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Effects of lure type, fish size and water temperature on hooking location and bleeding in northern pike (*Esox lucius*) angled in the Baltic Sea

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ABSTRACT

In recreational fishing, catch and release (C&R), where fish are released alive after capture, is commonly adopted to minimize fishing mortality. Injuries from hooking and the mode of de-hooking can affect survival probability, and the choice of angling gear can affect injury severity. We show for C&R angling for northern pike (*Esox lucius*) in the Baltic Sea that hooking location and size of fish captured vary among lure types. Hooking in gills and aorta increased bleeding severity, which was generally expressed more strongly in larger pike. Our results supported the notion that anglers can minimize injury in northern pike angling by the choice of appropriate gear. In addition, our study is one of the first to show that hooking location is also affected by water temperature; low temperatures tended to result in deeper hooking. Despite this, water temperature did not affect level of bleeding in pike, and low water temperatures may be beneficial as they likely reduce the overall stress response in released pike.

1. Introduction

Fishing mortality can affect the structure and function of fish stocks, and recreational angling is no exception (Lewin et al., 2006; Post et al., 2002). One possible measure to decrease the biological effects of recreational angling is to practice catch-and-release (C&R) fishing, defined as the immediate release of captured fish in a state that allows fish to survive (Arlinghaus et al., 2007). C&R is practiced mandatorily as a by-product of harvest regulations, but is also increasingly frequently conducted as a voluntary measure adopted by anglers (Allen et al., 2008; Bartholomew and Bohnsack, 2005). The general notion is that the C&R procedure bears potential for minimising fishing mortality, thereby reconciling angling use with conservation of fish stocks (Arlinghaus et al., 2007). However, at unlimited effort, unintended hooking mortality may still undermine sustainability (Coggins et al., 2007), and even if caught fish are released alive at their place of capture and survive, their behaviour and reproductive performance post release can be affected (Cooke et al., 2002; Ostrand et al., 2004; Richard et al., 2013). Documented behavioural effects of C&R include reduced movement (Arlinghaus et al., 2008a; Klefoth et al., 2008, 2011) and altered foraging propensity (Siepker et al., 2006; Stålhammar et al., 2012) as well as increased susceptibility to predators (Raby et al., 2013). Behavioural changes can hereby reduce growth rate (Klefoth et al., 2011; Siepker et al., 2006) and ultimately survival (Cooke and Philipp, 2004).

Hooking-related injury is among the most critical determinants of fish mortality post release (Bartholomew and Bohnsack, 2005; Muoneke and Childress, 1994). Hühn and Arlinghaus (2011) reported a 15.9% hooking mortality in a meta analysis across several species of importance in European fisheries, and Bartholomew and Bohnsack (2005) found a slightly higher mean hooking mortality of 18% from a meta analysis focusing more on marine fish species. Significant contributors to mortality were hooking in vital organs, use of natural bait which in some species leads to deeper hooking in the throat of fish (Arlinghaus et al., 2008b), J-hooks compared to circle hooks, removing hooks from deeply hooked fish, water depth of capture, high water temperatures as well as extended angling duration and handling times (Arlinghaus et al., 2007; Bartholomew and Bohnsack, 2005; Hühn and Arlinghaus, 2011). Injury in hooked

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fish ranges from just a small penetration wound, which likely is of no major concern for survival, to severe injury such as eye injury, organ and gill damage that may lead to substantial bleeding and cause mortality post release (Aalbers et al., 2004; Arlinghaus et al., 2008b; DuBois and Kuklinski, 2004). Probability of deep hooking has been shown to correlate with fish size (Alos, 2009), natural bait use in predatory fish (Arlinghaus et al., 2008b; DuBois and Kuklinski, 2004), hook type (Cooke and Suski, 2004), size of hooks (Alos et al., 2008), size of bait and lure (Arlinghaus et al., 2008b; Wilde et al., 2003), and angling technique (passive vs. active) (Alos, 2009; Grixti et al., 2007; Schill, 1996). Moreover, single hooks have been suggested to hook deeper relative to treble hooks in some species (Muoneke and Childress, 1994), but if treble hooks hook deeply they will result in more severe injury and potential for mortality (Muoneke and Childress, 1994). Such patterns likely vary strongly with hook size relative to fish gape size and feeding mode, and are difficult to generalize without species-specific studies.

Generally, fish hooked deeply in critical tissues such as gill, aorta or vasculature have a higher likelihood of substantial blood loss (Arlinghaus et al., 2008b; Burkholder, 1992), which can result in immediate mortality post release (Aalbers et al., 2004; Arlinghaus et al., 2008b; DuBois and Kuklinski, 2004). For smaller wounds, the bleeding usually stops quickly, and in many cases this is unlikely to result in elevated mortality, and indeed many fish that bleed survive after release (Arlinghaus et al., 2008b). In order to develop C&R as a management strategy, it is critical to further evaluate how different types of angling gear affect the severity of injury and bleeding. This is particularly important as gear choice can affect the impact of C&R on fish (FAO, 2008, 2012), and is also one of few variables anglers have direct control over. Here, we focus on the relationships between different types of lures and hooking location in the mouth of northern pike (*Esox lucius*) and the degree of subsequent bleeding, in light of fish size and water temperature.

Northern pike (hereafter refereed to as pike) is a popular species among anglers in both North America and Europe (Arlinghaus and Mehner, 2004; Paukert et al., 2001). Pike is also an important top predator in temperate freshwater food webs, constituting a structuring force in many systems (Craig, 2008; Findlay et al., 2005; Raat, 1988). Earlier results indicate that hooking mortality is relatively low (on average 7.1%) in esocids (Hühn and Arlinghaus, 2011), and it has been suggested that pike are relatively robust to injury and other handling-induced stressors (Arlinghaus et al., 2009; Arlinghaus et al., 2008a,b; Klefoth et al., 2011). Even though hooking mortality is low in pike, angler experience (Diodati and Richards, 1996; Meka, 2004; Newman and Storck, 1986) and bait type and size can influence hooking location and mortality in this species (Arlinghaus et al., 2008b; DuBois and Kuklinski, 2004). The only study in the literature on this topic, by Arlinghaus et al. (2008b), showed that natural bait, softbait (shads and jigs) and spoons were more likely to hook in critical locations than spinner and wobblers, especially when baits or lures were small. Arlinghaus et al. (2008b) did not find a relation between bleeding and size of pike or among bleeding and bait/lure size/type, but bleeding was the main determinant of initial mortality in their study, in concordance with DuBois and Kuklinski (2004). The field study by Arlinghaus et al. (2008b) was confined to comparatively small pike individuals with an average length of 51 cm total length and hence may not relate to situations where larger pike occur regularly, such as in the Baltic Sea. Here, we present new data to evaluate the impact of a wider range of lure types upon hooking location and subsequent bleeding in pike. We also analyzed the effects of water temperature and pike size, as these factors have been indicated to influence hooking-injury severity in other fish species (Alos, 2009; Cooke et al., 2003; Sullivan et al., 2013). Large pike have large gapes and may fit lures deeper into their mouths, increasing the risk of hooking in critical tissue. Large pike may also fight more vigorously than small individuals, potentially increasing relative probability of bleeding. Low water temperatures have been reported to decrease stress effects (Arlinghaus and Hallermann, 2007; Colotelo et al., 2012; Gale et al., 2013), while the relation to hooking location and bleeding remains unexplored.

2. Materials and methods

The study was conducted in the archipelago of the brackish Baltic Sea, near Mönsterås (57°1′53″N, 16°28′25″E), Söderköping (58°24′51″N, 16°42′43″E), Västervik (57°44′30″N, 16°42′22″E), Trosa (58°52′22″N, 17°36′15″E) and Stockholm (59°5′11″N, 17°41′41″E) in Sweden, between March 26 and June 6 in 2009. A total of 862 pike were caught and released during the period. Pike were captured from boat using regular spin fishing gear with cast weight up to 250 g and reels with multifilament line (Cortland Spectron and BFT Strike Wire Extreme) up to 40 kg break strength. All pike were caught with lures and the treble hook size was standardized to 2/0, VMC 8650 hooks, standard design with barbs. The lures used were categorized as bucktail, glider (lipless crankbait), softbait (soft plastics), spinfly (pike fly used with regular spinning gear), tailbait (lipless crankbait with a pin-jointed rubber tail) and crankbait (see illustrations in Table 1). The bait categories spinfly and bucktail had one treble hook while glider, crankbait, softbait and tailbait had two treble hooks. For lures with one single hook, such as softbait, the single hook was removed and replaced with one treble hook. For lures with three treble hooks, the middle hook was removed so only the front and rear hooks were used. We used comparably large (cf. Arlinghaus et al., 2008b) and similar-sized (18 ± 3 cm, mean ± SD) lures across lure types that were randomly chosen between fishing occasions.

Pike were landed as quickly as possible using a knotless rubber net or by gripping the pike by the gill operculum. All pike were placed on a soft unhooking mat and hooks were detached with long shaft pliers. Hooks that were placed around one or more gill rakers or in the aorta were cut to minimize tissue damage during removal. Surface water temperature, total length of the pike, hooking location in the mouth of pike, and level of bleeding were noted before releasing the pike at the site of capture. Hooking locations were classified into the categories lip, palate, gills or (ventral) aorta. Bleeding was assessed visually into categories none, moderate or substantial. No bleeding was defined as when bleeding could not be distinguished from the hooking, moderate bleeding as continuous but mild, and substantial bleeding as when pike were bleeding heavily and continuously.

The probabilistic relationships between lures used, hooking location, level of bleeding, water temperature and pike length were evaluated by multinomial logistic regression. Significant likelihood ratio test effects were further evaluated by comparing the response frequencies (of level of bleeding or hooking location) for each lure or hooking location with the overall response frequencies observed, using χ^2 tests. Moreover, an analysis of variance (ANOVA with Tukey's post hoc test) compared lengths of pike captured between lure types used.

3. Results

The 862 pike (39–113 cm total length, 67 ± 13 cm, mean ± SD) were caught at surface water temperatures ranging 2 to 22 °C. The different lures caught pike of different lengths ($F_{5,856} = 6.8$, $p < 0.001$), where tailbait compared to bucktail ($p = 0.002$), tailbait compared to glider ($p < 0.001$), and spinfly compared to glider ($p = 0.008$) captured significantly longer pike (Fig. 1). The average size (mean ± SD) of pike captured on bucktail were 64.9 ± 12.8 cm ($n = 74$), glider 65.4 ± 11.1 cm ($n = 410$), softbait 70.7 ± 10.3 cm

Table 1
The percentage hooking location in pike caught with different artificial baits. *p*-Values indicate if the pattern of bleeding deviates from the expected overall pattern.

Hooking location	Overall (%)	Bucktail (%)	Glider (%)	Softbait (%)	Spinfly (%)	Tailbait (%)	Crankbait (%)
Aorta	4.9	4.1	3.2	4.3	10.1	1.9	5.9
Gills	8.7	13.5	6.8	8.7	13.6	5.7	3.9
Lip	81.4	73.0	86.1	73.9	70.7	87.7	88.2
Palate	5.0	9.5	3.9	13.0	5.6	4.7	2.0
N	862	74	410	23	198	106	51
χ^2_3		7.69	1.52	13.56	9.76	3.38	5.22
p		>0.05	>0.5	<0.01	<0.05	>0.3	>0.1

Table 2
The percentage of pike with different levels of bleeding caught with different artificial baits. *p*-Values indicate if the pattern of bleeding deviates from the expected overall pattern.

Bleeding	Overall (%)	Bucktail (%)	Glider (%)	Softbait (%)	Spinfly (%)	Tailbait (%)	Crankbait (%)
None	87.2	82.4	88.5	95.7	80.8	93.4	92.2
Moderate	5.1	10.8	5.6	0	4.5	3.8	0
Substantial	7.7	6.8	5.9	4.3	14.6	2.8	7.8
N	862	74	410	23	198	106	51
χ^2_2		6.74	0.49	7.43	6.72	3.89	5.39
P		<0.05	>0.8	<0.05	<0.05	>0.1	>0.05

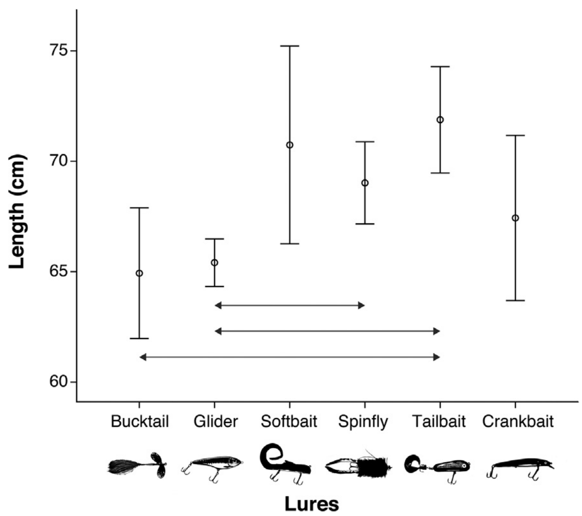

Fig. 1. Length (cm ± SE) of pike caught with different kinds of lures where arrows showing significant difference.

($n = 23$), tailbait 71.9 ± 12.5 cm ($n = 106$), crankbait 67.4 ± 13.3 cm ($n = 51$) and spinfly 69.0 ± 13.3 cm ($n = 198$). The majority of pike (81.4%) were hooked in the lip and did not bleed after unhooking (Tables 1 and 2). Five critically hooked (gills or aorta) pike with substantial bleeding died immediately, the rest swam away after release with unknown fates.

The different lures affected the probabilities of hooking location of pike ($\chi^2_{15} = 38.140$, $p < 0.001$). Here, softbait increased the frequencies of palate hooking, and spinfly increased aorta and gill hooking frequencies (Table 1). Water temperature also affected hooking location ($\chi^2_3 = 11.845$, $p = 0.008$), with hooking in gills and aorta being relatively more frequent at lower temperatures (Fig. 2). Pike length did not affect the probability of different hooking locations ($\chi^2_3 = 1.364$, $p = 0.714$). However, pike with substantial bleeding from hooking in palate or lip were longer (88 ± 24 cm, mean ± SD) compared to those with moderate bleeding (65 ± 11 cm, mean ± SD, $F_{1,28} = 12.5$, $p < 0.001$).

The probabilities for bleeding were affected by lure type ($\chi^2_{10} = 25.327$, $p = 0.005$). Bucktails significantly shifted the frequencies towards moderate bleeding, softbaits shifted frequencies towards no bleeding, while spin-flies increased the frequencies of substantial bleeding (Table 2). The bleeding levels from other lures did not deviate significantly from the general pattern (Table 2).

Hooking location in the mouth of caught pike affected the probability of the different levels of bleeding ($\chi^2_8 = 331.420$, $p < 0.001$). Hooking in aorta and gills produced disproportionally high frequencies of substantial and moderate bleedings, and overall low frequencies of the no bleeding category (Table 3). Hooking in lip or palate resulted in comparably low frequencies of substantial bleeding (Table 3).

Pike individual length also affected the probabilities of bleeding levels ($\chi^2_2 = 7.574$, $p = 0.023$), where longer pike had a relatively higher representation in the category of substantial bleeding (Fig. 3). Water temperature had no statistically significant effect on bleeding levels ($\chi^2_2 = 5.090$, $p = 0.078$).

4. Discussion

Our study revealed that different lures affected the probabilities of hooking location in the mouth and gills of pike C&R fishing. Previous work on hooking location in pike has shown that deep hooking increase with decreasing bait or lure size (Arlinghaus et al., 2008b), use of pike hooks (known as Swedish hooks) (DuBois et al., 1994) and use of natural bait (Arlinghaus et al., 2008b). Arlinghaus et al. (2008b) also found that hooking in critical areas of pike was more likely for softbait than for wobblers (i.e. hardbaits, crankbaits or plugs) and spinners. By contrast, in our study large softbait produced high frequencies of lip and palate hooking. The difference between the present results and those from Arlinghaus et al. (2008b) may be due to different fishing techniques and due to our larger overall size of lures used, that may have reduced the probability of deep hooking.

The use of spinfly in our study increased the probability of hooking in critical areas, i.e. the aorta and gills. We argue that the unfavourable hooking we found for spinfly could be due to bait shape. A spinfly appears large in the water but is made of soft

Table 3
The percentage of different levels of bleeding in pike caught at different hooking locations in the mouth. *p*-Values indicate if the pattern of bleeding deviates from expected overall pattern.

Bleeding	Overall (%)	Aorta (%)	Gills (%)	Lip (%)	Palate (%)
None	87.2	2.4	40.0	96.4	83.7
Moderate	5.1	7.1	21.3	2.7	14.0
Substantial	7.7	71.4	38.7	0.2	2.3
N	862	42	75	702	43
$\chi^2{}_2$		610.22	201.81	9.41	19.46
P		<0.001	<0.001	<0.01	<0.001

and flexible material, possibly making pike strike it in a way that increases risk of hooking deep in the fish mouth. It is also commonly fished slowly (i.e. more passively fished), potentially further increasing the risk of deep hooking, as slowly moving objects would be easier for pike to strike efficiently (i.e. deeply). Conversely, lures like softbait, glider and tailbait are made of hard wood or plastic, potentially decreasing the likelihood of deep hooking. Arlinghaus et al. (2008b) reported increased deep hooking of pike with natural bait compared to lures. Also, Muoneke and Childress (1994) suggested that artificial lures and flies tend to hook fish superficially relative to natural baits, leading to easy removal of hooks and decreased risk of damage to vital organs or tissues. By fishing more actively, the likelihood of deep hooking can be reduced compared to fishing passively (Schill, 1996; Sullivan et al., 2013). In our study, uniformly large softbait were fished actively, while softbait of different sizes were fished less actively in Arlinghaus et al. (2008b), which may explain their more frequent deep hooking. We suggest that specific artificial lures, such as the spinfly, should be avoided if the intention is to minimize injury and enhance survival for caught and released fish.

We showed that hooking location was related to the different levels of bleeding, in line with previous studies in pike (Arlinghaus et al., 2008b; Burkholder, 1992; DuBois et al., 1994). In our study, aorta and gill hooking produced disproportionately high frequencies of substantial and moderate bleeding, and high levels of blood loss. Arlinghaus et al. (2008b) found that deeply hooked (e.g. gills or aorta) pike exhibited more severe bleeding, and bleeding increased the risk of initial mortality. Although the majority (87%) of our pike did not bleed, suggesting a relatively low risk of mortality (Arlinghaus et al., 2008a; Burkholder, 1992), five pike died immediately from substantial bleeding from gills and/or aorta. This suggests an immediate need to avoid hooking in such critical tissue if the aim is to enhance survival post release in pike fisheries (Arlinghaus et al., 2008b).

Our results indicated that longer pike had a relatively higher frequency of substantial bleeding despite shallow hooking, in line with a study by Alos (2009) which showed a positive correlation between derbio (*Trachynotus ovatus*) size, hook depth and bleeding. However, our study shows that hooking location did not differ between sizes of pike captured. Sullivan et al. (2013) reported deeper hooking rates in larger stream-dwelling trout (*Oncorhynchus mykiss*). By contrast, Cooke et al. (2003) showed that smaller fish captured with circle hooks were more vulnerable to deep hooking than larger bluegill sunfish (*Lepomis macrochirus*) and pumpkinseed sunfish (*Lepomis gibbosus*). Disparate results show the need of species-specific information for C&R management. Pike are gape-size limited predators, and larger pike have larger gapes (Nilsson and Brönmark, 2000), which is why larger pike could more easily fit large baits or lures deep into the mouth. However, a relation between deep hooking and bait type was not found in this study, most likely because all baits were rather large, which reduces deep hooking in pike (Arlinghaus et al., 2008b) and other species (Wilde et al., 2003). However, despite similar hooking location, we found pike length to increase degree of bleeding. In particular, pike that showed substantial bleeding from hooking in palate or lip were longer (88 ± 24 cm) compared with those with moderate bleeding (65 ± 11 cm). This greater risk of bleeding could be due to that larger pike fought more vigorously than smaller fish, potentially leading to penetration of hooks deeper into the tissue, thereby increasing the severity of injury.

The length of pike captured differed between lure types used. Different sizes of bait and lures have been shown to affect the sizes of fish caught, where larger lures catch larger fish (Arlinghaus et al., 2008b; Wilde et al., 2003). Our results however indicated that different kinds of similar-sized, large lures also can affect the size of pike captured. Tailbait and spinfly caught larger pike compared to glider, as did tailbait compared to bucktail. The mechanism for the lures effect on size of fish remains unresolved.

There were disproportionately higher frequencies of hooking in the aorta and gills at low water temperatures, potentially linked to pike being a mesothermal species (Casselman and Lewis, 1996). By contrast, Cooke et al. (2003) showed that warm-water pumpkinseed sunfish were hooked deeper at 26 °C than at lower temperatures. These contrasting findings highlight that temperature dependency of deep hookings can be species specific. Pike spawn early in the spring at low water temperatures, and during this period pike aggregate spatially and are a relatively easy target for anglers. Kuparinen et al. (2010) also reported that catch rates increased at low water temperature in pike. At low water temperatures, anglers tend to fish the lures more slowly as this increases probability of hooking, potentially making it easier for pike to take the lure deeply into the mouth, with a higher risk of unwanted hooking. Therefore, the higher incidence of deep hooking at low water temperature might be related to intensified foraging and altered fisher behaviour. These arguments, along with our results, suggest that the pike spawning period may be unsuitable for high fishing pressure if the aim is to minimize negative effects of angling. Fortunately, however, deep hooking did not translate into greater bleeding at low water temperature in our study. At the same time, C&R fishing at low water temperatures enhances recovery and induces less mortality across a range of fish species (Cooke and Suski, 2005; Gustaveson et al., 1991; Schreer et al., 2001). Anglers are thus faced with some trade-offs associated with water temperature and C&R pike angling. While low water temperature affects hooking location (but not bleeding) negatively, it could be physiologically more benign to release mesothermal pike at low water temperatures. The unexpected results on effects of water temperature on C&R-related hooking location indicate complex patterns with ambiguous management implications for pike fisheries. However, as water temperature affected hooking location but not level of bleeding, low water temperature may be overall beneficial by reducing negative physiological and stress responses in pike to the C&R procedure.

In conclusion, we have shown that although the majority of pike captured in our study were hooked in the lip, hooking in critical areas can occur also with artificial lures, especially at low water temperatures. At similar hooking locations, injury rates (as judged

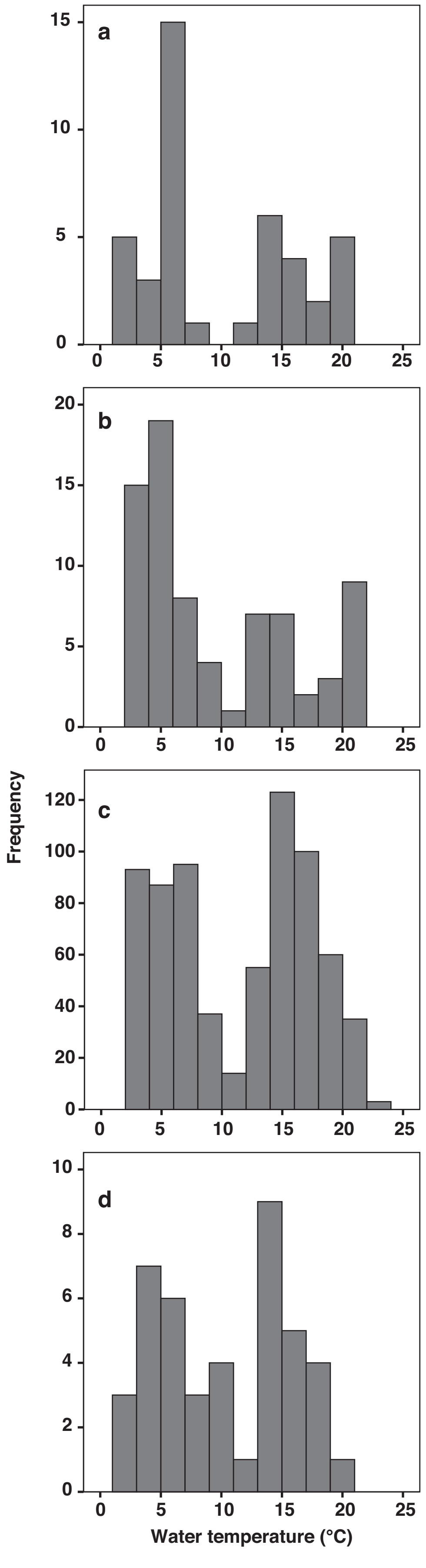

Fig. 2. The frequencies of hooking in (a) aorta, (b) gills, (c) lip and (d) palate depending on water surface temperature.

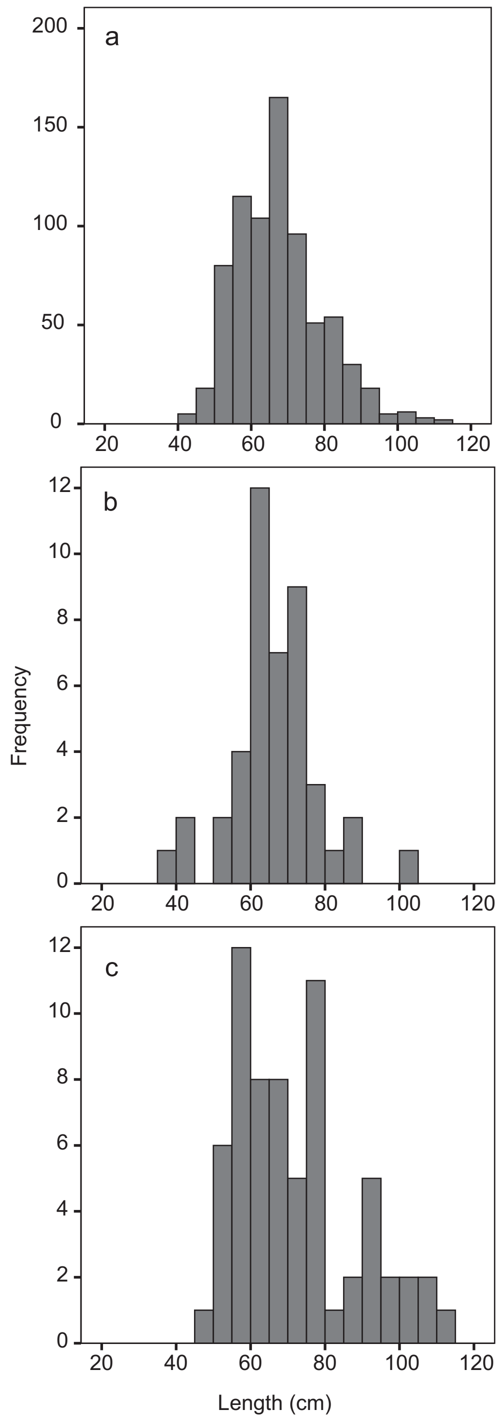

Fig. 3. The frequencies of bleeding categories (a) none, (b) moderate and (c) substantial in pike of different total body lengths.

by bleeding) seem to be higher in larger pike. If the intention of recreational fisheries is to minimize injury and enhance survival of caught and released pike, anglers should avoid selected artificial baits like the spinfly, and overall select larger lures that reduce deep hooking. Fishing at low water temperatures (e.g. around spawning season) can increase the frequency of deep hooking. Our results highlight the importance of proper lure choice, and that temperature- and size-dependent factors can influence injury severity in C&R pike fisheries.

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