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EDITED BY
 Thomas Quinn,
 University of Washington, United States

REVIEWED BY
 Emilio Sperone,
 University of Calabria, Italy
 Sophie Elliott,
 Game and Wildlife Conservation Trust
 (GWCT), United Kingdom

*CORRESPONDENCE
 Marie-Laure Acolas
 ✉ marie-laure.acolas@inrae.fr

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Predation risk in stocking programs: case study on a critically endangered diadromous species, the European sturgeon *Acipenser sturio*

Marie-Laure Acolas^{1*}, Jérémy Tourneur¹, Thibault Dindart¹,
 Frédérique Bau¹, François Druyer², Bénédicte Lalot¹,
 Coralie Roy-Camille³, Florent Lalanne¹, Vanessa Lauronce⁴
 and Géraldine Loot^{3,5}

¹National Research Institute for Agriculture, Food and Environment (INRAE), Aquatic ecosystems and global change Research Unit (UR EABX), Cestas, France, ²Center for Aquaculture, Fisheries and Environment in New Aquitaine (Capena), Gujan-Mestras, France, ³Center for Research on Biodiversity and Environment (CRBE), UMR 5300, Toulouse University, French National Centre for Scientific Research (CNRS), French National Research Institute for Sustainable Development (IRD), Toulouse INP, Toulouse, France, ⁴Migado, Le Passage, France, ⁵Institut Universitaire de France (IUF), Paris, France

Juveniles produced in hatcheries for stocking purposes can have compromised behavior compared to wild conspecifics, especially concerning inappropriate anti-predator responses. In this study, we focus on predation risk for *Acipenser sturio*, the last native sturgeon species of Western Europe. We first carried out a bibliographic study to identify potential predators along the migration journey from freshwater to marine environments. Then, predation risk was assessed for 3-month-old and 11-month-old juveniles, using two techniques: diet analysis of a top predator and telemetry tools. After the stocking of 3-month-old *A. sturio*, *Silurus glanis* diet was assessed using direct stomach content and molecular analysis of their feces via digital PCR. Eleven-month-old juveniles raised in captivity were equipped with acoustic predation tags and released in the wild to assess their predation rate during their downstream migration. Both experiments were conducted in two large rivers in the South West of France. Molecular analysis of *S. glanis* feces indicated a moderate predation on sturgeon (30% of the fecal samples), a level similar to that observed for *Cyprinus carpio* and *Faxonius limosus*. *Eriocheir sinensis* was detected in more than half of the samples, while *Anguilla anguilla* was consumed in 82% of the fecal samples. *Alosa* spp. were not detected in the feces analysis. No diadromous fish were detected in the direct stomach examination, which highlighted the usefulness of the molecular approach. Telemetry survey of older juveniles revealed a high predation rate in the Dordogne River, with more than 80% of the individuals released predated. In contrast, a moderate predation rate was observed in the Garonne River (14%), but 58% of the individuals considered non-predated reached the saline estuary in less than 3 days due to a peak of water flow the day following the release. In both rivers, predation occurred mainly within the 2 days of release, 86% and 75% of the predation events for Dordogne and Garonne Rivers, respectively. Our study

demonstrates that predation poses a significant risk to juvenile *A. sturio*, particularly immediately after release. We further propose differential strategies to enhance early survival in stocking conservation programs.

KEYWORDS

acoustic telemetry, diadromous fishes, downstream migration, fecal molecular analysis, juvenile, *Silurus glanis*, sturgeon

1 Introduction

Restoring threatened species is a key challenge of the 21st century, given the high anthropogenic pressures encountered over the past two centuries (e.g., Arthington et al., 2016; Hall et al., 2012; Hasselman and Limburg, 2012; Simkins et al., 2025). In addition to habitat protection, restoration, and direct protection measures that prohibit species exploitation, species translocations constitute a last-resort conservation action (Berger-Tal et al., 2019; Seddon et al., 2014). Within the frame of conservation translocation, re-stocking and re-introduction practices consist respectively of either releasing individuals in an existing population in poor condition to enhance its recovery or releasing them in their historical distribution range, where the species has disappeared, to re-establish a viable population (IUCN/SSC, 2013). Those released individuals can come from a healthy wild population, or, when the number of individuals is too low in the wild, juveniles can be produced in captivity from captive or wild breeders. These practices allow for increasing the number of individuals in the wild, maintaining the genetic diversity, and restoring the ecological function of the species. The success of these programs depends on several factors, such as the quality of the environment where individuals are released and their ability to adapt to natural conditions (e.g., Berger-Tal et al., 2019). Moreover, hatchery environment, which provides habitats of low structural complexity, can affect phenotypic development, notably by altering behavioral traits such as anti-predator responses (Olla et al., 1998; Johnsson et al., 2014). The lack of anti-predator responses can lead to increased mortality after release because, in hatcheries, fish are not exposed to chemical cues or attacks from potential predators (Álvarez and Nicieza, 2003; Cámara-Ruiz et al., 2019; Thompson et al., 2016). For diadromous fish, whose life cycle requires migration between environments of different salinities, predation risk changes in each environment, increasing the number of potential predators they can encounter. To survive, they must display strong anti-predator skills and adaptive capacity to co-evolve with their main predators (e.g., Gu et al., 2022; Marshall and Wund, 2017; Wilson et al., 2008). Over several generations in captivity, the selection process may reduce the fitness of hatchery-origin individuals, making them less adapted to the natural environment compared to their wild conspecifics (Araki et al., 2008; Huntingford and Adams, 2005). Fish from hatcheries can even have adverse effects on the genetic or ecological processes of wild populations (e.g. McMillan et al., 2023). In view of such results, it is crucial to assess these predation risks in specific programs to improve stocking design and ensure that releases contribute meaningfully to the population's recovery.

Acipenser sturio is the last native sturgeon species in Western Europe, and restocking occurs in France (Dordogne and Garonne Rivers) and Germany (Elbe River) mainly from 2007 to 2015 thanks to a captive stock of wild origin individuals built in the 1990s (Adam et al., 2019; Gessner et al., 2010). Stocking was based on a bet hedging strategy, fish were released at different ages, such as larvae, 3-month-old individuals, 1-year-old individuals and older to allocate risks between differential survival related to size and time spent in captivity. In France, a regular monitoring of the sustained population has confirmed the presence of those individuals in the estuarine environment (Lamour et al., 2024) as well as at sea (Charbonnel et al., 2024). These observations highlighted a relative success of the recovery program, despite the fact that natural reproduction has not yet been observed in the wild due to the late maturity of this species. Within this period, fish encountered in the estuary originated from different release ages and genetic families (Roques et al., 2018). The analysis of the downstream behavior of 9- to 12-month-old fish released in the Dordogne River in 2008 and 2009 suggested a relatively high survival (87% of fish released) up to the saline estuarine environment (Acolas et al., 2012). Among the risks that can be encountered by the species, such as mortality linked to bycatch (Breve et al., 2024; Rochard et al., 1997), environmental stressors and contaminants (Acolas et al., 2020; Delage et al., 2020; Lucas et al., 2021), predation risk was considered theoretically low and has never been assessed in the watershed. For other sturgeon species, such risk was also considered limited, especially when the fish grow as observed for white sturgeon *A. transmontanus* (e.g., Gadomski and Parsley, 2005). In a laboratory experiment on green sturgeon (*A. medirostris*), Baird et al. (2020) found that in the presence of alternative prey, blackbass (*Micropterus salmoides*) predated less on sturgeons. Furthermore, once sturgeon reached about 20 cm in total length (corresponding to 38-58% of the predator's length), predation diminished to zero. Similar results were also observed for pallid sturgeon (*Scaphirhynchus albus*) less than 10 cm when exposed to predators (channel catfish *Ictalurus punctatus* and smallmouth bass *Micropterus dolomieu*) with alternative prey (French et al., 2010).

Since the introduction of non-native species can alter predation pressures (Shave et al., 1994; Smith et al., 2008; Aloo et al., 2017; Crossman et al., 2018), some studies have highlighted the predation pressure exerted by Wels catfish (*Silurus glanis*) on anadromous fishes (Syvaranta et al., 2010). In the Garonne and Dordogne rivers, the numbers of Wels catfish, and thus the potential predation pressure, have increased a lot since our study on *A. sturio* downstream migration 16 years ago (Acolas et al., 2012). In the

Garonne and Dordogne rivers, Bouletreau et al. (2020) estimated that 80% of sea lampreys (*Petromyzon marinus*) were predated within a month during their spring spawning migration, attributing this predation to Wels catfish due to the scarcity of other predators capable of consuming lampreys, at the study sites. Wels catfish have also been identified as predators of shads (*Alosa* spp.), potentially disrupting their spawning behavior (Bouletreau et al., 2021) as well as Atlantic salmon (*Salmo salar*), opportunistically exploiting migrating fishes, which aggregate in front of fish passage facilities during their spawning run (Bouletreau et al., 2018). More generally, studies indicate that animals are often more vulnerable to introduced predators, as prey frequently fail to exhibit their usual anti-predator responses, or do so less effectively, when confronted with non-native rather than native predators (Shave et al., 1994; Smith et al., 2008; Crossman et al., 2018). For stocked fish, the lack of anti-predator response may be increased by their captive origin, which could differ from the wild origin individuals (Huntingford, 2004; Salvanes and Braithwaite, 2006). Since 2022, sturgeon stocking has been implemented again in the Dordogne and Garonne rivers (Anras, 2025) with low numbers (a few thousand from 2022 to 2025) thanks to the individuals born in captivity that start to mature. This new generation, with parents born in captivity, may, however, be more vulnerable to such predation risk than the previous generation with parents of wild origin. In this context, we clearly lack information about *in situ* quantification of predation events along the freshwater-seawater continuum for *A. sturio*.

Assessment of predation can be based on theoretical assumptions by crossing the ecological knowledge of the predators and prey, such as the predator-prey size relationship, as well as the predator's known type of diet in the literature (e.g., Brose et al., 2006; Gaeta et al., 2018). This approach is useful when field data are missing and provides a first evaluation of potential risk. However, it does not prove that the studied prey is really part of the predator's diet. To assess direct predation in the wild, different methods can be used. First, an intensive sampling combined with a diet analysis can be attempted, but it requires a large sampling effort and a long time in the laboratory to determine the species collected in the guts (e.g., Moncada et al., 2025). The visual and morphological analysis of predator stomach contents is the most common approach for prey identification (e.g., Guillerault et al., 2015). However, the digestion process often leads to a loss of information, which limits the precision and the identification (Symondson, 2002). Molecular analysis, especially metabarcoding, offers better prey identification (Aguilar et al., 2017). The analysis of catfish feces by metabarcoding has in particular shown its tendency to feed on several species of anadromous fish (Guillerault et al., 2017; Moncada et al., 2025). More recently, digital PCR (dPCR) has emerged as a method providing high precision, increased sensitivity, and very good reproducibility. It allows to detect and quantify very low DNA concentrations, and thus to identify rare species (Hou et al., 2023; Marques et al., 2024). When focusing on specific prey, especially rare and endangered species, this method may be the quickest and most reliable to implement.

Acoustic telemetry is arguably the most widely used method in fisheries research to study survival and behavior of fish in various aquatic environments (Cooke et al., 2004; Cooke et al., 2013; Hussey

et al., 2015; Jacoby and Piper, 2025). With tracking methodology ever developing and refining (Lennox et al., 2025), notably through the development of acoustic tags with increasingly smaller sizes and greater processing capabilities (Deng et al., 2015), acoustic telemetry can be used across a wide range of freshwater and marine applications. As science advances using this technology, researchers are trying to better understand how fish behave in a targeted environment. Despite this method being able to elucidate many aspects of movement behavior, including residency, home range, and migration, among others (reviewed in Matley et al., 2022; Klinard et al., 2025), one aspect that remains challenging is the study of the effect of predation in fish. Because predation can be a major cause of fish mortality, being able to accurately identify predation has become a key objective. Until recently, the only way to tell if a fish had been consumed was to examine the fine-scale tracks for its tag and try to determine if the movement patterns were indicative of the swimming path of a predator rather than the fish itself (Beland et al., 2001; Melnychuk et al., 2013). This approach was inexact at best and almost impossible with simple acoustic receiver detection arrays, without relying on statistical techniques that can be difficult to validate (Gibson et al., 2015; Schultz et al., 2017). Since then, other approaches have emerged (Klinard and Matley, 2020), including the use of acoustic tags with acceleration sensors to map the dynamics of predator activity and its associated predation pressure on prey (e.g., Laurioux et al., 2025). To passively detect predation, tilt-based and acid-based predation-sensing acoustic transmitters have also been developed. The tilt-based transmitters infer predation signals by changes in an animal's orientation, whereas the acid-based transmitters, which contain a digestible fuse (Allen et al., 2015), identify the approximate timing of predation events (if detected) and subsequent predator movements (while still retained in the gut). Performance of miniaturized acid-based predation tags has been demonstrated in both laboratory (Halfyard et al., 2017; Lennox et al., 2021) and field-based studies on different fish species (e.g., Daniels et al., 2019; Klinard et al., 2019; Bouletreau et al., 2020; Weinz et al., 2020; Kennedy et al., 2025; Shorgan et al., 2025). The main advantage of those predation tags lies in their ability to estimate the time elapsed since predation, even in cases of discontinuous detection. They provide precise information on the moment the tag is activated in predation mode. A single detection in activation mode is sufficient to confirm predation detection, although several detections are recommended by some authors (e.g., Schultz et al., 2017).

Combining literature review, a molecular approach, and telemetry tools, our study proposes an original method for assessing predation risk. First, we aim to identify potential predators of the different developmental stages of sturgeon (eggs, larvae, juveniles of varying size) along its migratory corridor (freshwater, estuary, ocean). Then, based on the assumption that predation pressure is more intense in freshwater in a restocking context, and in the presence of a non-native top predator, we propose two complementary studies in the wild to measure predation signals: for 3-month-old juvenile, following their stocking in the rivers Garonne and Dordogne, we study *Silurus glanis* diet thanks to stomach content and feces analysis; for 11-month-old juvenile we assess their predation rate thanks to acoustic telemetry.

contamination during DNA extraction. To check the extraction quality, DNA concentration and purity were measured with a NanoDrop (NanoDrop™ One, Thermo Scientific). While the main focus was on European sturgeon, other migratory species such as eel (*Anguilla anguilla*) and shad (*Alosa* spp.) were also included, along with species commonly observed in stomach content, like common carp (*Cyprinus carpio*), American crayfish (*Faxonius limosus*), and Chinese mitten crab (*Eriocheir sinensis*). Primers previously published for either quantitative PCR (qPCR) or dPCR were prepared at 10 μ M and applied for dPCR analysis of both feces and stomach contents (Castagné et al., 2024; Appendix 1). Positive controls were prepared by spiking DNA from target species into extraction reagents, except for the Chinese mitten crab, for which no reference DNA was available. Positive controls were diluted 1:1000 to avoid signal saturation during dPCR. A barcoding strategy was used, whereby each species was assigned a unique primer pair, enabling simultaneous identification and quantification of multiple species in a single multiplex. dPCR assays were conducted in three triplex reactions (M1-M3), to optimize primer compatibility and thermal characteristics within each multiplex, each including catfish and two other species. Multiplex M1 included primers for catfish, European sturgeon, and shads; M2 targeted catfish, eel, and carp; and M3 targeted catfish, American crayfish, and Chinese mitten crab. Each 40 μ l dPCR multiplex reaction mixture consisted of 10 μ l QIAcuity Probe PCR Kit, 3,2 μ l of primer F and R per species, 1,6 μ l of probe per species, and 6 μ l of extracted DNA. Digital PCR reactions were performed on the QIAcuity system in QIAcuity Nanoplate 26K 24well. PCR was performed with the following thermal conditions: 95 °C for 10 min followed by 40 cycles of 95 °C for 30s and 60 °C for 1 min, and 98 °C for 10 min. Each sample was analyzed in triplicate. To detect contamination during the dPCR setup, no-template controls (NTCs) were included on each dPCR nanoplate. Positive controls were included on every nanoplate to verify assay performance. All manipulations were performed in a dedicated clean area, with work surfaces cleaned with bleach and ethanol 70%, and equipment and consumables exposed to UV light before use. No amplification was observed in extraction blanks or NTCs throughout the study, indicating that contamination was effectively controlled. Fluorescence thresholds were set visually using negative controls to help distinguish positive and negative partitions. A sample was considered positive if at least one partition was positive in all three replicates, a conservative criterion chosen to reduce the risk of false positives from stochastic amplification of low or degraded fecal DNA. The number of positive partitions was then used to estimate the DNA concentration of each target fish species in copies per microliter. However, the high variability in the quantity of catfish fecal samples complicates direct interpretation of these values. To account for this variability, and following the approach described by Castagné et al. (2024), target species DNA concentrations were normalized relative to 10000 copies of catfish DNA per sample. This normalization provides a standardized relative measure that facilitates comparisons both between samples for a given target species and among different target species within a multi-species context.

2.3 Telemetry survey of 11-month-old stocked *A. sturio* equipped with acoustic predation tags

For this experiment, the individuals were born in captivity in spring 2024 and were reared using traditional methods (Carrera-García et al., 2017a; Chèvre et al., 2011). In January 2025, we selected 110 individuals, which were reared for 6 months in an outdoor 2x2m rearing tank, under a naturally attenuated photoperiod thanks to semi-opaque shade structures. This tank was supplied with a flow-through drill water (temperature mean 17.6 °C \pm Standard Deviation (SD) 0.4 °C and oxygen mean 8.6 mg L⁻¹ \pm SD 0.3) at a renewal flow rate of 0.9 to 1.4 m³ h⁻¹ gradually increased. The water level was 0.45 m, and rearing conditions were slightly enriched by 2 blocks placed on the bottom of the tank to simulate the variability of natural habitats in a simplified way. A light water current was created thanks to a small propeller (direction of the current changed every week). Fish were fed ad libitum with a mix of bloodworms and krill at a rationing rate of approximately 20% of the total biomass. A few days before acoustic tagging, the fish were split into two tanks, one for each river, and they were fasted for 24 hours before surgery.

One week apart, two batches of 55 juvenile *A. sturio* aged 11 months were equipped with acoustic telemetry predation tags (V7D-2H 69 kHz; 7 mm x 22 mm; 0.8 g in water; 141dB; lifespan 35–38 days; www.innovasea.com). These tags were activated (i.e., triggered) when the fish were predated, but there was a delay between the predation event and the tag sensor activation due to digestion time. This delay was likely to vary depending on the water temperature and, therefore, the predator's metabolism. The temporal resolution of Gen2 predation tags used in our study was 1 hour for rapid predation events (i.e., time elapsed since predation between 0–7 days) and could reach 16 hours (time elapsed since predation between 21–35 days). Tags were implanted into the peritoneal cavity in the same way as described in Carrera-García et al. (2017b). Once the fish were fully anesthetized using a 50-ppm solution of isoeugenol, they were placed on their backs in a V-shape support and fitted with a tube inserted into the mouth to maintain sedation (25-ppm isoeugenol). After placing a surgical drape, the skin was disinfected with 10% diluted hydrogen peroxide, incised 10 to 15 mm to insert the tag, and sutured using absorbable monofilament (Ethicon® PDS™ II 4–0) secured with sterile Leukoplast skin adhesive. The tagged fish were then transferred to a separate 4-m³ recovery tank, where they were kept in captivity for a week under the same environmental and feeding conditions as in their rearing tank, for post-surgery recovery. Fish measured 32.3–45.3 cm in Total Length (TL) (39.4 \pm SD 3.0) and 32.4–43.6 cm in Fork Length (FL) (38.5 \pm SD 3.0) for the Garonne and Dordogne batches respectively and weighed 115–294 g (199 \pm SD 44) and 89–267 g (179 \pm SD 40), which corresponds to a low tag burden of respectively 0.6–1.5% and 0.6–1.9% as recommended (e.g., Bridger and Booth, 2003). The first batch of tagged fish was released in the Garonne on May 5, 2025, and the second in the Dordogne on May 12, 2025. The release method was similar to that used for the 3-month-old juvenile. The release sites were located approximately 115 km upstream from the confluence of the two rivers that form the

Gironde estuary (Figure 1). A total of 29 receivers (VR2W 69 kHz, Innovasea®) deployed in arrays of 7 acoustic gates per river were placed along the downstream migration route of the tagged fish from freshwaters up to the upper saline estuary (Figure 1). Active real-time tracking (Omni-directional VR100-300) took place daily during the first 7 days post-release to try locating fish more precisely.

Mean daily river discharge and water temperature were calculated from data of Environmental Agency (SCHAPI-HydroPortail eaufrance.fr) and the MAGEST monitoring program of the water quality of the Gironde fluvial-estuarine system (<http://magest.oasu.u-bordeaux.fr/>), respectively. Temperature was also recorded hourly using dataloggers (Tinytag®) placed in the uppermost acoustic gates near the release sites, and mean daily water temperature was averaged by combining both upstream and downstream data records. Mean daily water flow was calculated from data at the gauging stations of Marmande and Pessac-sur-Dordogne for the Garonne and Dordogne rivers, respectively (Figure 1). During the telemetry study from May 1 to July 1, 2025, three peaks of high river discharge were observed in the Garonne, and the first one occurred 24 hours after the fish were released (Figure 2). Mean daily river discharge was higher for the Garonne ($465 \pm \text{SD } 261.1 \text{ m}^3 \text{ s}^{-1}$; range: $135\text{--}1480 \text{ m}^3 \text{ s}^{-1}$) compared to the Dordogne ($138.5 \pm \text{SD } 67.0 \text{ m}^3 \text{ s}^{-1}$; range: $48\text{--}323 \text{ m}^3 \text{ s}^{-1}$). Comparisons between the two are not very meaningful given the different sizes of their watershed (50670 km^2 for Garonne vs 14976 km^2 for Dordogne). However, the average flow observed in May in Garonne was only slightly below the interannual average flow for the reference period 1986–2025 (631 vs. $719 \text{ m}^3 \text{ s}^{-1}$), while that observed in May in Dordogne was significantly lower (192 vs. $273 \text{ m}^3 \text{ s}^{-1}$ over the 1996–2025 reference period). In June, the flows of both rivers were also significantly lower than the reference values. Mean daily water temperatures were comparable between the Garonne ($21.0 \pm 3.8 \text{ }^\circ\text{C}$; range: $15.7\text{--}29.0 \text{ }^\circ\text{C}$) and the Dordogne ($20.7 \pm 4.0 \text{ }^\circ\text{C}$; range: $15.2\text{--}28.3 \text{ }^\circ\text{C}$; Figure 2).

For this experiment, all procedures were designed to respect animal welfare. They were carried out in an approved experimental hatchery facility by the French Department of Agriculture (authorization B33-478-001) and followed the standards of the

National Ethical Committee of Animal Use for Scientific Purposes (authorization APAFIS 53804-202502191153957v3 from the French Ministry of Higher Education and Research).

2.4 Data analysis

The locations of catfish sampling sites in autumn 2024 and receiver arrays in spring 2025, as well as fish release sites, were mapped using QGIS software.

dPCR results were processed with QIAcuity Software Suite (QIAGEN), which provides DNA quantification per replicate based on the number of positive partitions. Further data processing was carried out in R (version 4.4.2) with the packages “dplyr”, “ggplot2”, “tidyverse”, “stringr”, “lubridate” and “multcomp”. Graphs displaying DNA quantification were plotted on a logarithmic scale to improve readability across the full data range.

The proportion of empty stomachs among the catfish sampled (i.e. vacuity rate) was estimated. The influence of gears on stomach vacuity was assessed using logistic regressions. The differences in fish size captured by the different gear were compared using non-parametric statistics (Kruskal-Wallis tests and Dunn *post-hoc* test with a Holm correction).

The proportion of predated fish in the telemetry experiment was estimated for each river based on the predation tag status recorded (i.e., raw sensor value switch from 1, untriggered, to 2 or more, triggered). When the tag was only recorded once post-release, we classified the individual as “unknown fate”.

3 Results

3.1 Potential predators along the sturgeons’ migratory continuum identified from literature

A review of the literature, combined with current knowledge of the species ecology, enabled us to compile a list of potential

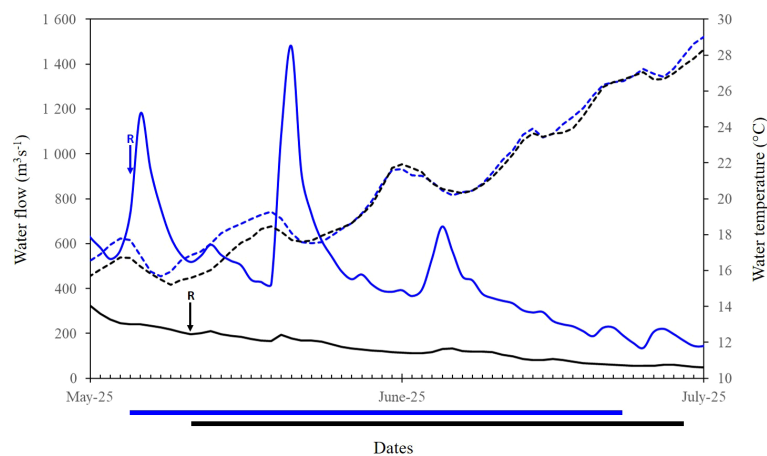


FIGURE 2

Environmental conditions during the telemetry study: daily mean water flow (solid lines) and water temperature (dotted lines) in Garonne and Dordogne (respectively, in blue and black colors). Vertical arrows indicate the dates of fish release (R) and horizontal lines the periods of acoustic monitoring on each river.

predators in freshwater, estuarine, and marine environments (Figure 3; Appendix 2). In freshwater, when sturgeons are in the egg, larval, or juvenile stages, a list of 16 potential predators was established. For the juvenile stage, the main potential predators are piscivorous fish, such as northern pike (*Esox lucius*), largemouth bass (*Micropterus salmoides*), zander (*Sander lucioperca*) and the Wels catfish (*Silurus glanis*). Some fish-eating birds, including the grey heron (*Ardea cinerea*) and the great cormorant (*Phalacrocorax carbo*), may also exert predation pressure. In estuarine environments, the risk of predation appears lower, likely due to the limited number of identified potential predators (4 species). These include medium-sized fish such as seabass (*Dicentrarchus labrax* and *D. punctatus*), larger meagres (*Argyrosomus regius*) and European conger (*Conger conger*), as well as very rare species like the tope shark (*Galeorhinus galeus*). During the marine growth phase, a greater number of predators is expected (15 listed), most of which are marine mammals.

3.2 Analysis of the predation of 3-month-old juvenile by a top predator via stomach content and molecular analysis

In total, 67 catfishes were sampled with a size range between 30 and 247 cm TL. The vacuity rate of the sampled catfish was 61.2% (66.7% in the Dordogne and 58.7% in the Garonne). Among the prey items directly identified in the stomach contents, neither the European sturgeon nor any other diadromous fish species was observed. The most frequently encountered prey were the Chinese mitten crab and the American crayfish (Figure 4).

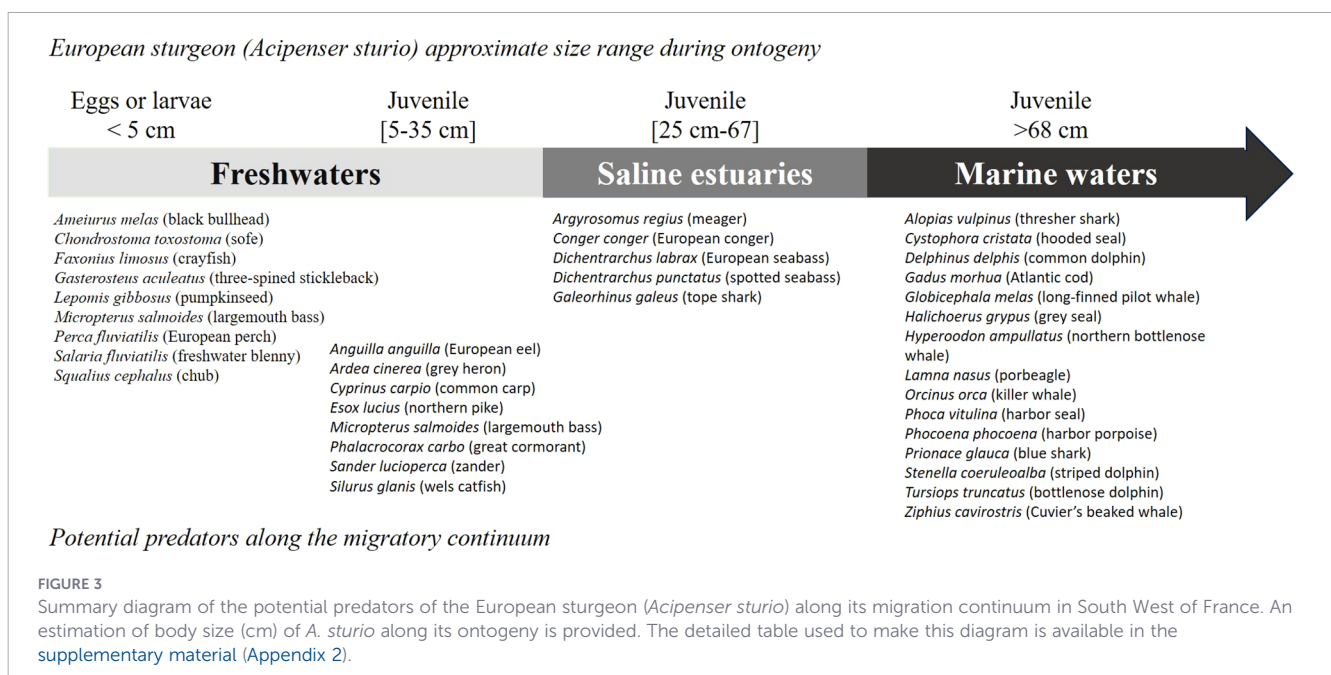
A significant difference in the size of catfish captured according to gears was highlighted (Kruskal–Wallis $\chi^2 = 15.23$, $df = 2$, $p = 0.00049$). Catfish captured with fyke nets were significantly smaller (mean TL 117.2cm from 30 to 247cm) than those caught with

longlines (mean TL 153.5cm from 120 to 246cm) ($p_{\text{Dunn post-hoc test}} = 0.038$) or gillnets (mean TL 183cm from 110 to 245cm) ($p_{\text{Dunn post-hoc test}} = 0.00075$), while no significant difference was found between longlines and gillnets ($p_{\text{Dunn post-hoc test}} = 0.33$). Stomach emptiness was significantly more likely in gillnet-captured fish compared to longlines (logistic regression, $p = 0.012$), whereas it did not differ significantly for fyke nets from either gear type (logistic regression, $p = 0.107$).

Four stomach content samples, which could not be visually interpreted, along with 17 fecal samples, were analyzed using dPCR (Table 1). European sturgeon DNA was detected in 30% of the fecal samples and in one stomach content. Most *A. sturio* detections were from the Dordogne River (4 detections among 5 samples), compared to the Garonne River (only 2 detections among 16 samples). Predation signals of *A. sturio* were detected the day after release, and up to seven days after, within the month of sampling.

Considering both rivers, Common carp and American crayfish showed detection rates similar to that of sturgeon (30% of feces). European eel and Chinese mitten crab were the most frequently detected species, found in 82% and 52% of the fecal samples, respectively. Shads were detected in only one stomach content sample.

DNA concentrations of the different target species, normalized to 10000 copies/ μl of catfish DNA, were measured for all fecal samples (Appendix 3; Figure 5). The highest values were found for Chinese mitten crab, with more than half of the samples showing over 8000 copies/ μl . Eel had a more even distribution, with only 7 samples below 1 copy/ μl , and one sample reaching the highest concentration recorded (207135.2 copies/ μl). Sturgeon and crayfish showed similar patterns, though crayfish had slightly higher values, and also more zeros (Figure 5). Common carp had mostly low values: 15 out of 17 samples were under 1 copy/ μl .



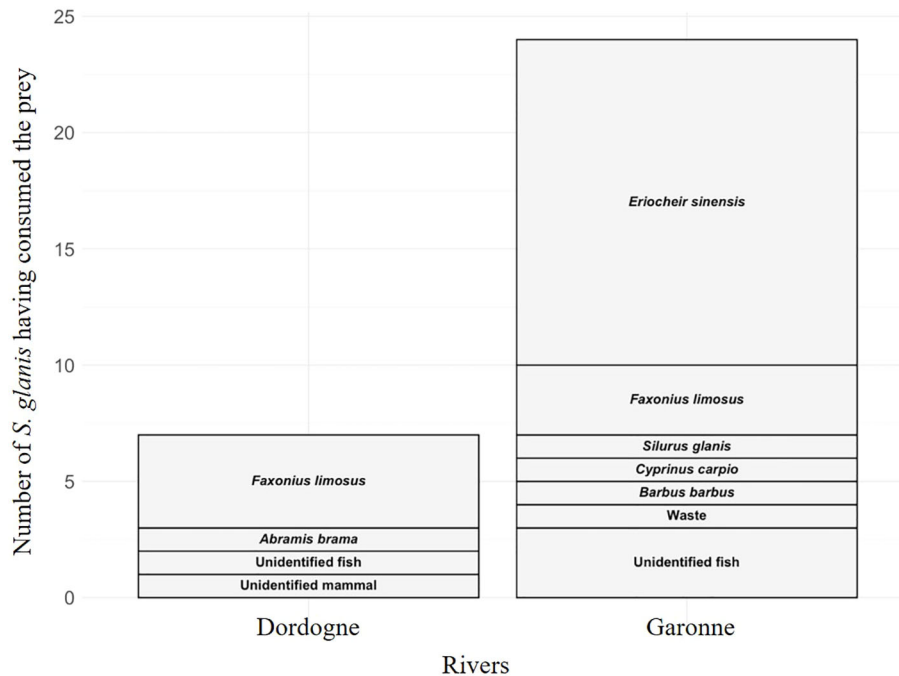


FIGURE 4

Number of Wels catfish that consumed each prey type in the Dordogne and Garonne Rivers, based on morphological analysis of direct stomach contents. Prey species common names are American crayfish *Faxonius limosus*, Chinese mitten crab *Eriocheir sinensis*, common barbel *Barbus barbus*, common carp *Cyprinus carpio*, freshwater bream *Abramis brama*, Wels catfish *Silurus glanis*. Waste correspond to an ointment tube.

3.3 Analysis of the predation of 11-month-old juvenile using telemetry tools

In the Garonne River, 8 fish were predated (14.5% of the fish released), 46 were considered alive as they were detected non-predated by the receivers arrays located at the mouth of the river or in the upper saline estuary, and 1 individual signal disappeared rapidly on the day of release (classified as unknown fate). Among the predated individuals, 6 were predated rapidly after release (less than 48h; Figure 6). The predators were detected within 0 to 145 hours after predation and located either close to the release site of Marmande (4 individuals) or in the tidal part of the river (2 individuals located about 50 to 90 km downstream from the release site). Two sturgeons were predated about 1 month (31 and 37 days) after release, one at the mouth of the Garonne and the other one at the mouth of the Dordogne, indicating that predators can travel between the two river mouths through the upper saline estuary. Those predators were detected 17 to 35 hours after predation. The estimated predation hours correspond to daylight hours (87.5% of the predated sturgeons i.e., 7 individuals), with one sturgeon having been predated at dusk.

With regard to individuals considered to be alive, more than 58% of them (i.e. 27 individuals) reached the mouth of the river in less than 3 days, with these downstream movements coinciding with the sharp increase in water flow (Figures 2, 6). Then, downstream migration behavior was observed for up to 47 days post-release, with two small peaks in fish arrivals at the river mouth at the time of increases in water flow, approximately 15 and 29 days after release (Figures 2, 6).

In the Dordogne River, 44 fish were predated (80% of the fish released). Seven were considered alive. Among them, 2 individuals

were detected at the mouth of the river or in the upper saline estuary 8 and 25 days after release, and 5 individuals were located by active tracking in the freshwater tidal area from 12 to 39 km downstream of the release site within 2 to 21 days after release. Four individuals disappeared rapidly on the day of release (classified as unknown fate).

Among the predated individuals, 38 (i.e., 86%) were predated rapidly after release (less than 48h), but further predation events were observed for up to 20 days after release. The predators were detected within 0 to 244 hours (average= 32 hours) after predation and were located up to 48 km downstream of the release site (most of them, i.e., 34 individuals, in the tidal part of the river) and another one at the mouth of the Dordogne River. The predation was estimated to have occurred primarily at night (63.6% of predated sturgeons, i.e. 28 out of the 44 predated), and mostly the night following their release (24 of the 28 predated at night).

At the time of rapid predation events, the average river flows and temperatures were 740 to 1180 m³ s⁻¹ and 16.9 to 17.7 °C in the Garonne (May 5 to 6), and 196 to 210 m³ s⁻¹ and 15.8 to 16.5 °C in the Dordogne (May 12 to 14).

4 Discussion

4.1 Predation risks along the migratory journey of stocked *A. sturio*

According to our literature analysis, the freshwater environment and the marine environment seem to correspond to

TABLE 1 Detection of target prey species by dPCR in feces and stomach contents of catfish sampled in the Dordogne and Garonne rivers.

Sample code	Date	River	Gear	Catfish size (cm)	<i>A. sturio</i>	<i>A. anguilla</i>	<i>Alosa</i> spp.	<i>C. carpio</i>	<i>F. limosus</i>	<i>E. sinensis</i>
F1	19 sept	Dordogne	Gillnet	230		x				
F2	19 sept	Dordogne	Gillnet	190	x	x				
F3	19 sept	Dordogne	Fyke net	102	x	x				
F4	20 sept	Dordogne	Gillnet	150	x	x				
F5	25 sept	Dordogne	Fyke net	82	x	x				
F6	15 sept	Garonne	Gillnet	230		x				x
F7	15 sept	Garonne	Fyke net	115				x		x
F8	15 sept	Garonne	Fyke net	215		x		x	x	
F9	15 sept	Garonne	Fyke net	165		x		x		x
F10	16 sept	Garonne	Gillnet	140		x				x
F11*	18 sept	Garonne	Fyke net	60	x	x				
F12	18 sept	Garonne	Longline	145		x		x	x	x
F13	19 sept	Garonne	Fyke net	87					x	x
F14	19 sept	Garonne	Longline	120		x			x	x
F15	24 sept	Garonne	Fyke net	40						
F16	8 oct	Garonne	Longline	147		x		x		x
F17	15 oct	Garonne	Fyke net	152		x			x	x
CS1	2 oct	Dordogne	Fyke net	134		x			x	
CS2	1 oct	Garonne	Longline	246						
CS3	8 oct	Garonne	Fyke net	125		x			x	
CS4*	18 sept	Garonne	Fyke net	60	x	x	x	x	x	

*Sample of feces and stomach of the same individual.

A cross indicates a significant detection of the target DNA (a sample was considered positive when all three replicate measurements were positive). "F" refers to the analysis of feces. "CS" refers to the analysis of stomach content. The number indicated after F or CS corresponds to the Wels catfish sampled.

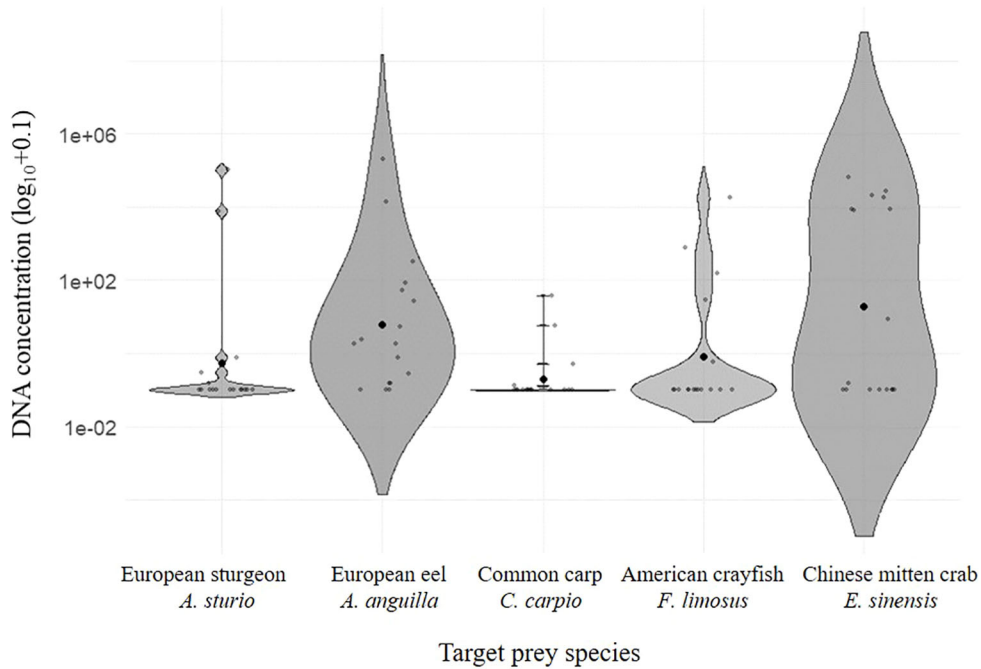


FIGURE 5

Distribution of DNA concentration of target prey species detected by dPCR in catfish feces. Since the dataset comprises numerous values close to zero alongside with substantially higher magnitudes, a logarithmic scale is used to allow optimal visualization of all values. The DNA concentration is expressed as the mean number of copies/ μ l. The data correspond to those presented in Appendix 2. The violin plot represents the density estimate of the DNA concentration, the more data points, the larger the violin is. Black dots represent mean.

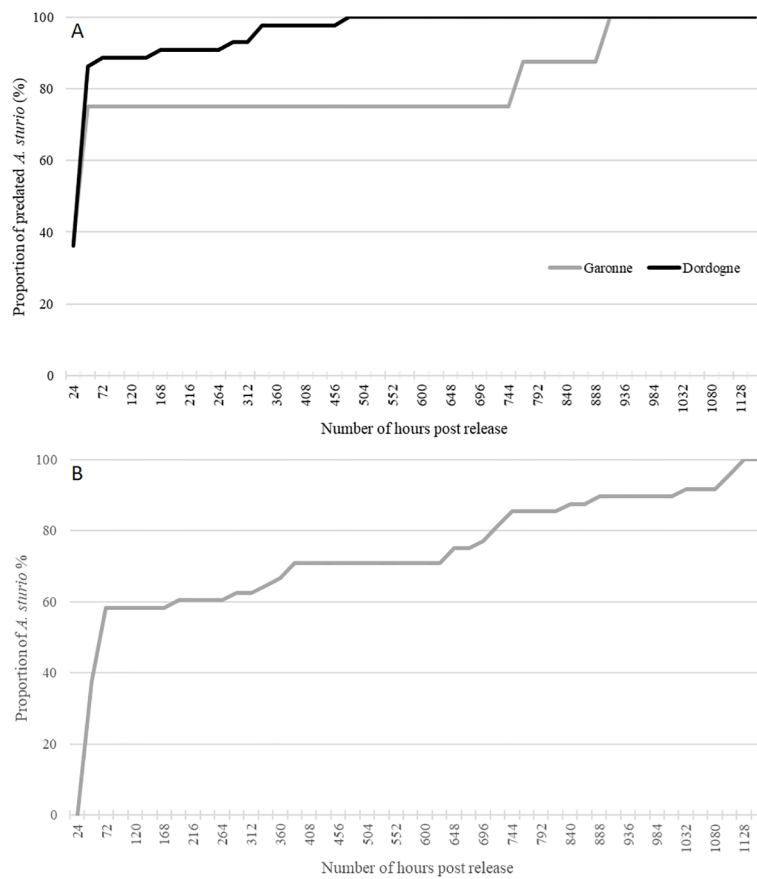


FIGURE 6

Cumulative proportion of *A. sturio* according to the number of hours post release. (A) correspond to *A. sturio* predated in both rivers and (B) to *A. sturio* released in the Garonne River reaching the mouth of the river or the upper saline estuary.

the habitats with the highest predation risks, while the estuarine environment appears to be less exposed. Freshwater predators are the most consistently documented in the literature, whereas predation risks in marine environments remain less understood and would require dedicated studies, given that *A. sturio* spend more than 90% of its life cycle at sea. Diet analysis of large marine predators would be very difficult to carry out at large scale, either due to the protected status of some predator species or to the logistical challenges of sampling at sea. We suggest analyzing the overlap between the suitable marine habitat of *A. sturio* (Charbonnel et al., 2024) and the distribution of potential predators to assess the risk as it has been done for other rare and protected species (e.g., Szesciorka et al., 2023; Trainor et al., 2014). In the studied saline estuary, we regularly sample the fish fauna, which provide us a good overview of potential predators. Generally, very few predators large enough to prey on sturgeon were present in the estuary. No specific studies of the diet of these larger predators have been conducted, but their low numbers strengthen the assumption of a relatively low predation risk in saline estuaries. Given the growing abundance of *Silurus glanis* in the watershed studied, their potential presence in the oligohaline sector of the estuary may need to be taken into consideration in the future.

Our field experiments directly illustrate the predation risk in freshwater. We highlighted a moderate predation on 3-month-old juveniles (detected in 30% of the feces of the *S. glanis* sampled) and a high predation on 11-month-old juveniles (80% of the individuals released in the Dordogne, the 14% observed in the Garonne being explained by increasing flow just after release, leading the individuals into the saline estuary). The moderate predation of 3-month-old individuals can however be discussed since our sampling was limited to the area around the release sites, and both sturgeon and catfish can move outside this area, which could lead to an underestimation of the predation rate. Previous research has shown that 3-month-old juveniles generally remain within 13 km downstream of release sites during the month following stocking (Carrera-Garcia et al., 2017b). Because sampling was limited to a 2 km reach, it cannot be determined whether the absence of detections reflects rapid downstream movements driven by environmental conditions. Likewise, it remains unclear whether catfish followed sturgeon during their downstream migration.

The number of sturgeons released during this study was low (a few thousand) compared to the stocking occurring in the past (tens of thousands), which could likely reduce predation pressure. As suggested by Näslund (2021), the high mortality in stocked individuals may be resolved by increasing the number of released animals, assuming that survival remains at similar levels regardless of the initial stocking density at a stocking site. Stocked animals often represent a sudden input of energy into the system, which increases local resource demand to sustain the new animals and increases the possible attraction of predators to the stocking site (Näslund, 2021). For cutthroat trout (*Oncorhynchus clarkii*), it has been shown that high prey abundance can increase their intensity of predation (Hansen and Beauchamp, 2014). But large numbers of fish schooling together could increase safety and can sometimes decrease predation risk in some species (see Polyakov et al., 2022). In fish stocking program, the stocking density on predation risk is

not clearly assessed to our knowledge. Thus, it would be useful to replicate this study with a larger number of individuals released into the river to test this hypothesis. If density plays a role in predation rate, the number of fish released as well as the number of release sites could be adjusted to reduce juvenile vulnerability.

4.2 Duration of predation after release and mitigation measure propositions to improve released fish fitness

Predation risk is supposed to decrease with ontogeny due to size-related defenses (e.g., Baird et al., 2020; Gadomski and Parsley, 2005) as illustrated in white sturgeon (Steel et al., 2019). This laboratory study highlighted that predation risk decreased from 70% at length 12 cm to 5% at length 23 cm. In our study of juvenile sturgeons measuring 32 to 45 cm in length, one would have expected a relatively low predation rate given their size-related defenses. However, we observed a high predation rate (80% of the fish released in the Dordogne). It can be assumed that the time spent in the hatchery (11 months) would disfavor them in terms of anti-predation behavior acquisition. Moreover, for both stages studied (3-month-old and 11-month-old), most predation signals were observed rapidly after release, within a week for the youngest ones and within 48 hours for the older juveniles. In post stocking studies, the highest predation rate was also observed rapidly after release for other species. Among other fish species released as juvenile, most predation was observed with a mean time below 90h after stocking for Chinook Salmon *Oncorhynchus tshawytscha* (Gravenhof et al., 2024) and predation was estimated to account for a large part of post-stocking mortality in the Japanese flounder *Paralichthys olivaceus* during the first week after release (Sudo et al., 2008). But such early mortality in stock enhancement due to predation is also observed in other taxa such as crustaceans where 53% of mortality within 24h post release was observed for Red king crab (*Paralithodes camtschaticus*) (Long et al., 2024) and peak of mortality due to predation occurred within 2h post release for rock lobsters (*Jasus edwardsii*) (Oliver et al., 2005). This suggests that it is a real issue in stocking practices, regardless of the taxa.

The predation observed quickly after release may be explained by the fact that individuals may not have time to adapt to the new condition (river water, current water flow, prey availability), which could have made them more sensitive than wild conspecifics (e.g., Näslund, 2021; Thompson et al., 2016). The individuals released in our field studies were not reared under enriched conditions, although they received light training before release, such as attenuated photoperiod and slight current velocity in their tanks. Better preparation for natural environments could help lower predation rates, as it was demonstrated that fish raised under non-enriched conditions showed lower survival and altered behavior (Hutchison et al., 2023), including European sturgeon (Carrera-Garcia et al., 2017b). Exposure to more variable spatial and feeding cues has been shown to improve fish behavior and survival (Braithwaite and Salvanes, 2005). Similarly, reducing rearing densities and enriching captive habitats can enhance fish condition (Johnsson et al., 2014). European sturgeons of this study were raised in drill water to maintain sanitary conditions in the

hatchery, but raising them in river water at least a few weeks before release may help them to acclimate more rapidly after stocking in the wild, exposing them to olfactory cues of the river. Enhancing current velocity in the tanks would also increase swimming performance to facilitate foraging and escape predators. Strong training to natural conditions a few weeks before release would therefore be important to consider in the future as a mitigation measure. As a preventive measure, applying target fishing pressure on identified predators, if their status is not threatened (i.e., *Silurus glanis* in Western Europe), at the release sites and further downstream in the weeks before release could help reduce predation pressure. This would give juveniles time to adapt to natural conditions and, at least temporarily, limit predation and increase early survival.

4.3 Predator identification

To study predation on 3-month-old juveniles in autumn, we focus on *S. glanis*, but we cannot exclude other predators present in the system that could increase predation pressure on this stage. According to the eDNA sampling in the rivers carried out in autumn (Appendix 4), fish species that could predate juvenile sturgeons were present in the same area of sampling: perch (*Lepomis gibbosus* and *Perca fluviatilis*), largemouth bass (*Micropterus salmoides*), chub (*Squalius cephalus*), pike (*Esox lucius*), and zander (*Sander lucioperca*) in addition to catfish. Some of these potential predators were captured by the fishing gears deployed but in very low numbers compared to catfish. They represented 1 to 3% of the fish captured (one pike of 40 cm, one zander of 55cm, and two perch of 20 cm; pers. com. F. Druyer) against more than 93% of *S. glanis*.

To study predation on 11-month-old sturgeons, the predation tags used can only tell us that the fish was eaten, but it does not give any information on the predator species. Pike and zander, present in the autumn sampling as well as Wels catfish, are the only fish that could be large enough to prey on them. Considering the size of the *A. sturio* released and the ratio proposed by Gaeta et al. (2018), predators should measure at least 70 cm. Although it is more likely that they were predated by catfish, given their abundance and large size in the watersheds, we cannot exclude some other predators, such as very large pike or zander. In addition, we have detected some tagged *A. sturio* that disappeared the day of release after only one record (unknown fate: 2 to 7% of the fish released in the Garonne and Dordogne, respectively). We can assume that these fish were predated by birds, which would explain their disappearance from the system, given that the two species of piscivorous birds described in the literature analysis (the grey heron and the great cormorant) were present in the watershed. Another hypothesis could be a predator fish that would have quickly left the study area, but this is unlikely since receivers arrays were present downstream and upstream of the release site. Even if it is unlikely, we cannot exclude tag failure or imperfect detection.

The condition of predated *A. sturio* remains questionable since dead individuals could be predated. Concerning the 11-month-old juveniles, the high survival proxy estimated in the previous telemetry experiment with movements of fish recorded for several

weeks (Acolas et al., 2012) weakened this hypothesis. Concerning the 3-month-old individuals, Carrera-Garcia et al. (2017b) estimated a survival proxy from 52% to 66% for fish raised with few enrichments, and therefore, we cannot rule out this possibility.

4.4 Predation of juveniles of diadromous fish

To our knowledge, there are few studies documenting predation of juvenile diadromous fish by catfish, except Castagné et al. (2024); Moncada et al. (2025), who assessed eel predation. Usually, studies focus on adults during their spawning migration (e.g., Bouletreau et al., 2020; Bouletreau et al., 2021). The present study documents predation of catfish on several juveniles of migratory fish, as sampling was conducted when only juveniles were present in freshwaters for the species considered (i.e., *A. sturio*, *A. Anguilla*, and *Alosa* spp.). The European eel was the species most frequently detected across the samples. DNA abundance estimates from feces were of a similar order to those of the Chinese mitten crab, which dominated the visually identified stomach contents (83% of non-empty stomachs and 35% of analyzed feces). In freshwater, immature stages of the European eel, ranging from glass eels to yellow eels, are the most common (e.g., Podda et al., 2023). These findings suggest a strong presence of eel in both the Garonne and Dordogne rivers, a pattern also confirmed by eDNA surveys (Appendix 4). Such availability may make eel an attractive prey for catfish, a concern given that the European eel is listed as Critically Endangered on the IUCN Red List. Shads were recorded only once, through DNA analysis of a catfish stomach content. The presence of *Alosa* spp. was confirmed by eDNA analyses at the sites sampled in autumn, which coincides with the downstream migration of juveniles (Baglinière et al., 2003). Catfish did not appear to target these shad juveniles preferentially, but it is also likely that shad were present only in low numbers.

4.5 Advantages and limitations of the methodologies used

The three approaches used in this study appear relevant to assess predation risk on a migratory fish along its migratory pathway.

The bibliography analysis allows a large-scale approach across different environments, but we consider this analysis as a first step to provide a preliminary list of candidate predators at large scale. This list could be refined in the future. For example, it could be completed using morphological analysis such as measuring the size of the predators' mouth that could really allow them to feed on the different stages of sturgeon. Analysis of the occurrence of predators and prey in the same habitat and at the same season could also constitute a valuable approach (e.g., Trainor et al., 2014).

Compared to more conventional approaches such as qPCR or metabarcoding, dPCR was selected for its sensitivity to rare species and its ability to provide accurate DNA quantification. Both advantages were confirmed in our study: traces of DNA from certain targets were detected at very low levels in some samples, and the quantitative results allowed a more detailed assessment of

catfish predation on *A. sturio* while also placing its consumption in the broader context of other prey species. Concerning our estimation of relative abundance, prey size may substantially influence the amount of DNA detected, which complicates direct numerical comparisons. In addition, high DNA quantities revealed by dPCR may also reflect recent predation events, since the amount detected may depend on the time elapsed since ingestion. The apparent abundance of crabs and crayfish in both stomach contents and feces could be overestimated, as the low digestibility of crustaceans may prolong their residence time in the stomach and slow down DNA degradation within the digestive tract (Andersen et al., 2016). Regarding the method used to sample predators, different fishing gear allows sampling of different size classes of *Silurus glanis*, which can be explained by the different size of their mesh/bait. Regardless of the fishing gears, we suggest using a much shorter soaking time, as this could increase the amount of fecal matter collected and decrease the stomach vacuity rate.

To our knowledge, this is the first study allowing direct estimation of predation rate on sturgeon thanks to predation tags. However, we cannot precisely locate the predation events in the watershed since the predators may be detected several hours after predation and can swim over large distances. Nevertheless, we can estimate the timing of predation, which allows us to estimate the proportion of predation occurring during the day versus at night. In the Garonne, predation detections occurred during daytime hours (but it only concerns six individuals), whereas in the Dordogne, they mainly occurred at nighttime hours, with most predation during the night following release. Given potential confounding factors, we cannot conclude on a nycthemeral pattern of predation.

There are some potential limitations of predation tags reported in the literature (e.g., tag retention, uncertainty in digestion delay, false positives). In our study, we are quite confident in tag retention since juveniles were kept in their tanks to recover for seven days after tagging and they were checked individually (tag emission and stiches) before transport to the release site. Between the act of predation and the moment when the tag sensor is activated, there is a delay due to digestion time and sensor triggering in predation mode, which is likely to vary depending on river temperature and therefore on the predator's metabolism. Nevertheless, the temporal resolution given for Gen2 predation tags, such as those used in our study, is one hour for rapid predation events, which correspond to most of the predation detected within 48 hours post-release. Even if false positives are always possible, although less frequent with Gen2 tags (Halfyard et al., 2017), the timing and location of predation events and the varied behaviors observed in predation mode outside typical migration patterns for the juveniles may suggest that there were indeed real predations on fish. However, a specific experiment aimed at clearly estimating false positive rates in these tags would be relevant in the future.

In both field experiments, predation rates were higher in Dordogne than in Garonne, but more data would be needed to conclude if there was a difference in predation risk between the two rivers. In the telemetry study, the high water flow following fish release into the Garonne caused most of the juveniles to move rapidly downstream outside the river, which reduced the number of fish in freshwater. We can also suppose that such high river flow may have adversely affected, even temporarily, the hunting behavior of predators. In addition,

professional fishermen actively targeted catfish that spring, which increased fishing pressure in the Garonne river (pers. com. F. Druyer) and may have lowered the predation pressure in that river. Regarding the assessment of predation on 3-month-old fish by catfish, the sample size was globally small, especially in the Dordogne, which limits the comparison between the two rivers. These results encourage further comparative studies between the two rivers. It would be worthwhile to increase the number of fecal analyses of *Silurus glanis* after a sturgeon stocking event and to assess overall prey abundance in the corresponding section of the two rivers.

4.6 Conclusion

Our study highlighted the predation risk along the migratory pathway of *A. sturio*, which was considered to be high in freshwater and marine environments but low in the estuarine environment. Fishes, birds, and marine mammals were considered in this large-scale approach. We provided the first evaluation from field experiments of predation rate in freshwater on 3- and 11-month-old stocked individuals. Predation was evaluated as moderate to high in the watersheds considered. The captive origin of these individuals, with little training before release, limiting anti-predator behavior, is proposed as an explanation for the observed predation rates, and propositions of mitigation measures are listed. In addition, the molecular analysis of the feces revealed a high predation pressure on eels and a low occurrence of predation on juvenile shad by Wels catfish. We considered the methodologies used in this study (literature analysis, telemetry tools with predation tags, and molecular analysis of predator feces) efficient and transposable for other juveniles of diadromous species. Together, these complementary approaches provide a robust framework for improving our understanding of predation risks and guiding future conservation efforts.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding author.

Ethics statement

The animal study was approved by National Ethic Committee of Animal Use for Scientific Purposes (authorization APAFIS 53804-202502191153957v3 from the French Ministry of Higher Education and Research). The study was conducted in accordance with the local legislation and institutional requirements.

Author contributions

M-LA: Project administration, Funding acquisition, Data curation, Writing – original draft, Supervision, Conceptualization,

Methodology. JT: Writing – original draft, Formal analysis, Visualization, Data curation. TD: Investigation, Writing – review & editing. FB: Formal analysis, Writing – original draft, Data curation. FD: Investigation, Writing – review & editing. BL: Investigation, Writing – review & editing. CR: Investigation, Writing – review & editing, Data curation. FL: Investigation, Writing – review & editing, Resources. VL: Supervision, Writing – review & editing. GL: Writing – review & editing, Methodology, Supervision.

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References

- Acolas, M. L., Davail, B., Gonzalez, P., Jean, S., Clérandeau, C., Morin, B., et al. (2020). Health indicators and contaminant levels of a critically endangered species in the Gironde estuary, the European sturgeon. *Environ. Sci. Pollut. Res.* 27, 3726–3745. doi: 10.1007/s11356-019-05139-5
- Acolas, M. L., Rochard, E., Le Pichon, C., and Rouleau, E. (2012). Downstream migration patterns of one-year-old hatchery-reared European sturgeon (*Acipenser sturio*). *J. Exp. Mar. Biol. Ecol.* 430–431, 68–77. doi: 10.1016/j.jembe.2012.06.026
- Adam, G., Lauronce, V., Rochard, E., Acolas, M. L., Souben, J., Tesseyre, D., et al. Plan national d'actions en faveur de l'esturgeon européen *Acipenser sturio* 2020-2029. La Défense, France: Ministère de la Transition écologique et solidaire. (2019).
- Aguilar, R., Ogburn, M. B., Driskell, A. C., Weigt, L. A., Groves, M. C., and Hines, A. H. (2017). Gutsy genetics: identification of digested piscine prey items in the stomach contents of sympatric native and introduced warmwater catfishes via DNA barcoding. *Environ. Biol. Fish.* 100, 325–336. doi: 10.1007/s10641-016-0523-8

Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fmars.2026.1724287/full#supplementary-material>

- Allen, W. W., Hemmings, S. E., and Johnson, S. V. (2015). "Acoustic tag having a digestible fuse," in *United States brevet US9095122B2*. Available online at: <https://patents.google.com/patent/US9095122/en>. (Accessed August 4, 2015)
- Aloo, P. A., Njiru, J., Balirwa, J. S., and Nyamweya, C. S. (2017). Impacts of Nile perch, *Lates niloticus*, introduction on the ecology, economy and conservation of lake Victoria, East Africa. *Lks. Reserv.: Sci. Policy Manage. For. Sustain. Use* 22, 320–333. doi: 10.1111/lre.12192
- Álvarez, D., and Nicieza, A. G. (2003). Predator avoidance behavior in wild and hatchery-reared brown trout: the role of experience and domestication. *J. Fish. Biol.* 63, 1565–1577. doi: 10.1111/j.1095-8649.2003.00267.x
- Andersen, N. G., Chabot, D., and Couturier, C. S. (2016). Modelling gastric evacuation in gadoids feeding on crustaceans. *J. Fish. Biol.* 88, 1886–1903. doi: 10.1111/jfb.12976
- Anras (2025). *Sturio*. Available online at: <https://eng-eabx.bordeaux-aquitaine.hub.inrae.fr/content/download/5356/56565?version=2>. (Accessed December 3, 2025)
- Araki, H., Berejikian, B. A., Ford, M. J., and Blouin, M. S. (2008). Fitness of hatchery-reared salmonids in the wild. *Evol. Appl.* 1, 342–355. doi: 10.1111/j.1752-4571.2008.00026.x
- Arthington, A. H., Dulvy, N. K., Gladstone, W., and Winfield, I. J. (2016). Fish conservation in freshwater and marine realms: status, threats and management. *Aquat. Conserv.-Mar. Freshw. Ecosyst.* 26, 838–857. doi: 10.1002/aqc.2712
- Baglinière, J.L., Sabatié, M.R., Rochard, E., Alexandrino, P., and Aprahamian, M.W. (2003). The allis shad *Alosa alosa*: biology, ecology, range and status of populations. In: J.L. Baglinière and P. Elie, editors. *Les aloses (Alosa alosa et Alosa fallax spp.): écobiologie et variabilité des populations*. Paris: INRA-Cemagref.
- Baird, S. E., Steel, A. E., Cocherell, D. E., Poletto, J. B., Follenfant, R., and Fangue, N. A. (2020). Experimental assessment of predation risk for juvenile green sturgeon, *Acipenser medirostris*, by two predatory fishes. *J. Appl. Ichthyol.* 36, 14–24. doi: 10.1111/jai.13990
- Beland, K. F., Kocik, J. F., VandeSande, J., and Sheehan, T. F. (2001). Striped bass predation upon Atlantic salmon smolts in Maine. *Northeast. Nat.* 8, 267–274. doi: 10.1656/1092-6194(2001)008[0267:SBPUAS]2.0.CO;2
- Berger-Tal, O., Blumstein, D. T., and Swaisgood, R. R. (2019). Conservation translocations: a review of common difficulties and promising directions. *Anim. Conserv.* 23, 121–131. doi: 10.1111/acv.12534
- Bouletreau, S., Carry, L., Meyer, E., Fillous, D., Menchi, O., Mataix, V., et al. (2020). High predation of native sea lamprey during spawning migration. *Sci. Rep.* 10, 6122. doi: 10.1038/s41598-020-62916-w
- Bouletreau, S., Fauvel, T., Laventure, M., Delacour, R., Bouyssonnie, W., Azemar, F., et al. (2021). The giants' feast': predation of the large introduced European catfish on spawning migrating Allis Shads. *Aquat. Ecol.* 55, 75–83. doi: 10.1007/s10452-020-09811-8
- Bouletreau, S., Gaillagot, A., Carry, L., Tétard, S., De Oliveira, E., and Santoul, F. (2018). Adult Atlantic salmon have a new freshwater predator. *PLoS One* 13, e0196046. doi: 10.1371/journal.pone.0196046
- Braithwaite, V. A., and Salvanes, A. G. V. (2005). Environmental variability in the early rearing environment generates behaviorally flexible cod: implications for rehabilitating wild populations. *Proc. R. Soc. Lond.* 272, 1107–1113. doi: 10.1098/rspb.2005.3062
- Breve, N. W. P., Urbanovych, K., Murk, A. T. J., Van Zwieten, P. A. M., Nagelkerke, L. A. J., and Kraan, M. (2024). Fishers' willingness to report incidental bycatches of endangered, threatened and protected fish species: the case of European sturgeon in the Northeast Atlantic ocean. *Mar. Policy* 162, 106056. doi: 10.1016/j.marpol.2024.106056
- Bridger, C. J., and Booth, R. K. (2003). The effects of biotelemetry transmitter presence and attachment procedures on fish physiology and behavior. *Rev. Fish. Sci.* 11, 13–34. doi: 10.1080/16226510390856510
- Brose, U., Jonsson, T., Berlow, E. L., Warren, P., Banasek-Richter, C., Blanchard, J. L., et al. (2006). Consumer–resource body-size relationships in natural food webs. *Ecology* 87, 2411–2417. doi: 10.1890/0012-9658
- Cámara-Ruiz, M., Santo, C. E., Gessner, J., and Wuertz, S. (2019). How to improve foraging efficiency for restocking measures of juvenile Baltic sturgeon (*Acipenser oxyrinchus*). *Aquaculture* 502, 12–17. doi: 10.1016/j.aquaculture.2018.12.021
- Carrera-García, E., Rochard, E., and Acolas, M. L. (2017a). European sturgeon (*Acipenser Sturio* L.) young of the year performance in different rearing environments - study within a stocking program. *Environ. Biol. Fish.* 99, 887–901. doi: 10.1007/s10641-016-0531-8
- Carrera-García, E., Rochard, E., and Acolas, M. L. (2017b). Effects of rearing practice on post-release young-of-the-year behavior: *Acipenser Sturio* early life in freshwater. *Endanger. Species. Res.* 34, 269–281. doi: 10.3354/esr00854
- Castagné, P., Martignac, F., Santoul, F., Blanchet, S., and Loot, G. (2024). Development of a duplex ddPCR assay for detection of the endangered European eels in the diet of the invasive European catfish. *Knowl. Manage. Aquat. Syst.* 425, 24. doi: 10.1051/kmae/2024020
- Charbonnel, A., Lassalle, G., Lambert, P., Quinton, E., Gessner, J., Rochard, E., et al. (2024). Travelling away from home? Joining global change and recovery scenarios to anticipate the marine distribution of diadromous fish. *Ecol. Indic.* 160, 111762. doi: 10.1016/j.ecolind.2024.111762
- Chèvre, P., Saint-Sevin, J., Mercier, D., Jacobs, L., and Williot, P. (2011). Chapter 33: Recent progress in larval rearing of the European sturgeon, *Acipenser sturio*. In: P. Williot, E. Rochard, N. Desse-Berset, F. Kirschbaum and J. Gessner, editors. *Biology and conservation of the Atlantic European sturgeon Acipenser sturio L. 1758*. Berlin, Heidelberg, Germany: Springer.
- Cooke, S. J., Hinch, S. G., Wikelski, M., Andrews, R. D., Kuchek, L. J., Wolcott, T. G., et al. (2004). Biotelemetry: a mechanistic approach to ecology. *Trends Ecol. Evol.* 19, 334–343. doi: 10.1016/j.tree.2004.04.003
- Cooke, S. J., Midwood, J. D., Thiem, J. D., Klimley, P., Lucas, M. C., Thorstad, E. B., et al. (2013). Tracking animals in freshwater with electronic tags: past, present and future. *Anim. Biotelem.* 1, 5. doi: 10.1186/2050-3385-1-5
- Crossman, J. A., Scribner, K. T., Forsythe, P. S., and Baker, E. A. (2018). Lethal and non-lethal effects of predation by native fish and an invasive crayfish on hatchery-reared age-0 lake sturgeon (*Acipenser Fulvescens Rafinesque 1817*). *J. Appl. Ichthyol.* 34, 322–330. doi: 10.1111/jai.13558
- Daniels, J., Sutton, S., Webber, D., and Carr, J. (2019). Extent of predation bias present in migration survival and timing of Atlantic salmon smolt (*Salmo salar*) as suggested by a novel acoustic tag. *Anim. Biotelem.* 7, 16. doi: 10.1186/s40317-019-0178-2
- Delage, N., Couturier, B., Jatteau, P., Larcher, T., Ledevin, M., Goubin, H., et al. (2020). Oxythermal window drastically constrains the survival and development of European sturgeon early life phases. *Environ. Sci. Pollut. Res.* 27, 3651–3660. doi: 10.1007/s11356-018-4021-8
- Deng, Z. D., Carlson, T. J., Li, H., Xiao, J., Myjak, M. J., Lu, J., et al. (2015). An injectable acoustic transmitter for juvenile salmon. *Sci. Rep.* 5, 8111. doi: 10.1038/srep08111
- French, W. E., Graeb, B. D. S., Chipps, S. R., Bertrand, K. N., Selch, T. M., and Klumb, R. A. (2010). Vulnerability of age-0 pallid sturgeon *Scaphirhynchus albus* to fish predation. *J. Appl. Ichthyol.* 26, 6–10. doi: 10.1111/j.1439-0426.2009.01356.x
- Gadomski, D. M., and Parsley, M. J. (2005). Vulnerability of young white sturgeon, *Acipenser Transmontanus*, to predation in the presence of alternative prey. *Environ. Biol. Fish.* 74, 389–396. doi: 10.1007/s10641-005-3038-2
- Gaeta, J. W., Ahrenstorff, T. D., Diana, J. S., Fetzer, W. W., Jones, T. S., Lawson, Z. J., et al. (2018). Go big or don't? A field-based diet evaluation of freshwater piscivore and prey fish size relationships. *PLoS One* 13, e0194092. doi: 10.1371/journal.pone.0194092
- Gessner, J., Tautenhahn, M., Von Nordheim, H., and Borchers, T. German action plan for conservation and restoration of the European sturgeon (*Acipenser sturio*). Bonn, Germany: Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU). (2010).
- Gibson, A. J. F., Halfyard, E. A., Bradford, R. G., Stokesbury, M. J. W., and Redden, A. M. (2015). Effects of predation on telemetry-based survival estimates: insights from a study on endangered Atlantic salmon smolts. *Can. J. Fish. Aquat. Sci.* 72, 728–741. doi: 10.1139/cjfas-2014-0245
- Gravenhof, D. A., Wuellner, M. R., Renner, E. A., and Fincel, M. J. (2024). Estimating predation rates of stocked juvenile chinook salmon using novel acoustic predation transmitters. *North Am J Fish Manage.* 44(2):438–448. doi: 10.1002/nafm.10992
- Gu, L., Qin, S., Sun, Y., Huang, J., Akbar, S., Zhang, L., et al. (2022). Coping with antagonistic predation risks: predator-dependent unique responses are dominant in *Ceriodaphnia Cornuta*. *Mol. Ecol.* 31, 3951–3962. doi: 10.1111/mec.16550
- Guillerault, N., Bouletreau, S., Iribar, A., Valentini, A., and Santoul, F. (2017). Application of DNA metabarcoding on feces to identify European catfish *Silurus glanis* diet. *J. Fish. Biol.* 90, 2214–2219. doi: 10.1111/jfb.13294
- Guillerault, N., Delmotte, S., Bouletreau, S., Lauzeral, C., Poulet, N., and Santoul, F. (2015). Does the non-native European catfish *Silurus Glanis* threaten French river fish populations? *Freshw. Biol.* 60, 922–928. doi: 10.1111/fwb.12545
- Halfyard, E. A., Webber, D., Del Papa, J., Leadley, I., Kessel, S. T., Colborne, S. F., et al. (2017). Evaluation of an acoustic telemetry transmitter designed to identify predation events. *Methods Ecol. Evol.* 8, 1063–1071. doi: 10.1111/2041-210X.12726
- Hall, C. J., Jordaan, A., and Frisk, M. G. (2012). Centuries of anadromous forage fish loss: consequences for ecosystem connectivity and productivity. *Bioscience* 62, 723–731. doi: 10.1525/bio.2012.62.8.5
- Hansen, A. G., and Beauchamp, D. A. (2014). Effects of prey abundance, distribution, visual contrast and morphology on selection by a pelagic piscivore. *Freshw. Biol.* 59, 2328–2341. doi: 10.1111/fwb.12436
- Hasselman, D. J., and Limburg, K. E. (2012). Alosine restoration in the 21st century: challenging the status quo. *Mar. Coast. Fish.: Dyn. Manag. Ecosyst. Sci.* 4, 174–187. doi: 10.1080/19425120.2012.675968
- Hou, Y., Chen, S., Zheng, Y., Zheng, X., and Lin, J. M. (2023). Droplet-based digital PCR (ddPCR) and its applications. *TrAC. Trends Anal. Chem.* 158, 116897. doi: 10.1016/j.trac.2022.116897
- Huntingford, F. A. (2004). Implications of domestication and rearing conditions for the behavior of cultivated fishes. *J. Fish. Biol.* 65, 122–142. doi: 10.1111/j.0022-1112.2004.00562.x
- Huntingford, F. A., and Adams, C. (2005). Behavioral syndromes in farmed fish: implications for production and welfare. *Behavior* 142, 1207–1221. Available online at: <http://www.jstor.org/stable/4536297>. (Accessed October 2005)

- Hussey, N. E., Kessel, S. T., Aarestrup, K., Cooke, S. J., Cowley, P. D., Fisk, A. T., et al. (2015). Aquatic animal telemetry: A panoramic window into the underwater world. *Sci. (New York N.Y.)* 348, 1255642. doi: 10.1126/science.1255642
- Hutchison, M., Butcher, A., and Norris, A. (2023). Conditioning to predators improves survival of stocked murray cod (*Maccullochella Pelelii*) fingerlings. *Mar. Freshw. Res.* 74, 1039–1049. doi: 10.1071/MF22242
- IUCN/SSC. *Guidelines for reintroductions and other conservation translocations*. Gland, Switzerland: IUCN Species Survival Commission. (2013).
- Jacoby, D. M. P., and Piper, A. T. (2025). What acoustic telemetry can and cannot tell us about fish biology. *J. Fish. Biol.* 106, 1260–1284. doi: 10.1111/jfb.15588
- Jego, S., Gazeau, C., Jatteau, P., Elie, P., and Rochard, E. (2002). Les frayères potentielles de l'esturgeon européen *Acipenser Sturio* L. 1758 dans le bassin Garonne-Dordogne. Méthodes d'investigation, état actuel et perspectives. *Bull. Fr. La. Pêche La. Piscic.* 365–366, 487–505. doi: 10.1051/kmae:2002047
- Johnsson, J. I., Brockmark, S., and Naeslund, J. (2014). Environmental effects on behavioral development consequences for fitness of captive-reared fishes in the wild. *J. Fish. Biol.* 85, 1946–1971. doi: 10.1111/jfb.12547
- Kennedy, R. J., Barry, J., Boyd, A., and Allen, M. (2025). Does phenology influence predation rate on Salmo trutta parr during lake migration? *J. Fish. Biol.* 106, 1334–1343. doi: 10.1111/jfb.15719
- Klinard, N. V., and Matley, J. K. (2020). Living until proven dead: addressing mortality in acoustic telemetry research. *Rev. Fish. Biol. Fish.* 30, 485–499. doi: 10.1007/s11160-020-09613-z
- Klinard, N. V., Matley, J. K., Fisk, A. T., and Johnson, T. B. (2019). Long-term retention of acoustic telemetry transmitters in temperate predators revealed by predation tags implanted in wild prey fish. *J. Fish. Biol.* 95, 1512–1516. doi: 10.1111/jfb.14156
- Klinard, N. V., Vandergoot, C. S., Briggs, A. S., Elliott, C. W., Faust, M. D., Fielder, D. G., et al. (2025). Integrating acoustic telemetry research into management: successes and challenges in the Laurentian Great Lakes. *Can. J. Fish. Aquat. Sci.* 82, 1–20. doi: 10.1139/cjfas-2024-0335
- Lamour, M., Le Barh, R., Merg, M. L., Grasso, F., Quinton, E., Rochard, E., et al. (2024). Using simulated environmental variables to assess the seasonal estuarine habitat selection of a critically endangered anadromous species (*Acipenser sturio*). *Estuar. Coast. Shelf. Sci.* 298, 108656. doi: 10.1016/j.ecss.2024.108656
- Lauriou, A., Huvener, C., Papastamatiou, Y., Planes, S., Ballesta, L., and Mourier, J. (2025). Abiotic drivers of the space use and activity of Gray Reef Sharks *Carcharhinus Amblyrhynchus* in a dynamic tidal environment. *J. Fish. Biol.* 106, 1520–1530. doi: 10.1111/jfb.15825
- Lennox, R. J., Mastrodimitropoulos, P. M. B., Flávio, H., Cyr, K., Deng, Z. D., Cooke, S. J., et al. (2025). How small can they go? Microelectronic tags for movement ecology of small aquatic organisms. *Fisheries* 50, 209–218. doi: 10.1093/fshmag/vua002
- Lennox, R. J., Nilsen, C. I., Nash, A., Hanssen, E. M., Johannesen, H. L., Berhe, S., et al. (2021). Laboratory and field experimental validation of two different predation sensors for instrumenting acoustic transmitters in fisheries research. *Fisheries* 46, 565–573. doi: 10.1002/fsh.10669
- Long, W. C., Daly, B. J., and Cumiskey, P. A. (2024). Optimizing release strategies for red king crab stock enhancement: effects of release timing. *Fish. Res.* 274, 106975. doi: 10.1016/j.fishres.2024.106975
- Lucas, J., Lefrançois, C., Gesset, C., Budzinski, H., Labadie, P., Baudrimont, M., et al. (2021). Effects of metals and persistent organic pollutants on the fitness and health of juveniles of the endangered European sturgeon *Acipenser Sturio* exposed to water and sediments of the Garonne and Dordogne rivers. *Ecotoxicol. Environ. Saf.* 265, 112720. doi: 10.1016/j.ecoenv.2021.112720
- Marques, V., Loot, G., Blanchet, S., Miaud, C., Planes, S., Peyran, C., et al. (2024). Optimizing detectability of the endangered fan mussel using eDNA and ddPCR. *Ecol. Evol.* 14, e10807. doi: 10.1002/ece3.10807
- Marshall, C. A., and Wund, M. A. (2017). The evolution of correlations between behavioral and morphological defense in Alaskan three spine stickleback fish (*Gasterosteus Aculeatus*): evidence for trait compensation and co-specialization. *Evol. Ecol. Res.* 18 (3), 1–15 305–322.
- Matley, J. K., Klinard, N. V., Barbosa Martins, A. P., Aarestrup, K., Aspillaga, E., Cooke, S. J., et al. (2022). Global trends in aquatic animal tracking with acoustic telemetry. *Trends Ecol. Evol.* 37, 79–94. doi: 10.1016/j.tree.2021.09.001
- McMillan, J. R., Morrison, B., Chambers, N., Ruggerone, G., Bernatchez, L., Stanford, J., et al. (2023). A global synthesis of peer-reviewed research on the effects of hatchery salmonids on wild salmonids. *Fish. Manage. Ecol.* 30, 446–463. doi: 10.1111/fme.12643
- Melnichuk, M. C., Christensen, V., and Walters, C. J. (2013). Meso-scale movement and mortality patterns of juvenile coho salmon and steelhead trout migrating through a coastal fjord. *Environ. Biol. Fish.* 96, 325–339. doi: 10.1007/s10641-012-9976-6
- Moncada, M., Nogueira, S., Ribeiro, D., Gago, J., Rodrigues, M., Alves, M. J., et al. (2025). Hidden in the gut: metabarcoding reveals overlooked predation by the invasive European catfish (*Silurus Glanis*). *J. Fish. Biol.* 1–15 doi: 10.1111/jfb.70152
- Näslund, J. (2021). Reared to become wild-like: addressing behavioral and cognitive deficits in cultured aquatic animals destined for stocking into natural environments—a critical review. *Bull. Mar. Sci.* 97, 489–538. doi: 10.5343/bms.2020.0039
- Oliver, M. D., Stewart, R., Mills, D., Macdiarmid, A. B., and Gardner, C. (2005). Stock enhancement of rock lobsters (*Jasus Edwardsii*): timing of predation on naive juvenile lobsters immediately after release. *N. Z. J. Mar. Freshw. Res.* 39, 391–397. doi: 10.1080/00288330.2005.9517320
- Olla, B. L., Davis, M. W., and Ryer, C. H. (1998). Understanding how the hatchery environment represses or promotes the development of behavioral survival skills. *Bull. Mar. Sci.* 62, 531–550. Available online at: <http://www.ingentaconnect.com/content/umrsmas/bullmar/1998/00000062/00000002/art00016>. (Accessed March 1, 1998)
- Podda, C., Culurgioni, J., Diciotti, R., Palmas, F., Amilhat, E., Faliex, E., et al. (2023). Exploring European eel *Anguilla Anguilla* (L.) habitat differences using otolith analysis in central-Western Mediterranean rivers and coastal lagoons from Sardinia. *Fishes* 8, 386. doi: 10.3390/fishes8080386
- Polyakov, A. Y., Quinn, T. P., Myers, K. W., and Berdahl, A. M. (2022). Group size affects predation risk and foraging success in Pacific salmon at sea. *Sci. Adv.* 8, eabm7548. doi: 10.1126/sciadv.abm7548
- Rochard, E., Lepage, M., and Meauzé, L. (1997). Identification et caractérisation de l'aire de répartition marine de l'esturgeon européen *Acipenser sturio* à partir de déclarations de captures. *Aquat. Liv. Resour.* 10, 101–109. doi: 10.1051/alr:1997011
- Roques, S., Berrebi, P., Rochard, E., and Acolas, M. L. (2018). Genetic monitoring for the successful re-stocking of a critically endangered diadromous fish with low diversity. *Biol. Conserv.* 221, 91–102. doi: 10.1016/j.biocon.2018.02.032
- Salvanes, A. G. V., and Braithwaite, V. (2006). The need to understand the behavior of fish reared for mariculture or restocking. *ICES. J. Mar. Sci.* 63, 346–354. doi: 10.1016/j.icesjms.2005.11.010
- Schultz, A., Afentoulis, V., Yip, C., and Johnson, M. (2017). Efficacy of an acoustic tag with predation detection technology. *North Am. J. Fish. Manage.* 37, 574–581. doi: 10.1080/02755947.2017.1290720
- Seddon, P. J., Griffiths, C. J., Soorae, P. S., and Armstrong, D. P. (2014). Reversing defaunation: restoring species in a changing world. *Science* 345, 406–412. doi: 10.1126/science.1251818
- Shave, C., Townsend, C., and Crowl, T. (1994). Antipredator behaviors of a fresh-water crayfish (*Paranephrops Zealandicus*) to a native and an introduced predator. *N. Z. J. Ecol.* 18 (1), 1–10 1–10.
- Shorgan, M. B., Reid, H. B., Ivanova, S. V., Fisk, A. T., Cooke, S. J., and Raby, G. D. (2025). Validation of a new acoustic telemetry transmitter for the study of predation events in small fishes. *J. Fish. Biol.* 106, 1531–1539. doi: 10.1111/jfb.15827
- Simkins, A. T., Sutherland, W. J., Dicks, L. V., Hilton-Taylor, C., Grace, M. K., Butchart, S. H. M., et al. (2025). Past conservation efforts reveal which actions lead to positive outcomes for species. *PLoS Biol.* 23, e3003051. doi: 10.1371/journal.pbio.3003051
- Smith, G., Boyd, A., Dayer, C., and Winter, K. (2008). Behavioral responses of American toad and bullfrog tadpoles to the presence of cues from the invasive fish, *Gambusia affinis*. *Fac. Publ.* 10(5), 743–748. doi: 10.1007/s10530-007-9166-1
- Steel, A. E., Hansen, M. J., Cocherell, D., and Fangue, N. A. (2019). Behavioral responses of juvenile white sturgeon (*Acipenser Transmontanus*) to manipulations of nutritional state and predation risk. *Environ. Biol. Fish.* 102, 817–827. doi: 10.1007/s10641-019-00873-8
- Sudo, H., Kajihara, N., and Fujii, T. (2008). Predation by the swimming crab *Charybdis japonica* and piscivorous fishes: a major mortality factor in hatchery-reared juvenile Japanese flounder *Paralichthys olivaceus* released in Mano Bay, Sado Island, Japan. *Fish. Res.* 89, 49–56. doi: 10.1016/j.fishres.2007.08.012
- Symondson, W. O. C. (2002). Molecular identification of prey in predator diets. *Mol. Ecol.* 11, 627–641. doi: 10.1046/j.1365-294X.2002.01471.x
- Syvaranta, J., Cucherousset, J., Kopp, D., Crivelli, A., Cereghino, R., and Santoul, F. (2010). Dietary breadth and trophic position of introduced European catfish *Silurus glanis* in the river Tarn (Garonne River basin), southwest France. *Aquat. Biol.* 8, 137–144. doi: 10.3354/ab00220
- Szesciorcka, A. R., Demer, D. A., Santora, J. A., Forney, K. A., and Moore, J. E. (2023). Multiscale relationships between humpback whales and forage species hotspots within a large marine ecosystem. *Ecol. Appl.* 33, e2794. doi: 10.1002/eap.2794
- Thompson, B. C., Porak, W. F., Leone, E. H., and Allen, M. S. (2016). Using radiotelemetry to compare the initial behavior and mortality of hatchery-reared and wild juvenile Florida bass. *Trans. Am. Fish. Soc.* 145, 374–385. doi: 10.1080/00028487.2015.1131739
- Trainor, A. M., Schmitz, O. J., Ivan, J. S., and Shenk, T. M. (2014). Enhancing species distribution modeling by characterizing predator-prey interactions. *Ecol. Appl.* 24, 204–216. doi: 10.1890/13-0336.1
- Weinz, A. A., Matley, J. K., Klinard, N. V., Fisk, A. T., and Colborne, S. F. (2020). Identification of predation events in wild fish using novel acoustic transmitters. *Anim. Biotelem.* 8, 28. doi: 10.1186/s40317-020-00215-x
- Wilson, M., Acolas, M. L., Bégout, M. L., Madsen, P., and Wahlberg, M. (2008). Allis shad (*Alosa alosa*) exhibit an intensity-graded behavioral response when exposed to ultrasound. *J. Acoust. Soc. America Expr. Lett.* 124, 243–247. doi: 10.1121/1.2960899