LIVING PLANET INDEX

MIGRATORY FRESHWATER FISHES

2024 UPDATE

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The Living Planet Index (LPI) for migratory freshwater fishes
2024 update

Technical report

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Glossary

Migration/Migratory	The movements animals undertake between critical habitats to complete their life cycle. Often, this is a seasonal or cyclical movement between breeding and non-breeding areas.
Migratory freshwater fish	In this report, any fish species classified in GROMS as catadromous, anadromous, amphidromous, diadromous or potamodromous.
Species	A group of living organisms consisting of similar individuals capable of exchanging genes or interbreeding.
Population	In the Living Planet Database (LPD), a population is a group of individuals of a single species that occur and have been monitored in the same location.
Time series	A set of comparable values measured over time. Here, these values are abundance estimates of a set of individuals of the same species monitored in the same location over a period of at least two years using a comparable method.
Index	A measure of change over time compared to a baseline value calculated from time series information.
Data set	A collection of time series from which an index is calculated.

Summary

Migratory fishes that spend all or parts of their life cycle in freshwater are highly threatened , and a previous analysis confirmed widespread catastrophic declines in their abundance. Here, we provide an update of these trends using an improved selection of species and data set extending further into the present. Based on abundance information from the Living Planet Database for 1,864 populations of 284 native migratory freshwater fish species, we find that globally, the index has declined by 81%. The majority (65%) of species have declined on average, while 31% have increased on average, with the majority of species trends being either very positive or very negative. Average declines have been more pronounced in Europe (−75%) and Latin America & Caribbean (−91%), and less in North America (−34%) and Asia-Oceania (−28%). The percentage of species represented was highest in the two temperate regions of Europe and North America, and Latin America & Caribbean (between 30 and 45%). Data was highly deficient for Asia-Oceania, and particularly Africa, for which no reliable trend could be produced. Populations that are known to be affected by local threats show an average decline of 96% while those not threatened at the population level have increased on average. Habitat degradation, alteration, and loss accounted for around a half of threats to migratory fish, while overexploitation accounted for just under one-third of recorded threats. Populations receiving management declined less than unmanaged ones, with most management activities relating to some form of fisheries management (42%; this included fishing restrictions, stocking, bycatch reductions, supplementary feeding and no-take zones), and this was most commonly cited in North America and Europe. Habitat management accounted for only 9% of recorded management activities, despite the prominence of habitat-related threats to populations in the data set. Recorded reasons for observed increases tended to be mostly unknown or undescribed, especially in tropical regions. Although both the species selection method and data set have been improved since the last report, data and knowledge gaps remain, and more quantitative data and analysis are needed to obtain a more detailed picture of how populations are changing and the different factors interacting and driving this change. We conclude with a list of recommendations for improving our understanding of the fate of migratory freshwater fishes and developing practical solutions that restore and protect them and the ecosystems upon which they depend.

Introduction

Migration consists of the cyclical, predictable movements animals undertake between critical habitats to complete their life cycle (Dingle & Drake 2007). In fish, it can be distinguished from other types of movement because it takes place between two or more well-separated habitats, occurs regularly (often seasonally), involves a large fraction of a population, and is directed rather than random (Northcote 1978). Migratory fishes occur around the world and may migrate short or long distances within or between rivers, lakes, oceans, and other waters. For many species, migration is required for survival and enhances individual fitness (Lucas & Baras 2001; Brink et al. 2018). Migratory fishes play essential ecological roles, and their declines impact Indigenous cultures, natural heritage, and vulnerable populations' livelihoods and nutrition (Noble et al. 2016; Funge-Smith & Bennett 2019).

Migratory fishes that spend all or parts of their life cycle in freshwater are highly threatened. Almost one in three of all freshwater species (Collen et al. 2014) and 25% of freshwater fish species are threatened with extinction (IUCN 2023), and migratory fishes are disproportionately threatened compared to non-migratory fishes (Darwall & Freyhof 2015). Further, the Convention on Migratory Species (CMS), which focuses on species that migrate across borders, highlighted in a recent report that 97% of CMS-listed fishes are threatened with extinction (UNEP-WCMC 2024). One of the largest issues leading to this alarming scenario is the loss of free-flowing rivers and blockage of migration routes (Grill et al. 2019; Belletti et al. 2020; Thieme et al. 2023; Keijzer et al. 2024), impairing movement and reducing the ability of fishes to complete their lifecycle (Winemiller et al. 2016). Dams and other river infrastructures change flow regimes, which affects the connectivity between habitats (Parasiewicz et al. 2023), and the timing and magnitude of lifecycle cues, and availability of habitat. Even small dams lead to potential range loss in many freshwater fish species globally (Keijzer et al. 2024). Flow regimes and ambient conditions are also fundamentally altered independently of water infrastructure by increasing levels of water abstraction (Sabater et al. 2018). Additional large-scale threats include overexploitation due to the cyclical and predicable patterns of movement of migratory fishes (Allan et al. 2005) and climatic changes, which can exacerbate the impacts of altered habitats on freshwater ecosystems (Ficke et al. 2007; Albert et al. 2021). Freshwaters are also affected by a bewildering array of pollutants from urban wastewater, industry, road run-off, agriculture, land use change and atmospheric deposition (Jaureguiberry et al. 2022). Also, emerging threats such as microplastic pollution and salinisation of freshwater ecosystems are of increasing concern (Reid et al. 2019). In light of these facts, it is important to gain an accurate picture of trends in migratory freshwater fish abundance and how these differ across regions.

This report presents an update of the global analysis from 2020 of trends in freshwater migratory fish populations (Deinet et al. 2020) using more recent and comprehensive data. Previously, migratory freshwater fish species were identified using their GROMS (Global Register of Migratory Species) category (Riede 2001). However, this categorisation is outdated, potentially leading to the omission of species that have changed taxonomy or were more recently described. In this update, we used more recent information from the IUCN Red List 2023 update, which included the first global freshwater fish assessment, specifically focusing on species that inhabit freshwater and are considered migratory (IUCN 2023). Trends were produced using the Living Planet Index (LPI) method (Loh et al. 2005; Collen et al. 2009; McRae et al. 2017). The LPI provides a global measure of the status of biological diversity. It tracks the average rate of change in abundance amongst monitored populations of vertebrate species in much the same way that a stock market index tracks the value of a set of shares or a retail price index tracks the cost of a basket of consumer goods. We apply the LPI method to assess the status of freshwater migratory fish at a global scale, examine regional trends in migratory freshwater fishes and explore possible drivers for the patterns we observe. We put the results in context with the recent literature on trends in freshwater migratory fishes and propose recommendations drawn from the findings in this report, other reports and literature, and insights from the authors/expert opinion.

Methods

For this report, we selected migratory freshwater fish species based on their movement pattern on the IUCN Red List (IUCN 2023), including only those coded as 'full migrant', 'altitudinal migrant', or 'nomadic'. This list was amended following expert advice from South America (Caldas et al. 2023), the Mekong (*Z. Hogan, pers. Comm.*) and Europe (*S. Nagy, pers. comm.*). For example, four European species considered to have migratory movement patterns in the Red List were removed entirely for this analysis (*Alburnus volviticus*, *Alosa agone*, *Barbus tauricus*, *Caspiomyzon hellenicus*), and one was excluded just for Europe (*Alburnus alburnus*). The final list of 1,255 migratory fish species was used to identify relevant data from the Living Planet Database (LPD) and to focus new data collection. We calculated trends for different cuts of the data using the Living Planet Index method (rlpi package, version 0.0.2.; see Appendix for more details), based on coding from the LPD on regions, zones, threats, management, utilisation and reasons for increase.

Results and discussion

Data set

We extracted, from the Living Planet Database (LPD; WWF/ZSL, 2024), abundance information for 1,864 populations of 284 native fish species that migrate into or within freshwater systems for some portion of their life history. These species will be referred to as 'migratory freshwater fishes' in this report. More information on the interpretation of the LPI ('The LPI, its calculation and interpretation') and a list of species (**Table A1**) can be found in the Appendix.

Data for migratory freshwater fishes were collected from a variety of sources for locations around the world (**Figure 1**). Time-series tended to be longer on average for populations in temperate regions (11 and 14 years for Europe and North America) than for tropical regions (7-10 years; **Figure A3**). Although most *populations* of freshwater migratory fishes were monitored in temperate regions (56%), the majority of *species* (68%) were monitored in tropical regions, especially in Asia and Oceania (**Table 1**). The 284 species represent 23% of the 1,255 freshwater migratory fish species currently known to occur globally, based on the IUCN Red List and experts. Although species representation for temperate and tropical zones was similar to the global representation, it varied for different regions – from 13-14% in Africa and Asia & Oceania to 45% in North America (**Table 1**).

Table 1. Number of populations and species of migratory freshwater fishes in the LPD, the number of currently known species (based on IUCN Red List and experts), and the percentage representation for each subset for which an index was calculated. Please refer to the appropriate sections for more detailed explanations of the different data sets.

Theme	Subset (LPD coding)	Monitored populations (migratory freshwater fish LPI)	Monitored species (migratory freshwater fish LPI)	Currently known species	% represented
Global		1,864	284	1,255	23%
Zone	*Temperate*	1,046	92	451	20%
	Tropical	818	194	939	21%
Region	*Africa*	100	30	230	13%
	Asia & Oceania	218	102	751	14%
	Europe	390	45	116	39%
	Latin America and Caribbean	533	84	284	30%
	North America	623	48	106	45%
Threats	*Threats present*	329	146	-	-
	No threats present	157	68	-	-
	Unknown threat status	1,378	185	-	-
Management	*Managed populations*	414	66	-	-
	Unmanaged populations	398	161	-	-
	Unknown management status	1,052	177	-	-
Utilisation	*Utilised populations*	578	180	-	-
	Non-utilised populations	129	51	-	-
	Unknown utilised status	1,157	165	-	-

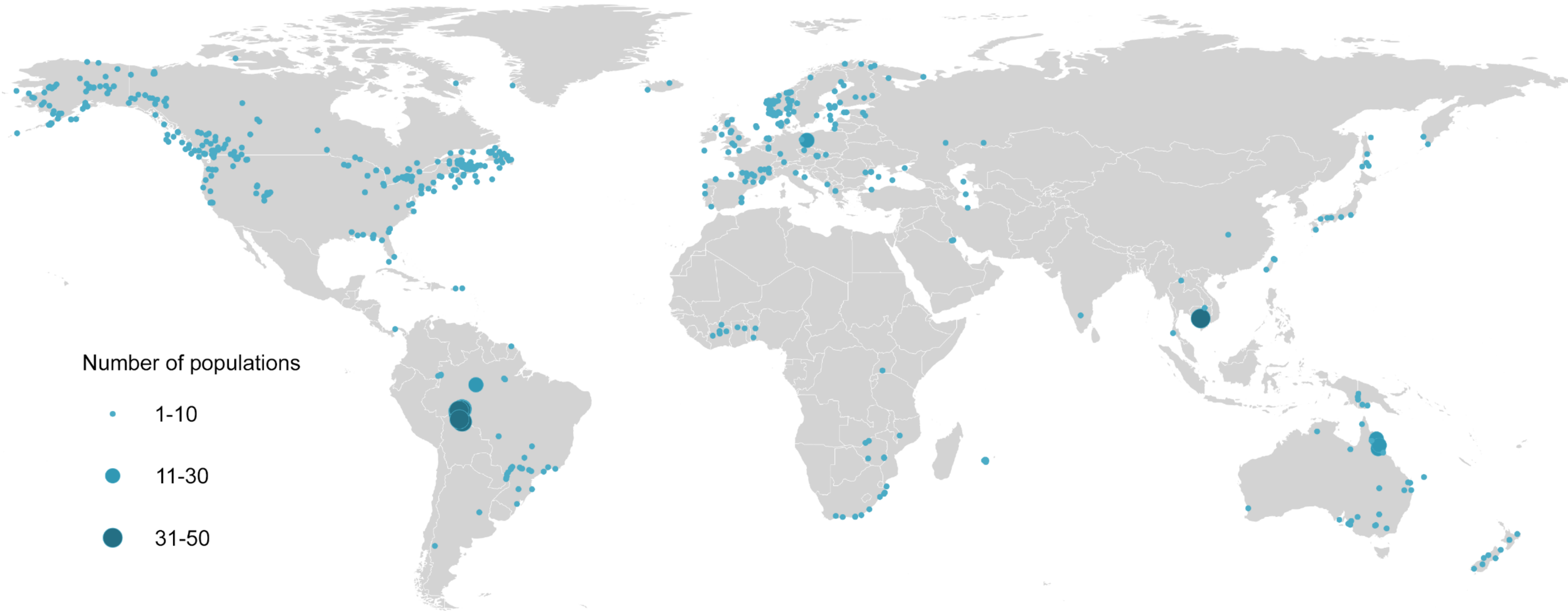

Figure 1. Global distribution of 1,864 monitored populations of 284 species of migratory freshwater fishes included in this analysis, taken from the Living Planet Database (LPD; WWF/ZSL, 2024). Different shades and sizes denote number of different populations at each location.

Global trend

The index for 284 monitored species shows a decline of −81% between 1970 and 2020 (bootstrapped 95% confidence interval: −63% to −91%; **Figure 2**), which is similar to the trend for freshwater vertebrate species overall (−83% over roughly the same period; WWF, 2022). This is equivalent to an average of −3.3% decline per year. Because the LPI describes average change, this means that although populations of these monitored species are, on average, 81% less abundant in 2020 than in 1970, some species have decreased more while some have decreased less or have even increased over that same period.

The majority (65%) of species have declined on average, while 31% have increased on average (**Figure 3**). When examining the total change for each species in more detail, we see that the majority of species trends are at the extremes, being either very positive or very negative (outermost bars in **Figure 4**). While there are plenty of species decreasing at a slower rate than the most extreme cases, instances of species increasing – ranging from around 5% to 100% – are observed much less. Stable species (i.e. those changing by less than 5% over the monitoring period) were infrequently identified in the data (**Figures 3 and 4**). Overall, this suggests that there are not just more declining species, but that declining species are showing a greater magnitude of change than increasing species are.

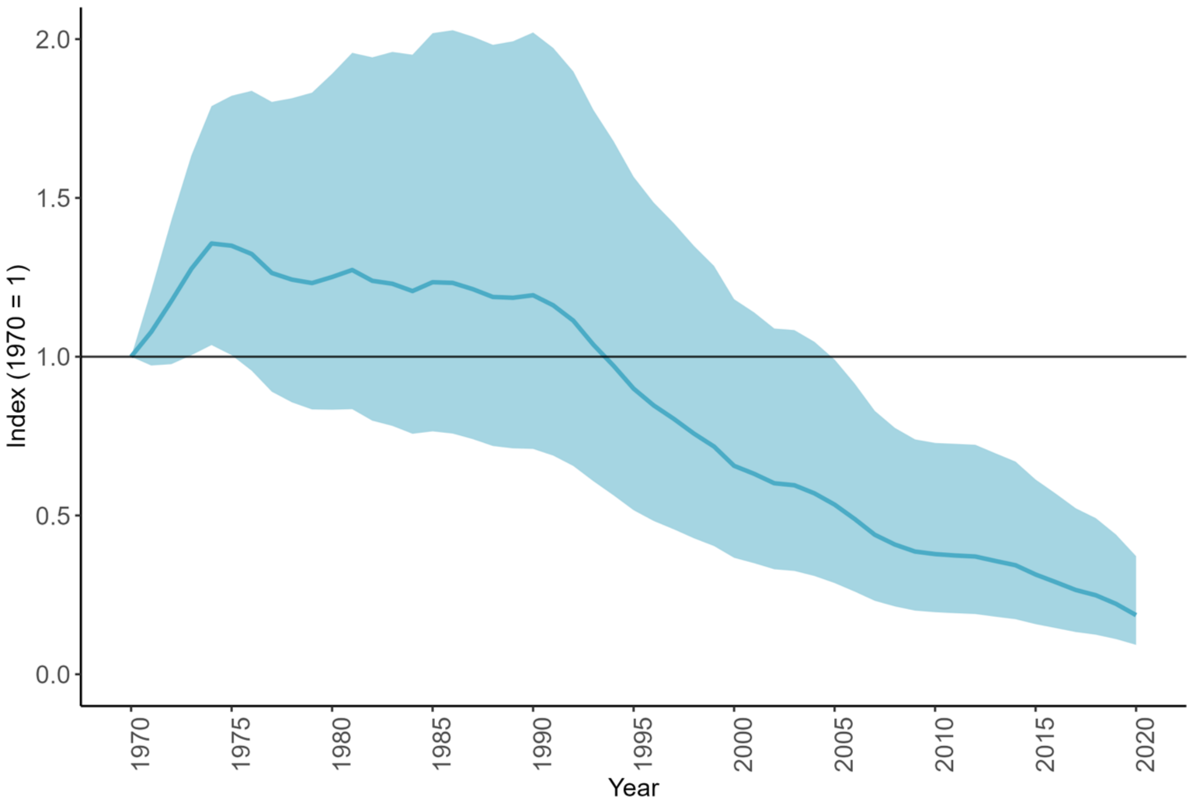

Figure 2. Index of abundance of 1,864 monitored populations of 284 species of migratory freshwater fishes, showing a decline of −81% between 1970 and 2020. The white line shows the Living Planet Index values, and the shaded areas represent the bootstrapped 95% confidence interval (−63% to −91%).

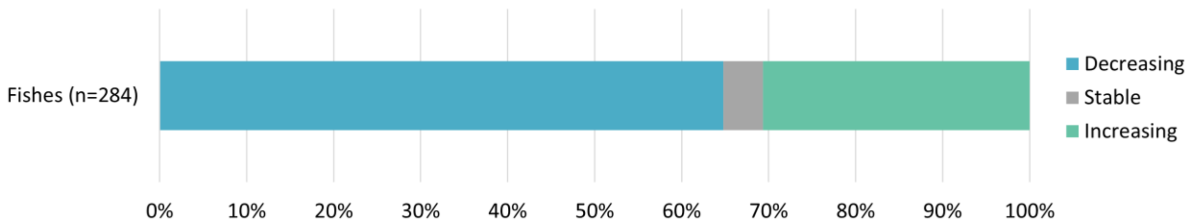

Figure 3. The proportion of 284 migratory freshwater fish species with a declining (n=184), stable (n=13) or increasing (n=87) species-level trend. A stable trend is defined as an overall average change among all populations of ±5%.

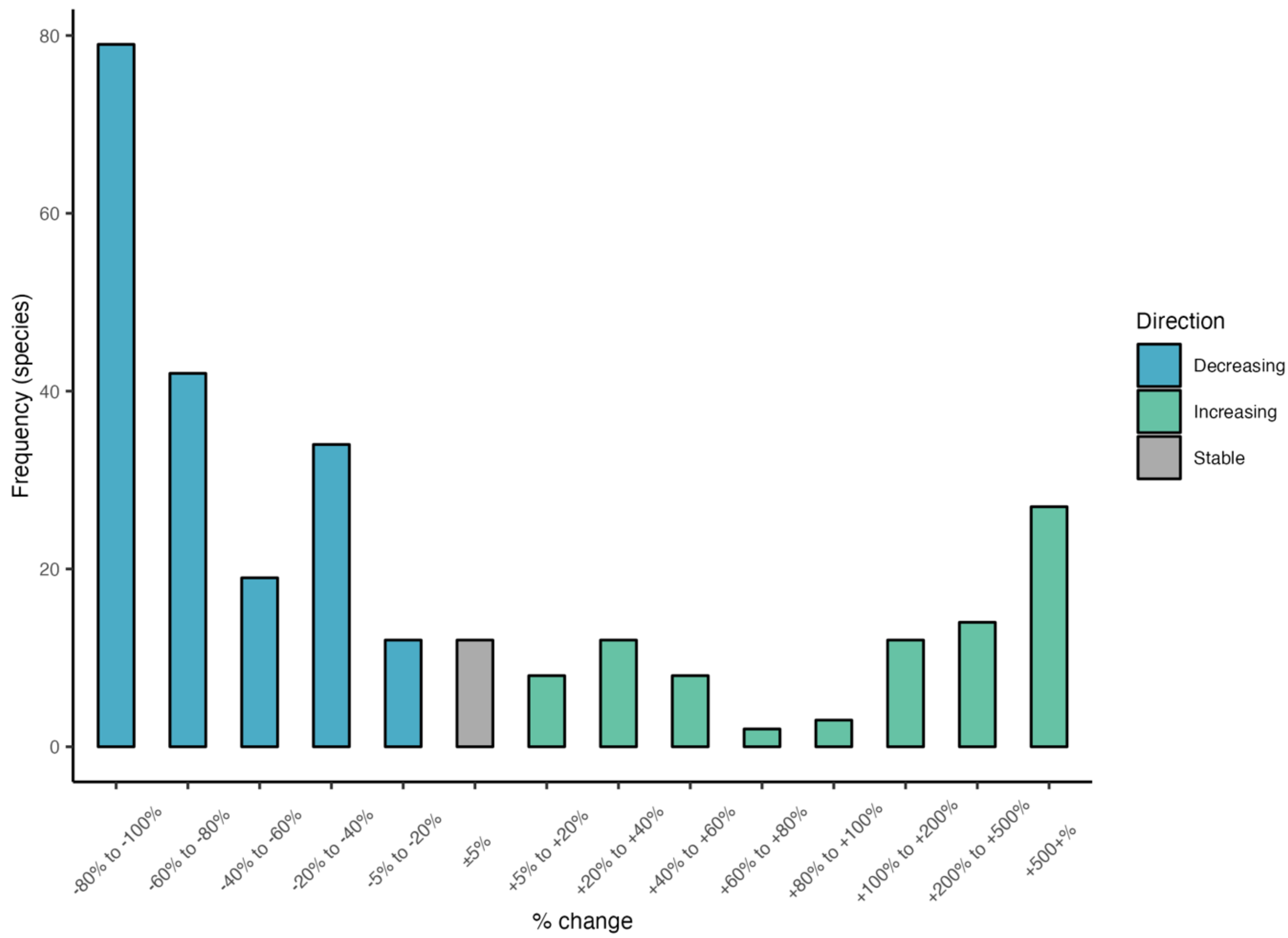

Figure 4. Histogram of the total average change of 284 migratory freshwater fish species. Please note that '±5%' represents a stable trend. Total change occurred over different time periods depending on data availability for each species.

After an initial increase in the early 1970s and a stable positive trend, the global index starts to show a negative slope, representing an overall average decline, compared to the baseline, from the mid-1990s (**Figure 2**). When examining average change by decade, it becomes clear that this negative change has occurred consistently across the last 30 years, ranging from an average change per year of −5.5% in the 1990s (attributable to a range of different species and locations; see **Figures 5 and 6**) to −6.85% in the 2010s (**Figure A1**). Limited data availability frequently accounts for changes in trends observed both at the beginning and the end of an index. In the early 1970s, many of the less than 200 populations of less than 50 migratory freshwater fish species contributing to the index (**Figure A2**) were on the rise in most regions (**Figure 6**), thereby producing an increasing trend. Conversely, towards the end of the index, there is a drop in available population data due to publication lags, resulting in fewer populations to evaluate (dropping from around 600 to 300 populations, and from around 100 to 65 species between 2015 and 2020; **Figure A2**). At this point, the available data indicate a negative change. During both time periods a smaller data set is more heavily influenced by the trends of a smaller number of populations in the data set (see 'Limitations' section).

The −81% average abundance change by 2020 (−72% by 2016) observed in this analysis is different to the −76% average decline by 2016 for species selected using their GROMS classification in the previous report (Deinet et al. 2020). This may be partly attributable to the difference in the size and species composition of the two data sets: the current migratory freshwater fishes LPI is based on 15% more species and 33% more populations, with only 963 populations and 124 species shared between them. However, extending the old index to 2020 – assuming a constant average annual change of 3% – results in a similar final trend value of −79%, despite the absence of an initially increasing trend before the 1990s. This suggests comparable overall declines in the species populations not shared between data sets using the two different selection methods.

Below, we explore the trends in different subsets of migratory freshwater fishes to elucidate any differences in the underlying data, for example, temperate and tropical areas, and biogeographic regions.

Tropical and temperate zones

The LPD divides the world into temperate and tropical zones based on biogeographic realms as defined by (Olson et al. 2001). The temperate zone includes the Nearctic and Palearctic (this roughly equates to North America, Eurasia north of the Himalayas, and North Africa), and the tropical zone (the remaining areas of the world). Migratory freshwater fishes have declined on average in both zones, although they have fared better in temperate compared to tropical areas (−71% vs −87%; **Figure 5**). The overall declines correspond to an average change of −2.4% per year for temperate populations and −4% per year for tropical populations. Both trends show a similar trajectory to the global index (**Figure 2**), with a positive change compared to the baseline until the mid-1990s, culminating in a steadily declining slope. The temperate trend is also reflected in the Europe region (**Figure 6**), which contributes around half of temperate species (**Table 1**). The tropical index shows a high degree of short-term fluctuations, as indicated by the wider confidence interval (**Figure 5**; see also **Figure 6**). Both indices represent around 20% of known migratory freshwater fish species (**Table 1**).

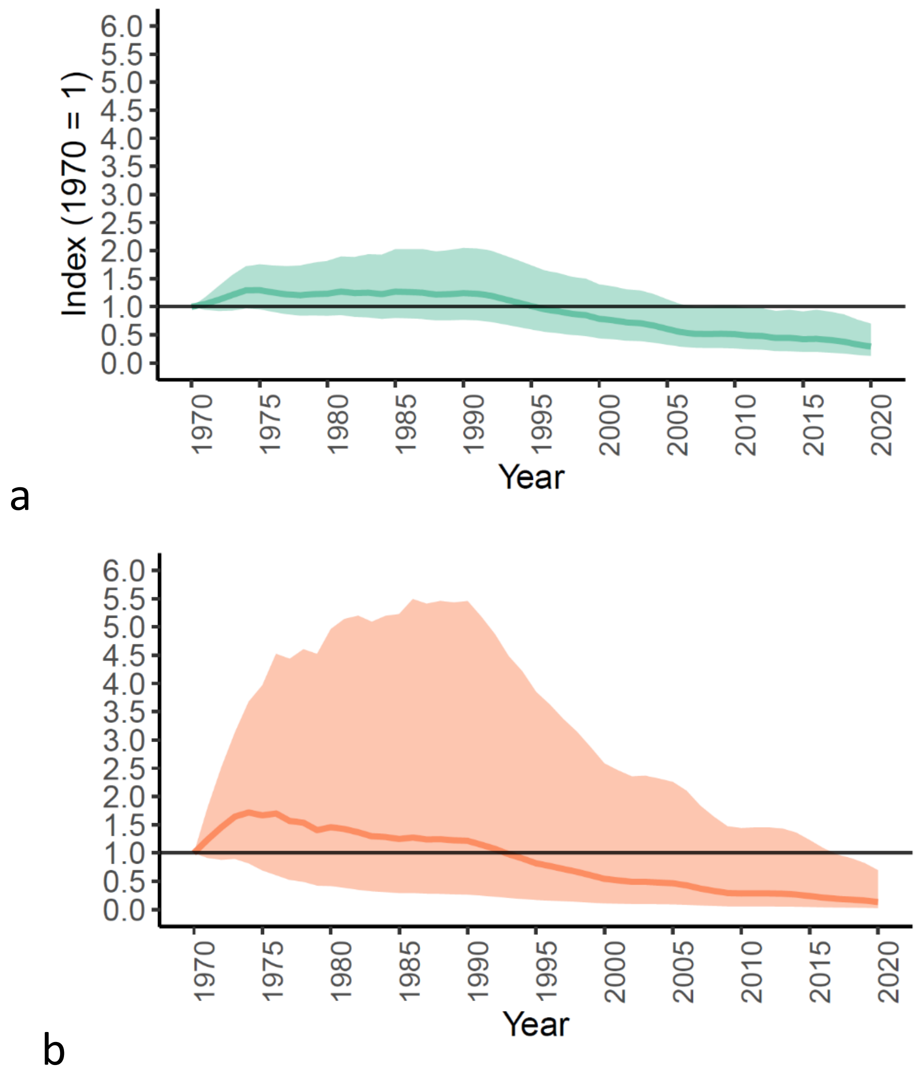

Figure 5. Index of abundance for monitored migratory freshwater fishes between 1970 and 2020 in a) temperate zones (−71%; 1,046 populations of 92 species) and b) tropical zones (−87%; 818 populations of 194 species). The bold lines show the Living Planet Index values, and the shaded areas represent the bootstrapped 95% confidence intervals.

The high variation of the tropical index is because many of the tropical species are represented by shorter time series (on average 9 years compared to 13 years in temperate populations). Short-time series result in a greater turnover of data, i.e. many time series enter and leave the data set at different times between 1970 and 2020. Thus, at any given time, fewer species may be contributing to the tropical index, making it more vulnerable to trends of a few populations or set of species.

It is also worth noting that temperate populations may have declined substantially prior to 1970, which would lead to a smaller overall decline from a more depleted state than in tropical areas.

Regions

The data set can be divided into different political regions, following the internationally accepted UN Geographic Region classification (United Nations Statistics Division (UNSD) n.d.). When examining trends for migratory freshwater fishes in this way, a picture of widespread average declines emerges, ranging from −28% in Asia-Oceania to −91% in Latin America and Caribbean (**Figure 6**). The trend for Africa is not shown because we lack confidence in it due to a small and biased data set.

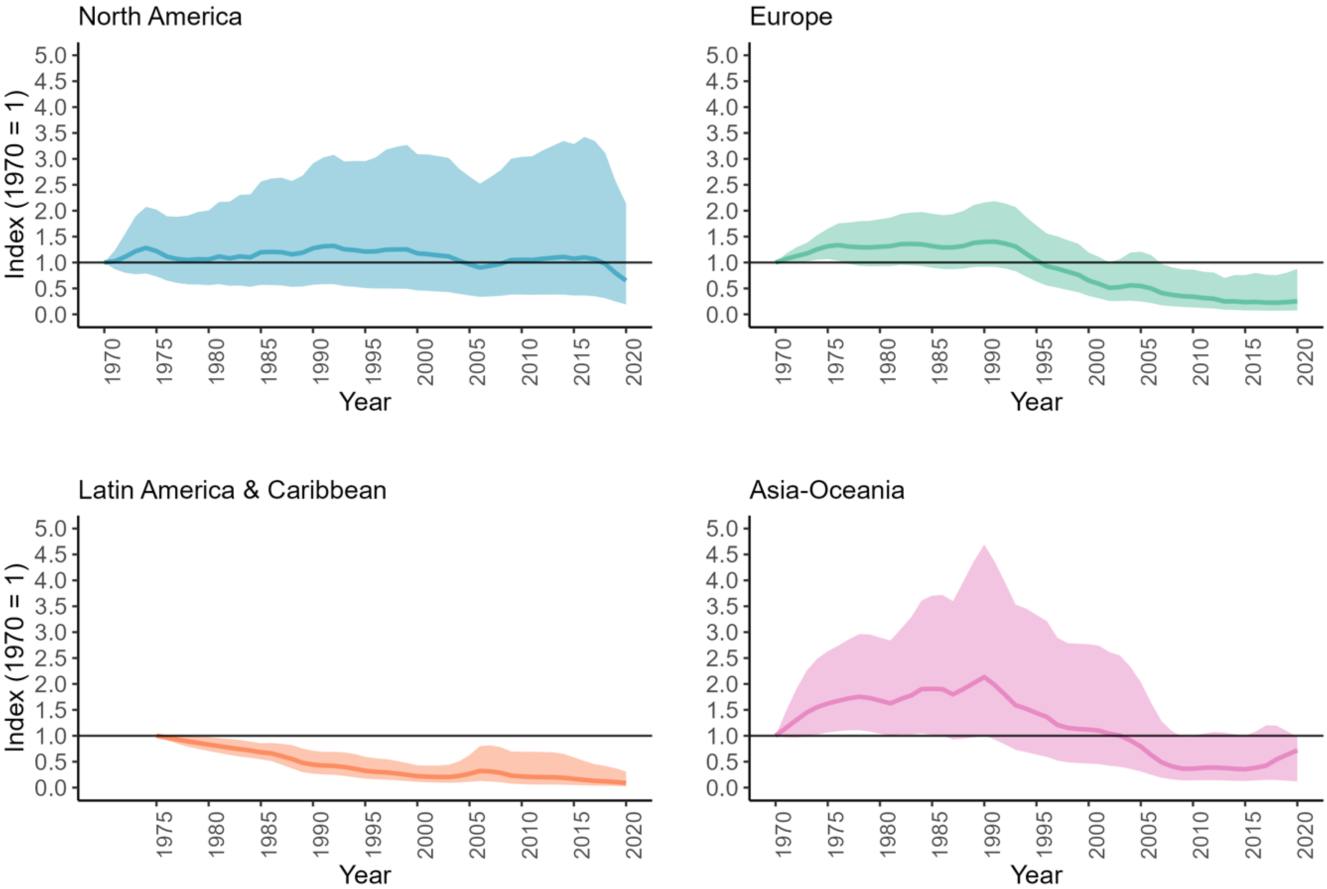

Figure 6. Index of abundance for monitored migratory freshwater fishes between 1970 and 2020 in North America (−34%; 623 populations of 48 species), Latin America and Caribbean (−91% since 1975; 533 populations of 84 species), Europe (−75%; 390 populations of 45 species) and Asia-Oceania (−28%; 218 populations of 102 species). The bold lines show the Living Planet Index values, and the shaded areas represent the bootstrapped 95% confidence intervals. Please note that the index for Africa is not shown here because we lack confidence in the resulting trend due to a small and biased data set. The Latin America & Caribbean index is for 1975-2020.

The Asia-Oceania index includes the highest number of species (**Table 1**), yet the trend is less smooth with more obvious fluctuations (**Figure 6**). This could be attributed to a number of different factors: shorter time series (8.5 years on average, compared to 11 and 14.5 for Europe and North America respectively; **Figure A3**) entering and leaving the indices at different times and causing abrupt changes in the index; monitoring biases leading to under- and overestimation of abundance at different times during the monitoring; and potentially real cyclical patterns in the abundance of some species. The

Asia-Oceania index is also the least representative, comprising data from only 14% of species known to occur there (**Table 1**).

There is large uncertainty in the North American trend given its wide confidence intervals throughout, which overlap with the baseline at the end. A drop in the number of available data is responsible for the accelerating decline after 2017 (**Figure 6**), as the remaining populations and species show a negative trend. The index suggests that the North American populations tend to be reasonably stable since the 1970s, aside from aforementioned recent decline. There may be several possible explanations for this. For example, much of the overall abundance of migratory freshwater fishes may have been lost prior to the baseline year due to overharvest post-European colonisation, the industrial revolution and dam construction (Humphries & Winemiller 2009; Waldman & Quinn 2022)., leading to a stable trend from a depleted state. In addition, although the North American index is the most representative at 45% of known species, its composition may be biasing it towards more stable trends – 30% are salmonids, 63% are managed species, and over a third are utilised species.

With an average −5% decline per year, the Latin America and Caribbean region shows the most pronounced overall decrease in population abundance, which is similar to the trend for all species groups from the equivalent Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) region (−94%; WWF, 2022). The trend is based on 84 species and follows the same steadily declining trajectory until the mid-2000s, after which it increases and then decreases again. This brief change is due to a number of potamodromous species from Brazil, which benefitted from a nutritional pulse following a drought in 2005 (Freitas et al. 2012).

The index for Europe, which is based on data from 45 species representing 39% of known species (**Table 1**), shows an average decline of −75% (**Figure 6**). It can be split into three phases: a positive change between 1970 and 1990; a period of accelerating decline until the early 2000s; and a slower decline thereafter (**Figure 6**). The middle period of the index appears to be influenced by several data sources, which benefit from closer examination for any update of the analysis in the future.

Threats

In the LPD, we record for each population whether there are local threats present, no threats are present or whether this information is unknown, based on information given in the data source. This particular 'threat status' is specific to the population and does not necessarily correspond to the threat status for a species or population as recorded in the IUCN Red List (IUCN 2023). When dividing the data set in this way, we see that populations where no threats are present have increased on average, while those with threats present show a serious average decline of −96% (**Figure 7**). Interestingly, species populations with unknown threat status, i.e. those where no specific threat is mentioned in the data source, show an average decline of −58% between 1970 and 2020. Because species populations with no threats present are increasing, this suggests that populations with unknown threat status are often still under pressure.

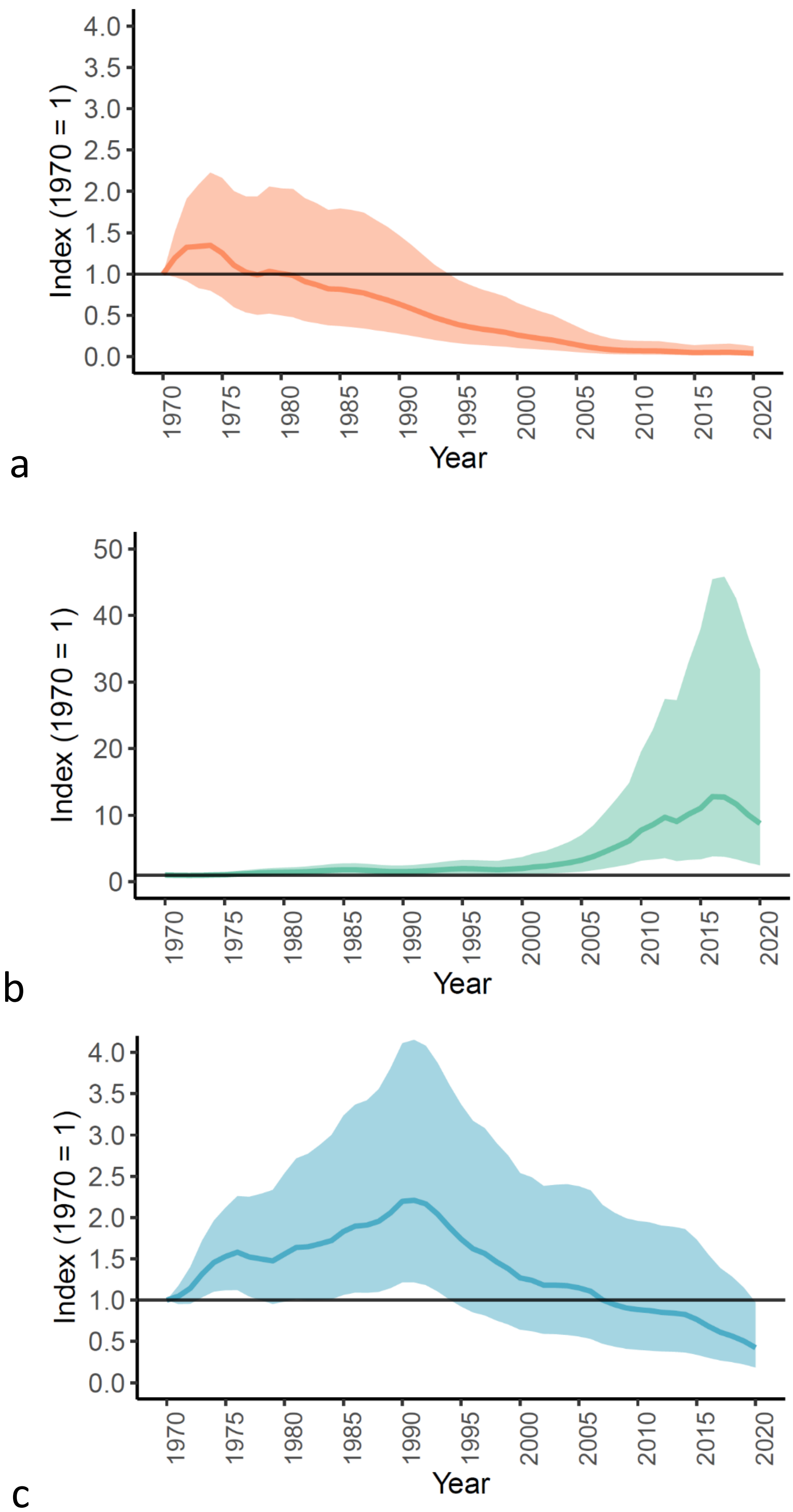

Figure 7. Index of abundance for monitored migratory freshwater fishes between 1970 and 2020 where a) threats are present (−96%; 329 populations of 146 species), b) no threats are present (+775%; 157 populations of 68 species) and c) with unknown threat status (−58%; 1,378 populations of 185 species). The bold lines show the Living Planet Index values, and the shaded areas represent the bootstrapped 95% confidence intervals. Please note that the y-axis scale is different for populations without local threats.

For populations where local threats are present, the LPD allows for up to three threats to be recorded for that population. They are grouped into broad categories, based on the Red List classification (IUCN 2023): habitat degradation and change, habitat loss, exploitation, invasive species, disease, pollution and climate change (**Table A2**). This more detailed information on population-specific threats was available for 328 populations of 146 species, totalling 581 recorded threats. Most populations were reported to be affected by a single threat (46%) while 31% reported two threats, and 23% three threats. The most reported threat was habitat degradation and change (35%), which together with habitat loss accounted for 50% of all reported cases (**Figure 8a**). The second most reported threat was overexploitation, which accounted for just under one-third of recorded threats (**Figure 8a**). At the regional level, habitat-related threats were the largest threat category in almost all regions, adding to more than 50% of all the threats in Africa, Asia and Europe (**Figure 8b**) Overexploitation was also widely cited as a threat in all regions, especially in Africa, Asia, and Latin America and Caribbean (**Figure 8b**).

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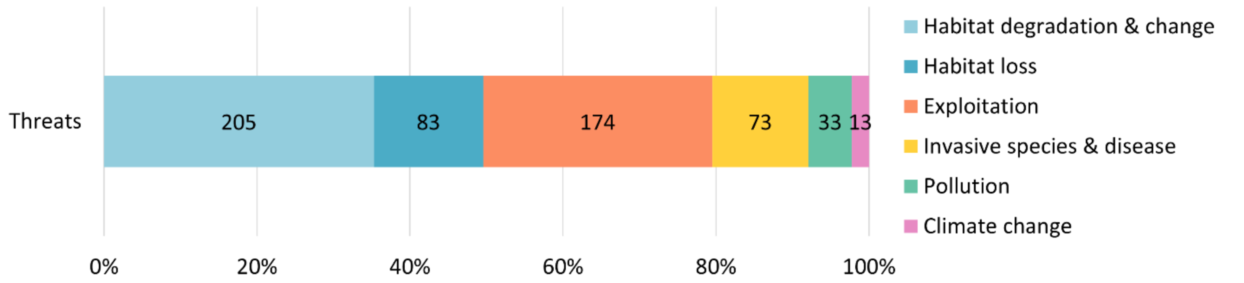

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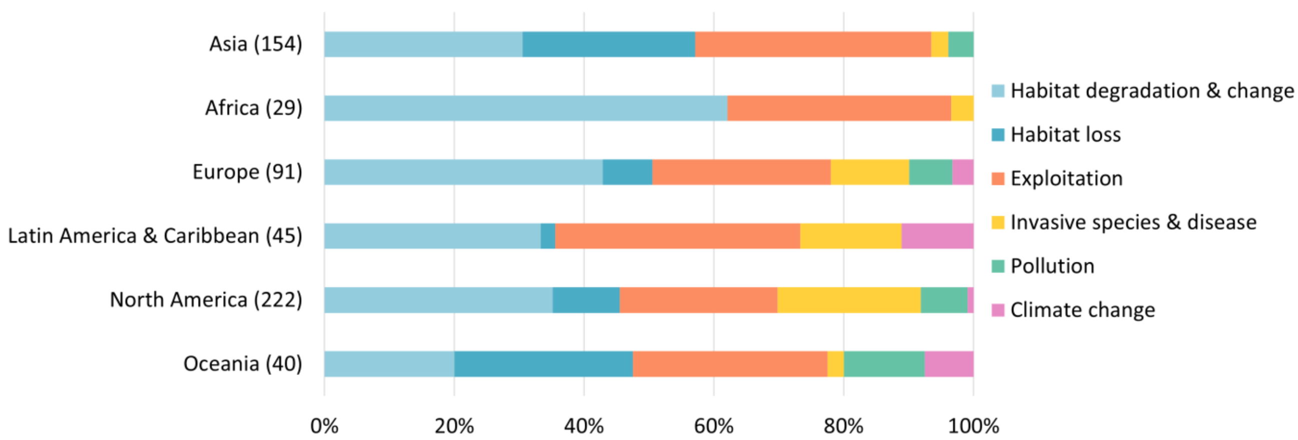

Figure 8. The distribution of threats for monitored migratory freshwater fishes a) globally and b) for different regions. Threat information was available for 328 populations of 146 species, totalling 581 recorded threats. The numbers in the bars (brackets) correspond to the number of times a threat was listed.

It is important to note that these figures give an indication of what is impacting the species populations in our data set, but they do not necessarily reflect threats to all migratory freshwater fish species globally or in different regions. Although habitat degradation, change and loss, and overexploitation are widespread issues for migratory freshwater fishes, other important threats are not reported in some of the regions (**Figure 8a**). This includes, for example, pollution (O'Brien et al. 2019; Jaureguiberry et al. 2022; IUCN 2023) and climate change (Ficke et al. 2007; Vertessy et al. 2019; IUCN 2023) where impacts may be more difficult to quantify.

In addition, even the more prominent habitat categories may be too broad to be informative, and a finer-scale reclassification similar to the IUCN Red List (IUCN 2023) may be useful in distinguishing between different drivers of change. Although detailed coding has been trialled successfully on some LPD freshwater data (Thorburn 2017), the information is still incomplete for the subset of migratory freshwater fishes.

Management

Management interventions may mitigate the effects of identified threats on species population trends. For migratory freshwater fish species, these interventions can take a variety of different forms, for example management of fisheries, habitat restoration, dam removal, setting up conservation areas, species-focused management and legal protection. Using information included in the LPD on whether a population is managed in this way, we find that populations of migratory freshwater fish species that have received some form of management have declined less (−43%) than unmanaged populations (−88%, **Figure 9**). This difference suggests that management could potentially have had a positive effect on these populations, although perhaps not as much of an effect as there not being threats present in the first place (**Figure 7b**).

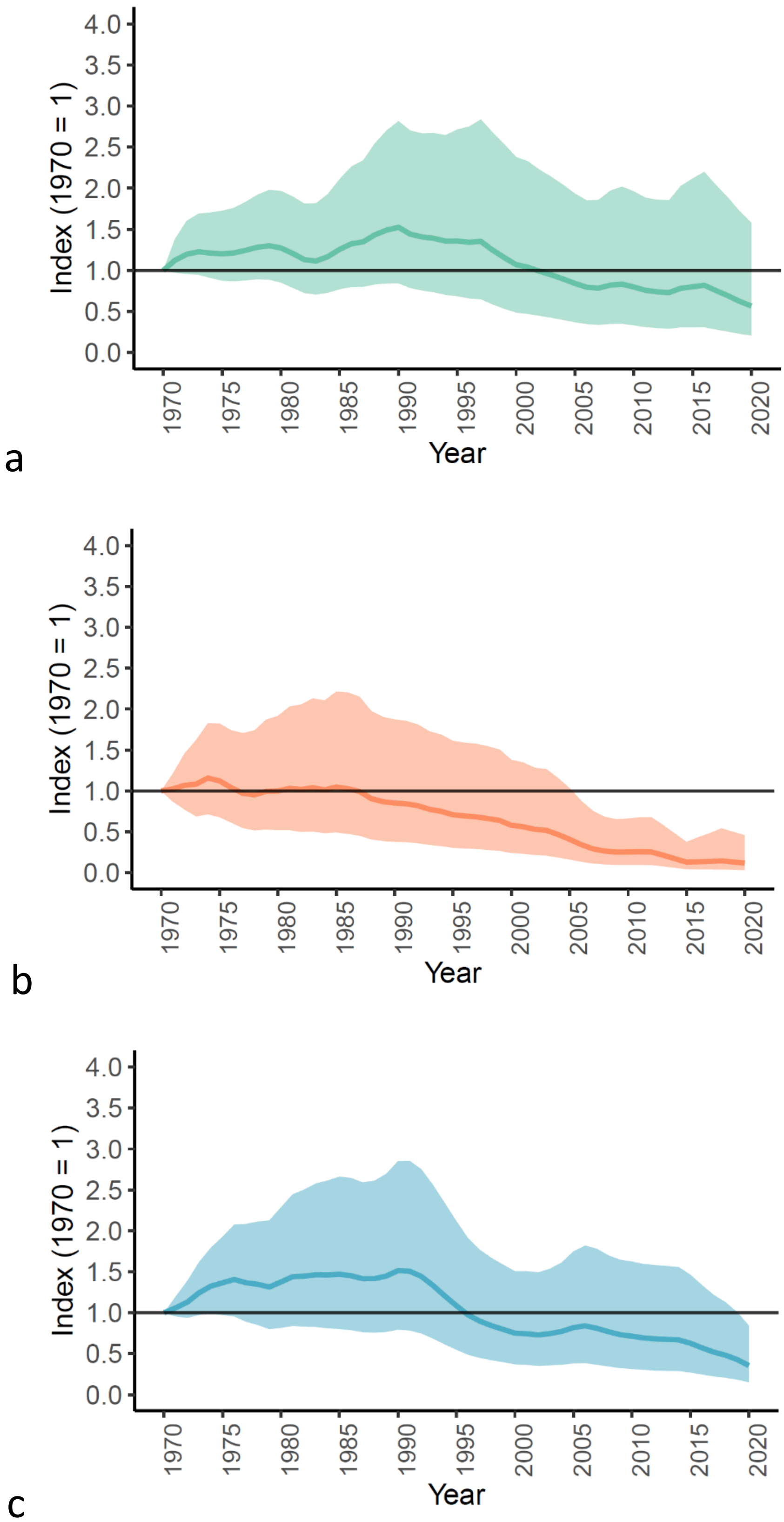

Figure 9. Index of abundance for monitored migratory freshwater fishes between 1970 and 2020 that are a) managed (−43%; 416 populations of 66 species), b) not managed (−88%; 398 populations of 161 species) and c) with unknown management status (-65%; 1,052 populations of 177 species). The bold lines show the Living Planet Index values, and the shaded areas represent the bootstrapped 95% confidence intervals.

In addition to recording whether a population is managed, more detail can be entered into the LPD about the nature of the management received, based on information given in the data source. Of the 414 populations of 66 species that were recorded as managed, the vast majority (382 or 92%) listed one management action, with 6% listing two, and 1% listing three. We combined the total of 452 reported management activities into broad categories (see **Figure 10** description) and found that most relate to some form of fisheries management (42%; **Figure 10**). Habitat management accounted for only 9% of recorded management activities, despite the prominence of habitat-related threats to populations in the data set (**Figure 8**). For 42% of managed populations, management activities were listed as 'unknown', i.e. no information was given about the nature of the management. While going back to the data source of each population in this index may help to fill some of these gaps, often the authors give no detail on management. Nevertheless, a more comprehensive understanding of the types of management actions being undertaken would be useful information to identify ways in which declines in migratory freshwater fishes may be reduced or reversed, or to establish which strategies are not associated with a positive trend.

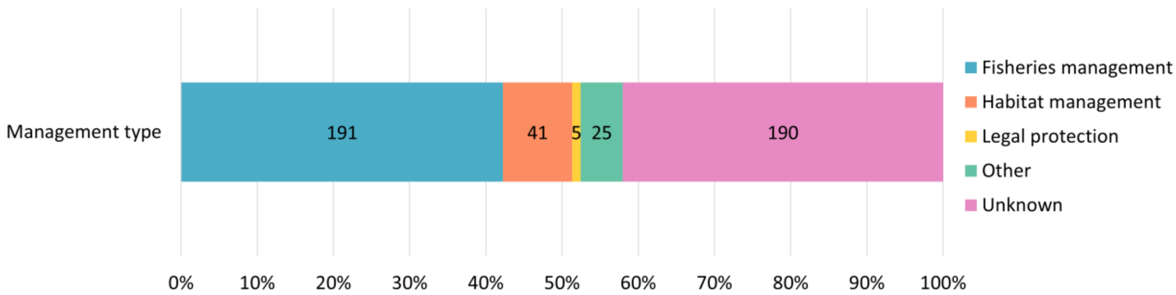

Figure 10. Management actions undertaken in managed populations of monitored migratory freshwater fishes. Management information was available for 414 populations of 66 species, totalling 452 recorded management actions. The numbers in the chart correspond to the number of times each management type was listed. Fisheries management includes fishing restrictions, stocking, bycatch reductions, supplementary feeding, no-take zones. Habitat management includes habitat restoration, habitat management, connectivity restoration, land use regulations, water quality management. Legal protection includes protected areas, species protection. Other includes management plan, removal of invasive species, threat management, tagging.

However, the difference in managed and unmanaged populations above may also be confounded by other factors such as life history, timing and efficacy of management, extent of enforcement/compliance monitoring, or the location of monitoring. For example, the majority of managed populations (80%) and species (43%) were monitored in North America, where there is an abundance of fisheries management agencies, better records of management activities, and which also shows one of the smallest overall average declines (**Figure 6**). By contrast, unmanaged species populations tend to be more evenly spread across regions. In addition, it is worth noting that many more populations included here are likely managed in some way even if no management is mentioned in the data source – for example, closed fishing seasons and other regulations may apply to many different species in different countries.

Lastly, it is worth noting that managed populations are still declining. Possible reasons for this could be that management is very recent, insufficient, ineffective, inappropriate, or even detrimental. For example, the use of hatchery-reared fish for stocking can lead to genetic introgression and is often carried out with strains less suited to the natural habitat which may negatively impact wild populations (Busack & Currens 1995; Claussen & Philipp 2023). In addition, there may be other threats to the population that are not being addressed by the implemented management such as impacts of climate change on species range changes. Our own results also point towards a mismatch between threat level and management focus as a potential reason for ineffective interventions. While management mainly use the tool of regulating fisheries exploitation (**Figure 9**), our analysis shows that the largest threat to freshwater migratory fishes is habitat degradation and loss (**Figure 8)**. This suggest that management efforts need to focus much more on removing structural barriers and restoring habitats, to increase the success rate of conserving freshwater migratory fish.

Reasons for population increase

To identify interventions that are successful, we examined consistently increasing populations in the migratory fishes LPI where the reasons for the increase are recorded. This information – coded into broad categories such as management, legal protection or removal of threat – is available for only a small number of populations and we show the results for each region below (**Figure 11**). Increases recorded in the temperate regions of Europe and North America have been primarily attributed to management (35% and 20% respectively) and unknown reasons (43% and 60% respectively). In tropical regions, almost all reasons were 'unknown' or 'other'. Many of the unknowns were from multi-species papers where there is little scope to provide details about each species individually. Unfortunately, limited information such as this can only provide a snapshot of what benefits specific populations and cannot be considered representative of each region.

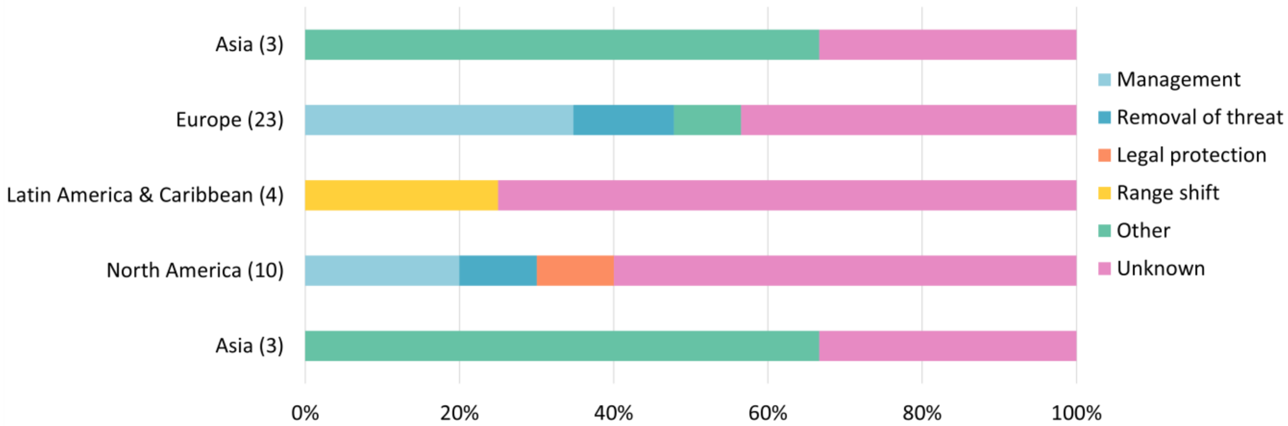

Figure 11. The distribution of reasons for increase for monitored migratory freshwater fishes. Information on reasons for an observed increase was available for 41 populations of 27 species, totalling 44 mentions of reasons. Multiple reasons may be listed for each population. The numbers in brackets correspond to the number of reasons listed in each region.

Results in context

The findings presented here indicate that migratory freshwater fishes have been declining since 1970 throughout their global distribution. This is true even using the more up-to-date migratory coding of the IUCN Red List compared to the GROMS coding in previous analyses (Deinet et al. 2020). Average declines are apparent in tropical and temperate zones, in all regions and even in those populations that are managed. The average species population decline of −81% is in line with the overall trend observed for all freshwater vertebrate populations (−83%; WWF, 2022), and with the previous migratory freshwater fishes LPI (Deinet et al. 2020). Along with the fact that the IUCN Red List has assessed around one-quarter of all freshwater fish species as threatened (Vulnerable, Endangered, or Critically Endangered), the future looks especially uncertain for migratory freshwater fishes. Specific findings are put into context below, as far as possible with the current dataset and taking into account the limitations of the study (see next section).

Regional declines are particularly pronounced in Europe (−75%) and Latin America & Caribbean (−91%)

The decline observed in Europe is in line with the fact that 37% of freshwater fish are threatened with extinction on the European Red List (Freyhof & Brooks 2011). There is a lack of free-flowing rivers in Europe (Grill et al. 2019), with a high level of fragmentation through dams (Barbarossa et al. 2020) and over 1.2 million estimated barriers (Belletti et al. 2020). The few rivers that remain unaffected by barriers (Garcia de Leaniz et al. 2019; Belletti et al. 2020; Parasiewicz et al. 2023) contain very few remaining viable migratory fish populations (Van Puijenbroek et al. 2019). Mechanisms are being developed to restore stream connectivity in Europe's rivers by removing barriers, starting with those that are obsolete (AMBER 2020). This is in line with the European Biodiversity Strategy, which aims to put Europe's biodiversity on the path to recovery by 2030 (European Commission 2020). It sets a target to restore at least 25,000 km of rivers into free-flowing rivers by 2030 through the removal of primarily obsolete barriers and the restoration of floodplains and wetlands (European Commission 2020). The recent European Parliament approval of the Nature Restoration Law (European Parliament 2024) – the key element of the Strategy – and its planned adoption by the Council represents a major step in addressing one of the main threats to migratory freshwater fishes in Europe.

Unlike in Europe, many large rivers are arguably still free-flowing in South America including the Amazon basin (Grill et al. 2019; Caldas et al. 2023), and these support the most biodiverse fish assemblages on Earth. Historically, policies have encouraged unsustainable practices (e.g. hydropower, mining, water diversion), and recent decades have witnessed a sharp increase in harmful activities (Pelicice et al. 2017) for many Neotropical fish. Although showing one of the largest average declines in this analysis, abundance change may not be fully captured due to limited data availability for the region in the LPD, and the situation may possibly be worse. For example, in the Falkland Islands the conservation status of native migratory fishes is critical and new data indicates that they are 2.9–4.5 times less likely to survive in streams invaded by non-native brown trout (Minett et al. 2023) than in control streams. Much of the current data come from estuarine regions or very large rivers (e.g. Amazon, Parana and La Plata) where there is a relatively good monitoring network based on freshwater fisheries catch data. Declines have been documented for some of the long-distance migratory fishes in the Amazon due to the construction of dams (Van Damme et al. 2019). This is of particular concern due to the high proportion of the fishery that depends on migratory fishes and the high intake of fish by local communities as a reliable source of protein (Duponchelle et al. 2021). In addition, recent years have seen drought affecting water levels in the Amazon and Pantanal (Thielen et al. 2021; Espinoza et al. 2024), and declines are predicted to get much worse with the increasing construction of dams in areas such as the Amazon (Barbarossa et al. 2020). While the inclusion of fish passage facilities in dam construction may help migratory fishes with the physical barrier, it is important to remember that behavioural and physiological thresholds may prevent these species from reaching suitable areas to complete their reproductive cycle in newly formed larger artificial reservoirs (Lopes et al. 2024).

Declines are less pronounced in North America (−35%)

While North America appears to show a less negative trend than other regions, it is characterised by a lack of long and free-flowing rivers (Grill et al. 2019) and high level of fragmentation through dams (Barbarossa et al. 2020). Dam removal has had a positive effect on fish abundance in some rivers (e.g. Penobscot, Kennebec, and Elwha; Bellmore *et al.*, 2019), in contrast to many other regions of the world that are expanding hydropower production (Zarfl et al. 2015; Carolli et al. 2023), but this is unlikely to be the explanation for the difference in trends. Major declines of many species populations in North America occurred prior to 1970 and have simply stabilised at a lower level over the past few decades. Most US dams were built between the 1830s and the 1950s, and fish have been intensively exploited since European settlement in the 1600 and 1700s (Humphries & Winemiller 2009). Many populations of sturgeon, paddlefish, salmon, American shad and river herring declined earlier than 1970 in tandem with built infrastructure blocking migration and access to habitats, pollution, overfishing or other threats (Humphries & Winemiller 2009; Waldman & Quinn 2022). This concept of 'shifting baselines' is problematic for the monitoring of population declines in fishes worldwide (Humphries & Winemiller 2009). In addition, although 45% of known species are represented, the composition of the North American data set may be biased towards more stable trends: geographically, towards rivers in northern parts of the region where unobstructed rivers are more prevalent; and taxonomically to salmonids (accounting for 30% of species), managed populations (63%), and utilised populations (36%, over half of which receive management). Over half of North American fish populations in the index receive some form of management, whereas for all other regions it is less than 15%. Most of the management actions recorded in our data set were classified as 'fisheries management' actions (e.g. fishing restrictions, stocking, bycatch reductions, supplementary feeding, no-take zones), which may produce more stable trends by default.

Asia-Oceania shows the smallest average decline of any region (−28%)

Asia-Oceania shows the smallest average decline of any region but with only 14% of species represented, it is possible that this may be an underestimate of the actual level of decline. Many migratory fish species with documented declines in Asia and Oceania are missing from the data set – Golden mahseer *Tor putitora*, Purple spotted gudgeon *Mogurnda adspersa*, Australian grayling *Prototroctes maraena* are just a few examples. A recent study from the Mekong – which produces 15 per cent of the world's annual inland fish catch, making it the largest inland fishery on the planet (Hughes 2024) – showed an 88% decline in catch data of 110 fish species, with significant declines for over 74% of these (particularly large-bodied ones), and across most migratory behaviours (Chevalier et al. 2023). As the Mekong is one of the most biodiverse river systems on Earth, supporting 899 known freshwater fish species of which 25% are endemics (Valbo-Jorgensen 2003) and 321 are migratory (Kang & Huang 2022), developments in this region are a major conservation concern (Dudgeon 2000; Hughes 2024). Our analysis indicated that exploitation, habitat loss and degradation are the most prevalent threats. Given plans to vastly expand hydropower in Asia (particularly in the Ganges-Brahmaputra, Indus, Irrawaddy, Salween and Mekong Basins), it is anticipated that habitat will be further degraded and lost, and that declines in migratory fishes will accelerate in the region in the coming decades (Ziv et al. 2012). In Australia, the impact of drought is a considerable threat to the flow regimes of rivers and the migratory fishes that depend on them (Morrongiello et al. 2011; Normile 2019; Vertessy et al. 2019).

Information is lacking for Africa

We were again unable to produce a trend for Africa due to limited data availability but there is undoubtedly reason for concern given the declines documented in the literature. Barriers such as dams and weirs are having a severe impact on migratory species of *Labeobarbus* (Shewit et al. 2017). Our analysis indicated that habitat impacts and exploitation are the most prevalent threats to African migratory freshwater fishes. Indeed, many species are facing multiple stressors associated with rapid development in the region, with hydrological alteration, invasive exotics, and climate change also noted as prominent threats (Fouchy et al. 2019). Unfortunately, there are few programmes actively monitoring fisheries across the continent, so time series are often scarce, and supporting monitoring should be a critical first step to identifying and mitigating declines.

Populations with documented threats declined by an average −96%

As would be expected, populations where local threats are present are declining more than those without. In the LPD, half of all reported threats to migratory freshwater fishes were related to habitat degradation, change and loss, and around 30% were related to exploitation. This aligns with previous research that suggested dam construction, changes in flow regime and fisheries-related harvest are among the greatest threats to freshwater species (Dudgeon et al. 2006; Cooke et al. 2023). Interestingly, these threats were consistently the most prevalent for migratory freshwater fishes for each individual region despite vastly different species and environments. However, the information available on threats in the LPD may not be detailed or complete enough. For example, a finer-scale recoding of the broad habitat categories may be useful in distinguishing between different drivers of change. Also, other important threats are not often reported, including pollution (e.g. O'Brien *et al.*, 2019; Jaureguiberry *et al.*, 2022) and climate change (e.g. Ficke, Myrick and Hansen, 2007; Vertessy *et al.*, 2019), where impacts may be more difficult to quantify. A recent assessment of freshwater fish species globally, for example, found that of those species that are at risk of extinction, 57% are affected by pollution, 17% by climate change, and 33% by invasive species and disease (IUCN 2023).

Populations where information on local threats is missing also declined

Populations where it is unknown whether local threats are present also showed a negative trend, which may suggest that these populations also face threats that are unknown or unrecognised, or go unreported. Fish are often understudied and lack information on abundance trends and extinction risk (Cooke et al. 2016). For example, despite the recent publication of the first global assessment for freshwater fish, around 18% (2,643 species, which include non-migrants) are still Data Deficient on the Red List (IUCN 2023). Biological assessment of fish in inland waters is inherently challenging but fortunately the toolbox for doing so is rapidly expanding (e.g. environmental DNA, electronic tagging, hydroacoustics; Lorenzen *et al.*, 2016). It will be prudent for managers to gather more information about these populations to assess why declines are being observed – and if there are overlooked threats leading to declines. For example, it has been suggested that recreational fisheries are leading to an 'invisible' collapse for fish populations in North America (Post et al. 2002). Similarly, it may be difficult for monitoring programmes to identify whether threats such as pollution or climate change are impacting a population – particularly for species where life-history data is lacking (Wootton et al. 2000).

Populations that receive a form of management decreased less than unmanaged ones

Remarkable recoveries of migratory fish populations are possible with management intervention, as is the case with the watershed-scale conservation of Westslope cutthroat trout (*Oncorhynchus clarkia*), pollution control benefitting anadromous fishes in the Delaware River, the restoration of longitudinal connectivity in Segura River, and dam removal in the Penobscot River (Brink et al. 2018). Somewhat in line with these examples, we found that managed populations in our data set tended to decline less than unmanaged ones, and for those few populations where more detailed information was available, most management actions were related to the regulation of fisheries. It may also be useful to examine the trends in species managed within a fishery versus species receiving other forms of management in the future.

However, there may be confounding factors that could explain differences in managed and unmanaged populations which would need to be examined closely in future analyses, e.g. life history, timing and efficacy of management, extent of enforcement/compliance monitoring, or the location of monitoring. For example, much of the data on management activities came from North America, where there is an abundance of fisheries management agencies, better records of management activities, and which also shows one of the smallest overall average declines. Here, most threats to migratory fishes were established in the early 20th century (e.g. dam construction, overfishing), so instead of management having a positive effect, perhaps the populations receiving management may be those that have already stabilised at a low level after historic declines not captured in this report.

Lastly, it is worth noting that managed populations are still declining, and possible reasons for this could be that management is very recent, insufficient, ineffective, inappropriate, or even detrimental. For example, the use of hatchery-reared fish for stocking can lead to genetic introgression and is often carried out with strains less suited to the natural habitat which may negatively impact wild populations (Busack & Currens 1995; Claussen & Philipp 2023). In addition, there may be other threats to the population that are not being addressed by the implemented management such as impacts of climate change on species range changes. Indeed, our data show a possible mismatch between the main management tool of fisheries regulations and the largest threat of habitat loss and degradation. This suggests that management efforts need to focus much more on removing barriers and restoring habitats, and to step out of the "comfort zone" of known, but ineffective or suboptimal, approaches.

The addition of management success data could be useful in evaluating this by modelling the connection between population declines or increases and management strategies in the future, including distinguishing between management actions that mitigate and management actions that conserve. In this context, it may also be useful to use a case study approach to better understand the context for instances where management did or did not yield improvements in wild, self-sustaining populations.

Recorded reasons for increases were mostly unknown or undescribed

In our data set, 41 populations of 27 species comprised information on why they have consistently increased. While these increases were often attributed to management intervention in temperate areas (35% in Europe, 20% in North America), most were unknown or undescribed (52% in Europe, 60% in America), especially in tropical regions (75%-100%). This is due to reasons for increase not being specifically discussed in the data source, and the difficulty in establishing causation between an increase in abundance and other factors in the absence of before/after monitoring (Smokorowski & Randall 2017). Despite these limitations, this case study-like approach is still useful for highlighting 'bright spots' of population increases, as these will allow others to learn and implement findings from successful halting or reversal of negative trends (Bennett et al. 2016).

Considerations

The current analysis of trends in migratory freshwater fishes is based on a more up-to-date selection of species and a larger data set extending further into the present. Despite these improvements, there are a number of considerations to keep in mind when interpreting the trends presented here.

Firstly, there is a need to further refine the reference list of species through involvement of experts from all regions. This would allow for removal of species not deemed to be migratory locally, as well as the inclusion of migratory species excluded due to unknown or unassessed movement patterns on the Red List (IUCN 2023) such as Goonch *Bagarius bagarius* or Chinese sturgeon *Acipenser sinensis*. Particular attention should also be paid to harmonising definitions of migratory behaviour, and differences between different taxonomic authorities.

Further, information on threats, management and reasons for increase is not complete, limiting the scope of the conclusions we can draw from our analysis of what impacts a species population positively or negatively. In addition, most of the information is from well-monitored regions such as North America as well certain species, and may not be universally applicable to other regions or species groups.

In addition, there are taxonomic and geographic gaps in the data, with species under-represented in a number of subsets, especially in Asia-Oceania and Africa (significantly so, see **Table A3**). For Africa, there is, in fact, not enough information to produce a reliable index. And although data were added from the Amazon and Mekong, there are still few species from here as well as other biodiverse tropical river basins such as the Congo and Yangtze. Many of the most highly migratory, transboundary, high profile 'flagship' species are also still missing, for example some of the migratory catfish from the Amazon, *Brycon* spp. from South America, Taimen, and *Tor* spp.

The length of a data series for a given population may vary greatly from a few years to multiple decades. For some regions, a small number of populations with short time series are influencing the trend at any given point in time, especially at the beginning and end. When based on a smaller number of species, an index is easily influenced by very negative (or positive) trends, so a change to a steeper slope (whether this is negative or positive) may not be representative of the actual trend if based on more species with longer time series length. However, while influencing the shape of different trends at different points in time, the final index value appears to be relatively unaffected when refining the data set to include only longer time series. We compared the original migratory freshwater fishes index to versions comprising only time series covering 5+ years or 10+ years, and found little difference in the overall decline (−81.4% vs −82.8% vs −80.8; see **Figure A4**).

Considering the above, any future update of the LPI for migratory freshwater fishes should focus on involving local experts more closely to further refine the list of species. Connecting with in-country researchers could also facilitate the mobilisation of data in languages other than English, which could help to close data gaps, particularly in tropical regions. For example, in the 2022 update of the global LPI, searches in Portuguese have rapidly expanded the data set for Brazil, trebling the number of species represented to over 1,000 in a few months (WWF 2022).

Conclusions and recommendations

This analysis represents another step towards quantifying trends and identifying drivers of change in migratory freshwater fish species globally. Although both the species selection method and data set have been improved since the last report, data and knowledge gaps remain, and more quantitative data and analysis are needed to obtain a more detailed picture of how populations are changing and the different factors interacting and driving this change. In addition, focusing on identifying positive developments could help with developing successful management strategies for freshwater migratory fish species. In Box 1, we present a list of recommendations for improving our understanding of the fate of migratory freshwater fishes and developing practical solutions that restore and protect them and the ecosystems upon which they depend.

Box 1. Recommendations for improving understanding of trends in migratory freshwater fishes, identifying their drivers, and developing practical solutions for the protection and restoration of the species and their habitats. Please note that the list is not presented in terms of priority nor is it entirely comprehensive.

Strengthening monitoring efforts
- Encourage and establish long-term monitoring in regions where information is scarce, (particularly Africa, South America, and Asia especially fish in the Congo, Mekong, Yangtze, Irrawaddy and Salween) - Develop, share and adopt standardised stock assessment methods that enable more direct comparison among systems (Bonar et al. 2017) - Identify and prioritise representative migratory fish species for long-term monitoring across different ecoregions (sampled approach) - Share innovative methods for population quantification to especially improve data inputs from less resourced areas (e.g. metabar coding for eDNA sampling methods) - Further improve representation in the LPD and refine the list of species of interest with the help of local experts
Protecting and restoring free-flowing rivers and swimways for migratory fishes (Stoffers et al. 2024)
- Recognise the importance of river connectivity for migratory fish and the multiple benefits they provide to ecosystems and society - Develop international, national and sub-national river basin planning and strategies to identify critical swimways and avoid development that would block or otherwise degrade them - Design measures for protection and restoration of migration routes that sustain ecologically, culturally and economically important fish species, in line with international policy such as the EU Biodiversity Strategy for 2030 (European Commission 2020) and the Kunming-Montreal Global Biodiversity Framework (UNEP (United Nations Environment Programme) 2022) - Evaluate existing policy mechanisms for river protection and create new mechanisms or designations if none exist (Moir et al. 2016) - Establish effective regional collaboration to protect, restore, and manage each swimway and safeguard swimways into the future

Addressing existing threats
- Investigate the relationship between life-history traits and external threats associated with the greatest declines in migratory freshwater fish species - Restore environmental flow regimes and river connectivity by targeted removal of barriers - Add effective fishways to existing barriers in locations where removal is not possible - Reduce pollution in freshwater ecosystems and their impact on the species dependent on them - Manage fisheries and avoid overexploitation including bycatch pressures via enforcement, sustainable yield, no-take zones, electronic monitoring and other measures - Mitigate the impacts of current and future climate change on migratory species - Encourage the adoption of management strategies outside of the known approaches of, e.g. fisheries regulations, which may be ineffective or suboptimal where species are affected primarily by habitat-related threats
Implementing ongoing conservation initiatives and commitments under international multilateral environmental agreements
- Include freshwater migratory species and swimways in National Biodiversity Strategic Action Plans and delivery of inland waters-related commitments under the Kunming-Montreal Global Biodiversity Framework (UNEP (United Nations Environment Programme) 2022) - Encourage countries to join the [Freshwater Challenge] that aims to restore 300,000 km of rivers and 350 million hectares of wetlands globally by 2030 - Increase rigor of free-flowing river quantification and qualification within EU River Basin Management Plan development and export lessons to other governmental bodies, e.g. river basin management authorities outside the EU - Ensure restoration and protection of rivers and swimways included in implementation of other multilateral environmental agreements such as Sustainable Development Goals (SDG 6.6), UNFCCC, and Ramsar Convention - Laud the recent addition of 2 Amazonian species to the Convention on Migratory Species (CMS n.d.), encourage the addition of further freshwater migratory fish species to the appendices, and establish regional agreements under CMS
Fostering public and political will
- Increase public awareness about the natural wonders of free-flowing rivers - Highlight the cultural, spiritual, health, ecological and economic benefits of freshwater biodiversity (Lynch et al. 2023) and of free-flowing rivers when properly functioning - Highlight that ongoing declines in migratory freshwater fishes is leading to millions of people worldwide losing these cultural, spiritual, health, ecological and economic benefits - Highlight the positive economic outcomes of river protection and restoration, including the economic benefits that migratory freshwater fish provide to societies worldwide - Encourage political investment through funding to address locally appropriate threats, and highlight the importance of involving diverse voices to ensure messaging to different publics is relevant (Januchowski-Hartley et al. 2024) - Increase public engagement via events and other outreach such as [World Fish Migration Day]

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Appendix

The LPI, its calculation and interpretation

The Living Planet index (LPI) is one of a suite of global indicators previously used to monitor progress towards the 2010 Biodiversity Target (UNEP 2006), the subsequent 2020 Aichi targets agreed by the Convention on Biological Diversity's (CBD) in 2010 (CBD 2010), and Is now is a component-level indicator for Goals A and B and Targets 4, 5 and 9 of the Kunming-Montreal Global Biodiversity Framework (UNEP (United Nations Environment Programme) 2020, 2022). It tracks trends in abundance of a large number of populations of vertebrate species in much the same way that a stock market index tracks the value of a set of shares or a retail price index tracks the cost of a basket of consumer goods. The data used in constructing the index are time series of either population size, density (population size per unit area), abundance (number of individuals per sample) or a proxy of abundance (e.g. the number of nests or breeding pairs recorded may be used instead of a direct population count). The underlying database (Living Planet Database, LPD; WWF/ZSL, 2024)currently contains data on 26,800 populations of around 5,600 vertebrate species from around the world, collected from a variety of sources.

Using a method developed by ZSL and WWF, species population trends are aggregated and weighted to produce the different Living Planet Indices. For each population, the rate of change from one year to the next is calculated. If the data available are from only a few, non-consecutive years, a constant annual rate of change in the population is assumed between each data year. Where data are available from many years (consecutive or not) a curve is plotted through the data points using a statistical method called generalized additive modelling. Average annual rates of change in populations of the same species are aggregated to the species level and then higher levels (Collen et al. 2009), and confidence intervals calculated using 10,000 iterations. A deeper dive for calculation of the global index can be found in The Living Planet Report 2022 (Westveer et al. 2022). Please note that although the global index is normally weighted by species richness in different taxonomic groups and geographic regions (McRae et al. 2017), this report is based on unweighted indices. This is because the indices presented are based on only one taxonomic class, and the coverage is not good enough to split geographically.

Like the global index presented biennially in the Living Planet Report, the index for migratory freshwater fishes starts at a value of 1 in 1970. If the LPI and confidence limits move away from this baseline, we can say there has been an increase (above 1) or decline (below 1) compared to 1970. These values represent the average change in population abundance – based on the relative change and not the absolute change – in population sizes. The shaded areas in each graph show 95% confidence limits. These illustrate how certain we are about the trend in any given year relative to 1970. The confidence limits always widen throughout the time series as the uncertainty from each of the previous years is added to the current year. For this report, we chose an end year of 2020 as this is latest year for which we have a good amount of data. Data availability decreases in more recent years because it takes time to collect, process and publish monitoring data, so there can be a time lag before these are added to the LPD.

Table A1. Species included in this analysis and the number of available populations for each.

Zone	Binomial	Common name	Number of populations
Temperate	*Abramis brama*	Freshwater bream	9
	Acipenser brevirostrum	Shortnose sturgeon	6
	Acipenser desotoi	Gulf sturgeon	7
	Acipenser fulvescens	Lake sturgeon	15
	Acipenser gueldenstaedtii	Danube sturgeon	3
	Acipenser medirostris	Green sturgeon	3
	Acipenser nudiventris	Fringebarbel sturgeon	1
	Acipenser oxyrinchus	Atlantic sturgeon	3
	Acipenser persicus	Persian sturgeon	1
	Acipenser ruthenus	Sterlet sturgeon	1
	Acipenser stellatus	Starry sturgeon	4
	Acipenser transmontanus	White sturgeon	10
	Alburnus chalcoides	Danube bleak	1
	Aldrichetta forsteri	Yellow-eye mullet	1
	Alosa aestivalis	Blueback herring / shad	2
	Alosa alabamae	Alabama shad	1
	Alosa alosa	Allis shad	2
	Alosa fallax	Twaite shad	3
	Alosa mediocris	Hickory shad	1
	Alosa pseudoharengus	Alewife	20
	Alosa sapidissima	American shad	11
	Anguilla anguilla	European eel	2
	Anguilla japonica	Japanese eel	2
	Anguilla rostrata	American eel	9
	Atherina boyeri	Big-scale sand smelt	3
	Ballerus ballerus	Zope	1
	Barbus barbus	Barbel	10
	Barbus prespensis	Briána	3
	Blicca bjoerkna	White bream	14
	Catostomus catostomus	Longnose sucker	2
	Catostomus commersonii	White sucker	13
	Chasmistes liorus	June sucker	1
	Chelon auratus	Golden grey mullet	1
	Chelon ramada	Thinlip grey mullet	1
	Chondrostoma nasus	Common nase	6
	Coregonus albula	Vendace	2
	Coregonus artedi	Lake herring / Cisco	7
	Coregonus autumnalis	Arctic cisco	1
	Coregonus lavaretus	European whitefish	7
	Cyprinus carpio	Common carp	3
	Dicentrarchus labrax	European seabass	2
	Entosphenus tridentatus	Pacific lamprey	3
	Esox lucius	Northern pike	22
	Galaxias maculatus	Inanga	3
	Gasterosteus aculeatus	Three-spined stickleback	12
	Gasterosteus wheatlandi	Blackspotted stickleback	68
	Gymnocephalus baloni	Danube ruffe	2
	Hucho hucho	Huchen	1

	Huso huso	Beluga	4
	Hypomesus transpacificus	Delta smelt	1
	Lampetra fluviatilis	River lamprey	1
	Lepisosteus oculatus	Spotted gar	1
	Leuciscus aspius	Asp	3
	Leuciscus burdigalensis	Beaked dace	2
	Leuciscus idus	Ide	3
	Leuciscus leuciscus	Common dace	8
	Lota lota	Burbot	14
	Microgadus tomcod	Atlantic tomcod	29
	Morone saxatilis	Striped bass	27
	Oncorhynchus clarkii	Cutthroat trout	6
	Oncorhynchus gorbuscha	Pink salmon	24
	Oncorhynchus keta	Chum salmon	37
	Oncorhynchus kisutch	Coho salmon	36
	Oncorhynchus mykiss	Rainbow trout / Steelhead trout	5
	Oncorhynchus nerka	Sockeye salmon / Red salmon	59
	Oncorhynchus tshawytscha	Chinook salmon	43
	Osmerus mordax	Rainbow smelt	10
	Parachondrostoma arrigonis	*No common name*	1
	Perca fluviatilis	European perch	40
	Petromyzon marinus	Sea lamprey	5
	Platichthys flesus	European flounder	9
	Pleuronectes platessa	European plaice	7
	Pomatoschistus microps	Common goby	4
	Psephurus gladius	Chinese paddlefish	1
	Ptychocheilus lucius	Colorado pikeminnow	10
	Pungitius pungitius	Ninespine stickleback	67
	Rutilus rutilus	Roach	34
	Salmo salar	Atlantic salmon	82
	Salmo trutta	Brown trout / Sea trout	73
	Salvelinus alpinus	Arctic char	7
	Salvelinus confluentus	Bull trout	29
	Sander lucioperca	Pikeperch / Zander	11
	Scaphirhynchus platorynchus	Shovelnose sturgeon	2
	Spirinchus thaleichthys	Longfin smelt	1
	Sprattus sprattus	European sprat	8
	Squalius cephalus	Chub	19
	Stenodus leucichthys	Inconnu / Sheefish	1
	Thaleichthys pacificus	Eulachon	5
	Thymallus arcticus	Arctic grayling	4
	Thymallus thymallus	Grayling	2
	Vimba vimba	Vimba bream	4
	Xyrauchen texanus	Razorback sucker	1
Tropical	*Agamyxis pectinifrons*	Whitebarred catfish	3
	Ageneiosus inermis	Manduba	12
	Ageneiosus ucayalensis	*No common name*	11
	Aldrichetta forsteri	Yellow-eye mullet	2
	Alestes baremoze	Silversides	4
	Ambassis agassizii	Agassiz's glassfish	2
	Ambassis miops	Flag-tailed glass perchlet	2
	Amblyrhynchichthys micracanthus	*No common name*	1
	Anguilla australis	Short-finned eel	5
	Anguilla dieffenbachii	New Zealand longfin eel	5

Anguilla japonica	Japanese eel	4
Anguilla marmorata	Giant mottled eel	10
Anguilla obscura	Pacific shortfinned eel	2
Anguilla reinhardtii	Speckled longfin eel	6
Anodontostoma chacunda	Chacunda gizzard shad	1
Anodus elongatus	*No common name*	12
Anodus orinocensis	*No common name*	2
Awaous acritosus	Roman nose goby	3
Awaous aeneofuscus	Freshwater goby	1
Awaous banana	River goby	1
Awaous tajasica	Sand fish	1
Barbonymus altus	Red tailed tinfoil	1
Barbonymus gonionotus	Silver barb	1
Bathygobius fuscus	Brown frillfin	3
Bidyanus bidyanus	Silver perch	2
Brachyplatystoma filamentosum	Kumakuma	3
Brachyplatystoma rousseauxii	Gilded catfish	5
Brachyplatystoma tigrinum	Tigerstriped catfish	2
Brachyplatystoma vaillantii	Laulao catfish	1
Brycinus imberi	Spot-tail	3
Brycinus leuciscus	Yellow-fin tetras	2
Brycinus macrolepidotus	True big-scale tetra	1
Brycinus sadleri	Sadler's robber	1
Brycon amazonicus	*No common name*	12
Brycon falcatus	*No common name*	6
Brycon hilarii	Piraputanga	1
Brycon melanopterus	*No common name*	6
Bunaka gyrinoides	Greenback gauvina	3
Butis butis	Duckbill sleeper	3
Caranx sexfasciatus	Bigeye trevally	5
Cirrhinus microlepis	Small scale mud carp	1
Coilia lindmani	Lindman's grenadier anchovy	1
Colossoma macropomum	Cachama	13
Cosmochilus harmandi	*No common name*	1
Cotylopus acutipinnis	*No common name*	14
Crossocheilus reticulatus	*No common name*	1
Curimata inornata	*No common name*	10
Cyclocheilos enoplos	*No common name*	1
Cynoglossus feldmanni	River tonguesole	1
Dajaus monticola	Mountain mullet	1
Dormitator maculatus	Pacific sleeper	1
Eleotris fusca	Dusky sleeper	2
Eleotris perniger	Smallscaled spinycheek sleeper	1
Enteromius mattozi	Papermouth	1
Enteromius paludinosus	Straightfin barb	1
Enteromius trimaculatus	Threespot barb	2
Eucinostomus melanopterus	Butterfish	2
Galaxias fasciatus	Banded kokopu	1
Gerres cinereus	Yellow fin mojarra	4
Giuris margaritaceus	Snakehead gudgeon	2
Glossogobius aureus	Golden tank goby	1
Glossogobius giuris	Tank goby	4

Gobiomorus dormitor	Bigmouth sleeper	2
Gobionellus oceanicus	Highfin goby	3
Helicophagus leptorhynchus	Rat-faced pangasiid	1
Hemibagrus spilopterus	Trey chhlan	1
Hemiodus semitaeniatus	Halfline hemiodus	4
Hemisorubim platyrhynchos	Porthole shovelnose catfish	11
Henicorhynchus siamensis	*No common name*	1
Hephaestus fuliginosus	Sooty grunter	5
Heterobranchus longifilis	Sampa	1
Hoplerythrinus unitaeniatus	Aimara	10
Hoplias aimara	*No common name*	1
Hydrocynus forskahlii	Elongate tigerfish	4
Hydrolycus scomberoides	Payara	11
Hypsibarbus malcolmi	Goldfin tinfoil barb	1
Iheringichthys labrosus	*No common name*	3
Kuhlia marginata	Dark-margined flagtail	1
Kuhlia rupestris	Rock flagtail	2
Labeo chrysophekadion	Black sharkminnow	1
Labeo congoro	Purple labeo	1
Labeo umbratus	Moggel	1
Labiobarbus leptocheilus	*No common name*	1
Labiobarbus siamensis	*No common name*	1
Laides longibarbis	*No common name*	1
Lates calcarifer	Barramundi	11
Leiopotherapon unicolor	Spangled perch	8
Leporinus cylindriformis	*No common name*	6
Leporinus desmotes	*No common name*	3
Leporinus fasciatus	Banded leporinus	12
Leporinus friderici	Threespot leporinus	13
Leporinus granti	*No common name*	1
Leporinus jamesi	*No common name*	6
Leporinus lacustris	*No common name*	4
Lobocheilos rhabdoura	*No common name*	1
Lycengraulis batesii	Bates' sabretooth anchovy	3
Maccullochella peelii	Murray cod	5
Macquaria ambigua	Golden perch	6
Macquaria australasica	Macquarie perch	1
Marcusenius ussheri	Djii	1
Mastacembelus armatus	Zig-zag eel	1
Megaleporinus obtusidens	*No common name*	2
Megaleporinus trifasciatus	*No common name*	12
Megalops atlanticus	Tarpon	3
Megalops cyprinoides	Indo-pacific tarpon	6
Mekongina erythrospila	Pa sa-ee	1
Melanotaenia fluviatilis	Murray River rainbowfish	2
Mesopristes argenteus	Silver grunter	3
Metynnis hypsauchen	Silver dollar	2
Metynnis lippincottianus	*No common name*	7
Mormyrops anguilloides	Cornish jack	1
Mugil cephalus	Flathead grey mullet	17
Myloplus rubripinnis	Redhook myleus	4
Mylossoma albiscopum	*No common name*	11

	Mylossoma duriventre	*No common name*	1
	Nematalosa nasus	Bloch's gizzard shad	1
	Neosilurus ater	Narrowfront tandan	5
	Notesthes robusta	Bullrout	6
	Notopterus notopterus	Bronze featherback	1
	Odontesthes hatcheri	Patagonian pejerrey	1
	Oligolepis acutipennis	Sharptail goby	1
	Oreochromis mossambicus	Mozambique tilapia	7
	Osteochilus microcephalus	*No common name*	1
	Osteoglossum bicirrhosum	Arawana	5
	Oxydoras niger	Thorny Catfish	11
	Oxygaster pointoni	*No common name*	1
	Pangasianodon gigas	Mekong giant catfish	1
	Pangasianodon hypophthalmus	Striped catfish	1
	Pangasius bocourti	Bocourt's catfish	1
	Pangasius conchophilus	Pa pho	1
	Pangasius larnaudii	Spot pangasius	1
	Paralaubuca typus	*No common name*	1
	Parambassis apogonoides	Iridescent glassy perchlet	1
	Parambassis wolffi	Duskyfin glassy perchlet	1
	Paramyloplus ternetzi	Pakusi	1
	Pellona castelnaeana	Amazon pellona	12
	Percalates novemaculeatus	Australian bass	3
	Percichthys trucha	Creole perch	1
	Petrocephalus bovei	*No common name*	4
	Phractocephalus hemioliopterus	Redtail catfish	11
	Piaractus brachypomus	Pirapitinga	12
	Pimelodus blochii	Bloch's catfish	11
	Pimelodus maculatus	*No common name*	6
	Pimelodus ornatus	*No common name*	2
	Pinirampus pirinampu	Flatwhiskered catfish	18
	Planiliza subviridis	Greenback mullet	3
	Platynematichthys notatus	Coroatá	3
	Platystomatichthys sturio	*No common name*	4
	Probarbus jullieni	Isok barb	1
	Probarbus labeamajor	Thicklip barb	1
	Prochilodus lineatus	Streaked prochilod	8
	Prochilodus nigricans	Black prochilodus	12
	Prosomyleus rhomboidalis	*No common name*	1
	Pseudaphritis urvillii	Congolli	3
	Pseudocrenilabrus philander	Southern mouthbrooder	1
	Pseudolais pleurotaenia	*No common name*	1
	Pseudoplatystoma corruscans	Spotted sorubim	3
	Pseudoplatystoma punctifer	*No common name*	11
	Pseudoplatystoma tigrinum	Tiger sorubim	12
	Puntioplites proctozysron	*No common name*	1
	Rhamdia quelen	*No common name*	4
	Rhaphiodon vulpinus	Biara	12
	Salminus brasiliensis	Dorado	7
	Schilbe intermedius	Silver catfish	3
	Schilbe mystus	African butter catfish	3
	Selenotoca multifasciata	Spotbanded scat	2

Semaprochilodus insignis	Kissing prochilodus	12
Semaprochilodus taeniurus	Silver prochilodus	2
Serrasalmus maculatus	*No common name*	12
Sicyopterus lagocephalus	Red-tailed goby	16
Sikukia gudgeri	Pa khao na	1
Sikukia stejnegeri	*No common name*	1
Sorubim elongatus	Slender shovelnose catfish	11
Sorubim lima	*No common name*	11
Sorubim maniradii	*No common name*	11
Sorubimichthys planiceps	Firewood catfish	8
Steindachneridion scriptum	*No common name*	1
Sundasalanx mekongensis	Pla thua ngorg	1
Synbranchus marmoratus	Marbled swamp eel	1
Syncrossus helodes	Tiger botia	1
Synodontis schall	Wahrindi	2
Tenualosa ilisha	Hilsa shad	1
Thryssocypris tonlesapensis	Anchovy rasbora	1
Tor khudree	Deccan mahseer	1
Tor remadevii	Hump-backed mahseer	1
Trachystoma petardi	Pinkeye mullet	3
Triportheus albus	*No common name*	12
Triportheus angulatus	*No common name*	12
Triportheus auritus	*No common name*	7
Triportheus culter	*No common name*	10
Triportheus rotundatus	*No common name*	1
Wallago attu	Wallago	1
Yasuhikotakia modesta	Redtail botia	1
Zungaro zungaro	Gilded catfish	12

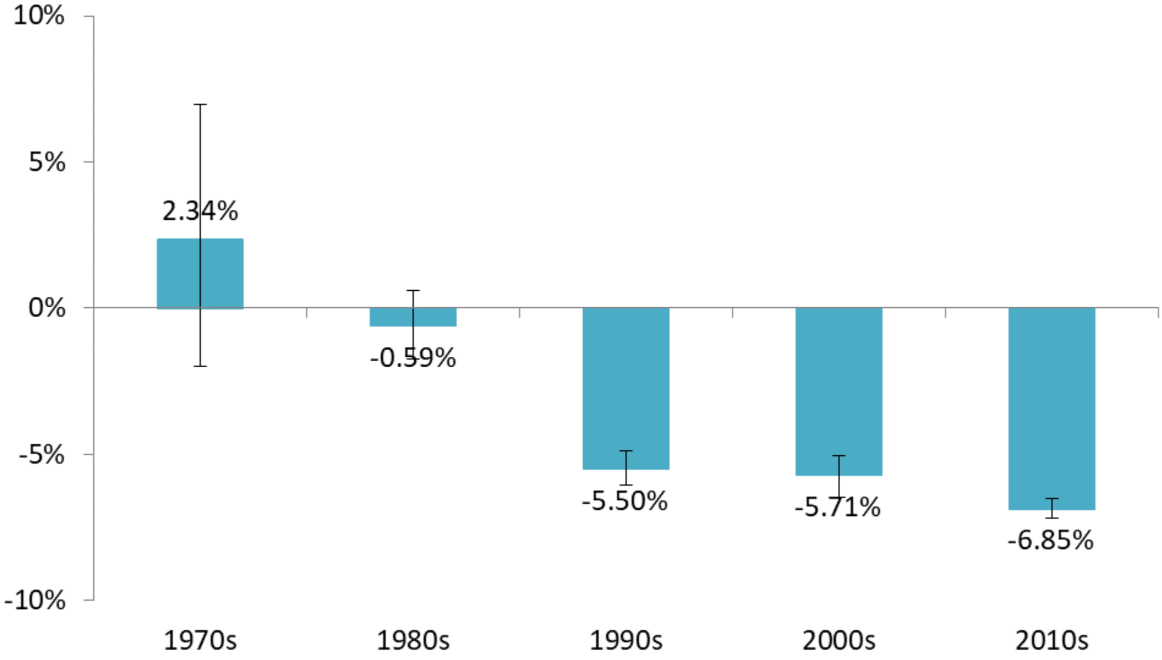


Figure A1. Average annual change in population abundance for 1,864 monitored populations of 284 species of migratory freshwater fishes by decade: 1970s, 1980s, 1990s, 2000s and 2010s.

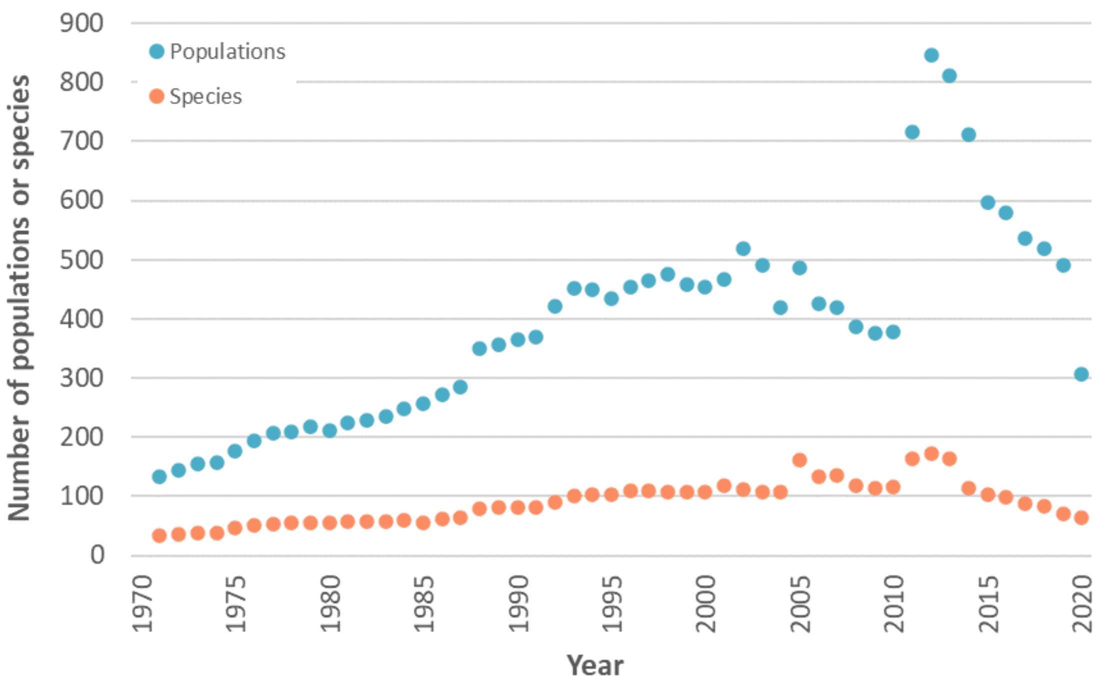
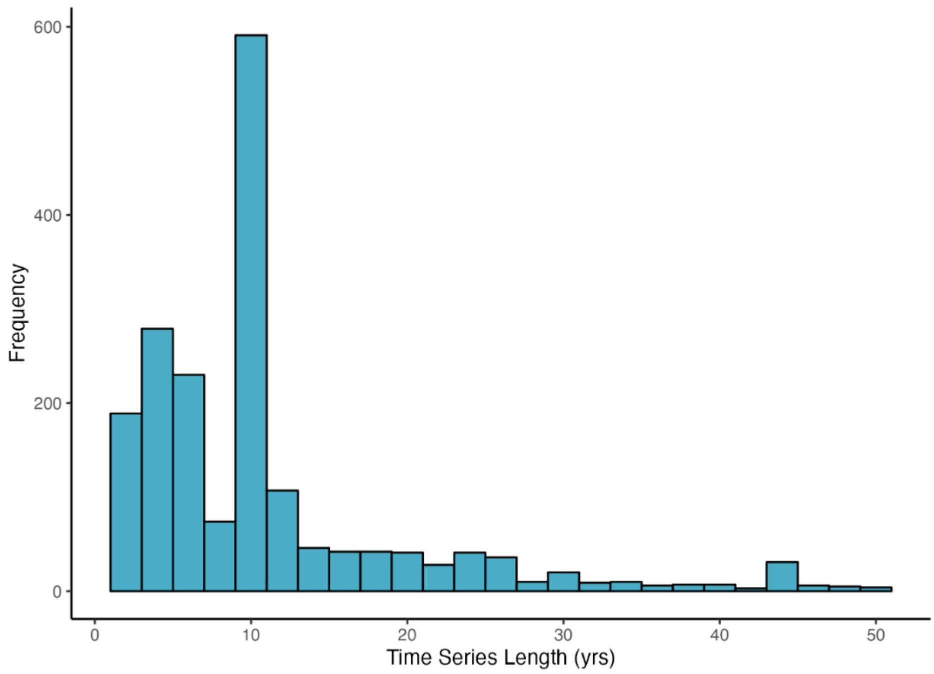
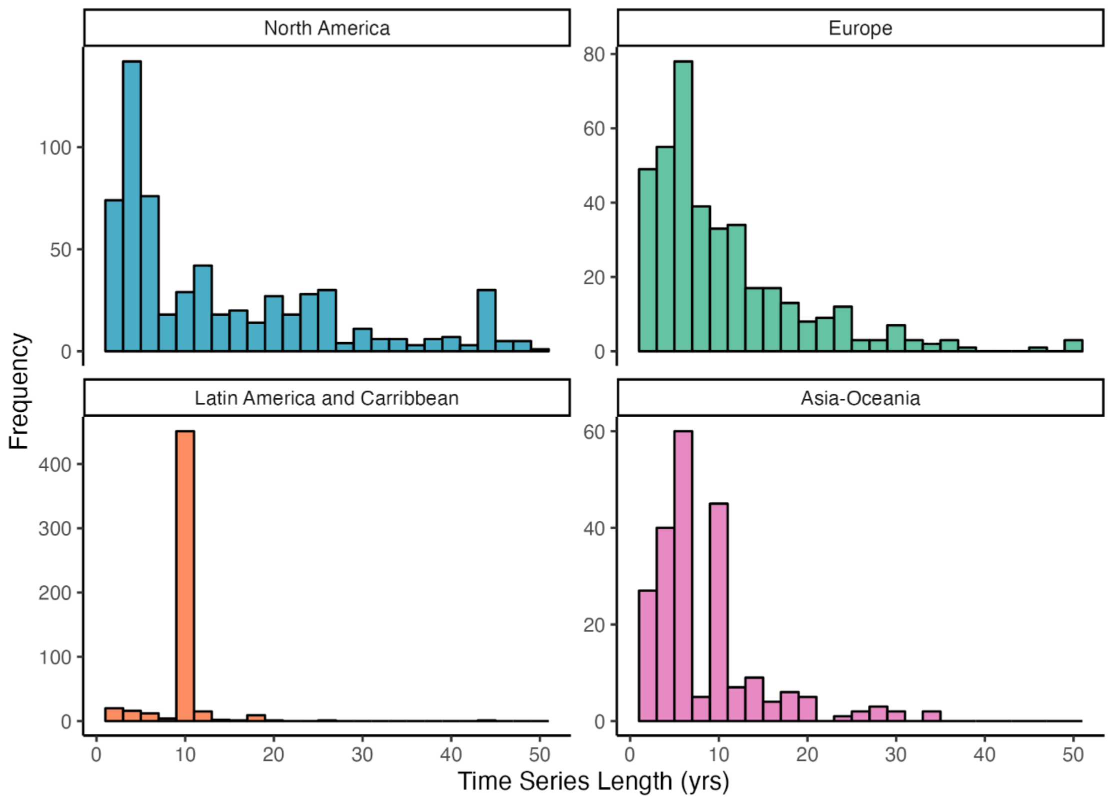


Figure A2. The number of populations (blue) and species (orange) contributing to the migratory freshwater fishes LPI in each year between 1970 and 2020.



a



b

Figure A3. Time series length between 1970 and 2020 for a) 1,864 populations of 284 species of migratory freshwater fishes; and b) by region (North America: 623 populations of 48 species; Europe: 390 populations of 45 species; Latin America and Caribbean: 533 populations of 84 species; and Asia-Oceania: 218 populations of 102 species).

Table A2. Descriptions of the different major threat categories used in the Living Planet Database (from WWF 2018). This classification is also followed by the IUCN Red List and based on Salafsky *et al.* (2008).

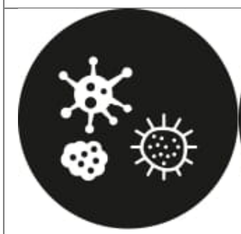
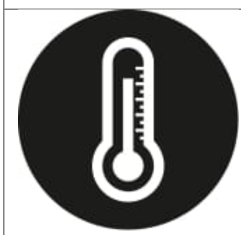
Symbol	Threat	Description
	Habitat change and degradation	This refers to the modification of the environment where a species lives, by complete fragmentation or reduction in the quality of key habitat. For freshwater habitats, fragmentation of rivers and streams and abstraction of water are common threats.
	Habitat loss	This refers to the modification of the environment where a species lives, by complete removal of key habitat.
	Overexploitation	There are both direct and indirect forms of overexploitation. Direct overexploitation refers to unsustainable fishing, whether for subsistence or for trade. Indirect overexploitation occurs when non-target species are killed unintentionally, for example as bycatch in fisheries.
	Pollution	Pollution can directly affect a species by making the environment unsuitable for its survival (this is what happens, for example, in the case of an oil spill). It can also affect a species indirectly, by affecting food availability or reproductive performance, thus reducing population numbers over time.
 	Invasive species and disease	Invasive species can compete with native species for space, food and other resources, can turn out to be a predator for native species, or spread diseases that were not previously present in the environment. Humans also transport new diseases from one area of the globe to another.
	Climate change	As temperatures change, some species will need to adapt by shifting their range to track suitable climate. The effects of climate change on species are often indirect. Changes in temperature can confound the signals that trigger seasonal events such as migration and reproduction, causing these events to happen at the wrong time (for example misaligning reproduction and the period of greater food availability in a specific habitat).

Table A3. Proportional representation of the data set used in this analysis. Proportion (LPI) is the proportion of species in the data set for each region or zone compared to the total number of species across all regions or zones.

Data set	Subset	Proportion (LPI)	Proportion (expected)	χ2		Representation
Region	*Africa*	0.11	0.18	9.40	***	under
	Asia & Oceania	0.36	0.36	52.69	***	under
	Europe	0.16	0.09	10.08	***	over
	Latin America and Caribbean	0.30	0.23	5.77	*	over
	North America	0.17	0.08	17.46	***	over
Zone	*Temperate*	0.38	0.46	4.58	*	under
	Tropical	0.49	0.47	0.26	NS	over

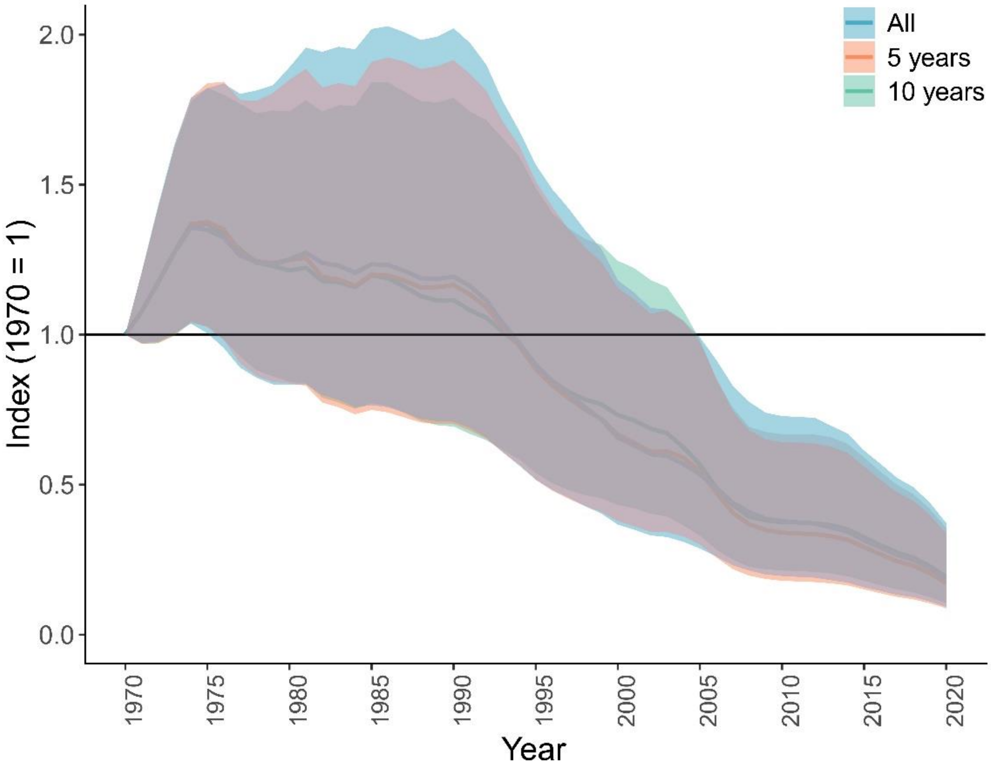


Figure A4. Sensitivity analysis comparing the migratory freshwater fishes LPI with refined data sets including only those time series contributing for at least 5 years (red) and at least 10 years (green). The bold lines show the Living Planet Index values, and the shaded areas represent the bootstrapped 95% confidence intervals.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