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Estimating and mitigating post-release mortality of European eel by combining citizen science with a catch-and-release angling experiment

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ABSTRACT

Several anguillid eel species have experienced severe population declines over the past decades, particularly the European eel (*Anguilla anguilla*), which is listed as critically endangered by the International Union for Conservation of Nature. To reduce fishing mortality, many European countries have introduced strict recreational eel fishing regulations increasing regulatory catch-and-release (C&R) practice. Despite high release rates, only limited information exists on the potential consequences of C&R on eels. A field experiment was conducted with pre-tagged eels in a semi-natural environment to investigate lethal and sublethal impacts of C&R. The experiment was combined with a citizen science study evaluating the effects of different hooks on catch rates, fish size, and hooking location to develop best practice guidelines. Short-term mortality (≤72 h) ranged from 0.0–18.2%, and adjusted long-term mortality (> 72 h) from 0.0–46.2% depending on treatments, resulting in adjusted total mortality rates between 8.4% and 64.4% at the end of the study period (≥43 d). The only significant predictor of mortality was the occurrence of bleeding from hooking injuries. Deep hooking was common, and only few deep-hooked eels for which the fishing line was cut and the hook left in place shed the hook after release. However, no significant effect of C&R on eel condition was found. The citizen science study showed that anglers can significantly decrease the catch of small eels, and thus release rates, by using large J-hooks. Furthermore, large J-hooks or circle hooks reduced the likelihood of deep hooking compared to small J-hooks. Post-release mortality of eels caught in recreational fisheries needs to be considered in future stock assessments and management plans to ensure conservation of the European eel. This study also highlights the strength of combining citizen science with experimental studies to develop best practice guidelines promoting fish conservation.

1. Introduction

Globally, several catadromous, anguillid eel populations including the American (*Anguilla rostrate*), Japanese (*Anguilla japonica*) and European eel (*Anguilla anguilla*) have experienced severe declines to less than 10% of their population levels compared to the 1970s, in recent decades (reviewed in Jacoby et al., 2015; Tzeng, 2016). This is particularly true for the European eel (hereinafter referred to as ‘eel’), a socio-economically important target species for both commercial and recreational fishers (e.g., Dekker, 2003; Dekker and Beaulaton, 2016; Dorow et al., 2010; Moriarty and Dekker, 1997; Ringuet et al., 2002), which has been listed as critically endangered by the International Union for Conservation of Nature (Jacoby and Gollock, 2014) and in Annex II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora to control its trade (CITES, 2014). Multiple potential threats, including fishing pressure, climate change, spread of parasites and diseases, increased predation, pollution, and waterbody obstructions have been identified (reviewed in Bevacqua et al., 2015; Dekker, 2008; FAO and ICES, 2007; Feunteun, 2002). Due to the critical stock situation, a council regulation of the European

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Union (EU) came into force in 2007 obliging all EU member states to provide national eel conservation management plans by 2009. These management plans aim to ensure escapement of at least 40% of the adult eels from river and coastal catchments into the sea, where they can spawn, relative to the estimated escapement without anthropogenic impacts (EC, 2007). Various management measures such as restocking, habitat improvements, and commercial and recreational fishing regulations have been introduced by EU member states to meet the 40% escapement target. Some countries (e.g., United Kingdom, the Netherlands, and Sweden) have prohibited all recreational harvest of eel to reduce recreational fishing mortality (Ferter et al., 2013; ICES, 2013, 2016a,b) while others introduced seasonal closures, bag limits or higher minimum landing sizes in the recreational fishery (ICES, 2013, 2016a,b).

Several studies have indicated that recreational eel harvest is substantial compared to the commercial fishery in some regions (Baisez and Laffaille, 2008; Dorow and Arlinghaus, 2011; ICES, 2016a,b; van der Hammen et al., 2015). A recent comparison of recreational and commercial eel landings from six European countries (Denmark, Italy, Lithuania, Norway, Poland, and the Netherlands) revealed that recreational landings represented at least 7–32% of the total landings in these countries (ICES, 2016a). Yet, for many European countries, recreational eel catch data are still missing or incomplete, and the proportion of the recreational catches might be even higher in some countries. Even though few studies quantifying release rates in European recreational eel fisheries are available, there are indications for substantial release rates in many countries, mainly as a result of recreational harvest regulations, i.e., bag limits, minimum landing sizes, and protection of the eel (Ferter et al., 2013; ICES, 2016a,b). For example, a nation-wide recreational fishery survey from the Netherlands showed a release proportion of 72%, corresponding to 890,000 released eels in 2010 (van der Hammen et al., 2015).

The underlying assumption of catch-and-release (C&R) is that the released fish survive (Arlinghaus et al., 2007). However, C&R can have both lethal and sublethal impacts on the fish, which may render recreational fishing regulations and conservation strategies, resulting in C&R, less effective (Arlinghaus et al., 2007; Coggins et al., 2007; Lewin et al., 2006) and may have negative consequences on the population level (Hessenauer et al., 2018; Kerns et al., 2012). Considering the precarious eel stock situation, and the significant releases in the recreational fishery, there is an urgent need to investigate lethal and sublethal consequences of C&R on eels to improve management and conservation (ICES, 2016a). To the best of our knowledge, there is only one study dealing with the post-release fate of eels caught with rod-and-line (Weltersbach et al., 2016). It focused on hook shedding and post-release fate of deep-hooked eels for which the fishing line was cut and the hook left in place (hereinafter referred to as deep-hooked, line-cut eels) monitored under unnatural holding conditions for 23 weeks. However, this study did not provide absolute post-release mortality estimates that may be used for stock assessment purposes (Weltersbach et al., 2016).

Beside the need for post-release mortality estimates, it is also important to develop and communicate best practice guidelines to minimize post-release mortality and sublethal effects of C&R on eels (Weltersbach et al., 2016). Such best practice guidelines should be evidence-based, and many studies exist where best practice guidelines have been developed for other species based on C&R experiments in the field or in the laboratory (reviewed in Brownscombe et al., 2017). However, there is a risk that best practice guidelines derived from experimental work do not represent real fishing practices, which may result in ineffective guidelines and low acceptance by the recreational fishing community (Brownscombe et al., 2017).

Citizen science provides an opportunity to involve members of the public in academic research programmes, and has gained increasing attention as a cost-effective tool for the collection of scientific data (e.g., Conrad and Hilchey, 2011; Roy et al., 2012; Silvertown, 2009; Thiel et al., 2014; Tulloch et al., 2013). Even though citizen science has become an important data source in recreational fisheries research (e.g., Fairclough et al., 2014; Granek et al., 2008; Papenfuss et al., 2015; Venturelli et al., 2016; Williams et al., 2015), only few studies focusing on C&R fishing and post-release mortality have incorporated citizen science in the past (but see e.g., Danylchuk et al., 2011; Mcclellan Press et al., 2016; Weltersbach and Strehlow, 2013). Nevertheless, the development of best practice guidelines can benefit from the inclusion of data collected by anglers on a voluntary basis leading to improvements in fisheries management and conservation (Cooke et al., 2017a; Granek et al., 2008).

To estimate post-release mortality and to develop best practice guidelines reducing negative impacts of C&R on eel, a C&R angling experiment combined with a citizen science study was performed. The C&R angling experiment was conducted with pre-tagged fish under semi-natural conditions to (i) estimate post-release mortality rates, (ii) identify factors affecting mortality, and (iii) investigate sublethal effects of C&R on physical condition of eels. The citizen science study involving voluntary eel anglers was conducted to evaluate (iv) catch rates, (v) length-frequency distributions, (vi) hooking locations, and (vii) angler attitude towards three different hooks (a J-hook model in two sizes and a circle hook). The results of both studies were used to develop species-specific best practice guidelines to increase post-release survival, mitigate the catch of undersized fish, and thus reduce recreational fishing mortality.

2. Material and methods

2.1. C&R angling experiment

2.1.1. Study site, tagging, and stocking

The C&R angling experiment was carried out in a freshwater pond system in Mecklenburg-Western Pomerania, Germany between May and September 2015. Three adjacent, drainable ponds (two angling ponds and one holding pond) with similar dimensions (rectangular; length × width × depth: 41 m × 9 m × 1.5 m) and muddy substrate were used. Each pond was supplied with flow-through freshwater ($5000\,L \times h^{-1}$) from a nearby river to ensure adequate water quality. The in- and outlets of the ponds were covered with nets (7 mm mesh size) to prevent eel escapement. Water inflow, water source, and light conditions were the same for all three ponds to ensure similar environmental conditions. To prevent predation by avian predators such as herons (*Ardea cinerea*) and cormorants (*Phalacrocorax carbo*), warning tape was fixed 1 m above the water surface at regular intervals (1.5 m) to act as a deterrent. The ponds contained some natural littoral and submerged vegetation (*Carex* spp. and *Myriophyllum* spp.) and were equipped with hiding places (ceramic pipes: 10 cm Ø × 100 cm length). Natural populations of invertebrates (e.g., Chironomidae and Lymnaeidae) and three-spined sticklebacks (*Gasterosteus aculeatus*) were available for the eels to feed on.

A total of 306 wild eels (yellow eel stage according to Durif et al., 2005) were caught using fyke nets by a local commercial fisher in several lakes of the Mecklenburg Lake Plateau in May and June 2015. These eels were transported to the study site in an aerated 1000-L tank in three batches. Upon arrival, all eels were anaesthetized using aqueous solution of 2-Phenoxyethanol ($1.5\,mL \times L^{-1}$), length measured (total length [TL] to the nearest cm), weighed (total weight to the nearest g), and individually tagged with passive integrated transponder tags (PIT tag; ID 162-8-PM, EURO I.D., Weilerswist, Germany; dimensions: 2.12 mm Ø × 9 mm length) inserted into the posterior abdominal cavity through a surgical incision (2 mm length). This tagging procedure has been proven to provide fast healing and high survival rates (Baras and Jeandrain, 1998; Weltersbach et al., 2016). After a 1 h recovery period in a container filled with fresh pond water, eels were distributed equally to two angling ponds, resulting in 153 eels in each pond by 11th of June 2015. TLs of the stocked eels ranged from 36 cm