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Catch and release angling for sea trout explored by citizen science: Angler behavior, hooking location and bleeding patterns

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ABSTRACT

Sea trout (anadromous brown trout, *Salmo trutta* L.) is a popular target species for angling in Denmark and many other countries. In most regions, angling for sea trout is regulated by measures such as minimum landing sizes, bag limits or seasonal closures. This can lead to high catch and release (C&R) rates. However, information about angler behavior, C&R practices, hooking locations and level of injury and bleeding, as well as post-release impacts on survival and growth, is largely missing for this species. In this study, we used a citizen science approach to investigate C&R practices of Danish sea trout anglers and to explore drivers for hooking location and bleeding. During the study period from January 2016 to August 2021, 35,826 sea trout caught by angling were reported by users of the citizen science platform. Spin fishing was the most popular angling method (46 %), followed by fly fishing (35 %), bombarda fishing (19 %) and natural bait fishing (1 %). The results confirmed that C&R is a very widespread practice among Danish sea trout anglers, and ≥80 % of all sea trout captured are being released, the majority because they are below the minimum landing size. Twenty-five percent of the caught sea trout bled, and 2 % showed heavy bleeding. Bleeding was related to hooking location (deeply hooked fish bled the most) and to angling method (fly-caught sea trout bled less than fish caught on spin fishing gear), but the role of these two factors varied with fish length. When looking at fish above the legal minimum size, the share of bleeders among the released sea trout was significantly lower compared to harvested fish, suggesting that anglers were more prone to harvest fish that bled. Further studies on lethal and sublethal effects of C&R on coastal sea trout are needed, ultimately aiming to provide fishery managers and anglers with species- and fishery-specific best practice C&R guidelines.

1. Introduction

Globally, recreational fishing is a popular outdoor activity (Hyder et al., 2018; Arlinghaus et al., 2019), and its environmental and socio-economic importance is increasingly recognized (Radford et al., 2018; Lewin et al., 2019; Arlinghaus et al., 2021). Although recreational fishers can use a variety of fishing gears, depending on local fishing regulations, the most common gear type used is rod-and-reel fishing, also known as angling (Arlinghaus et al., 2007).

Fishing for consumption is important for many recreational anglers (Cooke et al., 2018), but releasing all or a part of the catch is an increasingly common practice in many recreational fisheries, both in freshwater (e.g., Arlinghaus and Mehner, 2003) and marine environments (e.g. Ferter et al., 2013). The practice of catching and releasing a fish, assuming that it will survive, is termed catch and release (C&R) (Arlinghaus et al., 2007). Catch and release may be practiced due to decisions by the angler (i.e., voluntary C&R) or due to regulations like minimum landing sizes, bag limits, seasonal closures or species protection (i.e., mandatory C&R) (Arlinghaus et al., 2007). While the underlying assumption of C&R is that it has minimal impact on survival, growth and behavior of the released fish, it can have lethal and sublethal impacts (Bartholomew and Bohnsack, 2005; Cooke et al., 2013). The potential for such adverse impacts has led to several animal welfare debates (Arlinghaus et al., 2007; Cooke and Sneddon, 2007; Ferter et al., 2020). However, studies have shown that applying best handling practice prior to release can minimize the risk of adverse C&R impacts

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(Brownscombe et al., 2017). Thus, guidelines for good C&R practices can be species-specific, based on experimental studies, or of a more general matter, like minimizing air exposure or avoiding fishing during elevated water temperatures if species-specific guidelines are not available (Cooke and Suski, 2005).

Post-release mortality is species- and fisheries-specific and depends on several abiotic and biotic factors such as water temperature, air exposure, capture depth, fish condition and predation risk (Wood et al., 1983; Muoneke and Childress, 1994; Bartholomew and Bohnsack, 2005; Hühn and Arlinghaus, 2011). Nevertheless, hooking location (anatomical) and associated hooking injuries/bleeding have been identified as one of the most important factors influencing post-release mortality (Muoneke and Childress, 1994; Bartholomew and Bohnsack, 2005; Hühn and Arlinghaus, 2011). Fish that are deep-hooked or hooked in the gills have been shown to suffer from higher mortality than fish hooked in the lips (e.g., Weltersbach and Strehlow, 2013; Lewin et al., 2018). Hooking location depends, amongst others, on the lure and hook type used (Stein et al., 2012; Stålhammar et al., 2014; Weltersbach et al., 2019). Thus, the potential adverse effect of C&R depends largely on the tissue damage inflicted and the stress accumulated during landing and handling, which in turn depends on the type of gear and the abiotic and biotic conditions during catch.

In many recreational fisheries, information on hooking location, or lure and hook type is not readily available. The growing interest for digital data collection platforms (e.g., Skov et al., 2021) provides an opportunity to collect diverse data from anglers and explore their C&R behavior. This could for example be via electronic citizen science platforms working as smartphone applications that allow anglers to report information from fishing trips and the related catches (Venturelli et al., 2017; Gundelund et al., 2020). Citizen science, defined as the cooperation between members of the public and professional scientists, can have many advantages as a tool to engage and educate project participants and a way to conduct cost-effective research on large temporal and spatial scales (e.g., Bonney et al., 2009; Silvertown, 2009; Conrad and Hilchey, 2011). Citizen science projects are very relevant in fisheries research where the collaborative approach can fill key data gaps in fisheries science and support fishery management (Granek et al., 2008; Fairclough et al., 2014; Bonney et al., 2021). Depending on the type of citizen science project, information about sizes of captured fish and release rates, both mandatory and voluntary, as well as information about angling methods (e.g. fly vs spin fishing) are often collected (Venturelli et al., 2017).

One species, that has very high release rates upon capture is sea trout (anadromous brown trout, *Salmo trutta* L.) in the Baltic Sea (Ferter et al., 2013). Release rates of 70–80 % in Denmark, 52 % in Germany and 47 % in Sweden have been reported for the Baltic recreational sea trout fishery (Ferter et al., 2013; Weltersbach et al., 2021). Sea trout is an important target species in the Baltic Sea with recreational catches exceeding the commercial catches in several countries (ICES, 2021a). However, Baltic Sea trout stocks are under pressure in several regions due to high fishing mortality, poor habitat quality in some rivers, increasing predation and low recruitment (Jepsen et al., 2019; ICES, 2021b). In the Baltic recreational fishery, the species is regulated by minimum legal sizes (e.g., DK, 40 and 45 cm, respectively, DE 40 and 45 cm, respectively, SE, 50 cm, FI, 50 cm (coast) and 60 cm (rivers)), sometimes in combination with bag limits, seasonal and area closures. Additionally, anglers often release legal-sized sea trout voluntarily (ICES, 2021a; Blyth and Rönnbäck, 2022).

The first aim of this study was to describe C&R practices and angling characteristics including fish size, gear use and release rates from the Danish coastal sea trout fishery, using data from a digital citizen science platform. The second aim, was to explore how the occurrence of bleeding (i.e., a proxy for fish well-being) relates to gear type, hook size and type, fish size, hooking location and air temperature, based on data collected by a subset of citizen scientists.

2. Methods

Information on angling practices among Danish sea trout anglers as well as hooking location and level of bleeding were collected through the Danish electronic citizen science platform "Fangstjournalen" (e.g. Venturelli et al., 2017). Anglers who signed up as participants on the platform could submit data via a smartphone application (app) or through an internet browser (https://fangstjournalen.dtu.dk/). Using either the app or browser, the participants could report fishing trips and associated catches from both marine and freshwater environments. Fishing trip registration required some mandatory information (e.g., fishing location, trip duration, and target species). Catch reporting also included mandatory information, such as species, length or weight, fate of the catch (i.e., kept or released), and various optional information (e.g., bait or lure used). The platform also featured a connection to a weather service that automatically logged information such as air temperature. The design of the platform allowed researchers to add additional entries only visible to specific anglers, which made it possible to have subsets of "Fangstjournalen" participants collecting additional data. In this study, data from two distinct groups of participants fishing for sea trout were used, i.e., a) the general participants who provided data about sea trout angling including information about release rates of various size groups as well as fishing gear used and b) a subset of participants who provided additional information about hooking location, hook type and the occurrence and intensity of bleeding caused by hooking injuries.

2.1. Angling patterns for the Danish coastal sea trout fishery

Angling for sea trout was explored among the fishing trips submitted to the electronic platform from January 15th 2016 to August 17th 2021, indicating coastal sea trout as target species. The data included release rates (i.e., proportion of sea trout that were released), the size distribution of released sea trout, and information about the fishing gear used. Sea trout caught by different lure types/gears were divided into four overall angling method groups, namely spin fishing (i.e., spin fishing equipment using spoons and wobblers), fly fishing (i.e., fly fishing equipment), bombarda fly fishing (i.e., spin fishing equipment using bombarda floats and flies), and fishing with natural baits (i.e., spin fishing equipment using natural baits such as worms).

2.2. Hooking location and bleeding

Data related to angling practices, hooking location and level of bleeding was collected by a subset of the citizen scientist participants, i.e., a group of 14 highly experienced sea trout anglers (hereafter referred to as the panelists) predominantly angling for coastal sea trout on the Danish Island of Funen. These panelists had previously been recruited to another project that involved reporting all their fishing trips to the "Fangstjournalen" platform and collecting scale and tissue samples from harvested sea trout (Skov, unpublished data). Thus, they were familiar with the basics of trip and catch registration on the platform. In November 2017, the panelists were informed about the purpose and specifics of the C&R study (e.g., how to contribute with the additional data through "Fangstjournalen"). During the project, entries related to the catch were expanded exclusively for the panelists allowing them to provide additional information related to hooking location, hook type and size, and level of bleeding from the hook wound. More specifically, the panelists were able to choose from six anatomical hooking locations defined as hooked in the gills, esophagus, outer mouth, corner of mouth, back of mouth, or outside the mouth (i.e., foul hooking). In a similar manner, the panelists were able to choose from different predefined categories of hook types (i.e., treble hook, single J hook, single circle hook, or double hook), hook sizes (i.e., seven different categories; >1, 1–3, 4–6, 7–9, 10–12, 13–15, <15), and whether the hooks were barbed or barbless. Furthermore, three levels of bleeding were predefined (i.e.,

no bleeding, slight bleeding, and heavy bleeding). The panelists were instructed that heavy bleeding was defined as clear signs of bleeding including several drops of blood whereas slight bleeding was defined as visible blood but not tapping or running from the wound. In addition to the project specific entries listed above, panelists also reported the length or weight of their fish and fate (released or kept), which is mandatory for all citizen scientists using the digital platform. Data collection by the panelists was initiated in March 2018 and commenced in August 2021. The angling patterns of the panelists (i.e., release rates, size distribution of released fish and fishing methods) were also analyzed and compared with the general group of participants to investigate potential differences between the two groups.

2.3. Data analyses

The lengths of caught and released sea trout were compared between panelists and general citizen scientists using linear regression in which sea trout length served as the dependent variable and participant type served as the independent variable. Similarly, total release rates (regulatory and voluntary) and voluntary release rates (i.e., dependent variables) were compared between panelists and general citizen scientists (i.e., independent variable) using generalized linear models following a binomial distribution and a logit link. These comparisons were made to determine the representativeness of the panelist data compared to the general citizen science population.

The data collected from the panelists was used to identify drivers of bleeding in sea trout in relation to angling practice, hooking location, fish size and air temperature. More specifically, the effects of hooking location, fishing method (fly, bombarda, spin, and natural baits), hook size, hook type, fish length, air temperature, and all possible two-way interactions on the level of bleeding were investigated using a generalized linear model (GLM) following a Bernoulli distribution with a logit link. Data exploration was performed to identity potential outliers and collinearity (Zuur et al., 2010). In addition, the model's classification performance was investigated (i.e., correct classification rate, CCR).

Post-hoc inspection of the results from angling practices, hooking location, and level of bleeding were used to determine the usage of a Bernoulli GLM to model the level of bleeding. This involved recoding bleeding as a binary response variable (i.e., grouping heavy bleeding and slight bleeding), to account for a low sample size in the heavy bleeding category. Similarly, low sample sizes in some of the categories made it necessary to group hooking location into four distinct categories; deep hooking (i.e., esophagus, back of mouth and gills), corner of the mouth, outer mouth, and foul hooking (i.e., fish hooked outside the mouth region in the remaining parts of the body). Additionally, hook sizes were grouped into two distinct categories, namely sizes 4–6 and all hook sizes smaller than six. Hook sizes larger than four were removed due to low sample sizes. In a similar manner, circle hooks, barbless hooks, fish caught using natural baits and fish caught on lures with more than one hook (i.e., two, three and four hooks) were removed from the analyses due to low sample sizes. Thus, a total of 1337 sea trout were included in the bleeding analysis. No outliers were identified but some evidence of collinearity was identified. Data exploration revealed that angling method (i.e., spin, fly, and bombarda fishing) served as a proxy for hook type (treble and single J hooks). Spin fishing was primarily conducted using treble hooks, fly fishing was conducted using single J hooks, and bombarda fishing was also primarily conducted using single J hooks but had more catches with treble hooks compared to fly fishing (Supplementary Fig. S1). Therefore, hook type was removed from the analysis.

The final model was found using a stepwise selection approach based on Akaike's information criteria (AIC). Statistical significance of predictor variables was investigated using likelihood ratio tests. The final model was:

$$Bleeding_i \sim Bernoulli\ (\mu_i)$$

$$E(Bleeding_i) = \mu_i$$

$$Logit(\mu_i) = hooking\ location_i + fishing\ method_i + fish\ length_i + air\ temperature_i + hooking\ location_i\ x\ fish\ length_i + fishing\ method_i\ x\ fish\ length_i \cdot$$

To evaluate if anglers were more prone to harvest fish that bled, we compared the share of bleeders among harvested with the share of bleeders among released fish using an ordinal logistic regression. Only sea trouts that the panelists stated were above the legal minimum size were included in this analysis. All statistical analyses were conducted in R version 4.0.5 (R Core Team, 2021).

3. Results

3.1. Angling patterns of the Danish coastal sea trout fishery

In the period from January 15th 2016 to August 17th 2021, 1838 citizen scientists registered 35,826 captured sea trout on the citizen science platform. It was possible to identify the fishing method for 28,019 of the caught sea trout (Fig. 1A). Among the citizen scientists, spin fishing was the most popular fishing method (46 %), followed by fly fishing (35 %), bombarda fishing (19 %) and natural bait fishing (1 %) (Fig. 1A). Using data where anglers reported only one fish at a time (i.e., one sea trout registered as being released), it was possible to identify a length distribution based on 12,114 released sea trout (Fig. 1B). The majority of the released sea trout were below the size of 40 cm (60 %) where sea trout can be legally harvested in Denmark, but also larger fish of all sizes were reported as being released (Fig. 1B) reflecting that voluntary release was also very common among Danish sea trout anglers (i.e. release of fish above legal minimum size was 68 % of the reported captures). Overall, 81 % of the sea trout catches were reported as being released.

3.2. Panelists: Angling practices, hooking locations and level of bleeding

From March 2018 to August 2021, the 14 panelists registered 1692 captured sea trout using the electronic citizen science platform. It was possible to identify the angling method for 1628 of the caught sea trout. In contrast to the general citizen scientists, the fishing method practiced by the panelists was dominated by fly fishing with bombarda and spin fishing as subdominant methods (Fig. 1 A). Compared to released sea trout (reported as single captures) by the general citizen scientist anglers, the sea trout released by the panelists ($n = 1208$) were significantly smaller (df = 1, F= 32.5, $p < 0.001$), but the effect was small (i.e. ~1.5 cm shorter on average; Fig. 1B). Some differences were observed in the seasonal distribution of angling trips between citizen scientists and panelists ($Chi^2 = 84$, df = 11, $p < 0.001$), which indicates that the panelists have fewer trips during the summer period, and fish more often in spring and autumn compared to the general citizen scientists (Fig. 1 C). Additionally, the mean release rate of the panelists (84 %) was significantly higher than the general citizen scientists' (81 %) (df =1, LRT = 8.52, p = 0.004). However, the effect size was small (i.e., a difference of 3 %). In contrast, no difference was found when comparing voluntary release rates (df = 1, LRT = 0.08, p = 0.78), which were 68 % for both groups of anglers.

The panelists recorded the level of bleeding in 1514 sea trout (Fig. 2A) and hook size in 1479 of these cases (Fig. 2B). We found that 1179 sea trout were caught using single J hooks (78 %), 321 were caught using treble hooks (21 %) and 10 sea trout were caught using circle hooks (<1 %). In relation to barbs, we found that 1487 sea trout were caught using barbed hooks (98.5 %), whereas 23 were caught using barbless hooks (1.5 %). In addition, 1422 sea trout were caught using lures equipped with 1 set of hooks, 24 sea trout were caught with lures equipped with 2 sets whereas only 1 and 2 sea trout were caught using lures with 3 and 4 sets of hooks, respectively. Hooking location was reported from 1513 sea trout (Fig. 2C). The vast majority of sea trout

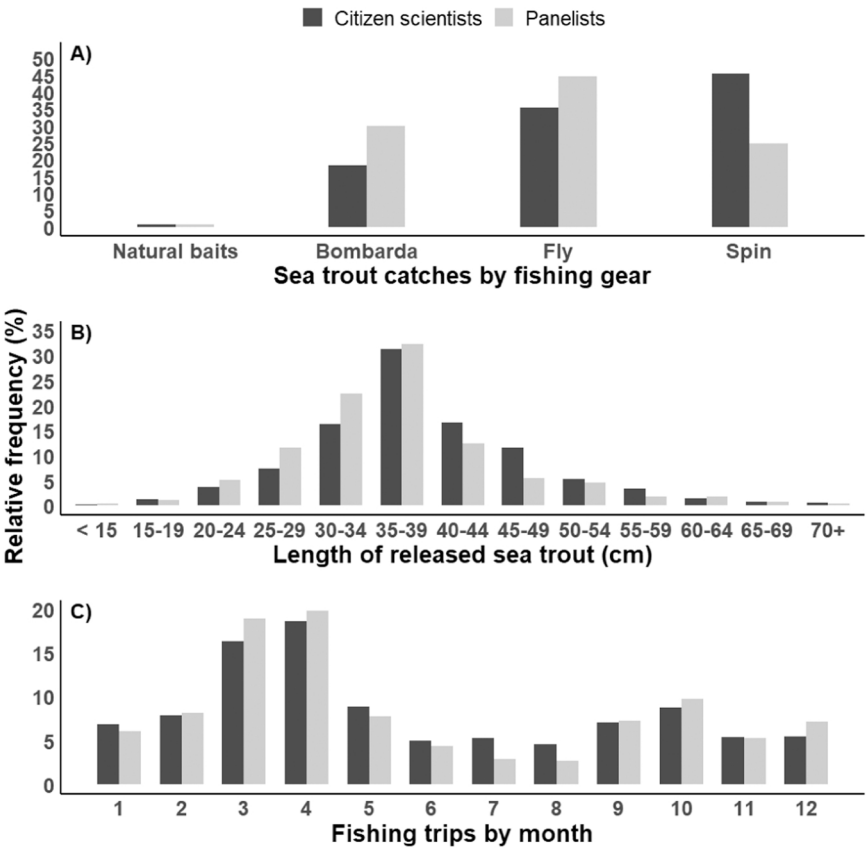

Fig. 1. A) Frequency of fishing methods reported for sea trout catches within the Danish coastal sea trout fishery by the general citizen scientists (dark grey) and the panelists (light grey). More specifically, natural baits (e.g., worms or shrimps), bombarda (i.e. a float that makes it possible to fish flies on spinning rods), fly fishing, and spin fishing. The numbers above the bars represent the total number of sea trout caught with the different methods. B) Length frequency distribution of sea trout that citizen scientists and panelists indicated as being released. C) Seasonal distribution of fishing trips for citizen scientists and panelists.

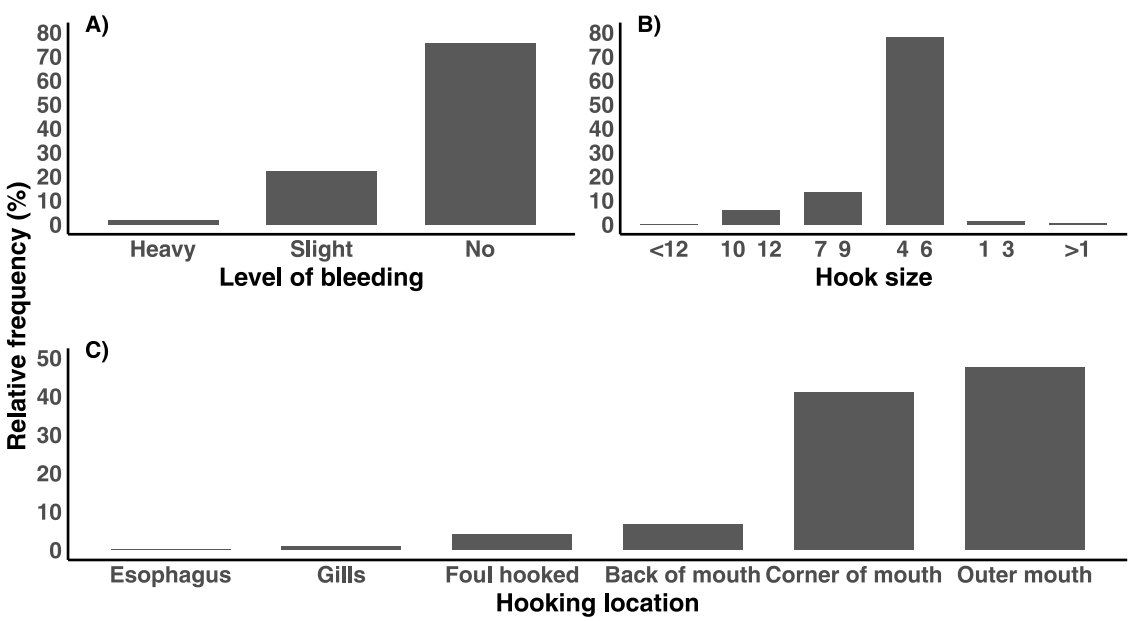

Fig. 2. A) Relative frequency of the level of bleeding corresponding to heavy bleeding, slight bleeding and no bleeding as reported by the panelists. B) Relative frequency of hook sizes used for sea trout fishing by the panelists. Smaller numbers represent larger hooks (i.e., size 1 is bigger than 3). C) Relative frequency of anatomical hooking locations of sea trout caught by the panelists.

were hooked in the outer mouth or in the corner of the mouth (Fig. 2C).

Hooking location varied between angling methods ($Chi^2 = 26$, df = 6, $p < 0.001$), where hooking in the outer mouth and foul hooking was most frequent in spin fishing whereas deep hooking and hooking in the corner of the mouth was most frequent in fly fishing (Fig. 3A). Hook type also seemed to relate to hooking location ($Chi^2 = 9$, df = 3, $p = 0.03$), where most deep hookings were observed for single hooks and most hooking in the outer mouth occurred with treble hooks (Fig. 3B). Smaller hooks caused more outer mouth hooking and larger hooks were more frequent in foul hooking and hooking in the corner of the mouth ($Chi^2 = 15$, df = 3, $p = 0.002$; Fig. 3C).

Due to missing values, the inclusion of length and air temperature

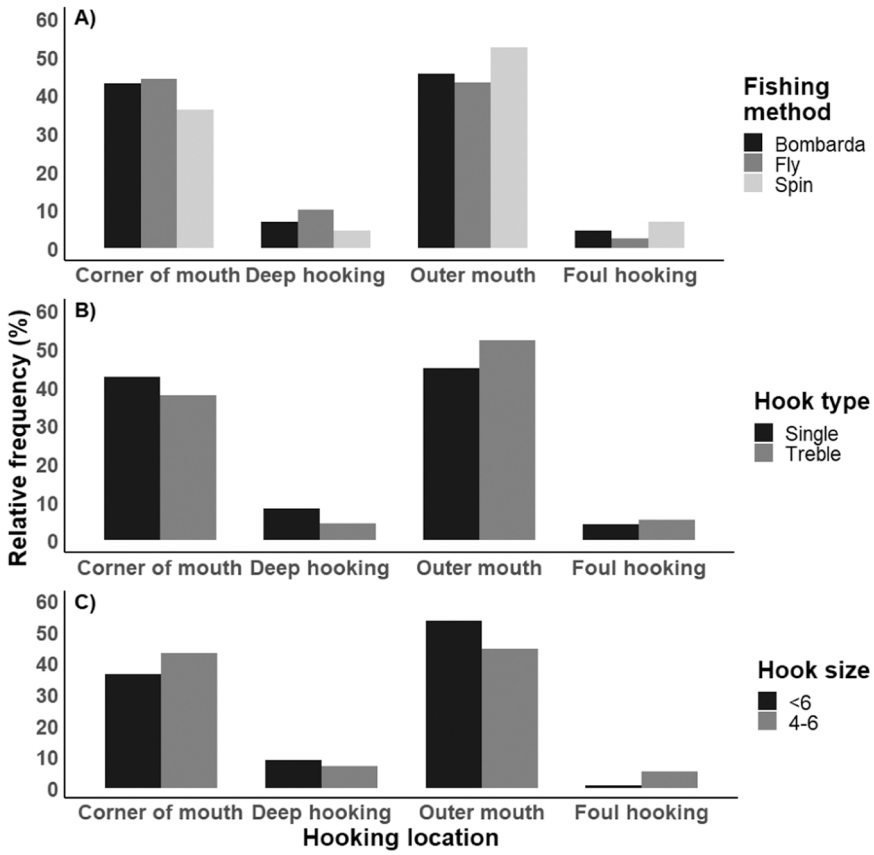

Fig. 3. Relative frequencies of hooking locations related to (a) angling method, (b) hook type and (c) hook size based on 1513 sea trout caught by the panelists.

left a total of 1274 sea trout to be modelled using a GLM with Bernoulli distribution. The final GLM model predicted the level of bleeding with 80 % accuracy and indicated several drivers of bleeding. Air temperature (df = 1, LRT =6.17, p = 0.01) had a significant effect on the risk of bleeding, which corresponds to a 0.6 % increase in risk of bleeding per unit increase in air temperature (i.e., an increase in air temperature from 0° to 20°C increases the risk of bleeding by 12 %). Additionally, the model indicated significant interaction effects between hooking location and fish length reported by the panelists (df = 3, LRT = 9.39, p = 0.03), and fishing method and fish length (df =2, LRT =7.83, p = 0.02) on bleeding (Fig. 4, Supplementary Figs. S2-S3). Specifically, deeply hooked sea trout showed a reduced risk of bleeding as length increased (Fig. 4A). A similar effect could be seen for fish caught using fly fishing gear,whereas, this pattern was not clear for fish caught using spin fishing tackle and bombarda (Fig. 4B). Overall, a higher share of sea trout caught by spin fishing bled (32 %) compared to fish caught by bombarda (29 %) and fly (16 %).

The share of bleeding sea trout above the legal minimum landing size that were released by the panelists (slight bleeding = 13.1 %, heavy bleeding = 1.5 %) was significantly lower than the share of bleeders among the harvested fish above minimum landing size (slight bleeding = 25.1 %, heavy bleeding = 4.1 %) (df = 1, LRT = 19.2, p < 0.001).

4. Discussion

The exploration of more than 30,000 sea trout catches reported by general citizen scientists and panelists confirmed previous assumptions about clear seasonal patterns in sea trout angling with peaks in spring and autumn. It also confirmed that sea trout anglers in Denmark practice C&R to a wide extent which supports previous studies (Ferter et al., 2013; Gundelund et al., 2021). The release of sea trout may be mandatory to comply with different management regulations such as

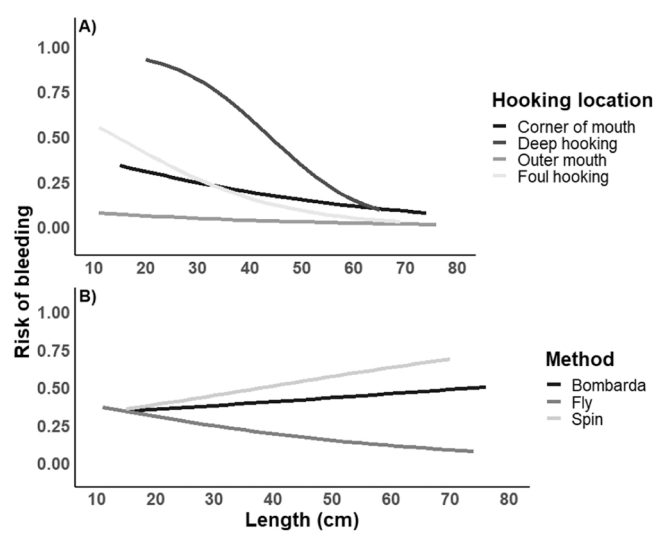

Fig. 4. Output from the logistic regression model showing A) the combined effect of anatomical hooking location and fish length, exemplified for fly fishing, on the risk of bleeding and B) the combined effect of fishing method and fish length, exemplified for fish being hooked in the corner of mouth, on the risk of bleeding. See Fig. S2 and S3 for more interaction figures.

minimum landing sizes and bag limits (Arlinghaus et al., 2007; Blyth and Rönnbäck, 2022). Nevertheless, the high release rate of sea trout above the minimum size limit observed among the panelists fishing on Funen (no bag limit), confirms that voluntary release rates can be significant in the coastal recreational sea trout fishery (i.e., close to 70 %). Reasons for voluntary release among sea trout anglers vary from anglers not liking to

eat fish to anglers having their own personal size limit (Skov et al. unpublished; Blyth and Rönnbäck, 2022). The citizen science data show that spin fishing is the most popular angling method for coastal sea trout in Denmark, followed by fly fishing and fishing with bombarda. These angling methods differ in the way they are conducted and based on information from the panelists, they also differ regarding the hook types used. Spin fishing is predominantly used in combination with treble hooks whereas fly fishing often includes the use of smaller single J hooks. Bombarda fishing is somewhere in-between with a higher use of treble hooks than fly fishing, but still much lower use than in spin fishing. In most cases, lures and flies were only equipped with one hook and the use of circle hooks and barbless hooks seemed not very widespread among the panelists.

4.1. Hooking location and bleeding

Most of the sea trout caught by the panelists were hooked in the outer mouth or in the corner of the mouth. In fact, the frequency of deep hooking (gills and esophagus) was only 1 % whereas 7 % were hooked in the back of the mouth. This relative low frequency of deep hooking may be species-specific (Muoneke and Childress, 1994; Bartholomew and Bohnsack, 2005; Hühn and Arlinghaus, 2011), but probably also reflects the angling methods mostly used by the panelists. These can generally be categorized as active angling methods, (e.g., when bait/lure is actively moved), in contrast to passive angling where the bait is at a fixed position at the time of the strike. Passive angling often gives the fish time to swallow the bait and consequently results in a higher frequency of deep-hooked fish which has been shown for other trout species (e.g., Persons and Hirsch, 1994; Schisler and Bergersen, 1996; Sullivan et al., 2013).

Hooking location reported by the panelists seemed to be influenced by angling method. For example, the occurrence of deep hooking was higher in fly fishing compared to spin fishing. This could relate to the total size of the lure/bait used for the different angling methods as deep hooking frequency increases when bait size decreases (Grixti et al., 2007; Arlinghaus et al., 2008; Brownscombe et al., 2017). The frequency of deep hooking may also relate to the fishing technique, such as how fast the bait is reeled in and how the hook is set (e.g. Alós, 2009; Stålhammar et al., 2014; Lennox et al., 2015) which could differ between the different angling methods, but we have no available information on this. However, it is interesting that the use of the bombarda method results in hooking locations that are intermediate between spin and fly fishing. The end gear used for bombarda angling is often a small fly imitation which is fished like a spin bait, i.e. with long casts and is likely often retrieved more quickly than when used on a fly rod. This may suggest that lower retrieval speed of the bait played a role for the higher deep hooking frequency among fly fished sea trout. The panelist reported a subset of sea trout as foul hooked, which is in line with findings of other studies (e.g. Gjernes et al., 1993; Davie and Kopf, 2006; Weltersbach et al., 2019). The frequency of foul hooking seemed higher when larger hooks and treble hooks were used.

Bleeding among fish caught on hook and line is frequently reported and has been associated with hooking location as discussed above. Similarly, the present study indicates that hooking location and fishing method play a significant role on the risk of bleeding for sea trout under saline conditions (e.g., heavy bleeding was most frequent when the fish was hooked in the gills and in the back of the mouth, and the risk of bleeding was lowest for fish caught on fly). However, when analyzed in detail it appears that bleeding risk likely relates to multiple factors that may interact with each other. For example, angling method interacts with fish size in a way that the risk of bleeding decreases as the size of sea trout caught by fly fishing increases. This does not seem to be the case for sea trout caught on spin fishing or bombarda. As we found no difference in hook size between these methods (as discussed below), the differences are likely caused by the differences in the dominating hook type among the angling methods (single J hook in fly fishing and treble hook in spin fishing, both hook types in bombarda fishing; Supplementary Fig. S1). It could also relate to the fishing technique e.g., the speed of the lure in the water or other factors that we are not aware of (e.g., variation in skills among anglers that use the different methods). We also found that bleeding risk was influenced by an interaction between fish length and hooking location. For example, smaller sea trout hooked deeply bled significantly more than larger sea trout, and larger sea trout hooked deeply bled most if they were caught by spin fishing and bombarda compared to fly fishing. The latter could relate to various factors specific to the different fishing methods. For example, studies have demonstrated more injuries on salmonids caught by spin fishing compared to fly fishing (e.g., Meka, 2004) which may be ascribed to differences in hook sizes between the terminal tackle used in the two modes (e.g., Gargan et al., 2015). However, we found no difference in hook size between methods and in line with other studies on salmonids (e.g., Taylor and White, 1992; Pauley and Thomas, 1993), the panelist data revealed no effect of hook size on bleeding patterns. However, the size span of hooks used by the panelists was relatively small and hook size effects may have been more apparent if a wider size span had been used.

Another potential reason for more bleeding among sea trout caught by spin fishing, could relate to the more frequent use of treble hooks in this method compared to fly fishing. This is in line with studies showing increased mortality of fish hooked deep with treble hooks compared to fish hooked deep with single hooks (e.g., Nuhfer and Alexander, 1992; Ayvazian et al., 2002), and that treble hooks generally are more likely to be embedded in sensitive areas (e.g., foul hooked, gullet, gills, and/or eyes) compared to J hooks (e.g., Trahan et al., 2021). On the other hand, several other studies have indicated that single hooks can cause more damage than treble hooks, and meta-analysis studies have not been able to make clear conclusions whether treble hooks or single hooks are likely to cause higher post-release mortality (Taylor and White, 1992; Bartholomew and Bohnsack, 2005; Hühn and Arlinghaus, 2011).

The use of barbless hooks could help minimizing hooking injuries and bleeding but may decrease catch efficiency (Cooke and Wilde, 2007). Barbless hooks are usually easier to remove and may result in less tissue damage (Brownscombe et al., 2017). However, as indicated by the panelist data the use of barbless hooks is likely uncommon in the Danish sea trout fishery.

Although affected by hooking location as well as fishing method, the panelist data suggested that bleeding decreased with fish size which aligns with previous studies (e.g. Meka, 2004). Still, the role of fish length on the adverse effects of C&R has been frequently discussed with results showing both increased mortality, reduced mortality and no effect with fish length (Bartholomew and Bohnsack, 2005), which most likely reflects a complex set of factors that vary with the length of the fish. Smaller fish clearly get a relative larger hook wound, which can result in more bleeding. On the other hand, larger fish may fight for a longer time which may lead to more fatigue, which ultimately may play a larger role for survival chances than bleeding as such.

The occurrence of bleeding increased with air temperature although the effect size was relatively low. As air- and water temperatures are correlated, the relationship might be explained by increased metabolism occurring when temperature increases. This is in line with numerous studies across species that have documented that post-release mortality increases with higher water temperature (Bartholomew and Bohnsack, 2005).

It is important to note that the proportion of bleeders discussed above reflect bleeding of sea trout upon capture and do not reflect bleeding patterns among released sea trout. In fact, among the released fish that were above the legal minimum landing size, the shares of slight bleeders as well as heavy bleeders were significantly lower than reported for the harvested fish. This could suggest that the panelist anglers were more prone to keep a bleeding fish, maybe because of a belief that bleeders have lower survival chances, which is in line with a study on Swedish Baltic sea trout anglers whose main reason for retention of a

certain fish was the perception of a low survival rate (Blyth and Rönnbäck, 2022).

4.2. Potential study limitations

Citizen scientists may not be fully representative for the general angler population (Gundelund et al., 2020). Therefore, care should be taken when extrapolating the citizen scientist data to the general angler population, not the least since the panelists only represented a small subset of all citizen science participants and an even smaller subset of the general Danish sea trout angler population. Furthermore, the panelists were experienced anglers likely with better skills with regards to handling and hook removal compared to the average angler. Hence, the reported bleeding patterns may have been different if less experienced anglers had been part of the panel (e.g., Meka, 2004). Moreover, we do not know if the propensity we observed among the panelist to harvest bleeding sea trout, is universal.

From the comparisons between the panelists and the general citizen scientists, we saw a tendency towards the panelists releasing fewer larger sea trout than the overall citizen scientists. This could be due to underreporting of sea trout below minimum landing size among the general citizen scientists which would imply that the release rate of 81 % estimated from the general citizen scientists is conservative. There are also indications that fly fishing was more popular among the panelists than among the general citizen scientists, and it is possible that barbless hooks and circle hooks are used more frequently by Danish sea trout anglers than found among the panelists. Having said that, spinning lures are usually equipped with larger hooks and often treble hooks by most manufactures, whereas most flies are equipped with smaller single hooks and to our best knowledge very rarely with barbless or circle hooks which indicates that the use of such hooks is rare in this fishery. As indication of resemblance in release behavior between the panelists and the general citizen science participants, we saw very comparable estimates of both mandatory and voluntary release rates. Likewise, the similarities in seasonal angling patterns among the general citizen scientists and the panelists support that their behaviors were related, suggesting some justification of using the panelists as proxy for the general citizen scientists.

4.3. Conclusion

This study confirms that C&R is common among recreational sea trout anglers in Denmark which is driven by both voluntary and mandatory reasons such as the release of fish below the minimum landing size. Various angling methods are used in this fishery which has implications for hooking locations and the occurrence of bleeding. The frequency of bleeding increased slightly with air temperature and was strongly influenced by hooking location and fishing method, both in combination with fish length. On average, bleeding was less frequent in fly fishing compared to spin fishing. This study illustrates how a citizen science approach can be used to explore angling practices and to collect information about hooking locations and levels of bleeding among the angled fish, here sea trout, directly from the fishery. Although useful for this matter, the citizen science approach provides no information on short- and long-term C&R impacts on angled sea trout. Anatomical hooking location in combination with occurrence of bleeding have been identified as one of the most important factors influencing post-release mortality (Muoneke and Childress, 1994; Bartholomew and Bohnsack, 2005; Hühn and Arlinghaus, 2011), and the present study suggests that 25 % of sea trout that were caught bled and that 2 % bled heavily. Even though a recent study by Blyth and Bower (2022) indicated high rates of post-release survival and generally limited stress responses to angling events for sea trout, particularly heavy bleeding implies an increased risk for post-release mortality and considering the high release rate of minimum 80 % found in this study we encourage further studies to explore potential lethal and sublethal impacts of C&R on coastal sea trout. Data from this study can help to develop the experimental design, and to adjust experimental results (Lewin et al., 2018; Weltersbach et al., 2018).

The use of citizen science data as a method to inform fisheries management is likely to increase in the future (Silvertown, 2009; Conrad and Hilchey, 2011; Bonney et al., 2021; Skov et al., 2021), and this study illustrates the potential of the method. This relates to data collection and, although not the focus of this study, it can also be a useful tool to inform citizens. For example, electronic citizen science platforms such as apps, could give citizens easy access to guidance and tips for best practice C&R fishing (Cooke et al., 2021).

CRediT authorship contribution statement

Christian Skov: Conceptualization, planning, data curation, Writing – original draft, Writing – review & editing, Project administration, Funding acquisition. Marc Simon Weltersbach: Writing – original draft, Writing – review & editing. Keno Ferter: Writing – original draft, Writing – review & editing. Casper Gundelund: Data curation, Data analysis, Writing – review & editing, Sissel K. Bertelsen: Data analysis, Writing – review & editing. Niels Jepsen: Conceptualization, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.fishres.2022.106451.

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