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Short communication

Escapement of silver-phase European eels, *Anguilla anguilla*, determined from fishing activities in a Mediterranean lagoon (Or, France)

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Escapement of silver eels from a Mediterranean lagoon was estimated by a capture–tagging–recapture and automated tag-reading study. The population of silver-phase eels in the lagoon was estimated to be 13.2 kg ha^{-1}, with an escapement rate from the commercial fishery of 76.8%.

Keywords: conservation plans, European eel, sustainable fisheries, tag-recapture.

Introduction

European eels, *Anguilla anguilla*, spend 3–20 years as elvers or yellow eels before becoming subadults (so-called silver eels), and these leave continental Europe to migrate across the Atlantic Ocean to spawn in the Sargasso Sea. Eels were traditionally abundant and even considered until 1984 to be a harmful species that needed to be eradicated from French continental waters (Baisez and Laffaille, 2005), but the species is now considered to be endangered (listed in Annex II of the Convention on International Trade in Endangered Species, CITES) and below its safe biological limits (ICES, 2006). Since the 1970s, the eel population has clearly been in decline, with reductions in abundance and recruitment (before the elver stage) of the order of 10–100 times, and a decline of >75% in total catches in Europe (Dekker, 2003a, b). The decline has been attributed mainly to anthropogenic effects, of which fishing is just one component (Moriarty and Dekker, 1997). Subsequently, by a European Council Regulation introduced at the end of 2007 (Council Regulation EC 1100/2007; Council of the European Union, 2007), measures were introduced in an effort to recover eel stocks. The regulation requires every Member State to draw up a national management plan for eels. A critical aspect of these plans is to permit the escapement to sea of at least 40% of the potential biomass of silver eels that would escape in the absence of anthropogenic influence. To do this, it is necessary to collect accurate and reliable data on abundance and escapement of silver eels. However, historical datasets are lacking, and such information is impossible to estimate for most river basins, especially in Mediterranean lagoons (Bevacqua *et al.*, 2007; Amilhat *et al.*, 2008). The aims of this study were therefore to (i) estimate the population of migrant silver eels in a Mediterranean lagoon, the Or Lagoon, France, (ii) estimate the fishing pressure on silver eels there, and (iii) to evaluate silver-eel escapement from the fishery using capture–tagging–recapture techniques and automated tag reading.

Methods

The Or Lagoon is in the Mediterranean near Montpellier (southern France). It has an area of ~3170 ha, and is ~11 km long and ~3 km wide (Figure 1). It is isolated from the sea by a sandy bar and is bordered to the south by the Rhône Canal at Sète, to the east by the Lunel Canal, and to the west by the Méjean Pond. The lagoon communicates directly with the sea at its southwestern tip via the Grau de Carnon, a channel 1050 m long, ~15 m wide, and ~1.50 m deep. The Porte de Carnon is a mobile dam established on this channel to preclude massive intrusions of saline water. The lagoon has a mean salinity of 18.

Silver eels were purchased from eight professional fishers working the lagoon. Silver eels in the region migrate annually between October and December (Amilhat *et al.*, 2008). The eels were captured and marked during three campaigns: the first

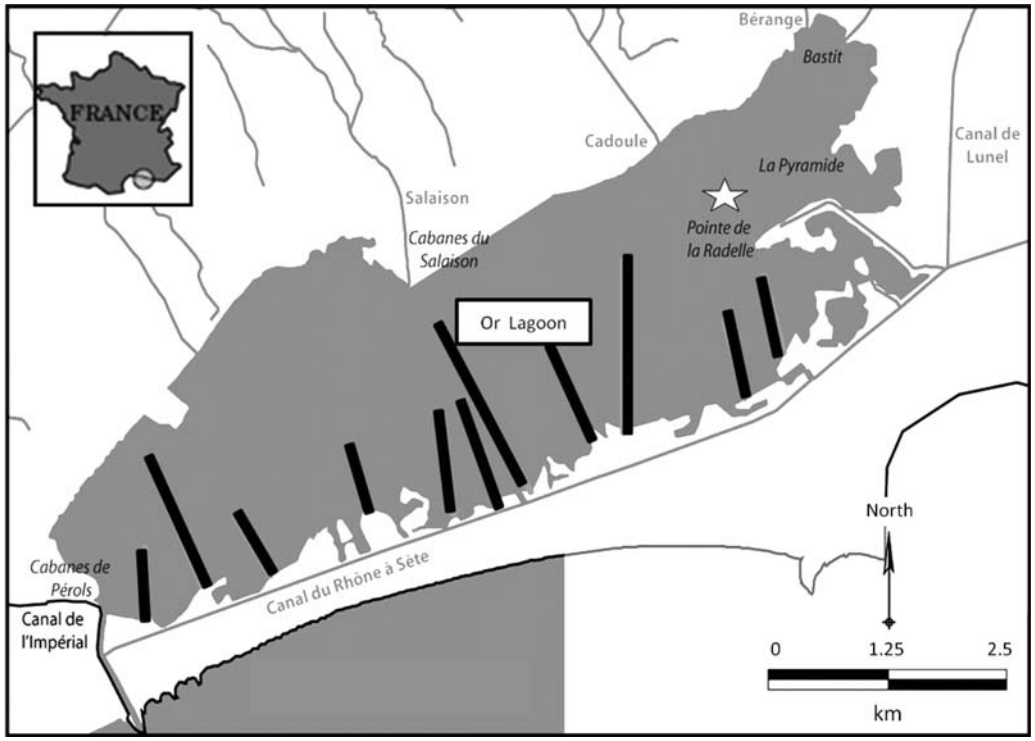

Figure 1. The Or Lagoon, showing the locations of the fixed net barriers (black bars) and the release location (star).

from 12 to 16 October 2009, the second some 2 weeks later, from 26 to 30 October, and the third slightly later still, from 12 to 13 November. Silver eels were identified according to Acou *et al.* (2005), measured to the nearest 1 mm (total length) and weighed to the nearest 1 g. Each was marked with a biocompatible ISO 24631 12-mm PIT tag, 2 mm in diameter. The PIT tags were inserted by a trocar into the visceral cavity of the eels after anaesthetizing them with Eugenol. Before inserting each tag and to preclude the transmission of disease between individuals, the equipment was disinfected with iodine.

Once the eels had been marked and measured, they were released back into the lagoon in batches, with the data on each release recorded so that the time at liberty could be determined for those subsequently recaptured. The first release was on 16 October 2009 for eels captured during the first campaign, then on 6 and 12 November for those captured during the second campaign and on 16 November for eels derived from the third campaign.

One of the drawbacks of the tag-marking method used is the possible loss of tags and mortality. We therefore tested for tag loss and potential mortality by holding 55 silver eels in a storage hamper (6 mm mesh size) lowered into the natural habitat (the Lunel Canal) for 2 weeks.

Recaptures were made by commercial fishers throughout the fishing season (October 2009 to January 2010) using 'capetchades' (net barriers) 400–1600 fm long with a mesh size of 6 mm at the base. All eels captured in the Or Lagoon are purchased by the same wholesaler, so all recaptured eels were checked at the wholesaler's premises when the eels were being sorted by size on a sorting table. That table ends in a hopper ~20 cm in diameter through which all the eels have to pass. An antenna and a receiver–recorder were placed in the hopper to determine the number of eels with PIT tags recaptured. Control PIT tags were used to check that the recording apparatus was working properly weekly.

SPAS software (Stratified Population Analysis System; Arnason *et al.*, 1996) and Petersen's grouped estimator (Seber, 1982) were used to estimate the abundance of silver eels in the lagoon. Confidence intervals (*CI*s) were calculated for α-values of 0.05. The level of exploitation was calculated by dividing the number of eels caught by the fishery by the estimated number of eels in the lagoon. Escapement was then calculated by subtracting the number of silver eels caught from the estimated number of silver eels present in the lagoon. The escapement rate is therefore the total escapement divided by the total number of silver eels estimated to have been in the lagoon.

Results and discussion

Over the three tagging campaigns, 711 silver eels, ranging from 350 to 805 mm, were captured and tagged (Table 1). The size distribution of those tagged was bimodal, with the first mode (mean size 407 mm, s.d. 22.6 mm; 67% of the eels) representing the male portion of the sample, and the second mode (mean size 602 mm, s.d. 74 mm; 33% of the eels) representing the female portion (Laffaille *et al.*, 2006).

In all, 23% ($n = 164$) of the tagged eels were recaptured between 16 October and 31 January (Table 1). On average, the time taken to emerge from the lagoon was 24 d (s.d. 20 d), but large numbers of these were recaptured within a week of release: 14.5% of batch 1 eels, 0.9% of batch 2, and 4.6% of batch 3. Apart from those, however, some of the eels tagged as batch 1 in October were recaptured in December and as late as January, demonstrating that the transit time in the lagoon could be >3 months for some eels.

The total yield of silver eels from the fishery (yellow and silver phases) between October 2009 and January 2010 was 9693 kg (Table 1), so according to the Petersen estimator, the abundance of silver eels in the lagoon would have been 41 827 kg

Table 1. The numbers of silver eels tagged and recaptured, and the fishery catches from October 2009 to January 2010.

		Number of eels recaptured				
Parameter	**Number of eels tagged**	**October**	**November**	**December**	**January**	**Total**
Batch 1	207	35	10	6	1	52
Batch 2	330	0	35	33	4	72
Batch 3	174	0	9	25	6	40
Batches 1–3	711	35	54	64	11	164
Catch (kg)		5 507	1 998	1 546	642	9 693
Catch (number)		23 738	8 611	6 665	2 766	41 779

Table 2. Estimated abundance of silver eels, the level of exploitation, and the escapement rate in the Or Lagoon.

Estimated abundance: pooled Petersen (and 95% *CI*)	**Standard error**	**Level of exploitation (%)**	**Escapement rate (%)**
180 290 (156 298–204 281)	12 241	23.2 (20.4–26.7)	76.8 (73.3–79.6)

(13.19 kg ha^{-1}; Table 2). The rate of exploitation by the fishery was therefore 23.2% (3.06 kg ha^{-1}), and the escapement rate of silver eels relative to current production 76.8% (10.13 kg ha^{-1}).

The method of tag and recapture used here involved internal tagging with a PIT tag, which is virtually invisible, rather than external colorimetric marking (Amilhat *et al.*, 2008). This made it possible to limit human counting error by avoiding the need for intervention by the people who catch or sample the eels. The recaptures were recorded automatically by a sensor that detected all tagged eels recaptured.

Petersen's grouped estimator (Seber, 1982), used in this study to estimate the abundance of silver eels in the lagoon, rests on several assumptions (Arnason *et al.*, 1996). The first is that there is no tag loss during the study. Of the 55 tagged eels tested, no mortality was observed, and no eel lost its tag during the 15-d test, and visual inspection of each eel showed that the incision site on 54 of the eels had already healed by the end of the test, confirming the reliability of the tagging method used here for European eels (Feunteun *et al.*, 2000). A second important assumption is that the likelihood of recapture is independent of whether or not the eels were tagged. It is always possible that the stress during handling and surgical procedures might interrupt the migration of silver eels for longer periods, reducing the catch of tagged eels relative to untagged eels and an underestimation of fishing mortality and overestimation of the population size and escapement rates. However, during our studies, many recaptures were made just after the eels had been released back into the water. The third critical assumption is that the probability that the tagged eels would be recaptured is >0 and that the population is an enclosed one. This latter assumption was only partly justified by our work, because the lagoon is not completely enclosed by fishery installations. Therefore, outward migration (silver eels leaving to sea) were still possible and could result in an overestimate of abundance. However, the same estimator has been used successfully by Rosell *et al.* (2005) in Lough Neagh and by Amilhat *et al.* (2008) in the Bages–Sigean lagoon, areas that are also not enclosed completely.

The estimated abundance of silver eels (13.2 kg ha^{-1}) in the Or Lagoon is much lower than that in the Bages–Sigean lagoon (30 kg ha^{-1}; Amilhat *et al.*, 2008), but higher than that in the lagoons of the Camargue (1.5 kg ha^{-1}; Bevacqua *et al.*, 2007) according to the recent data. The lesser abundance in the Or Lagoon than in the Bages–Sigean lagoon can certainly be attributed to a difference in accessibility between the two sites, and hence to a difference in fluvial recruitment between the two. There are no sluices to impede eel migration at Bages–Sigean, whereas the migration of eels in the Or Lagoon is hindered by a mobile dam. Such an installation, which is intended essentially to limit the upstream intrusion of saltwater, also has a major impact on colonization of the catchment area by migrating young eels (Laffaille *et al.*, 2007). However, the escapement rate of silver eels from the Or Lagoon (77%) is similar to that in such other systems as Lough Neagh in Northern Ireland (62–75%; Rosell *et al.*, 2005) and two Mediterranean lagoons (80–87%; Bevacqua *et al.*, 2007; Amilhat *et al.*, 2008). These estimates relate only to the silver eel phase during the 3–4-month fishing season, but the same fisheries remove a large number of yellow eels. Escapement of all stages of the eel life cycle needs to be taken into account for each system if one wishes to meet European regulations. Despite the heavy fishing pressure in these lagoons, the fixed nets used (mainly "capetchades") do not seem to block the passage of quite a large proportion of the silver eels. The eels migrate essentially during the periods of high flow (Acou *et al.*, 2008), when water levels are high, allowing them to swim over the nets (Rosell *et al.*, 2005). The same would be true too for yellow eels, the capture rate of which must also be fairly low given their relatively sedentary lifestyle (Laffaille *et al.*, 2005). In contrast, if critical phases of anoxia arise in lagoons, the eels become very active, and many are caught. The escapement rates currently estimated are similar in the three fisheries and lagoons mentioned here, but the possibility of temporal bias still needs to be highlighted, because perhaps there could have been downstream migration after the study ended. Some silver eels do not migrate for several years (Feunteun *et al.*, 2000; Rosell *et al.*, 2005), but such a situation is thought to apply to relatively few eels and usually in river basins fragmented by dams (Acou *et al.*, 2008).

To ensure the conservation of the European eel, it is necessary to collect accurate and reliable datasets on the escapement rate of silver eels, and the current preliminary tag–recapture operation, carried out in the Or Lagoon using PIT tags and an automated recapture sensor at the wholesaler's premises is an unique application that would not have been possible without the participation of the fish wholesaler and some of the fishers. Other methods could also have been used, of course (see the reviews of Amilhat *et al.*, 2008, and Bilotta *et al.*, 2011). However, the methodology described here could fairly easily be extrapolated to all Mediterranean lagoons and river basins in which there is exploitation of this biological phase of eels if the aim is to estimate the

biomass of silver eels in various areas, and to estimate fishing mortality and escapement. Many of the Mediterranean lagoons have just one or two narrow channels linking them to the sea, so are exploited by just a few fishers who deliver to a single wholesaler. Moreover, the methodology can be used also to estimate the rate of escapement of yellow eels and hence to estimate fishing mortality on the whole population of eels in these areas.

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