Monitoring Extinction Risk and Threats of the World’s Fishes based on the Sampled Red List Index

Rafael Miranda
University of Navarra
Imanol Miqueleiz (imiqueleiz@alumni.unav.es)
University of Navarra
William Darwall
International Union for Conservation of Nature
Catherine Sayer
International Union for Conservation of Nature
Nicholas Dulvy
Simon Fraser University
Kent Carpenter
Old Dominion University
Beth Polidoro
Arizona State University
Nadia Dewhurst-Richman
Zoological Society of London
Caroline Pollock
International Union for Conservation of Nature
Craig Hilton-Taylor
International Union for Conservation of Nature
Robin Freeman
Zoological Society of London
Ben Collen
University College London
Monika Böhm
Zoological Society of London

Research Article

Keywords: Fishes, Global assessment, IUCN Red List, conservation status, threatened species, biodiversity loss

Posted Date: December 21st, 2020

DOI: https://doi.org/10.21203/rs.3.rs-129206/v1

Version of Record: A version of this preprint was published at Reviews in Fish Biology and Fisheries on March 28th, 2022. See the published version at https://doi.org/10.1007/s11160-022-09710-1.

Abstract

Global biodiversity targets require us to identify species at risk of extinction and quantify status and trends of biodiversity. The Red List Index (RLI) tracks trends in the conservation status of entire species groups over time by monitoring changes in categories assigned to species. Here, we calculate this index for the world's fishes in 2010, using a sampled approach to the RLI based on a randomly selected sample of 1,500 species, and also present RLI splits for freshwater and marine systems separately. We further compare specific traits of a worldwide fish list to our sample to assess its representativeness. Overall, 15.1% of species in the sample were estimated to be threatened with extinction, resulting in an sampled RLI of 0.914 for all species, 0.972 in marine and 0.860 in freshwater ecosystems. Our sample showed fishing as the principal threat for marine species, and pollution by agricultural and foresty effluents for freshwater fishes. The sampled list provides a robust representation for tracking trends in the conservation status of the world's fishes, including disaggregated sampled indices for marine and freshwater fish. Reassessment and backcasting of this index is urgent to check the achievement of the commitments proposed in global biodiversity targets.

Introduction

In 2020, the UN Decade of Biodiversity came to its culmination, requiring a stocktake of the world's progress towards the Aichi Targets, set by the Convention on Biological Diversity in 2010. Following our failure to reach the previous 2010 target to achieve a significant reduction in the rate of biodiversity loss by 2010[1], many of the Aichi Targets are also not met[2]. This includes Aichi Target 12 which stipulates that "by 2020, the extinction of known threatened species has been prevented and their conservation status, particularly of those most in decline, has been improved and sustained[3]."

Threats continue to increase, resulting in declines in the abundance and distribution of species[4,5]. A recent global assessment of the state of biodiversity by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) estimated that up to one million species are at risk of extinction[6]. This estimate relies on inferences from the known extinction risk of species assessed by the International Union for Conservation of Nature (IUCN) Red List of Threatened Species, arguably the most comprehensive inventory on species' extinction risk worldwide[7]. The IUCN Red List utilises a set of five criteria to split the continuous scale of species' extinction risk into seven categories, ranging from Least Concern (LC) and Near Threatened (NT) to the threatened categories (Vulnerable VU, Endangered EN and Critically Endangered CR) to Extinct in the Wild (EW) and Extinct (EX); an additional category of Data Deficient (DD) is used for species with insufficient data to evaluate their extinction risk[8]. In 2019, the IUCN Red List reached the major milestone of 100,000 species assessed, the culmination of more than ten years of increased investment in species assessments through various targeted projects and a taxonomic and spatial expansion of the IUCN SSC Species Specialist Group network[9]. Monitoring global extinction risk of biodiversity[10,11] presents one way to track progress towards Aichi Target 12.

While the extinction risk of nearly all terrestrial vertebrates has been assessed[10,12], there are still substantial data gaps in other species groups[13–15]. To address this situation, the sampled Red List Index (sRLI) was devised to expand taxonomic coverage of the IUCN Red List in a way that also allows aggregation of under-represented species groups into global biodiversity indicators[11]. A random sample of 900 non-Data Deficient species (i.e. species with sufficient data to estimate extinction risk) from a highly speciose taxonomic group (i.e. a class or order or family) has been shown sufficiently large to accurately estimate the direction of trends in extinction risk[16] (e.g. for birds[11]). Subsequently, this approach has been applied to reptiles[17], dragonflies[18], plants[19] and freshwater molluscs[20]. Sampled assessments for other species groups are still work in progress (e.g., butterflies[21]). There is an urgent need to deliver the findings of these assessments given that new targets for biodiversity will be set at the 15th Meeting of the Conference of the Parties to the Convention on Biological Diversity in 2021.

Fishes are by far the most species-rich group of vertebrates, with 35,635 species currently recognised[22], approximately the same number of species as that of all non-fish vertebrates combined. Covering freshwater and marine habitats, assessing the status of the world's fish is of utmost importance to ecosystem function and human wellbeing. For example, marine fish provide a vital income and food source for coastal communities around the world, and are of particular importance in tackling micronutrient deficiencies in humans[23].

The IUCN Global Species Programme started the Global Marine Species Assessment in 2005, with the target to estimate the extinction risk of 20,000 marine species for their inclusion on the IUCN Red List, of which approximately 17,000 are marine fishes. Currently, extinction risk for more than 16,000 marine species has been evaluated[9], including reef-building corals[24], mangroves[25], seagrasses[26], sea snakes[27], sea cucumbers[28], and cone snails[29]. Most assessments have been for fishes (~ 11,700 species[9]), often spearheaded by taxon-specific IUCN Species Survival Commission (SSC) Specialist Groups, including hagfishes[30], tunas and billfishes[31], parrotfishes and surgeonfishes[32], groupers[33], sharks and rays[34], tarpons, ladyfishes and bonefishes[35], anguillid eels[36], porgies[37], and pufferfishes[38]. Many additional assessments of marine fishes have resulted from regional initiatives, further broadening the taxonomic coverage of the Red List[8]. These include nearly all nearshore and many deep sea marine fishes from the Mediterranean[39], Eastern Central Pacific[40], Western Central Atlantic and Gulf of Mexico[41,42], Oceania[43], European waters[44], Eastern Central Atlantic[45], and Persian Gulf[46].

More than 30,000 freshwater species have now been assessed for the IUCN Red List[9], including comprehensive assessments for freshwater crabs, shrimps and crayfish, and sampled assessments for freshwater molluscs[20,47,48]. The Freshwater Biodiversity Unit, within the IUCN Global Species Programme, has been central to the assessment effort for freshwater species, including fishes, generally carried out on a region-by-region basis[9]. There have been several regional assessments that include freshwater fishes, for instance for the Eastern Himalaya[49], the Western Ghats[50], Africa[51], Europe[52], Indo-Burma[53], Madagascar and the Indian Ocean islands[54], or Mexico[55], which have started to fill the assessment gap for freshwater fishes, and other freshwater species, on the IUCN Red List. Currently, the IUCN-Toyota Red List Partnership aims to complete the global comprehensive assessment of freshwater fishes .

Still, only 59% of fish have been assessed by the IUCN Red List (currently just over 20,000 species), compared to 91% of mammals, 100% of birds, 84% of amphibians and 70% of reptiles[9]. A sampled assessment of 1,500 fishes was initially completed in 2010, as part of the development of the sRLI as a global biodiversity indicator[11,56]. Here, we provide the long-overdue presentation and analysis of the results. We present the first global assessment of extinction risk for a random sample of fishes, highlighting major threats impacting fishes in marine and freshwater environments, and put the findings in the context of the conservation status of other non-fish species groups. We investigate the representativeness of the sRLI sample in terms of taxonomy, biological and ecological traits, to ensure that going forward, the sRLI for fishes presents a robust indicator which adequately reflects the high trait and ecological diversity of this species group. This global assessment is of particular importance since the sRLI for fishes is now due for reassessment to evaluate the trends in the conservation status of the world's fishes.

Results

Status of fishes

In the 1,500-species sample, 178 species (15.1% of sampled species) are threatened with extinction: 105 are Vulnerable, 40 Endangered and 33 Critically Endangered (Fig. 1a). Another 320 species (21.3%) were assessed as Data Deficient (1,180 species were non-Data Deficient). Thus, we obtained a lower threat estimate of 11.9%, and an upper threat estimate of 33.3%. Overall, 961 species were assessed as Least Concern, 41 as Near Threatened, and no species were assessed as Extinct or Extinct in the Wild. Just over half of our threatened species (51%) were assessed under restricted geographical range size (criterion B) and 38% under population reduction (criterion A). Only 17.4% of threatened species were classified based on criterion D2, while only two and four species were classified under criterion D/D1 (very small population size) and criterion C (small, declining populations), respectively (Fig. 1b). Recorded population trends of sampled species were mainly unknown (68%), although 11% showed decreasing populations, 20% were stable, and only three species (0.2%) showed increasing populations.

In our sample, 805 species were marine and 733 freshwater (38 species were found in both marine and freshwater). Percentage of species threatened with extinction varies from 4.7% threatened in marine fishes (lower: 3.5%; upper 28.9%) to 24.9% in freshwater fishes (lower: 20.8%; upper 37.4%, Fig. 1a). The sRLI in 2010 was 0.914 (N = 1,180 species) for the world's fishes, 0.972 for marine fishes and 0.860 for freshwater species (Fig. 1c).

The most commonly stated threat to fishes is exploitation (34.9%), especially for marine fishes (44%). However, pollution is the most prominent threat to fish species (49.4% of the 178 threatened species), particularly from agricultural or forestry effluent, domestic and urban wastewater and industrial eflfuents, and is particularly prominent for freshwater species (63%) (Fig. 2). Natural system modifications such as dams and channeling in freshwater ecosystems (9%), invasive species (6.5%), and habitat loss for urban development (4.9%) were also affecting species, especially threatened freshwater species (Fig. 2).

Normalised species richness in the sample is shown in Fig. 3. Highest species richness and threatened species richness for marine fishes in our sample are located in Southeast Asia, and secondarily around tropical islands in the Caribbean ocean. Data Deficient species richness of our sample was highest in Southeast Asian waters and along the north and western Australian coast. Freshwater species richness in our sample was highest in Southeast Asia and the Amazon Basin, whereas threatened species are concentrated mainly in Southeast Asia. Data Deficient freshwater species richness in our sample was highest in parts of Southeast and Eastern Asia.

Representativness of the Sampled List

In both the Global and the Sampled List of fishes, the largest order is the Perciformes, which includes both freshwater and marine species. The next largest orders are represented primarily or exclusively by freshwater species, such as the Cypriniformes, Siluriformes and Characiformes (Fig. 4). In terms of spatial distribution, both lists show that species richness is highest in the Western Central Pacific and Northwest Pacific. In inland waters, tropical areas of Asia and South America are the most species-rich areas. In terms of habitat preference, most fish species are in pelagic and benthopelagic habitats, followed by reef-associated ecosystems, in both the global and sample lists (Fig. 4). Chi-square tests showed no significant differences in the proportion of species among orders, FAO areas and preferred habitats between the Global and the Sampled List (Table 1). Similarly, there are no significant differences in estimated biological traits (life span, generation time, trophic level and vulnerability index) comparing Global and Sampled Lists (Table 2).

Table 1

Values of Chi-square distribution (χ^2), degrees of freedom (df) and probability values (*P*) comparing Global (33,112 spp.) and Sampled List (1,500 spp.) by orders, FAO areas and habitats, and considering total, and marine and freshwater species separately. Data was obtained from Fishbase (Froese & Pauly 2019).

	realms	χ^2	**Df**	***P***
Orders	total	36.31	46	0.846
	marine	33.85	36	0.571
	freshwater	25.75	34	0.844
FAO areas	total	33.99	25	0.108
	marine	15.60	18	0.620
	freshwater	12.26	6	0.056
Habitat	total	55.15	7	0.597
	marine	79.12	7	0.340
	freshwater	66.93	7	0.462

Table 2

Descriptive statistics (number N, mean, standard error SE and median) of biological traits, Mann-Whitney U test for equal medians (U) and Kolmogorov-Smirnov test for equal distributions (D) and associated probabilities, comparing features of Global (GL) and Sampled List (SL) of freshwater (FW) and marine (M) fishes included on Fishbase (Froese & Pauly 2019).

Traits	**realm**	**List**	**N**	**Mean**	**SE**	**Median**	**U**	***P***	**D**	***P***
Trophic level	FW	GL	14,848	3.04	0.48	3.10	4.71×10^6	0.562	0.045	0.145
		SL	712	3.03	0.50	3.11				
	M	GL	15,262	3.42	0.46	3.40	5.32×10^6	0.637	0.034	0.405
		SL	745	3.42	0.50	3.40				
Vulnerability	FW	GL	15,997	20.87	14.45	14.47	2.43×10^6	0.981	0.030	0.780
		SL	714	21.5	13.90	15.77				
	M	GL	15,854	27.37	16.04	24.72	3.91×10^6	0.440	0.034	0.498
		SL	745	27.36	15.40	24.73				
Life span	FW	GL	12,024	5.80	7.23	3.70	3.24×10^6	0.118	0.045	0.214
		SL	560	5.72	6.00	3.90				
	M	GL	13,265	7.73	7.94	5.40	4.26×10^6	0.354	0.043	0.183
		SL	657	7.28	6.30	5.10				
Generation time	FW	GL	12,011	2.21	2.56	1.51	3.25×10^6	0.214	0.043	0.282
		SL	558	2.15	2.00	1.58				
	M	GL	13,259	2.80	2.66	2.11	4.25×10^6	0.273	0.041	0.241
		SL	657	2.67	2.20	2.00				

Discussion

Our study provides a baseline of the exticntion risk of the world's fish, against which to track trends in the conservation status of fish in future. Overall, we show that 15% of fish species in our sample are estimated to be threatened with extinction and that threat is higher in freshwaters compared to marine systems. Our results confirm previous findings on the truly alarming conservation status of freshwater fishes[57,58]; in the same way that other freshwater biodiversity is highly threatened with extinction[13,20,48].

The overall sRLI for fishes is similar to the Red List Index for birds[12], and dragonflies and damselflies [18], and higher than for the remaining evaluated taxonomic groups (Fig. 1). Overall, the sRLI for marine fishes is the highest of the Red List indices calculated so far (bar the historical index estimated for reef-building corals pre-1998[24]). Our estimate of 4.7% of marine fish threatened with extinction is lower than threat levels found in other studies on extinction risk of marine fishes: regional shorefishes (5-9.4%[41,46]), sharks and rays (17.4%[34]), hagfishes (12%[30]), groupers (12%[33]), tarpons, ladyfishes and bonefishes (12.5%[35]), porgies (8.6%[37]), and pufferfishes (7.9%[38]). But we are not surprised as threat tends to be greatest in shallower waters and a random sample of marine fishes will have disproportionately greater deepwater species than the shallowwater taxa that have dominated early assessment priorities. The sRLI calculated for freshwater fishes is much lower and similar to the RLI for mammals and plants[19]. It is slightly higher than RLIs for other freshwater groups, with a lower estimated threat level (crayfishes[48], freshwater crabs[47] and shrimps[59]). However, note that the sRLI protocol was not developed to accurately estimate threat levels in a species group, but to accurately detect extinction risk trends in a species group over time[11]. Thus, any threat estimates from our sample should be treated with caution and may only be broadly indicative of overall levels of threat within fishes. However, work is ongoing to test the accuracy of threat estimates from sRLI samples.

The level of data deficiency in our Sampled List of fishes is comparable to that found in other species groups such as crayfish[48] and reptiles[17], and lower than that observed in freshwater crabs[47] and freshwater molluscs[20]. While Data Deficient species should be considered as potentially threatened until their status can be assessed[8], they cannot contribute to the Red List Index[10] unless their status can be predicted using trait-based methods. Reducing data deficiency is thus important to produce more robust knowledge on extinction risk patterns and RLI values in future[60]. With data deficiency in our sample highest in parts of Southeast Asia, this region would make a logical place to target to reduce DD, specifically for marine fish for which DD currently produces wide margins of uncertainty around estimated threat levels.

Population trends were lacking for many marine fishes beyond coastal areas, as most of our knowledge on the marine realm comes from coastal, intertidal or neritic habitats: for example, 73% of marine fish species assessed on the IUCN Red List occur in these habitats[9]. This is especially problematic since marine fishes were predominantly assessed as threatened under criterion A (Fig. 1B), i.e. because of a population reduction over ten years or three generations. Results offered by the Living Planet Index, a measure of the trends of global biodiversity based on population trends of vertebrate species from around the world[61], showed an average decline of around 52% for monitored marine vertebrate populations since 1970[62], compared to 84% for freshwater vertebrate populations[5]. This suggests that the risk of population declines for those species with unknown populations trends in our sample should not be underestimated, and that we need to push efforts towards better monitoring and estimating populations.

Fishes are among the most diverse classes of vertebrates with significant differences between marine and freshwater environmental realms. Despite differences between realms, our results consistently show exploitation and pollution are the main threats to both marine and freshwater fishes (Fig. 2). In the marine realm, overexploitation is overwhelmingly prominent in assessments of nearshore and epipelagic fishes[30,34,38]. Despite low overall threat levels of marine fishes in our study, in 2015 only 7% of globally assessed stocks were underfished according to the FAO[63], and increases in exploitation pressure in future may lead to further declines in species. Safeguarding marine fish diversity needs the urgent engagement of different stakeholders to ensure the sustainability of this resource while also addressing the United Nations Sustainable Development Goals, e.g. such as SDG2 on combatting hunger and malnutrition.

The impact of human settlements and cities around aquatic ecosystems and increasing water demand have led to the degradation of freshwater biodiversity[57,58], especially through water pollution, dams and water exploitation, river fragmentation, habitat loss, and establishment of non-native species[58], all threats which were prominently recorded in the sRLI assessments. Rivers are highly connected linear structures[64]: they are collectors of terrestrial impacts of the landscapes they drain, conducting them downstream. Management plans therefore need to consider the unique characteristics of freshwater systems and their high connectivity[64,65].

Our study provides the first in-depth test of representativeness of the sRLI -including the separate disaggregated indices obtained for marine and freshwater fishes- in terms of geographic, ecological and trait diversity. This is particularly important since the sRLI method at present randomly draws species from the species list; stratification of the sample was originally considered, but was rejected as a workable strategy due to the general lack of knowledge on any of these factors prior to the assessment process[11]. Thus far, tests have only been carried out to show that the recommended sRLI sample sizes are large enough to accurately reflect species group attributes regarding biogeographic realm, ecosystem types and taxonomy[11,16]. Representativeness is important since, for example, marine fishes that are restricted to the continental shelf, and especially those that occupy shallow habitats of less than 50 m depth, have a significantly higher proportion of threatened species compared to marine fishes that occur in waters deeper than 300 m[45], while on the other hand, deep sea fishes are often assumed to be Least Concern because of a lack of intense fishing pressure on these fishes, although low growth rates, late maturity, low fecundity and long lifespans of many deep sea fishes make them particularly vulnerable to any level of exploitation[66]. Here, we again showed that there were no significant differences in the proportions among taxonomic groups, geographic regions and habitat types between the Sampled and Global List of fishes, while also showing representativeness of other biological traits (life span, generation time, trophic level and vulnerability index). The Sampled List seems to not only be sufficiently large to accurately detect trend direction in the extinction risk of the world's fishes[11,16], but also to be representative of the world's fish taxonomic, trait and ecological diversity.

Recent work has shown that where assessments occur every ten years, samples of 400 non-DD species may be sufficient to accurately show direction of RLI trend of a group[16]. According to this, our study confirms the suitability and representativeness of calculated sRLIs for fishes, including the separate disaggregated indices obtained for marine (598 non-DD species) and freshwater fishes (610 non-DD species). Once completed, the data generated by the global freshwater assessment (carried out through the IUCN-Toyota Red List Partnership) can be uses to re-evaluate the representativeness of our sRLI sample of fishes, especially to see whether the spatial representativeness of our freshwater sample is broadly representative of overall freshwater fish species richness patterns (Fig. 3).

In this study, we calculated the baseline sRLI for 2010, the year in which the assessments of the selected 1,500 species was concluded. The index results published here provide the baseline towards monitoring global extinction risk in this highly species-rich group, allowing us to track future changes and trends in the conservation status of the world's fishes. Specifically, with the addition of subsequent assessments this index lets us track improvements or deteriorations in the status of the world's fishes, considering separately freshwater and marine species. A current reassessment would allow us to check how fishes fared against Aichi Target 12, and provide a starting point for better conservation action and management for these vital aquatic resources. Many of the original assessments have already undergone (20,878 species) or are in the process of reassessment of their IUCN Red List status. As such, a first step for reassessment of the sRLI is to collate recent assessments and update the status of those species which have undergone non-genuine changes in their assessment status in recent years (i.e. changes because of improved data rather than actual improvements or deteriorations in extinction risk status). Secondly, we need to prioritise reassessments of those species which were in threatened or Near Threatened categories in 2010, to allow in depth reassessment. As in other assessment processes, Least Concern species may be fast-tracked more rapidly through the assessment process[67]. Thirdly, in the absence of a reassessment for 2020, application of retrospective assessments to assess past extinction risk status from a present perspective[68–70] should be considered to derive long-term trends in extinction risk over time.

Aichi Target 12 for biodiversity has not been met[2]. Considering the existing priorities and limited conservation resources to establish an efficient reassessment of larger samples, the selected subset of species can inform current and future policy targets about trends on fish species conservation and help to allocate efforts and resources. Given that to date, fishes have been largely neglected in large-scale conservation analyses, likely due to an apathetic public perception of these animals[71,72] and a comparatively low level of research compared to other vertebrate groups, not only in non-commercial[73], but also charismatic species of fish[74], development and upkeep of an effective tool to communicate fish trends is urgently required. Current and updated assessments are necessary in the scenario of a changing world where threats and conservation status of biodiversity are constantly being modified[4,75]. For example, climate change is an emerging threat of freshwater ecosystems[57,75], though still features less prominently in IUCN Red List assessments. Other freshwater assessments have already noted climate change as a major future threat[20] and it is likely to become a more important threat in future reassessments of our sample.

Methods

A sampled Red List Index for the world's fish

In 2009, a random sample of 1,500 species (hereafter, the Sampled List) was drawn from the Eschmeyer's Catalog of fishes[22], with approximately 30,000 species recorded at that time, to evaluate the status and trends of fishes, according to the sRLI protocol[11]. A sample size of 900 non-Data Deficient species was considered sufficiently large to detect the correct trend direction in the extinction risk of a group, while a sample of 1,500 species was deemed to be large enough to also account for high levels of data deficiency in under-studied groups (up to 40%[11]). Extinction risk of every species in the sample was assessed according to the IUCN Red List Categories and Criteria[8] through consultation with experts of relevant IUCN SSC Specialist Groups and other species experts. Categories were assigned based on quantitative thresholds relating to population reductions (criterion A), restricted geographic distribution and decline or fragmentation (criterion B), population size and decline (criterion C), extremely small population size or restricted distribution (criterion D) and/or quantitative analyses (criterion E)[8].

We calculated proportions of threatened species in our sample by assuming that DD species will fall into threatened categories in the same proportion as non-DD species, as per previous studies on other species groups[12,20,48]:

$Prop_{thr}$ = (CR + EN + VU)/(N-EX-DD),

where N is the total number of species in the sample, CR, EN and VU are the numbers of threatened species, and DD and EX are the numbers of species in the Data Deficient and Extinct categories, respectively. To incorporate uncertainty introduced by DD species, we calculated upper and lower bounds of threat proportions by assuming that (a) no DD species were threatened [lower margin: $Prop_{thr}$ = (CR + EN + VU)/(N-EX)], and (b) all DD species were threatened [upper margin; $Prop_{thr}$ = (CR + EN + VU + DD)/(N-EX)]. We also estimated the sampled Red List Index in 2010, following the modified formula of Butchart et al.[76].

$$RLI_t = 1 - \frac{\sum_s W_{c(t,s)}}{W_{EX} \times N}$$

where W is the category weight (category weights increase from 0 for Least Concern in equal steps to 5 for Extinct and Extinct in the Wild) for S species at time t, and N is the total number of assessed species, excluding those considered DD. Thus, RLI values can vary from 0 (all species are Extinct) to 1 (all species are Least Concern). In this way, we produced an sRLI for all fish. A recent re-visit of the sRLI sample size, analysing data for a broader set of species than in the original sRLI paper by Baillie et al.[11], suggested that

200 to 400 non-DD species are sufficient to accurately detect trend in RLI[16]. Thus, we also produced sRLI values for freshwater and marine fish separately.

The threats impacting each species were recorded during the Red List assessments, following the IUCN's unified threats classification scheme[77]. We summarised the frequency of threats for threatened (VU, EN, CR) and non-threatened species (LC and NT). We also analysed species population trends, which are recorded as unknown, decreasing, stable and increasing populations on the IUCN Red List[8].

Species distribution was mapped – where possible - for all assessed species for which the distribution could be mapped (n = 1,484). For some species, specifically DD species, distribution data was too uncertain to allow mapping. To visualise the distribution pattern of our Sampled List, we selected only those parts of a species' distribution map where the species was considered extant or probably extant, resident, and native or reintroduced[67], resulting in 1,473 species remaining. We mapped species richness, threatened species richness and Data Deficient species richness of our sample by overlaying a grid with 1° grid cells onto the respective aggregated species' distribution and summing the number of species occurring in each grid cell. We normalised species richness relative to the richest cell to derive a synthetic pattern of species richness ranging from zero (no species present) to one (highest species richness), as described in Collen et al.[13]. We created richness maps for freshwater (n = 715) and marine species (n = 799), separately. All maps were created in R Studio v. 1.2.1335 and R Studio v. 3.6.0[78].

Taxonomic, ecological and biological trait data

To obtain a full picture of trait and ecology of the world's fishes, we extracted information on taxonomy, distribution, preferred habitat and biological traits for 33,112 fish species (hereafter termed Global List) from the FishBase online database[79]. We determined the number of species in each order according to the FishBase taxonomy, and obtained the number of species for marine and inland waters per FAO Major Fishing Areas (http://www.fao.org/fishery/area/search/). We extracted the following habitat information (particular habitat preferred by each species, adapted from Holthus and Maragos, 1995): pelagic, benthopelagic, demersal, reef-associated, bathypelagic and bathydemersal, according to the glossary of FishBase[79]. We summarised the number of species in each habitat type.

We collected the following biological traits from Fishbase[79]: life span, generation time, trophic level and vulnerability index. Life span is the approximate maximum age that fish of a given species are estimated to reach, and generation time is the average age of parents within the cohort. Trophic level is the position of fish in the food chain, determined by the number of energy-transfer steps to that level[79]. Trophic levels reported in FishBase are derived from Ecopath[80]. The index of intrinsic vulnerability to fisheries presented in FishBase is calculated via an expert system developed for fishes that integrates life history and ecological characteristics[81].

Subsequently, we compared the taxonomic, geographic, ecological and biological representativeness of this Global List against traits of our Sampled List, to assess whether the randomly Sampled List adequately represents taxonomic, spatial, and biological trait diversity of global fishes. Global and Sampled lists of fish species were tested for differences in the number of species among taxonomic orders, among FAO areas and among habitat types, using chi-square tests[78]. To assess the representativeness of biological traits, we used non-parametric analyses because the normal distribution assumption was not met in these data sets, even after data transformation. First, two-tailed (Wilcoxon) Mann-Whitney U test was used to examine whether the medians of the two samples were different. Second, Kolmogorov-Smirnov tests were used to assess whether the distributions were equal, independently of differences in other descriptive parameters as mean or variance[78].

Declarations

Acknowledgements

The Obra Social La Caixa and the Bancaria Caja Navarra Foundation grant co-author Rafael Miranda and Imanol Miqueleiz through an international mobility grant of the University of Navarra. Monika Böhm and the sRLI assessment process were supported by funding from the Rufford Foundation and Esmée Fairbairn Foundation. Coauthor Ben Collen died on May 19th 2018 aged 40 after he had been bravely battling bone cancer for 16 months. We want to acknowledge his friendship and affection. Rest in peace.

Author contributions

Conceptualization: R.M., B.C., M.B., R.F. Design: R.M., B.C., M.B., R.F. acquisition data and assessment proccesses: M.B., W.D., C.S, N.K.D., K.E.C, B.P., N.D.-R., C.P., C.H.-T. Statistical analysis: R.M., I.M., M.B. Graphic design: R.M., I.M., M.B. Writing-Original draft preparation: R.M., M.B. Methodology: R.M., B.C., R.F., M.B. Writing-Review & Editing: all authors.

Competing Interests Statement

Authors declare that we have no significant competing financial, professional, or personal interests that might have influenced the performance or presentation of the work described in this manuscript.

References

1. Butchart, S. H. M. *et al.* Global biodiversity: indicators of recent declines. *Science* **328**, 1164–8 (2010).
2. Secretariat of the Convention on Biological Diversity. *Global Biodiversity Outlook 5 Summary*. (2020).
3. Secretariat of the Convention on Biological Diversity. *The Strategic Plan for Biodiversity 2011-2020 and the Aichi Biodiversity Targets*. (2010).
4. Tilman, D. *et al.* Future threats to biodiversity and pathways to their prevention. *Nature* **546**, 73–81 (2017).

5. Almond, R. E. A., Grooten, M. & Petersen, T. *Living planet report 2020 - Bending the curve of biodiversity loss*. *WWF* (2020).
6. Ruckelshaus, M. H. *et al.* The IPBES Global Assessment: Pathways to Action. *Trends Ecol. Evol.* **35**, 407–414 (2020).
7. Rodrigues, A. S. L., Pilgrim, J. D., Lamoreux, J. F., Hoffmann, M. & Brooks, T. M. The value of the IUCN Red List for conservation. *Trends Ecol. Evol.* **21**, 71–76 (2006).
8. IUCN. *IUCN Red List Categories and Criteria: Version 3.1*. (2012).
9. IUCN. The IUCN Red List of Threatened Species. Version 2020-2. (2020). Available at: http://www.iucnredlist.org.
10. Butchart, S. H. M. *et al.* Measuring global trends in the status of biodiversity: red list indices for birds. *PLoS Biol.* **2**, e383 (2004).
11. Baillie, J. E. M. *et al.* Toward monitoring global biodiversity. *Conserv. Lett.* **1**, 18–26 (2008).
12. Hoffmann, M. *et al.* The Impact of Conservation on the Status of the World's Vertebrates. *Science (80-.).* **330**, 1503–1509 (2010).
13. Collen, B. *et al.* Global patterns of freshwater species diversity , threat and endemism. *Glob. Ecol. Biogeogr.* **23**, 40–51 (2014).
14. Meiri, S. & Chapple, D. G. Biases in the current knowledge of threat status in lizards, and bridging the 'assessment gap'. *Biol. Conserv.* **204**, 6–15 (2016).
15. Miqueleiz, I., Böhm, M., Ariño, A. H. & Miranda, R. Assessment gaps and biases in knowledge of conservation status of fishes. *Aquat. Conserv. Mar. Freshw. Ecosyst.* **30**, 225–236 (2020).
16. Henriques, S. *et al.* Accelerating the monitoring of global biodiversity: revisiting the sampled approach to generating Red List Indices. *Conserv. Lett.* **in press**, 1–9 (2020).
17. Böhm, M. *et al.* The conservation status of the world's reptiles. *Biol. Conserv.* **157**, 372–385 (2013).
18. Clausnitzer, V. *et al.* Odonata enter the biodiversity crisis debate: The first global assessment of an insect group. *Biol. Conserv.* **142**, 1864–1869 (2009).
19. Brummitt, N. A. *et al.* Green plants in the red: A baseline global assessment for the IUCN Sampled Red List Index for Plants. *PLoS One* **10**, 1–22 (2015).
20. Böhm, M. *et al.* The conservation status of the world's freshwater molluscs. *Hydrobiologia* (2020). doi:10.1007/s10750-020-04385-w
21. Lewis, O. T. & Senior, M. J. M. Assessing conservation status and trends for the world's butterflies: The Sampled Red List Index approach. *J. Insect Conserv.* **15**, 121–128 (2011).
22. Fricke, R., Eschmeyer, W. N. & van der Laan, R. Eschmeyer's catalog of fishes: genera, species, references. (2020). Available at: http://researcharchive.calacademy.org/research/ichthyology/catalog/fishcatmain.asp. (Accessed: 5th May 2020)
23. Hutchings, J. A. Collapse and recovery of marine fishes. *Nature* **406**, 882–885 (2000).

24. Carpenter, K. E. *et al.* One-Third of Reef-Building Corals Face Elevated Extinction Risk from Climate Change and Local Impacts. *Science (80-.).* **321**, 560–563 (2008).
25. Polidoro, B. A. *et al.* The Loss of Species: Mangrove Extinction Risk and Geographic Areas of Global Concern. *PLoS One* **5**, e10095 (2010).
26. Short, F. T. *et al.* Extinction risk assessment of the world's seagrass species. *Biol. Conserv.* **144**, 1961–1971 (2011).
27. Eifes, C. T. *et al.* Fascinating and forgotten: The conservation status of marine elapid snakes. *Herpetol. Conserv. Biol.* **8**, 37–52 (2013).
28. Purcell, S. W., Polidoro, B. A., Hamel, J. F., Gamboa, R. U. & Mercier, A. The cost of being valuable: Predictors of extinction risk in marine invertebrates exploited as luxury seafood. *Proc. R. Soc. B Biol. Sci.* **281**, (2014).
29. Peters, H., O'Leary, B. C., Hawkins, J. P., Carpenter, K. E. & Roberts, C. M. Conus: First Comprehensive Conservation Red List Assessment of a Marine Gastropod Mollusc Genus. *PLoS One* **8**, e83353 (2013).
30. Knapp, L. *et al.* Conservation status of the world's hagfish species and the loss of phylogenetic diversity and ecosystem function. *Aquat. Conserv. Mar. Freshw. Ecosyst.* **21**, 401–411 (2011).
31. Collette, B. B. *et al.* High Value and Long Life—Double Jeopardy for Tunas and Billfishes. *Science (80-.).* **333**, 291–292 (2011).
32. Comeros-Raynal, M. T. *et al.* The likelihood of extinction of iconic and dominant herbivores and detritivores of coral reefs: The parrotfishes and surgeonfishes. *PLoS One* **7**, (2012).
33. Sadovy de Mitcheson, Y. *et al.* Fishing groupers towards extinction: A global assessment of threats and extinction risks in a billion dollar fishery. *Fish Fish.* **14**, 119–136 (2013).
34. Dulvy, N. K. *et al.* Extinction risk and conservation of the world's sharks and rays. *Elife* **3**, e00590 (2014).
35. Adams, A. J. *et al.* Global conservation status and research needs for tarpons (Megalopidae), ladyfishes (Elopidae) and bonefishes (Albulidae). *Fish Fish.* **15**, 280–311 (2014).
36. Jacoby, D. M. P. *et al.* Synergistic patterns of threat and the challenges facing global anguillid eel conservation. *Glob. Ecol. Conserv.* **4**, 321–333 (2015).
37. Comeros-Raynal, M. T. *et al.* Key predictors of extinction risk in sea breams and porgies (Family: Sparidae). *Biol. Conserv.* **202**, 88–98 (2016).
38. Stump, E., Ralph, G. M., Comeros-Raynal, M. T., Matsuura, K. & Carpenter, K. E. Global conservation status of marine pufferfishes (Tetraodontiformes: Tetraodontidae). *Glob. Ecol. Conserv.* **14**, e00388 (2018).
39. Abdul-Malak, D. *et al. Overview of the Conservation Status of the Marine Fishes of the Mediterranean Sea. Gland, Switzerland and Malaga, Spain: IUCN. vii* (2011).
40. Polidoro, B. A. *et al.* Patterns of extinction risk and threat for marine vertebrates and habitat-forming species in the Tropical Eastern Pacific. *Mar. Ecol. Prog. Ser.* **448**, 93–104 (2012).
41. Linardich, C. *et al.* Extinction risk and conservation of marine bony shorefishes of the Greater Caribbean and Gulf of Mexico. *Aquat. Conserv. Mar. Freshw. Ecosyst.* **29**, 85–101 (2019).

42. Strongin, K. *et al.* Translating globally threatened marine species information into regional guidance for the Gulf of Mexico. *Glob. Ecol. Conserv.* **23**, e01010 (2020).
43. Pippard, H. *et al. The conservation status of marine biodiversity of the Pacific Islands of Oceania*. (IUCN, 2017).
44. Fernandes, P. G. *et al.* Coherent assessments of Europe's marine fishes show regional divergence and megafauna loss. *Nat. Ecol. Evol.* **1**, 0170 (2017).
45. Polidoro, B. A. *et al.* The status of marine biodiversity in the Eastern Central Atlantic (West and Central Africa). *Aquat. Conserv. Mar. Freshw. Ecosyst.* **27**, 1021–1034 (2017).
46. Buchanan, J. R. *et al.* Regional extinction risks for marine bony fishes occurring in the Persian/Arabian Gulf. *Biol. Conserv.* **230**, 10–19 (2019).
47. Cumberlidge, N. *et al.* Freshwater crabs and the biodiversity crisis: Importance, threats, status, and conservation challenges. *Biol. Conserv.* **142**, 1665–1673 (2009).
48. Richman, N. I. *et al.* Multiple drivers of decline in the global status of freshwater crayfish (Decapoda: Astacidea). *Philos. Trans. R. Soc. Lond. B. Biol. Sci.* **370**, 20140060 (2015).
49. Allen, D. J., Molur, S. & Daniel, B. A. *The Status and Distribution of Freshwater Biodiversity in the Eastern Himalaya*. (IUCN, and Coimbatore, India: Zoo Outreach Organisation, 2010).
50. Molur, S., Smith, K. G., Daniel, B. A. & Darwall, W. R. T. *The status and distribution of freshwater biodiversity in the western Ghats, India*. (IUCN, and Coimbatore, India: Zoo Outreach Organisation, 2011).
51. Darwall, W. R. T. *et al. The Diversity of Life in African Freshwaters: Under Water, Under Threat. An analysis of the status and distribution of freshwater species throughout mainland Africa*. *The diversity of life in African freshwaters: Underwater, under threat. An analysis of the status and distribution of freshwater species throughout mainland Africa* (International Union for Conservation of Nature, 2011).
52. Freyhof, J. & Brooks, E. *European Red List of Freshwater Fishes*. *European Commission (Hrsg.)* (2011). doi:10.2779/85903
53. Allen, D. J., Smith, K. G. & Darwall, W. R. T. *The Status and Distribution of Freshwater Biodiversity in Indo-Burma*. (International Union for Conservation of Nature, 2012).
54. Máiz-Tomé, L., Sayer, C. A. & Darwall, W. R. T. *Freshwater biodiversity in Madagascar and the Indian Ocean islands*. (2018).
55. Lyons, T. *et al. The status and distribution of freshwater fishes in Mexico*. (IUCN and ABQ BioPark, 2020).
56. Baillie, J. E. M., Griffiths, J., Turvey, S. T., Loh, J. & Collen, B. *Evolution Lost: Status and Trends of the World's Vertebrates*. (Zoological Society of London, 2010).
57. Pelayo-Villamil, P. *et al.* Global diversity patterns of freshwater fishes - potential victims of their own success. *Divers. Distrib.* **21**, 345–356 (2015).
58. Arthington, A. H., Dulvy, N. K., Gladstone, W. & Winfield, I. J. Fish conservation in freshwater and marine realms: status, threats and management. *Aquat. Conserv. Mar. Freshw. Ecosyst.* **26**, 838–857 (2016).

59. De Grave, S. *et al.* Dead shrimp blues: A global assessment of extinction risk in freshwater shrimps (Crustacea: Decapoda: Caridea). *PLoS One* **10**, 1–14 (2015).

60. Bland, L. M. & Böhm, M. Overcoming data deficiency in reptiles. *Biol. Conserv.* **204**, 16–22 (2016).

61. McRae, L., Deinet, S. & Freeman, R. The diversity-weighted living planet index: Controlling for taxonomic bias in a global biodiversity indicator. *PLoS One* **12**, 1–20 (2017).

62. WWF. *Living Blue Planet Report. Species, habitats and human well-being. WWF* **9**, (2015).

63. FAO. *The State of World Fisheries and Aquaculture 2018 - Meeting the sustainable development goals.* (2018).

64. Hermoso, V., Filipe, A. F., Segurado, P. & Beja, P. Freshwater conservation in a fragmented world: Dealing with barriers in a systematic planning framework. *Aquat. Conserv. Mar. Freshw. Ecosyst.* **28**, 17–25 (2018).

65. Hermoso, V., Abell, R., Linke, S. & Boon, P. The role of protected areas for freshwater biodiversity conservation: challenges and opportunities in a rapidly changing world. *Aquat. Conserv. Mar. Freshw. Ecosyst.* **26**, 3–11 (2016).

66. Baker, K. D., Devine, J. A. & Haedrich, R. L. Deep-sea fishes in Canada's Atlantic: Population declines and predicted recovery times. *Environ. Biol. Fishes* **85**, 79–88 (2009).

67. Red List Technical Working Group. Mapping standards and data quality for the IUCN Red List Categories and Criteria. Version 1.16. **1.16**, 30 (2018).

68. Hoffmann, M. *et al.* The changing fates of the world's mammals. *Philos. Trans. R. Soc. B Biol. Sci.* **366**, 2598–2610 (2011).

69. Di Marco, M. *et al.* A Retrospective evaluation of the global decline of carnivores and ungulates. *Conserv. Biol.* **28**, 1109–1118 (2014).

70. Kyne, P. M. *et al.* The thin edge of the wedge: Extremely high extinction risk in wedgefishes and giant guitarfishes. *Aquat. Conserv. Mar. Freshw. Ecosyst.* **30**, 1337–1361 (2020).

71. Darwall, W. R. T. *et al.* Freshwater biodiversity: a hidden resource under threat. in *Wildlife in a Changing World–An Analysis of the 2008 IUCN Red List of Threatened Species* (eds. Vié, J.-C., Hilton-Taylor, C. & Stuart, S. N.) 43 (IUCN, Gland, Switzerland and Cambridge, UK., 2009).

72. Pino-del-Carpio, A., Ariño, A. H. A. H. & Miranda, R. Data exchange gaps in knowledge of biodiversity: Implications for the management and conservation of Biosphere Reserves. *Biodivers. Conserv.* **23**, 2239–2258 (2014).

73. Reynolds, J. D., Webb, T. & Hawkins, L. Life history and ecological correlates of extinction risk in European freshwater fishes. *Can. J. Fish. Aquat. Sci.* **62**, 854–862 (2005).

74. McClenachan, L., Cooper, A. B., Carpenter, K. E. & Dulvy, N. K. Extinction risk and bottlenecks in the conservation of charismatic marine species. *Conserv. Lett.* **5**, 73–80 (2012).

75. Reid, A. J. *et al.* Emerging threats and persistent conservation challenges for freshwater biodiversity. *Biol. Rev.* **94**, 849–873 (2019).

76. Butchart, S. H. M. *et al.* Improvements to the Red List Index. *PLoS One* **2**, e140 (2007).

77. Salafsky, N. *et al.* A standard lexicon for biodiversity conservation: Unified classifications of threats and actions. *Conserv. Biol.* **22**, 897–911 (2008).
78. R Development Core Team. R: A language and environment for statistical computing. *R Foundation for Statistical Computing, Vienna, Austria.* (2019). Available at: https://www.r-project.org/.
79. Froese, R. & Pauly, D. FishBase. World Wide Web electronic publication. (2019). Available at: www.fishbase.org. (Accessed: 12th February 2019)
80. Pauly, D., Christensen, V. & Walters, C. Ecopath, Ecosim, and Ecospace as tools for evaluating ecosystem impact of fisheries. *ICES J. Mar. Sci.* **57**, 697–706 (2000).
81. Cheung, W. W. L., Pitcher, T. J. & Pauly, D. A fuzzy logic expert system to estimate intrinsic extinction vulnerabilities of marine fishes to fishing. *Biol. Conserv.* **124**, 97–111 (2005).

Figures

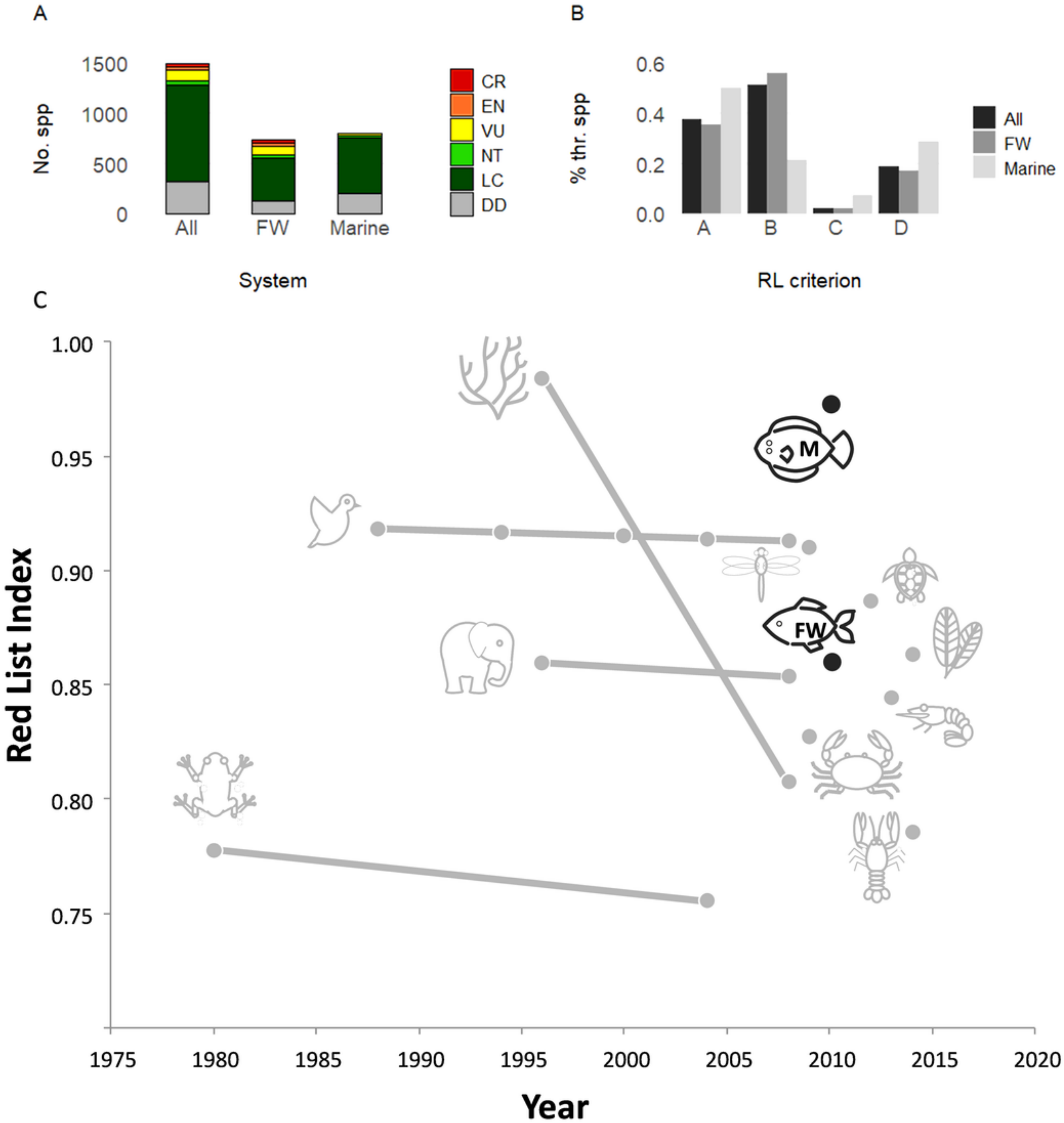

Figure 1

Status of the world's fishes, based on a random sample of 1,500 species: A) IUCN Red List Categories for the full sample, freshwater and marine species; B) Percentage of species assigned via the different IUCN Red List Criteria; C) Red List Indices for birds, mammals, amphibians and corals (source: IUCN), crayfish48, freshwater crabs47, freshwater shrimps59, and estimated Red List Indices based on a sampled approach for dragonflies and damselflies18, reptiles17, plants19 and fishes, distinguishing marine (M) and freshwater (FW) species (black circle, this study). Taxa not yet reassessed appear as a single point.

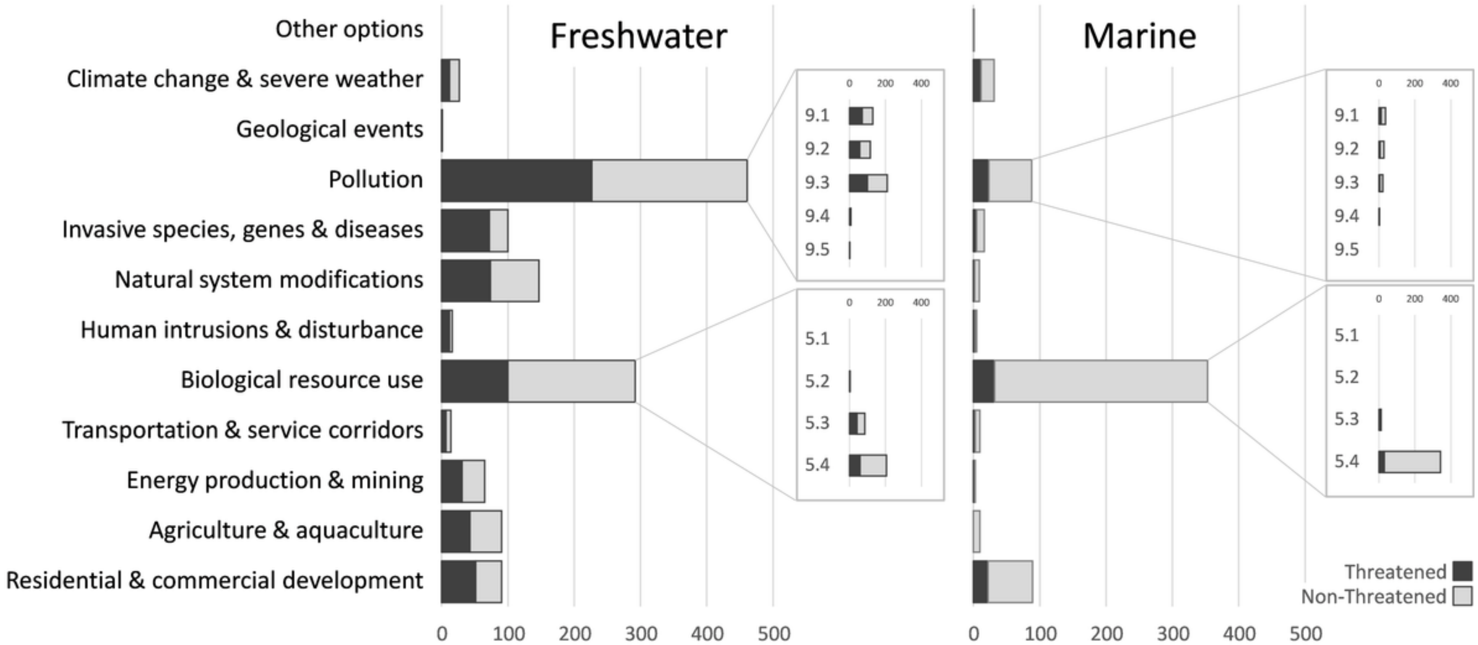

Figure 2

Number of species threatened (dark grey) and not threatened (light grey) classified to each of the main threat categories for the Sampled List of fishes of the IUCN Red List, distinguising marine and freshwater species. Threats are classified according to the Threats Classification Scheme (Version 3.2) of the IUCN Red List. Diagrams in the right show threat subcategories for biological resource use and pollution. 5.1: Hunting & collecting terrestrial animals, 5.2: Gathering terrestrial plants, 5.3: Logging & wood harvesting, 5.4: Fishing & harvesting aquatic resources, 9.1: Domestic & urban waste water, 9.2: Industrial & military effluents, 9.3: Agricultural & forestry effluents, 9.4: Garbage & solid waste, 9.5: Air-borne pollutants.

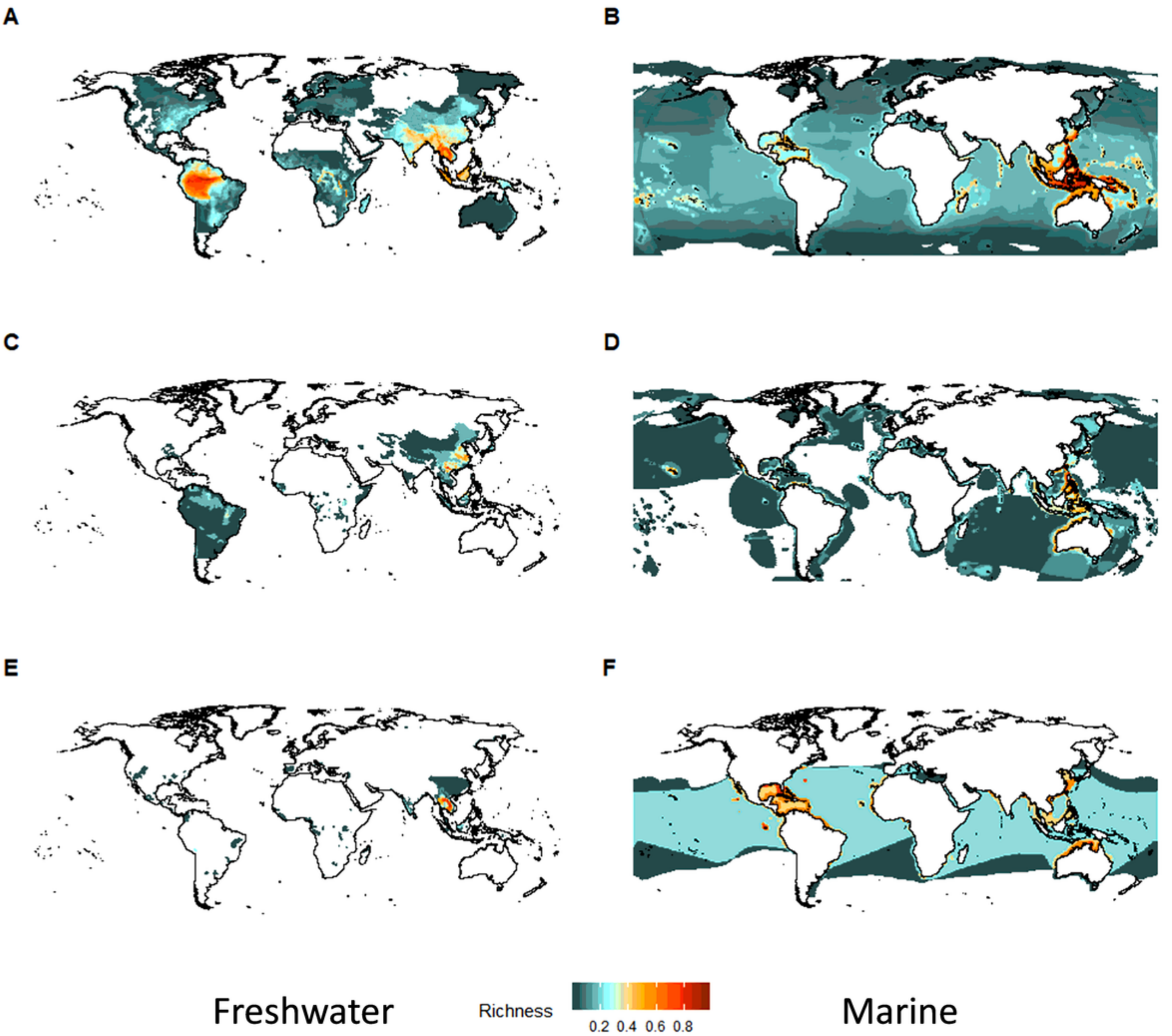

Figure 3

Species richness of the sampled assessment, showing normalised species richness per grid cell: A) all freshwater fish (n = 715 species); B) all marine fish (n = 799); C) Data Deficient (DD) freshwater fish (n = 119); D) DD marine fish (n = 201); E) threatened freshwater fish (CR, EN, VU; n = 144); F) threatened marine fish (n = 26).

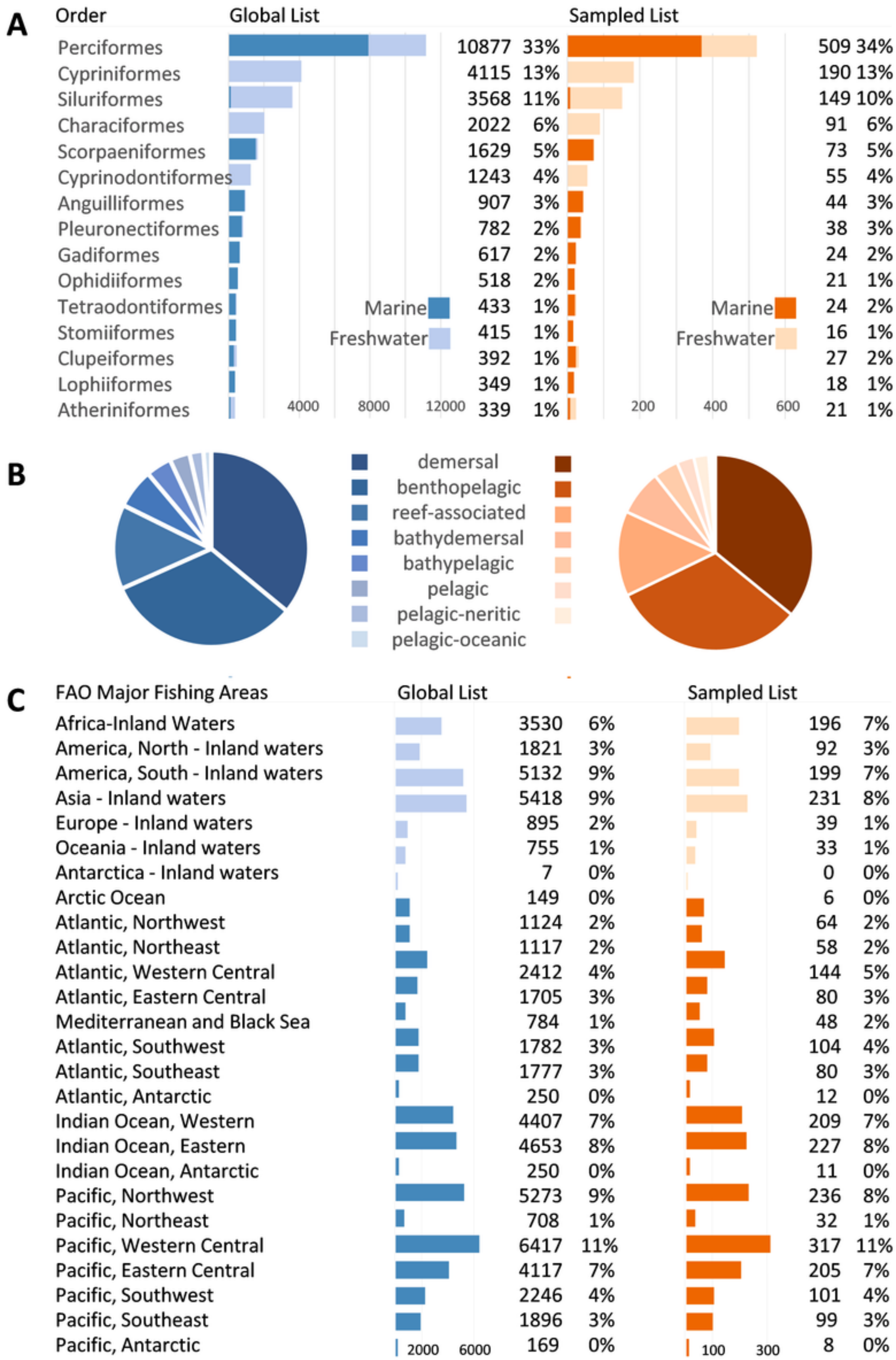

Figure 4

Comparison among Global List of fishes (blue) and Sampled list (brown) used to estimate the Sampled Red List indices for all fishes, and marine and freshwater species separately. A) Number of species belonging to the 15 more extensive orders; B) number of species distributed by FAO Major Fishing Areas; C) percentaje of species habitat preferences, according to Fishbase (adapted from Holthus and Maragos, 1995).