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SHORT COMMUNICATION

# Contribution of anadromous fish to the diet of European catfish in a large river system

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**Abstract** Many anadromous fish species, when migrating from the sea to spawn in fresh waters, can potentially be a valuable prey for larger predatory fish, thereby efficiently linking these two ecosystems. Here, we assess the contribution of anadromous fish to the diet of European catfish (*Silurus glanis*) in a large river system (Garonne, southwestern France) using stable isotope analysis and allis shad (*Alosa alosa*) as an example of anadromous fish. Allis shad caught in the Garonne had a very distinct marine $\delta^{13}C$ value, over 8‰ higher after lipid extraction compared to the mean $\delta^{13}C$ value of all other potential freshwater prey fish. The $\delta^{13}C$ values of European catfish varied considerably between these two extremes and some individuals were clearly specializing on freshwater prey, whereas others specialized on anadromous fish. The mean contribution of anadromous fish to the entire European catfish population was estimated to be between 53% and 65%, depending on the fractionation factor used for $\delta^{13}C$.

**Keywords** *Alosa alosa* · Anadromous fish · Migration · Mixing model · *Silurus glanis* · Stable isotopes

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## Introduction

Anadromous fish migrating from the sea to fresh waters to spawn can be an important food source to freshwater consumers at higher trophic levels (Garman and Macko 1998), a nutrient source to the whole ecosystem (MacAvoy et al. 1998; Kohler et al. 2008) and even to the offspring of these migrating fish (Bilby et al. 1998). Since many anadromous fish are also relatively large-bodied, their mass migrations may present an important food source to large-bodied predatory fish, thereby effectively linking marine and freshwater food webs. European catfish (*Silurus glanis*) is the largest European freshwater fish species and is native to Eastern Europe and western Asia but has been widely introduced throughout the Western Europe (Copp et al. 2009). Not much is known about the feeding ecology of European catfish outside its native range (Wysujack and Mehner 2005; Carol et al. 2007), but its main prey species are presumed to be mainly different cyprinids and bottom living fish species (Copp et al 2009). But as a large-bodied predator, European catfish could also utilize many anadromous species.

Stable isotope analysis (SIA) has been used to study animal migrations in terrestrial, marine, and freshwater ecosystems (McCarthy and Waldron 2000; Rubenstein and Hobson 2004; Harrod et al. 2005; Syväranta et al. 2008). Identifying migratory fish using SIA is easiest when the fish migrate between marine and fresh water systems, which differ greatly (up to 10−15‰) in their stable isotope values (Peterson and Fry 1987; Doucett et al. 1999). Marine food webs are typically enriched in the heavier carbon isotope ($^{13}C$) compared to freshwater food webs, and these distinct signatures are then taken up by the animals living in these ecosystems. Since it usually takes from several weeks to several months for the isotope ratios to change in fish muscle tissue (Hesslein et al. 1993), and because most of the change

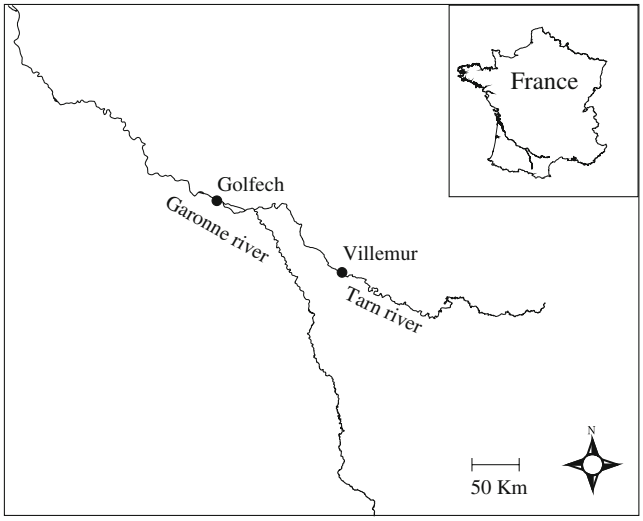


**Fig. 1** Map of the sampling areas in the River Garonne River near the town of Golfech, and in the River Tarn near the town of Villemur-sur-Tarn, southwestern France

is due to growth of the fish (Zuanon et al. 2006), non-growing migratory fish arriving in their new habitats can be identified by their divergent isotope values (MacAvoy et al. 2001).

The present study assesses the potential importance of anadromous fish in the diet of a large-bodied freshwater predatory fish. We used SIA to evaluate the contribution of marine derived carbon in the European catfish diet and underpinned the importance by comparing the data from a main river to its tributary, where damming has effectively prevented the migration of anadromous species.

## Materials and methods

The River Garonne, which is located in southwestern France (Fig. 1), has a very diverse fish community with many freshwater and some anadromous fish as potential prey species for European catfish. Most abundant of the freshwater species are cyprinids, mainly bleak (*Alburnus alburnus*), roach (*Rutilus rutilus*), rudd (*Scardinius erythrophthalmus*) and silver bream (*Abramis bjoerkna*). The anadromous species are allis shad (*Alosa alosa*), flathead mullet (*Mugil cephalus*) and sea lamprey (*Petromyzon marinus*) which migrate into the Garonne from the Atlantic Ocean. The River Tarn is a tributary of the Garonne and due to the presence of dams, anadromous fish cannot enter the Tarn, so upstream of the dams, the potential prey fish are mainly bleak, roach, and common bream (*Abramis brama*).

Specimens of European catfish and their potential prey fish were collected from the Garonne and the Tarn (Fig. 1) by local anglers during summer 2007. Both freshwater and marine prey were collected from the Garonne, but only allis shad was caught and analyzed to represent anadromous source. However, the $\delta^{13}C$ values of allis shad are a suitable approximation also for the other potential marine prey in the Garonne (Table 1). In addition, allis shad is a large-bodied (size range for migrating allis shad 48–61 cm, Lochet 2006) and an important anadromous species in the Garonne, although its numbers have recently been declining (Association Midago monitoring site at Golfech, http://www.migado.fr/php/Start.php). The total length (TL) of each fish was recorded, and a small piece of muscle tissue was dissected for SIA. Fin clips were used for catfish because these fish were released and stable isotopes of fin correlate closely with those of muscle tissue and allow non-lethal sampling for SIA (Jardine et al. 2005). All samples were oven dried (60°C for 48 h) and ground into a homogeneous powder using a mixer mill. Stable isotope analyses were undertaken at the Stable Isotopes in Nature Laboratory (University of New Brunswick, Canada) using a Carlo Erba NC2500 elemental analyser coupled to a Finnigan Mat Delta XP. Several laboratory standards (bass muscle, bovine liver, nicotinamide) were included in each analysis sequence to assure high precision of results.

**Table 1** Typical $\delta^{13}C$ values reported in the literature for anadromous prey and related fish species in the Garonne. Mean $\delta^{13}C$ values were searched from each reference (except for Drevnick et al. 2006, where only a range was given) and the values reported here are mean (±SD) when possible. The values have not been corrected for lipid content

| Species | $\delta^{13}C$ (‰) | Reference |
|---|---|---|
| Allis shad | −19.6±1.0 | F. Santoul (unpubl. data from River Loire); this study |
| Blueback shad (*A. aestivalis*) | −20.0±1.0 | Deegan and Garritt 1997; Garman and Macko 1998; MacAvoy et al. 1998, 2000 |
| Twaite shad (*A. fallax*) | −20.5 | Pasquaud 2006 |
| Alewife (*A. pseudoharengus*) | −18.5±0.6 | Garman and Macko 1998; MacAvoy et al. 2000 |
| American shad (*A. sapidissima*) | −20.2 | MacAvoy et al. 2000 |
| Thinlip mullet (*Liza ramado*) | −16.1 | Pasquaud 2006 |
| River lamprey (migrating) (*Lampetra fluviatilis*) | −19.8 | Adams et al. 2008 |
| Sea lamprey | −19.3 to −16.0 | Drevnick et al. 2006 |

Lipids are known to be $^{13}C$ depleted (DeNiro and Epstein 1977), and variable lipid content of tissues can introduce bias in SIA interpretations (Kiljunen et al. 2006). Since the muscle tissue of allis shad was notably more lipid-rich (higher and more variable C:N ratios, Table 2) than the muscle tissue of other potential prey, we corrected the $\delta^{13}C$ values using a recent revision of a lipid normalization model (Kiljunen et al. 2006). The model works best for fish muscle tissue and, since the European catfish fin clip samples had low and homogeneous C:N ratios, we did not apply it for fin samples.

We calculated diet contributions of anadromous species to European catfish individuals in the Garonne using $\delta^{13}C$ values of freshwater and anadromous prey in a two-source mixing model. We used the potential prey fish $\delta^{13}C$ values to represent end-member (source) values by calculating a mean $\delta^{13}C$ value for bleak, roach, rudd, and white bream (freshwater source) and allis shad (anadromous source). Since isotope mixing models can be highly sensitive to uncertainly surrounding their end-member mean values, we used a mixing model by Phillips and Gregg (2001), which incorporates the observed variation in source isotope values to calculate 95% confidence levels for contribution estimates. Mixing models are also sensitive to the trophic fractionation factors applied to calculate source contributions. The fractionation of $\delta^{13}C$ is assumed to be 0−1‰ (Peterson and Fry 1987) between each trophic step, thus we tested using 0, 0.5, and 1 ‰ factors in our calculations.

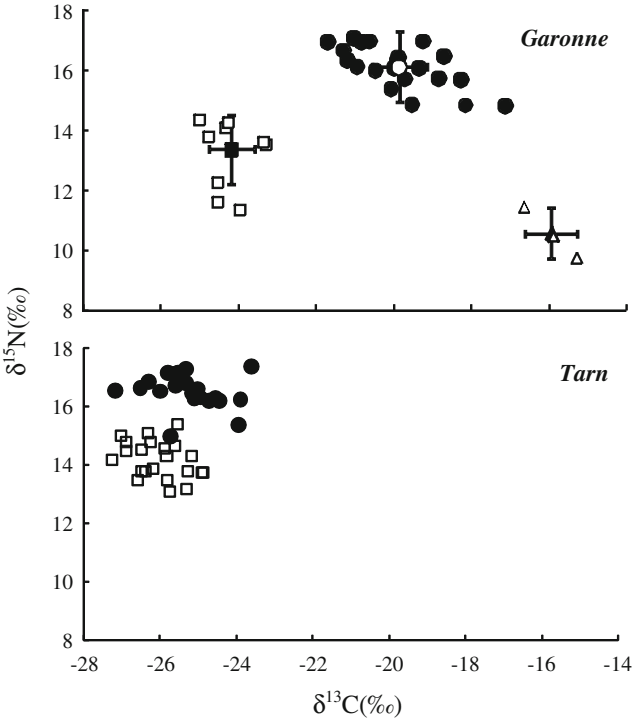


**Fig. 2** Carbon and nitrogen stable isotope biplots of European catfish and their potential prey fish (lipid extracted values) from the rivers Garonne (*upper panel*) and Tarn (*lower panel*). Individual values are given for European catfish (*filled circle*), allis shad (*open upright triangle*), and the freshwater prey fish (*open square*). Mean values and SDs used in the mixing model are given for allis shad (*closed upright triangle*), freshwater prey fish (*closed square*), and European catfish (*open circle*)

## Results

The $\delta^{13}C$ values of anadromous allis shad caught in the Garonne reflected a clear marine signature and were over 5‰ higher than freshwater species. Lipid normalization had negligible impacts on freshwater fish $\delta^{13}C$ values but a greater impact on allis shad $\delta^{13}C$ values, increasing the difference in $\delta^{13}C$ values between freshwater and anadromous prey to over 8‰ (Table 2). The freshwater prey fish in the Garonne and Tarn differed only slightly in their stable isotope values, those in the Tarn having somewhat lower $\delta^{13}C$ (≈2‰) and $\delta^{15}N$ values (≈1‰). European catfish individuals caught in the Garonne had considerably more enriched mean $\delta^{13}C$ values than those caught from the Tarn (Table 2, Fig. 2). The $\delta^{13}C$ values of in the Garonne were also associated with notably greater variation (Fig. 2). European catfish had consistently higher $\delta^{15}N$ values in both rivers compared to all prey fish highlighting their position at the top of the food chain.

Using either a 0, 0.5, or 1‰ trophic fractionation factors for $\delta^{13}C$ the calculations resulted in following mean (±95 % confidence limits) proportions (0–1) of anadromous species in European catfish diet; 0.53 (0.44–0.62), 0.59 (0.49–0.68) and 0.65 (0.54–0.75). Contributions for individual Europe-

**Table 2** Total length (TL) and stable isotope values of analyzed fish groups from the rivers Garonne and Tarn. $\delta^{13}C_{LE}$ indicates lipid normalized values

| | *n* | TL (mm) | $\delta^{13}C$ (‰) | $\delta^{15}N$ (‰) | C:N | $\delta^{13}C_{LE}$ (‰) |
|---|---|---|---|---|---|---|
| Garonne | | | | | | |
| European catfish | 21 | 1,522±282 | −19.8±1.2 | 16.1±0.7 | 3.2±0.1 | |
| Freshwater prey fish[a] | 9 | 131±35 | −24.6±0.6 | 13.2±1.1 | 3.2±0.1 | −24.2±0.6 |
| Allis shad | 3 | 517±29 | −19.3±0.9 | 10.6±0.9 | 6.3±2.1 | −15.9±0.7 |
| Tarn | | | | | | |
| European catfish | 22 | 635±398 | −25.2±0.9 | 16.6±0.7 | 3.4±0.3 | |
| Freshwater prey fish[a] | 24 | 148±43 | −26.3±0.9 | 14.1±0.6 | 3.0±0.1 | −26.2±0.9 |

[a] All potential freshwater prey fish species combined

All values reported are means (±SD)

an catfish in the Garonne varied widely from just over 0.30 to over 0.95, but there was only a weak and insignificant correlation between the size of European catfish individuals and contribution of anadromous species (Pearson $r_{21}$=0.35, $P$=0.116).

## Discussion

As expected, the freshwater fish in the Garonne differed considerably in their $\delta^{13}C$ values from allis shad, which migrates from the Atlantic Ocean to the Garonne to spawn. Lipid normalization of allis shad muscle tissues further increased the difference, allowing for a good separation of the two potential food sources of European catfish in the isotope mixing model. Our mixing model results indicated a considerable mean contribution (from 53% to 65% depending on fractionation factor) from anadromous fish to the diet of European catfish in the Garonne. Although only three individual allis shads were analyzed to represent the marine source, the clear $\delta^{13}C$ difference to other freshwater fish and the relatively low variation within these three individuals make them a reliable end-member for the mixing model. The Phillips and Gregg (2001) model clearly indicated that the difference between the isotope signatures of sources and the variation associated within them, were the factors most strongly affecting the resulting uncertainty estimates of diet proportions. In this study, the difference between the sources was large compared to the variation within them, hence increasing the sample sizes of source estimates would not have significantly increased the power of the model. Moreover, it is unlikely that having more individuals of allis shad would have affected the mean $\delta^{13}C$ value notably, since the typical reported $\delta^{13}C$ values for allis shad and other shad species, and for other potential marine prey in the Garonne, are almost identical (Table 1). The contribution from marine source was further ensured by comparing the stable isotope values between the Garonne and the Tarn, where the migration of anadromous fish is prevented by a dam. Although the mean size of European catfish caught in the Tarn was notably smaller than for those caught in the Garonne (Table 2), they occupied a trophic position consistent with their known feeding ecology (Wysujack and Mehner 2005; Copp et al. 2009) and both $\delta^{13}C$ and $\delta^{15}N$ values were in good agreement with the underlying freshwater prey. Also, the individuals of equal sizes from both rivers differed significantly in their $\delta^{13}C$ values (Mann–Whitney $U_{14,9}$= 52.5, $p$<0.001), and the individuals analyzed from the Tarn reflected a clear more negative freshwater $\delta^{13}C$ signature. European catfish in the Garonne also occupied an expected predatory trophic position, but the $\delta^{13}C$ values indicated more variation in their diet sources (Fig. 2). Increased isotope variance can reflect increased dietary breadth (Bearhop et al. 2004; Syväranta and Jones 2008) and is here likely a result of some European catfish individuals specializing more on the freshwater prey fish while others specialize more on anadromous fish. Moreover, allis shad and other anadromous prey may not be continuously available and European catfish might have to specialize more on the freshwater prey when anadromous prey are less abundant.

Our results clearly illustrate the importance of anadromous fish in the food web of the Garonne and its contribution to the diet of European catfish. The high contribution of marine carbon in tissues of European catfish also reflects the fact that anadromous prey is available at the time when the fish are growing and rapidly synthesizing new tissue. The Garonne is no exception in this, and allis shad and other anadromous fish are likely to be an important component of the food web in other large rivers as well, where their migration is not prevented. However, many anadromous fish populations have been severely declining throughout the Europe mainly due to water retention structures, overfishing, pollution, and deterioration of spawning grounds (Baglinière et al. 2003). Many of the anadromous fish species are now classified as vulnerable or endangered, and are listed in the Appendices of the EC Habitats Directive. In addition, future climate warming may increase the negative impacts on these fish populations (e.g., Lassalle et al. 2008). These factors may have unexpected but important implications to the ecosystems partly supported by anadromous fish, further increasing their conservational value.

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