

## *Is European catfish a threat to eels in southern France?*

AURELIA MARTINO<sup>a,\*</sup>, JARI SYVÄRANTA<sup>a,b</sup>, ALAIN CRIVELLI<sup>c</sup>, REGIS CEREGHINO<sup>a</sup> and FREDERIC SANTOUL<sup>a</sup>

<sup>a</sup>*EcoLab, Université de Toulouse, Toulouse, France*

<sup>b</sup>*Leibniz-Institute of Freshwater Ecology and Inland Fisheries, Berlin, Germany*

<sup>c</sup>*Station biologique de la Tour du Valat, Le Sambuc, Arles, France*

### ABSTRACT

1. European eel (*Anguilla anguilla*) is recognized as a critically endangered species in the northern hemisphere. Threats such as overfishing or pollution are well known as risks for eel populations. However, much less is known about the impact of introduced fish on European eels. In particular, introduced large-bodied predators could become new predators to eels.

2. The potential impact of European catfish (*Silurus glanis* L.) on an eel population in the Camargue, southern France was studied using a combination of stable isotope and gut content analyses.

3. Only large-bodied catfish (> 500 mm) can consume numerous fish prey. However, catfish mostly consumed crayfish (*Procambarus clarkii*), these prey items being found in 79% of the guts of the largest individuals. Eel was absent from the dissected catfish guts. A mixing model based on Bayesian inference revealed that catfish diet included only 5% (0–8.5%) of marine sources (both eel and mullet).

4. While local economic interests prompted ecological studies to assess whether catfish exerted a new and strong predatory pressure on eel, this study found that European catfish behaved as an opportunistic omnivore, and as such was not a direct threat as a predator on eel populations in the Camargue.

Copyright © 2011 John Wiley & Sons, Ltd.

Received 4 October 2010; Revised 7 January 2011; Accepted 5 February 2011

KEY WORDS: European eel; conservation; European catfish; stable isotope analysis; gut contents; Camargue

### INTRODUCTION

Among threatened aquatic animals, the European eel (*Anguilla anguilla* L., hereafter 'eel') is the focus of many conservation studies in the northern hemisphere (Dekker, 2000, 2003a; Haro *et al.*, 2000; Wirth and Bernatchez, 2003; Allen *et al.*, 2006). Many factors, closely related to its economic interest and/or destruction of its physical habitats by man, have led to its decline (Castonguay *et al.*, 1994; Loste and Dusserre, 1996; Moriarty and Dekker, 1997; Bevacqua *et al.*, 2007; Aprahamian and Walker, 2008). Eel is classified as Critically Endangered (CR) on the Red List of Threatened Animals of the International Union for Conservation of Nature (IUCN), and it is a listed species in Annex II of the European Community Habitats Directive 92/43/EEC.

Although fish invasions are recognized as a serious threat to freshwater ecosystems (Dudgeon *et al.*, 2006), much less is known about the impact of introduced fish on eels.

In particular, introduced predatory fish species can have serious implications for native species and food web structure (Vander Zanden *et al.*, 1999; Eby *et al.*, 2006; Copp *et al.*, 2009). More specifically, it may be assumed that introduced large-bodied predators (larger than native predators) could become new predators to adult native fish including eels, which normally reach a size-refuge against native predators such as pike. European catfish (*Silurus glanis* L., hereafter 'catfish') is the world's third largest freshwater fish and the largest European freshwater fish (Stone, 2007). Native to eastern Europe and western Asia, this catfish has been widely introduced outside its native areas owing to its popularity as a sport fish and in aquaculture (Copp *et al.*, 2009). In its introduced areas, adult catfish can be at least twice as large as the native piscivorous fishes but its potential impacts on other species are not always thoroughly understood (Copp *et al.*, 2009; Syväranta *et al.*, 2010) and may even depend on the catfish invasion stage (Carol *et al.*, 2009).

\*Correspondence to: Aurelia Martino, EcoLab, UMR 5245 (CNRS-UPS-INPT), Université de Toulouse, bât 4R3, 118, route de Narbonne, 31062 Toulouse Cedex 9, France. E-mail: aurelia.martino@gmail.com

In southern France, catfish was introduced in the Rhône delta in 1981–1982 (Rosecchi *et al.*, 1997). Subsequently, eel populations were found to decrease (COGEPOMI, 2006), which has raised concerns about possible adverse effects of catfish on eels. Specifically, local anglers and environmental managers postulated that catfish exerted a new and strong predatory pressure on eels. Beyond local concerns, this situation provides context to assess the impact of introduced freshwater predators on endangered anadromous fish such as eels, and, implicitly, on patrimonial and economic interests.

This study used a combination of gut content and stable isotope analyses (SIA) to evaluate the contribution of eel to the diet of catfish. The specific aim was to assess whether catfish, by predation, can adversely affect eel populations.

## MATERIAL AND METHODS

### Study area and sampling

The study area was located in the Rhône delta (Figure 1), southern France (43°34' N; 4°34' E). The Fumemorte Canal (depth = 1 m, width = 14 m) collects water from a complex network of channels spreading over 68 km<sup>2</sup> (Chauvelon, 1998). The main channel is 14.6 km long and, with the largest tributaries included, it forms a 32.5 km network. The Fumemorte Canal presents a raisable barrier designed to limit entrance of salt water. When the water flows from the nearby Vaccarès lagoon and submerges this barrier, most aquatic organisms can freely move from the canal to the lagoon and vice versa (Rosecchi and Crivelli, 1995).

Although it is widely distributed across European estuarine and inland waters, the decline of eel stocks is continuing over its geographical range (Dekker, 2003a,b; Feunteun, 2002), and this is also true of the Fumemorte canal since the 1980s. From 1995 to 2009, periodic sampling in the canal showed that population densities have decreased by 90% (Crivelli, unpublished data).

The fish community of the sampled area comprised 16 species (names according to Kottelat and Freyhof, 2007): topmouth gudgeon (*Pseudorasbora parva*), sandsmelt (*Atherina boyeri*), gudgeon (*Gobio gobio*), juveniles of pikeperch (*Sander*

*lucioperca*), three-spined stickleback (*Gasterosteus aculeatus*), bleak (*Alburnus alburnus*), pumpkinseed (*Lepomis gibbosus*), rudd (*Scardinius erythrophthalmus*), bream (*Abramis brama* and *Blicca bjoernka*), common carp (*Cyprinus carpio*), Prussian carp (*Carassius gibelio*), mullet (*Liza ramada* and *Mugil cephalus*), eel (*Anguilla anguilla*) and European catfish (*Silurus glanis*). The latter was recorded for the first time in the Fumemorte Canal in 1990, where it started to reproduce in 1999.

Invertebrates (*Gammarus*, *Procambarus clarkii*) and fish were caught in March, April and May 2009. Qualitative samples were taken in the main channel in 2009, in those sections where angling is forbidden (75% of the channel). Fyke nets (mesh size 1 mm, 6 mm and 14 mm) and gill nets (mesh size 27, 40, 55 and 80 mm) were used to capture 82 catfish, 66 fish and invertebrates for stable isotope analysis. Samples were directly frozen after catching. Fish were measured (total length TL mm) and small muscle samples of fish and crayfish were dissected later in the laboratory. Whole *Gammarus* were used for SIA after 24 h starvation of individuals (to clear the guts).

In addition, 134 catfish (>500 mm total length, i.e. potential predators to eels) were captured for gut content analysis in this sampling area using the same protocol. Fish were measured (total length TL mm) and their guts were dissected. Remains of prey were identified to species level to calculate their percentage of occurrence in catfish full gut contents. Gut contents were intended to complement the SIA (see below). Gut contents provide a snapshot of the diet compared with SIA, which integrates food habits over a long period, but they can provide a good overview of fish diet and better taxonomic resolution.

### Stable isotope analyses

Stable isotopes integrate food signature between 3 and 6 months, depending on the tissue used for the analyses and the regeneration time of that particular tissue.  $\delta^{13}\text{C}$  values reveal the origin of potential carbon sources assimilated by consumers and  $\delta^{15}\text{N}$  values represent the trophic level of organisms in the food web. The trophic position (TP) of an individual is connected to  $\delta^{15}\text{N}$  values and trophic level. In general,  $\delta^{13}\text{C}$  values increase by 0 to 1‰ between a prey and its predator (one trophic level) while  $\delta^{15}\text{N}$  values increase by

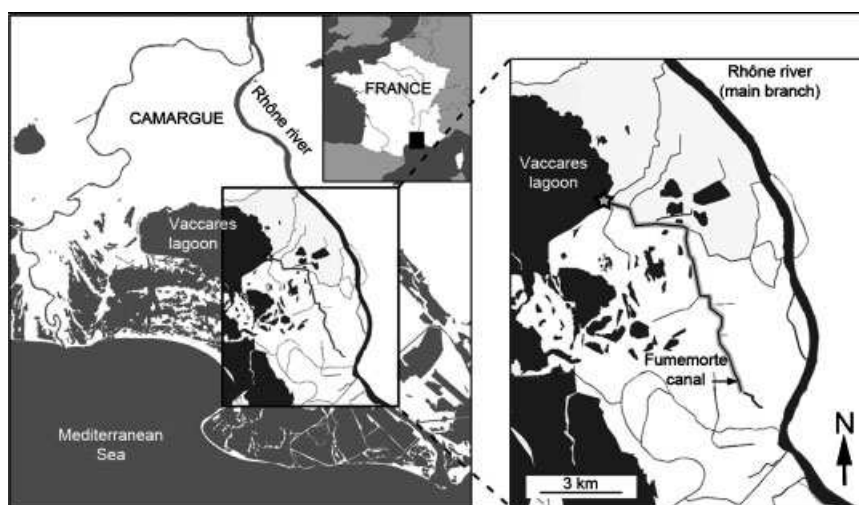


Figure 1. Map of the study area: the Fumemorte chanel, Camargue.

around 3‰ (Peterson and Fry, 1987). SIA has been used to study the impacts of non-native fish on native fish (Vander Zanden *et al.*, 1999; Syväranta *et al.*, 2010), and can also be used to identify fish migration between marine and fresh waters (McCarthy and Waldron, 2000; Harrod *et al.*, 2005), as well as utilization of marine prey within freshwater systems (Syväranta *et al.*, 2009). Marine fish are typically enriched in the heavier carbon isotope ( $^{13}\text{C}$ ) compared with freshwater fish, and migrating marine fish can be identified in freshwater systems by their higher  $\delta^{13}\text{C}$  values.

Crustaceans and fish muscle samples (all samples for SIA,  $n = 3\text{--}12$  for potential prey,  $n = 82$  for catfish) were oven dried at  $60^\circ\text{C}$  for 48 h and then ground into a fine homogeneous powder using a mortar and pestle. Approximately 0.2 mg of sample material was accurately weighed into small tin cups and stable isotope ratios of carbon and nitrogen were analysed in a Carlo Erba NC2500 elemental analyser (Carlo Erba, Milan, Italy) coupled to a Finnigan Mat Delta XP isotope ratio mass spectrometer (Thermo Finnigan, Bremen, Germany). Isotope ratios are reported in delta notation in accordance with international standards: Peedee Belemnite Carbonate for  $\delta^{13}\text{C}$  and atmospheric nitrogen for  $\delta^{15}\text{N}$ . Data were corrected using working standards (bass muscle, bovine liver, nicotinamide;  $\text{SD} < 0.2\text{‰}$  for both  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$ ) that were previously calibrated against International Atomic Energy Agency (IAEA) standards. All stable isotope analyses were performed at the Stable Isotopes in Nature Laboratory, University of New Brunswick, Canada.

### Data analyses and statistics

The food web of the Fumemorte fish community was depicted in the  $\delta^{15}\text{N}\text{--}\delta^{13}\text{C}$  graph (Figure 1) from baseline to top predators, using data obtained during the present study. To show a potential ontogenetic shift in catfish diet, relationships between length and  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values were studied from 82 catfish ranging from 60 mm to 1625 mm TL. Trophic positions for catfish and all other freshwater organisms in the food web were calculated using *Gammarus* sp. as  $\delta^{15}\text{N}$  baseline and following Vander Zanden *et al.* (1997):

$$\text{TP} = [(\delta^{15}\text{N}_{\text{fish}} - \delta^{15}\text{N}_{\text{gammarus}})/\Delta] + 2,$$

where  $\Delta$  is the trophic fractionation factor for  $\delta^{15}\text{N}$  values (3‰) and 2 is the trophic position for gammarus. Catfish were grouped into three size classes: TL < 200 mm, TL 200–500 mm and TL > 500 mm. The first class (< 200 mm) comprises 0+ and 1+ catfish, while the second class is constituted by immature catfish and the last class regroups fully grown individuals. The marine fish contribution to the catfish diet was calculated but only for fish > 500 mm TL. In fact, we consider that only fish > 500 mm are large enough to consume eels.

The SIAR (Stable Isotope Analysis in R) package (Parnell *et al.*, 2010) in R 2.9.2 (R Development Core Team, 2009) was used to calculate relative contributions from different prey groups to adult catfish diet, with particular interest in assessing the presence of marine fish. Potential prey was grouped into adult crayfish, freshwater fish (topmouth gudgeon, sandsmelt, bleak, pumpkinseed, bream, common carp and Prussian carp) and marine fish (mullet and eel), based on the gut contents of these larger catfish. The SIAR isotope mixing model uses Bayesian inference to estimate source contribution and allows the input of uncertainties, such as variation around the mean

isotope values of sources (prey) and fractionation factors, into the final model. Fractionation factors of  $0.5 \pm 0.2\text{‰}$  for  $\delta^{13}\text{C}$  and  $3.0 \pm 0.5\text{‰}$  for  $\delta^{15}\text{N}$  which fall within the range were used for those factors most often reported (Peterson and Fry, 1987; Vander Zanden and Rasmussen, 1999; Post, 2002). Statistics were performed using R and SPSS.

## RESULTS AND DISCUSSION

The  $\delta^{15}\text{N}\text{--}\delta^{13}\text{C}$  graph (Figure 2) presents the food web studied. Individuals originated from two different systems and food webs: those from the freshwater system with  $\delta^{13}\text{C}$  values lower than  $-22\text{‰}$ , and those from a marine system with  $\delta^{13}\text{C}$  higher than  $-17\text{‰}$  (i.e. mullet and eel). Some small catfish individuals were clearly feeding on invertebrates (*Gammarus*, juvenile crayfish) with  $\delta^{13}\text{C}$  values between  $-31$  and  $-28\text{‰}$  and  $\delta^{15}\text{N}$  between 10 and 12‰. Other larger individuals were more dependent on adult crayfish and/or were already piscivorous ( $-27$  to  $-26\text{‰}$  for  $\delta^{13}\text{C}$  and 12.5 to 14‰ for  $\delta^{15}\text{N}$ ). More specifically, it was found that differences in  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values existed between small-, medium- and large-bodied catfish, although the relationships between catfish TL and  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values (Figure 3) were not particularly strong. Small- and medium-sized catfish did not present large differences between their carbon and nitrogen isotope mean values ( $t$ -test,  $\text{df} = 48$ ,  $P = 0.16$  for  $\delta^{13}\text{C}$ ,  $P = 0.06$  for  $\delta^{15}\text{N}$ ), but small- and large-bodied and medium- and large-bodied individuals had significantly different mean values ( $t$ -tests, small- and large-bodied fish:  $\text{df} = 54$ ,  $P < 0.001$  for  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$ ; medium- and large-bodied fish:  $\text{df} = 56$ ,  $P < 0.001$  for  $\delta^{13}\text{C}$ ,  $P < 0.01$  for  $\delta^{15}\text{N}$ ). Small ontogenetic shifts in catfish diet were evident (Figure 2), particularly in the smallest sized catfish, as both  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values became higher with increasing catfish length. The calculated trophic positions (TP) (Table 1) showed similar results: differences existed between small- and large-, and between medium- and large-bodied catfish ( $t$ -tests, small- and large-bodied fish TP:  $\text{df} = 54$ ,  $P < 0.001$ ; medium- and large-bodied fish TP:  $\text{df} = 56$ ,  $P < 0.01$ ). Valadou (2007) speculated that the catfish was a voracious top predator with a predation impact on pike, pikeperch, crayfish and eel populations. However Pasquaud *et al.* (2010) considered eel as a top predator in the Gironde estuary (France). In the present study, unlike Wysjack and Mehner (2005), who found eels in the stomach contents of catfish (between 490 and 800 mm), eels were not observed in the guts of the study fish. According to the stomach content analyses, catfish mostly ate invertebrates, especially crayfish (*P. clarkii*, Table 2). Indeed, of the 134 individuals studied, only 58 had food in their stomach, and 79% of these contained remains of crayfish. Mullet, topmouth gudgeon and frog were the second most frequent prey with 7% and 5%, respectively, in gut contents (Figure 3). These results are consistent with Dogan and Gul (2004), Carol (2007), Carol *et al.* (2009) and Copp *et al.* (2009).

Using the SIAR to estimate diet contributions from crayfish, freshwater and marine fish, resulted in diet data very similar to the gut content data of similarly sized individuals (Table 2). Crayfish was identified as the most important prey for catfish (85% of the total diet; 74–95%, 95% Bayesian confidence interval (BCI), Figure 4), followed by freshwater fish (10%; 0–20%, 95% BCI), while marine fish

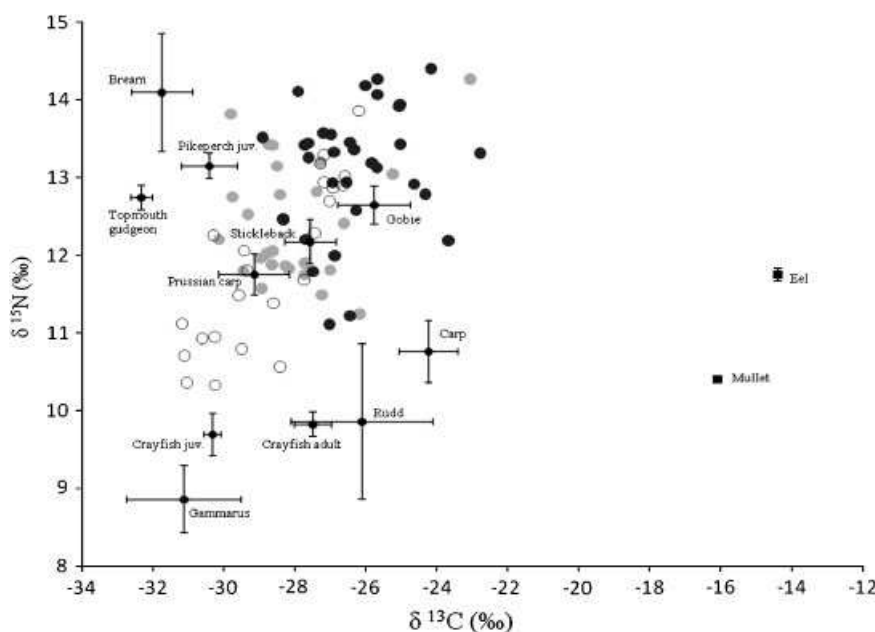


Figure 2.  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  biplot of the Fumemorte Canal food web. Mean values ( $\pm$ SE) are given for all other species except European catfish for which individual values are given (open symbols = small-bodied individuals; closed light grey symbols = medium-bodied individuals; closed dark grey symbols = large-bodied individuals).

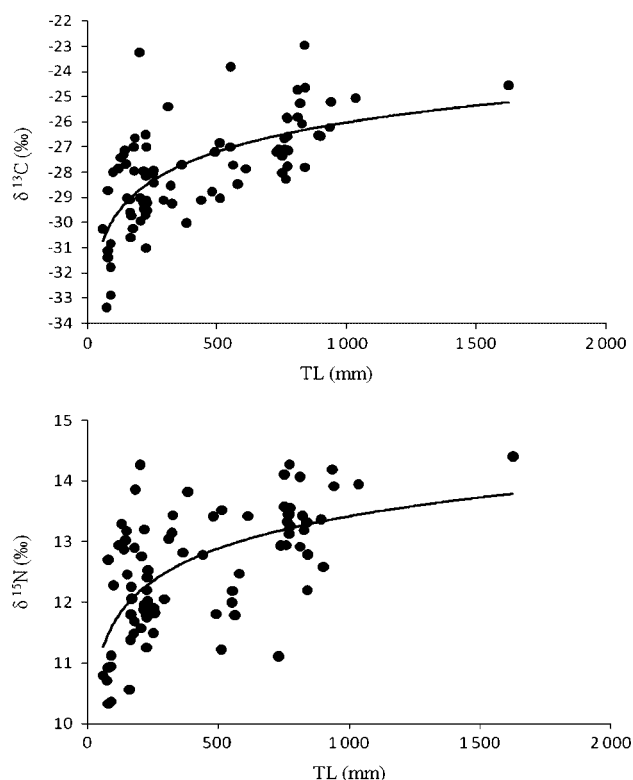


Figure 3. Relationships between European catfish TL (mm) and  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values (‰). Solid lines indicate fitted regression ( $\delta^{13}\text{C}$ :  $y = 1.675\ln(x) - 37.6$ ,  $r^2 = 0.45$ ,  $n = 82$ ;  $\delta^{15}\text{N}$ :  $y = 0.76\ln(x) + 8.1$ ,  $r^2 = 0.38$ ,  $n = 82$ ).

was consumed only minimally (5%; 0–8.5%, 95% BCI). The high diet contribution from crayfish agreed well with the gut content analyses, as did the low marine contribution. Of this 5% marine contribution, mullet is likely to make up the

Table 1. Total length, minimum and maximum length and trophic position (TP) for European catfish and each species analysed. All values are means ( $\pm$  SE). TP represents the trophic level of organisms in the food web, in relationship with  $\delta^{15}\text{N}$  values

Species	n	TL (mm)	min-max TL (mm)	TP
<i>Gammarus</i>	4	-	-	2
Crayfish juvenile	3	-	-	$2.28 \pm 0.1$
Crayfish adult	3	-	-	$2.32 \pm 0.1$
Topmouth gudgeon	4	40	40	$3.26 \pm 0.1$
Sand smelt	2	55	55	$3.13 \pm 0.1$
Gudgeon	5	$70 \pm 5$	50–80	$3.28 \pm 0.1$
Pikeperch juvenile	5	$99 \pm 49$	50–293	$3.43 \pm 0.1$
Three spined stickleback	4	$50 \pm 4$	40–55	$3.10 \pm 0.1$
Bleak	5	$102 \pm 11$	65–128	$2.97 \pm 0.1$
Pumpkinseed	5	$94 \pm 12$	63–130	$3.53 \pm 0.2$
Rudd	5	$154 \pm 15$	120–195	$2.33 \pm 0.3$
Bream	5	$116 \pm 17$	80–159	$3.75 \pm 0.3$
Carp	5	$120 \pm 37$	30–205	$2.63 \pm 0.1$
Goldfish	4	$231 \pm 37$	175–340	$2.96 \pm 0.1$
Mullet	5	$175 \pm 4$	159–183	-
Eel	12	$435 \pm 36$	195–590	-
European catfish	82	$433 \pm 35$	60–1625	$3.23 \pm 0.0$
small-bodied	24	$131 \pm 8$	60–184	$2.99 \pm 0.1$
medium-bodied	26	$279 \pm 17$	202–492	$3.19 \pm 0.1$
large-bodied	32	$785 \pm 35$	511–1625	$3.42 \pm 0.1$

majority as this species was also identified in the gut contents. Mullet was present in 7% of the full stomachs (Table 2), indicating that this prey item is occasional in catfish diet (Carol *et al.*, 2009; Syväranta *et al.*, 2009).

In the Camargue delta as in many other regions, aquatic resource managers, anglers, and stakeholders in general are concerned with the potential impact of alien predators on emblematic fish, especially when these species have high social and economic values. The fact that sport fishermen frequently use eels as an effective bait to catch catfish in some large rivers such as the Rhône probably prompted suspicion upon the

Table 2. Frequency of occurrence (%) of different prey in 134 stomach contents of European catfish for individuals > 500 mm; 76 were empty (56.7%)

Prey for catfish > 500 mm (n = 58) with full stomach contents		
Group	Species	Frequency (%)
Mammals	<i>Rattus</i> sp.	2
Amphibians	<i>Rana</i> spp.	5
Crustaceans	<i>Procambarus clarkii</i>	79
Fish	<i>Abramis brama</i>	3
	<i>Atherina boyeri</i>	3
	<i>Pseudorasbora parva</i>	5
	<i>Blicca bjoerkna</i>	2
	<i>Alburnus alburnus</i>	3
	<i>Cyprinus carpio</i>	3
	<i>Carassius gibelio</i>	3
	<i>Lepomis gibbosus</i>	2
	<i>Ameiurus melas</i>	2
	<i>Liza ramada</i>	7
	Unidentified fish	9

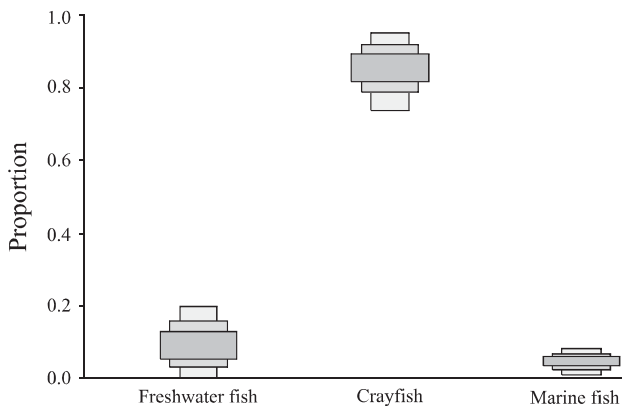


Figure 4. Fractional diet contribution (0–1) from crayfish, freshwater and marine fish to adult catfish using SIAR modelling. Boxes indicate 50%, 75% and 95% Bayesian credibility intervals for means.

catfish when eels were found to decline. In response to such concerns, the diet analyses showed that catfish is not a voracious top-predator, but rather an opportunistic omnivore (Copp *et al.*, 2009). It seems that European catfish has no direct effect on the eel population in the Camargue either by predation or through competition for the feeding niche. Figure 2 shows that catfish and eel do not rely on the same carbon source baseline, i.e. not on the same prey items. This observation is highly relevant to redirect conservation/management efforts on other potential causes of local (human-induced) disturbance. On the one hand, it may be argued that the contribution of eels to catfish diet is density-dependent. In other words, although catfish did not appear to prey significantly upon eels in the Fumemorte canal in recent years (i.e. when eel densities were low), further diet analyses should be carried out along a gradient of eel density in natural environments, to determine whether or not catfish preyed on eels in past years when eel abundance was higher. On the other hand, however, the analyses did show that catfish do not prey on native predatory fish such as pikeperch in the study area.

Although the data did not allow this hypothesis to be tested, the indirect effects of catfish on eels should be evaluated in the future. Introduced species can interact with native

species either directly by predation, competition, introduction of parasites or genetic changes (Simon and Townsend, 2003; Strayer, 2010), or indirectly through modifications of the physical habitat (Erwin, 2008, but probably not applicable to catfish) or through the creation of new links between species (Laland and Boogert, 2010). For example, introduced fish can modify invertebrate behaviour, and subsequently alter plankton biomass (Simon and Townsend, 2003). However, the results fit with recent insights into catfish diet in southern France (Syväranta *et al.*, 2010), where the species was found to prey primarily on cyprinid fish while predatory fish such as pike, pikeperch and largemouth bass were rarely or not eaten. We may therefore conclude that even if catfish occasionally eat eels (this study; Wysujack and Mehner, 2005; Gualtieri *et al.*, 2006), they do not constitute a direct threat to this species or to other predators.

## REFERENCES

- Allen M, Rosell R, Evans D. 2006. Predicting catches for the Lough Neagh (Northern Ireland) eel fishery based on stock inputs, effort and environmental variables. *Fisheries Management and Ecology* **13**: 251–260.
- Aprahamian M, Walker A. 2008. Status of eel fisheries, stocks and their management in England and Wales. *Knowledge and Management of Aquatic Ecosystems* **390–391**: article 07.
- Bevacqua D, Melia P, Crivelli AJ, Gatto M, De Leo GA. 2007. Multi-objective assessment of conservation measures for the European eel (*Anguilla anguilla*): an application to the Camargue lagoons. *ICES Journal of Marine Science* **64**: 1483–1490.
- Carol J. 2007. Ecology of an invasive fish (*Silurus glanis*) in Catalan reservoirs. PhD thesis, Universitat de Girona.
- Carol J, Benejam L, Benito J, Garcia-Berthou E. 2009. Growth and diet of European catfish (*Silurus glanis*) in early and late invasion stages. *Fundamental and Applied Limnology* **174**: 317–328.
- Castonguay M, Hodson PV, Couillard CM, Eckersley MJ, Dutil JD, Verreault G. 1994. Why is recruitment of the American eel, *Anguilla rostrata*, declining in the St-Lawrence river and gulf? *Canadian Journal of Fisheries and Aquatic Sciences* **51**: 479–488.
- Chauvelon P. 1998. A wetland managed for agriculture as an interface between the Rhone river and the Vaccares lagoon (Camargue, France): transfers of water and nutrients. *Hydrobiologia* **374**: 181–191.
- COGEPOMI. 2006. Programme de gestion de l'anguille sur les lagunes méditerranéennes 2006–2008. Direction Régionale de l'Environnement Rhône-Alpes Bassin du Rhône-Méditerranée, Lyon, France.
- Copp GH, Britton JR, Cucherousset J, Garcia-Berthou E, Kirk R, Peeler E, Stakenas S. 2009. Voracious invader or benign feline? A review of the environmental biology of European catfish *Silurus glanis* in its native and introduced ranges. *Fish and Fisheries* **10**: 252–282.
- Dekker W. 2000. A Procrustean assessment of the European eel stock. *ICES Journal of Marine Science* **57**: 938–947.
- Dekker W. 2003a. Did lack of spawners cause the collapse of the European eel, *Anguilla anguilla*? *Fisheries Management and Ecology* **10**: 365–376.
- Dekker W. 2003b. On the distribution of the European eel (*Anguilla anguilla*) and its fisheries. *Canadian Journal of Fisheries and Aquatic Sciences* **60**: 787–799.

- Dogan N, Gul A. 2004. Feeding biology of *Silurus glanis* (L., 1758) living in Hirfanli Dam Lake. *Turkish Journal of Veterinary and Animal Sciences* **28**: 471–479.
- Dudgeon D, Arthington AH, Gessner MO, Kawabata ZI, Knowler DJ, Leveque C, Naiman RJ, Prieur-Richard AH, Soto D, Stiassny MLJ, Sullivan CA. 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. *Biological Reviews* **81**: 163–182.
- Eby LA, Roach WJ, Crowder LB, Stanford JA. 2006. Effects of stocking-up freshwater food webs. *Trends in Ecology and Evolution* **21**: 576–584.
- Erwin DH. 2008. Macroevolution of ecosystem engineering, niche construction and diversity. *Trends in Ecology and Evolution* **23**: 304–310.
- Feunteun E. 2002. Management and restoration of European eel population (*Anguilla anguilla*): an impossible bargain. *Ecological Engineering* **18**: 575–591.
- Gualtieri M, Mecatti M, Diodato F. 2006. Growth of European catfish (*Silurus glanis* L.) in Florence province (Central Italy) and management proposals. *Journal of Freshwater Biology (Quaderni ETP)* **34**: 287–291.
- Haro A, Richkus W, Whalen K, Hoar A, Busch WD, Lary S, Brush T, Dixon D. 2000. Population decline of the American eel: implications for research and management. *Fisheries* **25**: 7–16.
- Harrod C, Grey J, McCarthy TK, Morrissey M. 2005. Stable isotope analyses provide new insights into ecological plasticity in a mixohaline population of European eel. *Oecologia* **144**: 673–683.
- Kottelat M, Freyhof J. 2007. *Handbook of European Freshwater Fishes*. Kottelat: Cornol, Switzerland and Freyhof, Berlin, Germany.
- Laland KN, Boogert NJ. 2010. Niche construction, co-evolution and biodiversity. *Ecological Economics* **69**: 731–736.
- Loste C, Dusserre K. 1996. La pêche sur l'étang de Bages-Sigean. Evolutions de 1985 à 1995 CEPRALMAR report, Montpellier.
- McCarthy ID, Waldron S. 2000. Identifying migratory *Salmo trutta* using carbon and nitrogen stable isotope ratios. *Rapid Communications in Mass Spectrometry* **14**: 1325–1331.
- Moriarty C, Dekker W. 1997. Management of European eel fisheries. *Fishery Bulletin* **15**: 1–110.
- Parnell AC, Inger R, Bearhop S, Jackson AL. 2010. Source partitioning using stable isotopes: coping with too much variation. *PLoS ONE* **5**: article number e9672.
- Pasquaud S, Pillet M, David V, Sautour B, Elie P. 2010. Determination of fish trophic levels in an estuarine system. *Estuarine Coastal and Shelf Science* **86**: 237–246.
- Peterson BJ, Fry B. 1987. Stable isotopes in ecosystem studies. *Annual Review of Ecology and Systematics* **18**: 293–320.
- Post DM. 2002. Using stable isotopes to estimate trophic position: models, methods and assumptions. *Ecology* **83**: 703–718.
- R Development Core Team. 2009. *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing: Vienna.
- Rosecchi E, Crivelli AJ. 1995. Sand smelt (*Atherina boyeri*) migration within the water-system of the Camargue, southern France. *Hydrobiologia* **300**: 289–298.
- Rosecchi E, Poizat G, Crivelli AJ. 1997. The introduction of freshwater fish and crayfish species in the Camargue: history, origins and changes in assemblages. *Bulletin Français de la Pêche et de la Pisciculture* **344–345**: 221–232.
- Simon KS, Townsend CR. 2003. Impacts of freshwater invaders at different levels of ecological organisation, with emphasis on salmonids and ecosystem consequences. *Freshwater Biology* **48**: 982–994.
- Stone R. 2007. Aquatic ecology: the last of the leviathans. *Science* **316**: 1684–1688.
- Strayer DL. 2010. Alien species in fresh waters: ecological effects, interactions with other stressors, and prospects for the future. *Freshwater Biology* **55** (Suppl. 1): 152–174.
- Syväranta J, Cucherousset J, Kopp D, Martino A, Cereghino R, Santoul F. 2009. Contribution of anadromous fish to the diet of European catfish in a large river system. *Naturwissenschaften* **96**: 631–635.
- Syväranta J, Cucherousset J, Kopp D, Crivelli A, Cereghino R, Santoul F. 2010. Dietary breadth and trophic position of introduced European catfish *Silurus glanis* in the River Tarn (Garonne River basin), southwest France. *Aquatic Biology* **8**: 137–144.
- Valadou B. 2007. Le silure glane (*Silurus glanis*, L.) en France. Evolution de son aire de répartition et prédiction de son extension. Conseil Supérieur de la Pêche, Fontenay-sous-Bois, France.
- Vander Zanden MJ, Rasmussen JB. 1999. Primary consumer delta C-13 and delta N-15 and the trophic position of aquatic consumers. *Ecology* **80**: 1395–1404.
- Vander Zanden MJ, Cabana G, Rasmussen JB. 1997. Comparing trophic position of freshwater fish calculated using stable nitrogen isotope ratios (delta N-15) and literature dietary data. *Canadian Journal of Fisheries and Aquatic Sciences* **54**: 1142–1158.
- Vander Zanden MJ, Casselman JM, Rasmussen JB. 1999. Stable isotope evidence for the food web consequences of species invasions in lakes. *Nature* **401**: 464–467.
- Wirth T, Bernatchez L. 2003. Decline of North Atlantic eels: a fatal synergy? *Proceedings of the Royal Society of London Series B - Biological Sciences* **270**: 681–688.
- Wysujack K, Mehner T. 2005. Can feeding of European catfish prevent cyprinids from reaching a size refuge? *Ecology of Freshwater Fish* **14**: 87–95.