Spatial heterogeneity and fish life traits correlated to freshwater fish population decline in France

Hétérogénéité spatiale et traits de vie associés aux déclins piscicoles en France

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RÉSUMÉ

La compréhension des dynamiques démographiques des espèces aquatiques et la compréhension des variations interspécifiques en fonction des traits écologiques et démographiques est crucial pour définir leur statut de conservation et élaborer des mesures de protection appropriées. Les taux de croissance en abondance et de biomasse pour 18 espèces de poissons d'eau douce communes en France ont été estimés à l'aide de données de pêches électriques issues des programmes de biosurveillance depuis 1990. L'hétérogénéité spatiale des tendances temporelles d'abondance et de biomasse à travers les différents bassins hydrographiques français a été évaluée pour les 18 espèces, ainsi que les corrélations avec les traits démographiques des espèces. Onze des 18 espèces étudiées ont montré une baisse significative de l'abondance et 14 ont décliné en termes de biomasse ; sept sont restées stables ou ont connu une croissance positive de l'abondance. Les principaux déclins ont été observés dans les bassins Adour-Garonne et Loire-Bretagne, où des mesures de gestion et de conservation sont nécessaires urgemment pour stopper l'érosion des populations piscicoles. Dans chacun des 5 bassins hydrographiques, nos résultats mettent en évidence des zones où la plupart des espèces communes étudiées ont montré des déclins significatifs. Parmi les traits démographiques et écologiques examinés, la stratégie de vie et la longueur maximale étaient significativement corrélées aux taux de croissance démographique des espèces, révélant que la baisse concernait principalement les espèces de grande taille à faible renouvellement des générations.

ABSTRACT

Understanding the population dynamics of aquatic species and how inter-specific variation in demographic and life history traits influence population dynamics is crucial to define their conservation status and design appropriate protection measures. The abundance and biomass growth rates for 18 common European freshwater fish species were estimated using data spanning 1990–2011 for 546 sites across France. Spatial heterogeneity in abundance and biomass trends across France were assessed and correlations with life history traits were investigated.

Amongst the 18 species, eleven of them have exhibited a significant decline in abundance and 14 species declined in biomass, seven remained stable or exhibited positive abundance growth rates; for four species, biomass was stable or increased. The main declines were observed in the Adour-Garonne and Loire-Bretagne, where management and conservation measures are urgently needed to halt the erosion of freshwater fish populations. In each of the 5 investigated RBDs, our results highlight areas where most of the common species we studied exhibited negative population growth rates. Of the demographic and ecological traits investigated, life-history strategy and maximum length were significantly correlated with species' population growth rates, revealing that the decline mainly concerned large-bodied species with slow life-histories. These results focus on 18 common European species representing 94% of fish captured during the study period within the French national monitoring programme and underline that more attention should be paid to the decline in common species.

KEYWORDS

Abundance, Biomass, Biomonitoring, Fish population dynamics, Population decline

Abondance, Biomasse, Biosurveillance, Dynamique des population piscicoles, déclin des populations piscicoles

1 INTRODUCTION

Freshwater ecosystems host at least 9.5% of described animal species, many of which are threatened by global or local pressures from anthropogenic activities. In Europe, human activities have degraded the morphology, hydrology, continuity, water quality, and water quantity of more than 70% of waterbodies, which in turn impacts biodiversity. As a result, fish are the second most-threatened taxa in Europe, with 37% of species considered as threatened by extinction and 2.5% as extinct, mostly salmonid species (Freyhof & Brooks, 2011). Understanding the population dynamics and, ultimately, the population growth rate (λ) in abundance and biomass of aquatic species is crucial to define species conservation status, and in turn to implement relevant conservation strategies for restoring river biodiversity, notably by focusing on the most-threatened species in decline. Furthermore, identification of geographical patterns in population trends can also provide scientific evidence to define region-specific environmental management and conservation planning, setting priorities where it is most needed and for the most vulnerable species.

Apart from determining population growth rate, understanding how inter-specific variation in demographic and life history traits influences population dynamics is crucial information for environmental managers. It is essential to identify which intrinsic ecological traits may render some species more vulnerable and contribute to risk factors in population decline. This information also allows the main drivers of population dynamics to be identified, so that relevant management actions can be proposed (Velez-Espino et al., 2006; Winemiller, 2005). Thus, assessing correlations between freshwater fish life history traits (especially demographic traits) and population dynamics should also be assessed to identify most vulnerable species; especially in widely distributed species not listed at risk of extinction for which even small variations in the abundance and biomass might result in substantial modifications of structure, function, and dynamics of communities at a large geographic scale (Gaston, 2010).

In this presentation, we aim at summarizing our results published in Santos *et al*., 2020 in *freshwater biology* and Santos *et al*., 2022 published in *journal of environmental management*. Using Nation-wide electrofishing datasets from the French Office for Biodiversity, we investigated areas of major population decline in common fish species' abundance and biomass. We investigated population trends at the national scale but also in each of the main River Basin District in Continental France. We further investigated the demographic and ecological traits correlated to the species population trends observed at the national scale. Finally, we will discuss our results comparing the recent literature published in France and Germany.

2 METHODS

2.1 Datasets

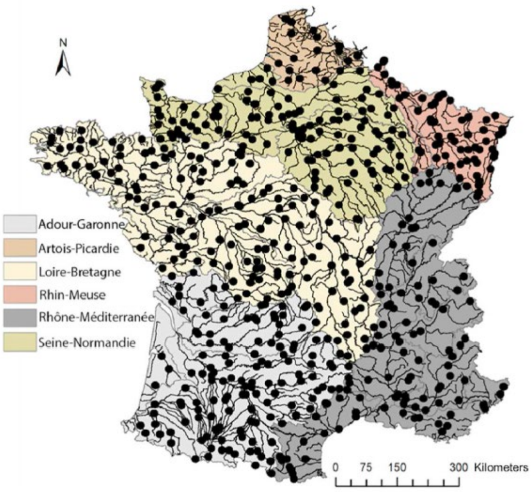

Figure 1 : Spatial distribution of the 546 sampling sites (black dots) in continental France distributed within the 6 River Basin Districts defined by the EU-Water Framework Directive (Adour-Garonne in bright grey, Artois-Picardie in Brown, Loire-Bretagne in beige, Rhin-Meuse in red, Rhône-Méditerranée in dark grey, and Seine-Normandie in green).

The monitoring started in 1990 and is ongoing, investigating freshwater fisheries of selected rivers across France. Sampling was carried out by the French Office for Biodiversity (formerly the French National Agency for Water and Aquatic Environments). Freshwater fish communities have been sampled using standardized electrofishing protocols adapted to river width and depth conducted either in Spring or Autumn (see Poulet et al., 2011 for more details). Captured fish were identified, counted, measured, and weighed before being released back into the river. From the survey sampling data of hundreds monitored sites, we selected a total of 546 sites homogeneously distributed across France (excluding sites in Corsica and overseas France) sampled between 1990 and 2011 to analyse only the longest available time series (ranging from 7 to 22 years with an average of 12 sampled years per site). To compare inter-annual abundance (as the number of fish captured) and biomass (as the total weight of fish captured), we selected a final dataset including 6,483 sampling events within these 546 sites, which were surveyed with the same protocol and in the same season (either Spring or Autumn). Abundance and biomass growth rates of 18 fish species in

France were assessed, representing 94.1% of the captured fish abundance and 88.4% of fish biomass of the 3,300,609 fish sampled.

2.2 Statistical analyses

We used Bayesian state-space models, modelling an observation process and a state process to assess abundance and biomass trends separately for each species. State-space models are time series models in which the true state of the population size observed each year is modelled considering the observed data and accounting for observation errors (See Santos et al., 2020, 2022 for more details, the model code is available).

To describe life history strategies, we performed a standardized principal component analysis (PCA) combining three demographic traits: absolute fecundity, lifespan, and age to female maturity. The mean absolute fecundity was log-transformed prior to analysis. Species' scores on the PCA-1 first axis was then used as a new synthetic *life history trait* variable. Finally, we conducted another PCA to analyze correlations among trends in abundance, biomass, and life history trait variables. Further linear regressions were computed to assess the correlations between species trends in abundance/biomass and quantitative biological traits.

3 RESULTS AND DISCUSSION

3.1 Population Dynamic at the national scale

Our results highlight that common and widely distributed freshwater fish species in France mostly exhibited nation-wide declines in abundance and biomass between 1990 and 2011. Our work demonstrates as well that large-bodied slow life-history species have exhibited higher population decline over the last decades than smaller-bodied fast life-history species. This observation accords with the general pattern observed worldwide in mammals, birds, reptiles and marine fish. Our findings show that 11 species exhibited significant decline in abundance, and 14 species exhibited decline in biomass. Of the 18 species, six remained stable and one exhibited positive abundance growth rate; three species remained stable in biomass and one species significantly increased.

Of the declining species we studied, the emblematic *A. Anguilla* and *E. lucius* are respectively ranked as Critically Endangered and Vulnerable by the IUCN in France *but most of the* taxa we found as declining such as *A. brama*, *R. rutilus*, *P. fluviatilis*, and *S. erythrophtalmus* are considered as Least Concern or data deficient by the IUCN as the global persistence of those species is not imperilled in the short term (UICN France, 2019). To pay more attention to the status and population dynamics of common species, Gaston and Fuller (2008) envisaged a categorization of species based on their level of population depletion to supplement IUCN extinction risk status. Furthermore, they have highlighted when population trends were more accurately assessed, the status of many common mammal, bird, and fish species have frequently been moved from Least Concern to Vulnerable or even Threatened with Extinction, underlining the importance of paying more attention to the conservation of common species through population trends analyses.

Of the demographic and ecological traits investigated, life-history strategy and maximum length were significantly correlated with species' population growth rates, revealing that the decline mainly concerned large-bodied species with slow life-histories (Figure 2).

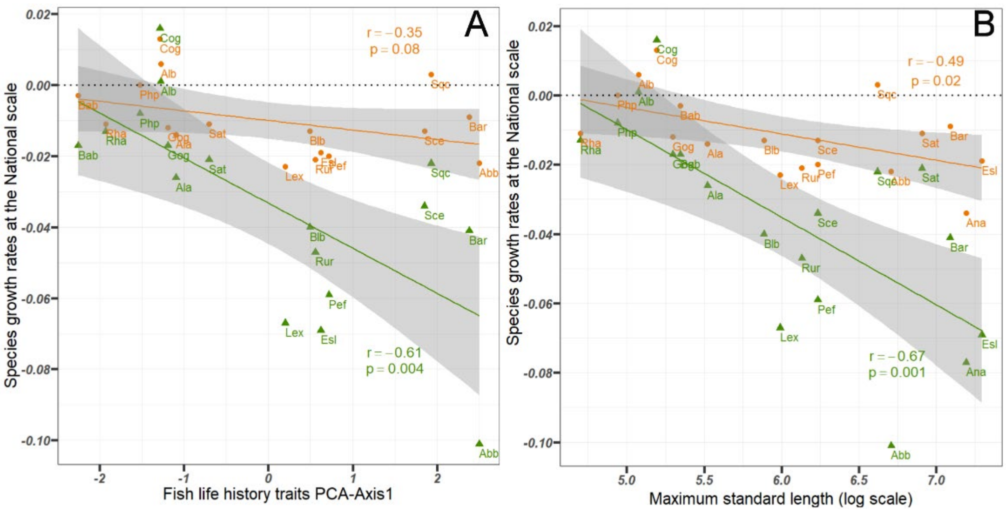

Figure 2 : Relationship between median posterior values of specific population growth rates (rnat) in abundance (orange) or in biomass (green)

and a) fish demographic traits (higher values for principal component analysis (PCA)-axis 1 correspond to a slower life history strategy) and b) species standard length (log scale in mm). Solid lines represent linear regressions and grey bands are 95% confidence intervals. Abb: Abramis brama; Ala: Alburnus alburnus; Alb: Alurnoides bipunctatus; Ana: Anguilla Anguilla; Bab: Barbatula barbatula; Bar: Barbus barbus; Blb: Blicca bjoerkna; Cog: Cottus spp.; Esl: Esox Lucius; Gog: Gobio spp. Gobio spp.; Lex: Leuciscus spp.; Pef: Perca fluviatilis; Php: Phoxinus spp.; Rha: Rhodeus amarus; Rur: Rutilus rutilus; Sat: Salmo trutta fario; Sce: Scardinius erythrophtalmus; Sqc: Squalius cephalus.

3.2 Population Dynamic at the River Basin District scale

By investigating population trends in abundance and biomass at the RBD scale, we were able to demonstrate *i)* heterogeneity (Fig. 3) in population trends between European management units in continental France and within each of them, highlighting the areas where most of the common freshwater fish species are declining in abundance and biomass. Nevertheless, our work highlights that some species such as *Rutilus rutilus*, *Anguilla anguilla*, *Esox spp*., *Leuciscus spp*., and *Salmo trutta* have experienced significant negative population growth rates in abundance, biomass or both variables in most of the five RBDs.

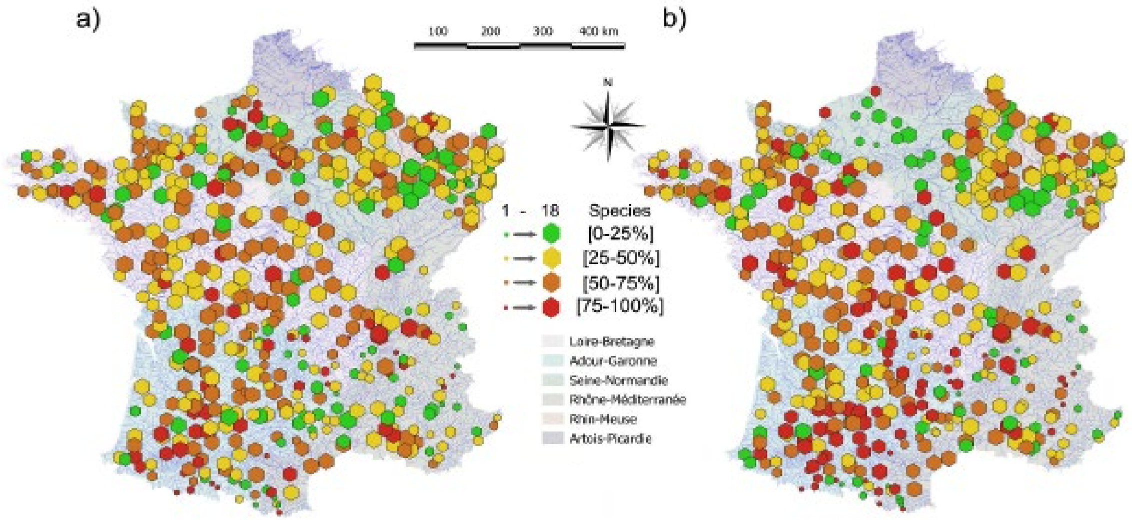

Figure 3 : Geographical distribution of fish decline in abundance (A) and biomass (B) in the five main continental France RBDs between 1990 and 2011 (Loire-Bretagne; Adour-

Standardized electrofishing methods provide insightful information on fish abundance, biomass and even size/age structure at the species level. This information is crucial to understand freshwater fish population dynamics, generate knowledge in fish ecology and safeguard invaluable field expertise of environmental managers. In this work we demonstrated that most of the common European freshwater fish species exhibited spatial heterogeneity in population trajectories across France. The level of fish population erosion estimated in the Adour-Garonne and Loire-Bretagne RBDs is concerning. Management and conservation measures are urgently needed to halt the degradation of fish populations in these RBDs. In the three others investigated RBDs, spatial heterogeneity in freshwater fish species population trends have been demonstrated and would require local management. These results will be discussed according to the recent literature published in Europe.