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The impact of catch-and-release angling on short-term behaviour and habitat choice of northern pike (*Esox lucius* L.)

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Abstract In the northern hemisphere, pike (*Esox lucius* Linnaeus) is one of the most important recreational fisheries resources, and regulatory or voluntary catch-and-release angling is common. No information is available about the potential sublethal impacts on pike that catch-and-release fishing may cause, such as behavioural alterations and changes in habitat choice after release. Radio telemetry with $N = 20$ pike was used to test the hypothesis that fish modify behaviour by reducing movement as a reaction to a catch-and-release event in a previously unfished, slightly eutrophic lake, having an area of 25 ha and located in northeastern Germany. During a 7-month tracking period, activity of pike was monitored for consecutive 24 h every week. Minimum displacement per hour (m) and distance to shore (m) were significantly lower upon the first post release tracking compared to tracking before the capture. Two tracking events after capture, both movement and distance to shore were similar to those measured during pre-angling. There were no significant relations between the change in movement and distance to shore and size of pike. In terms of habitat choice, pike significantly selected for reed and avoided the pelagic area over the whole study period that was not influenced by catch-and-release angling. The results indicated that catch-and-release induces short-term behavioural alterations in pike, probably explained by physiological disturbances and facilitated by evolved anti-predation behaviours. Such alterations, however, seem to be of short duration and reversible suggesting sublethal catch-and-release impacts on pike behaviour are limited.

Keywords Catch-and-release · Pike · Radio-telemetry · Recreational fishing · Sublethal impacts

Introduction

The northern pike (*Esox lucius* Linnaeus, hereafter termed pike) is a piscivorous fish species that is found in most lakes and slow rivers across the northern hemisphere (Craig, 1996). It is a popular target of

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commercial and recreational fisheries (Pierce et al., 1995; Arlinghaus and Mehner, 2004) and highly vulnerable to angling (Weithman & Anderson, 1978; Paukert et al., 2001). Across its geographic range, there are a variety of regulations that require release of some portion of the pike caught. For example, in Germany, pike is among the most popular species sought by recreational anglers (Arlinghaus, 2004). Most legal sized pike are removed for consumption (Arlinghaus & Mehner, 2004). However, sublegal fish are required to be released unharmed (Arlinghaus, 2007). In North America, Paukert et al. (2001) reported that pike length limits were less popular than bag limits, however, 13 of 34 states and provinces surveyed (38.2%) had established minimum length limits ranging from 457 to 762 mm to protect immature or small pike. Furthermore, 52.9% of the 34 states and provinces surveyed had special pike regulations such as high minimum length limits, protected slot length limits, maximum length limits and catch-and-release only. Regulatory catch-and-release fishing is associated with all harvest regulations mentioned above, but many anglers also practice voluntary catch-and-release pike angling. For example, catch-and-release rates in 7 Minnesota lakes in the USA ranged between 42 and 87% of the pike captured per year (Pierce et al., 1995). It is likely that at least in some jurisdictions and localities, voluntary catch-and-release of pike is very common.

Regardless of whether it is voluntary or mandatory, catch-and-release angling can offer a solution for pike overfishing, but could induce either lethal (Munoeke & Childress, 1994) or sublethal impacts (Cooke et al., 2002) on the released fish. Hooking mortality has been studied to some extent in pike (Weithman & Anderson, 1978; Burkholder, 1992; DuBois et al., 1994), however, sublethal impacts potentially impairing long-term growth and fitness (Cooke et al., 2002) have received limited attention. Sublethal impacts of catch-and-release may include a combination of injury, physiological disruptions and behavioural alterations post release (Cooke et al., 2002).

Angling-induced stress, likely one of the most severe forms of exercise for fish under normal environmental conditions (Wood, 1991), results in various changes in metabolic parameters such as blood and muscle lactate and glucose, ATP and phosphocreatine (Kieffer et al., 1995). Physiological disturbance associated with angling often takes 8–12 h to fully recover in many freshwater fish species (Kieffer, 2000). Specific for pike, Schwalme & Mackay (1985) reported elevated glucose levels 96 h post angling, suggesting that pike might take longer to recover from angling-induced stress when compared to other species. This physiological reaction may alter the behaviour of the fish post release (Cooke et al., 2002), but no studies are available to confirm this in a pike catch-and-release context.

Telemetry techniques seem to be suitable to assess the post release behaviour of pike after a catch-and-release event in situ (Cooke et al., 2002). Free swimming behaviour of fish can be studied by conventional locational telemetry (Lucas & Baras, 2000), but only in several recent accounts has this technology been applied to studies looking at catch-and-release angling (Cooke et al., 2002). Previous telemetry studies, which have assessed the behavioural responses of fish post catch-and-release have not found a consistent response, such as reduced activity or hyperactivity, across all the studied species. For example, in sharpnose shark [*Rhizoprionodon terraenovae* Richardson] Gurshin & Szedlmayer (2004) found reduced movement resulting from a catch-and-release event. Other studies reported reduced swimming speed in lemon sharks [*Negaprion brevirostris* Poey] (Sundström & Gruber, 2002), hyperactivity in largemouth bass [*Micropterus salmoides* Lacepède] (Cooke et al., 2000) and cichlids (Thorstad et al., 2004) and abnormal behaviour in Atlantic salmon (*Salmo salar* L.), as evidenced by downstream movements during spawning migrations (Webb, 1998; Mäkinen et al., 2000; Thorstad et al., 2003). A different set of post catch-and-release behavioural impact studies focused on the dispersal after displacement by fish caught in fishing tournaments. Wilde (2003) reported only 14% of caught and released largemouth bass returned to their original capture site, and non-tournament caught largemouth bass showed higher rates of return behaviour (Richardson-Heft et al., 2000; Ridgway, 2002).

Most telemetry studies concerning post release behaviour of fish have not properly accounted for pre capture behaviour (Cooke et al., 2002). For example, the effect of tagging immediately after capture usually cannot be seperated from the effect of being hooked and released (Bettoli & Osborne, 1998). As such, these studies were more observational than experimental (Cooke et al., 2002). In order to avoid this problem, in the present study individual pike were radio tagged, allowed two weeks to recover from surgery (cf. Jepsen et al., 2001) and then captured by angling. This procedure allowed to monitor behaviour in the same fish before and after a catch-and-release event.

The objectives of this study were to (i) assess changes in movement rate in response to a catch-and-release event, (ii) compare habitat choice before and after catch-and-release, and (iii) analyse the population's reaction on catch-and-release fishing. Based on existing research, it was hypothesized that pike modify their behaviour in response to a catch-and-release event by reducing movement.

Study area

The study was conducted on Lake Kleiner Döllnsee, a natural, 25 ha dimictic, shallow (mean depth 4.1 m, maximum depth 7.8 m) and slightly eutrophic lake (P concentration at spring overturn of 28 μg l^{-1}). It is located 80 km northeast of Berlin in the northeastern lowlands of Germany (N 52°59′32.1″, E 13°34′46.5″). The entire lake shoreline is surrounded by dense, 2–55 m wide belts of emergent macrophytes (*Phragmites australis*, *Typha latifolia*, *T. angustifolia*). In total, 14% of the lake surface was covered by emergent macrophytes, and 27% of the lake bottom was covered by submerged macrophytes (mainly *Ceratophyllum demersum*, *Najas minor*, *Potamogeton crispus*, *Myriophyllum alterniflorum*) with varying degrees of cover and structural complexity during the summer months. No commercial or recreational fishing is allowed on this lake. The lake has a natural, self reproducing and lightly exploited pike population due to experimental fishing. The fish community comprises 12 fish species according to recent surveys (unpublished data), two more than reported by Eckmann (1995). The top predators were pike and perch (*Perca fluviatilis* Linnaeus). Eel (*Anguilla anguilla* Linnaeus) and European catfish (*Silurus glanis* Linnaeus) were also present, as a result of stocking, albeit at low abundances.

Materials and methods

Capture and tagging

Twenty pike were caught using a battery-powered DC electro-fishing unit (Type EFGI 4000, 4 kW, Brettschneider Spezialelektronik, Chemnitz, Germany; 40 cm diameter ring anode) between April 21 and April 28 2005 and radio tagged on the day of capture. Holohil SB-2 transmitters with a length of 20 mm, diameter of 9 mm, weight in air of 5.2 g, battery life of 10 months and frequencies ranging from 150.023 to 150.431 MHz were used. Relative transmitter weight was ≤0.8% of pike's body mass (Table 1).

Pike were anaesthetised using a 100 mg l^{-1} solution of MS 222 until fish lost equilibrium and opercular rate became slow and irregular. The transmitters with external antennae were implanted into the body cavity through a 2–3 cm incision 3 cm behind the base of the left pectoral fin as outlined in Fredrich et al. (2003). A lateral body wall exit site was made for the transmitter antenna between the ventral and anal fin using a 15-cm long needle. The incision was closed by three individual stitches 10 mm apart. The duration of the operation ranged between 2 and 3 minutes and recovery time was between 3 and 5 min. After tagging the fish were measured to the nearest mm (total length) and weighed to the nearest g. Average length of the pike was 577 mm (range 450–755 mm) and average weight was 1402 g (range 580–2679 g, Table 1). An external sex determination was conducted following Casselman (1974), and concluded that 90% of the pike were females (Table 1). Water temperature at the time of tagging was 11°C measured in a water depth of 1.8 m. After tagging the recovered fish were released close to their individual capture point. Data collection started after a 2-week post operation recovery period. If a fish died the transmitter was retrieved by diving and implanted into a new fish with the same procedure as described before, resulting in a total of 25 tagged individuals over the study period.

Tracking

Radio tracking was performed manually from an electro-powered boat using a handheld receiver (Lotek SRX 400 Telemetry Receiver, Ontario, Canada) and a three-element Yagi antenna. Visual observations revealed that pike could be approached by boat to within approximately 2 m in shallow water before the presence of the boat elicited a flight response. In deeper water, the boat could be moved directly over the pike without eliciting a flight

Table 1 Descriptive data on radio-tagged pike in Lake Kleiner Döllnsee

Fish ID	Date of catch (2005)	Length (mm)	Weight (g)	Sex	Bait	Bait length (mm)	Hooking location	Bleedings
150.023	May 30	560	1104	♀	Baitfish	160	Upper jaw	No
150.052	June 01	522	845	♀	Baitfish	230	Upper jaw	No
	Aug. 09				Baitfish	100	Outside	No
150.073	July 20	511	912	♂	Baitfish	180	Gills	Yes
	Aug. 28				Baitfish	180	Outside	No
150.092	Oct. 12	523	901	♀	Baitfish	150	Lower jaw	No
150.110	Sept. 18	493	768	♀	Baitfish	200	Upper jaw	No
150.181	Sept. 19	630	1555	♀	Shad	160	Upper jaw	No
150.199	Aug. 26	630	1674	♀	Wobbler	120	Lower jaw	No
150.219	June 14	578	1343	♀	Shad	150	Outside	No
	June 22				Shad	140	Upper jaw	No
150.238	Sept. 11	733	2287	♀	Spinner	100	Lower jaw	No
150.258	June 02	593	1470	♀	Spoon	115	Lower jaw	No
	June 18				Spinner	80	Upper jaw	Yes
150.282	Oct. 26	587	1210	♀	Shad	160	Upper jaw	No
150.341	Sept. 10	543	1064	♀	Baitfish	190	Lower jaw	No
	Oct. 26				Shad	160	Upper jaw	No
150.372	Aug. 17	515	976	♀	Baitfish	190	Lower jaw	Yes
	Sept. 08				Baitfish	150	Upper jaw	No
150.431	Sept. 28	450	580	♀	Shad	160	Upper jaw	No
150.219/2	Sept. 07	690	1890	♀	Baitfish	180	Upper jaw	No
150.130	nc	738	2679	♀				
150.162	nc	755	3394	♀				
150.300	nc	730	2600	♀				
150.322	Aug. 18	475	910	♂	Baitfish	90	Upper jaw	No
150.391	nc	488	816	♀				
150.412	nc	462	640	♀				

Note that 150.219/2 means that this tag was implanted a second time due to mortality of the originally-tagged fish; nc = not caught

reaction. Once a fish was located the position was taken by a GPS unit (Garmin, etrex summit, UTM coordinates) referenced by a Trimble Navigation station (GPS Pathfinder Community Base Station System (PFCBS)) installed on shore at the research station. A tracking precision of ±6 m radius was determined by analyzing the position scattering of two dead fish over two weeks. It was assumed that tracking error was systematic. Tracking precision increased with water depth of the fish and decreased with increasing wind conditions. Moreover, sunny days allowed greater precision due to an improved satellite tracking of the GPS unit.

Each fish was tracked once a week for 24 h, with a 3-h sampling interval between trackings. Each fish was tracked once during this interval. This procedure resulted in eight positions per fish per tracking day, hence seven net movement rate estimates. If less than six positions were taken for an individual fish, the data were excluded from further analyses. The first tracking day each month was selected at random. After a start day was selected, fish were tracked every seventh day (systematic random sampling). Tracking took place from May 18 to November 30, 2005.

Experimental catch-and-release angling

Angling for pike took place between tracking days from May 26 to October 26, 2005. The gear and angling methods used were intended to reflect common tactics used by anglers. Pike were captured by medium-action pike rods (spinning and bait casting) and multifilament (17 kg) or monofilament (4.5 kg) test line. After hooking a pike, the fish was landed as quickly as possible by a knotless landing net or by hand. A variety of angling methods were applied. Artificial lures were actively fished by casting and trolling from a boat. Organic (natural) bait was passively fished. Natural bait was fished from both boat and shoreline, and handling of fish caught from the shoreline was identical to those caught from the boat. The following artificial lure types were used during this study, representing a number of different manufacturers: spinners, spoons, wobblers (also known as hard baits or crank baits), soft plastic baits (jigs and shads) or natural bait [dead fish of the species roach, (*Rutilus rutilus* Linnaeus), perch, or bream, (*Abramis brama* Linnaeus)].

All artificial lures were fished with at least one treble hook. Some soft plastic jigs and shads were fished with a single hook and one (small shads) or two (large shads) treble hooks. There was no effort to standardize hook sizes across all baits, because we wanted to use baits typically used for pike angling. Artificial baits were attached to a short steel leader (about 40 cm) to avoid losing deeply hooked pike. The only weight on the line came from the weight of the artificial lure. All hooks were barbed.

Organic bait was fished by attaching a steel leader (40 cm) to a swivel. A small float combined with an egg-shaped lead sinker (5 g) held the dead fish at a water depth chosen by the angler. Each bait was equipped with two treble hooks; one in the dorsal region and one in the pectoral region. Each angler was instructed to strike (i.e. set the hook) immediately after a bite was detected, in order to avoid deep hooking of pike that may have swallowed the natural bait. Some active fishing also took place with a natural bait, skewered on a firm steel wire with two treble hooks and weight with a 8-g egg shaped lead sinker attached to the wire in front of the head of the bait fish (known as Drachkovitch system by European anglers).

Fishing took place both selectively or unselectively for tagged pike. During unselective fishing, tagged pike were captured by chance. For selectively fishing radio tagged pike, the fish was located and a surface marker was placed beside the located position. The boat was anchored about ten m away and then either artificial lures or organic baits were cast toward the buoy. While unhooking, a soft, wet unhooking mat was used both, inside the boat and on the shoreline, as captured fish were placed on it to prevent angler-caused injury while unhooking fish. Typically, these type of unhooking mat is used by highly specialised carp, *Cyprinus carpio* Linnaeus, anglers in Europe, but not by pike anglers (personal observation). We nevertheless chose to use such devices in order to more homogenously treat our individual captures and control for handling stress. Unhooking was conducted within 30 s and, if necessary, the barb of the hook(s) was cut with a wire cutter to avoid further injury to deeply hooked pike. All fish captured were checked for injuries and general condition and then immediately released at the capture point. Table 1 reports the dates, baits and injuries of each captured and radio tagged pike.

Habitat mapping

A detailed map of the available habitats in Lake Kleiner Döllnsee was created to relate the habitats chosen by pike to the available habitats. In a first step, habitat features were screened by boat and the following identified: emerged and submerged macrophytes and a macrophyte-free pelagic area. All habitats without macrophytes were classified as pelagic habitats, which was typical at water depths >4 m. Then, the submerged macrophytes were classified into three classes to account for the impact of macrophyte cover on the habitat choice of pike: >0–74%, 75–99% and 100% cover per unit area. Emerged macrophytes were treated as an additional habitat category.

Scuba diving along transects was used to assess the occurrence of the different habitat types. In total, 28 transects were randomly selected covering the entire shoreline. Each transect was surveyed perpendicular to shore from the water's edge to the end of the vegetated area. Each transition zone between different habitat categories was marked with buoys. The buoy positions were recorded by GPS from a boat and later imported into Arc View 3.2. Habitat area polygons were created by interpolation and assigned to one of the five categories mentioned above. Diving took place on July 23, 2005 to allow for full expression of the biomass of macrophytes. After habitat mapping no significant reduction of submerged macrophyte coverage was observed until the end of the experimental time as determined by echosounding.

Data analysis

In order to investigate the short-term behavioural response of pike after a catch-and-release event, tracking data from just before the capture and tracking data immediately after the capture event (the first and second tracking) were used. It was assumed that analyses across all individuals would reflect the average reaction of the hooked population post catch-and-release.

At the population level, movement patterns before and after the angling event were evaluated using minimum distance moved per hour (MDPH) as an indicator of behavioural activity. MDPH was defined as the straight line distance between consecutive locations for the same fish, divided by the time elapsed between locating the fish. A mean value per individual fish per tracking day was computed for the eight contacts made with each fish on each 24 h track, resulting in seven net movements. Mean MDPH of all fish prior to and after the angling event were not normally distributed, according to Kolmogorov–Smirnov-tests ($P < 0.05$ in all cases), but data showed homogeneity of variances, indicated by Levene‘s tests ($P > 0.05$ in all cases). Therefore, paired *t*-tests were used for pairwise comparisons one tracking before and one and two trackings after a capture event as these test is relatively robust against deviations of the normality assumption (Zar, 1996). Since this procedure resulted in multiple comparisons, P values were Bonferroni–Holm corrected according to procedures outlined in Holm (1979).

Mean values of the shortest distance to shore (DTS) per fish per day were calculated. The mean values of DTS were computed by dividing the distance of each of the eight tracking points of a given fish to the shoreline by the number of tracking points of the individual fish. The shoreline was defined as the boundary of emerged macrophytes and open water because tracking within the reed belt was not possible and hence, the exact DTS of fish within emerged macrophytes was not known. However, distance to shore is a common expression in the literature and therefore it was not changed into a more exact description such as distance to emerged macrophytes. DTS of all tracking points were calculated using the software Fishtel 1.4 (Rogers & White, 2007). Mean DTS of all fish prior and after the capture event were compared using paired *t*-tests. Although the data were partly not normally distributed, according to Kolmogorov–Smirnov-tests ($P < 0.05$ in some cases), homogeneity of variances was found using Levene‘s test ($P > 0.05$ in all cases) and therefore paired *t*-tests were used. Again, these procedures resulted in multiple comparisons and therefore P values were Bonferroni–Holm corrected.

Spearman correlation analyses were used to determine relationships between the change in MDPH and DTS of pike after capture and the difference in water temperature (pre to post capture tracking), total length of the fish and time (h) elapsed between tracking events before and after capture. The activity change index of pike was expressed as the quotient between the mean MDPH/DTS after and before capture per fish. Values larger than 1 indicated increased movement or DTS after capture and values below 1 indicated decreased movement/DTS. Water temperature was expressed as a mean value of the different tracking temperatures. The change in water temperature was expressed as a quotient of the two tracking date values, similar to the estimation of the change in movement between tracking dates.

In order to examine if fish used the available habitat in a similar fashion before and after capture, a log-likelihood test statistic was used for each of the three tracking events. Selection ratios w that accounted for the nature of repeated samples per individual and their associated Bonferroni adjusted 95% confidence intervals were calculated as detailed in Rogers & White (2007) to determine if selection for or against a given habitat type occurred one tracking event prior to capture and the following two tracking events. Selection ratios were considered significant when the selection ratio together with the 95% confidence intervals were either greater or less than 1 (Rogers & White, 2007).

All statistical analyses were conducted with the SPSS software package version 11.5, at a type 1-error probability of $\alpha = 0.05$. The only exception was for analyses of the selection ratio, which were calculated by Fishtel 1.4.

Results

Radio-tagged pike were captured 27 times. Seven pike were never caught, eleven individuals were caught once, five individuals twice and two individuals three times. In total 7 out of the 27 capture events were excluded from the data set for the following reasons: immediate mortality, a capture within the recovery time of two weeks after tagging, or an additional capture before the individual was tracked a second time after release. This yielded a sample size of $N = 20$ (see Table 1 for capture history of these fish). In total 2 out of 27 pike died immediately after capture resulting in an immediate hooking mortality rate estimate of 7.4 ± 4.8%.

The first radio-tagged pike used for analysis was caught on June 1 and the last pike was caught on October 26, 2005 (Table 1). All 14 individuals used for analysis survived the first two weeks after the catch and release event as evidenced by substantial movement between tracking dates.

Movement of pike, measured by average MDPH, significantly decreased one tracking event after capture relative to the tracking event before the fish were captured (paired t-test, $t = 2.782$, df = 19, $P = 0.036$; mean MDPH ± SE before and after the catch 13.6 ± 3.1 m and 6.1 ± 1.3 m, respectively, Fig. 1). No statistical difference in MDPH was found between the pikes movement one tracking event before and two tracking events after capture. MDPH was found to increase significantly when comparing the first track post release and the second track post release (mean MDPH ± SE one and two tracks after the catch 6.1 ± 1.3 m and 9.9 ± 1.9 m, respectively, $t = -2.816$, df = 19, $P = 0.033$, Fig. 1).

Pike significantly decreased their DTS one tracking event after capture (mean DTS ± SE 22.4 ± 5.7 m) compared to the last tracking event before capture (mean DTS 34.3 m ± 7.4 m, $t = 2.814$, df = 19, $P = 0.033$, Fig. 2). No statistical differences in mean DTS were found when comparing the values from one track before and two tracks after and one and two tracks after capture (Fig. 2).

There were no significant correlations between the changes in MDPH and DTS before and after capture and changes in water temperature, total length of fish, and time elapsed between capture and the post capture tracking events (Spearman correlations, all P values > 0.05).

Pike were selective in the habitat they used prior to capture ($X^2_{\text{likelihood}} = 440.9$, df = 100, $P < 0.0001$), one tracking event after capture ($X^2_{\text{likelihood}} = 555.2$, df = 100, $P < 0.0001$) and two trackings after capture ($X^2_{\text{likelihood}} = 493.1$, df = 100, $P < 0.0001$). Selection ratios and their associated Bonferroni adjusted 95% confidence intervals revealed that pike avoided pelagic areas and strongly selected for reed throughout the data sampling period (Fig. 3). Thus, there was no significant change in habitat selection after capture, but there was a tend for increased selection for reed post capture.

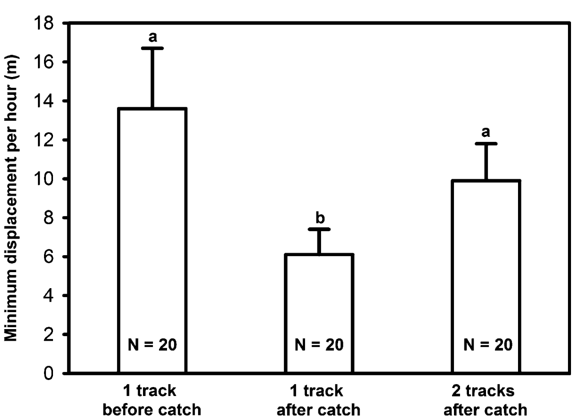

Fig. 1 Minimum displacement per hour (mean ± SE) of pike one track before and one and two tracks after the catch. Bars sharing the same superscripts are not significantly different after a Bonferroni–Holm adjustment

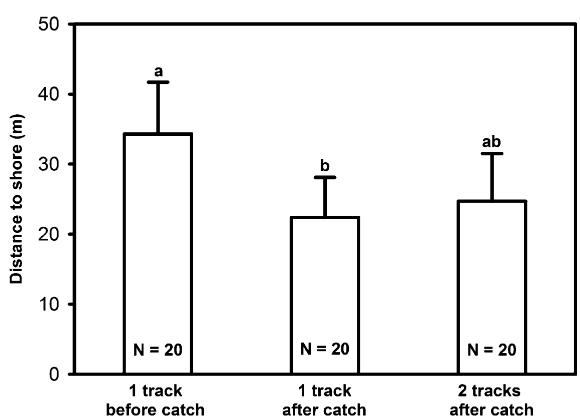

Fig. 2 Distance to shore (mean ± SE) of pike one track before and one and two tracks after the catch. Bars sharing the same superscripts are not significantly different after a Bonferroni–Holm adjustment

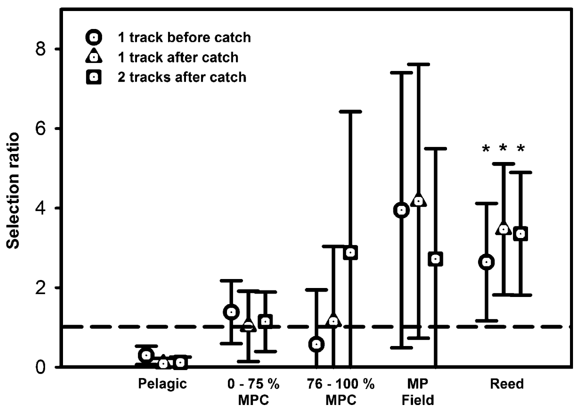

Fig. 3 Selection ratios and their associated Bonferroni adjusted 95% confidence intervals to show selection for (greater than one) or against (less than one) a given habitat type for pike one track before and one and two tracks after capture. *, significantly positive selection of the given habitat; MPC, macrophyte coverage

Discussion

The present study tested behavioural changes of a pike population observed prior to and after fish were angled from their natural environment. Therefore, comparisons before and after capture were possible (before-after-impact-design). This is a useful approach to assess the impact of catch-and-release angling in a "controlled" setting. Previous attempts at assessing this impact were done by monitoring behaviour after release without measuring the behaviour prior to capturing the same individual (e.g. Mäkinen et al., 2000; Thorstad et al., 2003; Wilde, 2003; Cooke & Philipp, 2004). The present study revealed that pike significantly reduce their movement after a catch-and-release event, and again, significantly increase their movement after a short while, reaching similar movement rates as before the capture event within a week (the maximum time interval between the first and second tracking after the catch). This is consistent with studies reporting decreased activity of fish in response to a catch-and-release event (Tsuboi & Morita, 2004; Young & Hayes, 2004) and with several telemetry studies that revealed short duration behavioural alterations in various species, such as downstream migration by Atlantic salmon (Webb, 1998; Mäkinen et al., 2000; Thorstad et al., 2003) and cichlids (Thorstad et al., 2004) and decreased movement rates following a short duration of hyperactivity in largemouth bass (Cooke et al., 2000) and sharpnose shark (Gurshin & Szedlmayer, 2004). Behavioural studies in smallmouth bass (*Micropterus dolomieu* Lacepède) showed that during parental care, nest-defending behaviour was impaired by catch-and-release fishing (Kieffer et al., 1995; Suski et al., 2003). For example, male smallmouth bass captured by angling were less willing or able to defend their broods than control fish (Suski et al., 2003) and smallmouth bass males hooked and played to exhaustion took four times longer to return to their nests than fish played briefly (Kieffer et al., 1995). However, consistent with the present study recovery from angling stress as indicated by resuming pre capture behaviour was found to be quick as was also reported elsewhere (Kieffer et al., 1995).

Reasons for reduced activity of pike after release in the present experiment are most likely related to the physiological disturbances associated with hooking, exhaustive exercise during fighting and air exposure during hook removal (Cooke & Suski, 2005). Angling-induced stress is one of the most severe forms of exercise for fish during normal environmental conditions (Wood, 1991). Schwalme & Mackay (1985) found that angled pike that experienced an angling-typical exercise had greatly elevated blood and muscle lactate and blood glucose values, which remained elevated for at least 96 h in the case of blood glucose. Lucas et al. (1991) reported high heart rate values for the first 12 h after angled and externally tagged pike were released. It is very likely that behaviour of post-released fish is altered, as long as physiological parameters have not fully recovered.

However, even when assuming that pike totally recover physiologically within the first few hours or days after capture, as it is typical for most angled freshwater fish (Kieffer, 2000), it is still possible that behavioural changes can occur for some period, e.g. movement decreases or remains low for a while. After full recovery these atypical behavioural patterns can be a result of short-term adaptive antipredation behaviour (Lind & Cresswell, 2005). Reduced activity to minimise the risk of predation was observed in various prey fish in response to the presence of predatory fish (e.g. Gilliam & Fraser, 1987; He & Kitchell, 1990; Werner, 1992; Biro et al., 2003). It is conceivable that reduced activity of pike is a consistent behavioural response to stimuli perceived negatively by the fish such as an attack by a bird or angling-induced disturbance (called behavioural syndromes by Sih et al., 2004). Hence, we speculate that the reduced movement after a catch-and-release event is a combined response of the pike to recover from the exhaustive exercise and a result of an evolutionary fixed or learned behavioural syndrome in response to negative stimuli.

The present study showed a significant decrease in DTS one track after fish were captured. This decrease in DTS vanished by the second track after capture suggesting fish had recovered from sublethal impacts caused by the catch-and-release event and had returned to behavioural patterns characteristic of the time prior to capture. Decreasing values of DTS affected by catch-and-release fishing suggest a shift towards structurally more complex vegetated areas in the reed belts close to the shoreline. However, as reed belts were positively selected before capture by pike as well, no significant increase in selection for reed after catch was found in the present study. We hypothesize that habitats preferred by pike during the normal life-cycle to effectively hunt or seek refuge from cannibalism (Grimm, 1994) are the same as those that are relevant to recover from an angling event, which would explain the lack of observed significant shift in selected habitats post release. In Lake Döllnsee, these highly preferred habitats seem to cover reed rather than submerged macrophytes as indicated by the lower 95% confidence intervals for submerged macrophytes encompassing 1. Moreover reed is available as a suitable habitat throughout the year, contrary to submerged macrophytes that die-off at cooler water temperatures, inducing pike to seasonally migrate between different vegetated habitats (Cook & Bergersen, 1988). We did not consider seasonality regarding the habitat choice of angled-and-released pike in the present study. Nevertheless, the results presented here indicate a strong preference for reed throughout the year and particularly after a catch event coupled with choice of habitats closer to shore.

Preference of pike for structurally rich vegetated habitats is well known (Carbine & Applegate, 1948; Bry, 1996; Jepsen et al., 2001), and hence is in agreement with our results. For example, Savino & Stein (1989) found pike to be ambush predators spending nearly all their time in the cover of a given habitat. Complex habitat structures and reed belts are well known as a refuge area for juvenile roach and perch as well (Lewin et al., 2004), and the abundance of fish in such habitats is strongly related to the physical complexity (Harmon et al., 1986). Skov et al. (2002) reported foraging pike strongly prefer structural habitats, especially in clearwater and independent of the abundance of prey fish, indicating that pike use structurally complex habitat structures as both cover to avoid cannibalism and as feeding habitat (sensu Grimm, 1994). The same habitats also seem to be used as refuge space after capture.

The behaviour of pike of reducing DTS in the short term is probably an adaptive response of angled and hence weakened pike to avoid cannibalism. Chapman & Mackay (1984) reported larger pike to be more often positioned at the macrophyte-open-water interface, while small pike were rarely there. Similar results were found by Rosell & Mac Oscar (2002) where large mature pike were not generally common in the immediate margin areas of the investigated lake. Engström Öst & Lehtiniemi (2004) showed fleeing reactions and a behavioural change in juvenile pike with the presence of a larger predator. Size-structured pike populations also show significant greater distances to the nearest potential cannibal individual compared to a similar sized conspecific (Nilsson, 2006). Hence, the preference of nearshore habitat after an angling event might be caused by anti-predation behaviour where the weakened fish attempts to avoid cannibalism while recovering from the stressor. It is possible that this behaviour is a combination of both, predator avoidance and stress recovery. These assumptions are supported by Cooke & Philipp (2004) where exhausted bonefish (*Albula* spp.) were eaten by sharks (several species) after being angled, possibly because of depletion of energy reserves and reduced fleeing abilities. Pike usually represent the top predator of a lake but they are still influenced by strong cannibalism (Kipling & Frost, 1970; Giles et al., 1986) and are therefore forced to exhibit successful anti-predation behaviour to survive. It can be assumed that after being played by anglers pike are weakened and are limited in their ability to flee. This is also indicated by the intense and quick accumulation of lactate in angled pike (Schwalme & Mackay, 1985) indicative of anaerobic metabolism and a quick reduction of available energy fuels. A reduction in activity and short-term displacement into less favourable habitats closer to shore might have an impact on the feeding behaviour of pike and influence post release growth (Siepker et al., 2006) and possibly fitness (Cooke et al., 2002). Whether this assumption is true, however, is unknown.

Conclusion

The results of this study suggest that there is a short-term interference on pike behaviour in a catch-and-release fishery, but that impacts are reversible and habitat choice after release is similar before and after a capture event. The quick recovery of pike after a capture event suggests minor sublethal impacts caused by anglers in catch-and-release fisheries. Therefore, management strategies based on catch-and-release, either partial or total, can be effective if the cumulative mortality is not high. In order to provide mechanistic explanations of observed behavioural alterations, further studies are needed on the long-term effects of catch-and-release linked with physiological data.

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References

Arlinghaus, R., 2004. Recreational fisheries in Germany – a social and economic analysis. Berichte des IGB 18: 1–160.

Arlinghaus, R., 2007. Voluntary catch-and-release can generate conflicts within the recreational angling community: a qualitative case study of specialized carp (*Cyprinus carpio* L.) angling in Germany. Fisheries Management and Ecology 14:161–171.

Arlinghaus, R. & T. Mehner, 2004. A management-oriented comparative analysis of urban and rural anglers living in a metropolis (Berlin, Germany). Environmental Management 33: 331–344.

Bettoli, P. W. & R. S. Osborne, 1998. Hooking mortality and behavior of stripped bass following catch and release angling. North American Journal of Fisheries Management 18: 609–615.

Biro, P. A., J. R. Post & E. A. Parkinson, 2003. From individuals to populations: prey fish risk-taking mediates mortality in whole-system experiments. Ecology 84: 2419–2431.

Bry, C., 1996. Role of vegetation in the life cycle of pike. In Craig, J. F. (ed.) Pike: Biology and Exploitation. Chapman & Hall, London, 45–67.

Burkholder, A., 1992. Mortality of northern pike captured and released with sport fishing gear. Alaska Department of Fish and Game; Fishery Data Series 92.

Carbine, W. F. & V. C. Applegate, 1948. The movement and growth of marked northern pike (*Esox lucius* L.) in Houghton Lake and Muskegon River. Transactions of the American Fisheries Society 32: 215–238.

Casselman, J. M., 1974. External sex determination of northern pike, *Esox lucius* Linnaeus. Transactions of the American Fisheries Society 103: 343–347.

Chapman, C. A. & W. C. Mackay, 1984. Direct observation of habitat utilization by northern pike. Copeia 1984(1): 255–258.

Cook, M. F. & E. P. Bergersen, 1988. Movements, habitat selection and activity periods of northern pike in eleven mile reservoir, Colorado. Transactions of the American Fisheries Society 117: 495–502.

Cooke, S. J. & D. P. Philipp, 2004. Behavior and mortality of caught-and-released bonefish (Albula spp.) in Bahamian waters with implications for a sustainable recreational fishery. Biological Conservation 118: 599–607.

Cooke, S. J. & C. D. Suski, 2005. Do we need species-specific guidelines for catch-and-release angling to conserve diverse fishery resources? Biodiversity and Conservation 14: 1195–1209.

Cooke, S. J., D. P. Philipp, J. F. Schreer & R. S. McKinley, 2000. Locomotory impairment of nesting male largemouth bass following catch-and-release angling. North American Journal of Fisheries Management 20: 968–977.

Cooke, S. J., J. F. Schreer, K. M. Dunmal & D. P. Philipp, 2002. Strategies for quantifying sublethal effects of marine catch-and-release angling: Insights from novel freshwater applications. American Fisheries Society Symposium 30: 121–134.

Craig, J. F., (ed.). 1996. Pike: Biology and Exploitation. Chapman & Hall, London.

DuBois, R. B., T. L. Margenau, R. S. Stewart, P. K. Cunningham & R. W. Rasmussen, 1994. Hooking mortality of northern pike angled through ice. North American Journal of Fisheries Management 14: 769–775.

Eckmann, R., 1995. Fish species richness in lakes of the northeastern lowlands in Germany. Ecology of Freshwater Fish 4: 62–69.

Engström-Öst, J. & M. Lehtiniemi, 2004. Threat-sensitive predator avoidance by pike larvae. Journal of Fish Biology 65: 251–261.

Fredrich, F., S. Ohmann, B. Curio & F. Kirschbaum, 2003. Spawning migrations of the chub in the River Spree, Germany. Journal of Fish Biology 63: 710–723.

Giles, N., R. M. Wright & M. E. Nord, 1986. Cannibalism in pike fry, *Esox lucius* L.: Some experiments with fry densities. Journal of Fish Biology 29: 107–113.

Gilliam, J. F. & D. F. Fraser, 1987. Habitat selection under predation hazard: test of a model with foraging minnows. Ecology 68: 1825–1862.

Grimm, M. P., 1994. The influence of aquatic vegetation and population biomass on recruitment of 0+ and 1+ northern pike (*Esox lucius* L.). In Cowx, I. G. (ed.), Rehabilitation of Freshwater Fisheries. Oxford, Blackwell, 226–234.

Gurshin, C. W. D. & S. T. Szedlmayer, 2004. Short-term survival and movements of Atlantic sharpnose sharks captured by hook-and-line in the north-east Gulf of Mexico. Journal of Fish Biology 65: 973–986.

Harmon, M. E., J. F. Franklin, F. J. Swanson, P. Sollins, S. V. Gregory, J. D. Lattin, N. H. Anderson, S. P. Cline & N. G. Aumen, 1986. Ecology of coarse woody debris in temperate ecosystems. Advances in Ecological Research 15: 133–302.

He, X. & J. F. Kitchell, 1990. Direct and indirect effects of predation on a fish community: a whole-lake experiment. Transactions of the American Fisheries Society 119: 825–835.

Holm, S., 1979. A simple sequentially rejective multiple test procedure. Scandinavian Journal of Statistics 6: 65–70.

Jepsen, N., S. Beck, C. Skov & A. Koed, 2001. Behavior of pike (*Esox lucius* L.) <50 cm in a turbid reservoir and in a clearwater lake. Ecology of Freshwater Fish 10: 26–34.

Kieffer, J. D., 2000. Limits to exhaustive exercise in fish. Comparative Biochemistry and Physiology Part A 126: 161–179.

Kieffer, J. D., M. R. Kubacki, F. J. S. Phelan, D. P. Philipp & B. L. Tufts, 1995. Effects of catch- and-release angling on nesting male smallmouth bass. Transactions of the American Fisheries Society 124: 70–76.

Kipling, C. & W. E. Frost 1970. A study of the mortality, population numbers, year class strengths, production and food consumption of pike *Esox lucius* L., in Windermere from 1944 to 1962. Journal of Animal Ecology 39: 115–157.

Lewin, W. C., N. Okun & T. Mehner, 2004. Determinants of the distribution of juvenile fish in the littoral area of a shallow lake. Freshwater Biology 49: 410–424.

Lind, J. & W. Cresswell, 2005. Determining the fitness consequences of antipredation behavior. Behavioral Ecology 16: 945–956.

Lucas, M. C. & E. Baras, 2000. Methods for studying spatial behaviour of freshwater fishes in the natural environment. Fish and Fisheries 1: 283–316.

Lucas, M. C., I. G. Priede, J. D. Armstrong, A. N. Z. Gindy & L. De Vera, 1991. Direct measurements of metabolism, activity and feeding behaviour of pike, *Esox lucius* L., in the wild, by the use of heart rate telemetry. Journal of Fish Biology 39: 325–345.

Mäkinen, T. S., E. Niemelä, K. Moen & R. Lindström, 2000. Behaviour of gill-net and rod-captured Atlantic salmon (*Salmo salar* L.) during upstream migration and following radio tagging. Fisheries Research 45: 117–127.

Muoneke, M. I. & W.M. Childress, 1994. Hooking mortality: a review for recreational fisheries. Reviews in Fisheries Science 2: 123–156.

Nilsson, P. A., 2006. Avoid your neighbours: size determined spatial distribution patterns among northern pike individuals. Oikos 113: 251–258.

Paukert, C. P., J. A. Klammer, R. B. Pierce & T. D. Simonson, 2001. An overview of northern pike regulations in North America. Fisheries 26(6): 6–13.

Pierce, R. B., C. M. Tomcko & D. H. Schupp, 1995. Exploitation of northern pike in seven small North-Central Minnesota lakes. North American Journal of Fisheries Management 15: 601–609.

Richardson-Heft, C. A., A. A. Heft & L. Fewlass, 2000. Movement of largemouth bass in Northern Chesapeake Bay: relevance to sportfishing tournaments. North American Journal of Fisheries Management 20: 493–501.

Ridgway, M. S., 2002. Movements, home range, and survival estimation of largemouth bass following displacement. American Fisheries Society Symposium 31: 525–533.

Rogers, K. B. & G. C. White, 2007. Analysis of movement and habitat use from telemetry data. In Brown, M. & C. Guy (eds), Analysis and Interpretation of Freshwater Fisheries Data, Chapter 14. American Fisheries Society, Bethesda, Maryland, 625–676.

Rosell, R. S. & K. C. MacOscar, 2002. Movements of pike, *Esox lucius*, in Lower Lough Erne, determined by mark-recapture between 1994 and 2000. Fisheries Management and Ecology 9: 189–196.

Savino, J. F. & R. A. Stein, 1989. Behavior of fish predators and their prey: habitat choice between open water and dense vegetation. Environmental Conservation 24: 287–293.

Schwalme, K. & W. C. Mackay, 1985. The influence of angling-induced exercise on the carbohydrate metabolism of northern pike (*Esox lucius* L.). Journal of Comparative Physiological Biology 156: 67–75.

Siepker, M. J., K. G. Ostrand & D. H. Wahl, 2006. Effects of angling on feeding by largemouth bass. Journal of Fish Biology 69: 783–793.

Sih, A., A. Bell & J. C. Johnson, 2004. Behavioral syndromes: an ecological and evolutionary overview. Trends in Ecology and Evolution 19: 372–378.

Skov, C., N. Jepsen, L. Jacobsen & S. Berg, 2002. Habitat use and foraging success of 0+ pike (*Esox lucius* L.) in experimental ponds related to prey fish, water transparency and light intensity. Ecology of Freshwater Fish 11: 65–73.

Sundström, L. F. & S. H. Gruber, 2002. Effects of capture and transmitter attachments on the swimming speed of large juvenile lemon sharks in the wild. Journal of Fish Biology 61: 834–838.

Suski, C. D., J. H. Svec, J. B. Ludden, F. J. S. Phelan & D. P. Philipp, 2003. The effect of catch-and-release angling on the parental care behavior of male smallmouth bass. Transactions of the American Fisheries Society 132: 210–218.

Thorstad, E. B., C. J. Hay, T. F. Næsje, B. Chanda & F. Økland, 2004. Effects of catch-and-release angling on large cichlids in the subtropical Zambezi River. Fisheries Research 69: 141–144.

Thorstad, E. B., T. F. Næsje, P. Fiske & B. Finstad, 2003. Effects of hook and release on Atlantic salmon in the River Alta, northern Norway. Fisheries Research 60: 293–307.

Tsuboi, J. & K. Morita, 2004. Selectivity effects on wild white-spotted charr (Salvelinus leucomaenis) during a catch and release fishery. Fisheries Research 69: 229–238.

Webb, J. H., 1998. Catch and Release: the survival and behaviour of Atlantic salmon angled and returned to the Aberdeenshire Dee, in spring and early summer. Scottish Fisheries Research Report 62: 1–16.

Weithman, A. S. & R. O. Anderson, 1978. Angling vulnerability of Esocidae. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 30(1976): 99–102.

Werner, E. E., 1992. Individual behavior and high-order species interactions. The American Naturalist 140: S5–S32.

Wilde, R. W., 2003. Dispersal of tournament-caught black bass. Fisheries 28(7): 10–17.

Wood, C. M., 1991. Acid-base and ion balance, metabolism, and their interactions, after exhaustive exercise in fish. Journal of Experimental Biology 160: 285–308.

Young, R. G. & J. W. Hayes, 2004. Angling Pressure and trout catchability: behavioral observations of brown trout in two New Zealand backcountry rivers. North American Journal of Fisheries Management 24: 1203–1213.

Zar, J. H., 1996. Biostatistical Analysis, 3rd edn. Prentice-Hall, London.