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RESEARCH PAPER — OPEN ACCESS

The biological condition of French rivers has not improved over the last seventeen years according to the national Fish-Based-Index (FBI)

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Abstract – We evaluate, for the first time, variations of the national Fish-Based-Index (FBI) over a seventeen-year period for 1583 sampled sites evenly distributed across the French territory. As far as we know this is one of the first studies analyzing the temporal trends of a fish-based biotic indicator for such a consistent set of records going back over almost two decades. Our results provide four important insights. First, the index is efficient in discriminating sites in good condition from sites experiencing anthropogenic disturbances. Second, according to the index, the ecological state of French riverine fish assemblages is rather poor, as around half of the assessed sites, thought to reflect the diverse conditions within the French riverine system, are significantly impaired. Third, according to the index, there is no noticeable amelioration through time of sites fish assemblage structure and function despite management efforts initiated two decades ago to comply with the EU's 2000 Water Framework Directive. Fourth, the index might start being influenced by climate change as early signs of response to warming are happening since the last 10 yr. According to the FBI, the current efforts for improving the biological condition of riverine systems in France are not yet creating desired outcomes.

Keywords: Freshwater / bioassessment / long-term monitoring / population dynamics / reference conditions

1 Introduction

Anthropogenic factors and associated processes responsible for threatening aquatic ecosystems and the decline of freshwater biodiversity have been clearly evident for decades. Major threats include habitat modification and pollution from land-use, habitat fragmentation and flow and thermal regimes alteration by dams, water abstraction for industry or irrigation, over-exploitation of natural populations and, more recently, non-native taxa introductions and climate change (Dudgeon, 2019; Oberdorff *et al.*, 2022).

Recognition of this adverse situation has led Europe to change, around two decades ago, its water policy. Indeed, since 2000, the European Water Framework Directive (WFD) requires Member States to protect and, where necessary, restore water bodies through improvement of their hydromorphological, chemical and biological characteristics. The aim is to maintain «healthy» freshwater ecosystems through preventing their deterioration and restoring their functioning when necessary. To meet part of the requirements of the WFD (*i.e.*, biological status), a multi-metric Fish-Based Index (FBI) was developed for French running waters to provide a baseline for measuring the responses of natural fish assemblages to anthropogenic disturbances and/or to rehabilitation efforts (Oberdorff *et al.*, 2001, 2002). The index uses the 'reference condition approach' that consists in comparing fish assemblages between sites exposed to potential stress against comparable sites in near-natural conditions. The full methodology used to develop the index is detailed in Oberdorff *et al.* (2002, 2021). The index is composed of 7 metrics based on occurrence and abundance data, and describing different aspects of the fish assemblage structure and function in reference sites covering all river types occurring in France. According to the index, a 'good status' is the minimum acceptable site quality that does not require measures for its improvement and where the biological elements deviate only slightly from near-natural reference conditions.

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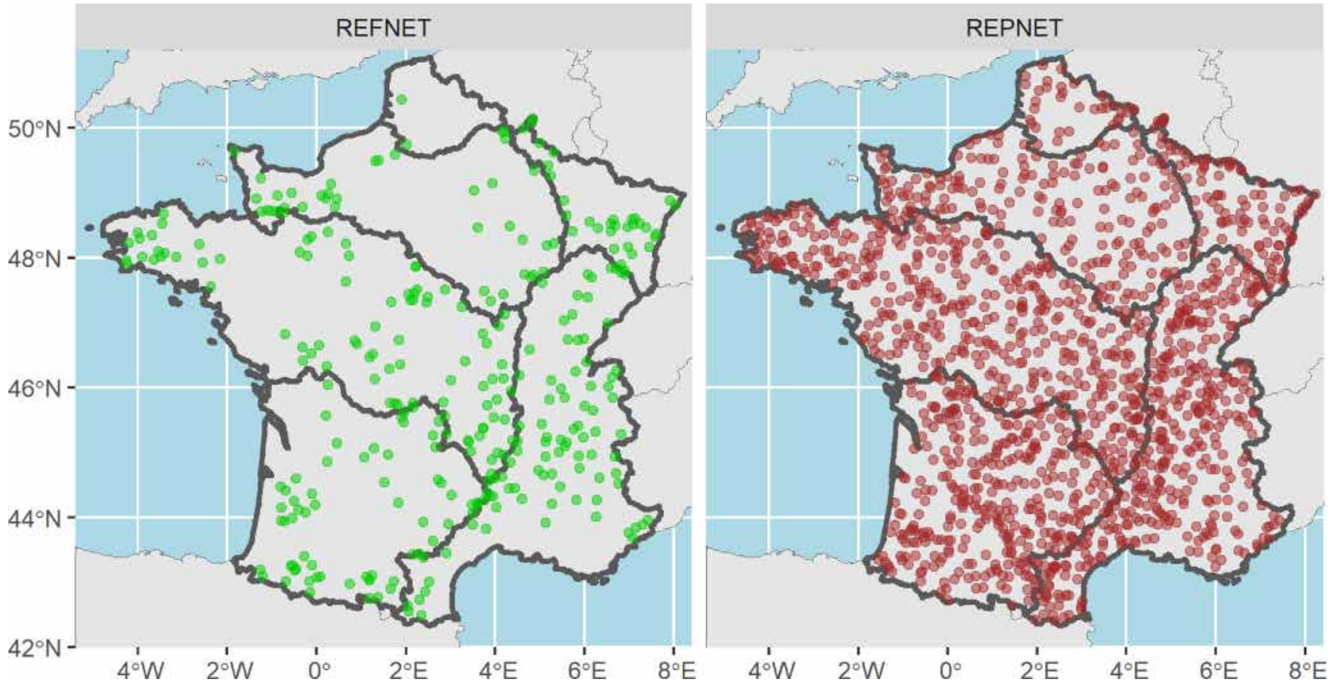

Fig. 1. Map of mainland France distinguishing the reference (REFNET) and representative (REPNET) networks. The two networks share 125 sites in common. The French territory is divided in 6 hydrological districts (*i.e.*, Northern district, Northeastern district, Seine Basin district, Atlantic district, Loire Basin district, Garonne Basin district, Rhône Basin district).

Since its development, the FBI is regularly applied through regional monitoring for reporting the condition of, and threats to, the biotic condition of French rivers. However, to date, there has been no overall synthesis realized at the national scale.

Here, we report for the first time the variation in FBI values over a seventeen-years period for 1583 sampled sites evenly distributed across the French territory. Our objectives were to (1) verify the overall index temporal sensitivity in discriminating between reference and disturbed sites; (2) give a general picture of the evolution of French rivers biotic condition over the period according to the index and its different components (*i.e.*, metrics and taxa); (3) examine the potential effects of climate change on the temporal variation in FBI and metrics scores, independently of other potential human disturbances and (4) discuss results in light of WFD requirements.

2 Materials and methods

2.1 Data

We used time-series data from the « Aspe » database hosting electrofishing surveys available for mainland France rivers (Irz *et al.*, 2022). The database, administrated by the French Biodiversity Office (Office Français de la Biodiversité, OFB, https://www.ofb.gouv.fr/), provides information on the sampling date, fish taxa and number of individuals captured for each survey. The database also provides metrics and index scores as well as the probability of presence for each of the 34 taxa contributing to the index. To comply with FBI calculation requirements, we selected surveys performed during the low flow period and following a standard protocol (T90–344, AFNOR, 2004) and, in case of multi-pass electrofishing, only fishes caught during the first pass were considered (Oberdorff *et al.*, 2002).

The final dataset covers the 2007-2023 period and aggregates 1583 sites that have been surveyed at least 7 yr, with a first survey in 2007 or 2008 and a last survey in 2022 or 2023. The dataset includes sites sampled as part of (i) the 'Surveillance Monitoring Network', deployed to comply with the European Water Framework Directive monitoring, (ii) the pre-existing 'Hydrobiological Network', and (iii) the 'Perennial Reference Network' set up in 2013 to monitor the temporal trends on a set of minimally impacted sites, selected based on their good water quality and hydro-morphological characteristics and on the absence of any significant anthropogenic pressure occurring in their upstream catchment. The former two datasets can be considered as representative of French rivers diversity in term of natural characteristics and human pressures. The latter dataset is considered as a reference one. These 3 datasets are fully independent of the ones that originally served to calibrate and test the index.

We further split the dataset in two subsets: (1) the 'Perennial Reference Network' (here after REFNET, encompassing 310 sites) and (2) the 'Surveillance Monitoring Network' and the 'Hydrobiological Network' that are both expected to give a representative picture of fish assemblages ecological state for the whole French riverine system (here after REPNET, encompassing 1398 sites) (Fig. 1). Note that REFNET and REPNET share 125 sites in common and that REFNET is biased towards headwater sites compared to REPNET. A description of sites sampling effort across time for the two datasets is given in Fig. S1.

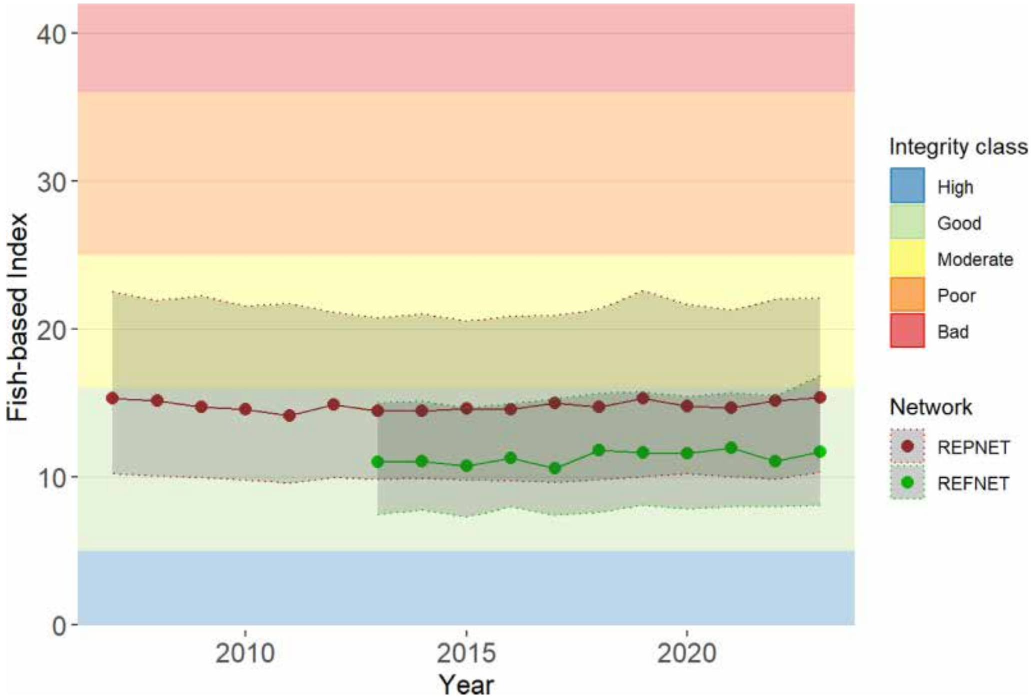

Fig. 2. Fish-based Index temporal trends for the sites belonging to the reference (REFNET) and monitoring (REPNET) networks. Points represent the annual median FBI value across sites and the ribbon the interquartile range.

2.2 Analyses

We used FBI values to analyze the evolution of French rivers biotic condition over time. This indicator combines seven metrics measuring complementary features of fish assemblages:

- Number of taxa (taxa richness): "total_nb_sp".
- Number of rheophilic taxa: "nb_rheophilic_sp".
- Number of lithophilic taxa: "nb_lithophilic_sp".
- Total density (number of individuals per m^2, log (n+1)-transformed): "total_dens_indiv".
- Density of individuals belonging to the tolerant guild (number of individuals per m^2, log (n+1)-transformed): "dens_tolerant_indiv".
- Density of individuals belonging to the omnivore guild (number of individuals per m^2, log (n+1)-transformed): "dens_omnivorous_indiv".
- Density of individuals belonging to the invertivore guild (number of individuals per m^2, log (n+1)-transformed): "dens_invertivorous_indiv".

Briefly, metrics are modelled using regional and local environmental descriptors known to influence riverine fish assemblages to obtain values (*i.e.*, models residuals) independent of these (natural) environmental factors. The residual values of each of the 7 metric models are further expressed into probabilities (p) and, after appropriate transformation of each metric probability (−2 log(p)), the final index score is obtained by summing the 7 metrics values. Whatever the metric, a value of 2 or lower is expected for a reference site whereas a value > 2 is expected for a disturbed site. The final index varies between 0 (*i.e.*, perfect match between theoretical and observed values) and an unbounded positive value obtained by adding the distances between theoretical and observed metric values. The cut-off level for assemblage 'impairment' is empirically set for an index value of 16 (*i.e.*, an index value <= 16 characterizes a reference site whereas a value > 16 characterizes a disturbed site) and scoring criteria (*i.e.*, index condition classes) are assigned according to whether the index value approximates, deviates somewhat from, or deviates strongly from this expected value (see Oberdorff *et al.*, 2002 for the scoring criteria definition).

The list of taxa contributing to each metric making up the FBI is available in Table S1 and Oberdorff *et al.* (2002). Note that, as the index was developed before recent taxonomical advances from molecular methods, some of the contributing taxa are now known to include several species (*e.g.*, see Denys *et al.*, 2020 for the genus *Phoxinus*). Therefore, some species were pooled before carrying out the taxa temporal trends to comply with the FBI taxonomy:

- All taxa from the *Barbatula, Carassius*, *Cottus, Esox, Gobio*, *Phoxinus* and *Thymallus* genera were considered at the genus level.
- The different varieties of common carp and ecotypes of brown trout were labelled as *Cyprinus carpio* and *Salmo trutta*, respectively.
- *Blicca bjoerkna* was pooled with *Abramis brama* and labelled *Abramis brama*.
- *Leuciscus burdigalensis* and *Leuciscus bearnensis* were pooled with *Leuciscus leuciscus* and labelled *Leuciscus spp*.

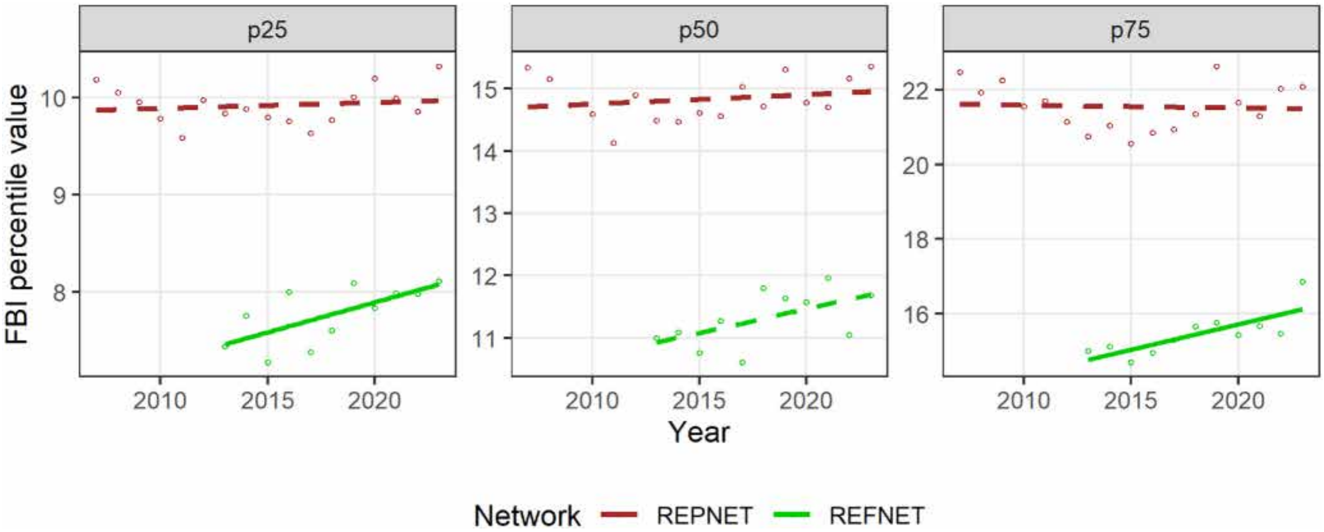

Fig. 3. Temporal trends in FBI scores using the 25th (p25) 50th (p50) and 75th (p75) percentiles for REPNET and REFNET. Solid regression lines indicate that the Mann-Kendall trend test is significant at the 5% threshold.

We first gathered from the Aspe database metrics and overall FBI values over time for the two subsets (*i.e.*, REFNET and REPNET) to (1) test (using both REFNET and REPNET) the power of the index in discriminating "reference" from disturbed sites, (2) highlight (using both REFNET and REPNET) potential significant temporal trends in sampled sites FBI total scores and metric values at the national scale, (3) evaluate (using exclusively REFNET) the potential effects of climate change on FBI values temporal variation, independently of any other potential human disturbances.

To assess in detail the changes in sites FBI total and metrics scores observed among years, we also analyzed within-site temporal dynamics of each of the 34 taxa composing the index. For this, we used 2 indicators calculated annually for each taxon. These two indicators are derived from field observations: the total density of individuals of a given taxon (median annual values of the number of individuals caught per 1000 m^2 across sites where the taxon is present, hereafter "Density") and the percentage of sites where the taxon is actually observed (hereafter "Occupancy_Rate").

Throughout the article, the temporal trends are assessed by a nonparametric, rank-based Mann-Kendall (MK) test (Mann, 1945; Kendall, 1975) on the annually-aggregated indicators values (annual median). MK is commonly used in water and climate sciences to test the significance of monotonous temporal trends (Yue and Wang, 2004). MK performs well for non-linear trends, does not require normal distributions and deals with missing values in time series (Yue and Pilon, 2004). However, the power of the MK test to detect trends in time series usually decreases for limited sample length and large sample variance (Wang *et al*., 2020). As MK does not provide a slope estimate, the trend lines and their statistical significance were assessed by using the Sen-Theil robust regression method (Sen, 1968; Theil, 1950). Although numerous bivariate correlations are presented, no correction for multiple comparisons is applied because each correlation is unique. More importantly, because the purpose here is not to test taxa-level or metric-level hypotheses but to display the relationships in a simple way allowing row-wise and column-wise analyses of the graphical output.

All the analyses were carried out with R software version 4.3.3 (Ihaka and Gentleman, 1996) and {aspe} R package dedicated to the processing of the Aspe database (Irz *et al.*, 2023). The code is available on Github (https://github.com/PascalIrz/fbi_trends).

3 Results

3.1 Trends in FBI overall values

Over the study period, the percentage of surveys displaying FBI values < 16 (Index Condition Class "Good" or above) is 77% for REFNET and 55% for REPNET (Fig. 2).

The REFNET dataset shows systematically higher FBI values compared to REPNET and displays an interquartile range inside the quality class 'Good' (except for year 2023) as defined by the FBI impairment threshold (FBI values < 16). There is no statistically significant change in FBI median scores over time, whatever the dataset (*p*-values of 0.34 and 0.12 for REPNET and REFNET, respectively). However, analyzing REFNET sites scores by quartiles using the 25th, 50th and 75th percentiles depicts an increasing degradation trend of sites through time, the lower and upper percentiles (*i.e.*, the 25th and 75th percentiles) showing statistically significant trends (Fig. 3, Table 1).

Regarding REPNET, annual FBI sites median values are all located in the quality class "Good" with interquartile range values varying between FBI quality classes "Moderate" and "Good" (Fig. 2). Analyzing REPNET sites scores using the 25th, 50th and 75th percentiles shows, contrarily to REFNET, no significant temporal trend, whatever the quartile (Fig. 3, Table 1). However, when restricting REPNET time period to match the one of REFNET (2013-2023), we can notice a significant increasing degradation trend of sites values through

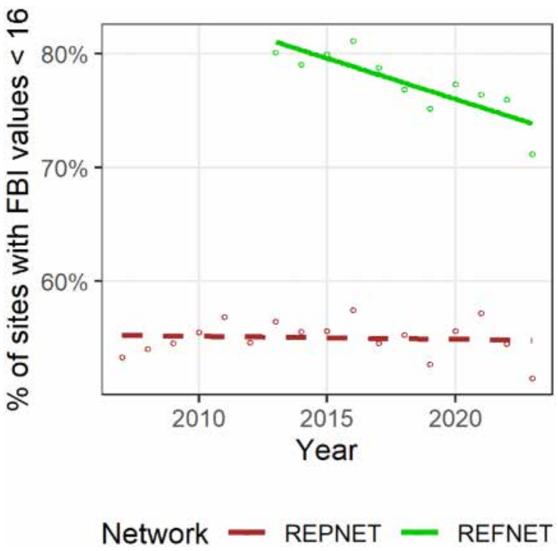

Fig. 4. Temporal trend in the annual percentage of sites displaying 'good' or higher conditions according to the FBI for REPNET and REFNET. The solid regression line indicates that the Mann-Kendall trend test is significant at the 5% threshold. Note that for REFNET the percentage of sites displaying 'good' or higher conditions falls from 81% to 74% in just 10 yr.

time (for the 50th and 75th percentiles) similar to the one depicted for REFNET (Table 1). This tendency toward degradation in sites values is still valid (for the 25th and 75th percentiles) after withdrawing the 125 sites shared with REFNET (Table S2).

Whereas most sites of REFNET and REPNET show no significant temporal sign of degradation or improvement (*i.e.*, 77.1 and 85.9% of sites, respectively), 15.8 and 8.9% of the sites show, however, a significant degradation and only 7.1 and 5.2% an improvement over time, respectively. This general tendency seems rather evenly spatially distributed (Fig. S2).

Moreover, the percentage of sites in 'good' conditions (FBI values < 16; Index Condition Class "Good" or above), while showing no trend for REPNET, significantly decreases through time for sites belonging to REFNET, indicating a general tendency toward sites degradation for this last dataset (Table 1, Fig. 4).

3.2 Trends in FBI metric values

Looking at the seven metrics constituting the index, two metrics for REFNET (*i.e.*, "number of rheophilic species" and "density of tolerant individuals") and one metric for REPNET (*i.e.*, "total density of individuals") show a significant tendency toward degradation over time (Fig. 5). Note, however, that even if the temporal trends are significant for the three metrics above, their median values remain within the range expected for sites in 'good' conditions (median metric values < 2 in the three cases).

We examined the temporal evolution of "Density" and "Occupancy_Rate", along with taxa contributing to the metrics (Table 2). The three richness metrics were evaluated using the following framework: a significant increasing trend of the "Occupancy_Rate" indicates that sites habitat suitability increases for a given taxon, whereas the reverse indicates a decrease in sites habitat suitability through time. The four remaining metrics, related directly to taxa density within sites, were only evaluated using the indicator "Density".

Nine taxa, over the 34 composing the index, showing no significant relationship with the two indicators, whatever the network, were not included in Table 2 but appear in Fig. S3. Whatever the network, the species *Salmo trutta* and *Anguilla anguilla* displayed clear unfavorable population trends over time whereas two taxa, *Phoxinus spp*. and *Rhodeus amarus*, show favorable population trends.

Concerning REFNET, site habitat suitability increased for *Barbatula spp*., *Gobio spp*., *Phoxinus spp*., *Rhodeus amarus*. Conversely, site habitat suitability decreased for *Anguilla anguilla*, *Salmo salar* and *Salmo trutta*. The degradation of the metric "number of rheophilic species" seems mainly driven by the loss of site habitat suitability for two species (*i.e.*, *Salmo salar* and *Salmo trutta*) and the degradation of the "density of tolerant individuals" metric by the density increase of two species (*i.e.*, *Barbatula spp.* and *Squalus cephalus*) (Table 2, Fig. S3).

Regarding REPNET, site habitat suitability increased for *Alburnoides bipunctatus*, *Alburnus alburnus*, *Lampetra planeri*, *Phoxinus spp*. and *Rhodeus amarus*. Conversely, site habitat suitability decreased for *Abramis brama*, *Ameiurus melas*, *Anguilla anguilla*, *Esox spp*., *Gobio spp*., *Lota lota*, *Parachondrostoma toxostoma*, *Rutilus rutilus* and *Salmo trutta*. The "total density of individuals" metric showed significant tendencies towards site degradation overtime mostly because of more individuals than expected under natural conditions, mainly driven by the density increase of six taxa (*i.e.*, *Alburnoides bipunctatus, Alburnus alburnus, Gobio spp., Phoxinus spp*. and *Squalus cephalus*) and more marginally by *Barbus barbus, Barbus meridionalis, Lepomis gibbosus, Rhodeus amarus* and *Scardinius erythrophtalmus* (latter 5 species had lower individual numbers) (Table 2, Fig. S3).

4 Discussion

We expected FBI scores to reflect a "High" or "Good" ecological status with no significant variation through time for sites belonging to REFSET and, for sites belonging to REPNET, significant FBI scores improvement due to management and/or rehabilitation efforts initiated to comply with the EU Water Framework Directive (WFD) requirements.

4.1 Temporal evolution of the biological condition of riverine ecosystems according to the FBI

Our research produced two encouraging results (1) 77% of the sites belonging to the REFNET evolve, as expected, inside the FBI quality class "Good" or higher (2) 55% of the sites belonging to REPNET, that are supposed to give a realistic picture of the ecological condition of French riverine ecosystems, display a 'good' ecological status according to the Index. These results suggest that, besides the fact that the FBI discriminates reference from impacted sites, the general biological condition of French rivers, according to fish assemblages, is not drastically impaired nationally. However, results from REFNET show that none of the FBI median

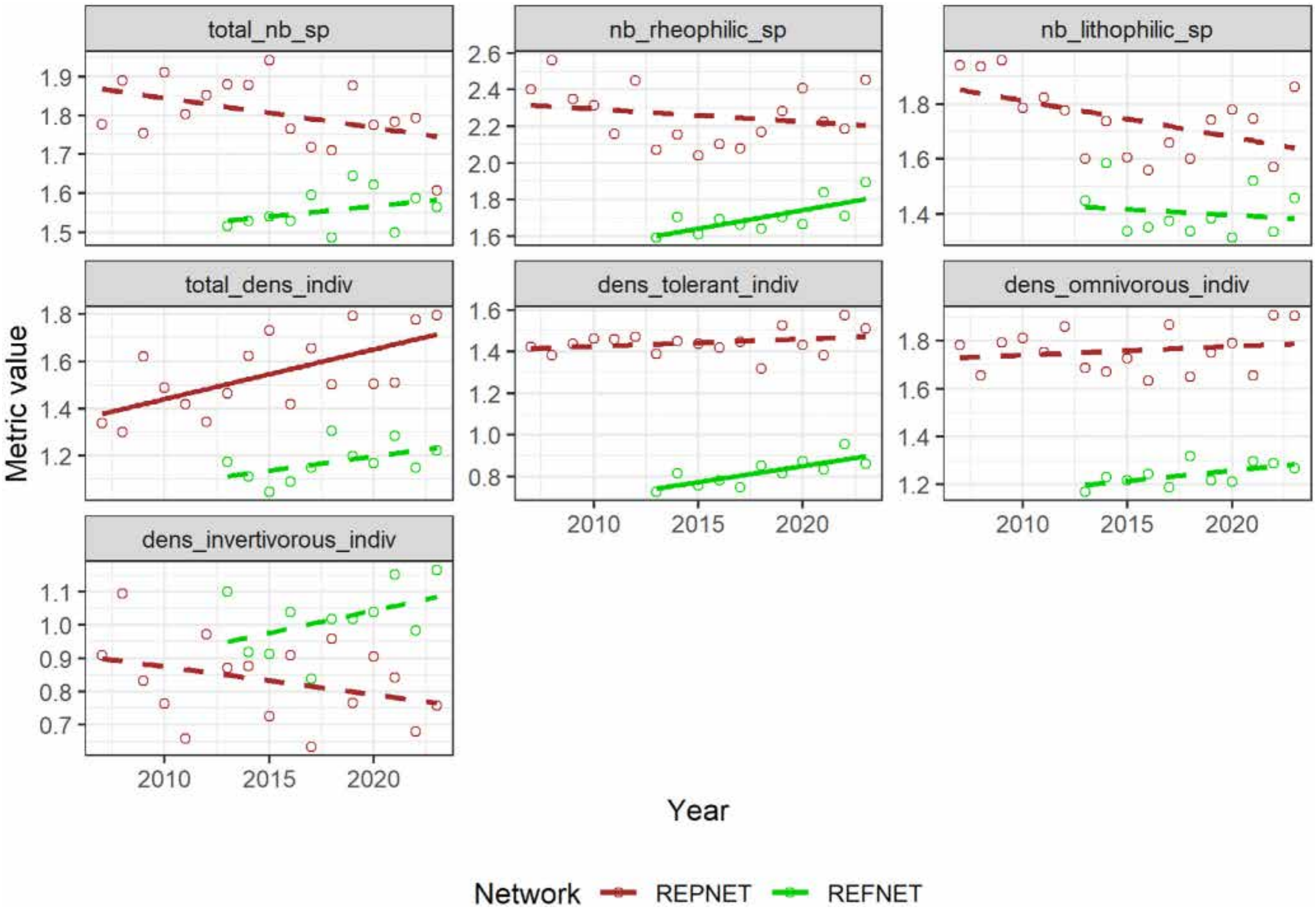

Fig. 5. Temporal trends in FBI metrics annual median values across sites for REPNET and REFNET. Solid regression lines indicate that the Mann-Kendall trend test is significant at the 5% threshold. It is worth noting that while all metrics but one (*i.e.*, "nb_lithophilic_sp") show temporal tendencies toward degradation for REFNET, four metrics (*i.e.*, "total_nb_sp", "nb_rheophilic_sp", "nb_lithophilic_sp" and "dens_invertivorous_indiv") show slight temporal trends toward amelioration for REPNET (although these last trends are not statistically significant).

annual sites values reached the "High" quality class, suggesting that, overall, sites constituting this dataset, also in overall good conditions, are not pristine. Moreover, the fact that around 45% of the REPNET sites are considered impacted according to the index shows that the WFD objective to obtain a 'good ecological status' or higher for water bodies is still far from being reached (EEA, 2018). Even more problematic, results from the REPNET offer no clear support for our expectation of an overall improvement in sites fish assemblage condition over time following two decades of implemented rehabilitation measures, as no significant trend in FBI total scores was noticed during the targeted period. Worth, when focusing on REFNET, we found a significant tendency toward sites degradation through time (note that sites degradation for REFNET is most probably resulting from climate change effects, see paragraph below). These results put in perspective the ones exposed in a recent study, using 222 sites sampled from 1994 to 2013 in France, and documenting a significant recovery of fish pollution-sensitive taxa as a result of an overall improvement of water quality (Tison-Rosbery *et al.*, 2022). During the time period of our study (2007–2023), analyzing REPNET sites, and according to ecological guilds defined in Oberdorff *et al.* (2002), only four of ten taxa considered intolerant (*e.g.*, species having a narrow water quality and habitat flexibility) showed some signs of improvement (*Alburnoides bipunctatus, Lampetra planeri, Phoxinus spp.* and *Rhodeus amaratus*) whereas two others showed some signs of degradation (*i.e.*, *Esox spp.* and *Salmo trutta*). Moreover, two of the four taxa (*i.e.*, *Alburnoides bipunctatus* and *Rhodeus amaratus*) showing signs of improvement are supposed to have increased their range mainly through human driven translocation and water temperature increase (Van Damme *et al.*, 2007; Keith *et al.*, 2020). The foregoing makes the Tison-Rosbery *et al.* (2022) statement of a recovery of pollution-sensitive taxa not fully supported by our results, at least during the time range of our study. Furthermore, still focusing on REPNET, all of the guild-based metrics constituting the index showed no significant trend over the time period analyzed, suggesting that the functional structure of assemblages did not change significantly over time. Moreover, the only metric showing a significant temporal trend, *i.e.*, the "total density of individuals", highlights signs of degradation towards more individuals than expected under natural conditions. This may reflect an increase in riverine

Table 1. Mann-Kendall test of monotonic temporal trend for the 25, 50 and 75th percentiles of annual FBI score for each network, along with the annual percentage of sites in 'good' condition (pc_good) according to the index (index condition class "Good"). The columns correspond to the Mann-Kendall test *p*-value (mk_pvalue), Sen-Theil slope (sens_slope), slope significance (sig) and trend interpretation (trend). Note that (1) a degradation involves a positive slope in the percentiles, but a negative one for 'pc_good', and (2) when analyzing REPNET from 2013 to 2023 the 50 and 75th percentiles show significant tendencies toward sites degradation.

Network	Period	Variable	mk_pvalue	Sens_slope	Sig	Trend
REFNET	**2013-2023**	**p25**	**0.043**	**0.0682**	**TRUE**	**Degradation**
REFNET	2013-2023	p50	0.119	0.0823	FALSE	Non-significant
REFNET	**2013-2023**	**p75**	**0.008**	**0.1225**	**TRUE**	**Degradation**
REFNET	**2013-2023**	**pc_good**	**0.003**	**-0.0059**	**TRUE**	**Degradation**
REPNET	2007-2023	p25	0.837	0.0021	FALSE	Non-significant
REPNET	2007-2023	p50	0.343	0.0257	FALSE	Non-significant
REPNET	2007-2023	p75	0.837	-0.0166	FALSE	Non-significant
REPNET	2007-2023	pc_good	0.837	0.0001	FALSE	Non-significant
REPNET	2013-2023	p25	0.161	0.0328	FALSE	Non-significant
REPNET	**2013-2023**	**p50**	**0.008**	**0.0619**	**TRUE**	**Degradation**
REPNET	**2013-2023**	**p75**	**0.008**	**0.1436**	**TRUE**	**Degradation**
REPNET	2013-2023	pc_good	0.119	-0.0024	FALSE	Non-significant

ecosystems overall productivity, most probably due to recurrent nutrient loadings from agricultural land to riverine systems following mineral and organic land fertilization (Poikane *et al*., 2019; Grizzetti *et al*., 2021), as other point sources nutrient loads from industry and urban wastewaters have been significantly reduced during the last decades (Carvalho *et al*., 2019). Climate change, through an increase in water temperatures and a decrease in river discharge (Seyedhashemi *et al*., 2023) likely exacerbated this last tendency (see below). Overall, our results are more in phase with results from recent studies using time series of freshwater invertebrate communities collected across European countries, including France. Since the 2010 s these communities plateaued or degradated (Haase *et al*., 2023; Sinclair *et al*., 2024). These last results and our own findings clearly indicate that the current scale and scope of rehabilitation policy and implementation fail in reducing anthropogenic impacts on French inland waters to meet the biological quality goals outlined in the WFD.

4.2 Climate change effects on FBI values

Climate change is known to alter freshwater ecosystems and their biodiversity by increasing water temperatures and changing flow regimes through changes in precipitation intensity and variability (reviewed in Knouft and Ficklin, 2017). This causes progressive changes in the structure and composition of assemblages through species local extirpation or species range shift (reviewed in Oberdorff, 2022). Consequently, considering the relatively large period covered, we anticipated here an eventual effect of climate change on FBI temporal values, independently of any other potential human disturbances. The dataset of reference sites (REFNET), covering a ten years period (2013–2023), allowed us to indirectly test this assumption, as this dataset includes exclusively sites experiencing minimal anthropogenic perturbation. At first glance, and contrary to our expectation, we found no significant temporal trends in median FBI sites values suggesting that the index did not detect effects of climate change on local fish assemblages during the studied period. However, when analyzing annual FBI values by quartiles we noticed significant sites temporal degradation tendencies for the lower and upper percentiles (*i.e.*, the 25th and 75th percentiles). Moreover, when breaking down the index by metric, we found temporal trends toward degradation for all metrics composing the index but one, *i.e.*, "number of lithophilic species"), the trends being statistically significant for two metrics (*i.e.*, the "density of tolerant individuals" and the "number of rheophilic species" metrics). Even if these trends toward degradation are not yet sufficient to downgrade most site FBI condition classes, the percentage of sites

Table 2. Cross analysis of the taxa temporal trends according to “Density” and “Occupancy_Rate” indicators and their contributions to the metrics composing the index. The blank cells indicate that the taxon does not contribute to the calculation of the metric. The metrics in bold are those displaying significant temporal trends. The arrows indicate the significant population indicator trend associated to the metric (*i.e.*, “Density” in case of the density-based metrics, “Occupancy_rate” in case of richness metrics). The dots mean that the taxon contributes to the calculation of the metric but displays no significant population trend. The slope significance threshold was set at 10% in order reduce the risk of missing some relationships (Wang *et al*., 2020). The taxa showing no significant trend either for “Density” or “Occupancy_rate” indicators for both datasets are not shown (9 species). However, these last taxa temporal tendencies are detailed in Fig. S3.

	REFNET							REPNET						
	Richness			Density				Richness			Density			
Taxon	total_nb_sp	**nb_rheophilic_sp**	nb_lithophilic_sp	total_dens_indiv	**dens_tolerant_indiv**	dens_omnivorous_indiv	dens_invertivorous_indiv	total_nb_sp	nb_rheophilic_sp	nb_lithophilic_sp	**total_dens_indiv**	dens_tolerant_indiv	dens_omnivorous_indiv	dens_invertivorous_indiv
Abramis brama	•			•	•	•		↘			•	•	•	
Alburnoides bipunctatus	•	•	•	•			•	↗	↗	↗	↗			↗
Alburnus alburnus	•			•	•	•		↗			↗	↗	↗	
Ameiurus melas	•		•	•			•	↘		↘	•			•
Anguilla anguilla	↘			•			•	↘			•			•
Barbatula spp.	↗			↗	↗			•			•	•		
Barbus barbus	•	•	•	•				•	•	•	↗			
Barbus meridionalis	•	•	•	•				•	•	•	↗			
Cottus spp.	•	•	•	•			•	•	•	•	•			•
Esox spp.	•			•				↘			•			
Gobio spp.	↗			•			•	↘			↗			↗
Lampetra planeri	•		•	•				↗		↗	•			
Lepomis gibbosus	•			•			•	•			↗			↗
Leuciscus spp.	•	•		•		•		↘	↘		•		•	
Lota lota	•	•		•				↘	↘		•			
Parachondrostoma toxostoma	•	•	•	•		•		↘	↘	↘	•		•	
Phoxinus spp.	↗		↗	↗				↗		↗	↗			
Rhodeus amarus	↗			•				↗			↗			
Rutilus rutilus	•			•	•	•		↘			•	•	•	
Salmo salar	↘	↘	↘	•			•	•	•	•	•			•
Salmo trutta	↘	↘	↘	•			•	↘	↘	↘	•			•
Sander lucioperca	•			•				•			•			
Scardinius erythrophthalmus	•			•		•		•			↗		↗	
Squalius cephalus	•			↗	↗	↗		•			↗	↗	↗	
Thymallus spp.	•	•	•	•			•	•	•	•	↗			↗

displaying a 'good' or higher ecological status dropped from 81 to 74% in just 10 yr. Taken together, these last results suggest that climate change is actually starting to reshuffle local fish assemblages leading to progressive shifts in their structure and composition, in line with earlier evidence (Daufresne *et al*., 2003; Comte and Grenouillet, 2013; Comte *et al*., 2013). Indeed, when analyzing REFSET sites at the taxa level, some taxa showed early signs of home range extension as a result of significant increases in site habitat suitability over time (*e.g.*, *Barbatula spp*., *Gobio spp*., *Phoxinus spp*., *Rhodeus amarus*). Other taxa showed signs of home range contraction (*e.g.*, *Anguilla anguilla*, *Salmo salar* and *Salmo trutta*). Whereas increased water temperature (Seyedhashemi *et al*., 2022) and a consequent increase in ecosystem productivity probably favors home range extension of the former species (Mantyka-Pringle *et al*., 2014), the reverse is expected for cold-water dependent species such as *Salmo salar* and *Salmo trutta* that seemed to have experienced reduced suitable habitat availability (Comte *et al*., 2013). It should be noted that the reference dataset (REFNET), that served here to test climate change effects independently of other potential anthropogenic disturbances, is biased towards headwater sites and their representative fish taxa. As such, we cannot discard the possibility that other taxa, more representative of downstream parts of the hydrological network, are also starting to experience changes in their home ranges directly due to warming, all the more as some taxa common to REFNET and REPNET displayed the same significant temporal tendencies (*Alburnoides bipunctatus*, *Alburnus alburnus*, *Anguilla anguilla*, *Phoxinus spp*., *Rhodeus amarus* and *Salmo trutta*). In addition, FBI values of both datasets showed comparable degradation tendencies (*i.e.*, a temporal decrease in the percentage of sites displaying a 'good ecological status') over the last 10 yr, although these last tendencies are not statistically significant concerning REPNET. Unfortunately, REPNET precludes rigorously validating this last assumption as it includes sites impacted by other anthropogenic disturbances.

5 Conclusion

We found that 45% of the sites considered representative of French rivers diversity in term of natural characteristics and human pressures (REPNET dataset) are significantly impaired and that no detectable trend toward improvement and thus no significant biological recovery from historical impairment occurred during the period. This suggests that the EU WFD objective of a 'good ecological status' for water bodies is still far from being reached in France. This apparent lack of progress towards meeting this WFD target emphasizes that further research is urgently needed to better understand the reasons behind this compliance failure, all the more as rivers water quality has increased since the last two decades, at least for some pollutants (EEA, 2018; Dézerald *et al*., 2020). Likely drivers impairing progress towards meeting this WFD target are the fragmentation of river networks by dams, weirs, culvets and fords that disrupt riverine systems connectivity and flow regimes (Blanchet and Tedesco, 2021) and diffuse sources of pollution from agriculture (*e.g.*, nutrients and pesticides loads; Carvalho *et al*., 2019), among others (Herlihy *et al*., 2020).

We also highlighted a significant negative effect of climate change on site FBI scores of our "reference" dataset (REFNET). Indeed, the percentage of sites in 'good condition' dropped from 81 to 74% over the last 10 yr. The FBI seems then more influenced by climate change for upstream sites (given that REFNET is primarily composed of headwaters sites). However, this leads us to propose refining taxa models that serve for index calculation, by integrating the new climatic conditions experienced by French rivers. Doing this should facilitate separating future effects of climate change *per se* from other anthropogenic pressures on local riverine fish assemblages.

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Authors' contributions

The study was designed by TO and PI. Data analyses were done by PI with support from all co-authors. The initial manuscript was written by TO and PI. All authors discussed the results and contributed to the final manuscript. All authors gave final approval for publication.

Supplementary material

The supplementary material can be downloaded from: https://github.com/PascalIrz/fbi_trends/blob/main/scripts/fbi_trends_supplementary_material.html

Fig. S1. Annual number of sites surveyed, with a distinction between belonging exclusively to REFNET (green bars), exclusively to REPNET (brown bars) and to both networks.

Fig. S2. Map of the Fish-based index trends for the REFNET sites, with the hydrographic basins limits.

Fig. S3. Description of taxa temporal trends using six indicators. Each point represents the annual median value of the indicator. Solid regression lines indicate that the Mann-Kendall trend test is statistically significant. The first two indicators "Density" and "Occupancy_rate" are fully described in the Methods section. The four other indicators are derived from the logistic models developed in Oberdorff *et al.* (2001) and giving the probability of occurrence of each of the 34 taxa as a function of a set of environmental characteristics. These models were originally fitted exclusively on reference (i.e., least-impacted) sites. We then considered a probability value over 50% as a predicted taxon presence and a probability below this threshold as a predicted taxon absence. These indicators are: (1) the percentage of sites where the taxon is predicted present and observed present (hereafter Confirmed_Presence), (2) the percentage of sites where the taxon taxon is predicted absent but observed present (hereafter Unexpected_Presence), (3) the percentage of sites where the taxon is predicted absent and observed absent (hereafter Confirmed_Absence) and (4) the percentage of sites where the taxon is predicted present but observed absent (hereafter Unexpected_Absence). When analyzed separately, these four indicators reflect temporal trends in the sites habitat suitability (or un-suitability) for a given taxon, according to the models.

Table S1. List of taxa contributing to each metric making up the FBI.

Table S2. Mann-Kendall test of monotonic temporal trend for the 25, 50 and 75th percentiles of annual FBI score for REPNET and REFNET, 2013-2013, excluding the sites that are shared between these networks. The rows in bold indicate a significant trend (mk_pvalue < 0.05).

Table S3. Count and proportion of the REPNET and REFNET sites according to the Fish-based index trends.

The Supplementary Material is available at https://www.kmae-journal.org/10.1051/kmae/2024007/olm.

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