Understanding Mortality of European Sea Bass (*Dicentrarchus labrax*) in Small-Scale Inshore Netting

Research Report

V1.0

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Cover image: Hauling a monofilament gillnet in Salcombe, January 2022, under exemption from D&S IFCA's Byelaws and dispensation from the Marine Management Organisation.

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Executive Summary

Unaccounted sources of fishing mortality, including post-release mortality of discards, can reduce the effectiveness of fishing regulations and the hamper efforts to manage stocks sustainably. It is therefore vital to understand the level of discarding and associated mortality in fisheries. European sea bass (*Dicentrarchus labrax*) is a particularly significant species in this regard: it is an important component of commercial and recreational fisheries that has experienced stock declines which in recent years have been managed via regulations that promote discarding, yet the survival of these discards is not always well-understood.

To address this, Devon and Severn Inshore Fisheries and Conservation Authority (D&S IFCA) collaborated with the University of Plymouth and a local fisher to assess the condition and mortality of sea bass discarded from small-scale inshore netting activities, which are underrepresented in previous discard mortality studies. In January 2022 and 2023, sea bass were caught in short lengths of monofilament gillnets which were set in the Salcombe-Kingsbridge Estuary (South Devon) for short deployment (soak) times of up to 80 minutes. This represents the small-scale netting for species such as grey mullet which has previously taken place locally. The sea bass were assessed to quantify the short- and medium-term impacts of netting on condition and mortality. A subset of these fish was then implanted with acoustic tags to investigate longer-term impacts of netting on mortality and behaviour.

Catch composition was unpredictable in the 32 net hauls conducted in this study, with an unreliable catch of grey mullet that varied between hauls. In 2023, 52% of the total catch was sea bass, while only 39% was mullet. The recent draft Fisheries Management Plan (FMP) for sea bass recognises that that sea bass should only be considered as ‘bycatch’ up to a certain proportion of the catch (potentially < 50%), and that many stakeholders consider the existing bycatch regulations have been too easy to exploit as it can be difficult to prove a difference between purposefully targeting sea bass and unavoidable bycatch. In this study in 2023, 44% of the net hauls which caught any fish included sea bass as >50% of the catch (while 55% of hauls included sea bass as >40% of the catch).

In this study, the sea bass experienced a mortality rate of 18.8% due to netting; however, taking into account all sources of uncertainty it is likely that the true mortality would be higher in real-world fishing conditions. Mortality was slightly higher when the net took longer to haul, indicating that discard mortality would increase as the catch size increases. Mortality of discarded sea bass appears to occur between approximately five minutes and several hours after capture, as the fish succumb to injuries, stress and/or exhaustion induced by the netting. The acoustic tracking data indicated good long-term survival prospects for those fish that were in good or excellent condition after capture, but the recovery rates for fish in worse condition are likely to be poor. The 18.8% mortality rate is much higher than the mortality rate observed for catch and release angling (5%), and higher than commercial hook and line fisheries (10.7%), but lower than estimates for static nets, drift nets and otter trawls when those gears are used with much longer soak times than tested here.

The tagged sea bass showed a high degree of site residency to the Salcombe-Kingsbridge Bass Nursery Area for most of the year, implying high hypothetical exposure to the kind of small-scale estuary-based netting activity studied here. The draft sea bass FMP has several proposed actions to achieve efficient sea bass stock replenishment, including considering a prohibition of fixed netting in designated Bass Nursery Areas. This prohibition is already in place in D&S IFCA’s District via the Netting Permit Byelaw and associated Permit Conditions, demonstrating D&S IFCA’s commitment to sustainable fisheries management.

1. Introduction

The European sea bass (*Dicentrarchus labrax*) is a high value species for both commercial and recreational fishers in the United Kingdom and Europe (Pickett and Pawson, 1994). In 2022 the commercial landings of the UK fishing fleet totalled 611.7 tonnes (with an estimated value of £5.94 million), most of which is caught by the under 10 m fleet (MMO, 2023). Of this, 336.5 tonnes (£3.54 million) was caught using hook and line, and 184.0 tonnes (£1.58 million) was from gill and entangling nets (MMO, 2023). Recreationally, sea bass is one of the most popular targets across the UK and Europe (Armstrong *et al.*, 2013), representing just under 10% of all fish caught by UK sea anglers in 2019 (Hyder *et al.*, 2021). In 2019, 3.35 million sea bass (totalling 2436 tonnes) were estimated to have been caught by UK recreational sea anglers, most of which (3.2 million, 2187 tonnes) are thought to have been released (Hyder *et al.*, 2021).

The spawning stock biomass (SSB) of the Northern Atlantic sea bass stock has rapidly declined in recent years, including dropping below “safe biological limits” (the B_{lim} threshold) in 2016 (ICES, 2022). The decline in SSB is thought to have occurred due to a combination of overfishing and environmental conditions leading to poor recruitment years (ICES, 2022). Strict conservation measures have since allowed the SSB to rise back above B_{lim}, but the SSB is depleted relative to past levels and remains below the Maximum Sustainable Yield (MSY) threshold (ICES, 2022).

Current management measures aim to reduce overall landings, including via closed areas, closed seasons, catch limits for specific metiers, and through the use of a Minimum Conservation Reference Size (Peverley and Stewart, 2021). Additional national management measures are in place, such as the designation of 34 Bass Nursery Areas, which restrict fishing for sea bass, or any other species of fish using sand eels as bait, by any fishing boat within any part of the designated areas (UK Government, 1999). Finally, fishers targeting sea bass in English inshore waters also have to comply with local IFCA regulations. IFCAs each have a set of byelaws in place regulating the fishing effort and gear in their Districts. Sea bass remains a non-quota species managed using landings limits, and is not subject to the landing obligation (MMO, 2020); therefore, when sea bass is caught with unauthorised gears or with authorised gears but over the authorised limit, the sea bass must be discarded. Therefore, there are often high levels of discards, particularly as sea bass exhibit schooling behaviours which can lead to large bycatch events; the rate of discards is also likely to increase as sea bass stocks recover in the future (Pickett and Pawson, 1994; Randall *et al.*, 2021).

The implications of high discard rates for SSB and stock recovery are uncertain, as the survival of discarded sea bass is currently poorly understood. Randall *et al.* (2021) recently assessed survival and condition of sea bass caught in large-scale at-sea fisheries using gears with relatively long soak times. They showed that short-term (at-vessel) mortality rates for sea bass vary considerably across different gear types from as low as 7% for otter trawls, to up to 68% of the catch when using static nets. Long-term survivability of the species (post-release) was less certain in this recent study due to small sample sizes of tagged fish, although many individuals were assessed to be in poor condition at the time of release (Randall *et al.*, 2021). However, survival rates from smaller-scale inshore activities with short soak times have not been studied. In light of this, as well as the extensive regulations surrounding sea bass fishing and the increasing potential for discards as stocks recover, it is important to understand how both short-term and long-term survival and condition of discarded sea bass varies across different fishery scenarios, as this information could be used to inform future management of sea bass fisheries.

Therefore, the aim of this study was to gain a better understanding of the mortality of sea bass that would be discarded as bycatch in small-scale gill netting activities in estuaries. This study focused on an area of south Devon where small-scale netting practices have previously been carried out. By collaborating with a local fisherman and a scientific team which was seeking to acoustically track the movements of sea bass, this study was able to use a range of assessment techniques combined with acoustic tagging of fish, to understand the short-, medium- and long-term impacts of netting on sea bass condition, mortality and behaviour.

2. Methods

In summary, European sea bass (*D. labrax*) caught in authorised netting activities were assessed for vitality post-capture and after a short period of recovery in holding tanks or sea cages, providing a short- and medium-term assessment of fish condition and mortality. A subset of these fish were then tagged with acoustic transmitters, under Home Office licence, allowing a longer-term assessment of mortality and behaviour.

2.1 Study location and timing

All netting activities were carried out in January 2022 and January 2023 in the Salcombe-Kingsbridge estuary (Figure 1), which is a designated Bass Nursery Area (BNA) (UK Government, 1999). Dispensation was granted by the MMO for fishing activities including temporary retention of undersize (<42 cm total length) sea bass for tagging purposes, and netting was authorised under exemptions from D&S IFCA's Netting Permit Byelaw and Inherited Byelaw 17 (Fixed Engines).

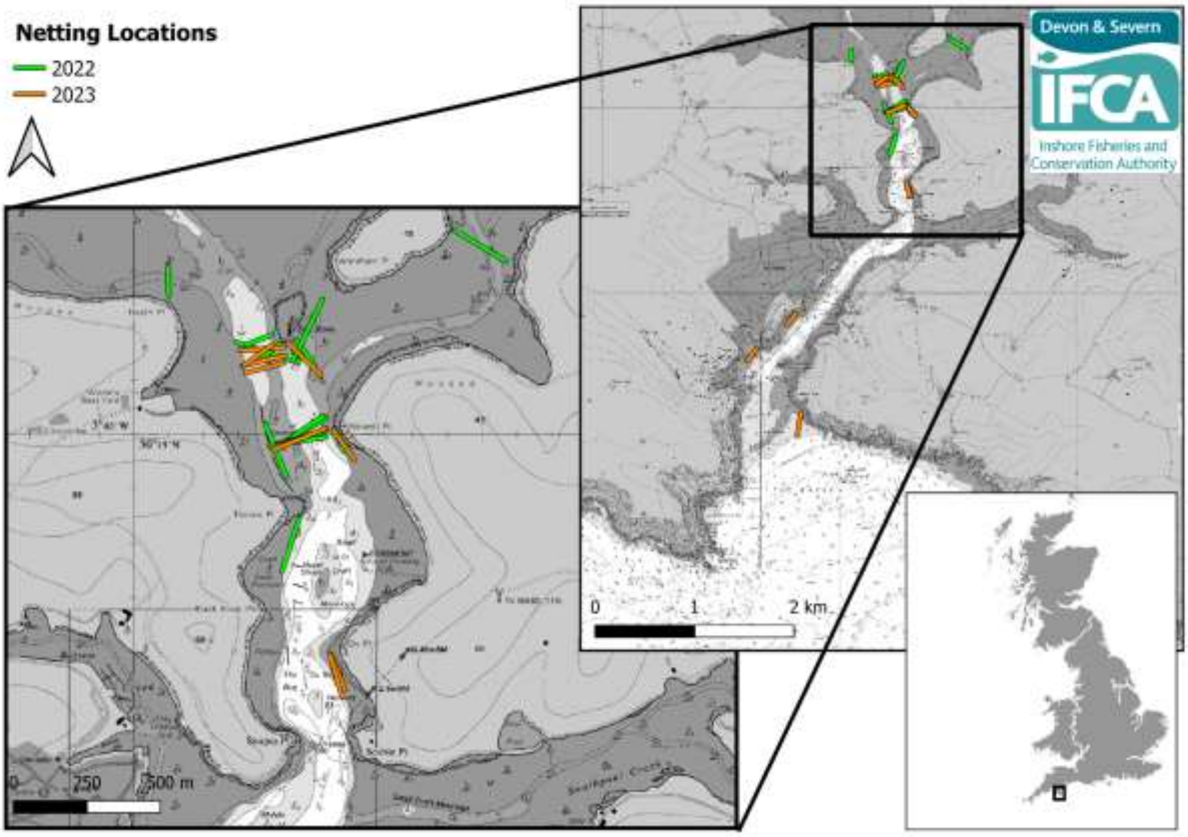

Figure 1. Study location near Salcombe, South West England, showing where nets were set in 2022 (green) and 2023 (orange).

2.2 Netting and sampling

On each fishing trip, the fisher was asked to conduct normal fishing activities. Short lengths (100–200 yards) of 2m depth monofilament gillnet with 100mm mesh were deployed for soak times (in-water deployment times) of between 12–80 minutes (mean ± SD 42.8 ± 17.1 minutes; gear shot to start of haul) or 25–102 minutes (mean ± SD 59.6 ± 19.3 minutes; gear shot to end of haul), with a gear haul time of 5–44 minutes (mean ± SD 16.7 ± 8.7 minutes).

Discarding of fish normally takes place as soon as any unwanted fish are identified in the sorting process. Catch was therefore removed from nets as the nets were hauled, and once sea bass were removed from the net, they were measured and assessed for 'vitality' and injuries (see below for assessment methods). These first vitality assessments either took place immediately upon removal of sea bass from the net, or after a short period of time in an on-board tank of sea water (450 litre capacity) if conditions on the netting boat were challenging. The on-board tank of sea water was half-filled and regularly refreshed, and was used to temporarily retain fish while the net was redeployed (if tides allowed) and while the sea bass were in transit to sea cages (c. 1m^3 with 10 mm mesh) (Figure 2) attached to a nearby pontoon. The fish were then able to recover in these cages before a second vitality assessment was carried out. These cages have routinely been used successfully for this purpose by the University of Plymouth tagging team. In 2023, some fish were placed in a flow-through tank on board a larger moored vessel (the “tagging vessel”) for their recovery phase. If no decrease in vitality for an individual was observed, then the sea bass was selected for tagging (see below for details of tagging).

Most fish were tagged on the day of capture after two vitality assessments, but some were retained in the recovery cages overnight. For these fish, the second assessment was completed after approximately one hour of recovery time post-capture and a third assessment conducted on the morning of tagging. After tagging was completed, the sea bass were given another period of recovery in a full 450 litre tank with constant water flow; if no decrease in vitality was observed then the tagged sea bass were released. At any stage, if the vitality deteriorated then the sea bass were terminated appropriately using a schedule one method.

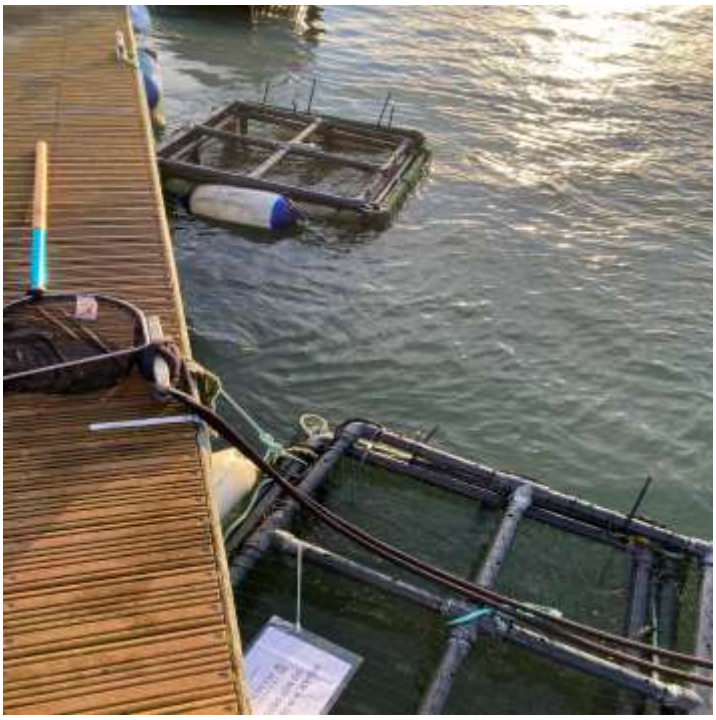

Figure 2. Sea cages used for temporary retention of sea bass alongside a pontoon at which the tagging vessel was tied up. The in-water sections of the cages were surrounded by a 10 mm mesh net. The lid of the cages was covered with a mesh of approximately 70 mm.

2.3 Vitality assessments

The total length of each fish was measured, then the health ('vitality') of fish was assessed using two methods applied by the Centre for Environment, Fisheries and Aquaculture Science (Cefas) for assessing sea bass vitality (Randall *et al.*, 2021): a semi-quantitative reflex and injury scoring method (Table 1 and Table 2) and a semi-quantitative assessment of the vitality of the individual fish (Table 3). This process typically took around 20 seconds to complete, of which up to 10 seconds involved holding the fish out of water.

The semi-quantitative reflex and injury scoring method consisted of a series of behavioural reflex tests that consistently produce unimpaired responses in both free-swimming and restrained fish, and could be scored rapidly in a replicable manner. As applied here, this method is based on six reflex impairments (Table 1) and twelve injury types (Table 2). The six reflexes deemed to be suitable indicators of sea bass vitality were: body flex, evade, head complex, righting, tail grab, and vestibular-ocular response (eye-roll) (Table 1). Reflex actions were scored as unimpaired (0) when strong or easily observed, or impaired (1) when not present or if in doubt of presence. Injury was scored as absent (0) when not present or in doubt of presence, and present (1) when clearly observed.

The semi-quantitative assessment of vitality was based on four defined ordinal classes, characterising fish as very lively and responsive (E, excellent) at one end of the scale to unresponsive (D, dead) individuals at the other end (Table 3).

Table 1. Vitality reflex descriptors used in assessment protocol applied to sea bass, adapted from (Randall *et al.*, 2021).

Reflex Name	Stimulus Action	Reflex Response
Body flex	Attempts to escape when restrained.	Vigorous flexing of the body and/or tail while held by the researcher, within five seconds.
Evade	Attempts to avoid capture.	Active swimming away either when attempting capture or released from testing.
Head complex	Regular pattern of ventilation with jaw and operculum.	Actively opens and closes jaw or operculum, within five seconds.
Righting	Returns to normal orientation when turned upside down.	Actively swims into correct orientation after being released upside down, within five seconds.
Tail grab	Burst movement away from tester.	Rapid forward motion following being held by tail, within five seconds.
Vestibular-ocular response	Eyes roll when body rotated around long axis.	The eye of the fish rolls within the socket to track the researcher, within five seconds.

Table 2. Injury descriptors used in assessment protocol applied to sea bass, adapted from (Randall *et al.*, 2021).

Injury Type	Injury description
Abrasion	Haemorrhaging red area from abrasion.
Bleeding	Obvious bleeding from any location.
Bruising body	A body injury to underlying tissues in which the skin is not broken, often characterized by ruptured blood vessels and discolorations.
Bruising fin	A fin injury to underlying tissues in which the skin is not broken, often characterized by ruptured blood vessels and discolorations.
Fin fraying	Fins damaged, possibly with slight bleeding.
Internal organs exposed	Internal organs exposed with wounds.
Net marks	Any type of clearly visible net marks on body from trawl, gillnet, etc.
Scale loss	Obvious area of scale loss.
Scratches	Thin shallow cut or mark on (a surface).
Partial bloating	Abdomen swollen, due to inflated swim bladder, slack to touch, fish floats at surface of tank when not swimming.
Full bloating	Abdomen swollen, due to inflated swim bladder, tight to touch, fish floats at surface of tank and cannot dive.
Wounding	Nicks or cuts on body.

Table 3. Description of the categories used to score the pre-discarding vitality of individual fish for the semi-quantitative activity method. Developed from Benoît, *et al*. (2010).

Vitality	Abbreviation	Description
'Excellent'	E	Vigorous body movement; no or minor external injuries only
'Good'	G	Weak body movement; responds to touching; minor external injuries
'Poor'	P	No body movement but fish can move operculum; minor or major external injuries
'Dead'	D	No body or operculum (gill cover) movements (no response to touching)

2.4 Tagging

In January 2022 and January 2023, a subset of the net-caught sea bass were tagged with an acoustic transmitter: 49 individuals in 2022 and 37 individuals in 2023. These were a subset of the individuals categorised as being in good or excellent condition. Two models of transmitter tag were used, both programmed to utilise a carrying frequency of 69 kHz; in 2022, Thelma Biotel HP9 tags were used (tag dimensions: 28 × 9 mm, 4.2 g weight in air) but in 2023, the Thelma Biotel V13 tag model was used due to its longer battery life (tag dimensions: 34 × 11.5 mm, 11.5 g weight in air). Based on minimum recorded fish weight, the maximum weight burden of the acoustic tags was 1.7% of body weight. A weight burden as high as 3.5% of the fish weight has previously been demonstrated as a suitable for this species (Lefrançois *et al.*, 2001; Bégout Anras *et al.*, 2003; Stamp *et al.*, 2021).

Each fish was anaesthetized with an induction dose of 80 mg/l MS-222 (Tricaine methanesulfonate) and positioned dorsally on a V-shaped cradle. A single transmitter tag was implanted within the peritoneal cavity via a small incision (10–15 mm) made slightly off the mid-ventral line between the pelvic fin and anus. Following tag implantation, the surgical site was closed using dissolvable sutures and medical grade adhesive. Analgesic was topically applied to the surgical site (Lidocaine 1% solution diluted to 1:10 with NaCl saline solution). Fish were then monitored within large holding tanks (450 l) for a minimum period of 1 h prior to release from the tagging vessel. All tagging procedures were conducted under a UK Home Office license (P81730EA5) by personal license holders with PILC entitlement. Dispensation was also provided by the relevant regulatory and land authorities. Transmitter tags were programmed to emit a randomized uniquely-coded ping once every 60 – 120 s, for detection by the acoustic telemetry receiver array (see below).

2.5 Tagging: Range testing

A range test tag, with comparable power output to those implanted within the fish, was deployed at a fixed location within the sample site at the time of fish tagging. Detection range was estimated using an Innovasea VR100 receiver and hydrophone which was deployed at increasing 50m distance intervals until 400m away from the range test tag. Successful tag detections were monitored for a 15 minute period at each distance interval. Range testing confirmed 60% ping detection at a range of 200-250 m. These results are consistent with other telemetry studies in the same sample site (Stamp *et al.,* 2021). The second receiver seaward of the tagging site was placed nearly mid-channel at a point where the channel width is approximately 370 m; therefore, fish going to sea following tagging had a high likelihood of detection. Other seaward receivers were placed in areas with channel widths of approximately 500 m. The upstream receiver was placed in an area with a channel width of approximately 620 m.

2.6 Acoustic telemetry receiver array

A total of four Innovasea VR2 acoustic receivers (underwater devices designed to detect ‘pings’ emitted by the acoustic tags) were deployed in Salcombe harbour (Figure 3). The receivers were opportunistically attached to existing structures e.g. channel markers or moorings. Upon successful detection of each tagged fish; the time, date and tag ID was recorded on each receiver. The data were periodically downloaded throughout the study.

2.7 Statistical analyses

The vitality assessments were summarised for each sea bass to give a dead/ alive status for each fish on release from the study. The probability of survival was then modelled using logistic regression as outlined in Appendix 1, to test whether probability of survival differed between years and/or was associated with fish length, or the soak or haul time of the gear. All data management and analyses were conducted in the software R, version 4.1.1 or later (R Core Team, 2021).

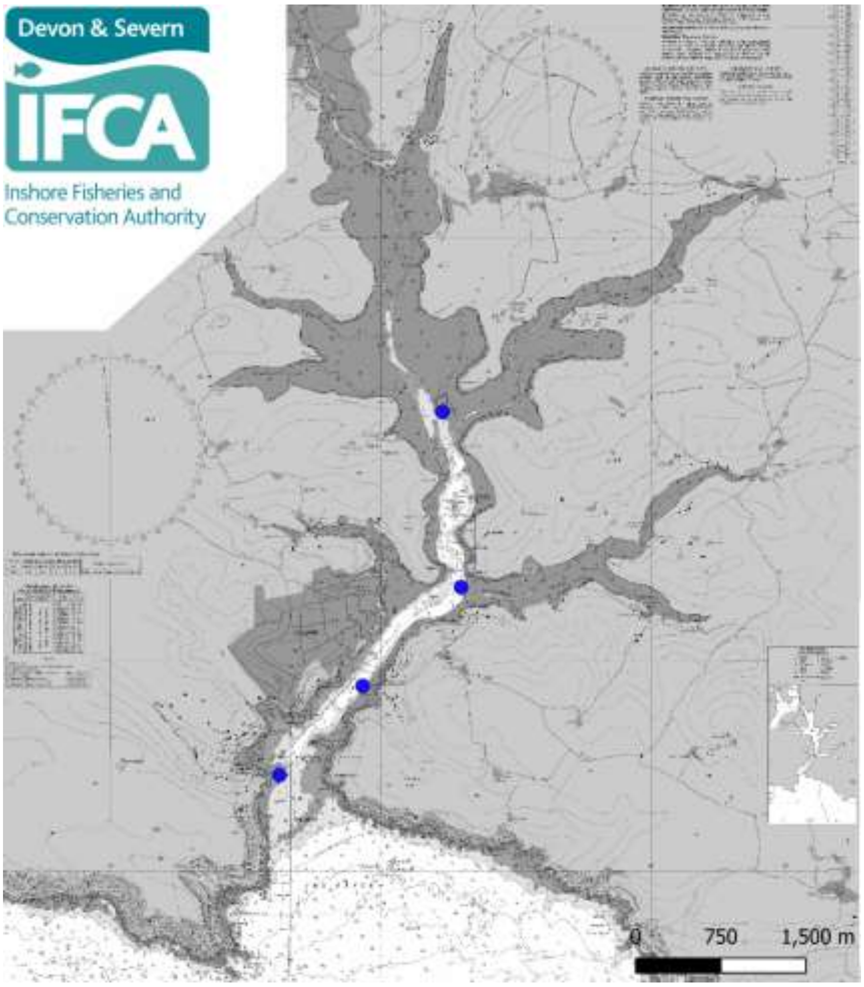

Figure 3. Locations of four underwater acoustic receivers in/near Salcombe harbour. The FISHINTEL tagging team have a larger array of acoustic receivers placed along the south coast, allowing detection of wider movements of sea bass tagged in Salcombe and elsewhere. See Figure 1 for wider geographical context.

3. Results

3.1 Summary of netting activity

During netting activities in January 2022 and January 2023, a total of 32 net hauls were completed (19 in 2022, 13 in 2023).

3.2 Catch composition

In the 32 hauls over 2022 and 2023, a total of 138 European sea bass (*D. labrax*) were caught, among a catch of mullet and a small number of other species. Figure 4 shows the count of each species caught for 2023; species other than sea bass were not fully counted in 2022. However, hauls in 2022 included a catch of a similar number of mullet, one seabird, two thornback rays and a shad.

As demonstrated by Figure 4, the catch composition using gillnets in the study area is unpredictable: in 2023 mullet (a likely target catch using this gear type) comprised anywhere between 0 – 100% of the catch, while sea bass (which cannot be landed for most of the year) comprised anywhere between 0 – 85%. Of the 141 fish caught in 2023, 73 (52%) were sea bass, while only 55 (39%) were mullet.

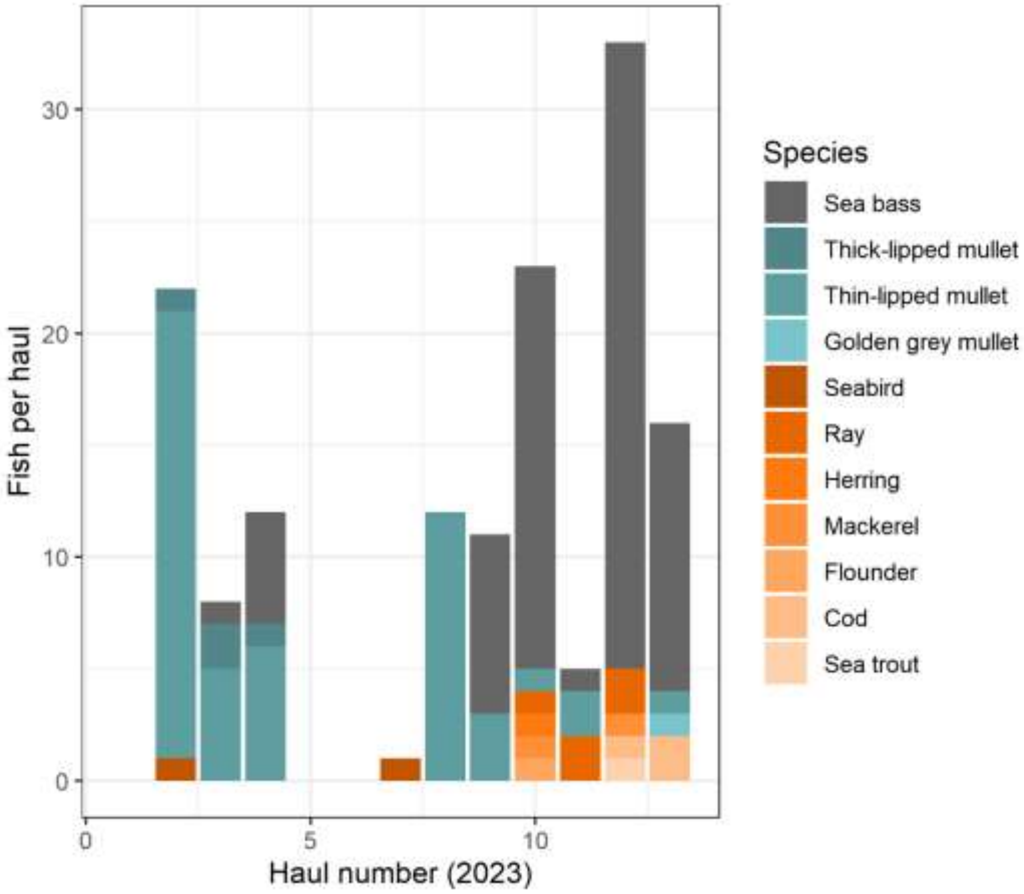

Figure 4. Catch composition of the 13 hauls conducted during the study period in 2023.

The spatial distribution of bass and mullet catches, including bass catch as a proportion of the bass and mullet catch (Figure A1.3), is outlined in detail in Appendix 1.2. The locations with highest mullet catch (off Ox Point; Figure A1.2) had no or low sea bass catches in 2022 and 2023 (Figure A1.1), though this area is known to be frequented by juvenile and adult bass, particularly in the hours before and after low tide, based on tagging by Stamp (2020) ().

3.3 Sea bass assessments

Of the 138 sea bass caught in the 100 mm mesh gill nets, 17 (12%) were undersize (<42 cm total length). A similar size distribution was caught in both years (Figure 5), with a mean (± standard deviation) total length of 45.2 (±3.1) cm in 2022 and 44.3 (±3.0) cm in 2023, and a modal length of 42 cm across the two years.

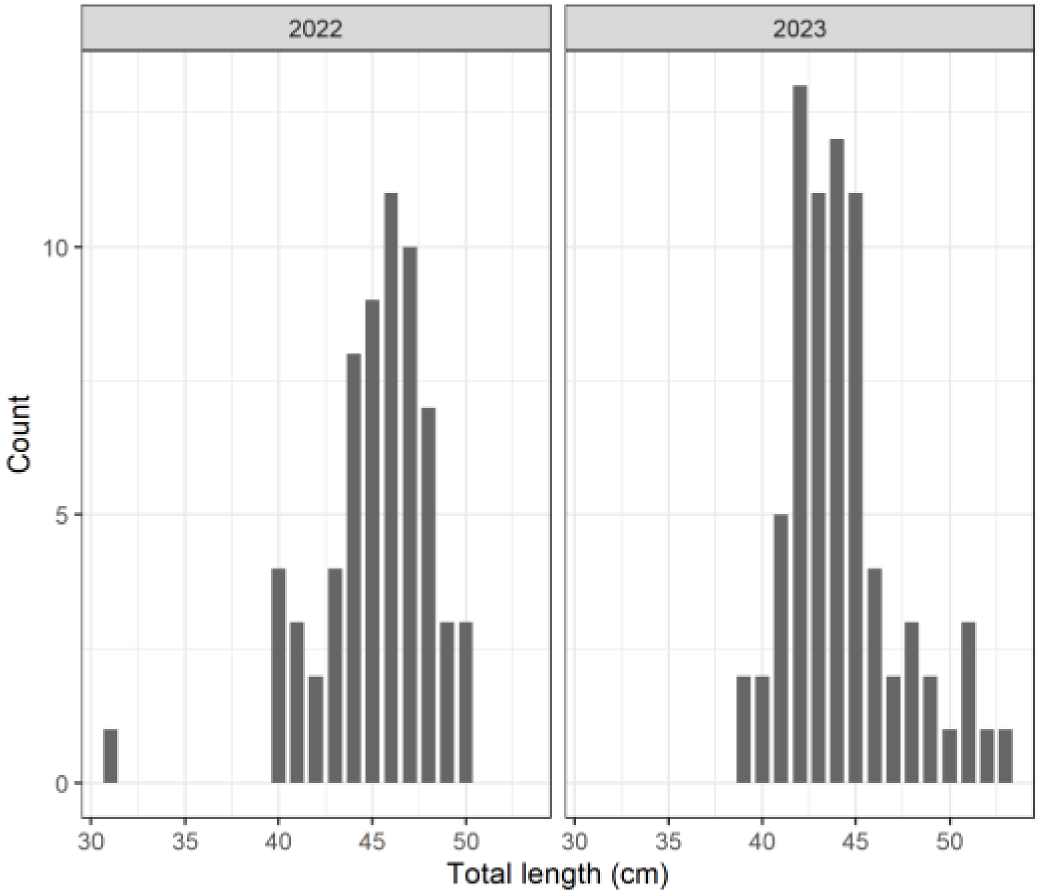

Figure 5. Length frequency histograms of sea bass caught in 2022 and 2023, based on total length (cm) (n = 65, 2022; n = 73, 2023).

Of the 138 sea bass caught, 17.4% (24) died, with similar proportional mortality in 2022 (10 out of 65, 15.4%) and 2023 (14 out of 73, 19.2%). Most (67%) of those that died showed delayed mortality that would not have been immediately evident at the point of capture. For example, many fish were assessed to be in poor condition at their first assessment shortly after capture and, although some were able to recover, a proportion deteriorated and later died (Figure 6). Fish were not individually identifiable between the first and second (or third) assessment; however, if it is assumed that any fish that died in later assessments were those that were previously assessed as poor (rather than as good or excellent), then this indicates that fish assessed as poor at the first assessment would go on to die in a later assessment in 37% of cases. Therefore, at least one or two out of the four fish released from the study in poor condition are likely to have subsequently died in the wild, raising the pre-tagging mortality rate to approximately 18.8%.

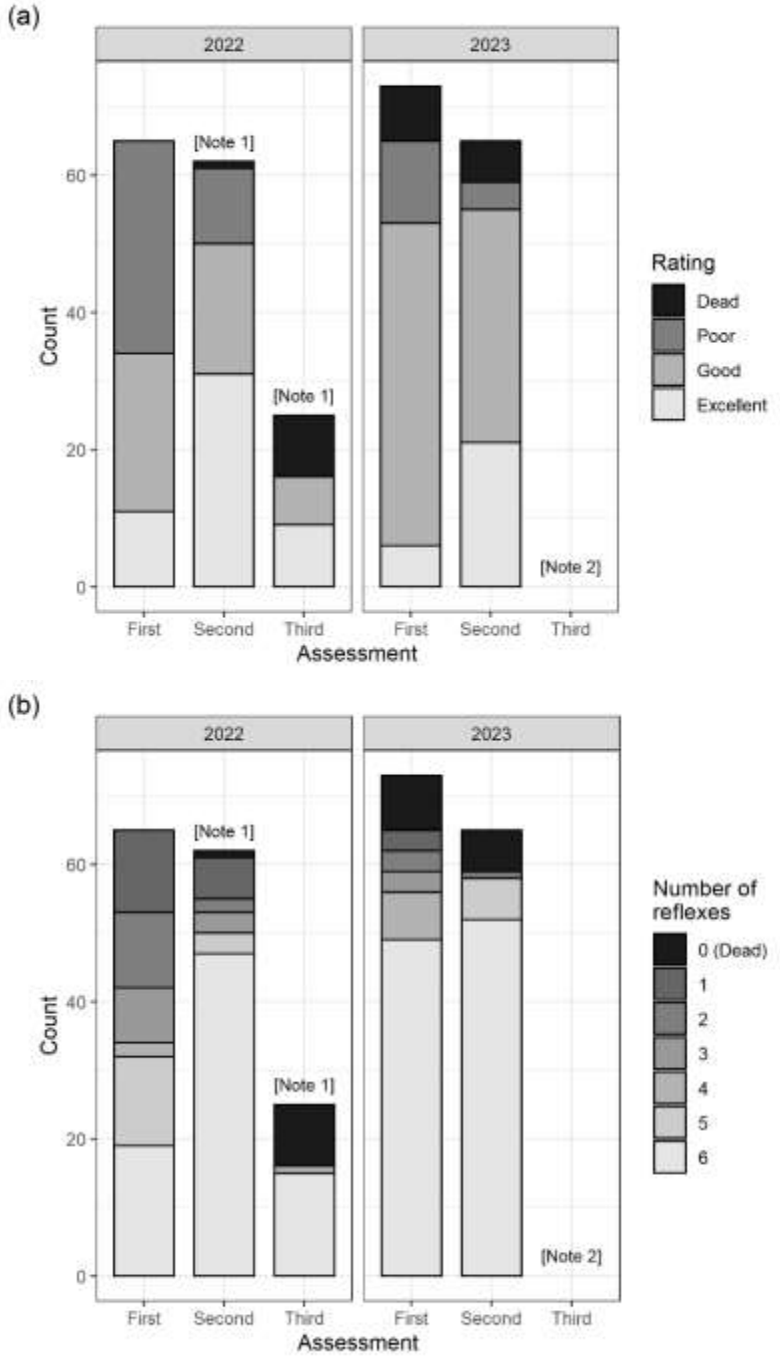

Figure 6. For all sea bass caught in 2022 and 2023: (a) Qualitative condition assessments, and (b) Number of reflexes exhibited by all fish, at each assessment. First assessments in 2022 were mostly carried out as the fish were removed from the net; first assessments in 2023 were carried out after a period of recovery (≥10 minutes) in on-board tanks. NOTE 1: The reduction in total count between assessments during 2021 is due to fish being tagged before their next assessment. All tagged fish were released in good or excellent condition. NOTE 2: Fish were tagged and released before a third assessment could be conducted in 2023. Only a first and second assessment was planned for each fish; third assessments conducted during 2022 were opportunistic.

The data suggest that a higher proportion of sea bass were dead when first assessed in 2023 compared to 2022. However, this is likely because in 2023 the fish had their first assessments ten or more minutes after capture, as they were taken from the net and transferred to an on-board tank of sea water, and were not assessed until the boat returned to the recovery sea cages on the pontoon. By contrast, in 2022 many fish were assessed immediately after they were removed from the net, so their deaths – which may have occurred within minutes of the first assessment – were not confirmed until the second assessment. The time in sea water tanks between removal from the net and the first assessment was clearly long enough for several fish to have died before the first assessment. There was no evidence for a relationship between sea bass length and mortality, and no evidence that mortality differed significantly between years. There was only limited evidence that mortality was dependent on the soak time of the net within the range of soak times tested here (12–80 minutes) (Appendix 1.3). However, there was moderate evidence that mortality was higher for fish that were caught in situations in which the net took longer to haul (Appendix 1.3; Figure A1.5).

A range of reflex impairments (Figure 6b) and injuries (Figure 7) were observed in the captured sea bass. Common injuries included net marks, body bruising, scale loss and fin fraying (Figure 7a,b); net marks and bruising often took some time to fully develop and show through, so were often clearer at the second assessment than the first. Therefore, though 85% of sea bass had at least one type of injury when first assessed, it is clear that most of those that appeared uninjured would later develop some form of net mark or bruising; indeed, 98% of sea bass were recorded as injured at the second assessment.

The fish assessed as being in worst condition exhibited a range of behaviours that appeared to predict their later death. These behaviours included flaring of the gill operculum and wide-open mouths (Figure 7b, c). Sea bass exhibiting these behaviours often also had rigid bodies, and an apparent inability to flex their bodies in response to external stimuli. These behaviours typically began in the net as the fish were being removed, but occasionally the onset was delayed and was not always apparent until after the fish were placed in water; in particular, diminishing responsiveness and ability to flex sometimes had a more gradual onset and became apparent in some fish with flared opercula that were initially able to swim when placed in the water. Bleeding and injuries from barotrauma (e.g. bloating) were rare (6% and 7% of fish, respectively), deep lacerations were only observed in one fish, and none were so severely injured that their internal organs were exposed.

Sea bass displaying only one or two of their six assessed motor reflexes at a given assessment would generally deteriorate in condition by the time of the following assessment. However, many of those assessed as being in poor condition but which retained three or more of their reflex responses often performed well in subsequent assessments. All sea bass had a similar recovery environment in which they experienced (natural or artificial) water flow, either in cages suspended in the water from which they were caught (Figure 2), or in tanks supplied with a constant flow of sea water (the vivier tank on board the tagging vessel).

(a) (b) (c)

Figure 7. Example images of injuries displayed by some sea bass caught in 2022, showing (a) net marks on dorsal surface, (b) extensive bruising to the body alongside flaring gill operculum and open mouth, (c) live fish with abnormal swimming behaviour, flared gill opercula and open mouths (contained with other fish in back right corner of tank which are displaying normal swimming behaviour).

3.4 Acoustic tracking

A total of 86 sea bass were tagged with acoustic transmitters under Home Office licence: 49 in 2022, 37 in 2023. The mean (± SD) fork length of tagged fish was 42.23 ± 2.45 cm (range 37 – 47 cm) across both years. The mean (± SD) weight of fish in 2022 was 1.07 ± 0.18 kg (range 0.65 – 1.42 kg). Fish weights were similar in 2023 but individual data were not available.

The acoustic receiver array in Salcombe (Figure 3) and along the south coast of England was used to detect tagged individuals. Data from the 2022 cohort of tagged fish are available for the period 4th January – 31st December 2022, but data for the 2023 cohort are currently only available for 22nd January 2023 – 27th March 2023 (Figure 8). No immediate mortality occurred as a result of the tagging procedure in either year.

In 2022, fish were detected by the receiver array for an average of 308.2 days post-tagging (range 42 – 402 days, standard deviation 79.4 days), indicating good long-term survival prospects for fish that were tagged in good or excellent condition post-netting. Out of the 49 fish in the 2022 cohort, 42 were detected regularly in Salcombe throughout the year; of the remaining seven, one was detected in Salcombe for 42 days after tagging, and was not subsequently detected in Salcombe or by other receivers. Two more were detected in Salcombe for a short period post-tagging, but left Salcombe and were not detected for several months before being detected at offshore receivers. The other four had more sporadic detections in Salcombe and at other receiver locations across the year (Figure 8). Tagged fish were largely absent from the estuary between March and July 2022. During this time, many fish were either conducting short coastal movements and returning periodically to Salcombe, or were detected at other receiver locations along the south coast (Figure 8). The majority of tagged fish displayed strong site residency behaviour at other times of year, including short periods of coastal movements from Salcombe.

In 2023, the minimum tracking period for any individual fish was 26 days, suggesting very high medium-term post-tagging survival of fish that were tagged in good or excellent condition post-netting. Most fish showed a degree of residency in Salcombe for at least 26 days post-tagging, as demonstrated by long periods of detection by acoustic receivers in

Salcombe (Figure 8). In some cases, detection records in Salcombe ceased after a period of residency (Figure 8); one of these fish is known to have been detected at an acoustic receiver in the Yealm estuary, though the fate of the remainder of the 2023 cohort will not be clear until additional data can be downloaded from the acoustic receiver array. However, the pattern in the available data appears similar to that of the same period in 2022. These data will allow presentation of more complete summary statistics on fish detections, and interpretation of longer-term survival and behaviour consequences for these fish.

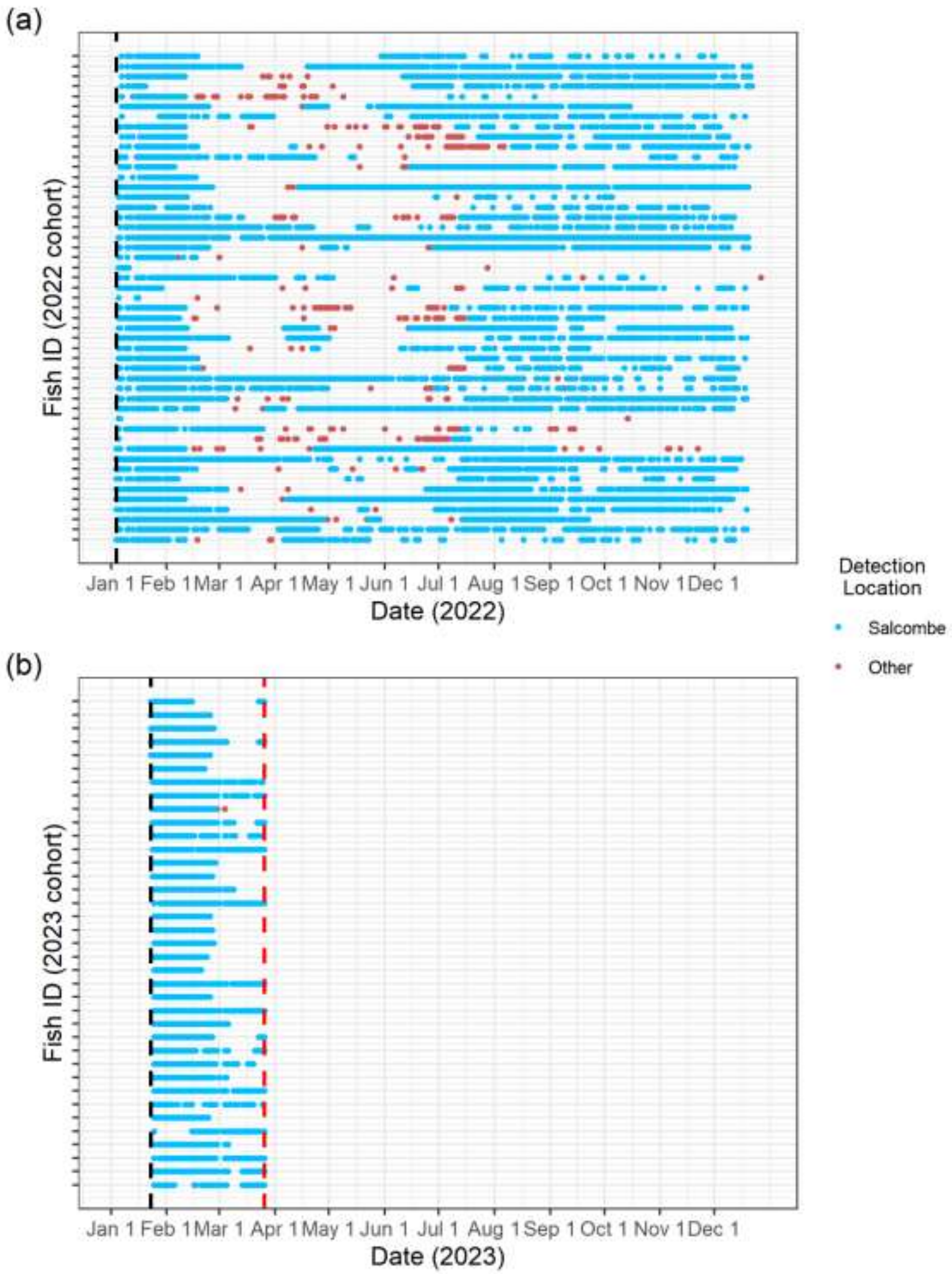

Figure 8. Abacus plot showing detection histories for (a) fish tagged in January 2022, and (b) fish tagged in 2023. The dashed vertical black lines indicate the start of the tagging and tracking period for each cohort, while the dashed vertical black line in (b) indicates the last date on which acoustic data were downloaded from the acoustic receivers. 'Other' detection locations include acoustic receivers along the south coast of Devon, including estuary mouths and wreck sites.

4. Discussion

Unaccounted sources of fishing mortality, including post-release mortality of discards, can reduce the effectiveness of fishing regulations and the hamper efforts to manage stocks sustainably (Coggins Jr *et al.*, 2007; Lewin *et al.*, 2018). It is therefore important to understand the level of discarding in fisheries, and the associated discard mortality. This section discusses the key results and implications of the research in terms of fishery management. Key issues dealt with include the delayed mortality seen in most sea bass that died following the netting, possible causes of variation in mortality, variable bycatch rates and their implications, and the transferability of these results to real-world fishing practices, which is discussed throughout.

4.1 Observed sea bass mortality

There was a mortality rate of between 17.4 – 18.8% for sea bass caught in gillnets in this study. Across two years of sampling, sea bass caught in gillnets showed low immediate mortality, but relatively higher delayed mortality. In particular, sea bass that were in poor condition at the time they were brought on board the fishing vessel were more likely to die within the following few hours: fish in poor condition at the first assessment are thought to have later died in at least 37% of cases. This indicates that one or two out of the four fish that were released from the study in poor condition are likely to have subsequently died in the wild, raising the mortality rate due to netting of untagged fish from 17.4% to approximately 18.8%. These are estimates of mortality before any tagging took place.

It is possible to compare the mortality estimate from gillnets in this study to studies of sea bass mortality due to other gear types. In a study by Cefas, Randall *et al.* (2021) assessed sea bass mortality due to drift nets (127 sea bass), static nets (149) and otter trawls (139). As outlined by Randall *et al.*, both net fisheries caught fish in shallow water (drift 2.7–5.8 m depth but one station at 27.0 m; static 3.8–6.8 m), while the otter trawls fished deeper (51.2–73.8 m). The at-vessel mortality rates were 7% for otter trawl, 12% for drift nets and 68% for static nets; it should be noted that the soak time for the static nets was much longer than that in the present study (average 22 hours versus approximately 43 minutes). It is also important to note that many of the fish caught by any gear with long soak times were released in poor condition, and Randall *et al*. concluded that many of those individuals were unlikely to have survived.

Randall *et al.* (2021) also estimated mortality in the commercial hook and line fishery to be 10.7%. Lewin *et al.* (2018) demonstrated mortality of 13.9% for sea bass caught by rod and line, primarily due to deep hooking when using natural baits. The same study found 0% mortality following catch and release angling using artificial lures, and estimated overall sea bass mortality due to catch and release angling of 5% for the northern sea bass stock (based on data from England, France, Belgium and the Netherlands).

Overall, most (67%) of the sea bass that died in the present study showed delayed mortality that would not have been immediately evident at the point of capture. This is similar to Lewin *et al.* (2018), who demonstrated that most of the sea bass that died following catch and release angling died within an hour of capture, and agrees with previous studies (reviewed by (Muoneke and Childress, 1994) which demonstrated that most post-release mortality occurs within a few hours or days of release. This indicates that mortality is unlikely to be seen by fishers at the vessel during any discarding process similar to that observed in this study, and therefore anecdotal observations of discard survival may be unreliable.

4.2 Observed sea bass injuries and reflex impairments

A range of injuries were recorded on 98% of all sea bass captured in this study; these injuries included bruising, fin fraying and scale loss. The implications of these injuries for later sea bass mortality are unclear, but it is known that scale loss can lead to delayed mortality by compromising osmoregulation (internal fluid/salt balance) or due to the onset of infection (Butcher *et al.*, 2010). The covering of fish skin produces a protective mucus layer that contains immune "defence factors" such as immunoglobins, lysozymes, and proteases; this protective layer can be damaged by netting and handling, while the stress of capture increases production of cortisol and stress hormones which suppress the immune system. Overall, these factors increase vulnerability to disease (Arlinghaus *et al.*, 2007).

The fish caught by Randall *et al.* (2021) were assessed for vitality and injury using the same methods as in the present study. The drift net fishery caught more unimpaired sea bass (38%) than either the static net (17%) or otter trawl fishery (22%); most static net-caught sea bass (68%) failed to respond to any of the six reflex tests and were considered dead at the time of assessment, though this was after a longer soak time than in the present study (average 22 hours, compared to 43 minutes here). Similarly, injuries were more common in static net-caught sea bass (72% injured compared to 98% here) than in fish caught using other gear types. Of the 149 sea bass caught in static nets by Randall *et al.*, 9% were removed from the nets in 'excellent' condition: similar to the 11.5% removed in excellent condition in this study. The injury rates found in the present study (98%) are therefore much higher than any of those observed by Randall *et al.* for any gear types, and the mortality rates were higher than those found in the otter trawl and drift net fisheries (though, as would be expected, lower than mortality in static nets set for long soak times).

4.3 Effect of haul time on sea bass mortality

It is likely that longer soak times are associated with higher mortality rates for sea bass caught in gillnets (e.g. results of Randall *et al.,* 2021), but there was no apparent effect of soak time across the narrow range of soak times tested here (12 – 80 minutes). However, there was limited evidence in this study that sea bass mortality was higher when the haul time was longer, possibly because of the stress placed on fish as the mesh distorts around their bodies during hauling, or due to exhaustion as fish again try to escape the net during the haul. This has several implications for real-world fishing activity, outlined below.

The haul time generally increases due to increased handling time, so will be longer when there are more fish in the net (or when there is more debris in the net that needs to be cleared during the haul). Therefore, the larger the catch (ie, the more successful the fishing), the higher the discard mortality is likely to be. The fisher involved in this study has often stated that the kind of netting studied here would usually be carried out at night. Reasons given for this include that catches tend to be higher than during the day as the fish are less able to see the net in the dark; furthermore, fishing at night was a reason given for why seabird bycatch observed here would not normally be expected. This may have two further implications; first is that higher catch rates at nighttime may increase the haul time and therefore increase discard mortality. Secondly, fishing at night may make it more difficult to avoid getting weed and other debris caught in the net, which is likely to increase the haul time and associated discard mortality.

4.4 Additional causes of variation in sea bass mortality and relevance to real-world fishing activity

The 18.8% mortality rate should be considered as a lower estimate of true mortality, which is likely to be higher under normal fishing conditions. In many cases, the fisher was observed to cut the net mesh away from around the sea bass in order to remove it from the net more gently than would occur in normal practice (in which the fish would be squeezed through the mesh and/or have the mesh pulled away from entangled body parts such as gill covers). This may have occurred in part as the fisher was aware that fish needed to be in good condition to allow for tagging. The fisher involved in the study had raised concerns that other elements of the process may have increased the mortality rate: (1) handling and air exposure during vitality assessments, (2) retention in sea cages rather than immediate return to the sea, and (3) effects of temperature on the fish (e.g. temperature shock when brought into cold air).

4.4.1 Handling and air exposure during vitality assessments

The fisher raised concerns that additional air exposure for sea bass being assessed after removal from the net may have increased mortality more than if the fish had been immediately returned to the sea. However, several lines of evidence suggest that this is unlikely. Firstly, the handling in air required for vitality assessments was approximately up to approximately 10 seconds per fish, so was a small fraction of the time that fish were being handled during extraction from the net – especially for those fish that were not cut out of the nets. In a study of catch and release angling, sea bass with minor hooking injuries showed no mortality following 180 seconds in air after a fight time (time on the hook) of 3 – 15 seconds (Lewin *et al.*, 2018), suggesting that the additional air exposure due to vitality assessments is unlikely to have increased mortality.

However, it is recognised that mortality following short periods of air exposure is likely to be higher when fish have been fighting with the capture gear for longer periods (Cooke *et al.*, 2001; Cooke and Suski, 2005; Thompson *et al.*, 2008; Lewin *et al.*, 2018), and if the gill membranes collapse (causing physiological stress) (Suski *et al.*, 2004; Lewin *et al.*, 2018). Long fighting periods are relatively likely in netting activities even with the short soak and haul times as tested here, and gill collapse may be more likely in net-caught compared to angled fish due to the pressure placed on the gills and gill covers by the net and during the process of removal from the net.

In addition, the handling experienced by fish during vitality assessments was simply being held for visual examination, compared to relatively rough handling during removal from the net. Due to the nature of this removal process, fish were generally held in air for longer than during the vitality assessments and often had to be gripped tightly (including near the gills and gill covers), squeezed through the net mesh, and/or have the mesh removed from fins or gill covers.

Furthermore, in the second year of this study the methods were adapted to more closely imitate the return to water after removal from the net. In 2023, fish were placed immediately into water after removal from the net (in an on-board tank regularly refreshed with seawater) and had their first vitality assessment approximately 10 minutes after recovery in the tank. By comparison, in 2022 the fish were assessed during transfer to the on-board tank. However, there was no difference in overall mortality between years, so the differences in method appear not to have affected mortality. The main difference observed was that more fish were found to be dead during the first assessment in 2023 than in 2022; as outlined in the results, the deaths of fish in 2022 may have occurred within minutes after the first assessment but were not confirmed until the second assessment. By contrast, in 2023 the time in sea water tanks between removal from the net and the first assessment was clearly long enough for several fish to have died before the first assessment.

Therefore, the exhaustion, physiological stress and physical injury caused by the capture and removal processes appear more likely to have caused sea bass mortality in this study than the air exposure during vitality assessments. The sea bass FMP has identified a medium-long term action to develop best-practice handling guidance to improve fish survival from commercial and recreational fisheries, recognising that improving discard survival is an important component of fisheries management. Finally, the fisher had indicated that a more usual approach to clearing a hauled net would be to haul the entire net then clear it while it is in the vessel; this is common to similar static gear fisheries, in part because it makes the haul easier, but would dramatically increase the duration of air exposure of any discards.

4.4.2 Retention in sea cages

During the study, the fisher raised further concern that retention of sea bass in the storage sea cages may increase mortality when compared to returning the fish directly to the same estuary; in particular, the fisher was concerned that the mesh of the sea cages was too small to allow adequate water flow to the fish, preventing their recovery. However, this appears unlikely to have been a significant problem for several reasons. Firstly, these sea cages have been used by the tagging team many times for many successful fish tagging operations. In addition, in 2023 some fish were held in the vivier tank on board the tagging vessel, instead of in the sea cages. The vivier tank had a constant flow of seawater pumped through it. The fish held in the vivier tank did not appear to differ in mortality or recovery rates from those held in the sea cages.

As demonstrated in this study, some fish deteriorated in condition in the few minutes after removal from the net. In some cases this included fish that appeared to show strong swimming behaviour but shortly succumbed to their stress or injuries and subsequently died. In such cases it is unlikely that these fish would have had better recovery rates in the estuary, where they would be swept passively in any current and vulnerable to predation (by seabirds at the surface, or crabs on the estuary bed). Even those that later improved in condition would have had a short period of greater vulnerability upon return to the estuary.

4.4.3 Effects of temperature

Another concern raised by the fisher was whether the study would be representative of discard mortality due to the cold temperatures at the time of the study, in particular whether the fish may experience a cold shock as they are brought into the air during the haul and catch sorting process. However, unless the discards are removed from the net while it is still in the water, any cold shock effects would be an unavoidable aspect of any such fishery (particularly when the usual practice may be to sort the catch and discard bycatch after hauling the entire net, rather than while the net is being hauled). The scientific evidence on temperature shock is not always clear but generally shows that fish are in worse condition and are more likely to die if brought out of the water into air temperatures that are substantially higher than the water temperature (Davis and Olla, 2002; Giomi *et al.*, 2008; Benoît *et al.*, 2010; Randall *et al.*, 2021).

Overall, the cold temperatures at the time of this study are likely to have increased the survival of discarded fish: post-capture condition is usually better during colder seasons, in part because the cold temperatures reduce metabolism and therefore reduce oxygen and energy requirements, making it easier for fish to recover from stress (Davis and Olla, 2002; Giomi *et al.*, 2008; Benoît *et al.*, 2010; Randall *et al.*, 2021). Furthermore, colder water holds a greater amount of dissolved oxygen than warmer water, making it easier for stressed fish to recover from the oxygen debt associated with struggling in the capture gear or being removed from the water (Arlinghaus *et al.*, 2007). Therefore, the mortality estimates gained in this study are likely to be relatively lower than at other times of year when the water temperature is higher (most other months apart from February and March).

4.5 Sea bass catch rates

Though the 18.8% mortality estimate from this research is relatively low, additional concerns remain regarding high sea bass catch rates. Of the 141 fish caught in 2023, 73 (52%) were sea bass, while only 55 (39%) were mullet. The catch composition using gillnets in the study area is unpredictable: in 2023 sea bass (which cannot be landed for most of the year) comprised anywhere between 0 – 85% of the total catch, meaning that possible rates of discard (and therefore total mortality) could be very high, especially when compared to the target catch. There appeared to be a particular hotspot for mullet capture (Figure A1.2), and bass catches in this area were low (Appendix 1.2). However, juvenile and adult bass are known to use this area of the estuary for a large proportion of their time (especially in the hours before low tide to after low tide, when these fishing activities have historically occurred) (Stamp, 2020), and this is just one of the areas identified as historically having been used by local fishers. Furthermore, the proportion of bass in the catch showed large geographical variation (Figure A1.3), with hauls from the same locations having bass as between 0 – 100% of the catch (when considering only mullet and bass). The catch composition is therefore clearly variable over both time and space, making it unpredictable in a given location.

Goal 4 of the draft Fisheries Management Plan (FMP) for sea bass is to '*Encourage and facilitate full compliance with bass regulations*', and has a medium-long term action to '*Consider reviewing the implications of re-defining bass 'bycatch' for netting by introducing a percentage catch composition limit (for example, <50% total catch) […]*'. The implications of this include a recognition that sea bass should only be considered as 'bycatch' up to a certain proportion of the catch. In this study in 2023, 44% of the net hauls which caught any fish included sea bass as >50% of the catch (while 55% of hauls included sea bass as >40% of the catch).

Annex 6 of the draft sea bass FMP states that "*Stakeholders across the board, from fishers to enforcement officers, agree that the current definition of unavoidable bycatch is too ambiguous to abide by and enforce. Stakeholders also pointed out that bycatch doesn't work in mixed fisheries area where it is impossible to avoid catching bass whilst netting or trawling. To avoid confusion, some fishers are calling for bass to become a target species; this would depend on the bass stock and gear used for fishing for bass. According to numerous stakeholders, the existing bycatch regulations have been too easy to exploit. In practice, it is often difficult to prove a difference between purposefully targeting bass and unavoidable bycatch*."

In addition, 12% of sea bass caught by the 100 mm mesh gillnets in this study were undersize (<42 cm total length), with a modal length across all sea bass of 42 cm. This is less than the modal length of 46 cm found to be caught by 100 mm mesh gillnets in a study in Jersey, which caught fewer undersize individuals (Government of Jersey, 2023). The relatively reduced selectivity demonstrated by the nets used in the present study likely stems from the fact that the nets were used in shallow water, in which the meshes were able to bunch up rather than hang vertically, encouraging capture of some undersize individuals.

4.6 Bass Nursery Areas and potential retention of sea bass

The study area hosts a Bass Nursery Area (BNA). Fishing for sea bass, or fishing for any species of sea fish using sand eels (*Ammodytidae spp)* as bait, by any fishing boat within any part of the Salcombe Harbour and Kingsbridge Estuary Bass Nursery Area is prohibited between 30th April and 1st January. At the time of writing, additional commercial restrictions mean that it is prohibited to retain sea bass in February and March. If a net fishery were to be active in the study area, it would be possible for any fisher with the relevant authorisation to retain sea bass larger than the minimum Conservation Reference Size (42 cm at time of writing) if caught in January (and in February or March if those restrictions are later changed). Mortality of these individuals would therefore be 100%.

The tagged sea bass showed a high degree of site residency to the Salcombe-Kingsbridge BNA for most of the year. This is supported by previous tagging work conducted by Stamp *et al.* (2021). Stamp *et al.* (2021) tagged rod and line-caught sea bass of a range of lengths (25.2 to 60.0 cm fork length) in the Salcombe-Kingsbridge Estuary, the Dart Estuary and the Taw-Torridge Estuaries, and demonstrated a high degree of tagging site residency at all sites, including over winter. These results imply high hypothetical exposure of sea bass of a range of sizes to the kind of small-scale estuary-based netting activity studied here.

The seventh goal of the draft Fisheries Management Plan for sea bass is '*Ongoing protection of the juvenile and spawning bass stock*', to enable efficient stock replenishment. The FMP has several proposed actions to achieve this, including considering a prohibition of fixed netting in sea bass nursery areas. This prohibition is already in place in D&S IFCA's District via the Netting Permit Byelaw and associated Permit Conditions, demonstrating D&S IFCA's commitment to sustainable fisheries management.

4.7 Future work

The acoustic tags implanted in sea bass in January 2023 will remain active until at least the end of 2023, allowing the movements of the tagged fish to be detected at a range of coastal and estuarine sites. When these data are downloaded from the acoustic receiver array, it will be possible to conduct additional analyses on the tagging data from both the 2022 and 2023 cohorts. These analyses will focus on the long-term survival and behaviour of these net-caught fish, and will compare their behaviour and survival to that of the rod and line-caught fish tagged by Stamp *et al.* (2021). It may also be possible to analyse in further detail the links between injury, vitality scores and later mortality vs survival, to better understand causes and/or signs of delayed mortality in living fish, and to test whether assessments of injury and/or vitality are useful predictors of mortality in discards.

5. Conclusions

This study identified a mortality rate of 18.8% for sea bass caught in shallow-set gillnets with short (<80 minute) soak times. This mortality estimate is lower than for nets or trawls with longer soak times, but substantially higher than in commercial or recreational hook-caught fisheries, especially those that use artificial lures as opposed to natural baits. Furthermore, when accounting for all sources of uncertainty it is likely that the mortality rate would be substantially higher than 18.8% in real-world fishing conditions. The high rates of sea bass catch and long periods of estuarine site residency observed in sea bass in this study imply a high exposure to hypothetical small-scale fishing pressure. Combined with their shoaling behaviour and use of estuaries that is similar to target species such as grey mullet, this high exposure appears to translate to high vulnerability to fishing pressure in estuarine environments. With this in mind, the best-case 18.8% discard mortality is likely to be a cause for concern given that estuaries represent highly-used essential habitat for juvenile and adult sea bass, and that the sea bass spawning stock biomass remains depleted relative to past levels and below the MSY threshold.

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Appendix 1. Supplementary methods and results

A1.1 Supplementary methods

The dead/alive status of fish upon release from the study was summarised (0 = dead, 1 = alive), allowing probability of survival to be modelled using a logistic regression (generalised linear model with binomial error structure and logit link function). The probability of survival was modelled in this way with the following potential explanatory variables: year, fish length, soak time of the capture net, haul time of the capture net, and the sum of soak and haul time of the capture net.

This process was used to generate a candidate set of models that were consistent with the data, and Akaike's Information Criterion (AIC) was used as the model selection criterion. Though the model with the lowest AIC score is likely to be the most parsimonious, AIC is only an estimate of parsimony Therefore, certain other models were considered as well: those within six AIC units of the lowest-AIC model. The null model was also created (with no predictor variables) and its AIC score generated, which found to be within the candidate set of best-fitting models (within 6 AIC units of the lowest AIC score). Any model with an AIC score within two AIC units of the null model was considered to perform no better than the null model and was disregarded, models with an AIC score 2–6 units lower than that of the null model provide moderate evidence for an effect of the predictor variable(s), while a model with an AIC score >6 units lower than that of the null model would have provided strong evidence of the effect of that predictor.

Model diagnostics were checked based on assessment of standardised, simulated residuals, generated using the R package 'DHARMa' (Hartig and Lohse, 2020), and variance inflation factors were assessed, demonstrating a lack of significant collinearity amongst predictors in all models in the candidate set (Zuur et al., 2010).

A1.2 Supplementary results: catch composition

The geographic distribution of sea bass and catches is shown in detail in Figure A1.1 and Figure A1.2, overleaf. Species other than sea bass were not fully counted in 2022, therefore it is only possible to display the sea bass catch as a proportion of the total sea bass and mullet catch for 2023 (Figure A1.3). Figure A1.1 shows the number of sea bass caught in each haul for both 2022 and 2023.

These figures demonstrate further that sea bass catches were variable even in very similar locations: sea bass were present in most hauls that contained fish, but the count of sea bass in hauls from the same location could vary between 0 (minimum per haul) and 28 (maximum per haul).

The location with highest mullet catch (off Ox Point; Figure A1.2) had no or low sea bass catches in 2022 and 2023 (Figure A1.1), but this area is known to be frequented by juvenile and adult bass, particularly in the hours before and after low tide, based on tagging by Stamp (2020) (Figure A1.4).

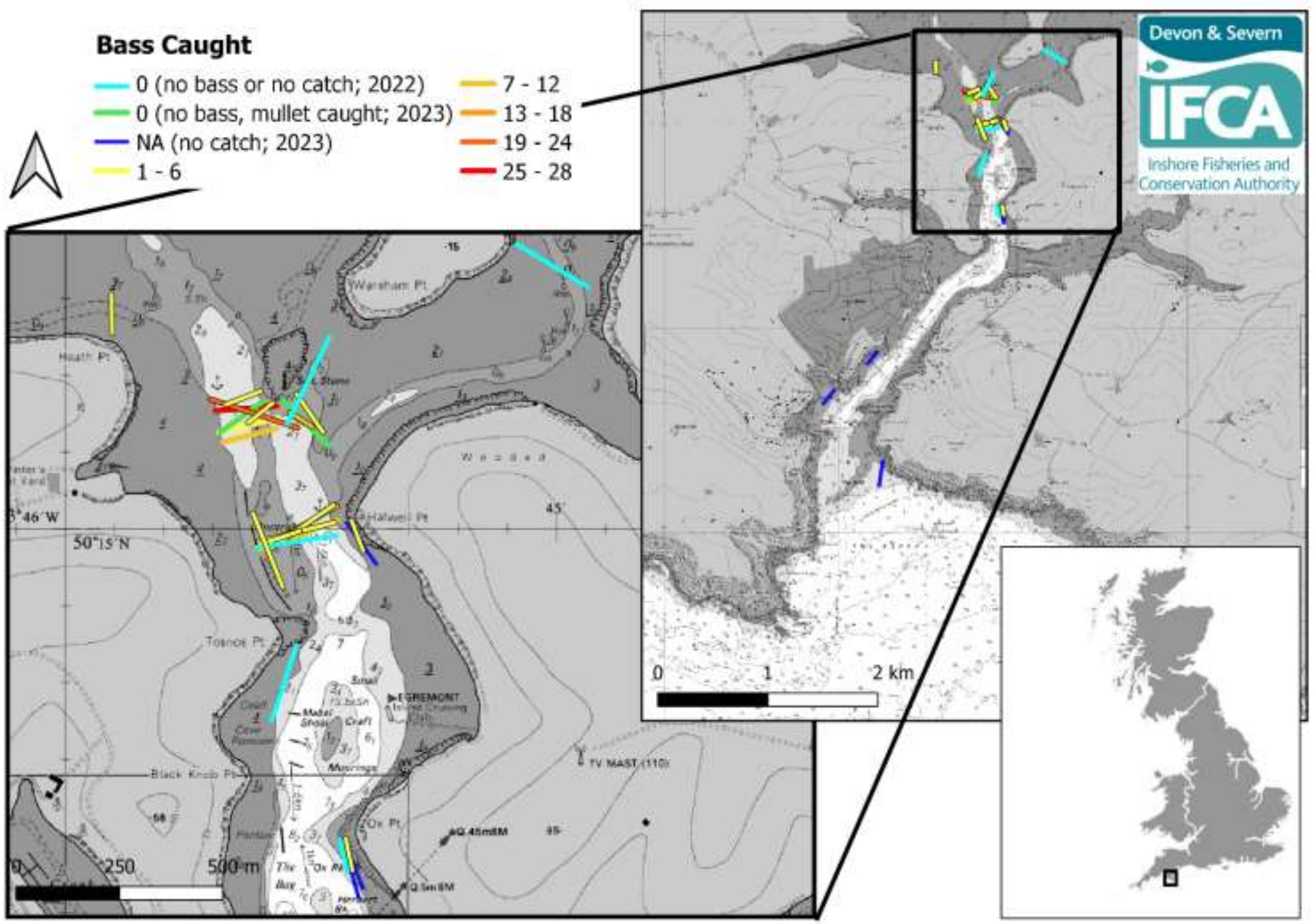

Figure A1.1. Number of sea bass caught in gillnets during 2022 and 2023, demonstrating that when a haul contained fish it had between 0 – 28 sea bass, and that locations in which some hauls contained no sea bass were the same locations in which sea bass catches could be high in both years. Hauls identified in blue had no catch of either mullet or sea bass (2023) or no catch of sea bass and no confirmed catch of mullet (2022). Hauls identified in green had a catch of mullet but no sea bass. All others had a combination of sea bass and mullet.

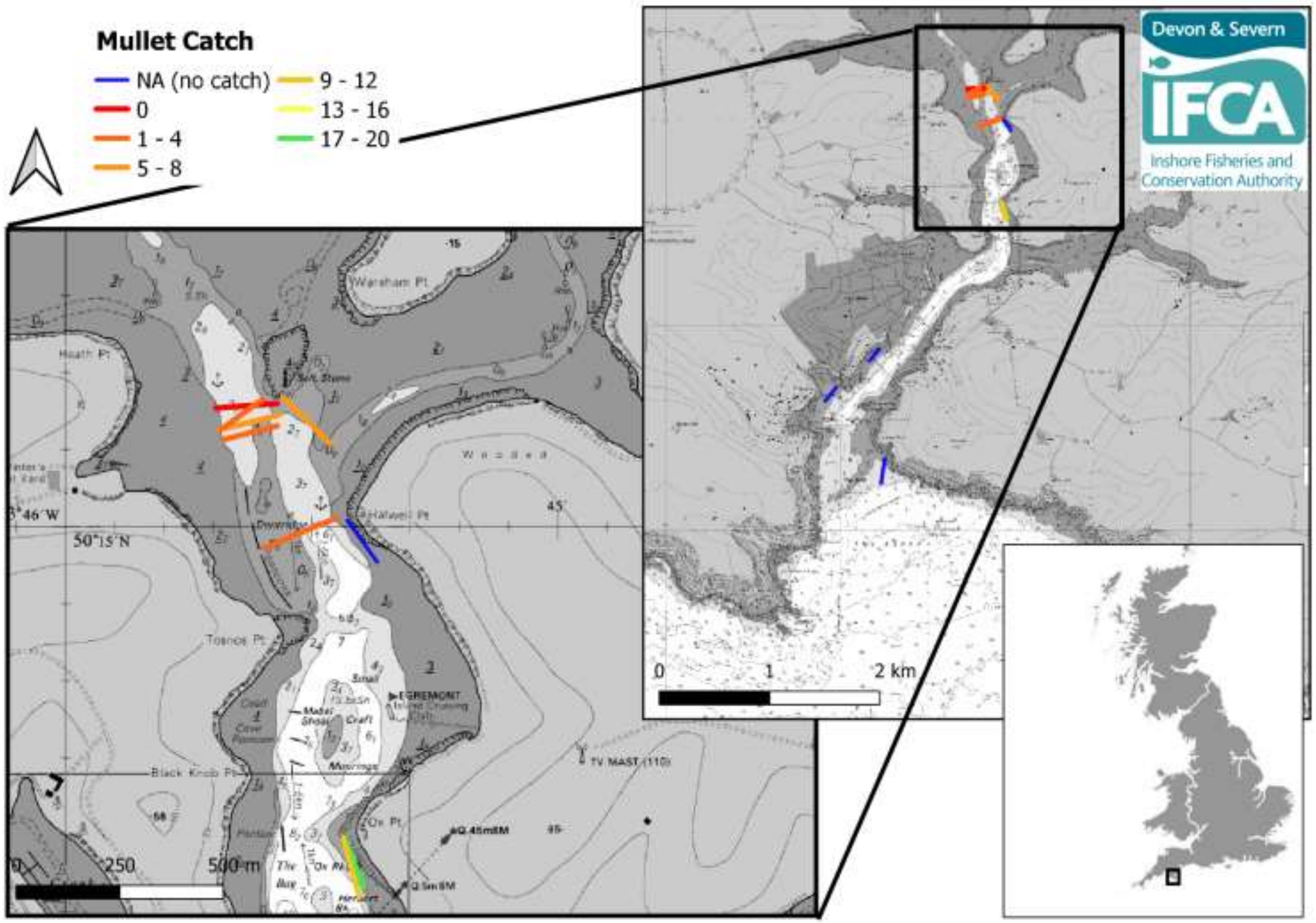

Figure A1.2. Number of mullet (thick-lipped, thin-lipped and golden grey) caught in gillnets during 2023, demonstrating that when a haul contained fish it had between 0 – 20 mullet, and that locations typically fished for mullet (including off Halwell Point and Ox Point) led to catches of 0 – 20 mullet in 2023. The locations with highest mullet catch (off Ox Point) had no or low sea bass catches in 2022 and 2023 (see previous figure), but this area is known to be frequented by juvenile and adult bass, particularly in the hours before and after low tide, based on tagging by Stamp (2020).

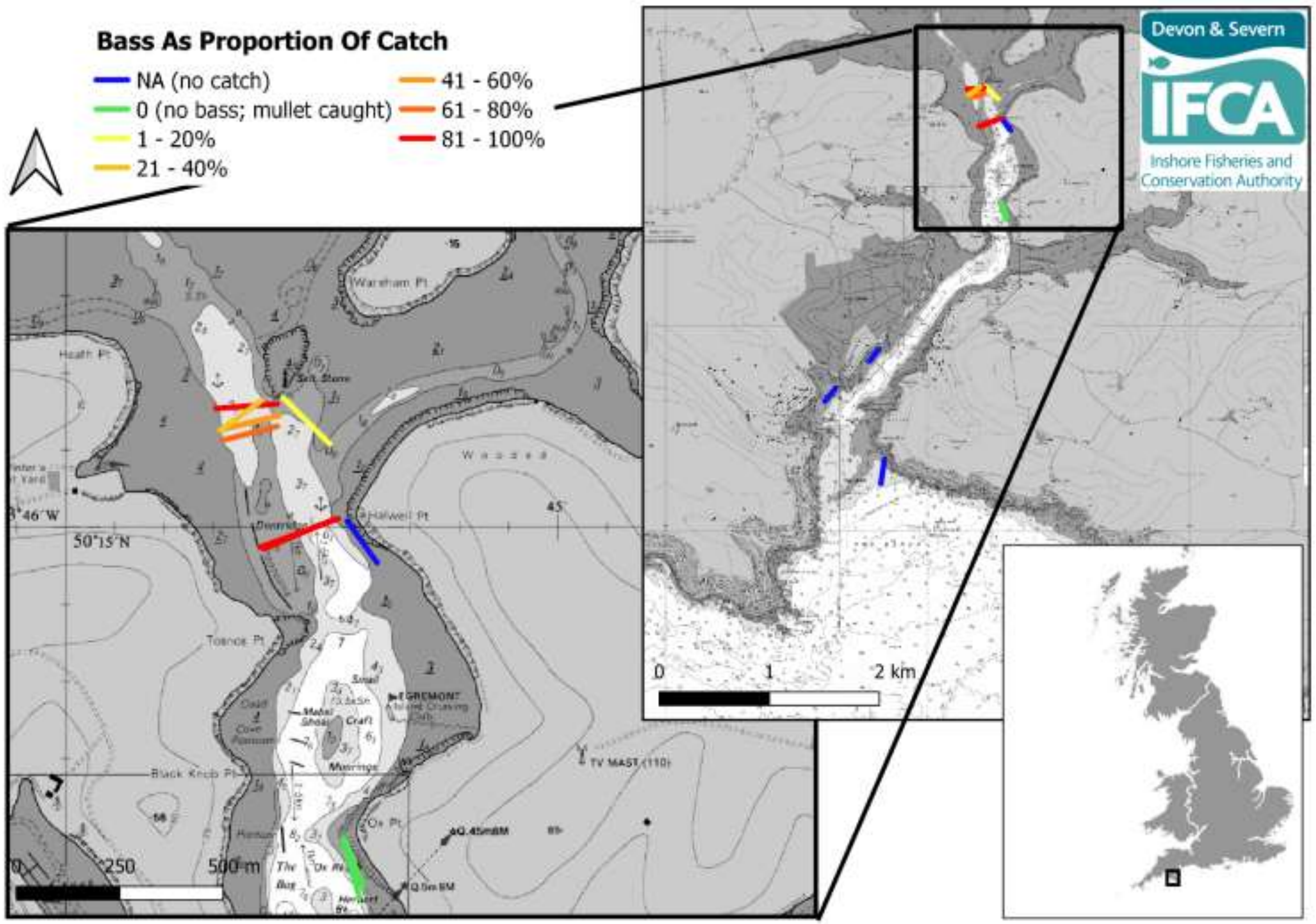

Figure A1.3. Proportion of sea bass caught in gill nets during 2023, displayed as a proportion of the catch of sea bass and mullet (ie not including other fish species). Hauls identified in blue had no catch of either mullet or sea bass, those identified in green had a catch of mullet but no sea bass. All others had a combination of sea bass and mullet.

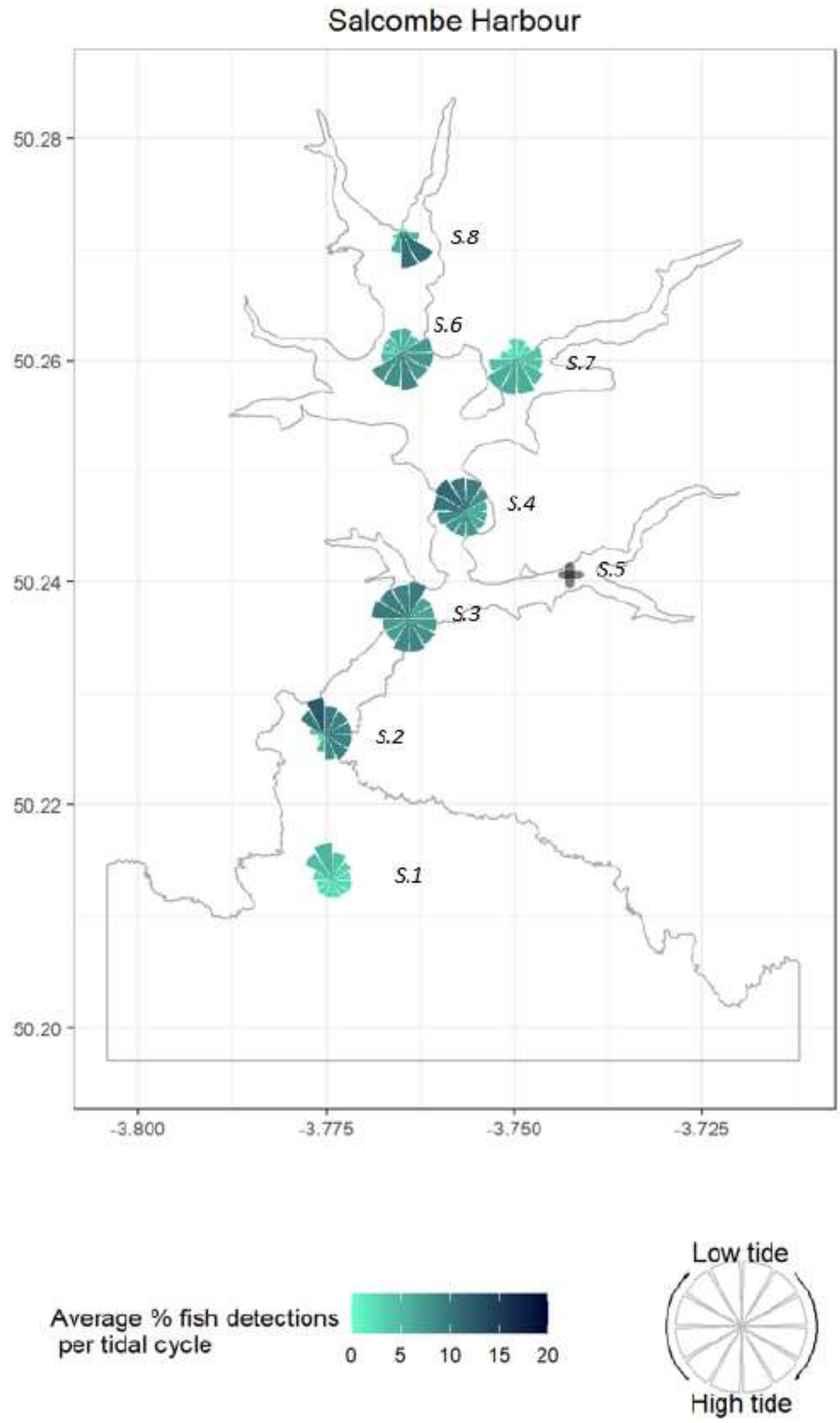

Figure A1.4. REPRODUCED WITH PERMISSION FROM STAMP (2020); DEPICTING AN AREA SIMILAR TO THAT IN THE PREVIOUS FIGURES. Average percentage of fish detections throughout the tidal cycle at various acoustic receiver stations within the study site. The size of each bar represents the relative difference in detections across the tidal cycle at each station, bar charts are colour coded on the same scale. Station s.5 is not shown due to a short deployment period of that acoustic receiver (1 day). The sea bass were highly likely to be detected between receivers S.2 and S.4 , particularly in the hours before, during and after low tide (these are areas and times at which netting has historically occurred in this site). These data are from fish tagged in Salcombe and tracked between August 2018 – July 2019.

A1.3 Supplementary results: probability of survival

The best-fitting model of probability of survival contained the predictor variable 'combined soak and haul time', indicating that the duration of time in the net is the principle determinant of probability of survival for sea bass caught in nets (model M_{final}, Table A1.1; Figure A1.5a). However, this appears to be driven largely by the length of time taken to haul the net: model M_a contains independent effects of soak time and haul time, and in this model the effect size of haul time is greater than that of soak time (Table A1.1). Furthermore, model M_a is a nested version of model M_b (with haul time as the only predictor), which performs almost equally well in terms of AIC as model M_a (Table A1.1). Therefore, of the two models, M_b is the more parsimonious. Model M_b demonstrates a negative relationship between haul time and probability of survival (Table A1.1; Figure A1.5b). There was no evidence that mortality differed between years or with sea bass length (neither model with these predictors out-performed the null model).

Table A1.1. Parameter estimates (with standard errors) and AIC assessment for logistic regression models of probability of survival of sea bass caught in nets. Showing the null model (M_{null}; with no predictor variables) and all models with lower AIC than the null. The model M_{final} is the final model, other models are labelled consecutively. SHT is the combined soak + haul time, HT is the haul time and ST is the soak time. All predictor variables were standardised to have a mean of 0 and variance of 1, meaning that the parameter estimates represent comparable effect sizes. LL is the log-likelihood of the model, ΔAIC is the difference in AIC score between that model and the model with the lowest AIC. Though model M_a has a lower AIC and ΔAIC value that M_b, Mb has fewer parameters and is therefore the most parsimonious of the two. All are within 6 AIC units of the null model, so provide only moderate evidence for effects of these predictors on probability of survival. Other predictors (length and year) were also tested but these models did not out-perform the null model.

Model	Parameter estimates				*LL*	*AIC*	*ΔAIC*
	Intercept	**SHT**	**HT**	**ST**			
M_{final}	1.618 (0.242)	-0.596 (0.240)	–	–	-61.97	127.93	0.00
M_a	1.625 (0.243)	–	-0.512 (0.212)	-0.357 (0.2457)	-61.38	128.76	0.83
M_b	1.591 (0.236)	–	-0.515 (0.217)	–	-62.46	128.91	0.98
M_{null}	1.508 (0.221)	–	–	–	-65.29	132.59	4.65

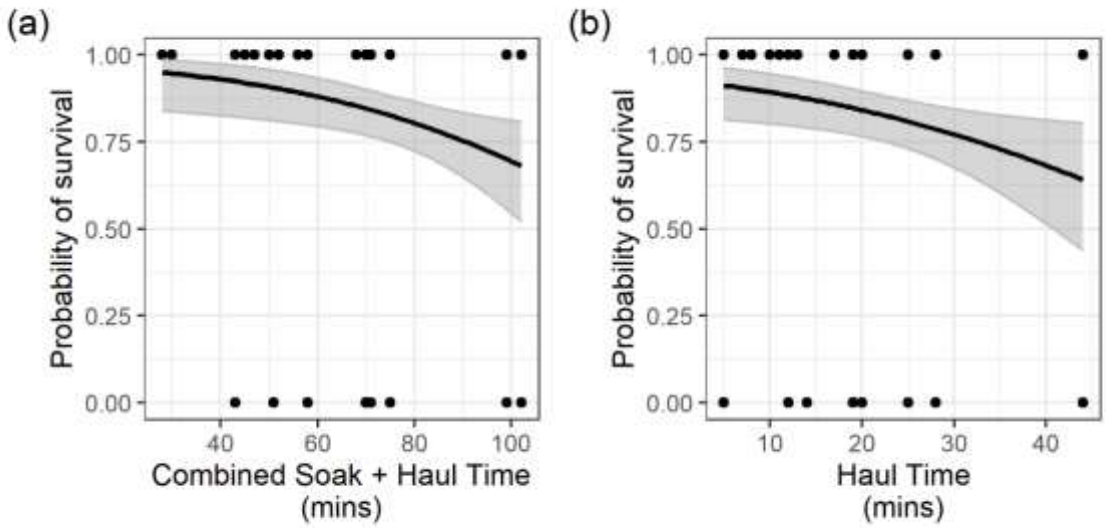

Figure A1.5 Effect plots based on logistic regressions of probability of survival, showing the predicted effect (black line) of (a) the combined soak + haul time (model M_{final}), and (b) haul time (model M_b) on probability of sea bass survival following netting. Also displaying 95% confidence intervals (grey shading). Each black circle represents multiple fish that either died (0) or were alive (1) upon release from the study after being caught in each haul of the gill nets (each circle may represent one or multiple individual fish).

References

Hartig, F., and Lohse, L. 2020, September 8. DHARMa: Residual Diagnostics for Hierarchical (Multi-Level / Mixed) Regression Models. https://CRAN.R-project.org/package=DHARMa (Accessed 26 January 2021).

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