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Downstream migration evolution of juvenile European sturgeon *Acipenser sturio* L. in the Gironde estuary

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The European sturgeon *(Acipenser sturio)* is a diadromous species that spawns in the rivers in late spring and early summer. The juveniles then spend around two years in the brackish waters (5 to 25 PSU) of the estuary zone before moving out to sea. This study describes the downstream migration evolution from October 1994 to August 1996 of juvenile sturgeon, born in the Gironde basin in the summer of 1994. For the purposes of the study, the inland section of the Gironde estuary was sampled by trawl monthly. The trawls - average duration 32 minutes, average length approx. 4 200 m - were conducted according to a sampling plan, stratified into 13 major zones from the oligohaline (0.5 to 5 PSU) to the polyhaline sectors (18 to 30 PSU) of the estuary. The study shows that the first members of the 1994 cohort (TL=27 cm) were caught in early March 1995 in the zones furthest upstream. A distinction appears between an initial period, in which the fish live mainly in the upstream zones of the marine estuary, and a second, starting from their second growth period (April 1996), in which the juveniles are split into two separate areas about twenty kilometres apart. The two zones are situated 18 km and 38 km respectively from the mouth of the estuary and they do not appear to be any different to their neighbours as regards to depth and type of bed. There is no significant biometric difference (length, weight) between the juveniles of the two zones. However, individual marking has helped to highlight exchanges of animals between the two sectors. The study shows that, within this large estuary of relatively homogeneous depth (4 to 10 m) and type of substrate (sand/mud, gravel), the juveniles inhabited two quite distinct zones in 1996 before they left the estuary for the sea.

Keywords : *Acipenser sturio*, downstream migration, estuary, habitat, juvenile

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Introduction

This work forms part of the European recovery programme for the common sturgeon, *Acipenser sturio L.* This species is considered in France as endangered and has been fully protected since 1982 (Lepage et Rochard 1995). At present, the common sturgeon is known to reproduce, for certain, only in the Gironde-Garonne-Dordogne river basin, France, in late spring and early summer. The Gironde estuary is the obligatory route for the juveniles between the river zone where they are born and the open sea where they spend most of their life. In its sea phase, this diadromous species occurs over a wide range; the Gironde population can be found from the Bay of Biscay to Scandinavia (Rochard et *al.* 1997).

The spatial distribution of the young sturgeon in the Gironde estuary has been known in general terms since the work of Magnin (1962). He noted seasonal migration by the juveniles from the ocean to the estuary, between late June and the end of September. Castelnaud and Trouvery (1984), after the 1982 fishing ban, distinguished fish less than three years old as never having been out to sea and fish more than three years old as already being out at sea. They showed that there were fish from one to more than three years old in the estuary in early May. Rochard (1992) presented a pattern of downstream migration for one cohort of young juvenile sturgeon over a period of two years. He used a salinity gradient to split the estuary into two reaches, from 0.5 to 5 PSU and from 5 to 30 PSU, and defined three stages of behaviour through the seasons.

In 1994, natural reproduction took place in the Garonne-Dordogne river system, five years after the previous one. The aims of the study were to draw a map of the distribution of young European sturgeon in the Gironde estuary, to characterize their concentration areas and to analyse their estuarine movement patterns in order to build a spatial model before their first journey to sea.

In the first instance, the results should be used as a basis to propose regulatory measures on gravel extraction and dredging activities, based on knowledge of the spatial distribution of young sturgeon in the estuary. Later on, they will be used to evaluate the possibility for young *A. sturio* to live in other European estuaries. This will be of importance for future European restoration programmes.

Material and Methods

Study area

The study was conducted in the lower part of the Gironde estuary in South West France. The Gironde estuary, formed by the Garonne and Dordogne rivers, is the estuary in Western Europe. It drains 71 000 km^2 of basin with a flow of about 1 000 $m^3 \cdot s^{-1}$ (Allen 1972). The study area was about 45 km long, divided into 10 main zones (n° 1 to 10) and three supplementary zones (n° 11, 12 and 15) (Figure 1), from the

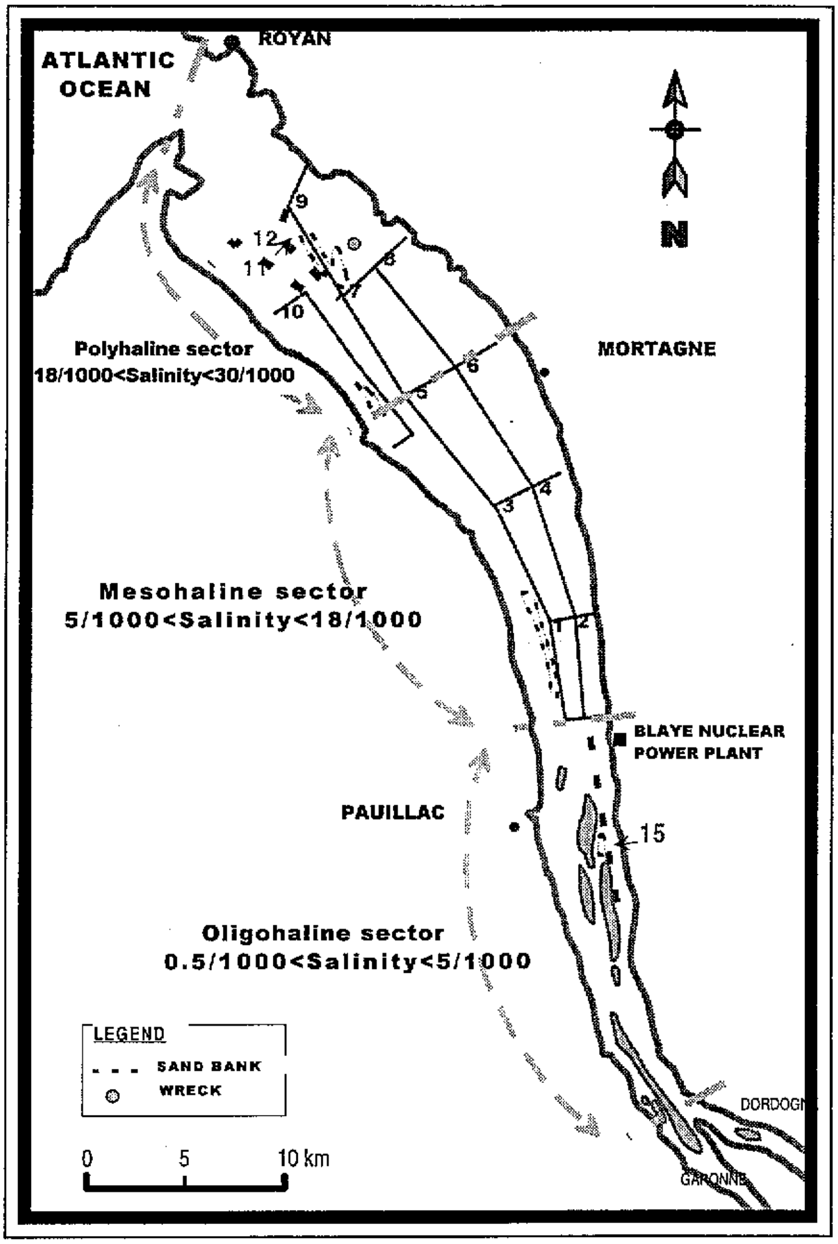

Figure 1 : Study area in the Gironde estuary in France. Main sampling zones are delimited by unbroken lines and supplementary zones by dotted lines.

oligohaline (0.5 to 5 PSU) to the polyhaline sectors (18 to 30 PSU), covering 75% of the trawlable estuary surface. Water depth ranges from 3 m close to the shelf in the upper zones to 26 m in a deep of zone 9. The bottom of the estuary is mainly a mixture of sand and mud, with the sandiest part in the lower sectors and the muddiest part in the upper sectors.

Sampling method and equipment

Samples were taken over a period of 23 months from October 1994 to August 1996. For easier processing, the data were grouped seasonally. A 12 m long catamaran-type trawling research ship was used to capture the juvenile sturgeons. A differential GPS for accurate positioning (± 5 m) and an inboard computer with Max Sea ® software for positioning on a map were used to collect and store the data during the experiment. The fishing gear was a bottom trawl, 13 m wide and 3.5 m in height with a cod end stretch mesh of 70 mm. Trawls were conducted during the day according to a sampling plan stratified into zones and tidal cycle, and repeated monthly in a uniform manner. The tow duration was approximately 30 min, at an average speed of 4.5 knots for trawls with the current and 1.5 knot against it. The speed is given by the GPS with an accuracy of 0.1 knot. According to the benthic habits of this species, the use of a surface unit of effort was chosen (CPUE = n.10 000 m^{-2}). Sampling surface is the product of the bottom trawl width and the tow length.

Sturgeon treatment

The sturgeon caught were handled carefully, mostly in a fish-tank supplied with air or pure oxygen. Their total and fork length were measured to the nearest centimetre, they were weight with a precision of 50 g and tagged with a specially designed sturgeon tag (Castelnaud *et al.*, 1991). For calculating age, a thin slice of the first pectoral fin ray was removed from the live fish. Afterwards, each fish was put back into the estuary. We used the recovery of tagged sturgeon to highlight movement between zones. For each sturgeon capture, a sample of bottom water was taken with a sampling bottle, for temperature and salinity control. All the other fish were identified and measured in order to point out a possible fish assemblage that might accompany the juvenile sturgeon during their estuarine stay.

We focused our attention on the 1994 cohort in the lower part of the Garonne-Dordogne system.

Statistical analysis was produced with the software SYSTAT 5.0; non parametric U-test from Mann and Whitney and H-test from Kruskal-Wallis were used.

Results

Sampling activity

Over the period of the experiment, 553 trawls were conducted for a total of 317 hours of fishing in the 10 main zones; 76 more trawls were performed in the three complementary zones, representing 41 hours of fishing. The trawls features are reported in Table 1. The mean surface sampled in the main zones was approximately 50 000 m^2 and 40 000 m^2 in the three others. The mean distance covered by a trawl is slightly over 4 200 m long at a mean depth of 8.5 m, which is the depth found in the estuary at mid-tide. All the trawls were done between 9h00 and 23h00. Fishing effort was similar during the flow and the ebb (p=0.275) as well as the heading direction of fishing upstream or downstream (p=0.136). Seasonal effort is reported in Table 2.

Table 1 : Main characteristics of trawls

	Min.	Max.	Mean	σ
Main zones (n= 553)				
Duration	12'	80'	34'	8' 79"
Tide coefficient	31	96	57	
Depth (m)	4.5	30.5	8.5	3.0 m
Surface sampled (m^2)	16 360	130 000	48 000	18 968
Distance covered (m)	1 300	11 082	4 233	1 418
Supplementary zones (n = 76)				
Duration	15'	61'	32'	7' 43"
Tide coefficient	31	96	58	
Depth (m)	6.0	12.5	9.0	1.7
Surface sampled (m^2)	2 295	71 500	41 415	13 411
Distance covered (m)	1 300	5 500	3 327	929

Table 2 : Distribution of the fishing effort by season

	Number of trawls	Fishing time	Surface in 10^4 m^2
Main zones (n= 553)			
Spring	178	102 h 48'	900.7
Summer	112	67 h 42'	604.4
Autumn	140	79 h 45'	577.9
Winter	123	67 h 12'	571.3
Supplementary zones (n= 76)			
Spring	35	17 h 25'	92.0
Summer	5	2 h 39'	21.1
Autumn	14	8 h 12'	61.4
Winter	22	12 h 31'	140.2

Of a total of 629 trawls, 98 were successful, cumulating 374 captures of 296 individuals. In fact, some fish were captured up to three times over the period of study, so the number of individuals is smaller than the number of captures. The global CPUE are 0.59 sturgeon per trawl. Differences are seen in Table 3, reporting the CPUE by season, as well as in Table 4, reporting this variable by zones. CPUE are maximal during spring and summer time and minimal during autumn. Two zones (1 and 7) show CPUE values 10 times higher than the others.

Table 3: Seasonal distribution of captures (C) and CPUE (in numbers of sturgeons per trawl conducted)

	C	CPUE
Main zones		
Spring	145	0.81
Summer	93	0.83
Autumn	34	0.24
Winter	78	0.63
Supplementary zones		
Spring	9	0.25
Summer	0	-
Autumn	0	-
Winter	15	0.68

Table 4 : Distribution of CPUE by zone and percentage of effective trawl by zone

Zones	C	CPUE (N/10 000 m²)	% of effective trawls
1	122	0.472	42.5
2	10	0.049	15.9
3	2	0.011	6.25
4	2	0.007	4.25
5	7	0.030	6.77
6	7	0.022	6.77
7	167	0.494	36.11
8	6	0.016	6.33
9	23	0.070	11.84
10	4	0.020	9.52
11	0	-	0
12	0	-	0
15	24	0.118	25.00
Whole	374	0.126	15.58

Temperature and salinity conditions were recorded on each sturgeon capture and temperatures ranged from 6.5 °C in the wintertime to 25° in July and August. Salinity varied from 0 to 25.5 PSU depending on high or low tide, the upstream or downstream position of the capture and the season of capture (table 5).

Table 5: Mean temperature and salinity measured at the end of effective trawls

	Salinity (PSU)				T (°C)			
main zones	mean	σ	min	max	mean	σ	min	max
1	9.2	2.9	2.5	13.3	20.2	3.2	8.0	25.0
2	5.8	3.5	2.0	10.5	12.8	5.5	6.0	24.0
3	4.0		4.0	4.0	6.5		6.5	6.5
4	10.1	6.5	5.0	21.5	9.5	4.5	7.5	17.5
5	10.3	1.3	8.7	12.0	13.6	2.3	12.5	17.0
6	15.0		15.0	15.0	8.0		8.0	8.0
7	11.2	5.5	4.0	25.5	15.2	4.6	7.0	23.2
8	12.5	6.8	7.0	21.0	13.5	3.7	11.0	19.0
9	12.7	7.3	4.5	25.0	12.8	5.0	7.0	23.0
10	15.0		15.0	15.0	10.0		10.0	10.0
15	0.5	0.7	0	2.0	12.0	0	12.0	12.0

Sturgeon capture features

Most of the individuals captured came from the 1994 cohort, which was born in the upstream rivers in late fall or early summer 1994 and migrated towards the estuary to arrive in March 1995. The first capture of sturgeon of the 1994 cohort (TL=27 cm) took place in early March 1995 in the furthest zones upstream. From that point until August 1996, mean length and weight increased regularly. Length doubled in 18 months, rising from 31.3 cm to 62.6 cm. For each sampling period, ranges of length and weight data are wide, indicating a highly variable growth rate in the same year class (Table 6).

Table 6 : Change in total length and weight of sturgeon trawled in the Gironde estuary between winter 1995 and summer 1996

	Mean	Min.	Max.	σ
Length (cm)				
winter 1995	31.3	26	42	4.3
spring 1995	35.7	25	43	5.6
summer 1995	48.3	42	55	5.5
autumn 1995	55.7	48	66	4.3
winter 1996	56.3	46	64	3.7
spring 1996	58.7	44	68	3.6
summer 1996	62.6	55	69	3.3
Weight (g)				
winter 1995				
spring 1995		not weighed		
summer 1995				
autumn 1995	713.5	450	1300	189.0
winter 1996	783.6	350	1100	157.0
spring 1996	880.7	400	1320	147.1
summer 1996	1107.0	710	1600	207.3

We found no significant differences in length or weight between the juveniles caught in zones 1 and 7 for the same period (Table 7).

Table 7 : Seasonal change in total length (cm) of sturgeon in zones 1 and 7

ZONE	SEASON	Mean	Min.	Max.	σ
1	Summer 1995	53.0	53	53	-
	Autumn 1995	50.7	48	53	1.97
	Winter 1996	55.0	55	55	-
	Spring 1996	58.2	44	65	3.90
	Summer 1996	62.6	55	69	3.01
7	Summer 1995	55.0	55	55	-
	Autumn 1995	57.5	50	66	4.43
	Winter 1996	56.0	46	64	4.54
	Spring 1996	59.1	49	68	3.22
	Summer 1996	62.0	56	69	3.95

Change over time

From October 1994 to February 1995, no juvenile sturgeon were captured in the trawling samples. The first juvenile arrived in the upper part of the estuary (zone 2 and 15) in the second week of March 1995. One more capture occurred in zone 5, around 10 km downstream. The mean water temperature of the estuary for March in these sectors was 10.1°C, while the mean water temperature of the Dordogne and Garonne rivers were respectively 8.5 and 9.7°C (Table 8). At that time of year, only a few sturgeon were already in the estuary and they mostly stayed in the upper part.

In spring 1995 sturgeon seemed to move upstream; they were detected only in zone 15. This also corresponds to the period of the year when they start to grow again after the winter interruption.

Table 8 : Water temperature (°C) in the Gironde estuary and in the Garonne and Dordogne rivers for the first half year of 1995

	Jan	Feb	Mar	Apr	May	Jun	Jul
Gironde Estuary	7.7	9.6	10.1	13.7	17.7	20.6	24.8
Dordogne River	7.1	8.2	8.5	11.8	15.8	20.5	25.9
Garonne River	6.5	9.3	9.7	13.2	16.3	19.3	25.3

In summer 1995, sturgeon were only detected a few kilometres further downstream in zone 1. It is supposed that most of the fish were still upstream and only a small proportion had started to move downstream. This coincides with the movement of several Gironde estuary populations such as the white shrimp (*Palaemon longirostris*), which is a potential prey for sturgeon (Aurousseau, 1984).

In autumn 1995, many sturgeon were found for the first time in zone 7. From this time onwards, it was considered that the population of juveniles splited into two preferential zones. This situation was to last for the rest of the survey. It also shows for certain the juveniles' osmoregulation capability, at least up to 25 PSU.

In winter 1995-1996, sturgeon were concentrated in the lower part of the estuary. This coincides with the downstream movement of the white shrimp. As in winter 1994-1995, this behaviour was interpreted as a flight from colder zones. During winter 1995-1996, according to incidental capture in sea (Lepage and Rochard, unpublished data) sturgeon had gained the ability to live in seawater and some of them left the estuary to reach the Atlantic Ocean.

In spring and summer 1996, some fish moved upstream from zone 7 and came to join the group in zone 1 as probably did some other sturgeon coming from upper areas. That resulted in an increase of abundance in the upper part.

Discussion

Sampling fish in large areas like estuaries is sometimes complicated. Trawling, already used to sample sturgeon in other rivers and estuaries (Mac Cabe *et al.*, 1993, Mac Cabe and Tracy 1994, Hasting *et al.*, 1987), appears to be efficient for juvenile *A. sturio* and enabled us to prospect the major part of the estuary. For technical reasons, some estuary habitats, like the navigation channel, were not sampled and it cannot be excluded that the sturgeon colonize these habitats as well as the study area.

The arrival of the yearlings in the upper estuary, where the salinity was close to zero before the end of winter 1995, is interpreted as a behaviour to avoid the colder temperature of the rivers. A similar pattern of movement is observed for juvenile *Acipenser oxyrinchus*. Many authors have found that young sturgeon move downstream for overwintering and upstream as the water temperature increases from spring time through to early summer (Dovel 1979, Lazzari *et al.* 1986, Bain 1997).

During spring 1995, commercial fishermen made incidental captures of young sturgeon (TL 25-40 cm) in their shrimp nets in the upper part of the estuary. They did not catch any sturgeon before the end of March. This strengthens the idea that, in 1995, the young juveniles did not arrive in the estuary before March.

Even if water temperature activates downstream migration, salinity seems to act as a limiting factor. During their first winter, young sturgeon were 6 to 9 months old and used only the upper part of the estuary. They probably did not yet have their osmoregulation capability and were not physically ready to move further downstream. We observed a progressive acclimatization to salt water and downstream movement during the first 18 months. Young sturgeon, born the previous summer, use that one and a half year period to acquire the ability to osmoregulate.

From the autumn of 1995 to the next summer, we observed considerable movements of some tagged individuals between polyhaline sectors (zone 7, 8 and 9) and mesohaline sector (zone 1) in both directions (Lepage and Rochard, unpublished data). During that period, the 1994 cohort revealed a preference for two zones (1 and 7). These zones are located downstream or upstream of sandbanks, 18 km and 38 km respectively from the mouth of the estuary and almost equidistant from the river bank. They do not appear to be any different from other zones nearby with regard to depth and type of bed. One (zone 1) is located in a low salinity sector (5 to 12 PSU) while the other (zone 7) is located in a higher salinity sector (18 to 25 PSU) (Figure 1). We hypothesize that the discriminating factor for the sturgeon presence could be the existence of sheltered areas. Zone 1 is somehow sheltered by the "Banc des Marguerites" and zone 7 is sheltered by the "Banc de St-Louis" and the "Banc de St-Estèphe" (Figure 1). Movement from one zone to the other probably depends on their osmoregulation capability. Samples of benthic organisms and sturgeon stomach contents (using non traumatizing methods) should be taken in order to better explain sturgeon concentration in these zones.

Conclusion

Young European sturgeon born the previous summer arrive in the Gironde estuary during their first winter (probably by the end of winter in 1995). They stay in the upper part of the estuary during the colder period and move upstream as the water temperature increases. From their second summer, juveniles progressively settle in the whole estuary giving preference to two sectors sheltered from the current. During their second winter, some stay in the lower part of the estuary and some head for the sea. From their second spring, they move upstream like most of the other juveniles of the estuarine population.

The movement pattern of the 1994 cohort adds new elements to our knowledge of the ecology of the species. To assess the variability of this pattern we are continuing the survey with this cohort and, also, with stocked sturgeon born in 1995 in our research station.

The two areas (zones 1 and 7) used preferentially by young sturgeons during their initial stay in the estuary need monitoring and careful management. These results enable us to recommend particular care for these zones which constitute essential habitats for this endangered species. We are using these arguments against a project to extract gravel from the estuary bed near the sensitive zones.

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