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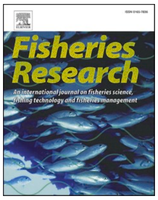

Full length article

Angler catch data as a monitoring tool for European barbel *Barbus barbus* in a data limited recreational fishery

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ABSTRACT

Large bodied freshwater fishes can be important target species for recreational anglers, with some species introduced intentionally to diversify angling experiences. European barbel *Barbus barbus* is an important target species in many riverine fisheries, including the River Severn and its River Teme tributary, western England, where it has supported a catch-and-release recreational fishery for approximately 50 years. The River Teme was renowned for the quality of its barbel angling from the 1980s. Since 2007, angler dissatisfaction has increased substantially in this fishery, being associated with alleged declines in the number of barbel being captured and in their population abundances. As there were few data available at that time to investigate these declines, data from periodic electric fishing surveys and some angler catch data were sourced. Analyses revealed temporal declines in the number of sampled barbel during electric fishing surveys, although the number of surveys was low, varied between years and did not target barbel specifically. Analyses of four angler catch data sets (1995–2022) involving more than 1000 captured barbel of 0.5–5.3 kg also revealed significant temporal declines in barbel catches (by number and catch-per-unit-effort). These catch declines were generally coincident with reductions in angler presence and effort on the river, suggesting low catches were a driver of angler dissatisfaction. These results provide empirical support for angler claims of substantial declines in barbel catches and abundances, and emphasise that even limited volumes of angler catch data are useful for understanding temporal changes in exploited but data limited fish populations.

1. Introduction

Analyses of angler catch data have been highly useful in demonstrating changes in the long-term composition of fish communities, where they can present a cost-effective approach to population monitoring (Radinger et al., 2019). Long-term catch data have been applied to understand changes in fish community structure in relation to improvements in water quality (e.g. Cooper and Wheatley, 1981; Cowx and Broughton, 1986), as well as the population status of large-bodied fishes of high sporting value (e.g. Pinder et al., 2015a, 2015b), including assessments of extinction risk (Pinder et al., 2020). These catch data are particularly useful in waterbodies where population monitoring is inherently difficult, such as in rivers whose physical characteristics constrain the use of standard methods such as electric fishing due to, for example, the combination of river depth, high flow and/ or poor access (Pinder et al., 2015; Radinger et al., 2019). In these situations, analyses of catch records from anglers provide an alternative or complementary method of population monitoring (Jones et al., 1995; Karlsson and Kari, 2020).

Recreational angling is a major introduction pathway of large-bodied non-native fishes into freshwater ecosystems (Banha et al., 2017; Britton, 2023). These species are released into fisheries to diversify angling experiences and increase angler satisfaction levels (Hickley and Chare, 2004; Banha et al., 2024). The benefits provided to recreational fisheries of non-native fishes then have to be balanced versus their potential for negatively impacting native fish assemblages, given that species introduced for angling have gone on to have deleterious impacts on native fish species richness through, for example, increased predation pressure (e.g. Pelicice and Agostinho, 2009; Glassic et al., 2023) and genetic introgression (e.g. De Santis et al., 2021; Hartman et al., 2024).

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Nevertheless, the importance of these fishes for enhancing angler catches and satisfaction levels in recreational fisheries (Britton and Nolan, 2021) means that detecting temporal changes in their population abundances is important (Radinger et al., 2019). The application of angler catch data to understanding long-term changes in the target populations must, however, consider that some angling methods are highly size- and species-selective, including strong angler selection for larger-bodied individuals of some species (Amat Trigo et al., 2017), especially by anglers specifically targeting specimen fish (Žák, 2021). The number of larger-bodied species captured can also be relatively low due to their relatively low abundance and catch avoidance through learning (Askey et al., 2006), limiting the size of datasets (Pinder et al., 2015a,b). Angler catches can also be limited by the influence of abiotic factors that affect the vulnerability of the fish to capture, such as temperature and river flows (Kuparinen et al., 2010; Britton and Nolan, 2021).

An example of a freshwater fish whose distribution has increased through introductions for angling is the European barbel *Barbus barbus* ('barbel') (Britton and Pegg, 2011). In Britain, this fish of the Cyprinidae family is found naturally only in eastern flowing rivers, but populations are now present in rivers in western and southern England following introductions for diversifying angling activities in these rivers (Wheeler and Jordan 1990; Antognazza et al., 2016). Following the release of 509 adult barbel in 1956 into the River Severn (western Britain) for fishery enhancement, a population established and then dispersed throughout the middle and lower river reaches (Wheeler and Jordan, 1990). Subsequent reports in the 1970s revealed barbel being caught by anglers in the River Teme, a major tributary of the lower River Severn (Hunt and Jones, 1975; Antognazza et al., 2016; Amat Trigo et al., 2017; Fig. 1). The River Teme subsequently developed in to a fishery renowned for the quality of its angling for barbel, especially in terms of anglers being able to catch relatively large numbers of individual fish between 2 and 4 kg (Britton et al., 2013). In general, concerns on the ecological impact of barbel on other species in the river have been limited (Gutmann Roberts and Britton, 2018a, 2018b; De Santis et al., 2019).

Following the establishment and dispersal of barbel in the River Severn, a series of studies were completed on their population biology during in the 1960s (e.g. Hunt and Jones, 1975), but with no specific studies completed on the River Teme (Britton et al., 2013). Anglers reported large declines in barbel catches in the River Teme from 2007, which has been coincident with a decline in angler presence (Gutmann Roberts, 2018). Investigating these claims of catch declines and how they relate to barbel population abundance has been inhibited by the limited quantitative data available for the river's fish populations. Age and growth studies based on scales collected from angler catches have indicated that the barbel population was comprised of slow growing but long-lived (>20 years) individuals (Britton et al., 2013; Amat Trigo et al., 2017). These long-lived individuals, resulting from strong year classes produced in the 1970s and early 1980s, suggested the population was vulnerable to declines in abundance if they were not being replaced by strong recent recruitment (Britton et al., 2013). However, the lack of available quantitative barbel population data prevented fishery managers from understanding the temporal patterns in their abundance and how they related to claims by anglers of declines. To overcome this data limitation, the objectives here were investigate the temporal patterns in the barbel population abundance of this river by sourcing and analysing any fisheries monitoring data and angler catch records that were available for this period. Assessment was also made in relation to how other species contributed to fisheries monitoring and angler catch data compared with barbel. Completing these objectives also provides insight into the complementarity of angler catch data and fisheries monitoring survey data collected by electric fishing.

2. Materials and methods

2.1. Study area and environmental data

The River Teme is approximately 122 km in length, draining a catchment of 1648 km^2. Barbel are restricted to its middle and lower reaches, with no barbel present upstream of the town of Ludlow, with most barbel related angling activity taking place downstream of the town of Tenbury Wells and through to its confluence with the River Severn (Fig. 1). In these areas of the river, its physical habitat mainly comprises of large pool and riffle sequences within a river channel of up

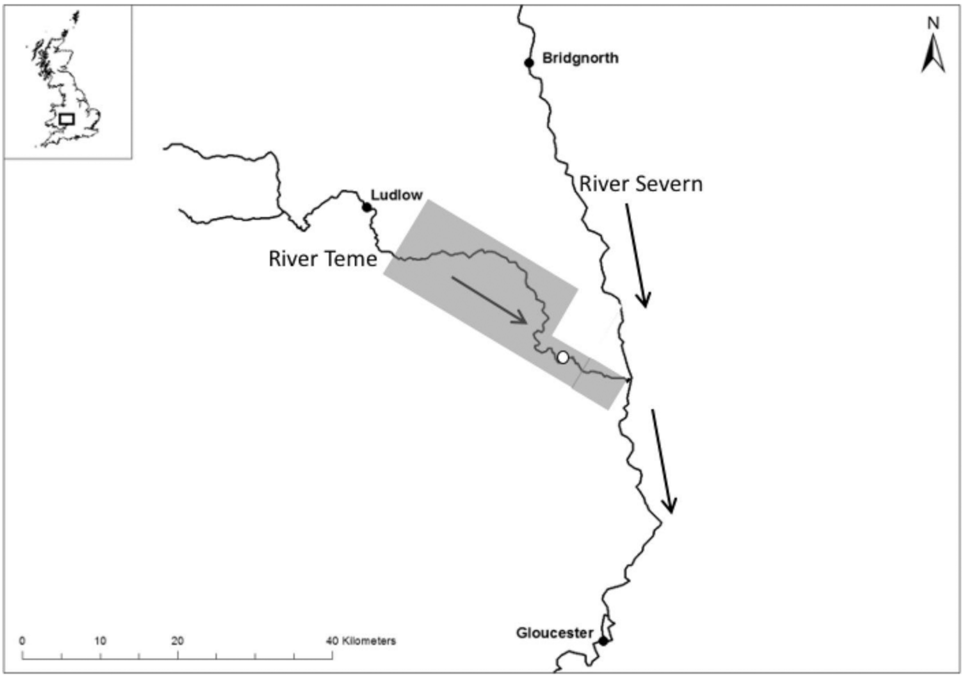

Fig. 1. Inset: location of the study area within Great Britain. Main map: Location of the River Teme study area (grey shaded area) in relation to the river generally and the town of Ludlow (upper limit of barbel *Barbus barbus* dispersal), and in the relation to the River Severn. Arrows show the direction of river flow. The filled circles show the location of important towns and the clear circle shows the location of the flow gauging station at Knightwick.

to 15 m width and depths generally < 2 m (Gutmann Roberts and Britton 2018). Whilst overhanging trees (primarily *Salix* spp.) are abundant in the riparian zone, there tends to be low levels of in-stream macrophyte cover. In the study reach, there is a cypriniform fish community of generally low diversity, with species present including chub *Squalius cephalus*, dace *Leuciscus leuciscus*, gudgeon *Gobio gobio,* bleak *Alburnus alburnus,* stone loach *Barbatula barbatula* and minnow *Phoxinus phoxinus* present, along with the translocated barbel (Gutmann Roberts and Britton, 2018). All angling for cypriniform fishes on the river uses catch-and-release methods.

A flow gauging station towards the downstream end of the river (Knightsford Bridge; Fig. 1) revealed a long-term Q95 (long-term flow rate exceeded 95 % of the time) of 2.04 m^3s^{-1}, Q50 (median flow rate) of 10.13 m^3s^{-1} and Q5 (flow rate exceeded 5 % of the time) of 62.8 m^3s^{-1} (CEH, 2018). This gauging station also provided the mean daily flow data that were used within subsequent multivariate models. As water temperature data were not available for the river across the entire period, daily mean air temperature data were used as a surrogate, using the Central England Temperature (CET; recorded in tenths of Celsius) (MetOffice, 2020).

2.2. Fisheries survey data and analyses

Data from fisheries monitoring surveys completed by the Environment Agency (the public authority in England responsible for inland fisheries regulation and management) were available from an online, open access database (Environment Agency, 2020), with data extracted for surveys from the relevant area of river (Fig. 1). The area of river sampled and the numbers of barbel and chub captured were extracted, as chub is also an important angler target species in the river. All of the extracted survey data had been collected by electric fishing, either from a boat or wading (depending on water depth). Some surveys involved only completing a single pass while others were completed using two-passes. Therefore, to ensure consistency in data analyses, where surveys had been completed using two-passes, the numbers of barbel and chub captured in only the first pass were used. Across these electric fishing surveys, between 50 and 350 m of river length was sampled using pulsed DC equipment. The final extracted dataset comprised of 30 electric fishing surveys completed on relevant reaches of the river between 1991 and 2015 and where barbel and/ or chub were present in samples, providing data for subsequent analyses on the number of barbel and chub captured, and the total area fished (Table 1).

2.3. Angler catch data and analyses

Angler catch data were sourced for the river following communications distributed to angling associations and individual anglers in the area. Although this resulted in numerous catch datasets being provided, most were unsuitable for analysis as they covered an insufficient number of years and/ or had key data missing (e.g. no records kept of days when no barbel were captured, resulting in inaccurate estimates of catches). However, four datasets were retained for analyses (Dataset 1–4; Table 1). The composition of each dataset differed slightly (Table 1). Although Datasets 2 and 3 appeared most similar, there were significant differences in effort between them (Permutational Univariate Analysis of Variance, PERANOVA, df = 471, $F = 4.33$, $P = 0.04$) and in the number of fish caught (PERANOVA, df = 472, $F = 33.32$, $P = 0.01$). Consequently, these retained datasets were analysed separately using different model structures (see next section). Nevertheless, these datasets were relatively consistent in the angling approaches that had been applied, with the principal methods used to capture barbel in the river based upon the use of static hook-baits (usually pelletized fishmeal or processed meat products) on the riverbed. These angling methods primarily target barbel of relatively large body sizes (Amat Trigo et al., 2017; Gutmann Roberts et al., 2017). Where recorded, the individual weights of captured barbel ranged between 0.5 and 5.3 kg.

Dataset 1 comprised of catch records of five anglers who visited the river each July between 2006 and 2016, fishing the same stretches of river with consistent angling methods. The data recorded included total angling effort per session (hours), and the number of barbel and other species captured per session. Dataset 2 was collected by an individual angler known to the authors for their high competence in barbel angling generally, with data collated between 2007 and 2016 (Table 1). The data provided were the dates fished, locations, effort applied (hours), and the number of barbel captured (Table 1). Dataset 3 was the most comprehensive dataset, providing catch data from an individual angler in all months of the angling season (June to March) between 2004 and 2013. The recorded data were date, effort (hours), the number of barbel captured and their sizes, and the number of other species captured (Table 1). Dataset 4 was collated by an individual angler, with the catch data available for each session fished on the river between 1995 and 2022 (date, the number of barbel captured; angling effort; Table 1). Where date of angling was available within the dataset then the mean daily flow (recorded at Knightsford Bridge; Fig. 1) and mean daily air temperature (as CET in tenths of Celsius) were determined for each angling session for use in models.

2.4. Statistical analyses

The dependent variable in all of the models used to analyse the temporal patterns in the catch data were the number of fish (as barbel or chub) captured. With count data being used then the models were always generalized Poisson linear mixed models (after assessing for overdispersion) all performed in the R environment (version 4.2.3; R Core Team, 2024) using the `glmmTMB` package (Brooks et al., 2017). The use of count data meant that the catch and effort (as area fished for electric fishing and time for angling data) were used separately within models, enabling the effect of effort on the number of fish captured to be included as a fixed factor (Lauretta et al., 2016; Britton and Nolan, 2021). Prior to model fitting, data exploration was conducted following the protocol outlined by Ieno and Zuur (2015). This included checking for missing values, outliers in the response and explanatory variables, homogeneity, zero inflation in the response variable, collinearity among explanatory variables, the balance of categorical variables, and the nature of relationships between the response and explanatory variables. The data for sample size were positively skewed and contained outliers, which had to be removed across all datasets to enable model fitting. Specifically, the fished area was reduced from 10800 to 5250 m^2 in the

Table 1
Information on the datasets used in the study, covering the methods used (E-fish = electric fishing), years covered, total effort (as number of electric fishing surveys (Fish surveys), the angling hours for DS 1–3, and angling days for DS4, and the total number and mean number of barbel *Barbus barbus* and chub *Squalius cephalus* captured per session per dataset. Error around mean values are 95 % confidence limits.

Dataset	Method	Years	Total effort	Total barbel	Mean barbel	Total chub	Mean chub
Fish surveys	E-fish	1991–2015	30 surveys	251	8.4 ± 2.9	191	5.3 ± 2.5
Dataset 1	Angling	2006–2016	6124 h	654	0.7 ± 0.1	229	0.3 ± 0.1
Dataset 2	Angling	2007–2016	400 h	215	3.2 ± 0.7	-	-
Dataset 3	Angling	2004–2013	2124 h	340	0.8 ± 0.1	110	0.3 ± 0.1
Dataset 4	Angling	1995–2022	495 h	120	1.2 ± 0.4	-	-

fisheries survey dataset; in the angler catch datasets, effort was only included when it was a maximum of 8 hours, and flow only when it was a maximum of 28.5 $cm^3 s^{-1}$. These adjustments reduced the number of data points from 30 to 27 in the fisheries survey dataset, from 886 to 813 in Dataset 1, from 68 to 56 in Dataset 2, from 474 to 433 in Dataset 3, and from 100 to 97 in Dataset 4.

The datasets had different combinations of variables available for testing and had to be tested with a range of different model structures. Consequently, four main models were used. The electric fishing dataset were analysed in Model 1, testing the effect of the area sampled and the year of sampling on the numbers of barbel and chub captured on each sampling occasion. Angler Dataset 1 used Model 2, which assessed the effect of angling effort and year on the number of captured barbel. Angler Datasets 2, 3 and 4 used Model 3, testing the effect of angling effort, year of angling, temperature, flow on the number of captured barbel (Table 1).

We modeled the count of fish (denoted as SS_{ijkl} — either barbel or chub — collected from sample i in year j at fishing site k) using a generalized Poisson distribution. This distribution is defined by an expected mean $\mu ijkl$ and a variance $\mu ijkl \times \nu ijkl$, where $\nu ijkl$ is a dispersion parameter that accounts for overdispersion or underdispersion in the data. The log of the mean $\mu ijkl$ is linked to the linear predictor $\eta ijkl$ as follows:

$\log(\mu_{ijkl}) = \eta_{ijkl}$

Model 1:

$\eta_{ijkl} = \beta_1 + \beta_2 \times Area\_fished_{\mathrm{ijkl}} + \beta_3 \times Year_j + (1|Site_k)$

Fixed Effects: The fixed effects in this model include the area fished ($Area\_fished_{\mathrm{ijkl}}$) and the year ($Year_j$). The coefficients β_1 to β_3 correspond to these predictors.

Random Effects: A random intercept for fishing site ($Site_k$) is included to account for variability across different sites, modeled as $Site_k \sim N(0, \sigma^2_{Site})$.

Model 2:

$\eta_{ijkl} = \beta_1 + \beta_2 \times Effort_{\mathrm{ijkl}} + \beta_3 \times Year_j$

Fixed Effects: This model considers the sampling effort ($Effort_{\mathrm{ijkl}}$) and the year ($Year_j$), with coefficients β_1 to $\beta_{3.}$

Model 3:

$\eta_{ijkl} = \beta_1 + \beta_2 \times Effort_{\mathrm{ijkl}} + \beta_3 \times Year_j + \beta_4 \times Temperature_{\mathrm{ijkl}} + \beta_5 \times Flow_{\mathrm{ijkl}}$

Fixed Effects: In the models, the fixed effects include sampling effort ($Effort_{\mathrm{ijkl}}$), year ($Year_j$), temperature ($Temperature_{\mathrm{ijkl}}$), and flow ($Flow_{\mathrm{ijkl}}$), with corresponding coefficients β_1 to β_5.

Following calculation of the GLMMs, the final analysis of the temporal relationship of the angler catches converted the number of fish captured in each angling session per dataset to catch per unit effort (CPUE; as number of fish captured/ duration of angling session). As the relationship between angling year was non-linear, the relationship was tested using quadratic regression.

3. Results

3.1. Electric fishing survey analyses

The results of the generalized Poisson regression model analysing the barbel electric survey data indicated significant reduction in barbel numbers over time (years), but the area fished did not have a significant effect (Table 2, Fig. 2A). The decrease in the number of captured barbel was apparent across the entire dataset and commenced much earlier than 2007 (Fig. 2A). For chub, none of the predictors in that model had significant effects, with no overall significant temporal pattern in the numbers captured by electric fishing (Table 2, Fig. 2B).

3.2. Angler catch datasets

In Dataset 1, there were significant effects of effort and year on the number of captured barbel (Table 3, Fig. 3). Higher effort resulted in more captured fish, whereas the year of angling had a negative effect, with a gradual temporal decline in the numbers captured (Table 3, Figs. 3A, 3B). For Dataset 2, year had a negative and temperature a positive significant effect on barbel counts, but effort and flow were not significant (Table 3, Fig. 4). In Dataset 3, the number of barbel captured was positively and significantly affected by angling effort and flow, year had a negative and significant effect, and temperature was not significant (Table 3, Fig. 5). In Dataset 4, year and flow had negative and significant effects on the number of captured barbel, with temperature and effort not being significant (Table 3, Fig. 6). The temporal relationship of CPUE was significant and negative for Datasets 1, 3 and 4 ($P < 0.05$, Fig. 7).

Table 2
Result of the Generalized Poisson Regression of the relationship between the numbers of barbel *Barbus barbus* and chub *Squalius cephalus* captured by electric fishing between 1991 and 2016 and the area fished and year of fishing. Significant P values are denoted by bold font.

Species	Coefficient	Log-Mean	95 % CI	P
Barbel	Intercept	167.20	71.40 – 263.01	**0.001**
	Fished area	−0.00	−0.00 – 0.00	0.907
	Year	−0.08	−0.13 – −0.03	**0.001**
Chub	Intercept	116.35	−41.12 – 273.82	0.148
	Fished area	0.00	−0.00 – 0.00	0.937
	Year	−0.06	−0.14 – 0.02	0.153

4. Discussion

The issue of a lack of data to assess temporal changes in this barbel fishery were overcome here through the sourcing of both electric fishing survey data and angler catch records. The electric fishing survey data revealed a temporal decline in the number of sampled barbel, although the decline was evident across all years and so commenced prior to 2007. Moreover, these surveys were rarely targeting the sampling of barbel specifically and were more focused on capturing a wider range of fish species from all available habitats, and thus barbel might have under-represented in some of the samples, limiting our ability to evaluate the results in the context of the angler complaints post-2007. Correspondingly, the sourcing and subsequent application of angler catch data arguably provide a more reliable temporal assessment of the adult barbel population, given that relevant catch analyses can generally provide biological insights into the specific components of the fish stocks that are being exploited (Radinger et al., 2019). Indeed, stock abundance and the number or mass of fish captured by anglers are often strongly related (Beard et al., 1997), although these relationships can be species-specific and are not always evident (Pierce and Tomcko, 2003). Where abundance and catch are related, these relationships can be linear (e.g. North, 2002) or non-linear (e.g. Abbott and Fenichel, 2013).

The angler-catch datasets all revealed that year always had a negative and significant effect on the numbers of barbel captured by anglers, while effort only had positive and significant effects in Datasets 1 and 3. When expressed as CPUE, temporal declines in catch rates were evident in all but Dataset 2. This consistent negative effect of year on barbel angler catches (as number and CPUE) were generally consistent with the results from the electric fishing, although differences in the sampling methods and the years with data available inhibit direct comparisons between these datasets. In entirety, these results provide empirical support that there has been a temporal decline in the number of barbel being captured by anglers on the river align to the high levels of angler dissatisfaction in the performance of this barbel fishery (Gutmann Roberts, 2018). In general, angler satisfaction is often positively related to the fishing experience (e.g. Arlinghaus et al., 2008; Nolan et al., 2019), with total angling effort and angling quality (as catch number and/ or size of captured fish) also positively related (e.g. Post et al., 2008; Johnston et al., 2010). Indeed, the relationship between angler density and the number or mass of captured fish has been suggested as

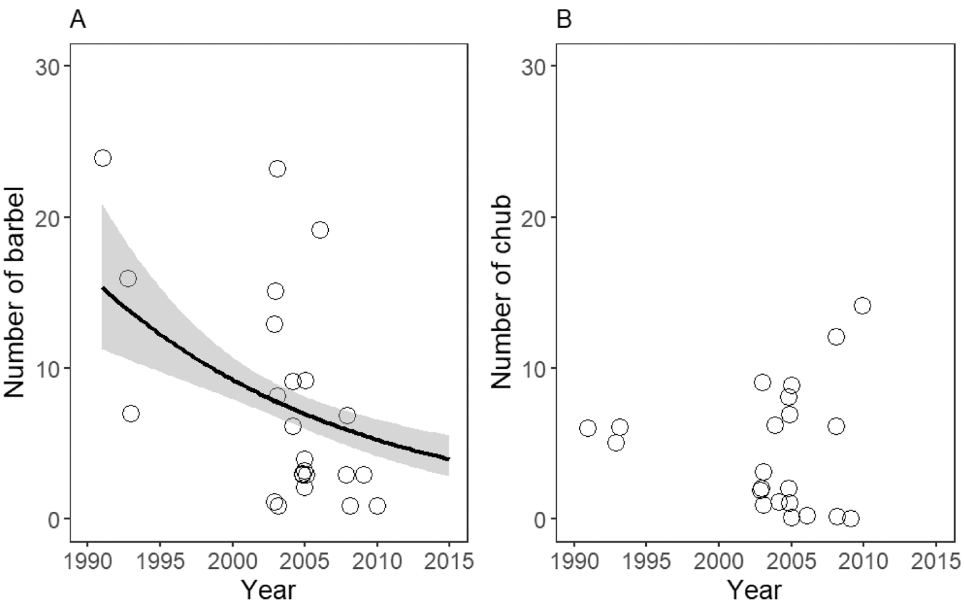

Fig. 2. Number of barbel *Barbus barbus* (A) and chub *Squalius cephalus* (B) sampled during the first pass of electric fishing surveys in the River Teme between 1991 and 2016, where the solid line represents the significant relationship between the variables according to the generalised linear mixed model and the grey shading is the 95 % confidence limits around this relationship.

Table 3

Results of the Generalized Poisson Regressions for the testing the relationship between angling effort and year on the number of barbel *Barbus barbus* captured by anglers in Dataset 1, and between angling effort, year, temperature and river flow for Datasets 2, 3 and 4. Significant P values are denoted by bold font.

Dataset	Coefficient	Log-Mean	95 % CI	P
1	Intercept	420.25	325.50 – 515.00	**<0.001**
	Effort	0.30	0.19 – 0.41	**<0.001**
	Year	−0.21	−0.26 – −0.16	**<0.001**
2	Intercept	205.91	11.14 – 400.68	**0.038**
	Effort	0.04	−0.07 – 0.15	0.518
	Year	−0.10	−0.20 – −0.01	**0.038**
	Temperature	0.01	0.00 – 0.02	**0.002**
	Flow	0.04	−0.02 – 0.10	0.207
3	Intercept	130.22	26.62 – 233.82	**0.014**
	Effort	0.34	0.26 – 0.43	**<0.001**
	Year	−0.07	−0.12 – 0.01	**0.012**
	Temperature	0.00	−0.00 – 0.01	0.179
	Flow	0.02	0.00 – 0.04	**0.048**
4	Intercept	117.71	44.73 – 190.69	**0.002**
	Effort	0.24	−0.11 – 0.60	0.173
	Year	−0.06	−0.10 – −0.02	**0.001**
	Temperature	0.00	−0.00 – 0.01	0.314
	Flow	−0.07	−0.13 – 0.00	**0.040**

analogous to a predator numerical response to variability in prey abundance (Post et al., 2008). Therefore, the general decline in barbel angler occupancy of the River Teme, which has been widely reported by angling associations in the catchment (Gutmann Roberts, 2018), is likely to be a function of the decreased angling success revealed here.

Changes in angler catches can indicate relative changes in fish population abundances (Cowx et al., 1986; North et al., 2002), although these inferences can be biased towards the species targeted specifically by anglers (Smith, 2002). This bias was not considered problematic here, given the anglers were targeting barbel specifically. Biases in catch data can also include the angling techniques used and the seasonal changes in the vulnerability of fish to angler capture (Getz et al., 2024; Smith et al., 2024). Here, in the catch datasets used, the angling methods were generally consistent and applied within specific spatial areas known by the anglers to be inhabited by barbel (Gutmann Roberts et al., 2019a), thus the fishing method was not considered as a confound across the datasets. The effect of seasonal changes on the vulnerability of barbel to capture was accounted for in datasets by controlling for the effects of temperature or flow in models where possible. North (1980) and North and Hickley (1989) both suggested that temperature was an important predictor of angler success in the nearby River Severn, with the importance of barbel in catches increasing rapidly between 5 and 15 °C; elevated flows were reported as affecting the mechanics of angling, preventing anglers from presenting their baits effectively. Here, when temperature was significant in models, its effect on catch was positive, with more barbel captured at warmer temperatures. For flow, there was some context dependency, with elevated flow rates both decreasing and increasing the number captured fish, depending on the dataset.

Although these results indicated the high utility of angler catch datasets for analysing temporal patterns in catches and thus also in the abundance of the exploited component of the barbel population, there was inconsistency across the datasets in relation to the type of data that were recorded (e.g. differences in how angling effort was recorded and across different timeframes). This meant that each dataset had to be analysed separately, rather than together in a single model that would have substantially increased statistical power. Consequently, where there is a management requirement to monitor angler catches in recreational fisheries that are based on specific species (such as barbel here), it is recommended that a standardised catch monitoring system is implemented to enable efficient recording of both appropriate metadata (e.g. date, time (effort), approximate location, angler demographic data, methods used) and the catch related data (e.g. number and size of fish captured by species, including when no fish are captured). Mandatory catch return systems are already in place for Atlantic salmon *Salmo salar* in England that provide data for informing conservation actions (e.g. Aprahamian et al., 2006). While such an approach might be unsuitable for species that lack conservation designations (including barbel), the adoption of formal catch reporting, allied with high participation by anglers, would help generate robust data for analysing temporal and spatial changes in fishery performance that will at least partially be driven by changes in the stock structure and abundance of the fish community (Radinger et al., 2019). Moreover, opportunities to implement appropriate recording schemes are increasing through the ‘apps’ that now available for use on smart phones that

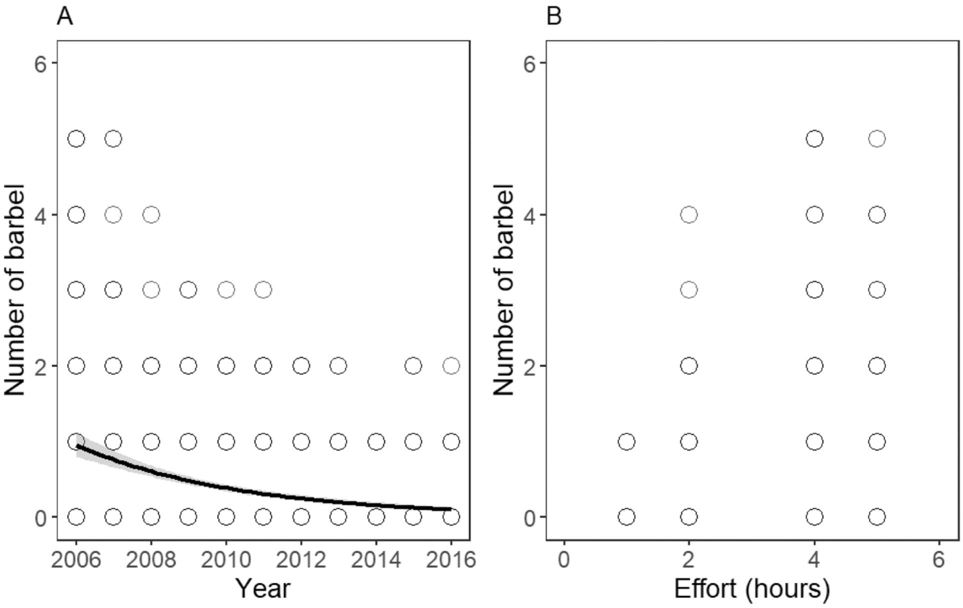

Fig. 3. Number of barbel *Barbus barbus* captured per angling session in the River Teme by year (A) and effort (B) in Dataset 1, where the solid line represents the significant relationship between the variables according to the generalised linear mixed model and the grey shading is the 95 % confidence limits around this relationship.

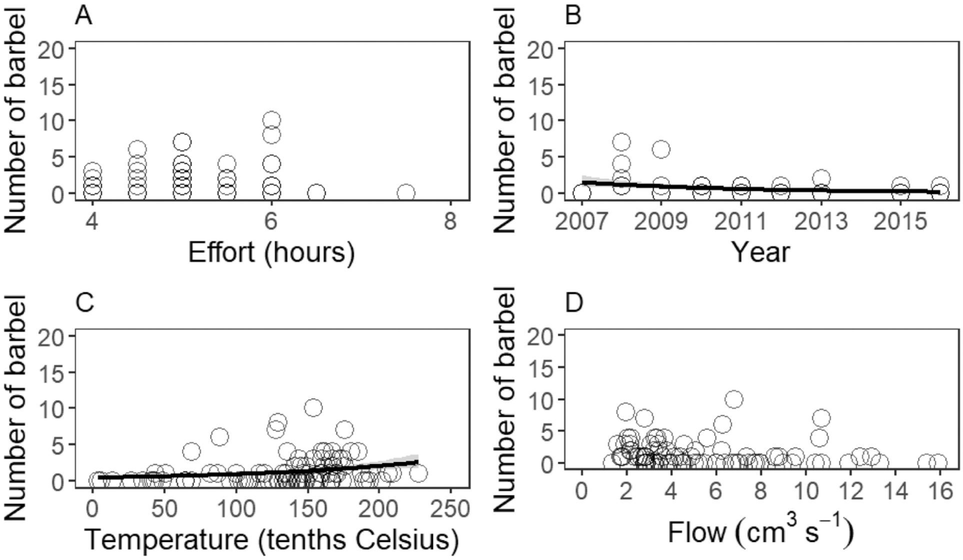

Fig. 4. Number of barbel *Barbus barbus* captured per angling session in the River Teme by year (A), effort (B), Temperature (C) and Flow (D) in Dataset 2, where the solid line represents the significant relationship between the variables according to the generalised linear mixed model and the grey shading is the 95 % confidence limits around this relationship.

provide diverse opportunities for anglers to interact with the resources and management of the fisheries they exploit (Venturelli et al., 2017; Britton et al., 2023). However, irrespective of how the angler catch data are collated, the data also need to consider limitations relating to the vulnerability of the focal population to angler capture. Fish populations often have a group of individuals that are relatively easy to catch, captured quickly and then show hook avoidance behaviours (Askey et al., 2006; Lovén Wallerius et al., 2020). Consequently, scaling up angler catch information to population level inferences might be skewed by catches mainly comprising of the specific phenotypes most vulnerable to capture and recapture (e.g Koeck et al., 2019).

This application of angler catch data for providing information on the relative abundances of this introduced and invasive barbel population is consistent with its application as a monitoring tool in other fish populations, where the results have helped the development of population management strategies (Granek et al., 2008; Pinder et al., 2015a, b). In many case studies where angler catch data have been applied as a monitoring tool, the focal species has been of relatively high economic value (food or recreationally), but now are being threatened, such as Atlantic salmon (Gee and Milner, 1980) and Hump-backed mahseer *Tor remadevii* (Pinder et al., 2020). Catch record monitoring has also been applied to the detection and spread of invasive fishes (Banha et al., 2015, 2017). In all cases, the use of angler catch data has proved to be a highly cost-effective alternative in providing temporal data on the fish stock that provided key insights into the long-term population patterns and trends in the exploited component of the stock (Pinder et al., 2015a). For barbel in the River Teme, however, there is a paradox in that although there is high angling performance and fishery management concern in

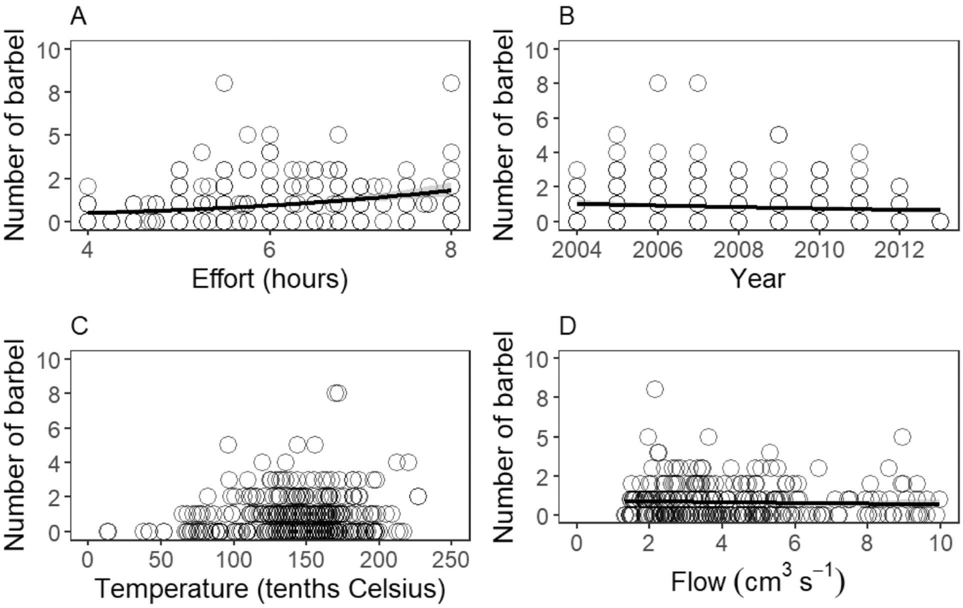

Fig. 5. Number of barbel *Barbus barbus* captured per angling session in the River Teme by year (A), effort (B), Temperature (C) and Flow (D) in Dataset 3, where the solid line represents the significant relationship between the variables according to the generalised linear mixed model and the grey shading is the 95 % confidence limits around this relationship.

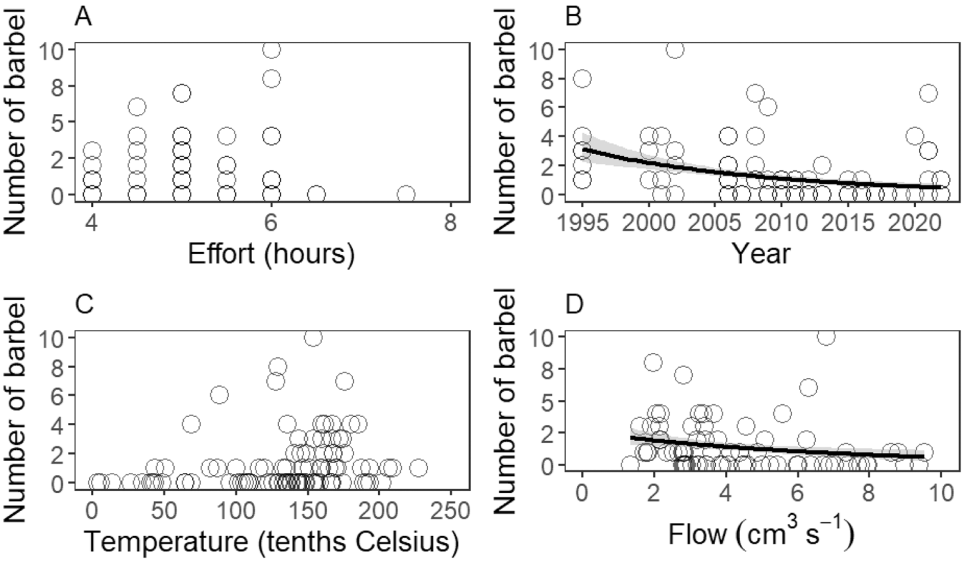

Fig. 6. Number of barbel *Barbus barbus* captured per angling session in the River Teme by year (A), effort (B), Temperature (C) and Flow (D) in Dataset 4, where the solid line represents the significant relationship between the variables according to the generalised linear mixed model and the grey shading is the 95 % confidence limits around this relationship.

the catch declines, the species is non-native to the river and only been captured regularly since the 1970s. Correspondingly, this potentially results in conflicting messages between regulators, managers, relevant angling and conservation stakeholders in how non-native species should be used within angling contexts more generally (Hickley and Chare, 2004). Already, anglers specialising on the non-native pikeperch *Sander lucioperca* elsewhere in the River Severn basin treat the species as naturalised with, for example, most captured fish being released, despite this being contrary to legislation (Nolan et al., 2019). Correspondingly, there is arguably a requirement for some reconciliation in the conservation messages being applied between non-native species that are used for enhancing angling versus those applied to non-native fish that are considered a pest, where management interventions can be severe (Britton and Brazier, 2006; Britton et al., 2011).

Should fishery regulators decide that promoting the restoration of this introduced barbel population of the River Teme is a management priority then the factors behind their decline require further investigation. Age and growth studies have revealed that adult barbel in the river are very slow growing but relatively long-lived (> 20 years) (Britton et al., 2013; Amat Trigo et al., 2017). Thus, the relatively high historical catches made by anglers were likely to have been supported by fish from year-classes produced in, for example, the 1980s when barbel were still colonising the river. The natural mortality of these year-classes, perhaps coupled with years of poor recruitment thereafter, could provide at least partial explanation of these adult barbel catch declines. The issue is not considered to relate to poor barbel reproduction, given that work between 2015 and 2017 revealed high numbers of 0+ barbel were present in the river each summer (a, 2018; b, 2020) and with the condition of

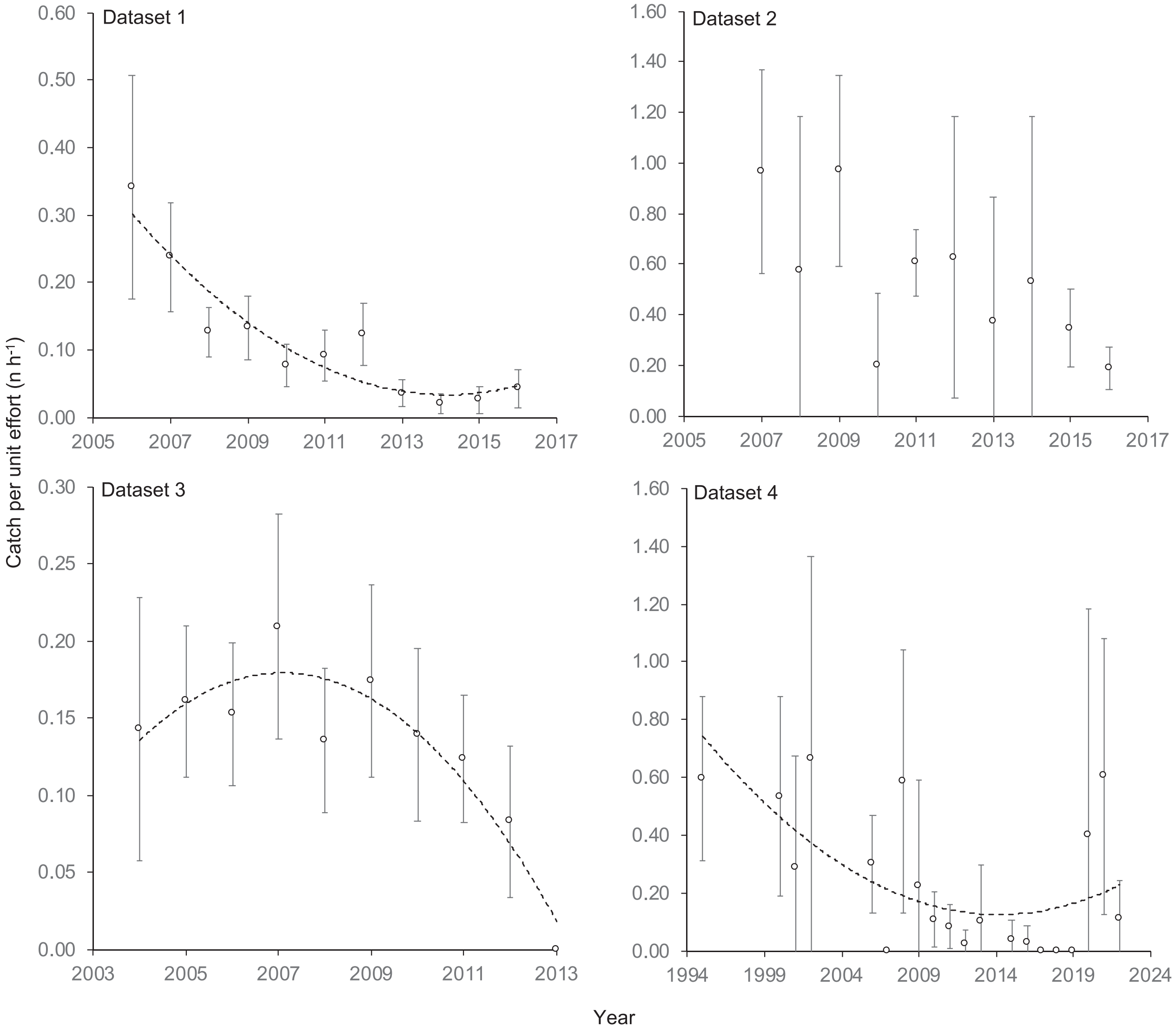

Fig. 7. Relationship of catch per unit effort over time for Datasets 1–4, where the dashed line represents the significant relationship according to quadratic regression (Dataset 1: $R^2 = 0.88$, $F_{2,8} = 32.89$, $P < 0.001$; Dataset 3: $R^2 = 0.87$, $F_{2,7} = 22.85$, $P < 0.001$; Dataset 4: $R^2 = 0.41$, $F_{2,17} = 5.81$, $P = 0.01$). Note that for clarity, both x and y axes have different ranges between each dataset.

spawning gravels not considered to be a constraint for redd creation (Gutmann Roberts et al., 2019b). It thus is more likely to be due to factors acting on the fish between after their first summer of life and their appearance in angler catches at weights of above 0.5 kg when they are likely to be at least 5 years old (Amat Trigo et al., 2017). This, however, requires further work to better understand the dynamics of this non-indigenous barbel population. This case study does, however, highlight that where angling regulators and fishery managers want to understand temporal (and spatial) patterns in fishery performance and fish population dynamics, more proactive approaches are required for collating data during periods of high angling satisfaction so that the reasons behind periods of reduced angling satisfaction can be more easily determined and understood.

Declaration of Competing Interest

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

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Data availability

Data will be made available on request.

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