Long-term trend analyses of fish assemblages in large French rivers

Analyse des tendances long-terme des communautés de poissons des grands fleuves français

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RÉSUMÉ

Les changements globaux affectent de manière croissante les écosystèmes d'eau douce et provoquent de fortes modifications dans la structure et le fonctionnement des communautés. Une meilleure compréhension des tendances écologiques passées est nécessaire afin de pouvoir anticiper et prédire les changements à venir. Dans ce but, des données de pêche électrique issues de la surveillance hydro-écologique de 11 centrales nucléaires françaises ont été assemblées. Ce jeu de données unique est constitué de 35 chroniques long-terme des assemblages de poissons de la plupart des grands fleuves français sur les 20 à 40 dernières années. Les changements communs à ces chroniques en termes d'abondances et de composition d'espèces, ainsi que de différentes métriques de diversité ont été testés en utilisant une méthode de méta-analyse nouvellement développée. Une augmentation des températures de l'eau et une diminution des débits ont tout d'abord été mises en évidence sur les 40 dernières années. Nous avons ensuite pu montrer une forte augmentation des abondances totales (+400%) et de la richesse spécifique (+50%) sur cette même période. Enfin, malgré une absence de tendance significative dans l'équitabilité et dans l'abondance relative des espèces non-natives et des espèces thermophiles, une importante méridionalisation des communautés de poissons de ces grands fleuves a été identifiée sur les quatre dernières décennies.

ABSTRACT

Global changes are increasingly affecting freshwater ecosystems resulting in strong modifications in the structure and functioning of aquatic assemblages over a relatively small period of time. A better understanding of observed ecological trends is needed to anticipate and forecast future ecosystem changes. For this purpose, data from the annual electrofishing campaigns conducted as part of the monitoring of 11 French nuclear power plants were assembled. This unique dataset is made up of 35 long-term time series on the fish assemblages of the major French rivers over the last 20 to 40 years. We conducted meta-analyses of trend statistics derived from these 35 biological time series to investigate the impact of global changes on the structure and functional characteristics of fish assemblages. Shared changes among time series in species abundances, assemblage compositions and diversity metrics were tested. Strong increase in water temperatures and decrease in discharges were shown. We demonstrated a great increase in total fish densities and species richness over the last 40 years, rising by 400% and 50%, respectively. While species evenness, relative abundances of non-native species and proportion of thermophilic species did not show significant changes, we observed a significant and clear northern shift of fish communities in these large rivers over the last four decades.

KEYWORDS

Fish community, Global changes, Long-term data, Meta-analysis, Tropicalisation

1 CONTEXT AND OBJECTIVES

Global changes are increasingly affecting freshwater ecosystems resulting in strong modifications in the structure and functioning of aquatic assemblages over a relatively small period of time. Long-term monitoring of these vulnerable ecosystems are required to better understand the past and forthcoming responses of aquatic communities to global changes. In a previous study involving long-term data of fish assemblages in large French rivers from 1980 to 2003, Daufresne & Boët (2007) were among the first to identify and characterize changes in the composition and structure of freshwater fish communities related to ongoing global changes. Through the analysis of an updated and extended version of the same dataset, we aimed to (1) build a methodological framework allowing the meta-analysis of long-term time series while accounting for the temporal and spatial autocorrelations inherent to our dataset, (2) identify trends in species abundances and community metrics over the last four decades, and (3) characterize recent changes in fish communities in comparison with previously identified trends.

2 MATERIAL AND METHODS

Long-term data on fish assemblages of several large French rivers collected as part of the hydro-ecological regulatory monitoring of 11 nuclear power plants (NPP) were considered in this study (Figure 1). These data were collected between one to four times a year using standardized electrofishing protocols by boat. Each of the 35 stations sampled were located either upstream or downstream from a NPP and these 35 time series covered a period of 18 to 37 years, all until 2015. Following Daufresne & Boët (2007), the abundances of the 40 different fish species sampled were standardised by unit effort to obtain a value of Catch Per Unit Effort (CPUE) corresponding to a number of individuals sampled during 20 minutes of fishing. For each species, the CPUE were finally averaged by biological year (from July to June next year) based on most cyprinids' hatching date.

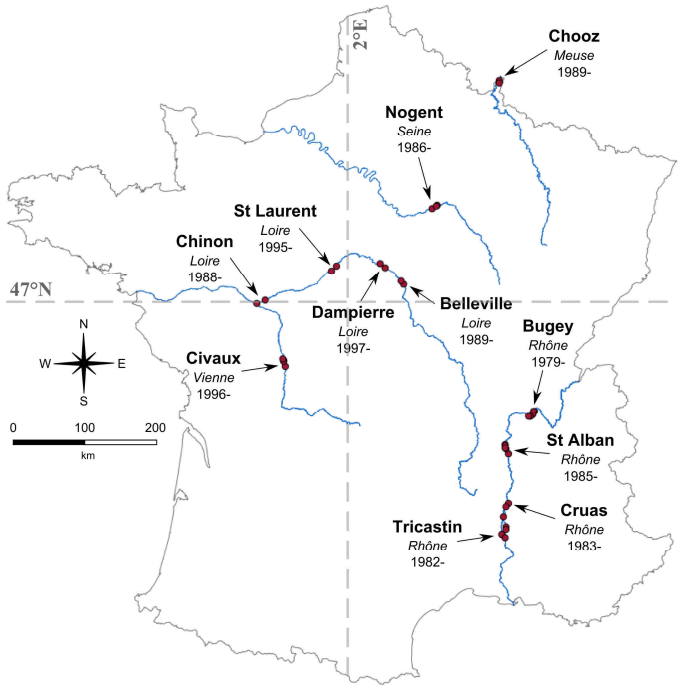

Figure 1. Location of the 35 stations studied distributed among 11 sites (NPPs), associated rivers and first year of the time series.

We then built a methodological framework allowing the meta-analysis of time series in two steps. First, a Mann-Kendall trend analysis is performed on each time series and the variance of the test statistic is corrected for temporal autocorrelation. Second, we adapted some functions of the *metafor* package (Viechtbauer 2010) of the R software to account for the uneven spatial distribution of the time series. This second step was achieved using an optimisation algorithm coupled to a matrix of spatial correlation between each station computed on the basis of their pairwise distance along the river network. Finally, both the Mann-Kendall statistic and its variance for each studied station are used as input of this meta-analysis framework. This allows the determination of a mean effect size and an associated confidence interval among the studied stations.

We applied the newly developed meta-analysis framework to identify trends in time series of flow discharge and water temperature, species CPUE and community metrics described below. First, we computed total CPUE, species richness, species evenness (Pielou's evenness index) and relative abundance of non-native species for each biological year of each time series. Following Daufresne & Boët (2007), we also classified the different species into three categories of affinity for high temperatures before computing the proportion of warm-water species. Similarly, we distinguished between southern, intermediate and northern species according to their latitudinal range at the European scale and computed the relative abundance of the species belonging to each of these three categories for each biological year of each time series.

3 RESULTS

We found a significantly decreasing trend in mean annual discharge and a significantly increasing trend in mean temperature during the reproduction period of most sampled fish species (from April to June) over the period 1980-2015 for the Loire and Rhône rivers.

When we applied our meta-analysis framework to identify changes in the CPUE of the 21 most common species over the studied period, we found that the CPUE of 2 species (i.e. pumpkinseed *Lepomis gibbosus* and rudd *Scardinius erythrophtalmus*) were significantly decreasing while those of 11 species (e.g. bitterling *Rhodeus amarus* and topmouth gudgeon *Pseudorasbora parva*) were significantly increasing. The trends in the CPUE of the 8 other species were not significant but tend to increase for 3 species and decrease for 5 species.

The meta-analyses performed on time series of community metrics for the 35 stations studied showed strong and significant increases in both total CPUE and species richness between 1980 and 2015 (Figure 2), rising by 400% and 50% on average, respectively. These changes were not accompanied by significant trends in evenness, proportion of warm-water species and relative abundance of non-native species (Figure 2). On the other hand, our analyses highlighted significant decrease and increase respectively in relative abundances of northern and southern species (i.e. species whose mid-latitudinal geographical range is located north or south from the station sampled, respectively).

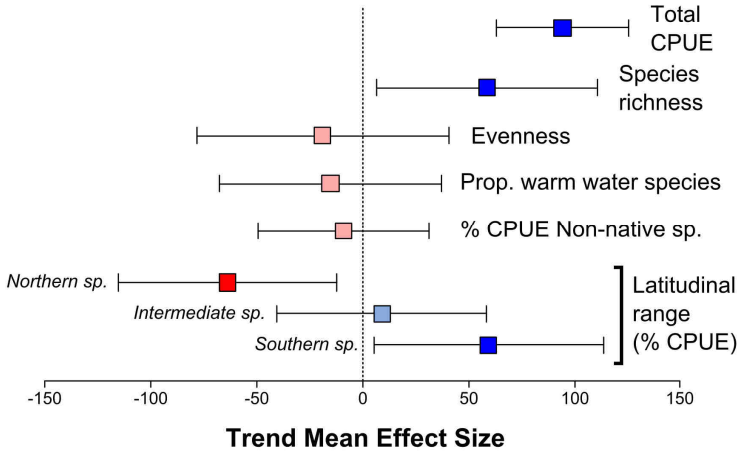

Figure 2. Results of the meta-analyses on trends in community metrics for the 35 stations studied. The trend mean effect size (square) and the confidence interval (whiskers) are represented. Positive (blue) or negative (red) mean effect size reflects increasing or decreasing trends, respectively. The trends are significant when the confidence interval does not overlap the value 0 (vertical dashed line).

We finally compared the results of the meta-analyses when applying or not the corrections for temporal and spatial autocorrelations and found that the tests were more conservative but more robust when both autocorrelation components were accounted for. This gave us a great confidence in the significant trends highlighted in this study.

4 CONCLUSION

In the present study, we developed a robust methodological framework to identify shared trends in spatial time series. The application of this framework to time series of fish assemblages allowed us to identify substantial changes in fish assemblages of some large French rivers between 1980 and 2015, such as strong increases in total fish abundances and species richness. Moreover, we found that these changes were associated with a phenomenon observed for one of the first times in fresh waters at large scale, also known as 'tropicalisation' (Vergés *et al.* 2014), which was characterized by strong opposing trends in relative abundances of southern and northern species. These results emphasize a significant and clear northern shift in the composition of the fish communities of these large rivers over the last four decades.

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