Comparative angler catch rates of native versus alien piscivorous fish in an invaded river fishery

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ABSTRACT

Recreational angling is a major introduction pathway for large-bodied alien fishes into freshwaters, where the fish are released to enhance angling success and increase angler satisfaction, despite this often resulting in invasive populations. There is a thus a need to understand the role of these alien species in angler catches to enable more informed risk-based decisions to be made on future releases. In England, the invasive, piscivorous pikeperch *Sander lucioperca* has been present in rivers since the 1960s. Anglers target invasive pikeperch in fisheries where the native piscivorous pike *Esox lucius* is also present; this includes two rivers in the lower Severn basin, western England (main River Severn and Warwickshire Avon). To assess the contributions of invasive pikeperch to angler catches, the aim here was to compare their catches with those of native pike in the lower Severn basin in relation to angling effort and methods, abiotic conditions, and fish size. In 307 angling sessions across 16 anglers where at least one fish was captured, 428 pike and 266 pikeperch were captured. In a sub-set of data from six anglers who submitted catch returns that included non-capture sessions, 78 % of sessions resulted in the capture of at least one pike or pikeperch. Catch rates of pike were significantly higher than pikeperch in the main River Severn but not the Avon. Captured pike were significantly larger than pikeperch, but pikeperch were larger relative to the maximum size each species reaches in England. Lures generally captured more pike than any other method, with these fish tending to be smaller than those caught on other methods; these patterns were not evident in pikeperch. Both species were captured across a broad range of river flow conditions (Q6 to Q99). Only 19 % of successful angling sessions resulted in the capture of both species, suggesting some species selectivity by anglers. These results emphasise that alien fish species can provide important angling resources in recreational fisheries, although management decisions on future introductions should still consider their ecological risks.

Keywords: *Esox lucius*; *Sander lucioperca*; lure angling; river angling.

1. Introduction

Analyses of angler catch data provide important information on the exploited component of fish communities, especially in water bodies where other sampling methods are difficult to deploy (Radinger et al., 2019). Angler catch data analyses have provided increased understandings of how fish communities have responded to improvements in water quality (e.g. Cooper and Wheatley, 1981; Cowx and Broughton, 1986) and have been used to assess the population status of large-bodied, imperilled species of high sporting value (e.g. Pinder et al., 2015a,b, 2020). Recreational angling is a major introduction pathway of large-bodied alien freshwater fishes (Gozlan et al., 2010; Britton and Orsi, 2012). These species are generally released into inland fisheries with the aim of enhancing angler catch rates and satisfaction (Hickley and Chare, 2004). Species such as European catfish *Silurus glanis*, peacock basses of the *Cichla* genus, and largemouth bass *Micropterus salmoides* are examples of species that have achieved relatively large distributions outside of their natural range through introductions driven by recreational angling (Hargrove et al, 2015; Banha et al., 2017; Rees et al., 2017).

A common characteristic of large-bodied alien fishes that have been released into inland waters for angling is their piscivory, which generally results in their occupation of a relatively high trophic position (Eby et al., 2006). Their established and invasive populations have then often had deleterious impacts on native fish assemblages through their piscivory (Eby et al., 2006; Menezes et al., 2012). Understanding how these alien fish species influence the species and size composition of angler catches is therefore important for helping fishery managers and regulators to make more informed risk-based and balanced decisions on future introductions (Copp et al., 2009; Britton and Orsi, 2012). Analyses can, for example, consider how the catch rates of these alien fishes compare to trophically analogous native species to identify their relative contributions to angler catch rates more generally. These analyses can, however, be confounded by a range of factors that affect catch rates, such as local weather conditions (e.g. temperature, wind speed), recent angling pressure (Kuparinen et al., 2010), the angling methods used (e.g. use of artificial versus natural baits; Arlinghaus et al., 2017), and differences in the competencies of the anglers who contributed to the dataset (e.g. Pinder et al., 2015a; Monk and Arlinghaus, 2017). Consequently, analyses of these angler catch data need to account for the effects of these abiotic factors whenever possible.

In England, pikeperch (or zander) *Sander lucioperca* is now invasive in some river basins, having first being released into open waters in the 1960s to provide an additional angler target species (Hickley, 1986). Pikeperch, a relatively large, obligate piscivore originating from eastern and central Europe, established populations that soon dispersed through rivers in central and southern England (Copp et al., 2003; Fickling and Lee, 1983; Nunn et al, 2007; Smith et al., 1998). They were targeted for capture by recreational anglers (Fickling and Lee, 1985) and, over time, angling practices increasingly used catch-and-release (fish released alive following their capture) (Hickley and Chare, 2004). Today, almost all captured pikeperch by angling are now released alive, despite this being contrary to extant legislation (Nolan et al., 2019a). Pikeperch now support important sport fisheries in some English rivers, where anglers perceive the species as a valued target fish that enhances the fishery, but that does not cause long-term ecological impacts (Nolan et al., 2019a).

The aim of this study was to thus compare the angler catch rates and body sizes of alien pikeperch versus native pike (the trophically analogous native piscivorous fish) in the catch-and-release fishery of the lower River Severn basin, western England, in which the two species were the only obligate piscivores present. The objectives were to: (1) assess the contributions of pike and pikeperch to angler catches, and assess how abiotic factors, including angling effort and method, temperature and river flow, affected their catch rates; (2) compare and contrast the body sizes of both species in angler catches and how this is influenced by the use of different angling methods; and (3) compare the catch rates of the two species to identify how pikeperch contributed to angler catches more generally.

Although the methods used to capture both species in the river are very similar, pikeperch tend to be more gape limited than pike, reducing the prey sizes they can ingest (Nilsson and Brönmark, 2000; Dörner et al., 2007). Also, pikeperch foraging consists mainly of active searching in open water (Turesson and Brönmark, 2004), whereas pike have greater foraging success in submerged vegetation than pikeperch, such as in littoral areas (Greenberg et al., 1995). In addition, pike grow to larger sizes in the study river (approximate largest body sizes: pike 14 kg, pikeperch 10 kg), although pikeperch are larger relative to the maximum size each species reaches in England. It was predicted here that both species would make similar contributions to angler catches and have similar catch rates, with the proportions of sessions where only pike or only pikeperch were captured not significantly deviating from equality, but with captured pike being of larger body sizes, irrespective of the angling methods used.

2. Methods

2.1 Study area and angler catch data

The study was conducted between June 2014 and August 2018. It was based on the fishery of the lower River Severn Basin in Western England, covering the main River Severn and its Warwickshire Avon tributary (Nolan et al., 2019b). On both rivers, no angling is allowed between 15th March and 15th June due to a mandatory closed season. The presence of impoundments (weirs, sluices) in the study area split the river into two sections. The first section covered two contiguous reaches on the River Severn and the second covered the lower reaches of the Warwickshire Avon (Nolan et al. 2019b). The River Severn reach was located primarily between Worcester and Upper Lode Weir (52.1819 N, 2.2241 W to 51.9943 N, 2.1735 W), providing a section of approximately 30 km length. In this section, river widths were to 40 m and depths were to at least 5 m. The section is known to support relatively large pikeperch, with fish captured over 10 kg, including the British rod caught record pikeperch of 10.9 kg (Angling Trust, 2019). The Warwickshire Avon reach (51.9955 N, 2.1579

W to 52.1152 N, 2.0702 W) was up to 20 m wide, with depths to 4 m. It is separated from the main River Severn by flow regulation structures that inhibit fish movements (two separate weirs) (Nolan et al. 2019b). The abiotic data collated for both rivers were river flow rates and temperature. Daily flow rate data for the River Severn were taken from the Saxons Lode gauging station (52.0497 N, 2.2005 W; Q95: 25.5 m^3s^{-1}, Q50: 53.6 m^3s^{-1}: Q5 of 287.0 m^3s^{-1} (National River Flow Archive, 2020), where Q95 represents the flow rate exceeded on 95 % of occasions, Q50 is the median flow rate and Q5 represents the flow rate exceeded on 5 % of occasions). Daily flow rate data for the Warwickshire Avon was taken from the Bredon gauging station (52.0336 N, 2.1173 W; Q95: 3.65 m^3s^{-1}, Q50: 9.68 m^3s^{-1} and Q5: 63.0 m^3s^{-1} (National River Flow Archive, 2020). As water temperature data were not available for the rivers across the entire period, daily mean air temperature data were used as a surrogate, using the Central England Temperature (CET) record (MetOffice, 2020).

2.2 Angler catch data

Data collection on the catches of anglers targeting piscivorous fishes on the rivers was facilitated by the Environment Agency, the inland fishery regulatory body of England, who established a pike angling network within the basin. Membership of this network was based on an existing group of anglers in the area that had been previously established on social media platforms, with each member recognised as being a competent angler for piscivorous fish species. On launch of the network, the anglers were provided training in how to record data on their catches, with these data including the date, duration (but not times of day) and location (for river: as the River Severn or Warwickshire Avon) of each angling session and, for each captured fish, its species, method of capture, and biometric data (fork length and weight). Fish weight was used as the primary biometric data here due to the significant relationship between fish length and weight, and due to the balances used by anglers to weigh fish considered to provide a more accurate representation of fish size across measurements taken by 16 anglers. These data were then submitted by the anglers to the Environment Agency at the end of each angling season (14th March). A total of 16 anglers submitted catch returns that were able to be utilised in analyses, although only six of the anglers also included information on angling sessions where no fish were captured. Methods of capture were ‘dead-bait’ (a dead fish is used as bait), ‘live-bait’ (a live freshwater fish is used as bait), and lures (an artificial imitation of a live fish). The anglers were not instructed where to fish and while they were likely to have preferred areas to fish, the habitats of both rivers are generally homogeneous due to their impounded nature. In all of the reaches used by the anglers, pike and pikeperch were present; a separate telemetry study based on acoustic telemetry has revealed both species occupy similar spatial areas (E. Nolan, unpublished data).

2.3 Data analyses

The sub-set of data from the six anglers who submitted no-capture data were used to test the effect on catch rate data of including data with and without information on no-capture angling sessions. This enabled identification of the effect of using capture-only data from all 16 anglers in subsequent analyses and evaluations. The initial step was to determine the proportion of no-capture versus capture sessions (overall and per angler). Then, a generalized linear model (GLM) with a binomial logistic response tested for differences between the anglers in their proportions of sessions where no fish were captured (0) and where at least one fish had been captured (1). Covariates in the model were angling effort (as number of hours fished in each angling session), air temperature, and the interaction of flow x river (given the marked difference in flow between the Severn (mean flow across all angling sessions: 60.7 ± 5.6 m^3s^{-1}) and Warwickshire Avon (12.2 ± 2.6 m^3s^{-1})). In all subsequent analyses based on catch data from all 16 anglers, the no-capture data from these six anglers were not included, as the target species during those sessions had not been recorded, preventing their allocation within the species-specific catch data.

To test for differences in the catch data between pike and pikeperch in each river, generalized linear mixed models (GLMM) were used. To test differences in the number of fish per species captured per session and river, the number of fish captured in each angling session was the dependent variable (Poisson loglinear distribution). The fixed effects were angling effort (length of the angling session in hours), air temperature and the interaction of flow and river. Angler identity was used in the model as a random effect. Model outputs were the overall significance of the model and the significance of each fixed effect, as well as the mean number of fish captured per session by species and river, with the significance of differences between these indicated by linearly independent pairwise comparisons with Bonferroni adjustment for multiple comparisons. To test differences in the number of fish captured per session by method, species and river, the same model structure was used, but with the inclusion of the interaction of method x river x species as a fixed effect. Similarly, to test the influence of flow rates on catches, the same model structure was also used, but with the flow rate during each angling session converted to its exceedance probability ('Q') from long-term flow data (1970 to 2018; National River Flow Archive, 2020). The Q values were then rounded to the nearest 5 % and used in the GLMM as a categorical variable. To test the differences in the number of fish captured per angling session per angler, a GLM was used where the fixed effects were angler identify, angling effort, the interaction of river x flow and river x species, and air temperature. The outputs of this model were as already described for the GLMMs.

The mean weights of captured pike and pikeperch were determined, and the significance of differences in the weight distribution between the species tested using a Mann Whitney U test (as the data were not normally distributed). Differences in the size of individual fish captured by species and angling method were then assessed in separate GLMs. In the models, angling method was the fixed effect and fish weight was the dependent variable; river was also used initially as a fixed effect but was removed from final models as it did not have a significant effect ($P > 0.05$). Linearly independent pairwise comparisons were used to report the significance of differences in the weights of each species between the angling methods.

The final analytical step was to test the relationship between the catch rates of pike and pikeperch during angling sessions. The initial step was to determine the proportion of angling sessions where only pike were captured, only pikeperch were captured and where both species were captured. These proportions were tested with a chi-square equality of proportions test to determine if they significantly deviated from equality. A GLMM (Poisson loglinear distribution) was then used to test for differences in the number of fish per species captured per session on days categorised as when only pike, only pikeperch and both species were captured. The fixed effects were angling effort, air temperature, the interaction of flow and river, angling method and river, with angler identity used as a random effect. Model outputs were the overall significance of the model and the significance of each fixed effect, and the mean number of pike and pikeperch captured in each category of successful angling session.

Throughout the Results, where variation is provided around the mean, it represents 95 % confidence limits.

3. Results

3.1 Catch and effort of anglers who recorded no-capture sessions

The six anglers who provided catch returns with and without fish capture completed 213 angling sessions. There were 47 sessions that did not result in fish capture (22 %; range between the anglers: 11 to 37 %). The GLM (binomial logistic distribution) testing for differences between anglers in their proportions of angling sessions with and without fish capture was not significant (Wald $\chi^2 = 8.12$, $P = 0.15$). In this model, the interaction of flow x river had a significant and positive effect ($P = 0.03$), but the effects of air temperature ($P = 0.52$) and angling effort ($P = 0.10$) were not significant. Across both species, the mean number of fish (irrespective of species) captured per angling session was 1.26 ± 0.18 when blank sessions were included in the analysis; this increased to 1.62 ± 0.19 when the blank sessions were omitted.

3.2 Factors affecting fish capture in both rivers

Across all 16 anglers and both rivers, there were 307 angling sessions when at least one fish (pike or pikeperch) was captured. The mean duration of these sessions was 5.5 ± 0.3 hours (range 1 to 19 hours). These sessions were completed in mean daily air temperatures of 10.6 ± 5.2 °C (range -1.2 to 20.8 °C). They resulted in 426 pike and 262 pikeperch being captured. The GLMM testing for differences between the numbers of pike and pikeperch captured was significant for the River Severn ($F_{1,305} = 4.09$, $P = 0.04$), with significantly higher numbers of pike captured per session than pikeperch (pike 1.85 ± 0.31; pikeperch 1.49 ± 0.36; $P = 0.04$). This was not, however, the case in the Warwickshire Avon ($F_{1,305} = 0.21$, $P = 0.65$; pike 1.32 ± 0.97; pikeperch 1.48 ± 0.99). In the model, the only fixed effect that had a positive and significant effect was angling effort ($P < 0.01$); flow (Severn flow $P = 0.35$; Avon flow $P = 0.65$) and air temperature ($P = 0.75$) were non-significant terms.

The GLMM testing for differences in the number of species captured by method and river revealed anglers caught more pike with lures than with dead- and live-bait on the River Severn (but not the Warwickshire Avon) (Table 1). The fishing method did not significantly affect pikeperch catches in either river (Table 1). In the River Severn, pike were captured at flows between 13.2 and 270 m^3s^{-1} (99.0 to 6.1 % exceedance probability) and pikeperch at flows between 16.3 and 208.0 m^3s^{-1} (94.0 to 11.1 % exceedance probability). The GLMM testing for differences in the number of fish captured according to flow was not significant, with no significant differences in the mean number of captured fish of both species across the range of flows encountered by anglers in sessions when at least one fish was captured (Fig. 1).

3.3 Size of captured fish

Across the two rivers, the weights of captured pike ranged between 0.14 and 12.11 kg (mean 3.10 ± 2.21 kg; length range 250 to 1065 mm) and pikeperch 0.12 to 8.11 kg (mean 1.97 ± 0.17 kg; length range 180 to 870 mm) (Fig. 2A). Captured pike were significantly larger than pikeperch (Mann Whitney test: U = 42434.0, $P < 0.01$). The GLM testing for differences in pike weights by method was also significant (Wald $\chi^2 = 7.82$, $P = 0.02$), where pairwise comparisons indicated that the mean weights of pike captured by dead-bait (3.48 ± 0.61 kg) were significantly higher than lures (2.68 ± 0.25 kg, $P = 0.02$), but not live-bait (2.61 ± 0.91; $P = 0.31$) (Fig. 2B). The GLM testing for differences in pikeperch weights by method was also significant (Wald $\chi^2 = 14.04$, $P = 0.02$), where pairwise comparisons indicated that the mean weights of fish captured by dead-bait (2.51 ± 0.36 kg) were significantly larger than lures (1.71 ± 0.22 kg, $P < 0.01$) but not live-bait (1.99 ± 0.62; $P = 0.47$) (Fig. 2C). For both pike and pikeperch, pairwise comparisons in the GLMs indicated that the differences in fish weights between lures and live-baits were not significant ($P > 0.05$).

3.4 Pike versus pikeperch catch rates

Of the 307 angling sessions, pike were captured in 225 sessions and pikeperch in 141 sessions. There were 166 angling sessions in which only pike were captured (54 %), 82 in which only pikeperch were captured (27 %), and 59 where both species were captured (19%). These proportions between the three categories significantly deviated from equality ($\chi^2 = 61.40$; $P < 0.01$), with higher proportions than expected of sessions where only pike were captured, but lower proportions of sessions where only pikeperch and both species were captured. The GLMM testing the number of pike and pikeperch captured in the three categories of sessions was significant ($F_{2,304} = 5.51$, $P < 0.01$). The effects of session category and angling effort were significant terms in the model ($P < 0.01$); air temperature, river, the interaction of river and flow, and angling method were all non-significant ($P = 0.12$ to 0.87). The mean number of fish captured during sessions when only pike were captured (1.43 ± 0.57) was not significantly different to when only pikeperch were captured (1.34 ± 0.51). However, the mean number of fish captured in sessions when both species were captured was significantly higher than for sessions where only pike and only pikeperch were captured (2.85 ± 1.14; $P < 0.01$ in both cases).

4. Discussion

The introduction of relatively large-bodied alien fish into freshwaters for angling enhancement has been a relatively common management practice in many areas of the world (Hickley and Chare, 2004). However, as these species are often piscivorous and result in deleterious impacts on native prey fish populations then understanding how these species contribute to angler catches is important for assessments of the cost-benefits of their introductions. The results of this study thus contribute to this body of knowledge of how these alien fishes can enhance angling performance in recreational fisheries. Comparisons between the angling exploitation of native pike versus alien pikeperch in the lower River Severn basin, western England, revealed that during angling sessions where at least one fish was captured, pike catch rates were significantly higher than those of pikeperch, contrary to the prediction. Captured pike were, however, significantly larger than pikeperch, as per the prediction, although pikeperch were larger relative to the maximum sizes achieved by the species in England. Only 19 % of 307 angling sessions where at least one piscivorous fish was captured actually resulted in the capture of both species. Anglers captured more pike when using artificial lures than other methods, whereas bait type did not affect catch rates for pikeperch. However, artificial lures tended to capture smaller fish of both species compared to dead-bait, but with pike to over 12 kg also captured on artificial lures.

In general, pike and pikeperch show some marked differences in their foraging behaviour and habitat utilisation with, for example, pike having a larger gape size than pikeperch, enabling the consumption of larger prey, and pikeperch foraging more actively in open water than pike (e.g. Greenberg et al., 1995; Nilsson and Brönmark, 2000; Turesson and Brönmark, 2004; Dörner et al., 2007). These differences appeared to enable the anglers to be selective in their approaches, despite using methods that were capable of catching both species, with few angling sessions where both species were captured. Thus, when anglers captured pikeperch, they were likely to be deliberately targeting them, such as by being more selective in their choice of lure or bait size (e.g. smaller bait sizes), and/ or presenting their baits in areas where pikeperch were more likely to be encountered (e.g. mid-channel rather than littoral areas). A major attraction of targeting pikeperch in the lower River Severn is their 'trophy' size, as they provide anglers with the opportunity to catch a relatively large individual for the species (Angling Trust 2019; Nolan et al., 2019a). That pikeperch tended to be specifically targeted by the anglers to catch, coupled with angler perceptions of them as a valued target species (Nolan et al., 2019a), is important. This is because the justifications of releasing non-native fish into recreational fisheries include diversifying angling opportunities and increasing angler satisfaction and catch rates (Hickley and Chare, 2004; Rees et al., 2017). Here, pikeperch has provided a new species for angler exploitation and some anglers appear to be sufficiently satisfied with their angling experiences that they target them specifically (Nolan et al., 2019a).

For other non-native fishes that have been used within recreational fisheries, largemouth bass have been released across the world to successfully create new angling opportunities, despite their impacts on native fish species richness (Gratwicke and Marshall, 2001). For example, Hargrove et al. (2015) revealed that in Southern Africa largemouth bass angling tournaments are very similar in character to those held in the species' native range in North America, with almost identical methods being used (primarily based on artificial lures) that result in similar catch rates, and that rarely capture native fishes. Pikeperch in England thus provide a further example of where the introduction of an alien piscivorous fish has resulted in the creation of new angling opportunities, but one where there has been reports of negative impacts on prey fish populations, particularly in canals (Hickley, 1986; Hickley and Chare, 2004). Correspondingly, it is strongly recommended that full risk assessment is completed before any further management decisions are taken on expanding the range of alien pikeperch for fishery enhancement in England so that their environmental risk can be considered carefully in relation to the angling benefits they might provide (e.g. Copp et al., 2009)

In the angling exploitation of pike, Arlinghaus et al. (2008), revealed that the use of bigger natural baits tended to attract larger pike and reduced the incidence of smaller individuals being hooked. In the lower River Severn fishery, it was apparent that catch rates of pike were higher when artificial lures were used, but with a higher proportion of smaller-bodied fish being captured than other methods (although artificial lures also resulted in fish > 12 kg being captured). In pikeperch, some selectivity for body size was similarly evident, with fish baits catching larger fish than lures, but with no differences in catch rates. Across both species, 198 pike and pikeperch were captured on lures. Given that a major factor increasing the likelihood of a fish striking a lure is its sensory perception of that lure (Nieman et al., 2020), then the participating anglers in the lower Severn basin appeared highly capable of matching their lures to the perceptual abilities of pike and pikeperch, which were likely to vary in different river conditions. This is potentially important in the lower River Severn basin, given that its river levels are heavily affected by recent precipitation rates, especially the main River Severn (Burt et al., 2002; Biggs and Atkinson 2011), where turbidity is increased in elevated flow rates. Nevertheless, pike were captured in the River Severn on lures in mean flows between Q99 and Q6, and pikeperch between Q94 and Q11, conditions in which turbidity levels were likely to vary considerably. At flow rates higher than Q6, it is likely that the river was either highly dangerous to fish or the high flows prevented the use of effective angling methods (North, 1980), resulting in negligible angling effort in these conditions.

In studies that analyse angler data, temperature is frequently reported as being a highly important factor influencing catch rates (Margenau et al., 2003; Kuparinen et al., 2010). Its influence usually relates to its strong influence on the activity, metabolism and foraging rates of the target species (Kuparinen et al., 2010). However, in this study, air temperature never had a significant effect on catches, with fish captured in air temperatures between -1.2 and 20.8 ^{o} C. This emphasises that the capture of pike and pikeperch occurred in most weather and river conditions. Note, however, that analyses relating to the influence of flow and temperature could not include no-capture angling sessions for all 16 anglers, given that sessions where no fish were captured were recorded inconsistently. Thus, the frequency of these no-capture sessions could have increased with extremes of temperature and flow. Also, the catch data were also provided by 16 anglers who specialised specifically in targeting these two species, and thus some bias in the catch rate might have also accrued from this. For example, had a wider range of anglers been used that had lower competencies in the methods used, lower catch rates might have been recorded, especially in more extreme conditions, such as low temperatures and high flows, when the probability of fish capture was likely to have been reduced.

In general, studies have indicated that biases in angler catch data relate to angling technique, seasonal changes in angling vulnerability and the influences of the repeated catch of the same fish (Gabelhouse and Willis, 1986). Here, the effect of angling techniques on the catch data was tested, revealing higher catch rates of pike when lures were used, but with larger pike captured when dead-bait methods were used. Seasonal changes on the vulnerability of pike and pikeperch to capture were generally accounted for in all analyses by using air temperature and flow within models (as temperature and flow rates vary seasonally). The potential influences of the repeated catch of the same fish on the angler data was, however, not accounted for in analyses, as these data were not routinely recorded, despite individual pike being able to be identified from images (e.g. Karlsson and Kari, 2020). Although anglers here occasionally took photographs of larger fish, this again was inconsistent across the dataset. However, as the comparisons being made here were primarily for comparing catch rates between the species rather than, for example, using them as a relative measure of population abundance (e.g. Jones et al., 1995; Karlsson and Kari, 2020), then this was also not considered to be a major issue.

In summary, it was apparent that the native pike and alien pikeperch fishery of the lower River Severn basin was able to sustain angler catch rates across a wide range of river conditions, from warm air temperatures and low flows through to cold air temperatures and relatively high flows. Anglers tended to capture one species or the other, and only occasionally captured both species during an angling session, thus their approaches could be considered as rather selective between the two species. Pike catch rates were higher than pikeperch, and involved the capture of larger fish, albeit not necessarily in relation to the maximum sizes these species can attain in British waters (Angling Trust, 2019). These results emphasise that large-bodied alien fish can have positive effects on angler catches and provide viable fisheries that anglers can exploit using similar methods as those used for targeting trophically analogous native fishes. However, decisions on the release of these species for angling should still be made according to their risk of causing ecological damage in their new environments, given the long history of large-bodied alien fishes having deleterious impacts on native fish populations and communities.

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Table 1. Results of the generalised linear mixed effects model testing differences in the number of pike and pikeperch captured by three different methods during 307 angling session on the Rivers Warwickshire Avon and Severn. (A) Overall test results by species and river. (B) Mean adjusted number of fish captured per species, method and river, where significant differences are marked in bold; in the model the significant fixed effects were angling effort (P < 0.01) and the interaction of river, species and method (P = 0.05); the non-significant fixed effects were air temperature (P = 0.91) and the interaction of river and flow (P = 0.47).

(A)

River		F	P
W. Avon	Pike	0.36	0.53
	Pikeperch	0.10	0.75
R. Severn	Pike	4.84	<0.01
	Pikeperch	0.94	0.39

(B)

River	Species	Method	Mean adjusted number of captured fish per session
W. Avon	Pike	Dead-bait	1.07 ± 0.99
		Lure	1.31 ± 1.08
	Zander	Dead-bait	1.49 ± 0.94
		Lure	1.14 ± 2.16
R. Severn	Pike	Dead-bait	1.66 ± 0.48
		Live-bait	1.51 ± 0.62
		Lure	**2.36 ± 0.30***
	Zander	Dead-bait	1.67 ± 0.60
		Live-bait	1.52 ± 0.72
		Lure	1.99 ± 0.32

*Difference between number of lure caught pike and both other methods significant at P = 0.04.

Figure captions

Figure 1. Mean number of fish captured in the River Severn between 2014 and 2018 according to flow rate (as exceedance probability value, Q) for (A) pike *Esox lucius* and (B) pikeperch *Sander lucioperca*, where the values presented are results of the generalized linear mixed model, where the overall model for both species was non-significant (pike $F_{18,221} = 1.25$, $P = 0.23$; pikeperch $F_{16,221} = 0.97$, $P = 0.49$). The fixed effects of effort and method were significant ($P < 0.01$, $P = 0.03$ respectively) but the effects of temperature and the interaction of species and Q were not significant ($P = 0.17$ and $P = 0.33$ respectively). Angler identity was included as a random factor in the model.

Figure 2. Box plots of the distribution of the weights of fish captured by anglers targeting piscivorous fishes in the lower River Severn basin between 2014 and 2018, where the horizontal lines represent the 10th, 25th, 50th, 75th and 90th percentiles, x represents mean weight and circles represent outlying data points, and where: (A) weights of all pike (n = 428) and pikeperch (n = 266); (B) pike by angling method, where D.B. = dead-bait (n = 67), L.B. = live-bait (n = 21) and lure = artificial lures (n = 272); and (C) pikeperch by angling method, where D.B. = dead-bait (n = 63), L.B. = live-bait (n = 21) and lure = artificial lures (n = 165).

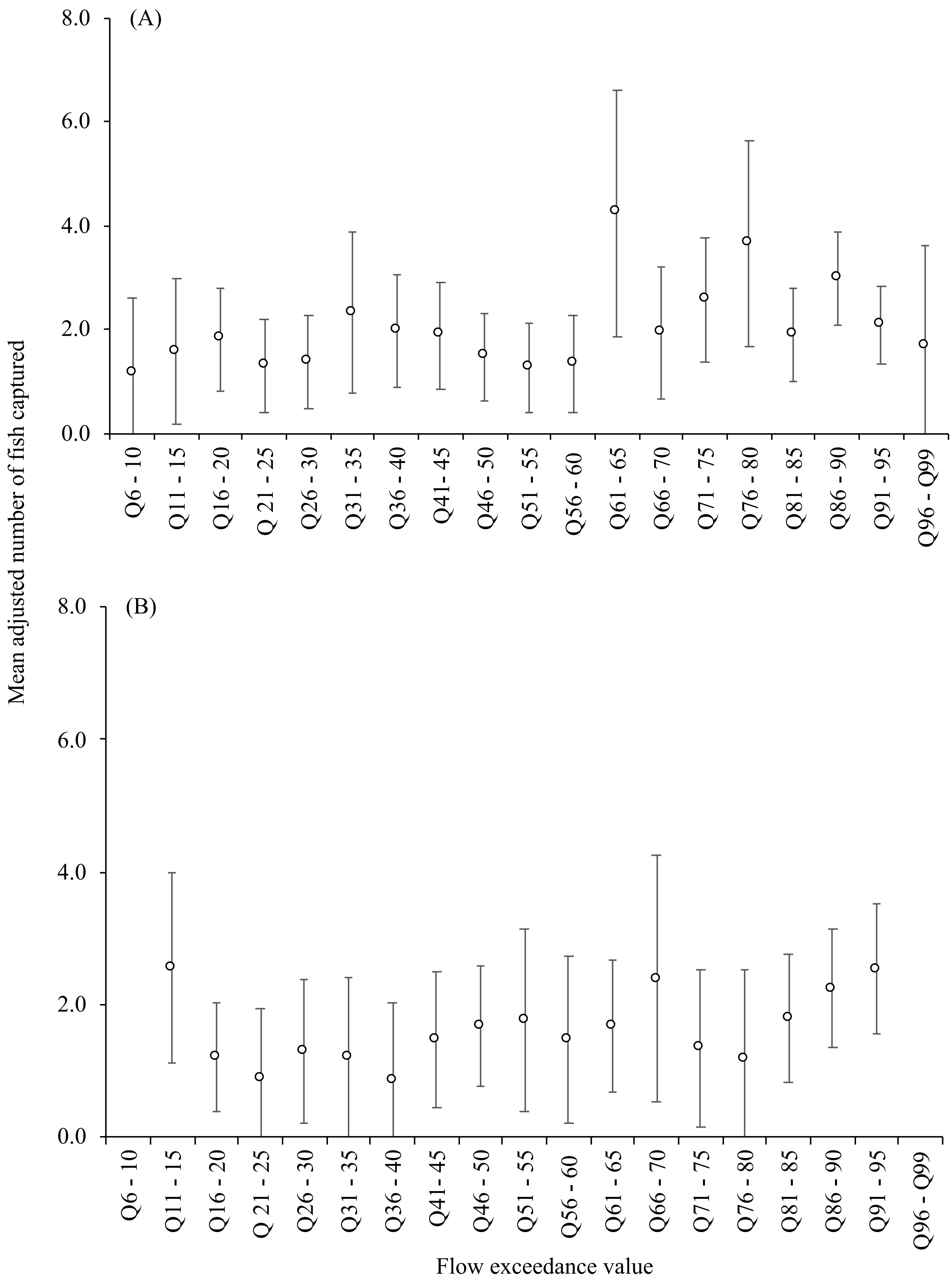
(A)
(B)
Mean adjusted number of fish captured
8.0
6.0
4.0
2.0
0.0
Q6 - 10
Q11 - 15
Q16 - 20
Q 21 - 25
Q26 - 30
Q31 - 35
Q36 - 40
Q41- 45
Q46 - 50
Q51 - 55
Q56 - 60
Q61 - 65
Q66 - 70
Q71 - 75
Q76 - 80
Q81 - 85
Q86 - 90
Q91 - 95
Q96 - Q99
Flow exceedance value

Figure 1.

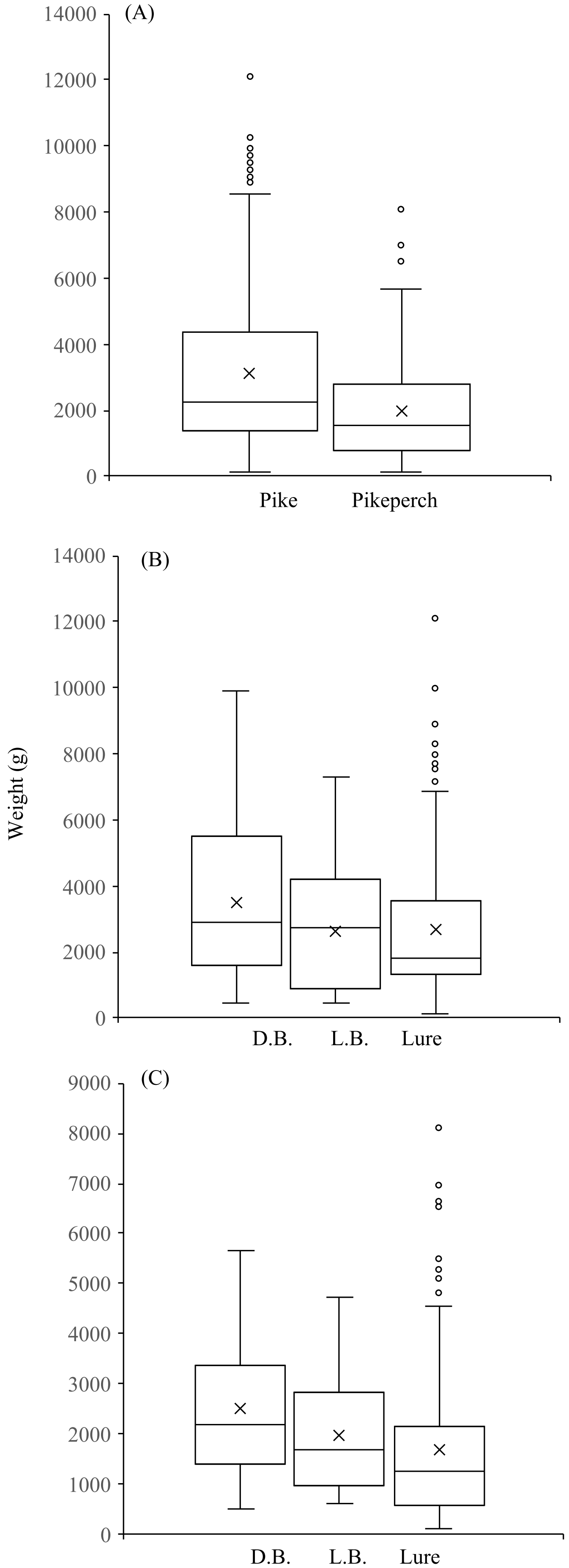
(A)
14000
12000
10000
8000
6000
4000
2000
0
Pike
Pikeperch
(B)
Weight (g)
14000
12000
10000
8000
6000
4000
2000
0
D.B.
L.B.
Lure
(C)
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
D.B.
L.B.
Lure

Figure 2.