

ARTICLE



Quantitative estimates of freshwater fish stocking practices by recreational angling clubs in France

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Abstract

Although freshwater fish stocking is widely used by managers, quantitative assessments of stocking practices are lacking in many countries. The general objective of the present study was to determine the quantity and characteristics of fish stocking in metropolitan France. Using a survey-based approach, stocking practices for 2013 by recreational angling clubs in France were quantified, which represented the bulk of fish stocking undertaken in that year. Stocking was found to be practiced by 88.6% of angling clubs in France, representing, on average, 65% of their annual budget. Overall, 22 species were stocked, including 13 native and nine non-native species, with strong variations among species in terms of life stages and body sizes used for stocking. Using Bayesian modelling, a total biomass of 2.029 t, representing approximately 90 million fishes, was estimated to be stocked in France in 2013. In terms of biomass, the most widely stocked species were rainbow trout *Oncorhynchus mykiss* (Walbaum), brown trout *Salmo trutta* L., roach *Rutilus rutilus* (L.), common carp *Cyprinus carpio* L. and northern pike *Esox lucius* L. A stocking volume of approximately 60 fishes or 1.5 kg of fish biomass per angler per year seems commonplace in industrialised countries for which data are available.

KEYWORDS

angling club, conservation, fisheries management, recreational fisheries, stock enhancement

1 | INTRODUCTION

Fish stocking constitutes a much used and occasionally abused management practice in freshwater ecosystems (Cowx, 1994). Stocking involves releasing fish into a managed ecosystem that were captured in a different ecosystem or, most commonly, produced semi-naturally or artificially in hatchery conditions. When the releases are conducted with species already present in an ecosystem, it is called stocking. By contrast, practices relying on the release of non-native species or genotypes are usually referred to as introductions (Cowx, 1994). In the present article, “stocking” refers to either type of practice. In most freshwater fisheries of industrialised countries, stocking is primarily performed for stock enhancement to increase fisheries catch (Lorenzen et al., 2012). Stocking is also used to conserve declining populations of exploited and/or endangered species or reintroduce extinct native species (Cowx, 1994; Lorenzen et al., 2012). In many central European countries, where freshwater fisheries are today dominated by recreational fisheries (Arlinghaus et al., 2002), stocking is typically performed by angling communities (clubs or associations) as owners of the fishing rights (Daedlow et al., 2011). Because some anglers also enjoy targeting introduced species, such as European catfish *Silurus glanis* L. in the Ebro basin (Cucherousset et al., 2018), the stocking of recreational fisheries commonly involves native, translocated native and non-native fish species (Eby et al., 2006). However, in many countries, the release of non-native species is prohibited by law and mainly occurs illegally (Aas et al., 2018; Copp et al., 2005; Johnson et al., 2009). By contrast, the release of non-native genotypes of native fish species into a given ecosystem from offspring from distant catchments remains commonplace in some countries (Arlinghaus, Cyrus, et al., 2015).

Stocking is a global phenomenon that represents a significant investment worldwide (Lorenzen, 2014), but the legal treatment of stocking practices is highly variable among countries and depends on the property rights regime (Daedlow et al., 2011). For example, in Germany and France, the stocking of non-native species, such as rainbow trout *Oncorhynchus mykiss*, is legal, whereas the same practice is prohibited in Norway (Aas et al., 2018). Similarly, stocking in some Scandinavian countries generally needs permission from a public authority (Aas et al., 2018; Sevä, 2013), whereas fish stocking in many central European countries can be carried out legally by fishing-rights holders, for example angling clubs or associations, without the consent of public agencies (Daedlow et al., 2011; Fujitani et al., 2017). Stakeholder opinions of stocking are highly divided, and their practices are highly influenced by social-ecological and governance contexts (Fujitani et al., 2020; Hasler et al., 2011; Riepe et al., 2017). Therefore, in practice it is difficult to maintain records of the stocking practices conducted by hundreds to thousands of local angling clubs, and the mandatory record-keeping of stocking practices is lacking in many countries (Aas et al., 2018). In this context, survey-based studies can provide a quantitative assessment of freshwater fish stocking practices at a national scale (e.g., Halverson, 2008; Hunt & Jones, 2018; Mickiewicz, 2013), and such studies are needed to provide basic data on the scope of the stocking practice.

The fate of stocked individuals and the efficiency of stocking practices are highly variable and strongly context-dependent (Cucherousset et al., 2007; Lorenzen et al., 2012; Roques et al., 2018). However, properly conducted stocking can deliver substantial benefits for fisheries catch (Johnston et al., 2018; Lorenzen et al., 2012). By contrast, stocking practices that are conducted in addition to naturally recruiting stocks often fail to deliver added benefits (Baer & Brinker, 2010; Hühn et al., 2014; Johnston et al., 2018). Stocking can also have negative impacts on the recipient ecosystem due to increased competition or predation (Eby et al., 2006; Vehanen et al., 2009) or by promoting genetic homogenisation through hybridisation (Laikre et al., 2010; Le Cam et al., 2015). The potential ecological effects of stocking with native species at the higher levels of biological organisation, such as recipient communities and ecosystems, is a topic demanding further study (Buoro et al., 2016; Cucherousset & Olden, 2020). Similarly, in some cases the stocking of non-native fishes can produce fisheries benefits (e.g. by developing a fishery that was not possible before), but this can also exert adverse ecological impacts at different levels of biological organisation (Cucherousset & Olden, 2011), including changes to ecosystem function (Alexiades et al., 2017; Baxter et al., 2004). Therefore, many environmental policies today are increasingly critical towards the release of non-native fishes or genotypes or ban them entirely. To understand better the potential biological and economic impacts of stocking, improved quantitative estimates of stocking practices at the national scale are needed in many countries of the world. The objectives of the present study were to: (1) determine the species and the life stages used for stocking; (2) quantify the amount (number and biomass) of fishes stocked annually in France; and (3) compare national-level estimates in France with other publically available national stocking estimates.

2 | MATERIALS AND METHODS

2.1 | Context and quantitative angling club survey method

A nationwide representative survey was performed among angling clubs in metropolitan France at the end of 2014 and early 2015 to obtain information about stocking practices in the year preceding the survey, that is 2013 (Riepe et al., 2017). Fishing rights of public waters (lentic and lotic ecosystems) in France are owned by angling clubs (Association Agréée pour la Pêche et la Protection du Milieu Aquatique – AAPPMA), which are responsible for the fisheries management (including stocking practices in public waters) and the protection of freshwater habitats for which they own fishing rights. In some cases, this is done in collaboration with local public fisheries agencies. The type of aquatic environments managed by angling clubs is highly diverse and encompasses the broad range of inland waters in France where angling occurs. These inland waters are distributed along a wide range of urban and rural settings, including alpine lakes, lowland rivers, headwater brooks and streams, canals



or artificial lakes, such as reservoirs and gravel pit lakes, which support a diverse fish fauna with a high proportion of non-native species (Kuczynski, Legendre, & Grenouillet, 2018).

The angling club survey was directed towards metropolitan France's 1.4 million in anglers (of public waters; Savidan & Berger, 2014). Approximately 21% (i.e., 808) of the 3809 angling clubs in France were sent a self-completion mail questionnaire and the associated material (i.e. a cover letter, a stamped return envelope and a data privacy statement). These angling clubs were randomly selected within each department (administrative unit) of mainland France, using a random-number generator, to ensure a structured geographical coverage. Following the modified, tailored design of Dillman et al. (2014), clubs that did not respond within 4 weeks were twice sent a reminder letter, and in the case of no response, the club was contacted by phone to encourage their participation. No answer was obtained in four of the 95 departments where the questionnaire was sent, three of which were located in the highly urbanised Paris area. Consequently, these four departments were excluded from all subsequent analyses. A previous survey in Germany using the same questionnaire (in German) revealed that respondent clubs did not differ from non-respondent clubs in terms of stocking practices (Riepe et al., 2017), so the same pattern was assumed for France.

The questionnaire was answered by the person who was responsible for fish stocking activities or who was able to report on them (i.e. a club's head or fisheries manager). It contained questions relating to several aspects of the club's freshwater management and associated practices, including future stocking intentions (Riepe et al., 2017). The questionnaire was developed, pre-tested and initially administered in Germany, field-tested there (Riepe et al., 2017) and then translated into French for use in the present study. The analyses were based on three aspects of the topic: that is the proportion of an angling club's budget allocated to stocking, whether stocking occurred in the club's waters in 2013 or not and, if stocking occurred, information about the stocked fishes, for example species name, minimum and maximum body size or mass of stocked individuals and quantity (biomass or number of individuals).

2.2 | Statistical analyses

The proportion of angling clubs that used fish stocking as a management practice in 2013 and the proportion of the angling clubs' budget allocated to stocking were calculated. The biomass and number of individual fish stocked by the angling clubs were then estimated. Because a vast majority of angling clubs reported either total biomass or number of fishes stocked for each species, body mass were converted into body length and vice-versa based on length-weight relationships available for each species from FishBase. The mean body mass and length of stocked fishes in each angling club was calculated from the minima and maxima of body mass and length reported. A hierarchical modelling approach was then developed to predict the biomass or number of fishes stocked

for unresponsive or un-sampled angling clubs based on information (stocking practices) collected from sampled angling clubs in a single and cohesive statistical framework. Specifically, the total biomass and number of fishes stocked for all angling clubs in France (sampled or not; $n = 3809$), stocked species and French departments were estimated using a hierarchical Zero-inflated Gamma-Poisson model. For each angling club i and species j , the biomass or number of fishes Y_{ij} , whether it is known or not, was sampled in a Poisson distribution such as:

$$Y_{ij} \sim \text{Poisson} (\kappa_{ij} \times Z_i) \quad (1)$$

with κ_{ij} the mean biomass or number of fish species j for the angling club i and Z_i its indicator of stocking practices taking the value 1 if angling club used fish stocking as a management practice, 0 otherwise.

First, because the indicator of stocking practices Z_i is only known for sampled angling clubs, the stocking practice of unresponsive or unsampled angling clubs was estimated based on stocking practices within the department. To do so, Z_i was sampled in a Bernoulli distribution depending on the probability to practice stocking ψ_d in a given department d :

$$Z_i \sim \text{Bernoulli} (\psi_d) \quad (2)$$

In other words, the parameter ψ_d gives the proportion of angling clubs in a given department d practicing stocking. This was performed at the department level which represents an important administrative level for angling clubs and a key driver of stocking practices (Fujitani et al., 2020).

Second, the mean biomass or number of fishes stocked (at log scale) for each angling club i and species j κ_{ij} was assumed to follow a normal distribution depending on parameters (mean and variance) observed at the department level d :

$$\log (\kappa_{ij}) \sim \mathcal{N} (\mu_{dj}, \sigma_{dj}) \quad (3)$$

The variability of stocking effort of each species within each department was considered when predicting biomass or number of fishes for un-sampled and unresponsive angling clubs. Finally, total stocking biomass and numbers for each species were estimated by summing the partially observed and estimated values Y of all angling clubs and by department.

2.3 | Model validation approach

To test whether the modelling approach provided suitable estimates of stocking practices, a rare and reliable database collected by the regional angling agency of southwestern France (Union des Federations du Bassin Adour-Garonne, UFBAG) was used. It contains stocking biomass in 15 departments in 2013 for Salmonidae only. These observed values were compared with the values estimated by the model, and the correlation between the

stocking biomass predicted by the model and those observed in the database was evaluated to test the reliability of the modelling approach.

The model was fitted within a Bayesian framework, allowing inferences for all parameters of the model, transfer of knowledge from sampled angling clubs to unsampled and unresponsive angling clubs, whilst measuring uncertainty around these parameter estimates. The joint posterior distributions of model parameters were obtained by means of Markov Chain Monte Carlo (MCMC) sampling, as implemented in the JAGS software in R using the package *rjags* (Plummer 2003). Non-informative, prior distributions were used for hyper-parameters. Three parallel MCMC chains were run, and 10,000 iterations were retained after an initial burn-in of 5000 iterations. A thinning of 1 was used and the check for autocorrelation convergence of MCMC sampling was undertaken using Brooks–Gelman–Rubin diagnostics (Brooks &

Gelman, 1998). Uncertainties in model parameters were reported using credible intervals at 90% ($CI_{90\%}$).

3 | RESULTS

3.1 | Stocking practices

The response rate to the survey was high (64%), with a total of 518 angling clubs answering the questionnaire. These clubs represented 13.5% of the total number of angling clubs in France. There was no obvious geographical pattern in the response rate to the questionnaire among departments within France (Figure 1). In total, 88.6% of the angling clubs that responded to the questionnaire ($n = 459$) declared that they stocked freshwater fishes in 2013. On average, stocking represented 65% of their budget of angling clubs, followed

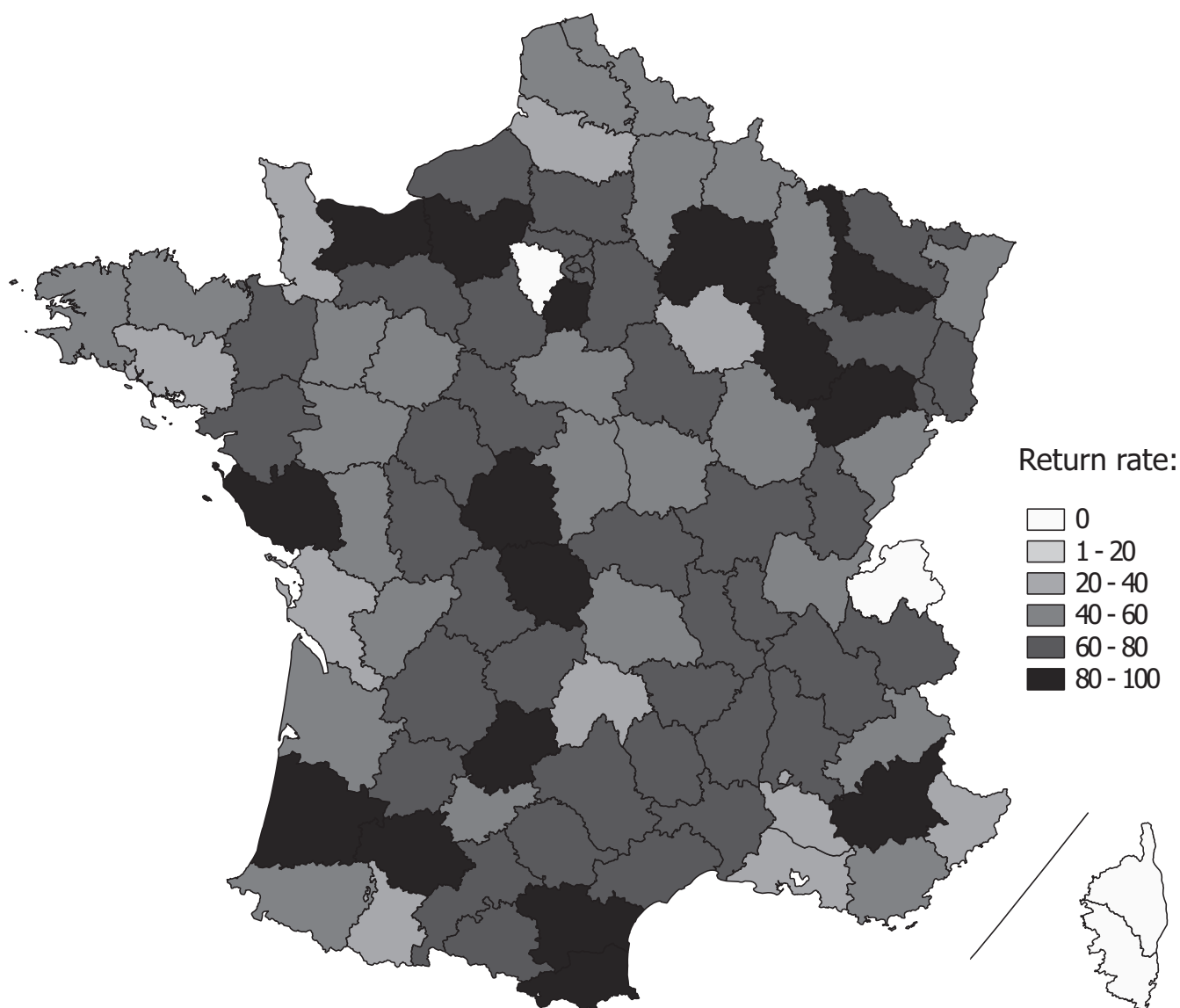


FIGURE 1 Return rate (%) to the questionnaire survey measured in each department in France. Departments with no answer ($n = 4$) were excluded from subsequent analyses



by environmental activities (e.g. maintenance of shorelines and angling spots, 14%), waterbody lease (13%) and habitat improvement (e.g. renaturation of water bodies or supply of spawning grounds; 8%). A total of 22 fish species (13 native and nine non-native) were stocked by angling clubs in France in 2013 (Table 1). Among the angling clubs that practiced fish stocking, the mean number of species stocked in each club was 2.8 (± 1.63 SD), ranging from one to eight species. The mean number of fishes reported to be stocked in 2013, which was also highly variable among clubs, was 224 kg (± 9 SD) and 347 individuals (± 62 SD) per angling club.

Two species stocked by >50% of clubs in France (Table 1), namely brown trout *Salmo trutta* L. and rainbow trout *Oncorhynchus mykiss* (Walbaum), were used by 86.3% and 61.0% of the clubs, respectively. They were followed by northern pike *Esox lucius* L. (40.7%), roach *Rutilus rutilus* (L.) (38.8%), tench *Tinca tinca* (L.) (19.0%), common carp *Cyprinus carpio* L. (17.6%),

Eurasian perch *Perca fluviatilis* (L.) (15.3%) and pikeperch *Sander lucioperca* (L.) (15.3%), largemouth bass *Micropterus salmoides* (Lacépède) (7.6%), gudgeon *Gobio gobio* (L.) (7.0%) or brook trout *Salvelinus fontinalis* (Mitchill) (4.1%). Finally, rare reports of species stocked by only one angling club included bleak *Alburnus alburnus* (L.), European whitefish *Coregonus lavaretus* (L.) and Arctic char *Salvelinus alpinus* (L.). The size distribution of individuals used for stocking was again highly variable among species (Figure 2). For the other species stocked by >15% of angling clubs, all life stages (young-of-the-year, juveniles and adults) were used for stocking but the distribution of stocked life stages was highly variable between species. A high proportion of adults was observed in rainbow trout and roach, and a high proportion of juveniles was observed in northern pike and pikeperch. The ratio between juveniles and adults stocked was more balanced in brown trout and common carp.

TABLE 1 List of the freshwater fish species used for stocking by angling clubs in France in 2013, percentage of angling clubs stocking each species (%) and estimated number of individuals (million) and biomass (t) stocked

Latin name	Common name	Status ^a	Clubs (%)	Number stocked (million)		Biomass stocked (t)	
				Median	90% CI	Median	90% CI
<i>Salmo trutta</i>	Brown trout	Native	86.3	22.44	20.69–23.97	461.31	443.72–479.49
<i>Oncorhynchus mykiss</i>	Rainbow trout	Non-native	61.0	3.23	3.08–3.40	687.17	657.00–719.12
<i>Esox lucius</i>	Northern pike	Native	40.7	21.72	16.22–25.91	132.01	122.08–141.55
<i>Rutilus rutilus</i>	Roach	Native	38.8	35.72	31.86–48.21	379.62	337.01–402.35
<i>Tinca tinca</i>	Tench	Native	19.0	0.92	0.84–1.02	57.90	54.32–62.10
<i>Cyprinus carpio</i>	Common carp	Non-native	17.6	0.76	0.68–0.82	191.10	173.42–204.62
<i>Perca fluviatilis</i>	Eurasian perch	Native	15.3	1.07	0.95–1.24	30.16	28.18–32.23
<i>Sander lucioperca</i>	Pikeperch	Non-native	15.3	1.25	0.98–1.37	30.51	27.72–33.07
<i>Micropterus salmoides</i>	Largemouth bass	Non-native	7.6	0.07	0.06–0.08	7.86	6.85–8.76
<i>Gobio gobio</i>	Gudgeon	Native	7.0	1.52	1.37–1.62	3.64	3.26–4.03
<i>Salvelinus fontinalis</i>	Brook trout	Non-native	4.1	0.06	0.05–0.06	13.86	12.40–15.15
<i>Thymallus thymallus</i>	Grayling	Native	1.5	0.09	0.05–0.13	2.96	2.30–3.43
<i>Scardinius erythrophthalmus</i>	Rudd	Native	1.1	0.12	0.10–0.13	4.96	4.17–5.71
<i>Carassius gibelio</i> ^b	Gibel carp	Non-native	0.7	0.04	0.03–0.04	1.49	1.30–1.67
<i>Ctenopharyngodon idella</i>	Grass carp	Non-native	0.4	<0.001	<0.001–<0.001	11.07	8.25–12.19
<i>Abramis brama</i>	Common bream	Native	0.4	0.01	0.01–0.01	2.51	1.90–2.85
<i>Hypophthalmichthys molitrix</i>	Silver carp	Non-native	0.4	<0.001	<0.001–<0.001	4.80	3.44–5.64
<i>Acipenser baeri</i> ^c	Siberian sturgeon	Non-native	0.2	<0.001	<0.001–<0.001	1.68	1.22–2.09
<i>Alburnus alburnus</i>	Bleak	Native	0.2	0.02	0.02–0.03	0.09	0.05–0.14
<i>Coregonus lavaretus</i>	European whitefish	Native	0.2	0.18	0.13–0.20	0.03	0.01–0.05
<i>Salvelinus alpinus</i>	Arctic charr	Native	0.2	<0.001	<0.001–<0.001	0.11	0.08–0.16
<i>Salmo salar</i>	Atlantic salmon	Native	0.2	0.25	0.19–0.30	0.58	0.42–0.77

Note: Reported estimates are median and 90% credible interval.

^aObtained from Keith et al. (2011) and defined at the country level.

^bPossible confusion with *Carassius carassius*.

^cPossible confusion with other *Acipenser* species, including hybrids thereof.

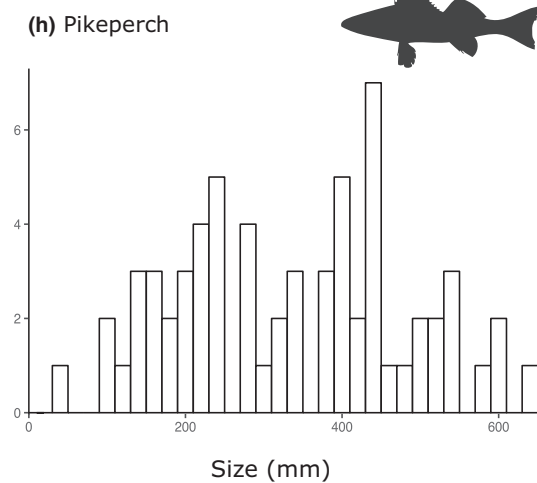
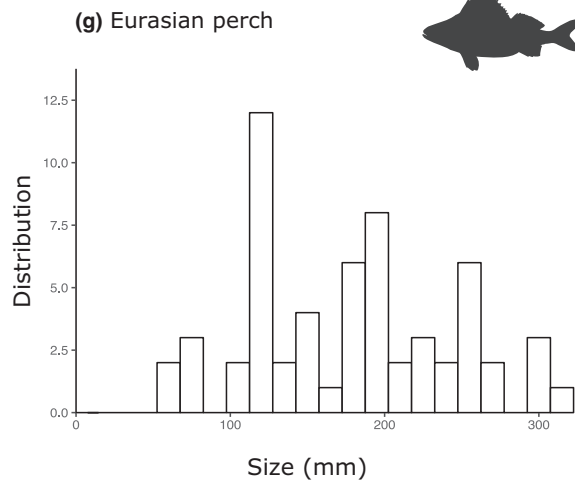
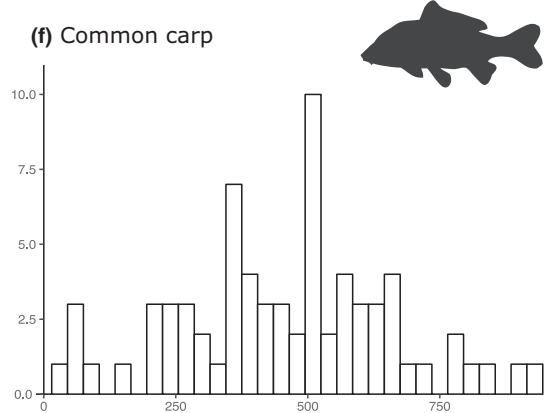
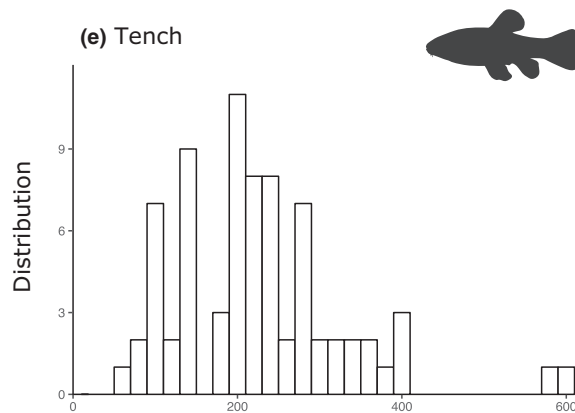
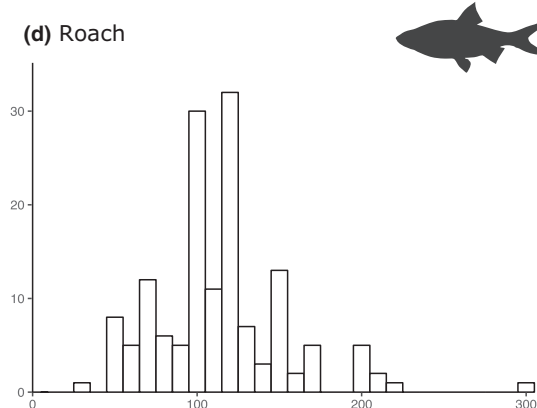
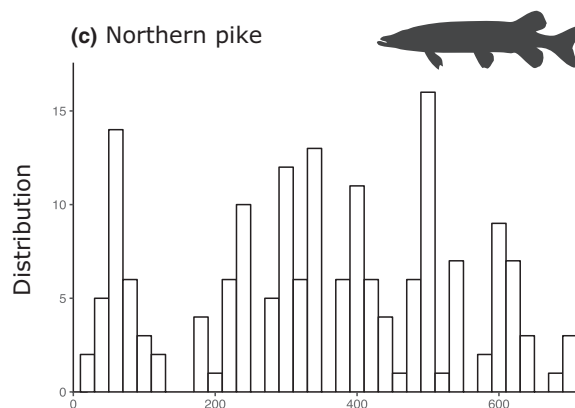
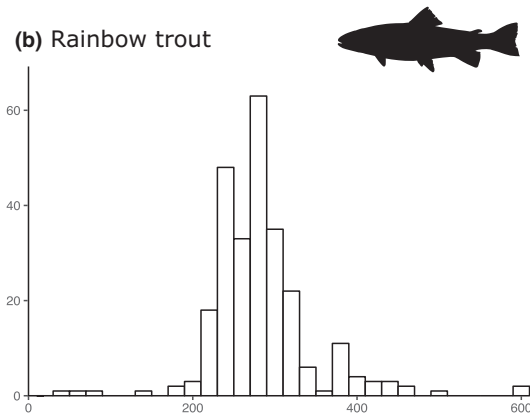
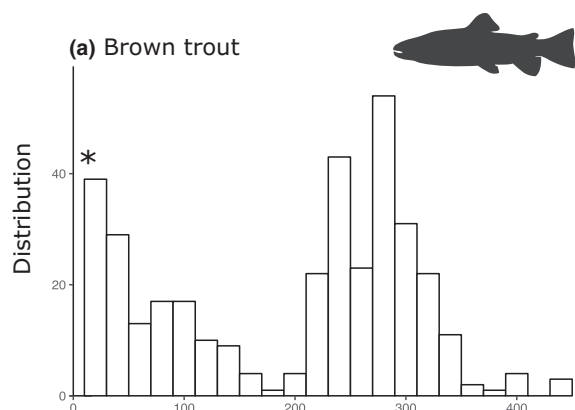




FIGURE 2 Distribution of the mean size (mm) of fish species stocked by angling clubs in France in 2013: (a) brown trout *Salmo trutta**, (b) rainbow trout *Oncorhynchus mykiss*, (c) northern pike *Esox lucius*, (d) roach *Rutilus rutilus*, (e) tench *Tinca tinca*, (f) common carp *Cyprinus carpio*, (g) Eurasian perch *Perca fluviatilis*, and (h) pikeperch *Sander lucioperca* (*Denotes the stocking of eggs reported by 11 angling clubs)

3.2 | Predicted stocking biomass and numbers

The biomass of Salmonidae stocked by angling clubs in southwestern France (data collected by the Regional angling agency, UFBAG: 269 t) fell within the range of the values predicted by the model (median biomass: 268 t; $CI_{90\%}$: 242–292). In addition, a significant and strong correlation was found between the values for stocking biomass of salmonids predicted by the model and the salmonid stocking biomass reported in each department of this region ($n = 15$, $r = 0.62$, $p = 0.014$, Figure 3). The statistical model was therefore confidently applied to estimate the total amount (biomass and number) of fishes stocking in France using the information reported by respondent angling clubs. An estimated 89 million fishes ($CI_{90\%}$: 82–387), or 2029 t ($CI_{90\%}$: 1939–2287) were stocked in France in 2013. In term of biomass, five species represented individually >5% of the biomass of fishes stocked (Figure 4, Table 1). Rainbow trout was the most stocked species (687 t; $CI_{90\%}$: 657–719; i.e., ≈34% of total stocked fish biomass), followed by brown trout (461 t; $CI_{90\%}$: 443–479; i.e., ≈23%), roach (379 t; $CI_{90\%}$: 337–402; i.e., 19%), common carp (191 t; $CI_{90\%}$: 173–204; i.e., 9%) and northern pike (132 t; $CI_{90\%}$: 122–141; i.e., 7%). In term of number of individuals stocked (Figure 4, Table 1), three species represented individually >5% of the number of stocked fishes: roach (36 million fish; $CI_{90\%}$: 32; 48; i.e., ≈40% of all stocked fishes), brown trout (22 million; $CI_{90\%}$: 21–24; i.e., 25%) and northern pike (22 million; $CI_{90\%}$: 15–27; i.e., 24%).

4 | DISCUSSION

The present study provides a rare empirical quantification of stocking practices at the country level in Europe, revealing that stocking is widely used by recreational angling clubs in France. Specifically, stocking as a management practice was found to represent a large proportion of their annual budget. In total, 22 species were stocked, which emphasises the widespread nature of fish stocking amongst angling clubs in France. This situation mirrors previous findings in Germany, where stocking was similarly widespread among privately organised angling clubs and angling clubs stocked a pool of 38 species (Arlinghaus, et al., 2015). The intensity and widespread nature of stocking and the reliance on a large species pool suggests that stocking-induced fish transfers of native species of different genotypes and partly of non-native species, such as rainbow trout and common carp, constitutes a common pattern of fish stocking.

Based on estimated stocking volume and the number of recreational anglers in metropolitan France, an estimated 64 fishes, or 1.5 kg of fish biomass, was released per recreational angler per year to support recreational fisheries in France during 2013.

Comparative quantitative estimates of stocking quantities at the national level are rare, but a few exist to put this value into perspective. In Germany, in 2010, the stocking volume per angler was approximately 53 fishes, or 2.5 kg fish/angler/year (Arlinghaus, et al., 2015). In the USA, it was estimated that 1.7 billion fishes (19.800 t) were stocked in 2004 (Halverson, 2008). There are 27.641 million anglers in the USA (Arlinghaus, et al., 2015), leading to stocking of 62 fish species and 0.7 kg/recreational angler/year. In Australia, the amount of fish stock was 12 million fishes and 131 t/year (Hunt & Jones, 2018). With 3.36 millions anglers (Arlinghaus, et al., 2015), stocking was estimated to be 3.6 fishes and 0.04 kg/angler/year. Except for Australia where stocking practices appear to be less intense, the number of fishes stocked per angler in France were similar to the values reported in Germany and the USA. However, difference regarding the biomass per angler indicate that smaller individuals are released in the USA and larger fishes are released in Germany. Overall, however, this comparative compilation of data suggests that one can expect roughly 60 fishes or 1.5 kg of fishes released per angler per year to support recreational fisheries in the industrialised world, assuming that the mean estimated for France, Germany and the USA broadly holds for other industrialised nations of the world (but see Hunt & Jones, 2018).

Stocking trends in the USA suggest that managers increasingly rely on larger fish sizes (Halverson, 2008), presumably because it was found that smaller fishes usually produce poorer stocking outcomes (Johnston et al., 2018). In general, the amount of fish stocked in France was variable among species, and within species there were variations in the biomass and in the number of individuals stocked. It appeared that species stocked at larger sizes, such as rainbow trout, were released in put-and-take fisheries for rapid recapture by anglers. Generally, based on anecdotal information and discussion with decision makers in France, stocking consignment size seems to be primarily determined by local objectives, fish availability and local angling culture.

Stocking practices have been grouped into different categories depending upon their aims (Arlinghaus, Lorenzen, et al., 2015; Lorenzen et al., 2012). Based on the list of species stocked and the quantities stocked per species, it seems that stocking performed by angling clubs in France is primarily of farmed species that do not reproduce naturally under local conditions (e.g. rainbow trout) and of non-native species (e.g. common carp, pikeperch) as well as for stock enhancement (e.g. roach, brown trout, northern pike). Unfortunately, it was not possible to determine whether the stocking measures were to compensate for the removal of fish by anglers or for conservation purposes – both types of stocking exist in France (Cucherousset et al., 2007; Le Cam et al., 2015).

The most stocked species in France were those targeted as specimen fishes by the recreational fisheries (Savidan & Berger,

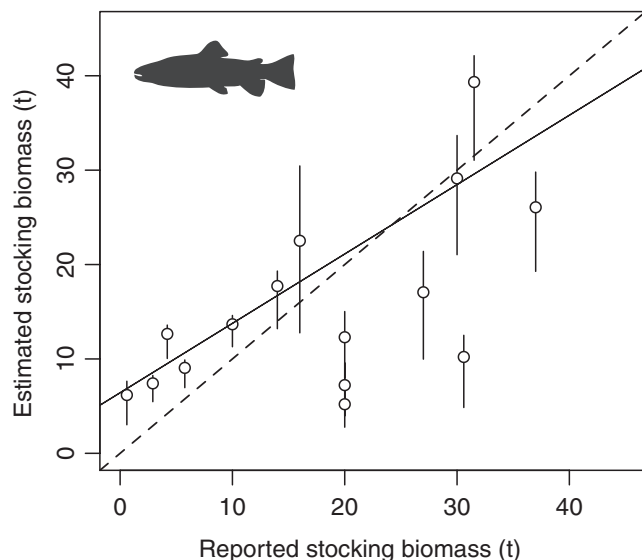


FIGURE 3 Stocked biomass (ton) of Salmonidae reported by angling clubs to the Regional angling agency in southwestern France (UFBAG, $n = 15$) and values predicted by the Bayesian model. Reported are the predicted median (circles) and 90% credible interval (line bars). The line represents the correlation line between observed and predicted values ($r = 0.62$, $p = 0.014$). The dashed line represents the $x = y$ relationship

2014) or those (e.g. roach) stocked as a prey for the specimen species, for example northern pike and pikeperch. Although 22 species were reported for use in stocking, other species are occasionally stocked, such as European minnow *Phoxinus phoxinus* (L.), European catfish and asp *Leuciscus aspius* (L.). These species were not included in the present study, which may reflect either sampling bias (e.g. rare events will less likely occur in surveys) or strategic bias (i.e. false reporting respondents, who did not declare their actual behaviours). However, given the strong overlap between the survey-derived stocking volume for salmonids and independent data, strategic bias was considered not to be strong in the survey.

Importantly, from a conservation perspective, of the 22 species stocked, nine were not native to France, and some of these have been reported to induce important ecological impacts in specific ecosystems and conditions in France and other regions of the world, for example common carp or largemouth bass (Cucherousset & Olden, 2011). For example, the stocking of largemouth bass or common carp by angling clubs may be legal in France, but these practices contribute to the spread of non-native species, with potential ecological impacts that remain unknown and likely highly context-dependant (Vilizzi et al., 2015). In addition to the potential ecological effects of non-native species, further investigations should also account for the potential risks associated with the stocking of native domesticated fishes and how they might impact recipient ecosystems, including through introgression with wild conspecifics (Cucherousset & Olden, 2020).

Stock enhancement to rebuild populations, that is for the conservation of an endangered species, is also used by angling clubs

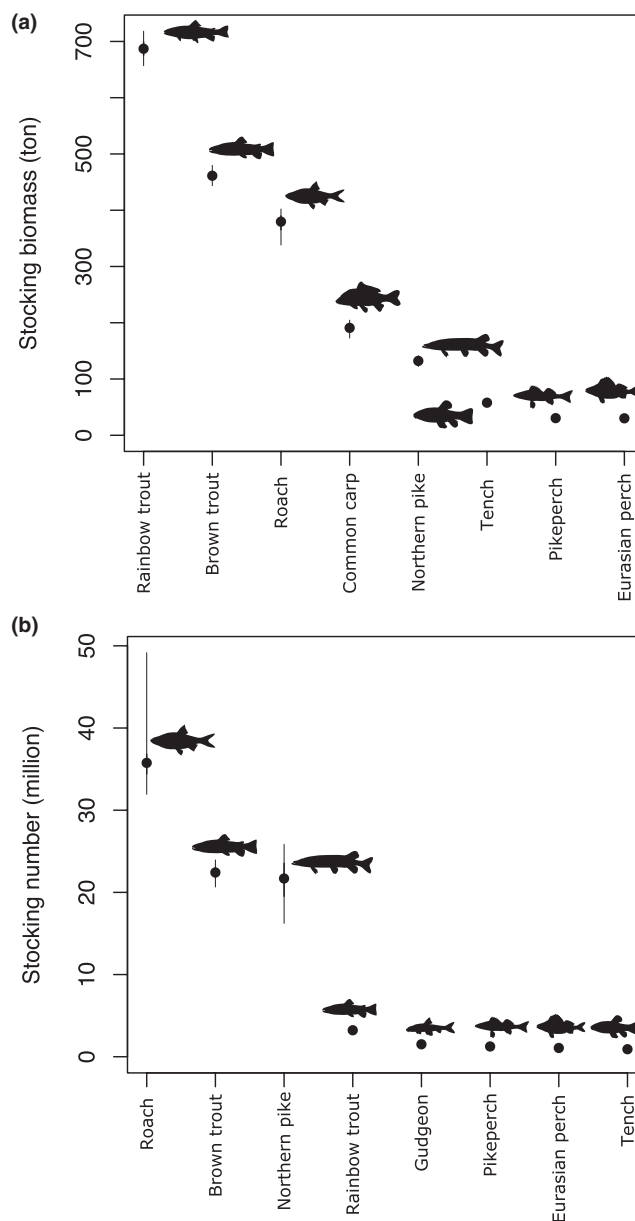


FIGURE 4 Predicted quantity of fish stocked by angling clubs in France in 2013: (a) biomass (t), and (b) number (million). Only the eight most stock species are reported on each panel. Reported are the median (filled circles) and 90% credible intervals (line bars)

in France, such as Atlantic salmon *Salmo salar* L. Such cases were rare in the present study, which contrasts the regular occurrence of conservation stocking in Germany (Arlinghaus, et al., 2015). This is because conservation stocking in France is not performed by angling clubs, but by publically funded conservation programmes. This is the case for European sturgeon *Acipenser sturio* L. (Carrera-García et al., 2016) and Atlantic salmon (Le Cam et al., 2015). The present study could not account for unauthorised stocking nor for stocking performed in private water bodies, which are very common in some areas of the country. As such, the results represent an underestimate of the extent of fish stocking in France.

In conclusion, stocking remains a much-debated practice, and its efficacy strongly depends on local conditions (Johnston et al., 2018).



Stocking may be associated with a range of ecological risks, such as the (deliberate or accidental) introduction of non-native species and release of non-native genotypes of native species with various degrees of domestication that may modify intraspecific biodiversity (Buoro et al., 2016). On the other hand, stocking activities by recreational angling clubs help sustain local fisheries and thereby represent a considerable investment into France's natural resources. In general, the approach taken in planning a stocking programme should involve rigorous, unbiased cost-benefit analysis to balance any potential socio-economic benefits against any possible adverse economic and ecological impacts (Lorenzen et al., 2010). At the national scale, about 60 fishes or about 2 kg of fish biomass are stocked per angler per year in France. This quantification of the extent of stocking represents a first step in the provision of basic data upon which to base future work on the risks and benefits of fish stocking in European recreational fisheries.

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