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Juvenile sturgeon (*Acipenser sturio*) habitat utilization in the Gironde estuary as determined by acoustic telemetry

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Abstract

A congregation area for young European sturgeon *Acipenser sturio*, an endangered species, was found in the Gironde estuary using acoustic telemetry. Between May and August 1999, sixteen young sturgeons, aged 4 to 5 years (total length: 82-122 cm, weight: 2.35-8.10 kg) were captured by trawling and tagged with a coded ultrasonic transmitter. Manual tracking was conducted 2 to 3 days a week until November 1999. Sturgeon movements were observed over periods of six hours, both during day or night. No significant behavioral differences in terms of swimming speed were observed between daytime and night-time. Most of the movements observed, occurred in the same direction than the tidal current, and their velocity was often slower than the flow. Only a few lateral movements were observed, and young sturgeons tended to congregate in an area located in the middle of the estuary, where the average depth is 7 m. The congregation area, obtained using the minimum convex polygon, represented a total surface of 32.6 km^2, but the Dirichlet tesselation with 95% of all positions showing a site fidelity, gave an area with a surface of 19.4 km^2. The use of a restricted portion of the estuary might be due to the very low number of individuals in the sturgeon population, but could also be due to the spatial distribution of polychetes worms, their favorite prey.

Introduction

The European sturgeon *Acipenser sturio* is one of the nine diadromous sturgeon species in the world (Rochard *et al*., 2001; Birstein, 1993). The species has already been extirpated from a large part of its former distribution area. The last zone where a population is still present, though scattered, and where individuals complete their life cycle is located in France (Lepage and Rochard, 1995; Williot *et al*., 1997). European sturgeons migrate along the Atlantic coast of Europe from the Bay of Biscay to the Bristol Channel and the North Sea (Rochard *et al*., 1997). It has been listed as an endangered species in France since 1982, and is now protected by national and international conventions (Lepage and Rochard, 1995; Pustelnik and Guerri, 2000), over all its current distribution area. In order to protect the species efficiently, knowledge on essential spawning and feeding habitats needs to be increased. The last known reproduction areas for the European sturgeon are in France: in the Garonne and Dordogne rivers (Castelnaud *et al*., 1991; Williot *et al*., 1997). A recent survey established that near 27 suitable spawning grounds were still available (Jego *et al*., 2002), but the feeding habitat remains poorly investigated (Brosse *et al*., 2000a). Before reaching the Atlantic Ocean, the young spend several months in the Gironde estuary (Magnin, 1959; Castelnaud *et al*., 1991). After a period of early acclimatization of 15 months, juvenile European sturgeons appear to be highly tolerant to salinity variations (Rochard *et al*., 2001). From 1995 to 1997, trawling surveys were conducted in the Gironde estuary to identify the estuarine habitat of the juveniles. Two areas of concentration were identified, and movements between these two areas occurred frequently.

This study aimed to identify the movements of the juveniles in the Gironde estuary and in particular the influence of tidal and nycthemeral cycles on their behaviour. The congregation area is described in terms of trophic habitat. A second objective was to control the presence of juvenile sturgeon in sectors which could not be sampled by trawling.

Materials and methods

Study area

The study area is the Gironde estuary in the southwest of France (Fig. 1). This estuary is the widest in Europe (635 km^2 of surface at high tide in the marine estuary). It drains 81,000 km^2, with a mean flow of about 1,000 m^{3}s^{-1} (Allen, 1972). Maximum width is 11 km. Mean depth is about 8 m at mid-tide. There are two navigation channels, a natural one on the right side, with depths ranging from 4 to 20 meters and an artificial one on the left side, with a depth ranging from 7 to 30 meters. Several islands lay between these channels, in the upper part and on sandy-muddy banks in the lower part. The bottom of the estuary is mainly a mixture of sand and mud with the sandiest part in the lower estuary and the muddiest part in the upper estuary. There are two ebb and two flood tides each day, lasting about 6.2 hours. The tidal range is approximately 5 meters. The salinity follows a gradient according to the strength of the tide and the river flow, it varies from 0 to 30 ppt from where the Garonne and Dordogne rivers meet to the mouth of the estuary. In the muddiest part of the estuary, the turbidity can be as high as 1 gl^{-1} near the surface and up to 50 gl^{-1} over the bottom in the maximum turbidity area (Latouche et and Jouanneau, 1994). This area, changing with the tide, can spread on 20 to 60 km, depending on the river outflow and the neap or spring tide (Sottolichio, 1999). The water temperature in the estuary ranges between 6 °C in January to 26 °C in July (Maurice, 1994).

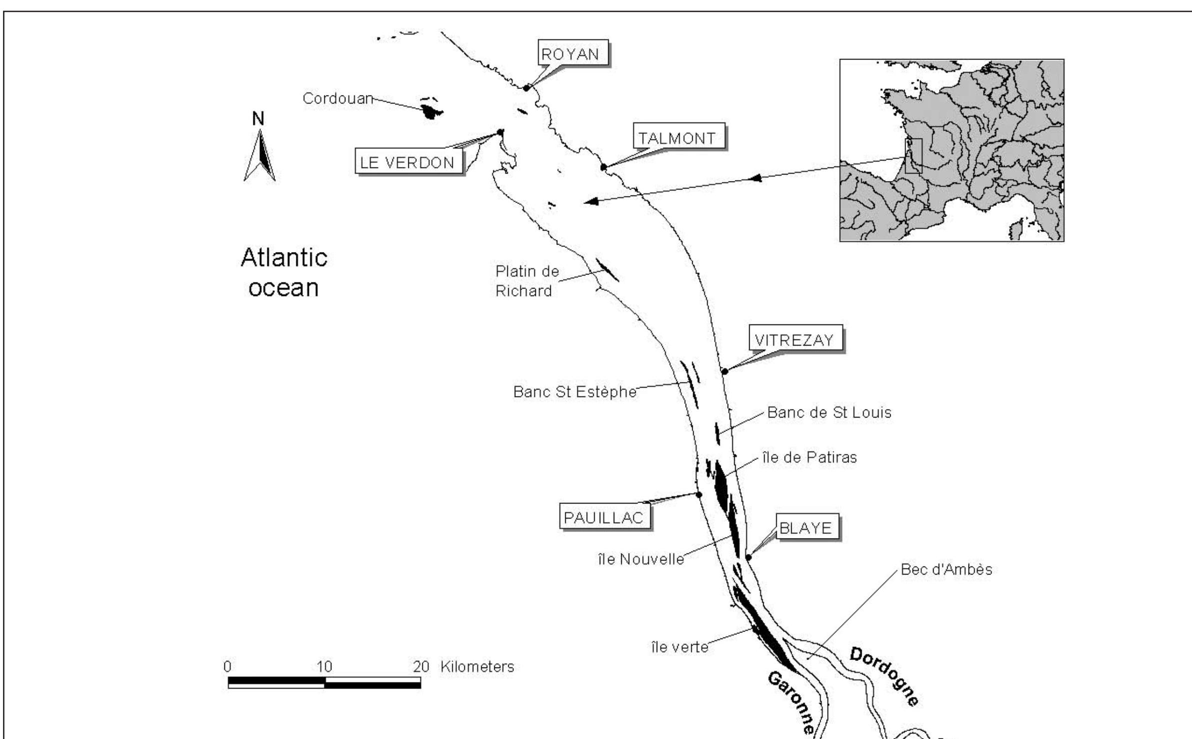

Fig. 1 – Gironde estuary

Capture and tagging

The juvenile sturgeons were captured during trawling surveys between May and August 1999 with a 12 m trawling boat. The duration of the tows was limited to approximately 30 minutes in order to catch live fish in good condition. When a juvenile sturgeon was captured, total length (TL) to the nearest centimeter below and the total weight (TW) to the nearest 50 g below were measured.

Sixteen juveniles were equipped with ultrasonic coded transmitter (model, CAFT 16-1 from Lotek) working on a frequency of 65.5 kHz. The fish weight ranged from 2.35 to 8.10 kg (mean ± s.d. 4.67 ± 1.46) and the fish length ranged from 82 to 122 cm TL (mean ± s.d. 99 ± 10.29). The weight of the tag never exceeded 1.06% of the fish weight. The lifetime of the tag was 225 days. Tracking was carried out over a period that did not exceed 167 days (Table 1).

The tags were attached externally at the base of the dorsal fin with a U shape stainless steel wire, generally used to make a spring, so that it kept the form we gave to it. A plastic cylinder was added on the free side of the wire before it was inserted into the muscle, through the base of the dorsal fin. We used a plastic cylinder instead of the plastic plate supplied by Lotek, since the round shape of the plastic cylinder prevented the wound caused by the cutting edge of the plastic plate. The fish were handled mostly in a tank with an air diffuser during tagging operations. Tagging did not last more than 3 minutes and most of the time less than 2 minutes with an experimented operator.

Table 1 – Capture and tagging histories for *Acipenser sturio* tracked between June and November 1999 in the Gironde estuary.

Fish number	Total length (cm)	Total Weight (kg)	Date of capture	Number of days at risk	Number of times located	Total time of tracking (h : mm)
71	96	3.30	27.5.1999	140	6	28:07
134	101	5.00	8.6.1999	127	6	25:04
121	122	8.10	8.6.1999	48	1	00:05
143	91	4.00	8.6.1999	-	0	00:00
115	95	4.30	8.6.1999	167	5	04:05
163	95	4.40	21.6.1999	155	8	29:25
142	100	4.70	21.6.1999	64	8	30:07
138	95	4.10	21.6.1999	64	5	16:08
109	106	5.10	22.6.1999	114	10	26:42
139	85	2.90	22.6.1999	153	12	21:16
74	100	5.30	21.7.1999	124	5	05:22
150	111	6.00	21.7.1999	124	7	11:25
165	114	7.00	21.7.1999	118	0	00:00
151	82	2.35	21.7.1999	-	0	00:00
168	97	4.30	21.7.1999	115	4	22:02
153	94	3.85	17.8.1999	-	0	00:00

Monitoring

The receiver used was the model SRX-400 (Lotek Marine Technologies Inc.) linked to an ultrasonic converter, that transforms the high frequency (HF) signal (65.5 kHz) to ultra high frequency (UHF)

(150.065 MHz). Then an omni directional hydrophone was fitted with a baffle in order to make it directional on 180 °. A 5 m boat powered with a 70 HP outboard engine was used for tracking, and the surveys were only carried out when weather conditions were good and safe for the people and equipment.

As the Gironde estuary is very large (11 km at the widest part) and the distance for signal detection was more or less 500 m with the engine stopped, we had to use a research grid traced on a marine map of the estuary in order to explore the whole estuary with its lateral sub tidal mud flat, navigation channels and sand banks. At each localization, the engine was stopped in order to minimize extraneous noises. The position of the fish was recorded using differential global positioning system (DGPS) with an accuracy of 2 m. The maximum distance determined for signal detection was 800 m, and for decoding 250 m; however these distances were reduced when turbidity was high. We avoided tracking fish on spring tide because of the high turbidity and because the high speed of the current resulted in a more difficult positioning. The implemented strategy was to monitor individual fish over a complete tidal cycle (flood-ebb). Part of the monitoring was performed so as to observe whether behaviours differed between daytime and night-time in terms of swimming speed. In order to obtain a good image of young sturgeon behaviour, we attempted to monitor a new fish for each survey. When tracking a fish during a complete tidal cycle, as many fish as possible were spot positioned without leaving the main tracked fish . Several tests were carried out to establish a relationship between the real distance and the signal strength obtained by the receiver. The variability of turbidity in the Gironde estuary prevented us from establishing any operational relationship between distance and signal strength. The position of the fish was recorded every 10 min during the continuous tracking. Every 30 min, we took a water sample from the bottom of the estuary in order to measure temperature, salinity, conductivity and suspended matter.

Over the 6-month monitoring period, 46% of the sturgeons were located from 7 to 10 times, 38% from 4 to 6 times, 15% only once, and 4 fish were never located. Twelve fish were tracked from 5 min to 30 hours in cumulative time. A total of 456 fixes were done in 26 effective days (Table 1).

For the first fish tracked in June 1999, we proceeded to a 24 hour tracking in order to have information on the stress period following handling of the fish and to compare the behaviour (route and swimming speed) with further trackings.

Data analysis

All the positions were reported on GIS (ESRI, ArcView, v. 3.2 and ArcView spatial analyst v.2.0a). Speed and distance between two positions were calculated with the same software. Only the points obtained from the continuous tracking were used for speed calculation. We used the minimum convex polygon to estimate the total surface used by the tagged fish during the six month tracking.

We performed a site fidelity test on each track using a user script "Animal movement v.2.04" (Hooge and Eichenlaub, 1997) under ArcView 3.2 in order to define if the trajectory showed a significant attachment to the site or not. We statistically compared each real track to a hundred randomly produced tracks composed of the same number of fixes. We made a Dirichlet tesselation on all the fixes in order to determine the main occupation area that can be considered as the preferred habitat (including 95 % of the fixes and excluding outliers). This method was chosen because of its poor sensitivity to autocorrelation (Wray *et al*., 1992).

The swimming speed was calculated using the distance and the time between two locations of a track. It was then considered as a ground speed. A mixed model with random effect "fish" on the intercept was used to compare swimming speeds by diel and by tidal phase.

The data concerning the habitat and the sturgeon diet, were provided by a study conducted over all the Gironde estuary (Brosse, 2003).

Results

Of the 16 tagged fish, 4 were never found by tracking: one of them was recaptured by trawl with a non functioning transmitter. No mortality was observed either during the tagging itself or after fish release in the estuary. We never found any sturgeon in the navigation channel during this monitoring period, neither on the left side of the estuary, nor around the wrecks or other sectors where we were not able to sample by trawling.

The fish that was tracked during 24 hours after being tagged had a swimming speed much higher during that period. It reached a maximum speed of 1033 cms^{-1} and had a mean swimming speed of 154 cms^{-1} whereas the mean speed of the same fish during its following tracking was between 26 cms^{-1} and 36 cms^{-1} depending on the day of tracking.

During the study, the water temperature close to the bottom ranged from 10.4 to 23.1 °C and the salinity ranged from 15.5 to 31.1 ppt. The fish were able to support a daily variation of salinity of 10.5 ppt.

Young sturgeons tended to stay in a congregation area (a maximum of 6 fish were identified at a given moment) located near the middle of the estuary (Figs. 2 and 3). When we consider all locations, the minimum convex polygon gave a surface of 32.6 km^2, but the Dirichlet tessellation with 95% of all positions showing a site fidelity, gave an area of 19.4 km^2 (Fig. 4) whereas the core of sturgeon activity occurred inside a narrow area of 2.6 km^2 (50% of all locations). We overlaid the result obtained by the Dirichlet tessellation and the map of the benthic fauna of the estuary (Fig. 4), and we noticed that tube dwelling polychetes were principally located in the congregation area.

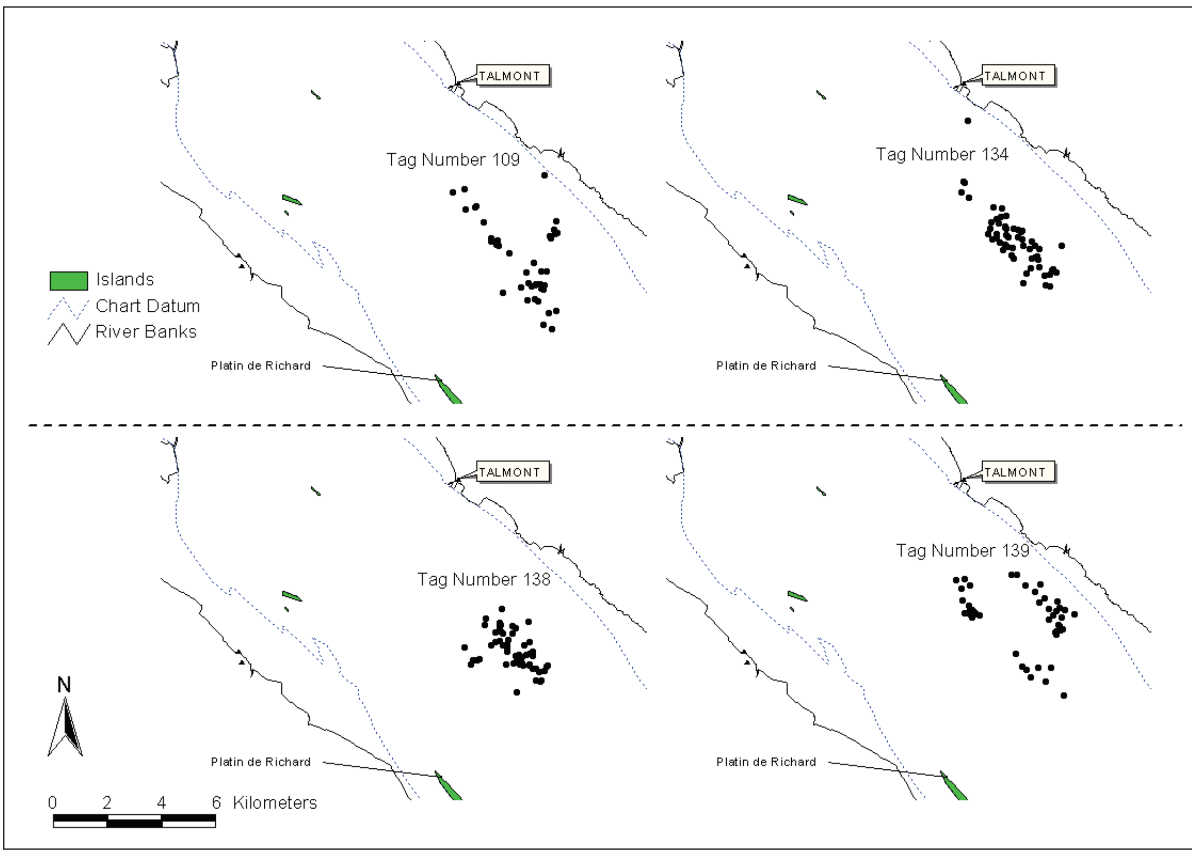

Fig. 2 – Maps of all the fixes recorded the six months tracking for the fish tag 109, 134, 138 and 139.

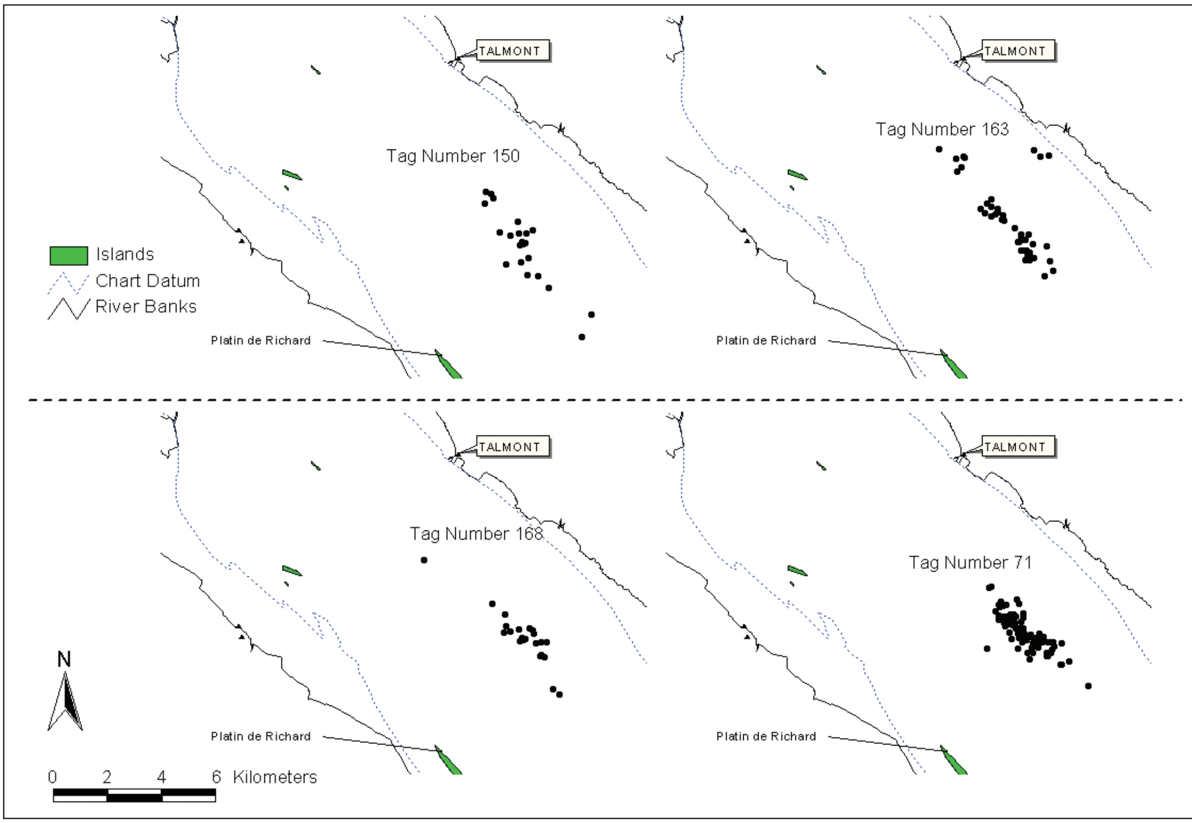

Fig. 3 – Maps of all the fixes recorded in the six months tracking for the fish tag 150, 163, 168 and 71.

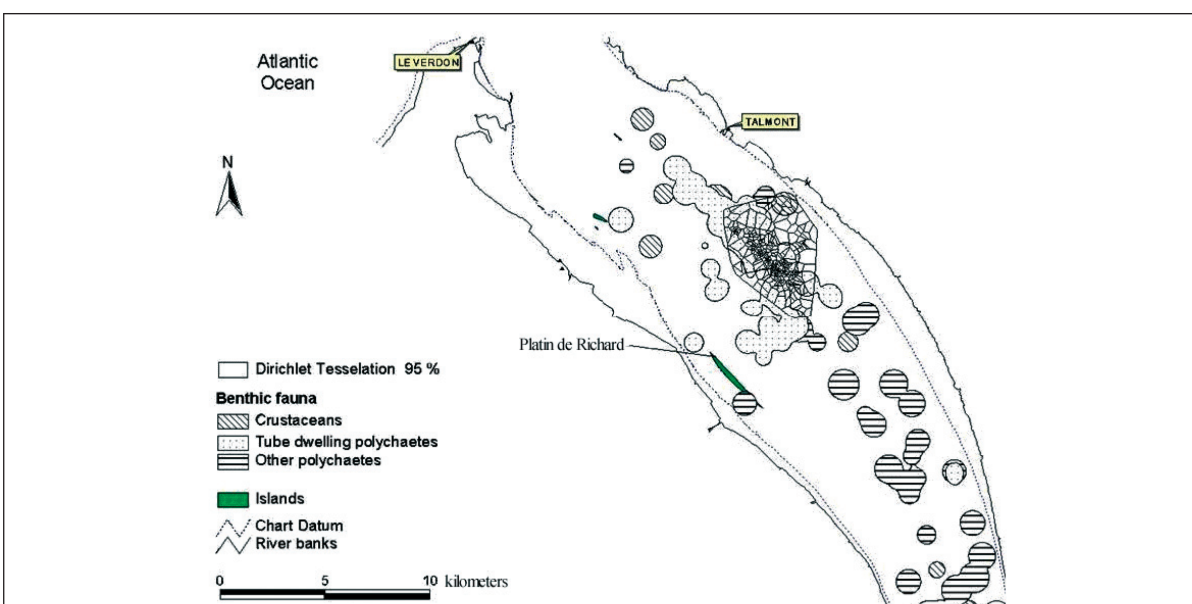

Fig. 4 – Congregation area estimated by Dirichtlet tessellation and details of the benthic fauna of the Gironde estuary.

Fish strayed away from their catching point by 400 m to 19 km (mean 4.2 km, s.d. 2.9 km) during the entire study period. Sturgeons exhibited movements mostly oriented following the direction of the tidal current: downstream movements during ebb and upstream movements during flood.

No significant diel interaction effects were observed on the swimming speed (mixed model, p =0.555) between daytime and night-time and no significant difference were observed in the swimming speed between flood and ebb tide (mixed model, p =0.278).

Discussion

We verified the stress caused by the capture and tagging, comparing the swimming speed and the total distance travelled immediately after being tagged and the observations done after 2 to 10 days. It appeared that the stress caused by the capture and handling of the fish affected the swimming speed of the fish for one full day. With Pacific salmon (*Oncorhynchus spp*.), handling of the fish shows to be disturbing and to affect their travel speed and direction during several hours after release (Ogura and Ishida, 1995).

After tagging, some sturgeons were released outside the congregation area, but all these fish homed back to this area (32.6 km^2). This zone represents less than 10% of the estuary's surface. Moser and Ross (1995) found that young Atlantic sturgeon *Acipenser oxyrhinchus* moved little and remained a long time in the same area. Use of discrete areas for extended periods of time seems to be common for sturgeon, and has been described for other species (Buckley and Kynard, 1985; Hall *et al*., 1991; Kieffer and Kynards, 1993; Bain, 1997; Foster and Clugston, 1997; Collins *et al*., 2000). A precise selection of the location where they live may indicate that they require a particular habitat. A high abundance of their favourite preys (polychetes worms) in the area could explain the congregation of sturgeon on this area (Brosse *et al*., 2000a). However, other factors could be important like bathymetry, sediment, fall of bed and current shed in the choice of this habitat. Nevertheless, very few individuals compose the sturgeon population at present and we must be careful in interpreting strictly these results to define what should be the feeding habitat for sturgeon in the estuary. Stomach content analyses show a diversity of 12 taxa of preys, and there were very few empty stomachs in young *A. sturio*, at least throughout the diurnal period (Brosse *et al*., 2000b). Monitoring using acoustic telemetry showed that the activity rhythm is similar between night and day. Therefore, it seems that these fish can eat throughout the day. A similar feeding activity was observed with shortnose sturgeon *Acipenser brevirostrum* (McCleave *et al.,* 1977). On a captive stock of *A. sturio* aged 1$^+$, activity rhythms were predominant during the night (Staaks *et al*., 1999). Over the study period, most of the observed movements consisted in short up or downstream movements (< 10 km) greatly influenced by the tidal cycle. Moser and Ross (1994) showed that swimming of *Acipenser oxyrhynchus* and *A. brevirostrum* in estuaries were well oriented to tidal current directions and mainly against the current. Swimming against the current could ensure that sturgeons do not drift too far from their feeding habitat. Salinity does not seem to be an important parameter for *A. sturio* as the fish were able to support a daily variation of salinity of 10.5 ppt.

This tracking experiment highlighted the behaviour of the juvenile sturgeon in the Gironde estuary. It confirms the use of the area which was determined by the trawling data (Rochard *et al*., 2001) and shows that juveniles do not forage in the shallow areas near the shore nor in the navigation channel where trawl sampling was impossible.

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