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Estimating post-release mortality of European sea bass based on experimental angling

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European sea bass (*Dicentrarchus labrax*) is an important target species for recreational and commercial fisheries. In recent years, the spawning stock biomass has declined markedly in some areas, and strict management measures have been introduced. However, the development of appropriate stock assessment and fisheries management has been hampered by a lack of information on post-release mortality. This study investigated post-release mortality of sea bass captured with common recreational fishing gear under experimental conditions in an aquaculture facility over 10 d. Three experiments investigated: (i) the effects of different bait types; (ii) the impact of prolonged air exposure; and (iii) the impact of deep hooking on post-release mortality. By combining the experimental results with country-specific information on sea bass angling practices, estimates of post-release mortality are provided for the northern sea bass stock. No mortality was observed for sea bass captured on artificial baits. The use of natural baits resulted in a mortality of 13.9% (95% $CI = 4.7–29.5\%$), which was associated with deep hooking, hooking injuries, and prolonged air exposure. The use of artificial baits and short air exposure (≤ 30 s) increased survival probability, whereas deep hooking resulted in 76.5% (95% $CI = 50.0–93.2\%$) mortality. Depending on country-specific angling practices, post-release mortality estimates ranged from 2.8% to 9.1% (mean = 5.0%, 95% $CI = 1.7–14.4\%$) for northern sea bass. Despite these relatively low mortality estimates, post-release mortality should be considered in stock assessments as its cumulative impact may be high. Moreover, post-release mortality can be reduced by implementing species-specific best practice guidelines.

Keywords: catch-and-release, deep hooking, *Dicentrarchus labrax*, discard mortality, hook and line fishing, hooking injuries, recreational fisheries, reflex and condition indicators, stock assessment

Introduction

Marine recreational fishing is a highly developed and popular activity in Europe, involving millions of people (Pawson *et al.*, 2008; Cisneros-Montemayor and Sumaila, 2010; Hyder *et al.*, 2017). Recreational fishers catch substantial quantities of marine fish (e.g. Coleman *et al.*, 2004; Cooke and Cowx, 2004; Hyder *et al.*, 2017), and recreational catches exceed commercial catches in some fisheries (Lloret *et al.*, 2008; Strehlow *et al.*, 2012). To minimize the impacts of angling (rod and line fishing) on fish stocks while maintaining angling opportunities, catch-and-release (C&R) fishing has become a widespread practice among anglers and fisheries managers (Policansky, 2002). Anglers practice mandatory C&R due to harvest regulations (e.g. bag or size limits, protected species), but also voluntary C&R due to conservation ethics (Sutton, 2003) or other personal motivations (Arlinghaus *et al.*, 2007; Cooke and Sneddon, 2007). Differences in C&R practices between countries are attributed to cultural backgrounds, angler orientations, and catch rates. For example, C&R fishing has a long tradition in the UK whereas anglers from eastern and southern European countries are often more consumption oriented (Arlinghaus *et al.*, 2007; Ferter *et al.*, 2013). The magnitude of C&R is highly variable, but often substantial (Cooke and Cowx, 2006; Ferter *et al.*, 2013). A study by Ferter *et al.* (2013) revealed that European marine anglers release >50% of the total catch (in numbers) of Atlantic cod (*Gadus morhua*), pollack (*Pollachius pollachius*), sea trout (*Salmo trutta*), and European sea bass (*Dicentrarchus labrax*) in some countries.

Despite angler's intentions, not all released fish survive (see Muoneke and Childress, 1994; Bartholomew and Bohnsack, 2005 for review), and stress and injuries can impact on physiology, behaviour, and fitness (Schreer *et al.*, 2005; Arlinghaus *et al.*, 2009; Pinder *et al.*, 2016). When C&R is a common practice, even low levels of post-release mortality can substantially increase total recreational fishing mortality for certain species (Kerns *et al.*, 2012). In addition, C&R fishing may act as selective force that potentially affects the population-level recruitment, and the quality of the fishery in the long-term (Philipp *et al.*, 2009; Sutter *et al.*, 2012).

The European sea bass is an important target species for commercial and recreational fisheries along the coasts of the northeast Atlantic, the Mediterranean, and the Black Sea (Rangel and Erzini, 2007; Armstrong *et al.*, 2013; Pérez-Ruzafa and Marcos, 2014; Rocklin *et al.*, 2014; Zarauz *et al.*, 2015; van der Hammen *et al.*, 2016; Doyle *et al.*, 2017). Anglers appreciate sea bass for its fighting abilities and culinary qualities (Colman *et al.*, 2008), and the estimated catches of sea bass taken by anglers represent 27% of the total landings from the stock in the central and southern North Sea, English and Bristol Channel, Celtic and Irish Sea (ICES IVb&c, VIIa, d-h, hereinafter: northern stock) (ICES, 2016; Hyder *et al.*, 2017). The spawning stock biomass of the northern sea bass stock has declined due to high fishing mortality and the impact of unfavourable climatic conditions on recruitment, resulting in stricter commercial and recreational harvest regulations (ICES, 2016). The minimum landing size for sea bass was increased from 36 to 42 cm for commercial and recreational fishermen in 2015. During the first half of 2016, only C&R fishing was allowed for anglers, and a one-fish bag limit per day per angler was applied for the second half of 2016 (EC, 2015a, b). Although all European Union Member States are obliged to evaluate the recreational catches of sea bass (EC, 2009), studies on the impact of recreational fisheries on sea bass are scarce (but see Rangel and Erzini, 2007; Armstrong *et al.*, 2013; Rocklin *et al.*, 2014; Zarauz *et al.*, 2015; van der Hammen *et al.*, 2016). Data for assessing potential effects of C&R fishing as a management tool to maintain sea bass stocks is limited, although the proportions of released sea bass range from 19% to 77% depending on country (Ferter *et al.*, 2013), and are likely to increase after the implementation of stricter harvest regulations (Harper *et al.*, 2000). Length-based harvest regulations have been suggested as one reason for the increased release proportions for sea bass in the UK (Pickett *et al.*, 1995). Veiga *et al.* (2010) found that the small size of fish was the main reason for releasing sea bass in the recreational shore fishery in southern Portugal. Unaccounted sources of fishing mortality such as sea bass post-release mortality can reduce the effectiveness of fishing regulations (Coggins *et al.*, 2007) and affect the ability to manage fisheries sustainably (ICES, 2016; Hyder *et al.*, 2017). Given the importance of recreational fishing for sea bass management, and the lack of robust data on mortality of recreationally caught and released sea bass, the estimation of post-release mortality and identification of C&R-related key stressors is important to develop appropriate management strategies.

This study aimed to: (i) estimate post-release mortality of sea bass (up to 10 d) captured with commonly used recreational fishing gear (experiment 1); (ii) identify key factors influencing post-release mortality and thereby develop best practice guidelines that improve post-release survival (experiments 1–3); and (iii) provide a first estimate of the otherwise unaccounted recreational post-release mortality of sea bass for the northern stock by combining experimental results with country-specific information on sea bass angling practices.

Material and methods

All experiments were carried out in accordance with animal care regulations, and the experimental protocols were approved by the ethics committee of the Federal State Office for Consumer Protection, Food Safety and Veterinary Services of Hamburg, Germany (reference: 62/15).

Study site, data collection, and rearing conditions

The experiments were conducted in an indoor recirculating aquaculture facility of the Institute for Hydrobiology and Fisheries Science at the University of Hamburg in Germany in 2015. At the outset of the experiments, all sea bass were held in one circular holding tank [300 × 140 cm (diameter × height), flow-through 1000 l h^{-1}] connected to a sea water recirculating system that provided constant water flow after mechanical and biological water treatment. Water and air temperature, pH, and dissolved oxygen were automatically measured (water temperature: HTFJ, Temperature control®; pH: RHES-Pt-SE, ProMinent®; dissolved oxygen: DOP, Dryden Aqua®), and the salinity was monitored daily with a hand-held probe (Cond 340i, WTW®). The mean salinity was 16.1 PSU (*SD* = ±0.1 PSU), mean pH 7.3 (*SD* = ±0.3), and mean concentration of dissolved oxygen 9.8 mg l^{-1} (*SD* = ±0.4 mg l^{-1}). The water temperature was held constant at 18.0 °C (*SD* = ±0.001 °C) during the study period. The average air temperature was 20.0 °C (*SD* = ±0.2 °C) during fish capture and handling. Fish were exposed to a 13 h light and 10 h dark photoperiod cycle with two 30 min twilight periods. After capture, all fish were length measured [total length (TL) to the nearest cm], weighed [total weight (TW) to the nearest g], and tagged with individually numbered t-bar anchor tags (TBA-2, Hallprint Pty Ltd®) inserted into the muscular tissue at the base of the first dorsal fin. After data collection and tagging, all fish were randomly placed into ten holding tanks [100 × 100 × 70 cm (length × width × height), flow-through 100 l h^{-1}] located in the same room and connected to the same recirculating system, where they were kept for 10 d to estimate post-release mortality. The mean number of fish in each holding tank was 19.3 (*SD* = ±4.2). Fish were fed with commercial feed once a day (Marico Mistral, 8 mm pellets, raw protein 50%, raw fat 15%, Coppens®). The holding tanks were checked daily, and all dead fish were removed from the tanks, identified by their tag number, measured and dissected to determine potential cause of death (e.g. physical hooking injuries). Sea bass were classified as dead when they showed common death signs such as no operculum and body movements, flaring of the gills, and rigor mortis.

Experiment 1: effects of different bait types on post-release mortality of sea bass

This experiment investigated the effects of common angling methods on sea bass post-release mortality using artificial and natural baits. Fish were caught with a rod and reel filled with 7 kg breaking strain braided fishing line. A sinking wobbler (65 mm, 13 g with two barbed treble hooks size 8), and a shad (75 mm with a 4 g jighead and a 2/0 sized barbed single hook) were used, representing two common artificial bait types and hook styles for sea bass. The baits were attached to a 60 cm monofilament leader line (0.27 mm Ø and 7.0 kg breaking strain), and actively fished (spin fishing) to simulate common sea bass angling practice with artificial baits. To simulate natural bait fishing for sea bass, a paternoster rig with a long-shank Aberdeen style barbed single hook (size 1/0) attached to a single dropper loop (20 cm) of monofilament line (0.27 mm Ø and 7.0 kg breaking strain) was used. The hook was baited with a lugworm (*Arenicola marina*) and the paternoster rig was attached to a 20 g fishing weight. After casting the paternoster rig into the holding tank, the fishing line was tightened to facilitate bite detection. Both for artificial and natural baits, the hook was set immediately upon detecting a bite, and fighting time and air exposure duration were kept as short as possible.

In experiment 1, a total of 97 sea bass were captured, 29 of which were caught on shad (treatment 1), 32 on wobbler (treatment 2), and 36 on natural bait (treatment 3). Prior to dehooking, the anatomical hooking location was recorded and grouped into one of five categories: (i) “mouth hooking” (lips, tongue, oral cavity); (ii) “deep hooking” (gills, oesophagus, stomach); (iii) “head” (outside, head area); (iv) “foul hooking 1” (outside but hook penetrating body cavity); and (v) “foul hooking 2” (outside, hook penetrating remaining body areas). The hooks were carefully removed by hand or using pliers. Visible injuries were described, and bleeding was characterized as none, light, or heavy. The elapsed time from setting the hook to landing the fish was recorded as fighting time. Before release into randomly selected holding tanks, all fish were measured, weighed, and assessed for three reflexes and two injury indicators. For reflex testing, individual fish were held in a restraining device (polyethylene tank) for up to 30–40 s. The reflexes were assessed as follows: eye reflex (vestibular-ocular response), body turn (righting reflex), and tail grab, and each reflex was assessed categorically (0 = unimpaired, 1 = impaired; see Davis, 2007, 2010). For testing the eye reflex, fish were held in the air and rotated around the longitudinal body axis. The reflex was rated as positive when the focus of the eye rotated within the orbit and refocused on the investigator. Body turn was tested by placing the fish upside down just below the water surface in the restraining device. A positive response was noted, when the fish actively righted itself within 3 s. Tail grab response was assessed by grabbing the tail of the fish while in the water, and the response was judged as unimpaired when the fish tried to burst-swim immediately after contact. In addition to the reflex testing, two injury indicators—(i) “presence/absence of deep hooking” and (ii) “presence/absence of heavy bleeding”—were ascertained and scored categorically (0 = absence, 1 = presence). A combined condition score was calculated from the reflex and injury assessment results for each fish, as the proportion of the five indicators that were impaired for each individual fish. The scores could range from 0 (no reflexes impaired and no injury indicators) to 1 (all reflexes impaired and both injury indicators present) (Brownscombe *et al.*, 2017).

Experiment 2: influence of prolonged air exposure on post-release mortality of sea bass

The objective of the second experiment was to investigate the effects of prolonged air exposure on post-release mortality and reflex impairment of sea bass. All sea bass were captured with the same paternoster rig baited with lugworms as used in experiment 1. The hook was set immediately after the bite, fighting time was kept to a minimum, and only mouth-hooked fish were included to minimize confounding effects on mortality due to hooking injuries. Tagging and measurements were performed in the same way as in experiment 1, but fish were exposed to air for 180 s (treatment 1; $n = 20$) and 300 s (treatment 2; $n = 10$), respectively. The duration of air exposure was chosen as it represents the “worst-case scenario” of air exposure that could occur during an angling event (Arlinghaus *et al.*, 2009; Lamansky and Meyer, 2016). During air exposure, fish were placed into an empty but wet plastic bucket, and not handled further. Before release into a randomly selected holding tank, condition scoring was conducted as described for experiment 1.

Experiment 3: influence of deep hooking on post-release mortality of sea bass

Seventeen sea bass were caught to assess post-release mortality of deep-hooked sea bass after hook removal. To increase the likelihood of deep hooking, the same single hook (size 1/0) as used in experiment 1 and 2 attached to a 60 cm monofilament leader line (0.27 mm Ø and 7.0 kg breaking strain) and baited with a lugworm was fished with a slack line. The hook setting was delayed giving the fish sufficient time to swallow the bait. After setting the hook, the fish was landed, the hook was removed carefully by hand or using pliers, and the fish was tagged, measured, and examined as in the previous experiments. Fighting time and air exposure were minimized before releasing the fish into a randomly selected holding tank.

Control group

In total, 50 sea bass were included in the experiments as control group to account for potential additional mortality caused by tagging, handling, and rearing (Wilde, 2002; Pollock and Pine, 2007). Control fish were caught with a knotless dip net, and underwent the same treatment (handling, tagging, condition scoring, and holding) as angled fish. After capture and data collection, groups of five randomly selected control fish were released into each of the ten holding tanks.

Estimating a fishery-wide C&R-related mortality for the northern sea bass stock

During a workshop at the ICES Working Group on Recreational Fisheries Surveys (WGRFS) in 2016, national experts from France, the Netherlands, England, and Belgium were asked to provide relevant information on recreational sea bass angling practices in their countries, e.g. the proportion of shore-/boat-based angling and commonly used baits in terms of released fish (ICES, 2017). The information provided was either based on expert elicitation supported by qualitative inquiries of stakeholders [e.g. local authorities, guiding operators and angler associations—Belgium (T. Verleye and F. van Winsen, pers. comm.) and France (M. Bellanger, pers. comm.], and/or on quantitative data from national recreational fisheries surveys [England (Armstrong *et al.*, 2013 and K. Hyder, pers. comm., unpublished survey data) and the Netherlands (M. de Graaf and T. van der Hammen, pers. comm., unpublished preliminary survey data)]. The country-specific information on the numbers of released fish (from Hyder *et al.*, 2017), the proportion of shore-/boat-based angling and bait type were then used to extrapolate post-release mortality rates and the confidence intervals derived from experiment 1 to subsequently estimate mean sea bass post-release mortality (in numbers and percentages) for the northern stock.

Data analysis

Unless otherwise specified, all statistical analyses and calculations were conducted using the software R version 3.3.1 (R Development Core Team, 2016). For all statistical hypothesis testing the significance level was set at $\alpha < 0.05$.

Experiment 1: effects of different bait types on post-release mortality of sea bass

Post-release mortality rates were calculated with the equations proposed by Wilde (2002) for C&R experiments containing a control group. The corresponding 95% confidence intervals were derived using the Clopper-Pearson exact method in the R package "binom" (Dorai-Raj, 2014). A Bayesian generalized mixed model (GLMM) based on Markov chain Monte Carlo (MCMC) techniques with a logit link function and a binomial probability distribution was developed to model the relationship between sea bass post-release mortality and potential predictor variables [using the R packages "MCMCglmm" (Hadfield, 2016) and "Coda" (Plummer *et al.*, 2017)]. The Bayesian approach was chosen due to data separation, which happens in models with binary or categorical outcomes when explanatory variables predict the outcome perfectly (Gelman, 2004; Rainey, 2016). The final model with lowest deviance information criterion (DIC) included the explanatory variables bait type (shad, wobbler, and natural bait), fighting time (continuous variable), air exposure duration (categorically coded as $\leq$30 s, 31–60 s, and $>$60 s), and bleeding (presence and absence). Survival was the binary response variable, and fighting time was standardized (z-transformation) to improve predictive ability and to facilitate comparison between parameters (Grueber *et al.*, 2011). The individual holding tanks were included as random effects, but hooking location was not considered a separate factor because it was confounded with bait type. TL was excluded from the final model because it did not improve the goodness-of-fit of the model and the differences in TLs were negligible. Interaction terms were excluded because a priori data exploration did not indicate the occurrence of interactions. MCMC sampling was run 300 000 times with a burn-in period of 30 000, and a thinning interval of 10. The model was assumed to have converged when no pattern was found in the trace plots and Geweke values were within 2 standard deviations of zero (Sinharay, 2003). Autocorrelation between random samples from the chains was assumed to be negligible where a rapid and continuous decline of the autocorrelation was observed in the autocorrelation plots (Hamra *et al.*, 2013).

Due to heterogeneity of variances (Levene's test), non-parametric Kruskal–Wallis tests (KW tests) were used to investigate differences in air exposure duration, fighting time, and TL between sea bass caught on the three different baits. Where a significant result was found, pairwise comparisons were done using Mann–Whitney *U* tests (MW *U* tests) with a Bonferroni–Holm correction applied to account for multiple comparisons (Holm, 1979). The non-parametric tests were performed using the software PAST version 3.14 (Hammer *et al.*, 2001). Fisher's exact test was used to test for differences in the condition scores of fish caught on the different baits.

Experiment 2: influence of prolonged air exposure on post-release mortality of sea bass

Post-release mortality and 95% confidence intervals were calculated as described for experiment 1. To test for differences in fighting time, TL, and condition scores between fish exposed to air for 180 s and 300 s, respectively, MW *U* tests were used to account for heterogeneity of variances (using PAST version 3.14; Hammer *et al.*, 2001). Fisher's exact tests were used to test for differences in the incidence of bleeding, reflex impairment, and mortality between both treatments, and potential associations between the occurrence of bleeding and reflex impairment. To investigate the relationship between reflex impairment, TL, and fighting time, the point serial correlation coefficient was calculated using the R package "ltm" (Rizopoulos, 2013).

Experiment 3: influence of deep hooking on post-release mortality of sea bass

Post-release mortality and the corresponding 95% confidence intervals were calculated as described for experiment 1. MW *U* tests were used to investigate differences in TL, air exposure duration, fighting time, and condition scores between fish that died and survived for 10 d [using PAST version 3.14 (Hammer *et al.*, 2001)]. To estimate the survival probability of deep-hooked sea bass after release over the 10-d holding period, a Kaplan–Meier survival analysis was conducted using the R package "Survival" (Therneau and Lumley, 2009).

Control group

A non-parametric KW test followed by pairwise MW *U* tests (with Bonferroni–Holm correction) was used to test for differences in TL between fish used in the three experiments and the control group using PAST version 3.14 (Hammer *et al.*, 2001).

Estimating a fishery-wide C&R-related mortality for the northern sea bass stock

To estimate a fishery-wide C&R mortality of sea bass for the northern stock, mean post-release mortalities (in numbers) split into shore- and boat-based fishing, and artificial and natural bait fishing were calculated for each country by multiplying the number of released fish by the proportion of shore-/boat-based releases, the proportion of artificial and natural bait fishing and the corresponding mortality rates from experiment 1. Where both artificial and natural baits were used simultaneously (mixed fishing), the proportion was split equally between the two bait types. The 95% confidence intervals for post-release mortality were calculated by applying the confidence intervals of the mortality rates for artificial and natural bait fishing (shad and wobbler for artificial bait fishing combined) from experiment 1.

Results

In total, 144 sea bass were angled and 50 control fish were captured with a dip net during the experiments. The control fish showed no reflex impairment, no injuries, and no mortality during the 10-d holding period. In general, TL differences were small between experiments, but control group fish were significantly smaller than fish in the angling experiments (Table 1).

Experiment 1: effects of different bait types on post-release mortality of sea bass

The majority (72%) of sea bass were hooked in the mouth in experiment 1 (Figure 1). While none of the sea bass caught on artificial baits were deep-hooked, deep hooking occurred in seven out of 36 sea bass (19.4%) caught on natural bait. In total, five out of 97 sea bass died after release, four of them within 1 h of release. Post-release mortality of sea bass caught on natural bait was 13.9% (95% *CI* = 4.7–29.5%), whereas neither sea bass captured on shad (95% *CI* = 0.0–11.9%) nor on wobbler (95% *CI* = 0.0–10.9%) died (Table 1). Dissection showed that all dead fish suffered severe internal organ injuries (oesophagus/stomach) and heavy bleeding as a result of deep hooking and hook removal.

The Bayesian GLMM showed that the occurrence of bleeding was a significant predictor of mortality, whereas short air exposure times ($\leq$30 s) and the use of artificial baits significantly increased the likelihood of survival (Table 2). Overall, 69 sea bass (71.1%) showed no indication of bleeding, whereas 21 hooking events (21.7%) resulted in light bleeding and seven sea bass (7.2%) showed heavy bleeding (Table 1). Post-release mortality was also associated with relatively long air exposure times (mean ± $SD = 54.4 \pm 33.1$ s), compared to a mean air exposure duration of 20.8 s ($SD = \pm 10.3$ s) for all other captured sea bass. The air exposure duration was highest for sea bass caught on natural bait and lowest for sea bass caught on shad (Table 1; KW test: $H = 15.4$, $p < 0.001$). Follow-up pairwise comparisons found significant air exposure differences only between the individuals caught on shad compared to fish caught on wobbler or natural bait (MW *U* test shad vs. wobbler: $U = 219$, $p < 0.01$; shad vs. natural bait: $U = 271$, $p < 0.01$). Sea bass captured on natural bait had both the longest air exposure and fighting times (Table 1; KW test: $H = 21.4$, $p < 0.001$; MW *U* test wobbler vs. natural bait: $U = 250.5$, $p < 0.001$; shad vs. natural bait: $U = 229$, $p < 0.001$), whereas the fighting times of sea bass caught on wobbler and shad did not differ significantly (Table 1; MW *U* test: $U = 450$, $p > 0.05$). Fighting times ranged from 3 s to 16 s (Table 1), and did not influence the likelihood of survival significantly (Table 2). The TL of sea bass ranged between 28 cm and 36 cm (Table 1), and did not differ significantly between fish caught on the three bait types (Table 1; KW test: $H = 1.79$, $p > 0.05$). The individual holding tank did not influence post-release mortality (Table 2).

Irrespective of the bait, sea bass did not show impairments of any of the three reflexes in experiment 1. Overall, mean condition scores ranged from zero for sea bass caught on wobbler to 0.007 ($SD = \pm 0.04$) for sea bass caught on shad, and 0.07 ($SD = \pm 0.14$) for those caught on natural bait. Condition was impaired (positive score) more frequently in fish caught on natural compared to

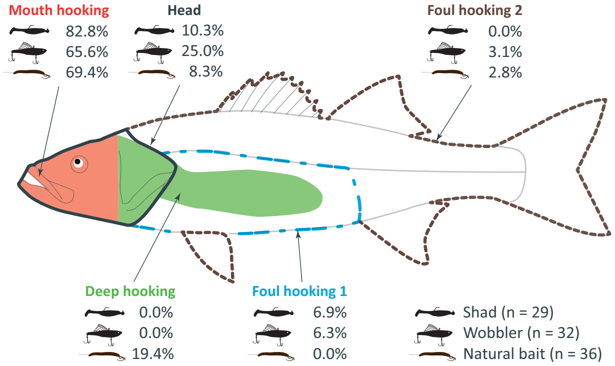

Figure 1. Incidences (%) of anatomical hooking locations for sea bass caught on shad, wobbler (both artificial baits), and natural bait in experiment 1. Anatomical hooking locations were defined as (i) "mouth hooking" (lips, tongue, oral cavity), (ii) "deep hooking" (gills, oesophagus, stomach), (iii) "head" (outside, head area), (iv) "foul hooking 1" (outside but hook penetrating body cavity), and (v) "foul hooking 2" (outside, hook penetrating remaining body areas).

Table 1. Summary of sea bass caught in the three experiments (E) showing the bait type, number of fish in each treatment (*n*), mean total weight (TW), mean total length (TL), mean fighting time (Fight), mean air exposure duration (Air) (all ± standard deviation (*SD*)), occurrence of bleeding (classified as none, light, and heavy), number of dead fish (*n*), and post-release mortality (M) including 95% confidence intervals for each treatment after 10 d.

							Bleeding (%)			Mortality		
E	Bait type[a]	*n*	TW (g) mean (*SD*)	TL (cm) mean (*SD*)	Fight (s) mean (*SD*)	Air (s) mean (*SD*)	None	Light	Heavy	Dead (*n*)	M (%)	*CI* (%)
1	SH	29	331.9 (83.6)	30.8 (2.7)	6.6 (2.2)	15.9 (6.8)	69.0	31.0	0.0	0	0.0	0.0–11.9
1	W	32	329.4 (80.1)	30.1 (2.4)	6.6 (2.2)	25.2 (12.9)	84.4	15.6	0.0	0	0.0	0.0–10.9
1	NB	36	318.2 (83.7)	30.0 (2.2)	8.8 (2.3)	27.4 (20.4)	48.0	28.0	24.0	5	13.9	4.7–29.5
2	NB	20	318.1 (79.5)	30.3 (2.4)	7.5 (2.9)	180.0 (0.0)	75.0	20.0	5.0	0	0.0	0.0–16.8
2	NB	10	332.5 (93.4)	30.3 (1.9)	7.8 (2.2)	300.0 (0.0)	70.0	20.0	10.0	1	10.0	0.3–44.5
3	NB	17	328.2 (87.8)	30.2 (2.6)	9.0 (2.1)	85.7 (36.3)	0.0	11.8	88.2	13	76.5	50.0–93.2
C[b]	N/A	50	284.3 (66.4)	28.4 (2.0)[c]	N/A	7.4 (1.5)	N/A	N/A	N/A	0	0.0	0.0–7.1

[a] SH: shad, W: wobbler, NB: natural bait.

[b] C: control group.

[c] Significant difference to the TL of fish used in the experiments 1, 2, and 3, (Median: C = 28 cm, E1 = 31 cm, E2 & 3 = 30 cm, KW test: $H_{TL} = 23.6$, $p < 0.001$, MW *U* test: $U_{C\text{-}E1} = 1{,}335$, $p < 0.001$, $U_{C\text{-}E2} = 403.5$, $p < 0.01$, $U_{C\text{-}E3} = 252.5$, $p < 0.05$).

Table 2. Summary of the final Bayesian logistic mixed model describing the relationship between post-release survival of angled sea bass from experiment 1 after a 10-d holding period and holding tank (random effect), bait type (reference category: natural bait), fighting time, air exposure duration (reference category: >60 s), and presence/absence of bleeding (reference category: absence of bleeding).

		95% *CI*			
Parameter	**Coeff.**	**Lower**	**Upper**	**Eff. sampl.**	***p*-MCMC**
Holding tank	1.37	0.34	2.94	9355.0	–
Intercept	−1.56	−14.13	11.12	1505.2	0.842
Shad	9.40	−0.70	21.56	267.1	0.048*
Wobbler	11.69	2.49	21.59	514.2	0.002*
Fighting time (s)	0.75	−0.39	1.99	1221.1	0.161
Air exposure 31–60 s	4.34	−1.73	10.58	4707.9	0.137
Air exposure ≤30 s	7.55	1.15	14.03	2341.2	0.007*
Bleeding	−8.49	−17.59	−0.39	217.7	0.014*
DIC: 16.42	–	–	–	–	–

95% *CI*: showing lower and upper bound of the 95% confidence interval; Coeff.: coefficients; Eff. Sampl. (effective sample size): number of samples taken to adjust for autocorrelation in the chains; *p*-MCMC < 0.05 (*) indicates a significant difference of the estimated coefficient from zero; DIC: deviance information criterion.

fish caught on artificial bait (Fisher's exact test, $p < 0.01$). The highest individual condition scores (0.4) were found in sea bass caught on natural bait due to deep hooking and heavy bleeding, and were a reliable indication of post-release mortality.

Experiment 2: influence of prolonged air exposure on post-release mortality of sea bass

Air exposure for 180 s prior to release did not result in any mortality, and only one out of ten sea bass died after an air exposure period of 300 s (post-release mortality = 10%, 95% $CI = 0.3$–44.5%) (Table 1). Consequently, sea bass post-release mortality did not differ significantly between air exposure treatments (Fisher's exact test, $p > 0.05$). All fish in both treatments were hooked in the mouth and no critical hooking injuries occurred. Neither fighting time (MW *U* test 180 s vs. 300 s treatment: $U = 86$, $p > 0.05$) nor TL differed significantly (MW *U* test 180 s vs. 300 s treatment: $U = 98.5$, $p > 0.05$) between the 180 s and 300 s air exposure treatments, indicating similar capture characteristics (Table 1).

No individuals exhibited impairments of the eye or body turn reflex. However, after 180 s air exposure 15% of sea bass had impairment of the tail grab reflex, and 20% of sea bass showed an impaired tail grab reflex after 300 s air exposure, but this difference was not significant (Fisher's exact test, $p > 0.05$). The mean condition score was higher for the 300 s air exposure treatment (mean = 0.06, $SD = \pm 0.08$) than for the 180 s treatment (mean = 0.04, $SD = \pm 0.14$), but this difference was not significant (MW *U* test 180 s vs. 300 s treatment: $U = 98$, $p > 0.05$). However, the fish that died after 300 s of air exposure did not have reflex impairments. Neither total length, nor fighting time was correlated with tail grab reflex impairment (point serial correlation: $r = 0.14$ and $r = 0.20$, respectively), and there was no association between the occurrence of bleeding and reflex impairment (Fisher's exact test, $p > 0.05$).

Experiment 3: influence of deep hooking on post-release mortality of sea bass

The post-release mortality was 76.5% (95% $CI = 50.0$–93.2%) for deep-hooked sea bass after the 10-d holding period (Table 1). Fish that died post-release and those that survived the holding period did not differ in TL, air exposure duration or fighting time (Table 1; MW *U* tests, all $p > 0.05$). The Kaplan–Meier survival analysis showed that the median survival time of deep-hooked sea bass was 1 h (95% $CI = 1$–214 h) reflecting that 76.9% of the mortality occurred within 1 h of release (Figure 2). Deep hooking was always accompanied by bleeding, and dissection showed that post-release mortality had most likely resulted from fatal hooking injuries to vital organs. In 85% of the dead sea bass, the hook had penetrated the oesophagus or the stomach, and hook removal had led to lethal injuries of the oesophagus, stomach, liver, heart and gills. The surviving fish did not show any indications of severe physical hooking injuries. Deep hooking was related to long periods of air exposure (29–182 s), as hook removal of deep-hooked fish was aggravated compared to mouth-hooked fish leading to prolonged handling times. The mean condition score was 0.38 ($SD = \pm 0.07$) and ranged from 0.2 to 0.4 for individual sea bass. The positive score values resulted only from deep hooking and heavy bleeding, as none of the sea bass showed indications of reflex impairment for the three reflexes tested. The condition scores did not differ significantly between deep-hooked fish that had died and those that had survived the 10-d holding period (MW *U* test: $U = 21.5$, $p > 0.05$).

Estimating a fishery-wide C&R-related mortality for the northern sea bass stock

Most anglers preferred active to passive angling methods, and used artificial baits such as spoons, shads or wobblers more frequently than natural baits (Table 3). However, bait choice depended on angling location, and natural baits were preferably used in shore-based compared to boat-based recreational fisheries. In England and Belgium, the proportion of use of natural baits was higher for shore-

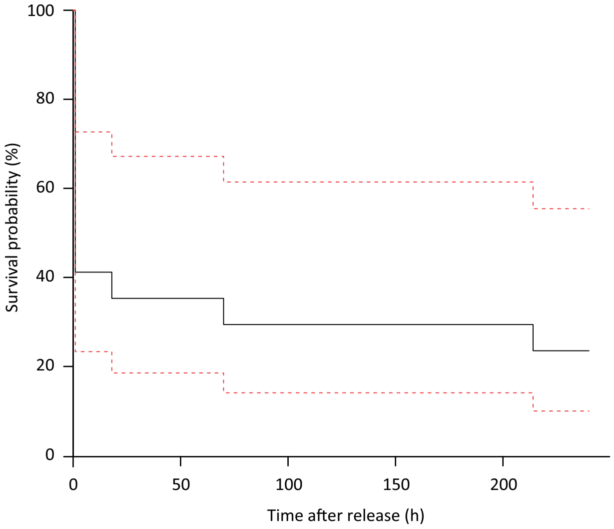

Figure 2. Kaplan–Meier survival curve showing the probability of deep-hooked sea bass surviving the 10-d holding period in experiment 3. The solid line represents the estimated Kaplan–Meier survival function and the dotted lines the 95% confidence intervals.

Table 3. Information on sea bass angling practices (proportion of released fish caught on artificial (AB), natural (NB), and mixed (Mix) bait, and proportion of shore and boat releases) based on expert elicitation or survey data; harvest and releases (in numbers and biomass, data from 2009–2013 depending on country), and mean post-release mortality (including 95% confidence intervals (CI)) are presented by country and sea area for the northern sea bass stock (ICES areas IV b&c and VII a, d–h).

Country and sea area (ICES areas)	Proportion (%) bait (in terms of released fish)		Proportion (%) of overall release (shore/boat)	Numbers (biomass in tonnes) of recreational harvest and releases	Estimated mean mortality in numbers (CI)	
	Shore	**Boat**			**Shore**	**Boat**
Belgium Southern North Sea (IVc)	AB: 15[a] NB: 85[a]	AB: 90[a] NB: 10[a]	35/65[a]	Harvest: 51 000 (60) [e] Release: 59 000 (25) [e]	AB: 0 (0-183) NB: 2 440 (825-5 178)	AB: 0 (0-2 036) NB: 533 (180-1 131)
England North Sea, Channel, Irish Sea (IV b&c & VII a, d-h)	AB: 9[b] NB: 84[b] Mix: 7[b]	AB: 26[b] NB: 48[b] Mix: 26[b]	18/82[b]	Harvest: 243 000 (285)[e] Release: 467 000 (197)[e]	AB: 0 (0-620) NB: 10 224 (3 457-21 698)	AB: 0 (0-8 811) NB: 32 469 (10 979-68 910)
France North Sea, Channel (VII d-h)	AB: 80[c] NB: 20[c]		50/50[c]	Harvest: 781 000 (940)[e] Release: 904 000 (332)[e]	AB: 0 (0-21 334) NB: 12 566 (4 249-26 668)	AB: 0 (0-21 334) NB: 12 566 (4 249-26 668)
Netherlands Southern North Sea (IVc)	AB: 62[d] NB: 38[d]		N/A	Harvest: 284 000 (183)[e] Release: 232 000 (97)[e]	AB: 0 (0-8 487) NB: 12 254 (4 144-26 007)	

[a] Thomas Verleye and Frankwin van Winsen (pers. comm.).

[b] Armstrong *et al.* (2013) and K. Hyder (pers. comm.), unpublished survey data.

[c] Manuel Bellanger (pers. comm.).

[d] Martin de Graaf and Tessa van der Hammen, unpublished preliminary survey data.

[e] Hyder *et al.* (2017).

based compared to boat-based angling, and the percentage of released fish was higher for boat-based compared to shore-based angling. Using a post-release mortality of 13.9% (95% $CI = 4.7$–29.5%) and 0.0% (95% $CI_{\text{shad and wobbler combined}} = 0.0$–5.9%) for sea bass captured on natural and artificial baits, respectively—derived from experiment 1—country-specific mean post-release mortality rates for sea bass were calculated from numbers of released fish (shore- and boat-based angling combined). The estimated mean post-release mortality was 2.8% (95% $CI = 0.9$–10.6%) in France, 5.0% (95% $CI = 1.7$–14.5%) in Belgium, 5.3% (95% $CI = 1.8$–14.9%) in the Netherlands, and 9.1% (95% $CI = 3.1$–21.4%) in England (Table 3) resulting in an overall mean post-release mortality rate of 5.0% (95% $CI = 1.7$–14.4%) for the northern sea bass stock.

Discussion

The impacts of C&R are species- and fisheries-specific, and influenced by various abiotic and biotic factors (Bartholomew and Bohnsack, 2005; Siepker *et al.*, 2007). This makes generalizations of results obtained from specific C&R studies challenging (Cooke and Suski, 2005). Given the decline in the northern European sea bass stock, the importance of recreational sea bass fishing, high release rates, and the lack of information on post-release mortality, there was a need to estimate post-release mortality and identify key stressors influencing post-release mortality. The present study identified factors influencing sea bass mortality after C&R and provides first country-specific post-release mortality estimates for northern sea bass that can be used in stock assessment and sea bass management.

Post-release mortality of sea bass

The overall mean post-release mortality rate of sea bass obtained from experiment 1 was low (5.2%), and ranged from 0.0% to 13.9% depending on bait type (Table 1). There is no other published study available that has investigated post-release mortality of sea bass after C&R. However, a similar mean post-release mortality rate of 9% has been reported for recreationally caught striped bass (*Morone saxatilis*) in saltwater (Diodati and Richards, 1996). Striped bass belongs to the same family and has similar life history traits to sea bass (Pickett and Pawson, 1994). A meta-analysis of 274 C&R mortality estimates including both marine and freshwater species showed a higher mean mortality rate of 18% (median 11%, range 0–95%) indicating that sea bass may be relatively robust to C&R-related stressors in comparison to other species (Bartholomew and Bohnsack, 2005).

In this study, 78.9% of the dead sea bass died within 1 h of release. This is similar to several other studies showing that most post-release mortality occurs within a few hours or days of release (see Muoneke and Childress, 1994 for review). Thus, is it likely that the 10-d holding period was sufficiently long to cover the majority of mortality due to the C&R event. The absence of mortality in the control group indicated that tagging, handling, short air exposure, and post-release holding conditions did not affect sea bass mortality, and that the observed post-release mortality resulted from C&R-related stressors.

Factors influencing post-release mortality of sea bass

Post-release mortality was mainly influenced by the bait type used, and mortality only occurred in fish caught on natural bait. Sea bass caught on natural baits were more likely to be deep-hooked leading to severe hooking injuries and heavy bleeding. In addition, deep hooking aggravated hook removal resulting in longer handling and air exposure times. The high mortality observed in experiment 3 underlined the mortality risks associated with deep hooking and hook removal, and is in line with other studies from marine and freshwater environments (Diggles and Ernst, 1997; Stålhammar *et al.*, 2014). The high deep hooking risk associated with the use of natural baits and passive angling methods is most likely due to the fact that natural baits are recognized and accepted faster by the fish, and that delayed reaction times associated with passive bait angling allowed the fish to ingest bait and hook (Lennox *et al.*, 2015).

Heavy bleeding as mortality predictor should be viewed in connection with the anatomical hooking location, because both are closely related. In particular, hooking injuries in the oesophagus, stomach, or intestine result in severe bleeding (Muoneke and Childress, 1994), and lead to increased post-release mortality in numerous species (e.g. Millard *et al.*, 2003; Weltersbach and Strehlow, 2013). Deep hooking and associated heavy bleeding are among the most important factors determining post-release mortality (Muoneke and Childress, 1994; Bartholomew and Bohnsack, 2005). Only 19.4% of sea bass captured on natural baits were deep-hooked when using tight lines and striking immediately (experiment 1), whereas all fish were deep-hooked when fishing with a slack line and delayed hook setting (experiment 3). This highlights the importance of angling practices in determining post-release mortality, and the potential to develop best practice guidelines that could reduce post-release mortality if C&R is used as a management tool. The experiments confirmed that the use of natural baits increased the risk of deep hooking but indicated additionally that appropriate fishing methods and hook setting techniques may reduce the likelihood of deep hooking (Lennox *et al.*, 2015).

Fish captured by anglers are often exposed to air (e.g. for hook removal, measurements, or photographs), and even within short exposures gill lamellae can collapse and the inhibition of gas exchange in the gills may lead to physiological stress (e.g. extracellular acidosis, build-up of metabolites, cardio-vascular alterations; Suski *et al.*, 2004). Depending on environmental conditions and duration, the impact of air exposure on post-release mortality may be exacerbated if the fish is subjected to a prolonged fighting time prior to air exposure (Cooke *et al.*, 2001; Cooke and Suski, 2005; Thompson *et al.*, 2008). Experiment 1 showed that brief air exposures reduced the likelihood of mortality, but it was not possible to separate the impacts of air exposure and injury resulting from deep hooking, as deep hooking was always associated with prolonged handling periods and severe hooking injuries. Experiment 2 showed that sea bass with minor hooking injuries could withstand up to 180 s of air exposure following a fighting time of 3–15 s. The results indicate that the vulnerability of sea bass to prolonged air exposure periods ($\leq$3 min) under the given conditions (short fighting times, 20 °C air temperature and no extra handling) was relatively low. Other studies found a similar resilience to prolonged air exposure periods in various species including gilthead sea bream (*Sparus aurata*; Arends *et al.*, 1999), largemouth bass (*Micropterus salmoides*), and smallmouth bass (*Micropterus dolomieu*; White *et al.*, 2008). The two air exposure times used in experiment 2 were chosen to represent extreme periods of handling time during angling practice, and the periods anglers commonly expose sea bass to air may be much shorter. However, because different stressors act additive or multiplicative on mortality (Gingerich *et al.*, 2007), even short periods of air exposure may increase post-release mortality when fish are exhausted due to long fighting times. If limited air exposure does not cause mortality, it may lead to various sublethal effects that may impact long-term survival (Arlinghaus *et al.*, 2009), or lead to performance impairments that may expose released fish to predators (Schreer *et al.*, 2005).

In the present study, fighting time did not significantly predict post-release mortality of sea bass. Severe physiological disturbances resulting from burst swimming when a fish tries to escape during retrieval can deplete energy stores, and impact acid-base and ionic balance (Wood *et al.*, 1983; Barton, 2002), and the severity of physiological disturbances is positively correlated to exhaustion (Bettoli and Osborne, 1998; Kieffer, 2000). Although the impact of stress on post-release mortality in the present study could not be excluded, fighting times in the experiments were short. Under natural environmental and fishing conditions, fighting times are likely to be longer and therefore may have more impact. Nonetheless, the effects of fighting time on post-release mortality in other species are not consistent, because fighting time-related effects may be shaped by environmental and fishing gear-related factors, and the condition of individual fish (Bettoli and Osborne, 1998; Schlenker *et al.*, 2016).

Assessment of reflex impairment and injury indicators

Despite the popularity of sea bass as a recreational fisheries target species with high release numbers, no reflexes have been validated for the estimation of sea bass post-release mortality. The present study showed that the reflexes body turn, tail grab and eye reflex alone were not good predictors of post-release mortality in sea bass under laboratory conditions, although evidence from laboratory and field studies indicated that reflex impairment indicators successfully predicted post-release mortality for a number of other fish species (Davis, 2010; Campbell *et al.*, 2010; Lennox *et al.*, 2015). Several studies demonstrated that reflex impairment is associated with increased accumulation of blood lactate, depressed muscle pH, or increased haematocrit concentrations (McArley and Herbert, 2014). However, the congruency of reflexes or mortality and physiological stress indices can widely vary (McArley and Herbert, 2014, Brownscombe *et al.*, 2017). Although injuries generally lead to physiological stress (Gadomski *et al.*, 1994), it is possible that the injuries observed in the present experiments in combination with short fighting and air exposure times may not have led to the physiological stress reactions manifested by reflex impairment. The eye reflex was never impaired in this study, but is also often the last to become impaired in other species (Brownscombe *et al.*, 2017). In contrast, the tail reflex indicated that the physiological stress following prolonged air exposure was related to the magnitude of the stressor as it has been also shown for other species (Lennox *et al.*, 2016). As the tail reflex involves the use of white myotomal musculature it is likely to be the first to become impaired as a result of metabolic acidosis following capture stress (Brownscombe *et al.*, 2014; Raby *et al.*, 2015). Even if the tail reflex does not predict delayed mortality, it indicates the potential for an impaired escape response that is important for survival after release (Danylchuk *et al.*, 2007). In contrast, the eye reflex is controlled by the autonomic nervous system and its impairment is caused by a combined breakdown of neural and muscle functions. Its impairment usually indicates a high level of physiological and neurological stress, and is associated with a high mortality risk (Raby *et al.*, 2015). Nevertheless, reflex impairment indicators are useful, especially when combined with injury traits because reflex and injury assessments are easy and rapid (<20 s), and the results can be combined into a simple condition score that indicates fish vitality before release (Davis, 2010; Brownscombe *et al.*, 2017). The present study confirmed the proposal by Brownscombe *et al.*

(2017) that an assessment based on the combination of injury indicators and reflexes may provide a more comprehensive assessment of post-release mortality then an assessment based solely on reflex testing. A combination of other or more reflexes may further increase the reliability of an assessment of sea bass post-release mortality and future work should aim to identify candidate reflexes, and to identify any link between angling practice, reflex impairment and post-release mortality in sea bass.

Potential study limitations

Although laboratory experiments with artificially reared fish provide valuable information, which can be controlled for handling-induced mortality or stress, and may identify relevant biologically thresholds, they have nonetheless major shortcomings. Post-release mortality depends upon interactions between multiple angling-, species-, and environment-related factors, which could not be fully covered in the present study. This study was performed with similar-sized (24–36 cm) sea bass obtained from aquaculture facilities. Hatchery-born and reared fish may differ from wild fish in morphology, physiology, behaviour, genetic composition, and stress response (Brown and Day, 2002), and wild fish may be more susceptible to handling stress than aquaculture-reared fish (Salonius and Iwama, 1993). Further differences may result from the stable, artificial environment in the recirculating aquaculture facility. Many studies have shown that the impacts of angling-related stressors on fish are influenced by environmental variables (Bartholomew and Bohnsack, 2005; Arlinghaus *et al.*, 2007). High water temperatures, for example, can increase post-release mortality in several species, as fish become more sensitive to physiological disturbances caused by increased metabolism and low dissolved oxygen levels in the water. However, the water temperature during the experiments represented common sea surface temperatures in the northern sea bass stock area during summer (BSH, 2017), so is likely to be representative of the main fishing season. The pH was lower than in a natural marine environment (Salt *et al.*, 2013), but sea bass has a large natural range, inhabiting brackish and marine environments, and is tolerant to temperature and pH variations (Algers *et al.*, 2008).

The study was restricted to sea bass with TLs lower than the current minimum size limit of 42 cm, as small fish are more likely to be released (Ferter *et al.*, 2013; Veiga *et al.*, 2010). Fish size can be a source of variability in physiological disturbances (Fabrizio *et al.*, 2008). However, size effects of stress responses to angling are not consistent, so the relationship may be species-specific and depend upon additional environmental factors (Lukacovic and Uphoff, 2006).

Post-release mortality is strongly influenced by angling depth, angling method, handling technique, and terminal gear type (e.g. different hook sizes and types). For example, if sea bass are caught in water depths >10 m and rapidly brought up to the surface, barotrauma may increase post-release mortality as shown for other species (Bartholomew and Bohnsack, 2005, but see Ferter *et al.* 2015). Even though the data from expert elicitations and national recreational fisheries surveys indicated that the most common angling methods and bait types were used in the present experiments, these may not have been representative across all regions. However, it is likely that the methods, baits, and hook types chosen represented the majority of terminal tackle used in recreational sea bass fisheries, as passive and active angling methods, artificial and natural baits, and treble and single hooks were used.

Most mortality occurred within hours or a few days of release, so a holding period of 10 d was sufficient to evaluate delayed mortality directly related to capture and handling stress (Muoneke and Childress, 1994). However, sublethal effects including reduced growth rates due to decreased feeding activity (Siepker *et al.*, 2006; but see Pope and Wilde, 2004) or impacts on the reproductive fitness (Ostrand *et al.*, 2004; Suski *et al.*, 2003; Siepker *et al.*, 2009; Pinder *et al.*, 2016) may occur, but were not investigated in the present study. In addition, under natural conditions, even short behavioural disturbances of released fish may increase post-release mortality in the presence of aquatic or avian predators (Danylchuk *et al.*, 2007).

Estimating a fishery-wide C&R-related mortality for the northern sea bass stock

It is not possible to determine a default post-release mortality from a single experiment, which is valid for all recreational sea bass fisheries, due to the number of factors that can influence mortality (Cooke and Suski, 2005). Collection of information on fishing practices that have been identified as important factors influencing post-release mortality may help to extrapolate experimentally derived post-release mortality rates to provide more robust estimations of post-release mortality across a fishery. The present study indicated that post-release mortality of northern sea bass may be relatively low, so current management measures (e.g. bag limits and minimum size limits) requiring the release of sea bass most likely reduce recreational fishing mortality while maintaining angling opportunities. Given the estimated mortality rates and the magnitude of recreational releases for the northern sea bass stock, post-release mortality should be considered in future stock assessments to ensure sustainable management of the stock. Nonetheless, the preliminary estimation of post-release mortality needs further validation due to the limitations of the experiments and the uncertainties of the expert elicitations concerning sea bass fishing practices. Moreover, some factors influencing post-release mortality and sublethal effects were not considered (Kerns *et al.*, 2012). The use of information on recreational fishing practices seems to be a valuable approach to extrapolate mortality rates derived from individual studies for the use in stock assessments. Thus, further studies are needed collecting representative information on recreational sea bass fishing practices in Europe to enable extrapolation of mortality rates between stocks and fisheries.

Conclusions and management implications

Generally, C&R can help to reduce the overall fishing mortality of exploited fish stocks and thereby maintain fishing opportunities if carried out properly with regard to the species and environment, and by sufficiently skilled and educated anglers (Muoneke, 1992; Cooke and Suski, 2005). The present study indicates that most recreationally caught and released sea bass are likely to survive, but the results should be interpreted with caution as the experimental angling situation may not be a representation of the natural conditions. Nonetheless, when combined with information from recreational sea bass fishing practices, this study represents the first step in estimating post-release mortality for the recreational fishery on sea bass, which is an important parameter for future stock assessments. To corroborate these mortality rates and assess sublethal effects, further studies are needed that include mark-recapture or biotelemetry studies in the field (Pollock and Pine, 2007). Such studies should cover various habitats, seasons, and environmental conditions, not least because C&R may be less successful if conducted during periods of extreme water temperatures or during the reproductive period. The impacts of C&R on sea bass survival can be minimized through the use of adequate angling and handling techniques. Fishing with artificial baits rarely led to deep hooking reducing hooking injuries and bleeding, and is likely to result in higher survival of released fish. When using natural baits, it is important to use fishing techniques that allow fast bite detection and minimize the likelihood of deep hooking (Grixti *et al.*, 2007; Lennox *et al.*, 2015). In case of deep hooking, post-release mortality may be minimized by not attempting to remove the hooks. Although not investigated for sea bass, some studies on other species found higher survival rates of deep-hooked fish, if the line was cut and the hook left in place (Aalbers *et al.*, 2004; Fobert *et al.*, 2009; but see Weltersbach *et al.*, 2016). Fighting time and air exposure duration should be minimized to reduce physiological stress, and excessive C&R practice during reproduction periods and extreme water temperatures should be avoided. Even though C&R regulations can be an effective tool to reduce fishing mortality of sea bass in European marine recreational fisheries, stock assessments should account for post-release mortality to ensure sustainable fisheries management and species-specific best practice guidelines may help to reduce post-release mortality.

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