rivers of Brittany and Lower Normandy (data of the Réseau Hydrobiologique et Piscicole 1985-2001 of the Conseil Supérieur de la Pêche: Baglinière E., Pers. Comm.).

Nevertheless, the abundance of salmon juveniles in the Oir basin is very variable according to year: the density fluctuates between 1.5 and 17.4 ind./100 m² and only exceeds the 10 ind./100 m² in four years out of seventeen (Fig. 3). In other respects, this abundance varies in space and is usually higher in the upstream sections, be it in the main river or in the La Roche Brook. The upstream stretch (4 km long) between the bridge Oir and the Mill of Buat has nearly half of the overall riffle surface and its average density between 1996 and 2001 is 14.1 ind./100 m² (2.5 to 33.3 ind./100 m²). In a same way, the average density in the La Roche Brook (of which 2 km is accessible) during 17 years is 23 ind./100 m² (0.3 to 60 ind./100 m²), meaning that this brook is the best productive zone of all the Oir basin (Fig. 3).

The strong spatio-temporal variability of abundance is essentially due to the younger age class (0+), which is largely prevailing (80.4 %). The variability depends mainly on the abundance and the composition (sea age) of the adults ascending the Oir, which are the two essential parameters governing the spawning potential. Theses parameters are under the control of four factors which can be synergetic (Baglinière *et al.*, 2002):

- *The rod and line exploitation rate.*

If angling is not allowed on the Oir, such is not the case on the Sélune, where the exploitation rate could be close to 50 % of the whole stock and nearly 75 % of the spring salmon component (multi-sea winter fish). Moreover, the Sélune is one of the two rivers of the whole area where the consumption of the Total Authorised Captures (or TAC; procedure explained in Prévost and Porcher, 1996) is the highest. Since 1996, the catches have been very close to the TAC and have even exceeded it five times (Tab. 4).

Table 4. Consumption of the TAC on Rivers Sée and Sélune, 1996-2001.

	Consumption of the TAC (%)					
Year	1996	1997	1998	1999	2000	2001
River Sée	62	68	45	99	138	139
River Sélune	89	108	84	214	92	159

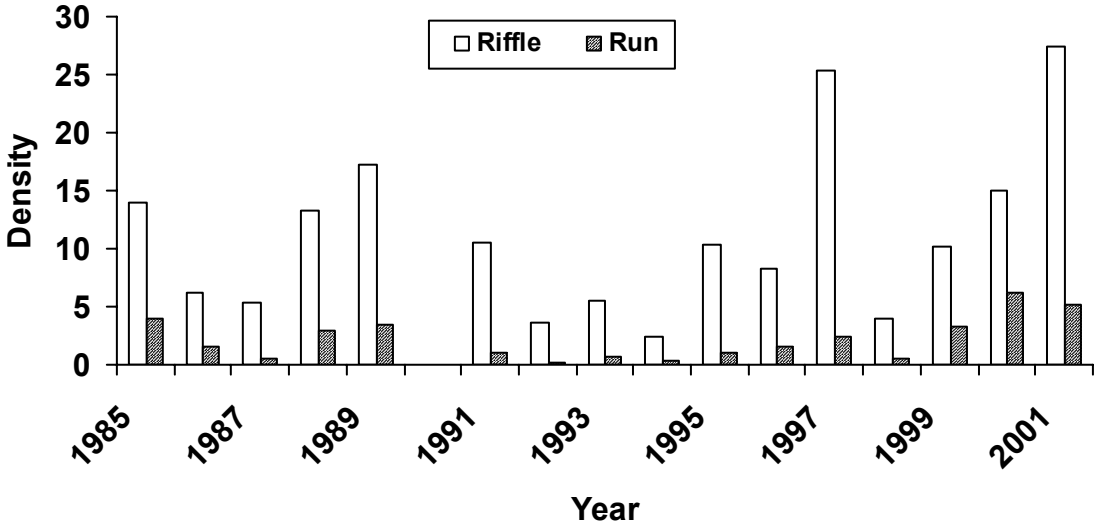

Figure 2. Evolution of Atlantic salmon juveniles densities (ind./100 m2) by habitat in the Oir, 1985- 2001.

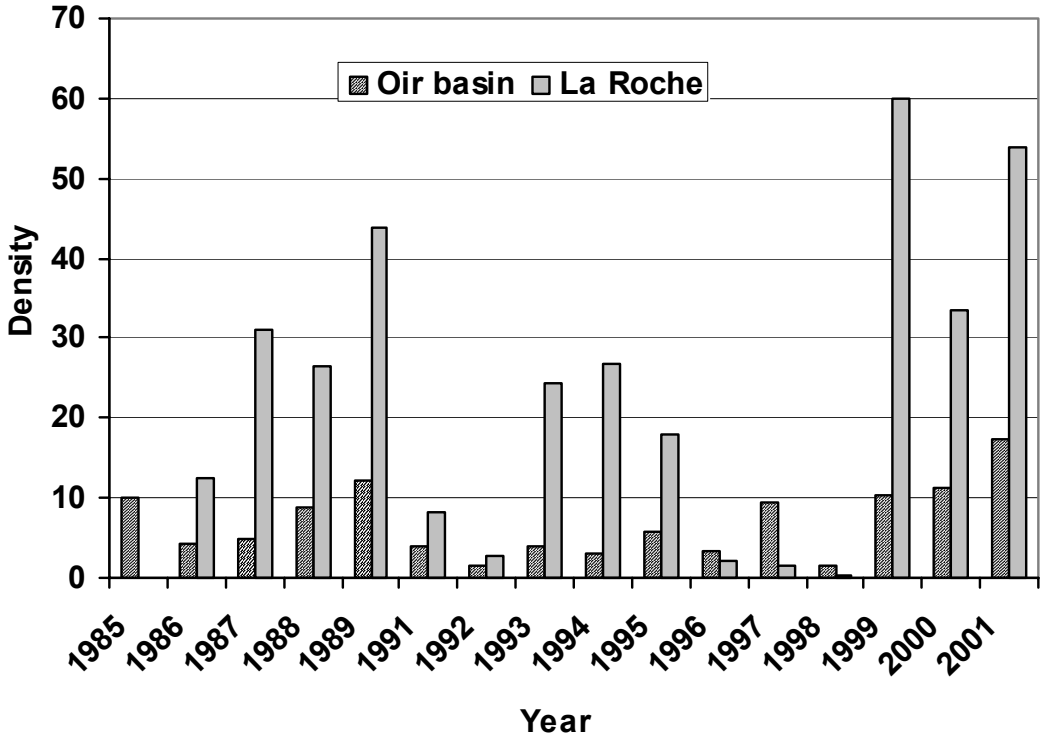

Figure 3. Mean density (ind./100m²) of salmon juveniles in River Oir and La Roche Brook, 1985-2001.

- *Potential exchanges of fish between the Rivers Sée and Sélune.*

The current studies carried on to modelize the population dynamics of salmon in the River Oir suggest a high probability of exchanges between the Rivers Sée and Sélune, and the existence of a meta-population (Rivot, 2003). As a consequence, a common TAC has recently been established for the two rivers. These exchanges are likely to occur mainly from the Sée towards the Sélune because the latter has a far smaller juveniles production area because of two large hydro-electric dams in its lower reaches. It is then necessary to consider the rate of exploitation of the salmon on the Sée when dealing with the management and the conservation of the populations of the Rivers Oir and Sélune.

- *The diminution of the spring salmon component.*

The component of spring salmon is considered very vulnerable, given its steep decrease in the stocks of the North-East Atlantic and in France (Anonymous, 2001; Baglinière *et al.*, 2004) (Fig. 4a and 4b). This situation is also observed in the River Oir where the multi-sea winter salmon component only accounts for 6 % of the stock on average during the 1992-2001 period (Fig. 5). Now, these fish are not only of larger size but also mainly females. As a consequence, there is a diminution of the egg deposition in this drainage basin, which is not compensated by the grilse increase observed since 1992, because these fish include a majority of males. Given the sex proportions and the fecundity of females of these two components (grilses / spring salmon) in the Oir, the loss of eggs from the spring salmon would require a multiplication by 4.36 of the number of grilses.

- *The hydrological conditions before and during the spawning time.*

The variability of discharge first plays a role in the attractivity of the Oir compared to the River Sélune. Secondly, this variability strongly influences the conditions of circulation in the River Oir by allowing to pass through certain obstacles and by modulating the access to the best zones spawning zones, in the upper course of the river and in the La Roche Brook.

The effect of the above factors (number and composition of the adults, flow conditions) on the number of juveniles is perfectly illustrated by the observations made on the La Roche Brook. The low level of production during certain years is only the result of fewer spawners at the mating time, and sometimes no spawner at all. It is by no means explained by a modification of the habitat, which permanently remains of better quality than in the main river.

Production of migrant juveniles

The number of smolts varies according to the year of downstream migration from 236 to 2,403 and by cohort from 75 to 2,563 individuals. The majority of the migrants are 1+ year old, the 2 year old smolts only accounting for 18.2 % on average per migration year and 11.5 % per cohort (Fig. 6A and 6B).

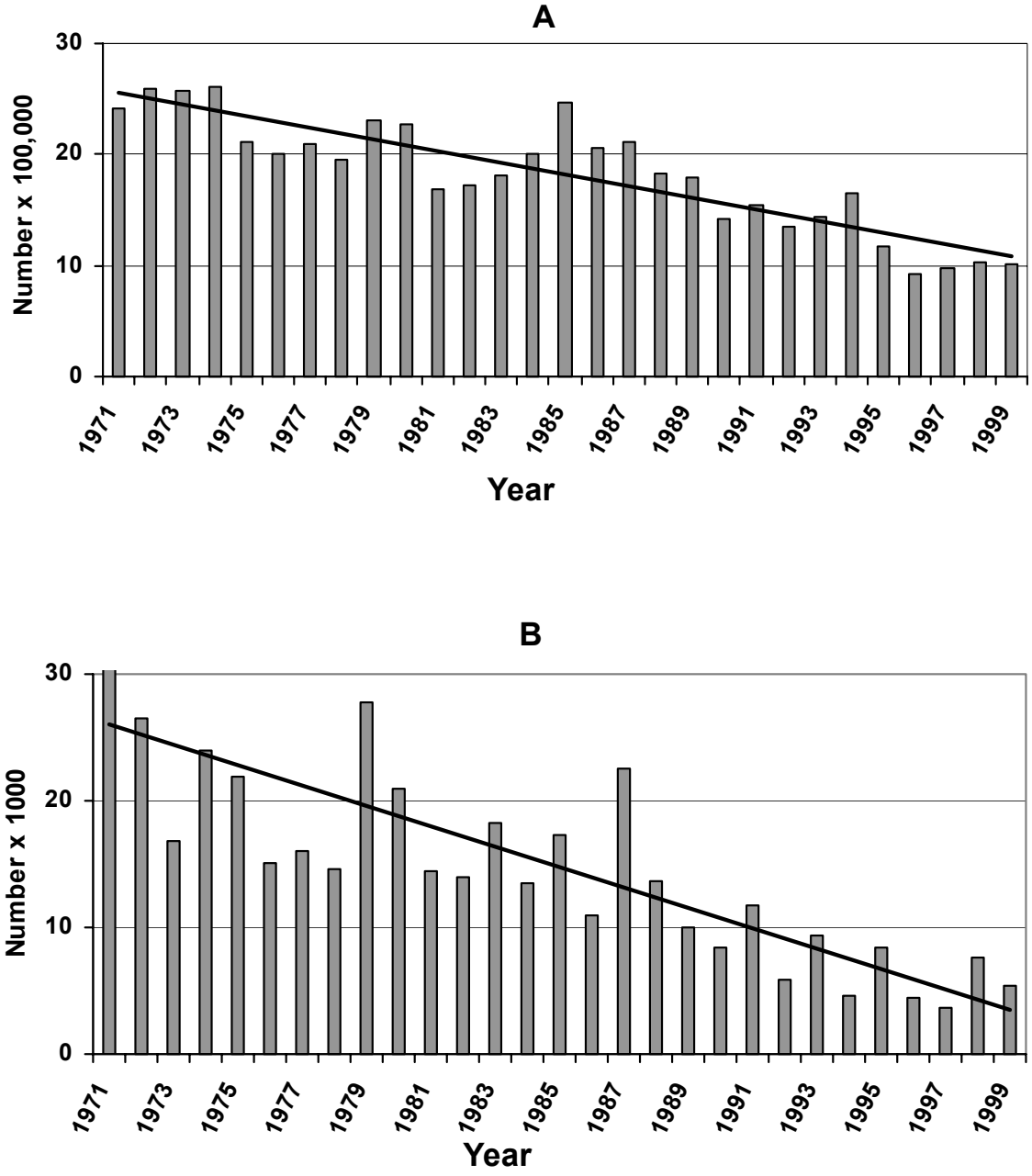

Figure 4. Estimated number of multi-sea winter salmon returning to the rivers of North-east Atlantic (A) and France (B) before exploitation, 1971-1999 (after Anonymous, 2001).

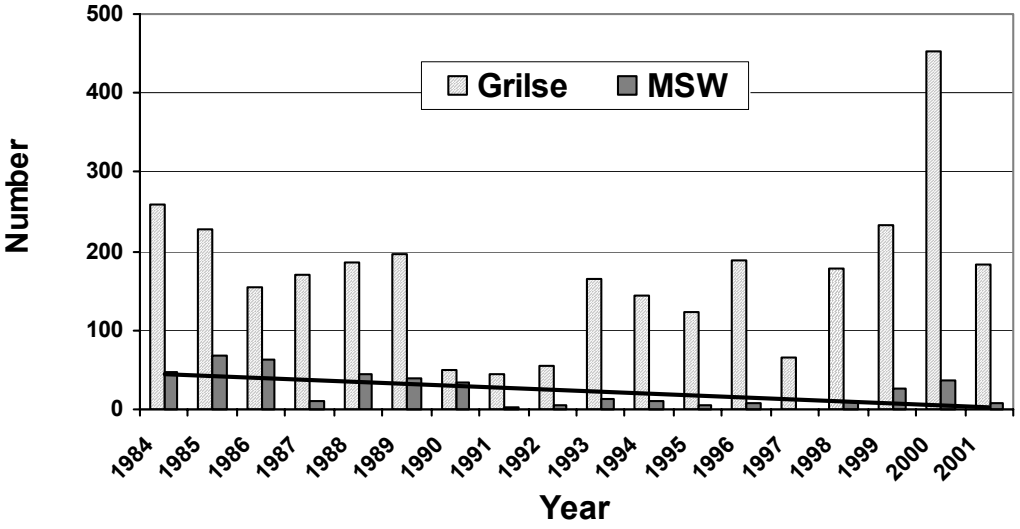

Figure 5. Number of salmon returning to the River Oir by sea-age, 1985-2001.

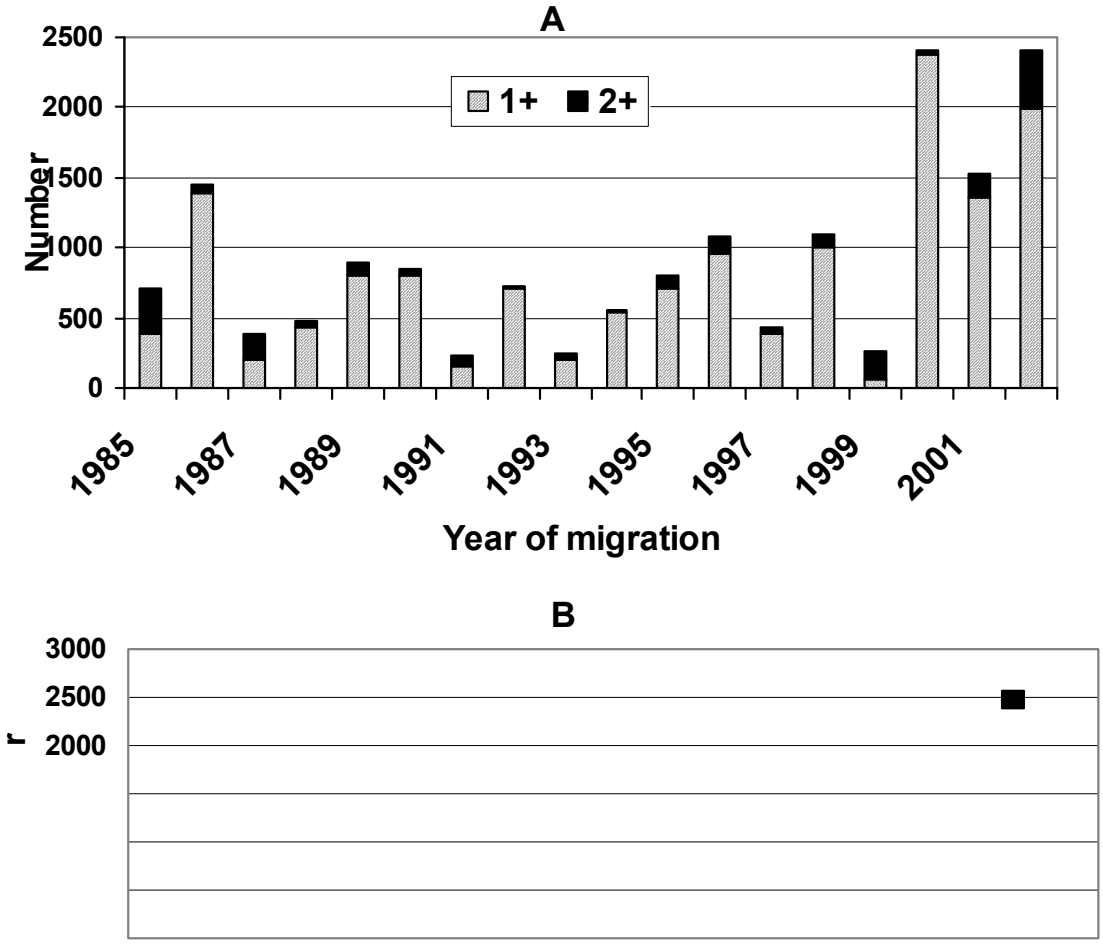

Figure 6. Distribution of age classes of smolts from River Oir by year of migration (A) and by cohort (B), 1984-2002.

There is a strong relationship between the number of resident juveniles during year n and the total number of smolts that migrate during year n+1, as well as between the density and the biomass of 0+ juveniles and the number of smolts produced by cohort (Tab. 5). This means that: (1) the variability of the number of the migrating juveniles produced by cohort (ratio of 1 to 34) is strongly related to the number of the resident juveniles; (2) the smolt production of the drainage basin depends essentially of the quantity (number) and of the quality (size) of the juveniles 0+ produced. This last finding confirms the weak importance of the 2+ age class in the total production of smolts in the drainage.

Table 5. Regressions between the number of smolts (Nsm) and several variables; pa0 = 0+ parr ; pa1 = 1+parr ; D = density ; Biom = biomass ; sm1 = 1 year smolt.

variables	Number of smolts		
	Equation	R^2	Fisher test
Npa0+Npa1	Log Nsm = 0,8237 Log (Npa0+Npa1) + 0,199	0,7375	$p<10^{-3}$
Dpa0	Log Nsm = 0,7677 Log Dpa + 5,472		$p<10^{-3}$
Biom(pa0)	Log Nsm = 0,831 Log Biom(pa0) - 1,517	0,8426	$p<10^{-4}$
Biom(pa0)	Log Nsm1 = 0,8754 Log Biom(pa0) - 2,07	0,854	$p<10^{-3}$

The production of migrant juveniles can be expressed by the number of smolts produced by 100 m² of riffle-rapid equivalent, a synthetic variable resulting from the sum of the riffles, the rapids and 20% of the run areas (Prévost and Porcher, 1996). On the basin of the Oir, the total surface considered takes into account the main course and three of its tributaries: the Pont-Lévesque, Moulin du bois and La Roche Brooks. The average number of smolts calculated in 17 years (3 smolts/100 m²) places the Oir exactly in the norm established for all the rivers of the Armorican Massif by Prévost and Porcher (1996). Nevertheless, this average is strongly drawn upwards by three years or cohorts (1985-1986, 1999-2000 and 2000-2001, 1+ smolts only) as the above defined norm is only equalled or exceeded in 7 years out of 17 (Fig. 7A). This shows that the productivity of the drainage basin is rather moderate and strongly variable. In opposition, certain stretches are more productive, like La Roche Brook, that produces on average 4.7 smolts/100 m² per year and 4.8 smolts/100 m² per cohort, with exceptional values in 1999-2000 (17.6-19.9 smolts/100 m²). Its annual production equals or exceeds the regional norm 9 times out of 13 (Fig. 7B). This brook ensures a minimum production in the drainage basin, during years when the densities are very small on the Oir itself, by accounting for up to 50.7 % of the overall smolt production (Baglinière *et al.,* 2002). This stresses the importance of protecting this small tributary.

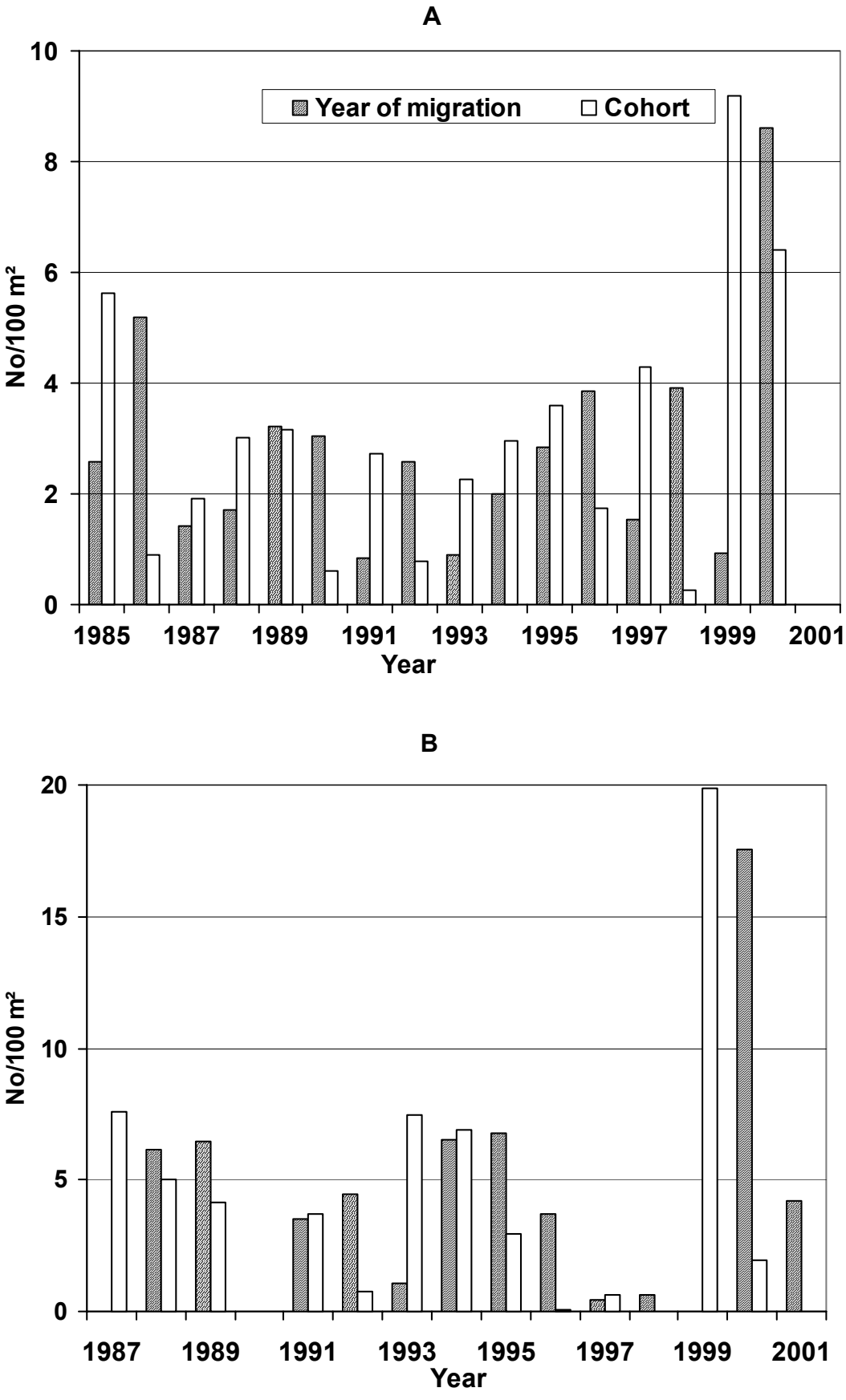

Figure 7. Number of smolts produced per 100 m² of riffles and rapids in the Oir (A) and in La Roche Brook (B), 1985-2001.

Survival during the juvenile phase

The yearly estimation of the egg deposition and of the smolt number allows to evaluate the rate of survival from the egg to the smolt. This rate varies strongly (from 0.044 to 1.07 %; Fig. 8) and is lower than in the rivers of Canada and of the United Kingdom (Fig. 9) which are not (or much less) disturbed by human activities (Prévost *et al.,* 1996; Cunjack and Therrien, 1998, unpublished data). Nevertheless, it is necessary to moderate this conclusion because the mean rate of survival from egg to smolt (0.43 %) is slightly superior to the figure of the Catamaran Brook, a third order tributary of the River Miramichi: 0.36 % in eight years (Cunjack and Therrien (1998) and unpublished data). It is also in the range of values observed by Gibson (1995) *in* Cunjack and Therrien (*ibidem*), in one river of Newfoundland: 0.28-1.06 % in six years of monitoring.

A further analysis of this survival rate from egg to smolt shows that:

1- The winter survival between the stages 0+ and 1+ varies from 31 to 64.4 % but remains high on average: 50.9 % (Fig. 10).

2- The survival between the egg and the stage 0+ is more variable (0.1 to 2.5 %) and is very low on average, 1.15 % (Fig. 8), if compared to the Catamaran Brook (26 %, from 7.0 to 63.2 %, in 11 years) (Cunjak and Therrien, *ibidem*). The lack of correlation between the rate of survival from the egg to the stage 0+ and the density of juveniles in autumn suggest there is no density dependent mortality and that the difference is mainly due to a strong mortality during the under-gravel phase or during the first weeks of life.

This hypothesis has been confirmed by experiments made on under-gravel survival (Claude, 1996). Theses operations have been carried on with small cylindric cages filled with gravels of suitable size and with eggs laid by wild spawners. These "artificial spawning redds" have been buried in the river bottom in several points of the Oir and of the La Roche Brook, which were identical to natural spawning zones. Nevertheless, due to bad weather conditions, the eggs could only be buried as eyed eggs. The results show that the average rates of survival are small for both rivers and decrease as time passes by. They are of 22.3 to 35.3 % until hatching but only attain 8.1 to 11 % until the emergence (Claude, *ibidem*). Other experiments with brown trout consisted in introducing green eggs in the bottom of two tributaries of the River Oir of different geological substrates: granite mixed with cornean schist (La Roche Brook) and sedimentary schist (Moulinet Brook), the latter being the prevailing substrate in the Oir drainage system. The results showed that (Tab. 6):

- The rates of survival from the egg to the emerging fry, 0.81 to 10.6 % on average, are low to very low if compared with those obtained by the same method on the Catamaran Brook (40 to 62 % Cunjak, Pers. Comm. in Bardonnet and Baglinière (2000)). Nevertheless, the figures of River Oir are probably under-estimated for salmon because the gravel size seems to influence positively the rate of survival.

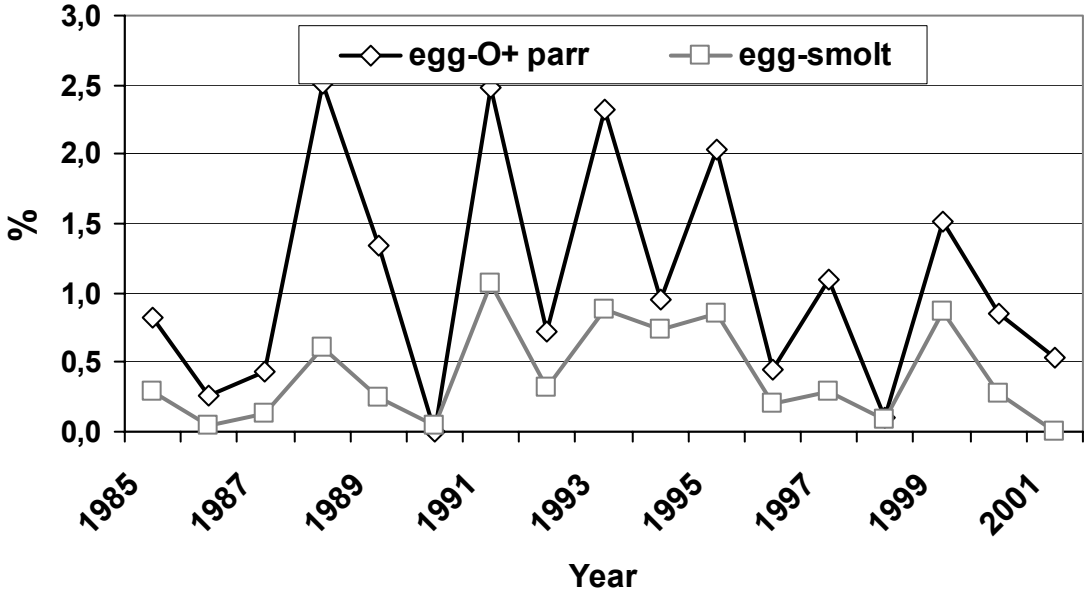

Figure 8. Survival rate (%) from the egg to the 0+ parr and to the smolt by cohort in the River Oir, 1985-2001.

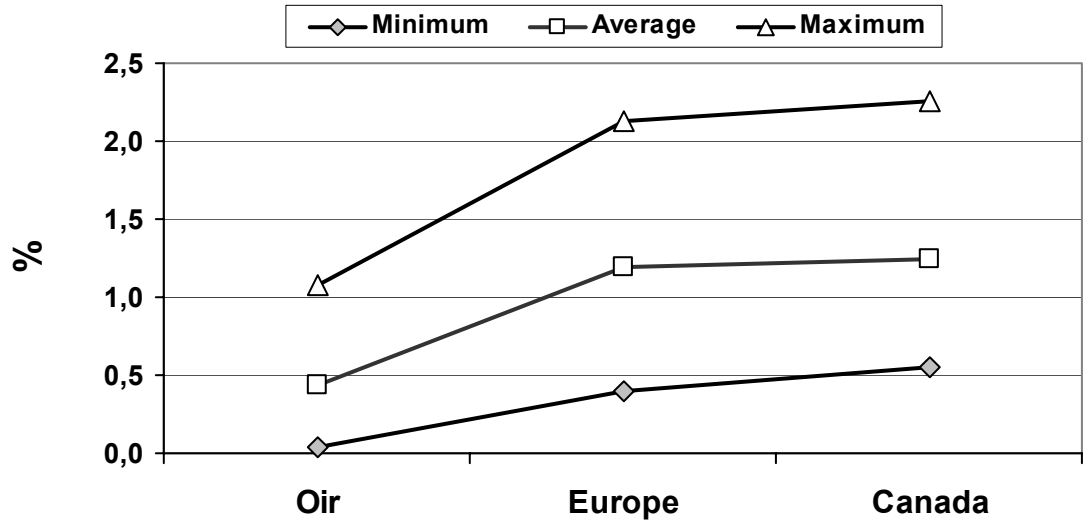

Figure 9. Survival rate from egg to smolt in several salmon populations, after Prévost *et al.* (1996)

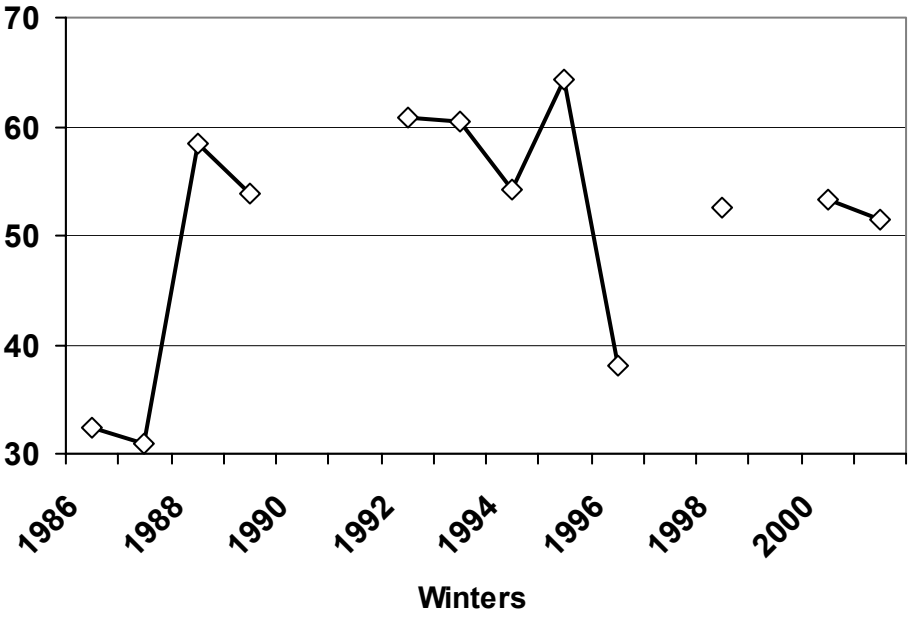

Figure 10. Winter survival rate of young salmon between 0+ and 1+ in the River Oir

This arises from a recent experiment during which the rate of survival from the green egg to the eyed egg was 1.4 times higher in the experimental cages filled with pebbles (suitable for salmon) than in those containing gravels adequate for brown trout (Tab. 7). In other respects, all these experiments are subject to a strong variability between the replicas, whatever the river and the year. This variability is likely to come from the important modifications, at a very short spatio-temporal scale, of the physico-chemical conditions (especially dissolved oxygen) in the bottom of the rivers (Massa, 2000).

Table 6. Survival rate (%) since the green egg stage for brown trout in two tributaries of the Oir (Massa *et al.*, 1998; Massa, 2000 and unpublished data).

Year	Under gravel phase	Survival (%)	
		Moulinet	La Roche
1996	Egg – emergence	0.0	20.0
1997	Egg – hatching	3.3	7.7
	Egg – emergence	2.8	6.3
1998	Egg – hatching	1.5	4.6
	Egg – emergence	0.8	2.8
1999	Egg – hatching	10.0	54.0
	Egg – emergence	0.5	17.8
2000	Egg – emergence	0.0	2.4
2001	Egg – hatching	3.1	-
	Egg – emergence	-	14.1
Average	Egg – hatching	4.9	20.8
	Egg – emergence	0.8	10.6

Table 7. Survival rate (%) from the green egg stage to the eyed egg stage in brown trout according to the size of the substrate: gravels suitable for trout or for salmon (U3E INRA, unpublished data).

Group	Survival (%)
Control group in fish factory	88.7
Vibert box, "trout model"	46.4 - 57.3
Vibert box, "salmon model"	71.0 - 75.2

- The rates of survival vary according to the nature of the substrate. They are far lower in rivers with sedimentary schist substrate, which is finer and more easily choked up. The silt deposition leads to a lack of oxygen and a denitrification (made possible by the fair abundance of nitrates in the water of these brooks) leading to the formation of nitrites that can explain the increased mortality (Massa *et al.*, 2000a). These observations agree with those of Witzel and MacCrimon (1983) and Magee *et al.* (1996) who concluded on the importance of an adequate habitat quality to ensure the survival of eggs and of alevins in the spawning redds.

- The survival rate strongly depends on the flow conditions during the incubation. The mortality between the fertilization and the hatching is high (up to 55 % and more) for low flows and decreases during the successive periods of high discharge. It is the reverse for the stage between hatching and emergence (Massa *and al.*, 2000b).

According to these observations, it appears that the bottleneck of the production of salmon juveniles relies more in the incubation than in the first weeks of life of the fish. Moreover, these experiments have pointed out the preponderant parameters influencing the higher smolt production in La Roche Brook. The most important one is the quality of the spawning zones and beds determined by the substrate composition, granite and cornean schist being much less prone to choking up after silt deposition and than the sedimentary schist substrate of the main river.

Conclusion

The acquisition of this biological and ecological data series on the salmon population of the River Oir (17 years) and the recent research on stock-recruitment relationship and on population dynamics modelization have led to the general conclusion that the salmon population is characterised at the same time by a strong inter-annual variability and by a certain difficulty to self sustain. This results from two synergetic factors. The first is a

decrease of the egg deposition due to the strong diminution of the spring salmon component (multi-sea winter fish). This diminution is observed in the species range and seems due to a lower survival in a globally modified North Atlantic ocean. This trend does not seem to show any sign of reversal (Anonymous, 2001). The second is the relatively low smolt productivity of this water system, already mentioned in a previous study (Prévost *et al.,* 1996), caused by a certain degradation of the general quality of the habitat (reproduction of adults and of rearing of juveniles). Given the pedological context of the drainage basin (thick and silty soils), this degradation is largely attributable to the agricultural practices (Armour *et al.,* 1991; Knapp and Matthews, 1996). The pasturing on the banks and the watering-places in the river bed, the corn fields which leave the land uncovered in autumn and winter and increase the soil erosion, as well as the industrial breeding modify the physico-chemical composition of water, and create, among other impacts, a significant silt deposition on the river bottom. Because of this silt deposition on the spawning redds, the under-gravel phase and the first weeks of life of the alevin are the bottleneck of a self-sustaining salmon population in this human impacted river system.

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