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Dispersal patterns of Atlantic salmon juveniles

by

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ABSTRACT

The spatial and temporal patterns of dispersal of Atlantic salmon were analyzed over one year in a small brook of the Basque Country (SW France). Dispersal just after emergence was studied with 8 drift nets placed 10 to 800 m downstream from an artificial redd stocked with 15 000 eyed eggs. Subsequent distribution of parr was determined by electrofishing inventories conducted in June, October and February in representative sections of the stream including habitat 750 m upstream and 2400 m downstream from the redd. Survival from egg planting to first dispersal in March was 62.5 % and 10 % over one year. Early dispersal following emergence lasted 12 days for the majority (95 %) of the fry population. Most fry (73 %) settled within the first 200 m downstream from the redd, and 93 % within the first 400 m. Early dispersal did not extend further than 800 m downstream. In June, parr were found 2400 m downstream and 500 m upstream, with 68 % of the population established within 900 m downstream, and only 4 % upstream. In October, distribution was not different, while in February 56 % of the parr were found within 900 m downstream and 11 % upstream. This experiment showed that dispersal from a single redd was extensive downstream and that it occurred mostly at the time of emergence and during the following two months. After June, movements were quite limited, except that upstream colonisation increased during the following winter.

1 - INTRODUCTION

At emergence from the gravel nest, the fry of salmonid fish typically disperse in the initial rearing habitat. It is generally held that dispersion in Atlantic salmon is limited (Egglishaw & Shackley, 1973 ; Kennedy, 1982). Fry exhibit territorial behaviour quickly after emergence (Kalleberg, 1958) which leads to a gradual dispersal from the redds (Le Cren, 1973). However, some authors (Hay, 1989 ; Elson, 1957) had found that dispersal could be extensive at different juvenile stages. In an experiment in a 50-m section of an artificial stream channel, Marty & Beall (1989) looked at the spatial and temporal patterns of dispersal of Atlantic salmon fry from an artificial redd. They found a massive downward displacement occurring in a short time, with over 50 % of the fry population moving beyond the 50 m downstream limit. In this experiment, we wanted to verify the patterns of dispersal in a natural stream system, determine the extreme range of migration and precise its timing. Since it lasted over one year in a stream virgin of salmon, important information on survival between the different early stages could also be procured.

2 - MATERIAL AND METHODS

2.1 Study site

The experiment was conducted in the Lapitxuri brook, a tributary of the Nivelle River (Fig. 1) at the France-Spain border, in the Basque country. The Lapitxuri flows through a wooded watershed (mostly oak, chestnut and alder) on primary layers of schist and quartzite (see Marty *et al.*, 1986 for more details). Water temperatures vary between 4 and 21°C and flows between 0.06 and 10 $m^3.s^{-1}$. During the early part of the study (March), discharge stayed between 0.3 and 0.6 $m^3.s^{-1}$. No salmon occur naturally in this part of the watershed, but there is a fair population of brown trout. Eel, dace, gudgeon and lamprey are other common species.

The area between the INRA experimental station and the confluence with the Nivelle, i.e. 2800 m, was mapped in November 1988. Main characteristics of the stream (dimensions, morphology, substrate types) were determined to establish a classification of homogenous zones in riffle, flat or pool habitats. A stretch of 200 m, located about 400 m downstream from the INRA experimental station and homogenous in its gradient, width and velocity characteristics, was selected as the prime site of experimentation.

2.2 Biological material

Eggs were collected from wild salmon (Nivelle stock) on 7 December, fertilized with sperm from males of the same stock and incubated at the INRA hatchery. A group of 15 000 eyed eggs was sorted and counted, placed in Vibert boxes and buried in a single artificial redd excavated at the upstream end of the selected stretch (Fig. 1).

2.3 Emergence and early dispersal

Dispersal of downstream moving fry just after emergence was monitored with modified fyke nets at the end of which wooden live boxes were attached. Each net, made of nylon netting with 3 mm mesh opening, had the following dimensions : length 1.65 m ; height 0.38 m ; width at the upstream was 0.25-0.5 m, adjustable according to the desired water flow. The flow filtered by each net was targeted at a relatively low value of 5 %, in order to be able to operate as long as possible in high velocity water (0.6-0.7 $m.s^{-1}$) and to sample downstream moving fry without affecting too much the fry population size. The filtering capacity of each net was estimated with velocity and depth measurements (3 to 11) made along a transect in front of the opening. On 13 March, nets were placed 12, 46, 86, 152, 207, 405, 605 and 805 m downstream from the redd, and a small upstream trap was positioned 10 m upstream. Selection of downstream trap sites was based on 2 sets of criteria :

- to have comparable conditions with an experimental stream channel where a similar experiment was conducted in more controlled conditions ;

- to have comparable conditions between traps concerning depth (no greater than 0.3 m), water velocities (between 0.6 and 0.7 $m.s^{-1}$), distance from the bank (1.5 m) and substrate profiles (areas with major obstacles such as boulders or logs were avoided).

Traps were visited every morning and the fry enumerated and removed to the INRA hatchery. Samples of fry were collected every 5 days and preserved in 4 % formalin for further analysis (length, weight, stomach content). Trapping was interrupted on 4 April by a spate. The nets could not be put back in place due to the high water conditions that prevailed thereafter. During the period of migration, temperatures, water levels and turbidity were recorded near the redd site.

* Estimate of the downstream moving population

The estimated number of fry passing by a trap (Ne) was obtained by the daily fry captures in the trap (N), multiplied by the average percentage of total flow filtered by the trap (q) according to the formula : $Ne = N \times 100/q$

The assumption was made that fry were randomly distributed in the water column when migrating downstream.

* Estimate of the resident fry population

In order to analyse the distribution of fry, we used the differences between the estimated number of fry passing at successive traps to indicate the number of fry that settled in the corresponding area (Nr) : $Nr = N_{ei} - N_{e(i+1)}$ where i is the ith trap.

For simplification, we did not take into account mortalities due to predation or competition, which may have occurred during this period.

2.4 Dispersal of parr

Electrofishing population inventories were conducted around the median dates of 14 June 1989, 10 October 1989 and 28 February 1990. The De Lury method (Seber & Le Cren, 1967) was used (3-4 runs in June, 2 runs in October and February) in sample sections ranging in size from 71 to 191 m^2, representative of biotopes in each of the 7 stretches of stream considered (Fig. 1). The population in each stretch and over the whole study area was estimated according to Baglinière & Champigneulle (1986). Fishing efficiency varied from 0.76 to 1 in June, 0.86 to 1 in October and 0.82 to 1 in February.

3 - RESULTS

3.1 Fry at emergence

3.1.1 Temporal patterns of dispersal

The daily captures are presented in table 1. Duration of emergence until the removal of the trap on 4 April was 23 days. 95 % of captures occured within 12 days (23 March to 2 April) in the traps closest to the redd (T1 to T3). The modal day of captures was 27 March in T1, 28 March in T2, 29 March from T3 to T6. The only fry found in T8 was captured on 30 March. This shows that dispersal occurred very rapidly over the first 600 m downstream from the redd.

3.1.2 Survival and distribution of fry

The captures in trap 1 give the closest estimate of survival from egg planting to emergence (Table 1). Since some fry may have settled in the first 12 meters between the redd and trap 1, an estimated figure of 100 fry, derived from the number of fish which had settled or disappeared in the 34 meters between trap 1 and trap 2, was taken for this section. This gives an estimated population size of 9400 fry surviving from egg planting to emergence and first dispersal, i.e. a survival rate of 62.5 %.

The estimated numbers of fry settling at different distances from the redd are presented in figure 2. 73 % of surviving fry settled within the first 200 m downstream from the redd, with 55.4 % in the 50-150 m zone. 93.1 % of all fry are found within 400 m from the redd. None were captured in the upstream trap. During this early dispersal phase, very few fry travelled beyond the 800 m trap.

3.1.3 Size of downstream moving fry

A two-way analysis of variance was made on weights of samples of fry collected in traps T1, T2 and T3 at 3 different dates (24 March, 29 March and 2 April). A significant difference occured between dates ($F = 12.43$, $P < 0.01$ %) but not between traps at the same date ($F = 1.03$, $P = 36.2$ %). Mean weights increased from 0.19 g on 24 March to 0.22 g on 2 April.

3.2 Parr

3.2.1 Dispersal and densities

The total estimated population size in the study zone was 5005 parrs in June, 2502 in October and 1482 in February (Table 2). In mid June, parr had spread until 2400 m downstream from the redd (confluence with the Nivelle river, Fig. 1) and also 750 m upstream (Fig. 3). The majority (68.1 %) remained within the first 900 m downstream ; 87.7 % were found within 1600 m downstream, while a small proportion (3.7 %) settled upstream (Table 3).

In October, distribution of parr was quite similar : 60.4 % were within 900 m downstream from the redd, 89.4 % within 1600 m and 6 % upstream (Table 3). During winter, there were no major changes and in February, 55.7 % of the population were found within 900 m downstream from the redd, 84.2 % within 1600 m, and 11 % upstream.

Highest densities were observed in zones closest to the redd. Maximum densities per 100 m^2 were 114 parr in June, 38 in October and 20.3 in February. The increase in densities in the upstream zone (2.7 parr.100 m^{-2} in June and October, 3.7 individuals in February) indicated an active upstream movement of juvenile salmon during the winter period.

3.2.2 Growth and survival

The growth of the salmon population was fast (Table 4). Mean size after one year in the stream was 89.3 mm. Numbers of fish decreased regularly during the period (Fig. 4). Minimum survival from eyed eggs to yearling fish was 9.9 % (Table 2).

4 - DISCUSSION

After emergence at the end of March in the Lapitxuri, Atlantic salmon fry dispersed downstream over a short twelve days period. This is in agreement with the observations made in natural stream systems by Randall (1982), Hay (1989), Gustafson-Greenwood & Moring (1990). The spate that interrupted the trapping operations occurred at just the end of the first dispersal wave described by Beall & Marty (1989) and Marty & Beall (1989). This downstream movement, as indicated by the captures in traps placed at different distances from the redd, was rapid and not just progressive. Fry covered 40-50 m per night in the first hundred meters, and some travelled 300 m or more within the same night. Movement was also massive with an estimated 73 % of the surviving population settling within 200 m from the redd. In this early phase, amplitude of downstream colonisation did not appear to exceed 800 m. A similar result is reported by Hay (1989) on the Girnoch Burn. He observed fry movements 743 m downstream from an isolated redd, and an upstream colonisation of 166 m. We did not observe any upstream movement at this early stage in spite of the operation of a trap placed 10 m above the redd.

In order to estimate the number of fry settling in the sections between traps, we made the assumption of negligible mortalities during this period. This claim seemed to be supported by the pattern shown in Fig. 4 and by the size of the population estimated in June (over 5000). Some mortalities may have occurred during movement, but since dispersal was massive and very fast, and occurred mostly at night (Marty & Beall, 1987) predation must have been limited. Moreover, competition can be dismissed as a source of mortality at this stage because this dispersal occurred before the onset of territorial behaviour (Marty & Beall, 1989). The downstream moving fry were actively feeding and growing and not in a moribund state as the brown trout described by Elliott (1986) in Black Brows Beck.

Parr had distributed themselves 2.5 months after emergence 750 m upstream and 2400 m downstream from the emergence site. The majority was found within 1600 m downstream, with little changes during the first year. These observations are at variance with those of several authors who note a colonisation of. short amplitude. For Egglishaw & Shackley (1973, 1980), Kennedy (1988), Gustafson-Greenwood & Moring (1990), fry settle within 100 m downstream from the redd and no further than 400-600 m. Following the first two or three weeks after emergence, the fry are supposed to be very sedentary with a weak capacity for dispersal (Mc Crimmon, 1954 ; Saunders & Gee, 1964 ; Symons, 1969 ; Bulleid, 1973 ; Le Gault & Lalancette, 1987). However, Elson (1957) found that hatchery parr released at high densities could migrate up to 800 m upstream from the release site and 1600 m downstream. Some winter movements occurred upstream in our case, because densities observed in this zone increased between October and February, while they decreased in other sections. This may be related to upstream movement of parr during the spawning period.

Growth is usually rapid in our latitude. However, it was a little slower in the Lapitxuri than in the Nivelle proper (74 mm in October versus 86-94 mm, Dumas 1991). It is comparable to that found in Brittany by Bagliniere & Maisse (1989) on a small tributary of the Scorff.

Survival to emergence and early dispersal (62.5 %) or to yearling parr (9.9 %) falls within the range of high values cited by Bley & Moring (1988) for this species at similar stages. Survival during incubation to emergence was found to be much lower in the Nivelle River and quite comparable in an artificial stream located on the Lapitxuri River (Beall et al., 1991). These results can be attributed to the good quality of the spawning habitat in the Lapitxuri and in the artificial stream.

This experiment gives important information on the stocking procedure with eggs or fry at the end of yolk sac absorption. It shows that emerging fry possess a large dispersal capability, mostly downstream. Egg planting sites or fry release points can be spread every 300 or 400 m without risks of clumping and threats for subsequent survival. On the other hand, older, fed fry or young parr will have to be regularly distributed over the whole zone to be stocked, because they have a sedentary behaviour under normal conditions of density.

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Table 1 : Effective (N) and estimated (Ne) numbers and cumulated percentage (% cum) of fry captured in traps during the emergence and early dispersal period. q = Mean % of total flow passing in traps.

TRAPS	T1			T2			T3			T4			T5			T6			T7			T8		
q	3,37			3,97			4,77			3,38			4,49			4,95			5,32			5,00		
DATES	N	% cum	Ne	N	% cum	Ne	N	% cum	Ne	N	% cum	Ne	N	% cum	Ne	N	% cum	Ne	N	% cum	Ne	N	% cum	Ne
13/3	2	0.6	59	0	0.0		0	0.0		0	0.0		0	0.0		0	0.0		0	0.0		0		
14/3	0	0.6		0	0.0		0	0.0		0	0.0		0	0.0		0	0.0		0	0.0		0		
15/3	0	0.6		1	0.3	25	0	0.0		0	0.0		0	0.0		0	0.0		0	0.0		0		
16/3	1	0.9	30	0	0.3		0	0.0		0	0.0		0	0.0		0	0.0		0	0.0		0		
17/3	0	0.9		0	0.3		0	0.0		0	0.0		0	0.0		0	0.0		0	0.0		0		
18/3	0	0.9		0	0.3		1	0.3	21	0	0.0		2	1.8	45	0	0.0		0	0.0		0		
19/3	2	1.5	59	0	0.3		0	0.3		0	0.0		0	1.8		0	0.0		0	0.0		0		
20/3	0	1.5		0	0.3		1	0.6	21	1	0.9	30	0	1.8		0	0.0		0	0.0		0		
21/3	1	1.8	30	0	0.3		0	0.6		0	0.9		0	1.8		0	0.0		0	0.0		0		
22/3	2	2.4	59	0	0.3		1	0.9	21	0	0.9		0	1.8		0	0.0		0	0.0		0		
23/3	5	4.0	148	10	3.1	252	4	2.2	84	0	0.9		0	1.8		0	0.0		0	0.0		0		
24/3	20	10.4	594	14	7.0	352	17	7.6	356	5	5.2	148	2	3.6	45	0	0.0		0	0.0		0		
25/3	38	22.5	1128	23	13.4	579	16	12.6	335	4	8.6	118	5	8.0	111	1	3.0	20	2	10.5	38	0		
26/3	44	36.6	1306	37	23.8	931	17	18.0	356	14	20.6	414	8	15.1	178	2	9.1	40	0	10.5		0		
27/3	45	51.0	1335	37	34.2	931	28	26.8	587	4	24.0	118	6	20.4	134	0	9.1		0	10.5		0		
28/3	38	63.1	1128	65	52.4	1635	22	33.7	462	15	36.8	444	4	23.9	89	2	15.2	40	0	10.5		0		
29/3	39	75.6	1157	53	67.2	1333	69	55.5	1447	28	60.7	828	22	43.4	490	13	54.6	263	3	26.3	56	0		
30/3	27	84.2	801	42	79.0	1057	36	66.9	755	11	70.1	325	17	58.4	379	3	63.7	61	2	36.8	38	1	100.0	20
31/3	19	90.3	564	21	84.9	528	30	76.4	629	10	78.6	296	13	69.9	290	3	72.8	61	1	42.1	19	0	100.0	
1/4	12	94.1	356	28	92.7	704	36	87.8	755	12	88.9	355	22	89.4	490	3	81.9	61	4	63.2	75	0	100.0	
2/4	9	97.0	267	11	95.8	277	25	95.7	524	5	93.2	148	5	93.8	111	1	84.9	20	5	89.5	94	0	100.0	
3/4	3	98.0	89	7	97.8	176	11	99.2	231	8	100.0	237	7	100.0	156	5	100.0	101	2	100.0	38	0	100.0	
4/4	6	100.0	178	8	100.0	201	3	100.0	63	0	100.0		0	100.0			100.0		0	100.0		0	100.0	
Total	313		9288	357		8981	317		6646	117		3461	113		2517	33		667	19		357	1		20

Table 2 - Evolution of salmon survival (numbers and rates) from the eyed stage in the R. Lapitxuri.

Date	Stage	Numbers	Survival (%)	Survival from preceding stage (%)
02/15/1989	Eyed egg	15,000	100	
04/04/1989	Fry	9,368	62.5	62.5
06/14/1989	Fingerling	5,005	33.4	53.3
10/10/1989	Fall parr	2,505	16.7	50.0
02/02/1990	Yearling	1,482	9.9	59.2

Table 3 - Numbers and percentages of salmon juveniles found at different distances from the redd in the R. Lapitxuri.

Date	Distance from redd (m)	06/14/1989		10/10/1989		02/28/1989	
		N	%	N	%	N	%
Upstream	0 - 50	94	1.9	57	2.3	36	2.4
	50 - 150	91	1.8	92	3.7	128	8.6
Downstream	0 - 300	1602	32.0	472	18.9	271	18.8
	300 - 900	1805	36.1	1038	41.5	554	37.4
	900 - 1600	981	19.6	725	29.0	422	28.5
	1600 - 2400	432	8.6	118	4.7	71	4.8

Table 4 - Linear growth of juvenile salmon at different times of year in the R. Lapitxuri, a brook not colonized by the species.

Date	Number measured	Fork length (mm)	Standard deviation
4 april 1989	148	28.1	1.2
14 june 1989	1,121	50.5	14.5
10 october 1989	366	74.1	13.6
28 february 1990	211	89.3	15.0

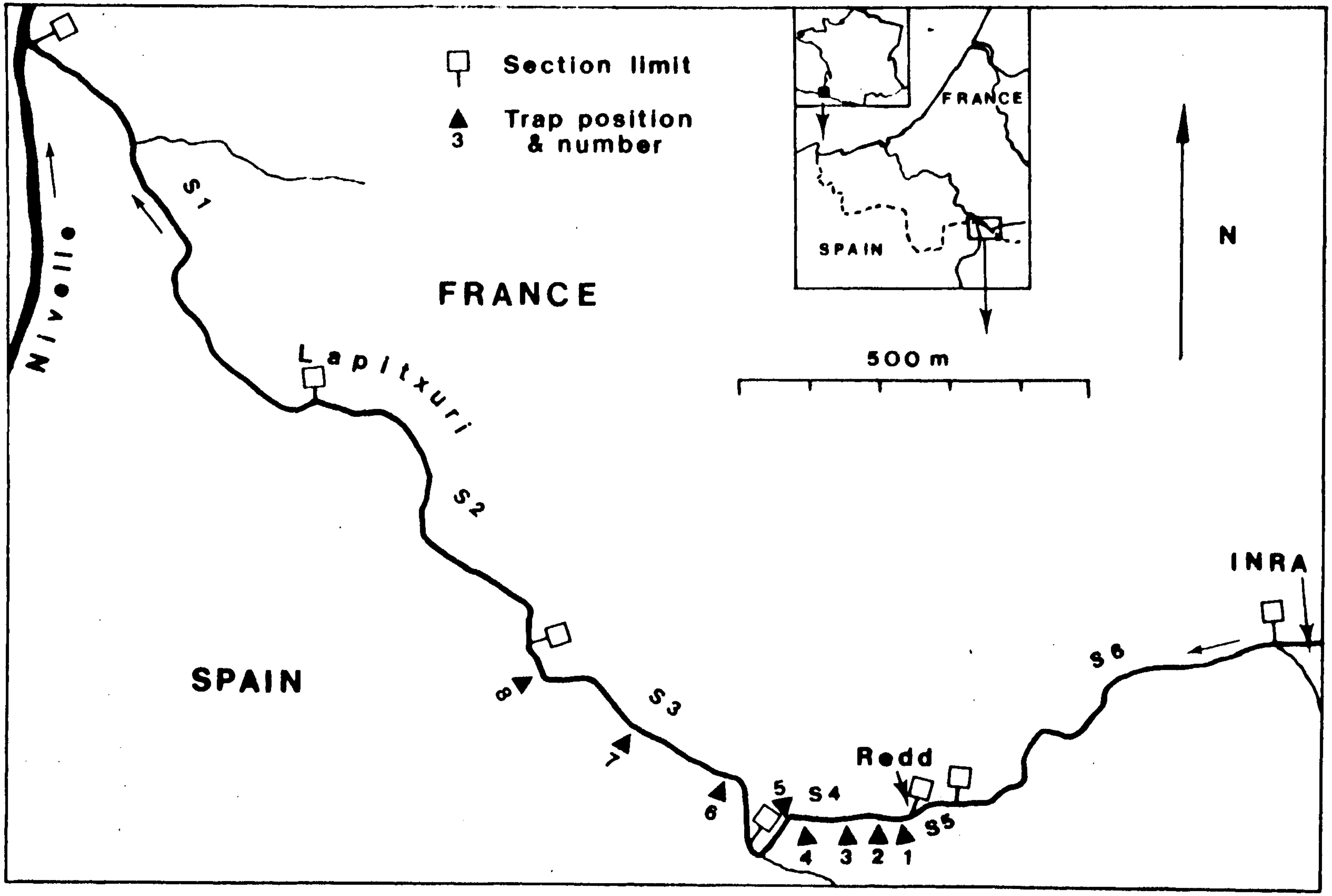

Figure 1 - Situation of the study site in the Lapitxuri brook, tributary of the Nivelle River in S.W. France. Positions of the traps and limits of sections used for electrofishing inventories are also indicated.

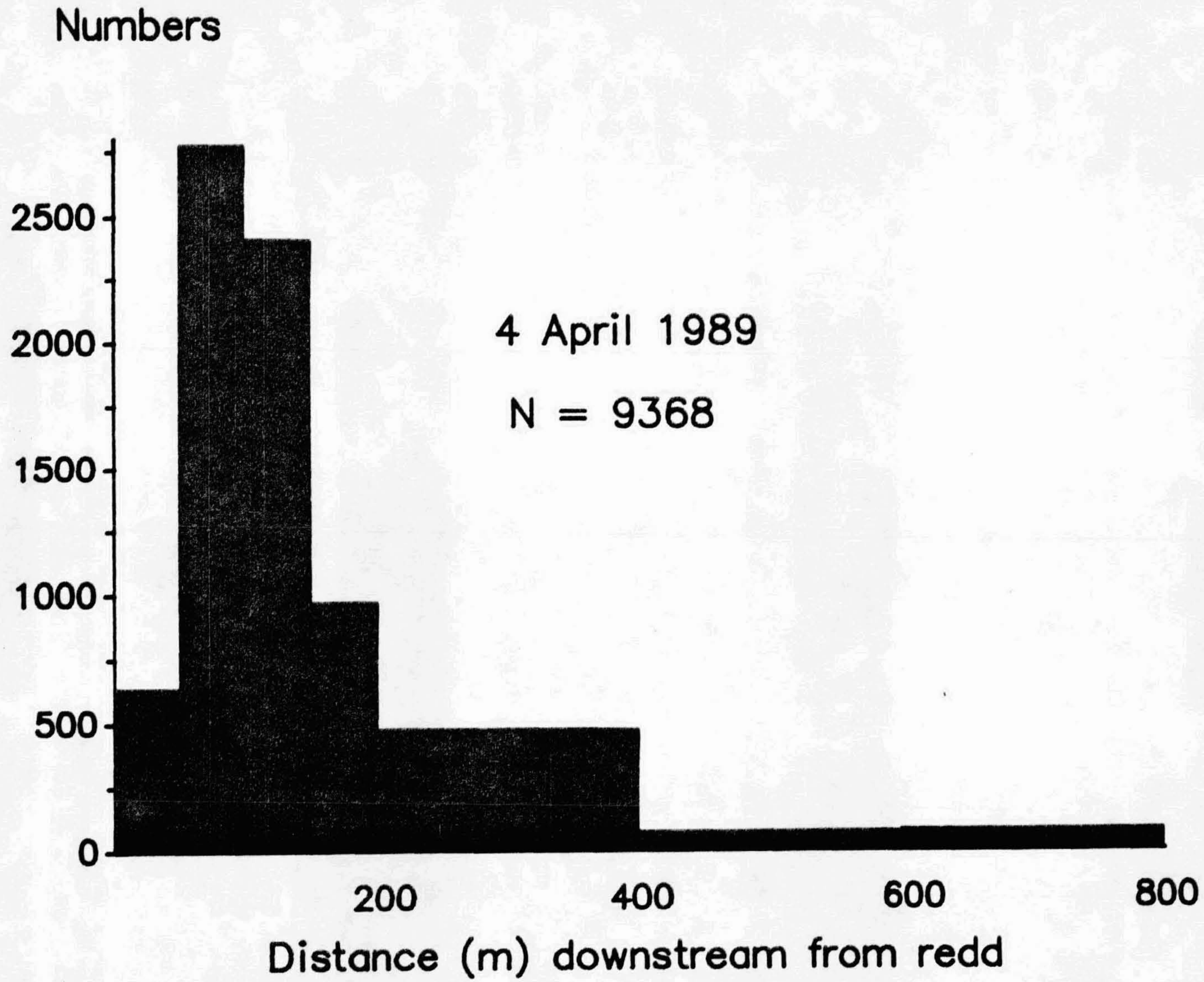

Figure 2 - Distribution of Atlantic salmon fry on 4 April 1989, downstream from an artificial redd in the Lapitxuri brook, as estimated from captures in trap nets.

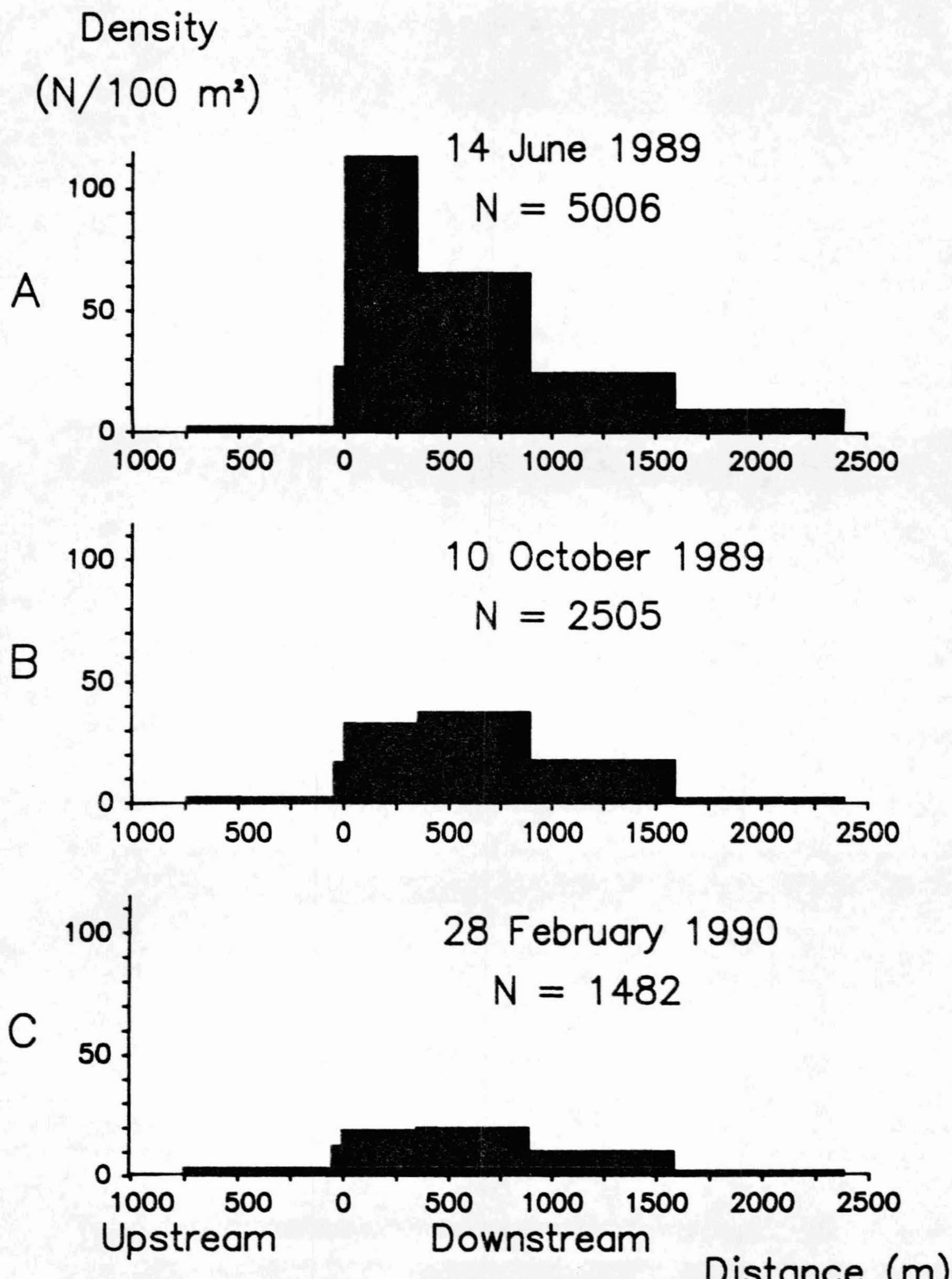

Figure 3 - Distribution of parr densities upstream and downstream from an artificial redd in the Lapitxuri brook, as estimated from electrofishing inventories in June and October 1989 and February 1990.

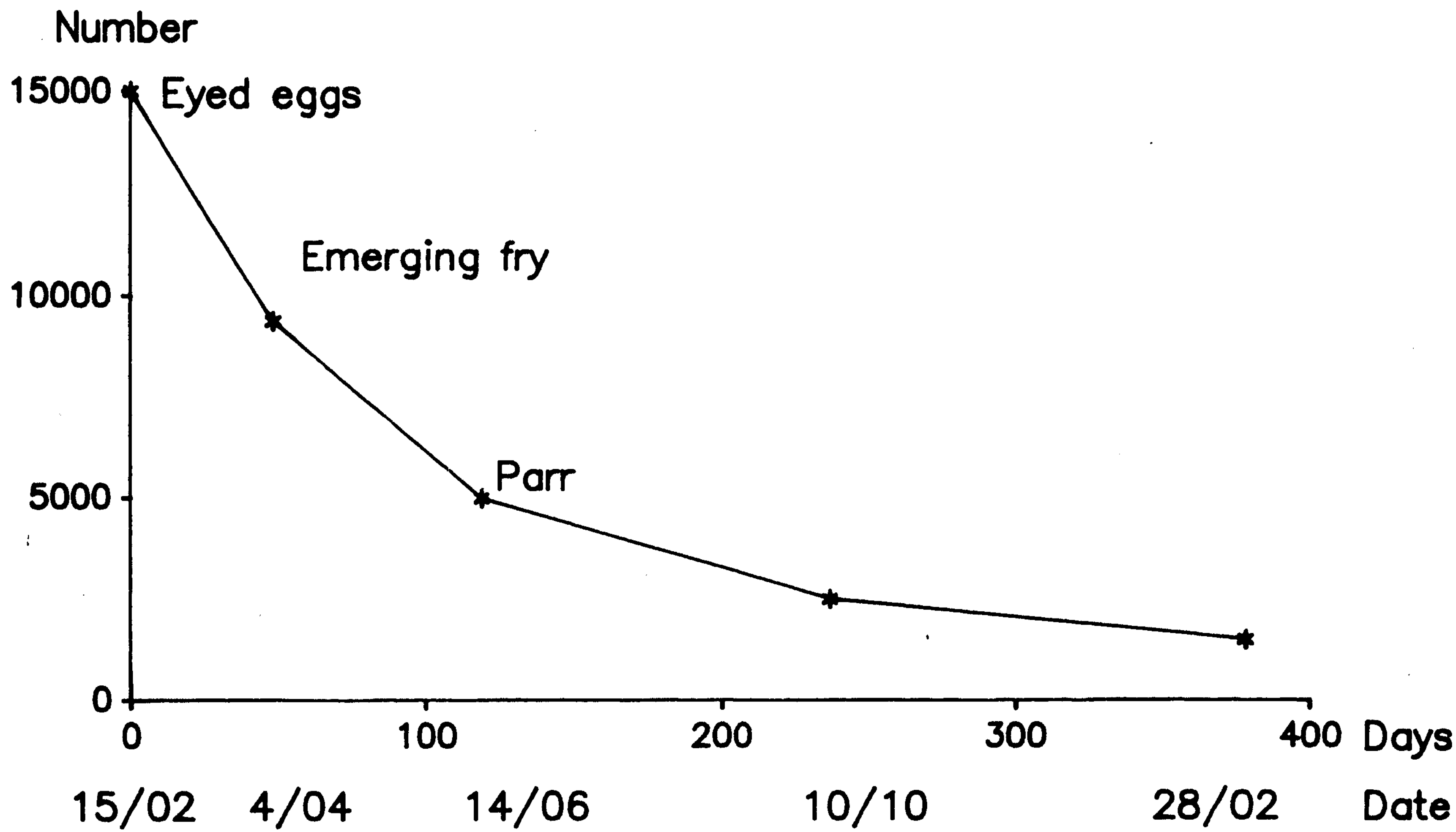

Figure 4 - Evolution of numbers of Atlantic salmon juveniles in the Lapitxuri brook, from eyed egg to yearling parr.