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Does Survey Angling CPUE Reflect Population Density of Northern Pike (*Esox lucius*) in Small Boreal Lakes?

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ABSTRACT

Knowing the relationship between catch per unit effort (CPUE) and population density is crucial for the management of recreational fisheries. We conducted standardized angling for pike in 16 lakes (3.4–22.1 ha) to test whether lure type, color, and pike density affect CPUE and the size of captured fish. Angling CPUE (fish h^{-1} km^{-1}) was statistically significantly related to pike density (fish ha^{-1}), despite the high variation and uncertainty in CPUE estimates. Lure type affected CPUE, whereas water temperature, use of a boat, time of day, and transect fishability had no effect. CPUE was higher when using spoons compared to spinnerbaits, but lure color (fluorescent vs. natural) had no effect. The length of captured fish was not dependent on lure type or color. Our results suggest that a predefined protocol may help reduce variation in CPUE data; however, it does not yet allow for reliable estimation of pike density.

1 | Introduction

Knowledge-based management requires simple and reliable tools to monitor changes in fish stocks in relation to fishing, and to provide long-term data of human-induced environmental changes (i.e., brownification, eutrophication).

Boreal lakes are often too small and numerous to be assessed using routine freshwater fish stock monitoring methods such as standard gillnet surveys (Olin et al. 2016) or even using catch-only models (van Gemert et al. 2022), as information on total catch rates is usually missing. Furthermore, the standard gillnetting provides poor estimates for large predatory fish (Hamley 1975; Turunen et al. 2024). Therefore, novel methods to assess stock metrics in these lakes are needed.

Northern pike (*Esox lucius*), thereafter pike, is a widely spread predatory fish species in North America and Europe (Paukert et al. 2001; Arlinghaus and Mehner 2004; Craig 2008). The vulnerability of pike stocks to open-access fisheries was recognized decades ago (Weithman and Anderson 1976; Goedde and Coble 1981; Mosindy et al. 1987) and is still an ongoing topic (Bergström et al. 2022; Fitzgerald et al. 2023; Roser et al. 2025). In the Baltic Sea, pike catches in recreational fisheries have been declining (Bergström et al. 2022), and many of the stocks are fully exploited if not overharvested (Fitzgerald et al. 2023).

When fishery management cannot rely on fisheries-independent data sources, angling diary data and other angler data can be used as a basis for catch per unit effort (CPUE)-based management approaches (Harris et al. 2021; Bergström et al. 2022; Dainys et al. 2022). Catchability q is a key variable connecting the catch rate and abundance via fishing effort f ($CPUE = fqN$) (Harley et al. 2001). When constant catchability can be assumed (not always the case; i.e., hyperdepletion after gillnet removal fishing, Pierce and Tomcko 2003), angling CPUE data can be applied to monitor relative changes in fish populations, such as positive or negative trends in population size (Harris et al. 2021; Bergström et al. 2022). Nevertheless, CPUE data have many sources of variation including highly variable fish recruitment that adds uncertainty to management decision-making with catch-based indicators (Allen and Pine 2000). Previous studies have suggested that predicting pike density with angling CPUE is very difficult due to extensive variation in CPUEs (Pierce and Tomcko 2003; Arlinghaus et al. 2016). However, if angling CPUE data could be reliably related to fish density by reducing method-related variation, it would ease the development of strategic management scenarios and estimation of the total fish production in lakes (Olin et al. 2016; Turunen et al. 2023; Vainikka et al. 2024).

Catchability of pike varies among different fishing methods and technical variations (Pierce and Tomcko 2003; Roser et al. 2025) but standardizing these factors may provide a better understanding of the relationship between pike CPUE and population variables (i.e., size structure, density). Still, recreational fishing catches may not provide good measures of fish abundance. For example, fishing catches of species and populations with aggregated distribution (Turunen et al. 2023) or that are under heavy fishing pressure (i.e., learning lure avoidance, selection) (Beukema 1970; Lucas et al. 2023; Roser et al. 2025), may not properly reflect the abundance. Also, several uncontrollable environmental factors can affect the catch rates (Kuparinen et al. 2010; Olin et al. 2016; Turunen et al. 2023). However, fishing method-, fisher-, and weather-related variation in CPUE may be controlled if fishing is conducted following a predefined protocol, which may allow the possible estimation of fish density or size structure (Olin et al. 2016; Turunen et al. 2023; Tibblin et al. 2023).

Angling is one of the most popular recreational fishing methods in the Nordic countries (Pokki et al. 2021; Stensland et al. 2025; van den Heuvel et al. 2025). In boreal lakes, angling is used to target large-bodied predatory fishes such as pike, pikeperch (*Sander lucioperca*), and perch (*Perca fluviatilis*) (Salmi et al. 2006; Eklöf et al. 2023). The angling gear consists of a reel, rod, line, and bait, which together form a tool for catching fish from shorelines or from a boat (van den Heuvel et al. 2020; Pokki et al. 2021). Both natural and artificial baits are used, while the latter types are referred as lures. The angling lures are made of multiple soft and hard materials and show an enormous variety of sizes, shapes, and colors with the main purpose of mimicking edible subjects to target species or provoke the aggressive response. Pike are very tolerant of hooking related injuries; however, small lures tend to cause more hooking in critical locations compared to large lures (Arlinghaus et al. 2008). Although angling is a popular recreational activity and often completely or partly open-access (van den Heuvel et al. 2020), its impacts on fish stocks are often widely unknown, predisposing stocks to potential overfishing (Degerman et al. 2001; Sarvala et al. 2020). The evaluation of angling catch rates in relation to fish abundance is needed to sustainably manage recreational fishing pressure not only in small boreal lakes but in wide variety of recreationally exploited waterbodies (van den Heuvel et al. 2020; Turunen et al. 2023).

Our aim here was to study the relationship between CPUE of standardized angling-based survey method and population density of pike in boreal lakes with low fishing pressure, where population density can reliably be estimated by mark-recapture method and significant hook avoidance effects can be avoided. The secondary objective was to assess the effects of different lure types and color variations on CPUE in survey angling, and the effects of the lure types on fish injuries. We hypothesized that survey angling CPUE would be positively related to pike density and that lure type and color would have a minor effect on CPUE and fish size due to their pre-selection.

2 | Methods

2.1 | Survey Angling

To control for the variation arising from variable angling techniques and gears, we used a predefined angling method for survey fishing (Figure 1 and Table S1). To control for seasonal activity differences of pike, survey fishing was conducted in late summer-autumn when CPUE was not affected by spawning and the weather conditions are assumed to be more stable. To control for daily differences in fish activity, fishing was conducted on at least two separate days with 1–4 transects fished per day. During a day, fishing was conducted in the morning (9:00–12:00) or in the afternoon (14:00–17:00) in a randomly selected transect in a shallow depth zone (< 3 m). Transects were pre-measured on the depth contour map, and in the small study lakes, a few transects were sufficient to cover all the relevant shoreline areas. The length of a transect was 1000 m when fishing from a boat (an angler and a rowing assistant in a boat) and 500 m when fishing from a shore. The transects for boat users were longer than for shoreline anglers due to the experience-based assumption that angling is faster and easier with a boat. Transect fishability was visually evaluated before fishing using four categories, from unfishable (score 4) with disturbing structures (i.e., vegetation, bushes, or soft shorelines) covering over 50% of the transect area to an easy-to-fish (score 1) transect (Table S1). Transects deemed unfishable were excluded from further consideration, and sampling moved on to a randomly selected reserve transect.

During the survey angling, the angler moved along the transect for 1 h and applied four different lure types in random order (15 min per type). The approximate length of a cast is 40 m, but it may vary according to the fishing environment, different lure types, and anglers. The applied lure types (specific lure models used) were spoon (Helmi-Räsänen 90 mm, Kuusamon Uistin, Kuusamo, Finland), jerkbait (Westin Swim intermediate 53 g, Westin Fishing, Gydevang, Denmark), softbait (Storm Suspending 40 g, Rapala VMC Corporation, Helsinki, Finland), and spinnerbait (DaBush, Savage Gear, Gadstrup, Denmark), each with natural and unnatural coloration matching two water color classes (see below). However, closely resembling lures were occasionally used if the original lure was not available due to being lost during the fishing. The spoon had one treble hook (three hooks connected to one shank), the jerkbait had two treble hooks, the softbait had one treble hook and one single hook, and the spinnerbait had one single hook. To control for the visibility of different colors in clear vs. humic waters, lakes with water color below 50 mg Pt^{-1} were fished with lures representing silvery natural coloration of roach (*Rutilus rutilus*) and yellow-red-green, fluorescent "fire tiger" mimicking a perch. The lakes with water color over 50 mg Pt^{-1} were fished with lures representing black-green-red

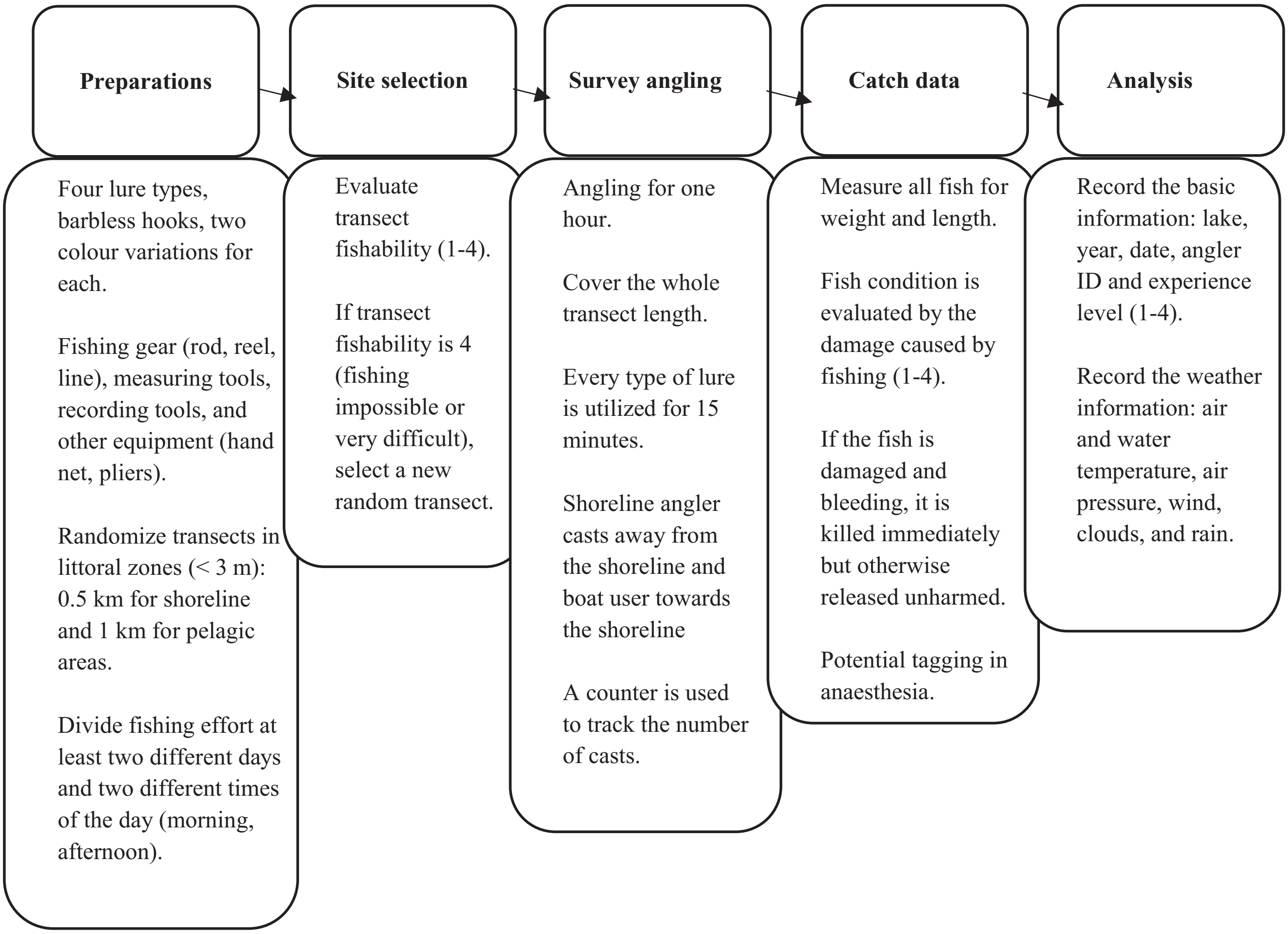

FIGURE 1 | Schematic workflow of survey angling. A more detailed description of the survey is found in the supplement (Table S1).

naturally colored perch and fluorescent orange-gold color as maximally visible non-natural coloration.

When fishing the predetermined transect, the number of casts, caught fish, escaped fish, lure-nibbling fish, scared fish (Table S2) and time was recorded, and water temperature was measured. On most occasions, the responsible angler was accompanied by an assistant who made all the data recording. All captured pike were measured for length and weight and evaluated visually for condition to detect any fishing-related injuries (Table S1). The fish condition had four categories: in the category four, the fish was severely damaged, and it was not returned to the lake but killed for ethical reasons (and as required by Fishing Act (379/2015) 58 a §). In the category three, hooks were attached deeply in the mouth or gills, and bleeding was abundant but stopped. Fish may have had moderate ruptures (tearing of oral tissues) in the mouth. In the category two, hook or hooks were attached deeply in the mouth of the fish or gills, but bleeding was minimal and stopped shortly. In the category one, fish had only small injuries in the mouth and lure removal was easy and fast (Table S1). Individual anglers' experience level was self-evaluated using four categories from the first-timer to an active and experienced angler (fishing at least 10 times per year) (Table S1). However, due to the nature of this study, a certain level of experience was required to ensure the capability to perform survey fishing, but species-specific fishing experience for pike was not required.

2.2 | Study Lakes

The survey angling was conducted in 16 lakes in total. The largest number of the studied lakes ($n = 7$) were located in Lieksa municipality (North Karelia, eastern Finland) (Table 1), four in Rovaniemi municipality (Lapland, northern Finland), two in Hämeenlinna municipality (Kanta-Häme, southern Finland), two in Kolari municipality (Lapland, northern Finland), and one in Kemijärvi municipality (Lapland, northern Finland) (Table 1).

2.3 | Pike Mark-Recapture

The population density of pike > 350 mm was estimated in a total of eight lakes (Table 2). Mark-recapture fishing was conducted on multiple occasions during 2018, 2021, and 2024 using wire traps and fyke nets in spring and angling and Nordic gillnets in the following summer and fall. Additionally, 5 m long tube-model traps were used in 2024. Lake Aitalampi was assessed twice (2021 and 2024). Marking was performed by using T-anchor tags in Majajärvi, Valkea-Kotinen, Peräjärvi, Pieni Kangaslampi, and Iso Kangaslampi (Table 2). Previous T-anchor tagging in Majajärvi and Valkea-Kotinen (Tiainen et al. 2017) was used in addition to the 2018 mark-recapture fishing with adjustment for annual natural mortality with a

TABLE 1 | Basic statistics of fishing trials and the lakes ($N=16$) where the predefined survey angling was conducted.

Lake	Municipality	Area (ha)	Angling effort (hours)	Total catch (ind.)	Number of transects fished	Date of fishing	Coord. N (ETRS-TR35FIN)	Coord. E (ETRS-TR35FIN)
Aitalampi (2021)	Lieksa	12.8	5.8	4	3	2/8, 4/8, 24/9, 30/9/2021	7,017,121	695,069
Aitalampi (2024)	Lieksa	12.8	3	8	2	8/8, 12/8/2024	7,017,121	695,069
Hirsikankaan Rasku	Lieksa	5.5	3	2	3	6/8, 17/8/2021	7,008,932	683,093
Inkijärvi	Rovaniemi	79.8	8.4	5	4	2/7, 4/7/2018	7,396,569	479,898
Iso Kangaslampi	Lieksa	6.4	2	0	2	25/8, 19/10/2018	7,010,512	684,487
Kaivoslampi	Lieksa	17.4	3	3	2	5/8, 12/8/2024	7,012,241	683,847
Kalliojärvi	Kemijärvi	113.8	7.5	2	2	7/8, 9/8/2018	7,394,421	488,103
Kielijärvi	Rovaniemi	222.1	7.9	6	4	18/7, 6/8/2018	7,391,496	484,050
Laukkujärvi	Kolari	134.2	8	15	2	9/7, 10/7/2018	7,431,564	388,213
Majajärvi	Hämeenlinna	3.4	3	4	1	11/9, 12/9/2018	6,788,172	399,990
Mikkelinlampi	Rovaniemi	15.7	4.1	5	2	5/7/2018	7,437,480	448,005
Perälampi	Rovaniemi	22.2	21	20	2	25/6, 29/8, 3/9, 18/9/2018	7,394,098	451,275
Pieni Kangaslampi	Lieksa	3.5	2	2	2	25/8, 19/10/2018	7,010,284	684,921
Roukojärvi	Kolari	38.5	4.1	6	1	9/7, 10/7/2018	7,432,252	383,688
Synkkä-Rasku	Lieksa	4.9	3	0	2	6/8, 17.8/2021	7,010,401	681,988
Valkea-Kotinen	Hämeenlinna	3.6	4.2	8	1	11/9, 12/9/2018	6,791,330	396,000
Valkealampi	Lieksa	10.2	5.2	2	3	2/8, 4/8, 30/9/2021	7,016,960	695,576

TABLE 2 | Pike (> 350 mm) density estimates in the study lakes (estimation year indicated) and the number of marked individuals in mark-recapture fishing.

Lake	Marked total	Recaptures	Return-%	*N*	95% LCI	95% UCI	Estimate (n ha^{-1})	Method	Year
Aitalampi	33	3	8.1	133	54	328	10.4	Schnabel	2021
Aitalampi	19	4	9.8	167	74	401	13	Petersen	2024
Hirsikankaan Rasku	5	1	16.7	6	2	12	1.1	Schnabel	2021
Kaivoslampi	10	2	9.1	83	30	203	4.8	Petersen	2024
Majajärvi	45[a]	12	85.7	52	45	78	15.4	Petersen	2018
Perälampi	58	11	39	117	79	183	5.3	Schnabel	2018
Synkkä-Rasku	10	2	16.7	18	6	43	3.7	Schnabel	2021
Valkea-Kotinen	53.7[a]	11	68.8	76	60	130	21.3	Petersen	2018
Valkealampi	8	1	11.1	14	4	27	1.4	Schnabel	2021

Note: Density estimates are derived using Schnabel or Petersen method with Chapman modification (Chapman 1951, 1954). Return-% = recaptures/all captures × 100.
[a]Adjusted with natural mortality = 0.2 and tag loss = 5.7%.

commonly used value ($M = 0.2$), which may be a slight underestimate (Arlinghaus et al. 2009), but a conservative compromise for marked individuals of different sizes. Also, we adjusted for shedding of T-anchor tags in markings that lasted over 195 days (5.7%, Hühn et al. 2014). Clipping a small piece of the right ventral fin was used as a capture mark in the rest of the study lakes. Fin clipping was performed on anesthetized fish (using benzocaine 30 mg L^{-1}). We assumed that there was no loss of anchor tags or cut marks during the relatively short mark-recapture periods in each lake. The single recapture-based Petersen method (Chapman 1951) was used in 2018 for Majajärvi and Valkea-Kotinen, and in 2024 for Kaivoslampi and Aitalampi to calculate the population size estimates due to the clear separation of sampling into two intensive fishing periods. The Schnabel method (Chapman 1954) was used for Peräjärvi and Lieksa region lakes (angling and wire traps) in 2021 due to continuous sampling and tagging during the summer.

2.4 | Statistical Methods

The relationship between angling catch-per-unit-effort (CPUE) (fish $hour^{-1} km^{-1}$) and pike density (fish $hectare^{-1}$) was evaluated using generalized linear models (GLM) with Poisson distributions. This relationship was studied using a dataset of eight lakes with both pike density estimates and survey angling results. The tested explanatory variables were pike density (fish ha^{-1}), transect fishability (categorical (1–3)), use of boat (1 = boat, 0 = shoreline), time of day (morning, afternoon), cast rate (cast $hour^{-1}$), and water temperature (°C). Transect fishability was used as a factor to test if the complexity of the transect affected fishing and, therefore, influenced the catch rate. The utilization of a boat was used as a factor to test differences in catch rate between boat and shoreline fishing. Time of day was used as a factor to account for possible activity differences by the time of day. Cast rate was added to the model to estimate the possible effect of a faster cast rate. Water temperature was used as a covariate to account for the possible effect of water temperature on fish activity. Weather variables relating to the fishing occasion were not further tested to avoid overfitting models with too many variables. However, fishing efforts were divided into at least two different days and daytimes, which alleviated the effect of local weather phenomena (wind, rain, cloudiness). Test fishing was not conducted during storms or other extreme weather events.

Angler experience was not included as a factor because most of the anglers (9 out of 10) evaluated themselves in a single category of active anglers. The models used the log (hour × km) during a fishing occasion as an offset to relate the catch to the time and distance fished (catch rate = fish $hour^{-1} km^{-1}$).

The backward stepwise elimination of the least significant terms by p-value was used to construct the final models, and AIC (Akaike information criterion) and analysis of variance (ANOVA) were used to select the most parsimonious model. The models were fitted using the R-software version (4.4.1). Angler ID was not included as a random factor due to the small number of observations per angler, which led to singular fit issues. However, the effect of angler was evaluated when testing the effect of lure type using the full data set (see below). For testing the suitable number of fishing trips per lake required to observe CPUE-density relationship (8 lakes), we conducted a resampling-based power analysis. We fitted Poisson GLM models (CPUE~density + offset) with varying number of fishing trips per lake. For each lake, observations were subsampled without replacement (=bootstrapped) from the empirical CPUE data. We formed scenarios with 1, 2 and 3 fishing trips per lake, and each scenario was simulated 1000 times. For each simulation, a GLM was fitted, and the statistical significance of the density effect was recorded. The proportion of significant simulations of CPUE-density relationship ($\alpha = 0.05$) allowed to observe how sampling effort affects the probability to detect a statistically significant relationship.

A single observation in the GLM model for CPUE (fish $hour^{-1} km^{-1}$) was determined as an hour of standard angling, which consisted of four different types of lures (~15 min with varying numbers of casts). Therefore, a single catch resulting from an hour of fishing could compose of pike caught with multiple lures. For evaluating the effect of lure types on CPUE, we reformatted the full dataset (16 lakes) into 15-min segments. The effect of lure type on CPUE (fish $hour^{-1} km^{-1}$) was estimated using generalized linear mixed models (GLMM) with a Poisson error distribution. The explanatory variables included lure type, color, and use of a boat (boat or shore), while random factors were lake and angler ID. Date was omitted from the random factors due to low variation and to relieve an otherwise too complex random structure. The models used the log (hour × km) during each fishing occasion as an offset to relate catch counts to time and fished distance. Pike density was not included as an explanatory variable because the density data were not available for all lakes. However, the lake was included as a random factor to account for between-lake variability, including differences in pike density. Model fits were evaluated using conditional AIC using *cAIC4* package (Säfken et al. 2021) and ANOVA in R. Differences in catch rates between lure types were assessed using post hoc comparisons with Tukey's correction. Post hoc tests were conducted using *emmeans* package (Lenth 2025) in R. The effect of lure type on the length of caught pike was tested using a linear mixed-effect model (LMM), with lure type as a fixed effect and lake as a random factor. The model was tested against a null model (no fixed variable) using ANOVA to determine whether lure type significantly affected caught pike length. The LMM was fitted using the *lme4* package in R (Bates et al. 2015).

A simplified model describing the relationship between pike CPUE (fish $hour^{-1} km^{-1}$) and pike density (fish ha^{-1}) was constructed using Type II regression (major axis regression) to account for measurement error in both included variables (Marjomäki et al. 2015). We fitted a standardized major axis regression due to different units in the measured variables (Warton et al. 2006). The linear relationship between variables was tested using Pearson's correlation coefficient and t-test.

Type II regression was fitted using *lmodel2* package in R (Legendre 2024). In addition, a simple Poisson regression between CPUE and pike density was fitted with an offset term log ($hour^{-1} km^{-1}$), given the general suitability of Poisson regression

TABLE 3 | The generalized linear model of angling CPUE (fish $hour^{-1} km^{-1}$) of the northern pike (*Esox lucius*) in relation to pike density (fish ha^{-1}), fishability of transect (1–3), boat use (boat vs. shoreline), water temperature (°C), time of day (morning vs. afternoon), and cast rate.

Model	AIC	χ^2	df	*p*
Angling CPUE~density + fishability + boat + daytime + casts + water temperature	131.7			
Angling CPUE~density + fishability + boat + casts + daytime	129.7	< 0.01	1	0.937
Angling CPUE~density + fishability + boat + casts	128.0	0.29	1	0.591
Angling CPUE~density + fishability + boat	126.3	0.27	1	0.602
Angling CPUE~density + fishability	124.7	0.40	1	0.526
Angling CPUE~density	**124.7**	**1.98**	**1**	**0.160**
Angling CPUE~1	128.	5.78	1	0.016

Note: Model selection was performed using backward stepwise selection based on the *p*-value. Models were additionally compared using Akaike's information criterion (AIC), and analysis of variance (ANOVA) by comparing each candidate model with a reduced explanatory term to the model without the reduction. A statistically significant result indicates a better fit for the original, more complex model. The most parsimonious model is highlighted in bold. Number of lakes = 8, observations = 50.

for count data. These models were fitted to visualize the CPUE-density relationship from hour-based fishing catches. Mark-recapture estimates were calculated using *FSA* package (Ogle et al. 2023) in R (4.3.1).

3 | Results

3.1 | Relationship Between Pike Density and CPUE

A total of 51.1 h of survey angling was conducted across eight lakes with estimated pike densities. Mark-recapture estimated density of pike ≥ 350 mm varied between 1.1 (fish ha^{-1}) and 21.3 (fish ha^{-1}) (Table 2). The best Poisson regression model explaining the CPUE (fish $hour^{-1} km^{-1}$) included only pike density (fish ha^{-1}) ($\beta = 0.05$, S.E. = 0.02, $z = 2.51$, $p = 0.012$, Table 3). Fishability of the transect, time of the day, use of a boat, cast rate, or water temperature had no statistically significant effects (Figure 2 and Table 3). To address the measurement error in pike density estimates, we fitted a standardized major axis regression between angling CPUE (fish $hour^{-1} km^{-1}$) and pike density (Pearson $r = 0.41$, 95% CI = 0.15–0.62, $t = 3.1$, df = 48, $p = 0.003$) (Figure 3).

In the bootstrap analysis, there was 7.3% (CI = 5.8%–9.1%) probability to observe significant CPUE-density relationship with one survey angling trip per lake (8 lakes). Probability to observe the relationship with two trips per lake was 23.5% (CI = 21%–26%) and with three trips per lake it was 44.1% (CI = 41.0%–47.2%).

3.2 | Variation of the Catch in Relation to the Used Lures

A total of 95.2 h of angling was conducted in the 16 lakes with and without population density estimates. ANOVA comparison of pike CPUE models suggests that lure color (fluorescent vs. natural) had no significant effect on catch rate (Table 4). A model including lure type as a fixed variable had a better fit than a model with only the random structure (ANOVA, $\chi^2 = 10.7$, df = 3, $p = 0.014$, Table 4). *Post hoc* analysis revealed a significant CPUE difference between spoon and spinner bait ($z = 2.86$, df = inf, $p = 0.022$, Table 5). A spoon had the largest mean CPUE (fish $hour^{-1} km^{-1}$) (mean ± SE: 6.6 ± 1.5), whereas a spinnerbait had

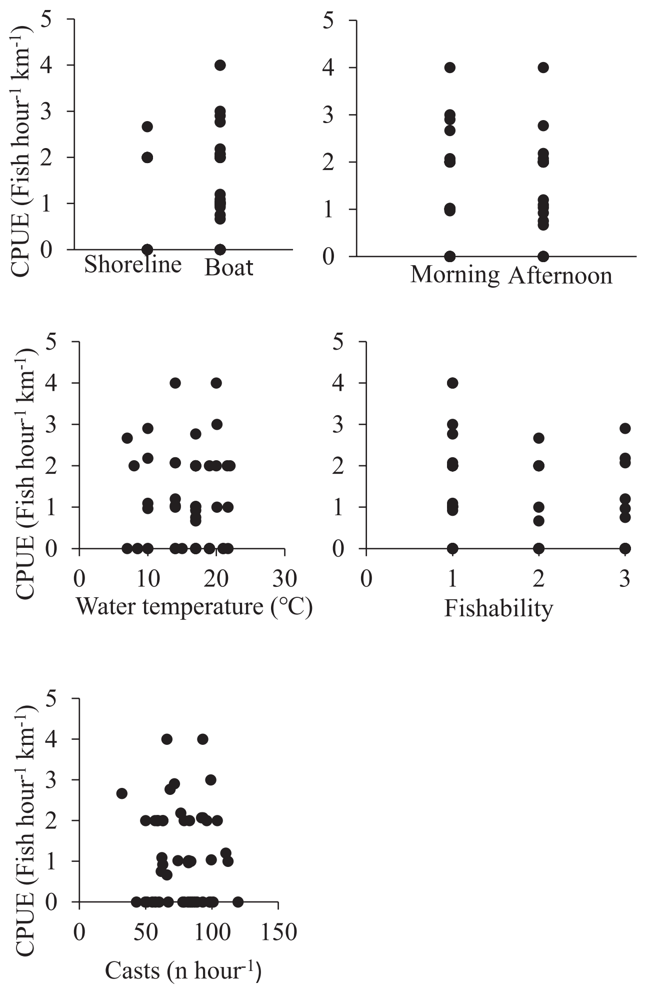

FIGURE 2 | The non-significant relationship between CPUE and studied covariates: Use of a boat (boat, shoreline), time of day (morning, afternoon), water temperature (°C), fishability of transect (1–3), and casts (n $hour^{-1}$).

the lowest CPUE (2.8 ± 0.8) (Table S3). Comparison of different random structures suggested that including angler ID as a random factor did not significantly improve the model fit (ANOVA, $\chi^2 = 1.69$, df = 1, $p = 0.194$). The lowest cAIC was achieved with a model including angler ID and lake ID (cAIC = 426.9); however, it had no great difference (ΔcAIC = 1.6) to a model with only lake as a random factor (cAIC = 428.5).

In modeling the length (cm) of caught pike (caught fish = 93, number of lakes = 16, Table S4), inclusion of lure type did not improve the model fit in comparison to the null model (ANOVA, $\chi^2 = 0.900$, df = 3, $p = 0.826$). Also, ΔAIC was 5.4, supporting the null model.

In total, 17 fish of 90 (18.9%) were classified as condition category 4 and were killed due to excessive hooking injuries. Most of the captured fish were categorized as being in good ($n = 38$, 42.2%) or moderate ($n = 34$, 37.8%) condition (Figure 4). One fish (2.2%) fell into the tolerable category, and condition details were missing for three individuals. Jerk was worst for pike with 31.3% ($n = 5$) of the fish in condition category 4, whereas spinnerbait produced the lowest share of severely injured category 4 fish (6.7%, $n = 1$) (Figure 4).

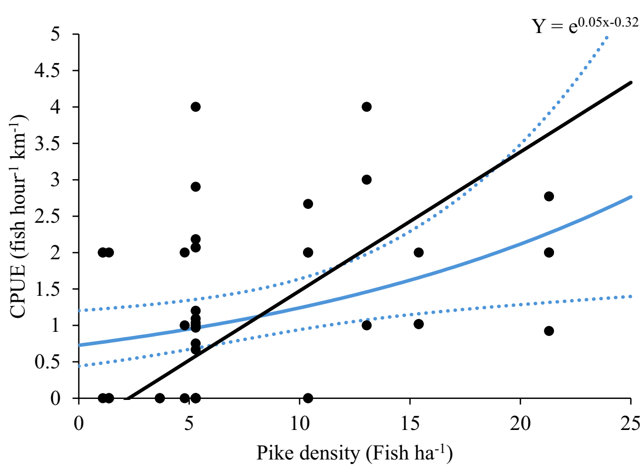

FIGURE 3 | The relationship between recreational angling standard pike CPUE (fish hour^{-1} km^{-1}) and pike density (fish ha^{-1}) in eight small boreal lakes. The black line represents standardized major axis regression. The blue line represents Poisson regression ($z = 2.51$, df = 49, $P = 0.012$) with 95% confidence intervals (blue dashed line).

4 | Discussion and Conclusions

Catch rate in the survey angling overall was positively related to pike density in the studied lakes. However, the hourly catches varied significantly as observed in previous studies (Weithman and Anderson 1976; Pierce and Tomcko 2003; Arlinghaus et al. 2016; Karlsson and Kari 2020), making it very difficult to

TABLE 5 | Post hoc comparisons of lure types in explaining CPUE based on the full generalized linear mixed model (CPUE~lure + (1|lake) + (1|angler)).

Comparison	Ratio	S.E.	z	p
Jerk versus spoon	0.5	0.1	−2.43	0.071
Jerkki versus spinnerbait	1.2	0.4	0.50	0.958
Jerk versus softbait	0.9	0.3	−0.44	0.972
Spoon versus spinnerbait	**2.4**	**0.7**	**2.86**	**0.022**
Spoon versus softbait	1.7	0.5	2.04	0.172
Spinnerbait versus softbait	0.7	0.2	−0.94	0.784

Note: p-values were adjusted using Tukey's method. CPUE ratios were back-transformed to the response scale (fish hour^{-1} km^{-1}). *p*-values were obtained from the standard normal distribution. Statistically significant difference is highlighted in bold.

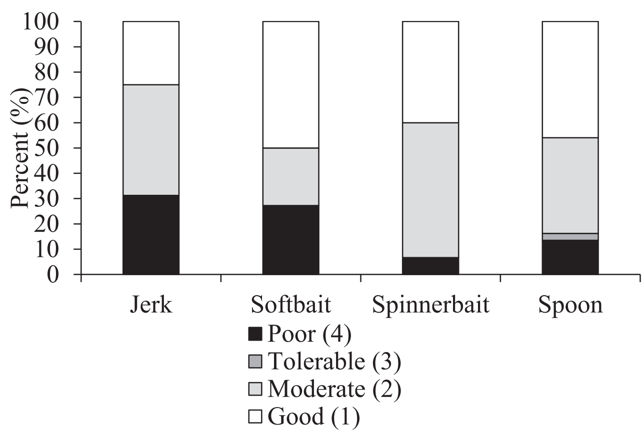

FIGURE 4 | Fish hooking condition percentages in four condition classes for jerk (total pike catch = 16), softbait ($n = 22$), spinnerbait ($n = 15$), and spoon ($n = 37$).

TABLE 4 | Generalized linear models of pike angling CPUE (fish hour^{-1} km^{-1}) in relation to lure type, lure color (unnatural vs. natural), and use of boat. Model fit was compared using the conditional Akaike's information criterion (cAIC), and analysis of variance (ANOVA) against the more complex model.

Akaike's information criterion				ANOVA		
Model	**cAIC**	**LogLik (cond.)**	**df**	χ^2	**df**	**p**
CPUE~lure + boat + color + (1|lake) + (1|angler)	426.9	−199.2	14.3			
CPUE~lure + boat + (1|lake) + (1|angler)	425.2	−199.2	13.4	0.40	1	0.528
CPUE~lure + (1|lake) + (1|angler)	**425.5**	**−199.9**	**12.9**	**2.41**	**1**	**0.121**
CPUE~1 + (1|lake) + (1|angler)	429.9	−205.2	9.8	10.67	3	0.014

Note: Statistical significance indicates a better fit for the original non-reduced model. The most parsimonious model is highlighted in bold. Number of lakes = 16, Observations = 364.

make any precise predictions for the population density based just on a few angling occasions. The results highlight both the importance of controlling variance in CPUEs and having several point estimates (even across years) in order to provide meaningful averages for any management implications (Allen and Pine 2000). However, our results point out that a coordinated way of collecting CPUE data from a rather small number of lakes can provide a statistically significant CPUE-density relationship, although there are sources of error in both CPUEs and density estimations, and we did not track total effort for analysis of any systematic changes in catchability. High variance in hourly catch rates emphasizes the importance of repeating the survey angling several times, preferably on multiple days. Furthermore, our bootstrap analysis of angling trips per lake suggests that the probability of observing a CPUE-density relationship is under 44.1% with three or less trips per lake. This highlights the importance of having more than three survey trips per lake to reliably detect a CPUE-density relationship.

We used four types of fishing lures that were commonly used in pike fishing at the time of the study. Lure type had a significant effect on catch rate; however, the only statistically significant difference was between spoon and spinnerbait in favor of the spoon. Previous studies have suggested a better catch rate for softbaits in comparison to a spoon (Arlinghaus, Laskowski, et al. 2017b), but we did not observe a similar result. The size of the lures was rather large to reduce the possibility of hooking fish from the gills (Arlinghaus et al. 2008), and the lure type did not explain the size of the caught pike as observed by Arlinghaus et al. (2017a). The lure color (fluorescent vs. natural) had no effect on catch rates. Similar results have been found for largemouth bass (*Micropterus salmoides*) (Moraga et al. 2015) as well as for perch (Radinger et al. 2026). However, we used differently colored lure sets for clear and dark-watered lakes to control for the conditions with the aim of eliminating the lure color differences, and as such, this standardization was successful. The results might be different if all the colors were applied in all types of waters. Overall, the results support the idea that pike is a rather opportunistic feeder (Craig 2008; Cathcart et al. 2019) and is thus a well-suited species for citizen science data collection due to its relatively easy catchability. The differences in catchability of different lure types might become more elaborated in waters with heavy fishing pressure since fish learn to avoid the commonly used lure types (Beukema 1970; Lucas et al. 2023; Roser et al. 2025).

In general, the proportion of pike with hooking injuries assumed to be potentially fatal, 18.9% of all pike caught, was higher than in other studies (Arlinghaus et al. 2008; Stålhammar et al. 2014). This may be related to a quite conservative view of the survivable condition of pike needed for mark-recapture, compared with studies directly determining the mortality of catch-and-release angling but also to the fact that the test fishers were not specialized pike anglers. The highest percent for fatal-assumed hooking injuries was with jerk-type lures, whereas the lowest was with spinnerbait. This may be explained by the number of hooks in different lure types, which had a perfect positive ordinal correlation with fatal injury percentages. Previous studies have suggested that the number of hooks explains the rate of injuries for fish (Mandelman et al. 2014; Trahan et al. 2021; Czarkowski et al. 2023), however, the opposite results have also been found (DuBois et al. 1994). However, also fishing style with different lures can vary, which may affect the place of hooking (Larsen et al. 2024). Generally, barbless hooks should be favored over the barbed ones due to faster unhooking (Trahan et al. 2021) and lure shedding after accidental line snaps (Pullen et al. 2019). Our results suggest that from the four types of lures studied, a spoon might be a good compromise for recreational anglers due to the highest catch rate and the second lowest fatal-assumed injury percent. For angling surveys, it may be beneficial to utilize different lure types, especially in lakes where there may be existing fishing pressure that may have induced hook-avoidance behavior for certain types of lures (Beukema 1970).

We did not observe variables relating to fishability of the transect, or the time of the day having significant effect on CPUE. This may be due to the standardization of the angling, which guides the effort to easily fished areas and controls the fishing time and length of the fished transect (Cheng et al. 2023; Lewin et al. 2023). Angler's experience is typically considered an important factor affecting the angler's capability to find good fishing spots (Ward et al. 2013; Dassow et al. 2020; Turunen et al. 2023) and skill to perform fishing sufficiently (Monk and Arlinghaus 2018; Futamura et al. 2025). In our study, most of the anglers performing the survey were rather experienced general anglers (fishing for over 10 days annually), as the defined protocol also required some skill for an angler to be able to follow it. This meant that we did not observe the effect of experience or skill on CPUE in this study by testing angler ID as a random factor in the models. This suggests that only little variation originated from the anglers with the same experience level, which however, does not naturally mean that such variation would be irrelevant if larger angler populations engaged in survey angling. Direct use of estimated fishing days annually could possibly be a better approach to assess the experience of a fisher (Ward et al. 2013) or use questionnaires to assess fisher skill level (Monk and Arlinghaus 2018; Futamura et al. 2025). However, it is desirable that the survey angling is conducted by persons with sufficient experience in pike angling, reducing the possible effect arising from an inability to hook or land the fish with various lure types (Meka 2004; Capizzano et al. 2021), and to ensure secure and humane handling of fish.

Different environmental variables such as high wind speed, water temperature, and moon-phase have been recognized to affect the pike catch rate (Kuparinen et al. 2010). Wind speed is suggested to have a positive effect on pike catch rate, where the mechanism may be related to pike's feeding activity in wind-induced water turbidity (Nilsson et al. 2009). Also, wind increases underwater motion and noise, which may impact pike's activity. Due to a limited data set, we did not assess the effect of wind; however, in small lakes, wind-induced turbidity may be a minor variable due to weak wave formation in a small surface area. Water temperature has been suggested on many occasions as an important variable affecting the pike catch rate (Stoner 2004; Kuparinen et al. 2010). Kuparinen et al. (2010) found a negative correlation between catch rate and water temperature, and suggested that one reason could be physiological stress in high water temperature that may decrease the feeding activity (Bevelhimer et al. 1985). Another explanation was that high water temperature may increase the activity of prey fish, meaning that the fishing lure may have a competitive disadvantage (Kuparinen et al. 2010). In our results, water temperature did not affect CPUE, which may be caused by our standardization of test fishing periods to autumn months and not to the period of cold water in spring (after spawning) or during summer months, when water temperature reaches its peak.

Among small lakes (<40 ha), the pike densities (≥350 mm) can vary dramatically, ranging from only a few to more than 50 individuals per hectare (Margenau et al. 1998; Pierce and Tomcko 2005; Tiainen et al. 2017). The littoral zone is essential habitat for pike, and its quantity can explain the variation in pike density between lakes (Pierce and Tomcko 2005). In our study lakes, pike density varied from 1.1 to 21.3 individuals per hectare. Especially in the study lakes located in eastern Finland, there were lakes with very low pike density estimates. These lakes often had steep shorelines with little aquatic vegetation, missing the preferred substrate for pike spawning and cover for juvenile individuals (Lappalainen et al. 2008). Mark-recapture estimates were especially low for lakes Hirsikankaan Rasku and Synkkä-Rasku, which also displayed very low catch rates in angling.

Pike is a visual predator that inhabits shallow littoral lake areas for its ambushing type of predation (Harper and Blake 1991; Craig 2008; Turunen et al. 2024) but also may express activity in pelagic zones (Kobler et al. 2009). The spatial distribution of pike has been shown to follow the ideal free distribution (Haugen et al. 2006), where pike optimizes its food intake by balancing between the densities of competitors and forage fish. This makes their distribution relatively even across the lake surface area, following the abundance of food resources, such as perch and roach (Heikinheimo and Korhonen 1996). This is important, since strong aggregation into certain spots in a lake would easily produce catch hyperstability of catch rates (Dassow et al. 2020; Turunen et al. 2023). Furthermore, species with active movement and large foraging areas may instead induce hyperdepletion of CPUE, especially if a proportion of the population displays passive behavior with a low fishing capture rate (Alós et al. 2019). Therefore, we suggest that methods that may be suitable for pike may not be directly that for percids or any other predators forming shoals or showing otherwise more aggregated distribution. It is also necessary that survey angling follows the idea of randomized transects, as otherwise the anglers would probably only fish where they visually deem best for catching pike.

Recreational angling has already been utilized as a method for monitoring lakes and collecting data (Karlsson and Kari 2020; Bergström et al. 2022). Especially, the long-term logbook data from anglers can be utilized to follow trends in pike populations but also derive the actual catch per effort data for fisheries management purposes (Bergström et al. 2022). Furthermore, photographs taken by anglers have been utilized for deriving mark-recapture estimates from pike spot patterns (Karlsson and Kari 2020; Kristensen et al. 2020). Taking photographs of caught pike, for example, with a smartphone, during survey angling could provide valuable data on individual capture histories. This could be further used to estimate growth rates, density, and catchability for fisheries management purposes. Nevertheless, for citizen science-based data collection with open platforms (e.g., mobile apps), it is essential to adjust the possible biases caused by the user selectivity and under-reporting of zero catches (Gundelund et al. 2020, 2023). To further improve existing catch reporting applications used widely around the world, an option for reporting more standardized catch rates could be considered. An openly available survey protocol could produce vast amounts of data to be used in research and management. Encouraging anglers to collect data in a more structured way, that is, using random transects and predetermined gear, could enable the derivation of more accurate stock metrics.

To conclude, our study provides a promising example of angling CPUE being positively related to the actual fish population density in nearly pristine boreal lakes. This is not always evident in most fisheries, and for the applications, there are important limitations arising from the fisheries themselves, as fish catchability can strongly depend on the fishing effort. The high statistical error in catch rates suggested that detailed constraints for angling surveys may not always provide great benefits. When conducting angling surveys, important variables include accounting for the fishing effort (time and area covered) and using randomized fishing spots. Strong control over daytime, shoreline habitats, boat use, and number of casts may not result in major improvements in CPUE accuracy. Furthermore, the effect of lure type may be minor and the effect of lure color absent; however, due to the possible learning behavior, a small array of lure types should be used for angling surveys in heavily fished areas. Our study highlights the further need for development of angling-based survey methods to detect and control the major sources of uncertainty in CPUE data.

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Ethics Statement

Experimental fishing was conducted according to the Finnish Fishing Act (379/2015), permitted exceptions to use a large number of Nordic survey nets (by North Karelian ELY-center (Dnro POSELY/710/2021)), and research licenses from Parks & Wildlife Finland. No animal experimentation was performed in this study. Fish marking was performed under anesthesia according to the governmental decree 1165/2023.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data collected in this study are openly available in Figshare at https://doi.org/10.6084/m9.figshare.28430537.v1.

References

Allen, M. S., and W. E. Pine. 2000. "Detecting Fish Population Responses to a Minimum Length Limit: Effects of Variable Recruitment and Duration of Evaluation." *North American Journal of Fisheries Management* 20: 672–682.

Alós, J., A. Campos-Candela, and R. Arlinghaus. 2019. "A Modelling Approach to Evaluate the Impact of Fish Spatial Behavioural Types on Fisheries Stock Assessment." *ICES Journal of Marine Science* 76: 489–500.

Arlinghaus, R., J. Alós, T. Pieterek, and T. Klefoth. 2017a. "Determinants of Angling Catch of Northern Pike (*Esox lucius*) as Revealed by a Controlled Whole-Lake Catch-And-Release Angling Experiment—The Role of Abiotic and Biotic Factors, Spatial Encounters and Lure Type." *Fisheries Research* 186: 648–657.

Arlinghaus, R., T. Klefoth, A. Kobler, and S. J. Cooke. 2008. "Size Selectivity, Injury, Handling Time, and Determinants of Initial Hooking Mortality in Recreational Angling for Northern Pike: The Influence of Type and Size of Bait." *North American Journal of Fisheries Management* 28: 123–134.

Arlinghaus, R., K. L. Laskowski, J. Alós, et al. 2017b. "Passive Gear-Induced Timidity Syndrome in Wild Fish Populations and Its Potential Ecological and Managerial Implications." *Fish and Fisheries* 18: 360–373.

Arlinghaus, R., S. Matsumura, and U. Dieckmann. 2009. "Quantifying Selection Differentials Caused by Recreational Fishing: Development of Modeling Framework and Application to Reproductive Investment in Pike (*Esox lucius*)." *Evolutionary Applications* 2: 335–355.

Arlinghaus, R., and T. Mehner. 2004. "A Management-Orientated Comparative Analysis of Urban and Rural Anglers Living in a Metropolis (Berlin, Germany)." *Environmental Management* 33: 331–344.

Arlinghaus, R., T. Pagel, T. Hühn, and T. Rapp. 2016. "Einheitsfanganalysen Als Praxisnahes Hilfsmittel Zur Abschätzung Der Fischbestandsentwicklung in Binnengewässern." *Fischerei & Fischmarkt in Mecklenburg-Vorpommern* 2: 30–41.

Bates, D., M. Maechler, B. Bolker, and S. Walker. 2015. "Fitting Linear Mixed-Effects Models Using lme4." *Journal of Statistical Software* 67: 1–48.

Bergström, U., S. Larsson, M. Erlandsson, et al. 2022. "Long-Term Decline in Northern Pike (*Esox lucius* L.) Populations in the Baltic Sea Revealed by Recreational Angling Data." *Fisheries Research* 251: 106307.

Beukema, J. J. 1970. "Acquired Hook-Avoidance in the Pike *Esox lucius* L. Fished With Artificial and Natural Baits." *Journal of Fish Biology* 2: 155–160.

Bevelhimer, H. A., R. A. Stein, and R. F. Carline. 1985. "Assessing Significance of the Physiological Differences Among Three Esocids With a Bioenergetics Model." *Canadian Journal of Fisheries and Aquatic Sciences* 42: 57–69.

Capizzano, C. W., D. R. Zemeckis, E. A. Jones, et al. 2021. "Reducing Bycatch Impacts in Recreational Fisheries: Case Study Examining Terminal Tackle in the Multispecies Gulf of Maine Groundfish Fishery." *Fisheries Management and Ecology* 28: 338–350.

Cathcart, C. N., K. J. Dunker, T. P. Quinn, et al. 2019. "Trophic Plasticity and the Invasion of a Renowned Piscivore: A Diet Synthesis of Northern Pike (*Esox lucius*) From the Native and Introduced Ranges in Alaska, U.S.A." *Biological Invasions* 21: 1379–1392.

Chapman, D. G. 1951. "Some Properties of the Hypergeometric Distribution With Applications to Zoological Censuses." *University of California Publications in Statistics* 1: 131–160.

Chapman, D. G. 1954. "The Estimation of Biological Populations." *Annals of Mathematical Statistics* 25: 1–15.

Cheng, M. L., C. J. Rodgveller, J. A. Langan, and C. J. Cunningham. 2023. "Standardizing Fishery-Dependent Catch-Rate Information Across Gears and Data Collection Programs for Alaska Sablefish (*Anoplopoma fimbria*)." *ICES Journal of Marine Science* 80: 1028–1042.

Craig, J. F. 2008. "A Short Review of Pike Ecology." *Hydrobiologia* 601: 5–16.

Czarkowski, T. K., K. Kupren, A. Hakuć-Błażowska, and A. Kapusta. 2023. "Fish Hooks and the Protection of Living Aquatic Resources in the Context of Recreational Catch-and-Release Fishing Preactise and Fishing Tourism." *Water* 15: 1842.

Dainys, J., E. Jakubavičiūtė, H. Gorfine, et al. 2022. "Impacts of Recreational Angling on Fish Population Recovery After a Commercial Fishing Ban." *Fishes* 7: 232.

Dassow, C. J., A. J. Ross, O. P. Jensen, et al. 2020. "Experimental Demonstration of Catch Hyperstability From Habitat Aggregation, Not Effort Sorting, in a Recreational Fishery." *Canadian Journal of Fisheries and Aquatic Sciences* 77: 762–769.

Degerman, E., J. Hammar, P. Nyberg, and G. Svärdson. 2001. "Human Impact on the Fish Diversity in the Four Largerst Lakes of Sweden." *Ambio* 30: 522–528.

DuBois, R. B., T. L. Margenau, R. S. Stewart, P. K. Cunningham, and P. W. Rasmussen. 1994. "Hooking Mortality of Northern Pike Angled Through Ice." *North American Journal of Fisheries Management* 14: 769–775.

Eklöf, J. S., J. P. Hansen, B. K. Eriksson, et al. 2023. "Effects of Seasonal Spawning Closures on Pike (*Esox lucius* L.) and Perch (*Perca fluviatilis* L.) Catches and Coastal Food Webs in the Western Baltic Sea." *Fisheries Research* 263: 106674.

Fitzgerald, C. J., J. S. Droll, S. Shephard, C. T. Monk, T. Rittweg, and R. Arlinghaus. 2023. "Length-Based Assessment of an Exploited Coastal Pike (*Esox lucius*) Stock (Rügen, Southern Baltic Sea) Underscores the Crucial Relevance of Growth and Natural Mortality for Assessment Outcomes." *Fisheries Research* 263: 106667.

Futamura, R., C. W. Lau, D. Hagg, et al. 2025. "Impacts of Angler Skill and Hook Size on Catch and Welfare Outcomes in Freshwater Recreational Pole Fishing." *North American Journal of Fisheries Management* 45: 1096–1107.

Goedde, L. E., and D. W. Coble. 1981. "Effects of Angling on a Previously Fished and an Unfished Warmwater Fish Community in Two Wisconsin Lakes." *Transactions of the American Fisheries Society* 110: 594–603.

Gundelund, C., R. Arlinghaus, H. Baktoft, K. Hyder, P. Venturelli, and C. Skov. 2020. "Insights Into the Users of a Citizen Science Platform for Collecting Recreational Fisheries Data." *Fisheries Research* 229: 105597.

Gundelund, C., P. Venturelli, B. W. Hartill, K. Hyder, H. J. Olesen, and C. Skov. 2023. "Spatiotemporal and Multispecies Comparisons Bewteen a Citizen Science Platform and Recall Surveys in Recreational Fisheries." *Marine Policy* 155: 105780.

Hamley, J. M. 1975. "Review of Gillnet Selectivity." *Journal of the Fisheries Research Board of Canada* 32: 1943–1969.

Harley, S. J., R. A. Myers, and A. Dunn. 2001. "Is Catch-Per-Unit-Effort Proportional to Abundance?" *Canadian Journal of Fisheries and Aquatic Sciences* 58: 1760–1772.

Harper, D. G., and R. W. Blake. 1991. "Prey Capture and the Fast-Start Performance of Northern Pike *Esox lucius*." *Journal of Experimental Biology* 155: 175–192.

Harris, D., D. Johnston, and D. Yeoh. 2021. "More for Less: Citizen Science Supporting the Management of Small-Scale Recreational Fisheries." *Regional Studies in Marine Science* 48: 102047.

Haugen, T. O., I. J. Winfield, L. A. Vøllestad, J. M. Fletcher, J. B. James, and N. C. Stenseth. 2006. "The Ideal Free Pike: 50 Years of

Fitness-Maximizing Dispersal in Windermere." *Proceedings of the Royal Society: Biological Sciences* 273: 2917–2924.

Heikinheimo, O., and A. P. Korhonen. 1996. "Food Consumption of Northern Pike (*Esox lucius* L.), Estimated With a Bioenergetics Model." *Ecology of Freshwater Fish* 5: 37–47.

Hühn, D., T. Klefoth, T. Pagel, P. Zajicek, and R. Arlinghaus. 2014. "Impacts of External and Surgery-Based Tagging Techniques on Small Northern Pike Under Field Conditions." *North American Journal of Fisheries Management* 34: 322–334.

Karlsson, K., and E. Kari. 2020. "Recreational Anglers as Citizen Scientists Can Provide Data to Estimate Population Size of Pike, *Esox lucius*." *Fisheries Management and Ecology* 27: 367–380.

Kobler, A., T. Klefoth, T. Mehner, and R. Arlinghaus. 2009. "Coexistence of Behavioural Types in an Aquatic Top Predator: A Response to Resource Limitation?" *Oecologia* 161: 837–847.

Kristensen, E., K. Sand-Jensen, K. T. Martinsen, M. Madsen-Østerbye, and T. Kragh. 2020. "Fingerprinting Pike: The Use of Image Recognition to Identify Individual Pike." *Fisheries Research* 229: 105622.

Kuparinen, A., T. Klefoth, and R. Arlinghaus. 2010. "Abiotic and Fishing-Related Correlates of Angling Catch Rates in Pike (*Esox lucius*)." *Fisheries Research* 105: 111–117.

Lappalainen, A., M. Härmä, S. Kuningas, and L. Urho. 2008. "Reproduction of Pike (*Esox lucius*) in Reed Belt Shores of the SW Coast of Finland, Baltic Sea: A New Survey Approach." *Boreal Environment Research* 13: 370–380.

Larsen, M. H., O. J. Palder, C. Gundelund, N. A. Schnedler-Meyer, H. D. Ravn, and C. Skov. 2024. "Anatomical Hooking Location and Bleeding Occurrence in Northern Pike (*Esox lucius*) Caught in Recreational Catch-And-Release Angling in a Lake With Reduced Prey Fish Availability." *Fisheries Research* 273: 106906.

Legendre, P. 2024. "lmodel2: Model II Regression." https://CRAN.R-project.org/package=lmodel2.

Lenth, R. 2025. "emmeans: Estimated Marginal Means, Aka Least-Squares Means." https://CRAN.R-project.org/package=emmeans.

Lewin, W.-C., M. S. Weltersbach, K. Haase, C. Riepe, and H. V. Strehlow. 2023. "Potential Biases in Angler Diary Data: The Impact of the Diarist Recruitment Process on Participation Rates, Catch, Harvest, and Effort Estimates." *Fisheries Research* 258: 106551.

Lucas, J., A. Ros, J. Geist, and A. Brinker. 2023. "Effects of Behavioral Strategies on Catchability, Bait Selectivity, and Hunting Behavior in Northern Pike (*Esox lucius*)." *Canadian Journal of Fisheries and Aquatic Sciences* 80: 1890–1905.

Mandelman, J., C. Capizzano, W. Hoffman, et al. 2014. "Elucidating Post-Release Mortality and "Best Capture and Handling" Methods in Sublegal Atlantic Cod Discarded in Gulf of Maine Recreational Hook-And-Line Fisheries." In *NOAA Bycatch Reduction Engineering Program 2013 Annual Report to Congress*. NOAA.

Margenau, T. L., P. W. Rasmussen, and J. M. Kampa. 1998. "Factors Affecting Growth of Northern Pike in Small Northern Wisconsin Lakes." *North American Journal of Fisheries Management* 18: 625–639.

Marjomäki, T. J., M. Paloniemi, T. Keskinen, J. Kuha, and J. Karjalainen. 2015. "Empirical Estimation of Accumulation-Induced Change in Gill Net Catchability: Mind the Observation Errors." *Open Fish Science Journal* 8: 13–22.

Meka, J. M. 2004. "The Influence of Hook Type, Angler Experience, and Fish Size on Injury Rates and the Duration of Capture in an Alaskan Catch-and-Release Rainbow Trout Fishery." *North American Journal of Fisheries Management* 24: 1309–1321.

Monk, C. T., and R. Arlinghaus. 2018. "Eurasian Perch, *Perca fluviatilis*, Spatial Behaviour Determines Vulnerability Independent of Angler Skill in a Whole-Lake Reality Mining Experiment." *Canadian Journal of Fisheries and Aquatic Sciences* 75: 417–428.

Moraga, A. D., A. D. Wilson, and S. J. Cooke. 2015. "Does Lure Colour Influence Catch Per Unit Effort, Fish Capture Size and Hooking Injury in Angled Largemouth Bass?" *Fisheries Research* 172: 1–6.

Mosindy, T. E., W. T. Momot, and P. J. Colby. 1987. "Impact of Angling on the Production and Yield of Mature Walleyes and Northern Pike in a Small Boreal Lake in Ontario." *North American Journal of Fisheries Management* 7: 493–501.

Nilsson, P. A., L. Jacobsen, S. Berg, and C. Skov. 2009. "Environmental Conditions and Intraspecific Interference: Unexpected Effects of Turbidity on Pike (*Esox lucius*) Foraging." *Ethology* 115: 33–38.

Ogle, D. H., J. C. Doll, A. P. Wheeler, and A. Dinno. 2023. "FSA: Simple Fisheries Stock Assessment Methods. R Package Version 0.9.5." https://CRAN.R-project.org/package=FSA.

Olin, M., J. Tiainen, M. Kurkilahti, M. Rask, and H. Lehtonen. 2016. "An Evaluation of Gillnet CPUE as an Index of Perch Density in Small Forest Lakes." *Fisheries Research* 173: 20–25.

Paukert, C. P., J. A. Klammer, R. B. Pierce, and T. D. Simonson. 2001. "An Overview of Northern Pike Regulations in North America." *Fisheries* 26: 6–13.

Pierce, R., and C. M. Tomcko. 2005. "Density and Biomass of Native Northern Pike Populations in Relation to Basin-Scale Characteristics of North-Central Minnesota Lakes." *Transactions of the American Fisheries Society* 134: 231–241.

Pierce, R. B., and C. M. Tomcko. 2003. "Variation in Gill-Net and Angling Catchability With Changing Density of Northern Pike in a Small Minnesota Lake." *Transactions of the American Fisheries Society* 132: 771–779.

Pokki, H., J. Pellikka, P. Eskelinen, and P. Moilanen. 2021. "Regional Fishing Site Preferences of Subgroups of Finnish Recreational Fishers." *Scandinavian Journal of Hospitality and Tourism* 21: 442–457.

Pullen, C. E., R. Arlinghaus, R. J. Lennox, and S. J. Cooke. 2019. "Telemetry Reveals the Movement, Fate, and Lure-Shedding of Northern Pike (*Esox lucius*) That Break the Line and Escape Recreational Fisheries Capture." *Fisheries Research* 211: 176–182.

Radinger, J., M. Braun, A. Jechow, et al. 2026. "Effectiveness of Fluorescent Angling Lures on Catch Outcomes in European Perch (*Perca fluviatilis*) Under Ambient Light Conditions." *Canadian Journal of Fisheries and Aquatic Sciences* 83: 1–16.

Roser, P., J. Radinger, F. Feldhege, M. Braun, and R. Arlinghaus. 2025. "Getting Scarce and Lure Shy: Impacts of Recreational Fishing on Coastal Northern Pike (*Esox lucius*) Abundance, Size Structure and Vulnerability to Angling." *Fisheries Management and Ecology* 32: e12769.

Säfken, B., D. Rügamer, T. Kneib, and S. Greven. 2021. "Conditional Model Selection in Mixed-Effects Models With cAIC4." *Journal of Statistical Software* 99: 1–30.

Salmi, P., A. L. Toivonen, and J. Mikkola. 2006. "Impact of Summer Cottage Residence on Recreational Fishing Participation in Finland." *Fisheries Management and Ecology* 13: 275–283.

Sarvala, J., H. Helminen, and A.-M. Ventelä. 2020. "Overfishing of a Small Planktivorous Freshwater Fish, Vendace (*Coregonus albula*), in the Boreal Lake Pyhäjärvi (SW Finland), and the Recovery of the Population." *Fisheries Research* 230: 105664.

Stålhammar, M., T. Fränstam, J. Lindström, J. Höjesjö, R. Arlinghaus, and P. A. Nilsson. 2014. "Effects of Lure Type, Fish Size and Water Temperature on Hooking Location and Bleeding in Northern Pike (*Esox lucius*) Angled in the Baltic Sea." *Fisheries Research* 157: 164–169.

Stensland, S., C. Skov, S. Agnarsson, et al. 2025. "A Delphi-Study to Identify Drivers of Future Angling Participation in Five Nordic Countries." *Fisheries Management and Ecology* 32: e12735.

Stoner, A. W. 2004. "Effects of Environmental Variables on Fish Feeding Ecology: Implications for the Performance of Baited Fishing Gear and Stock Assessment." *Journal of Fish Biology* 65: 1445–1471.

Tiainen, J., M. Olin, H. Lehtonen, K. Nyberg, and J. Ruuhijärvi. 2017. "The Capability of Harvestable Slot-Length Limit Regulation in Conserving Large and Old Northern Pike (*Esox lucius*)." *Boreal Environment Research* 22: 169–186.

Tibblin, P., K. Bergström, H. Flink, et al. 2023. "Higher Abundance of Adult Pike in Baltic Sea Coastal Areas Adjacent to Restored Wetlands Compared to Reference Bays." *Hydrobiologia* 850: 2049–2060.

Trahan, A., A. D. Chhor, L. LaRochelle, A. J. Danylchuk, and S. J. Cooke. 2021. "Influence of Artificial Lure Hook Type on Hooking Characteristics, Handling, and Injury of Angled Freshwater Gamefish." *Fisheries Research* 243: 106056.

Turunen, A., N. Lappalainen, H. Huuskonen, and A. Vainikka. 2024. "Counting Fish at Night Using Artificial Light: Transect Survey of Common Bream Abramis Brama and Northern Pike *Esox lucius* Abundance as an Example." *Journal of Fish Biology* 106: 1–5. https://doi.org/10.1111/jfb.15988.

Turunen, A., A. Salgado-ismodes, H. Huuskonen, et al. 2023. "Ice Fishing Reveals Size Structure but Not Abundance of Eurasian Perch in Small Boreal Lakes." *Fisheries Management and Ecology* 30: 99–108.

Vainikka, A., A. Turunen, A. Salgado-Ismodes, et al. 2024. "Biomass and Sustainable Yields of Eurasian Perch (*Perca fluviatilis*) in Small Boreal Lakes With Respect to Lake Properties and Water Quality." *Fisheries Research* 271: 106922.

van den Heuvel, L., Ø. Aas, S. Agnarsson, et al. 2025. "Future Trends in Angler Behavior Based on a Delphi Study in the Nordic Countries." *Fisheries Management and Ecology* 32: e12760.

van den Heuvel, L., M. Blicharska, S. Blyth, and P. Rönnbäck. 2020. "Catch Reporting in Recreational Fishing: Swedish Anglers' Attitudes and Preferences, and the Effect of Social Factors." *Fisheries Research* 223: 105444.

van Gemert, R., D. Koemle, H. Winkler, and R. Arlinghaus. 2022. "Data-Poor Stock Assessment of Fish Stocks Co-Exploited by Commercial and Recreational Fisheries: Applications to Pike *Esox lucius* in the Western Baltic Sea." *Fisheries Management and Ecology* 29: 16–28.

Ward, H. G., P. J. Askey, and J. R. Post. 2013. "A Mechanistic Understanding of Hyperstability in Catch Per Unit Effort and Density-Dependent Catchability in a Multistock Recreational Fishery." *Canadian Journal of Fisheries and Aquatic Sciences* 70: 1542–1550.

Warton, D. I., I. J. Wright, D. S. Falster, and M. Westoby. 2006. "Bivariate Line-Fitting Methods for Allometry." *Biological Reviews* 81: 259–291.

Weithman, A. S., and R. O. Anderson. 1976. "Angling Vulnerability of Esocidae." Paper Presented at the Proceedings of the Annual Conference of the Journal of the Southeastern Association of Fish and Wildlife Agencies, 99–102. https://seafwa.org/sites/default/files/journal-articles/WEITHMAN-99.pdf.

Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Table S1:** Detailed description of the survey angling protocol of northern pike. **Table S2:** Other reported observations in standard angling. **Table S3:** CPUE (fish $hour^{-1} km^{-1}$) of four different lure types. LCL, lower 95% confidence interval; UCL, upper 95% confidence interval. **Table S4:** Total length (cm) of the measured pike during survey angling in the study lakes.