

Effects of commercial fishing and predation by cormorants on the *Anguilla anguilla* stock of a shallow eutrophic lake

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Mortality of eels *Anguilla anguilla* in a large shallow lake in France due to predation by the cormorant *Phalacrocorax carbo* was found to be moderate when compared to fishery catches over a 9 year period. The results show that, contrary to previous extrapolations made at the pan-European scale, *P. carbo* predation in shallow lakes is not invariably a major contributor to *A. anguilla* mortality, even in the presence of large colonies.

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Key words: fishery; natural mortality; *Phalacrocorax carbo*.

Possible causes of declines in glass eel recruitment of the European eel *Anguilla anguilla* (L.) since the early 1980s include changes in oceanic and continental factors (Feunteun, 2002; Knights, 2003; Starkie, 2003; Wirth & Bernatchez, 2003; Friedland *et al.*, 2007; Bonhommeau *et al.*, 2008). Predation is one of the factors contributing to natural mortality during the continental growth stages and its limitation is considered as a possible management option to restore *A. anguilla* populations (ICES, 2007). Nevertheless, data on *A. anguilla* predation is severely lacking in the scientific literature (Tesch, 2003). Among potential natural predators, birds are most efficient and are thought to be a key controlling factor in a number of *A. anguilla* populations (ICES, 2007). Because of its spectacular increase and its strong geographical expansion in Europe since the 1970s (Marion, 1997a; van Dam & Asbirk, 1997), the cormorant *Phalacrocorax carbo* (L.) has often been suggested to consume large amounts of *A. anguilla* (Carss & Ekins, 2002; ICES, 2007; Żydelis & Kontautas, 2008). This reputation has resulted in conflicts with fisheries and aquaculture (Kirby *et al.*, 1996; Carss, 2003). No studies, however, have compared the effects of avian and fishery mortalities over a long period of time. The aim of the present study was to assess predation on *A. anguilla* by a cormorant colony in comparison to the losses incurred due to the commercial fishery over 9 years in Lake Grand-Lieu (Brittany, north-west France).

Lake Grand-Lieu (47°05' N; 1°39' W) is a large, very shallow (0.70–1.20 m in summer), turbid, eutrophic, natural floodplain lake of variable surface area (40–63 km²), depending on the annual water regime (Paillisson & Marion, 2006).

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During summer, the lake's permanently flooded area is restricted to extensive beds of floating-leaved plants (*c.* 10 km²), consisting mainly of nymphaeid patches, and a central area of entirely open water (10 km²). Roughly 20 km of the lake margin (20 km²) is covered by a floating peat fen that supports the largest cormorant colony in France [505–1379 breeding pairs over 1999–2007 (Marion, 2008)] and a small wintering population (80–320 birds). Cormorants use several feeding areas beyond the lake (Paillisson *et al.*, 2004), but the majority of birds feed in lake waters, particularly during the breeding season. The other bird species consuming *A. anguilla* such as ardeids (herons and egrets) forage mainly outside the site (Marion, 1989). A traditional centuries-old fishery, currently composed of fyke net fishermen, almost exclusively focuses on *A. anguilla* (Adam & Elie, 1993; Carpentier *et al.*, 2003). It is controlled by the central authorities who limit the number of fishermen to a maximum of eight, as well as the types and number of fishing gears and types of boats. Fish surveys were conducted in the open (vegetated and unvegetated) and shoreline areas during the summer (1–10 days; 5–31 July depending on the year) from 1999 to 2007 (except 2004) using point abundance sampling by electrofishing [$n = 99–423$, depending on the year; using EFKO F.E.G. 8000 apparatus (www.efko-gmbh.de), fishing variables 400–600 V and 6–10 A and a 300 mm diameter anode thrown from a boat to a distance of 8–10 m away from the operator to reduce disturbance (Cucherousset *et al.*, 2006)]. Fishes were identified to species level, fork length (L_F) measured to the nearest mm and immediately released into the water. Fish body mass was derived from *in situ* specific length and mass equations (Adam & Elie, 1993). Fish relative densities and biomass were estimated as catch per unit effort (CPUE; means \pm S.E., weighted by the sampling effort in the different lake areas), which was the number or biomass of fish per point sample, and then $\log_{10}(x + 1)$ transformed due to the skewed frequency distribution. From 1999 to 2007, cormorant diet was analysed from prey items ($n = 45–411$) regurgitated by birds when observers approached them either on the nest or during mass feeding bouts in central open water and vegetated areas. L_F (to the nearest mm) was determined for fresh fishes or estimated using relationships between other morphological measurements (*e.g.* body depth or pre-pectoral length) when fishes were partially digested (Froese & Pauly, 2007); their biomass was derived from length and mass equations (Adam & Elie, 1993). *Anguilla anguilla* relative abundance and biomass in cormorant diet were calculated. Annual cormorant consumption of *A. anguilla* was calculated using the method detailed in Engström (2001) and Carpentier (2003). This required information on the number of cormorants (breeding pairs, nestlings, fledglings, immature prospectors and wintering birds), their daily food intake [data obtained from literature; reviewed by Carpentier (2003), and *in situ* at the Grand-Lieu colony for breeders and nestlings using automatic weighing balances placed under cormorant nests (Carpentier & Marion, 2002)], the proportion of *A. anguilla* in their diet and the time period under consideration for each bird life stage. Data on annual catches of the fishery were based on official statistics from the Departmental Prefecture over the 1999–2007 period. No information was provided on the size of *A. anguilla* caught by the fishery, the size selectivity of fyke nets being >330 mm (Adam, 1997). All mean values are provided with S.E.

The fish community of the lake was largely dominated by cyprinid species from 1999 to 2007 [$87.90 \pm 2.87\%$ in relative abundance, notably sunbleak *Leucaspisus delineatus* (Heckel), common bream *Abramis brama* (L.) and roach *Rutilus rutilus*

(L.)]. The other species, including predators like pike *Esox lucius* L., perch *Perca fluviatilis* L. and zander *Sander lucioperca* (L.), comprised <5% of the relative abundance. *Anguilla anguilla* only represented 0.30–3.33% of the total CPUE in numbers of the fish community over the study period. *Anguilla anguilla* CPUE decreased over the study period both in numbers and biomass (Fig. 1; one-way ANOVA test, $F_{7,1956}$, $P < 0.001$). Pair-wise comparisons (Tukey HSD *post hoc* test) revealed a significant drop in *A. anguilla* CPUE between the periods 1999–2001 and 2002–2007 (Fig. 1; $P < 0.05$). No particular pattern was observed for the other species over this period (unpubl. data). Mean \pm s.e. annual total length (L_T) of fish ranged from 260.7 ± 23.3 mm (in 2000) to 449.9 ± 26.2 mm (in 2003) over the nine year period ($n = 37$ –101, depending on the year). Mean L_T of *A. anguilla* captured in 2003 was significantly higher than mean values calculated for all other years (one-way ANOVA test, $F_{7,454}$, $P < 0.001$, Tukey HSD *post hoc* test, $P < 0.001$ for all combinations including 2003).

Fishermen, who focused mostly on *A. anguilla* (78.14–85.82% of the total catches; Fig. 2), harvested between 23 581 and 37 317 kg of *A. anguilla* per year over the study period. The other species caught in the fishery were *E. lucius*, *S. lucioperca*, *R. rutilus*, rudd *Scardinius erythrophthalmus* (L.), tench *Tinca tinca* (L.) and *A. brama*. Although the trend in commercial catches of *A. anguilla* decreased slightly over the study period (linear regression, $r^2 = 0.51$, $n = 9$, $P < 0.05$; Fig. 2), it was not consistent with the *A. anguilla* CPUE (in biomass) decrease in the lake (Pearson correlation, $r = 0.50$, $n = 9$, $P > 0.05$). The absence of data on the L_T of *A. anguilla* caught by the fishery precludes any comparison with the L_T of *A. anguilla* caught by electrofishing.

Anguilla anguilla was a minor prey species in cormorant diet during the study: 0.00–8.46% in abundance ($4.45 \pm 1.07\%$) and 0.00–12.68% in biomass ($5.84 \pm 1.53\%$; Fig. 1), cyprinids being the main prey ($73.67 \pm 2.73\%$ in numbers

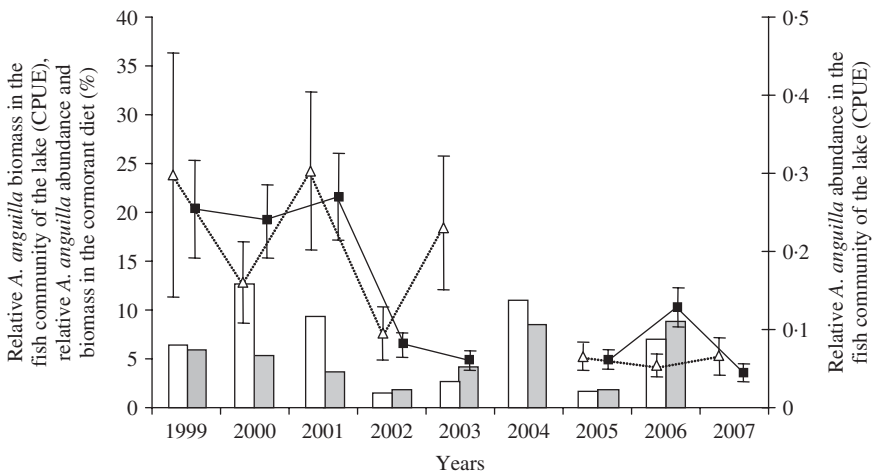


FIG. 1. Catch per unit effort (CPUE) of *Anguilla anguilla* in number (—■—) and in biomass (—△—) (mean \pm s.e. of the two descriptors per point sample) in Lake Grand-Lieu from 1999 to 2007 (except in 2004) and *A. anguilla* relative abundance (▒) and biomass (□) in cormorant diet from 1999 to 2007 (no *A. anguilla* in the diet in 2007).

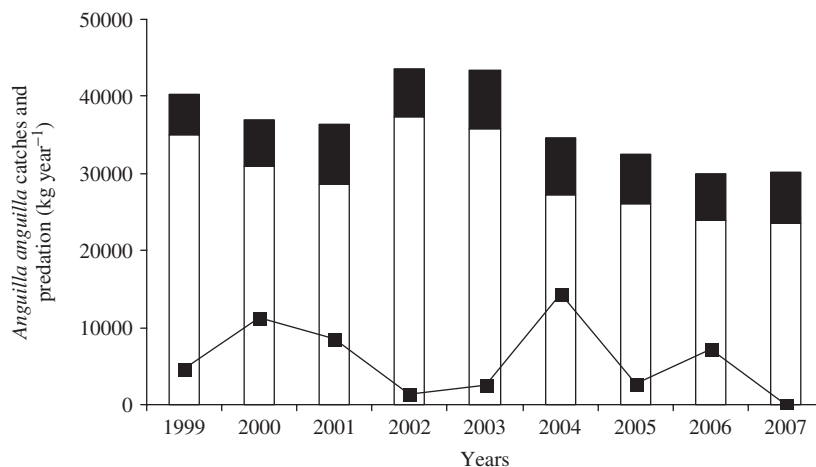


FIG. 2. Fishery catches of *Anguilla anguilla* (□) and other species (■) and cormorant predation on *A. anguilla* (—■) in Lake Grand-Lieu from 1999 to 2007.

and $58.54 \pm 3.33\%$ in biomass over the study period). No particular temporal trend was found in relative abundance and biomass of *A. anguilla* consumed over the study (linear regression, $r^2 = 0.02$ and $r^2 = 0.24$, $n = 8$, $P > 0.05$, respectively), and changes in annual relative abundance and biomass of *A. anguilla* in cormorant diet were not related to *A. anguilla* CPUE values in the lake over the study period (Pearson correlation, $r = 0.48$ and 0.20 , respectively, $n = 9$, $P > 0.05$). *Anguilla anguilla* predated by cormorants ranged from 120 to 520 mm with a mean L_T of 316 ± 11 mm ($n = 69$, 1999–2007). The number of *A. anguilla* in the cormorant diet was too limited to perform comparisons in *A. anguilla* size between years ($n = 0$ –18, depending on the year) or to compare with the *A. anguilla* stock. Estimated annual cormorant consumption of *A. anguilla* ranged from absence of predation in 2007 to 14 492 kg in 2004 and the mean \pm s.e. value was 5854 ± 1631 kg year⁻¹ (Fig. 2).

Discrepancies were found in temporal trends between *A. anguilla* CPUE (with significant declines after 2001) and fishery data. It cannot be excluded that facing the decrease in *A. anguilla* stocks, fishermen increased their fishing effort (increasing fishing time and area, and number of hauls). Differences between fishing techniques (e.g. in size-selectivities) may have resulted in differences in trends between electrofishing CPUE and fishery yields. The decrease in *A. anguilla* stocks in Lake Grand-Lieu, however, remains largely unexplained. Indeed, the relatively small decline in *A. anguilla* glass eel recruitment in the Loire (20 km from Lake Grand-Lieu) observed since 1996 (Bonhommeau *et al.*, 2008) did not coincide with changes in mean annual *A. anguilla* size in Lake Grand-Lieu between years. Other factors which may affect the *A. anguilla* stock of the lake include local factors such as recent recurrent toxic cyanobacteria blooms that are known to affect the body condition and possibly the survival of *A. anguilla* (Acou *et al.*, 2008).

Predation level of *A. anguilla* by cormorants was lower in Lake Grand-Lieu when compared to values presented in other aquatic ecosystems (Marion, 1997b). For example, it has been estimated that *A. anguilla* provide 12% of the diet biomass in summer and 3–6% in winter in various habitats in 19 European countries (ICES,

2007). In addition, in France, *A. anguilla* in the wintering cormorant diet represented only 0.4% of their prey in numbers (Fonteneau *et al.*, 2009). The present results are therefore not surprising given the low relative CPUE of *A. anguilla* in the fish community, which is largely dominated by cyprinids. This low relative abundance of *A. anguilla* could also explain inter-annual variations in cormorant diet. The results highlight the need for long time periods when assessing *A. anguilla* stock predated by cormorants because of probable large inter-annual variations, possibly resulting also from potential changes in bird population. Cormorant predation (for the whole feeding area) represented $20 \pm 6\%$ of the Grand-Lieu fishery catches (0–53% depending on the years) and is lower than a pan-European estimate of 30–50%, extrapolated from commercial catches in 1993–1994 (ICES, 2007). The fishery was therefore the major cause of *A. anguilla* mortality. Moreover, the present *A. anguilla* intake by cormorants is probably overestimated as they are known to also forage in neighbouring wetlands where abundant prey communities including *A. anguilla* are available (Feunteun *et al.*, 1999). The relatively low predation of *A. anguilla* by cormorants when compared to fishery catches can be also partly explained by the fact that birds mainly forage in open waters during the daylight period (Carpentier, 2003) when *A. anguilla* are inactive and probably hide in more complex habitats such as vegetated areas. Conversely, the fishery catches *A. anguilla* actively foraging for food at night. Moreover, as shown elsewhere (Kirby *et al.*, 1996; Leopold *et al.*, 1998), the diet of cormorants is mainly composed of a few dominant prey species in the fish community (Carpentier *et al.*, 2003).

In conclusion, the study highlighted the need for long time periods when assessing cormorant predation because of possible large inter-annual variations between years. It also showed that cormorant predation in shallow lakes is not invariably a major contributor to *A. anguilla* mortality, even when overall predation pressure by fish-eating birds is large.

We are particularly grateful to numerous people for their assistance during field work. We also thank B. Knights and two anonymous referees for valuable comments on a previous draft of the manuscript and A. Curd for English improvement. The research was carried out under licence of the Préfecture de la Loire-Atlantique (Bureau de la Réglementation de l'Environnement) and financed by DIREN des Pays de la Loire, Région des Pays de la Loire and SESLG.

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